Test results of cycle 1 innovations

Report on initial test results

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Preface

This deliverable D2.2 report presents the work that has been performed by BRIGAID partners and the external innovators who are supported by BRIGAID to test innovations for the 1st innovation development cycle. The work presents a joint effort of WP2 (Floods), WP3 (Droughts) and WP4 (Extreme weather).

This report involves a preliminary version of the Deliverable D2.2, presenting the initial test results of the different cycle 1 external and internal innovations.

Chapter 1: Introduction

Background: BRIGAID's objectives

Studies from the IPCC indicate that Europe is particularly prone to risks of river and coastal floods, droughts resulting in water restrictions and damages from extreme weather events such as heat waves and wildfires. Evidence is now ever stronger that damages from these natural hazards will increase. Evaluations also show a huge potential to reduce these risks through adaptation strategies. Although there is no lack of research institutes and entrepreneurs such as start-ups that develop innovative solutions, only 6% of the European companies are capable of testing and demonstrating their innovations. Many fail to complete the innovation development cycle due to a lack of resources in terms of funds, knowledge of testing and networks to engage with end users and investors early on. BRIGAID aims to help innovators to overcome these limitations by bridging this gap that is sometimes also referred to the valley of death (see Figure 1).

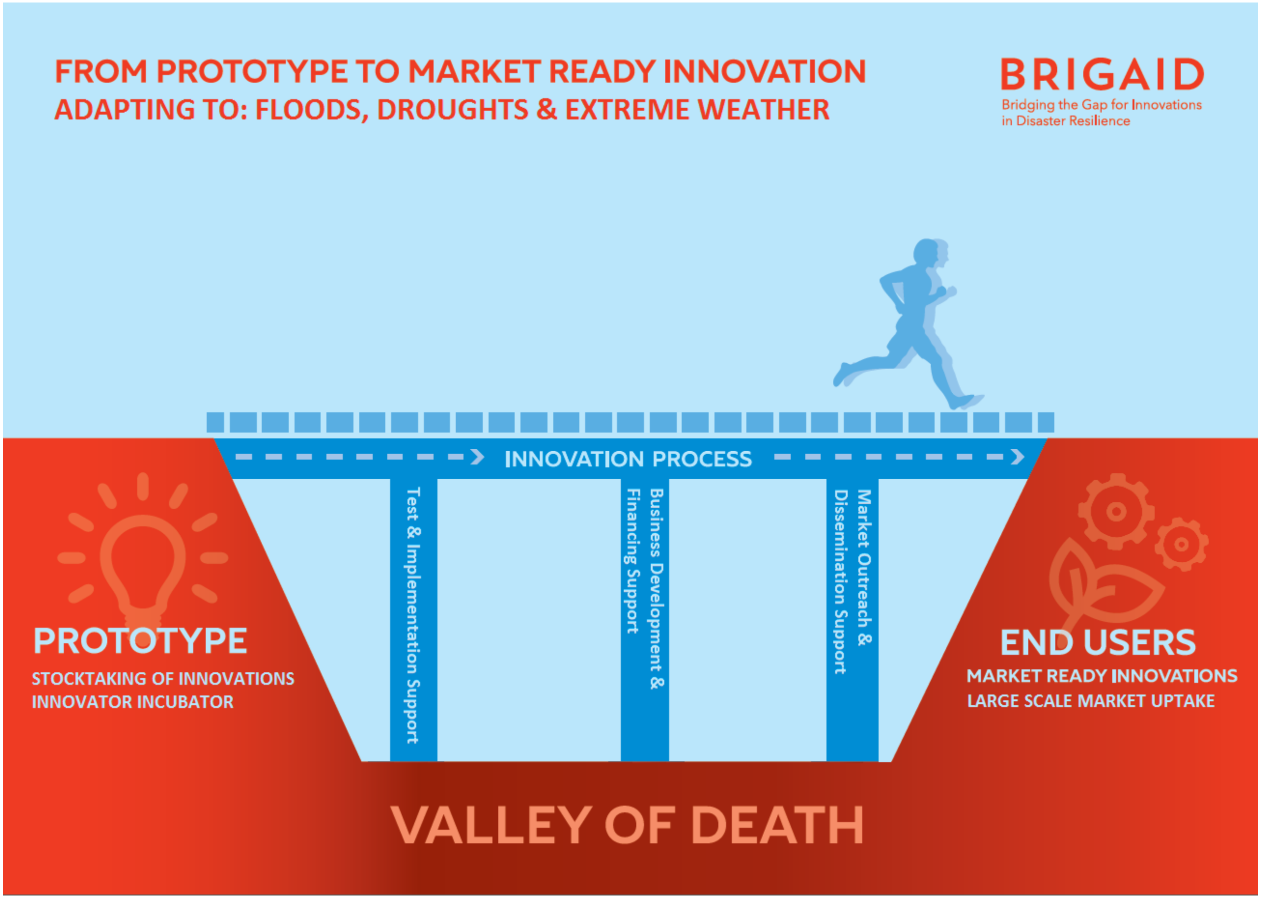


Figure 1. BRIGAID's conceptual approach with three types of support for innovations.

The gap refers to a combined lack of methodologies and support that are needed to turn already existing innovations into complete and market ready products. BRIGAID's ambition is to provide structural, ongoing support for innovations in climate adaptation by developing an innovative mix of methods and tools, that should become a standard for climate adaptation innovations. To achieve this, BRIGAID follows a 2-layered approach:

- First, BRIGAID's unique mix of methods and tools consists of three elements:
  - ✓ A framework that evaluates the effectiveness of innovations and the organizational and governance requirements.
  - ✓ A business development and financing model for climate adaptation innovations.
  - ✓ An online interactive platform that presents innovations and connect innovators, end users, qualified investors, and grants and fiscal incentives advisors throughout Europe.

- Second, these methods and tools are validated in the project by reviewing promising innovations on floods, droughts and extreme weather, improving the most promising ones, and bringing the top 20-30 innovations with the highest socio-technical and investment readiness to the market.

This is being done in 3 phases, the so-called innovation development cycles (see Figure 2). This deliverable reports on the testing of the innovations selected for the 1st innovation development cycle.

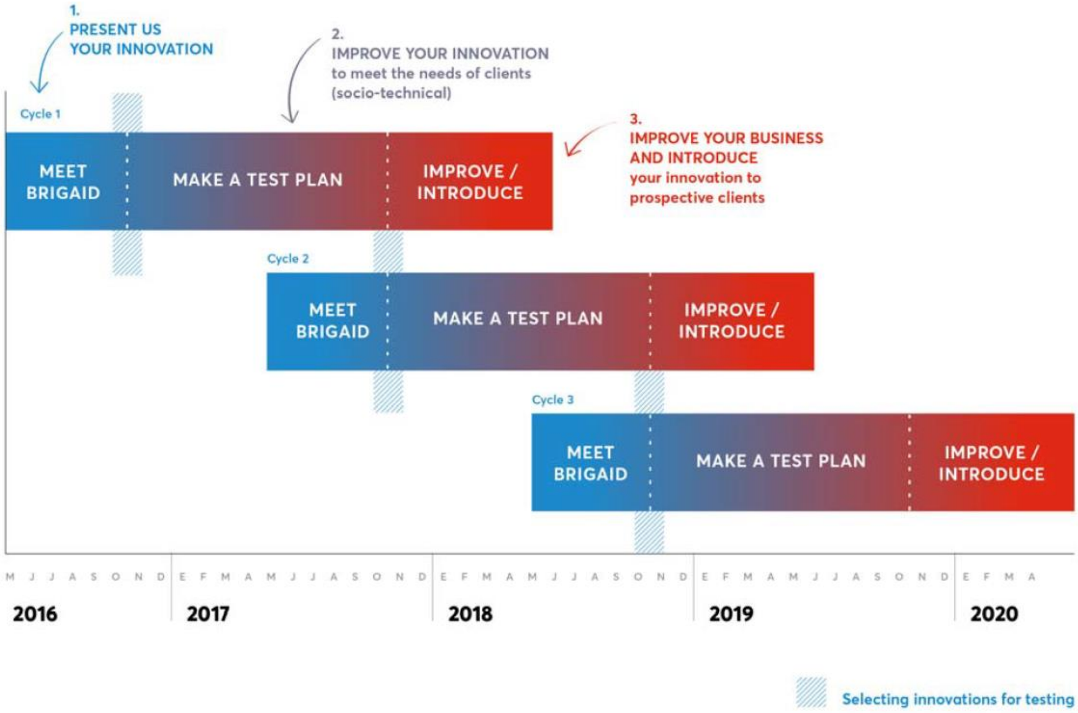


Figure 2. BRIGAID's three innovation development cycles.

Overview of 1st Cycle innovations

For the 1st innovation development cycle, 16 innovations were selected, 10 by internal project partners and 6 by external partners. The latter were supported by a testing budget provided after a careful selection procedure, called the “stocktaking” budget and process. Details about this process and the selection of the 1st cycle innovations can be found in the BRIGAID Deliverables D2.1, D3.1 and D4.1.

An overview of the 1st cycle innovations is provided below.

Innovations from consortium partners

Table 1 presents an overview and short description of the innovations from the BRIGAID consortium partners. These innovations cover a wide range in terms of innovation typologies and hazards. For instance, a number of innovations focus on monitoring using sensory systems such as airborne and underwater drones, GNSS antennas, satelite and glass fibre for the purpose of monitoring, early warning and/or forecasting. A few systems provide hazard information that can be used to define adaptation measures, while others also assist in the development, planning and evaluation of adaptation strategies. There are also a number of innovations that aim directly to reduce the exposure to damaging events by using (flexible) flood barriers and green roofs, mechanical or IT-smart technologies for saving water and improving crop water status, or treatment technologies for reusing diary wastewater.

A more detailed description of these innovations is available in the BRIGAID Climate Innovation Window: http://climateinnovationwindow.eu Links to individual innovations are provided in Table 1.

Table 1. Cycle 1 innovations from consortium partners.

Nr	Name	Short description	Organization	Hazard
1	eEM-DAT	Expanded EM-DAT disaster database to the European level. CRED will adapt the EMDAT global database for the EU level, increasing the resolution to district (admin 3) and state (admin 2), by collecting more detailed data. This tool will be called eEM-DAT (European EM-DAT), and will be tested in 3 or 4 pilot countries. http://climateinnovationwindow.eu/innovations/expanded-em-dat-disaster-database-european-level-eem-dat	UCL	Multi hazards
2	OBREC	Overtopping BReakwater for Energy Conversion. OBREC was developed and patented by the Second University of Naples, IT. It consists of a rubble mound breakwater with a front reservoir designed to capture the overtopping waves in order to produce electricity. http://climateinnovationwindow.eu/innovations/obrec	University of Bologna	Coastal floods
3	MyFloodRisk	In the EU many citizens are at risk of floods. Although science based flood maps does exist, such as the EU Flood Directive maps, these	HKV Consultants	River & Coastal Floods

Nr	Name	Short description	Organization	Hazard
		maps are non-uniform, without climate change projections and their availability as reusable GIS files is extremely limited. Hence, online pan-European floods maps that can be easiliy accessed by researchers, businesses and citizens are still unavailable. The EU FP7 project RAIN developed pan-European maps for various hazards for a set of defined time periods and climate scenarios. Based on these data, HKV Services launches an app providing flood information in a user friendly and clear manner for all EU countries. http://climateinnovationwindow.eu/innovations/my-flood-risk		
4	Flip-Flap cofferdam	Flip-Flap Cofferdam is designed to prevent floods in urban areas. It can be used as boardwalk (walkway) around the clock. When flood emergency arises it is raised in vertical position and locked into the concrete gutter. In this position it acts just like a regular flood protection wall. Material is PVC sheet piles. http://climateinnovationwindow.eu/innovations/flip-flap-cofferdam	Spectrum Construct SRL	River floods
5	ThirdEye: Flying Sensors to support farmers' decision making	Flying Sensors, sometimes referred to as drones, provide high resolution information on crop status. Our innovation provides this information at: (i) an ultra-high spatial resolution, (ii) an unprecedentedly flexibility in location and timing, (iii) a spectrum outside the human eye. The latter is very important since this information shows potential threats to crops such as droughts, diseases, fertilizer stress, about 10-days earlier compared to the human eye observation. http://climateinnovationwindow.eu/innovations/thirdeye	FutureWater	Drought
6	Water+ Furrow Diker	The Water+Furrow Diker is an innovative equipment which allows for the maximization of the collection and harvesting of rainfall water and irrigation drainage at the root plant zone. It is operated with wheel tractors of 35-80 HP. Soil modeling with dike furrows shape is carried in: a) row crops when height is of 30-60 cm; b) vineyards, during spring-summer-autumn period. http://climateinnovationwindow.eu/innovations/water-plus-furrow-diker	S.C. AQUAPROIECT S.A.	Drought
7	infoSequia	A fully-integrated satellite-based web-mapping service for the operational monitoring of drought impacts. http://climateinnovationwindow.eu/innovations/infosequia	FutureWater	Drought
8	GM4W - GeoGuard Module for	Water vapour GNSS monitoring at high spatial resolution to support probabilistic heavy rain nowcasting. Low-cost GNSS receivers and	Geomatics Research & Development	Extreme precipitation

Nr	Name	Short description	Organization	Hazard
	Water vapor monitoring	antennas are used to deploy spatially dense networks of units capable of monitoring the integrated content of atmospheric water vapor with high spatial and temporal resolutions. http://climateinnovationwindow.eu/innovations/water-vapour-gnss-monitoring	(GReD) srl	
9	AEWMS - Active Eco-Wildfire Management System & Strategic Fuel Management	Innovative method to planning and execution of Strategic Forest Fuel Management and Prescribed Burning techniques in forests to reduce risk of wildfire. http://climateinnovationwindow.eu/innovations/active-eco-wildfire-management-system	GIFF Lda	Wildfires
10	FireAd - Fire Risk Monitor Advisor	An approach to improve wildfire forecast in context of drought conditions. The decision support tool monitors and assesses the risk of wildfires. Outputs can be incorporated in Apps or platforms for decision support in forest planning, forest management and wildfire management. http://climateinnovationwindow.eu/innovations/fire-risk-monitor	Centro de Ecologia Aplicada "prof. Baeta Neves"	Wildfires

Innovations from non-consortium partners (stocktaking)

Innovations from external organizations have been identified from platforms and personal networks / contacts of BRIGAID partners (Table 2). Also these innovations cover a broad range of typologies including planning and evaluation of adaptation measures, sensory measurement systems, software systems that estimate and/or present hazard data for monitoring, control and communication, innovations that reduce impacts of floods or extreme precipitation, systems to promote water saving, or increase the efficiency of water use in agriculture.

A more detailed description of these innovation is available in the BRIGAID Climate Innovation Window.

Table 2. Innovations identified from external organizations (stocktaking).

Nr.	Name	Short description	Hazard	Organization	Identified through
1	SCAN	Software tool to evaluate and optimize water management strategies in the light of climate change and other trends such as the increasing urbanization, population growth and water demand. The tool can be used to analyze the integrated water system, while focusing primarily on hydrology and hydraulics (rivers, floodplains and urban drainage systems). http://climateinnovationwindow.eu/innovations/scan	River floods, Extreme precipitation	Sumaqua	KU Leuven

Nr.	Name	Short description	Hazard	Organization	Identified through
2	EVAPO-CONTROL	Polyethylene modular floating covers to supress evaporation losses and algae growth in water reservoirs http://climateinnovationwindow.eu/innovations/evapo-control	Drought	ARANA Water Management S.L.	FutureWater
3	Water from Heaven	Drinking water made of rain from own roof. Sustainable water purification and storage for dry seasons. http://climateinnovationwindow.eu/innovations/water-heaven-hemelswater	Drought, Extreme precipitation	Water Innovation Consulting	HKV & KU Leuven
4	ARIEL - soil moisture retrieval by microwave remote sensing	ARIEL is a microwave radiometer-processing system able to provide remote soil moisture (SM) data without additional ground-based infrastructure. ARIEL can be placed on-board aircrafts, drones or ground vehicles. http://climateinnovationwindow.eu/innovations/ariel-soil-moisture-retrieval-microwave-remote-sensing	Drought	Balam Ingenieria de Sistemas	FutureWater
5	HYDROVENTIV	The Hydroactive Smart Roof System; modular trays device for retaining and dissipating rain water on roof, with outflow control delayed, piloted by a remote system control for optimizing water resource. http://climateinnovationwindow.eu/innovations/hydroactive-smart-roof-system-hydroventiv	Extreme precipitation, Drought	Le PRIEURE	KU Leuven
6	Tube barrier	The TubeBarrier is a temporary embankment; quick and easy to deploy to prevent floods and in case of industrial leakage or water storage. TubeBarrier uses water to block the rising water, is small to store and can be easily be installed over hundreds of meters by just two persons. http://climateinnovationwindow.eu/innovations/tubebarrier	Floods	TubeBarrier	VP delta

Scope of this report and reading guide

This report describes the process of testing of the cycle 1 innovations and the testing results so far. The report is structured as follows:

- Chapter 1: Introduction
- Chapter 2: Overall procedure for testing of the innovations
- Chapter 3: Summary of test reports of cycle 1 innovations
- Appendix 1: Complete overview of testing reports of cycle 1 innovators

Chapter 2: Overall process for testing the innovations

Outline of the testing process

The goal of the innovation testing in BRIGAID is to advance the innovation in terms of its social, technical, and market readiness, and to bring it step-by-step closer to successful market uptake.

The testing was supported by the BRIGAID's **Testing and Implementation Framework (TIF)**. This TIF provided innovators with guidelines for developing test plans to evaluate the socio-technical effectiveness of their innovation. The goal of the test plans is to increase the technical readiness level (TRL) of the innovation, its social acceptance/readiness, and its potential for market uptake. A **desk study** involving different steps were suggested to provide innovators with the information needed to develop a comprehensive test plan for their innovation.

The first step was to perform a **qualitative analysis of socio-technical Key Performance Indicators (KPIs)**. The TIF was designed to help the innovator understand how the KPI relate to the socio-technical effectiveness of the innovation and how they are affected by the design or physical characteristics of the innovation (BRIGAID WP5 Assessment). For example, for a physical/structural innovation, the innovator qualitatively analyzed the reliability of the innovation by brainstorming all possible failure modes. Because this analysis depended on the external conditions that surround the innovator and on the end users, it was for several innovators also based on the outcomes of the BRIGAID WP6 and WP7 Assessments, such as the PESTEL analysis, the market segmentation and the attractiveness scoring. The latter assessments are not included in this report but are available for some innovators in their Description and Assessments Report.

The second step was to **propose tests that address (the different components) of each KPI**. These tests were designed to assess the performance of the innovation on each KPI. Using the same example as above, tests were designed to assess the probability of occurrence of each of the failure modes that were identified. If a field-site application of the innovation was already known, the innovator provided information about the boundary conditions (required) for testing.

The next step was the **implementation of the tests including all practicalities**.

The final step was to **provide the results from the tests so far**. Results so far were evaluated to provide a measure of reliability based on the test(s) performed. Note that the goal of the testing is that the performance of the tests will increase the TRL of the innovation by bringing it from concept to prototype to an operational innovation.

<u>Regarding the timing</u>: Figure 2 shows the timing that was aimed for the testing of innovations. However, due to the long stocktaking process during the 1^{st} cycle, also because of the stocktaking procedure that had to be developed and fine-tuned and the difficulties with setting up the stocktaking contracts, and the time-consuming tasks to be carried out before and during the testing, there is a delay in the planned period for the testing of the 1^{st} cycle innovations. For most 1^{st} cycle innovations the tests are currently ongoing but not completed yet. The tests will go on for several more months, but this report presents the test results so far.

<u>On an important note</u>, not all innovators followed all steps. Given that during the BRIGAID's 1^{st} cycle the TIF was still under development, it was not available in its current final version during

most of the 1st cycle testing period. Moreover, internal innovators were involved in the try-out of the initial versions of the TIF. That is why some of the innovators applied initial versions of the TIF, others later versions of the TIF, and some did only make little use of it. This explains why the level of detail of the testing results and the link with the TIF is different for different innovators in this report. The testing reports by the different innovators involve one or more of the following elements. Few innovators applied the final TIF tool developed.

The responsibilities for testing are as follows:

- The innovator has the end responsibility for writing a sound test plan and reporting the results of testing;
- WP2-4 leaders provide the first line of support and general review of the test plan and test results;
- WP5-7 provide the second line of support in application of their frameworks and additional support in testing when needed.

Description of the innovation

Recognizing that a single set of testing guidelines will not work for all innovations included within BRIGAID, the TIF considers two typologies of innovations based on the classifications made by the IPCC:

- Engineered or built environment innovations (e.g., temporary flood barrier)
- Technological and informational innovations (e.g., early warning/monitoring system)

Each typology requires different testing guidelines because its behavior and/or purpose is different; however, the KPIs are relevant and applicable to all types.

Therefore, the innovators first described the general characteristics of the innovation. While doing so, they indicated whether the innovation is an engineered/built (physical) or a technological innovation. If relevant, they included a sketch/bayesian network, graphic, or picture of the innovation or prototype.

Technical Readiness Level (TRL) of the innovation

Because the testing approach somehow depends on the Technical Readiness Level (TRL) of the innovation, this TRL was provided together with a justification.

The TRL is a metric used to assess the maturity of a technology. The scale consists of nine levels where each level characterizes the progress in the development of a technology, from the initial idea (Level 1) to the full uptake of the product into the marketplace (Level 9) (see Table 3 for definitions).

Table 3. Description of the different TRLs.

Level	Description
Level 1	**Basic Research.** Basic principles are observed and reported. Lowest level of technology readiness. Scientific research begins to be translated into applied research and development. Examples might include fundamental investigations and paper studies.
Level 2	**Applied Research.** Technology concept and/or application formulated. Once basic principles are observed, practical applications can be formulated. Examples are limited to analytic studies and experimentation.
Level 3	**Critical function, proof of concept established.** Active research and development is initiated. Laboratory studies aim to validate analytical

	predictions of separate components of the technology. Examples include components that are not yet integrated or representative.
Level 4	**Laboratory testing of prototype component or process.** Design, development and lab testing of technological components are performed. Here, basic technological components are integrated to establish that they will work together. This is a relatively "low fidelity" prototype in comparison with the eventual system.
Level 5	**Laboratory testing of integrated system**. The basic technological components are integrated together with realistic supporting elements to be tested in a simulated environment. This is a "high fidelity" prototype compared to the eventual system.
Level 6	**Prototype system verified.** The prototype, which is well beyond that of level 5, is tested in a relevant environment. The system or process demonstration is carried out in an operational environment.
Level 7	**Integrated pilot system demonstrated**. Prototype is near, or at, planned operational system level. The final design is virtually complete. The goal of this stage is to remove engineering and manufacturing risk.
Level 8	**System incorporated in commercial design**. Technology has been proven to work in its final form under the expected conditions. In most of the cases, this level represents the end of true system development.
Level 9	**System ready for full scale deployment**. Here, the technology in its final form is ready for commercial deployment.
>Level 9	**Market introduction**. The product, process or service is launched commercially, marketed to and adopted by a group of customers (including public authorities).

Technological KPIs

The following technological KPIs were considered in the TIF:

- ✓ Reusability of the innovation;
- ✓ Reliability of the innovation;
- ✓ Technical Effectiveness (or Performance) of the innovation.

Each of these KPIs is hereafter summarized, together with the objectives for the innovators while evaluating the KPIs during their desk study and during the testing.

Reusability of the innovation

Reusability is a metric that encompasses the temporary- or permanent-nature of the innovation; its effectiveness is measured by whether an innovation is designed for single or repetitive use (and how *durable* the structural components of the innovation are). It also provides information about the long-term operation and maintenance requirements. In BRIGAID, we consider three categories of innovations:

1. *Permanent*: innovations that are permanently installed (or always in operation) and must be designed to withstand the hazard event and/or daily loading without (or with minimal) repairs (e.g., structural dikes/levees);
2. *Semi-permanent*: innovations that are permanently installed at the location, but are only operated during the hazard event;

3. *Temporary*: innovations that are operated prior to/during the hazard event, but removed completely after the event has ended.

The innovators described the intended *reusability* of the innovation based on the definitions given above and proposed a test plan to assess the expected *reusability* of the (components of the) innovation. For semi-permanent and temporary innovations, they identified the expected percent of the innovation that is reusable after each use and which components (if any) would need to be replaced. They also estimated the expected product lifetime based on decomposition of the materials used.

Reliability of the innovation

Reliability is a metric used to evaluate the performance of an innovation during a hazard event; it is typically expressed as the complement of the failure probability (i.e., reliability = 1 – probability of failure). In general, BRIGAID will focus on two primary failure modes:

1. *Implementation Failure*: failure to implement the innovation due to, e.g., insufficient lead-time, power outage, human or logistical issues, etc. (note: this category does not apply to permanent engineered/built (physical) innovations);
2. *Technical Failure*:
    a. *For Engineered/Built (physical) Innovations, it refers to* failures to resist physical loads during exposure to the hazard event;
    b. *For Technological Innovations, it refers to* failures to (effectively) predict hazard event.

The innovators analyzed the Reliability of the innovation by identifying all possible failure modes that would lead to implementation failure and/or technical failure. These were considered in the test plan to evaluate these failure modes. They also described whether these tests are undertaken in a controlled or operational testing environment (dependent on the TRL).

Technical effectiveness (or performance) of the innovation

Technical Effectiveness is a metric to evaluate the risk reduction potential of an innovation (assuming no implementation or technical failures occur). In BRIGAID, risk is defined as a function of probability, exposure, and vulnerability; where probability refers to the likelihood of the hazard occurring, exposure refers to the presence of elements at risk, and vulnerability refers to the conditions of people, their property, and activities in an area. In this context, risk reduction can be obtained by reducing either the probability of exposure to or the vulnerability associated with a hazard. Following this line of thinking, effectiveness is measured as:

1. *(for Engineered/Built (physical) Innovations)*: the ability of the innovation to reduce the probability of or exposure to the hazard (e.g., by reducing water levels).
2. *(for Technological Innovations)*: the ability of the innovation to reduce the vulnerability associated with a hazard (e.g., by increasing lead-time for disaster response).

The innovators analysed the Effectiveness of the innovation either in terms of its capacity to reduce the probability of exposure or vulnerability to the hazard. And they developed test(s) to determine the effectiveness of the innovation in reducing risks during disaster events. These tests are being described in the innovator reports, including the test locations and details. Initial test results are also reported.

Social KPIs

In terms of social KPI's, the TIF defined the following indicators to address the Social Readiness of the innovations:

Demographic conditions: this indicator involves the extent to which an adaptation is appropriate for the characteristics of target populations according to factors including age, gender, educational level, social grade and location.

Basic user requirements: this indicator involves the extent to which an adaptation satisfies basic user requirements for usefulness and ease-of-use.

- Adaptations that are more useful are seen as able to enhance a direct users' job performance; motivate direct users by improving outcomes so as to enhance job performance, pay or conditions; bring outcomes that have a pay off in the future; fit with the reference groups working culture; outperform precursor technologies; enhance one's image or status; be consistent with pre-existing organisational expectations; yield demonstrably positive results.
- Adaptations that are easier to use are seen as being relatively free from effort; easy to perform the required behaviours; less difficult to understand; complemented with factors in the environment that make operation easier to accomplish; visible for others to learn easily; avoiding of anxious or emotional reactions.

Psychological concerns: this indicator involves the extent to which an adaptation poses 'dread' and 'unknown' psychological risk factors.

- 'Dread risk' includes the extent to which adaptations and their risks are controllable or uncontrollable; dreadful or not; globally catastrophic or not; consequentially fatal or not; equitable or not; directed towards individuals or groups; applicable to future generations or not; easily reduced or not; increasing or decreasing over time and voluntary or involuntary.
- 'Unknown risk' includes the extent to which adaptations and their risks are observable or not; knowable to those exposed or not; immediate or delayed in their impact; new or old and known or unknown to science.

Sociocultural preferences: this indicator involves the extent to which an adaptation appeals to the adherents of 'hierarchical', 'individualist' and 'egalitarian' forms of sociocultural organisation.

- Adaptations that are more compatible with hierarchical preferences are larger in scale; employ high technology; perform a managerial 'fix' to the problem; attend to long-term climate risks; bring control over the system to be adapted; be entrusted to public administrative routines; be deployed under hypothetical public consent; be held liable for failures through redistributive means; be targeted at helping those whose harm would destabilise institutions and be implementable through incentive regulation or command-and-control measures.
- Adaptations that are more compatible with individualist preferences are appropriate in scale relative to cost; employ technology that is appropriate relative to cost; facilitate business as usual under climate risk; attend to immediate climate risk; exploits the system to be adapted; be entrusted to successful individuals or businesses; be deployed under revealed consent; be held liable for failures through loss-spreading means; be targeted at helping whoever wants to adapt and be implementable through fiscal incentives or research and development support measures.
- Adaptations that are more compatible with egalitarian preferences are smaller in scale; employ low technology; prioritise the most vulnerable to climate risk; attend to long-term climate risk now; seeks to make the system to be adapted more sustainable; be entrusted

to civil societies and collective will; be deployed under explicit public consent; be held liable for failures through means of strict-fault; be targeted at helping all those affected by climate risk and be implementable through informational or command-and-control measures.

Technical expectations: this indicator involves the extent to which an adaptation can satisfy diverse expectations of effective, environmentally benign, affordable and safe technical performance.

- Alternative efficacy criteria include the capacity of the adaptation to lessen climate impacts; remain operational for longer periods of time and successfully address its intended effects; be developed in a timely fashion; draw on available resources and work with well-established states of knowledge.
- Alternative environment criteria include the capacity of the adaptation to pose a lower carbon footprint over its lifecycle; minimise its direct impacts on the environment; minimise any side effects or unintended impacts on the environment; minimise the risk of ‘unknown unknowns’; avoid the perception of ‘messing with nature’; maximise the reversibility of any impacts it has and avoid transboundary impacts.
- Alternative economic criteria include the capacity of the adaptation to be commercially viable; be affordable to produce and acquire for direct users and end beneficiaries; be desirable in terms of balancing end costs and benefits; cost effective; economically sustainable over time and provide return on any investments, in particular public funding
- Alternative safety criteria include minimising direct impacts, side effects and unintended effects on humans.

Wider societal questions: this indicator involves the extent to which an adaptation can satisfy diverse questions of political, public, ethical and co-beneficial social performance.

- Alternative political criteria include the capacity of the innovation to facilitate intergovernmental or interregional cooperation; be open and transparent during design; operation; results and impacts; operate within existing governance frameworks and be both politically acceptable and viable.
- Alternative public criteria include the capacity of the innovation to attend to social and cultural differences in acceptability between and within countries; minimising negative socioeconomic impacts and maximising positive ones; attending to questions about the purposes of the technology, the trustworthiness of those involved, the sense of inclusion and agency, the speed and direction of innovation and fair distribution of social benefit
- Alternative ethical criteria include the capacity of the innovation to be widely available and accessible; adhere to principles of intragenerational and intergenerational distributive justice; be guarded against the possibility of misuse; avoid feeding into situations where the rich get richer; attend to questions about democratic ownership and control;
- Alternative co-benefits criteria will depend on the adaptation in question.

While describing the characteristics of their innovation, the innovators did this in light of the definitions above and proposed a test plan to assess the social performance of the innovation. Some innovators scored each of the social KPIs. This was done for the target population or direct end-users (DEU) as follows.

Demographic conditions: The grading on this ranged from one (inappropriate) to five (appropriate). The appropriateness was gauged based on the target population expected demographics such as age, gender, education, social grade and location (end-users).

Basic user requirements: This indicator involves the extent to which an adaptation satisfies basic user requirements for usefulness and ease-of-use. It ranges from 1 (low) to 5 (high).

Psychological concerns: This indicator involves the extent to which an adaptation poses “dread” and “unknown” psychological risk factors. It ranges from 1 (low) to 5 (high).

Sociocultural preferences: This indicator involves the extent to which an adaptation appeals to the adherents of ‘hierarchical’, ‘individualist’ and ‘egalitarian’ forms of sociocultural organisation (Table 5). It ranges from 1 (low) to 5 (high).

Technical expectations: This indicator involves the extent to which an adaption can satisfy diverse expectations of effectiveness, environmentally benign, affordable, and safe technical performance. These indicators range from 1 (low) to five (high).

Wider societal questions: This indicator involves the extent to which an adaptation can satisfy diverse questions of political, public, ethical and co-beneficial social performance (Table 7). It ranges from 1 (low) to 5 (high).

TIF Tool

The TIF tool developed by BRIGAID WP5 consists of 5 tables, each one dedicated to assessing one of the different aspect of the innovations’ overall performance and readiness, as also described above:

- Societal acceptance – questions designed to identify areas of possible societal concern over an innovation
- Technical performance – questions designed to identify areas of possible technical concern over an innovation
- Environmental impacts – questions designed to identify areas of possible environmental concern over an innovation
- Sectoral impacts – questions designed to identify areas of possible sectoral concern over an innovation
- Summary of results – the overall performance of an innovation and a break-down of performance against societal, technical, environmental and sectoral questions and specific issues.

Chapter 3: summary of test reports

This chapter provides a summary of the testing reports for both the internal and external innovations selected for cycle 1. The full reports are provided in Appendix 1.

Content of the test reports

Test report consist of the following elements:

- ✓ Name of the innovator and authors of the report
- ✓ Description of the innovation
- ✓ Desk study results
- ✓ Description of the test plan
- ✓ Testing results so far

A summarized **description of the innovation**. This description can also be found in the Climate Innovation Window.

The **desk study results** aim to describe the (intended) performance of the innovation using the answers that the innovators provided to the Desk Study questions designed by the BRIGAID WP5 team. This description includes, if relevant, the loads on the innovation or the input(s)/output(s) to the innovation. When possible, a description is given of the factors that may influence the reliability of the innovation, and an indication of the most important failure modes. These formed the basis for the design of the test plan. Any testing that had already been performed prior to the BRIGAID testing is described as well.

The **test plan** provides a description of planned laboratory testing that is to be done based on the design criteria (i.e., "boundary conditions") defined in the desk study. The BRIGAID tests to evaluate the governing (or critical) failure modes are described. This can be in the laboratory environment or through operational testing. If the TRL of the innovation is greater than 5, results are provided of the testing that has already been completed (e.g., reusability, reliability, technical effectiveness). If the innovation is at TRL 6-8, a description is provided of the BRIGAID operational testing based on the (foreseen) boundary conditions in the operational environment (i.e., physical loading (e.g., water level); required safety factor or reliability; (external) operating conditions) and of the tests that will be completed to calculate the reusability, reliability, and technical effectiveness of the innovation. Information is provided about the location of the tests, about the loading conditions created (and over what time frame), the equipment used, and the expected results.

Finally, a summary is given of the results of the **testing results** so far, and this for each experiment in the designed test plan. It may also be identified whether there are additional tests required or whether changes will be made to the original prototype to increase reliability or decrease vulnerability before moving forward.

Status summary of test reports in C1

Table 4 provides an overview of the progress of testing activities and contains the following information:

- Estimated TRL at the start of BRIGAID, the current estimated TRL and the planned TRL are the end of BRIGAID;
- Overall testing progress indicates whether activities are on schedule or delayed;
- Testing activities comprise 1) performing a desk study and making a test plan, 2) performing laboratory tests (TRL4-5) and/or 3) operational test (TRL6-7). The colour scheme indicates (in steps of 25%) the extent to which activities have been completed:
  - ✓ Green: activities complete according to planning
  - ✓ Orange: activities delayed
  - ✓ Grey: planned activities in BRIGAID that have not started

Table 4 shows that most of the testing activities proceed according to plan:

- 14 innovations (87,5%) are on schedule 2 innovations (12,5%) are delayed. Both delayed innovations are flexible flood protection systems that require test basins and custom made equipment:
  - ✓ Flip Flap Dam will be tested in the facility “Flood Proof Romania” that will be constructed as part of the BRIGAID project by NAAR. The design, permits, and tendering of the project has taken more time than expected. The test facility for the Flip Flap Cofferdam has been integrated in the design of Flood Proof Romania and is therefore delayed. As a result, also the test plan is only partially complete.
  - ✓ Tubebarrier is tested in “Flood Proof Holland”, a test facility for flexible flood barriers of the TU Delft. For testing additional tubes, a new type of ground anchors and a wave machine had to be constructed. Also, additional expertise was needed to support the innovator with the test plan. All these issues have been solved and the testing plan has been completed. The wave machine is currently being developed and tests of Tubebarrier are expected start in February 2018.
- 3 innovations (19%) have completed their test activities: ThirdEye, Water+Furrow Diker, ARIEL.
- 2 innovations perform laboratory tests only (TRL4-5), 10 innovations perform both laboratory and operational field tests TRL4-8), and 4 innovations perform field test only (TRL6-8).

For a detailed explanation on the test results of each of the innovations we refer to Appendix 1.

Table 4. Overview of progress in testing activities.

Internal Innovation		**TRL**			**Testing**	**Activities**			
		start	*current*	*end*	*Overall progress*	*Desk study +Test plan*	*Laboratory testing*	*Operational testing*	*Remarks*
1	eEM-DAT	5	7	8	On schedule				
2	OBREC	5	5	6	On schedule				
3	MyFlood Risk	4	6	7	On schedule				
4	Flip-Flap cofferdam	4	4	6	Delayed				Construction of test facility Flood Proof Romania delayed
5	ThirdEye	4	5	6	On schedule				
6	Water+ Furrow Diker	4	7	8	On schedule				
7	infoSequia	4	6	7	On schedule				
8	GeoGuard Module for Water vapor monitoring	6	6	8	On schedule				
9	Active Eco-Wildfire Management System	7	7	8	On schedule				
10	Fire Risk Monitor Advisor	5	5	7	On schedule				
External Innovation		**TRL**			**Testing**	**Activities**			
		start	*current*	*end*	*Overall progress*	*Desk study + Test plan*	*Laboratory testing*	*Operational testing*	*Remarks*
1	SCAN	4-5	6	8	On schedule				
2	EVAPO-CONTROL	5	6	8	On schedule				
3	Water from Heaven	5	5	8	On schedule				
4	ARIEL	5	7	7	Complete				
5	HYDROVE NTIV	5	5	9	On schedule				
6	Tubebarrier	5	5	7	Delayed				Delivery of ground anchors and hiring external expertise

Appendix 1: Testing reports of cycle 1 innovators

Reports on the testing and implementation activities are provided next and this for each of the internal and external innovations selected for cycle 1.

The following elements are reported:

- ✓ Name of the innovator and authors of the report
- ✓ Description of the innovation
- ✓ Desk study results
- ✓ Description of the test plan
- ✓ Testing results so far

Note that the summarized description of the innovation can be also be found in the Climate Innovation Window.

The **desk study results** aim to describe the (intended) performance of the innovation using the answers that the innovators provided to the Desk Study questions designed by the BRIGAID WP5 team. This description includes, if relevant, the loads on the innovation or the input(s)/output(s) to the innovation. When possible, a description is given of the factors that may influence the reliability of the innovation, and an indication of the most important failure modes. These formed the basis for the design of the test plan. Any testing that had already been performed prior to the BRIGAID testing is described as well.

The **test plan** provides a description of planned laboratory testing that is to be done based on the design criteria (i.e., “boundary conditions”) defined in the desk study. The BRIGAID tests to evaluate the governing (or critical) failure modes are described. This can be in the laboratory environment or through operational testing. If the TRL of the innovation is greater than 5, results are provided of the testing that has already been completed (e.g., reusability, reliability, technical effectiveness). If the innovation is at TRL 6-8, a description is provided of the BRIGAID operational testing based on the (foreseen) boundary conditions in the operational environment (i.e., physical loading (e.g., water level); required safety factor or reliability; (external) operating conditions) and of the tests that will be completed to calculate the reusability, reliability, and technical effectiveness of the innovation. Information is provided about the location of the tests, about the loading conditions created (and over what time frame), the equipment used, and the expected results.

Finally, a summary is given of the results of the **testing results** so far, and this for each experiment in the designed test plan. It may also be identified whether there are additional tests required or whether changes will be made to the original prototype to increase reliability or decrease vulnerability before moving forward.

Internal innovators (consortium partners)

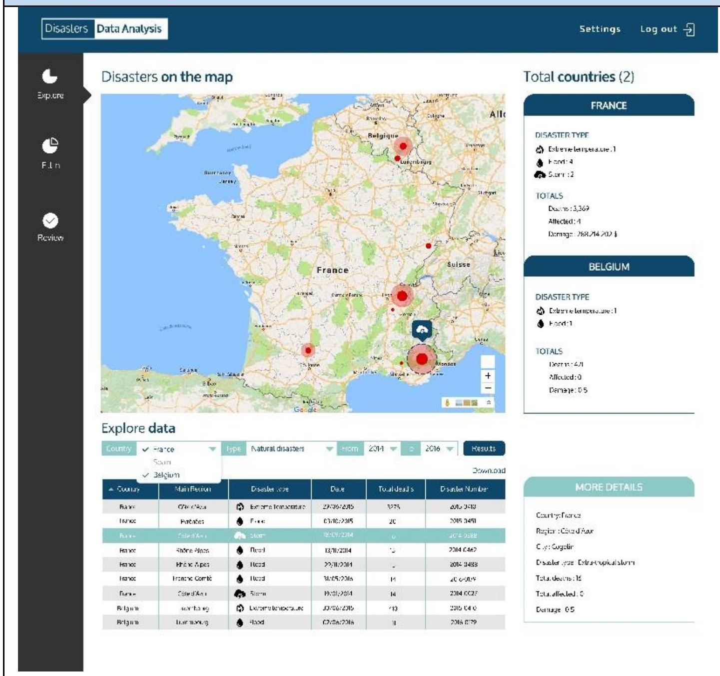
1. Innovation: eEM-DAT - European EM-DAT Disaster Database

Innovator: Université catholique de Louvain (UCL) - Centre for Research on the Epidemiology of Disasters (CRED) (BRIGAID consortium partner)

Contributing authors: Joris van Loenhout (UCL), Alexandria Williams (UCL)

Innovation description

The description of eEM-DAT below is also available from the Climate Innovation Window, http://climateinnovationwindow.eu/innovations/expanded-em-dat-disaster-database-european-level-eem-dat

Name
Expanded EM-DAT Disaster Database (eEM-DAT)
Short description
CRED will adapt the EM-DAT global database for the EU level, increasing the resolution to district (admin 3) and state (admin 2), by collecting more detailed data. This tool will be called eEM-DAT (European EM-DAT), and will be tested in 3 or 4 pilot countries.
Sketch/Photograph of the innovation

Types of hazard(s) that the innovation aims to mitigate
River floods: fluvial floods resulting from discharges that exceed flood protection levels; the high-river discharges are caused by heavy precipitation in the river basin.

Coastal Floods: resulting from high sea water levels and wave impact that exceed flood protection levels; these hydraulic conditions are caused by storm surges.

Droughts: sustained and extensive occurrence of below average water availability. Resulting in water scarcity when drought conditions cause long-term imbalances between water availability and demands.

Heatwaves: prolonged period of excessively hot, and sometimes also humid, weather relative to normal climate patterns of a certain region.

High winds speeds: resulting in damage to buildings, (critical) infrastructure networks and other objects

Heavy precipitation / pluvial floods: rainfall events that result in 1) (urban) floods due to exceedance of: drainage capacity, and 2) flash floods, defined as rapid flooding of low-lying areas, generally within a few hours after heavy rainfall events such as thunderstorms.

Other (specify): Wet landslides, cold spells

Working principle of the innovation

A tool that used a standardised and structured method to collect, validate and analyse climate-related disaster impact data. This leads to an evidence base for the development of disaster risk reduction policy. Our task is to pilot-test this tool in the appropriate ministries or institutes in a country, and assess the feasibility for national authorities to use it.

The tool is technological in nature and is a web application based on the existing EM-DAT interface (www.emdat.be). EM-DAT (Emergency Events Database) is an international disaster database, of which the main objective is to serve the purpose of humanitarian action and influence policy change at national and international levels. EM-DAT contains essential core data on the occurrences and effects of over 22,000 mass disasters in the world from 1900 to the present day. The database is hosted by the Centre for Research on the Epidemiology of Disasters (CRED).

The new application, called eEM-DAT (European Emergency Events Database), will have the same variables as the existing EM-DAT database, but will consist of an interface that can be used to enter disaster data on a local and regional level, including geo-location. This is more specific than the original database and will allow for a concentrated understanding of disaster impact on an area. Historical disaster data from EM-DAT will also be included in eEM-DAT. An additional option is the extraction of data by different variables, such as area, year or disaster type. The tool will also offer options to visualise the data in different ways, such as on a map or in charts. It will have a user-friendly interface, since the persons working with the tool are not familiar with the existing database. The final product will be the property of Université catholique de Louvain (UCL).

Added value / main differentiating element from conventional approach(es)

The new application is unique and aims to:

- ✓ create a standardized and structured method of collecting and validating disaster impact data across Europe;
- ✓ provide a user-friendly tool for governments, health ministries, and other relevant stakeholders to obtain evidence in order to create evidence-based policy change;
- ✓ compile disaster and climate-related disaster impact data in one place.

Critical success factors / limitations
The success of the tool will be determined by its use among stakeholders for research and gaining new knowledge on disasters at the micro-level. The limitation of this will be on the acceptability of the tool by stakeholders and on the funding required to maintain and update the database.

Desk study

Summary

The new application, called eEM-DAT (European Emergency Events Database), is a continuously operated database system. It will have the same variables as the existing EM-DAT database, but will consist of an interface that can be used to enter disaster data on a local and regional level, including geo-location. This is more specific than the original database and will allow for a concentrated understanding of disaster impact on an area. Historical disaster data from EM-DAT will also be included in eEM-DAT. An additional option is the extraction of data by different variables, such as area, year or disaster type. The tool will also offer options to visualise the data in different ways, such as on a map or in charts. It will have a user-friendly interface, since the persons working with the tool are not familiar with the existing database. The final product will be the property of Université Catholique de Louvain (UCL).

The innovation will address the following hazards: river and coastal floods, droughts, heatwaves, high winds, heavy precipitation, wet landslides, and cold spells.

The innovation will use software or IT-product/components to process or present information. It will be used as an informational and educational tool to increase knowledge and awareness through research. It will also indirectly provide economic and financial incentives through mitigating the impact of disasters by policy changes based on research to identify and quantify risks and/or evaluate adaptation strategies. Finally, this research may result in changes in laws, regulations and government policy to reduce risk.

Thus, the technical effectiveness can be summarized as an innovation that decreases vulnerability through: increasing knowledge and/or awareness of disasters, and changing human behavior and policies towards disasters. While the innovation's risk reduction cannot be quantified in terms of units of measurement, we can measure the tool's effectiveness through identifying the number of users per year. We rated our innovation at TRL5 as it is built off a previously existing and currently used tool- EM-DAT. Thus, there has been some real-world testing from which we can build upon.

As the innovation is technical in nature, it has an undefined lifetime. However, this depends on the availability of users to input data on disasters and perform system updates to continue functioning. Validation of entries is, also, ideal. Thus, these components require funding for upkeep and maintenance of the system and are limited by this, in effect.

The technical failure modes do not pose a high risk and if do occur, do not cause harm if the system temporarily malfunctions. The modes of error include: server crashes and electrical failures. Mostly, however, the error modes that pose the greatest threat are non-technical in nature: human reporting error and/or lack of interest by end-users.

To address these error modes we propose the following: The main source of failure, human reporting errors, can be addressed using a validation tool where entries are randomly checked for accuracy and completeness, as well as personnel training.

The second source of failure is lack of interest by end-users. To ensure the database and platform are of use and can be used by end-users, a stakeholder workshop will be held with representatives from 5 countries. Testing will focus on: usefulness for practice, user friendliness, and reliability/software malfunctions in system. Furthermore, for reducing software malfunctions we will have a one-year contract with the developer to fix any potential issues that arise.

Server crashes and electrical failures are random and outside the control of eEM-DAT managers. Thus, these will not be tested.

Technical Readiness Level (TRL)

The TRL of eEM-Dat is estimated at TRL-5. The original tool, EM-DAT, has been used at the global level for several years and eEM-DAT is based on this. Thus, the basic technological components are integrated and only need a few added adjustments to be ready for testing in the relevant environment. The original database is a first prototype, with a second to be developed, and tested for BRIGAID.

The end TRL is estimated to be at TRL-8 with the system completed and qualified through field testing.

Reusability

As a technological and web-based innovation, the eEM-Dat is considered permanent and ongoing with little maintenance required. As an online platform, it requires few physical resources and is designed for repetitive use by international parties.

There is already data available in the EM-DAT which can be used within eEM-DAT to add a historical perspective to the more geographically precise platform.

In regards to sustainability and durability, the database only needs to be updated with most recent disaster data, which can be input via a user-friendly platform. Occasionally, a software update or routine website maintenance will be required to keep the system running smoothly and efficiently. Such updates require little time or resources, and will positively affect the continuous operability.

The EM-DAT database has been operational for more than 20 years and has been cited frequently in peer-reviewed articles and used by various stakeholders within the international community. Thus, the original database is a strong basis for the new innovation and has proven to be very durable.

Reliability

Implementation failure

The eEM-DAT innovation has the potential for programming “bugs” when first being implemented, which is common in any new online platform. During the testing phase, most of the “bugs” will be identified and corrected. However, some small changes may still need to be made after real-world implementation of the innovation. There is a one year maintenance contract that exists with the developer of eEM-DAT, which can ensure removal of all issues and updating, accordingly.

While power outages are uncommon, they are still a slight risk to reliability both during implementation and real-world use of the database and its platform. Power outages can cause the server to go down in the area it is being hosted by, yet this is a rather unlikely scenario. As these are random events caused by outside sources, there is no way to test or evaluate the failure.

Another form of potential implementation failure could arise when the target audience (representatives from target audiences in EU member state) are not willing to install or use the software in their organization. A workshop will be organized during the development of the software, in order to maximally optimize the software to the end users' wishes and requirements.

Other sources of failure could be lack of funds to support the system, failure to properly input data into the system by human error, and lack of human capital to maintain and update the system.

Thus, the reliability of the innovation is, overall, quite high and does not pose a threat of failure during a hazard event. The performance of eEM-DAT during a hazard event is irrelevant as the innovation will not be used during a hazard, only after to collect, validate, and analyse climate-related disaster impact data.

Technical failure

The innovation is not used for predicting hazard events. Thus, there is little risk of technical failure. However, a technical failure could be due to data errors or incorrect data analysis that leads to false conclusions.

To evaluate this reliability, the system is tested through pilot testing, where surveys and user feedback are collected and used for tuning the system. Furthermore, data is being validated through human review to ensure data has been entered correctly.

Technical Effectiveness (or Performance)

As a technical innovation, eEM-DAT will be effective in reducing vulnerability associated with a hazard through supplying data for evidence-based policy changes. These policy changes will mitigate the impact of disasters on affected populations through better preparedness and response measures. Thus, the innovation has an effect on reducing vulnerability and can be large and far-reaching.

The innovation is tested in field-studies, where appropriate ministries or institutes in a country use the tool to conduct preliminary analyses. The pilot-testing, in three countries, assess the feasibility for national authorities to use it. Then, when disasters occur, the authorities can evaluate whether the application is also usable in a real-life setting. Once the process of data entry and continuous updates has been implemented, we are quite confident that national governments and other end users use the database also to change policy, as has been proven by the existing EM-DAT database.

Social readiness

To address the Social Readiness, the six indicators were scored in relation to the eEM-DAT innovation. The indicators were evaluated for direct end-users (DEU), which include insurance companies, government agencies, policymakers, and disaster response organisations.

Demographic conditions

The grading ranges from one (inappropriate) to five (appropriate). The appropriateness is assessed based on the target population expected demographics (end-users).

Factor	Direct end-user	Comments

	(DEU)	
Age	5	All users will be working professionals and thus, the online tool will be appropriate for users of working age
Gender	5	No difference in gender is made among the users of the application
Education	3	This is rated a 3 as some end-users will be unfamiliar with using the system or the analysis capabilities based on their professional background level. A user-friendly design will minimize this effect.
Social grade	5	
Location	5	The application can be used internationally as it is online web-based tool

Basic user requirements

This indicator involves the extent to which an adaptation satisfies basic user requirements for usefulness and ease-of-use. It ranges from 1 (low) to 5 (high).

Factor	**Direct end-user (DEU)**	**Comments**
Usefulness	3	The innovation will be used to create evidence-based policy change related to minimizing disaster impact and improving disaster planning and response strategies. The innovative tool will enhance job performance through providing access to data that can implement positive change in the future through policies. This indicator has been given a three as it is unknown to what extent the added value will be appreciated by stakeholders in the field, in addition to what is already available through the regular EM-DAT database. We will investigate this further during a stakeholder workshop that is scheduled to take place, to optimally link the application with requirements from the field.
Ease of use	4	As a database, in general, requires some level of knowledge surrounding data analysis, not all stakeholders will be familiar with the innovation's correct use. However, a user-manual and user-friendly platform will be provided to minimize these effects.

Psychological concerns

This indicator involves the extent to which an adaptation poses “dread” and “unknown” psychological risk factors. It ranges from 1 (low) to 5 (high).

Factor	Direct end-user (DEU)	Comments
Dread	1	The innovation poses no psychological risk as it is a database that collects data AFTER a disaster event has occurred. The results of the data analysis will be used to improve policies to protect the population at risk in future events.
Unknown	1	A database has little unknown risk as it will not be used to predict disasters, only analyse better ways in which to prepare for a disaster event and respond after.

Sociocultural preferences

This indicator involves the extent to which an adaptation appeals to the adherents of ‘hierarchical’, ‘individualist’ and ‘egalitarian’ forms of sociocultural organisation. It ranges from 1 (low) to 5 (high).

Factor	Score	Comments
hierarchical	4	The innovation is mostly egalitarian as it is smaller in scale, requires little technology, and targets helping those affected by climate risks through informational measures. It is also hierarchical as the innovation will be entrusted to public administrators and bring some control over the system to be adapted through policy changes. We feel the innovation is least associated with the individualist form of sociocultural organisation.
individualist	2	
egalitarian	5	

Technical expectations

This indicator involves the extent to which an adaption can satisfy diverse expectations of effectiveness, environmentally benign, affordable, and safe technical performance. These indicators range from 1 (low) to five (high).

Factor	Score	Comment
Efficacy	5	This is one of the innovation’s purposes. It seeks to lessen climate impact through disaster response and preparedness data by drawing on available resources over the long-term. Once the innovation is implemented, little resources will be required for its ongoing use.
Environmental	4.5	There is little to no environmental effects from the innovation

effects		as it is a web-based application.
Affordability	4	There will be little cost related to the innovation, and in relation to the high value of the damages, we consider that the innovation costs are not very high compared with the potential benefits from policy change and minimising disaster impact. Furthermore, the innovation is sustainable over time and requires little public funding, though some will be continuously required (e.g. staff needs to add new disaster events to the database, which requires time). The commercial availability and reception of the innovation is unknown at this time, thus a rating of 4.5
Safety	4.5	There is a small risk that the policy changes will not have the desired effect in reducing the impact of disaster events. This could be considered a side effect of the innovation. However, we do not foresee any issues directly related to safety with respect to the innovation.

Wider societal questions

This indicator involves the extent to which an adaptation can satisfy diverse questions of political, public, ethical and co-beneficial social performance. It ranges from 1 (low) to 5 (high).

Factor	**SCORE**	**Comment**
Political	5	The utilization of the innovation is intended to be helpful for the implementation of better policies surrounding disasters. It will save the local communities money with better preparedness and response through evidence-based strategies at the local level. It will enhance cooperation between data providers and users of the data.
Public	4	The innovation has the potential to save lives through improving community response and understanding disasters on a local or regional area and preventing their impact.
Ethical	4	As with any database, collecting data from an area in which it may or may not serve to influence policy has some small ethical issues from a data standpoint (with respect to selective data entry). Furthermore, insurance companies could theoretically use the data to change prices of premiums. However, overall we see these issues as minor, since there is not an obvious and major gain by certain stakeholders.
Co-benefits	4	The innovation will also promote research, since it increases data availability, and a better understanding of disaster impacts on the local and regional community. The innovation will neither improve nor diminish climate change or CO_2 footprints, but is mainly aimed at reducing its impact.

Test plan

Laboratory testing

Testing of the Technical KPIs	
Design Criteria (i.e., Intended Technical Effectiveness)	
Intended (quantitative) level of risk reduction	NA
Intended Safety Factor or Reliability	NA
Reliability	
System malfunctions	Description of Testing: This will be measured through pilot testing during the workshop by entering, searching for, and extracting data from the eEM-DAT prototype.
	Expected Results: Reduced # of malfunctions
Usefulness for practice/user friendliness	Description of Testing: This will be measured during the workshop and any suggestions for improvement will be taken into account during finalization of tool.
	Expected Results: An accepted tool that will be widely used by many different end-users.
Reusability	
Percent of the innovation needed to be repaired after each operation	Description of Testing: Based on the workshop the prototype will be developed into a final product.
	Expected Results: A finalized product based on feedback from end-users.
Lifetime of structural and/or material components	Description of Testing: NA
	Expected Results: NA

Operational testing

Testing of the Technical KPIs	
Design Criteria (i.e., Required Technical Effectiveness)	
Required level of risk reduction	NA
Required Safety Factor or Reliability	NA
(External) Operating Conditions	NA
Indicators	# of countries using tool for data entry after one year (target: 7); # of requests/downloads for data after one year (100 requests/country); questionnaires to users after first year (end of 2018).
Reliability	
Human reporting	Description of Testing:

error	Random validation of entries and traning of data entry personnel.	
	Expected Results: Minimizing data entry errors.	
Server crashes	Description of Testing: As the server is part of CRED, we control the operational reliability of it. No testing will occur but we will assess the # of crashes during 1st year of implementation.	
	Expected Results: We expect this has a low probability to occur	
Electrical Failures	Description of Testing: No testing will occur but we will assess the # of failures during 1st year of implementation.	
	Expected Results: We expect this has a low probability to occur.	
Reusability		
Percent of the innovation needed to be repaired after each operation	Description of Testing: 1 year contract with developer of system to fix any potential malfunctions within the system as they arise.	
	Expected Results: Minimum # of malfunctions in final product after first year of implementation	
Lifetime of structural and/or material components	Description of Testing: NA	
	Expected Results: NA	

Testing results

Test Summary	
Description of Test (and Goals)	**Lab Testing Design**: Our tool will be pilot tested using a stakeholder workshop for country representatives in September/October 2017. The meeting date will be coordinated around existing meetings that hold similar data focal points who can also attend our meeting in Brussels. Representatives, chosen from the Disaster Loss working group, from five selected countries will be administered questionnaires while testing the tool. These questionnaires will measure usefulness for practice, user friendliness, and reliability/technical issues. Workshop testing results will be available by November 2017. Based on lab testing results, our tool will be adapted to fit the needs of users. **Operational Testing**: After the final version is developed, we will use social media and other dissemination materials to promote the tool and raise awareness. An end-of-year assessment will be carried out in December 2018. Included in the assessment will be qualitative results from a questionnaire distributed to country representatives and data users to evaluate the tool for improvements. The operational indicators are described in Table 4-2 and will be used to evaluate innovation

<table>
<tr><td></td><td>usability and user-friendliness.</td></tr>
<tr><td>Test Results</td><td>
On the 7th of November, a workshop was held to lab-test the eEM-DAT platform prototype during the 10th EU Disaster Loss Data Working Group event, which was held from November 6-8, 2017. This workshop was developed in collaboration with KU Leuven and Technical University Delft. However, due to limited avaibility of dates, they were not able to attend the workshop, but we maintained the workshop as we needed to keep the BRIGAID project timeline. Overall, there were around 20 participants. From UCL, the workshop was planned, organized, and carried out by Dr. Joris van Loenhout, Pascaline Wallemacq, and Alexandria Williams. B12 Consulting, the company that developed the platform, were also attended to assist with the event. The persons present from B12 Consulting were Michel Herquet, Simon Weisser and Mihailo Backovic. We received generous support from Laura Schmidt from ECHO and Afonso do Ó from the Joint Research Centre, in preparing for the event.

The agenda of the workshop was to:

1) Inform participants on the importance of reporting on disaster impacts and the new platform through a presentation and poster (30 minutes);

2) Demonstrate the platform (30 minutes);

3) Provide an interactive session to participants to test the device (1 hour);

4) Allow the participants to provide their feedback in the form of a discussion session and online survey (45 minutes).

</td></tr>
</table>

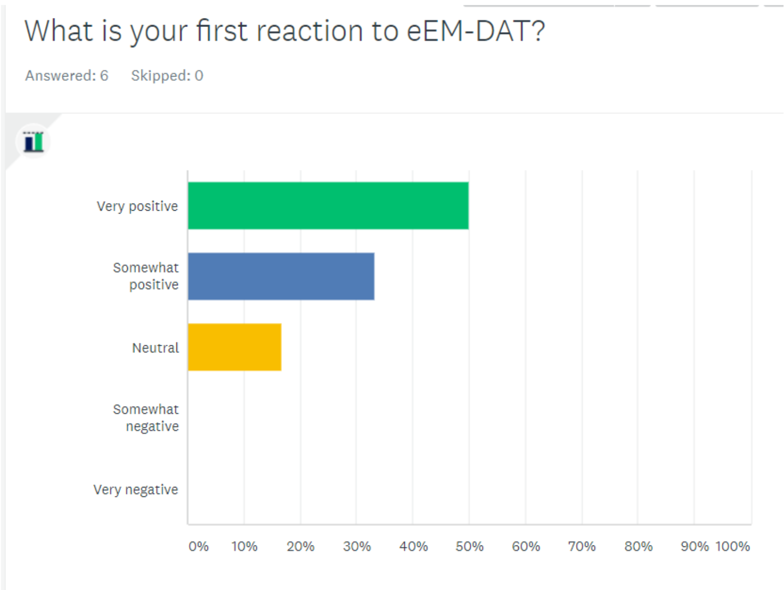
Feedback:

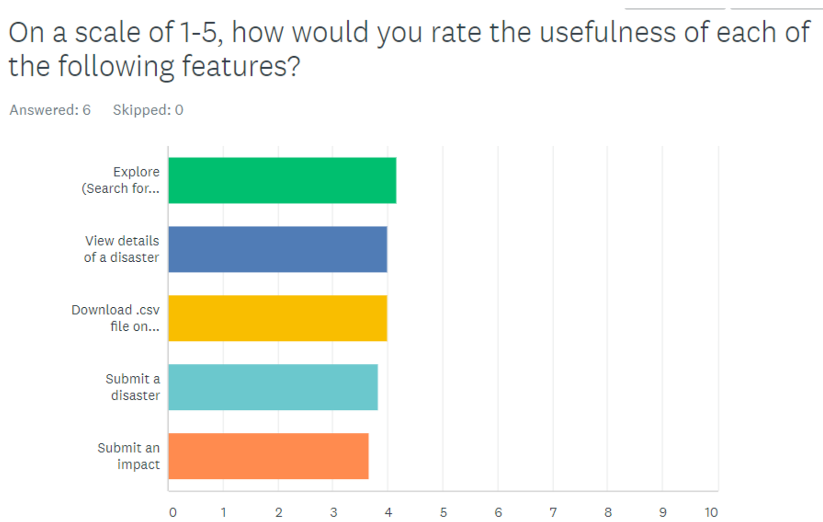
During the discussion session, comments were received with the most notable listed below. Some points will be discussed further in the section on "Challenges."

- Limited platform functionality within Mozilla Firefox and Internet Explorer web browsers; the platform worked best with Chrome.
- Several participants wanted the option to complement the tool with an already established national system. They wanted to import their data into eEM-DAT, instead of entering manually.
- The question was raised what the added value for countries is to share their data and use this system on a voluntary-basis. This also brought up the point of who would be responsible at the country level. It will be challenging to find ONE responsible country manager.
- It can be complex to collect information at regional level and data are instead usually collected by hazard/disaster type. For the local level, this must be collected individually as it is not well reported.
- Who would end-users be? Some participants suggested citizens or people working within education and research at the university level.
- People raised questions about data reliability, especially for risk assessment and quantative data analysis.

Survey results:

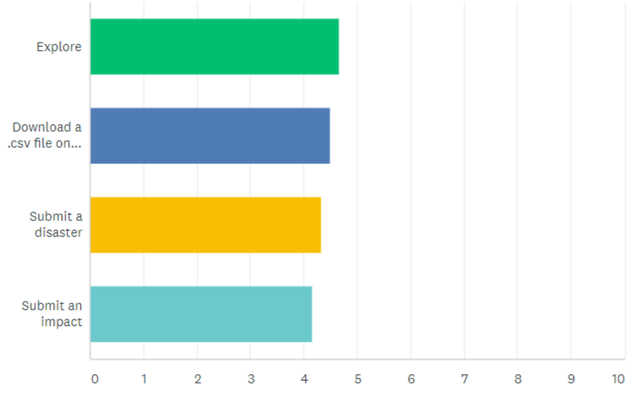
The online survey was completed by six participants. The overall feedback was positive and most thought eEM-DAT would be useful for themselves or for other acquaintances:





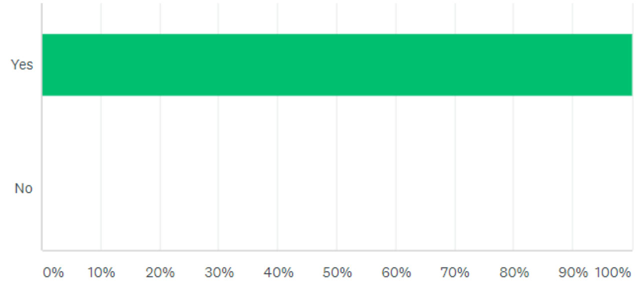
On a scale of 1-5, how would you rate the ease of use for each of the following features?

Answered: 6 Skipped: 0



Would you use this platform in your work?

Answered: 6 Skipped: 0



Challenges:

Three main challenges revolve around what the added value is for a country, who is responsible for managing the platform at the national and sub-national levels, and who the end-users are.

Overall, this particular group did not consider themselves responsible for implementing the tool in their country, and it was difficult for them to point out who would be. They stated it is already an issue to determine which governmental department would be responsible for this and finding just one country administrator would be difficult. Furthermore, many see filling out the information as a burden, instead of something that would make their work easier, e.g. since they have to report on similar indicators for Sendai.

Moving forward with the project, we will need to strategize and rethink the targeting of countries and how to present the value of the tool. The questions to explore further are: Who, within the country, do we target? And how do we show them the added value of the tool? Once data is being entered by countries, its use by end-users will follow.

Additional Tests	

Required/Proposed Future Tests	

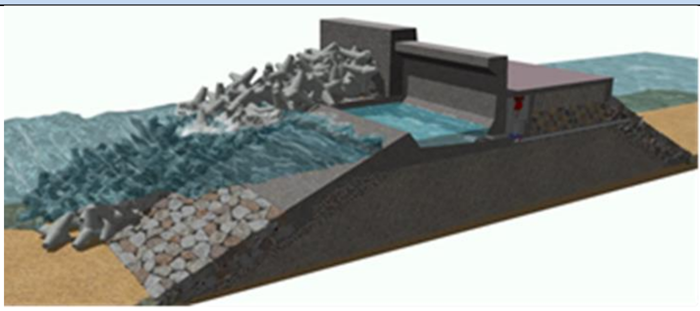
2. Innovation: OBREC - Overtopping Breakwater for Energy Conversion

Innovator: University of Bologna (UNIBO) (BRIGAID consortium partner)

Contributing authors: Barbara Zanuttigh (UNIBO), Giuseppina Palma (UNIBO)

Innovation description

The description of OBREC below is also available from the Climate Innovation Window, http://climateinnovationwindow.eu/innovations/obrec

Name
OBREC: Overtopping BReakwater for Energy Conversion
Short description
Overtopping BReakwater for Energy Conversion. OBREC was developed and patented by the Second University of Naples, IT. It consists of a rubble mound breakwater with a front reservoir designed to capture the overtopping waves in order to produce electricity.
Sketch/Photograph of the Innovation

Which hazard(s) is the innovation designed to mitigate?
Coastal floods
How does the innovation work?
To overcome the high costs of installations of Wave Energy Devices and of the energy transfer to the shore, an innovative solution has been developed by the Second University of Naples. This Overtopping BReakwater for the Energy Conversion (OBREC) is a multifunctional device, which combines harbor protection and energy production. The OBREC device consists of a concrete top element, which can be installed in new or existing breakwater, e.g. during maintenance operations. It is provided with a sloping plate that conveys the overtopping waves inside a reservoir, which later flow in the rear chamber, where the turbines should be installed. The front reservoir captures the overtopping waves to produce electricity. The energy can be then extracted via low head turbines, which should be powered by a constant hydraulic head. During the BRIGAID project, the OBREC cross section should be optimized in

order to improve its performance, i.e. minimize the risk and increase the energy production in terms of discharges rates flowing inside the rear chamber. The electrical components could be investigated only once the final configuration is defined. Since part of the overtopping waves is absorbed by the system, the OBREC device reduces the overtopping discharge at the rear side of the structure, thanks also to the crown wall located at the end of the reservoir and provided with a parapet, which redirects the waves inside the reservoir and towards the sea. The OBREC device therefore reduces the risk of flooding and increase the level of safety of the port area.
Added value / main differentiating element from conventional approach(es)
Other onshore devices have been installed in the recent past in Europe without becoming a commercial opportunity. For instance, REWEC3 is another wave energy converter integrated in harbor defence. OBREC is an overtopping device, while REWEC3 is an oscillating water column device (as well as Pico, Limpet, etc). The OBREC can be designed and installed also when doing maintenance and does not require the adhoc construction of caissons breakwaters as the REWEC3.
Critical success factors / Limitations

Desk study

Technical effectiveness

1. How will the innovation reduce the **risk** of [**hazard**]? (Select all that apply)
   ☐ decrease probability of occurrence of the hazard, for example by:
      ☐ reduction in load(ing)
      ☐other(s): ____
   ☑ decrease exposure, for example by:
      ☑ reduction in the area affected
      ☑ other(s): reduction of flood depths and velocities
   ☐ decrease vulnerability, for example by:
      ☐ increase in lead time
      ☐ increase in adaptive capacity
      ☐ increase in knowledge and/or awareness
      ☐ changes in human behavior
      ☐ other(s): ____

2. What is the intended (quantitative) level of **risk reduction**? (Select all that apply and fill in the blank)
   ☐ reduce water level by ____ (units)
   ☐ reduce flow velocities by ____ (units)
   ☐ increase lead time by ____ (units)

☐ increase water quality by ____ (units)

☐ decrease water evaporation by ____ (units)

☐ decrease temperature by ____ (units)

☐ other(s): ____

☑ N/A: the innovation's risk reduction cannot be quantified in terms of units of measurement.

N.B. In our case, the risk reduction is compared to a traditional rubble mound breakwater and can be evaluated as percentage of flooding depths and velocities.

3. Has the innovation been tested previously and can the innovation achieve the [**intended level of risk reduction**] without failure?
☑ Yes. TRL level 5 (per the definitions used by BRIGAID; from Q1)

☐ No.

Reusability

1. Is the innovation (select one):
☑ permanent

☐ semi-permanent

☐ temporary

N.B. The potentially semi-permanent components of the device, i.e. the turbines, will not be installed during the BRIGAID project. Therefore, it is hard to assess which could be the response of the these components during the extreme events (i.e. questions 8, 9 and 10).

2. What is the expected lifetime of the innovation (all types) based on its components.

50 years (units: e.g., number of hazard events, days, months, years)

3. Describe the maintenance required for the innovation to reach its maximum lifetime. (Upload any maintenance and operation protocols which are already available)

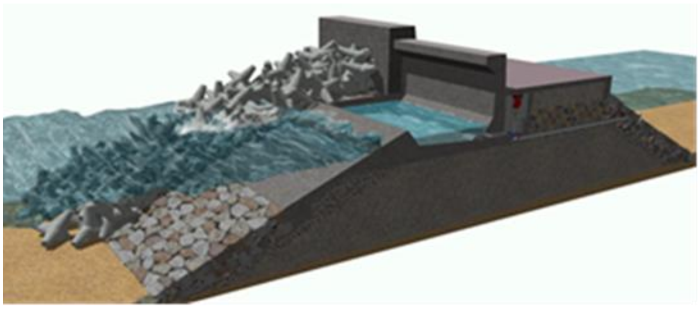
Cleaning the exposed surfaces and specifically, the pipe holes from fouling and potential sedimentation. These information are related to the permanent structure, i.e. what will be investigated during the BRIGAID project.

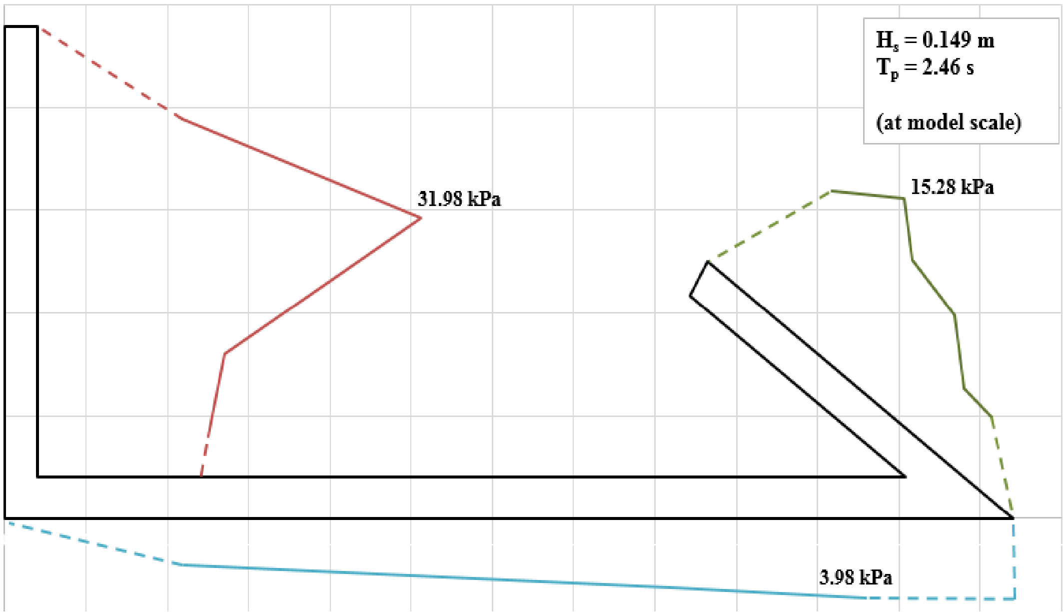
☐ Yes, I have uploaded additional operation and maintenance documents.

☑ No, I have not.

Reliability

1. Draw a diagram showing the operation of the innovation and the design loads acting on the innovation.





2. Generate a fault tree.
   a. Identify all possible technical failure modes of the innovation (Select all that apply)
      ☑ overtopping/overflowing
      ☐ instability
         ☐ vertical
         ☐ horizontal
         ☐ rotational

N.B. This aspect was already addressed during the design/construction of the pilot plant.

☑ seepage/leakage/piping

☐ structural failure

☐ debris impacts

☐ components fail

☐ other(s): ___________

b. If the innovation is **semi-permanent or temporary**, identify the implementation failure modes (Select all that apply)

☐ installation

☐ necessary installation equipment missing/malfunctions

☐ obstruction of implementation site or innovation

☐ human error

☐ component installed incorrectly

☐ insufficient time

☐ other(s): ___________

N.B. The potentially semi-permanent components of the device will not be investigated during the BRIGAID project. However, the reduction of the effectiveness of the device, i.e. how the rear chamber behaves during the extreme events, will be analyzed monitoring the pilot plant.

3. Rank the failure modes in order of importance (greatest to least) (i.e., identify the primary failure modes).

❶ Piping

❷ Overtopping

4. Identify a testing facility (or laboratory) (from Q2)

Pilot site in the port of Naples (Italy).

5. Describe whether all failure modes can be addressed and all intended design/functionality (and hazards (e.g., waves)) can be tested in the testing facility (e.g., waves and debris impacts). List all failure modes which cannot/will not be tested.

Based on laboratory experiments, OBREC device has already overcome stability tests. The pilot site will allow to verify the dynamics between the reservoir and the rear chamber during the extreme events. This aspect will affect the effectiveness of the device, i.e. the energy production and the risk minimization. It will not be

TIF Tool results

1	Technical Readiness	0%	25%	50%	75%	100%
1.1	**Effectiveness**					
1.1.1	The innovation reduces 100% the exposure to the hazard			√		
1.1.2	The innovation reduces 100% the vulnerability to the hazard			√		
1.1.3	The confidence level that the innovation is 100% effective also considering climate change scenarios is high			√		
1.2	**Reusability**					
1.2.1	The innovation is permanently operated (withstand the hazard event and daily loading with minimal repairs)/implemented					√
1.2.2	The innovation is operating only during the event	√				
1.2.3	The innovation is temporarily used prior and during the event	√				
1.3	**Reliability**					
1.3.1	The confidence level that the innovation fulfiffs its intended function is high					√
1.3.2	The confidence level that the innovation properly works in correspondence with the event is high					√
1.3.3	The innovation has not reached a sufficient testing level		√			
1.4	**Exploitability**					
1.4.1	The innovation can be installed / used in different sites across Europe without adjustments	√				
1.4.2	The innovation requires minimum adjustments to be installed /used in different sites across Europe (no new tests / upgrade involved)				√	
1.4.3	The innovation requires new testing / substantial upgrade if used in different sites across Europe		√			
1.5	**Costs**					
1.5.1	The innovation is modular (opposite: monolythical)					√
1.5.2	The innovation requires components designed ad hoc / specific materials			√		
1.5.3	The innovation is likely to withstand with minimal maintenance			√		
1.6	**Innovation**					
1.6.1	The innovation benefits 100% of the techincal synergies deriving from the share of different functions (for instance, risk reduction and reduction of CO emissions or enhanced recreational activities)				√	
1.6.2	The innovation is the demonstration of a 100% new concept				√	
1.6.3	The innovation uses innovative materials	√				

2	Societal Readiness	Yes/No	Score	Readiness	Close
2.1	**Psychometric Risk Factors**		**2**	**Far**	
	1. Does your innovation use any materials that might be considered unfamiliar (such as nanomaterials or genetically modified materials)? Yes or no	No	1		
	2. Will members of the public affected by your innovation be the ones to decide whether or when to use it? Yes or no	No	0		
	3. Does your innovation involve visible infrastructure (such as physical barriers) or visible land use changes (such as woodland removal)? Yes or no	Yes	0		
	4. Could the deployment of your innovation disrupt daily activities, for example through road closures? Yes or no	No	1		
2.2	**Inflexibility Indicators**		**3**	**Far**	
	5. Does your innovation require large amounts of capital investment? Yes or no	Yes	0		
	6. Does your innovation require a long lead time between users placing an order and it becoming operational? Yes or no	Yes	0		
	7. Does your innovation require new infrastructure or significant changes to existing infrastructure? Yes or no	No	1		
	8. Does your innovation involve releasing any materials into the environment (such as sprays or coatings)? Yes or no	No	1		
	9. Are your potential users likely to have a single mission, for example to protect ecosystems? Yes or no	No	1		
2.3	**User Accepance Constructs**		**4**	**Close**	
	10. Does your innovation take less time to deploy than incumbent alternatives (such as sand bags for floods or fire nozzles for wildfires)? Yes or no	No	0		
	11. Would the use of your innovation require special training? Yes or no	No	1		
	12. Will help and support be available to users of your innovation? Yes or no	Yes	1		
	13. Innovations can either reinforce or change users' existing ways of working. Does your innovation reinforce existing ways of working? Yes or no	No	0		
	14. Are the effects of your innovation directly publicly tangible (such as seeing flood defences working or hearing a warning system)? Yes or no	Yes	1		
	15. Adaptations can either be deployed permanently or temporarily. Is your innovation deployed permanently? Yes or no	Yes	1		
2.4	**Responsibility Dimensions**		**1**	**Close**	
	16. Are members of the public involved in shaping the research, development, demonstration and deployment of your innovation? Yes or no	Yes	1		
2.5	**Implementation Contexts for Sociocultural Preferences**	**A**	**B**	**C**	
	17. What would your innovation primarily protect? (A) public infrastructure, (B) private properties or (C) the environment	√			
	18. Who would pay for your innovation? (A) government authorities, (B) private companies or (C) local communities	√	√		
	19. Who would implement your innovation? (A) government authorities, (B) private companies or (C) local communities		√		
	20. How would compensation be made in the event of your innovation failing? Through (A) government compensation, (B) project insurance or (C) responsible parties			√	

3	Environmental Readiness	0%	25%	50%	75%	100%
3.1	**Eco-compatibility**					
3.1.1	The innovation does not require a huge footprint (area) for implementation				√	
3.1.2	The innovation is likely to result into effects (trade-offs) at local scale only					√
3.1.3	The innovation is likely to result only in temporary effects (trade-offs)					√
3.1.4	The innovation improves the landscape quality	√				
3.1.5	The innovation does not affect existing habitats			√		
3.2	**Pollution**					
3.2.1	The innovation does not include exposed components/parts that may generate debris					√
3.2.2	The innovation does not include any source of noise/vibration		√			
3.2.3	The innovation does not foresee any accidental spill of oil/other substances					√
3.2.4	The innovation does not affect water, soil, or air quality					√
3.3	**Green design**					
3.3.1	The innovation includes specific design features to reduce CO_2 emissions					√
3.3.2	The innovation includes specific design features to preserve ecosystem services	√				
3.3.3	The innovation includes specific design features to enhance biodiversity		√			
3.3.4	The innovation is 100% made of recycling materials	√				

Impacts screening

4	Impacts	0%	25%	50%	75%	100%
4.1	**Agriculture**					
4.1.1	The innovation results in an increase in area for agricultural production	√				
4.1.2	The innovation will improve the agricultural production conditions (soil quality, water availability)	√				
4.1.3	The innovation will increase the variety of agricultural production (crops, dairy farming, meat production, fruit trees, fishery, aquaculture, etc.)	√				
4.1.4	The innovation will result in higher yields of agricultural production	√				
4.2	**Energy**					
4.2.1	The production and operation of the innovation demands less energy than current measures	√				
4.2.2	The innovation will reduce energy demand (in general or for specific sectors)			√		
4.2.2	The innovation improve conditions for energy production (e.g. by favouring cooling water conditions for energy plants)	√				
4.3	**Forestry**					
4.3.1	The innovation results in an increase in area for wood production	√				
4.3.2	The innovation will improve the wood production conditions	√				
4.3.3	The innovation results in an increase in area available for non-wood production	√				
4.3.4	The innovation will improve the non-wood production conditions	√				
4.4	**Health**					
4.4.1	The innovation will reduce the number of fatalities by a reduction in exposed area		√			
4.4.2	The innovation will reduce the number of fatalities by a change in exposure characteristics			√		
4.4.3	The innovation will recuce the number of affected people (decrease exposed area)			√		
4.4.4	The innovation will reduce the number of affected people by a change in exposure characteristics			√		
4.5	**Infrastructure**					
4.5.1	The innovation does offer opportunities to increase the quality of the built environment (residential, commercial, and industrial)		√			
4.5.2	The innovation does not affect the area available for urban developement					√
4.5.3	The innovation does not affect the transport capacity (roads, railway roads and airports)					√
4.5.4	The innovation does not affect supply networks (power and water processing and management infrastructure)					√
4.6	**Nature**					
4.6.1	The innovation results in an increase in nature area	√				
4.6.2	The innovation will result in an increase in habitat types	√				
4.6.3	The innovation will improve biodiversity (more and increase of rare species, and subsequently high quality habitats)		√			
4.7	**Tourism**					
4.7.1	The innovation will result in an increase of recreational area	√				
4.7.2	The innovation will improve the recreational attractiveness of the area		√			
4.7.3	The innovation will lead to an extension of the tourism season	√				

Test plan

The activities (Phases) of the test plan already performed are described, giving an idea of which will be the work to be done during the entire BRIGAID project. The Phases are aimed to satisfy a certain Key Performance Indicator (KPI).

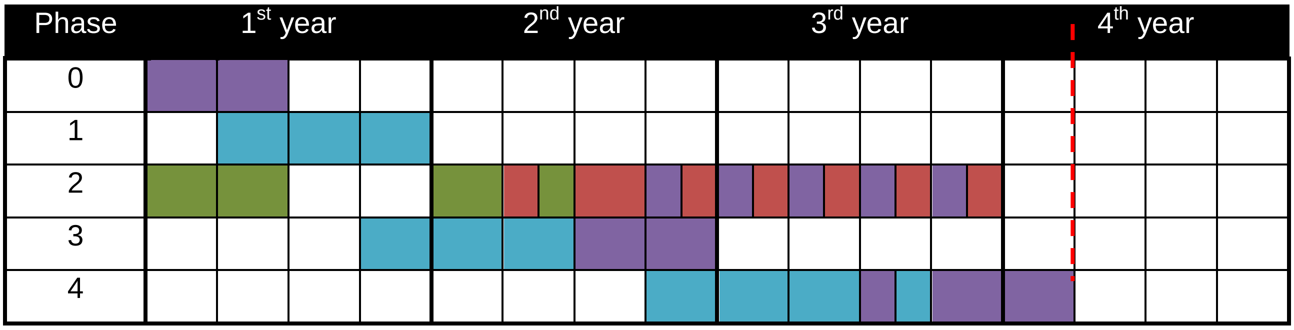
Phase 0 regards the assessment of the *effectiveness* of the innovation, performed by means of 2 laboratory test campaigns. Phase 1 involves the calibration, with a single-phase code, of a 2D numerical model (based on the laboratory tests) and a sensitivity analysis related to some geometrical parameters with respect to the hydraulic and structural performance of the OBREC device. In this Phase the intent is to maximize its *effectivness*, while investigating its *exploitability*. All the activities performed are aimed to increase the level of fullfillment of all the KPIs, and moreover the reusability.

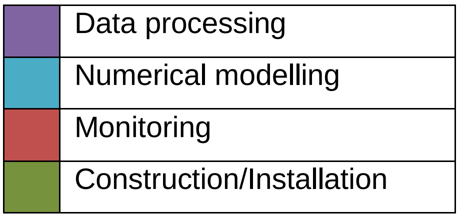
The methodologies used for the test plan involve both physical and numerical modelling.

The Technology Readiness Level (TRL) of the OBREC is 5, which by definition means that:

"*The technology is validated in relevant environment. Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so they can be tested in a simulated environment. Examples include "high-fidelity" laboratory integration of components*."

The following table describes, from a qualitative point of view, the time schedule of the activities during the entire project and the method used to be performed:





The activities are defined as Phases, and will be described specifically in the next Sections. Each Phase presents several Sub-Sections here reported:

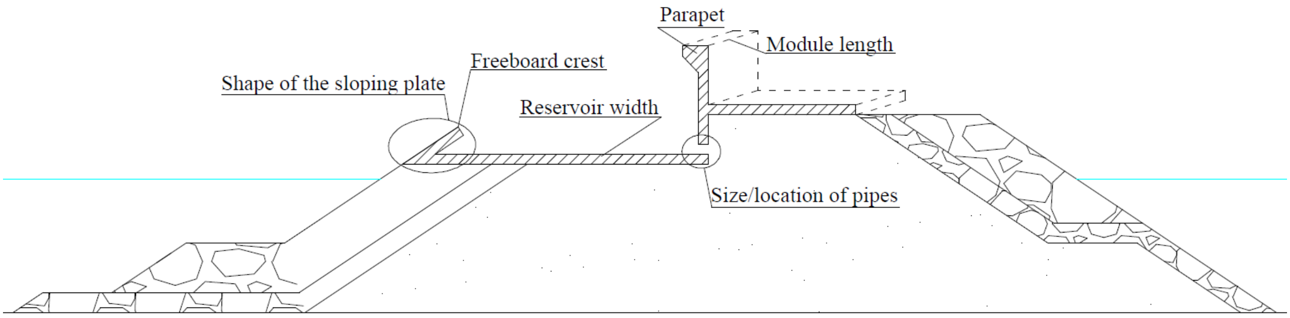
- Abstract: summary of the goals of the specific Phase/activity;
- Methodology: instruments used;
- Specific Title: description of the specific Phase/activity;
- Outcomes: the results obtained.

Next table reports, in a schematic way, how a geometrical parameters (see figure) affects a specific Key Performance Indicator (KPI). The KPIs are useful to evaluate the performance of the innovation.

Parameter	Effectivness	Reusability	Exploitability	Cost	Phase	Methods		
Parapet	√				0/1/2			

Reservoir width	√				0/1	
Shape of the sloping plate	√		√		1	
Freeboard crest	√		√		3	
Module length		√		√	4	
Size/Location pipes	√	√		√	4	

OBREC reference structure, provided with the main geometric parameters:



For this specific case, the *effectivness* is twofold, i.e. maximize the energy production and minimize the risk. Therefore, all the geometric parameters shown in the figure, except the module length, affect this KPI. The shape of the sloping plate together the freeboard crest play a key role on the *exploitability*. Their design is closely linked to a specific climate, i.e. a specific site. The *costs* are, instead, strictly related to the module length and the size/location of the pipes, which could increase the complexity of the device. Actually, these two latter parameters influences, even if not directly, the *reusability* of the device. This KPI is a metric that encompasses the functionality structural lifetime, and operation and maintenance requirements of the innovation. For the OBREC case, it is more related to the hypothetical electrical companonts, i.e. the turbines, which will not be installed during the BRIGAD project. However, the module length and the size/location of the pipes affect the dynamics inside the rear chamber (moreover during the extreme events), where the turbines will be installed. Therefore, preliminary considerations/solutions could be developed already during the BRIGAID project.

Phase 0: Assessment of the effectivness of the innovation

Summary

We present the results of the two laboratory campaigns, aimed to assess the effectivness of the OBREC device. More than 200 tests were performed, evaluating the wave reflection coefficient, the overtopping discharge rates and the pressures acting across the structure. The hydraulic and structural performance were investigated by varying some geometrical parameters related both to the breakwater and the device itself.

Methodology

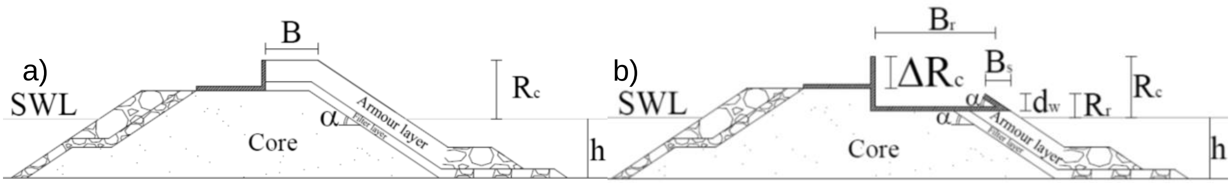
Review of the laboratory tests.

Analysis

A preliminary phase, concluded before the beginning of the BRIGAID project, consisted of 2 laboratory campaigns carried - out at the Aalborg University (Denmark) in 1:30 scale (measures reported at prototype scale in this document), in 2012 and 2014 respectively. The structures were tested under irregular wave series, containing at least 1000 waves, which were generated based on the JONSWAP spectrum.

The first campaign was focused on the difference of the hydraulic performance between the OBREC and a traditional rubble mound breakwater, previously tested by Nørgaard et al. (2013). A total of 48 tests were carried-out, considering 2 configurations, which differ only for the height of the sloping plate (d_w, in next figure), i.e. $d_{w,low}$ = 2.25 m and $d_{w,high}$ = 3.75 m, at prototype scale. The OBREC offshore slopes (armour and plate) have an inclination of α = 34° and the average size of the rocks (in terms of nominal diameter D_{n50}) are: D_{n50} = 1.5 m for the armour layer, D_{n50} = 0.6 m for the filter layer, D_{n50} = 0.06 m for the core part. The laboratory structure width at the bottom is 76.8 m and the reservoir width B_r = 18 m. The horizontal and vertical projection of the sloping plate, B_s and d_w, depend on the structure configuration, while the sloping plate and the crown wall freeboard crest, R_r and R_c, depend also on the water depth and so the wave conditions (see next table**Error! Reference source not found.**). For the extreme conditions, a special configuration rovided with a parapet (named nose), placed on top of the crown wall, was tested to reduce the overtopping discharge at the rear side of the crown wall (Van Dooslaer and De Rouck, 2010). The 2014 configurations were then all designed with such a parapet (as shown in next figure), because of its effectiveness.

Traditional rubble - mound breakwater with vertical Crown-wall face protected by armour units. b) Innovative rubble-mound breakwater with frontal reservoir for energy production (From Vicinanza et al., 2014):



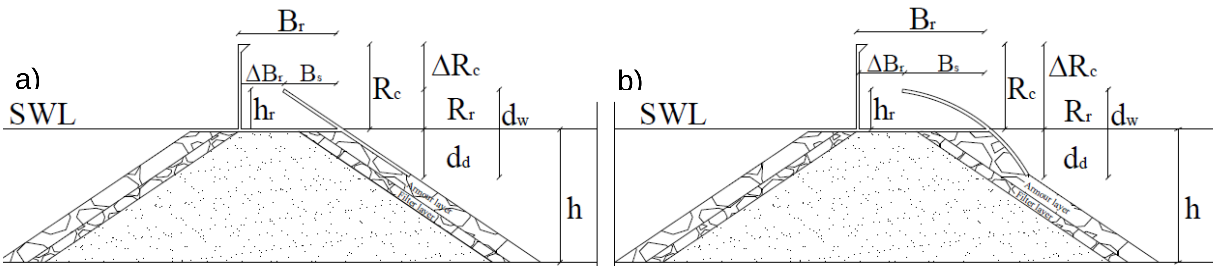
The laboratory tests of the second campaign were focused on several geometrical aspects to optimize the OBREC design, increasing the potential energy production. A total of 200 tests were carried - out, whose main characteristics are synthesised in next table. Preliminary results on the hydraulic performance have been already presented by Iuppa et al. (2016). The tested structures involved 2 different profiles of the sloping plate, as shown in the figure:

1) a flat profile with a slope angle equal to 34°, according to the research conducted by Kofoed (2005), aimed to maximize the overtopping discharge;

2) a curved sloping plate, where the slope angle varies linearly between 52° to 17°, which represents an adaptation from the convex profile tested by Kofoed (2002).

Each of this configuration was analysed by varying the distance between the crown wall and the beginning of the sloping plate ΔB_r (see figure). The following 3 values were used: ΔB_r = 3 m, i.e. small configuration; ΔB_r = 6 m, i.e. large configuration; ΔB_r = 9 m, i.e. extra-large configuration. The rubble mound material characteristics were: D_{n50} = 1.5 m for the armour layer; D_{n50} = 0.6 m for the filter layer; D_{n50} = 0.15 mm for the core.

The two configurations of the device: a) flat configuration (α equal to 34°); b) curved configuration (varies linearly between 52° and 17°):



Main wave and geometrical characteristics of the 2 laboratory campaigns, at prototype scale:

	h [m]	**H_{m0} [m]**	**$T_{m-1,0}$ [s]**	**R_c [m]**	**R_r [m]**	**B_r [m]**
2012	(min–max)	(min–max)	(min–max)	(min–max)	(min–max)	(min–max)
Extreme conditions	9 - 10.2	4.23 - 5.31	9.2 - 12.4	6 - 7.2	2.25 - 3.75	12.45 - 14.64
Extreme conditions with nose	10.2	4.35 - 4.83	9.1 - 12.5	6	1.05 - 2.55	12.45 - 14.64
Production conditions	8.1	1.11 - 4.14	5.8 - 11.7	8.1	3.15 - 4.65	12.45 - 14.64
2014						
Small structure	8.1 - 10.5	0.6 - 3.6	4.2 - 12	4.41 - 6.81	1.35 - 3.87	6.57 - 13.8
Large structure	8.1 - 10.5	1.5 - 3.9	4.2 - 12	4.41 - 6.81	1.35 - 3.87	6.57 - 13.8
Extra-Large structure	8.1 - 10.5	1.5 - 3.54	4.2 - 12	4.41 - 6.81	1.35 - 3.87	6.57 - 13.8

In both the campaigns, the measurements were aimed at obtaining:

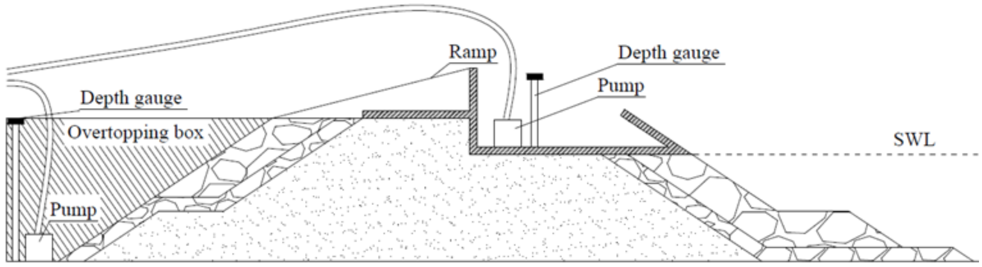
- the wave reflection from the structure, derived from 3 resistance wave gauges positioned in front of the structure, according to Klopman and van der Meer (1999) recommendations;
- the pressures across the structure, measured on the sloping plate, on the reservoir outside bottom (to evaluate the uplift pressures) and on the crown wall;
- the average overtopping discharge both at the front reservoir $q_{reservoir}$ (in ordinary conditions) and inshore the crown wall q_{rear} (in extreme conditions).

In 2012, the water overtopping the reservoir was controlled by depth gauges, which activated the pumps to allow the water discharging from the reservoir above a fixed threshold water level. The wave volumes overtopping the crown wall were collected into a box inshore the structure, where a similar control of the water discharge was performed by means of depth gauges. In both cases, the values of $q_{reservoir}$ and q_{rear} were reconstructed by the combination of the signals acquired from the depth gauges and the pumps (see next figure). It was observed that, only during the extreme tests, the lab equipment was insufficient to pump-out all the water from the reservoir. This saturated condition of the reservoir reproduces the real functioning of the device during the extreme events.

In 2014, the procedure remained the same a part for the measurement of the $q_{reservoir}$, i.e. the overtopping accumulation box was connected to the frontal reservoir by a PVC pipe that passed through the structure.

The location, the number and the size of the pipes which link the reservoir with the wave chamber (where the turbines will be installed), was not analysed during this preliminary phase. This aspect, that mostly affect the theoretical production rate, will be further investigated.

Laboratory cross section of the 2012 campaign, provided with the instruments for the overtopping discharge rates measurements (From Vicinanza et al. 2014):



Phase 1: Design optimization of the cross section to maximize effectiveness

Summary

Phase 1 involves the calibration of the 2D numerical model, by means the IH-2VOF single-phase code, according to the discharge rate in the front reservoir and the wave reflection coefficient. The calibrated model allowed to perform a sensitivity analysis focused on the reservoir width and the shape of the sloping plate, to generalize the OBREC cross section, and so the installation. Furthermore, the effectiveness of a parapet, to minimize the discharge rate at the rear site of the crown wall, was investigated.

Methodology

Single-phase 2D numerical modelling (IH-2VOF).

Calibration of the numerical model

The numerical modelling of the OBREC device, based on the 2012 campaign, is aimed to support its design optimization, improving both the hydraulic and the structural performance. IH-2VOF is a 2DV RANS-VOF single-phase code developed by the University of Cantabria (Losada et al., 2008) and it is used to calibrate and test the OBREC model. The considered tests wave conditions, i.e. ordinary and extreme ones, are reported in next table, together with the main geometrical characteristics.

Main wave and geometrical characteristics used for the numerical modelling, at prototype scale:

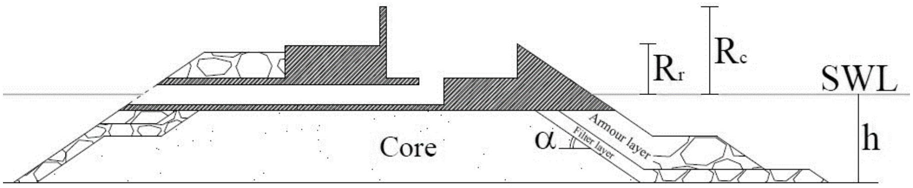
Test	**h [m]**	**H_{m0} [m]**	**$T_{m-1,0}$ [s]**	**R_c [m]**	**R_r [m]**	**B_r [m]**
	(min–max)	(min–max)	(min–max)	(min–max)	(min–max)	(min–max)
Ordinary conditions	8.1	2.31 - 4.47	7.3 - 11.4	8.1	3.15 - 4.65	18
Extreme conditions	10.2	5.79	9.9 - 12.8	6	1.05 - 2.55	18

The numerical domain reproduced the physical model tests as close as possible. Some changes to the OBREC cross section (shown in next figure) are needed to assure model stability and correct representation of the physical processes:

- to allow the emptying of the reservoir, a pipe is introduced between the reservoir and the area landward the structure, while in the physical model the overtopping discharge is pumped–out;
- to avoid numerical instabilities, the space between the plate and the reservoir is filled-in and the thickness of the upright section is increased.

The 2D numerical wave flume, 20 m long, is divided in 3 zones along the x direction and 1 along the vertical (in the y direction). It is provided with a mesh, whose resolution depends on the position of the structure and on the wave characteristics.

Schematization of the OBREC device (2012 campaign):



The calibration of the 2D model is carried - out to optimize the representation of both Kr and qreservoir at the same time, in ordinary conditions (see table).

The representation of the OBREC porous layers implied the definition of several parameters such as the porosity n, the linear friction coefficient α, the non-linear friction coefficient β, the added mass coefficient cA and the nominal diameter D_{n50}. The model calibration is performed by varying the value of n and by keeping constant all the other material parameters, which are set from the literature (Van Gent, 1995; Lynett, 2000; Hsu, 2002). The values of D_{n50} are the same as in the model tests; α is set equal to 1000, while β equals 1.1, 1.0 and 0.8 for the armour layer, the filter layer and the core, respectively. A series of simulations are carried out to achieve the best compromise between the reproduction of the experimental values of K_r and qreservoir, being the latter the reference parameter as it is the most important to assess the device operation.

During the extreme tests, it was observed that the lab equipment was insufficient to pump-out the water from the reservoir. Therefore, in the numerical modelling, the reservoir is closed to reproduce as closest as possible the laboratory conditions. The pressures are represented with $p_{2\%}$ values, i.e. the mean of the 2% of the highest values.

Investigation of the main geometrical parameters

This sensitivity analysis is focused on the relevance of the reservoir width Br and the shape of the sloping plate on the OBREC hydraulic and structural performance. It is performed considering only the 2012 dw,high configuration. Next figure shows the defined configurations, i.e. M1 - M6. Next table summarizes the geometrical characteristics of each configuration.

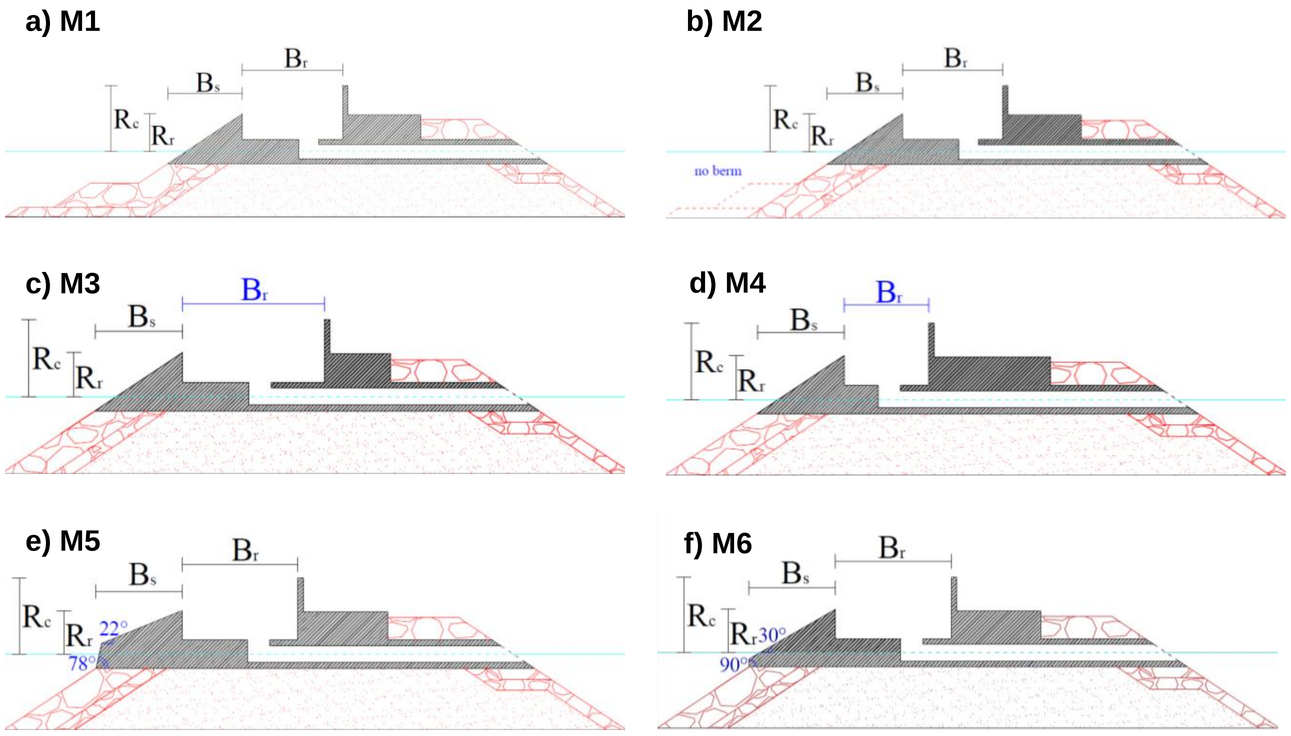
The comparison between M1 and M2 is used to assess the effect of the berm on the hydraulic and structural performance, to account the integration of this device also in existing breakwaters without berms. The other configurations focus on the effect of:

- the reservoir width B_r, to analyze the saturation of the reservoir, trying to maximize the potential energy production, the pressures acting on the crown wall and the q_{rear};
- the shape of the sloping plate, to propose a more general OBREC cross section, independent from the breakwater offshore slope, without compromising the hydraulic performance.

The basic idea is to propose an OBREC top element that can be generally applicable to different sites, by changing the parameters R_r and B_s that should be tuned on the local wave climate.

Two combined slopes were considered. The 90°+30° shape (see figure**Error! Reference source ot found.**) is adopted according to 2 research aimed to improve the development of the overtopping WECs (Nam et al., 2008; Kofoed, 2002). The 78°+22° (**Error! Reference source not ound.**e) shape was chosen not to reproduce the OBREC prototype installed in the port of Naples (which has similar characteristics), but only to show the sensitivity of the hydraulic performance to this parameter.

Original dw,high configuration (M1) (a); Conf. without a berm (M2) (b); Br = 15 m (M3) (c); Br = 9 m (M4) (d); Sloping plate 78°+22° (M5) (e); Sloping plate 90°+30° (M6) (f):



Geometrical characteristics of the configurations in previous figure, at prototype scale:

Configuration	Berm	R_c [m]	R_r [m]	B_s [m]	B_r [m]	$\alpha_{off,\ plate}$ [°]
M1	×	8.1	4.65	9.22	12.3	34°
M2	/	8.1	4.65	9.22	12.3	34°
M3	/	8.1	4.65	9.22	9	34°
M4	/	8.1	4.65	9.22	15	34°
M5	/	8.1	4.65	9.22	12.3	78°+22°
M6	/	8.1	4.65	9.22	12.3	90°+30°

Testing results

Phase 0: Assessment of the effectivness of the innovation

Physical campaign

The results obtained from the 2012 campaign show that the OBREC configuration is characterized by similar or reduced values of K_r with respect to traditional rubble mound breakwaters. The inclusion of the submerged part of the sloping plate in the 2014 design improves the overtopping rates, however it increases K_r. This increase of K_r can be also induced by the absence of the berm, according to the results obtained by Zanuttigh et al. (2009), with respect to the structure of 2012 campaign.

The overtopping discharge in the reservoir can be roughly approximated by the general formula related to a slope provided by EurOtop (2016), by including a greater friction reduction factor γ_f = 0.7 than for traditional permeable structures.

To ensure similar safety level of traditional breakwaters, the OBREC has to be provided with a parapet capable to reduce the average rear overtopping discharge qrear by 50–60%.

The selection of the best profile of the sloping plate should be further investigated to balance the energy production and the safety level of structure, i.e. reducing the q_{rear}.

Outcomes of Phase 0

The OBREC optimized design should include:

- the parapet in the OBREC crown wall;
- the extension of the sloping plate along the submerged structure slope.

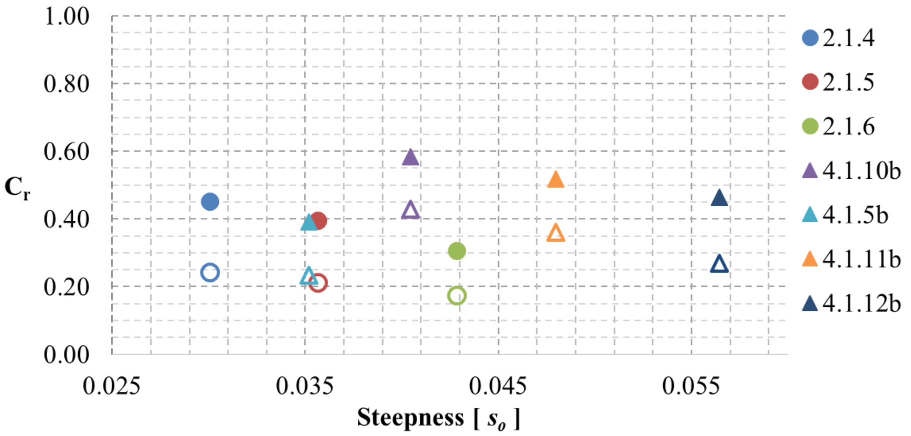
Phase 1: Design optimization of the cross section to maximize effectivness

Calibration of the model

The values of K_r are derived from 3 wave gauges positioned in the numerical flume as in the experiments, while the values of qreservoir by integrating (along the vertical) cell by cell the horizontal velocity component, measured at the end of the sloping plate, multiplied by the cell height.

Next figure shows the numerical values of K_r, which systematically overestimate the experimental ones. The deviation is on average the 35%.

Experimental vs. numerical reflection coefficients Kr:

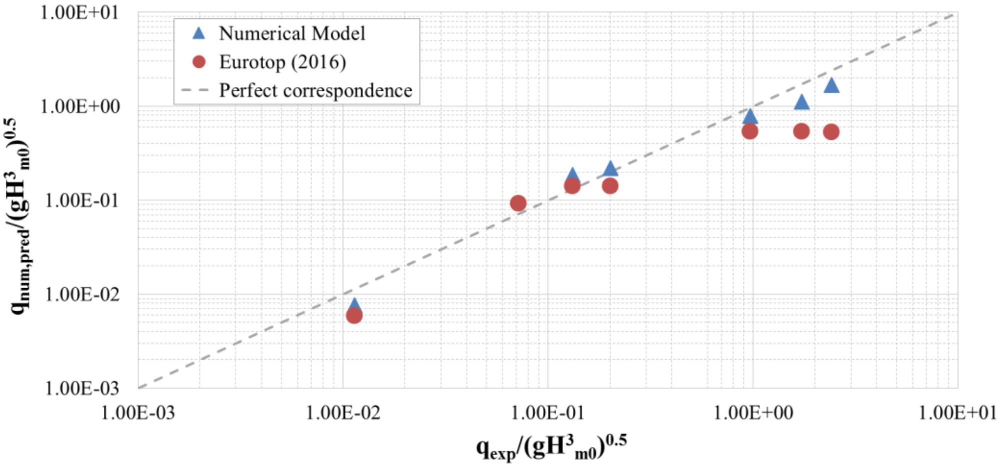


The numerical qreservoir are compared with the experimental measurements and theoretical predictions by EurOtop (2016), i.e. following equations, in next figure. The lower the values of q, the better the agreement among experiments qexp and both the numerical model qnum and the formulae qpred. With increasing q, the values of q_{num} are closer to q_{exp} than q_{pred}.

$$\frac{q}{\sqrt{gH^3{}_{m0}}} = \frac{0.023}{\sqrt{\tan\alpha}}\gamma_b \cdot \xi_{m-1.0} \cdot \exp\left[-\left(2.7\frac{R_c}{\xi_{m-1.0} \cdot H_{m0} \cdot \gamma_b \cdot \gamma_f \cdot \gamma_\beta \cdot \gamma_v}\right)^{1.3}\right]$$

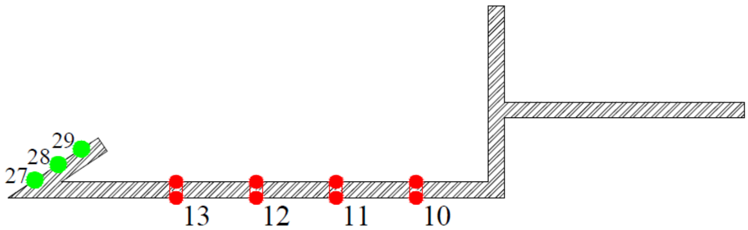
with a maximum: $$\frac{q}{\sqrt{gH^3{}_{m0}}} = 0.09 \cdot \exp\left[-\left(1.5\frac{R_c}{\xi_{m-1.0} \cdot H_{m0} \cdot \gamma_f \cdot \gamma_\beta}\right)^{1.3}\right]$$

Experimental vs. numerical vs. EurOtop (2016) average overtopping discharges in the front reservoir qreservoir (at model scale):



The pressure analysis is focused on the OBREC performance in extreme conditions (see **Error! eference source not found.**). The position of the pressures gauges is shown in next figure.

Position of the pressure transducers related to the sloping plate and the reservoir:



Error! Reference source not found. Next table reports the values of $p_{2\%}$ along the sloping plate, he bottom (uplift pressures) and inside the reservoir (downward pressures), only for the $d_{w,low}$ case. The numerical model gives cautious values with respect to the experimental ones, both for the sloping plate and the reservoir bottom part. A good estimation of the uplift pressures is very useful considering that they represent the main destabilizing force, in the overall stability of the breakwaters top element, according to the Goda theory (1973). The numerical model gives also an additional information, where no direct comparison with the experimental data is possible, i.e. downward pressures.

Values of p2% [kPa] along the sloping plate and inside the reservoir (i.e. uplift and downward values), at model scale:

Water gauges	Laboratory [kPa]	Numerical model [kPa]
27	27.6	47.1
28	40.2	42.9

29	36.3	46.8
13$_{uplift}$	48.6	61.5
12 $_{uplift}$	38.1	57.6
11 $_{uplift}$	34.5	53.4
10 $_{uplift}$	30	48.9
13$_{downward}$	/	47.1
12 $_{downward}$	/	42.9
11 $_{downward}$	/	46.8
10 $_{downward}$	/	52.5

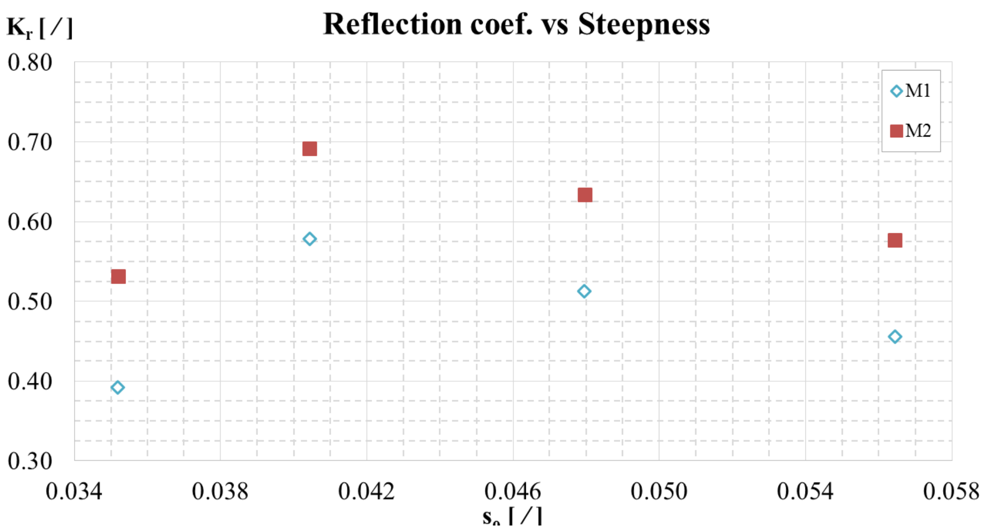
The numerical model IH-2VOF can be used to extend the experimental database and to provide indications for design optimization. The calibrated model allows to derive values of the average overtopping discharge that are well in agreement with the measurements, at least for low overtopping. The numerical reflection analysis tends to sistematically overestimate the K_r values. In extreme conditions, the uplift pressures in the reservoir and in the lower part of the sloping plate are well represented, if the structure is properly modified to reproduce the tested conditions. Numerical simulations provided information on loads acting on different part of the structure also where no experimental data are available (a.o. downward pressures in the reservoir).

The relevance of the berm

In this Sub-Section the relevance of the berm on the OBREC performance is discussed. The hydraulic and the structural behaviour of the configurations M1 and M2 is analysed in terms of K_r, $q_{reservoir}$ and pressures acting on the structure.

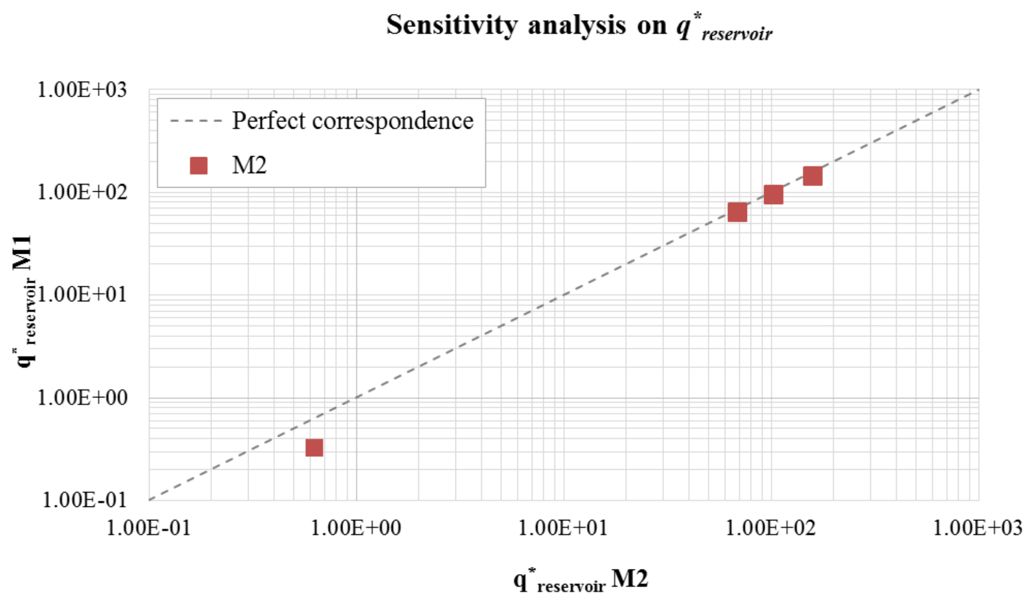
The M2 configuration shows greater K_r values than M1, for all the ordinary wave conditions (see next figure, where s_o is the wave steepness), according to the results already obtained by Zanuttigh et al. (2009).

M1 and M2 Kr results vs. the wave steepness so, under ordinary conditions only:



The OBREC performance in terms of $q^*_{reservoir}$ remains constant, as it is shown in next figure, at least for the tests characterized by the greater discharge rates. This unexpected behavior is justified by the greater measured K_r. Strong reflection of regular type of waves (swell waves) usually leads to increase the erosion of sediment at the toe of the structure. Close to shipping channels, it may also lead to hinder for navigation. Therefore, in case of OBREC installation in rubblemound breakwaters not provided with a berm, the design of a toe protection should be included.

M1 vs. M2 qreservoir, under ordinary conditions only, at model scale:



The pressure analysis is performed considering only the extreme wave conditions. The experimental and the numerical pressures are reported in terms of p_{250}, which corresponds to the non-exceedance level of about 99.7%.

As already anticipated in the previous Sub-Section, during the extreme tests, the lab equipment was insufficient to pump-out the water from the reservoir. Therefore, for this analysis reservoir is closed as in the laboratory experiments.

Next table reports the experimental and numerical pressures acting along the sloping plate, on the reservoir (i.e. uplift pressures) and at the crown wall.

Laboratory (Lab) vs. numerical uplift pressures p250, values in kPa (the numbers correspond to the gauges indicated in the next figure):

Model	10	11	12	13	14	15	6	7	8	9	1	2	3	4
Lab	49.8	46.2	43.2	43.5	54.6	58.8	62.7	56.7	55.2	45.6	82.5	80.1	81	50.1
With berm	50.4	45	39	32.7	30.3	17.4	69	63.9	58.5	52.5	65.4	53.1	45.6	29.1
Without berm	50.7	45.9	40.5	33.6	32.1	18.6	68.4	63.3	58.2	52.2	63.3	51.6	39.6	27.3

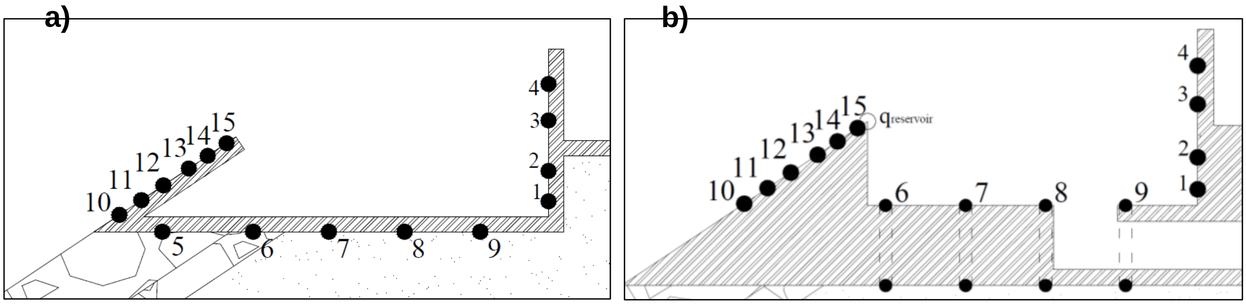
The absence of the berm does not change the general trend, leading to slightly higher statistical values, as for the downward pressures inside the reservoir (next table). The numerical models give a good estimation of the pressure values mainly in the lower part of the sloping plate and at the bottom outside of the reservoir. The discrepancy among the numerical and the experimental pressures at the crown wall increases from the bottom to the top.

Numerical downward p250, values in kPa (the numbers correspond to the gauges indicated in next figure):

Model	6	7	8	9
With berm	51.3	48	54	61.8
Without berm	51.9	48	54.9	62.1

It is important to highlight that the modelling of complex structures, such as the OBREC device, is not always sufficient to obtain the complete and accurate description of its structural response. In this study, the dynamics related to violent wave impacts with very short duration may be strongly affected by the compressibility of the air pocket (Contestabile et al., 2016). The air entrainment process was not examined in details in the lab and is not reproduced by this version of the IH-2VOF. Therefore, the actual values of the pressures at prototype conditions may substantially differ from the measurements and from the computations. The dynamics inside the reservoir and on the wall will be further investigated thanks to the monitoring of the pilot installed in 2016 in the port of Naples, combined with multi-phase numerical modelling that will be performed with the OBREC software (see Phases 2, 3 and 4).

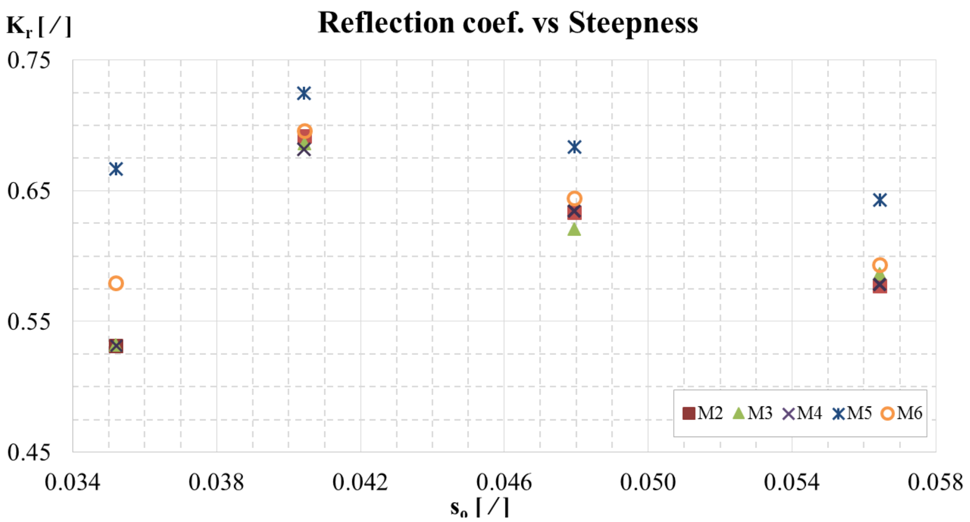
Water gauges across the structure: a) laboratory model, b) numerical model (the two cross sections have the same scale highlighting the necessary modifications to the numerical scheme):



Width of the reservoir and shape of the sloping plate

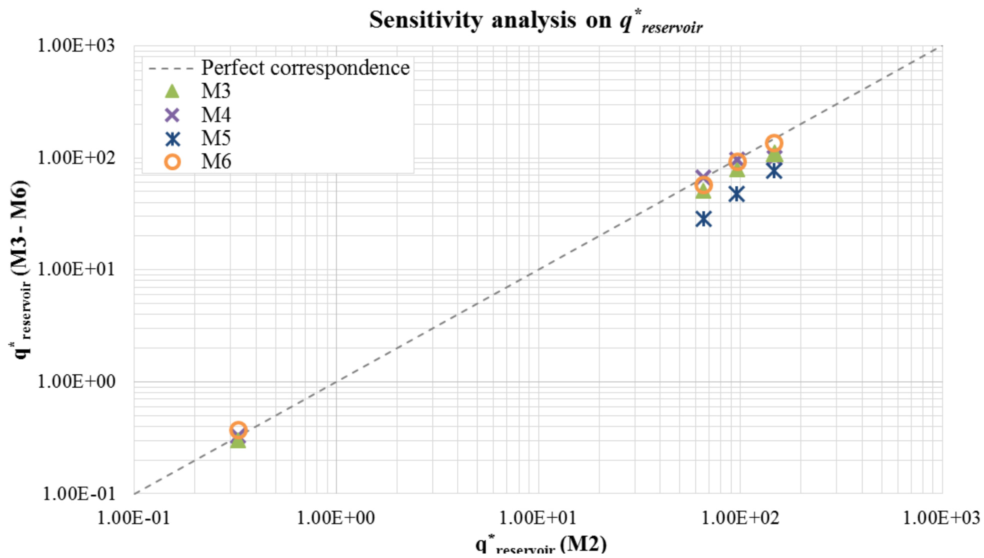
In this Sub-Section, the hydraulic performance of the M2 - M6 configurations (not provided with a berm) are here analysed in terms of $q_{reservoir}$ and K_r. The greater the overtopping, the lower the reflection. Next figure shows the values of K_r according to s_o. M3 and M4 have the same values of K_r which characterize M2, confirming that the size of the reservoir does not affect the reflection phenomenon. M6 shows values of K_r similar to M2, while M5 is characterized by the greatest values for all the ordinary wave conditions. This result can be explained because the first sloping part of the plate ends respectively above and below the still water level in M5 and in M6. Furthermore, the vertical projection of the M5 first segment (78°) is 4 times the M6 vertical part, affecting both the reflection and the run-up phenomena, reducing the overtopping discharge.

M2 - M6 Kr, under ordinary conditions only:



The $q_{reservoir}$ results related to the change of B_r (see next figure), show that M3 is characterized by an under-dimensioned reservoir, while M4 is oversized. The lowest values of $q_{reservoir}$ are achieved with M5, in agreement with the analysis of K_r. M6 gives the best values of $q_{reservoir}$ also in the case of the mildest wave attack.

M2 vs. M3 – M6 qreservoir, under ordinary conditions only, at model scale:



The assessment of the wave loads on the structure is performed by using many pressure transducers, which were placed, where possible, in the same position of the experimental ones, to perform a consistent analysis. The pressures are analyzed in terms of p_{250}, which corresponds to the non-exceedance level of about 99.7%. This statistical value are preferred because of the difference in the sample frequency of the numerical simulations, i.e. 50 Hz, and the experiments, i.e. 1500 Hz. A higher sample frequency would be needed if the numerical model considered the compressibility of the air fluid, which usually leads to the highest and more rapid peaks, not so easy to be recorded. Therefore, the lower numerical sample frequency affects the results related to those device areas particularly exposed to the impulsive wave components, such as the highest part of the sloping plate and the crown wall.

Next table reports the values of p_{250} across the structure, i.e. where the comparison with the experimental results is possible: the sloping plate, the crown wall and the bottom part of the reservoir (uplift pressures).

p250 values acting on the sloping plate, the crown wall and the bottom part of the reservoir (uplift pressures) in kPa:

Wg	M2	M3	M4	M5	M6
10	50.7	49.2	53.1	41.1	49.8
11	45.9	43.8	47.7	38.7	44.1
12	40.5	37.8	41.1	36.3	38.1
13	33.6	31.8	34.5	25.2	28.8
14	32.1	30.9	32.7	30.3	23.7
15	18.6	22.8	17.1	14.7	18.6
6	63.3	64.2	0	60.3	61.8
7	51.6	53.1	0	47.4	49.5

8	39.6	40.8	0	33.6	37.8
9	27.3	24	0	26.7	27.6
1	68.4	66	69	70.2	68.1
2	63.3	60.3	64.5	65.1	63
3	58.2	54.3	60	59.4	57.9
4	52.2	/	54.9	53.1	52.2

It is important to highlight that the underestimation of the greater values of $q_{reservoir}$ affects the evaluation of the pressures in the numerical model.

The values of p_{250} recorded along the sloping plate do not show any relevant difference among the different configurations. M3 shows generally lower values than M2, because of the backwash coming from the reservoir, which saturated before than the other configurations; while M4 values indicate the opposite behavior. Slightly lower values of the pressures are found for M5, together with M6. The peculiar shape of these two configurations leads to greater stresses on the first segment of the sloping plate profile, while lowering the pressures on the second part, which is the only one provided with pressure transducers.

The qreservoir underestimation implied a less saturated reservoir, decreasing the number of waves which directly hit the crown wall. In the case of M4, there are no pressures on the crown wall, since all the discharge is flowing down in the wider reservoir, leading to an unstressed crown wall even in extreme conditions. For M6, but moreover for M5 the same considerations related to the sloping plate values are valid. As shown in the table, all the configurations give cautious values of the uplift pressures.

The numerical model gives an additional information related to the dynamics inside the reservoir, in terms of downward pressures, where no direct comparison of numerical versus experimental data of pressures is possible. M3 shows the greatest values of pressures according to its B_r, while M4 the lower ones for what concern the second part of the reservoir according to their B_r. M5 and M6 do not show any big differences with respect to the value recorded by the M2 configuration.

Pressures acting inside the reservoir in kPa, with the same abscissa of the pressure transducers related to the uplift pressures:

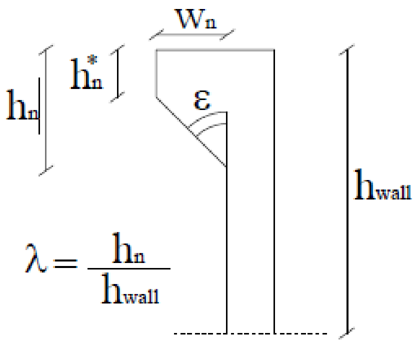
Wg	M2	M3	M4	M5	M6
6in	51.9	55.2	52.5	52.2	53.1
7n	48	52.5	46.2	47.7	48.6
8in	54.9	61.8	49.2	54.9	54.6
9in	62.1	/	54.9	59.4	60.3

Harbor safety

The harbor safety is evaluated in extreme conditions in terms of q_{rear}, which represents the average overtopping discharge at the rear side of the crown wall.

In the 2012 campaign, the OBREC showed greater q_{rear} values compared to a traditional rubble mound breakwater with similar overall dimensions. To reduce the q_{rear} affecting the harbor side, the introduction of a parapet was preferred with respect to an increasing of the height of the crown wall. As a matter of fact, it was observed that the parapet redirects the up-rushing waves back into the front reservoir. It has been designed according to the research conducted by Van Doorslaer et al. (2015). The influence of the geometrical parameters such as the height of the wall and of the nose and the angle of the parapet, i.e. h_{wall}, h_n and ε in next figure, were investigated (Van Doorslaer & De Rouck, 2010). An optimal angle which combines a good reduction of the q_{rear} and not too high uplift forces was found for ε values of 30° to 45°. Although the parameter ε is the dominant geometric variable, wave overtopping also decreases when the nose of the parapet h_n is greater, and thus when λ increases (see figure). Best reduction was achieved for λ ≥ 0.3. Therefore, two parapet configurations were considered, i.e. λ = 0.3 and ε = 30° and 45°. In both the cases, the total height of the parapet h_n is equal to 1.98 m, while h^*_n (see figure) was set equal to 0.6 m for a correct representation of the parapet geometry. The resulting thickness of the parapet w_n is equal to 0.72 m and 1.38 m, for ε = 30° and 45°, respectively. The measures are reported at prototype scale.

Parapet provided with the main geometrical parameters:



Next table reports the q_{rear} results with and without the parapet. Considering the results related to the simple crown wall, the reservoir width B_s is the geometrical parameter that mainly affects the overtopping on the rear side of the crown wall (see M3 and M4 results). A relative decrease of B_s of 25% results in increasing of the q_{rear} value of the 40%. Enlarging B_s up to a 25% resets the value of q_{rear}. The shape of the sloping affects has a minimum effect on q_{rear}, as for instance the M5 case.

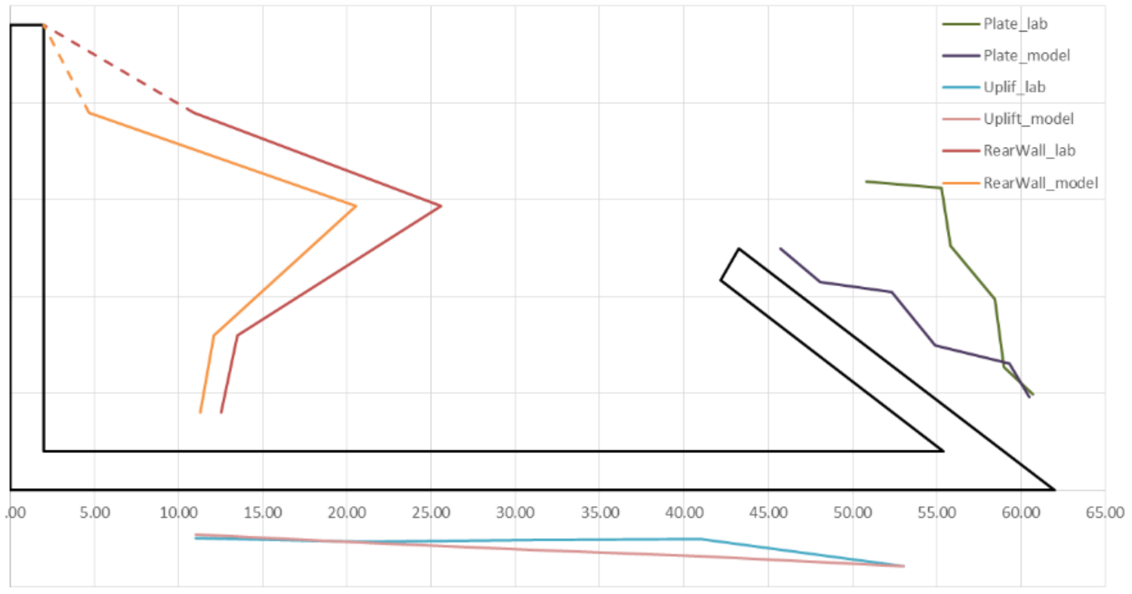
Average overtopping discharge at the rear side of the crown wall, without parapet, with ε = 30° and 45°:

	q_{rear} [l/s/m]					
	M1	**M2**	**M3**	**M4**	**M5**	**M6**
Crown wall	76.50	73.51	102.74	0.00	61.70	72.58
Crown wall and parapet (ε=30°)	46.01	49.30	31.22	0.00	41.08	50.94
Crown wall and parapet (ε=45°)	42.72	41.08	21.36	0.00	37.79	46.01

For the configurations provided with a parapet inclined of 30°, the reduction of the q_{rear} is on average of 34%, except for the M3 case in which is 70%. A parapet inclined of 45°, produces a reduction on average of 41% and 80% for the M3 case. Its small reservoir width does not allow the full development of the wave, increasing the reduction rate with respect to those configurations provided with a well or over-dimensioned reservoir.

However, the OBREC performance in extreme conditions cannot be evaluated considering only the absolute values of q_{rear}, but also the consequences in terms of pressures inside the reservoir. The parapet returns the up-rushing wave seawards, passing in this case through the reservoir. This new dynamic results to increase the pressures acting on the crown wall.

Next figure shows the comparison between the laboratory and the numerical maximum pressures:



It shows qualitatively the pressures acting on the crown wall of the M6 structure according to the configurations considered. The location pressure transducers was maintained the same of the laboratory (already shown before) to make a consistent analysis. As expected the greatest increment is in correspondence of the gauge 17 and 22 where a direct contact between the wave and the parapet occurs.

Outcomes of Phase 1

The OBREC optimized design should include:

- the presence of a toe in case OBREC is installed in a breakwater without a berm;
- the parapet with 30° inclination in the crown wall.

Improvements of the OBREC effectiveness in terms of productivity and of the OBREC exploitability can be achieved with the combined 90° + 30° inclination of the sloping plate.

Improvements of the OBREC effectiveness in terms of risk reduction can be obtained with a sufficiently narrow reservoir that is operating full-section for most of the year. This issue is further investigated in Phases 2 and 3.

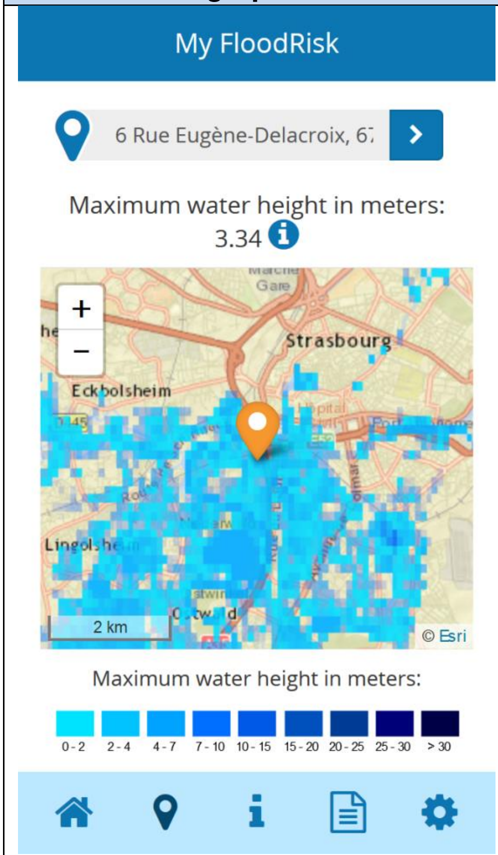
3. Innovation: MyFloodRisk

Innovator: HKV Consultants (BRIGAID consortium partner)

Contributing authors: Teun Terpstra (HKV Consultants)

Innovation description

The description of MyFloodRisk below is also available from the Climate Innovation Window, http://climateinnovationwindow.eu/innovations/my-flood-risk

Name
My Flood Risk?
Short description
Series of mobile phone apps showing potential flood depths thoughout the EU
Sketch/Photograph of the Innovation

Which hazard(s) is the innovation designed to mitigate?
River & coastal floods: In the EU many citizens are at risk of floods from rivers, seas and heavy rainfall. Reliable, science based information does exist, such as the EU Flood Directive maps. Unfortunately, these maps are

non-uniform, of various methodologies, scenarios, coverage, resolution, and without climate change projections. On top of it their availability as reusable GIS files is extremely limited. Hence, online pan-European floods maps that can be easiliy accessed by researchers, businesses and citizens are still unavailable. The EU FP7 project RAIN therefore developed pan-European maps for various hazards for a set of defined time periods and climate scenarios using EURO-CORDEX climate data. Based on these data, HKV Services launches a series of apps providing this information in a user friendly and clear manner, for each country in the EU. The innovation is related to the following themes: Disasters and ICT: ✓ software or IT-product/components to process or present information ✓ informational and education aspects to increase knowledge and awareness
How does the innovation work?
The app is available per EU country in the app stores. For each country there is a basic app containing the flood depths with an estimated return period of 10 years, based on the IPCC climate predictions for the period 1971-2000. A series of pro apps also contain data for longer return periods (30, 100, 300, 1000 years) and future climate projections (2050, 2100). The Pan-European flood maps were prepared within project “Risk Analysis of Infrastructure Networks in response to extreme weather” (RAIN). RAIN received funding from the European Union’s Seventh Framework Programme for research, technological development and demonstration under grant agreement no. 608166.
Added value / main differentiating element from conventional approach(es)
EU citizens are provided with easy access to science based information about one of the most destructive natural hazards in the EU, through modern day technology. It stimulates awareness of floods, and provides a starting point for modern day risk communication by local authorities. HKV invites national, regional and local authorities in the EU to validate the data against local data sets.
Critical success factors / Limitations
Presented data from the RAIN project were made using large-scale datasets and are intended for providing an European-wide overview of present and future probability of occurrence of extreme weather hazards. Extreme caution should be made when drawing local-scale conclusions from the maps. No liability is accepted for any errors or omissions in the data or associated information and/or documentation. HKV invites national, regional and local authorities in the EU to validate the data against local data sets.

Technology Readiness Level (TRL)

TRL6 : The apps are launched in the summer of 2017. The software is already completely tested and reliable, as the app is based on the existing Dutch equivalent OverstroomIk? Improvements or updates are based on user experiences and feedback, e.g. with regard to language and functionality. HKV invites national, regional and local authorities in the EU to validate the data against local data sets.

Desk study

Technical effectiveness

4. How will the innovation reduce the **risk** of [**hazard**]? (Select all that apply)
☐ decrease probability of occurrence of the hazard, for example by:

    ☐ reduction in load(ing)

    ☐other(s): ____

☐ decrease exposure, for example by:

    ☐ reduction in the area affected

    ☐ other(s): reduction of flood depths and velocities

☑ decrease vulnerability, for example by:

    ☐ increase in lead time

    ☐ increase in adaptive capacity

    ☑ increase in knowledge and/or awareness

    ☐ changes in human behavior

    ☐ other(s): ____

5. What is the intended (quantitative) level of **risk reduction**? (Select all that apply and fill in the blank)
☐ reduce water level by ____ (units)

☐ reduce flow velocities by ____ (units)

☐ increase lead time by ____ (units)

☐ increase water quality by ____ (units)

☐ decrease water evaporation by ____ (units)

☐ decrease temperature by ____ (units)

☐ other(s): ____

☑ N/A: the innovation's risk reduction cannot be quantified in terms of units of measurement.

6. Has the innovation been tested previously and can the innovation achieve the [**intended level of risk reduction**] without failure?
☑ Yes

    The app is based on the Dutch app "OverstroomIk" (see https://www.hkv.nl/nl/werkvelden/veiligheid-en-crisisbeheersing/57-overstroom-ik.html). MyFloodRisk is intended for the European market and therefore the data, how the data are organized in the app and the business model are different The app therefore contains new features and functionalities that must be developed and tested.

☐ No.

Reusability

1. Is the innovation (select one):
   ☐ an early warning system (i.e., information is delivered to the end user)

   ☐ a monitoring system (i.e., information is retrieved by the end user)

   ☑ other: an app informing citizens and businesses about the potential flood depths at their location

2. Is the innovation (select one):
   ☑ continuously operated (i.e., data are always available)

   ☐ only operated prior to/during a hazard event

3. If the innovation is **only operated prior to/during a hazard event**, describe the intended operation (protocol) of the innovation.

   Not applicable

4. What is the expected lifetime of the innovation (all types) based on its components.

   _____ (units: e.g., number of hazard events, days, months, years)

   The lifetime depends on the availability of newer and/or better data. Current data originate from the EU RAIN project. In some countries other (better) data sources are available.

5. Describe the maintenance required for the innovation to reach its maximum lifetime. (Upload any maintenance and operation protocols which are already available)

   Maintenance relates to 1) data quality, 2) compatibility when individual software components are updated, 3) incorporating user feedback. No protocols are needed.

   ☐ Yes, I have uploaded additional operation and maintenance documents.

   ☑ No, I have not.

Reliability

1. Generate a fault tree or FMECA
   a. Identify all possible technical failure modes of the innovation (Select all that apply)
      ☑ system under/overpredicts hazard

☐ lead-time is too short

☐ warning delivery or monitoring advisory is delayed

☑ other(s): limited server capacity when too many people use the app at the same time

b. If the innovation is **only operated prior to/during a hazard event**, identify the implementation failure modes (Select all that apply)
☐ end-user fails to act on warning (this does not apply to monitoring systems)

☐ other(s): ___________

2. Rank the failure modes in order of importance (greatest to least) (i.e., identify the primary failure modes).
   1. The features and functionalities in the app do not work properly (in a technological sense). E.g., the presents an incorrect flood map.
   2. The data presented by the app are not correctly interpreted
   3. The data in the app are not in line with local information (e.g., developed as part of the Flood Directive) leading to misperceptions, disbelief or ambiguity among users
   4. The server capacity is limited leading unavailability of requested information (from the Geo Server)

3. Describe whether all failure modes can be addressed and all intended design/functionality can be tested. List all failure modes which cannot or will not be tested.

All failure modes can be addressed:

No.	Failure	Solution
1	The features and functionalities in the app do not work properly (in a technological sense). E.g., the presents an incorrect flood map.	In-house usability tests by independent testers (i.e., not the developers)
2	The data presented by the app are not correctly interpreted.	In-house (and possibly out-house) usability tests by independent testers (i.e., not the developers)
3	The data in the app are not in line with local information (e.g., developed as part of the Flood Directive) leading to misperceptions, disbelief or ambiguity among users.	Include a clear disclaimer. Invite flood risk authorities to include other (better) data and discuss the app with potentially interested parties.
4	The server capacity is limited leading unavailability of requested information (from the Geo Server).	When peaks in downloads / visits occur, these will be evaluated. Additional server capacity can be connected but this is a cost / benefit decision.

4. During testing, will the innovation be calibrated and/or validated against historical events?
☐ Yes. Choose all that apply: ☐ calibrated ☐ validated

☑ No, data (flood maps for different return periods) has been developed in the EU Rain project. A possibility is to develop a crowd sourcing function to collect data on real events. This is currently not part of the app.

5. During testing, will the innovation be calibrated and/or validated for real-time events?
   ☐ Yes. Choose all that apply: ☐ calibrated ☑ validated

   ☑ No, this is currently not part of the app.

Test plan

This test plan consists of so-called laboratory tests and operational tests. The laboratory test comprise all tests that are performed before the app is launched in the Apple and Google Play stores. The operational tests comprise all tests that are performed after the app has been publised in the app stores.

No.	Failure	Solution	Laboratory / Operational
1	The features and functionalities in the app do not work properly (in a technological sense). E.g., the presents an incorrect flood map.	In-house usability tests by independent testers (i.e., not the developers)	Laboratory
2	The data presented by the app are not correctly interpreted	In-house usability tests by independent testers (i.e., not the developers)	Laboratory
		Out-house usability tests by independent testers (i.e., not the developers); e.g. in different countries	Operational
3	The data in the app are not in line with local information (e.g., developed as part of the Flood Directive) leading to misperceptions, disbelief or ambiguity among users	Include a clear disclaimer. Invite flood risk authorities to include other (better) data	Operational
4	The server capacity is limited leading unavailability of requested information (from the Geo Server)	When peaks in downloads / visits occur, these will be evaluated. Additional server capacity can be connected but this is a cost / benefit decision.	Operational

Laboratory tests

Objective

The main goal of the laboratory tests is to test the failure meechanisms #1 and #2:

No.	Failure	Solution	Laboratory / Operational
1	The features and functionalities in the app may not work properly (in a technological sense). E.g., the presents an	In-house usability tests by independent testers (i.e., not the developers)	Laboratory

	incorrect flood map.		
2	The data presented by the app are not correctly interpreted	In-house usability tests by independent testers (i.e., not the developers)	Laboratory

Tests 1 and 2

Rational
Test 1: The features and functionalities in the app may not work properly in a technological sense. E.g., the app presents an incorrect flood map. Test 2: The data presented by the app are not correctly interpreted.
Facility
In-house usability tests by two independent testers (i.e., not the developers) will be performed.
Equipment
A prototype of the app is used (in "test flight"), that is downloaded on an I-phone and Samsung phone. A checklist containing all functionalities is be used to verify all functionalities.
Protocol
The test protocol is a checklist / questionnaire that is used to collect usability data from the testers. The checklist evaluates test 1 and test 2 and determines the actions/issues that need to be addressed by the development team. The development team uses a SCRUM methodology to solve these issues. Once issues have been solved the test protocol is applied again to check that all issues have been addressed properly. If no new issues arise the test is completed. Appendix 1 contains the test protocol.
Expected Results
A few iterations are expected to solve all issues and approve the app. Once test 1 and 2 have been completed the app can be launched in the Apple and Google Play stores.

Operational tests

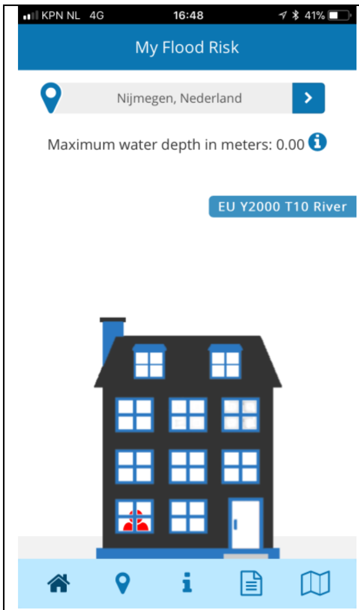
Operational tests are performed once the app has been launched in the Apple and Google Play stores. These tests will include:

No.	Failure	Solution	Laboratory / Operational
2	The data presented by the app are not correctly interpreted	Out-house usability tests by independent testers (i.e., not the developers); e.g. in different countries	Operational
3	The data in the app are not in line with local information	Include a clear disclaimer. Invite flood risk authorities	Operational

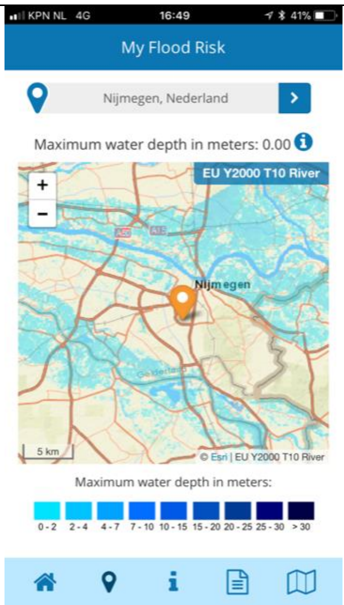
	(e.g., developed as part of the Flood Directive) leading to misperceptions, disbelief or ambiguity among users	to include other (better) data	
4	The server capacity is limited leading unavailability of requested information (from the Geo Server)	When peaks in downloads / visits occur, these will be evaluated. Additional server capacity can be connected but this is a cost / benefit decision.	Operational

Testing results

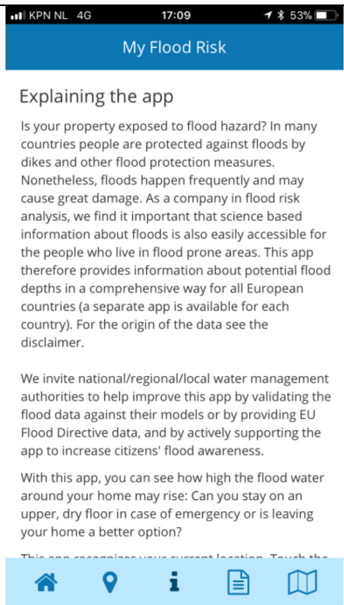
The app MyFloodRisk is based on the Dutch app OverstroomIk. The lay-out and technology are similar, but as MyFloodRisk focuses on the EU both the data and how these are organized and presented required development of new functionalities. The Table below contains print screens of the current version of the app. The information is presented in English. This version of the app was tested in Test 1 and Test 2.



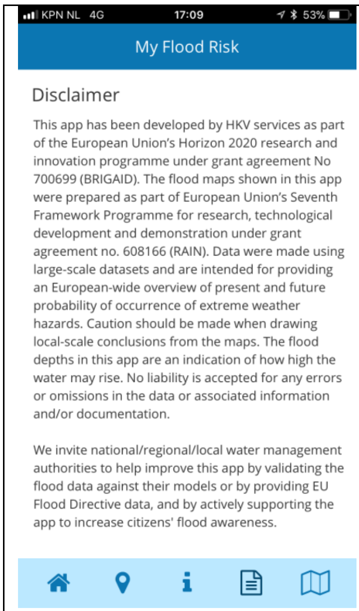
1. Home screen



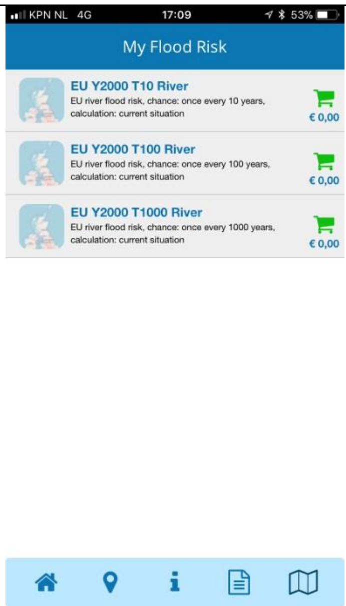
2. Map screen



3. Info screen



4. Disclaimer screen



5.Purchase/download screen

Applying the test protocol resulted the following findings:

Test 1: Technology

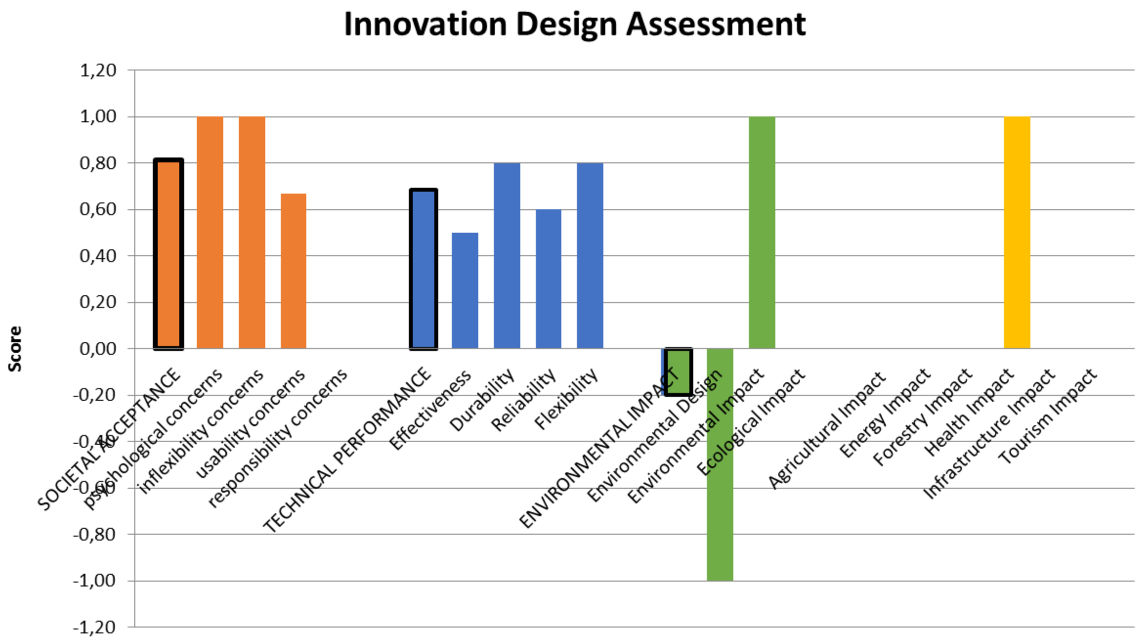
- All technological functions worked as expected, except in the information icon of the Home and Map screen where one could not return to the main page due to failure of the ‘<’ function.

Test 2: Interpretation

- Many issues were found with regard to interpretation. E.g. the app presents water depths relative to the average terrain height. This information missed so people wondered what the water depths precisely represented precisely. Also questions arose about return periods (i.e. flood probability) and climate projections.
- A number of icons were not self-explanatory and are reconsidered.
- Spelling errors were corrected and wording was improved, the info page will be rewritten after all other improvements have been implemented.

Results from the TIF Tool:

In addition to the test protocol the TIF Tool was applied to measure the TRL improvement and to check societal and technical issues for improvement, and sectoral and environmental impacts. The figure below shows the profile of MyFloodRisk.



The figure results in the following insights:

Societal acceptance

In a general MyFloodRisk received a good score except on the sub dimension “responsibility”. I.e., on the question “How would compensation be made in the event of your innovation failing?” HKV does not accept liability for errors or inaccuracies in the data, or in the accessibility of the data at all times. Especially in case of imminent flooding the experience is that traffic on the server where data are stored increases, resulting in inaccessibility.

Technical performance

Scores were generally satisfying except on effectiveness and reliability. Effectiveness is somewhat low because the app provides information and aims to satisfy citizens’ information need and increase flood awareness. Indirectly a higher flood awareness may stimulate adaptation to floods.

Reliability scored somewhat low due to potential inaccessibly in times of flood events, because traffic to server is beyond its capacity.

Environmental impact

The app MyFloodRisk has no environmental impacts. The negative and positive bar on the aspects environmental design and impact cannot be explained and likely are the result of bugs in the TIF tool. This will be fed back to BRIGAID WP5 who is responsible for improving the tool.

Sectoral impact

No direct sectoral impacts are expected. However, easier access to flood risk data may positive effects on “health” because it may lead indirectly to fewer fatalities and a lower number of people affected by floods in the future.

Technological readiness level

The picture below shows the technological development status of MyFloodRisk. The profile shows that at the start of the project the app was on TRL4. After implementation of the issues resulting from the tests the app will be on TRL6. The app is then ready for launch to the app stores which is considered as the operational environment. Subsequent tests will be performed to check functionality, obtain experiences with downloads and server capacity and approach potential parties that may be interested to further implement the app as part of flood risk policy in the EU.

TIF Tool sheet:

		To be completed at the start of the project						*To be completed at the time of interim reports*		
TRL	**Question**	**Start of Project**			**Anticipated End of Project**			**Current status**		
		Yes	**No**	**N/A**	**Yes**	**No**	**N/A**	**Yes**	**No**	**N/A**
TRL 1	**Basic principles observed and reported.**									
TRL 2	**Technology concept and/or application formulated.**									
TRL 3	**Analytical and experimental critical function and/or characteristic proof-of-concept.**									
4	Has societal acceptance testing of individual components been performed?		x		x			x		
4	Has performance of components and interfaces between components been demonstrated?		x		x			x		
4	Does draft system architecture plan exist?	x			x			x		
4	Have end user technology/system requirements been documented (e.g., reliability requirements)?	x			x			x		
4	Has component compatibility been demonstrated?	x			x			x		
4	Does technology demonstrate basic functionality in simplified environment?		x		x			x		
4	Have performance characteristics been demonstrated in a laboratory environment?		x		x			x		
4	Have low-fidelity assessments of system integration and engineering been completed?		x		x			x		
TRL 4 Achieved	**Component and/or breadboard validation in laboratory environment.**									
5	Have internal system interface requirements been documented?	x			x			x		
5	Has analysis of internal interface requirements been completed?		x		x			x		
5	Can all system specifications be simulated and validated within a laboratory environment?		x		x			x		
5	Is the laboratory environment high-fidelity?	x			x			x		
5	Have individual component functions been verified through testing?		x		x			x		
5	Have objective and threshold operational requirements been developed? (e.g., has the intended reduction in risk been quantified? Is the end-user requirement for reliability known?)			x			x			x
5	Has a Product Breakdown Structure or Fault Tree been developed? (i.e., have all potential failure modes been identified and documented?)			x			x			x
5	Has the reliability of the fully integrated prototype been estimated using desk study calculations?			x			x			x
5	Have the social, technical, and environmental design of the innovation been assessed? (TIF tool applied, i.e. stage-gate tool)		x		x			x		
TRL 5 Achieved	**System/subsystem model or prototype demonstration in a laboratory environment.**									
6	Have system integration issues been addressed?		x		x				x	
6	Is the operational environment fully known?	x			x			x		
6	Have the current and future (i.e., under climate change) hazard conditions in the intended operational environment been documented?	x			x			x		
6	Has the technical and/or climate lifetime of the innovation been estimated?	x			x			x		
6	Have performance characteristics (i.e., social, technical, and environmental) been verified in a simulated operational environment?		x		x				x	
6	Has prototype been tested in a simulated operational environment and shown to withstand the intended hazard loads *without* failure?		x		x				x	
6	Does the prototype successful reduce the intended/threshold level of risk (i.e., by reducing the hazard and/or its consequences) in a simulated operational environment?			x			x			x
6	Have the operation and maintainence protocols over the lifetime of the innovation been established and documented?			x			x			x
6	Has system been tested in realistic environment outside the laboratory?			x			x			x
6	Has engineering feasibility been fully demonstrated?			x			x			x
TRL 6 Achieved	**System/subsystem model or prototype demonstration in a relevant environment.**									

Actions for further development:

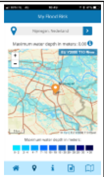
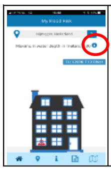
The following actions will be performed:

- Solve the issues that resulted from the tests
- Continue to the phase of operational testing
- Put effort in marketing the product by approaching potential foreign flood risk management authorities.

Test protocol:

Laboratory tes	1
Objective	Confirm that the features and functionalities in the app work properly (in a technological sense). E.g., the app presents the correct flood map.
Test	In-house usability tests by independent testers (i.e., not the developers)
Protocol	The app is downloaded on an Iphone and Samsung phone. With each phone a usability test is performed, each by another independent HKV using the protocol below employee resulting in 2 test reports)

Laboratory tes	**2**
Objective	Evalluate whether the presented information is correctly interpreted
Test	In-house usability tests by independent testers (i.e., people not involved in the project)
Protocol	Continuation of test 1. Each tester is asked for his/her interpretation of the texts

Screen picture	Location	Question		Responses			Issue for develoment team	Test 1 or 2
	Home & Map	1	Location	Yes	No	Remarks		Test
		a	Tapping the location icon (left of the tekst bar) results in printing the GPS location in *Home* and *Map* and showing the location on the *Map*					1
		b	Tapping the address bar shows the text "provide address or location"					1
		c	Providing a location like *Rotterdam* results in loading the address / location in the text bar and showing it on the map					1
	MAP	2	Go to the *Map* page and randomly select a flooded location in the EU	Yes	No			Test
		a	Were you able to navigate through the map easiliy (zoom function, shifting through the map)?					2
		b	Were you able to select a location easiliy by ticking in the Map?					2
	Home	3	Go to the *Home* screen and write down the following information in "remarks"	Yes	No			Test
		a	The exact location / address from the location bar (entered in Q2)					1
		b	Maximum water depth					1
		c	Climate scenario Y....					1
		d	Return period T...					1
		e	River or Sea					1
		f	Number of floors flooded in the picture					1
	Map	4	Is the information in the *Map* identical to the info in *Home* provided in Q3a-e?					1
	Home + Map	5	Next to waterdepth is an information icon 'i'	Yes	No			Test
		a	Is the meaning of 'water depth' clearly explained?					2
		b	Is the meaning of Y, T, River/Sea clearly explained?					2
		c	When touching the < icon, did you return to the previous page? (i.e., Home/Map)					2
	Buy new maps	6	Go to the final screen where you can buy new maps , and answer the following questions.	yes	no			Test
		a	The flood map Y2000 T10 is for free, additional floods maps can be purchased. Is it clear to you that you have access to one flood map only?					2
		b	Is it clear to you which information you will have when buying the additional flood maps?					2
		c	Is it clear to you how you can perform a purchase?					2
		d	Try to purchase all maps one by one. Did this work properly?					1 and 2
	Explanation about the app	7	Go to the bolded 'i' screening "Explaining the app"	yes	no			Test
		a	Is the information textually clear to you?					2
		b	Do you miss any info in order to understand the app?					2
		c	Would you reorganize or relocate certain info to another location in the app?					2
	Disclaimer	8	Go to the disclaimer screen in the app	yes	no			Test
		a	Is the information textually clear to you?					2
		b	Do you miss any info in order to understand the app?					2
		9	You have now navigated through all screens.	yes	no			Test
		a	Are the icons in navigation bar at the bottom clear to you?		No			2
		b	Did you find it easy to navigate and find your way through the app?	Yes				2
		c	Do you have any suggestions for improvement?	Yes				2

4. Innovation: Flip Flap Cofferdam

Innovator: Spectrum Construct

Contributing authors: Daniel Soiman, Sebastian Bude (Spectrum Construct)

Innovation description

The description of SCAN below is also available from the Climate Innovation Window, http://climateinnovationwindow.eu/innovations/flip-flap-cofferdam

Q1: Name of the innovation
Flip-Flap cofferdam

Q2: Specific issue/problem
The Flip-Flap dam is designed for urban areas prone to river flooding. In case of a flood threat the height of the levee can be increased up to the safety standard. The Flip-Flap Dam offers a solution for at least two situations: 1) when there is insufficient space to further increase the height and widen the base of the levee, and 2) to retain spatial quality and keep the physical barrier between river and city as small as possible.

Q3: Brief description
Flip-Flap Cofferdam is designed to prevent floods in urban areas. It can be used as boardwalk (walkway) around the clock. When flood emergency arises it is raised in vertical position and locked into the concrete gutter. In this position it acts just like a regular flood protection wall. Material is PVC sheet piles.

Q4: Contact information.
Name: Daniel Soiman
Company: Spectrum Construct SRL
Country: Romania
Website: http://www.spectrum-construct.ro/en/
Email Address: daniel@spectrum-construct.ro
Phone Number: +40 747 074 202

Q5: Climate related risk(s) the innovation addresses
River floods: fluvial floods resulting from discharges that exceed flood protection levels; the high-river discharges are caused by heavy precipitation in the river basin.

Q6: Themes applying to the innovation
Urban areas, Water safety

Q7: Summary of how the innovation works
When flood warning is in effect, a team of maximum four people will go to the site with minimum tools (wrenches). They will take out the PVC panels that lay horizontally and mount them vertically in the foundation gutter. After the wall is in vertical position there will be, at certain distance, galvanized steel pipes fasten to the steel infrastructure in the gutter. On top

of the wall there will be mounted "U" shaped profiles that will be fasten, by thread, to the pipes, sealing the bottom of the wall to the base of the gutter through a rubber gasket that is laid there.

Q8: Added value and/or main differentiating element
- very simple infrastructure
- wall is always at location, doesn't need storage and transportation
- ready for installation immediately when flood danger is signaled
- no need for any special machinery/ tools to install
- no need for skilled labor
- can be installed at a very high speed

Q9: Limitations/conditions under which the innovation does not work or is less effective
To be completed

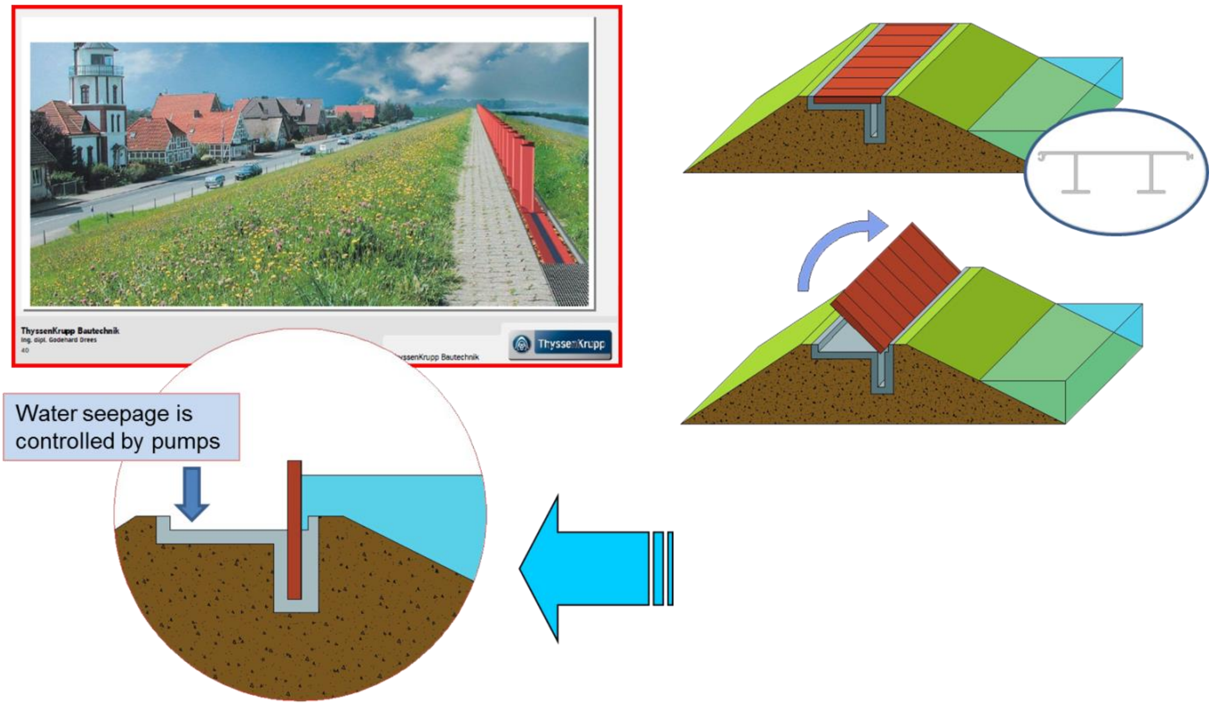
Q10: Technology Readiness Level (TRL) of the innovation
TRL 4. Technology validated in lab. Basic technological components are integrated to establish that they will work together. This is relatively “low fidelity” compared with the eventual system. Examples include integration of “ad hoc” hardware in the laboratory.

Q11: Explanation of the TRL
Prototype will undergo testing in Flood Proof Romania

Q12: Price
Purchase price: To be decided
Rental price: To be decided

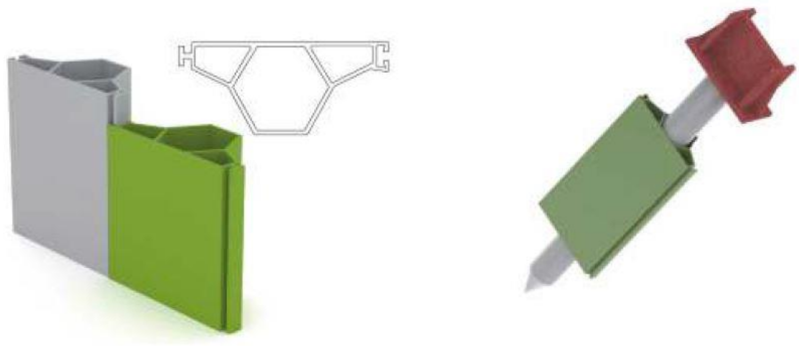
Q13: Picture to of the innovation

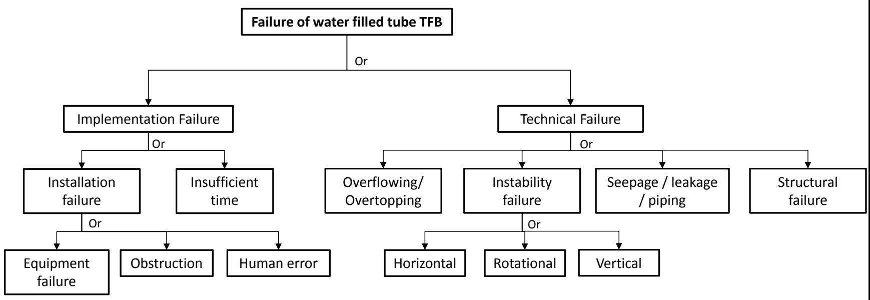
FlipFlap Dam



Desk study

Technical description		
Which of the following characteristics does the innovation have?	☑	**structural/physical components that are engineered and built at a fixed location**
	☐	software or IT-product/components to process or present information
	☐	ecosystem/nature-based aspects (inspired and supported by nature)
	☑	**mobile (deployable) object/components that require human action**
	☐	informational and education aspects to increase knowledge and awareness
	☐	encourages changes in human behavior or insist on immediate action
	☐	provides economic and financial incentives
	☐	methodology to identify and quantify risks and/or evaluate adaptation strategies
	☐	changes in laws, regulations and government policy to reduce risk
Technical specs of the innovation and its functionality. Provide a reference to documents if available.	**Structure** • Foundation of reinforced concrete • PVC sheet piles are horizontally located on the foundation and can be used as a board walk/bycicle path **PVC sheet piles** • Dimensions / weight • made of 93.5% recycled material and are 100% recyclable at the end of construction life span; • environmental friendly (do not interfere with the environment and are not affected by environment in any way) • For detailed technical specs see ….(reference)	

<table>
<tr><td rowspan="4"></td><td colspan="2">Parts (stored underneath the PVC sheet piles)
• Galvanized steel pipes to fasten the steel infrastructure in the gutter.
• "U" shaped steel profiles that will be fastened to the pipes by steel thread
• rubber gasket to sealing the bottom of the wall to the base of the gutter.</td></tr>
<tr><td colspan="2">Design picture of concrete foundation</td></tr>
<tr><td colspan="2">
PVC sheet piles (what are the measures and do we see here on the right?)</td></tr>
<tr><td colspan="2">Design picture of U shaped profile, steel pipes, rubber gasket and a sketch showing them mounted to the foundation gutter to support the sheet piles</td></tr>
<tr><td colspan="3">Qualitative assessment of technical KPIs</td></tr>
<tr><td>Reusability</td><td colspan="2"></td></tr>
<tr><td rowspan="3">Nature of the innovation</td><td>☐</td><td>permanent</td></tr>
<tr><td>☑</td><td>semi-permanent, , operation protocol to be made</td></tr>
<tr><td>☐</td><td>Temporary</td></tr>
<tr><td>Percent of the innovation needed to be repaired after each operation</td><td colspan="2">X%. Explanation:
• Under design conditions the Flip-Flap cofferdam is not expected to fail. In those case no damage is expected and the Flip-Flap dam can be 100% reused. However, in the PVC sheet piles may be damaged by debris impacts and must be replaced afterwards. We roughly estimate that X in 100 sheet piles needs replacement, this requires verification in tests.
• All components such as the steel pipes, U profiles, threat and rubber gasket are stored underneath the sheet piles (at location). It is intended to reuse all components after a flood event, but parts may be damaged or get lost.</td></tr>
<tr><td>Expected lifetime of structural and/or material components</td><td colspan="2">• structure / foundation of reinforced concrete: 100 years;
• (hot galvanized) steel base in the gutter, and steel pipes and U profiles: 100 years;
• PVC sheet piles 25 years;
• Rubber gasket: yet unknown..</td></tr>
</table>

	We recommend that sheet piles are replaced after X years.	
Inspection and maintenance requirements to maximize lifetime	Requirements: • Yearly inspection of visual damage and checkpoints. • After deployment check on damage and completeness. • Additional operation and maintenance documents: not yet available	
Storage requirements when the innovation is not in use	All parts such as steel pipes, U shaped profiles, thread, and rubber gasket are stored at location underneath the PVC sheet piles.	
Technical performance	How will the innovation reduce the risk of [hazard]?	
Decrease probability of occurrence	☐	reduction in load(ing)
	☑	**others: temporary increase of flood protection level**
Decrease exposure	☐	reduction in the area affected
	☑	**other(s): not applicable**
Decrease vulnerability	☐	increase in lead time
	☐	increase in adaptive capacity
	☐	increase in knowledge and/or awareness
	☐	changes in human behavior
	☑	**other(s): not applicable**
Intended (quantitative) level of risk reduction	☐	reduce water level by ____ (units)
	☐	reduce flow velocities by ____ (units)
	☐	increase lead time by ____ (units)
	☐	increase water quality by ____ (units)
	☐	decrease water evaporation by ____ (units)
	☐	decrease temperature by ____ (units)
	☑	**other(s): water levels up to 100 cm are blocked. This means a reduction in flood probability.**
Reliability		
Draw a diagram showing the operation of the innovation and the design loads acting on the innovation	Provide a sketch showing design loads and calculations showing that the FFD is able to resist the design loads	
Fault tree		
Technical failure modes	Height:	
	☑	**overtopping/overflowing**: the Flip-Flap dam is designed to block 100 cm of water. If overtopping occurs, the PVC sheet piles should remain stable because they are kept in place by the U shaped profile that is mounted to the gutter by steel pipes.
	Instability:	

	☑	**vertical** ??
	☑	**horizontal**: ??
	☑	**rotational**:
	☑	**seepage/leakage/piping**: flood water may run underneath the Flip Flap Dam.
	Structural failure:	
	☑	**debris impacts**: debris may cause damage to the PVC sheet piles. It requires further testing to see how this affects functionality.
	☑	**components fail**: Steel components are unlikely to fail because …
	☑	**other(s): -**
Implementation failure modes	Installation:	
	☑	**equipment missing/malfunction**: there is a risk that parts are missing (e.g., steel pipes, U-shaped profiles, ruber gasket requires, steel thread)
	☑	**obstruction**: like with all temporary flood barriers the location has to be cleared (e.g., remove parked cars, etc.).
	☑	**human error**: installation errors include • Sheet piles and supporting parts are not correctly installed
	Others:	
	☑	**insufficient time:** it is estimated that X persons can install X metres in X hours.
	☐	other(s): ___________? Must be tested
Ranking of most important failure modes	1. **Instability.** Explanation … 2. **Overtopping**. Explanation … 3. **Installation errors.** Explanation ….	
Tests performed in the past		
Describe any tests that have been performed on the prototype or on its individual components	None	
Technology Readiness Level (TRL)		
Evaluate the current TRL level of the innovation	☐	1. Basic Principles Observed. Basic principles are observed and reported. Lowest level of technical readiness. Scientific research begins to be translated into applied research and development. Examples might include fundamental investigations and paper studies.
	☐	2. Technology Concept Formulated. Innovation concept and/or application formulated. Once basic principles are observed, practical applications can be formulated. Examples are limited to analytic studies and experimentation.
	☐	3. Experimental Proof of Concept. Active research and development is initiated. Laboratory studies aim to validate analytical predictions of separate components of the innovation. Examples include components that are not yet integrated or representative.
	☑	**4. Technology Validated in Lab. Design, development and lab testing of innovation components are performed. Here, basic innovation components are integrated to establish that they will work together. This is a relatively “low fidelity” prototype in comparison with the eventual system.**
	☐	5. Technology Validated in a Simulated Environment. The basic innovation components are integrated together with realistic supporting elements to be tested in a simulated environment. This is a “high fidelity” prototype compared to the eventual system.
	☐	6. Technology Demonstrated in an Operational Environment. The prototype, which is well beyond that of level 5, is tested in a relevant environment. The system or process demonstration is carried out in an

		operational environment.
	☐	7. System Prototype Demonstration in an Operational Environment. Prototype is near, or at, planned operational system level. The final design is virtually complete. The goal of this stage is to remove engineering and manufacturing risk.
	☐	8. System Complete and Qualified. Innovation has been proven to work in its final form under the expected conditions. In most of the cases, this level represents the end of true system development.
	☐	9. Actual System Proven in an Operational Environment. Here, the innovation in its final form is ready for commercial deployment.

Test Plan

The Flip Flap Cofferdam will be tested in Flood Proof Romania. The building of the test polder has been delayed due to: 1) more time was need for the deasign and construction permits, 2) finding a constructor to build the test polder.

Has to be completed. This is updates once the design of the test basin and construction are final/completed

Test Results

Has to be completed. This is updates once the design of the test basin and construction are final/completed

5. Innovation: ThirdEye - Flying Sensors to support farmers' decision making

Innovator: FutureWater (BRIGAID consortium partner)

Contributing authors: Alberto de Tomás (FutureWater), Johannes Hunink (FutureWater), Sergio Contreras (FutureWater), Nadja den Besten (FutureWater), Peter Droogers (FutureWater)

Innovation description

The description of ThirdEye below is also available from the Climate Innovation Window, http://climateinnovationwindow.eu/innovations/thirdeye

Name

ThirdEye: Flying Sensors to support farmers' decision making

Short description

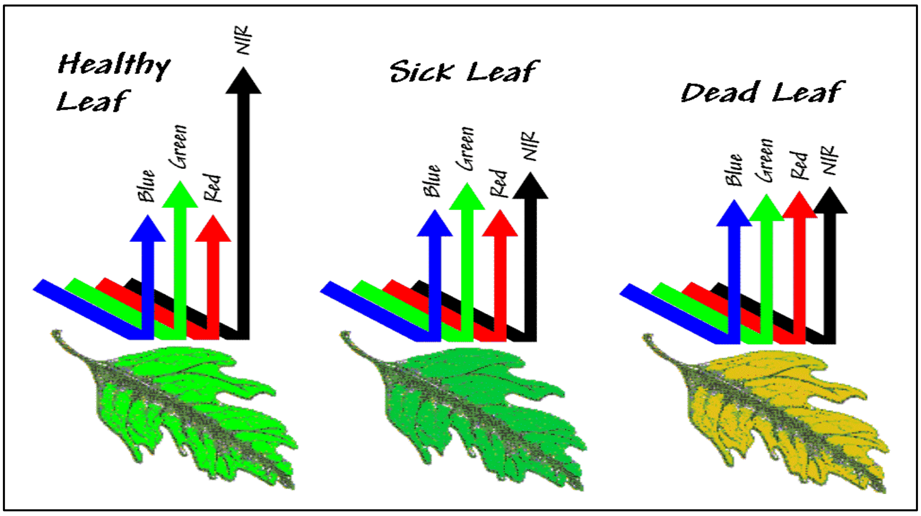
Farmers are confronted more and more with the consequences of climate change. Water shortages, higher temperatures, shifting seasons, more extreme events, amongst others, pose a threat to crop production by amplified droughts, heat stresses, and diseases. Farmers have to respond to this threats by adopting early response and decision-making actions from improved real-time information of their current crop status and forecasts.

Flying Sensors, sometimes referred to as drones, provide high resolution information on crop status. Cameras installed onboard measure the reflection of near-infrared light (NIR), as well as visible light. Our innovation provides this information at: (i) an ultra-high spatial resolution, (ii) an unprecedentedly flexibility in location and timing, (iii) a spectrum outside the human eye. The latter is very important since this information shows potential threats to crops such as droughts, diseases, fertilizer stress, about 10-days earlier compared to the human eye observation.

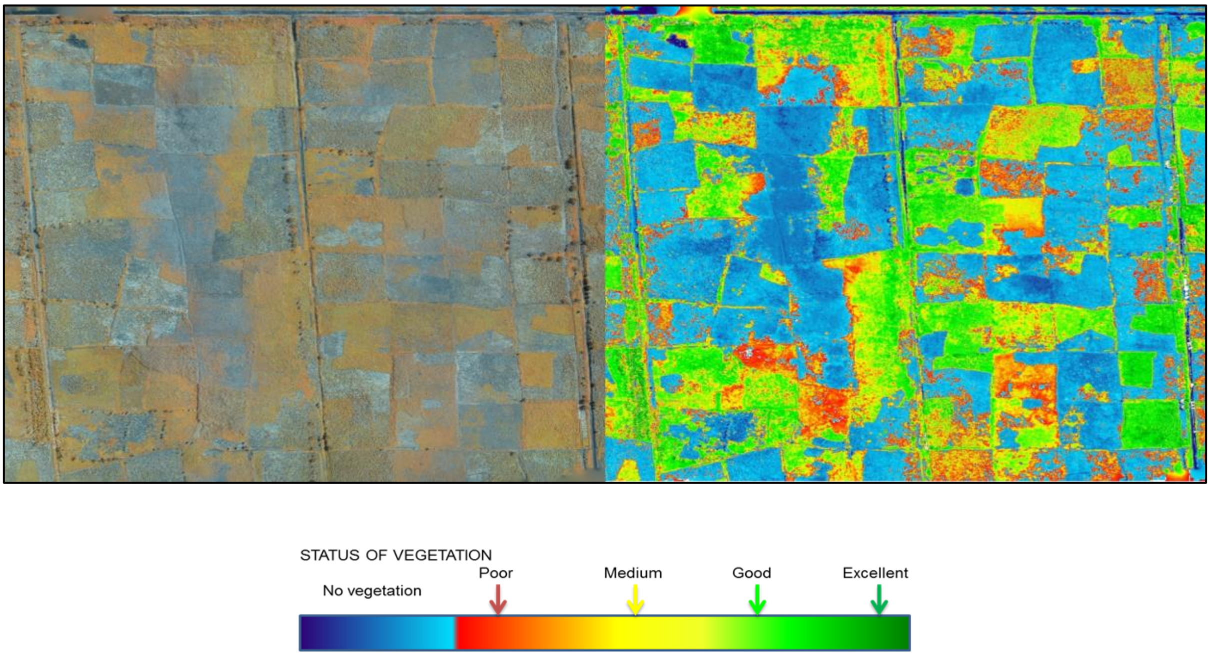
Multi-copter and fixed-wing configuration of a Flying Sensor:

Normalized Difference Vegetation Index (NDVI), for instance, provides an indication of crop stress by distinguishing damaged plant material from healthy plant material. The basic principle of NDVI relies on the fact that, due the spongy layers found on backsides, leaves reflect more light in the near infrared, in stark contrast with most non-plant object. When the plant becomes dehydrated or stressed, the spongy layer collapses and the leaves reflect less NIR light, but the same amount in the visible range. Thus, mathematically combining these two signals can help differentiate plant from non-plant and healthy plant from sickly plant.

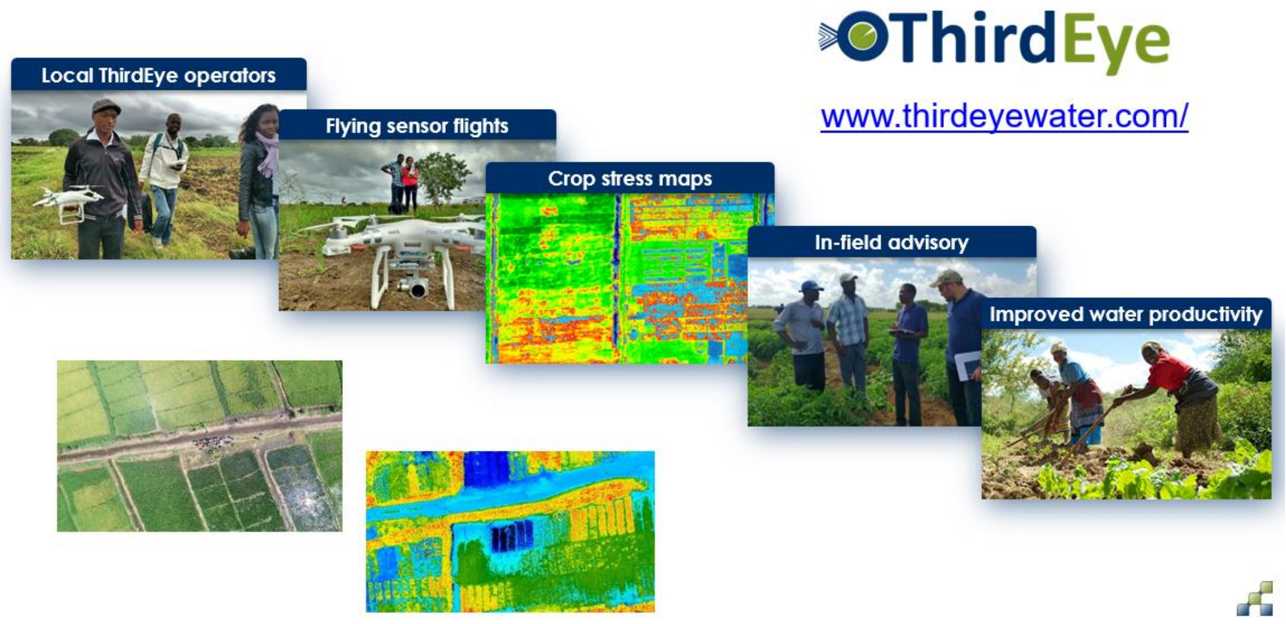
Examples of reflections in different band widths (spectra):



Status of vegetation. NIR next to NDVI (mixed crops) gives an overview of which areas need most attention:



Sketch/Photograph of the Innovation



Which hazard(s) is the innovation designed to mitigate?

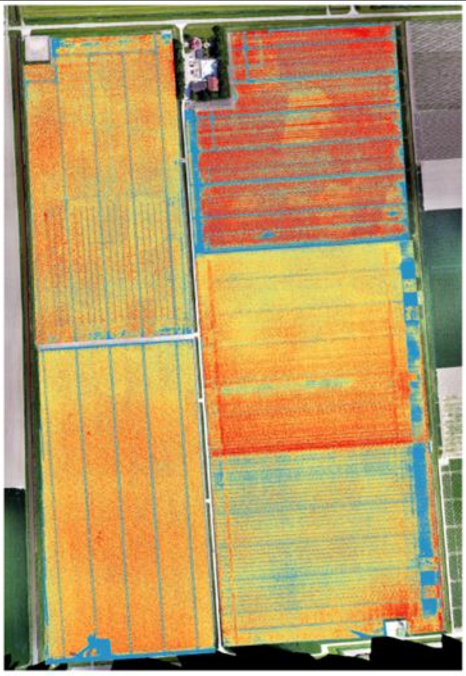
Droughts: Sustained and extensive occurrence of below average water availability. Resulting in water scarcity when drought conditions cause long-term imbalances between water availability and demands.

Themes to which the innovation applies: Agriculture, Water availability, Disasters and ICT

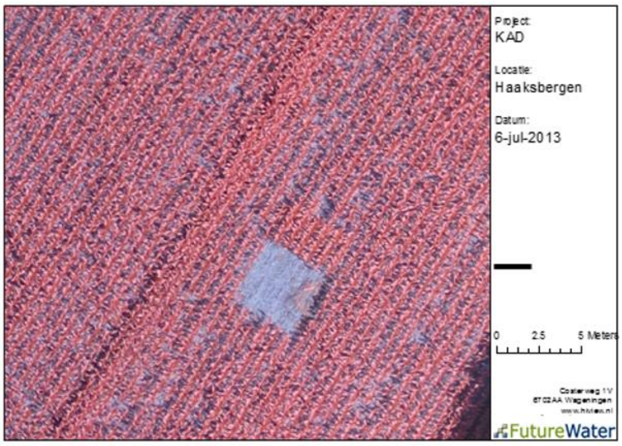
How does the innovation work?

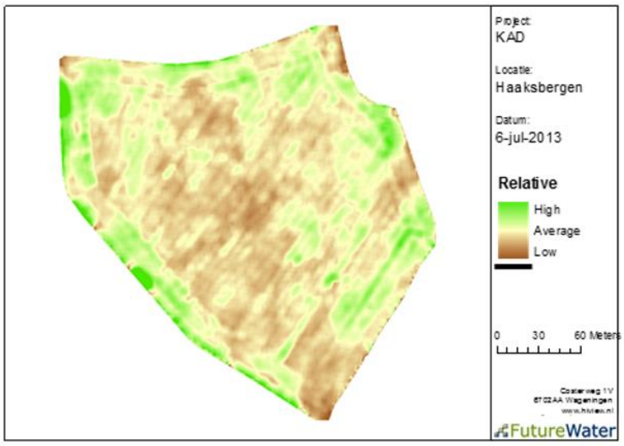
Flying Sensors (drones) are equipped with high resolution cameras that collect information in the near-infrared spectrum. Compared to the human eye, crops stress can be seen in the near-infrared about 10 days earlier providing farmers ample time to respond. Special focus will be put on disease detection by looking at in-field scale variability and the evolution of a stress location over a couple of days. The latter will be done by innovative image analysis and forecast procedures based on extrapolations from earlier stage measurements.

Flying Sensor information. Current crop status (left) and forecasted crop stress based on near-infrared anomalies (right). Results from fields in Netherlands (Swifterband) on 2-Jul-2014:



Flying Sensors‘ characteristics. Level of detail that can be obtained (left), and 10 days forecast of climate sensitive locations in the field (right):

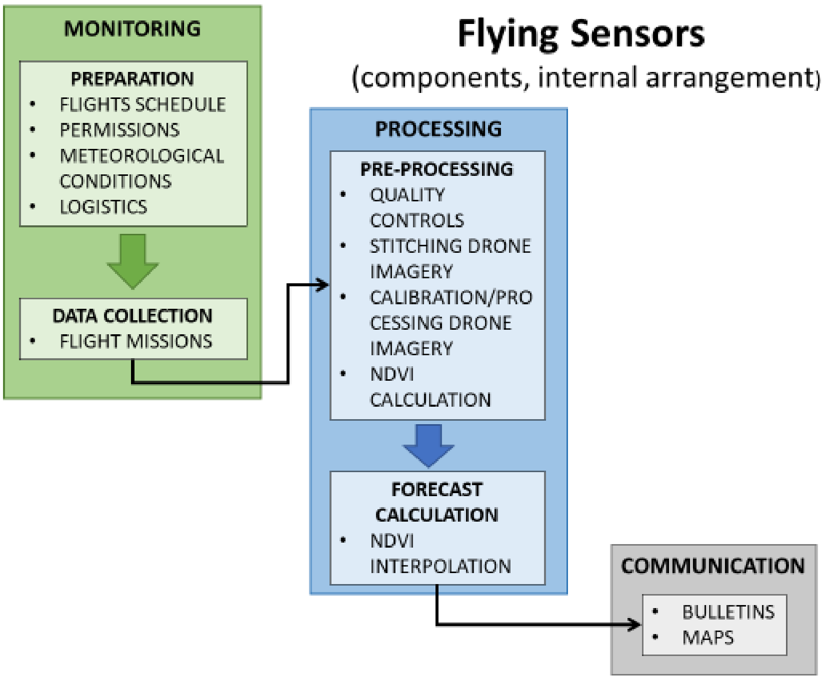




The ThirdEye innovation consists of three components/subsystems:

- A monitoring subsystem (TRL7) which retrieve raw data on the current status of crops.
- A processing subsystem (TLR3-4) which process the raw data provided by the monitoring subsystem, and analyses those data to forecast crop status in the short-term (7/10-days ahead).
- A communication subsystem (TRL3-4) which provides farmers with processing outputs in form of maps and bulletins helping them to adapt its management strategy to minimize risks in yield production.

Flying Sensors internal structure:



Added value / main differentiating element from conventional approach(es)

The ThirdEye technology is unique and can hardly be compared to any other existing crop information system. The main differential features refer to:

1) The ultra-high resolution (1 cm),

2) The flexibility in observation timing (thanks to the near infra-red detection, crop stress is seen 10-days earlier compared to the human eye), and

3) The innovative disease/stress evolution detection.

Critical success factors / Limitations

ThirdEye is relatively new and for some specific crops relationships between near infra-red information and crop stressors (diseases, fertilizer, water) might be less accurate. It is however expected that this issue will be resolved in few years by getting these relationships more accurately. Other potential limitation that may cause ThirdEye failures or low performance is related with existence of unfavorable weather conditions during the use of the flying sensors. In general, wind speeds above 5-10 m/s (this value is flying sensors-specific) reduce strongly the overall performance or even impede the use of this technology.

Desk study

In this section, the most relevant issues related with the innovation are provided.

Technical Effectiveness refers to the intended capacity of the innovation to reduce risk from a specific hazard(s)	- What type of hazard(s) does the innovation address? - Which characteristic(s) does the innovation have? - How will the innovation reduce the risk of the hazard(s)? - What is the intended (quantitative) level of risk reduction? - Has the innovation been tested previously and can the innovation achieve the intended level of risk reduction without failure? - What is the current estimated technical readiness level (TRL) of the innovation?
Reliability refers to the likelihood that the innovation fulfills its intended functionality over its lifetime	What are the inputs/outputs to the innovation? (Which inputs/outputs can be controlled by the innovator?) What are the possible technical failure modes of the innovation? If the innovation is only operated prior to/during a hazard event, what are the possible implementation failure modes? Which failure modes are most likely to occur or are most critical? Is there available historical data against which to test the innovation? During testing, will the innovation be tested in real-time?
Durability refers to the intended use and lifetime of the innovation	Is the innovation continuously operated or is it only operated prior to/during a hazard event? If the innovation is only operated prior to/during a hazard event, what is the intended operation (protocol) of the innovation? What is the expected lifetime of the innovation based on its components? - What are the maintenance requirements for the innovation to reach its maximum lifetime?
Flexibility refers to the capacity of the innovation to be sold/deployed in other locations than originally envisioned	Where will the innovation be marketed/sold? What is the (potential) size of the market for the innovation under current climate conditions? under future climate conditions? Is the innovation made up of modular components (or, alternatively, are the innovation's components customizable)? Does the innovation require significant adjustment to be installed in a new location/used at different sites throughout Europe? Are the material components of the innovation easily obtained within the potential market(s)? What is the material cost of the innovation?

Intended functionality/performance

The main intended functionality of ThirdEye is to improve farm management decisions by enabling more efficient and increased crop production. Due to the proven skill of NDVI data for monitoring and forecasting crop health status, an interpolation method is implemented to the ThirdEye technology in order to produce -several days ahead- forecasts of crop health status, which include health anomalies, on the basis of current and previous information. The interpolation method assumes a linear growth of the NDVI values for a certain type of crop and follows a linear interpolation between two NDVI datasets. This innovative solution would allow farmers to better anticipate to health-related crop issues and reduce the risk of not obtaining optimum crop yields by putting into practice appropiate mitigation actions.

Technical Readiness Level

ThirdEye entered BRIGAID at TLR 4 (Technology validated in lab: Basic technological components are integrated to establish that they will work together. This is relatively “low fidelity” compared with the eventual system. Examples include integration of “ad hoc” hardware in the laboratory). The collection of raw data through ThirdEye technology (Monitoring Subsystem) has been positively demonstrated and applied quite extensively under different environmental boundary conditions (TRL7). However, the processing and transformation of these data into 10-days ahead forecasts is somewhat lagging and it has been estimated at TLR4.

ThirdEye aims at reaching TRL6 (technology demonstrated in relevant environment) with assistance from BRIGAID. In order to get this milestone, testing at some specific fields/crops need to be undertaken where data will be collected using flying sensors. We expect with the raw data collections that some minor issues have to be overcome, especially during the calibration phase. During the BRIGAID testing activities, most emphasis will be put on transforming the raw data in forecasting of crop performance. This will be done by (i) focusing at the NIR that shows potential crop failure 10 days ahead, and (ii) using a series of past observations and a forecasting (extrapolation) procedure.

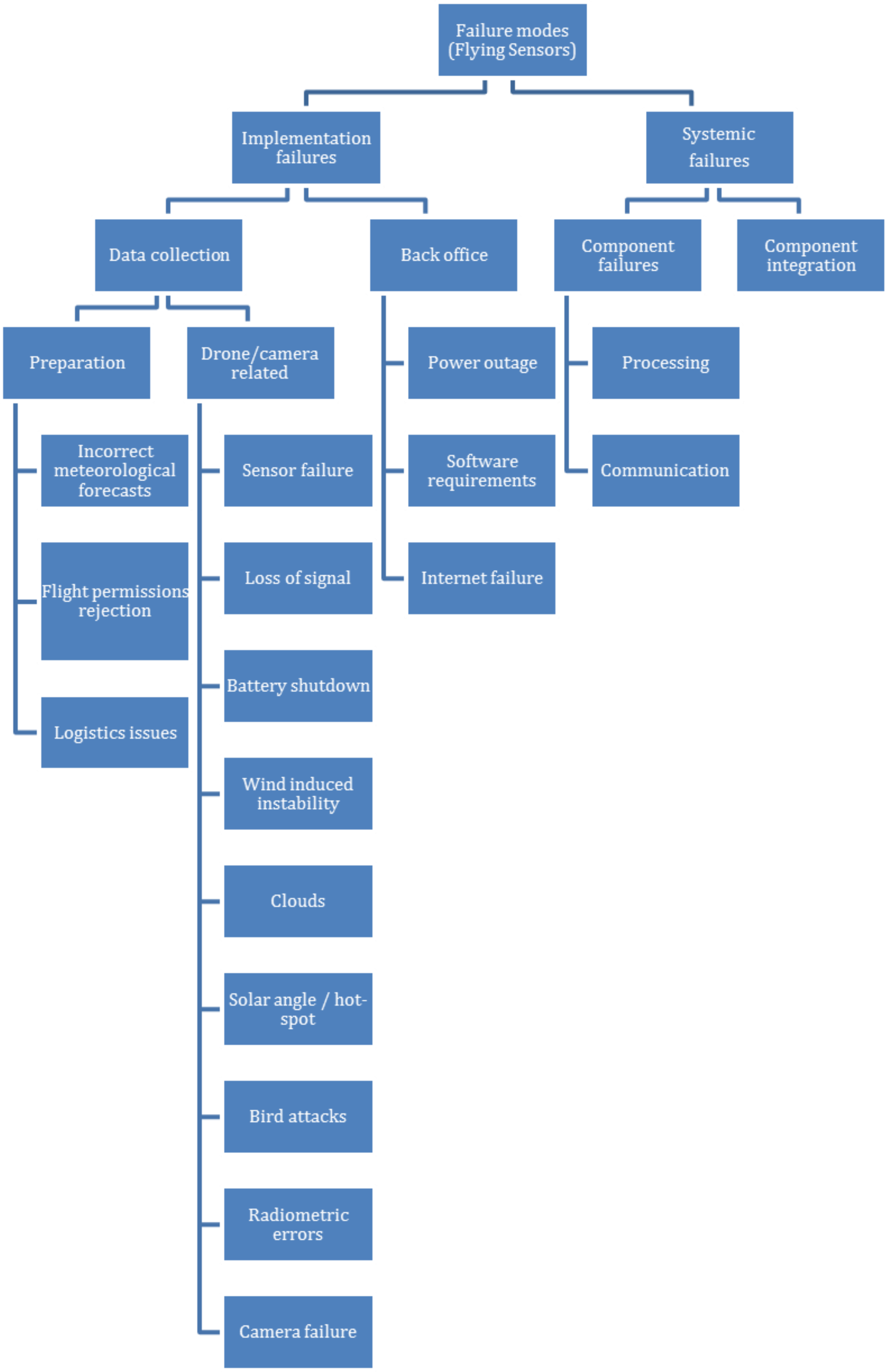
Previous testing activities

ThirdEye (www.thirdeyewater.com) started as a company initiative by FutureWater and HiView, initially created with the support of USAID in the prestigious Securing Water for Food program. ThirdEye has evolved since 2014 from a start-up to becoming the leading company in Mozambique as to mapping and monitoring services for farmers based on aerial images. Next to the service for smallholder farmers, ThirdEye delivers various services to medium and large sized farmers. ThirdEye technologies have been thoroughly tested and validated and are currently providing the following services:

- Large-scale, detection of crop stress 10 days in advance.
- Crop status mapping on tablets for real time usage in the field.
- Monitoring of land use.
- Identification of areas.
- Monitoring of channels and river-beds.

Qualitative assessment of failure modes and risks

Failure modes identified for ThirdEye:



Failure risk matrix of the primary risks:

Item	Component - Risk	Likelihood of occurrence[1]	Consequence/Impacts	Mitigation action
Implementation Failures				

Item	Component - Risk	Likelihood of occurrence[1]	Consequence/Impacts	Mitigation action
Preparation	Incorrect meteorological forecasts	Probable	Delay in monitoring phase.	Re-schedule flight mission.
	Flight permissions rejection	Probable	Critical. The absence of permissions blocks flight missions.	Permissions must be obtained before sheduling flight missions.
	Logistics issues (transportation)	Ocassional	Delay in monitoring phase.	Logistics must be set before flight missions, according to schedule.
Drone/camera related	Sensor failure	Probable	Critical. Absence of data.	Equipments must be checked before flight missions.
	Loss of signal	Probable	Critical. Damage of drones.	Equipments must be checked before flight missions.
	Battery shutdown	Probable	Critical. Damage of drones.	Equipments must be checked before flight missions.
	Wind induced instability	Probable	Noise in data. Mismatch between datasets boundary conditions.	Flight missions will be (re)-schedule/carried out under optimum weather conditions.
	Clouds	Probable	Errors in data. Mismatch between datasets boundary conditions.	Flight missions will be (re)-schedule/carried out under optimum weather conditions.
	Solar angle, hot-spot effects	Probable	Errors in data. Mismatch between datasets boundary conditions.	Flight missions will be (re)-schedule/carried out at solar zenith.
	View angle	Probable	Errors in data. Mismatch between datasets boundary conditions.	Flight missions will be (re)-schedule/carried out at the same view angle.
	Bird attacks	Occasional	Critical. Damage of drones.	Flight missions will be postponed.
	Radiometric errors	Frequent	Errors in data.	Radiometric

Item	Component - Risk	Likelihood of occurrence[1]	Consequence/Impacts	Mitigation action
				calibration using calibration panels.
	Camera failure	Probable	Critical.	Flight missions will be (re)-schedule.
Back office failures	Power or internet outage	Remote	Delay in the processing phase.	Re-launch processing.
	Software requirements	Occasional	Critical	Technical supporting
Systemic failures				
Component failures	Processing	Frequent	Radiometric errors	Radiometric correction. Quality controls.
	Processing	Probable	Drone imagery stitching errors	
	Communication	Occasional	Runtime error	Debugging source code
Component integration	Failure during the processing-communication integration	Critical	Delay in the deployment outputs	Programming improvements. Quality controls.

[1] Select: Frequent, Probable, Ocassional, Improbable, Not evaluated

Test plan

Summary

Current status of testing activities planned for ThirdEye:

Testing phase	Key Performance Indicator – Testing activity	Testing site	Period of testing	Status (Completed/In progress)
Laboratory Testing phase (TRL4-5)	Test 1: Technical reliability.	FW's IT facilities	05/2017 - 05/2017	Completed
Operational Testing phase (6-8)	Test 2: Inherent system reliability. Setting up forecast system and validation.	Mozambique farm (crop 1)	05/2017 - 10/2017	Completed
		Spanish farm (crop 2)	09/2017 - 11/2017	Completed
	Test 3: Technical effectiveness. Evaluation of risk reduction.	-	-	Not performed

Test 1. Technical reliability at laboratory conditions

Rational and protocol

Two technical reliability components for ThirdEye have been evaluated during the laboratory testing phase. The first reliability component relates to whether the sensor system is able to collect the raw data (surface radiometric data). This concept is closely related to implementation failures (or failures which affect to the monitoring component) and will be tested by performing a raw data collection under various environmental boundary conditions. The second component refers to systemic failures which affect the forecasting/processing component, and whether the raw data collected by sensors can be converted into forecasts. Several algorithms were applied and tested on its reliability based on the consistency of the outputs. A list of potential failure modes was previously identified for ThirdEye during the Desk Study Assessment. Based on testing outputs, the failure-risk class matrix preliminary identified and presented before is updated.

Facility

FutureWater's IT facilities at The Netherlands and Spain.

Equipment

The following equipment has been used for the purpose of this test:

- FutureWater´s computers.
- AgiSoft PhotoScan: software for processing and stitching drone imagery.
- QGIS: software for computing NDVI images and performing interpolations, as well as computing zonal statistical analysis.

Protocol

The testing exercise cosisted in the implementation of the ThirdEye technology FutureWater's IT facilities, detecting systematic failures before releasing the final product. Techniques of sofware quality control (static and dynamic verification) and diagnostic metrics (e.g. bugs and runtime errors per line of code, code coverage, program execution time, number of lines of code) were used to quantify the likelihood of occurrence of failures. Flying Sensors´ testing plan will consist of 4 main testing dimensions (see table next), each of them formulated to indentify a specific type of product defects.

Testing dimensions to evaluate Flying Sensors system reliability:

Testing dimensions	Description
Unit Test	Imagery quality testing. Raw quality assessment and pre-processing algorithms are individually tested for each observation date
Integration Test	Individual software modules are combined and tested as a group.
System Test	The test is conducted on a complete, integrated system to evaluate the system´s compliance with its specified requirements (Flying Sensors back-end).

Each testing dimension was evaluated according to several indicators which inform about their overall functionality and performance (see table next).

Test cases for each testing type:

Test case	Indicator	Mitigation actions
Functionality	Type of defects (bugs, runtime errors) Number of defects	Debugging defects
Performance	Execution time	Tasks optimization and improvement

Test 2. Inherent system reliability at operational conditions

Rational

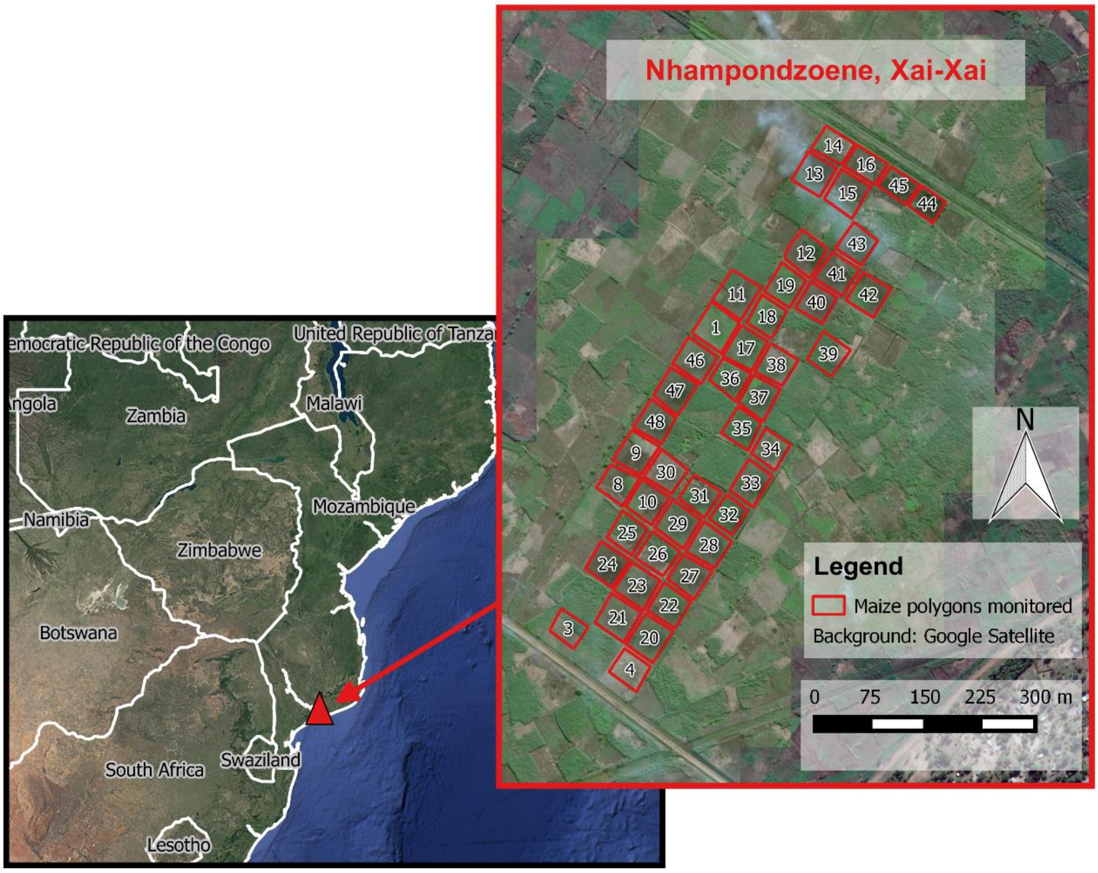
This testing exercise aims to demonstrate the ability of ThirdEye warnings as reliable indicators for crop performance. This reliability component was evaluated by comparing simulated-forecasted NDVI outputs to actual NDVI measurements taken afterwards. The test was planned to be performed at two pilot farms located in Mozambique and Spain.

Facility

Mozambique experimental sites

The pilot facility in Mozambique is located in Xai-Xai, in the Gaza province (south of Mozambique). The pilot area (31 ha) is situated in a district of the local irrigation and drainage authority (Regadio do Baixo Limpopo, RBL), inside a zone called Nhampondzoene (see next figure). Testing activities were performed from the beginning of May until the end of October'17 (see next table). A total of 22 drone flights over 44 rainfed maize fields were performed (see next figure). The 44 maize fields have an average size of 0.25 hectares. The crops produced on the fields are primarily for domestic use.

Location of the pilot area in Mozambique: Xai-Xai. Gaza:



Testing activities in Mozambique:

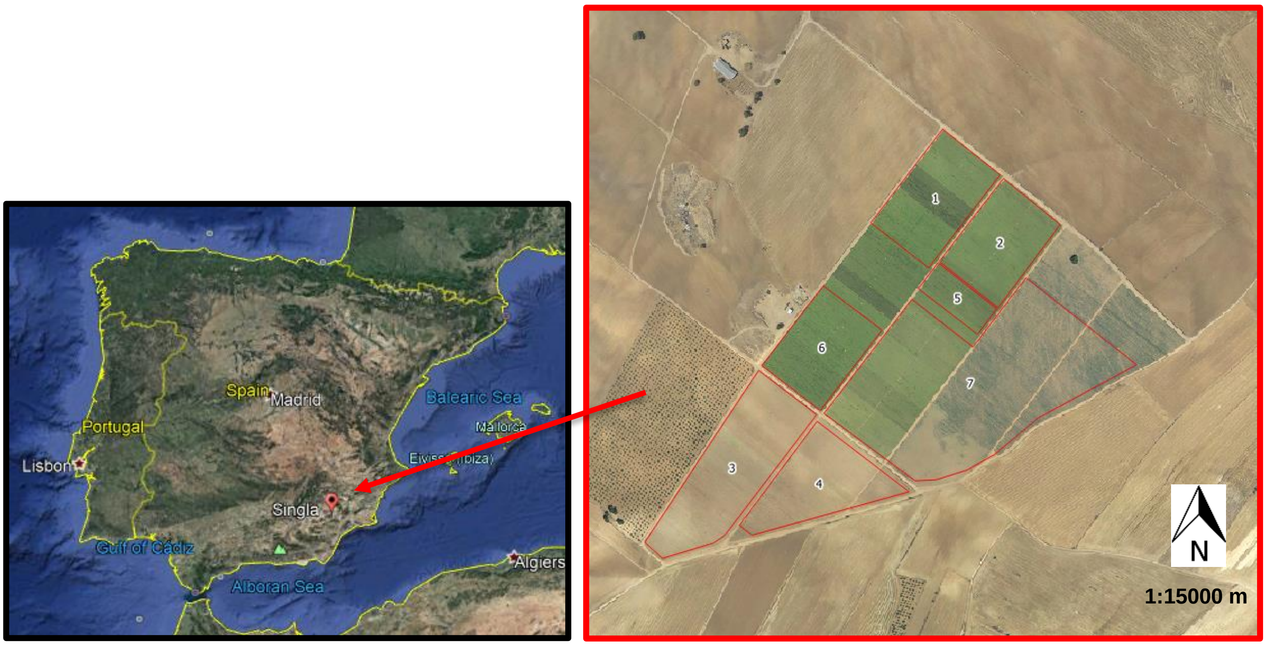
Testing activity	Testing site	XUTM; YUTM	Testing/flight dates	Comments (e.g. crops)
Test 1	Mozambique – Xai-Xai	3753928; -2877798	20170515	Rainfed maize
Test 2	Mozambique – Xai-Xai	3753928; -2877798	20170522	Rainfed maize
Test 3	Mozambique – Xai-Xai	3753928; -2877798	20170529	Rainfed maize
Test 4	Mozambique – Xai-Xai	3753928; -2877798	20170609	Rainfed maize
Test 5	Mozambique – Xai-Xai	3753928; -2877798	20170616	Rainfed maize
Test 6	Mozambique – Xai-Xai	3753928; -2877798	20170624	Rainfed maize
Test 7	Mozambique – Xai-Xai	3753928; -2877798	20170629	Rainfed maize
Test 8	Mozambique – Xai-Xai	3753928; -2877798	20170706	Rainfed maize
Test 9	Mozambique – Xai-Xai	3753928; -2877798	20170715	Rainfed maize

Testing activity	Testing site	XUTM; YUTM	Testing/flight dates	Comments (e.g. crops)
Test 10	Mozambique – Xai-Xai	3753928; -2877798	20170720	Rainfed maize
Test 11	Mozambique – Xai-Xai	3753928; -2877798	20170729	Rainfed maize
Test 12	Mozambique – Xai-Xai	3753928; -2877798	20170806	Rainfed maize
Test 13	Mozambique – Xai-Xai	3753928; -2877798	20170813	Rainfed maize
Test 14	Mozambique – Xai-Xai	3753928; -2877798	20170820	Rainfed maize
Test 15	Mozambique – Xai-Xai	3753928; -2877798	20170827	Rainfed maize
Test 16	Mozambique – Xai-Xai	3753928; -2877798	20170903	Rainfed maize
Test 17	Mozambique – Xai-Xai	3753928; -2877798	20170910	Rainfed maize
Test 18	Mozambique – Xai-Xai	3753928; -2877798	20170917	Rainfed maize
Test 19	Mozambique – Xai-Xai	3753928; -2877798	20170925	Rainfed maize
Test 20	Mozambique – Xai-Xai	3753928; -2877798	20171001	Rainfed maize
Test 21	Mozambique – Xai-Xai	3753928; -2877798	20171015	Rainfed maize
Test 22	Mozambique – Xai-Xai	3753928; -2877798	20171025	Rainfed maize

Spanish experimental site

The pilot facility in Spain is located in Singla (Murcia region, southeast of Spain). The pilot area (70 ha) is situated in an agricultural district (see next figure). Testing activities were performed from middle September until middle November'17 (see next table), with a total of 8 drone flights over 7 irrigated vegetables fields (mainly lettuce and parsley, etc.) (see next figure). All the monitored crop plots had different sizes, ranging from 3 to 12 hectares. Crops produced on the fields are for commercial use.

Location of the pilot area in Singla (Murcia region, Spain):



Testing activities in Spain:

Testing activity	Testing site	XUTM; YUTM	Testing/flight dates (YYYYMMDD)	Comments (e.g. crops)
Test 1	Spain – Singla	588837; 4206698	20170918	Irrigated vegetables (lettuces, parsley)
Test 2	Spain – Singla	588837; 4206698	20170925	Irrigated vegetables (lettuces, parsley)
Test 3	Spain – Singla	588837; 4206698	20171002	Irrigated vegetables (lettuces, parsley)
Test 4	Spain – Singla	588837; 4206698	20171011	Irrigated vegetables (lettuces, parsley)
Test 5	Spain – Singla	588837; 4206698	20171022	Irrigated vegetables (lettuces, parsley)
Test 6	Spain – Singla	588837; 4206698	20171029	Irrigated vegetables (lettuces, parsley)
Test 7	Spain – Singla	588837; 4206698	20171107	Irrigated vegetables (lettuces, parsley)
Test 8	Spain – Singla	588837; 4206698	20171114	Irrigated vegetables (lettuces, parsley)

Equipment

For the Mozambique´s testing site, a multicopter drone (Phantom 3 Advanced) with a 12 Mpix. camera onboard was used. The standard RGB camera was converted to a NIR-Green-Blue lens. Due to the camera modification, flights could be used to compute NDVI maps with a spatial resolution of 0.10 m.

For the Spanish testing site, two multicopter drones (S-90 and Inspire-1) with a Parrot Sequoia camera onboard were used. The camera was equipped with 5 lenses: RGB (16 Mpix.), Green, Red, Red Edge and Near Infrarred (1.2 Mpix.) allowing to compute NDVI maps with a spatial resolution of 0.10 m.

Protocol

The following protocol and tasks were implemented at both Mozambique and Spain testing sites:

1. Monitoring activities

1.1. Preparation activities

1.1.1. Design of flights campaigns and missions
Flights are scheduled for every week during the testing campaign.

1.1.2. Obtening flight permissions
Flights permissions are requested for the scheduled dates and obtained before each flight.

1.1.3. Checking of meteorological conditions
Meteorological forecasts are checked in advance for the scheduled date, in order to re-schedule the testing flight in case of adverse conditions.

1.1.4. Checking of logistics
All equipment is checked and prepared for transportation prior to the scheduled date.

1.2. Data collection activities

1.2.1. Flight missions
Drone flights are conducted at solar zenith for each sheduled date.

2. Processing activities

2.1. Pre-processing

2.1.1. Quality control
Drone imagery is checked during and after each testing flight in order to find errors and re-schedule the flight, if needed.

2.1.2. Stiching drone imagery
Drone imagery is stiched following the workflow described in next figure.

2.1.3. Calibration / Processing of drone raw imagery
Drone raw imagery is calibrated and processed following the workflow described before.

2.1.4. Post-processing and retrieval of NDVI values
Prior to the calculation of NDVI, images are resampled from 0.10 m to 1 m in order to reduce image quality issues or NDVI distorsions due to the presence of bare soil (low NDVI values). Afterwards, maps of NDVI values are computed using the Red and Near-Infrared radiometric data, accoring to the general formula:
NDVI = $\frac{R_{NIR} - R_{Red}}{R_{NIR} + R_{Red}}$

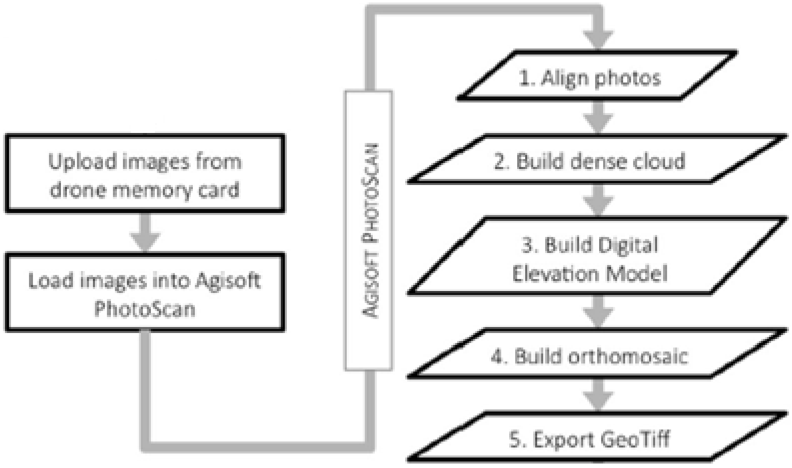
2.2. Forecast calculation

2.2.1. NDVI interpolation

2.2.1.1. Selection of valid dates for testing the interpolation. Next tables describe the selected dates from each testing site processed for interpolation following an image quality criteria. Quality issues are taken into account.

2.2.1.2. NDVI forecast calculation.
NDVI forecasts are computed following the interpolation method described before.

Workflow of the of the image processing in AgiSoft PhotoScan:



Selected dates for Mozambique:

Mozambique interpolated dates	Date estimated	Days in between	Forecasted days
20170624-20170629	20170706	5	7
20170629-20170706	20170715	7	9
20170706-20170715	20170720	9	5
20170715-20170720	20170729	5	9
20170720-20170729	20170806	9	8
20170729-20170806	20170813	8	7

Selected dates for Spain:

Spain Interpolated dates	Date estimated	Days in between	Forecasted days
20171002-20171011	20171029	9	18
20171011-20171029	20171107	18	9
20171029-20171107	20171114	9	7

The selection of dates for the Spanish testing site was rather small due to image quality issues, making them not fully available for testing the reliability of the forecast subsystem.

Operational testing

Test 3. Technical effectiveness in relevant simulated environment

Technical effectiveness requires to quantify how the risk of crop anomalies is reduced when the innovation is adopted (compared with a business as usual or current practice). This would require to compare the crop performances observed between those fields or part of them in which actions were advised by ThirdEye technology, and those ones in which no actions were adopted. Differences in crop yield, for instance, might be used as performance indicators. However, due to the commercial/consumptive character of the Mozambique and Spain testing sites, no control areas for testing were allowed by farmers, and hence available for this study. This test was not performed during the 1st BRIGAID innovation cycle, but it has been planned as a future action to be addressed after improving the forecasting component and its technical reliability.

Testing results

Test 1. Technical reliability at laboratory conditions

Next table summarizes the laboratory test results used for assessing the technical reliability of ThirdEye.

Technical reliability tests results:

Test case	Indicator	Results	Mitigation actions
Unit test	Type of failures Number of failures Execution time	Image quality issues 2 Optimum	Resampling spatial resolution
Integration test	Type of failures Number of failures Execution time	Bugs 1 Mid-slow	Debugging; Optimization: tasks automation
System test	Type of failures Number of failure Execution time	Runtime errors 2 Slow	Debugging failures; Optimization: tasks automation

Some image quality issues were found during the imagery processing, e.g. bright stripping (see left panel in next figure in which the left border close to the path is unusually brighter than the right border. This radiometric issue is most likely related to some of the following factors:

- Bidirectional/hot-spot effects during the flight caused by an inappropriate solar angle or drone path direction, or
- Optical effects related to camera lenses geometry.

Example of image (NDVI) quality issue (stripping) on date 20170918 for the Spanish testing site. Left image corresponds to the orthomosaic composite, right image corresponds to a single image of the composite:

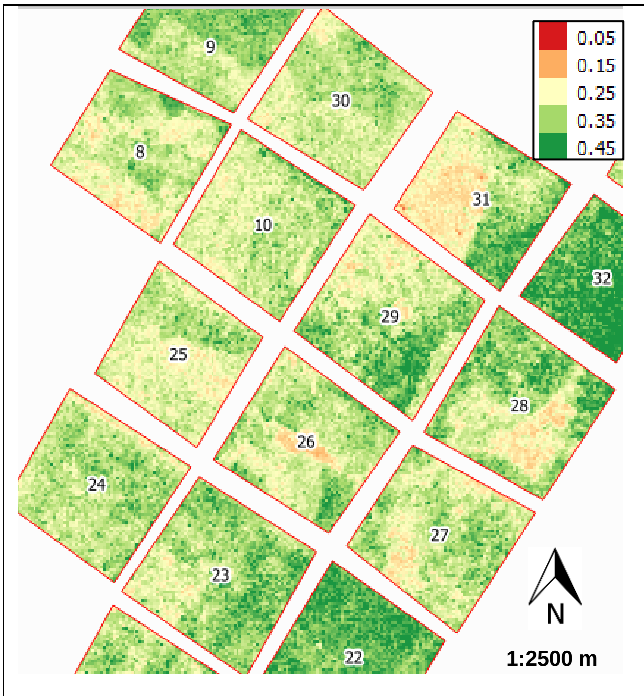
Test 2. Inherent system reliability at operational conditions

In order to be able to evaluate the system reliability of this innovation, the following tasks were performed:

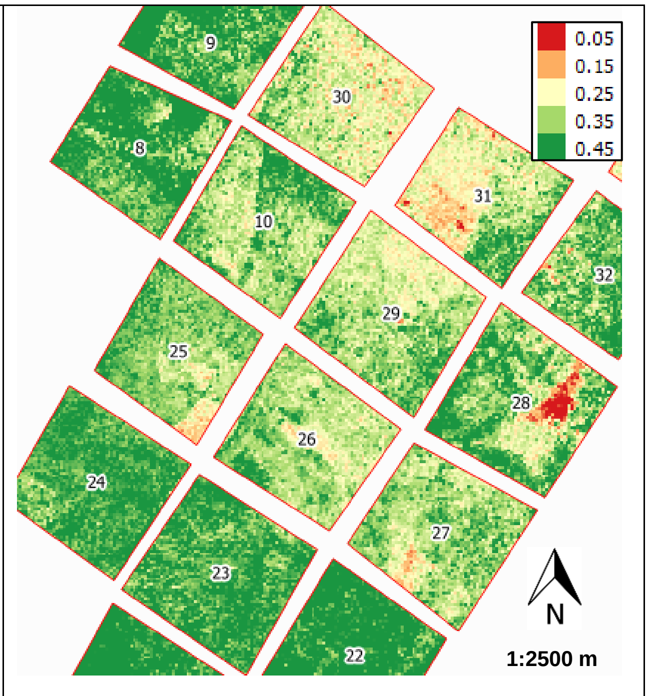
- Calculation of absolute differences between predicted and actual NDVI values.
- Reclassification of absolute differences, setting an agreement / not agreement boundary of 0.15 between forecasted and actual NDVI values.

Next figures show maps of actual vs. forecasted NDVI values and agreement/not agreement maps for the forecasted dates, while summarizes the overall performance of ThirdEye for the different testing sites. Next table summarizes the overall performance results retrieved for the Spanish testing sites.

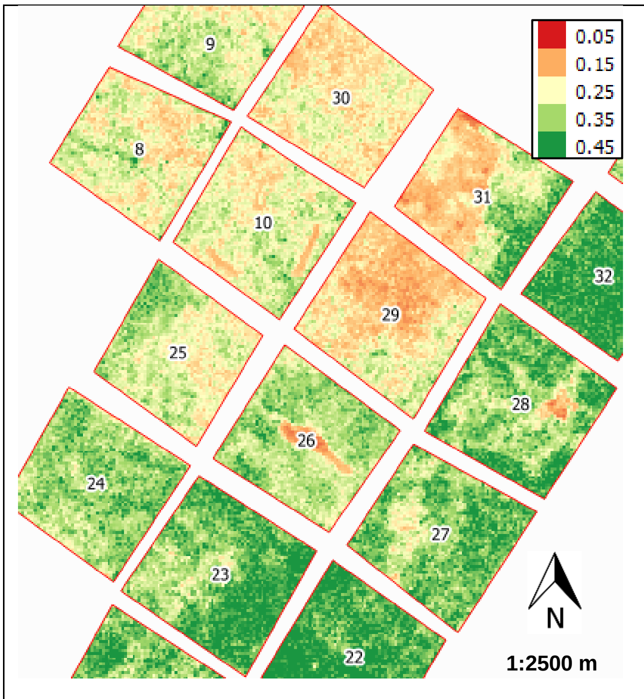
Maps of NDV real values vs. forecasted values for the Mozambique testing site:



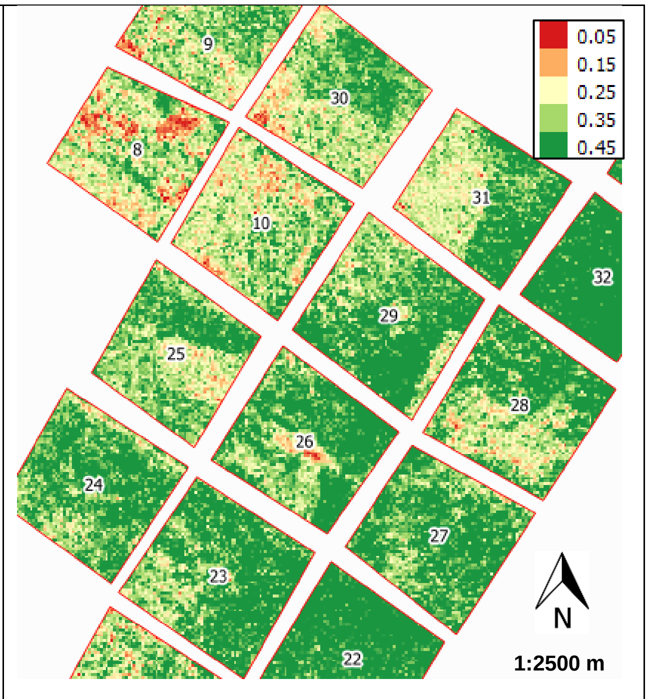
20170706_NDVI_real



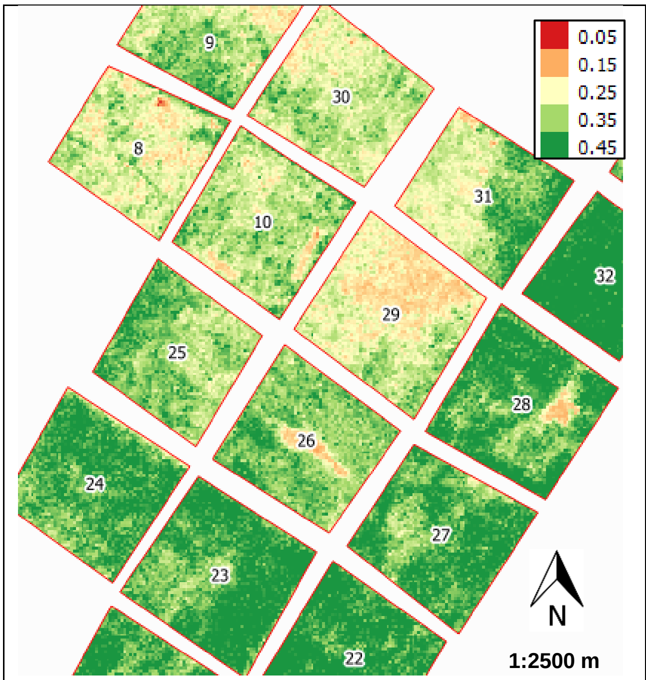
20170706_NDVI_forecast



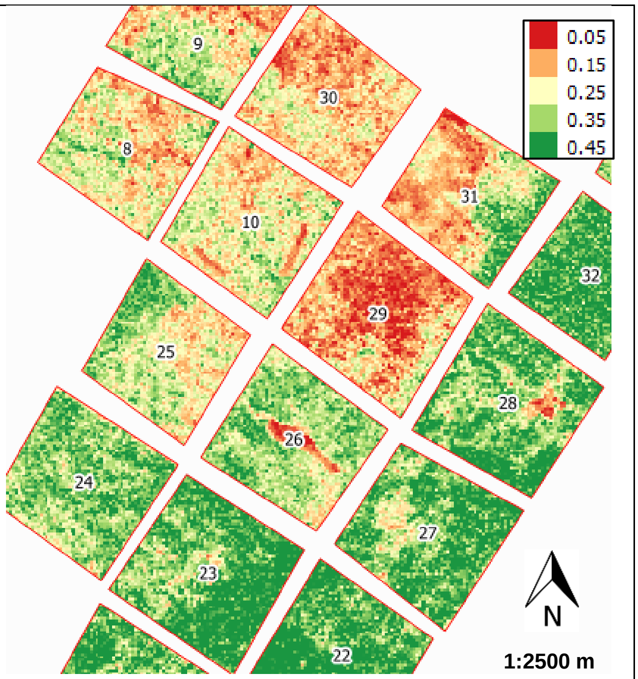
20170715_NDVI_real



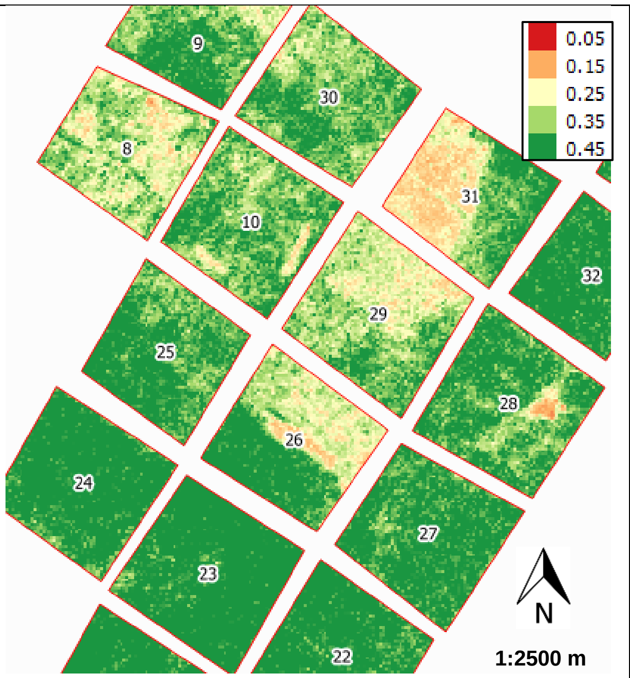
20170715_NDVI_forecast



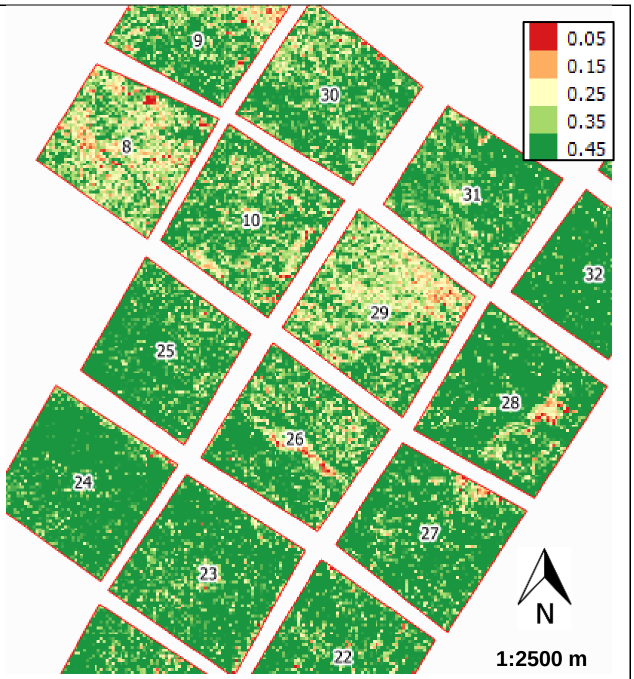
20170720_NDVI_real



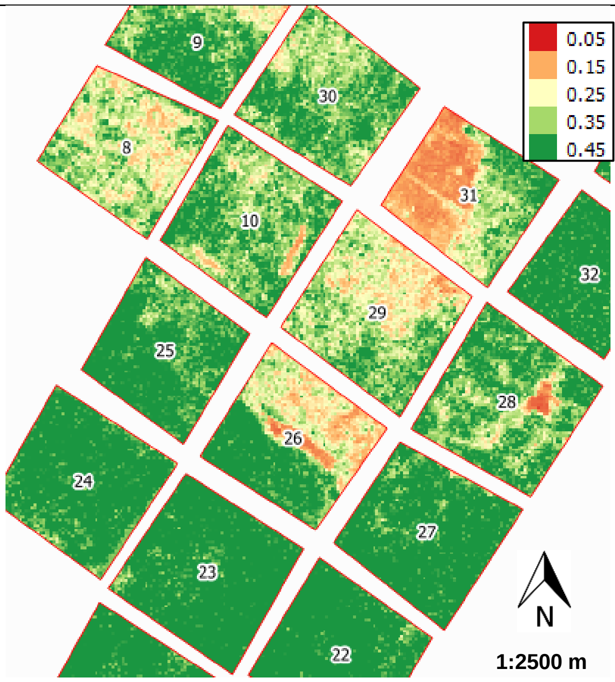
20170720_NDVI_forecast



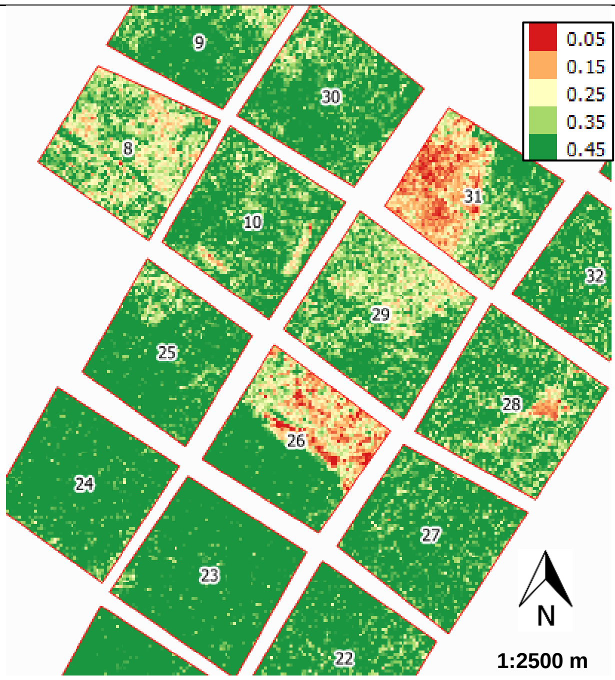
20170729_NDVI_real



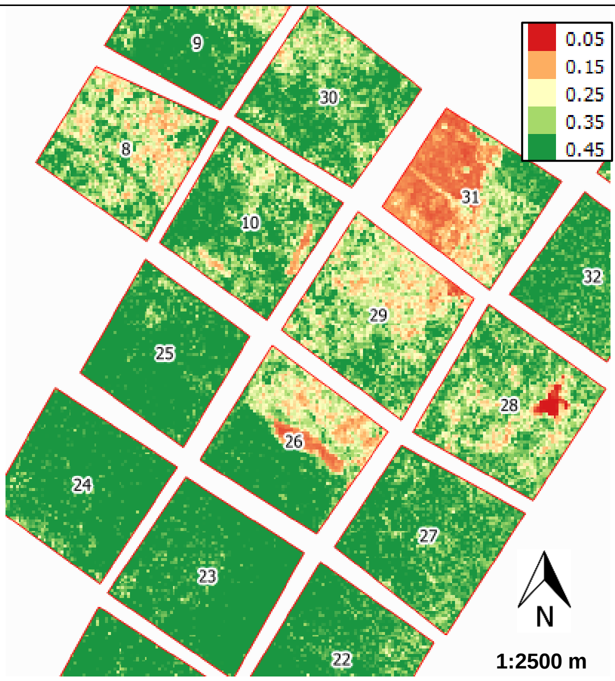
20170729_NDVI_forecast



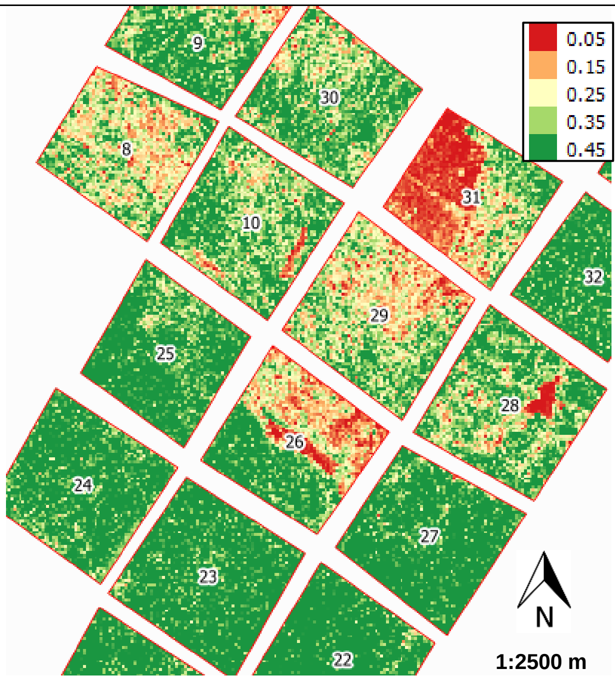
20170806_NDVI_real



20170706_NDVI_forecast

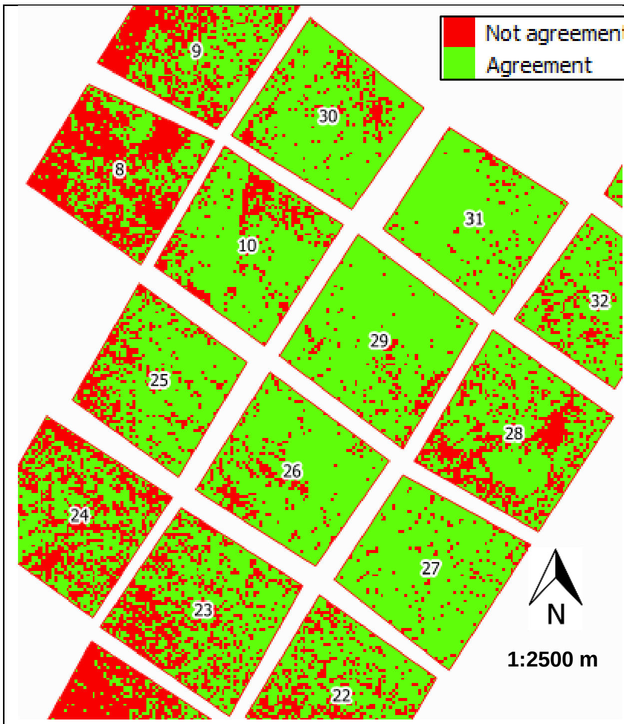


20170813_NDVI_real

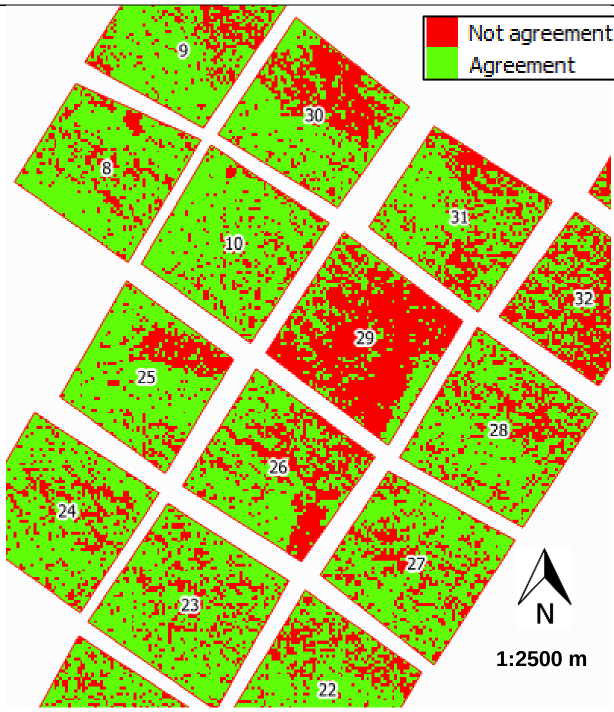


20170813_NDVI_forecast

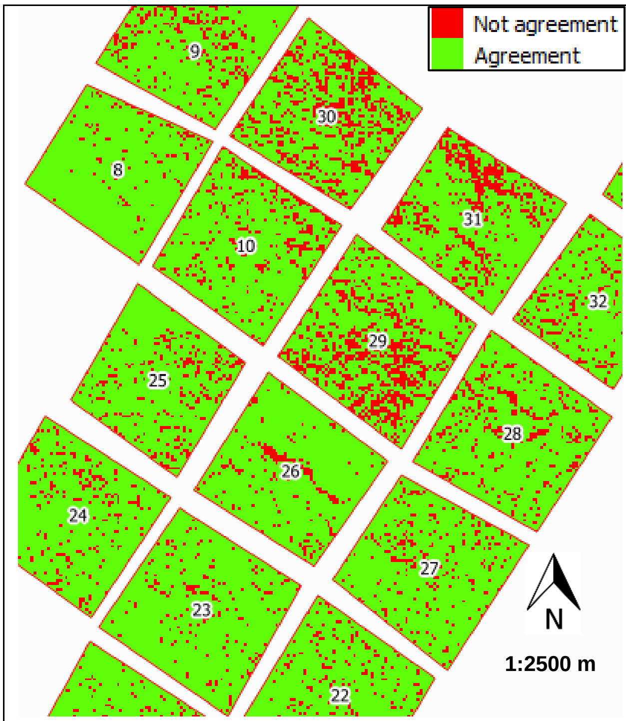
Maps of NDVI forecasted agreement/not agreement for the Mozambique testing site:



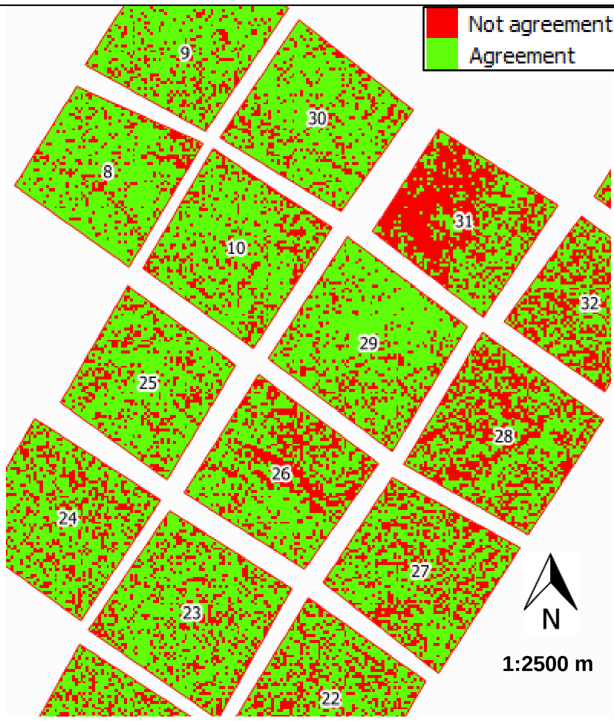
20170706_agreement



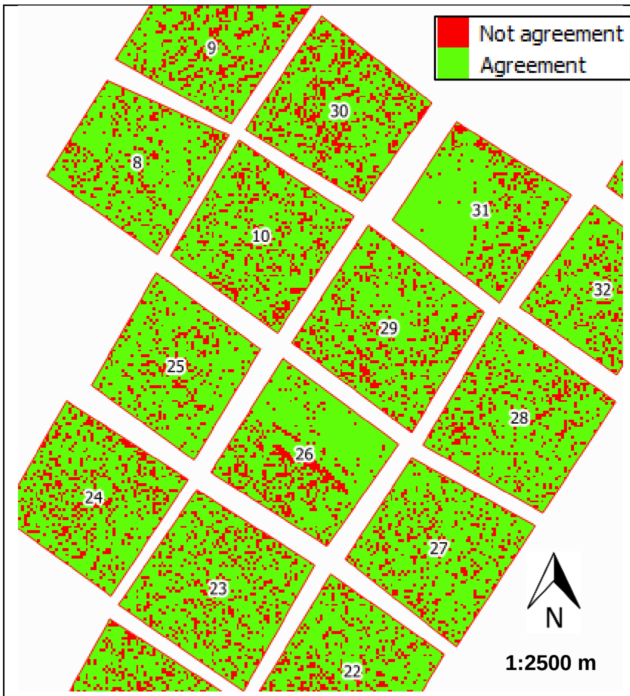
20170715_ agreement



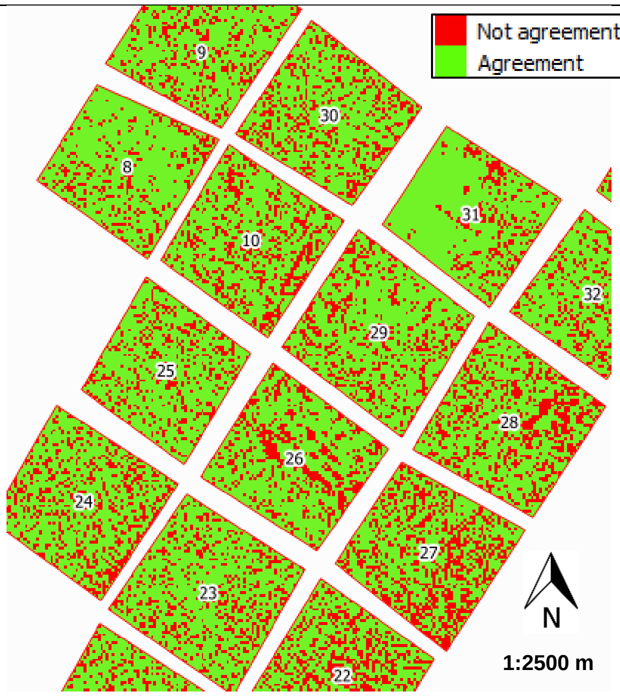
20170720_ agreement



20170729_ agreement



20170806_ agreement

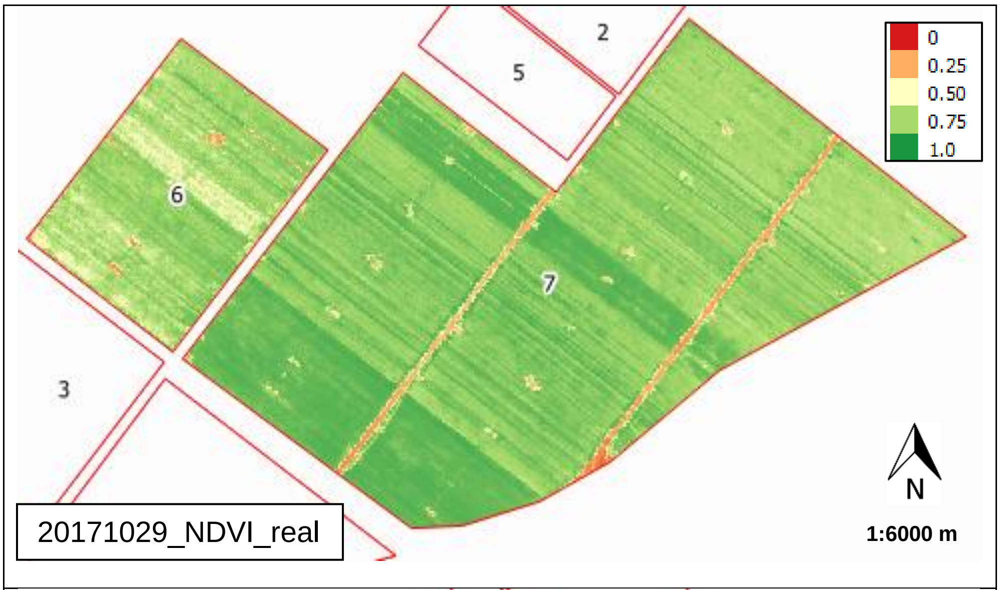


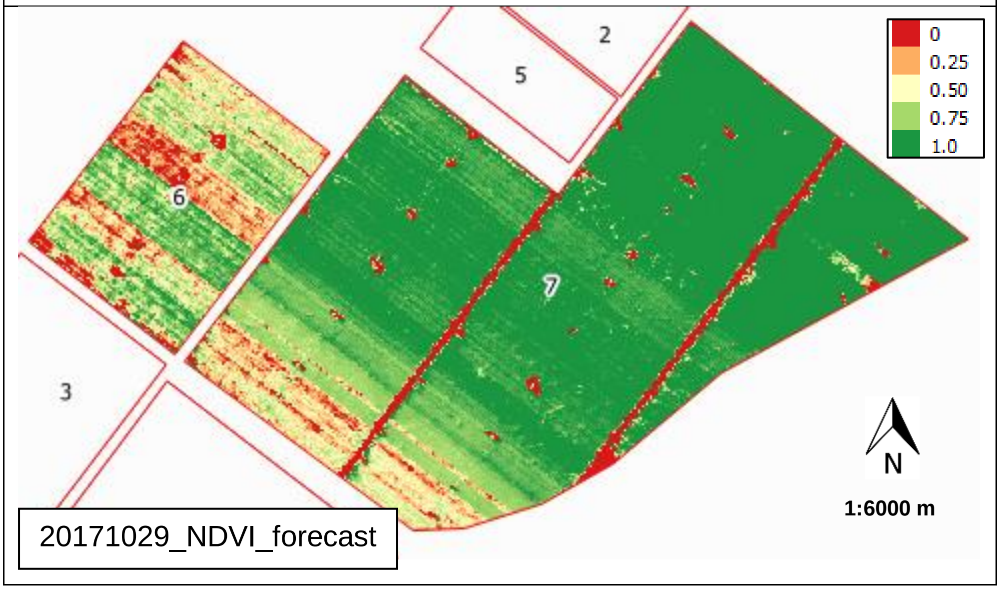
20170813_ agreement

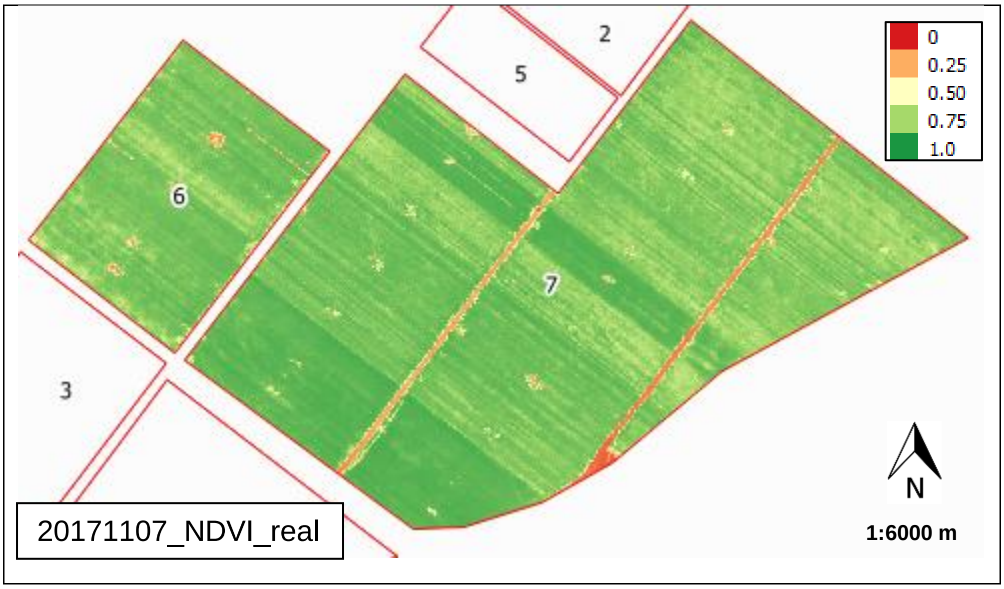
Performance results for the Mozambique testing site:

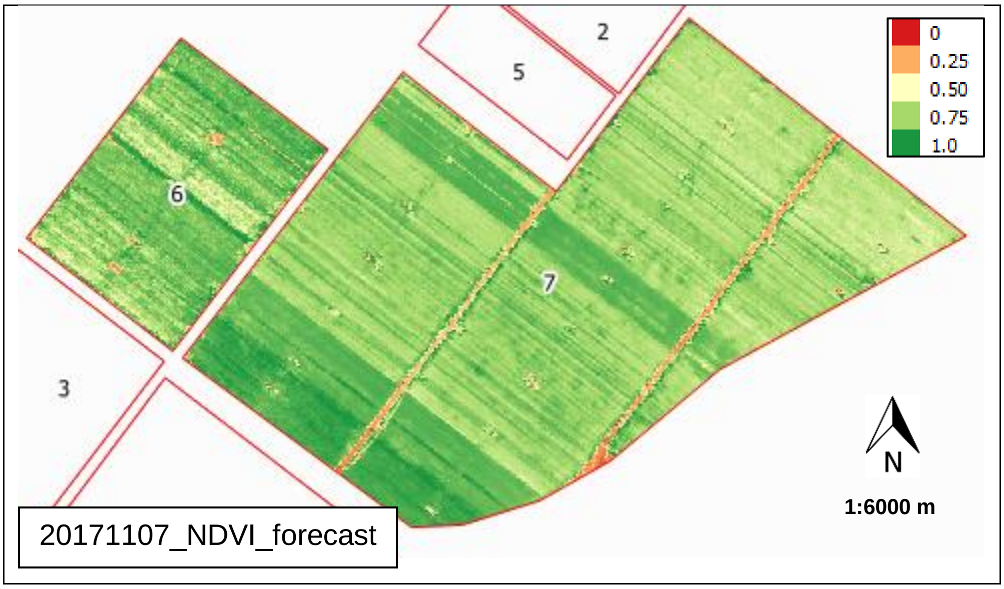
Date	Agreement (%)	No agreement (%)
20170706	74.3	25.7
20170715	65.8	34.2
20170720	86.1	13.9
20170729	69.2	30.8
20170806	76.7	23.3
20170813	73.7	26.3
TOTAL	**74.3**	**25.7**

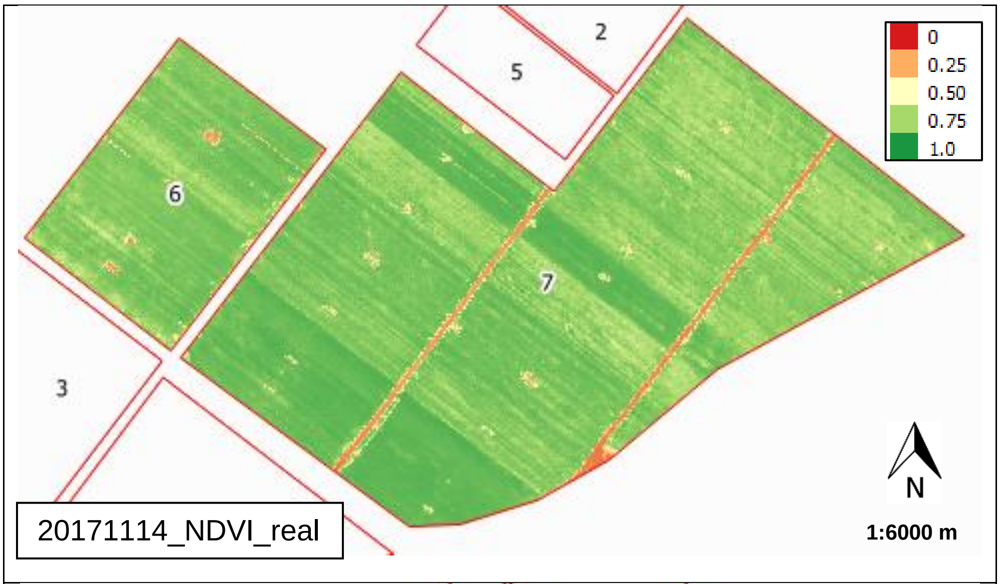
Maps of NDV real values vs. forecasted values for the Spanish testing site:

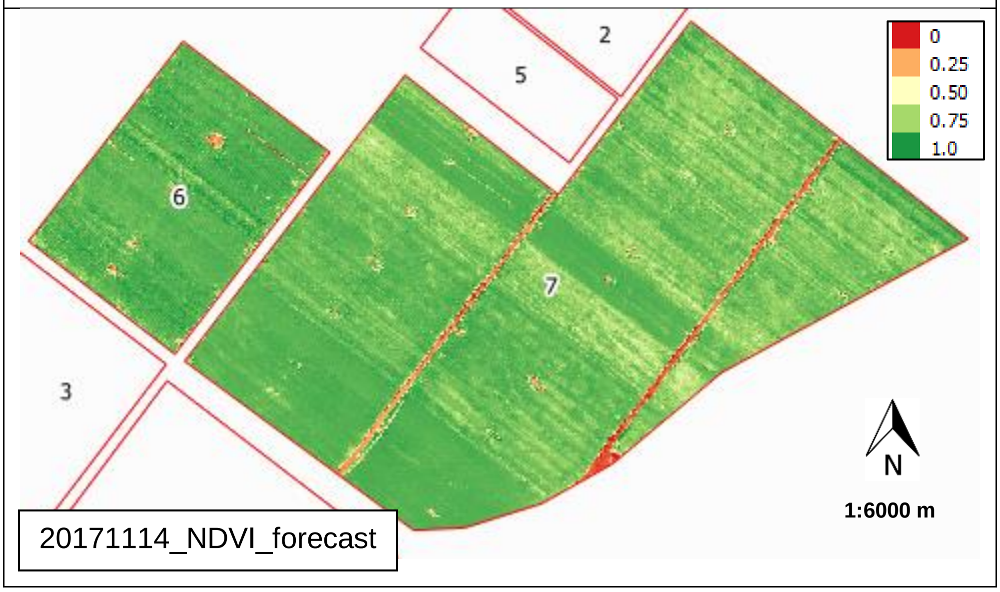




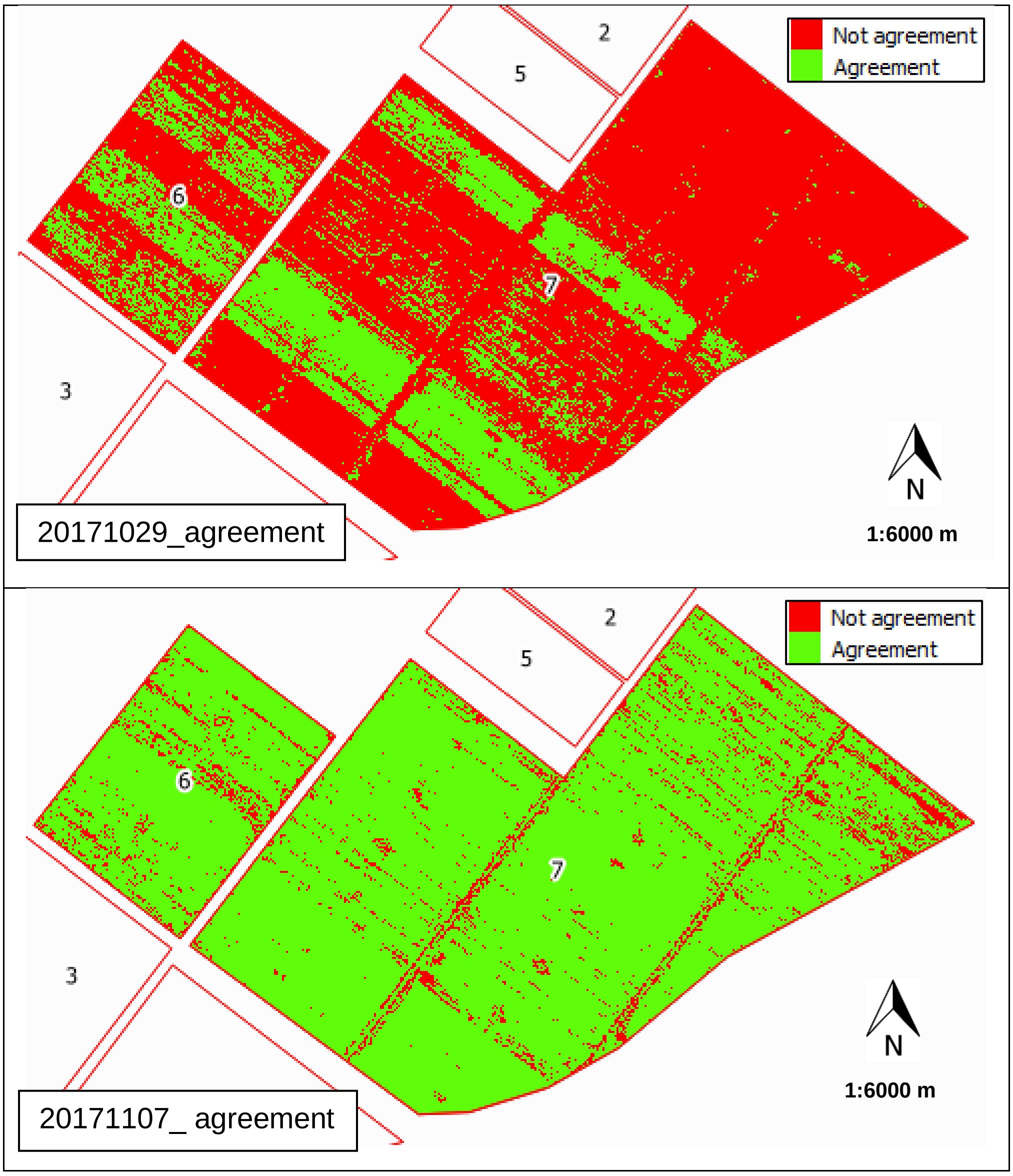


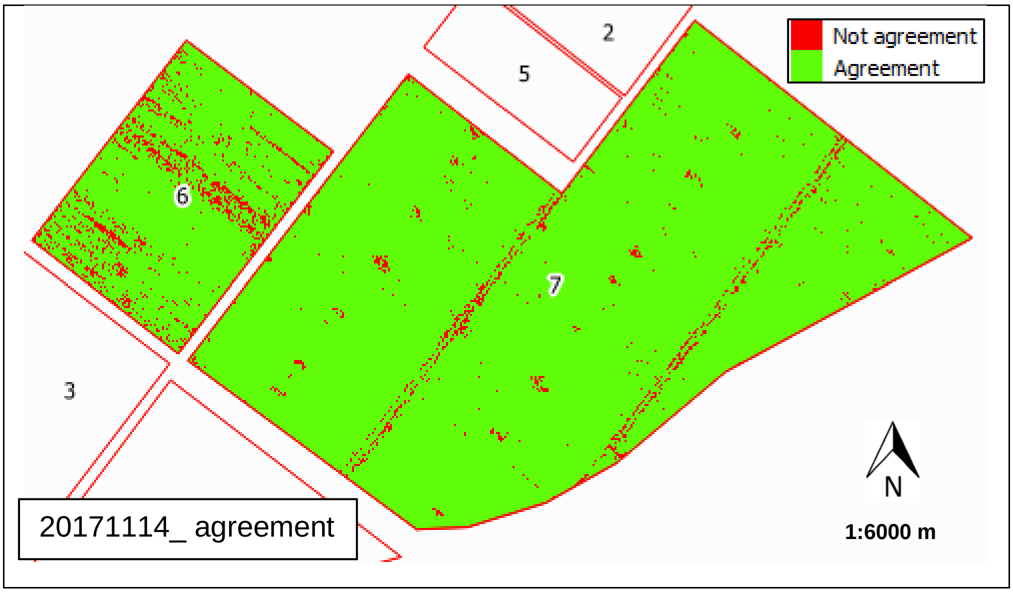

2
5
6
7
3
0
0.25
0.50
0.75
1.0
N
1:6000 m
20171107_NDVI_forecast


2
5
6
7
3
0
0.25
0.50
0.75
1.0
N
1:6000 m
20171114_NDVI_real


2
5
6
7
3
0
0.25
0.50
0.75
1.0
N
1:6000 m
20171114_NDVI_forecast

Maps of NDVI forecasted agreement/not agreement for the Spanish testing site:





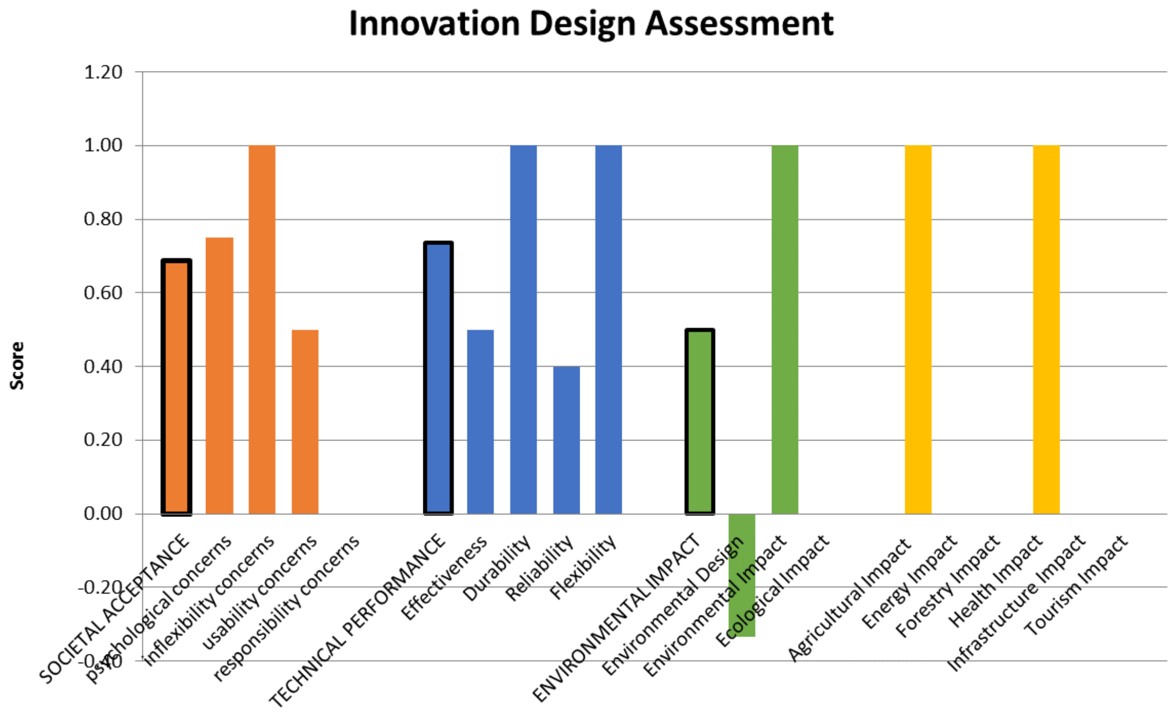
Performance results for the Spanish testing site:

Date	Agreement (%)	Not agreement (%)
20171029	37.7	62.3
20171107	91.5	8.5
20171114	94.8	5.2
TOTAL	**76.6**	**25.4**

In general, results show good performance (75% agreement), with a dependency on the type of crop and stage of the growing period. Monitoring NDVI on a frequent basis with drone imagery might reveal NDVI anomalies (abnormal low values) during the growth period of a certain crop. However, interpolating dates might lead to some errors on the forecasted outputs. For instance, if the second date of the interpolation has lower values than the first one, the forecasted date will have even lower values than the other two dates due to the negative slope of the interpolation. This reveals NDVI health-related anomalies but also incorrect NDVI forecasted values, when the lower values of the second date, compared to the first date, are due to image quality errors, such as those ones showed before. Additionally, misalignment between interpolated images might, likewise, lead to incorrect NDVI forecasted values. Furthermore, on well irrigated crops such as in the Spanish testing site, NDVI is likely to present slightly differences or variability within each plot, which make more difficult to distinguish between healh-related anomalies or image quality issues.

TIF Tool results

Overall assessment of ThirdEye using the BRIGAID's TIF Tool:



Overall results of the TIF Tool Assessment for ThirdEye:

1	Your innovation raises	few	societal concerns overall, having scored	11	out of a possible	16	and is	close	from/to SOCIETAL READINESS.
1.1	Your innovation raises	few	psychological concerns, having scored	3	out of a possible	4	and is	close	from/to societal readiness.
1.2	Your innovation raises	few	inflexibility concerns, having scored	5	out of a possible	5	and is	close	from/to societal readiness.
1.3	Your innovation raises	many	usability concerns, having scored	3	out of a possible	6	and is	far	from/to societal readiness.
1.4	Your innovation raises	many	responsibility concerns, having scored	0	out of a possible	1	and is	far	from/to societal readiness.
2	Your innovation raises	few	technical concerns overall, having scored	14	out of a possible	19	and is	close	from/to being ready in terms of its TECHNICAL DESIGN.
2.1	Your innovation raises	few	concerns related to its technical effectiveness, having scored	2	out of a possible	4	and is	close	from/to being ready/effective in terms of its technical design.
2.2	Your innovation raises	many	concerns related to its durability, having scored	5	out of a possible	5	and is	close	from/to being ready/effective in terms of its technical design.
2.3	Your innovation raises	no	concerns related to its reliability, having scored	2	out of a possible	5	and is	far	from/to being ready/effective in terms of its technical design.
2.4	Your innovation raises	many	concerns related to its flexibility, having scored	5	out of a possible	5	and is	close	from/to being ready/effective in terms of its technical design.
3	Your innovation raises	many	environmental concerns overall, having scored	4	out of a possible	8	and is	close	from/to being ready in terms of its ENVIRONMENTAL DESIGN.
3.1	Your innovation raises	many	concerns related to its Environmental Design having scored	-1	out of a possible	3	criteria. Your innovation may have a	negative	on the environment.
3.2	Your innovation raises	no	concerns related to its Environmental Impact, having scored	5	out of a possible	5	criteria. Your innovation may have a	positive	on the environment.
3.3	Your innovation raises	ERROR	concerns related to its Ecological Impact, having scored	0	out of a possible	0	criteria. Your innovation may have a	ERROR	on the environment.
4.1	Your innovation raises	no	concerns related to Agricultural Impacts, having scored positively on	4	out of	4	criteria. Your innovation may have a	positive	impact on the Agricultural Sector.
4.2	Your innovation raises	undetermined	concerns related to Energy Impacts, having scored positively on	0	out of	0	criteria. Your innovation may have a	undetermined	impact on the Energy Sector.
4.3	Your innovation raises	undetermined	concerns related to Forestry Impacts, having scored positively on	0	out of	0	criteria. Your innovation may have a	undetermined	impact on the Forestry Sector.
4.4	Your innovation raises	no	concerns related to Health Impacts, having scored positively on	4	out of	4	criteria. Your innovation may have a	positive	impact on the Health Sector.
4.5	Your innovation raises	undetermined	concerns related to Infrastructure Impacts, having scored positively	0	out of	0	criteria. Your innovation may have a	undetermined	impact on the Infrastructure Sector.
4.6	Your innovation raises	undetermined	concerns related to Tourism Impacts, having scored positively on	0	out of	0	criteria. Your innovation may have a	undetermined	impact on the Tourism Sector.

The responses for each section of the TIF Tool are detailed hereafter:

1	Societal acceptance assessment	
	Answer the following 16 questions by writing Yes or No in the corresponding cells.	**Yes or No?**
1	Does your innovation use any materials that might be considered unfamiliar (such as nanomaterials or genetically modified materials)?	No
2	Will members of the public affected by your innovation be the ones to decide whether or when to use it?	Yes
3	Does your innovation involve visible infrastructure (such as physical barriers) or visible land use changes (such as woodland removal)?	Yes
4	Could the deployment of your innovation disrupt daily activities, for example through road closures?	No
5	Does your innovation require large amounts of capital investment?	No
6	Does your innovation require a long lead time between users placing an order and it becoming operational?	No
7	Does your innovation require new infrastructure or significant changes to existing infrastructure?	No
8	Does your innovation involve releasing any materials into the environment (such as sprays or coatings)?	No
9	Are your potential users likely to have a single mission, for example to protect ecosystems?	No
10	Does your innovation take less time to deploy than incumbent alternatives (such as sand bags for floods or fire nozzles for wildfires)?	Yes
11	Would the use of your innovation require special training?	Yes
12	Will help and support be available to users of your innovation?	Yes
13	Innovations can either reinforce or change users' existing ways of working. Does your innovation reinforce existing ways of working?	Yes
14	Are the effects of your innovation directly publicly tangible (such as seeing flood defences working or hearing a warning alert system)?	No
15	Adaptations can either be deployed permanently or temporarily. Is your innovation deployed permanently?	No
16	Are members of the public involved in shaping the research, development, demonstration and deployment of your innovation?	No
	Answer the following 4 questions by writing A, B or C in the corresponding cells.	**A, B or C?**
17	What would your innovation primarily protect? (A) public infrastructure, (B) private properties or (C) the environment	B
18	Who would pay for your innovation? (A) government authorities, (B) private companies or (C) local communities	B
19	Who would implement your innovation? (A) government authorities, (B) private companies or (C) local communities	B
20	How would compensation be made in the event of your innovation failing? Through (A) government compensation, (B) project insurance or (C) responsible parties	B

2	Technical Design	
	Answer the following questions by writing Yes or No in the corresponding cells.	**Yes or No?**
1	Does the innovation provide significant technical advantage(s) relative to a traditional/conventional measures?	Yes
2	Does your innovation physically prevent a hazard from occurring?	No
3	Does your innovation require combination with other interventions and/or activities in order to reduce risk (e.g, flood warning system in combination with a flood barrier or a fire warning system in combination with controlled burning)?	Yes
4	Will the innovation require additional testing and/or substantial upgrades when considering future hazard conditions (i.e., considering climate change)?	No
5	Is the lifetime of the innovation limited by climate change? (i.e., will climate change affect the estimated life(time) of the innovation?)	No
6	Does the innovation require frequent inspection and maintainence to reach its intended lifetime?	No
7	Are the materials or software needed for maintanence and/or repair easily obtained and can they be integrated by the end-user?	Yes
8	Is the innovation designed to be used repetitively or continuously operated over its lifetime?	Yes
9	Can the innovation be operated without repair and/or replacement of components during a hazard event?	Yes
10	Does the innovation exhibit vulnerabilities during testing and/or demonstration (e.g., structural: sliding or rotation, or technological: errors)?	Yes
11	Is there a critical component in the innovation's structural or technological design that could lead to catastrophic failure?	Yes
12	Does your innovation rely on the delivery of services or materials (e.g., structural components, data) outside of your control to be successfully operated during a hazard event?	No
13	Does your innovation require the execution of tasks by humans to be successfully operated during a hazard event?	Yes
14	Can the vulnerability of your innovation to human error be easily reduced through improvements in operational protocols and/or end-user training?	Yes
15	Is the innovation modular (opposite: monolithic) and can it be easily installed or applied at different sites across Europe without adjustment?	Yes
16	Does the innovation require additional testing and/or substantial upgrades (e.g., new components) if used at different sites across Europe?	No
17	Will the size of the market for the innovation (in Europe) will significantly decrease (>50%) due to future hazard conditions (i.e., considering climate change)?	No
18	Have relevant end-users have been identified and contacted and has a need for this innovation observed?	Yes
19	Are the advantages of the innovation derived from its multi-functionality (e.g., reduction of carbon emissions or enhanced recreational activities)?	Yes

3	**Environmental Characteristics**	
Answer the following questions by writing A, B, or C, in the corresponding cells.		**A, B or C?**
3.1	**Environmental Design**	
3.1.1	Does the innovation deliberately use ecosystems and their services, or mimic or preserve natural processes? (A) Yes (B) No	B
3.1.2	How does the change in footprint (area) required for implementation on-site compare to conventional measures or the present situation? (A) Increase space required (B) Decrease space required (C) No Impact on space required	C
3.1.3	How does the construction or operation of the innovation affect the quantity of greenhouse gases in the environment (e.g., as CO_2 or CH_4)? (A) Increase (B) Decrease (C) No Impact	C
3.1.4	Is the innovation made from recycled or recycable materials? (A) Yes (B) No	B
3.1.5	Does the innovation include specific design features or components which preserve or enhance ecosystem services? (A) Yes (B) No	A
3.2	**Environmental Impact**	
3.2.1	How does the innovation impact the quality of surface water? (A) Improve (B) Worsen (C) No Impact	C
3.2.2	How does the innovation impact the quantity of available surface water? (A) Increase (B) Decrease (C) No Impact	A
3.2.3	How does the innovation impact the quality of ground water? (A) Improve (B) Worsen (C) No Impact	C
3.2.4	How does the innovation impact the quantity of available ground water? (A) Increase (B) Decrease (C) No Impact	A
3.2.5	How does the innovation impact the quality of the sea water? (A) Improve (B) Worsen (C) No Impact	C
3.2.6	How does the innovation impact soil quality? (A) Improve (B) Worsen (C) No Impact	C
3.2.7	How does the innovation impact air quality? (A) Improve (B) Worsen (C) No Impact	C
3.2.8	Does the implementation (or construction) of the innovation generate debris? (A) Yes (B) No	B
3.2.9	Does the implementation (or construction) of the innovation generate noise or vibration? (A) Yes (B) No	B
3.2.10	How does the innovation impact landscape quality? (A) Improve (B) Worsen (C) No Impact	A
3.3	**Ecological Impact**	
3.3.1	How does the innovation impact the spatial extent of protected nature area? (A) Increase (B) Decrease (C) No Impact	C
3.3.2	How does the innovation impact the quality of protected habitats? (A) Improve (B) Worsen (C) No Impact	C
3.3.3	How does the innovation impact the number protected species (e.g., birds, vegetation, fish, mammals)? (A) Increase (B) Decrease (C) No Impact	C
3.3.4	How does the innovation impact the spatial extent of non-protected nature area? (A) Increase (B) Decrease (C) No Impact	C
3.3.5	How does the innovation impact the quality of non-protected habitats? (A) Improve (B) Worsen (C) No Impact	C
3.3.6	How does the innovation impact the number non-protected species (e.g., birds, vegetation, fish, mammals)? (A) Increase (B) Decrease (C) No Impact	C

4	Sectoral Impacts	
Answer the following questions by writing A, B or C in the corresponding cells.		A, B or C?
4.1	Agriculture	
4.1.1	How does the innovation impact the total area available for agricultural production? (A) Increase (B) Decrease (C) No Impact	A
4.1.2	How does the innovation impact agricultural production conditions (e.g., by increasing soil quality or water availability)? (A) Improve (B) Worsen (C) No Impact	A
4.1.3	How does the innovation impact the variety of agricultural products (e.g., crops, dairy, meat, fruit, fish, aquaculture) that can be produced or are available? (A) Increase (B) Decrease (C) No Impact	A
4.1.4	How does the innovation impact the total yield of one or more agricultural products? (A) Increase (B) Decrease (C) No Impact	A
4.2	Energy	
4.2.1	How does the innovation impact the energy production capacity (e.g., by generating energy or increasing energy distribution)? (A) Increase (B) Decrease (C) No Impact	C
4.2.2	How does the innovation impact the reliability of energy production (e.g. by improving cooling water conditions for energy plants)? (A) Increase (B) Decrease (C) No Impact	C
4.2.3	How does the innovation impact the efficiency of energy production? (A) Increase (B) Decrease (C) No Impact	C
4.2.4	How does the innovation impact the carbon footprint of the end-user? (A) Increase (B) Decrease (C) No Impact	C
4.3	Forestry	
4.3.1	How does the innovation impact the total area available for wood production (including timber and biomass)? (A) Increase (B) Decrease (C) No Impact	C
4.3.2	How does the innovation impact wood production conditions (e.g., by increasing forest resilience or water availability)? (A) Improve (B) Worsen (C) No Impact	C
4.3.3	How does the innovation impact the total area available for non-wood production (including cork, fruit, honey, mushrooms, pastures, game and fishing)? (A) Increase (B) Decrease (C) No Impact	C
4.3.4	How does the innovation impact non-wood production conditions (e.g., by increasing forest resilience or water availability)? (A) Improve (B) Worsen (C) No Impact	C
4.4	Health	
4.4.1	How does the innovation impact the number of fatalities in the area exposed to the hazard? (A) Increase (B) Decrease (C) No Impact	B
4.4.2	How does the innovation impact the number of people affected by the hazard in their physical health (i.e., number of people injured)? (A) Increase (B) Decrease (C) No Impact	B
4.4.3	How does the innovation impact the number of people affected by the hazard in their mental/physo-social health? (A) Increase (B) Decrease (C) No Impact	B
4.4.4	Does the innovation emit or release chemicals or products that are harmful to humans? (A) Yes (B) No	B
4.5	Infrastructure	
4.5.1	How does the innovation impact the quality of the built environment (I.e., residential, commercial, and industrial)? (A) Improve (B) Worsen (C) No Impact	C
4.5.2	How does the innovation impact the total area available for urban development? (A) Increase (B) Decrease (C) No Impact	C
4.5.3	How does the innovation impact the capacity of existing transportation systems (e.g., roads, railways, waterways, and airports) or create new capacities? (A) Increase (B) Decrease (C) No Impact	C
4.5.4	How does the innovation impact the reliability of existing transportation systems (e.g., roads, railways, waterways, and airports)? (A) Increase (B) Decrease (C) No Impact	C
4.5.5	How does the innovation impact the transport capacity of critical infrastructure networks (e.g., power, water, waste management)? (A) Increase (B)	C
4.5.6	How does the innovation impact the reliability of critical infrastructure networks (e.g., power, water, waste management)? (A) Increase (B) Decrease (C) No Impact	C
4.6	Tourism	
4.6.1	How does the innovation impact the total area available for recreational activities? (A) Increase (B) Decrease (C) No Impact	C
4.6.2	How does the innovation impact the attractiveness of the area for recreational activities? (A) Increase (B) Decrease (C) No Impact	C
4.6.3	How does the innovation impact the length of the tourist season? (A) Increase (B) Decrease (C) No Impact	C

TRL assessment:

Climate Adaptation Innovation Readiness	
Innovation:	ThirdEye
Organization:	FutureWater
Starting TRL	TRL4
Anticipated Ending TRL	TRL6
Current Status	TRL5
Actual Ending TRL	-

BRIGAID Stages	TRL	Question	*To be completed at the start of the project*						*To be completed at the time of interim reports*			*To be completed at the end of the project*		
			Start of Project			**Anticipated End of Project**			**Current status**			**Actual End of Project**		
			Yes	No	N/A	Yes	No	N/A	Yes	No	N/A	Yes	No	N/A
Desk Study	**TRL 1**	**Basic principles observed and reported.**												
	TRL 2	**Innovation concept formulated.**												
	TRL 3	**Analytical and experimental critical function and/or characteristic proof-of-concept.**												
Stage 1: Laboratory Testing	4	Has societal acceptance testing of individual components been performed?	x						x					
	4	Has performance of components and interfaces between components been demonstrated?		x					x					
	4	Does draft system architecture plan exist?		x					x					
	4	Have end user technology/system requirements been documented (e.g., reliability requirements)?		x					x					
	4	Has component compatibility been demonstrated?	x						x					
	4	Does technology demonstrate basic functionality in simplified environment?	x						x					
	4	Have performance characteristics been demonstrated in a laboratory environment?		x					x					
	4	Have low-fidelity assessments of system integration and engineering been completed?		x					x					
	TRL 4 Achieved	**Innovation validated in a laboratory environment.**												
	5	Have internal system interface requirements been documented?		x					x					
	5	Has analysis of internal interface requirements been completed?		x					x					
	5	Can all system specifications be simulated and validated within a laboratory environment?		x					x					
	5	Is the laboratory environment high-fidelity?		x					x					
	5	Have individual component functions been verified through testing?		x					x					
	5	Have objective and threshold operational requirements been developed? (e.g., has the intended reduction in risk been quantified? Is the end-user requirement for reliability known?)		x						x				
	5	Have all potential failure modes been identified and documented?		x					x					
	5	Has the reliability of the fully integrated prototype been estimated using desk study calculations?		x						x				
	5	Have the social, technical, and environmental design of the innovation been re-assessed? (TIF tool applied, i.e. stage-gate tool)		x					x					
	TRL 5 Achieved	**Innovation prototype demonstrated in a laboratory environment.**												
Stage 2: Operational Testing	6	Have system integration issues been addressed?		x					x					
	6	Is the operational environment fully known?		x					x					
	6	Have the current and future (i.e., under climate change) hazard conditions in the intended operational environment been documented?		x						x				
	6	Has the technical and/or climate lifetime of the innovation been estimated?		x						x				
	6	Have performance characteristics (i.e., social, technical, and environmental) been verified in a simulated operational environment?		x						x				
	6	Has prototype been tested in a simulated operational environment and shown to withstand the intended hazard loads *without* failure?		x						x				
	6	Does the prototype successful reduce the intended/threshold level of risk (i.e., by reducing the hazard and/or its consequences) in a simulated operational environment?		x							x			
	6	Have the operation and maintainence protocols over the lifetime of the innovation been established and documented?		x					x					
	6	Has system been tested in realistic environment outside the laboratory?		x					x					
	6	Has engineering feasibility been fully demonstrated?		x						x				
	TRL 6 Achieved	**Innovation model or prototype demonstrated in a relevant environment.**												
	7	Have all interfaces been tested individually under stressed and anomalous conditions?		x						x				
	7	Has technology or system been tested in a representative operational environment and shown to withstand the expected hazard loads?		x						x				
	7	Has the reliability of the prototype been quantified and validated in a representative operational environment?		x						x				
	7	Are available components representative of production components (i.e., will the innovation be ultimately produced using the same materials as used in testing; is the prototype to-scale)?		x						x				
	7	Have vulnerabilities to human error been effectivley minimized?		x						x				
	7	Has fully integrated prototype been demonstrated in actual or simulated operational environment?		x						x				
	TRL 7 Achieved	**Innovation prototype demonstratied in an operational environment.**												
	8	Are all technology/system components form, fit, and function compatible?		x						x				
	8	Is technology/system form, fit, and function compatible with operational environment?		x						x				
	8	Has technology/system form, fit, and function been demonstrated in operational environment and shown to withstand the expected hazard load(s) without failure?		x						x				
	8	Have the operational and maintanence costs over the lifetime been estimated and documented?		x						x				
	8	Have the social, technical, and environmental design of the innovation been re-assessed? (TIF tool applied, i.e. stage-gate tool)		x						x				
	TRL 8 Achieved	**Actual system completed and qualified through test and demonstration.**												
	TRL 9	**Actual system proven through successful mission operations.**												

Conclusion and upcoming activities

By the time of joining BRIGAID, ThirdEye was considered as a flying sensor system that was succesfully providing different operational servicees in Mozambique. Although conceptualized, the forecasting component of ThirdEye was not fully integrated and tested. As consequence, ThirdEye was set at TRL4.

With the support of BRIGAD, FutureWater has:

- integrated both components into one full and functional system
- performed different flight campaigns and mission in diferent operational sites (Mozambique and Spain) in order to create a large imagery database useful for testing purposes
- evaluated and tested the main failure modes of ThirdEye along all the acquisition and processing stages.
- tested the inherent reliability of the system, i.e. its ability to provide accurate short-term forecasts of crop health/disease.

After the 2017 testing activities, ThirdEye almost fully reached a TRL5. However, several issues are still pending of being addressed in order to reduce the risk of failures during the monitorig/sensoring stage, and to increase the reliability of forecast outputs.

Upcoming activities:

- To establishing a standardized protocol for making the drone flights (monitoring stage), specifying the same parameters for each flight during the testing campaign: flight direction, solar angle, laps, altitude.
- Test the usefulness of other vegetation indices that could be more informative to detect crop stress, and predict crop health status (e.g. Normalized Difference Red-Edge Index which uses Red-Edge information instead of the Near-Infrarred)
- To perform an accuracy assessment to analyze the influence of local variability, errors in FS-data collection and modelling uncertainties (inputs, processing and outputs).
- To combine radiometric/NDVI data with auxiliary terrain data (e.g. Digital Elevation Models (DEM) obtained from drone imagery) in order to create plant height and biomass maps as surrogates of crop health status.
- To use thermal imagery and thermal-related stress indices as proxies of crop performance.
- To use crop growth models previoulsy calibrated with drone imagery outputs.
- To test other interpolation methods, such as neural networks or multivariate regressions, able to digest a higher number of relevant variables or surface properties.

6. Innovation: Water+ Furrow Diker

Innovator: Aquaproject (BRIGAID consortium partner)

Contributing authors: Ioana Dragran (Aquaproject), Ilie Biolan (Aquaproject), Costel Biolan (Aquaproject), Catalin Popescu (Aquaproject)

Innovation description

The description of Water+ Furrow Diker below is also available from the Climate Innovation Window, http://climateinnovationwindow.eu/innovations/water-plus-furrow-diker

Name

Water Plus+ Furrow Dike Machinery

Short description

Furrow diking is commonly used by farmers in arid and semiarid regions to improve water-to-soil contact for better absorption and reduced evaporation of irrigation water. By enhancing water capture and percolation, furrow dikes may prolong the time that rainwater supplies moisture to the crop. This technique has been widely accepted and applied in the Western United States.

Water+ Furrow Diker creates a series of basins and dams in the furrow between crop rows to help catch and absorb water from precipitation or overhead irrigation. It also breaks up and loosens soil surface crust that would otherwise impede infiltration and promote runoff and ponding, which lead to evaporation.

Sketch/Photograph of the Innovation

Furrow diking concept. Left pannel: Runoff of rain is retained by furrow dikes for continued infiltration (right), but this water is lost from undiked (left) fields. Right pannel: The most common type of furrow diker is the tripping paddle type, which is often used concurrently with cultivation of ridge till fields after planting (taken from Jones and Baumhardt, 2003):

Which hazard(s) is the innovation designed to mitigate?

Droughts: Sustained and extensive occurrence of below average water availability. Resulting in water scarcity when drought conditions cause long-term imbalances between water availability and

demands. Heavy precipitation: Rainfall events that result in 1) (urban) floods due to exceedance of: drainage capacity, 2) flash floods defined as rapid flooding of low-lying areas generally within a few hours after heavy rainfall events such as thunderstorms; and 3) hail resulting in damage to buildings, (critical) infrastructure networks and other objects (typically vehicles) Themes to which the innovation applies: Agriculture, Water availability
How does the innovation work?

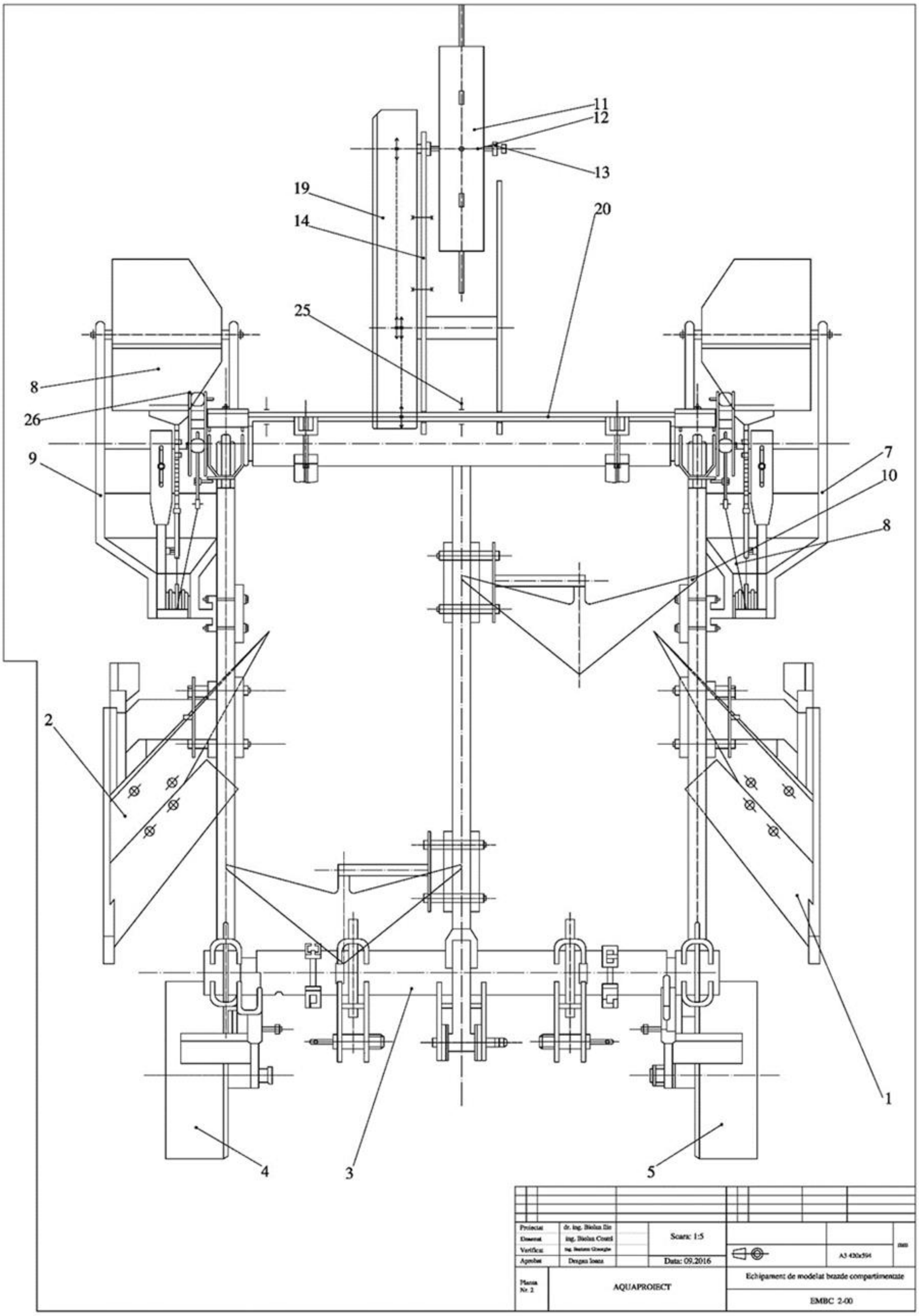
Water+ Furrow Diker is an innovative equipment which maximize the collection and harvesting of rainfall water and irrigation drainage, and prevent the generation of runoff and soil erosion. The machinery is operated with wheel tractors of 35-80 HP. The engineering design of the innovation is shown in Two different engineering solutions have been designed and adapted for covering row crops and vineyards, respectively. Soil modeling with the furrow diker are recommended to be applied: a) in row crops, when crop height reaches 30-60 cm (in Romania, this condition accounts between May, 15th – June, 15th for spring crops, or between July, 15th – August, 15th for summer crops); b) in vineyards, when during the spring-summer period (March, 15th-September, 1st) and/or the autumn period (October, 15th –November, 15th).

The furrow diker for row crops (DMBC) consists of a frame, two wheels and a maximum of five working sections (DMBC-5). Each working section is integrated by a knife chisel ripper for loosening soil, a lister plow for making furrows and an impeller with paddles for the furrow diking. The separation distance between furrows is 70 cm whether the five working sections are used.

The furrow diker developed for vineyards (EMBC) will consist of a frame, two wheels, and a maximum of two working sections and two knive arrows centrally positioned (EMBC-2). Each section work is integrated by a plow for making furrows and an impeller with paddles for the furrow diking. Arrow cultivator blades will weed area simultaneously with the two dike furrows made in the protection zone near the rows of vines. The separation distance between furrows is 2.2 m whether the two working sections are used.

Furrow dikers developed by Aquaproiect. Upper and below-left plates show the DMBC-5 diker for weeding crops; below-right plate shows the EMBC-2 diker for vineyards:

Block diagram of the DMBC-5 diker:



Added value / main differentiating element from conventional approach(es)
The main added value features of the Water+ Furrow Diker refer to: A) The agromachine makes possible the generation of dike furrows in a single pass, and simultaneously with the cultivation, increasing the possibilities of rainfall collection and/or water harvesting, and B) Easy integration with other existing equipments (e.g. plows).

Critical success factors / Limitations
• The minimum distance between crop lines is stated at 70 cm (row crops) and 1.8 (tree/ vineyards). • Soil moisture content is a limiting factor which affect the overall performance. Soil moisture content must be in the 50%-70% range to guarantee the best performance. • The diker can work on all types of soils only if the soil was previously plowed up to 20cm in depth. • Water+ Furrow Diker requires to be used at the right cropping growth period. This period depends on the cropping system. In row crop systems, crop height must be 30-60 cm which is reached between May, 15th and June, 15th for spring row crops, or between July, 15th- August, 15th for summer row crops. In vineyards, the furrow diker should be used during the spring-summer-autumn period, i.e. between March, 15th to September, 1st , or between October, 15th to November, 15th. • The Water+ Furrow Diker works properly with slope gradients of less than 5%.

Desk study

Summary

In this section, the most relevant issues related with the innovation are provided.

Indicator	Desk Study Questions
Technical Effectiveness refers to the intended capacity of the innovation to reduce risk from a specific hazard(s)	- What type of hazard(s) does the innovation address? - Which characteristic(s) does the innovation have? - How will the innovation reduce the risk of the hazard(s)? - What is the intended (quantitative) level of risk reduction? - Has the innovation been tested previously and can the innovation achieve the intended level of risk reduction without failure? - What is the current estimated technical readiness level (TRL) of the innovation?
Reliability *refers to the likelihood that the innovation fulfills its intended functionality over its lifetime*	- What are the loads that act on the innovation? - What are the possible structural failure modes of the innovation? If the innovation is semi-permanent or temporary, what are the possible implementation failure modes? - Which failure modes are most likely to occur?

Indicator	Desk Study Questions
	- Is there a facility where these failure modes can be tested? - Which failure modes cannot be tested?
Durability refers to the intended use and lifetime of the innovation	- Is the innovation permanent, semi-permanent, or temporary? - If the innovation is semi-permanent or temporary, what percent of the innovation needs to be replaced after each event? - What are the storage requirements for the innovation? - What is the expected lifetime of the innovation based on its structural components? - What are the maintenance requirements for the innovation to reach its maximum lifetime?
Flexibility refers to the likelihood that the innovation fulfills its intended functionality over its lifetime	- Where will the innovation be marketed/sold? What is the (potential) size of the market for the innovation under current climate conditions? under future climate conditions? - Is the innovation made up of modular components (or, alternatively, are the innovation's components customizable)? - Does the innovation require significant adjustment to be installed in a new location/used at different sites throughout Europe? - Are the material components of the innovation easily obtained within the potential market(s)? What is the material cost of the innovation?

Intended functionality/performance

The intended performance of the Water+ Furrow Diker is to increase crop production by up to 51%, through the reduction of the damages caused by droughts. This is being reached by improving the retention and harvesting of rainfall water, and promoting a more uniform distribution of water in rainfed and irrigated agrosystems. Through the soil modelling technique, the innovation is expected to provide an optimal retention of rainfall water in the root zone of crops and a better canopy microclimate (through an increase of the air humidity). These two processes will promote and keep optimal soil moisture conditions for crop growth for longer periods of time, which will finally increase crop production in a significant way.

Technical Readiness Level

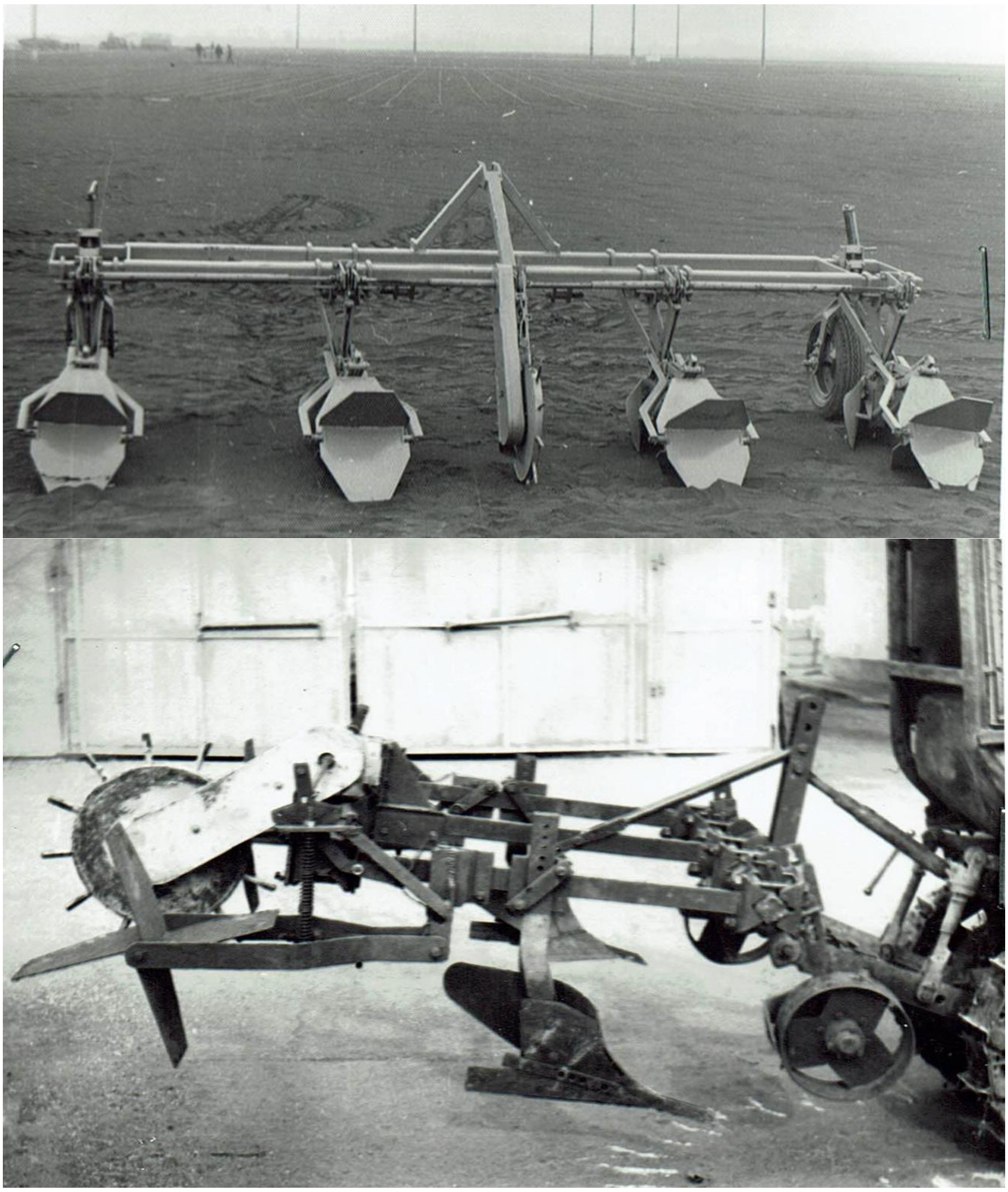
Water+ Furrow Diker entered BRIGAID with a TLR4 (Technology validated in lab: Laboratory testing of prototype component or process).

With the BRIGAID's support, Water+ Furrow Diker aims to reach a TRL8 (actual system proven in operational environment, and ready for full scale deployment).

Previous testing activities

A first prototype of the machinery was designed, manufactured, and prelimarly tested during the Romanian Communist Period (1980s) in a relevant controlled environment. The innovation activities were performed by the Institute of Research for Irrigation and Drainage Baneasa-Giurgiu. Unfortunately and due to lack of funds, the prototype was destroyed during the Communist Revolution (1989), and not pursued or implemented further.

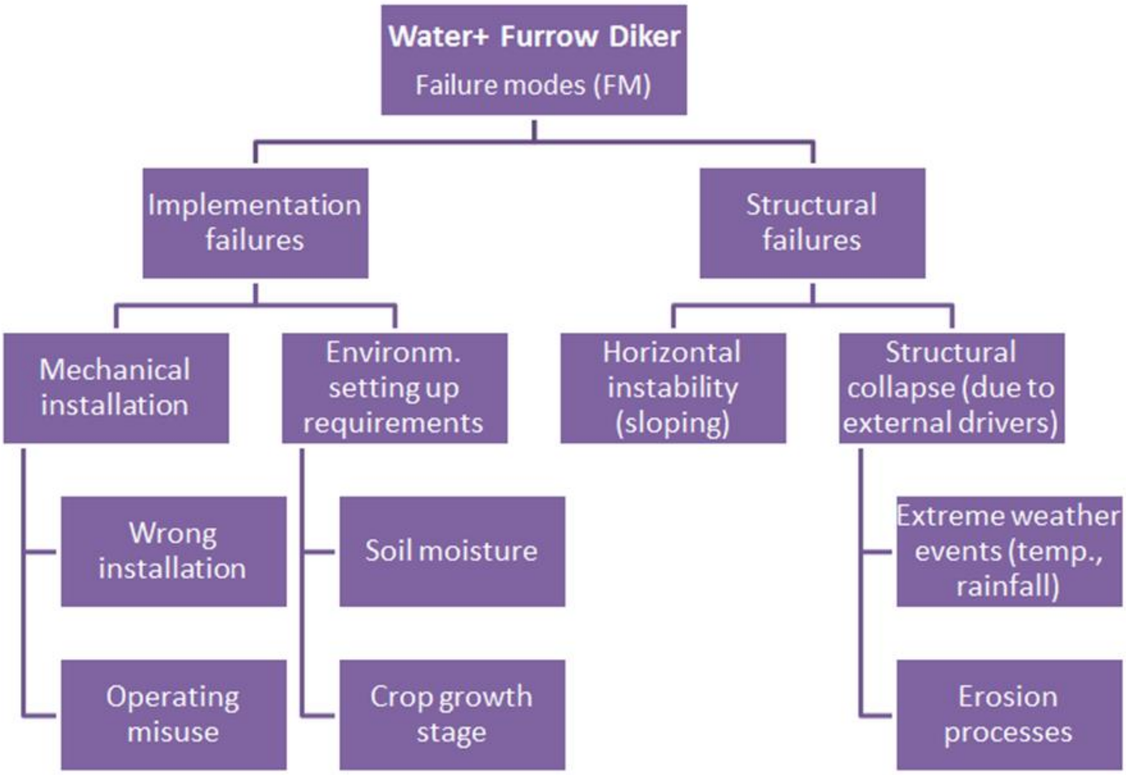
Previous prototypes developed during the 1980s:



Within the framekwork of BRIGAD, the first prototypes are rescued and technologically improved by the Aquaproiect project team led by Mr. Ilie Biolan, and the manufactoring support provided by INMA (National Institute for Agriculturale Machinery). The prototype was finalized in April 2017, and different manufacturing and pre-operational tests (overall functionality, strength, aggregate stability, mechanical and energy parameters calibration) were performed during the 2017, April 24th – May 2nd period.

Qualitative assessment of failure modes and risks

Failure modes identified for Water+ Furrow Diker:



Failure risk matrix of the primary risks:

Rank	Primary failures	Likelihood of occurence	Consequences /Impacts
1	Soil moisture content lower than the minimum threshold required for operating (testing) the innovation	Occasional	Critical
2	Inability to allow healthy soil aeration	Not evaluated	Critical
3	Structural collapse due to soil erosion processes (usually triggered after high intensity rainfall events)	Remote	Critical

Test plan

Summary

Current status of testing activities planned for the Water Plus+ Furrow Dike Machinery:

Activity	Status	Execution period	Comment
Basic & Applied Research. Prototype development and manufactoring.	Completed	Jan/17 – May/17	
Laboratory testing / Manufactoring testing	Completed		Positivily evaluated
Testing under operational conditions (1st cycle)	Completed	May/17 – Nov/17	Implementation and structural failures detected. Technological improvements are required. The new system needs to be tested.
Analysis of KPIs	Completed	Nov/17	New tests are advised.
End-user feedback	Completed	Dec/17 – Jan/17	Surveyes shared with end-users. Responses evaluated.
Technological improvements	Planned for 2nd cycle	Jan 2018- March 2018	As below

Laboratory testing

Activities and Performance Indicators

Rational of testing activites performed at laboratory conditions:

Testing of the Technical KPIs at Laboratory Conditions	
Design Criteria (i.e., Intended Technical Effectiveness)	
Intended (quantitative) level of risk reduction	To increase crop production by up to 51%, through the reduction of the damages caused by droughts. This is being reached by improving the retention and harvesting of rainfall water, and promoting a more uniform distribution of water to irrigated crops.
Intended Safety Factor or Reliability	Mechanical Parameters met
Reliability	
Mechanical parameters	*Description of Testing* Testing at prototype’s manufacturer’s site, in field conditions
	Expected Results Proper functioning from the mechanical point of view as intended in design concept;

Durability		
Percent of the innovation needed to be repaired after each operation	*Description of Testing* In field testing for mechanical parameters testing	
	Expected Results It is expected that some adaptation of manufacturing to be undertaken at initial lab testing (app. 7-10%) in order to reach 100% functional mechanical parameters.	
Lifetime of structural and/or material components	*Description of Testing* Repeat laboratory testing after testing in operating conditions during 2017-2020.	
	Expected Results 100 % of the innovation can be reused after maximum loading conditions for the product’s lifetime (10 years)	

Testing facilities

In laboratory conditions the prototype is being tested at the National Institute of Research – Development for Agriculture Machinery (INMA) (Bucharest, Romania), institution which is being acting as our subcontractors for execution of the prototype.

Operational testing

Activities and Performance Indicators

Overview of testing activites performed at operational conditions:

Design Criteria (i.e., Required Technical Effectiveness)	
Required level of risk reduction	To increase crop production by up to 51%, through the reduction of the damages caused by droughts. This is being reached by improving the retention and harvesting of rainfall water, and promoting a more uniform distribution of water to irrigated crops.
Required Safety Factor or Reliability	Properly functioning from the mechanical point of view;
(External) Operating Conditions	Optimal soil moisture; skilled personnel for operating a tractor of 35-80 HP. Soil modeling with dike furrows shape is carried in: a) row crops when height is of 30-60 cm (May15 - June15, for spring row crops, and July15 - August15, for summer row crops; b) vineyards, during spring-summer-autumn period (March15 - September1, and October15 –November15.
Reliability (state variables)	
Optimal soil moisture	*Description of Testing* Soil moisture at the plant’s root zone will be periodically monitored at two experimental sites, i.e. a ‘control’ site where the innovation is not used, and a ‘experimental’ site where the Water+ Furrow Diker is

	used.
	Expected Results Optimal soil humidity at plant's root for a longer period of time wih usage of innovation
Plant's growth	*Description of Testing* Visual inspections and comparison of plant growth rates of rainfed and irrigated crops between 'control' (without furrow diking) and 'experimental' (with furrow diking) sites.
	Expected Results Higher growth rates are expected in those sites where furrow diking has been implemented.
Crop Production	*Description of Testing* Measurements and comparison of field data retrieved visual inspections and crop yield measurements at the end of the growing seasons of rainfed and irrigated crops between 'control' (without furrow diking) and 'experimental' (with furrow diking) sites.
	Expected Results Significantly higher crop production when using the innovation
Durability	
Percent of the innovation needed to be repaired after each operation	*Description of Testing* Corn and sun flower non-irrigated crop areas (app2 ha each)
	Expected Results 100% of the innovation can be reused after maximum loading conditions
Lifetime of structural and/or material components	*Description of Testing* Use for up to app. 6 months/year during the recommended time period, subject to operated area
	Expected Results The expected lifetime of the innovation (all types) based on its components is 10 years.

Testing facilities

Facilities employed during the operational testing phase:

Name	Location	Activity / boundary conditions	Testing period
Marculesti Agriculture Farm	Giurgiu County (Romania)	Operational testing in row crops – Testing of DMBC-5	COMPLETE
Murfatlar Station - Experimental Research and Development Station for Viticulture and Winemaking	Constanta County (Romania)	Operational testing in vineyards – Testing of EMBC-2	PARTIALLY COMPLETE
Baneasa Station - Research and Development Station for Fruit Tree Growing	Bucharest (Romania)	Operational testing in fruit tress – Testing of EMBC2	Suspended.

Testing results

Laboratory testing

The first field tests (small scale level) were to perform adjustments of technical parameters and to evaluate the functioning of the subassemblies. Tests of functionality, strength, aggregate stability, and mechanical and energy parameters were evaluated.

Several failures related with the functionality of the main subassembles features and the design of several technical parameters were detected during the testing. Malfunctions were repaired and tests were run again in plots without crops and with crops at their optimum level of growth.

In the video is attached to this report (also available through the innovation profile at the Climate Innovatoin Window) it is illustrated part of the laboratory testing done on INMA field in Bucharest.

Operational testing

Critical technical and implementation failures were registered during the operational tests. These consist of:

- Very high level of oil compactation in Marculesti area due to high precipitation season and operational technology of several tractor runs before testing our equipment. This led to improper functioning of singular features of the system (sections 4 and 5 of the furrow machine that are bocated behind the tractor's wheels)

- Mechanical weakness of several active features, i.e, soil picking knife and furrows elements

See next for the detailed report in which outputs of the operational testing activities are presented.

Assessment by end users

In order to survey the usefulness of the system and the concerns of the end-users who implemented the prototype in their fields, a short questionnaire was designed and distributed among them after the end of the operational test campaign. The survey was implemented in Dec'17 – Jan'18. In total four surveys were completed. Individual responses are detailed hereafter. Based on the responses and fedbacks provided by end-user, several conclusion were extracted and new actions have been designed to improve the prototype (see Upcoming Activities described hereafter).

All end-users confirmed the usefullness of such an equipment for their activities.

Conclusions and upcoming activities

By the time of joining BRIGAID, Aquaproiect had designed two Water+ Furrow Diker prototypes and checked the functionality some singular features/components under laboratory conditiions. The TRL of Water Furrow Diker was set at 5.

With the support of BRIGAD, Aquaproiect has:

- Completed functional prototype of equipment in two constructive solutions (for crops and vineyards/ trees)

- Tested the equipment in laboratory conditions
- Reached agreements with end-users for testing the equipment in the field in operational conditions
- Tested the equipment in the field in operational conditions
- Received important feedback from end-users also confirmed in signed questionnaires which will help improve the prototype in 2018

All activities and achievements have been reached as planned.

After the 2017 testing activities, Water+ Furrow Diker reached a TRL5 (see Appendix D). Because testing of both prototypes under operational conditions were not successfully met during the first testing cycle, a new testing cycle is advised after the adoption of some new technological improvements.

Upcoming activities:

a) In order to respond proactively to the deficiencies of testing cycle 2017 (improper functioning of Section 2 & 4 of the furrow machine) (sections which are behind the tractor's wheels) and weakness of active elements observed), the following modifications will be made to the prototype:

– Modifying of constructive characteristics(L,l, material) of reversible knife element, making it more resistant and also lowering this part for a more in depth soil penetration
– Modifying of constructive characteristics(L,l, material) of other active elements
– Flexibility in adjusting the use or no-use of certain sections (ex.: 2 & 4 or 5)
– Modify the distance between the two sections of the equipment made for trees/ wine production in order to minimize the negative effect for the subsequent use of tractor

Thus, the main constructive modifications will target solving of the deficiencies observed during 2017 testing, and will also lead to a higher use coverage for our equipment (see next table).

Technological features actually adopted in the 2017 version prototype, or planned for being included in the new 2018 version:

Activity covered	**Prototypes**	
	2017 version	**2018 version**
Picking *scarificare (ro)*	No	Yes
Furrows *raritat(ro)*	Yes	Yes
Dike furrows *Brazde compartimentate (ro)*	Yes	Yes
Improved soil penetration	No	Yes

b) After the technological improvement of the 2017 version prototype, the new (the 2018 version) will not need further constructive modifications. It is expected that technological improvements and their laboratory testing will be finished on March, 31st.

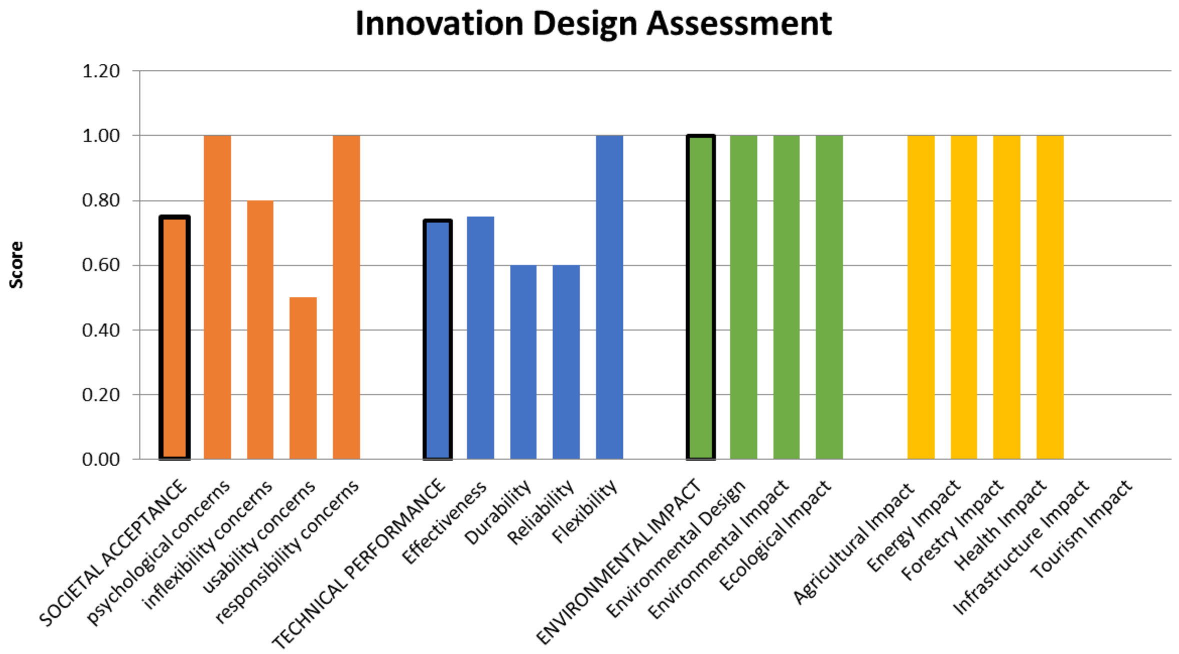
c) Additional testing field sites are expected to be included for the 2018 campaigns in order to 1) increase the number and typology of cropping systems evaluated and to compare the effectiveness of Water+ Furrow Diker against the current practices, and 2) reach more conclusive feedback from farmers. New testing locations are expected to be included in the testing plan at the end of February of 2018.

d) A new full testing plan under operational conditions will be finalized before April 15th, once technological improvements are adopted, with in field testing expected to start after May 15th, 2018.

e) Our aim is to use the testing planned during year 2019 for dissemination purposes.

TIF Tool results

Overall assessment of Water+ Furrow Diker using the BRIGAID's TIF Tool:



Overall results of the TIF Tool Assessment for Water+ Furrow Diker:

1	Your innovation raises	few	societal concerns overall, having scored	12	out of a possible	16	and is	close	from/to SOCIETAL READINESS.
1.1	Your innovation raises	few	psychological concerns, having scored	4	out of a possible	4	and is	close	from/to societal readiness.
1.2	Your innovation raises	few	inflexibility concerns, having scored	4	out of a possible	5	and is	close	from/to societal readiness.
1.3	Your innovation raises	many	usability concerns, having scored	3	out of a possible	6	and is	far	from/to societal readiness.
1.4	Your innovation raises	few	responsibility concerns, having scored	1	out of a possible	1	and is	close	from/to societal readiness.
2	Your innovation raises	few	technical concerns overall, having scored	14	out of a possible	19	and is	close	from/to being ready in terms of its TECHNICAL DESIGN.
2.1	Your innovation raises	few	concerns related to its technical effectiveness, having scored	3	out of a possible	4	and is	close	from/to being ready/effective in terms of its technical design.
2.2	Your innovation raises	few	concerns related to its durability, having scored	3	out of a possible	5	and is	close	from/to being ready/effective in terms of its technical design.
2.3	Your innovation raises	few	concerns related to its reliability, having scored	3	out of a possible	5	and is	close	from/to being ready/effective in terms of its technical design.
2.4	Your innovation raises	few	concerns related to its flexibility, having scored	5	out of a possible	5	and is	close	from/to being ready/effective in terms of its technical design.
3	Your innovation raises	no	environmental concerns overall, having scored	13	out of a possible	13	and is	close	from/to being ready in terms of its ENVIRONMENTAL DESIGN.
3.1	Your innovation raises	no	concerns related to its Environmental Design having scored	4	out of a possible	4	criteria. Your innovation may have a	positive	on the environment.
3.2	Your innovation raises	no	concerns related to its Environmental Impact, having scored	7	out of a possible	7	criteria. Your innovation may have a	positive	on the environment.
3.3	Your innovation raises	no	concerns related to its Ecological Impact, having scored	2	out of a possible	2	criteria. Your innovation may have a	positive	on the environment.
4.1	Your innovation raises	no	concerns related to Agricultural Impacts, having scored positively on	3	out of	3	criteria. Your innovation may have a	positive	impact on the Agricultural Sector.
4.2	Your innovation raises	no	concerns related to Energy Impacts, having scored positively on	1	out of	1	criteria. Your innovation may have a	positive	impact on the Energy Sector.
4.3	Your innovation raises	no	concerns related to Forestry Impacts, having scored positively on	4	out of	4	criteria. Your innovation may have a	positive	impact on the Forestry Sector.
4.4	Your innovation raises	no	concerns related to Health Impacts, having scored positively on	1	out of	1	criteria. Your innovation may have a	positive	impact on the Health Sector.
4.5	Your innovation raises	undetermined	concerns related to Infrastructure Impacts, having scored positively on	0	out of	0	criteria. Your innovation may have a	undetermined	impact on the Infrastructure Sector.
4.6	Your innovation raises	undetermined	concerns related to Tourism Impacts, having scored positively on	0	out of	0	criteria. Your innovation may have a	undetermined	impact on the Tourism Sector.

The responses for each section of the TIF Tool are detailed hereafter:

1 Societal acceptance assessment	
Answer the following 16 questions by writing Yes or No in the corresponding cells.	**Yes or No?**
1 Does your innovation use any materials that might be considered unfamiliar (such as nanomaterials or genetically modified materials)?	No
2 Will members of the public affected by your innovation be the ones to decide whether or when to use it?	Yes
3 Does your innovation involve visible infrastructure (such as physical barriers) or visible land use changes (such as woodland removal)?	No
4 Could the deployment of your innovation disrupt daily activities, for example through road closures?	No
5 Does your innovation require large amounts of capital investment?	No
6 Does your innovation require a long lead time between users placing an order and it becoming operational?	No
7 Does your innovation require new infrastructure or significant changes to existing infrastructure?	No
8 Does your innovation involve releasing any materials into the environment (such as sprays or coatings)?	No
9 Are your potential users likely to have a single mission, for example to protect ecosystems?	Yes
10 Does your innovation take less time to deploy than incumbent alternatives (such as sand bags for floods or fire nozzles for wildfires)?	Yes
11 Would the use of your innovation require special training?	Yes
12 Will help and support be available to users of your innovation?	Yes
13 Innovations can either reinforce or change users' existing ways of working. Does your innovation reinforce existing ways of working?	Yes
14 Are the effects of your innovation directly publicly tangible (such as seeing flood defences working or hearing a warning alert system)?	No
15 Adaptations can either be deployed permanently or temporarily. Is your innovation deployed permanently?	No
16 Are members of the public involved in shaping the research, development, demonstration and deployment of your innovation?	Yes
Answer the following 4 questions by writing A, B or C in the corresponding cells.	**A, B or C?**
17 What would your innovation primarily protect? (A) public infrastructure, (B) private properties or (C) the environment	B
18 Who would pay for your innovation? (A) government authorities, (B) private companies or (C) local communities	B
19 Who would implement your innovation? (A) government authorities, (B) private companies or (C) local communities	B
20 How would compensation be made in the event of your innovation failing? Through (A) government compensation, (B) project insurance or (C) responsible parties	B

2 Technical Design	
Answer the following questions by writing Yes or No in the corresponding cells.	**Yes or No?**
1 Does the innovation provide significant technical advantage(s) relative to a traditional/conventional measures?	Yes
2 Does your innovation physically prevent a hazard from occurring?	Yes
3 Does your innovation require combination with other interventions and/or activities in order to reduce risk (e.g, flood warning system in combination with a flood barrier or a fire warning system in combination with controlled burning)?	Yes
4 Will the innovation require additional testing and/or substantial upgrades when considering future hazard conditions (i.e., considering climate change)?	No
5 Is the lifetime of the innovation limited by climate change? (i.e., will climate change affect the estimated life(time) of the innovation?)	No
6 Does the innovation require frequent inspection and maintainence to reach its intended lifetime?	Yes
7 Are the materials or software needed for maintanence and/or repair easily obtained and can they be integrated by the end-user?	Yes
8 Is the innovation designed to be used repetitively or continuously operated over its lifetime?	Yes
9 Can the innovation be operated without repair and/or replacement of components during a hazard event?	No
10 Does the innovation exhibit vulnerabilities during testing and/or demonstration (e.g., structural: sliding or rotation, or technological: errors)?	Yes
11 Is there a critical component in the innovation's structural or technological design that could lead to catastrophic failure?	No
12 Does your innovation rely on the delivery of services or materials (e.g., structural components, data) outside of your control to be successfully operated during a hazard event?	No
13 Does your innovation require the execution of tasks by humans to be successfully operated during a hazard event?	Yes
14 Can the vulnerability of your innovation to human error be easily reduced through improvements in operational protocols and/or end-user training?	Yes
15 Is the innovation modular (opposite: monolithic) and can it be easily installed or applied at different sites across Europe without adjustment?	Yes
16 Does the innovation require additional testing and/or substantial upgrades (e.g., new components) if used at different sites across Europe?	No
17 Will the size of the market for the innovation (in Europe) will significantly decrease (>50%) due to future hazard conditions (i.e., considering climate change)?	No
18 Have relevant end-users have been identified and contacted and has a need for this innovation observed?	Yes
19 Are the advantages of the innovation derived from its multi-functionality (e.g., reduction of carbon emissions or enhanced recreational activities)?	Yes

3	Environmental Characteristics	
Answer the following questions by writing A, B, or C, in the corresponding cells.		**A, B or C?**
3.1	**Environmental Design**	
3.1.1	Does the innovation deliberately use ecosystems and their services, or mimic or preserve natural processes? (A) Yes (B) No	A
3.1.2	How does the change in footprint (area) required for implementation on-site compare to conventional measures or the present situation? (A) Increase space required (B) Decrease space required (C) No Impact on space required	C
3.1.3	How does the construction or operation of the innovation affect the quantity of greenhouse gases in the environment (e.g., as CO_2 or CH_4)? (A) Increase (B) Decrease (C) No Impact	B
3.1.4	Is the innovation made from recycled or recycable materials? (A) Yes (B) No	A
3.1.5	Does the innovation include specific design features or components which preserve or enhance ecosystem services? (A) Yes (B) No	A
3.2	**Environmental Impact**	
3.2.1	How does the innovation impact the quality of surface water? (A) Improve (B) Worsen (C) No Impact	C
3.2.2	How does the innovation impact the quantity of available surface water? (A) Increase (B) Decrease (C) No Impact	A
3.2.3	How does the innovation impact the quality of ground water? (A) Improve (B) Worsen (C) No Impact	C
3.2.4	How does the innovation impact the quantity of available ground water? (A) Increase (B) Decrease (C) No Impact	A
3.2.5	How does the innovation impact the quality of the sea water? (A) Improve (B) Worsen (C) No Impact	C
3.2.6	How does the innovation impact soil quality? (A) Improve (B) Worsen (C) No Impact	A
3.2.7	How does the innovation impact air quality? (A) Improve (B) Worsen (C) No Impact	A
3.2.8	Does the implementation (or construction) of the innovation generate debris? (A) Yes (B) No	B
3.2.9	Does the implementation (or construction) of the innovation generate noise or vibration? (A) Yes (B) No	B
3.2.10	How does the innovation impact landscape quality? (A) Improve (B) Worsen (C) No Impact	A
3.3	**Ecological Impact**	
3.3.1	How does the innovation impact the spatial extent of protected nature area? (A) Increase (B) Decrease (C) No Impact	C
3.3.2	How does the innovation impact the quality of protected habitats? (A) Improve (B) Worsen (C) No Impact	A
3.3.3	How does the innovation impact the number protected species (e.g., birds, vegetation, fish, mammals)? (A) Increase (B) Decrease (C) No Impact	C
3.3.4	How does the innovation impact the spatial extent of non-protected nature area? (A) Increase (B) Decrease (C) No Impact	C
3.3.5	How does the innovation impact the quality of non-protected habitats? (A) Improve (B) Worsen (C) No Impact	C
3.3.6	How does the innovation impact the number non-protected species (e.g., birds, vegetation, fish, mammals)? (A) Increase (B) Decrease (C) No Impact	A

4	Sectoral Impacts	
Answer the following questions by writing A, B or C in the corresponding cells.		**A, B or C?**
4.1	**Agriculture**	
4.1.1	How does the innovation impact the total area available for agricultural production? (A) Increase (B) Decrease (C) No Impact	C
4.1.2	How does the innovation impact agricultural production conditions (e.g., by increasing soil quality or water availability)? (A) Improve (B) Worsen (C) No Impact	A
4.1.3	How does the innovation impact the variety of agricultural products (e.g., crops, dairy, meat, fruit, fish, aquaculture) that can be produced or are available? (A) Increase (B) Decrease (C) No Impact	A
4.1.4	How does the innovation impact the total yield of one or more agricultural products? (A) Increase (B) Decrease (C) No Impact	A
4.2	**Energy**	
4.2.1	How does the innovation impact the energy production capacity (e.g., by generating energy or increasing energy distribution)? (A) Increase (B) Decrease (C) No Impact	C
4.2.2	How does the innovation impact the reliability of energy production (e.g. by improving cooling water conditions for energy plants)? (A) Increase (B) Decrease (C) No Impact	C
4.2.3	How does the innovation impact the efficiency of energy production? (A) Increase (B) Decrease (C) No Impact	C
4.2.4	How does the innovation impact the carbon footprint of the end-user? (A) Increase (B) Decrease (C) No Impact	B
4.3	**Forestry**	
4.3.1	How does the innovation impact the total area available for wood production (including timber and biomass)? (A) Increase (B) Decrease (C) No Impact	A
4.3.2	How does the innovation impact wood production conditions (e.g., by increasing forest resilience or water availability)? (A) Improve (B) Worsen (C) No Impact	A
4.3.3	How does the innovation impact the total area available for non-wood production (including cork, fruit, honey, mushrooms, pastures, game and fishing)? (A) Increase (B) Decrease (C) No Impact	A
4.3.4	How does the innovation impact non-wood production conditions (e.g., by increasing forest resilience or water availability)? (A) Improve (B) Worsen (C) No Impact	A
4.4	**Health**	
4.4.1	How does the innovation impact the number of fatalities in the area exposed to the hazard? (A) Increase (B) Decrease (C) No Impact	C
4.4.2	How does the innovation impact the number of people affected by the hazard in their physical health (i.e., number of people injured)? (A) Increase (B) Decrease (C) No Impact	C
4.4.3	How does the innovation impact the number of people affected by the hazard in their mental/physo-social health? (A) Increase (B) Decrease (C) No Impact	C
4.4.4	Does the innovation emit or release chemicals or products that are harmful to humans? (A) Yes (B) No	B
4.5	**Infrastructure**	
4.5.1	How does the innovation impact the quality of the built environment (I.e., residential, commercial, and industrial)? (A) Improve (B) Worsen (C) No Impact	C
4.5.2	How does the innovation impact the total area available for urban development? (A) Increase (B) Decrease (C) No Impact	C
4.5.3	How does the innovation impact the capacity of existing transportation systems (e.g., roads, railways, waterways, and airports) or create new capacities? (A) Increase (B) Decrease (C) No Impact	C
4.5.4	How does the innovation impact the reliability of existing transportation systems (e.g., roads, railways, waterways, and airports)? (A) Increase (B) Decrease (C) No Impact	C
4.5.5	How does the innovation impact the transport capacity of critical infrastructure networks (e.g., power, water, waste management)? (A) Increase (B) Decrease	C
4.5.6	How does the innovation impact the reliability of critical infrastructure networks (e.g., power, water, waste management)? (A) Increase (B) Decrease (C) No Impact	C
4.6	**Tourism**	
4.6.1	How does the innovation impact the total area available for recreational activities? (A) Increase (B) Decrease (C) No Impact	C
4.6.2	How does the innovation impact the attractiveness of the area for recreational activities? (A) Increase (B) Decrease (C) No Impact	C
4.6.3	How does the innovation impact the length of the tourist season? (A) Increase (B) Decrease (C) No Impact	C

TRL assessment:

Climate Adaptation Innovation Readiness

Innovation:	Water+ Furrow Diker
Organization:	Aquaproject
Starting TRL	TRL4
Anticipated Ending TRL	TRL8
Current Status	???
Actual Ending TRL	-

BRIGAID Stages			*To be completed at the start of the project*						*To be completed at the time of interim reports*			*To be completed at the end of the project*		
	TRL	**Question**	**Start of Project**			**Anticipated End of Project**			**Current status**			**Actual End of Project**		
			Yes	**No**	**N/A**	**Yes**	**No**	**N/A**	**Yes**	**No**	**N/A**	**Yes**	**No**	**N/A**
Desk Study	**TRL 1**	**Basic principles observed and reported.**												
Desk Study	**TRL 2**	**Innovation concept formulated.**												
Desk Study	**TRL 3**	**Analytical and experimental critical function and/or characteristic proof-of-concept.**												
Stage 1: Laboratory Testing	4	Has societal acceptance testing of individual components been performed?	X			X			X					
	4	Has performance of components and interfaces between components been demonstrated?	X			X			X					
	4	Does draft system architecture plan exist?	X			X			X					
	4	Have end user technology/system requirements been documented (e.g., reliability requirements)?	X			X			X					
	4	Has component compatibility been demonstrated?	X			X			X					
	4	Does technology demonstrate basic functionality in simplified environment?	X			X			X					
	4	Have performance characteristics been demonstrated in a laboratory environment?	X			X			X					
	4	Have low-fidelity assessments of system integration and engineering been completed?	X			X			X					
	TRL 4 Achieved	**Innovation validated in a laboratory environment.**												
	5	Have internal system interface requirements been documented?	X			X			X					
	5	Has analysis of internal interface requirements been completed?	X			X			X					
	5	Can all system specifications be simulated and validated within a laboratory environment?	X			X			X					
	5	Is the laboratory environment high-fidelity?	X			X			X					
	5	Have individual component functions been verified through testing?	X			X			X					
	5	Have objective and threshold operational requirements been developed? (e.g., has the intended reduction in risk been quantified? Is the end-user requirement for reliability known?)	X			X			X					
	5	Have all potential failure modes been identified and documented?	X			X			X					
	5	Has the reliability of the fully integrated prototype been estimated using desk study calculations?	X			X			X					
	5	Have the social, technical, and environmental design of the innovation been re-assessed? (TIF tool applied, i.e. stage-gate tool)			X	X			X					
	TRL 5 Achieved	**Innovation prototype demonstrated in a laboratory environment.**												
Stage 2: Operational Testing	6	Have system integration issues been addressed?		X		X			X					
	6	Is the operational environment fully known?		X		X			X					
	6	Have the current and future (i.e., under climate change) hazard conditions in the intended operational environment been documented?		X		X			X					
	6	Has the technical and/or climate lifetime of the innovation been estimated?		X		X			X					
	6	Have performance characteristics (i.e., social, technical, and environmental) been verified in a simulated operational environment?		X		X			X					
	6	Has prototype been tested in a simulated operational environment and shown to withstand the intended hazard loads *without* failure?		X		X			X					
	6	Does the prototype successful reduce the intended/threshold level of risk (i.e., by reducing the hazard and/or its consequences) in a simulated operational environment?			X	X			X					
	6	Have the operation and maintainence protocols over the lifetime of the innovation been established and documented?		X		X				X				
	6	Has system been tested in realistic environment outside the laboratory?		X		X			X					
	6	Has engineering feasibility been fully demonstrated?		X		X			X					
	TRL 6 Achieved	**Innovation model or prototype demonstrated in a relevant environment.**												
	7	Have all interfaces been tested individually under stressed and anomalous conditions?		X		X			X					
	7	Has technology or system been tested in a representative operational environment and shown to withstand the expected hazard loads?		X		X				X				
	7	Has the reliability of the prototype been quantified and validated in a representative operational environment?		X		X			X					
	7	Are available components representative of production components (i.e., will the innovation be ultimately produced using the same materials as used in testing; is the prototype to-scale)?		X		X				X				
	7	Have vulnerabiliities to human error been effectivley minimized?		X		X			X					
	7	Has fully integrated prototype been demonstrated in actual or simulated operational environment?		X		X			X					
	TRL 7 Achieved	**Innovation prototype demonstratied in an operational environment.**												
	8	Are all technology/system components form, fit, and function compatible?		X		X				X				
	8	Is technology/system form, fit, and function compatible with operational environment?		X		X			X					
	8	Has technology/system form, fit, and function been demonstrated in operational environment and shown to withstand the expected hazard load(s) without failure?		X		X				X				
	8	Have the operational and maintanance costs over the lifetime been estimated and documented?		X		X				X				
	8	Have the social, technical, and environmental design of the innovation been re-assessed? (TIF tool applied, i.e. stage-gate tool)			X	X			X					
	TRL 8 Achieved	**Actual system completed and qualified through test and demonstration.**												
	TRL 9	**Actual system proven through successful mission operations.**												

7. Innovation: infoSequia

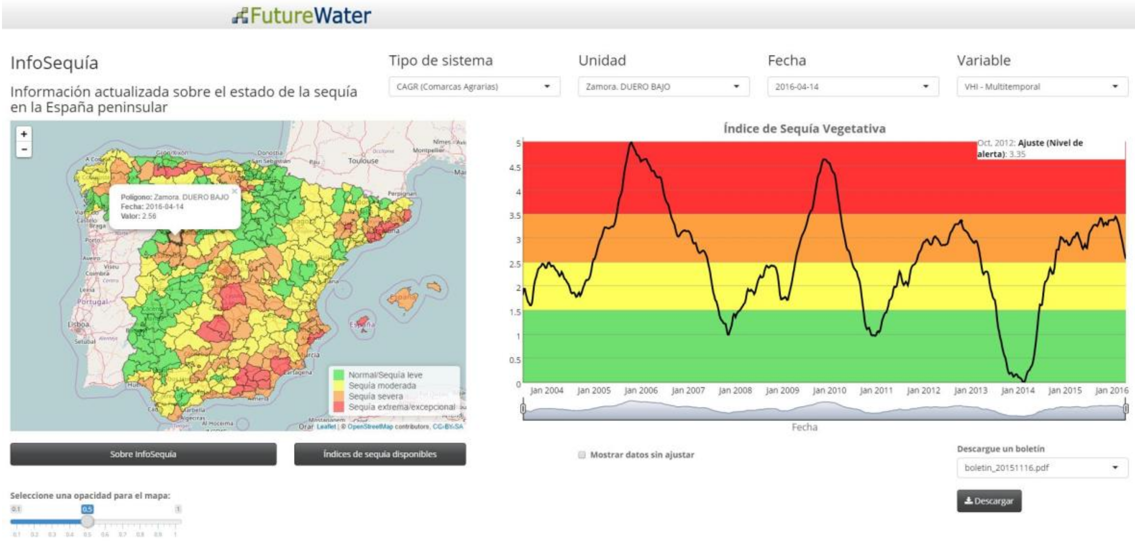
Innovator: FutureWater (BRIGAID consortium partner)

Contributing authors: Sergio Contreras (FutureWater), Alberto de Tomás (FutureWater), Johannes Hunink (JH) (FutureWater)

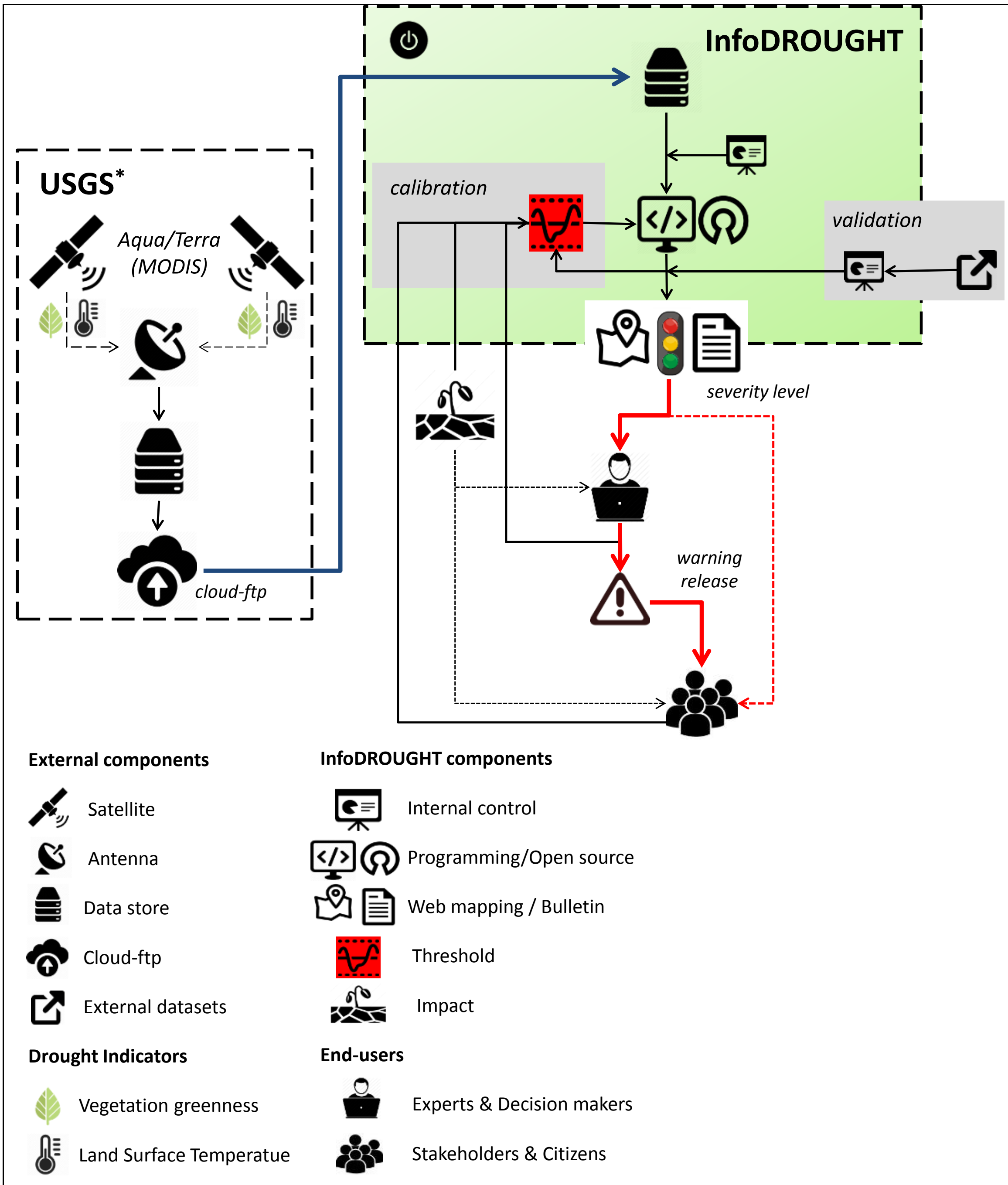
Innovation description

The description of infoSequia below is also available from the Climate Innovation Window, http://climateinnovationwindow.eu/innovations/infosequia

Name
InfoSequia: An operational web-mapping service for the monitoring of drought impacts
Short description
Drought monitoring (DM) is a key component of risk-centered drought preparedness plans and drought policies (WMO, 2006). DM systems provide decision makers with timely and reliable access to information on which mitigation action can be based. InfoSequia is a satellite-based DM and delivery system that can complement existing operational DM systems based on local observations. InfoSequia provides new functional capabilities for: a) the operational satellite-based tracking of the severity and spatial extent of drought impacts on forestry and agriculture sectors, b) the dissemination and provision of drought information in a faster and easier way. InfoSequia (www.infosequia.es) is a web-mapping climate service for the operational monitoring of droughts and their impacts. It provides straightforward and weekly information on the drought conditions of a region through simple and interactive functionalities. InfoSequia is a Drought Monitoring toolbox that can easily be integrated in existing Early Warning Decision Support Systems. The core of the system includes a set of algorithms which automatically collects satellite data from the cloud, processes and generates severity drought indices and portable bulletins, and feeds a web-mapping service from which all the information can be interactively queried and downloaded. InfoSequia is a site- and user-tailored system with a flexible and modular structure. The calibration (threshold definitions) and validation of the system is performed by combining expert knowledge and auxiliary impact assessments and datasets. Different technical solutions (basic or advanced versions) or deployment options (open-standard or restricted-authenticated) can be purchased by end-users and customers according their needs.
Sketch/Photograph of the Innovation
InfoSequia web interface (www.infosequia.es):



Which hazard(s) is the innovation designed to mitigate?
Droughts: Sustained and extensive occurrence of below average water availability. Resulting in water scarcity when drought conditions cause long-term imbalances between water availability and demands. Themes to which the innovation applies: Disasters and ICT
How does the innovation work?
InfoSequia consists of a set of fully-integrated algorithms written under an open-source multisource GIS-programming environment (Phyton, R, QGIS, Shiny-RStudio). The system runs on FutureWater's computing facilities, and it depends on two external components not directly managed by our company: (1) the 'satellite data provision system' consisting of satellite platforms (Aqua/Terra) and MODIS sensors onboard, antennas and the data sharing infraestructure, all managed by NASA (US National Aeronautics and Space Administration), and (2) the external-cloud server (*shinyapps.io*. by RStudio) in which the web-mapping InfoSequia app is hosted. Sketch of the InfoSequia monitoring system (v1.0). The current version of infoSequia uses satellite data from NASA-USGS:



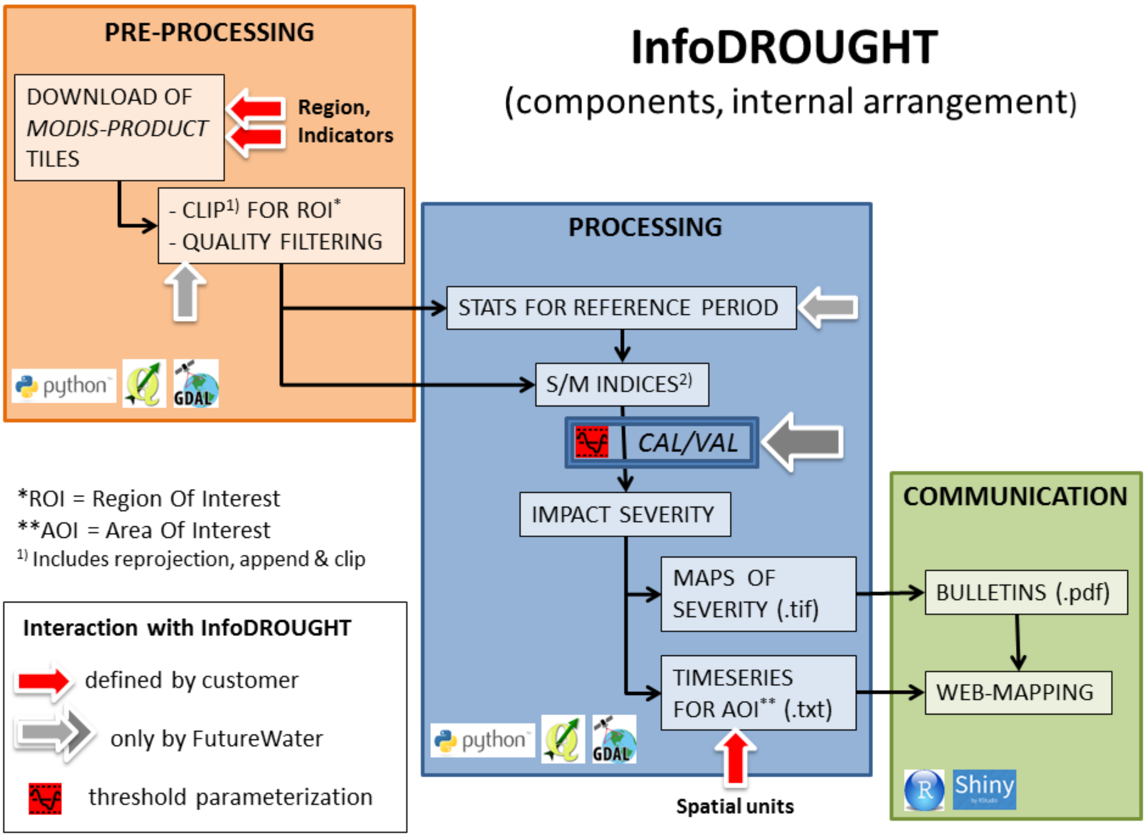
InfoSequia has a programming structure integrated by three main modules (pre-proccessing, processing and communication) with connected-cascade task-specific algorithms. Algorithms in the pre-processsing and processing modules have been coded in a Phyton-QGIS-GDAL open source environment, while the algorithms in the communication module have been codified using R or R-shiny.

According to their needs, customers define, with the support of FutureWater experts, the region of interest, the number and type of satellite-based indicators to be used, and the level/s of spatial aggregation (spatial units) adopted for showing severity warnings.

The system requires to parameterize thresholds to convert drought index values into severity classes. This task is addressed by FutureWater experts adopting a calibration-validation approach and using external-auxiliary data on drought severity and impacts.

The general programming code has been optimimally designed to manage potential runtime in a fast and secure way. This guarantees fast responses to customers in case of system failures.

Internal structure of infoSequia (v1.0):



Added value / main differentiating element from conventional approach(es)

InfoSequia is an operational and site- and user-specific tailored system with friendly and easy-of-use web-mapping functionalities. It is characterized by its high flexibility and modular structure, so different options can be purchased by clients: basic- or advanced-tool versions are available; deployment can also be open-based (standard deplyoment) or proffesional (requires authentication).

Critical success factors / Limitations

NA

Desk study

In this section, the most relevant issues related with the innovation are provided.

Indicator	Desk Study Questions
Technical Effectiveness refers	- What type of hazard(s) does the innovation address? - Which characteristic(s) does the innovation have?

to the intended capacity of the innovation to reduce risk from a specific hazard(s)	- How will the innovation reduce the risk of the hazard(s)? - What is the intended (quantitative) level of risk reduction? - Has the innovation been tested previously and can the innovation achieve the intended level of risk reduction without failure? - What is the current estimated technical readiness level (TRL) of the innovation?
Reusability refers to the intended use and lifetime of the innovation	- Is the innovation continuously operated or is it only operated prior to/during a hazard event? If the innovation is only operated prior to/during a hazard event, what is the intended operation (protocol) of the innovation? - What is the expected lifetime of the innovation based on its components? - What are the maintenance requirements for the innovation to reach its maximum lifetime?
Reliability refers to the likelihood that the innovation fulfills its intended functionality over its lifetime	- What are the inputs/outputs to the innovation? (which inputs/outputs can be controlled by the innovator?) - What are the possible technical failure modes of the innovation? If the innovation is only operated prior to/during a hazard event, what are the possible implementation failure modes? - Which failure modes are most likely to occur? - Is there available historical data against which to calibrate/validate the innovation? - Will the innovation be calibrated/validated in real-time during testing?

Technical Readiness Level

InfoSequia is currently in TLR4 (*technology validated in lab (laboratory testing of prototype component or process*)). The prototype has been sucessfully designed and formulated, and data processing algorithms and communication functionalities (web-mapping and generation PDF bulletins) have been partially integrated and tested in a desktop environment. At the present, a beta-version of the tool is available throughout www.infosequia.es.

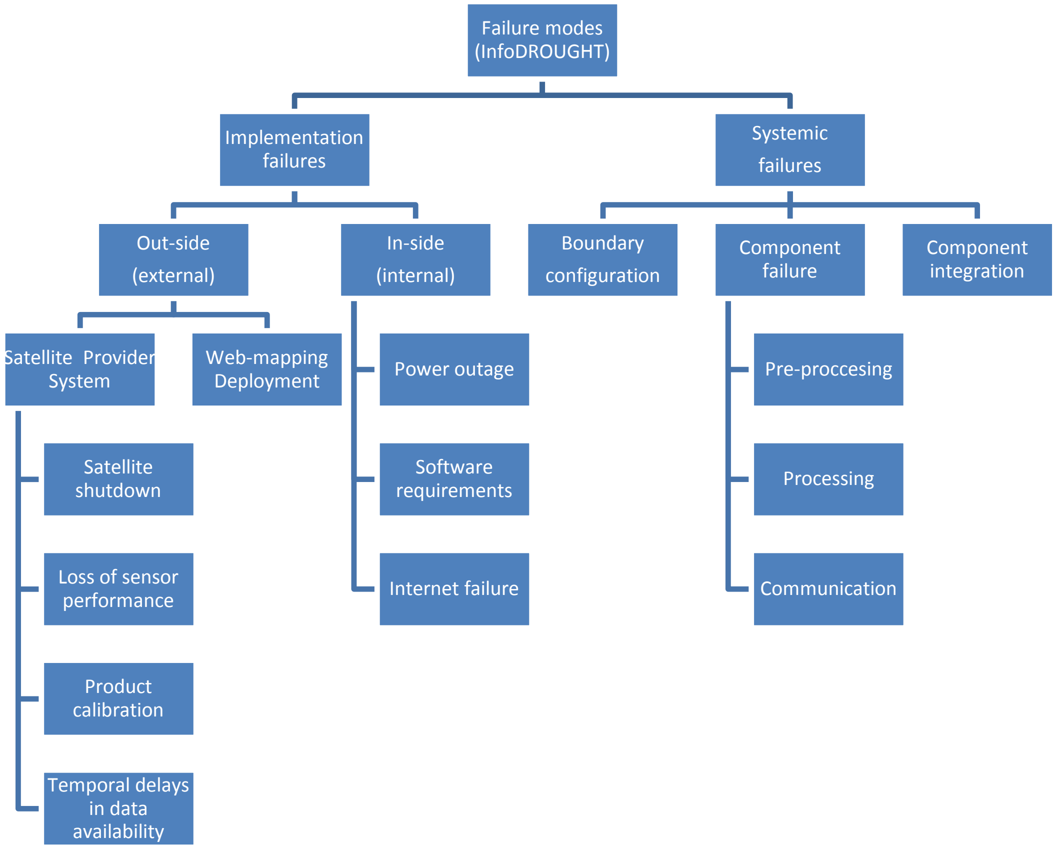
InfoSequia aims to reach a TRL8 (actual system proven in operational environment, and ready for full scale deployment) with assistance from BRIGAID. Several technological improvements need still to be addressed to make the system fully integrated and operational under laboratory conditions (from TLR4 to TLR5). The testing of InfoSequia under a relevant operational environment (from TLR5 to TLR7) will be addressed in collaboration with a Spanish Water Basin Authority which is supporting the co-design specifict tests (e.g. definition of decision rules) to assess the overall technological effectiveness of InfoSequia as a complementary tool to its current drought monitoring system.

Previous testing activities

InfoSequia started in 2013 in the framework of a 3-year project co-funded by FutureWater and the Spanish Ministry of Economy and Competitiveness through the Torres Quevedo grant. InfoSequia is part of the GEISEQ toolbox, a Support System for the integral management of droughts developed by FutureWater. From its beginning, the prototype has been continuosly improved and desk-tested to guarantee the right functioning of their components, and an easy deployment in other regions.

Qualitative assessment of failure modes and risks

Failure modes identified for InfoSequia:



Failure risk matrix of the primary risks:

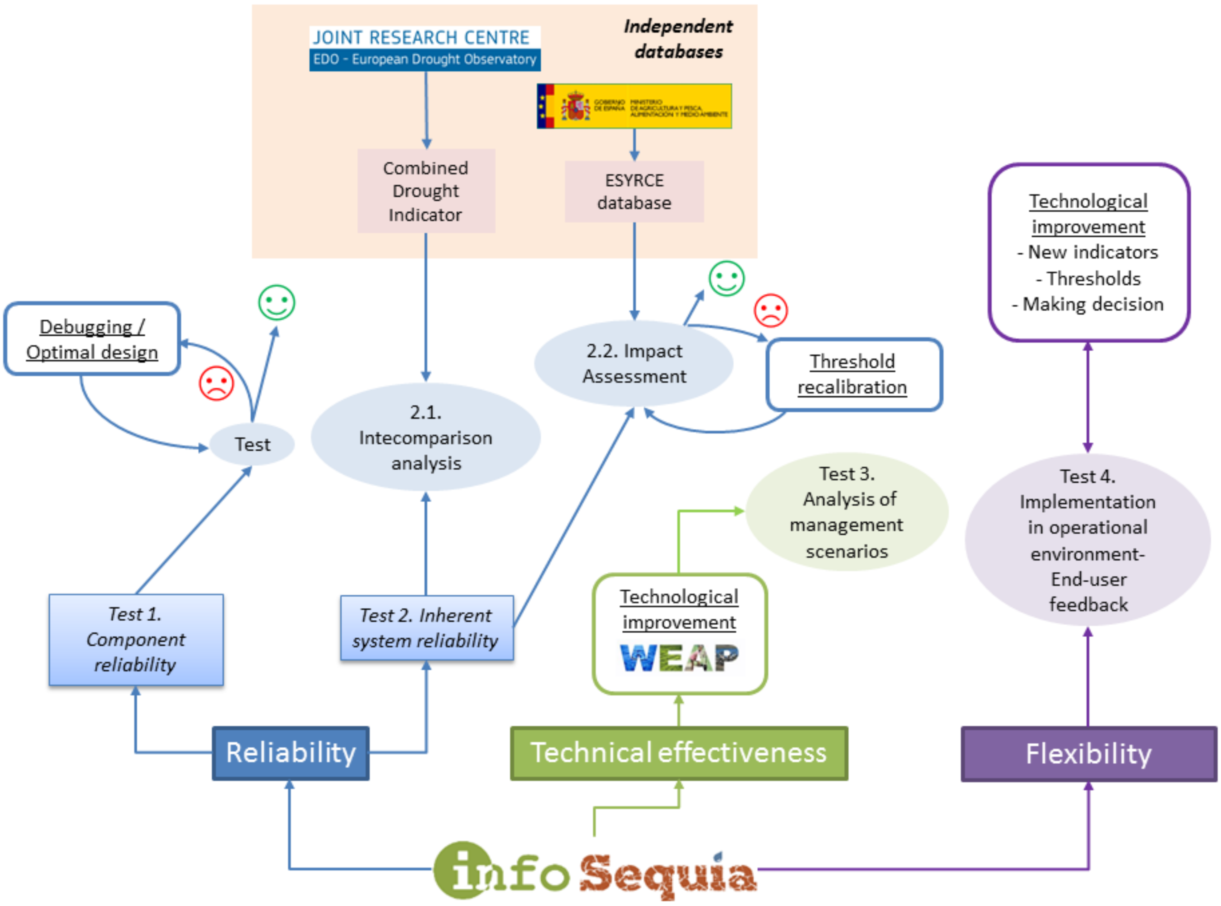
Item	Component - Risk	Likelihood of occurrence	Consequence/Impacts	Mitigation action
Implementation Failures				
Satellite Provider System	Satellite shutdown	Remote (increasing over time)	Catasthopic (system collapse). Alternative solutions would lead changes in the spatial granularity and temporal covarage/resolution of the outputs.	Change of satellite-data provider / Recoding / Recalibration of outputs
	Satellite/sensor degradation and loss of performance	Occasional	(e.g. permanent loss of spatial coverage)	Recoding – Addition of new programming functions to fix loss of signal quality and data gaps.
	Product calibration (e.g. new collection of products)	Probable	Changes in values reported. New datasets needs to be computed and published.	Recalibration
	Delay in processing of satellite raw data (> 15 days), or due to maintenance activities	Occasional-Probable	Small delay in the provision of outputs. Maintenance will strongly impact if it lasts >1 month.	Provide error message and related info
Web-mapping Deployment System	E.g. limited bandwidth	Probable	Long loading time.	Intensify the cloud hosting service
In-System failures	Power or internet outage	Remote	Very small delay in the provision of outputs	Re-launched – Quality control
	Software requirements	Occasional	Critical	Technical supporting
Systemic failures				
Boundary configuration	End-user and internal settings	Probable	Critical	Configuration-setting template. Error alerts.
Component failures	Component failure (software bug)	Frequent	Runtime error	Debugging source code
Component integration	Failure in the Processing-Communication integration	Critical	Delay in the deployment outputs	Programming improvements. Quality control

Test plan

Testing activities planned under the framework of BRIGAID, their current status and their relationship with technical Performance Indicators are listed in the next table and schematically represented in next figure.

Testing phase	Key Performance Indicator – Testing activity	Testing site	Period of testing	Status (Completed/In progress)
Laboratory Testing phase (TRL4-5)	Test 1: *Component reliability*. Detection of technical failures and debugging and improvements in internal design	Simulated environment - Iberian Peninsula	05/2017 - 12/2017	Completed
	Test 2: *System reliability*. Intercomparison analysis. Relationship of drought indices and impacts on crop yields.	Simulated environment - Iberian Peninsula	05/2017 – 12/2017	Completed
Operational Testing phase (6-8)	Test 3. *Technical effectiveness*. System Dynamic Modelling and analysis of management scenarios	Simulated environment – Segura River Basin (SE Spain)	05/2017 – 12/2017	Completed
	Test 4. *Flexibility*. Implementation in operational environment. Integration in Control Centre Room.	Cauca River Basin (Colombia)	10/2017 -	In progress

Rational diagram of infoSequia testing:



Laboratory testing

During the Laboratory Testing phase, several testing tasks were performed in a simulated environment which consists in:

1. Evaluating the *component reliability* of the innovation (Test 1) and optimizing the performance of each component.

2. Evaluating of *system reliability* of the innovation through the verification (calibration/validation) of system outputs against historical or real-time observations (Test 2.1), or impact analyses (Test 2.2).

Test 1. Component realiability

Rational and protocol

This test was addressed through 2 tasks:

1.a. Identifying systemic failure modes related with configuration, processing and integration issues (see **Error! Reference source not found.**).

1.b. Increasing the technical reliability of the innovation by improving the prototype to minimizing the potential failures or identifying mitigation actions.

The testing exercise will consist in the implementation of the system in FutureWater's IT facilities using boundary conditions independent from those ones originally employed during the prototype configuration. Techniques of sofware quality control (static and dynamic verification) and diagnostic metrics (e.g. bugs and runtime errors per line of code, code coverage, program execution time, number of lines of code) are used to quantify the likelihood of occurrence of failures for different test cases (functionality, performance and Graphical Use Interface) and testing dimensions (Unit test, Integration test, System test, and API test). Different code improvements were implemented to identify failures, retrieve dignostic metrics and increase the traceability of the different components of infoSequia and to evaluate how much performance is increased. According the failure modes detected and the metrics retrieved, technical mitigation or risk reduction actions (e.g. debugging, code and design optmization) were adopted.

The successful completetion of a test will be evaluated in terms of a set of exit/closure criteria (e.g. critical failures, run rate, or pass rate).

Testing dimensions to evaluate InfoSequia system reliability:

Testing dimension	Description
Unit Test	Each individual component-module is tested separately (boundary configuration module, pre-processing module, processing module, communication module).
Integration Test	Individual modules are combined and tested as a whole under a single system configuration.
System Test	InfoSequia as a whole is tested under different system configurations (*InfoSequia back-end*). Two configuration modes will be tested: - Historical mode processing - Operational mode processing (near-real time) mode.
API Test	The all system application is tested (*InfoSequia front-end*).

Facility and equipment

Test were performed with FutureWater IT facilities. Programming (Python, R) and GIS (QGIS) open software was employed.

Test 2. System realiability

Rational and protocol

InfoSequia is a monitoring system which provides spatially-distributed signals of drought severity based on satellite-based indicators. Because of its complex nature (creeping-cascade hazard), the definition of a drought requires the innovator to evaluate large number of environmental, management and social factors. As consequence, “ground-truth” data for droughts or their impacts is usually lacking, unaccurate, or hardly available. To cope with this generalized lack of geodatabases with long and accurate timeseries of real drought observations, a multi-testing approach will be adopted consisting in the implementation of different testing exercises, and the use of independent database (see box). All tests will be performed at the Spanish national level and will adopt an historical perspective in which past spatio-temporal patterns of independent drought indices and impacts are compared against the outputs provided by infoSequia. Proposed tests include:

- Test 2.1. Benchmarking analysis of drought severity levels computed from the combined VHI index and the Combined Drought Index -CDI- reported by infoSequia and the European Drought Observatory (EDO), respectively. The level of agreement/disagreement beetween different monitoring systems were quantified through contingency tables. The raw data used for the contingency analysis was the occurrence/no occurrence of drought events reported in the 2nd dekads of March, May, October and December 2012.

- Test 2.2. Impact assessment using the ESYRCE crop yield database.

Box: Multi-approach testing framework to evaluate inherent system reliability

Test 2.1. Benchmarking analysis against the European Drought Observatory outputs (EDO)
EDO regularly provides maps with drought warning levels (watch, warning and alert) which are retrieved from the combination of meteorological, hydrological and satellite-based drought indices. This test consits in a contingency analysis which aims to evaluate the patterns of agreement (spatial and temporal coherence or matching) between both monitoring systems at the agriculture county level.

Test 2.2 Impact assessment: Drought Severity and Crop Yield Anomaly (ESYRCE database)
An statistical approach was adopted (regression models) to quantify the sign and the strength of correlations between the drought indices provided by infoSequia, and rainfed crop yield anomalies retrieved from the Spanish Annual Survey of Crop Areas and Yields (ESYRCE database). The ESYRCE database (Ares, 2010) provides annual values of crop yields based on field surveys accounted by experts over a statistically representative matrix of plots (0.5 ha) located along all the Spanish national territory.The analysis was performed for the 2003-2015, and the study has been submitted to a scientific peer-review journal.

Facility and equipment

Auxiliary data from independent database. All the auxiliary data was downloaded from open datasources (European Drought Observatoru) or requested to different public institutions (Spanish Ministry of Agriculture and Environment). Computer, and statistical software.

References:

Outputs from these analysis have been presented at different international conferences and are part of a scientific paper, i.e.

- García-León, D., Contreras, S., Hunink, J.E. Drought sensitivity changes of rainfed cereals in Spain assessed with remote sensing. Submitted to *Journal of Agronomy and Crop Science* (under review)

- Contreras, S., García-León, D., Hunink, J.E., 2017. InfoDROUGHT: Technical reliability assessment using crop yield data at the Spanish-national level. *2017 EGU General Assembly*, Viena (Austria). Poster. *Geophysical Research Abstracts*, Vol. 19, EGU2017-14660.

- García-León, D., Contreras, S., Hunink, J.E., 2016. A bird's eye view: Measuring drought sensitivity of Spanish crop yields. 41 Simposio de la Asociación Española de Economía, Bilbao. Oral presentation.

Operational testing

During the Operational Testing phase, several testing tasks were performed to quantify the *technical effectivennes* of infoSequia, and its *flexibility* to be implemented operationally under other boundary conditions. Two tasks were performed:

1. Evaluating the *technical effectivennes* of infoSequia.

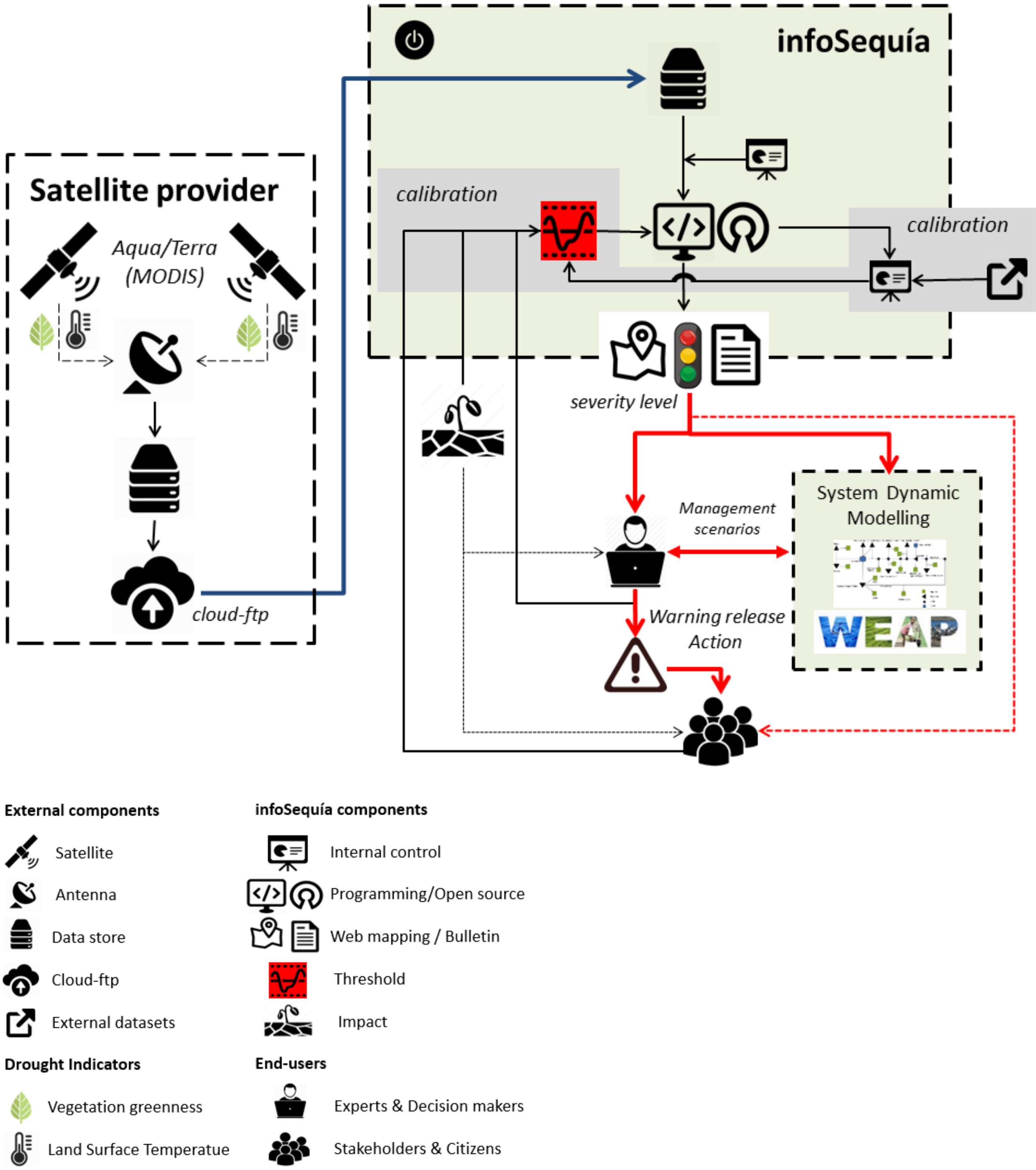
2. Evaluating the flexibility of infoSequia by integrating the system into an operational "Control Room Center", and by checking the probability of compliance by the end user

Test 3. Technical effectiveness in relevant simulated environment

Rational and protocol

This testing exercise aims to demostrate, using a System Dynamic Modelling approach, the ability of InfoSequia's warnings as reliable indicators for water management. This effectiveness will be evaluted through the integration of infoSequia warnings into a Water Allocation Model -WAM- (see next figure). The test aimed to explore how much useful the integration of systems could be in improving the operational management of a basin. The overall effectiveveness of infoSequia is then evaluated in terms of its ability to improve the performace metrics of water resource system (e.g. Demand Satisfaction Index and Demand Reliabilty Index).

Improved version of infoSequia with the link to the WEAP Dynamic Model:

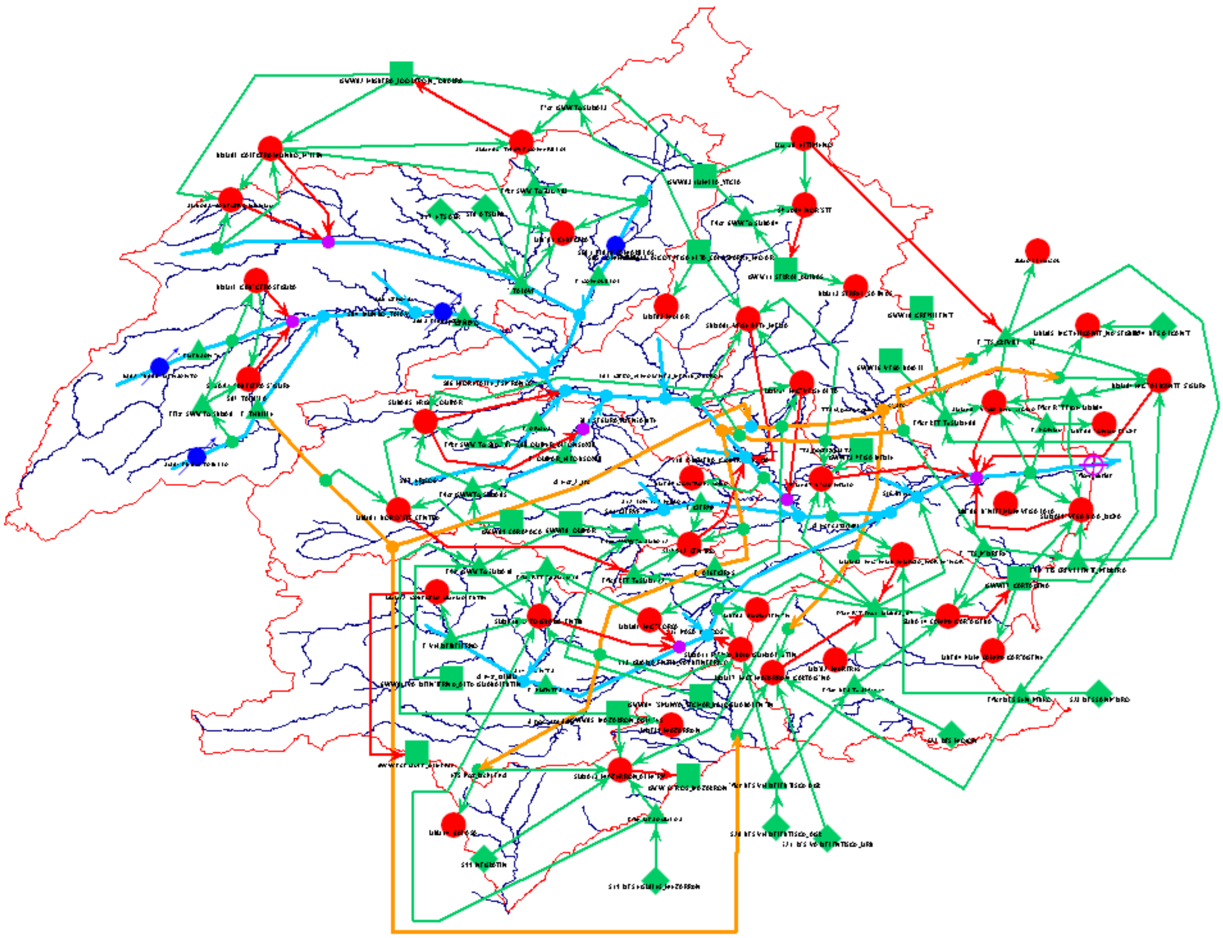


Facility and equipment

WEAP (System Dynamic Modelling Software); Water Allocation Model for the Segura River Basin - WEAP_Segura- (developed and improved by FutureWater in the framework of the Spanish GEISEQ, and H2020 BRIGAID and IMPREX projects). The WEAP_Segura model (topology, feature parameters, and operational rules) were set up in collaboration with the Segura Water

Basin Authority -stakeholder- and in agreement with the current Basin Hydrological Plan and the Basin Drought Plans.

WEAP_Segura model:



Test 4. Flexibility

To test this indicator, infoSequia is being implemented in a real case in Colombia (Cauca River Basin) in combination with other European (Dutch) technologies. The project consists in the design and implementation of a Water Management Information Centre (WMIC) in the Corporación del Valle del Cauca (CVC, i.e. the Environmental Regional Authority of the Cauca Department - Colombia). The WMIC will integrate operational and real-time monitoring systems (e.g FEWS-IDEAM, infoSequia, CVC-GeocastNET) and simulation models (FEWS-ESCASES) under the umbrella of an unique management platform (Hydronet).

InfoSequia will be tailored for the local conditions, and different participatory events were (and are being) realized with the technical staff and other stakeholders to promote the co-design of the whole system.

This project represents an unique opportunity to evaluate the overall flexibility of infoSequia under very different physical, technical and social boundary conditions where this was previously calibrated and validated. Preliminary results of this activity are expected to be reported at the end of summer of 2018.

Testing results

Test 1. Component realiability

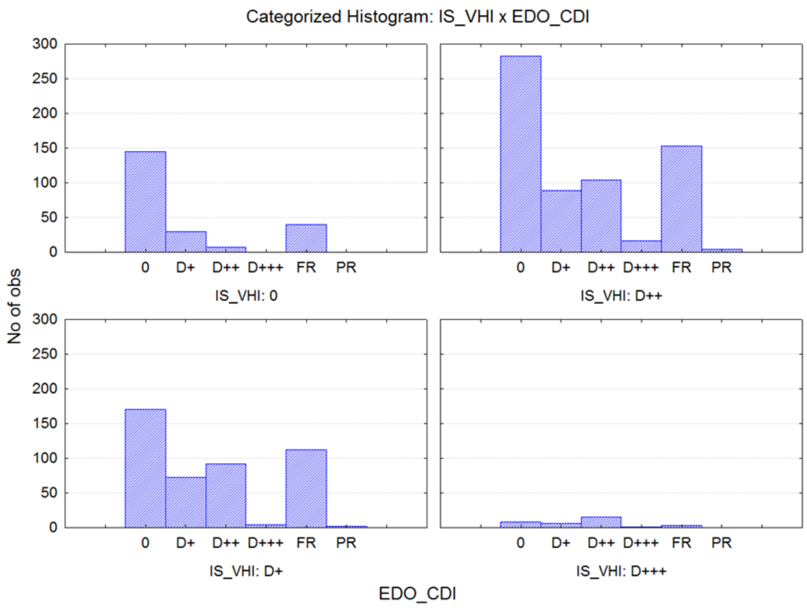
TBC

Test 2. System realiability

Test 2.1

The histogram with the total observations of drought severity levels for the combined indices reported by infoSequia (IS_VHI) and the EDO (EDO_CDI) are shown in next figure, while the contingency table and the diagnostic metrics are show in next table.

Categorized histograms of severity categories of the combined drought indices retrieved from infoSequia and EDO systems. Each observation refers to the most frequent severity categories observed at each Spanish agricultural county. Categories: A) infoSequia (IS_VHI): 0 = no drought, D+ = slight drough; D++ = moderate/severe; D+++ = extreme/exceptional; B) EDO (EDO_CDI): 0 = no drought, D+ = Watch; D++ = Warning; D+++ = Alert; FR and PR refer conditions of full and partial vegetation recovery, respectivelyt:



Contingency table of drought events detected by infoSequia and EDO systems:

	InfoDROUGT = All	European Drought Observatory		
	EDO = All	No event	Event	TOTAL
Info-DROUGHT	No event	**871**	7	
	Event	50	**430**	**480**
			437	
	Total of Agreements	**1301**		
	Total of Disagreements	57		
	% of Agreements	**95.80 (33.05% refers to detected events)**		
	Detected_ID / Detected_EDO	1.10		

Test 2.1

Several conclusions were extracted from this analysis:

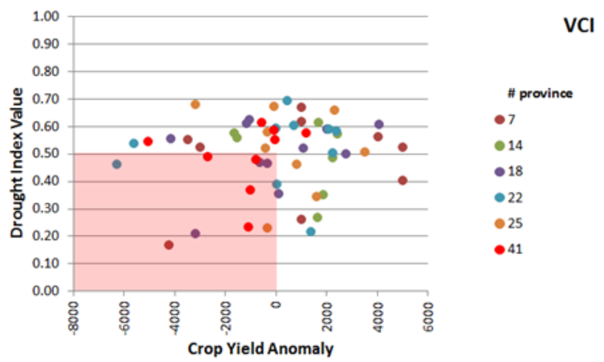
- A weak positive correlation was demostrated between crop yield anomalies and the severity of the drough conditions by the Vegetation Condition Index and the Temperature Condition Index

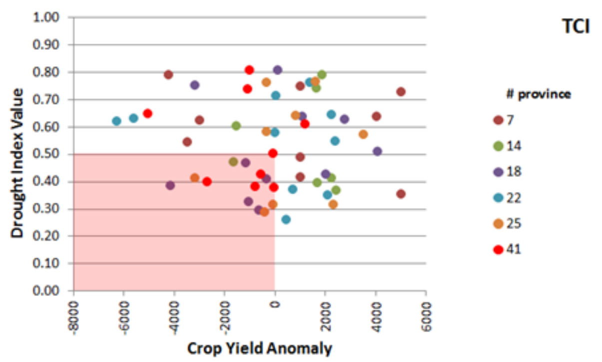
- Best fitting (statistical significance and R^2 values) were reached for the combination of VCI-TCI values.

- Drought indices were positively and moderately correlated with yield and yield anomaly values (in agreement with similar studies). The relative contribution of each infoSequia Drought Index (VCI or TCI) to explain yield anomalies increases as closer is to the end of the growing season period. Total variance explained by the general MLR model ranged between 25-30% for wheat and barley, respectively.

- Non-linear Yield-VHI relationships were found, whith higher sensitivities (slopes) as drought-VHI severity increases.

Scatterplot of interannual maize yield anomalies against infoSequia VCI (Vegetation Condition Index) (left pannel) and TCI (Temperature Condition Index) (right pannel) at different province units (province level) (Top); Contingency tables (Below):





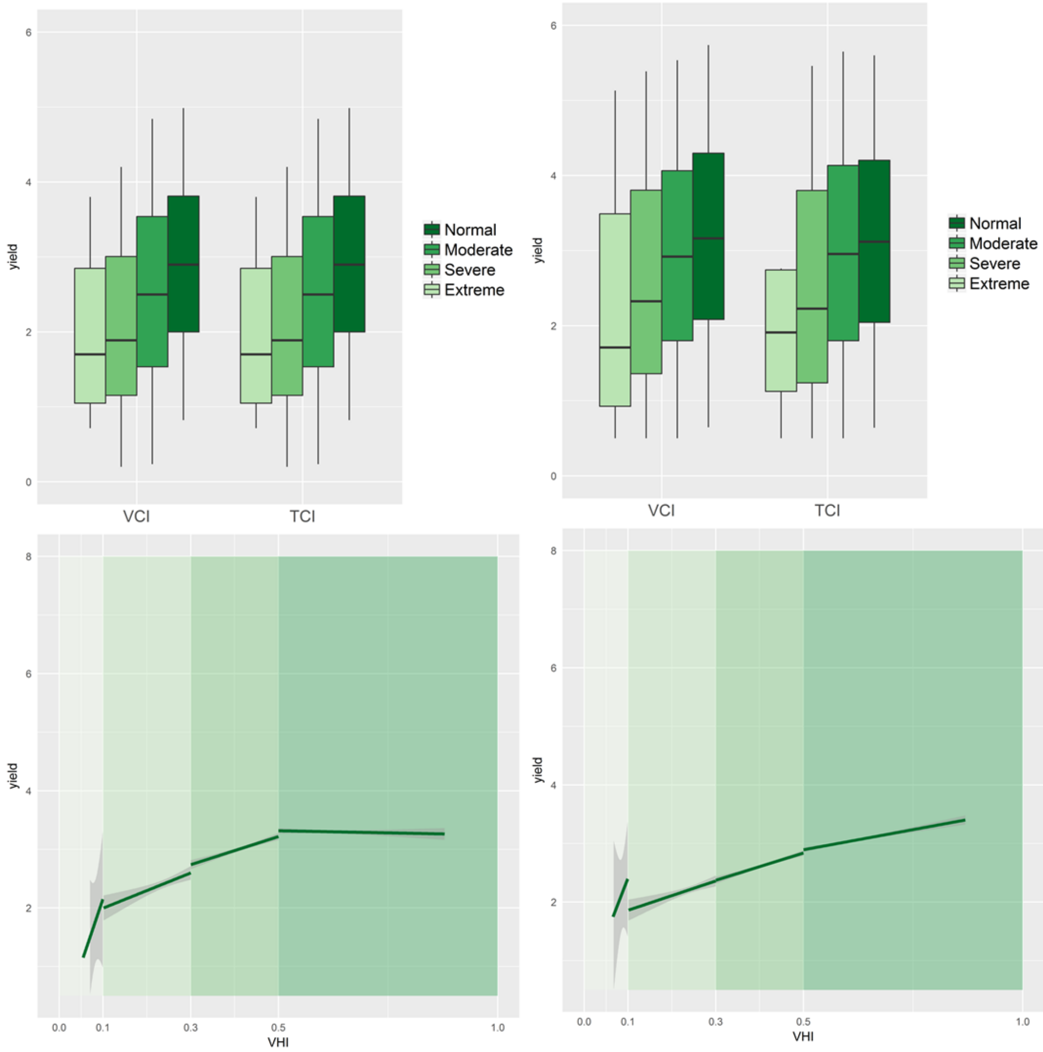
VCI Drought threshold = 0.5	Crop Anomaly: Impact (negative value)	Crop Anomaly: No impact	TOTAL
Info-DROUGHT: No event	34	29	63
Info-DROUGHT: Event	21	26	47
		55	

Overall % of hits (years in red area)	19.1
% of drought years with negative impacts on crops	38.2

TCI Drought threshold = 0.5	Crop Anomaly: Impact (negative value)	Crop Anomaly: No impact	TOTAL
Info-DROUGHT: No event	31	29	60
Info-DROUGHT: Event	24	26	50
		55	

Overall % of hits (years in red area)	21.8
% of drought years with negative impacts on crops	43.6

Boxplots of observed yields (Tn/ha) against VCI-TCI severity categories; Stepwise linear regression between observed yield values (Tn/ha) and VHI severity categories (Bottom):



Test 3. Technical effectiveness in relevant simulated environment

A management scenario of deficit irrigation linked to the drought index (VHI) retrieved from infoSequia was evaluated (see next table) to explore the ability of the full system (infoSequia-WEAP_Segura) in reducing the water unmet demand at the basin scale. Total volumes are reported for the 2002-2010 simulation period and for year 2005 when the region suffered a very severe drought (see results next). The spatial pattern of this unmet demand is also provided by the modelling system.

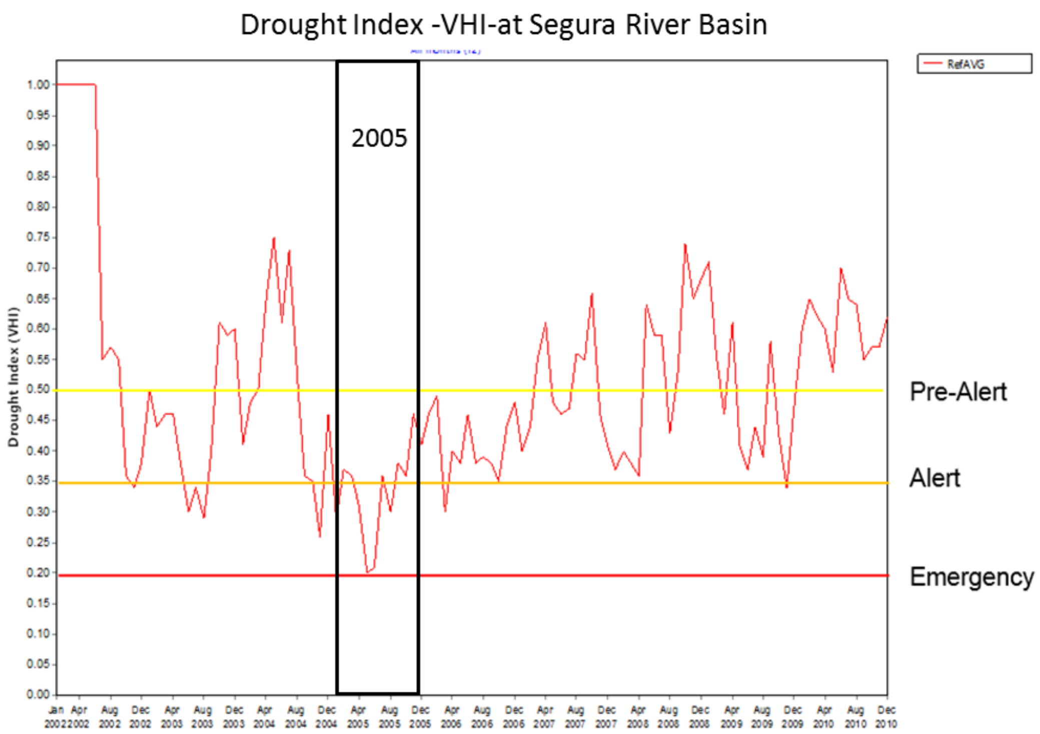
Irrigation scenario simulated for drought conditions:

VHI value	Drought Warning	Deficit irrigation scheme (reduction of crop water requirement against basal value)
1.0 – 0.5	Normal condition	No reduction
0.5 – 0.35	Pre – alert	10%
0.35 – 0.20	Alert	20%
< 0.20	Emergency	40%

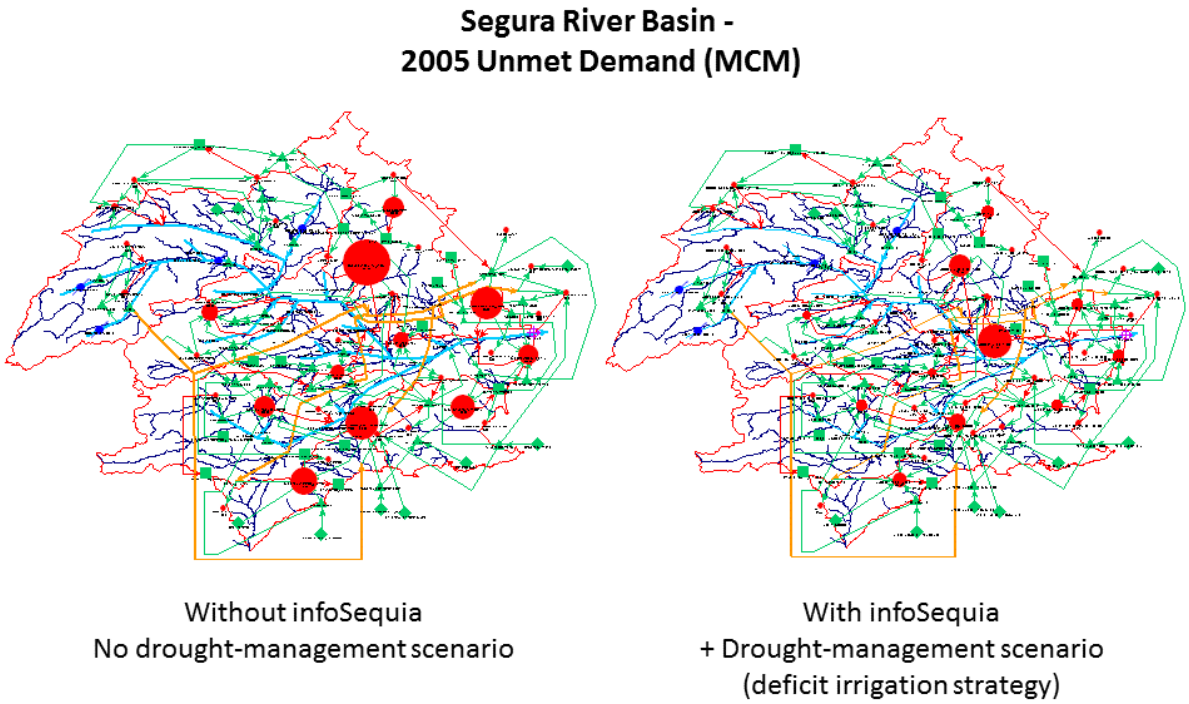
Volumes of total unmet demand (MCM/year) in irrigated agriculture in the Segura basin with and without considering drought management scenarios:

Period	Unmet Demand (MCM/year) (all basin)		
	No drought-based irrigation management	With drought-based irrigation management	Diff
2002 – 2010	422	469	47
2005	415	297	-118

Drought vegetation index (VHI) dynamics in the Segura basin in the period 2002-2010:

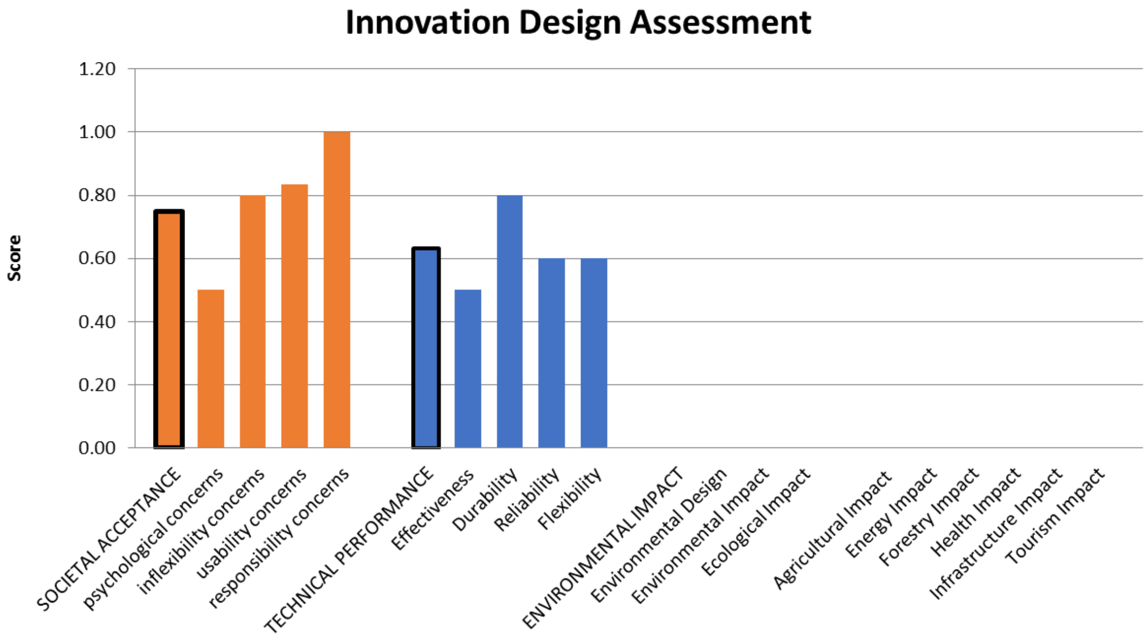


Spatial pattern de unmet demand in the Segura basin in year 2005:



TIF Tool results

Overall assessment of infoSequia using the BRIGAID's TIF Tool:



Overall results of the TIF Tool Assessment for infoSequia:

1	Your innovation raise	few	societal concerns overall, having scored	12	out of a possible	16	and is	close	from/to SOCIETAL READINESS.
1.1	Your innovation raises	few	psychological concerns, having scored	2	out of a possible	4	and is	close	from/to societal readiness.
1.2	Your innovation raises	few	inflexibility concerns, having scored	4	out of a possible	5	and is	close	from/to societal readiness.
1.3	Your innovation raises	few	usability concerns, having scored	5	out of a possible	6	and is	close	from/to societal readiness.
1.4	Your innovation raises	few	responsibility concerns, having scored	1	out of a possible	1	and is	close	from/to societal readiness.
2	Your innovation raise	few	technical concerns overall, having scored	12	out of a possible	19	and is	close	from/to being ready in terms of its TECHNICAL DESIGN.
2.1	Your innovation raises	few	concerns related to its technical effectiveness, having scored	2	out of a possible	4	and is	close	from/to being ready/effective in terms of its technical design.
2.2	Your innovation raises	many	concerns related to its durability, having scored	4	out of a possible	5	and is	close	from/to being ready/effective in terms of its technical design.
2.3	Your innovation raises	few	concerns related to its reliability, having scored	3	out of a possible	5	and is	close	from/to being ready/effective in terms of its technical design.
2.4	Your innovation raises	few	concerns related to its flexibility, having scored	3	out of a possible	5	and is	close	from/to being ready/effective in terms of its technical design.
3	Your innovation raise	many	environmental concerns overall, having scored	0	out of a possible	4	and is	far	from/to being ready in terms of its ENVIRONMENTAL DESIGN.
3.1	Your innovation raises	many	concerns related to its Environmental Design having scored	0	out of a possible	2	criteria. Your innovation may have a	undetermined	on the environment.
3.2	Your innovation raises	many	concerns related to its Environmental Impact, having scored	0	out of a possible	2	criteria. Your innovation may have a	undetermined	on the environment.
3.3	Your innovation raises	undetermined	concerns related to its Ecological Impact, having scored	0	out of a possible	0	criteria. Your innovation may have a	undetermined	on the environment.
4.1	Your innovation raise	undetermined	concerns related to Agricultural Impacts, having scored positively on	0	out of	0	criteria. Your innovation may have a	undetermined	impact on the Agricultural Sector.
4.2	Your innovation raise	undetermined	concerns related to Energy Impacts, having scored positively on	0	out of	0	criteria. Your innovation may have a	undetermined	impact on the Energy Sector.
4.3	Your innovation raise	undetermined	concerns related to Forestry Impacts, having scored positively on	0	out of	0	criteria. Your innovation may have a	undetermined	impact on the Forestry Sector.
4.4	Your innovation raise	undetermined	concerns related to Health Impacts, having scored positively on	0	out of	0	criteria. Your innovation may have a	undetermined	impact on the Health Sector.
4.5	Your innovation raise	undetermined	concerns related to Infrastructure Impacts, having scored positively c	0	out of	0	criteria. Your innovation may have a	undetermined	impact on the Infrastructure Sector.
4.6	Your innovation raise	undetermined	concerns related to Tourism Impacts, having scored positively on	0	out of	0	criteria. Your innovation may have a	undetermined	impact on the Tourism Sector.

The responses for each section of the TIF Tool are detailed hereafter:

1	Societal acceptance assessment	
Answer the following 16 questions by writing Yes or No in the corresponding cells.		**Yes or No?**
1	Does your innovation use any materials that might be considered unfamiliar (such as nanomaterials or genetically modified materials)?	No
2	Will members of the public affected by your innovation be the ones to decide whether or when to use it?	No
3	Does your innovation involve visible infrastructure (such as physical barriers) or visible land use changes (such as woodland removal)?	No
4	Could the deployment of your innovation disrupt daily activities, for example through road closures?	Yes
5	Does your innovation require large amounts of capital investment?	No
6	Does your innovation require a long lead time between users placing an order and it becoming operational?	No
7	Does your innovation require new infrastructure or significant changes to existing infrastructure?	No
8	Does your innovation involve releasing any materials into the environment (such as sprays or coatings)?	No
9	Are your potential users likely to have a single mission, for example to protect ecosystems?	Yes
10	Does your innovation take less time to deploy than incumbent alternatives (such as sand bags for floods or fire nozzles for wildfires)?	Yes
11	Would the use of your innovation require special training?	No
12	Will help and support be available to users of your innovation?	Yes
13	Innovations can either reinforce or change users' existing ways of working. Does your innovation reinforce existing ways of working?	Yes
14	Are the effects of your innovation directly publicly tangible (such as seeing flood defences working or hearing a warning alert system)?	No
15	Adaptations can either be deployed permanently or temporarily. Is your innovation deployed permanently?	Yes
16	Are members of the public involved in shaping the research, development, demonstration and deployment of your innovation?	Yes
Answer the following 4 questions by writing A, B or C in the corresponding cells.		**A, B or C?**
17	What would your innovation primarily protect? (A) public infrastructure, (B) private properties or (C) the environment	C
18	Who would pay for your innovation? (A) government authorities, (B) private companies or (C) local communities	A
19	Who would implement your innovation? (A) government authorities, (B) private companies or (C) local communities	A
20	How would compensation be made in the event of your innovation failing? Through (A) government compensation, (B) project insurance or (C) responsible parties	B

2	Technical Design	
Answer the following questions by writing Yes or No in the corresponding cells.		**Yes or No?**
1	Does the innovation provide significant technical advantage(s) relative to a traditional/conventional measures?	Yes
2	Does your innovation physically prevent a hazard from occurring?	No
3	Does your innovation require combination with other interventions and/or activities in order to reduce risk (e.g, flood warning system in combination with a flood barrier or a fire warning system in combination with controlled burning)?	Yes
4	Will the innovation require additional testing and/or substantial upgrades when considering future hazard conditions (i.e., considering climate change)?	No
5	Is the lifetime of the innovation limited by climate change? (i.e., will climate change affect the estimated life(time) of the innovation?)	No
6	Does the innovation require frequent inspection and maintainence to reach its intended lifetime?	No
7	Are the materials or software needed for maintanence and/or repair easily obtained and can they be integrated by the end-user?	No
8	Is the innovation designed to be used repetitively or continuously operated over its lifetime?	Yes
9	Can the innovation be operated without repair and/or replacement of components during a hazard event?	Yes
10	Does the innovation exhibit vulnerabilities during testing and/or demonstration (e.g., structural: sliding or rotation, or technological: errors)?	Yes
11	Is there a critical component in the innovation's structural or technological design that could lead to catastrophic failure?	No
12	Does your innovation rely on the delivery of services or materials (e.g., structural components, data) outside of your control to be successfully operated during a hazard event?	Yes
13	Does your innovation require the execution of tasks by humans to be successfully operated during a hazard event?	No
14	Can the vulnerability of your innovation to human error be easily reduced through improvements in operational protocols and/or end-user training?	Yes
15	Is the innovation modular (opposite: monolithic) and can it be easily installed or applied at different sites across Europe without adjustment?	No
16	Does the innovation require additional testing and/or substantial upgrades (e.g., new components) if used at different sites across Europe?	Yes
17	Will the size of the market for the innovation (in Europe) will significantly decrease (>50%) due to future hazard conditions (i.e., considering climate change)?	No
18	Have relevant end-users have been identified and contacted and has a need for this innovation observed?	Yes
19	Are the advantages of the innovation derived from its multi-functionality (e.g., reduction of carbon emissions or enhanced recreational activities)?	Yes

3	Environmental Characteristics	
Answer the following questions by writing A, B, or C, in the corresponding cells.		**A, B or C?**
3.1	**Environmental Design**	
3.1.1	Does the innovation deliberately use ecosystems and their services, or mimic or preserve natural processes? (A) Yes (B) No	C
3.1.2	How does the change in footprint (area) required for implementation on-site compare to conventional measures or the present situation? (A) Increase space required (B) Decrease space required (C) No Impact on space required	C
3.1.3	How does the construction or operation of the innovation affect the quantity of greenhouse gases in the environment (e.g., as CO_2 or CH_4)? (A) Increase (B) Decrease (C) No Impact	B
3.1.4	Is the innovation made from recycled or recycable materials? (A) Yes (B) No	B
3.1.5	Does the innovation include specific design features or components which preserve or enhance ecosystem services? (A) Yes (B) No	
3.2	**Environmental Impact**	**C**
3.2.1	How does the innovation impact the quality of surface water? (A) Improve (B) Worsen (C) No Impact	C
3.2.2	How does the innovation impact the quantity of available surface water? (A) Increase (B) Decrease (C) No Impact	C
3.2.3	How does the innovation impact the quality of ground water? (A) Improve (B) Worsen (C) No Impact	C
3.2.4	How does the innovation impact the quantity of available ground water? (A) Increase (B) Decrease (C) No Impact	C
3.2.5	How does the innovation impact the quality of the sea water? (A) Improve (B) Worsen (C) No Impact	C
3.2.6	How does the innovation impact soil quality? (A) Improve (B) Worsen (C) No Impact	C
3.2.7	How does the innovation impact air quality? (A) Improve (B) Worsen (C) No Impact	B
3.2.8	Does the implementation (or construction) of the innovation generate debris? (A) Yes (B) No	B
3.2.9	Does the implementation (or construction) of the innovation generate noise or vibration? (A) Yes (B) No	C
3.2.10	How does the innovation impact landscape quality? (A) Improve (B) Worsen (C) No Impact	
3.3	**Ecological Impact**	**B**
3.3.1	How does the innovation impact the spatial extent of protected nature area? (A) Increase (B) Decrease (C) No Impact	C
3.3.2	How does the innovation impact the quality of protected habitats? (A) Improve (B) Worsen (C) No Impact	C
3.3.3	How does the innovation impact the number protected species (e.g., birds, vegetation, fish, mammals)? (A) Increase (B) Decrease (C) No Impact	C
3.3.4	How does the innovation impact the spatial extent of non-protected nature area? (A) Increase (B) Decrease (C) No Impact	C
3.3.5	How does the innovation impact the quality of non-protected habitats? (A) Improve (B) Worsen (C) No Impact	C
3.3.6	How does the innovation impact the number non-protected species (e.g., birds, vegetation, fish, mammals)? (A) Increase (B) Decrease (C) No Impact	C

4	Sectoral Impacts	
Answer the following questions by writing A, B or C in the corresponding cells.		A, B or C?
4.1	Agriculture	
4.1.1	How does the innovation impact the total area available for agricultural production? (A) Increase (B) Decrease (C) No Impact	C
4.1.2	How does the innovation impact agricultural production conditions (e.g., by increasing soil quality or water availability)? (A) Improve (B) Worsen (C) No Impact	C
4.1.3	How does the innovation impact the variety of agricultural products (e.g., crops, dairy, meat, fruit, fish, aquaculture) that can be produced or are available? (A) Increase (B) Decrease (C) No Impact	C
4.1.4	How does the innovation impact the total yield of one or more agricultural products? (A) Increase (B) Decrease (C) No Impact	C
4.2	Energy	
4.2.1	How does the innovation impact the energy production capacity (e.g., by generating energy or increasing energy distribution)? (A) Increase (B) Decrease (C) No Impact	C
4.2.2	How does the innovation impact the reliability of energy production (e.g. by improving cooling water conditions for energy plants)? (A) Increase (B) Decrease (C) No Impact	C
4.2.3	How does the innovation impact the efficiency of energy production? (A) Increase (B) Decrease (C) No Impact	C
4.2.4	How does the innovation impact the carbon footprint of the end-user? (A) Increase (B) Decrease (C) No Impact	
4.3	Forestry	C
4.3.1	How does the innovation impact the total area available for wood production (including timber and biomass)? (A) Increase (B) Decrease (C) No Impact	C
4.3.2	How does the innovation impact wood production conditions (e.g., by increasing forest resilience or water availability)? (A) Improve (B) Worsen (C) No Impact	C
4.3.3	How does the innovation impact the total area available for non-wood production (including cork, fruit, honey, mushrooms, pastures, game and fishing)? (A) Increase (B) Decrease (C) No Impact	C
4.3.4	How does the innovation impact non-wood production conditions (e.g., by increasing forest resilience or water availability)? (A) Improve (B) Worsen (C) No Impact	
4.4	Health	C
4.4.1	How does the innovation impact the number of fatalities in the area exposed to the hazard? (A) Increase (B) Decrease (C) No Impact	C
4.4.2	How does the innovation impact the number of people affected by the hazard in their physical health (i.e., number of people injured)? (A) Increase (B) Decrease (C) No Impact	C
4.4.3	How does the innovation impact the number of people affected by the hazard in their mental/physo-social health? (A) Increase (B) Decrease (C) No Impact	C
4.4.4	Does the innovation emit or release chemicals or products that are harmful to humans? (A) Yes (B) No	
4.5	Infrastructure	C
4.5.1	How does the innovation impact the quality of the built environment (I.e., residential, commercial, and industrial)? (A) Improve (B) Worsen (C) No Impact	C
4.5.2	How does the innovation impact the total area available for urban development? (A) Increase (B) Decrease (C) No Impact	C
4.5.3	How does the innovation impact the capacity of existing transportation systems (e.g., roads, railways, waterways, and airports) or create new capacities? (A) Increase (B) Decrease (C) No Impact	C
4.5.4	How does the innovation impact the reliability of existing transportation systems (e.g., roads, railways, waterways, and airports)? (A) Increase (B) Decrease (C) No Impact	C
4.5.5	How does the innovation impact the transport capacity of critical infrastructure networks (e.g., power, water, waste management)? (A) Increase (B) Decrease	C
4.5.6	How does the innovation impact the reliability of critical infrastructure networks (e.g., power, water, waste management)? (A) Increase (B) Decrease (C) No Impact	
4.6	Tourism	C
4.6.1	How does the innovation impact the total area available for recreational activities? (A) Increase (B) Decrease (C) No Impact	C
4.6.2	How does the innovation impact the attractiveness of the area for recreational activities? (A) Increase (B) Decrease (C) No Impact	C
4.6.3	How does the innovation impact the length of the tourist season? (A) Increase (B) Decrease (C) No Impact	C

TRL assessment:

Climate Adaptation Innovation (T) Readiness Levels	
Innovation:	**InfoSequia**
Organization:	FutureWater
Starting TRL	4
Anticipated Ending TRL	7
Current Status	5
Actual Ending TRL	???

BRIGAID Stages	TRL	Question	*To be completed at the start of the project*						*To be completed at the time of interim reports*			*To be completed at the end of the project*		
			Start of Project			**Anticipated End of Project**			**Current status**			**Actual End of Project**		
			Yes	**No**	**N/A**	**Yes**	**No**	**N/A**	**Yes**	**No**	**N/A**	**Yes**	**No**	**N/A**
Desk Study	**TRL 1**	**Basic principles observed and reported.**												
Desk Study	**TRL 2**	**Innovation concept formulated.**												
Desk Study	**TRL 3**	**concept.**												
Stage 1: Laboratory Testing	4	Has societal acceptance testing of individual components been performed?		X						X				
Stage 1: Laboratory Testing	4	Has performance of components and interfaces between components been demonstrated?	X						X					
Stage 1: Laboratory Testing	4	Does draft system architecture plan exist?		X					X					
Stage 1: Laboratory Testing	4	Have end user technology/system requirements been documented (e.g., reliability requirements)?		X					X					
Stage 1: Laboratory Testing	4	Has component compatibility been demonstrated?	X						X					
Stage 1: Laboratory Testing	4	Does technology demonstrate basic functionality in simplified environment?	X						X					
Stage 1: Laboratory Testing	4	Have performance characteristics been demonstrated in a laboratory environment?	X						X					
Stage 1: Laboratory Testing	4	Have low-fidelity assessments of system integration and engineering been completed?	X						X					
Stage 1: Laboratory Testing	**TRL 4 Achieved**	**Innovation validated in a laboratory environment.**												
Stage 1: Laboratory Testing	5	Have internal system interface requirements been documented?	X						X					
Stage 1: Laboratory Testing	5	Has analysis of internal interface requirements been completed?	X						X					
Stage 1: Laboratory Testing	5	Can all system specifications be simulated and validated within a laboratory environment?	X						X					
Stage 1: Laboratory Testing	5	Is the laboratory environment high-fidelity?	X						X					
Stage 1: Laboratory Testing	5	Have individual component functions been verified through testing?	X						X					
Stage 1: Laboratory Testing	5	Have objective and threshold operational requirements been developed? (e.g., has the intended reduction in risk been quantified? Is the end-user requirement for reliability known?)		X					X					
Stage 1: Laboratory Testing	5	Have all potential failure modes been identified and documented?	X						X					
Stage 1: Laboratory Testing	5	Has the reliability of the fully integrated prototype been estimated using desk study calculations?		X					X					
Stage 1: Laboratory Testing	5	Have the social, technical, and environmental design of the innovation been re-assessed? (TIF tool applied, i.e. stage-gate tool)		X					X					
	TRL 5 Achieved	**Innovation prototype demonstrated in a laboratory environment.**												
Stage 2: Operational Testing	6	Have system integration issues been addressed?	X						X					
Stage 2: Operational Testing	6	Is the operational environment fully known?	X						X					
Stage 2: Operational Testing	6	Have the current and future (i.e., under climate change) hazard conditions in the intended operational environment been documented?			X				X					
Stage 2: Operational Testing	6	Has the technical and/or climate lifetime of the innovation been estimated?		X						X				
Stage 2: Operational Testing	6	Have performance characteristics (i.e., social, technical, and environmental) been verified in a simulated operational environment?		X						X				
Stage 2: Operational Testing	6	Has prototype been tested in a simulated operational environment and shown to withstand the intended hazard loads *without* failure?	X							X				
Stage 2: Operational Testing	6	Does the prototype successful reduce the intended/threshold level of risk (i.e., by reducing the hazard and/or its consequences) in a simulated operational environment?			X						X			
Stage 2: Operational Testing	6	Have the operation and maintainence protocols over the lifetime of the innovation been established and documented?	X						X					
Stage 2: Operational Testing	6	Has system been tested in realistic environment outside the laboratory?			X				X					
Stage 2: Operational Testing	6	Has engineering feasibility been fully demonstrated?	X								X			
Stage 2: Operational Testing	**TRL 6 Achieved**	**Innovation model or prototype demonstrated in a relevant environment.**												
Stage 2: Operational Testing	7	Have all interfaces been tested individually under stressed and anomalous conditions?		X					X					
Stage 2: Operational Testing	7	Has technology or system been tested in a representative operational environment and shown to withstand the expected hazard loads?		X						X				
Stage 2: Operational Testing	7	Has the reliability of the prototype been quantified and validated in a representative operational environment?		X						X				
Stage 2: Operational Testing	7	Are available components representative of production components (i.e., will the innovation be ultimately produced using the same materials as used in testing; is the prototype to-scale)?			X						X			
Stage 2: Operational Testing	7	Have vulnerabiliities to human error been effectivley minimized?		X					X					
Stage 2: Operational Testing	7	Has fully integrated prototype been demonstrated in actual or simulated operational environment?		X						X				
Stage 2: Operational Testing	**TRL 7 Achieved**	**Innovation prototype demonstratied in an operational environment.**												
Stage 2: Operational Testing	8	Are all technology/system components form, fit, and function compatible?		X					X					
Stage 2: Operational Testing	8	Is technology/system form, fit, and function compatible with operational environment?		X						X				
Stage 2: Operational Testing	8	Has technology/system form, fit, and function been demonstrated in operational environment and shown to withstand the expected hazard load(s) without failure?		X						X				
Stage 2: Operational Testing	8	Have the operational and maintanence costs over the lifetime been estimated and documented?			X						X			
Stage 2: Operational Testing	8	Have the social, technical, and environmental design of the innovation been re-assessed? (TIF tool applied, i.e. stage-gate tool)			X						X			
	TRL 8 Achieved	**Actual system completed and qualified through test and demonstration.**												
	TRL 9	**Actual system proven through successful mission operations.**												

8. Innovation: GM4W - GeoGuard Module for Water vapor monitoring

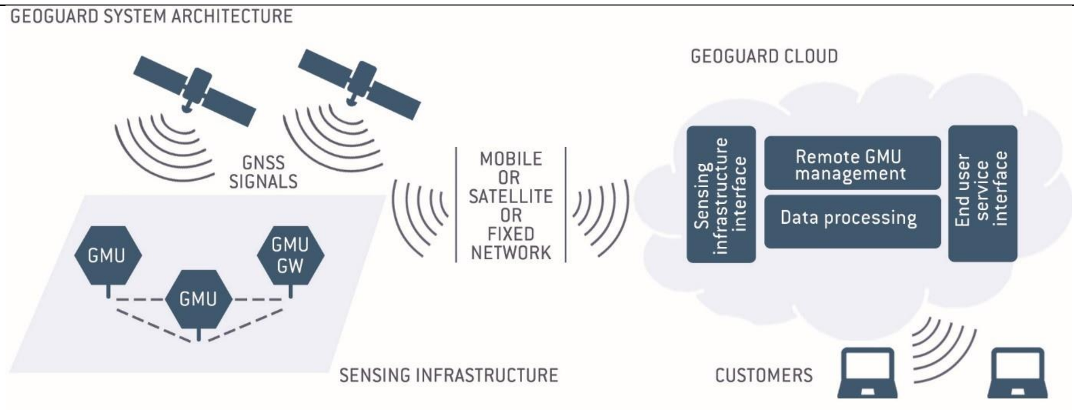
Innovator: Geomatics Research & Development s.r.l. (GReD) (BRIGAID consortium partner)

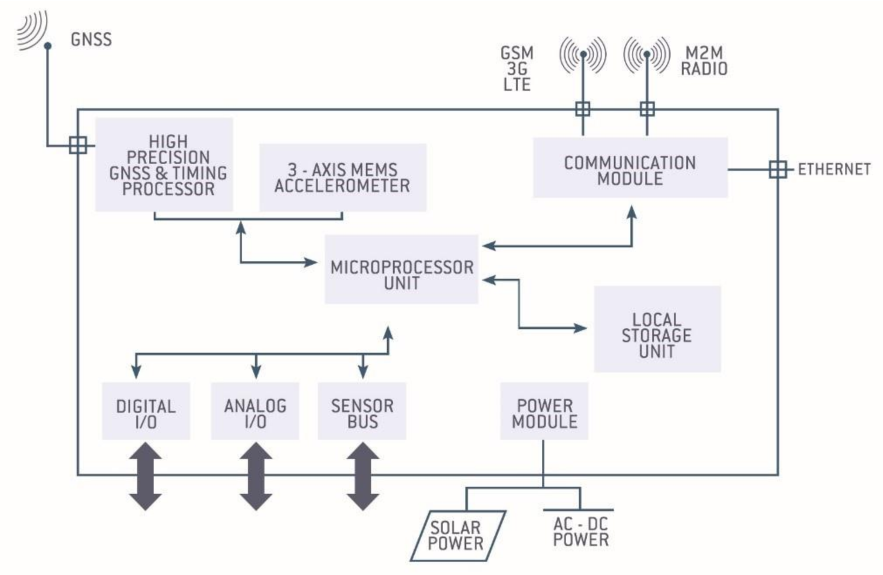
Contributing authors: Eugenio Realini (GReD), Lisa Pertusini (GRED)

Innovation description

The description of GM4W below is also available from the Climate Innovation Window, http://climateinnovationwindow.eu/innovations/water-vapour-gnss-monitoring

Name
GeoGuard Module for Water vapor monitoring (GM4W)
Short description
The innovation provides new technology for the reliable and continuous water vapour monitoring with high horizontal resolution. It is based on low-cost single-frequency Global Navigation Satellite Systems (GNSS) receivers, designed and developed by Geomatics Research & Development s.r.l. (GReD) through a collaboration with Proteco Consortium. They can also be used to detect the deformation and movements of the ground (e.g. landslides, subsidence) and critical infrastructure (e.g. dams, bridges, high voltage towers, …) and are designed to be able to operate under all weather conditions. They have already been tested in operational environments for more than a year. These units will be produced and deployed in BRIGAID planned test sites (Rotterdam and Monterosso al Mare), and will provide the raw GNSS data needed for PWV retrieval. Further integration of the PWV product with high-resolution radar data in cities will be tested in order to enhance the monitoring and forecasting of small scale extreme rain storms and related pluvial floods in cities. The latter will be done in collaboration with TU Delft.
Sketch/Photograph of the Innovation





The photos shown next provide some impressions. The first photo is one of the units deployed to monitor a landslide in northern Italy, while the second photo is a unit deployed at the Fukushima Renewable Energy Institute of AIST (FREA) in Japan, to monitor precipitable water vapor (for experiments related to the optimal management of solar farms).

Which hazard(s) is the innovation designed to mitigate?
Heavy Precipitation/Pluvial Floods: rainfall events that result in 1) (urban) floods due to

exceedance of: drainage capacity, and 2) flash floods, defined as rapid flooding of low-lying areas, generally within a few hours after heavy rainfall events such as thunderstorms

Precipitable water vapour (PWV) at local scale can be a precursor of rainfall. Local-scale amount of PWV at a height of 1 km increases from about 30 minutes to 1 hour before the formation of rain drops because of the ground surface convergence process. That is why PWV is useful to be assimilated into numerical weather prediction models, to enhance the forecasting of deep convection that may result in heavy rainfall.

Such enhanced prediction of deep convective rainfall allows to obtain improved rainfall nowcasts for urban areas (cities) and floods from urban drainage systems (storm water or sewer systems) or small rivers that have short response time to rainfall. Improved nowcasts would lead to improved warning against such floods. The innovation hence is important to increase to preparedness of authorities, crisis managers but also the larger public against the increased frquency and intensity of extreme rain storms indiced as a result of climate change (Willems et al., 2012).

Reference:

Willems, P., Olsson, J., Arnbjerg-Nielsen, K., Beecham, S., Pathirana, A., Bülow Gregersen, I., Madsen, H., Nguyen, V-T-V. (2012), 'Impacts of climate change on rainfall extremes and urban drainage', IWA Publishing, 252p., Paperback Print ISBN 9781780401256; Ebook ISBN 9781780401263

How does the innovation work?

Monitoring the temporal and spatial variability of precipitable water vapour (PWV) at a local scale is important to improve the probabilistic nowcasting and forecasting of localized sudden storms and heavy rain, that can have spatial scales down to few kilometres. Local fluctuations of PWV, in fact, may be associated with increases of water vapour in the lower troposphere, which cause deep convection that may result in heavy rainfall. Before the initiation of convection, convergence of water vapour near the ground surface occurs. Previous studies reported that the local-scale amount of water vapour at a height of 1 km increases from about 30 minutes to 1 hour before the formation of rain drops because of the ground surface convergence process. This local-scale signal can be a precursor of rainfall, which would be useful to be assimilated into numerical weather prediction models, thus it is deemed important to detect it by high-resolution PWV measurements.

Global Navigation Satellite Systems (GNSS) provide a PWV monitoring method that is continuous in time with high observation rates (contrary to radiosondes), and not adversely affected by meteorological conditions, nor requiring calibration (contrary to microwave radiometers). Several countries have already deployed networks of continuously operating dual-frequency (DF) GNSS stations, typically to measure ground deformations; in some cases, these networks are already used also for PWV monitoring at operational level, which is then assimilated into numerical weather prediction models. However, even the densest regional GNSS networks available, such as GEONET in Japan, have inter-station distances of the order of tens of kilometres, which is not sufficient for the accurate detection of local fluctuations of water vapour. A densification of existing networks, at least in urban areas, is necessary to provide reliable and continuous water vapour monitoring with sufficiently high horizontal resolution. Low-cost single-frequency (SF) GNSS receivers are a solution to this problem.

GNSS PWV is retrieved from tropospheric zenith wet delays (ZWDs), typically estimated by a Precise Point Positioning adjustment of the observed pseudo-ranges between a receiver and all the satellite in view at a given epoch. The interaction between GNSS signals and the atmosphere, in fact, results in a reduced propagation speed, with respect to the vacuum, which translates to an

observed extra-path usually referred to as atmospheric delay. Meteorological applications require just the portion of delay due to the troposphere water vapour content, which implies the removal or modelling of the delay component due to the interaction with the ionosphere. While DF observation combinations allow for such removal, when using SF observations, the ionospheric delay has to be modelled. In this regard, the Satellite-specific Epoch-differenced Ionospheric Delay (SEID) model, developed at the German Research Centre for Geosciences (GFZ), is used in our solution. GReD has already designed and developed SF GNSS-based monitoring units through a collaboration with a hardware company based in Genoa (Proteco Consortium). These units are used to provide a monitoring service called GeoGuard (http://www.geoguard.eu/) to detect the deformation and movements of the ground (e.g. landslides, subsidence) and critical infrastructure (e.g. dams, bridges, high voltage towers, …). The GeoGuard Monitoring Units (GMUs) are designed to be able to operate under all weather conditions, and have already been tested in operational environments for more than 1 year. These units will be produced and deployed in BRIGAID planned test sites (Rotterdam and Monterosso al Mare), and will provide the raw GNSS data needed for PWV retrieval.
Added value / main differentiating element from conventional approach(es)
Our approach is based on low-cost GNSS receivers and antennas, allowing for the deployment of a higher number of monitoring units. Consequently, this provides information about the spatial distribution of water vapour at a higher horizontal resolution.
Critical success factors / Limitations
At present atmospheric water vapour monitoring systems require very expensive instrumentation, such as microwave radiometers, radiosondes, geodetic GNSS receivers, etc. Our innovation is the first on the market to provide a cost-effective solution that is able to achieve the needed results in terms of retrieved water vapour accuracy. Some meteorologists may have doubts about the usefulness of GNSS-derived precipitable water vapor assimilation; this is due to the fact that this kind of technique is relatively new and some countries do not yet make use of it. For example, GNSS-derived water vapor is routinely assimilated by the Japan Meteorological Agency, the Swiss Meteo Service and the Danish Meteorological Institute, but this is not happening yet in Italy. Not all meteorologists are used to assimilate precipitable water vapor information coming from GNSS ground stations, so some effort on their part will be required (e.g. adding the integrated amount of water vapour as assimilated data into numerical weather prediction models).

Desk study

Summary

The most important failure modes include:

- Failure in obtaining authorization to install the monitoring units at the optimal (planned) locations;
- Failure to obtain weather station data (pressure, temperature) from local agencies;
- Weather station data are not reliable;
- Real-time data gaps due to 3G network failures;
- The error of real-time satellite orbits and clocks does not allow to achieve the expected accuracy in the water vapor estimates;
- The error caused by the interpolation of the ionospheric delay does not allow to achieve the expected accuracy in the water vapor estimates;
- Failure to improve the nowcasting/ forecasting of heavy rain.

The innovation was already tested for the following components/functionalities:

- monitoring unit reliability in terms of firmware functions (GNSS data acquisition/storage/transfer), resistance to temperature extremes and weather events (rain, hail, etc);
- GNSS receiver unit reliability, in terms of observation noise (< 50 cm for code range observations, < 5 mm for phase range observations) and data availability (> 90% over 24 hours timespan);
- ionospheric delay interpolation accuracy, when dual-frequency stations are closer than 50 km;
- 3G data transfer reliability was tested in different areas/environments: in remote areas in Italy, mobile connectivity can be unavailable also for several hours; in this case, observations are stored locally, and they are transferred as soon as the mobile connectivity is restored;
- both real-time orbits/clocks accuracy and the improvement of heavy rain nowcasting/forecasting were evaluated at academic level (e.g. Kyoto University, in collaboration with GRED staff).

Technical Readiness Level (TRL)

TRL 6. Technology demonstrated in relevant environment.Representative model or prototype system, which is well beyond that of TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in a simulated operational environment.

The hardware (i.e. the monitoring units which will be deployed on the field) is at TRL 9, since the same GNSS units have been used by large clients of GReD for critical infrastructure (i.e. bridges, dams, high-voltage towers) and land (i.e. landslides) displacement monitoring for more than 1 year.

The overall water vapour monitoring system, which includes innovative (server-side) components such as the local ionospheric delay modelling and the continuous estimation of tropospheric delays, from which the integrated amount of precipitable water vapour can be inferred. This is more likely at TRL 6, since the technology has been demonstrated in relevant environment, namely by dedicated dense networks deployed for testing; however, it was not demonstrated in an actual operational environment, where water vapor data would have to be analysed for probabilistic nowcasting in order to issue timely early warnings.

Reusability

Describe the intended reusability of the innovation based on the definitions given above:

One of the possible applications of GNSS receivers networks is to monitor atmospheric water vapour, e.g. in the framework of an early warning system for nowcasting or forecasting local heavy rain. Nevertheless, when we apply this system to monitor wide areas, we may need to install several hundreds of GNSS receivers in order to obtain a significant monitoring capability. In order to keep down the system cost, we use low-cost single-frequency GPS receivers (basically the same chipsets that are used within smartphones and car navigation systems). However, it is necessary to compensate for the ionosphere-induced delay, which cannot be estimated with a single-frequency signal. Therefore, we have successfully tested local ionosphere models that interpolate the ionospheric delay in order to compensate the single-frequency measurements. Local ionospheric models to be used with a dense network of low-cost receivers can be estimated by using existing dual-frequency GNSS receivers located in the vicinity of the network, as for example those belonging to existing national/regional networks. In collaboration with Proteco, a consortium of ICT enterprises based in Genoa, we have designed and developed IP67-certified weather-proof monitoring units, since this kind of units exploiting low-cost GNSS receivers was not available on the market. Although developed with the main target of precise GNSS monitoring of critical infrastructure and/or terrain deformation/movement, the same units can be used also for atmospheric water vapour monitoring, when local ionospheric models are used as explained above.

Under some constraint reg. the installation of the GNSS receivers network, it is expected that the technology can be applied to any area in the world. The convective rainfall estimation envisaged here is most useful in urban areas (cities), such that it can be applied on the basis of urban pluvial flood estimation, forecasting or nowcasting (= short-term forecasting) and warning.

Propose a test plan to assess the expected reusability of the (components of the) innovation:

The tropospheric delays / precipitable water vapour GNSS monitoring stations will be deplyed at two pilot sites: ***Rotterdam and Monterosso al Mare***. In both cases, the new low-cost (single-frequency) stations will complement the existing geodetic (dual-frequency) ones, with the aim of allowing for water vapour monitoring at higher spatial resolution. Geodetic stations will also have the role of providing a means to generate a local ionospheric delay model, that is needed to remove the ionospheric contribution from the single-frequency observations of low-cost receivers.

The spatiotemporal behaviour of GNSS-derived high-resolution water vapour data will be analysed with respect to precipitation observed by X-band weather radar(s?) in collaboration with other BRIGAID WP4 participants. The retrieved tropospheric delays/water vapour data will be used to enhance the probabilistic nowcasting / NWP forecasting of heavy rain over the two test areas.

Initial steps:

1) GReD has already informed Proteco, the company producing the hardware for the GNSS monitoring units (through an existing partnership with GReD), about the test plans and schedule. We have already started working out the details about the basic requirements of the monitoring units, so that Proteco can add the BRIGAID monitoring units to its production pipeline. The aim is to have the monitoring units ready by the beginning of the "Test plans" phase reported in the WP4 time planning (around KO+7).

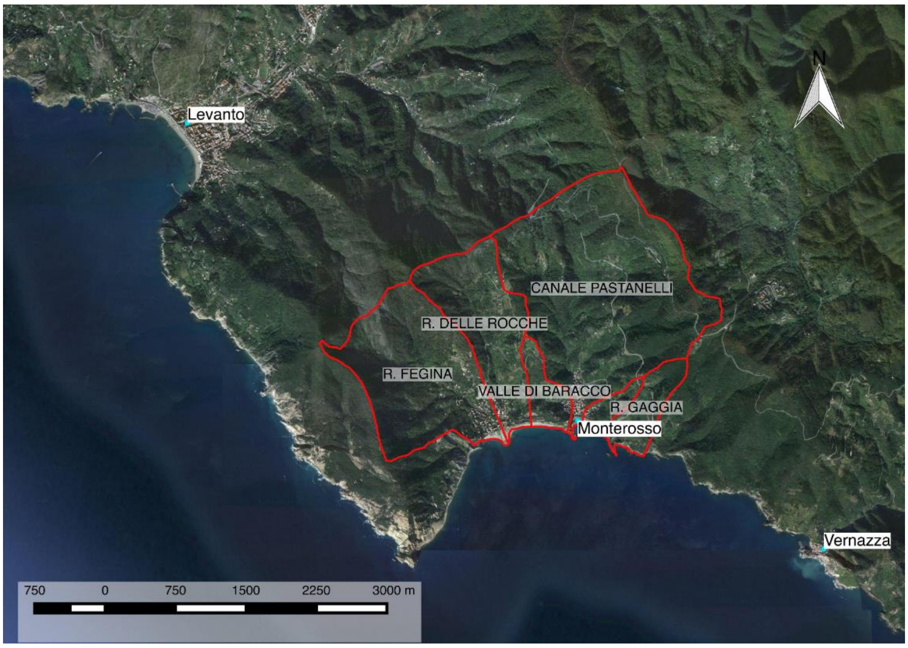
2) We will need start soon selecting candidate installation sites in/around Rotterdam and in/around Monterosso al mare. Depending on the installation sites, the monitoring units' requirements can be refined (e.g. are photovoltaic panels necessary? Is mobile data transfer required? etc.); if possible, it would be preferable to choose sites that already have wired electricity, since photovoltaic panels increase the units' cost significantly. Wired Internet connection would be nice, but that's often not easy to achieve.
   The selection of installation sites in Monterosso al Mare will be carried out by GReD in collaboration with Proteco (since they are headquartered not so far from Monterosso) and with Monterosso municipality staff (contacts with them are already existing). For the selection of candidate sites in/around Rotterdam we will need to work in close collaboration with TU Delft.

3) GReD can already retrieve GNSS observations from the existing geodetic stations in Italy. The data of some of the geodetic stations in/around Rotterdam are already available on public archives, but other stations will require to interact with the local operator of the stations to gain access to their observations.

Monterosso al Mare deployment:

In collaboration with the Monterosso al Mare Municipality technical staff (i.e. geologists in charge of hydrogeological risk mitigation plans), we have identified the main hydrographic (catchment) basins around the town.

Hydrographic basins around Monterosso al Mare:



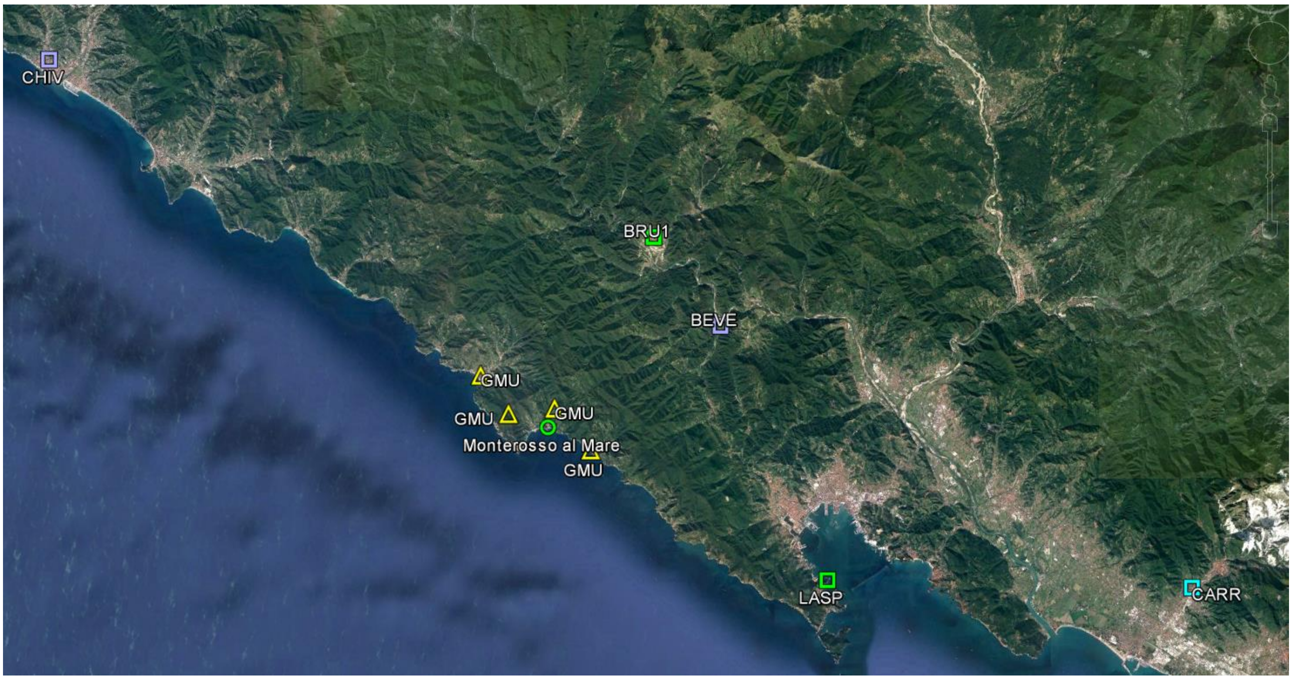
We are considering deploying one GNSS unit in each of the two main basins ("Fegina" and "Pastanelli"), as well as one in Levanto and one in Vernazza municipalities (hypothetical deployment in next figure).

Example of possible deployment of 4 GeoGuard Monitoring Units (GMUs) around Monterosso al Mare:

Given the significant terrain height difference in this area, it will be important and challenging to keep the GNSS antenna height difference as low as possible (in order to avoid biases in the estimated water vapour amount).

Next figure shows the planned Monterosso GNSS network surrounded by the closest already existing dual-frequency geodetic stations.

Monterosso GNSS network and nearest five permanent GNSS stations:

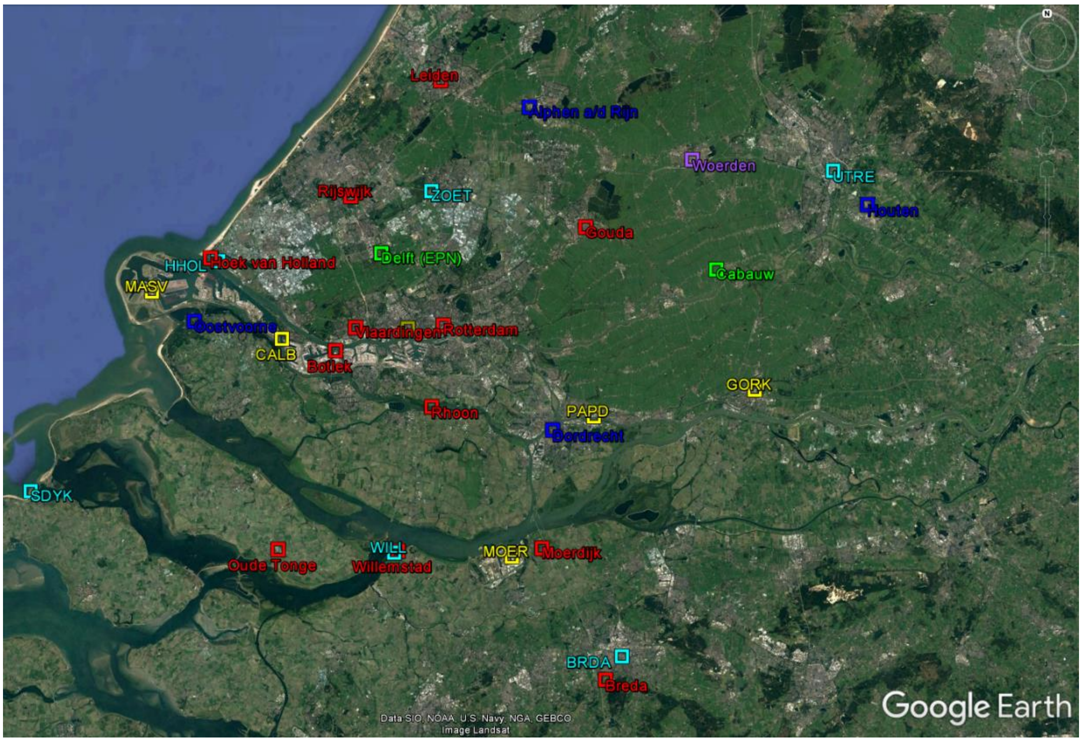


The availability of existing weather stations and C-band radar data in the area of interest is currently under investigation. We are currently considering to equip each GMU with pressure and temperature (low-cost) sensors, in case the existing hydrometeorological stations data are not available and/or too far away.

Rotterdam deployment:

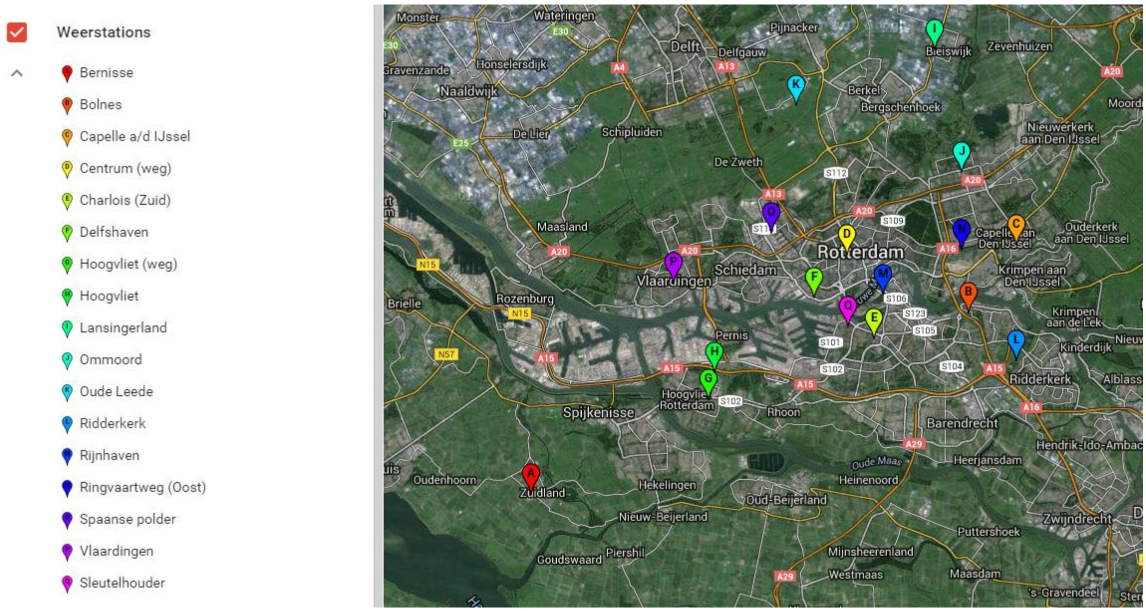
The deployment here is less problematic, at least from the point of view of station height difference and geometric distribution of permanent GNSS stations (see next figure).

Permanent GNSS stations (both public and private) in and around Rotterdam:



Weather stations data in and around Rotterdam are available (see next figure).

Weather stations in Rotterdam area:



Update March 2017

Requirements were finalized for the two test sites. In Rotterdam 4 stations with photovoltaic panel will be deployed, of which 1 station with temperature, pressure and relative humidity sensors. The deployment will be carried out by TU Delft staff with GReD's on-site support. In Monterosso al Mare we will deploy 4 stations with photovoltaic panel (a weather station was recently deployed on the rooftop of Monterosso municipality building and its data is available to GReD). The deployment in Monterosso will be carried out by Proteco (GReD’s partner company, who designed and produces the monitoring units hardware), since they are based in Genoa, that is not far from Monterosso al Mare.

All the monitoring units will be carrying a new GNSS module that does not track just GPS (as in the previous version), but also the EU system Galileo, and the Russian GLONASS. Demonstration of the usefulness of Galileo is very important for the EU.

All the units should be ready by April 2017, in line with the test schedule.

The next step is to choose precise locations for the deployment, 4 in Rotterdam and 4 in Monterosso, and to perform site inspections in order to evaluate any specific requirements for each unit deployment.

For semi-permanent and temporary innovations, identify the expected percent of the innovation that is reusable after each use and which components (if any) would need to be replaced:

The stations monitor continuously, it is not possible to define “each use”.

Estimate the expected product lifetime based on decomposition of the materials used:

The expected lifetime of the GMU hardware is 3 years. The component with the shortest lifetime is the battery attached to the photovoltaic panel.

Are there any results of previous tests? (e.g., if lifetimes of the structural components are already known or tested):

Some GMUs were deployed 2 years ago and are still operational. We don’t have examples longer than that, simply because before 2 years ago the GMU was not designed yet.

Reliability

Identify all possible failure modes that would lead to implementation and technical failure in the form of a fault tree:

No.	Mechanism
1	**Errors during implementation**
1a	Failure in obtaining authorization to install the monitoring units at the optimal (planned) locations
1b	Failure to obtain weather station data (pressure, temperature) from local agencies
2	**Technical failure of the measure**
2a	The error of real-time satellite orbits and clocks does not allow to achieve the expected accuracy in the water vapor estimates
2b	The error caused by the interpolation of the ionospheric delay does not allow to achieve the expected accuracy in the water vapor estimates
2c	Weather station data are not reliable
2d	Real-time data gaps due to 3G network failures
3	**Technological failure**
3a	Failure to improve the nowcasting/forecasting of heavy rain

Test plan to evaluate failure modes. Also, describe whether these tests will take place in a controlled or operational testing environment (dependent on the TRL):

No.	Mechanism	Test plan
1	**Errors during implementation**	
1a	Failure in obtaining authorization to install the monitoring units at the optimal (planned) locations	**Monterosso al Mare test site**: the municipality technical staff have already agreed to help us finding suitable locations to deploy the monitoring units, where there should not be authorization problems **Rotterdam test site**: we are discussing with local authorities to find suitable deployment locations
1b	Failure to obtain weather station data (pressure, temperature) from local agencies	**Monterosso al Mare test site**: we are going to contact ARPA Liguria (regional environmental protection agency) to verify the availability of existing weather station data; Monterosso al Mare municipality technical staff are going to install a new weather station on top of the municipality building

		Rotterdam test site: we have already verified that there are about 15 weather stations within Rotterdam urban area that can provide the needed pressure and temperature data
2	**Technical failure of the measure**	
2a	The error of real-time satellite orbits and clocks does not allow to achieve the expected accuracy in the water vapor estimates	A given dataset will be post-processed with final orbits and clocks products (typically available with 2-3 weeks latency) and with those obtained in real-time. The water vapor estimates in the two cases will be compared to verify that the real-time water vapor error is within an acceptable range
2b	The error caused by the interpolation of the ionospheric delay does not allow to achieve the expected accuracy in the water vapor estimates	One of the single-frequency monitoring units will be co-located with an existing dual-frequency station; the estimated water vapor from the single-frequency unit (with ionospheric delay interpolation) and that from the dual-frequency station will be compared to verify that the error is within an acceptable range
2c	Weather station data are not reliable	Existing weather station datasets will be analyzed to verify the data quality and their continuous availability
2d	Real-time data gaps due to 3G network failures	This issue may be related mostly to the **Monterosso al Mare** deployment, where some units might necessarily be installed far from urban areas to ensure a good geometry of the monitoring network; we will try to verify the 3G network coverage in the interested areas in advance (although it might be difficult to verify its stability over long timespans). In **Rotterdam** city area 3G connectivity is not expected to be an issue.
3	**Technological failure**	
3a	Failure to improve the	After having identified suitable candidates for

	nowcasting/forecasting of heavy rain	the heavy rain event, the results of probabilistic nowcasting and/or numerical weather prediction forecasting of that event with and without GNSS-derived water vapor will be analyzed and compared.

Are there any results of previous tests?:

No.	Mechanism	Test plan
1	**Errors during implementation**	
1a	Failure in obtaining authorization to install the monitoring units at the optimal (planned) locations	GReD has already faced this problem during GeoGuard stations deployment for landslides monitoring. The deployment for PWV monitoring could introduce some additional complication due to the urban environment.
1b	Failure to obtain weather station data (pressure, temperature) from local agencies	GReD managed to obtain pressure, temperature and precipitation data from the local agencies in Lombardia Region (ARPA Lombardia) and Piemonte Region (ARPA Piemonte) in Italy. For the specific deployment of BRIGAID, Monterosso al Mare Municipality staff already confirmed that they will share their weather station data. As for Rotterdam, we included temperature and pressure sensors in one of the units that will be deployed there.
2	**Technical failure of the measure**	
2a	The error of real-time satellite orbits and clocks does not allow to achieve the expected accuracy in the water vapor estimates	Previous experiences carried out by Kyoto University gave good results.
2b	The error caused by the interpolation of the ionospheric delay does not allow to achieve the expected accuracy in the water vapor estimates	Previous experiences carried out by GReD in collaboration with Kyoto University gave good results.
2c	Weather station data are not reliable	Previous experiences were made with ARPA Lombardia and ARPA Piemonte weather stations. GReD developed software that detects and excludes outliers, fills in short data

		gaps and, if needed, smoothes the time series.
2d	Real-time data gaps due to 3G network failures	When GReD faced this issue in landslide monitoring, developed a system within the GMUs that stores the data locally until the 3G connection comes back, then sends all the unsent datasets.
3	**Technological failure**	
3a	Failure to improve the nowcasting/forecasting of heavy rain	GReD is already running a GMU on the rooftop of its headquarters building, and we are currently studying the precipitable water vapor monitored by it before and during two heavy rain events that happened in July 2016. Results will be shared within BRIGAID as soon as they are finalized

Technical Effectiveness (or Performance)

Analyse the Technical Effectiveness of the innovation either in terms of its capacity to reduce the probability of exposure or vulnerability to the hazard:

The improvement of heavy rain nowcasting/forecasting would both increase the lead-time for disaster response by civil/hydrogeological protection agencies and reduce the exposure of the population to floods related to torrential rain events.

Propose a plan to test the risk reduction potential of the innovation. (Note: such a test requires knowing the boundary conditions in the operational environment or the proposed location (or market) for implementation/sale of the innovation):

Typically, water vapor convergence associated to convective storm clouds occurs about 30 minutes to 1 hour before the formation of rain drops. After identifying suitable candidates for the heavy rain event, the results of probabilistic nowcasting and/or numerical weather prediction forecasting of that event with and without GNSS-derived water vapor will be analyzed and compared to evaluate the technical effectiveness of the innovation.

Are there any results of previous tests?:

Previous extensive testing carried out by GReD staff and Kyoto University staff demonstrated the effectiveness of the solution with single-frequency observations carried out by geodetic-class receivers. As regards specific tests with the low-cost GMU stations, GReD has been running a GMU on the rooftop of its headquarters building since more than 1 year ago, and we are currently studying the precipitable water vapor monitored by it before and during two heavy rain events that happened in July 2016. Results will be shared within BRIGAID as soon as they are finalized.

Social readiness

It is important to define who is the end-user of our innovation: GNSS stations used for atmospheric water vapor monitoring can be seen as new sensors, deployed in and around urban areas, that are used by “intermediate end-users”, expert in weather forecasts, to improve the predictions of heavy rain. These improved predictions will then reach the “final end-users”, i.e. the general public.

The use of GNSS technology to monitor precipitable water vapor is seen by intermediate end-users (e.g. meteorologists, civil protection agencies) like an augmentation of the existing weather station network, which is perceived by both the intermediate and final end-users as useful instrumentation to improve weather forecast models.

Currently we are witnessing an increase in the number of heavy rainfall events throughout Europe, often insisting over vulnerable areas, which have been seriously damaged in several occasions (e.g. heavy rain-induced floods in Liguria Region, Italy, basically happening every year). This fact has raised awareness on the need for more reliable weather forecast, so our innovation adaptation is expected to be positively received by the population.

To address the Social Readiness, six indicators were scored in relation to precipitable water vapor monitoring by GNSS.

Demographic conditions

It ranges from one (inappropriate) to five (appropriate). Being seen only as an augmentation of the already existing and positively perceived weather stations, all the scores are appropriate.

Demographic conditions indicators:

Factor	Score
Age	5
Gender	5
Education	5
Social grade	5
Location	5

Basic user requirements

This indicator involves the extent to which an adaptation satisfies basic user requirements for usefulness and ease-of-use. It ranges from 1 (low) to 5 (high). Here the target are the intermediate end-users, since meteorology experts are the only ones who will make direct use of precipitable water vapor measurements.

Basic user requirements indicators:

Factor	Score	Comments (for the intermediate end-users)
Usefulness	4	Some meteorologists may have doubts about the usefulness of GNSS-derived precipitable water vapor assimilation; this is due to the fact that this kind of technique is relatively new and some countries do not yet make use of it. For example, GNSS-derived water vapor is routinely assimilated by the Japan Meteorological Agency, the Swiss Meteo Service and the Danish Meteorological Institute, but this is not happening yet in Italy.
Ease of use	3	Not all meteorologists are used to assimilate precipitable water vapor information coming from GNSS ground stations, so some effort on their part will be required (e.g. adding the integrated amount of water vapour as assimilated data into numerical weather prediction models)

Psychological concerns

The scores for the "Dread" and "Unknown/known" for the installations of GNSS antennas in the territory (i.e. as perceived by both intermediate users and the general public).

Psychological concerns:

Factor	Score	Comments
Dread	1	
Unknown	2	People who are familiar with weather stations might not recognize GNSS antennas

Sociocultural preferences

This indicator involves the extent to which an adaptation appeals to the adherents of 'hierarchical', 'individualist' and 'egalitarian' forms of sociocultural organisation. It ranges from 1 (low) to 5 (high)

Sociocultural preferences:

Factor	Score	Comments
hierarchical	5	The innovation will attend to long term climate risk, it will employ high technology potentially on a large scale, it will be deployed under hypothetical public consent.
individualist	5	
egalitarian	5	

Technical expectations

These indicators range from 1 (low) to five (high).

Technical expectations:

Factor	Score	Comment
Efficacy	4	Better knowledge of the spatial and temporal distribution of precipitable water vapor is important to improve heavy rain forecasts. The efficacy of each monitoring unit is somewhat reduced because of the “low-cost” approach compared to traditional GNSS stations, but it is required to make it economically viable to monitor water vapor over wide areas with sufficiently high spatial resolution.
Environmental effects	5	No negative environmental effects are foreseen.
Cost benefit ratio	5	The innovation is designed with a “low-cost” approach in mind, of course “low” compared to traditional techniques for water vapor monitoring. The cost benefit ratio is thus expected to be high, especially considering the benefits of providing more reliable early warnings, in terms of potentially saving human lives
Side effects	1	GNSS antennas are passive receivers, they do not transmit signal. Each unit is equipped with a mobile communication device for data transfer, but this is nothing different from a common smartphone in terms of signal transmission

Wider societal questions

This indicator involves the extent to which an adaptation can satisfy diverse questions of political, public, ethical and co-beneficial social performance. It ranges from 1 (low) to 5 (high).

Wider societal questions:

Factor	Score	Comment
Political	5	GReD already got positive feedback from local administrators of regions/cities subject to heavy rain-related disasters, as they see the deployment of new instruments that may provide more reliable warnings to the population as something beneficial not only from the practical point of view, but also from the political point of view.
Public	4	It might be difficult to properly convey the benefits that this kind of innovation bring to the general public, but basically we are meeting a widespread need of more advanced monitoring capability towards weather events that may result in severe hazard.
Ethical	5	
Co-benefits	5	

Test plan

Laboratory testing

NA

Operational testing

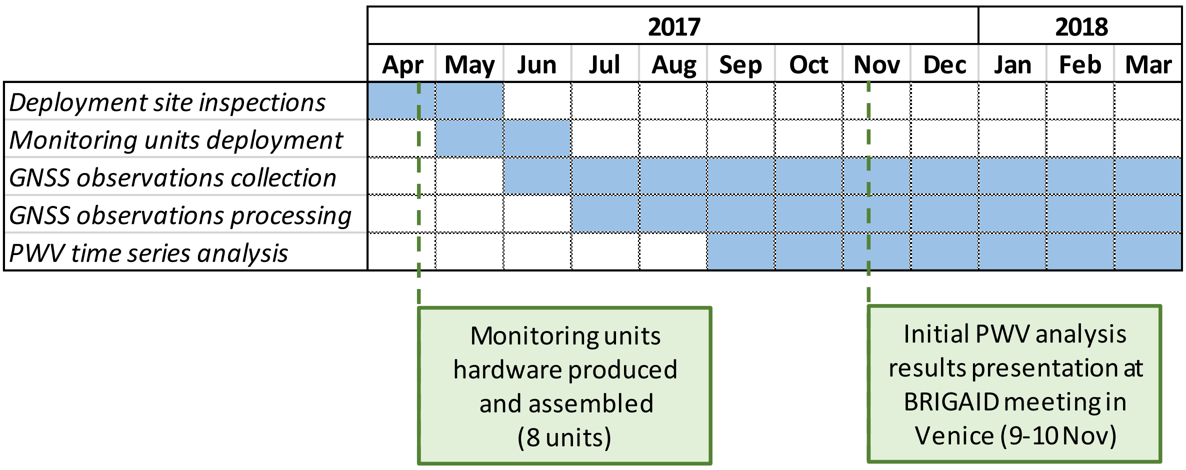
Testing of the Technical KPIs

Design Criteria (i.e., Required Technical Effectiveness)	
Required level of risk reduction	Increase lead time by 1 hour
Required Safety Factor or Reliability	NA
(External) Operating Conditions	NA
Reliability	
Failure in obtaining authorization to install the monitoring units at the optimal (planned) locations	Description of Testing: Monterosso al Mare test site: the municipality technical staff have agreed to help us finding suitable locations to deploy the GM4W monitoring units, where there should not be authorization problems. Rotterdam test site: we are discussing with local authorities to find suitable deployment locations.
	Expected Results: All the needed authorizations will be acquired to deploy the monitoring stations.
Failure to obtain weather station data (pressure, temperature) from local agencies	Description of Testing: Monterosso al Mare test site: we are going to contact ARPA Liguria (regional environmental protection agency) to verify the availability of existing weather station data; Monterosso al Mare municipality technical staff are going to install a new weather station on top of the municipality building. Rotterdam test site: we have already verified that there are about 15 weather stations within Rotterdam urban area that can provide the needed pressure and temperature data.
	Expected Results: At least one weather station for each test site will be found.
Weather station data are not reliable	Description of Testing: Existing weather station datasets will be analyzed to verify the data quality and their continuous availability.
	Expected Results: Measured temperature and pressure time series are expected to have data availability higher than 90% over 1 day.
Real-time data gaps due to 3G network failures	Description of Testing: This issue may be related mostly to the Monterosso al Mare deployment, where some units might necessarily be installed far from urban areas to ensure a good geometry of the monitoring network; we

	will try to verify the 3G network coverage in the interested areas in advance (although it might be difficult to verify its stability over long timespans). In Rotterdam city area 3G connectivity is not expected to be an issue.
	Expected Results: In Monterosso al Mare, 3G connectivity might have instabilities, that are accounted for by storing data locally until connectivity is restored. In Rotterdam, 3G connectivity is expected to be stable.
The error of real-time satellite orbits and clocks does not allow to achieve the expected accuracy in the water vapor estimates	Description of Testing: A given dataset will be post-processed with final orbits and clocks products (typically available with 2-3 weeks latency) and with those obtained in real-time. The water vapor estimates in the two cases will be compared to verify that the real-time water vapor error is within an acceptable range.
	Expected Results: Water vapor obtained by means of real-time orbits and clocks is expected to have higher systematic/random errors compared to when using final orbits and clocks, but still within the acceptable range to identify water vapor spatio-temporal variations associated with the development of convective storms.
The error caused by the lower quality of the receiver hardware, and from the interpolation of the ionospheric delay does not allow to achieve the expected accuracy in the water vapor estimates	Description of Testing: One of the single-frequency monitoring units will be co-located with an existing dual-frequency station; the estimated water vapor from the single-frequency unit (with ionospheric delay interpolation) and that from the dual-frequency station will be compared to verify that the error is within an acceptable range.
	Expected Results: Water vapor obtained from the single-frequency receiver is expected to have higher systematic/random errors compared to that obtained from the dual-frequency receiver, but still within the acceptable range to identify water vapor spatio-temporal variations associated with the development of convective storms.
Reusability	
Percent of the innovation needed to be repaired after each operation	Description of Testing: The innovation is continuously operated.
	Expected Results: The innovation is continuously operated.

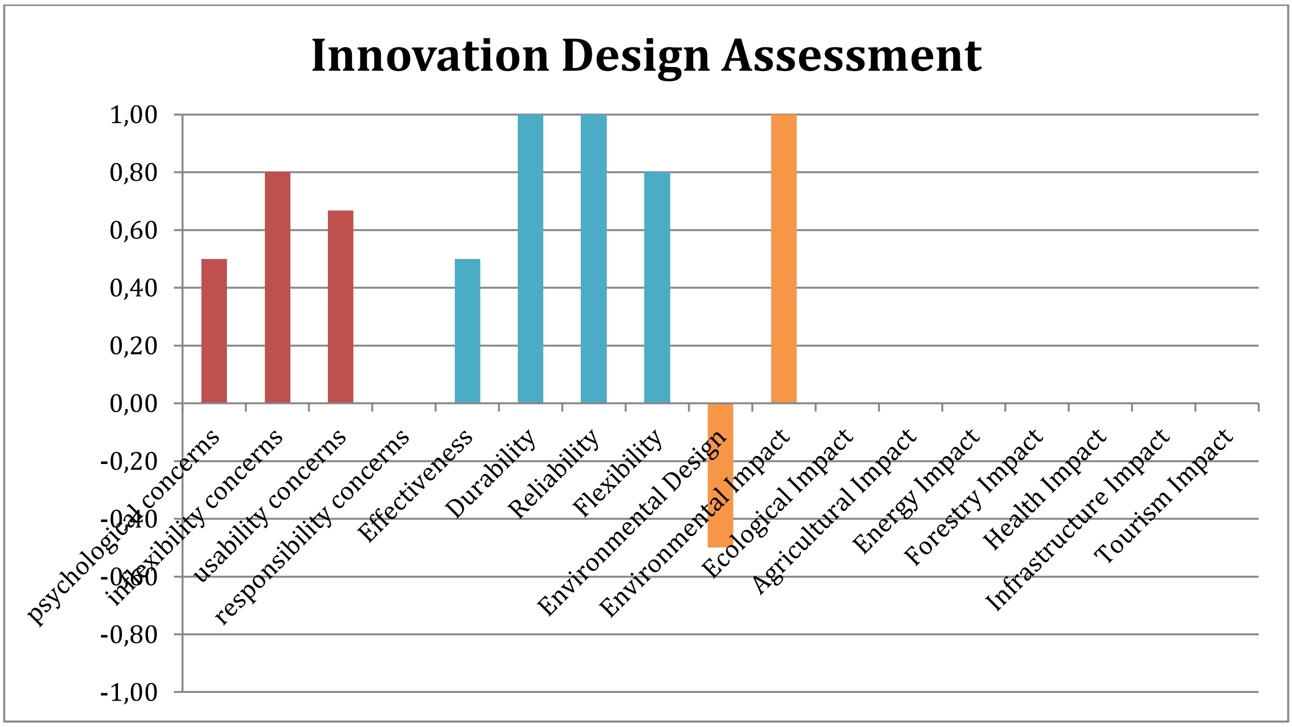
Lifetime of structural and/or material components	Description of Testing: The only component of the monitoring stations that poses a limiting factor to the hardware lifetime is the battery. A mean time between failures (MTBF) of 3 years is considered for it, and therefore for the monitoring station as a whole.
	Expected Results:
Technical effectiveness	
Failure to improve the nowcasting/ forecasting of heavy rain	Description of Testing: After having identified suitable candidates for the heavy rain event, the results of probabilistic nowcasting and/or numerical weather prediction forecasting of that event with and without GNSS-derived water vapor will be analyzed and compared.
	Expected Results: The nowcasting/forecasting with GNSS-derived water vapor is expected to predict convective heavy rain events better than without it.

The operational test plan activities will be carried out from April 2017 to March 2018, according to the following GANTT:



Testing results

Test plan activities were carried out in agreement with the guidelines and tools provided by the BRIGAID TIF, MAF+ and PPIF frameworks. The application of the TIF framework provided the results represented in the figure below, showing a good performance of the GReD innovation both on the societal and technical sectors; the only negative parameter is the environmental design of the innovation, due to the fact that the innovation does not include specific design features or components which preserve or enhance ecosystem services, and that it is not made of recycled or recycable materials.



The test plan activities included identifying suitable locations to deploy the GRED innovations, i.e. the GNSS stations for water vapor monitoring, in the Rotterdam area and in the Monterosso al Mare area. Potential locations were first identified on Google Earth satellite images, also according to a network geometry useful for water vapor monitoring. Then the potential sites were scouted in person by GRED staff (Monterosso site) and TUD staff (Rotterdam site). A short list of four locations in Rotterdam and four locations in Monterosso al Mare was defined. In parallel, the GNSS stations hardware was ordered, and the stations supports (steel poles, clamps, …) were designed to fit each different site, and produced. Formal approvals by local authorities to deploy the GNSS stations were asked for both Rotterdam and Monterosso al Mare sites. It took a long time, but the formal approvals were obtained for both Monterosso al Mare and Rotterdam.

Details on initial testing period

Operational Test Summary	
Description of Test (and Goals)	A first site inspection at Monterosso al Mare was conducted on April 10th 2017, with the goal of verifying the technical and administrative feasibility of the deployment of the stations. GRED staff conducted the site inspection, together with the Monterosso al Mare municipality technical staff and Proteco staff.
Test Results	

The four potential deployment sites (BR01, BR02, BR03, BR04 in the figure below), initially chosen by means of Google Earth imagery, were inspected. The exact locations where the steel pole that supports the GNSS antenna, the monitoring unit box and the photovoltaic panel will be attached were identified successfully.

The four sites were chosen according the following criteria:

- inter-station distance > 3 km
- Monterosso al Mare urban area within the 4-sided area defined by the stations
- easily reached by car (for both deployment and maintenance)
- possibility to attach the monitoring units to existing walls/rocks (i.e. no need to build concrete foundations, etc).

Inter-station distances are reported in the table below:

	BR01	BR02	BR03	BR04
BR01		5.3 km	5.5 km	9.7 km
BR02			3.3 km	5.4 km
BR03				4.4 km
BR04				

BR01:

This site falls within the Municipality of Levanto (NW of Monterosso al Mare). The monitoring unit could be attached to one of these rocks:

… or a small concrete foundation could be built in this location:

An alternative could also be be to exploit this pre-existing iron pole, but we need to investigate whether it falls within public or private ground:

BR02:
This site falls within the Municipality of Monterosso al Mare. An abandonded building (former Italian Navy Observatory) could be used to deploy the monitoring unit (e.g. attached to the side of the roof):

BR03:
This site falls within the Municipality of Monterosso al Mare, near the Soviore Sanctuary. The monitoring unit could be attached to one of the walls of an unfinished building lying just in front of the Sanctuary. The building was started several years ago but it was never completed; now it is a state of abandonment:

<table>
<tr><td></td><td>
BR04:
This site falls within the Municipality of Vernazza (SE of Monterosso al Mare). The monitoring unit could be attached to an existing concrete shelf (rock protection for the road below), or deployed through a small concrete foundation:
</td></tr>
<tr><td>Additional Tests Required/Proposed Future Tests</td><td>Monterosso al Mare municipality technical staff is going through the administrative/bureaucratic steps needed to get formal permissions to deploy the units within Cinque Terre National Park (within which Monterosso al Mare is located).</td></tr>
</table>

Operational Test Summary	
Description of Test (and Goals)	Check the availability of weather station data for the Monterosso al Mare site.
Test Results	Monterosso al Mare municipality technical staff installed a new weather station on top of the municipality building, and they will share its pressure, temperature data for BRIGAID tests.
Additional Tests Required/Proposed Future Tests	Verify that the weather station is providing data according to the required rate (30 seconds).

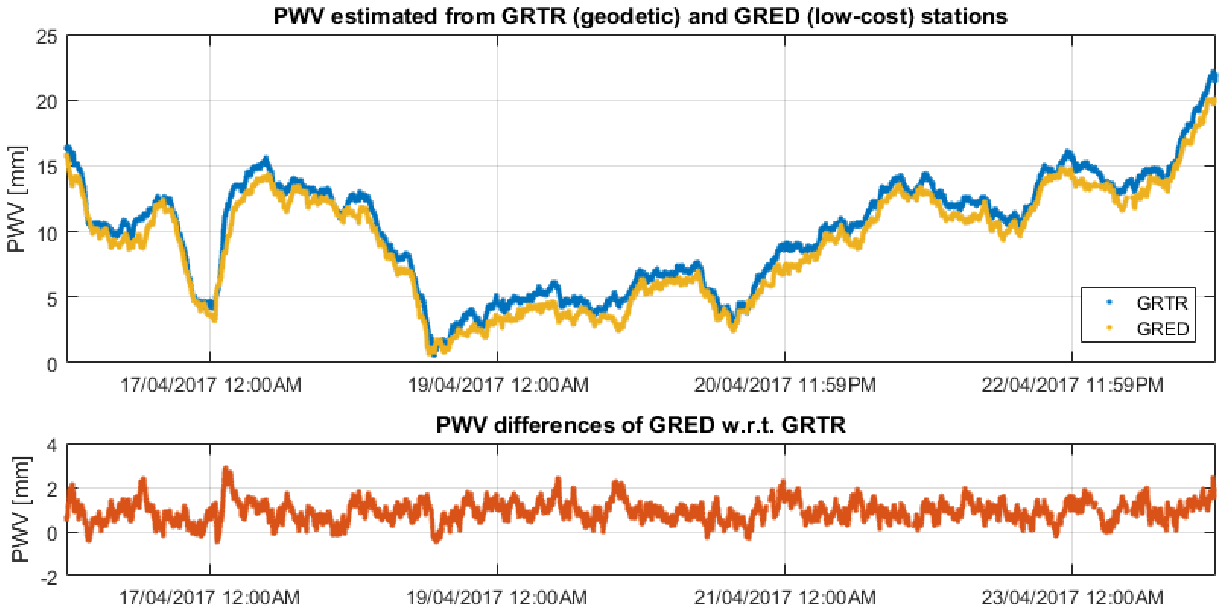
Operational Test Summary	
Description of Test (and Goals)	A single-frequency monitoring units was co-located with an existing dual-frequency station on the rooftop of GReD office building. The goal is to verify the performance of the low-cost instrumentation for water vapor retrieval, compared to a state-of-the-art geodetic instrument.
Test Results	

	A GNSS signal splitter was also temporarily used to connect both dual-frequency and single-frequency receivers to the same antenna: 
Additional Tests Required/Proposed Future Tests	The estimated water vapor from the single-frequency unit (with ionospheric delay interpolation) and that from the dual-frequency station will be compared to verify that the error is within an acceptable range.

Details on next testing period

Data from pre-existing stations, both high-cost (geodetic) and low-cost (mass-market) ones, are being used to verify the correct functioning of the GReD GNSS data processing software that is going to be used to retrieve water vapor from the BRIGAID stations. The software, called goGPS (http://www.gogps-project.org/) is an open source software platform, founded and developed by GReD staff since 2007. For BRIGAID, its algorithms and code were modified in order to retrieve the amount of precipitable water vapor from low-cost GNSS receivers and antennas. Since low-cost receivers track GNSS signals on only one frequency (L1), it is needed to remove the ionospheric delay from their observations by other means than the combination of two frequencies (which is the standard procedure when high-cost, geodetic receivers are used). Moreover, the internal oscillator of low-cost receivers is much less stable than their geodetic counterparts, and this needs to be taken as well into account in the data processing. In order to enable the testing of the innovation within BRIGAID, goGPS code was modified to retrieve the ionospheric delay from nearby pre-existing GNSS stations (typically four), interpolate it in correspondence of the low-cost station, and remove the interpolated value from the low-cost station observations. Since data from several stations are being processed together, it is specially important to synchronize them correctly. Therefore, the errors introduced by the low-cost oscillator of the BRIGAID innovation had to be accounted for in the goGPS processing engine as well.

Once all these software upgrade steps have been completed, their proper functioning was tested on data collected by pre-existing GNSS stations. Preliminary results obtained from these data are shown below:



The precipitable water vapor (PWV) retrieved from a pre-existing low-cost GNSS station (GRED) was compared to that of a co-located geodetic dual-frequency GNSS station (GRTR). The figure shows that PWV variations over time are well captured by the low-cost GRED station, despite the lower quality of the receiver and antenna hardware, and the needed interpolation and removal of the ionospheric delay. The above figure shows only 1 week for the sake of clarity, but statistics of the difference between the two PWV time series were computed over a period of 20 days: the GRED results show a bias of 0.5 mm and a standard deviation of 0.4 mm, which is an acceptable error for the application of the innovation to support heavy rain forecasts.

As regards the hardware-related activities, the eight low-cost GNSS stations were sent to the planned deployment locations, i.e. four to TU Delft, for the Rotterdam deployment, and four to Monterosso al Mare Municipality for the deployment in the surroundings of the municipality itself.

The hardware components needed to assemble the GM4W monitoring units were ordered in February 2017, and arrived in April 2017. Assembly of the 8 units that are going to be deployed to carry out BRIGAID operational test plan activities is underway and almost completed. The following picture shows 7 of the 8 units assembled and ready for testing:

At the moment of writing this report, three stations were deployed in Rotterdam, and three in Monterosso al Mare.

The planned deployment sites for Rotterdam:

The first BRIGAID station (BG02) was deployed on 1 September 2017, on the rooftop of a TU Delft building:

This first station location was chosen due to the presence of a GNSS permanent station (geodetic, dual frequency receiver), that allows for a direct validation of the water vapor retrieved by the BRIGAID station. Preliminary validation results carried out by TU Delft show that the amount of precipitable water vapor retrieved by this first BRIGAID station was consistent with that retrieved from the nearby geodetic station (r.m.s. of about 1 mm), in agreement with the results based on pre-existing stations data shown before.

The BG04 station was deployed at Spaanse Polder on a flat rooftop, co-located with a pre-existing weather station:

The BG01 station was deployed at Delfshaven, also in this case on a flat rooftop, co-located with a pre-existing weather station:

The deployment of the BG03 station is awaiting permission to access the premises, which is expected to be obtained in January 2018. The relocation of the first station from TU Delft to Rotterdam city center is currently being evaluated.

As regards Monterosso al Mare, the planned deployment sites are shown in the figure below:

The BR03 station was deployed near the Soviore Sanctuary, located 1.5 km north-northeast of the Monterosso al Mare village:


The BR04 station was deployed near the San Bernardino village, southeast of Monterosso al Mare:


The BR02 station was attached to an abandoned building of the Italian Navy at Punta Mesco, southwest of Monterosso al Mare:

The deployment of the BR01 is planned for January 2018.

9. Innovation: AEWMS - Active Eco-Wildfire Management System & Strategic Fuel Management

Innovator: Gestão Integrada e Fomento Florestal, Lda (GIFF) (BRIGAID consortium partner)

Contributing authors: Carlos Loureiro (GIFF), António Salgueiro (GIFF), Marco Ribeiro (GIFF)

Innovation Description

The description of AEWMS below is also available from the Climate Innovation Window, http://climateinnovationwindow.eu/innovations/active-eco-wildfire-management-system

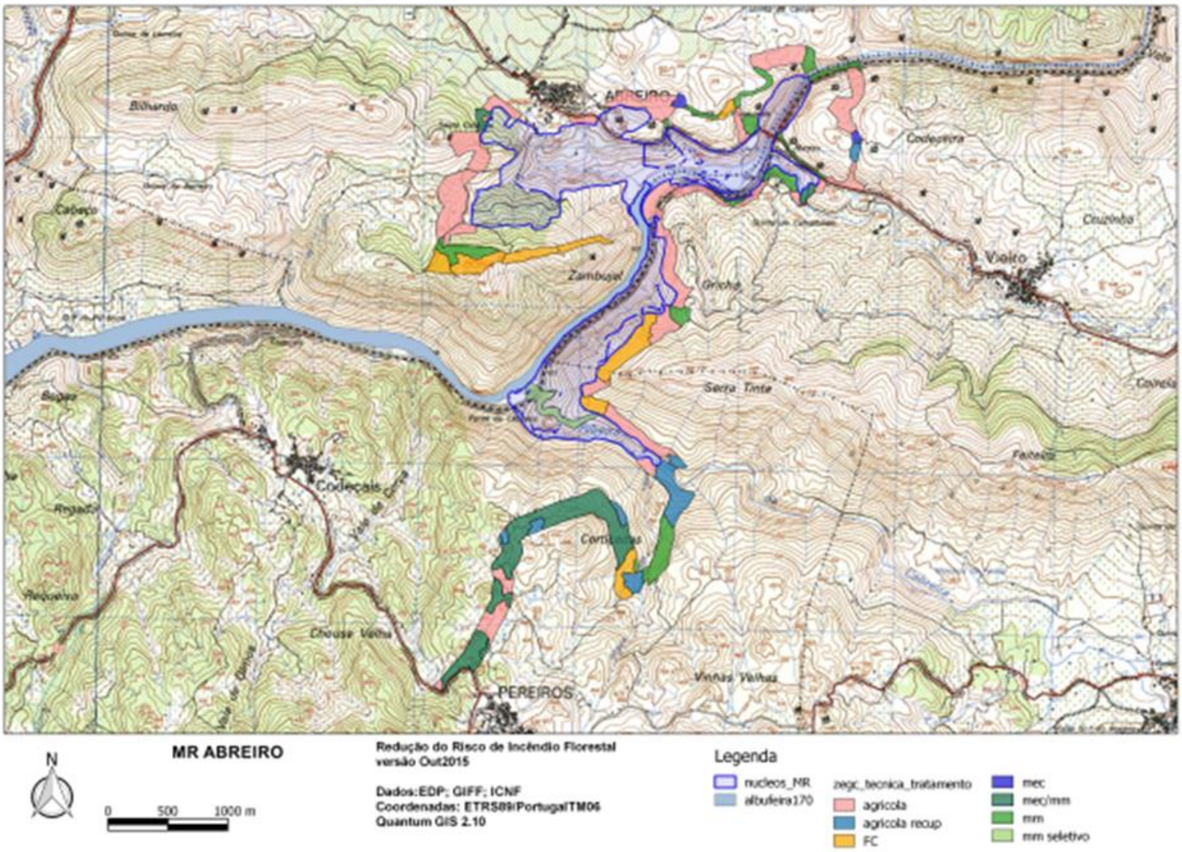
Name
Active Eco-Wildfire Management System (AEWMS)
Short description
This innovation is a methodology for forest fuel management planning, for protection against fire, with an approach based on analysis of historical and current risk, in association with type of vegetation, and associated fuel models, present in the area, and seeks to select the best intervention sites for fuel management. This new perspective search to increase the success of suppression actions (firefighting), in forest fires may occur in the area to be protected. The selection of treatment areas also takes into consideration the traditional land use and ecological characteristics of vegetation, as well as their adaptation to fire, proposing the best techniques for the management of forest fuels, including prescribed burning.
Sketch/Photograph of the Innovation
Example of an intense wildfire:  Low intensity fire – example of a prescribed fire in pine forest:

Prescribed burning area used to stop wildfire (coming from left side) to protect fores area (right side):

Example of use of agricultural areas to stop continuity in fire propagation:

Workflow for implementation and testing of the innovation:

Example of map of the fuel treatment areas proposal for one of the test areas:



Which hazard(s) is the innovation designed to mitigate?

This innovation address wildfires, that can occur in forest or shrub lands, and that can be production or conservation areas. The main objective is reduce the propagation of fire in the landscape and fire hazard.

How does the innovation work?

Protecting forest ecosystems against wildfires and promoting climate-resilient forest management measures in Europe is key to increasing the capacity of these areas to adapt to climate change and for a green growth transition economy. The aim of this methodology is to propose an Active Eco-Wildfire Management System (AEWMS) as an innovative method to the planning and execution processes Strategic Forest Fuel Management of and Prescribed Burning techniques in forests and conservation areas to reduce risk of wildfire in a sustainable way. AEWMS promotes growth simultaneously improving environmental, economic and social impacts management, while reducing pollution and greenhouse gas emissions, minimizing waste and the inefficient use of natural resources, protecting and maintaining biodiversity. AEWMS strengths the techniques existents in the market, reflecting strong enhancements in the rate of execution (per ha/day), at low cost and reducing carbon emissions.

Forest fuels management to reduce the risk of fire is usually applied locatlly and scaled without taking into account their effectiveness in solving the problem. The solutions brought by AEWMS have a productive character and its uniqueness is based on principles of efficiency, promoting the use of resources and green economy. Some already well tested in practical environment, other than being tested at applied research and in real field conditions, now need to be applied in operational environment. AEWMS comprises Strategic Fuel Management methodology developed within GIFF, which has already been planned to some areas in Portugal. To assess the operational implementation of this innovations there are two steps that must be adressed.

Actually, most of the plans made don´t have been completely executed in the field, so there are not enough information about the operational effect of the proposals. In some cases the forest area was affected by wildfires before the execution of the proposals, and therefor some evaluation of the validity of the proposals can be done.

The methodology for assessing the potential of fire propagation in the areas to be protected follows the next steps.

Objectives	Methods	Results
Analysis of historical fires	Cartography analysis, field work, exchange and gathering of information with local age nts (managers, firefighting and civil protection services)	Definition of typology of fires and associated conditions.
Definition of simulation scenarios	Fuel model; Identification of the meteorological conditions for simulation; Simulation of fire behavior.	Initial diagnosis of fire hazard with simulation results.
Location of critical points and fire suppression opportunities	Simulations and terrain cartography analysis; Fire Alignment Analysis	Identification of priority fuel management zones
Definition of the Strategic Fuel Management Areas	Cartographic analysis and field work	First proposal
Validation and final proposal	First field validation of treatment proposals; Office work: Simulation with new scenario of fuel treatments for validation and final design of ZEGC.	Proposals and recommendations

Added value / main differentiating element from conventional approach(es)

The proposed approach to planning prevention measures at the landscape level includes the recovery of traditional land uses with agroforestry practices and the management of vegetation ecologically adapted to fire, leading to a replacement with less intense fire regimes and low environmental impact. Fuel management techniques will includes the use of precribed fire. The location of strategic fuel management areas will consider the best use for fire supression actions.

Critical success factors / Limitations

There are some critical factors for good planning and for the success of plan implementation.

Planning

- Fundamental a good characterization of land use and vegetation in the area, and its conversion into fuel models - implies quality results of fire behavior simulation and of fire danger mapping.

- Existence of records and cartography of the fire history for the intervention area

- Survey of fire prevention existing structures and conservation status.

- Good knowledge of weather patterns associated with fire risk.

Implementation

- Ensure proper execution of fuel management treatments - placement and techniques,

- Ensure that strategic supression zones have good accessibility conditions

- Ensure that local firefighting services are aware of the treatments areas and how they can take advantage of these strategic areas of forest fuel treatment.

- Carry out, annually prior to the fire season, a fuels assessment and provide necessary maintenance work.

Limitations

Planning is done on the basis of the available knowledge for the management area. The effectiveness of strategic areas for fuel management in protecting forest or conservation areas is limited by fire behavior - fire line intensity and rate of spread. Extreme weather conditions (associated with long periods of drought in conjunction with high winds), can originate extreme fire behavior, that can affect combat capacity and jeopardize the effectiveness of the plan.

Desk Study

Summary

This innovation addresses wildfires. Is main caractheristiques are:

- Is inspired in ecosystem fire resilience features;
- Encourage human behavior change in face of land use and fire fighting strategies;
- Is a methodology to identify and evaluate risk and propose adapted management strategies.

Concerning **technical effectiveness** in reduction of wildfire risk, the innovation will reduce the probability of an area be affected by fire, by reduzing fuel load and fuel continuity, wich leads to a reduction of the size and severity of fire.

The effect of this new methodology as been tested using fire simulators, and at present is at TRL level of 6/7.

According to the definition by the BRIGAID Technical Testing Protocol:

- A *technological or an informational* innovation reduce risk by decreasing the consequences of the hazard by enabling, or encouraging, the end-user (or stakeholders) to take action to reduce exposure or vulnerability to a hazard.

- *Technological innovations* deliver hazard or risk information to an end-user such that the end-user is prompted (or required) to take specific actions to reduce exposure or vulnerability to the hazard. The (technical) effectiveness of the innovation is dependent on the completion/performance of these actions.

Our innovation is a new methodology for planning fuel management, according to wildfire hazard assessment. To test the proposed approach, the plan developed for an operational area must be implemented, and field work must be implemented before fire season (june to october). We consider that AEWMS is a technological innovations that needs to be built in (executed) for evaluation of the reliability and reusability.

After implementation in the area, the effect of fuel treatment will decrease over time, and fuels treatments will need to repeated for maintain the hazard redution. The duration of fuel treatment effectiveness depends on several factors, such as vegetation type, site fertility, type of treatment, soil use, climate, etc., requiring complementary research

To plan strategic fuel management, we need input information about the wildfire history for the area, digital elevation model, land use maps and fuel models maps. Also the current location of fire prevention infrastructures.

This information will be used to run fire simulators, calculate wilfire danger maps and planning the fuel management proposals.

Factors that may influence the reliability of the innovation:

IMPLEMENTATION FAILURE (related to human error)

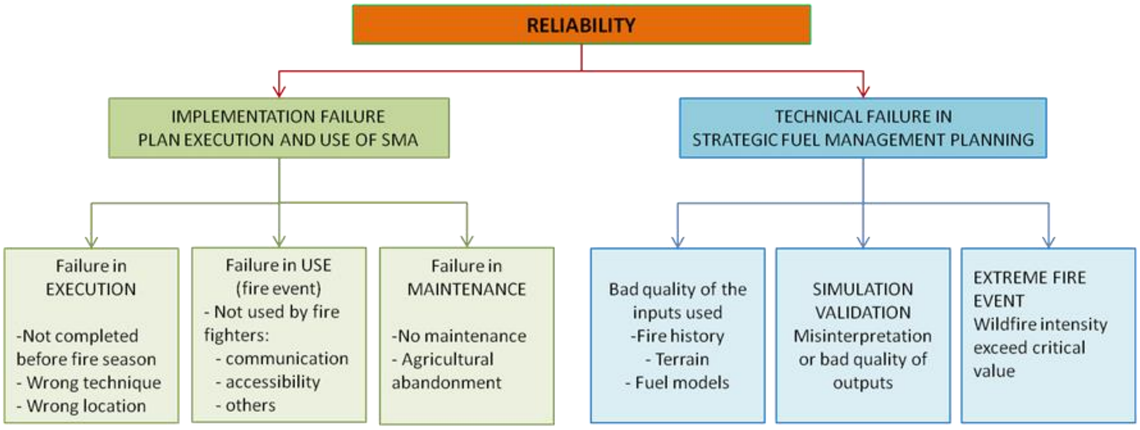
- Strategic Management Areas (SMA) weren't used by supression
- Failure in fuel treatment – wrong technique or wrong location
- Failure in maintenance of SMA – fuel treatment repetion before fuel load exceed critical value

TECHNICAL FAILURE

Failure in planing process:

- Error in land use mapping and fuel model classification – implie failure in the predicted Fire Intensity and associated Supression Capacity
- Error in fire simulation to test proposed plan – quality of the inputs used or misinterpretation
- Failure in predicte best location of the SMA
- Wildfire intensity exceed critical value

Failure fault tree:



Two different kind of failure modes can be identified: technical failure and implementation failure. The technical failure is more related to the planning phase and with the quality of inputs and outputs data.

During the implementation of the plan in the selected test areas, failure in the execution and use of the Strategic Management Areas will be evaluated.

Technical Readiness Level (TRL)

Level 7 – Some plans have been made at operational level.

Currently this planning methodology was proposed for some areas in Portugal, in production forests and conservation areas protection. Some of the planned management proposals were partially implemented, but there isn't enough information about the performance in operational environments.

Monitoring and a consistent evaluation of the post-planning and implementation phase weren't done. Next works require the compilation and evaluation of data related to operational effects on the spread of fire and suppression actions in real fire conditions.

Reusability

Describe the intended reusability of the innovation based on the definitions given above:

The strategic fuel management planning that is made considering the current landscape scenario, that's encompass land use and fuel model (with fuel load evaluation) and resulting wildfire hazard. Usually, the plan is made for a three to five years period, and following that period must be updated according to land use changes, fire history and forest fuels build-up.

Propose a test plan to assess the expected reusability of the (components of the) innovation.

To test the reusability of the innovation, it is necessary that, after the implementation of the plan, an evaluation of effect in the fire regime (monitoring and assessment), and final adjustment of proposed plan.

The evaluation will be carried out taking into account the following aspects:

- Implementation - evaluation of the quality of the implementation work
- Monitoring vegetation regrowth / fuel load recovery according to the management technique used
- Occurrence of fires that reached the areas of strategic management
- Effects on fire behavior (sucess / failure) - limit / verified conditions
- Use by firefighting / limit of combat capability
- Identification of land use changes in the areas of strategic fuel management plots.

Example before and after treatment in one of the management plot

For semi-permanent and temporary innovations, identify the expected percent of the innovation that is reusable after each use and which components (if any) would need to be replaced:

Considering the initial planning work needed for the implemention of a strategic fuel management for a first period, the planning updating only require around 25% of the initial planning work.

Estimate the expected product lifetime based on decomposition of the materials used:

NA

Are there any results of previous tests? (e.g., if lifetimes of the structural components are already known or tested):

NA

Reliability

Identify all possible failure modes that would lead to implementation and technical failure in the form of a fault tree:

IMPLEMENTATION FAILURE (*related to human error*)

- Strategic Management Areas (SMA) weren't used by supression
- Failure in fuel treatment – wrong technique or wrong location
- Failure in maintenance of SMA – fuel treatment repetion before fuel load exceed critical value

TECHNICAL FAILURE

Failure in planing process:

- Error in land use mapping and fuel model classification – implie failure in the predicted Fire Intensity and associated Supression Capacity
- Error in fire simulation to test proposed plan – quality of the inputs used or misinterpretation
- Failure in predicte best location of the SMA
- Wilfire intensity exceed critical value

No.	Mechanism
1	Errors during implementation
1a	Failure in finishing treatments before wildfire season

1b	Failure in location of SMA
2	Technical failure of the measure
2a	Size of treatment areas not enough to stopo wildfire
2b	Access to SMA by firefightint was not possible
3	Technological failure
3a	Simulation errors – simulation models aren't acurat with real fire situation
3b	Fire intensity above critical supression capacity.

Test plan to evaluate failure modes. Also, describe whether these tests will take place in a controlled or operational testing environment (dependent on the TRL):

Tests will be developed in an operational environment, with the implementation of a Strategic Fuel Management Plan made for the protection of conservation Areas in the Tua River Basin (Northern Portugal). The test will be dependent on the occurrence of forest fires in the treated areas.

It also will be made a evaluation of a former plan that was made in 2012 (Coruche – Center-south Portugal), but is still waiting to be completely executed (requiring funding).In this case we have been analising the ocorrence of wildfires and potential efect of proposed SMA (not executed) in fire propagation.

No.	Mechanism	Test plan
1	Errors during implementation	
1a	Strategic Management Area (SMA) weren't used by supression	
1b	Failure in fuel treatment implementation – wrong technique or wrong location	
1c	Failure in maintenance of SMA – fuel treatment repetion before fuel load exceed critical value	
2	Technical failure of the measure	
2a	Error in land use mapping and fuel model classification – implie failure in the predicted Fire Intensity and associated Supression Capacity	
2b	Error in fire simulation to test proposed plan – quality of the inputs used or misinterpretation	
2c	Failure in predicte best location of the SMA	

3	Technological failure	
3a	Simulation errors – simulation models aren't acurat with real fire situation	
3b	Wilfire intensity exceed critical value	

Are there any results of previous tests?:

NA

Technical Effectiveness (or Performance)

Analyse the Technical Effectiveness of the innovation either in terms of its capacity to reduce the probability of exposure or vulnerability to the hazard:

The occurrence of forest fires is related to human activity and risky human practices. The propose of the innovation is not the elimination of any fire but to change landscape conditions in order to change the fire regime.

The proposed methodology for fuel management aims to reduces the probability of the fire to affect the area to be protected, reducing fire severity. The planning of the location of the fuel treatment areas at strategic locations increases their efficiency in changing the behavior of the fire, reducing the speed of propagation, reducing the intensity of the front and contributing to a more rapid containment of the fire, which results in the reduction of the size of the burned areas. That also promote conditions for a greater probability of success in firefighting.

Propose a plan to test the risk reduction potential of the innovation. (Note: such a test requires knowing the boundary conditions in the operational environment or the proposed location (or market) for implementation/sale of the innovation):

Risk reduction potential

1. First approach – simulation with Fire Propagation at Landscape Level using Simulator (Farsite and FlamMap): evaluation of the effect of the SMA in the Potential Bruned Area Size and in the Fire Line Intensity classes Burned Area (Fire Severity). The main objective is to reduce propagation of fire in the conservation/forested areas, and to reduce the amount of area that burn above supression threshold for Fire Line Intensity (more than 2000 kW/m)

2. Second approach – evaluation of SMA effect in real wildfire scenario: this evaluation depends on the ocurrence of wildfire event during the testing period (Summer 2017). To collect suitable data fire must 'touch' the fuel treatment areas, coming from outside the area to be protected. Data about fire behaviour, meteorological data and supression actions. The probable scenarios will be:

i. wildfire stop in the fuel treated areas;

ii. wildfire decrease the intensity and rate o spread allowing an efficient firefighting;

iii. wildfire decrease the intensity and rate o spread, but no firefighting was done and fire cross the SMA and burned the protected area

iv. Wildfire behaviour don't change inside treated areas (fire behaviour above the threshold value)

Are there any results of previous tests?:

NA

Social readiness

Assess demographic conditions – age, gender, educational level, social grade and location of target populations:

Reduction of wildfire hazard adress diferent target populations, according to the location of the area that will be object of the fuel management plan. Since most of the plans adress the protection of forest or conservation places located in rural areas, we can say that those are the target population to be considered. In most of the mediterranean countries (including Portugal), rural population are aged, and with reduced level of literacy.

Assess basic user requirements:

The new approach to fuel management planning improve usefulness of results, by reducing area burned by a wildfire, wich reduce total losses in forest and environmental values. Adaptation only requires a different approach to resource allocation. Once the decision is made, based on the new planning assumptions, its execution does not differ from most of the traditional applications of fuel treatments, differing only in the cases of localized application of controlled fire. Also, resulting from the new planning aproach, firefighting operations are easier to accomplish, leading to a more effectiveness of fire supression operations.

Assess psychological concerns:

Adaptation does not lead to risk, but rather reduces the preexisting risk (intense forest fire). The techniques used are based on technical and scientific studies and their effects are temporary and close to nature. Expected reduction in psychological concerns in individuals and in the community, resulting in increased sense of security.

Assess sociocultural preferences:

Adaptation is more compatible with ‘individualist’ and ‘igualitarian’ organisation, less with ‘hierarchical’:

- Is appropriate in scale and in technology relative to cost;
- Attend to long-term climate risk now;
- Seeks to make the system to be adapted more sustainable;
- Be deployed under explicit public consent

Assess technical expectations:

- Efficacy
    - Reduce climate impact
    - Operationality is dependent on time since fuel treatment, decreasing over time, depending on the used treatment technique, the type of vegetation or the use of the soil (agricultural, forestry or nature conservation
- Environmentaly friendly

  - This approach is based on nature characteristics, such as the resilience of vegetation to fire, and aims to reduce the intensity and size of forest fires and fire impacts on nature (plants, animals, soil, water, air)
  - All treatments technics are chosen with minimum impact on soil erosion in mind, and are "reversible" (if maintenance of fuel treatments is not done)
  - Where possible, the choice of treatment site is made according to other objectives, such as animal habitats, wildlife feeding areas, or traditional land use.
- Affordable
  - Is more cost effective (optimization of investments in fuel treatment)
  - Provide return of investments by protecting forests and conservation areas
  - Reduce fire supression costs
- Safe, preventing potential fire damages.

Test Plan

Laboratory Testing

NA. The innovation is at TRL 6-7.

Operational Testing

Testing of the Technical KPIs	
Design Criteria (i.e., Required Technical Effectiveness)	
Required level of risk reduction	In the areas selected for strategic fuel management, fuel load must be reduced below 7 ton/ha (fine dead fuels); Live fuels continuity must be eliminated; access to strategic areas must be unblocked.
Required Safety Factor or Reliability	Fire behavior inside the strategic management areas must be within the supression capacity – Fire Line Intensity below 2000 kW/m.
(External) Operating Conditions	Firefighting must be effetive before fire cross the treatment area, if wildfire start outside the forest area to be protected. Non managed areas (like agricultural areas that complement the plan) must maintain 'not burn' conditions. If supression capacity for terrestrial fire team is exceded, supression strategies must be changed (aerial or indirect attack).
Reliability	
Effect on fire behavior	**Description of Testing:** Strategic Management Areas must be evalueted during and/or after a fire event, to measure the effect on fire behavior: fire intensity, rate of spread, severity,…
	Expected Results: Redution on fire spread and fire intensity.

Improvement of firefighting capability	**Description of Testing:** Evaluation with the firefighting services of the use this areas to support a more effective fire supression; use or non use (why?) of the areas, results, improvement, …
	Expected Results: Increase efficiencyof fire suppression.
Best placement of strategic fuel management areas	**Description of Testing:** Effect of SMA in fire propagation in the landscape; fire size; burned area inside protected area.
	Expected Results: Reduction in fuel continuity, fire propagation and burned area.
Reusability	
Evaluation of the quality of the implementation work	Assessment of implementation before fire season.
Monitoring vegetation regrowth	Annual monitoring of fuel load in the strategic manegemnt areas. If necessary repeat fuel treatments.
Identification of land use changes in the areas	Monitoring land use inside area of strategic planning.
Effects on fire behavior	Assessement of effect of management areas on fire behavior, in case of fire event.
Percent of the innovation needed to be repaired after each (operation)	Description of Testing: NA
	Expected Results:
Lifetime of structural and/or material components -	Description of Testing: NA
	Expected Results:

Operational Testing Protocol

Step 1 – Define the operational environment

- Boundary conditions for the operational environment – wildfire intensity below 2000 kW/m.
- Technological Innovation
    a. How technical effectiveness will be measured
        i. Collect historical wildfire data for the Test Area
        ii. Testing innovation with fire simulation software
        iii. Evaluation in real fire scenario

Step 2 – Evaluate the technical effectiveness of the innovation under operational conditions

- Maximum capacity in operational environment – evaluation in real fire events;

- Technological Innovation
    a. Overall risk without the innovation vs risk with innovationn implemented
        i. Calculated with simulation results
        ii. Validated with real scenario results

Step 3 – Evaluate reliability of the innovation under operational conditions

- Maximum capacity in operational environment
- Technological Innovation
    a. Repeat tests of step 2, using new data
        i. Inherent reliability (table B-5)
        ii. Technical reliability. Identification of potential human error; define preventive measures to reduce human error probability, and vulnerability to implementation error.

Step 4 – Check reusability in operational conditions

- Evaluate the rate of recovery for vegetation after fuel treatment; effect of technique used in the treatment.
- Define maintenance requirements.

Testing results

Selection of test area location

As part of the original planning, during the last year (2016) selection of test areas were made according to availability of local partners. Two locations were initially selected, one in northern Portugal – Vale do Tua – and the other in centre-southern – Coruche. Planning of strategic forest fuel treatments was been made for the two locations, but only has been possible to prepare one of the sites – Vale do Tua, due to restrictions of manpower and financement for field work implementation. Local partners involved were the Forest Owners Associations of Coruche and Murça.

Pre and post treatment evaluations have been made. Initial fire hazard assessment has been made during the Strategic Fuel Management Plan elaboration. Two test areas in Vale do Tua have been selected for implementation of the plan – Amieiro and Carlão. The objective is to protect two nature conservation areas from wildfires propagating from outside.

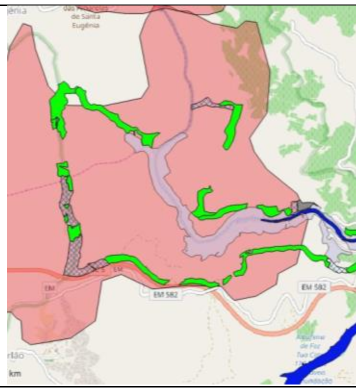
Implementation of test areas

Field work was done during end of winter and spring 2017, in order to implement fuel treatment before wildfire season. Because of the weather conditions, fire weather index increased to high levels before the official ‘wildfire critical period’ and the first fires in the region started before end of June. At that time only one of the selected test areas, Amieiro, had all the strategic treatment areas finished. The other area, Carlão, was partially done.

Planned and executed treatment areas

Conservation area	Total conservation area (ha)	Planned treatment area (ha)	Executed treatment area (ha)

Amieiro	149	43	43
Carlão	57	22	15

		
Location of test areas in Northern Portugal	**Amieiro Test Area** Purple – Conservation area Green – Agriculture Diagonal X – Strategic Fuel management areas	**Carlão Test Area** Purple – Conservation area Green – Agriculture Diagonal X – Strategic Fuel management areas Red – Wildfire 2017

Testing

The occurrence of forest fires is an event dependent on environmental variables (topography, fuels and meteorology) that determine the magnitude of the phenomenon, but which in spatial terms behaves like a stochastic phenomenon.

The occurrence of wildfire in the test area of Vale do Tua (Northern Portugal) was expected considering the history of fires in the region and the environmental conditions. Nevertheless the trajectory of the fire only can be predicted knowing the environmental conditions at the time.

On the dawn of July 16th a wildfire starts 10 km from our test area and was considered extinct during morning. Fire restart in the early afternoon and burn during the next 3 days. Final total burned area 4691 ha.

On the 17 of July this wildfire affected the ‘Carlão’ test area, which had not been completely finished. Nevertheless, fire propagation crossed a strategic fuel treatment area that was finished and that could be used as a firefighting opportunity.

Results

Fire doesn’t stop at the planned fuel treatments. – The propose of planning strategic areas for wildfire suppression implies that human resources involved in firefighting take advantage of the created opportunities, and that was not the case in this wildfire. The wildfire reaches the test area at the second day of burning. Firefighting resources were dispersed by a large area and concentred near the villages. A correct fire analyses was not done by the Incident Command System.

Some areas have not be completely treated for fuel reduction. – Carlão test site was not planned to be use this year and the extreme weather conditions (drought and vegetation moisture) were above predicted interval.

The planned location of the strategic fuel treatment areas was well predicted. – Fire arrives as predicted by our simulations and propagation follows the predicted paths.

The post-fire evaluation in the test area shows that there was a change in the fire behaviour with reduction of the fire intensity, expressed by lower crown volume scorched and tree mortality inside the treated areas. (see photos in Annex 1)

Improving

Agricultural areas in severe drought conditions are not efficient as fuel breaks in fire propagation. Complementary vegetation reduction treatment must be done before fire season.

Fuel treatments inside the strategic management areas must use the most efficient techniques, like prescribed fire, reducing residual fine fuels.

Future simulation scenarios must considered more extreme meteorological conditions (wind temperature, relative humidity and fuel moisture)

Fire fighters must be trained to take advantage of the firefighting opportunity, created by fire behaviour change (less intensity and rate of spread) in these strategic treatments areas. Demonstration

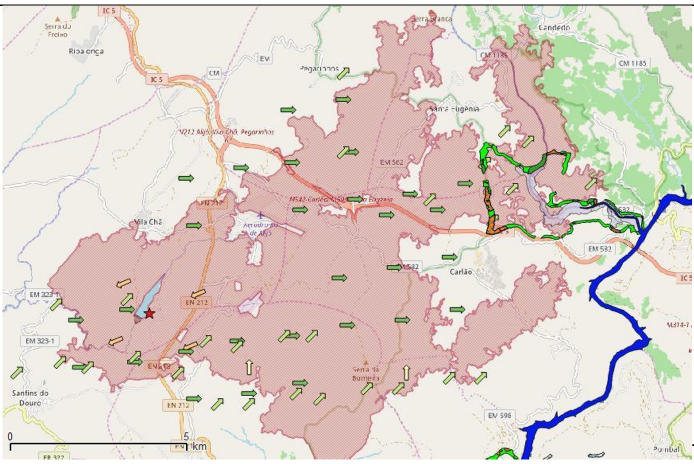
Final remarks

The year 2017 was the most catastrophic and deadly in the history of forest fires in Portugal, primarily because of extreme drought conditions, high temperatures and consequent extremely high danger of forest fires, aggravated by the results of the last years forestry and civil protection policies.

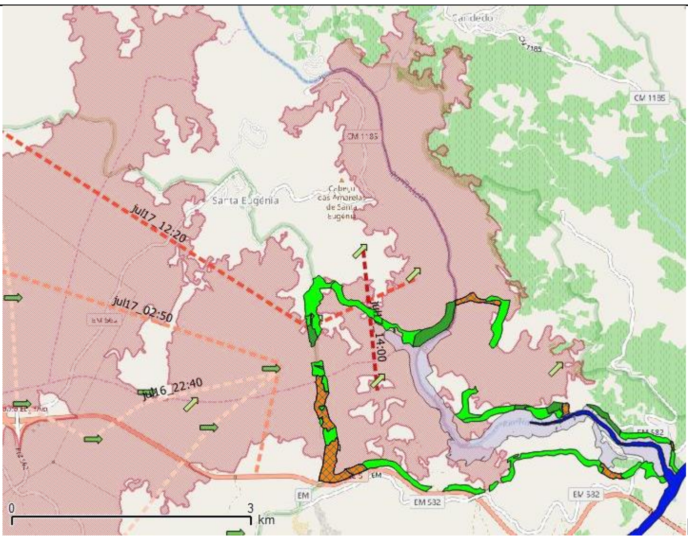
Even in this context, only part of the test area was affected by fire on July 17th, due to a fire that began on July 16th and finish on the 18th.

Constraints identified were on an unplanned scale, which affected expected performance for the implemented fuel management infrastructures. Main failures detected are due to decision errors in firefighting human resources, which may have been motivated by the unavailability of resources.

This new context must lead to a reformulation of the methodology developed by the company in order to reduce associated human error and improve performance.



Total burned area and propagation vectors



Fire front location and propagation vectors in Carlão Test Site. The planned Treatment site predicted fire arriving from West.

Annex

Test area plot before wildfire.

Fuel treatments were made inside plot (blue line).

Test area plot after wildfire.

Tree crowns remain green, compared with trees outside the treatment area. Second assement made in Octuber confirm that this trees don't died.

10. Innovation: FireAd - Fire Risk Monitor Advisor

Innovator: Instituto Superior de Agronomia, CEABN/ISA, University of Lisbon (CEABN/ISA) (BRIGAID consortium partner)

Contributing authors: Conceição Colaço (CEABN/ISA), Susana Dias (CEABN/ISA)

Innovation description

The description of FireAd below is also available from the Climate Innovation Window, http://climateinnovationwindow.eu/innovations/fire-risk-monitor

Name
Decision support tool for monitoring and assessing the risk of wildfires in drought conditions SHORT NAME: Fire Risk Monitor Advisor (FireAd)
Short description
The innovation Fire Risk Monitor is an ITC-desk solution able to regularly advice to forest and fire managers on windows of opportunity for forest management practices aiming at reducing the risk of wildfires. The tool generates maps of wildfire (or ignition) risk probability based on the retrieval and analysis of meteorological and drought indices (i.e. SPI), landscape metrics, and vegetation loads. This decision support tool comprises several modules addressing different time scales of forest and fire management. Each module benefits from previous modelling of the links between droughts (extent and intensity) and burned area, forest types and fire selectivity or weather conditions and wildfire ignition and spread. The spatial visualization of the modelling outputs in a user-friendly way will promote a timely planning for silviculture activities, such as prescribed burning (PB) for reduction of fuel loads or the use of suppression fire or firefighting. The innovation helps forest and fire managers who want to keep the forest protected to select the best period for forestry practices.
Sketch/Photograph of the Innovation

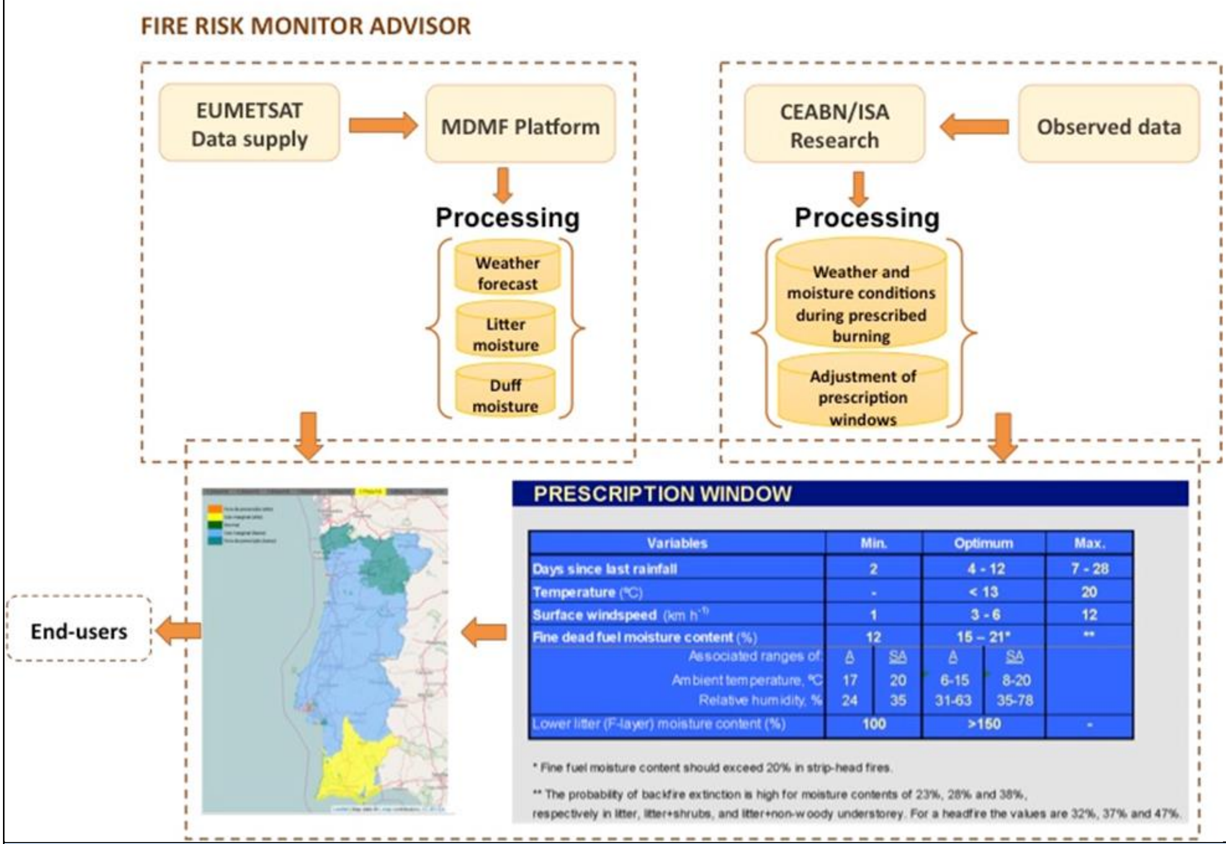


Figure 1 – Sketch of the innovation

Which hazard(s) is the innovation designed to mitigate?

The innovation Fire Risk Monitor (FireAd) aim at mitigate the risks related with uncontrolled fire in an area of combustible vegetation that occurs in the countryside. Fire ignition and spread are both enhanced by cumulated drought, high temperature, low relative humidity and the presence of wind. Reduction of wildfire hazard is the primary reason for the use of prescribed burning (PB).

Prescribed burning on a pine stand

Certified technician applying the prescribed burning technique to reduce fuels

How does the innovation work?

The working flow of our innovation can be divided in two different, but complementary groups: the implementation flow and the financial flow.

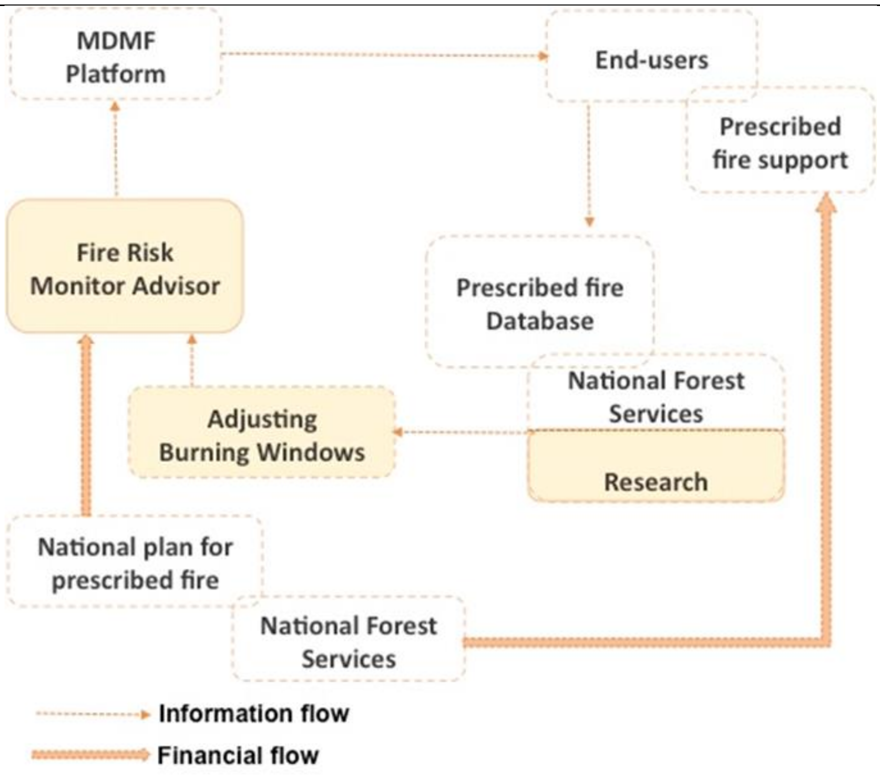
Implementation flow:

Our innovation will work as a loop that can be seen starting or finish at an online platform (MDMF). As we can see in the figure, the platform output will be potential used by end-users, these will use this information as a decision support of prescribe burning. After using the information a real situation, the recorded data of this event will be sent and recorded in prescribed fire database managed by National Forest Services. These data sets will be analyzed by a research team (CEABN/ISA), and will then be used to create and adjust burning windows. Finally, these prescription windows will be used as an input to the platform.

Financial flow:

There is a fund for prescribed burning (National Plan for prescribed fire), which finance the implementation and operation of prescribed fires. This support will be used by the end-users of our innovation. Our proposal is that short percentage of these funds should be allocated to the management and maintenance of the innovation after the project.

Workflow of the innovation:



Added value / main differentiating element from conventional approach(es)
The main differentiating element is the possibility to aggregate in a single platform all the meteorological, spatial and vegetation information in order to give the most accurate previsions for a safe and efficient use of fire as a tool for preventing wildfires.
Critical success factors / Limitations

Desk study

Summary

Our innovation addresses the **wildfire hazard** which is enhanced by extreme weather events like drought and heat waves, and have the **following characteristics**:

- software or IT-product/components to process or present information
- informational and education aspects to increase knowledge and awareness
- encourages changes in human behavior or insist on immediate action
- methodology to identify and quantify risks and/or evaluate adaptation strategies
- changes in laws, regulations and government policy to reduce risk

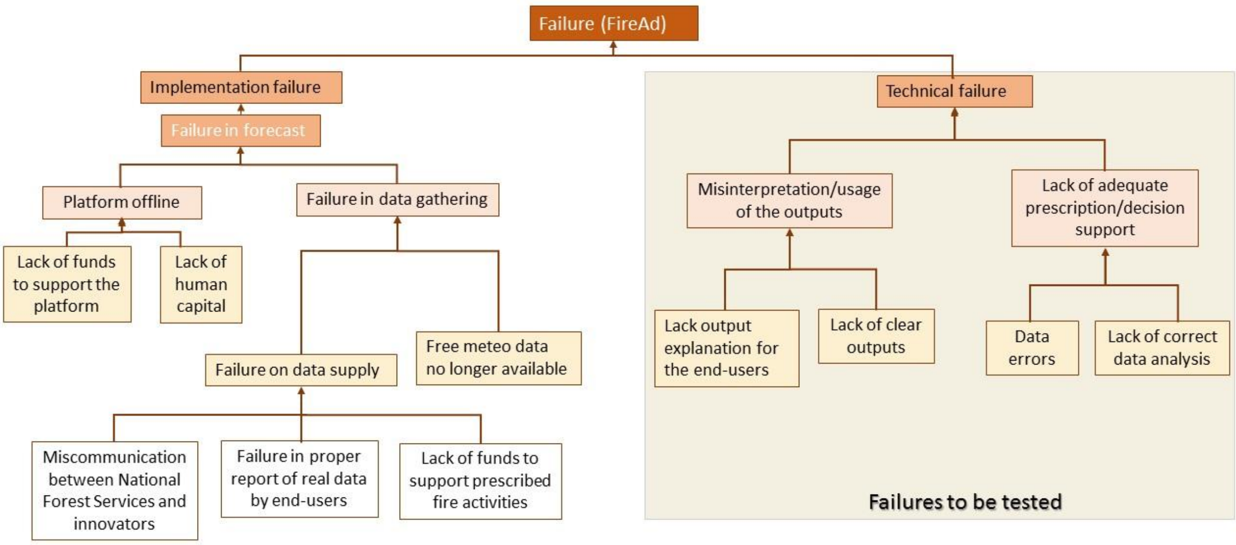
Regarding the **technical effectiveness**, this innovation aims to reduce the wildfire risk by helping forest technitians to reduce the fuel load in critical areas, which by consequence can decrease the probability of the fire risk occurrence. Simultaneously it will decrease exposure, by reducing the area affected. It can also decrease the vulnerability since it can increase the adaptive capacity, help to increase the knowledge and/or awareness of the wildfire risk, which can also lead to changes in human behavior

The innovation FireAd, at the moment at least, cannot be quantified in terms of units of measurement. The present **TRL level is 5**.

FireAd is a **technological innovation**. Concerning **reusability,** the innovation is a **monitoring system**, which is **continuously operated**. Since it is a **permanent innovation**, the expected lifetime will be **several years** considering that it will work as long as the data (e.g. meteo, vegetation, fires) and interest is on.

As the innovation will be hosted in a digital platform, as long as the platform as the proper maintenance, we foresaw a **lifetime product**.

Innovation reliability



FireAd failures "fault tree"

Ranking of the failure modes

As seen in previous figure, two different sources of failure modes can be identified: technical and implementation.

The most important failure regards the implementation since the lack of funds and data availability are critical for the operationality of the innovation.

While the technical failures can be addressed and tested in the platform with the end-users information, the implementation failures can not be tested, and if they occur the innovation is no longer viable.

Testing will allow the innovation to be validated and calibrated by using historic and real time events data. The timing for the tests will be different according to the data to be used.

However in the scope of the test plan, for each of the identified cause of failures some measures can be identified to overcome this critical limitations.

Technical Readiness Level (TRL)

The FireAd is currently at level 5 (TRL 5): Technology is validated in relevant environment; the technological components of our innovation system are integrated with reasonably realistic supporting elements so they can be tested in a simulated environment; examples include high-fidelity laboratory integration of components.

Approach designed and formulated. Pre-processing, processing and communication functionalities have been successfully integrated and tested in a relevant desktop environment. Until now, the exiting technology allowed for opportunity windows that were not validated and there was a lack of communication between information available and the end-users. The information required for prescribed burning must be adjusted and permanently updated.

Future steps: Local validation exercises are in progress; preliminary results are promising but required more in depth analysis. Auxiliary datasets of existing prescribed burning must be considered during the design of the testing plan.

With our innovation, we expect to:

- Improve the communication with end-users;
- Improve the process on reporting data by end-users to the National Forest Services;
- Validate the adjustments on burning windows;
- Testing the integration and implementation of the Fire Risk Monitor Advisor in the platform;
- Disseminate the platform online in a friendly-user format.

Reusability

Describe the intended reusability of the innovation based on the definitions given above:

Fire Risk Monitor Advisor is an operational system that will be permanent fed by real data provided by the end-users. The platform will provide information for a 3 days window, which will allow end-users to prepare the prescribed burning operations. Moreover, this information will be available on a daily basis-. The National Plan for Prescribed Fire should support the maintenance costs of the innovation. Also the innovation can be maintained by having contracts between end-users and the developer of the innovation (in this case CEABN/ISA).

Propose a test plan to assess the expected reusability of the (components of the) innovation.

The reusability of the innovation will be dependent upon the following conditions:

- updated information supplied by end-users, which will feed the prescribed fire database;
- information gathered from the usability of the innovation outputs, which allowed us to make ongoing adjustments and improvements on the communication process. This will bridge the gap between science and practice;
- training a subset of national forest and fire managers on the use of modelling outputs on decision support tools;
- dissemination of test results and their applicability to other regions during workshops and thematic exhibitions;
- the innovation will be implemented in a freeware approach and a user-friendly environment that can be easily obtained on the web;

- our customers for prescribe burning are a restricted group but once the product is available it can easily be adapted to other customer groups (e.g. those needing windows of opportunities for controlling pest in forest stands);
- this approach could be implemented to other likely support decision systems such as suppression fire, firefighting and forest planning.

For semi-permanent and temporary innovations, identify the expected percent of the innovation that is reusable after each use and which components (if any) would need to be replaced:

NA

Estimate the expected product lifetime based on decomposition of the materials used:

As the innovation will be hosted in a digital platform, as long as the platform as the proper maintenance, we foresaw a lifetime product.

Are there any results of previous tests? (e.g., if lifetimes of the structural components are already known or tested):

NA

Reliability

Identify all possible failure modes that would lead to implementation and technical failure in the form of a fault tree:

Two different sources of failure can be identified: technical and implementation.

Implementation failures:

I. Failure on data supply, leads to a failure in forecast. Main root causes are discriminated below:

Ia) Lack of funds to support the platform operation (platform offline) and data gathering, leads to a discontinuity;

Ib) Lack of funds to support prescribed fire activities;

Ic) Failure to proper report of real data by end-users;

Id) Miscommunication between National Forest Services and innovators;

Ie) Lack of human capital to maintain the innovation, such as data analysis for adjusting the prescription windows.

Technical failures (see the table):

II. Misinterpretation or usage of the outputs, due to:

IIa) Lack of clear outputs;

IIb) Lack of outputs explanation for the end-users.

III. Lack of adequate prescriptions/decision support, derived by:

IIIa) Lack of correct data analysis.

IIIb) Data errors.

Information for decision:

		Observed data Prescription fire	
		Inside conditions	**Outside conditions**
Implementation recommendation	**Inside window**	Hit	False alarm
	Outside window	Miss	Correct decision

Test plan to evaluate failure modes. Also, describe whether these tests will take place in a controlled or operational testing environment (dependent on the TRL):

The test plan to evaluate the several points on WP5 assessment rely mostly on a survey and interviews that will be applied in different moments of the project to assess the different stages of the innovation. For instance, to test the “Misinterpretation or usage of the outputs” an inquiry will be applied to a sample of PB certified technicians, to validate the usefulness and the accuracy of the data provided by the innovation. This test plan will be implemented in an operational testing environment.

Concerning the technical failure related to “Lack of adequate prescriptions/decision support” the test plan will be done by data analysis of previous prescribed fire meteorological windows of opportunity in order to validate the different prescriptions which follow criteria summarised in the table above.

Are there any results of previous tests?:

Given that our innovation is meant to update and put online the PB windows of opportunity in a user-friendly way, there were several tests made in controlled environment, computational and others that allows to have preliminary data on the subject (Fernandes et al., 2002 ; Fernandes & Botelho, 2003 ; Pinto et al., 2014)

References:

Fernandes, P., Botelho, H. & Loureiro, C., 2002. Manual de Formação para a Técnica de Fogo Controlado. Departamento Florestal, Universidade de Trás-os-Montes e Alto Douro (UTAD). Vila-Real. http://www.cifap.utad.pt/Fernandes_Manual_Forma%E7%E3o%20T%E9cnica%20Fogo%20Controlado.pdf

Fernandes, P.M., Botelho, H.S., 2003. A review of prescribed burning effectiveness in fire hazard reduction. International Journal of Wildland Fire 12: 117-128. (doi:10.1071/WF02042)

Pinto, A., Fernandes, P., Loureiro, C., 2014. Guia de Fogo Controlado em Eucaliptal – FIREGLOBULUS. GIFF & UTAD. Vila-Real. http://www.giff.pt/fireglobulus/downloads/GUIA-FIREGLOBULUSpt.pdf

Technical Effectiveness (or Performance)

Analyse the Technical Effectiveness of the innovation either in terms of its capacity to reduce the probability of exposure or vulnerability to the hazard:

Well established methods to design prescribed burning are still missing, and tools to optimized prescribe fire are required. Moreover, the current online product available to assist fire and forest managers on their prevention activities do not target the users of prescribe fire or forest protection and do not include weather information at the right temporal and spatial scale.

Our innovation, by promoting the best use of prescribed burning and optimizing opportunity windows to this activity, will likely lead to an efficient reduction of the fuel loads that in turn increase wildfires in the fire season. By enhancing the proper use of prescribed burning by 10%, a substantially decrease in the wildfire area is expected together with less intensive fireline which consequently will diminished the damages from the wildfire event. However, conclusive statements concerning the hazard-reduction potential of prescribed fire, are not easily generalized and will ultimately depend on the overall efficiency of the entire fire management process (Fernandes & Botelho, 2003).

Propose a plan to test the risk reduction potential of the innovation. (Note: such a test requires knowing the boundary conditions in the operational environment or the proposed location (or market) for implementation/sale of the innovation):

The test plan encompass two complementary approaches:

A first oriented to obtain the perception by end-users of the risk reduction potential of the FireAd. For that we will conduct an inquiry applied to the end-users and possibly some interviews to key stakeholders focus on assessing how FireAd may facilitating the use of prescribed burning. It will be a three step process were the first is aimed at understand the current situation, how end-users use the so far available information, current needs and expectations; it will also be asked about their experience with examples when the use of prescribed fire has influenced the behaviour of a real fire by:

1) Directly stopping a wildfire;

2) Decrease the intensity of the wildfire allowing a more secure, fast and efficient firefighting;

3) Decrease the intensity of the wildfire diminishing the damages and losses in forest stands, habitats and wildland-Urban interfaces (WUI).

In a second step end-users will be in contact with our innovation and will be allowed to tested in simulated conditions and later on, in real conditions before (winter/spring) and during a fire season (summer).

The last step in involve a second inquiry about end-users perception on how FireAd permed during the test months, if it allowed to improve prescribe burning conditions, etc..

A second and complementary approach relies on applying the information about real wildfires to evaluate the outcomes of these fires (in terms of fire scar, impacts and firefighting operations) with and without the FireAd. A simulation of the burning path and areas affected from big wildfires can be assessed entering the variable of the strategic use/non-use of the prescribed burning technique, following the Fernandes & Botelho (2003) methodology.

Are there any results of previous tests?:

Not prior to BRIGAID.

Social readiness

The use of prescribed fire is seen differently across regions in Portugal due to its historical usage. In areas where this tool has been applied (e.g., in pine stands), it has been seen as a powerful tool to reduced fuel loads. However, the use of fire to fight fire is still perceived for the general public as a paradox.

Currently, and following an intensive fire season in 2016, there is a trend in policies to run in the direction of prescribed fire usage. Furthermore, our innovation will be integrated in user-friendly digital platforms, easy to manage by general population, and thus promoting social readiness.

To address the Social Readiness, six indicators were scored in relation to our innovation. In some of them, the scores are given considering the group of direct end-users (PB technicians, foresters, firefighters, but mostly the first group), or the general public, that includes both rural and urban population.

Demographic conditions

It ranges from one (inappropriate) to five (appropriate). When it is considered the direct end-users and since the innovation was design to their benefit, all the scores are completely appropriate. However, since it is a free tool on the web, if the tool is used by the general public (GP) there are some remarks which are present in the table in the column of comments.

Demographic condition indicators:

Factor	Direct end-user (DEU)	General Public (GP)	Comments (for the General Public)
Age	5	5	
Gender	5	5	
Education	5	3	If someone from the GP wants to use the innovation, it will need some meteorological literacy and technical skills in order to understand and use the innovation outputs in a correct manner.
Social grade	5	5	
Location	5	3	There is a higher risk perception on the use of fire by the urban population compared with the rural ones, which traditionaly uses fire as a agricultural and forest cleaning or management tool. For that, if the urban population sees the smoke plume resulting from prescribed fires, can become more apprehensive (see table in psychological concerns.

Basic user requirements

This indicator involves the extent to which an adaptation satisfies basic user requirements for usefulness and ease-of-use. It ranges from 1 (low) to 5 (high).

Basic user requirements indicators:

Factor	Direct end-user (DEU)	General Public (GP)	Comments (for the general public)
Usefulness	5	3	The innovation for the GP can be useful for the correct and safe use of fire. Only persons with specific permits can burn larger agriculture areas, but if it is only to burn wood debris that is not mandatory.

Ease of use	5	3	See the comment above about the education level.

Once again, we consider that for the direct end-users the "Usefulness" and "Ease of use" the scores are very high, however for the general public the scores are in the middle.

Psychological concerns

The scores for the "Dread" and "Unknown/known" contribute for the fire risk perception. Our answers reflect the risk perception we believe the end-users and general public have in relation with the innovation that implies the use of fire in the landscape. Values range from 1 (low dread and known) to 5 (high dread and unknown). The score 2 for the direct end-users in relation to dreadness has to do with the risk that surrounds the use of fire, even when this risk is pretty low.

Psychological concerns:

Factor	**Direct end-user (DEU)**	**General Public (GP)**	**Comments (General Public)**
Dread	2	3/4	In Portugal it exists the cultural use of fire especially in rural areas. However, if by one side the rural population would score a low dread and known score, on the other side, the urban population has a different relation with fire so the consequences of using the innovation and increasing the PB frequency can increase the score for the two variables.
Unknown	1	3/4	

Sociocultural preferences

This indicator involves the extent to which an adaptation appeals to the adherents of 'hierarchical', 'individualist' and 'egalitarian' forms of sociocultural organisation. It ranges from 1 (low) to 5 (high).

Sociocultural preferences:

Factor	**Score**	**Comments**
hierarchical	3	The innovation will attend to long term climate risk although their use is not on a large scale. It will be used on a individual level, in a local scale,
individualist	4	
egalitarian	3	

Technical expectations

These indicators range from 1 (low) to five (high). The scores are given considering the direct end-users.

Technical expectations:

Factor	**Direct end-user (DEU)**	**Comment**
Efficacy	5	That is one of the innovation purposes.
Environmental effects	4	POSITIVE environmental effects since it diminish the uncertainties for the technical use, increasing the environmental and prevention benefit effects minimizing any side effects or unintended impacts on the environment. The correct use of the innovation can have a direct effect on the

		quality of the PB which will decrease the carbon footprint resulting from the wildfires.
Cost benefit ratio	4	Although there is some difficulty from our side to calculate the innovation cost, in relation to the high value of the damages, we consider that the innovation cost is not very high compared with the potential benefits.
Side effects	2	Since the innovation is intended to promote the use of PB, one of the negatives side effects can be the smoke produced by the burning, which can be harmful for people with respiratory diseases.

Wider societal questions

This indicator involves the extent to which an adaptation can satisfy diverse questions of political, public, ethical and co-beneficial social performance. It ranges from 1 (low) to 5 (high).

Wider societal questions:

Factor	SCORE	Comment
Political	5	The utilization of the innovation can be helpful for the implementation of the National Plan for PB. Simultaneously the use of PB can have the purpose of landscape design for wildfire prevention, which will cross borders and can facilitate intergovernmental or interregional cooperation.
Public	4	Using the innovation, the efficacy of the PB can increase, which will lead to a wider social benefit since the economics/social/environmental/health wildfire impacts will decrease.
Ethical	4	It is a very democratic technological tool, however there is always the risk of being misused by people who have bad intentions and wants to burn the forest. Simultaneously since it promotes the use of fire as a technical tool, it can create some disagreement bettwen different groups of the society (eg. NGO) not only about the use but also about where to use it (near villages or hospitals, nature conservation areas, etc)
Co-benefits	5	From our point of view the co-benefits can be large, with positive implications in all the other factors above. Not only can promote a better wildfire prevention with benefits in general, but also can promote the forest valorization by decreasing the risk, can help to manage nature conservation areas, diminish the carbon footprint of the country, among other co-benefits.

In synthesis, we realize by the scores given to the different factors, that our innovation, in relation the direct users, is very well positioned with several high scores not generating the feeling of dread or of something unknown. However, there are some points that need to be looked carefully when considering the general public especially when referring to the psychological concerns and basic user requirements indicators. The use of fire as a management tool, can be dangerous if not used properly, which can create a high perception of risk by the general public.

As mentioned above, the main tool to assess the different indicators and to implement the test plan will be an inquiry to be sent in different phases of the BRIGAID project. First to a sample of our end-users (PB certified Technicians), but enlarging this group to other possible end-users, mentioned in the market segmentation analysis as selected stakeholders.

Test plan

Laboratory testing

Testing of the Technical KPIs	
Design Criteria (i.e., Intended Technical Effectiveness)	
Intended (quantitative) level of risk reduction	Reduce large wildfires by increasing the amount of area treated with prescribed fire in around 10%.
Intended Safety Factor or Reliability	NA
Reliability	
“Misinterpretation or usage of the outputs”	Description of Testing: Inquiry to be applied to a sample of PB certified technicians.
	Expected Results: Validation of the usefulness and the accuracy of the data provided by the innovation.
“Lack of adequate prescriptions/decision support”	Description of Testing: Data analysis of previous prescribed fires (historical data) meteorological windows of opportunity.
	Expected Results: Validation and calibration of the different prescribed burning windows of opportunity in relation to the different prescriptions.
Reusability	
Percent of the innovation needed to be repaired after each operation	Description of Testing: Subject the platform to a overload of users for 1 hour. After this period determine if the platform didn’t colapsed and if all the outputs components were provided with accuracy and with no delay to the end-users.
	Expected Results: Confirming the resilience and capacity of the platform to respond to a large amount of simultaneous users.

Operational testing

NA

Test plan timetable

Tasks	2017								2018			
	may	june	jul	aug	sept	out	nov	dec	jan	feb	mar	apr
1st Questionnaire - current situation												
Real time FireAd testing for precribed burning												
2nd Questionnaire - usefulness and reliability of FireAd												
Associated test for risk reduction potential of FireAd												
Calibration, validation and simulation through quantitative methods (*e.g.,* R2, NSE, Monte Carlo simulations)												

Testing results

The test relies mostly on a survey and interviews that will be applied in different moments of the project to assess the different stages of the innovation.

A first orientation is to obtain the perception by end-users of the risk reduction potential of the FireAd. A first step will include an inquiry applied to the end-users and possibly some interviews to key stakeholders focusing on assessing how FireAd may facilitate the use of prescribed burning. It will be a three step process were the first one is aimed at understanding the current situation, how end-users use the so far available information, current needs and expectations.

In a second step end-users will be in contact with our innovation and will be allowed to test in simulated conditions and later on, in real conditions before (winter/spring) and during a fire season (summer).

The last step involves a second inquiry about the end-users perception on how FireAd allowed to improve prescribe burning conditions.

Associated with the previous test plans, a complementary approach will address the risk reduction potential of the innovation. For that, during the survey it will also be asked the end-users experience with practical examples about how the use of prescribed fire has influenced the behaviour of a real fire by:

1) Directly stopping a wildfire;

2) Decreasing the intensity of the wildfire allowing a more secure, fast and efficient firefighting;

3) Decreasing the intensity of the wildfire diminishing the damages and losses in forest stands, habitats and wildland-urban interfaces (WUI).

The outcomes of the previous questions will be complemented with simulations of the burning path and areas affected from large wildfires with or without the use of prescribed burning following the Fernandes & Botelho (2003) methodology.

The first phase of testing for the FireAd innovation is still ongoing.

It relies mostly on personal contact with the end-users of the innovation. A list of the current technicians in prescribed burning was updated. To each entry of the list we sent an email (see Annex) presenting the project, our innovation and the need to gather a set of end-users willing to participate in the testing phase. We then explain that the testing phase is mainly based on surveys and that the first step is to reply to a questionnaire aiming at understanding the current situation regarding the availability and use of meteorological data needed to plan the activity of prescribed burning.

The questionnaire was addressed to all the valid certified technicians in prescribed burning (n=104) in Portugal. The first set of questions (1 to 3) regards the characterization of the technicians (name, age, class and year of certification approval). The next questions (4 to 7) describes the activities done during the past years: region/district where the technician operates, the average number of prescribed burnings per year and the area covered.

The next set of questions were about the sources of meteorological information used for schedule their activities: From several data sources, the technician was asked to select the most used and to provide the satisfaction level (1 – not at all, to 5 – totally) according to: a) available information, b) user friendly level; c) usefulness and adequacy of the forecast to decide the onset of the activity; d) reliability of the forecast for the local/region of interest.

The last two open questions allowed to perceive the technician opinion about:

a) the most important and useful information that is needed to improve accuracy in the prescribed burning plan and schedule;

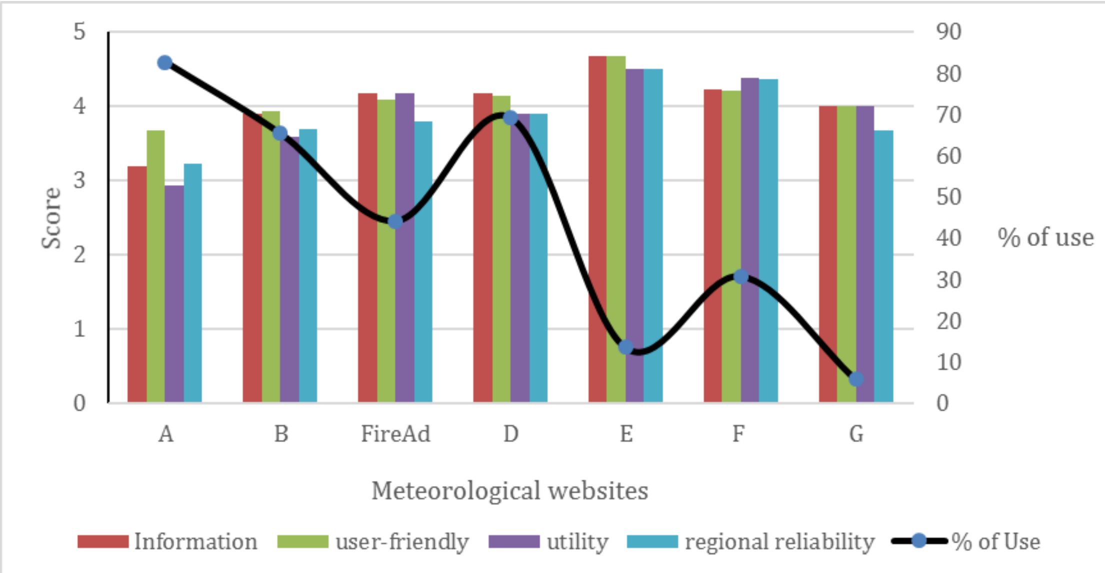
b) the available tools/websites to fulfil the needs of meteorological data in order to improve the burning plan and the efficiency of the prescribed burning.

The survey was sent at the end of April 2017 and the deadline to reply is set to May 15th. A week before the deadline an email was sent to all the listed end-users, as a remainder to deliver the replies.

We got 50% of replies.

As a main result we realize that there are at least seven different meteorological websites (including our platform) which are used by the Portuguese Prescribed Burning technicians (PBt) to gather the meteorological information needed.

However only three of them are known and used by more than 50% of the respondents. Concerning the specific characteristics of the different websites, like the information available and the presence of a user-friendly interface all platforms receives a good or fair (website A) evaluation by the technicians. However, when it comes to the utility of the information to help decide when to burn, only three receive a good score (above 4) and our platform is included. The reliability of the meteorological data in the PBt specific region is the characteristic that receives the lower score in general and only two of the websites receive a good score (above 4), but the percentage of users of those platforms is below 31%.



Around 80% of the replies consider that the available tools/websites fulfil their needs of meteorological data. However they don't follow just one website to make their decision. An average of 3 websites are used by each technician to gather the information.

In relation to the most important and useful information that is needed to improve accuracy in the prescribed burning plan and schedule, we realize that in our platform most of the information referred by the respondents was already available on FireAd. The ones that are not in FireAd, we are still discussing and analysing the possibility and utility to include it so that we can improve our innovation.

In general FireAd has some good evaluations, however it is not completely known by our public. One of our next steps will be to promote it in conferences, meetings and with direct contact where the PBt can get to know the platform and start to use it in an experimental phase.

Our Business Plan is ongoing and during the month of August we worked with WP6 to do the MAF assessment for our innovation wich is already finished.

Concerning the second phase for the testing, a first part of it was held in the middle of November during the FireCAMP and TREXAlto Minho, where we presented our platform to about 50 prescribed burning (PB) technicians and asked them to validate the information provided by our innovation answering to a questionnaire online. This phase of the testing is dependent on the meteorology (PB can only be performed in the wet season, and until the middle of November, Portugal was under a very severe drought, hence the conditions are not suitable to perform this technique).

In the beginning of 2018 until March/April we will be in contact with the several technicians in order to monitor the meteorological conditions when they do prescribed burning and with that, validate our algorithm for the opportunity windows to burn efficiently.

This 2nd questionnaire online will focus specifically on our platform and the questions are related to:

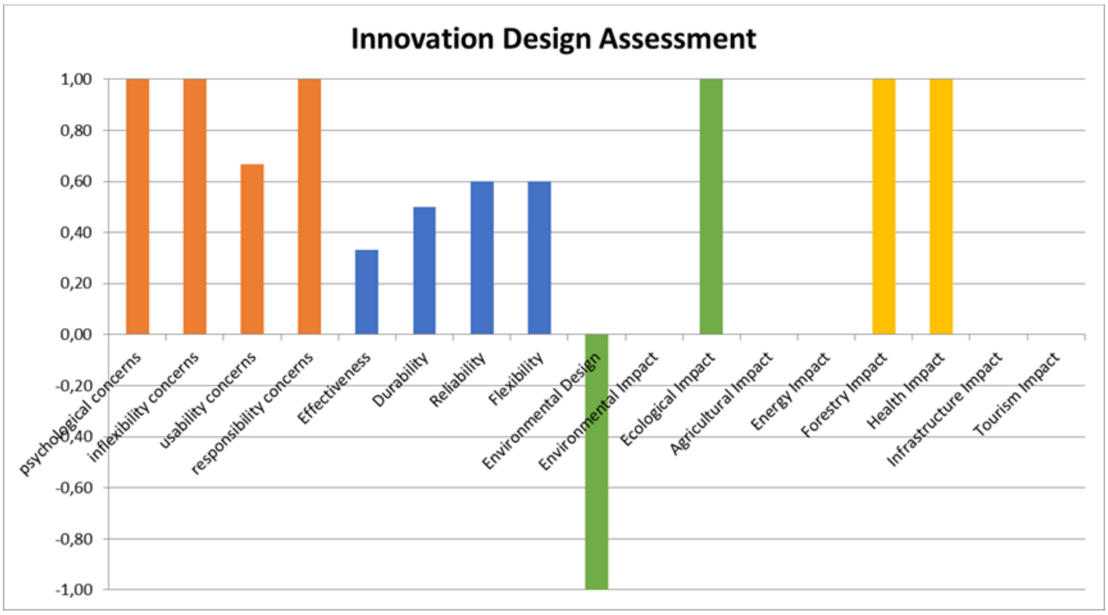
a) Interface – easy access, content organization, utility of the information provided;

b) Quality of the information – precision for each type of vegetation to burn;

c) Satisfaction;

d) Willingness to pay for the information.

Concerning the TIF tool, after answering to it, we have realized that in general our innovation fulfils all the requirements. However, it can still be improved in particular in the technical performance (Blue). Regarding the environmental and sectoral impacts, the TIF tool is not working so well as you can see in the graphic.



Annex: Questionnaire to forest technicians

Questionnaire sent to the forest technicians certified in prescribed burning (in Portuguese) and an example of the e-mail sent to them (in Portuguese):

BRIGAID

INSTITUTO SUPERIOR D AGRONOMIA Universidade de Lisboa

Centro Ecologia Aplicada "Prof. Baeta Neves"

Inquérito aos técnicos credenciados em Fogo Controlado (FC) em Portugal

O Centro de Ecologia Aplicada "Prof. Baeta Neves", do ISA, participa no projecto europeu "BRIGAID - Bridges the Gap for Innovations in Disaster resilience" cujo objectivo é promover inovações que ajudem a combater os impactes das alterações climáticas. Estando uma dessas inovações ligada ao uso do fogo controlado, pretendemos conhecer o grau de satisfação dos técnicos credenciados nesta actividade quanto às diferentes ferramentas/websites disponíveis como fontes de informação meteorológica para definirem a prescrição do fogo controlado e saída para execução do FC, bem como as necessidades de informação sentidas neste campo.

Porque a sua opinião é importante, agradecíamos que nos respondesse a este inquérito. Prometemos não tomar mais do que 5 a 10 minutos do seu tempo.

Obrigada!

1. Nome ______________________________

2. Idade ______________________________

3. Ano em que obteve a credenciação ______________

4. Qual o distrito(s) onde faz mais fogo controlado? ____________________________

5. Realizou alguma acção de fogo controlado nesta temporada de 2016/2017?

Sim____ Não _____

6. Qual o número aproximado de Planos Operacionais de Queima que realiza por temporada de fogo controlado? ______

7. Aproximadamente, qual a área média queimada por temporada? _______

8. Quais as fontes de informação meteorológica que utiliza habitualmente para auxiliar na decisão operacional para ir para o terreno queimar (pode selecionar várias opções)?

- IPMA ___

- Windguru ___

- Site da Fundação D. Luís (Faculdade de Ciências) ____

- MeteoIST (Instituto Superior Técnico) ____

- Outro ____ Qual/quais_______________________________________

Para mais informações sobre o projecto BRIGAID: http://brigaid.eu/ ou http://www.isa.utl.pt/ceabn/ 1

9. Qual o seu nível de satisfação (1 – nada satisfeito; 5 – Muito satisfeito) quanto a:

Sitios	Informação disponibilizada	Facilidade de utilização	Utilidade para decidir a ida para o terreno queimar	Fiabilidade das previsões para a sua região de actuação
IPMA				
Windguru				
Site da Fundação D. Luís (Faculdade de Ciências)				
MeteoIST (Instituto Superior Técnico)				
Outro. Qual?				
Outro. Qual?				

9. As ferramentas/websites disponíveis respondem às necessidades de informação meteorológica para a tomada de decisão de ir queimar ou não (janelas de oportunidade)? Sim _____ Não_____

Se não, explique porquê ____
____
____
____

10. Na sua opinião, qual a informação que considera mais importante e útil para ser utilizada pelos técnicos credenciados em FC com o intuito de optimizar a realização dos fogos controlados? ____
____
____
____

Mais uma vez, muito obrigada pela sua colaboração!

Pretende receber os resultados deste inquérito: Sim _____ Não_____

Para mais informações sobre o projecto BRIGAID: http://brigaid.eu/ ou http://www.isa.utl.pt/ceabn/ 2

Example of the mail sent to 104 Forest Technitians (in portuguese)

"Exmo Sr Pedro Carrilho

Vimos por este meio solicitar a sua colaboração, enquanto Técnico(a) credenciado(a) em Fogo Controlado, no preenchimento de um pequeno inquérito. Pretendemos conhecer o seu grau de satisfação quanto às diferentes ferramentas/websites disponíveis como fontes de informação meteorológica para definir a prescrição e saída para execução do fogo controlado, bem como as necessidades de informação sentidas neste campo.

O inquérito foi elaborado no âmbito do projecto europeu H2020 "BRIGAID - Bridges the Gap for Innovations in Disaster resilience" cujo objectivo é promover inovações que ajudem a combater os impactes das alterações climáticas. O Centro de Ecologia Aplicada "Prof. Baeta Neves" do Instituto Superior de Agronomia coordenado pelo professor Francisco Castro Rego, é um dos parceiros deste projecto no qual uma das inovações se encontra ligada ao uso do fogo controlado.

Porque a sua opinião é muito importante para a progressão deste trabalho, agradecíamos que nos respondesse a este inquérito até ao dia **15 de Maio (2a feira)**. Prometemos não tomar mais do que **5 a 10 minutos** do seu tempo. Pode responder directamente no ficheiro Word anexo e enviá-lo com as repostas como reply a este mail.

Muito obrigada pela atenção e tempo dispensado

Conceição Colaço

Susana Dias

Francisco Rego"

Para mais informações sobre o projecto BRIGAID: http://brigaid.eu/ ou http://www.isa.utl.pt/ceabn/ 3

External innovators (stocktaking)

1. Innovation: SCAN - Software tool to evaluate Climate AdaptatioN strategies

Innovator: Sumaqua (external innovator) but related to KU Leuven (BRIGAID consortium partner)

Contributing authors: Vincent Wolfs (KU Leuven, Sumaqua)

Innovation description

The description of SCAN below is also available from the Climate Innovation Window, http://climateinnovationwindow.eu/innovations/scan

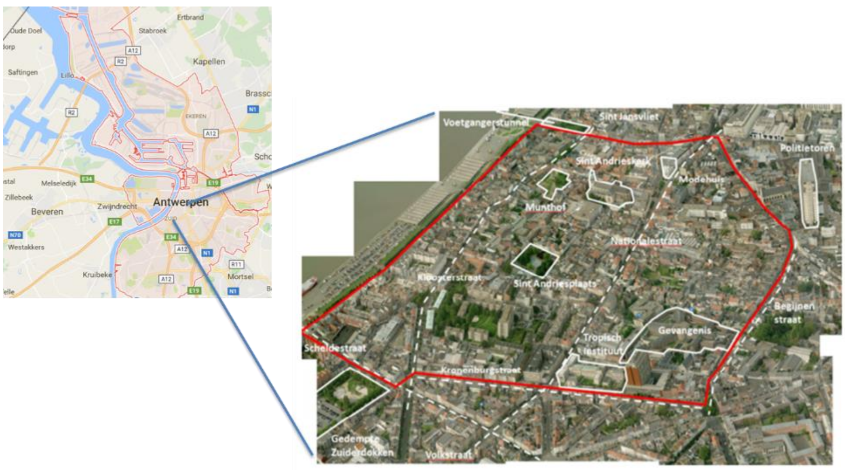
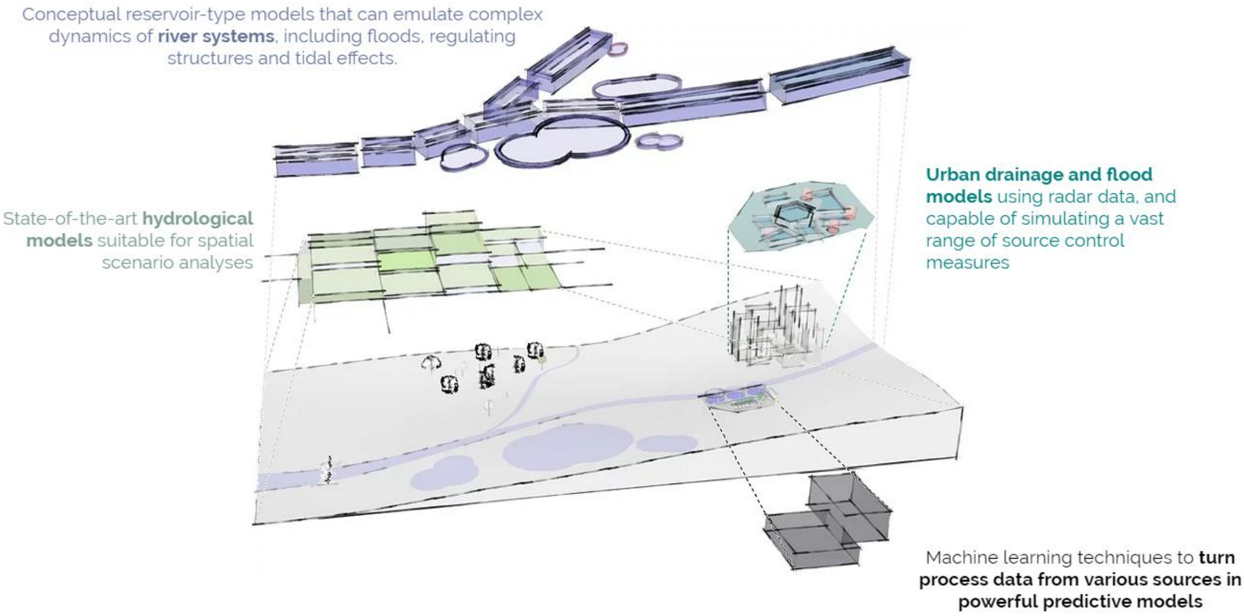
Name
SCAN: Software tool to evaluate Climate AdaptatioN strategies
Short description
The innovation "SCAN: Software tool to evaluate Climate AdaptatioN strategies" is a tool to evaluate and optimize water management strategies in the light of climate change and other trends (such as the increasing urbanization, population growth and water demand, …). The tool can be used to analyze the integrated water system, while focusing primarily on hydrology and hydraulics (rivers, floodplains and urban drainage systems). The tool will be tested by implementation for the Wijk Sint-Andries at Antwerp. The two BRIGAID innovations that so far will be tested at Antwerp, Hydroactive Smart Roof System (HYDROVENTIV) (innovator: Le Prieuré / vegetal ID) and WaterforHeaven (Hemel(s)water) (innovator: WIC), will provide test results and these test results will be used to conceptualize and simulate the effect of these innovations on reducing the urban flood risk and enhancing the local water availability. By an upscaling approach, the impact on the entire village will be simulated. This will be done for given assumptions on the numbers of different types of innovations that are feasible to be implemented at the entire area of the village and their locations. Also various combinations of different types of innovations will be evaluated. This will be done for both current (historical) and future climate conditions. 

Figure: Location of the Wijk Sint-Andries at Antwerp for which the tool will be implemented to evaluate the impact reduction of BRIGAID innovations (or combinations of innovations) reg. the urban flood risk and the local water availability
Sketch/Photograph of the Innovation

Which hazard(s) is the innovation designed to mitigate?
SCAN is a tool to evaluate and optimize water management strategies in the scope of climate change and other trends (such as the increasing urbanization, population growth and water demand, …).
How does the innovation work?
The proposed tool combines several highly innovative modelling approaches that simulate the response of hydrological and hydraulic systems (rivers, floodplains and sewer systems). The modelling approaches are flexible and modular, enabling the user to create models tailored to the intended applications. Also, the level of model detail is adaptable, thereby obviating the creation of overly complex and too rigid models. Different temporal and spatial scales can be covered. Several theoretical case studies were already performed. Details about the developed modelling approaches and case studies are published in several articles in international journals and presented at international conferences (e.g. Wolfs et al., 2015. Modular conceptual modelling approach and software for river hydraulic simulations. Environmental Modelling & Software 71, pp. 60-77) Due to their flexibility and very short calculation times, the created models are ideally suited for various applications requiring numerous or long term simulations, and integrated analyses: - Simulate the effect of climate scenario's, land use changes, etc. - Real-time applications, including intelligent control and warning systems - Evaluate and optimize strategies: from the installation of green roofs, up to the installation of large scale retention basins along rivers and sewer systems;

- Possibility to link the models with other user defined modules, enabling truly integrated analyses on catchment scale - Account for uncertainties and probabilistic analyses through ensemble runs
Added value / main differentiating element from conventional approach(es)
Software packages exist that can model parts of the water system. However, these packages suffer from major drawbacks, impeding their use for integrated analyses, and for analyses requiring a large number of runs (e.g. to optimize designs, or to quantify uncertainties through ensemble runs). More specifically, they employ hydrodynamic models, which are too slow and overly complex for many applications; In addition, these models are not opensource, impeding interfacing with other modules. Therefore, these packages are not direct competitors to our technology. Compared to other (conceptual and process-based/detailed) modelling approaches, our technology is: - more accurate and robust. We can deal with complex flow dynamics (e.g. reverse flow, backwater effects, …). Also, important elements can be modelled explicitly, such as dike levels, hydraulic structures and their controls, etc. - expandable and flexible architecture. Therefore, we can interface our models with other user-defined modules and easily add model elements (e.g. innovations from other partners, such as controllable green roofs, retention basins, infiltration/irrigation facilities, …) - Computationally very efficient: the models can simulate scenarios up to a million times faster than detailed hydrodynamic models, while the results are comparable.
Critical success factors / Limitations

Technology Readiness Level (TRL)

Our technology is TRL 4 to 5: the models underlying our tools have been validated in theoretical experiments and have been compared to other existing and commercially available modelling approaches (i.e. a proof-of-concept). The results of these tests have been published in international scientific journals. In addition, the models were already incorporated in several smaller scale projects (i.e. validation in relevant settings). However, to exploit the potential of the approach fully, additional large-scale testing in Belgium and abroad are necessary. Also, experience in operational settings is required to ensure the technology can be deployed efficiently. Such tests will also increase the market exposure, and can act as exemplary projects for potential end-users. In addition, the software tool that combines the different approaches is only a preliminary version. Additional developments are necessary to improve the robustness and user-friendliness.

Test plan

Note: Through BRIGAID, a Testing and Implementation Framework (TIF) was provided during the test cycle. This TIF provides guidelines for developing test plans to evaluate both the technical and social effectiveness of our innovation. However, the BRIGAID's TIF mainly focuses on "physical" *innovations and test sites, while the proposed innovation is a software tool. Therefore, the TIF is not entirely elaborated in this test plan.*

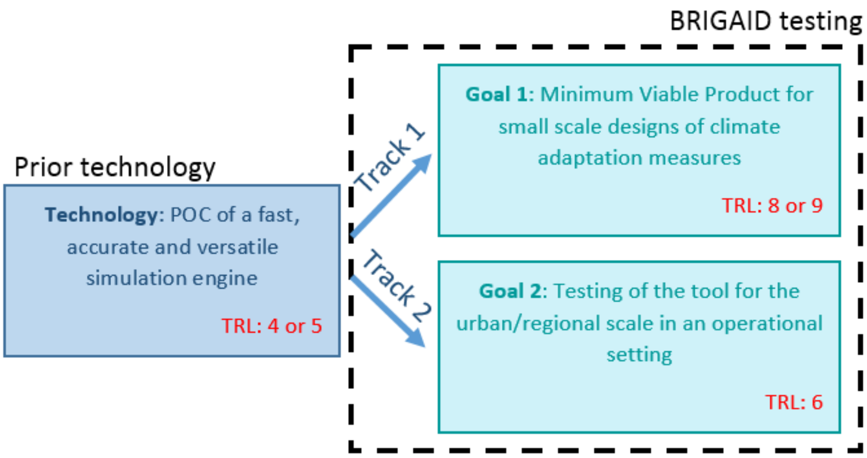
Goals

The innovation aims to quantify adaptation measures and strategies in the light of climate change. Examples of such measures are blue-green infrastructure (e.g. infiltration ponds, multifunctional buffers, …), (collective) rainwater harvesting, intelligent control, etcetera. While the underlying technology is the same for "small" and "urban/regional" scales (a fast and adaptive simulation engine to quantify hydraulic designs), the use of the technology is very different. In this test plan, a "small" system implies that the tool can be applied without any prior calibration of the tool's parameters. Hence, the technology can be applied directly as a "design tool" for building new infrastructure and adaptation measures. However, for applications at the "urban/regional" scale, the existing system and state must be mimicked before adequate strategies can be developed. This implies prior calibration of the tool's (model) parameters. Hence, the latter requires additional (and more complex) steps when applying the tool.

Therefore, this test plan sets two distinct goals:

- Goal 1: Translate the Proof-of-Concept (POC) technology into a Prototype (PRO), and subsequently into a Minimum Viable Product (MVP) for designing blue-green climate adaptation measures on a "small" scale;
- Goal 2: Test the technology for the "urban/regional" scale in an operational environment.

To reach these goals, two tracks are elaborated during the test phase. The first track aims to launch a MVP, while the second track tests the technology on a larger scale in operational settings. Both tracks are elaborated in more detail below. Although both tracks are described separately, both will be conducted simultaneously. Also, the results from one track can be used in another. For instance, the requiste market analysis when evolving from POC to MVP in Track 1 can also be used to adjust the testing in Track 2.

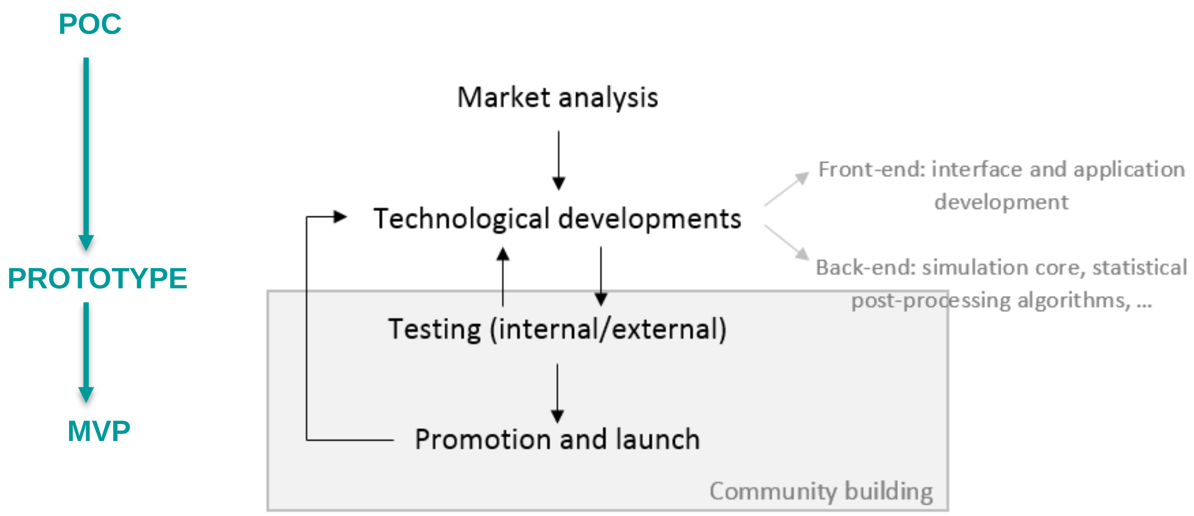


After the BRIGAID's testing phase, the tool developed in track 1 will be elaborated further using the results from track 2. This will follow the same cycle as track 1, leadng eventually to a new product launch. This second product development falls outside the scope of the BRIGAID test cycle.

Track 1: From POC to PRO and MVP: small-scale design tool climate adaptation measures

The first track aims to translate the technology into a commercial Minimum Viable Product (MVP). This MVP should enable the end-user to quantify the impact of climate change on small scale water systems in terms of mass balances, overflows and floodings. Small scale water systems refer to blue-green solutions at the level of a house, industrial plant or allotment, and include infiltration ponds, buffers, rainwater harvesting, etcetera.

To achieve this goal, a market analysis is required to identify needs and opportunities, the existing technology must be improved and new developments are required, testing is required of the tool by internal and external partners, and the tool should be promoted and launched. The following scheme denotes the most important steps in this process.



Essential in the BRIGAID testing phase will be the establishment of a **community** around our innovation, including at least 10 local partners that are key for a successful product launch. Such partners will include sewer management companies, engineering firms, authorities (sewer and water systems), and expert platforms. Part of this community will act as testing panel to (1) audit the functioning of the system (see if it is technically correct and compliant with their needs), (2) provide feedback for further improvements, and (3) to pitch new ideas and applications. In addition, the community will also be leveraged to promote the innovation.

The testing phase will try to obtain a **prototype** 3 months after the start of the test program that can be distributed among (part of) the community. The prototype will have the same application form and basic functionalities as the final intended MVP. Based on feedback and tests, this prototype will be iteratively adjusted and distributed again amongst the community in cycles of 1.5 months. After sufficient iterations and testing (at least 3), this results in a **minimum viable product**.

Simultaneously, the team will participate at professionaly oriented events and workshops to promote the tool. These promotional activities will start when the testing phase begins, and last through the entire testing phase.

During this test phase, community building will focus mainly on Belgian local partners. This to ensure that the MVP fully addresses the needs of (and opportunities within) a specific end-user group. Indeed, international clients may have different (conflicting) needs, such as for instance other reporting standards, model customs, inputs (such as rainfall data), etcetera. By focusing solely on one specific market in this test phase, we obviate the difficulties of such conflicting interests. However, after the test phase, we plan to roll out the tool internationally. Therefore, the tool will already be multi-lingual (Dutch, French and English), and be built on a modular and easy to adapt framework. This enables the team to easily add new functionalities for different market segments. The BRIGAID community will used to promote the tool internationally.

Note that prior to this testing phase, a short market analysis was conducted through contacts at KU Leuven (BRIGAID partner). From this, a first short list of required technological developments with highest priority was selected (internal reporting only). This list will lateron be completed with new insights of the BRIGAID testing phase.

Track 2: Testing urban/regional scale in operational settings

Apart from developing a MVP in track 1 (up to TRL 8 or 9, thus including commercialization), technical testing is carried out in track 2 to test the technology on a larger urban/regional scale in operational settings. The goal is evolve from the current TRL 4 and to reach TRL 6 or 7 after the test phase. This means that the tool can be used “internally” (i.e. by skilled persons with a certain level of expertise through partnerships) to carry out consulting projects, but external parties cannot use the tool yet (hereto, a TRL of at least 8 is required). Further developments up to TRL 8 or 9 will be carried out after the testing phase (so outside the scope of this test plan).

Testing the software on the urban/regional scale in operational settings will focus on the following technical elements:

- Ensuring that the hydraulic model (in the tool) will be able to mimic the existing water system in a simplified yet consistent manner. Hereto the model must be calibrated to data and or existing (more detailed and often fragmented) models. If needed, new model structures will be developed and added to the framework.
- Making the tool and model compatible with relational database management systems (DBMS) such as SQL. This enables the tool to tap into (real-time) sensor data, and store model simulation results in databases for future (external) use.
- Developing visualizations to communicate both the model structure (the components of the model underlying the tool in general) and the results. This include Cloud solutions to enable external partners to view and interact with the results without the use of any software.
- Ensuring that the tool can deal with various adaptation strategies.

Note that for reaching TRL 8 or 9, additional technological developments are necessary, such as API and GUI development. Such developments fall outside the scope of this test phase.

The above technical elements will be tested and elaborated during the test phase by executing different applications. In this test plan, three specific applications are proposed, of which two are other BRIGAID innovations from the first test cycle:

- HYDROVENTIV: intelligent green roof. SCAN aims to upscale the results from the test phase of the innovation HYDROVENTIV. The green roof will be installed at one location in Antwerp and be intensely monitored over a period of one or more years. A SCAN model will be developed of the sewer system of the city of Antwerp and the HYDROVENTIV green roof will be implemented in this SCAN model. The following questions will be answered through SCAN using long term simulations (100 years of rainfall):
    - Can the intelligent green roof have an impact on urban floods? How much roofs are needed?
    - Can these green roofs counter the effects of climate change on urban floods? To what extent?
    - Should the design of the intelligent green roof be altered (more storage, faster emptying, …)?
    - What is the optimal control strategy of the green roof?
    - Does the green roof have an impact on city heat stress?

  - Does this green roof have an impact on the WWTP (fewer runoff reaches the WWTP)?
  - Etc.
- Water from Heaven ("Hemelswater"). Similar to the application above involving the HYDROVENTIV green roof, a SCAN model of the city of Antwerp will be used to upscale the effects of the Water from Heaven innovation. Through this upscaling, the impact of the innovation can be assessed for a much larger area.
- Policy making in Flanders for the "Beleidsplan Ruimte Vlaanderen". This policy plan investigates different spatial planning scenario's, including a ban on additional pavement in Flanders and various land use change restrictions. In this application, we can use a SCAN model on the level of Flanders to investigate the impact of such policy on urban floods and WWTPs across Flanders. This policy plan also draws much media attention. If SCAN succeeds in translating the policy concepts into numbers for the selected KPI for Flanders, we could profit from the media attention to promote our innovation both nationally and internationally.

To execute these applications, a fixed procedure will be followed for each:
- Step 1: Collection of data to calibrate (and validate) the model (see step 2). This involves data collection on the urban sewer system's infrastructure (pipes, buffers, pumps, …), connected areas (contributing area, …), recently flooded areas, etcetera. The city of Antwerp was deliberately chosen for 2 applications as a detailed full hydrodynamic InfoWorks ICM model is available. Such detailed model yields enough information to calibrate and validate a SCAN model. For the third application, the whole of Flanders is considered. As information on every single sewer system is unavailable, a more "conceptual" approach will be followed, leading to more simplified SCAN models. These two extreme situations (much versus very little information available) ensures that SCAN can be tested extensively.
- Step 2: Calibration and validation of the SCAN model. The goal of this step is to ensure that the SCAN model matches the current state of the system accurately. This test plan analyses of the current technology succeeds in mimicking the system, or additional technical developments are needed.
- Step 3: Implementation of adaptation measures and strategies. Based on the application, different measures will be implemented (a controllable green roof in various configurations in the first application, collective rainwater harvesting and reuse in the second application, and widespread use of various blue-green measures or land use changes on policy level).
- Step 4: Simulations, analysis and dissemination of the results. SCAN uses long term simulations of 100 years of rainfall, and optionally perturbed for different climate scenarios. These millions of simulation data (a time step of just 30 seconds is used during simulations) will be translated into tangible results and KPI's using statistical post-processing algorithms. Different communication strategies and visualization options will be tested and presented for end-users.

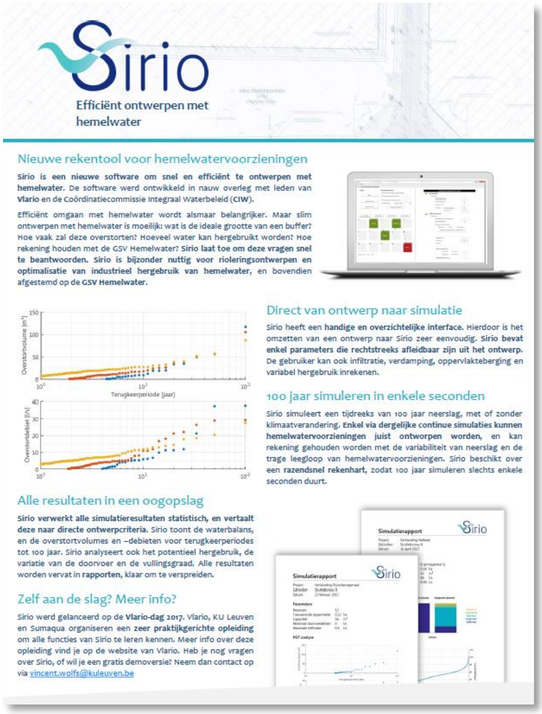
Testing results

To distinct the valorization of the technology on the "small" scale, versus that on the "urban/regional" scale, the innovation team decided to use different product names. Therefore, the SCAN innovation was separated into the:
- **Sirio** product, a tool focusing on the design of climate adaptation measures on a small scale
- **SCAN**, the innovation focusing on the urban and regional scale.

Hence, track 1 focuses on the testing and developments for Sirio, while the second track focuses on SCAN.

Track 1: From POC to PRO and MVP: small-scale design tool climate adaptation measures (“SIRIO”)

From the start of the BRIGAID testing phase, a **commercialization strategy** was set up that includes “product branding”. Therefore, a logo was created for Sirio together with informative leaflets that can be distributed at events.


Sirio
Efficiënt ontwerpen met hemelwater

Nieuwe rekentool voor hemelwatervoorzieningen

Sirio is een nieuwe software om snel en efficiënt te ontwerpen met hemelwater. De software werd ontwikkeld in nauw overleg met leden van **Vlario** en de Coördinatiecommissie Integraal Waterbeleid (**CIW**).

Efficiënt omgaan met hemelwater wordt alsmaar belangrijker. Maar slim ontwerpen met hemelwater is moeilijk: wat is de ideale grootte van een buffer? Hoe vaak zal deze overstorten? Hoeveel water kan hergebruikt worden? Hoe rekening houden met de GSV Hemelwater? **Sirio laat toe om deze vragen snel te beantwoorden. Sirio is bijzonder nuttig voor rioleringsontwerpen en optimalisatie van industrieel hergebruik van hemelwater**, en bovendien afgestemd op de **GSV Hemelwater.**

Direct van ontwerp naar simulatie

Sirio heeft een **handige en overzichtelijke interface.** Hierdoor is het omzetten van een ontwerp naar Sirio zeer eenvoudig. **Sirio bevat enkel parameters die rechtstreeks afleidbaar zijn uit het ontwerp.** De gebruiker kan ook infiltratie, verdamping, oppervlakteberging en variabel hergebruik inrekenen.

100 jaar simuleren in enkele seconden

Sirio simuleert een tijdreeks van 100 jaar neerslag, met of zonder klimaatverandering. **Enkel via dergelijke continue simulaties kunnen hemelwatervoorzieningen juist ontworpen worden,** en kan rekening gehouden worden met de variabiliteit van neerslag en de trage leegloop van hemelwatervoorzieningen. Sirio beschikt over een **razendsnel rekenhart,** zodat 100 jaar simuleren slechts enkele seconden duurt.

Alle resultaten in een oogopslag

Sirio verwerkt alle simulatieresultaten statistisch, en vertaalt deze naar directe ontwerpcriteria. Sirio toont de waterbalans, en de overstortvolumes en –debieten voor terugkeerperiodes tot 100 jaar. Sirio analyseert ook het potentieel hergebruik, de variatie van de doorvoer en de vullingsgraad. Alle resultaten worden vervat in **rapporten,** klaar om te verspreiden.

Zelf aan de slag? Meer info?

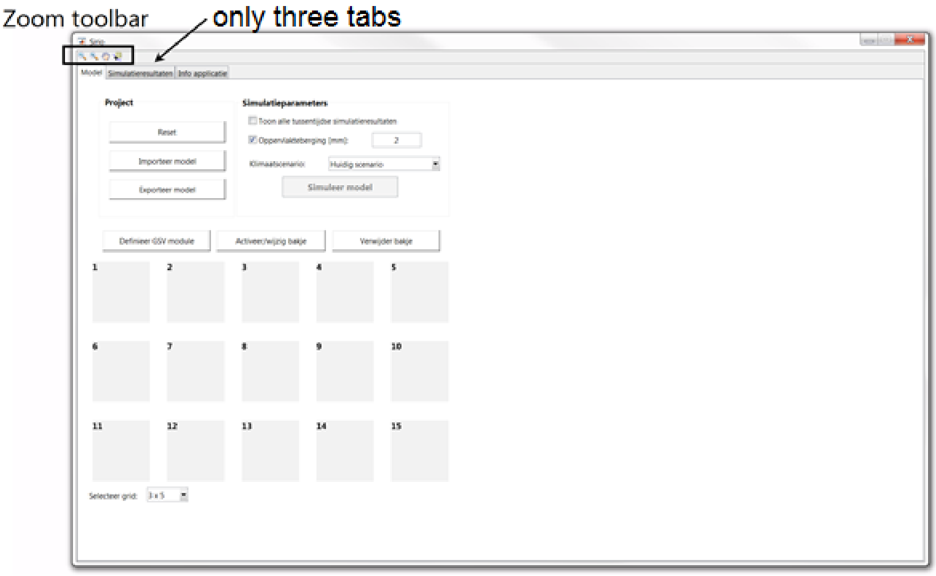
Sirio werd gelanceerd op de **Vlario-dag 2017.** Vlario, KU Leuven en Sumaqua organiseren een **zeer praktijkgerichte opleiding** om alle functies van Sirio te leren kennen. Meer info over deze opleiding vind je op de website van Vlario. Heb je nog vragen over Sirio, of wil je een gratis demoversie? Neem dan contact op via vincent.wolfs@kuleuven.be

Also, a **community** of (potential) end users around the product was built. Today (January 2018), this community includes amongst others:

- Sewer management companies: Infrax, Aquafin, Pidpa and Farys
- Government: VMM, Provincie Oost-Vlaanderen, Provincie Antwerpen, Provincie Limburg, Stad Leuven, Agentschap Wegen en Verkeer, …
- Consultation/supporting platform Vlario
- Engineering firms: CITV (Walloon region), 20+ companies from Flanders
- Consulting firm KPMG
- International: Retenja (Poland), RioNED (the Netherlands), Steinhardt (Germany)
- …

Within this community, a smaller technical steering group was erected to support the testing and new developments of the prototype. This technical steering group consists of engineers from Infrax, Aquafin, Pidpa and Farys. They all participate voluntarily. This group regularly meets to discuss new functionalities proposed by other end-users. This steering group also tests new these new functions before being released to the public.

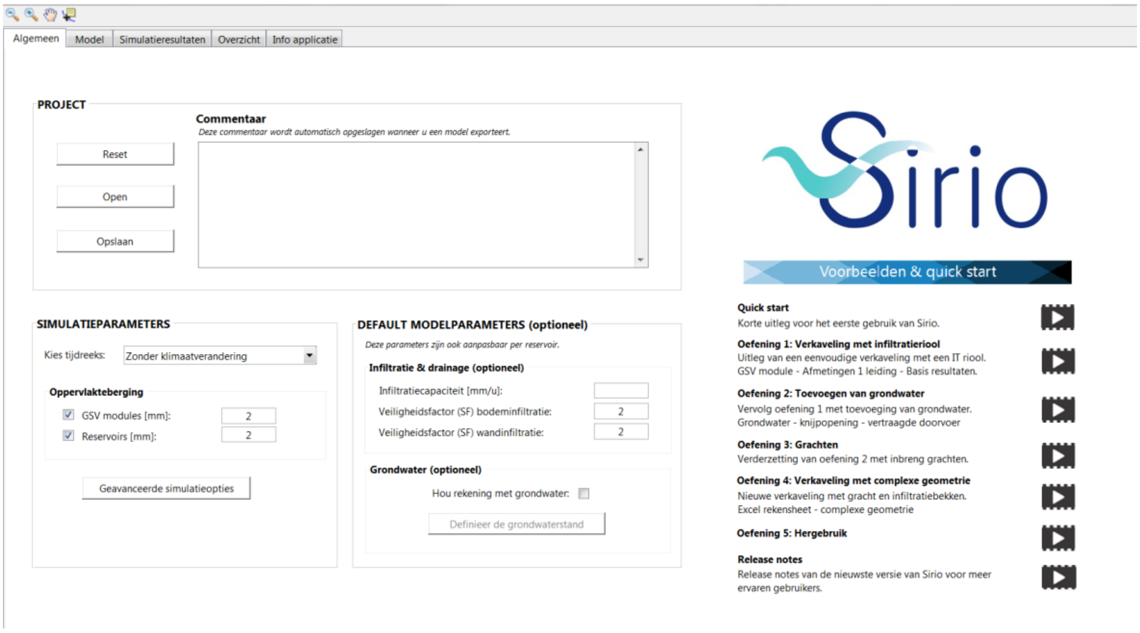
A first basic **prototype** was developed and made available to the steering group around January 2017.



FIRST PROTOTYPE (January 2017)

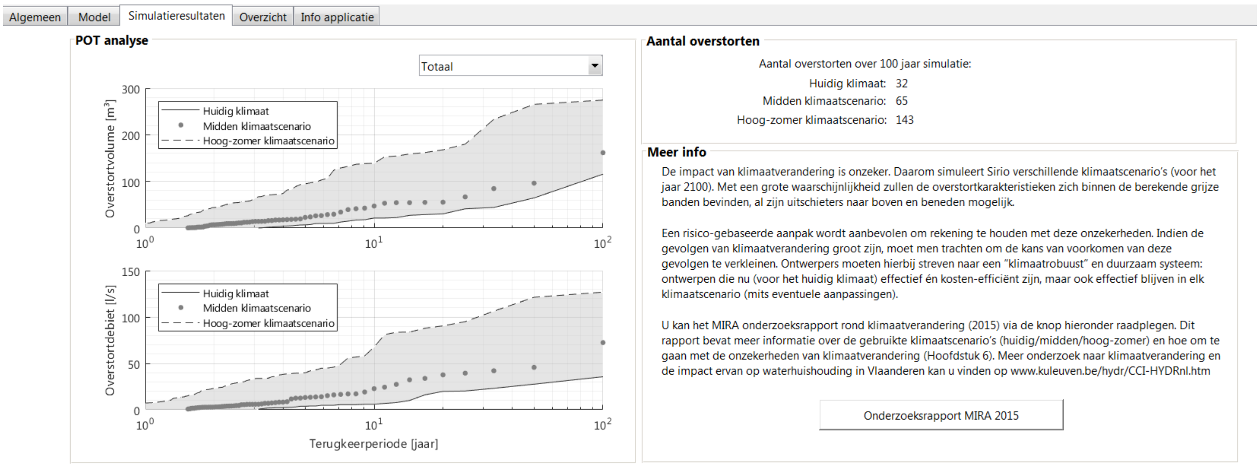
Later, new prototypes were launched for testing by the technical committee. The interface was translated from Dutch to English and French, and a manual was created (109 pages). Recently, instruction videos were added to the interface. This facilitates the first use of the software.

Most recent interface (of the MVP)



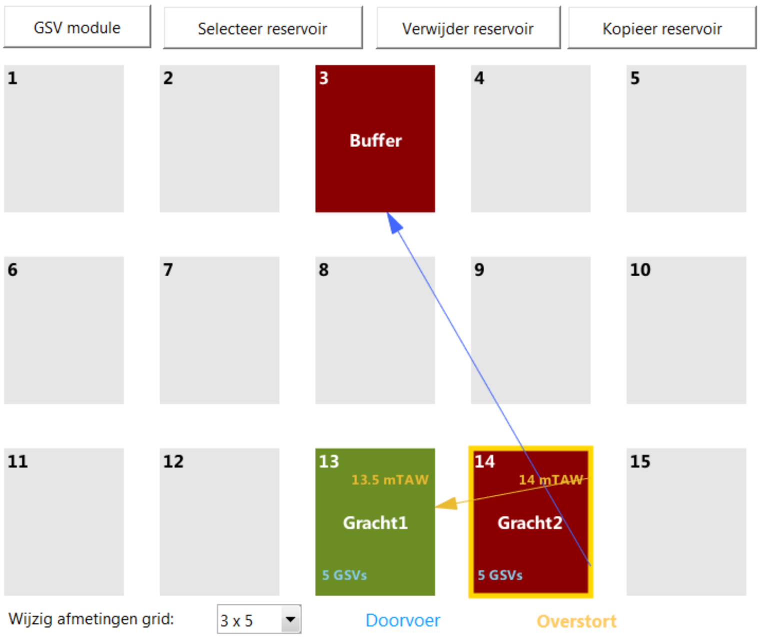
Also, a climate change interface was added to the software. It allows end users to simulate the impact of climate change on their design.

Interface to see the impact of climate change on a specific hydraulic design

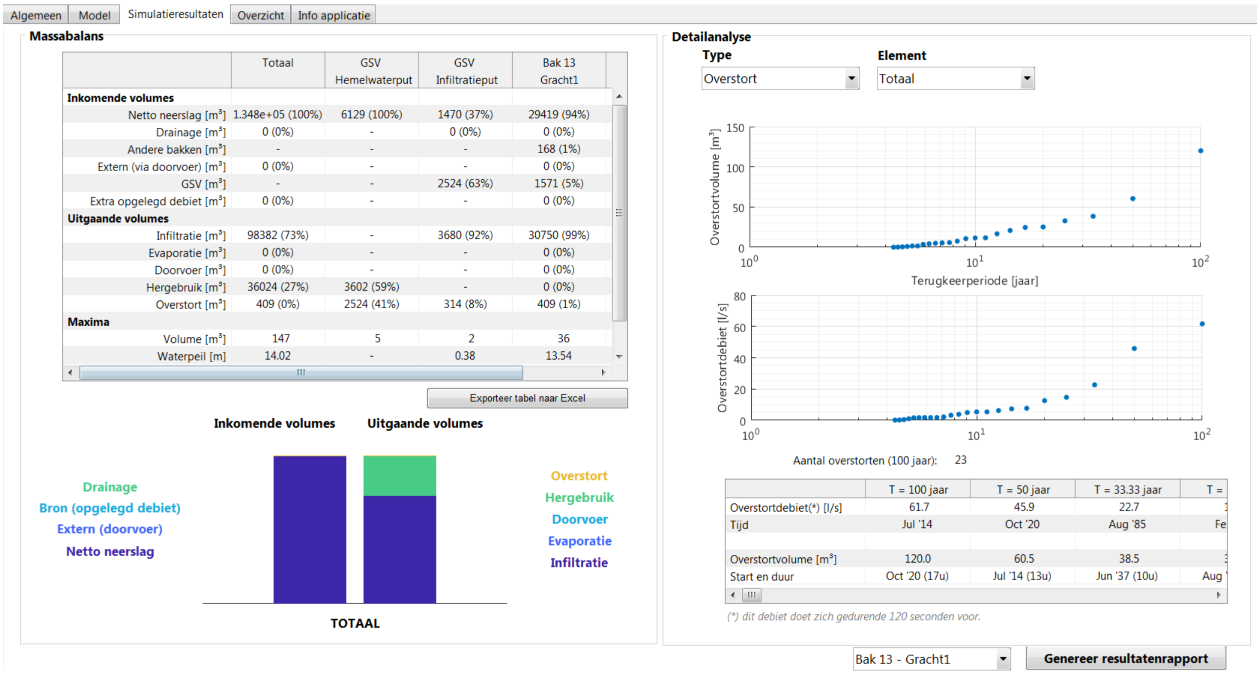


	T = 100 jaar	T = 50 jaar	T = 33.33 jaar	T = 25 jaar	T = 20 jaar	T = 16.67 jaar	T = 14.29 jaar	T = 12.5 jaar	T = 11.11 jaar
Overstortdebieten [l/s]									
Huidig klimaat	35.6	27.6	23.1	20.2	19.8	16.1	10.0	7.8	6.8
Midden klimaatscenario	72.4	45.7	42.0	39.4	37.6	33.8	32.3	27.4	24.3
Hoog-zomer klimaatscenario	126.8	121.3	106.3	95.0	90.5	87.9	83.8	83.6	81.0
Overstortvolumes [m³]									
Huidig klimaat	115.5	64.6	44.1	41.2	30.4	28.8	27.2	22.3	21.5
Midden klimaatscenario	161.5	96.2	84.5	66.8	55.5	55.1	54.4	54.4	53.2
Hoog-zomer klimaatscenario	274.4	265.2	233.1	180.0	167.8	161.8	158.8	154.4	152.7

The current model interface was developed after multiple iterations with the Sirio community. The result is an easy to use, interactive and clear overview of the different model components. The interface acts as plug-and-play, where new model elements can easily be added, modified or removed. Future developments will focus on the inclusion of GIS.



The simulation results are presented in a scheme that was elected after consultation with potential and actual end users. The simulation results include a mass balance report (indicating the origins and uses of water), an overflow analyses, rainwater harvesting analysis, analyses of drought conditions, etc. Also, a standard report was created after consultation with the sewer management companies Infrax, Aquafin, Farys and Pidpa. They can ask end users for this report, which is generated automatically with a single button click.



In the **back-end**, new functionalities were added. After thorough testing, it was decided to build a **completely new and more advanced simulation engine**. A new simulation engine would allow additional functionalities, faster simulations and facilitates later addition of new functions. This new simulation engine has the additional following new features compared to the first prototype:

- Simulation of drowned overflow (overflow can have positive and negative flows).
- An adaptive and intelligent time step. Sirio automatically determines the most optimal time step on the fly: during dry periods, Sirio applies a larger time step than average, while a small time step is used during periods with high rainfall intensities or when the system dynamics indicate instabilities.
- A set of post-processing algorithms was converted to C++ programming language and implemented in the simulation core itself. This simplifies and speeds up the post-processing significantly.
- Enhanced flexibility to model different systems (more options to connect separate model elements etc.)
- …

These front and back end testing and developments led to a first **minimum viable product** (MVP) around June 2017. A second version of the MVP Sirio (including the newly built simulation engine) was rolled out at the end of November 2017.

To promote the software and to improve the product – market fit, Sirio was showcased at **many events and workshops**, mainly organized through Vlario (part of the small steering committee):

- Vlario-day, March 2017, the biggest sewer technology event in Belgium: presentation (audience of 500+ professionally-oriented people and media coverage) and boot where people could try the software for the first time in public (prototype).
- Presentations for clusters of municipalities, organized in:
  - Keerbergen (Province Vlaams-Brabant), 28th September 2017
  - Wommelgem (Province Antwerp), 3rd October 2017
  - Gent (Provincie Oost-Vlaanderen), 5th October 2017
  - Heusden-Zolder (Province Limburg), 10th October 2017
  - Brugge (Province West-Vlaanderen), 24th October 2017

- Dedicated training sessions. Each session comprised one full afternoon or evening in which the participants could test the software and give feedback. Such training sessions were organized on the following dates, and attended by 95 people from different companies:
    - 25th April 2017
    - 27th April 2017
    - 4th May 2017
    - 10th May 2017
    - 4th December 2017
    - 6th December 2017
    - 7th December 2017

In March 2018, Sirio will be presented at the Stormwater conference in Gdansk, Poland. This will be the first international event at which Sirio is presented and can be tested by the public. Sirio is also presented through the website www.sumaqua.be/sirio

Today, Flanders counts more than 50 companies and organizations that use Sirio to design small scale water systems and blue-green climate adaptive solutions. Thus, we conclude that track 1 of our BRIGAID test project was a huge success. In less than one year, we succeeded in translating the technology from a TRL 4/5 (proof of concept) into a commercial product (TRL 8/9).

Track 2: Testing urban/regional scale in operational settings (“SCAN”)

This second track involves testing of and developments for SCAN for three applications (urban/regional level):

- Application 1: upscaling the effects of the HYDROVENTIV innovation (also in the BRIGAID test cycle) to the level of the city of Antwerp
- Application 2: upscaling the effects of the Water from Heaven (Hemelswater) innovation (also in the BRIGAID test cycle) to the level of the city of Antwerp

- Application 3: Policy making for the “Beleidsplan Ruimte Vlaanderen”: assess the impact of land use changes and related policy regulations on urban floods and WWTP across Flanders.

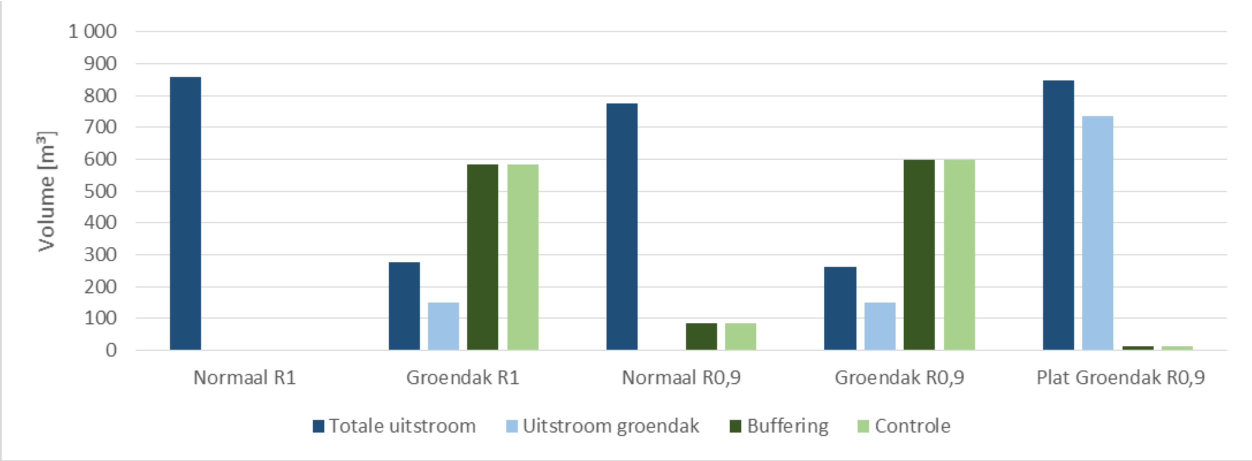
Applications 1 and 2

As the testing results of the HYDROVENTIV and Water from Heaven innovations are not yet available at this stage, the innovators of SCAN currently implemented similar systems in the hydraulic models for upscaling. This does not affect the validity of the test program for SCAN. The results of the HYDROVENTIV and Water from Heaven will be implemented in a later stage.

Hereby, detailed InfoWorks ICM models of part of the city of Antwerp were used besides the conceptual SCAN approach to gain additional insights into the system of Antwerp. The detailed InfoWorks ICM model of the city of Antwerp was elaborated with 2D zones to represent urban floods more accurately. Also, the model results were validated based on data of recent flood events assembled by the fire brigaid of Antwerp. A validation analysis showed that the InfoWorks ICM model delivers relatively accurate results, although local deviations are possible. Most zones that are flood prone in the InfoWorks ICM model effectively flood regularly in reality.

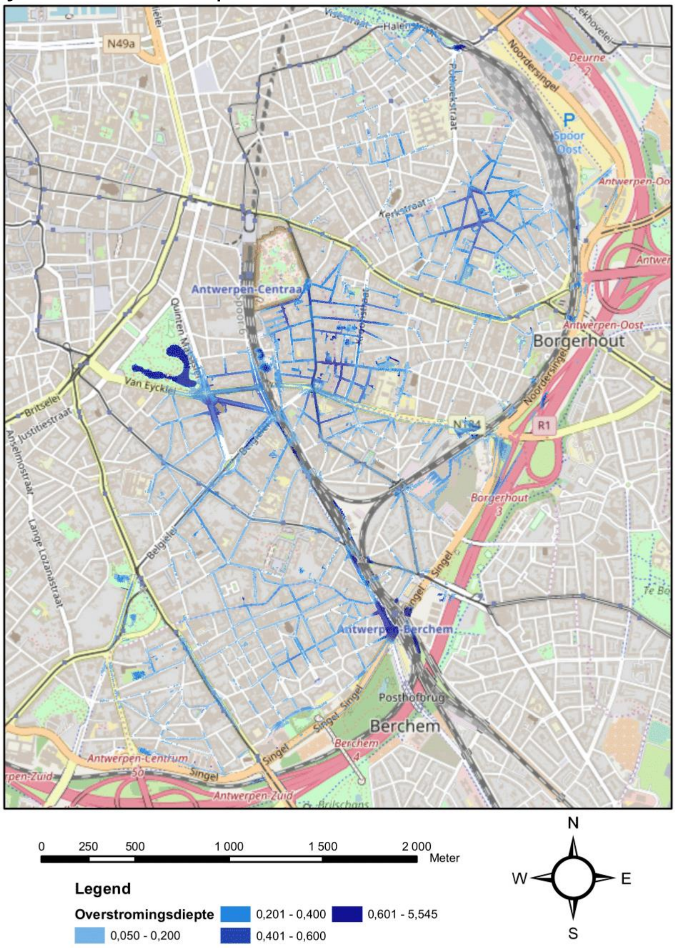
Next, different configurations of green roofs were implemented in the models and tested. Locations where green roofs can be created in the future were identified through maps made available by the city of Antwerp.

Different configurations of the green roof were simulated and analyzed individually, and then implemented in the larger model covering the historical part of the city of Antwerp (within the highway).



The results were also linked to GIS (QGIS software). Currently, a 2D depth spreading algorithm is being tested to produce more accurate urban flood maps. This algorithm will be linked to the simulation core representing the underground system after completion.

First results of flood maps of the city of Antwerp after implementing green roofs (InfoWorks).



The results showed that source control measures such as green roofs can be implemented, but **further testing is needed**. Therefore, we will continue to test our innovation. In the next months, the following items will be added/tested further:

- Closer and more extensive calibration and validation of the SCAN model to the sewer system of the city of Antwerp.
- GIS depth spreading algorithm to produce more realistic urban flood maps and bidirectional interaction between the surface and subsurface in simulations.
- Implementation of the results of the HYDROVENTIV and Water from Heaven in the model.

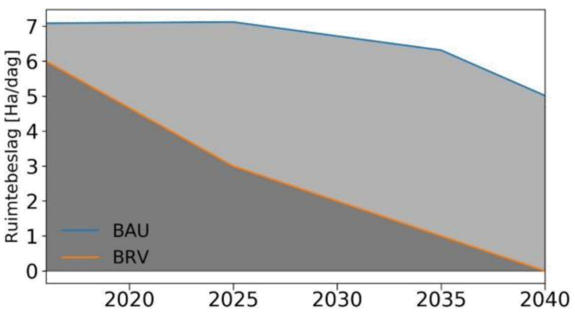
- Simulate climate change scenarios to quantify the impact of source control measures on urban flood risks.

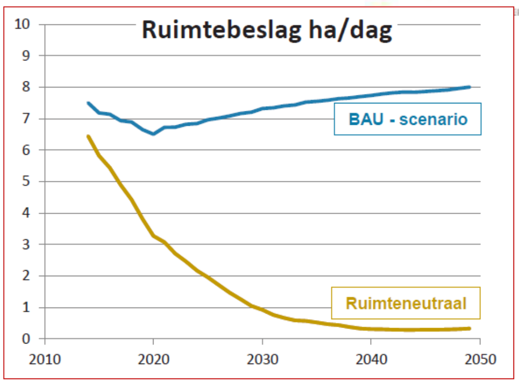
Application 3

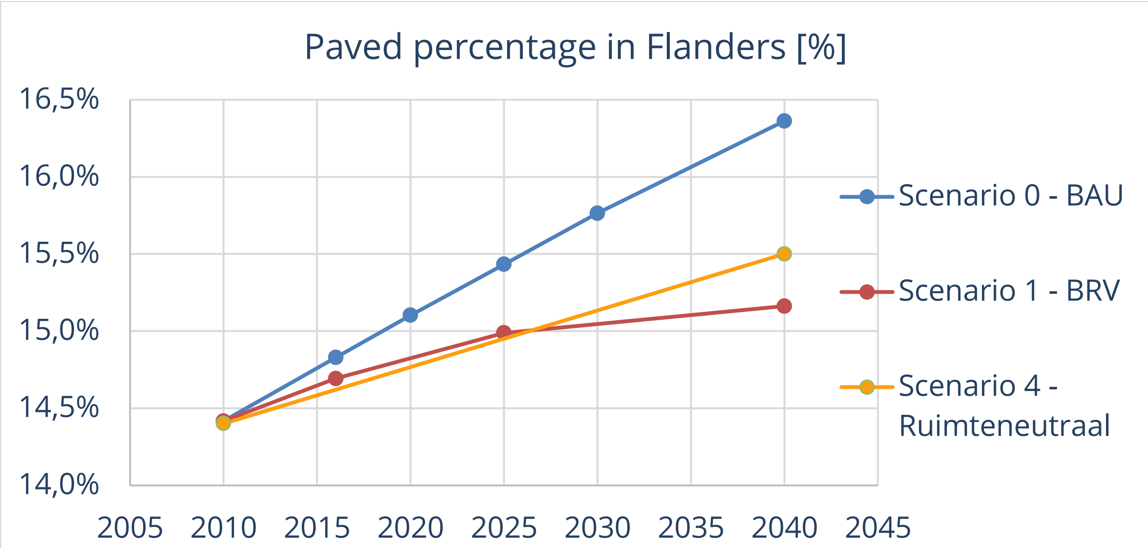
The third application quantifies the impact of land use changes on flood risks amongst Flanders. Policy makers currently investigate different new regulations. In this application, we tried to translate different scenarios into tangible results for the regional level of Flanders for the increased risk of flooding (i.e. the relative increase of flood frequency for different scenarios) and the required capacity increase to maintain the same flood safety. Both indicators will be assessed in a conceptual manner (using SCAN simulations) for the whole of Flanders as detailed information on each sewer system is unavailable.

Hereto, we first developed multiple spatial scenarios for the whole of Flanders based on discussions with Ruimte Vlaanderen (policy makers) and sewer managers in Flanders. The scenario creation focused on population maps, and maps with land uses and pavement. The following scenarios were created for time horizons 2015 (considered to be current state), 2020, 2025, 2030 and 2040:

- Business as usual ("BAU"): no major policy changes. Hence, land take will continue at the same rate as the last 5 years. Residential areas and industry will have the same ratio of paved and pervious areas as current. These maps were supplied by the Flemish government.
- BRV: "Beleidsplan Ruimte Vlaanderen". This is the scenario currently being considered by the Flemish government. This scenario drastically reduces new land take (-50% by 2025 and -100% by 2040; the latter meaning that there will be no new land take by 2040). The pavement in open spaces (agriculture, forestry and nature reserves) should drop by 20% by 2050, and the paved area for hard destinations (residential areas, industry, transport infrastructure, ports, etc.) should maintain the level as in 2015.
- "Ruimteneutraal scenario". This scenario reduces the new land take even further than the BRV scenario, while there are less strict pavement goals as the BRV. These maps were also provided by the Flemish government.

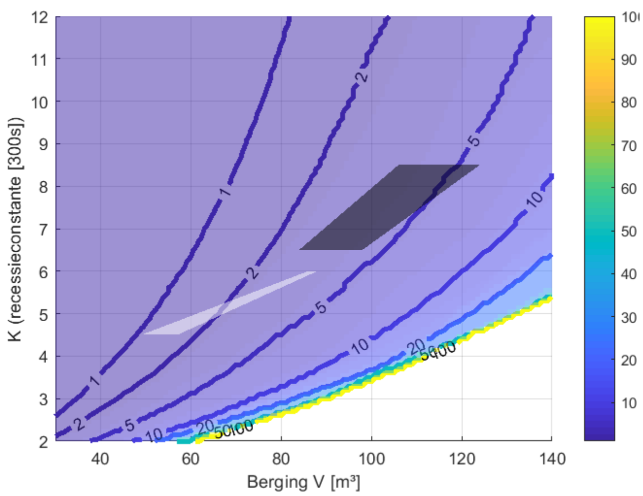


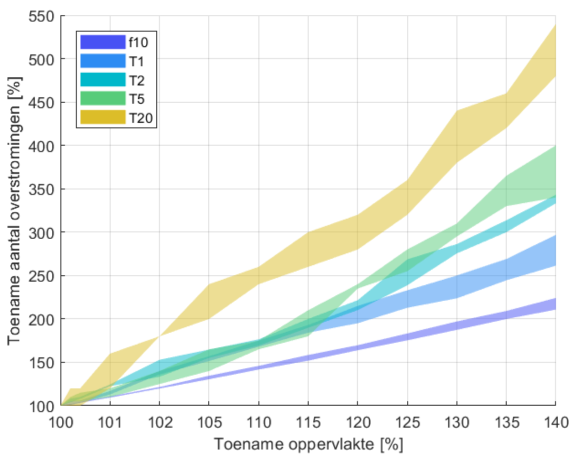




Then, hydrodynamic model simulation results (InfoWorks ICM) were analyzed for two case studies in Flanders: Kortessem and Merksem. A conceptual SCAN model with few adaptable parameters was successfully calibrated for these two case studies. The calibration of the SCAN model focused on composite storms with a frequency of occurrence between 10 times a year (f10), and a return period of 20 years. The results showed that a simple SCAN model with only two parameters managed to predict the flood frequency sufficiently accurate.

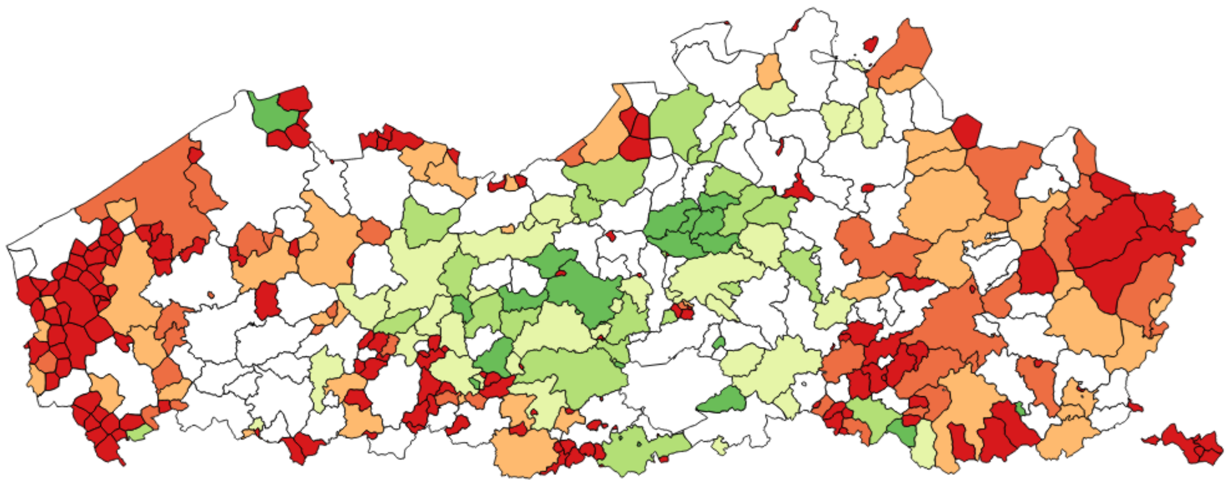
Next, the SCAN model was scaled up to the level of Flanders. However, detailed information on every sewer system in Flanders were lacking. Therefore, the two parameters of this conceptual SCAN model cannot be determined precisely a priori. To overcome this issue, a sensitivity analysis was performed to assess the impact on the two selected indicators (i.e. increase in flood frequency and the requisite increase in sewer capacity to maintain the same level of flooding) for systems with different SCAN parameterizations, but similar safety levels (of floodings). Based on information on recent flood events, the safety level of each sewer system in Flanders can be determined.





The results showed that, given the safety level of the current sewer system, both indicators can be quantified. The uncertainty on the parameterization is small compared to the overall impact of the land use change. However, it was also seen from the results that the current safety level of the sewer system is relevant for the indicator quantification, and needs to be taken into account. This is, however, easily possible with the SCAN approach.

Hereafter, the developed SCAN model was then linked to the GIS interface in which the spatial scenarios for population and pavement were developed (QGIS). Next, simulations were conducted using 100 years of rainfall data, followed by a statistical post-processing of the results. These results were then converted back into the GIS interface. Hence, a bidirectional coupling with the GIS platform was established. In addition, the results were published online in interactive maps through the QGIS Cloud environment. This enabled other parties to consult the created maps during meetings and consultation rounds.



From this 3rd application, we conclude that:

- The SCAN model in its current form is able to represent a sewer system on a regional scale in a highly schematic way for top-level strategic planning.
- The SCAN model can be used to quantify the impact of land use change scenarios on flood frequencies.
- A GIS link was established, in which temporal and spatial information from GIS (in this case changing contributing areas for every sewer system in Flanders) was used as input for the SCAN simulations. Hereafter, results of SCAN were translated back into GIS.
- The results from SCAN were published in the cloud using QGIS Cloud in the form of interactive maps.

Further investigations will focus on making the GIS interfacing automatic, and adding new features to the cloud environment.

The results will also be presented at the Vlario-day 2018 (with media coverage). This enables us to promote the SCAN approach.

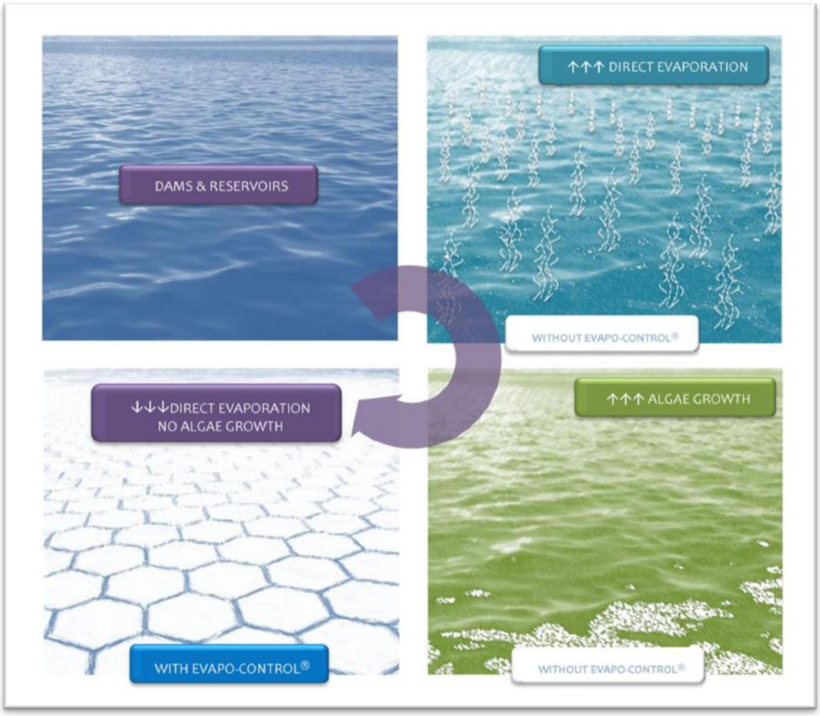
2. Innovation: EVAPO-CONTROL

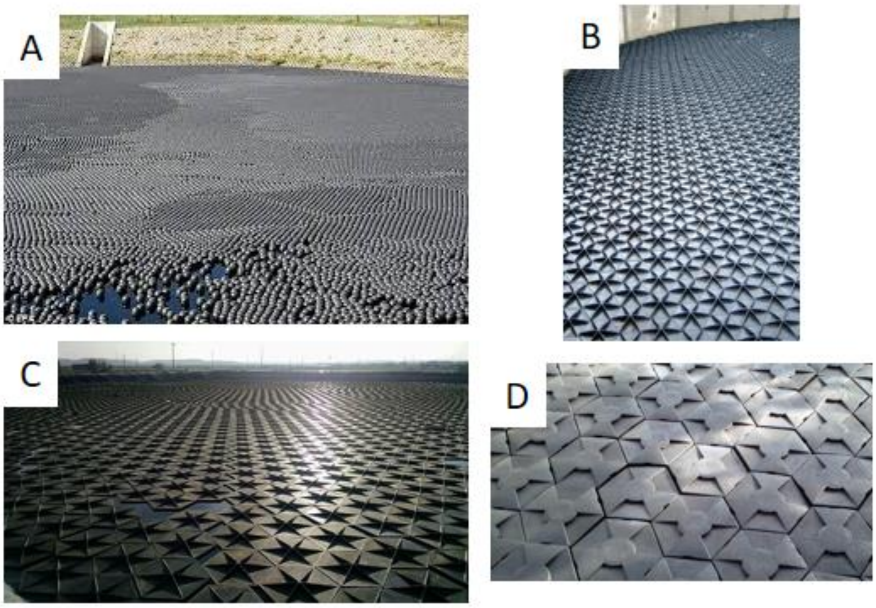
Innovator: ARANA Water Management S.L. (external innovator)

Contributing authors: Jose Miguel Gimeno Martínez (ARANA)

Innovation description

The description of EVAPO-CONTROL below is also available from the Climate Innovation Window, http://climateinnovationwindow.eu/innovations/evapo-control

Name
EVAPO-CONTROL
Short description
Polyethylene modular floating covers to suppress evaporation losses and algae growth in water reservoirs
Sketch/Photograph of the Innovation
EVAPO-CONTROL®  Examples of modular floating covers. A) Armor BallTM by AWTT; B) Hexa-Cover(R) by LemTecTM; C) AquaLoc by Sentinel Manufacturing; D) HexprotectTM by AWTT; Furrow diking concept:



Which hazard(s) is the innovation designed to mitigate?

Droughts:

In many arid and semi-arid regions, a primary source of water is from large numbers of small farm dams. Consequently, minimising water losses from such dams is fundamental to the ongoing economic viability of farm production. Construction costs and the energy intensity of pumping water long distances make supply of water from more well-watered regions infeasible (Hassan et al., 2015). Proposed open water evaporation mitigation techniques include wind sheltering by trees (Hipsey, 2002), reservoir deepening (Pereira et al., 2002), sand storage dams/managed aquifer recharge (Wipplinger, 1958), chemical monolayers(Barnes, 1986); continuous coverings of the entire reservoir (Finnand Barnes, 2007) and floating devices (Burston, 2002).

Floating covers include modular and flat sheet covers that float on the water surface. They reflect a proportion of the incoming solar radiation and act as physical barriers to the passage of water vapourboth vertically and horizontally. Unlike suspended covers, the floating covers are supported by thewater itself. Floating covers have been designed predominantly for small storages. Various colours, materials and shapes have been applied in practice. Modular covers predominately donot fully cover the water surface, which allows water to vaporise through the uncovered gaps. As aresult, the energy input is only partially reduced and wind can still blow away humid air. The water-saving efficiency is dependent upon the design and the shape of themodules, as well as the material (Yao et al., 2010).

A thorough evaluation of the full range of evaporative loss reduction technologies including floatingmodules and suspended shading covers has been detailed by the National Centre for Engineering inAgriculture (NCEA) (Howard and Schmidt, 2008).

Themes to which the innovation applies: Agriculture, Water availability, Water quality

How does the innovation work?

Hexagonal floating modules of 0.06 m^2 are placed in the water reservoir one by one. Once modules are joined each other up to cover all the water surface, water losses due to direct evaporation are reduced, and the penetration of sunlight and photosynthesis (and hence algae

growth) are prevented. Modules adapt well to water level changes by staying in the irrigation reservoir slopes. Overall, the system is expected to bear wind speeds up to 90 km/h and have a minimum lifespan of 10 years.
Added value / main differentiating element from conventional approach(es)
Modular units are lighter than other existing floating modular covers, and their implementation in reservoirs is easier than other floating membranes and shade covers. Maximum effectiveness of EVAPO-CONTROL has been achieved combining an optimal modular design with an advanced polymers transformation process. These advantages make the manufacturing of modules cheaper and more economically feasible than other current solutions. Floating modules adapt to any reservoir geometry -already built or under construction-. No additional engineering modifications in reservoirs are required.
Critical success factors / Limitations
A loss of performance may be expected at wind speeds higher than 90 km/h (maximum physical load), or for periods of use greater than 10 years (although the expected lifespan of the polymer is minimum 15 years). The modules are engineer-designed to come back to their performance position after a wind event. Modules do rotate on their axes, never moving out of reservoir, and come back to their original position after wind event.

Desk study

Summary

In this section, the most relevant issues related with EVAPO-CONTROL are provided.

Indicator	Desk Study Questions
Technical Effectiveness **refers to the intended capacity of the innovation to reduce risk from a specific hazard(s)**	- What type of hazard(s) does the innovation address? - Which characteristic(s) does the innovation have? - How will the innovation reduce the risk of the hazard(s)? - What is the intended (quantitative) level of risk reduction? - Has the innovation been tested previously and can the innovation achieve the intended level of risk reduction without failure? - What is the current estimated technical readiness level (TRL) of the innovation?
Reliability refers to the likelihood that the innovation fulfills its intended functionality over its lifetime	- What are the loads that act on the innovation? - What are the possible structural failure modes of the innovation? If the innovation is semi-permanent or temporary, what are the possible implementation failure modes? - Which failure modes are most likely to occur? - Is there a facility where these failure modes can be tested? - Which failure modes cannot be tested?

Indicator	Desk Study Questions
Durability **refers to the intended use and lifetime of the innovation**	- Is the innovation permanent, semi-permanent, or temporary? - If the innovation is semi-permanent or temporary, what percent of the innovation needs to be replaced after each event? - What are the storage requirements for the innovation? - What is the expected lifetime of the innovation based on its structural components? - What are the maintenance requirements for the innovation to reach its maximum lifetime?
Flexibility **refers to the likelihood that the innovation fulfills its intended functionality over its lifetime**	- Where will the innovation be marketed/sold? What is the (potential) size of the market for the innovation under current climate conditions? under future climate conditions? - Is the innovation made up of modular components (or, alternatively, are the innovation's components customizable)? - Does the innovation require significant adjustment to be installed in a new location/used at different sites throughout Europe? - Are the material components of the innovation easily obtained within the potential market(s)? What is the material cost of the innovation?

Intended functionality/performance

EVAPO-CONTROL is a permanent engineered/built enviroment innovation which prevents evaporation water losses and algae growth in small resevoirs. The intended functionality/performance of EVAPO-CONTROL is to reduce direct evaporation by a minimum of 75% and reduce the algae growth by 50% in small agricultural reservoirs.

Technical Readiness Level

EVAPO-CONTROL entered BRIGAID with a TLR5 (*Technology validated in relevant environment: Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting features so they can be tested in a simulated environment. Examples include "high-fidelity" laboratory integration of components*).

With the BRIGAID's support, EVAPO-CONTROL aims to reach a TRL8 (actual system proven in operational environment, and ready for full scale deployment).

Previous development and testing activities

First activities started in 2016. Since then, three manufactured versions based on a first prototype (1st generation, G1) were tested under laboratory conditions focusing on the overall performance of the system through visual inspections and wind stability tests.

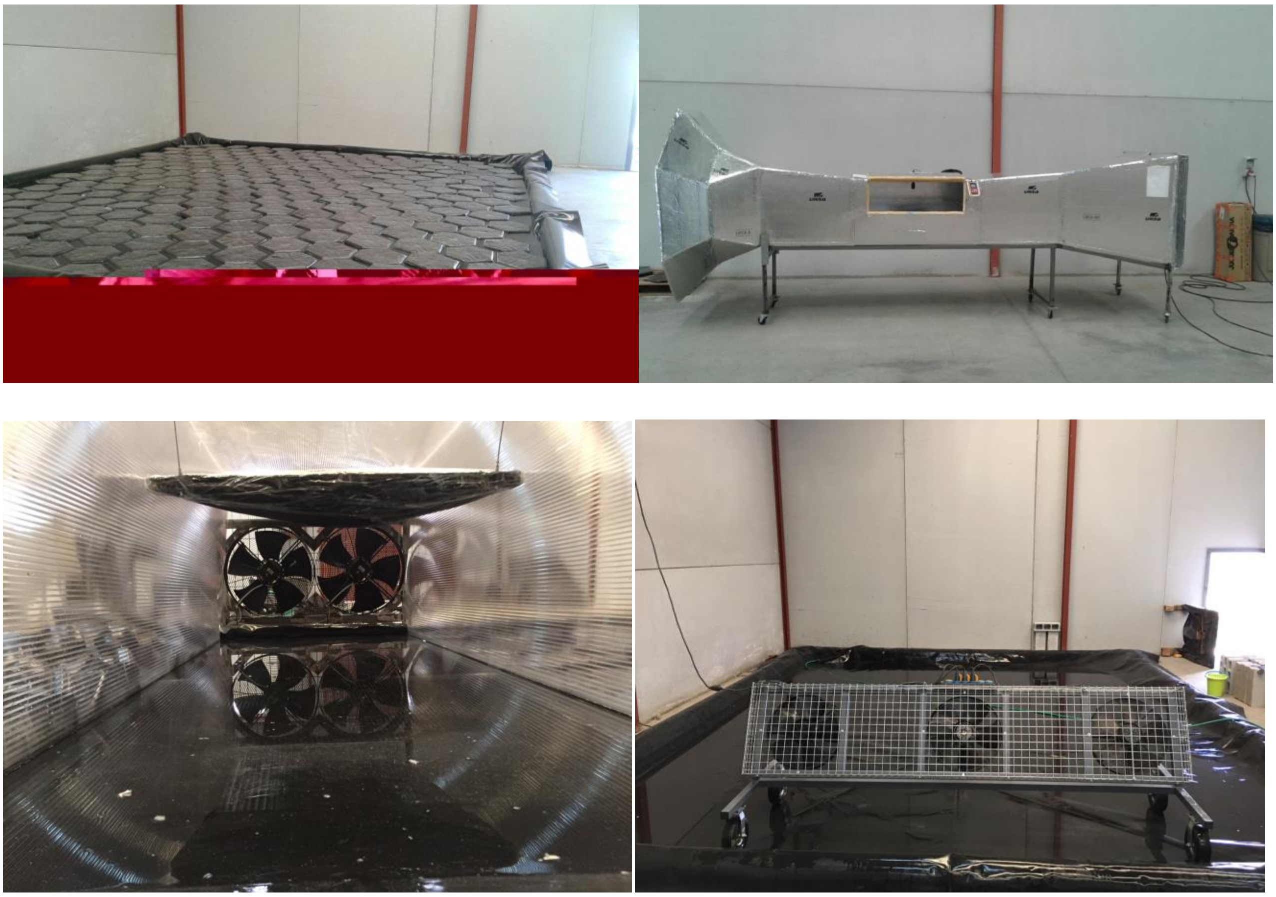
Tests with 300 small-scale floating modules (G1) of 0.15 m^2 each allowed to adopt several technological improvements over G1 leading to the 2nd prototype (G2).

Activities in the frame of BRIGAID project aim to manufacture enough floating G2 modules at scale 1:2 using an experimental machine to cover a 1.500 m^2 reservoir. Additional laboratory tests (wind tunnel and lifespan tests) and functionality tests in an operational environment were performed in collaboration with a research institution at SE Spain, Universidad Politécnica de Cartagena.

The preliminary results of G2 under operational conditions showed a good performance in evaporation reduction and a mecanical performance that need to be improved (repositioning of modules after wind events).

At September 17 started a re-designing process of the modules in order to improve their mecanical performance. This process, still in progress, has led to the design of the 4th generation of modules (G3) which are being tested from January 18 in collaboration with the Universidad Politécnica de Cartagena.G3 modules are smaller (the area has been reduced to 0.06 sqm), and have a higher height/area ration than G2 modules.

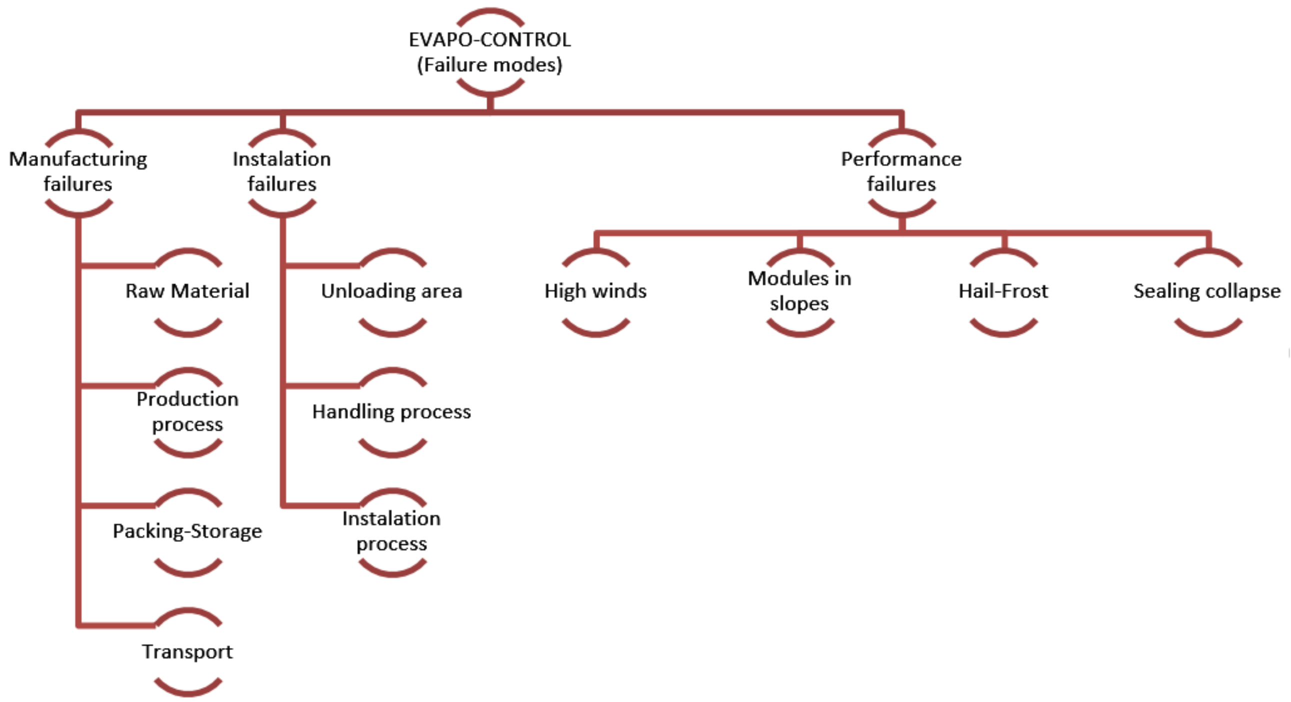
EVAPO-CONTROL first prototype (G1) (Up-Left); Off-water Wind tunnel. Down-left: In-Water Wind Tunnel (Up-Right); In-Water Medim Scale Wind Simulator (Down-Right):



Qualitative assessment of failure modes and risks

Failure modes identified for EVAPO-CONTROL are shown in next figure (failure tree), while a failure-risk class matrix is shown in next table.

Fault tree for EVAPO-CONTROL:



EVAPO-CONTROL failure risk matrix:

Rank	Component risk	Likelihood of occurence	Consequences /Impacts	Mitigation actions
1	Loss of modules due to wind or friction forces *Drivers of risk:* - Reservoir full of water (roating-flying modules) - Reservoir walls too steep (roating-flying modules) - Low water level in the reservoir (potential puncture)	Very high	Critical	Tumbler Ballasting System created to reduce both risks
2	Installation failures or risks *Drivers of risk:* - Cutting edges of modules and/or packaging - Security risks - Wrong implementation (speed in throughing modules to the water surface)	High	Critical-Marginal	Instalation protocol described
3	Installation failures due to: - Ground-puncture by abrasion - Transportation	Medium	Marginal	Installation Protocol described
4	Wearing of module’s seal resistence due to negative air/water temperatures (frost events) and/or rigidity of raw material	Medium	Marginal	Quality CheckProtocol for raw material seal resistance described

Mitigation actions adopted during the testing of the system consisted of:

- Design of a *Tumbler Ballasting System* to allow modules to rotate on their own axes so high winds can not move outside the reservoir, even if they are placed on the reservoir slopes.

- Preparation of an *Installation Protocol* in order to guide the deployment of the modules by installers and to reduce the risks on health and safety.

Preparation and description of a *Quality Check Protocol* for assuring that raw material fits with technical requirements (rigidity, sealing properties...)

Test plan

Testing activities planned under the framework of BRIGAID, their current status and their relationship with technical Performance Indicators are listed in the next table and schematically represented in the below figure.

Previous activities and testing activities planned for the EVAPO-CONTROL:

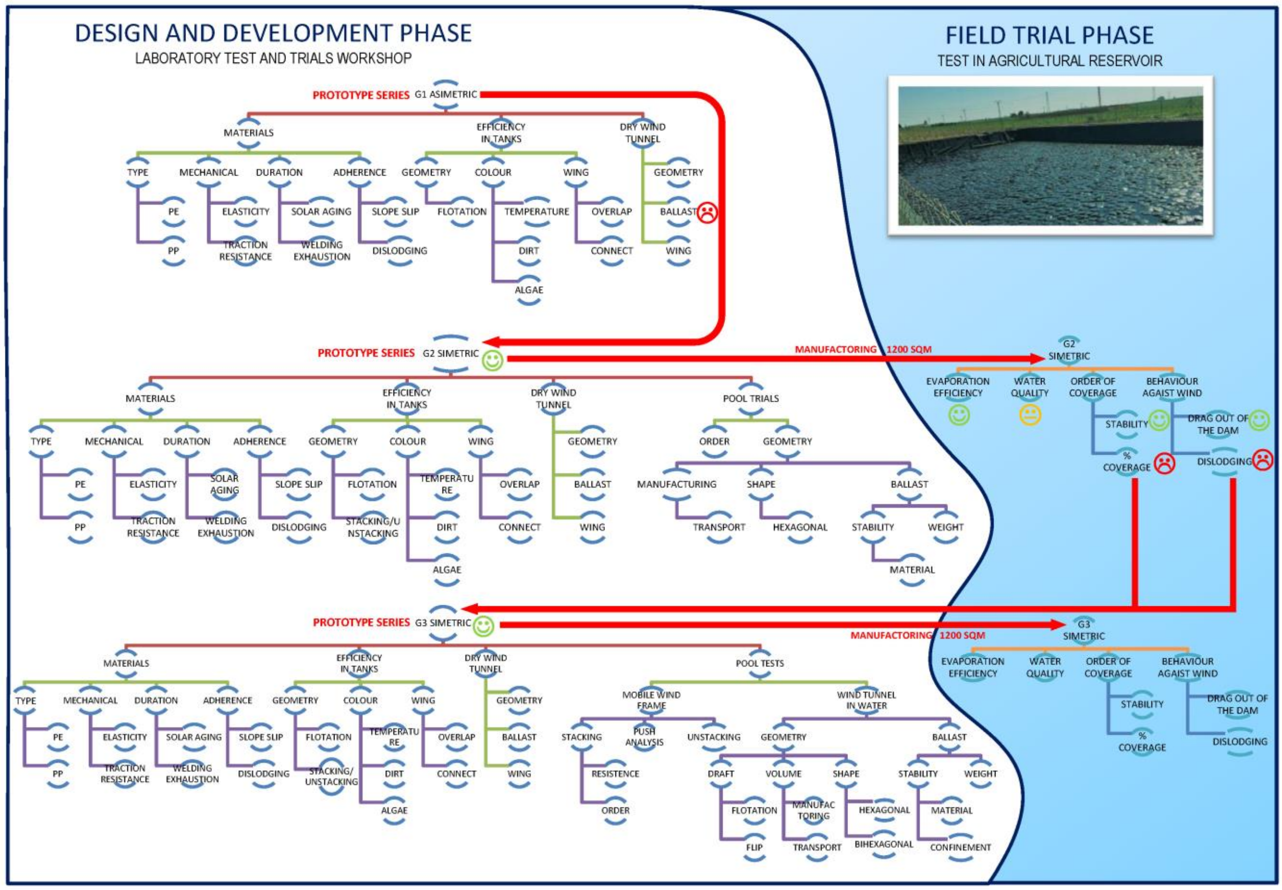
Activity	Status	Comment
1. Design and testing of 1st prototype (G1)	In progress	Not covered by BRIGAID
2. Design 2nd prototype (G2)	Completed	Not covered by BRIGAID
3. Laboratory testing of 2nd and 3rd prototypes (G2 & G3)		
3.1. **Test 1.** Wind testing	Completed	Support requested
3.2. **Test 2.** Performance testing (water losses assessment in indoor conditions)	Completed	Spport requested
3.3. **Test 3.** UV light lifespan testing	Suspended	Support requested
4. Operational testing of 2nd prototype (G2)		
4.1. **Test 4.** Performance testing (water losses and algae growth assessments) + (wind resistance)	In progress	Support requested
5. Operational testing of 3rd prototype (G3)		
5.1. Test 3. UV light lifespan testing	Planned - Delayed	
5.2. Test 4. Performance testing (water losses and algae growth assessments) + (wind resistance)	Planned in upcoming months	

Testing activities under laboratory conditions (Test 1 + Test 3) were performed in the ARANA's indoor facilities located in Lorca (Spain), while the operational testing of EVAPO-CONTROL was realized in a small resevoir located at the Tomás Ferro UPCT experimental station (Cartagena, Spain: 37º 41' 18'' N, 0º 56' 56'' W).

Because operational testing of G2 modules showed a non-optimal mechanical performance, UV lifespan tests were finally suspended. As consequence the budget for the UV testswere reallocated for technological improvement and re-design of G2 into a new prototype (G3), its production and testing on operational conditions with the collaboration of the Universidad Politécnica de Cartagena.

UV lifespan tests are planned to be executed on G3 once first results of the operational tests are reached.

Rational diagram of EVAPO-CONTROL testing:



Test 1: Wind tunnel tests

Rationale

To quantify the **technical reliability** of EVAPO-CONTROL under laboratory conditions.

The threshold objective of wind resistance for modules maintaining was stated in 35 km/h. Wind values above this threshold only occurs during 0.8% of the times in the SE Spain according to the daily wind measurements collected at the “Aeropuerto San Javier (Murcia)” (actual values extracted from AEMET (Spanish National Agency of Meteorology)). This station has registered the highest wind daily average value of all Spain. If only the summer period is considered, when the evaporation rates are the highest ones, the % of occurrence of daily average wind values >35 km/h (see table).

Temporal analysis of wind values at the Aeropuerto de San Javier meteorological station:

Average speed (km/h) (period 2000-2010)	% days over the year	
	Total	May-Sep
>10	75,2%	
>15	41,4%	19,2%
>20	17,6%	7,3%
>25	5,5%	1,7%

>30	2,5%	0,7%
>35	0,8%	0,2%

Tests aimed to quantify the wind speed for which modules flip/rotate, and to evaluate the mechanical behaviour after the rotation. Two types of wind tests were perfomed:

1. Without water. These tests are designed to analyze the aerodynamic behaviour of the modules under simulated conditions of low water level in the reservoir and modules resting on the slopes. These tests contributes to better design and find the optimal loads for avoiding the loss loss of modules out of reservoir area.

2. With water: These tests are designed to investigate and reduce the impact of winds in the module's performance (evaporation control). In these tests, the moment in which modules rotate and their capacity to return to their original position in water-filled reservoir is evaluated under conditions of increasing wind velocities (up to 35 km/h). Better performance is reached as higher is the wind speed at which modules rotate.

Facilities

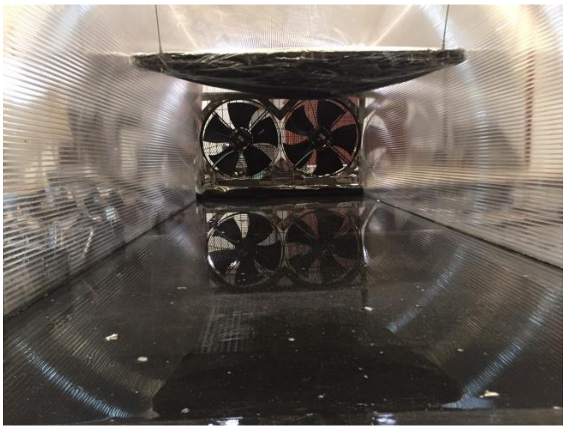
Two owned-made wind tunnels located at our indoor facilities.

Equipment

1.- Wind tunnel able to generate wind velocities up to 90 km/h for testing aerodinamic behaviour without the presence of water (see next figure).

2.- Wind tunnel able to generate wind velocities up to 35 km/h for testing hydrodinamic and aerodinamic behaviour in a water pool of 36 m^2.

ARANA wind tunnel facilities. Right: for testing aerodynamic behaviour out of the water, Left: for testing hydrodynamic and aerodinamic behaviours with water:



Protocol

1. Tests performed without water (simulation of conditions of low water level n the reservoir and modules resting on the slopes): Monitoring of the aerodynamic behaviour of a module under increasing wind velocities up to 90 km/h. Test is finished when the module rotates.

2. Tests performed with water: Monitoring of the overall mechanical behaviour of a set of modules put in a 36 m^2 pool and subjected to increasing wind velocities up to 35 km/h.

Test 2: Effectiveness at laboratory conditions

Rationale

To monitor evaporation losses of water in small-scale shallow-depth pools to quantify the evaporation control effect of different technological prototypes against a control -not covered- experiment.

Facility

ARANA experimental site.

Equipment

5 shallow-depth pools of 2,5 m^2 each.

Changes in water level of the pools were monitored using scaled pipe tubes and daily measured.

Small pools and detail of the scaled pipe tubes:

Protocol

Comparison of daily water levels manually measured in covered pools with scaled pipe tubes against measurments taken in a control -not covered- pool. The five pools consists of:

- Pool 1: a Poliethylene layer mimicing one of the potential solutions to reduce evaporation.
- Pool 2: ‘control’ pool - open pool with no protection.
- Pools 4 and 5, for EVAPO-CONTROL prototypes.

Test 3: UV Lifespan

Rationale

To quantify the **reusability** and commercial life of EVAPO-CONTROL.

Facility

CETEC (Centro Tecnológico del Calzado y del Plástico). It is a certified Spanish public-private company able to provide specialized services for testing the shel life of polymers.

Equipment

Aging chambers in which UV light and hidroscopic conditions are simulated. UV light lamps are able to speed up the process of aging up to 10 times *vs* sun light.

Protocol

To place the weakest parts of the module, i.e. those in which deformation during the production of the module stresses and reduces the thickness of the polymer used.

To check traction resistance of the parts of the module with a frequency of the equivalent to 6 months of UV light exposure.

Test 4: Technical effectiveness under operational conditions

Rationale

Monitoring of water level changes and water quality, and wind resistance (mecanical behaviour)

Facility

UPCT's *Tomas Ferro* Experimental Station. The facility is managed by the Polytechnic University of Cartagena (UPCT).

Location of UPCT experimental site:

Equipment

Meteorological station; Water depth probe; Multiparameter quality probe; Datalogger. For upcoming testing activities, a video camera is planned to be installed to monitor the mechanical performance of EVAPO-CONTROL modules. UAV technology may be also provided by an external service to accurately quantify the evolution of open-free water coverage along the testing period, and specially after strong wind events.

Protocol

The irrigation pond was monitored during a 6-month period (from 8th July to 17th December). Before the testing period, the experimental reservoir was remained uncovered to quantify and calibrate a physically-based UPCT's model for estimating pond evaporation. After, EVAPO-CONTROL G2-modules were deployed (see next figure), and water level changes and algae growth were monitored. The evaporation reduction coefficient during the period of maximum direct evaporation (summer-autumn) was retrieved by comparing actual measurements of water level changes and evaporation against estimates of direct evaporation provided by the calibrated evaporation model.

The impact of wind velocity will also be evaluated during the testing period through the continuous monitoring of wind conditions and using overhead imagery (UAV technology provided by an external service).

EVAPO-CONTROL (G2 prototype) just after its deployment in the experimental reservoir (Jul'17):

Testing results

Test 1: Wind tunnel tests

The original prototype was re-designed up to 3 times thanks to the data retrieved from the wind tests (including the test under operational conditions).

With wind velocities above 35 km/h, the most recent -G3- prototype

Wind test results of EVAPO-CONTROL:

Ballasting (kg/m^2)	Average speed for starting rotation (km/h)			
	"Without water" tests[1)]		"With water" test	
	G2	G3	G2	G3
3,50	28,50	22,50	-	24,60
5,00	32,80	25,20	-	28,90
7,50	35,10	27,50	-	32,50
10,00	36,10	27,70	-	33,70

[1)] Values of 39.5 km/h were reached for the competitor *Hexacover*

Conclusions:

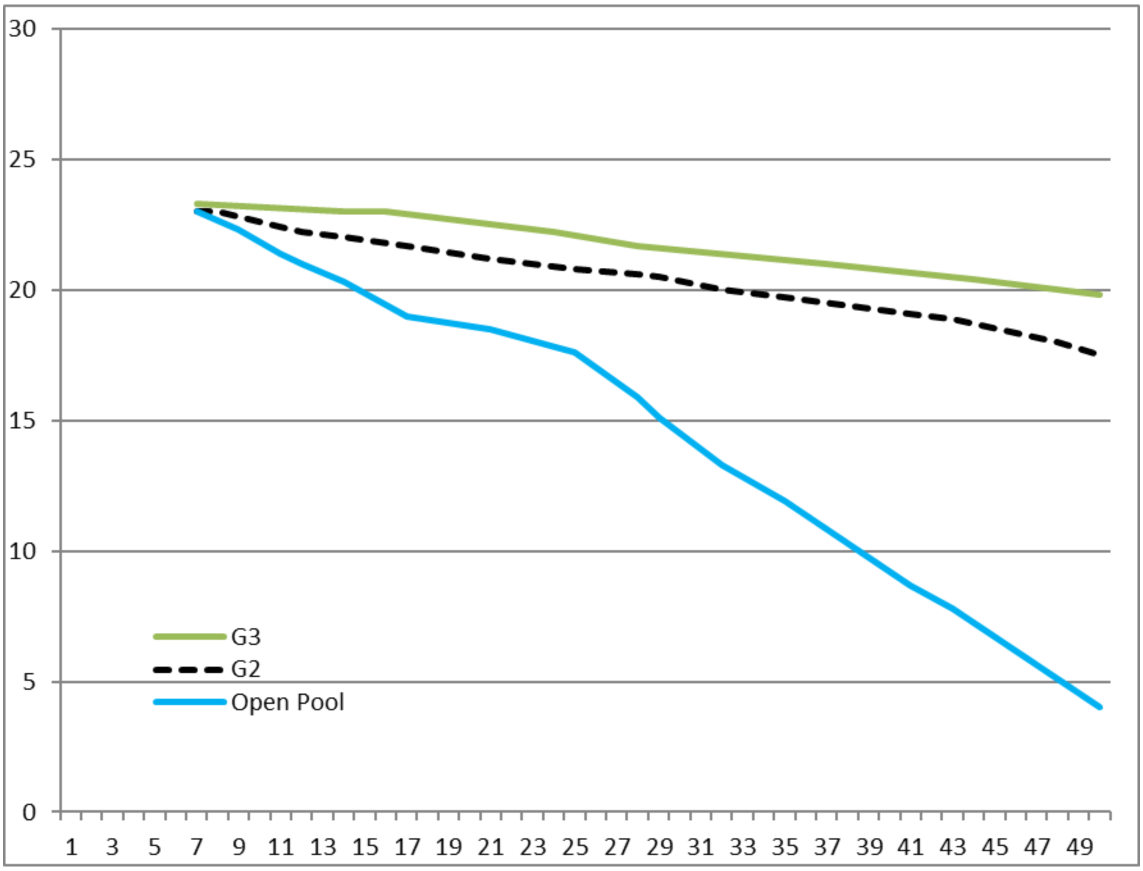
- G2 modules in wind test "without water" behaved similar than the main competitor (Hexacover). These results suggested that similar behaviour than the competitor would be expected under operational conditions.
- G3 modules showed a worse resistance to winds than G2 in wind tests "without water".

- G3 showed a higher wind resistence in tests with the presence of water than in test with no water. This is because, with water modules bear/support each other and the presure needed for rotation is higher. When G3 started to rotate the total area of the pool covered by the modules was reduced by half at the end of the wind test, but the coverage was totally recovered to its initial state sometime after.
- G2 and G3 modules flipped/rotated during tests with no water, but never flied because the tumbler ballasting system made them to rotate at ground level.

Test 2: Effectiveness at laboratory conditions

Next figure shows the technolgical effectiveness (evaporation control) of G2-G3 prototypes in open water pools during a period of 50 days. The evaporation reduction rates reached in pools with G2 and G3 modules were 76% and 85%, respectively. Reduction rates were higher as smaller were the modules used (as smaller the modules, the interface among them (overlaping of contours) is better solved).

Evolution of water level and evaporation losses in open water pools without EVAPO-CONTROL (blue line), and with EVAPO-CONTROL (G2 and G3 prototypes in dashed black line and green line, respectively):



Test 3: UV Lifespan

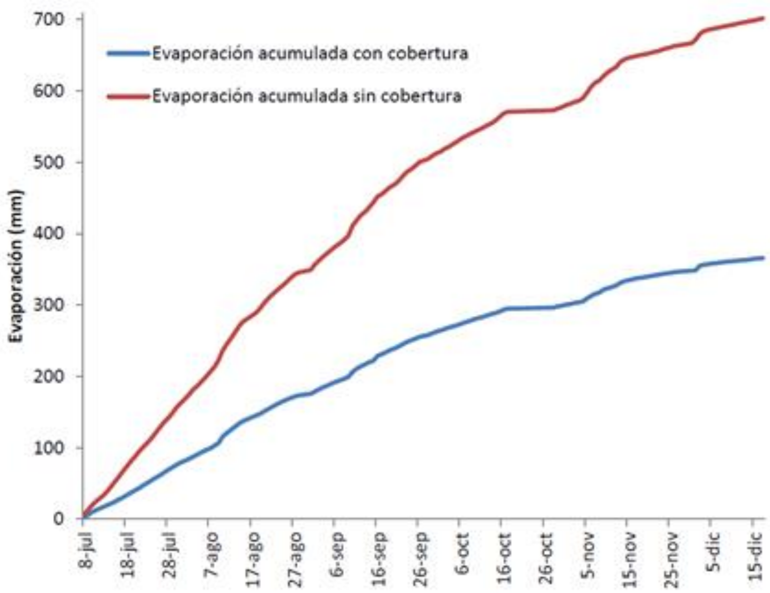
Test not started yet. Delayed until the operational testing of G3 is positively reached.

Test 4: Technical effectiveness under operational conditions

Evaporation reduction

During the testing period, the reduction factor during this period was estimated in 48,42% with values ranging between 43,3% and 54,3% during the period (next figure).

Accumulated evaporation in a moderate-size reservoir in SE Spain without EVAPO-CONTROL (red line, estimated values retrieved using a calibrated evaporation model) and with EVAPO-CONTROL modules (blue line, actual measurements):



Wind resistance

Under operational conditions, modules tested (G2 prototype) showed an unexpected behaviour with high winds, but still enough lower than those tested under laboratory conditions.

After events of high speed winds, not all the modules returned to their initial position. Although initially modules covered almost 100% of surface, and after different wind events the EVAPO-CONTROL coverage ranged between 1/3 and 2/3 of the total area of the reservoir at the end of the testing period.

The highest wind speed measured during the testing period took place on 1th of December with 58,2 km/h. None module left the reservoir due to this wind event.

Water quality

Next table shows values of temperature, pH, conductivity, solved oxigen, turbidity and chrophyll at 5 depths. Measurements were taken before deploying EVAPO-CONTROL (7th July), during (17th July, 18th September, 28th October) and at the end of the testing period on 12th December.

Temperature and water quality measurements in the experimental reservoir during the testing of EVAPO-CONTROL (G2 prototype):

Profundidad (m)	Tª Agua (ºC)	CE (mS / cm)	pH	Clorofila-a (µg / L)	Oxígeno disuelto (mg / L)
07/07/2017					
0,2	26,79	5,80	9,36	0,15	8,06
0,5	26,80	5,80	9,36	0,15	8,06
1,5	26,79	5,80	9,37	0,14	8,01
2,5	26,81	5,83	9,38	0,15	7,76
3,5	28,43	11,93	9,02	0,41	7,39
PROMEDIO	**27,12**	**7,03**	**9,30**	**0,20**	**7,85**
17/07/2017					
0,2	28,21	6,00	9,39	0,115	6,445
0,5	28,21	6,00	9,38	0,115	6,4
1,5	28,2	6,00	9,39	0,13	6,215

Profundidad (m)	Tª Agua (ºC)	CE (mS / cm)	pH	Clorofila-a (µg / L)	Oxíigeno disuelto (mg / L)
2,5	28,19	6,00	9,375	0,13	5,905
3,5	28,23	6,55	9,325	0,13	5,58
PROMEDIO	**28,21**	**6,11**	**9,37**	**0,12**	**6,11**
18/09/2017					
0,2	25,61	7,40	9,20	1,19	9,48
0,5	25,58	7,40	9,21	1,12	9,49
1,5	25,42	7,40	9,19	1,87	9,53
2,5	25,38	7,40	9,19	3,11	9,54
3,5	-	-	-	-	-
PROMEDIO	**25,49**	**7,40**	**9,19**	**1,82**	**9,51**
24/10/2017					
0,2	20,78	8,10	9,16	0,62	9,62
0,5	20,92	8,10	9,15	0,58	9,58
1,5	20,85	8,10	9,15	0,59	9,56
2,5	20,99	8,10	9,15	0,53	9,55
3,5	20,75	8,10	9,15	0,49	9,56
PROMEDIO	20.86	**8,10**	**9.15**	**0,56**	**9,57**
12/12/2017					
0,2	11,76	**8,60**	**9,14**	**0,17**	**9,80**
0,5	12,11	**8,60**	**9,13**	**0,18**	**9,75**
1,5	12,07	**8,60**	**9,13**	**0,17**	**9,76**
2,5	12,28	**8,60**	**9,13**	**0,06**	**9,78**
3,5	12,27	**-**	**-**	**-**	**-**
PROMEDIO	**12,09**	**8,6**	**9,13**	**0,14**	**9,77**

Results show that conductivity increased as consequence of the loss of water due to evaporatoin, chrolophyll-A (a surrogate of algae level) contents remained low despite the high observed temperatures, while contents of dissolved oxigen shows common values typically found in water reservoirs located in the region.

Conclusions of operational testing at the experimental site

Extracted from the consultancy-technical report provided by Prof. Dr. Victoriano Martínez Álvarez and colleagues to ARANA Water Management (Polytecnich University of Cartagena – UPCT)

"Despite the issues with the mechanical behaviuor of the modules, which did not covered 100% of the reservoir surface, the evaporation reduction rate was 48.4% after the testing period (from 7th July to 17 December).

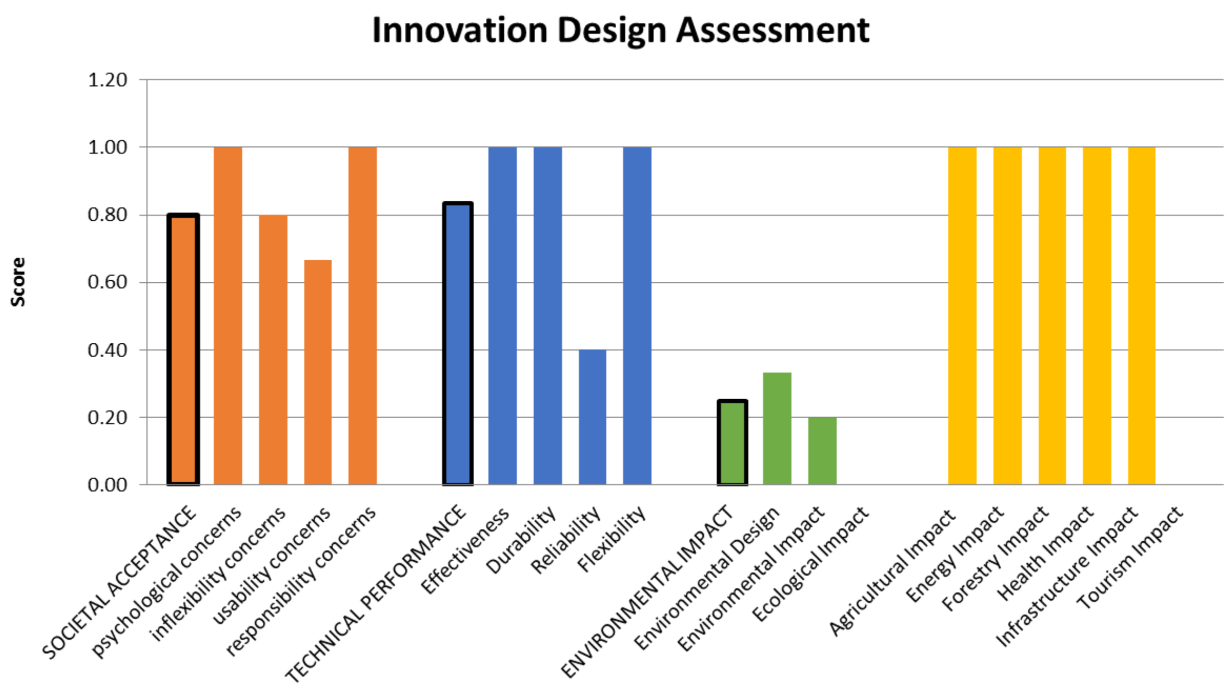
Taking into account that the reservoir has just shown levels of coverage of 1/3 to 2/3 of its surface, a positive result can be extracted because the extrapolation of the measured reduction rates to a 100% of coverage might get to final evaporation reduction rate close to 90%. This estimation will be tested as soon as the new G3 prototype with a better mechanical behavior is ready for testing.

If the issues related to the mechanical behaviuor of the modules are solved, and the evaporation reduction rate of almost 90% is confirmed, then the EVAPO-CONTROL modules will show a high effectiveness as a technique for reducing evaporation in irrigation reservoirs, being fully competitive from a technical point of view against other solutions available in the market.

Regarding the effects induced by EVAPO-CONTROL on water quality, no significant increase of algae in the reservoir was observed, despite that the test was done during the hottest period of the year. The changing environmental conditions during the testing period due to the impact of winds on the EVAPO-CONTTROL coverage do not allow to make other conclusions on this issue.

TIF Tool results

Overall assessment of ARIEL using the BRIGAID's TIF Tool:



Overall results of the TIF Tool assessment for EVAPO-CONTROL:

1	**Your innovation raise**	**few**	**societal concerns overall, having scored**	**12**	**out of a possible**	**15**	**and is**	**close**	**from/to SOCIETAL READINESS.**
1.1	Your innovation raises	few	psychological concerns, having scored	3	out of a possible	3	and is	close	from/to societal readiness.
1.2	Your innovation raises	few	inflexibility concerns, having scored	4	out of a possible	5	and is	close	from/to societal readiness.
1.3	Your innovation raises	few	usability concerns, having scored	4	out of a possible	6	and is	close	from/to societal readiness.
1.4	Your innovation raises	few	responsibility concerns, having scored	1	out of a possible	1	and is	close	from/to societal readiness.
2	**Your innovation raise**	**few**	**technical concerns overall, having scored**	**15**	**out of a possible**	**18**	**and is**	**close**	**from/to being ready in terms of its TECHNICAL DESIGN.**
2.1	Your innovation raises	few	concerns related to its technical effectiveness, having scored	3	out of a possible	3	and is	close	from/to being ready/effective in terms of its technical design.
2.2	Your innovation raises	no	concerns related to its durability, having scored	5	out of a possible	5	and is	close	from/to being ready/effective in terms of its technical design.
2.3	Your innovation raises	no	concerns related to its reliability, having scored	2	out of a possible	5	and is	far	from/to being ready/effective in terms of its technical design.
2.4	Your innovation raises	many	concerns related to its flexibility, having scored	5	out of a possible	5	and is	close	from/to being ready/effective in terms of its technical design.
3	**Your innovation raise**	**many**	**environmental concerns overall, having scored**	**2**	**out of a possible**	**8**	**and is**	**far**	**from/to being ready in terms of its ENVIRONMENTAL DESIGN.**
3.1	Your innovation raises	many	concerns related to its Environmental Design having scored	1	out of a possible	3	criteria. Your innovation may have a	negative	on the environment.
3.2	Your innovation raises	many	concerns related to its Environmental Impact, having scored	1	out of a possible	5	criteria. Your innovation may have a	negative	on the environment.
3.3	Your innovation raises	ERROR	concerns related to its Ecological Impact, having scored	0	out of a possible	0	criteria. Your innovation may have a	ERROR	on the environment.
4.1	**Your innovation raise**	**no**	**concerns related to Agricultural Impacts, having scored positively on**	**3**	**out of**	**3**	**criteria. Your innovation may have a**	**positive**	**impact on the Agricultural Sector.**
4.2	**Your innovation raise**	**no**	**concerns related to Energy Impacts, having scored positively on**	**1**	**out of**	**1**	**criteria. Your innovation may have a**	**positive**	**impact on the Energy Sector.**
4.3	**Your innovation raise**	**no**	**concerns related to Forestry Impacts, having scored positively on**	**2**	**out of**	**2**	**criteria. Your innovation may have a**	**positive**	**impact on the Forestry Sector.**
4.4	**Your innovation raise**	**no**	**concerns related to Health Impacts, having scored positively on**	**2**	**out of**	**2**	**criteria. Your innovation may have a**	**positive**	**impact on the Health Sector.**
4.5	**Your innovation raise**	**no**	**concerns related to Infrastructure Impacts, having scored positively c**	**1**	**out of**	**1**	**criteria. Your innovation may have a**	**positive**	**impact on the Infrastructure Sector.**
4.6	**Your innovation raise**	**ERROR**	**concerns related to Tourism Impacts, having scored positively on**	**0**	**out of**	**0**	**criteria. Your innovation may have a**	**ERROR**	**impact on the Tourism Sector.**

The responses for each section of the TIF Tool are detailed hereafter:

1 Societal acceptance assessment		
Answer the following 16 questions by writing Yes or No in the corresponding cells.		**Yes or No?**
1	Does your innovation use any materials that might be considered unfamiliar (such as nanomaterials or genetically modified materials)?	No
2	Will members of the public affected by your innovation be the ones to decide whether or when to use it?	Yes
3	Does your innovation involve visible infrastructure (such as physical barriers) or visible land use changes (such as woodland removal)?	No
4	Could the deployment of your innovation disrupt daily activities, for example through road closures?	No
5	Does your innovation require large amounts of capital investment?	No
6	Does your innovation require a long lead time between users placing an order and it becoming operational?	No
7	Does your innovation require new infrastructure or significant changes to existing infrastructure?	No
8	Does your innovation involve releasing any materials into the environment (such as sprays or coatings)?	No
9	Are your potential users likely to have a single mission, for example to protect ecosystems?	Yes
10	Does your innovation take less time to deploy than incumbent alternatives (such as sand bags for floods or fire nozzles for wildfires)?	Yes
11	Would the use of your innovation require special training?	No
12	Will help and support be available to users of your innovation?	Yes
13	Innovations can either reinforce or change users' existing ways of working. Does your innovation reinforce existing ways of working?	No
14	Are the effects of your innovation directly publicly tangible (such as seeing flood defences working or hearing a warning alert system)?	Yes
15	Adaptations can either be deployed permanently or temporarily. Is your innovation deployed permanently?	No
16	Are members of the public involved in shaping the research, development, demonstration and deployment of your innovation?	Yes
Answer the following 4 questions by writing A, B or C in the corresponding cells.		**A, B or C?**
17	What would your innovation primarily protect? (A) public infrastructure, (B) private properties or (C) the environment	B
18	Who would pay for your innovation? (A) government authorities, (B) private companies or (C) local communities	B
19	Who would implement your innovation? (A) government authorities, (B) private companies or (C) local communities	B
20	How would compensation be made in the event of your innovation failing? Through (A) government compensation, (B) project insurance or (C) responsible parties	B

2 Technical Design		
Answer the following questions by writing Yes or No in the corresponding cells.		**Yes or No?**
1	Does the innovation provide significant technical advantage(s) relative to a traditional/conventional measures?	Yes
2	Does your innovation physically prevent a hazard from occurring?	Yes
3	Does your innovation require combination with other interventions and/or activities in order to reduce risk (e.g, flood warning system in combination with a flood barrier or a fire warning system in combination with controlled burning)?	No
4	Will the innovation require additional testing and/or substantial upgrades when considering future hazard conditions (i.e., considering climate change)?	No
5	Is the lifetime of the innovation limited by climate change? (i.e., will climate change affect the estimated life(time) of the innovation?)	No
6	Does the innovation require frequent inspection and maintainence to reach its intended lifetime?	No
7	Are the materials or software needed for maintanence and/or repair easily obtained and can they be integrated by the end-user?	Yes
8	Is the innovation designed to be used repetitively or continuously operated over its lifetime?	Yes
9	Can the innovation be operated without repair and/or replacement of components during a hazard event?	Yes
10	Does the innovation exhibit vulnerabilities during testing and/or demonstration (e.g., structural: sliding or rotation, or technological: errors)?	No
11	Is there a critical component in the innovation's structural or technological design that could lead to catastrophic failure?	Yes
12	Does your innovation rely on the delivery of services or materials (e.g., structural components, data) outside of your control to be successfully operated during a hazard event?	Yes
13	Does your innovation require the execution of tasks by humans to be successfully operated during a hazard event?	No
14	Can the vulnerability of your innovation to human error be easily reduced through improvements in operational protocols and/or end-user training?	No
15	Is the innovation modular (opposite: monolithic) and can it be easily installed or applied at different sites across Europe without adjustment?	Yes
16	Does the innovation require additional testing and/or substantial upgrades (e.g., new components) if used at different sites across Europe?	No
17	Will the size of the market for the innovation (in Europe) will significantly decrease (>50%) due to future hazard conditions (i.e., considering climate change)?	No
18	Have relevant end-users have been identified and contacted and has a need for this innovation observed?	Yes
19	Are the advantages of the innovation derived from its multi-functionality (e.g., reduction of carbon emissions or enhanced recreational activities)?	Yes

3	Environmental Characteristics	
Answer the following questions by writing A, B, or C, in the corresponding cells.		**A, B or C?**
3.1	**Environmental Design**	
3.1.1	Does the innovation deliberately use ecosystems and their services, or mimic or preserve natural processes? (A) Yes (B) No	A
3.1.2	How does the change in footprint (area) required for implementation on-site compare to conventional measures or the present situation? (A) Increase space required (B) Decrease space required (C) No Impact on space required	C
3.1.3	How does the construction or operation of the innovation affect the quantity of greenhouse gases in the environment (e.g., as CO_2 or CH_4)? (A) Increase (B) Decrease (C) No Impact	A
3.1.4	Is the innovation made from recycled or recyclable materials? (A) Yes (B) No	A
3.1.5	Does the innovation include specific design features or components which preserve or enhance ecosystem services? (A) Yes (B) No	A
3.2	**Environmental Impact**	
3.2.1	How does the innovation impact the quality of surface water? (A) Improve (B) Worsen (C) No Impact	A
3.2.2	How does the innovation impact the quantity of available surface water? (A) Increase (B) Decrease (C) No Impact	A
3.2.3	How does the innovation impact the quality of ground water? (A) Improve (B) Worsen (C) No Impact	C
3.2.4	How does the innovation impact the quantity of available ground water? (A) Increase (B) Decrease (C) No Impact	C
3.2.5	How does the innovation impact the quality of the sea water? (A) Improve (B) Worsen (C) No Impact	C
3.2.6	How does the innovation impact soil quality? (A) Improve (B) Worsen (C) No Impact	A
3.2.7	How does the innovation impact air quality? (A) Improve (B) Worsen (C) No Impact	C
3.2.8	Does the implementation (or construction) of the innovation generate debris? (A) Yes (B) No	A
3.2.9	Does the implementation (or construction) of the innovation generate noise or vibration? (A) Yes (B) No	A
3.2.10	How does the innovation impact landscape quality? (A) Improve (B) Worsen (C) No Impact	C
3.3	**Ecological Impact**	
3.3.1	How does the innovation impact the spatial extent of protected nature area? (A) Increase (B) Decrease (C) No Impact	C
3.3.2	How does the innovation impact the quality of protected habitats? (A) Improve (B) Worsen (C) No Impact	C
3.3.3	How does the innovation impact the number protected species (e.g., birds, vegetation, fish, mammals)? (A) Increase (B) Decrease (C) No Impact	C
3.3.4	How does the innovation impact the spatial extent of non-protected nature area? (A) Increase (B) Decrease (C) No Impact	C
3.3.5	How does the innovation impact the quality of non-protected habitats? (A) Improve (B) Worsen (C) No Impact	C
3.3.6	How does the innovation impact the number non-protected species (e.g., birds, vegetation, fish, mammals)? (A) Increase (B) Decrease (C) No Impact	C

4	Sectoral Impacts	
Answer the following questions by writing A, B or C in the corresponding cells.		**A, B or C?**
4.1	**Agriculture**	
4.1.1	How does the innovation impact the total area available for agricultural production? (A) Increase (B) Decrease (C) No Impact	A
4.1.2	How does the innovation impact agricultural production conditions (e.g., by increasing soil quality or water availability)? (A) Improve (B) Worsen (C) No Impact	A
4.1.3	How does the innovation impact the variety of agricultural products (e.g., crops, dairy, meat, fruit, fish, aquaculture) that can be produced or are available? (A) Increase (B) Decrease (C) No Impact	A
4.1.4	How does the innovation impact the total yield of one or more agricultural products? (A) Increase (B) Decrease (C) No Impact	A
4.2	**Energy**	
4.2.1	How does the innovation impact the energy production capacity (e.g., by generating energy or increasing energy distribution)? (A) Increase (B) Decrease (C) No Impact	C
4.2.2	How does the innovation impact the reliability of energy production (e.g. by improving cooling water conditions for energy plants)? (A) Increase (B) Decrease (C) No Impact	C
4.2.3	How does the innovation impact the efficiency of energy production? (A) Increase (B) Decrease (C) No Impact	C
4.2.4	How does the innovation impact the carbon footprint of the end-user? (A) Increase (B) Decrease (C) No Impact	B
4.3	**Forestry**	
4.3.1	How does the innovation impact the total area available for wood production (including timber and biomass)? (A) Increase (B) Decrease (C) No Impact	C
4.3.2	How does the innovation impact wood production conditions (e.g., by increasing forest resilience or water availability)? (A) Improve (B) Worsen (C) No Impact	C
4.3.3	How does the innovation impact the total area available for non-wood production (including cork, fruit, honey, mushrooms, pastures, game and fishing)? (A) Increase (B) Decrease (C) No Impact	A
4.3.4	How does the innovation impact non-wood production conditions (e.g., by increasing forest resilience or water availability)? (A) Improve (B) Worsen (C) No Impact	A
4.4	**Health**	
4.4.1	How does the innovation impact the number of fatalities in the area exposed to the hazard? (A) Increase (B) Decrease (C) No Impact	C
4.4.2	How does the innovation impact the number of people affected by the hazard in their physical health (i.e., number of people injured)? (A) Increase (B) Decrease (C) No Impact	C
4.4.3	How does the innovation impact the number of people affected by the hazard in their mental/physo-social health? (A) Increase (B) Decrease (C) No Impact	B
4.4.4	Does the innovation emit or release chemicals or products that are harmful to humans? (A) Yes (B) No	B
4.5	**Infrastructure**	
4.5.1	How does the innovation impact the quality of the built environment (I.e., residential, commercial, and industrial)? (A) Improve (B) Worsen (C) No Impact	A
4.5.2	How does the innovation impact the total area available for urban development? (A) Increase (B) Decrease (C) No Impact	C
4.5.3	How does the innovation impact the capacity of existing transportation systems (e.g., roads, railways, waterways, and airports) or create new capacities? (A) Increase (B) Decrease (C) No Impact	C
4.5.4	How does the innovation impact the reliability of existing transportation systems (e.g., roads, railways, waterways, and airports)? (A) Increase (B) Decrease (C) No Impact	C
4.5.5	How does the innovation impact the transport capacity of critical infrastructure networks (e.g., power, water, waste management)? (A) Increase (B) Decrease	C
4.5.6	How does the innovation impact the reliability of critical infrastructure networks (e.g., power, water, waste management)? (A) Increase (B) Decrease (C) No Impact	C
4.6	**Tourism**	
4.6.1	How does the innovation impact the total area available for recreational activities? (A) Increase (B) Decrease (C) No Impact	C
4.6.2	How does the innovation impact the attractiveness of the area for recreational activities? (A) Increase (B) Decrease (C) No Impact	C
4.6.3	How does the innovation impact the length of the tourist season? (A) Increase (B) Decrease (C) No Impact	C

TRL assessment:

Climate Adaptation Innovation - Technological Readiness Levels

Innovation:	EVAPOCONTROL
Organization:	ARANA WM
Starting TRL	TRL5
Anticipated Ending TRL	TRL8
Current Status	TRL6
Actual Ending TRL	---

		To be completed at the start of the project						*To be completed at the time of interim reports*			*To be completed at the end of the project*		
TRL	**Question**	**Start of Project**			**Anticipated End of Project**			**Current status**			**Actual End of Project**		
		Yes	**No**	**N/A**	**Yes**	**No**	**N/A**	**Yes**	**No**	**N/A**	**Yes**	**No**	**N/A**
TRL 1	**Basic principles observed and reported.**												
TRL 2	**Innovation concept formulated.**												
TRL 3	**Analytical and experimental critical function and/or characteristic proof-of-concept.**												
4	Has societal acceptance testing of individual components been performed?		X					X					
4	Has performance of components and interfaces between components been demonstrated?		X					X					
4	Does draft system architecture plan exist?			X				X					
4	Have end user technology/system requirements been documented (e.g., reliability requirements)?	X						X					
4	Has component compatibility been demonstrated?			X				X					
4	Does technology demonstrate basic functionality in simplified environment?	X						X					
4	Have performance characteristics been demonstrated in a laboratory environment?	X						X					
4	Have low-fidelity assessments of system integration and engineering been completed?	X						X					
TRL 4 Achieved	**Innovation validated in a laboratory environment.**	**4**	**2**	**2**	**0**	**0**	**0**	**8**	**0**	**0**	**0**	**0**	**0**
5	Have internal system interface requirements been documented?		X					X					
5	Has analysis of internal interface requirements been completed?	X						X					
5	Can all system specifications be simulated and validated within a laboratory		X					X					
5	Is the laboratory environment high-fidelity?	X						X					
5	Have individual component functions been verified through testing?	X						X					
5	Have objective and threshold operational requirements been developed? (e.g., has the intended reduction in risk been quantified? Is the end-user requirement for reliability known?)	X						X					
5	Have all potential failure modes been identified and documented?	X						X					
5	Has the reliability of the fully integrated prototype been estimated using desk study calculations?	X						X					
5	Have the social, technical, and environmental design of the innovation been re-assessed? (TIF tool applied, i.e. stage-gate tool)	X						X					
TRL 5 Achieved	**Innovation prototype demonstrated in a laboratory environment.**	**7**	**2**	**0**	**0**	**0**	**0**	**9**	**0**	**0**	**0**	**0**	**0**

Conclusions and upcoming activities

By the time of joining BRIGAID, ARANA had only one non-optimal prototype (G1). The TRL of ARIEL was set at 5.

With the support of BRIGAD, ARANAS has:

- re-designed the original G1 modules for getting an improved 2nd generation of modules (G2)
- tested G2 under laboratory and operational conditions;
- re-design the G2 prototype into a 3rd generation of modules (G3). G3 prototype includes a new *Tumbler Ballasting System* to allow modules to rotate on their own axes
- tested G3 under laboratory conditions
- made an Installation Protocol for guiding the deployment of EVAPO-CONTROL, and a Quality Check Protocol for assuring that raw material fits with the technical requirements.

After the 2017 testing activities, BRIGAID reached a TRL6. The operational testing of the G3 prototype is required to reach the TRL7.

Upcoming activities:

During the upcoming months, ARANA will:

- test under operational conditions the new G3 prototype
- improve the monitoring of the mechanical and aerodynamic performance of EVAPO-CONTROL under operational conditions through the installation of a video camera and/or the use of UAV imagery
- prepare a communication and marketing campaign to properly target potential customers.

With the upcoming testing activities, we expect to completely reach the TRL8 stage.

3. Innovation: Water from Heaven / Hemel(s)water

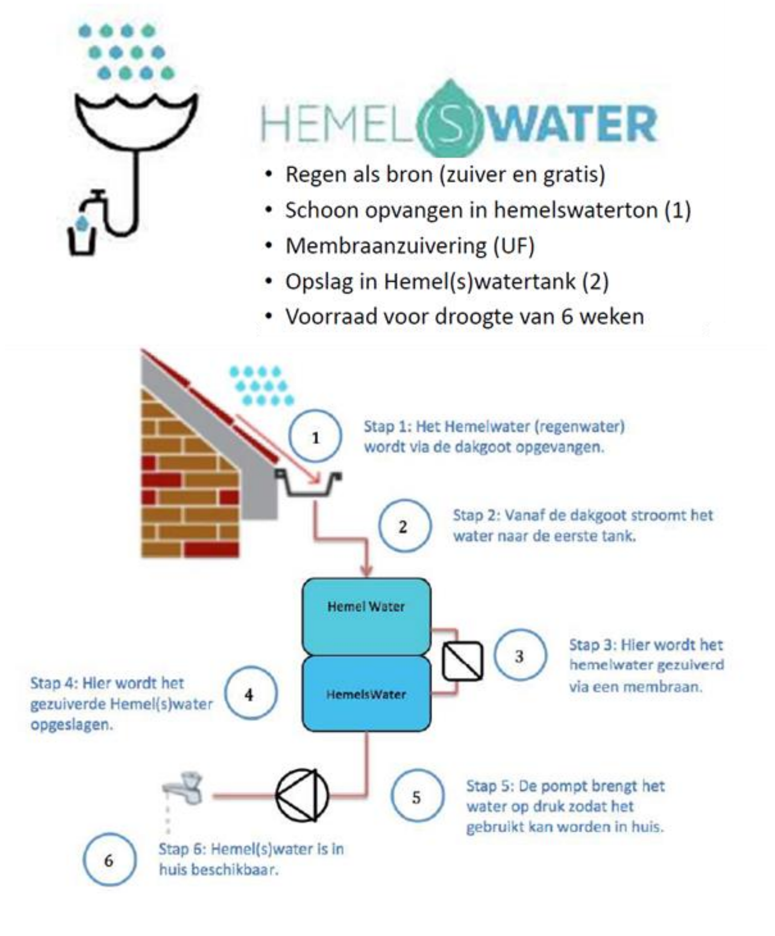
Innovator: Water Innovation Consulting (WIC) (external innovator)

Contributing authors: Albert Jansen (WIC)

Innovation description

The description of ARIEL below is also available from the Climate Innovation Window, http://climateinnovationwindow.eu/innovations/water-heaven-hemelswater

Name
WaterforHeaven (Hemel(s)water)
Short description
The WaterforHeaven (Hemel(s)water) innovation aims to produce drinking water from rain water collected from a single (own) roof. It provides sustainable water purification and storage for dry seasons, hence will cope with the problems of drought and water availability. Using such small scale, decentralized system for own drinking water supply, citizens do depend less on the centralized water supply network. At the scale of a city, the innovation will complement the existing drinking water supply system.
Sketch/Photograph of the Innovation


HEMEL(S)WATER
• Regen als bron (zuiver en gratis)
• Schoon opvangen in hemelswaterton (1)
• Membraanzuivering (UF)
• Opslag in Hemel(s)watertank (2)
• Voorraad voor droogte van 6 weken
1
Stap 1: Het Hemelwater (regenwater) wordt via de dakgoot opgevangen.
2
Stap 2: Vanaf de dakgoot stroomt het water naar de eerste tank.
Hemel Water
HemelsWater
3
Stap 3: Hier wordt het hemelwater gezuiverd via een membraan.
4
Stap 4: Hier wordt het gezuiverde Hemel(s)water opgeslagen.
5
Stap 5: De pompt brengt het water op druk zodat het gebruikt kan worden in huis.
6
Stap 6: Hemel(s)water is in huis beschikbaar.

Which hazard(s) is the innovation designed to mitigate?
Droughts: sustained and extensive occurrence of below average water availability. Resulting in water scarcity when drought conditions cause long-term imbalances between water availability and demands. Heavy precipitation / pluvial floods: rainfall events that result in 1) (urban) floods due to exceedance of: drainage capacity, and 2) flash floods, defined as rapid flooding of low-lying areas, generally within a few hours after heavy rainfall events such as thunderstorms.
How does the innovation work?
Rain water is collected from the roof and stored in a storm water collection tank (large enough to collect extreme rainfall). Then by gravity the water is purified by an utrafiltration membrane system that removes bacteria and viruses. The water is stored in a purewater tank, large enough to overcome droughts. An optional pump allows the treated water be brought in house for showering etc.
Added value / main differentiating element from conventional approach

It contributes to local rain water storage and helps to overcome droughts. It makes people independent from water suppliers. The water quality is safer and healthier and produced in a sustainable way.
Critical success factors / Limitations
Acceptance by local people needed. Proof of good quality (drinking water standards) would help.

Technology Readiness Level (TRL)

Our technology is TRL 5: Two prototypes are tested at different environments: 1) A first pilot was installed at Ecovillage Boekel in February 2016 and is still running 2) A second pilot was performed at Heijmans One (a mobile house). Heavenly water together with the Tesla power wall made this house utility independent.

Test plan

Rational
BRIGAID's budget is requested to test a new and promising technology that solves two problems: • Heavy rainfall by long time storage and treatment to drinking water standard (scarce product) • This project makes it possible / provides the opportunity to have independent researchers evaluating the innovation • The project provides support to reach the European market The BRIGAID tests aim at several goals: • To demonstrate that rainwater collection contributes to prevention of water problems in the city • That the produced drinking water meets the drinking water standards • That Denutritor technology will remove NH4× and TOC < 0,2 mg/l (according to drinking water standards) • That CFU/ml after longer storage stays within standards < 100 mg/l • Show/confirm the easy maintenance
Facility
A rainwater treatment installation will be set up for testing at the following BRIGAID test site: • At Leuven: At a KU Leuven building: detailed testing will be done of the chemical quality of the treated water, with kind support by prof. Ilse Smets and hear team + students
Equipment
The following equipment is needed:

- Below the rainwater collection pipe (rainwater collected from the building roof), the rainwater treatment facility will be installed including a pump
- One additional Denutritor to remove NH4 and TOC via I3-Innovative technologies
- Installation of the equipment by Belgian plumber
- Certified analytical analysis in Belgian drinking water laboratory

Protocol

The test site involves a building from which the rainwater is more than normal polluted with bacteria or nutrients.

Samples will be taken at regular time moments (about once a week) and the samples will be analyzed in the laboratory. The analyzed quality will be evaluated by prof. Smets and improvements suggested if needed.

In this way, it will be evaluated whether the drinking water standards are met. At the same time, the different concerns by Water-link reg. the water quality will be evaluated.

It will be tested whether the Denutritor technology succeeds to remove NH4× and TOC < 0,2 mg/l (according to the drinking water standards).

It will be tested whether CFU/ml after longer storage stays within standards < 100 mg/l.

Finally, the easy maintenance of the system will be demonstrated. The KU Leuven staff will evaluate/confirm or disagree.

The installations will be placed this summer (2017) such that the testing can start shortly after summer. The installations will be put in place for a period of at least 6 months, ev. to be extended to a 1-year period. The extension of the testing period will be evaluated after 6 months.

Expected Results

The expected results from the tests are:

- Answer on the question whether the innovation may provide a safe and reliable option to contribute to the prevention of water problems in the city
- Answer on the question whether the produced drinking water meets the drinking water standards
- Answer on the question whether the Denutritor technology will remove NH4× and TOC < 0,2 mg/l (according to drinking water standards)
- Answer on the question whether CFU/ml after longer storage stays within standards < 100 mg/l
- Confirmation or not on the easy maintenance of the innovation

Budget request

Please specify the *eligible costs* for which budget is requested from BRIGAID.

Costs are detailed as follows:

• Rainwater treatment installation: material cost between € 5.000 and € 8.000 (2 m^3 installation including pump) • One additional Denutritor to remove NH4 and TOC via I3-Innovative technologies: € 1.000 • Installation of the equipment by a Belgian plumber: ca € 2.000 • Analytical costs by Belgian drinking water laboratory: € 9.000 – 12.000
If applicable, please describe any resources that have already been acquired or additional external budget that is available (or being requested from other sources) for testing.
Additional to the equipment WIC, I3 and Hatenboer Water will make man hours and travel costs available, of ca € 10.000
Any other comments:
Timing: The installations will be placed this summer (2017) such that the testing can start shortly after summer. The installations will be put in place for a period of at least 6 months, ev. to be extended to a 1-year period. The extension of the testing period will be evaluated after 6 months. Note that KU Leuven / Sumaqua will conduct the upscaling from the test results on one single roof to many roofs and evaluate the cumulative effect at the scale of a larger area of the city of Antwerp. This upscaling will be done based on Sumaqua's SCAN tool.

Testing results

3 test locations were identified at Antwerp + 1 test location at KU Leuven (which would make the testing easier and cheaper: the water samples can be analyzed for free in a KU Leuven laboratory of the Chemical Engineering department). We had negotiations with the local drinking water company Water-link and with prof. Ilse Smets at KU Leuven. On 31 March, we had a local meeting discussing the testing with the City of Antwerp (the climate adaptation manager), the innovator (WIC), the local drinking water company Water-link and a group of local citizens. It was concluded that a detailed risk analysis has to be conducted to avoid that local people get sick when drinking water of poor quality. The final decision was therefor to install the system at a KU Leuven site in close collaboration with the technical staff of KU Leuven (who kindly provided support and make a test location available). The system was succesfully installed on 26 October. Prof. Ilse Smets from KU Leuven kindly volunteered to have her students contributing to the testing (as part of the students' project work). The technical staff of KU Leuven still have to put some material around the installation to avoid that it will get frozen during the winter season.

The Water from Heaven test installation at the KU Leuven building:

Picture: The “Hemel(s)water” installation, currently being tested at the premises of the KU Leuven in Heverlee, Belgium.

The “Hemel(s)water” concept starts with clean water collection from roofs and particles removed with a filter. This water is than temporary stored in a rainwater tank. A nitrification unit removes ammonium, followed by membrane filtration system that removes bacteria, virusses and dissolved molecules to make pure water of drinking water standards (http://albertwic.wixsite.com/water/projects).

The “Hemel(s)water” installation (see picture) was installed on the premises of the KU Leuven on October 28, 2017. The installation is connected to the rain drainage pipe of a classified building, served by a substantial amount of its slated roof, at a position where a very limited number of tree leaves can get stuck in the roof gutter. The hydraulic as well as the water treatment performance was tested during a first six week period.

As for the hydraulic aspects, the performance can be denoted as excellent. Due to abundant rainfall during those 6 weeks, the installation filled up in few days time, directly validating the gravitationally based filtration.

As for the water quality, and, hence, treatment performance aspects, chemical as well as microbiological parameters need to be tested.

The table below summarizes the results of the chemical parameters that were tested. When comparing the obtained values with the indicated legal norms in Flanders1, it is clear that the installation performs satisfactorily. The indicated ‘target norm’ for ammonium of <0.2 mg/L is a target set by the designer of the Hemel(s)water installation and is not met yet. Actual nitrification could not have been expected during this first acclimatization period which coincided with autumn/winter weeks but is expected to start up when the ambient temperature starts to rise.

What is, however, remarkable is that the values after filtration are often higher than before filtration. This counterintuitive result can have a dual explanations: either the measurement accuracy is too low and replicas need to be taken, either the installation, which was not rinsed with water before this first trial, still contained chemicals (e.g., from the glue or membrane) from the manufacturing phase.

Regarding the microbiological parameters the average of 6 measurements (spread over two sampling dates) indicate that 4 to 6 colonies of the indicator organism E. coli were present in 1 mL, in the unfiltered as well as the filtered water. The norm for drinking water is very strict and equal to zero colonies per mL. Microbiologically the installation does, hence, not meet the norms yet.

The installation was drained after this first trial period and is restarted on January 29, 2018. The effect of remaining chemicals should be minimized during the second sampling campaign.

	nitrate [mg/L]	nitrite [mg/L]	ammonium [mg/L]	COD [mg/L]	pH	conductivity [µS/cm]
drinking water norms	50 mg/L	0.10 mg/L	0.50 mg/L	/	6.5-9.2	2100 µS/cm
target value	25 mg/L		0.20 mg/L			
11/20/17						
tank 1 (unfiltered)	0.975	0.038	0.265	12.2	6.99	131.2
tank 2 (filtered)	0.681	0.026	0.360	89.1	6.86	62.3
11/27/17						
tank 1 (unfiltered)	0.362	<0,015	0.131	n.m.	6.88	74.0
tank 2 (filtered)	0.595	<0,015	0.260	n.m.	6.72	44.4
12/4/17						
tank 1 (unfiltered)	0.5	0.048	0.169	n.m.	7.31	n.m.
tank 2 (filtered)	0.43	0.033	0.218	n.m.	6.85	n.m.
12/11/17						
tank 1 (unfiltered)	<0,23	<0,015	0.078	n.m.	n.m.	n.m.
tank 2 (filtered)	0.537	0.021	0.174	n.m.	n.m.	n.m.
12/18/17						
tank 1 (unfiltered)	0.405	<0,015	0.085	10.4	7.38	427
tank 2 (filtered)	0.431	0.017	0.142	15.5	6.81	406

Table. Chemical parameters tested during the first 6 week sampling campaign. Tank 1 (unfiltered) is the upper collection tank. Tank 2 (filtered) is the lower collection tank containing the membrane filtered water. <0.23 or <0.015 denotes the detection limit and n.m means “not measured”.

[1]Besluit van de Vlaamse Regering van 13 december 2002 houdende reglementering inzake de kwaliteit en levering van water bestemd voor menselijke consumptie. https://navigator.emis.vito.be/mijn-navigator?woId=32360

4. Innovation: ARIEL - soil moisture retrieval by microwave remote sensing

Innovator: BALAM Ingeniería de Sistemas S.L. (external innovator)

Contributing authors: Roger Jové (BALAMIS)

Innovation description

The description of ARIEL below is also available from the Climate Innovation Window, http://climateinnovationwindow.eu/innovations/ariel

Name
ARIEL - soil moisture retrieval by microwave remote sensing
Short description
LONG NAME: ARIEL, soil moisture retrieval by microwave remote sensing SHORT NAME: ARIEL OVERVIEW/VISION: High-resolution monitoring of soil moisture at the land surface level ARIEL is a microwave radiometer that provides remote soil moisture data. What cameras cannot see beyond surface, Balamis sensors can. ARIEL is a non-intrusive method able to effectively retrieve soil moisture over small and large areas easily. ARIEL can be placed on-board aircrafts, UAVs (Unmmanned Aerial Vehicles) and ground vehicles.
Sketch/Photograph of the Innovation

ARIEL block diagram:

Which hazard(s) is the innovation designed to mitigate?

Climate related risk(s) the innovation addresses:

- Droughts: Sustained and extensive occurrence of below average water availability. Resulting in water scarcity when drought conditions cause long-term imbalances between water availability and demands.
- Wildfires: Uncontrolled fire in an area of combustible vegetation that occurs in the countryside. Fire ignition and spread are both enhanced by cumulated drought, high temperature, low relative humidity and the presence of wind.

Themes the innovation applied to: Agriculture, Forests, Water availability

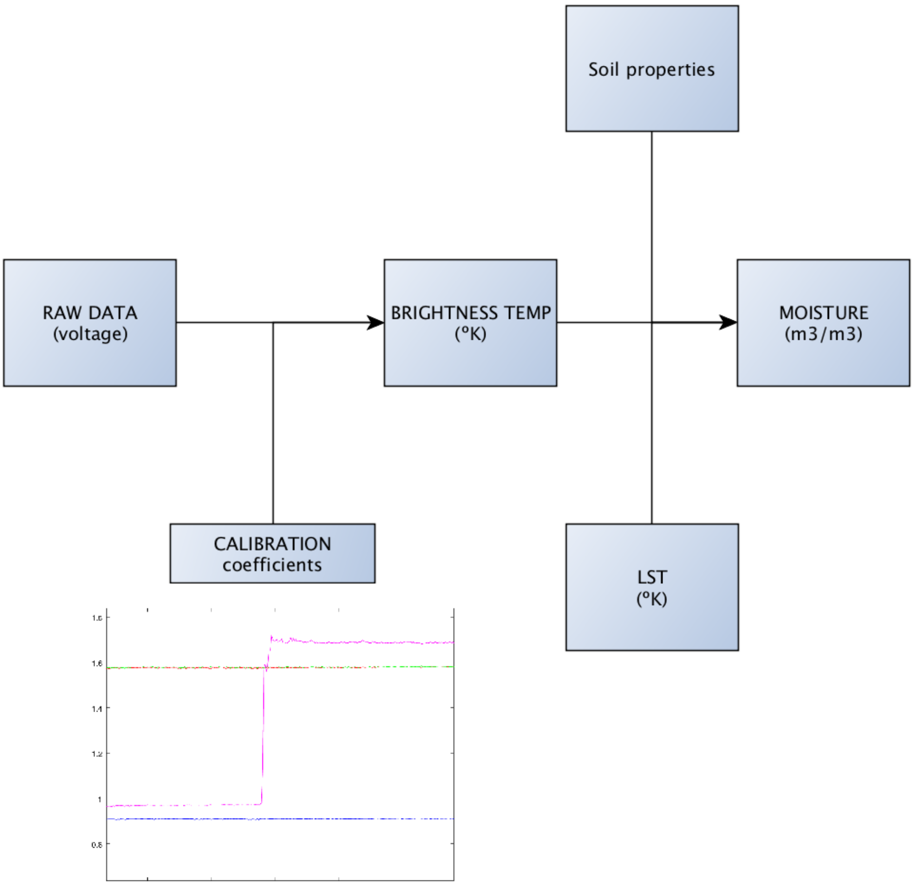
How does the innovation work?

ARIEL is a L-band radiometer. Such system measures natural thermal emission of the bodies within the microwave spectra, precisely at 1.41 GHz (L-band). If the instrument is pointed towards the soil, it is able to measure soil moisture. It requires a power supply from 12 to 24V, and consumes a max. of 50 W.

ARIEL can be installed on-board different platforms: aircrafts, unmanned aerial vehicles (UAV), and ground vehicles like tractors and ATVs. It requires a mechanical interface with the platform to be used on. Its installation takes less than 10 min. in ground vehicles and UAVs, and needs to be homologated in aircrafts. The antenna has to be adapted to existing “holes” for Earth observation in the fuselage, and data is synchronized with other systems using an internal GPS time stamp.

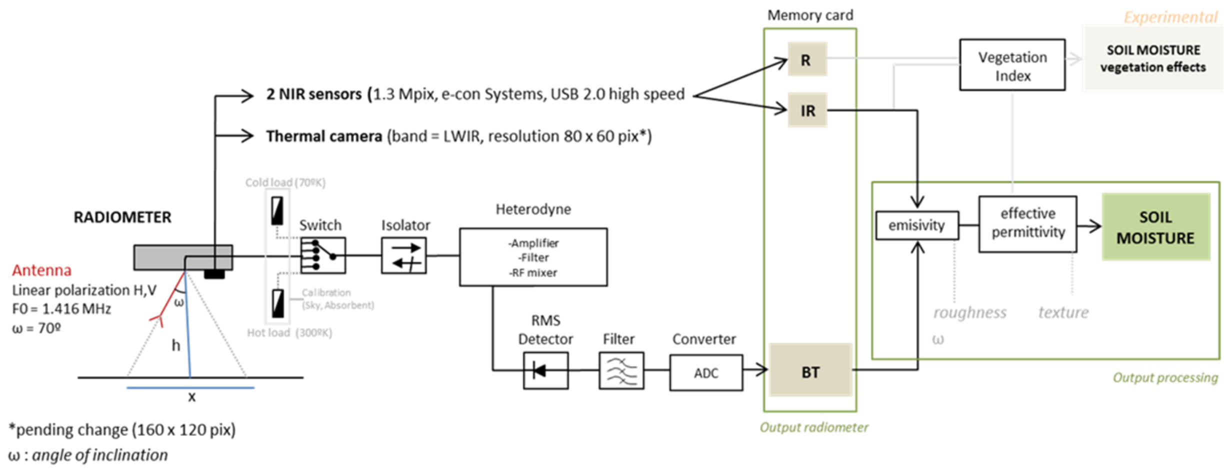
The sensor requires thermal stability. In order to achieve this technical requirement, the system is heated 10~15 Celsius above air temperature. It takes about 5 min to have a minimum stability and about 15 min to make the system fully stable (accurate timings depend on environment conditions).

General workflow of ARIEL sensor data flow:



Previous figure shows the general workflow of the ARIEL radiometer in a simplified way. Two processing phases are distinguished: Firstly, ARIEL captures the thermal emission of the surface as voltage (V) values, and converts it into values of brightness temperature (BT) based on an internal calibration process. The internal calibration of the sensor needs to be reached under conditions of thermal stability and no electronic interferences (noise). Both data, V and BT, are internally georeferenced using the ARIEL’s GPS and stored in CSV format, and need to be downloaded to a PC for addressing the post-processing phase. During the second processing phase, BT values are finally converted on soil moisture values and maps using GIS software and land surface auxiliary data (e.g. Land Surface Temperature, Vegetation Index retrieved with multispectral and thermal cameras, and soil properties -texture-). The internal arrangement of ARIEL components is shown in next figure.

Operational diagram and internal arrangement of ARIEL components:



Added value / main differentiating element from conventional approach

The main added value / features of ARIEL refer to:

- ARIEL provides a high density of soil moisture data over large areas without requiring ground-based infrastructure.

- It is an extremely compact and light radiometer (up to 1.6 kg, for the “UAV” version)

- It is possible to combine the L-band radiometer with multispectral cameras. The combination of both instruments allows to increase the spatial resolution of the outputs by using disaggregation algorithms.

Critical success factors / Limitations

ARIEL has reached a level of protection of IP63 (spraying water resistant). Two critical factors require a special attention: a) compensation of the different view angles resulting during the flight campaigns, and b) accurate georeferentation of the raw data with the correct antenna footprint. Additionally, the use of disaggregation algorithms during the post-processing requires data of high quality in order to get accurate soil moisture maps.

Desk study

Summary

Performance Indicator	Desk Study Questions
Technical Effectiveness refers to the intended capacity of the innovation to reduce risk from a specific hazard(s)	- What type of hazard(s) does the innovation address? - Which characteristic(s) does the innovation have? - How will the innovation reduce the risk of the hazard(s)? - What is the intended (quantitative) level of risk reduction? - Has the innovation been tested previously and can the innovation achieve the intended level of risk reduction without failure? - What is the current estimated technical readiness level (TRL) of the innovation?
Reliability refers to the likelihood that the innovation fulfills its intended functionality over its lifetime	What are the inputs/outputs to the innovation? (Which inputs/outputs can be controlled by the innovator?) What are the possible technical failure modes of the innovation? If the innovation is only operated prior to/during a hazard event, what are the possible implementation failure modes? Which failure modes are most likely to occur or are most critical? Is there available historical data against which to test the innovation? During testing, will the innovation be tested in real-time?
Durability refers to the intended use and lifetime of the innovation	Is the innovation continuously operated or is it only operated prior to/during a hazard event? If the innovation is only operated prior to/during a hazard event, what is the intended operation (protocol) of the innovation? What is the expected lifetime of the innovation based on its components? - What are the maintenance requirements for the innovation to reach its maximum lifetime?
Flexibility refers to the capacity of the innovation to be sold/deployed in other locations than originally envisioned	Where will the innovation be marketed/sold? What is the (potential) size of the market for the innovation under current climate conditions? under future climate conditions? Is the innovation made up of modular components (or, alternatively, are the innovation's components customizable)? Does the innovation require significant adjustment to be installed in a new location/used at different sites throughout Europe? Are the material components of the innovation easily obtained within the potential market(s)? What is the material cost of the innovation?

Intended functionality/performance

ARIEL is an informational innovation which provide maps of soil moisture. The radiometer can be installed in ground vehicles, UAVs (unmanned aircraft systems), or manned aircrafts. The vehicle follows the path of a previously defined track/flight plan. When the track/flight is finished, the sensor is uninstalled, and the raw data stored in the system (in .csv format) can be downloaded into a PC. Using GIS software, raw data is post-processed and interpolated to retrieve a soil moisture map.

Technical Readiness Level

ARIEL entered BRIGAID with a TLR5 (Technology validated in relevant environment: Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting features so they can be tested in a simulated environment. Examples include “high-fidelity” laboratory integration of components).

With the BRIGAID’s support, ARIEL aims to reach a TRL7 (Innovation prototype demonstrated in an operational environment).

TRL assessment:

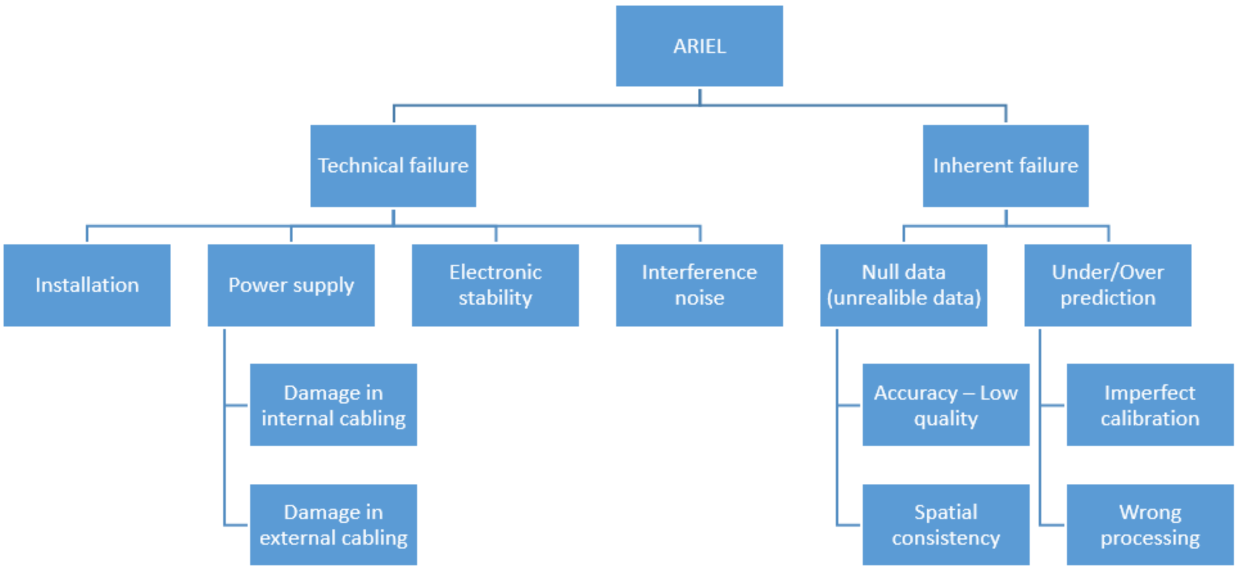
BRIGAID Stages			*To be completed at the start of the project*						*To be completed at the end of the project*			Comments
	TRL	Question	Start of Project			Anticipated End of Project			Actual End of Project			
			Yes	No	N/A	Yes	No	N/A	Yes	No	N/A	
Desk Study	TRL 1	**Basic principles observed and reported.**	x			x			x			
	TRL 2	**Innovation concept formulated.**	x			x			x			
	TRL 3	**Analytical and experimental critical function and/or characteristic proof-of-concept.**	x			x			x			
Stage 1: Laboratory Testing	4	Has societal acceptance testing of individual components been performed?	x			x			x			
	4	Has performance of components and interfaces between components been demonstrated?	x			x			x			
	4	Does draft system architecture plan exist?	x			x			x			
	4	Have end user technology/system requirements been documented (e.g., reliability requirements)?	x			x			x			
	4	Has component compatibility been demonstrated?	x			x			x			
	4	Does technology demonstrate basic functionality in simplified environment?	x			x			x			
	4	Have performance characteristics been demonstrated in a laboratory environment?	x			x			x			
	4	Have low-fidelity assessments of system integration and engineering been completed?	x			x			x			
	TRL 4 Achieved	**Innovation validated in a laboratory environment.**										
	5	Have internal system interface requirements been documented?	x			x			x			
	5	Has analysis of internal interface requirements been completed?	x			x			x			
	5	Can all system specifications be simulated and validated within a laboratory environment?	x			x			x			
	5	Is the laboratory environment high-fidelity?	x			x			x			
	5	Have individual component functions been verified through testing?	x			x			x			
	5	Have objective and threshold operational requirements been developed? (e.g., has the intended reduction in risk been quantified? Is the end-user requirement for reliability known?)		x		x			x			Interference issues with drones have been identified. No interferences found in ground and aricraft versions.
	5	Have all potential failure modes been identified and documented?		x		x			x			Potential failures: electromagnetic interferences, vibration resistance, and cold joint (during production stage)
	5	Has the reliability of the fully integrated prototype been estimated using desk study calculations?		x		x			x			System tested
	5	Have the social, technical, and environmental design of the innovation been re-assessed? (TIF tool applied, i.e. stage-gate tool)		x		x			x			Done
	TRL 5 Achieved	**Innovation prototype demonstrated in a laboratory environment.**										
Stage 2: Operational Testing	6	Have system integration issues been addressed?		x		x			x			System fully integrated (ground and aircraft versions). System mechanically integrated in drones, but electromagnetic test did not succeed.
	6	Is the operational environment fully known?		x		x			x			
	6	Have the current and future (i.e., under climate change) hazard conditions in the intended operational environment been documented?			x			x			x	
	6	Has the technical and/or climate lifetime of the innovation been estimated?	x			x			x			System is specifically designed for not failing. There is no planned obsolescence in its design.
	6	Have performance characteristics (i.e., social, technical, and environmental) been verified in a simulated operational environment?		x		x			x			System tested in field
	6	Has prototype been tested in a simulated operational environment and shown to withstand the intended hazard loads *without* failure?		x		x			x			
	6	Does the prototype successful reduce the intended/threshold level of risk (i.e., by reducing the hazard and/or its consequences) in a simulated operational environment?			x			x			x	This is an informational innovation. The system provides soil moisture data. How this information is used will depend on the end-user.
	6	Have the operation and maintainence protocols over the lifetime of the innovation been established and documented?		x		x			x			
	6	Has system been tested in realistic environment outside the laboratory?		x		x			x			
	6	Has engineering feasibility been fully demonstrated?		x		x			x			
	TRL 6 Achieved	**Innovation model or prototype demonstrated in a relevant environment.**										
	7	Have all interfaces been tested individually under stressed and anomalous conditions?		x		x			x			Differences in voltage supply, mechanical vibrations
	7	Has technology or system been tested in a representative operational environment and shown to withstand the expected hazard loads?		x		x			x			System working rightly on ground and aircraft platforms. Failures detected when was tested mounted on drones (too many interferences)
	7	Has the reliability of the prototype been quantified and validated in a representative operational environment?		x		x			x			
	7	Are available components representative of production components (i.e., will the innovation be ultimately produced using the same materials as used in testing; is the prototype to-scale)?		x		x			x			
	7	Have vulnerabilities to human error been effectivley minimized?		x		x			x			GUI to use the sensor developed
	7	Has fully integrated prototype been demonstrated in actual or simulated operational environment?		x		x			x			
	TRL 7 Achieved	**Innovation prototype demonstratied in an operational environment.**										
	8	Are all technology/system components form, fit, and function compatible?		x		x			x			System working rightly on ground and aircraft platforms. Failures detected when was tested mounted on drones (too many interferences)
	8	Is technology/system form, fit, and function compatible with operational environment?		x			x			x		
	8	Has technology/system form, fit, and function been demonstrated in operational environment and shown to withstand the expected hazard load(s) without failure?		x			x			x		Partially (only for ground and aircraft versions)
	8	Have the operational and maintance costs over the lifetime been estimated and documented?		x			x			x		
	8	Have the social, technical, and environmental design of the innovation been re-assessed? (TIF tool applied, i.e. stage-gate tool)		x			x			x		

Previous development and testing activities

ARIEL is an innovation derived from a previous prototype developed by the Technical University of Catalonia (UPC). At the time when Balamis applied to BRIGAID, the company had a non-optimal first terrestrial prototype, and started to develop the airbone and UAV versions.

Qualitative assessment of failure modes and risks

Failure modes identified for ARIEL:



Preliminary-tentative failure-risk class matrix:

1	Interference & Noise (levels too high)	Frequent	Critical	The radiometer may not be compatible with the platform. Some data may be lost or discarded.
2	Electronic stability (damages in internal electronics)	Improbable	Critical. System cannot be operated for a few weeks.	System needs to be repaired by the company. Recalibration is needed.
3	Power supply (internal cabling is damaged)	Improbable	Critical. System cannot be operated for a few weeks.	System needs to be repaired by the company. Recalibration is needed.
4	Power supply (external cabling is damaged)	Occasional	Marginal	Repair the cable in situ. System cannot be operated for a few minutes.
5	Under/over prediction of hazard or environmental variable	Occasional	Marginal	Algorithms need to be adjusted with the correct parameters.
6	Null data	Improbable	Critical	System needs to be repaired / measurement done again

[1] Select: Frequent, Probable, Occasional, Improbable, Not evaluated

[2] Select: Critical, Marginal, Negligible, Not evaluated

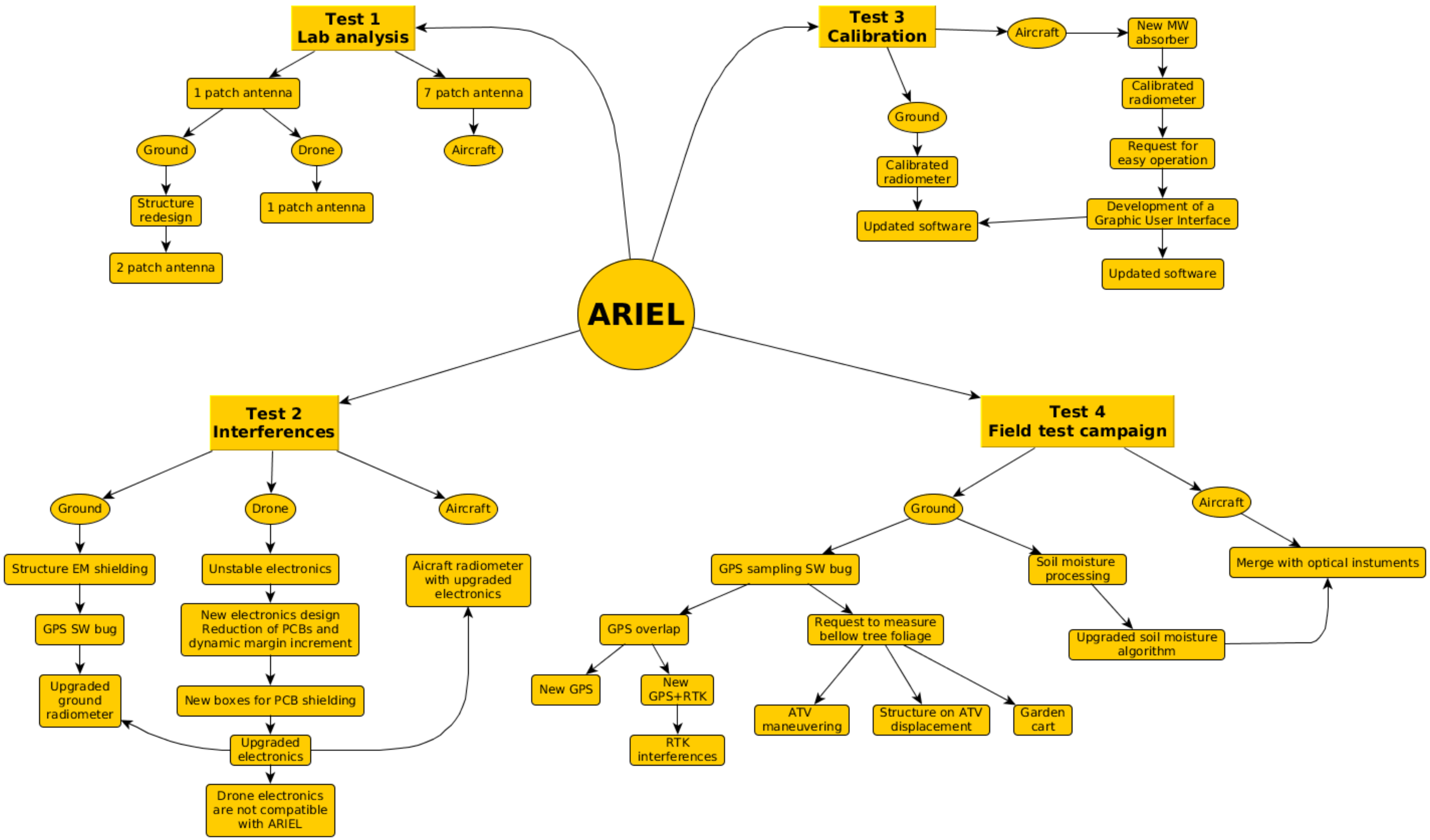
Test plan

Planned and current status of ARIEL testing activities:

Testing phase	Activity (Key Performance Indicator)	Period of testing1	Status (Completed/In progress)	Comments
Laboratory testing	Test 1: Analysis of testing requirements (Technical Reliability)	Sep/2017	Done	Improvement on antenna design for ground version
Operational testing	Test 2: Interference tests between ARIEL and UAV platforms. 5 campaigns. (Technical reliability)	Sep/2017	Done	ARIEL is compatible with ground ATV, and Cessna Caravan aircraft. ARIEL is NOT compatible with the tested drones.
	Test 3: Calibration and accuracy tests. 2 campaigns. (Inherent system reliability)	Oct/2017	Done	Ground, UAV and aircraft versions calibrated
	Test 4: Overall validation in experimental agriculture fields. 6 campaigns. (Inherent system reliability)	It will depend on crop requirements	Partially	1 aircraft and 5 ground-ATV testing campaigns
	Technological amendments & improvements	Not initially planned	Done	Improvements on electronic boards (better dynamic margin) Improvements on electronics casing (interference mitigation) Improvements on antenna design (ground version) Improvement on mechanical structure (new design) Improvements on UAV version (weight reduction)

[1] (according to the approved testing plan)

Rational diagram of ARIEL testing:


ARIEL
Test 1
Lab analysis
1 patch antenna
7 patch antenna
Ground
Drone
Aircraft
Structure redesign
1 patch antenna
2 patch antenna
Test 3
Calibration
Aircraft
New MW absorber
Calibrated radiometer
Request for easy operation
Development of a Graphic User Interface
Updated software
Ground
Calibrated radiometer
Updated software
Test 2
Interferences
Ground
Drone
Aircraft
Structure EM shielding
GPS SW bug
Upgraded ground radiometer
Unstable electronics
New electronics design Reduction of PCBs and dynamic margin increment
New boxes for PCB shielding
Upgraded electronics
Drone electronics are not compatible with ARIEL
Aicraft radiometer with upgraded electronics
Test 4
Field test campaign
Ground
Aircraft
GPS sampling SW bug
GPS overlap
New GPS
New GPS+RTK
RTK interferences
Request to measure bellow tree foliage
ATV maneuvering
Structure on ATV displacement
Garden cart
Soil moisture processing
Upgraded soil moisture algorithm
Merge with optical instuments

Field campaigns performed to test ARIEL:

Date	Location	Test – Campaign (reference in the text)	Description & Comments
30/03/2017	Can Cartró	T2 – C1	Drone interference test
25/04/2017	Agramunt	T4 – C1	Terrestrial testing / validation
02/05/2017	Port Ainé	T4 – C2	Terrestrial Testing
08/05/2017	Molerussa	T2 – C2	Drone test
		T4 – C3	Terrestrial Validation
03/07/2017	Mollerussa	T4 – C4	Terrestrial Validation
11-12/09/2017	Can Cartró	T4 – C6	Mapping campaign
14/09/2017	Mollerussa	T2 – C3	Drone test
		T4 – C5	Terrestrial validation
14/11/2017	Can Cartró	T2 – C4	Drone interference test
26/11/2017	Can Cartró	T3 – C1	Aerial Calibration
28/11/2017	BCN Airport	T3 – C2	Aerial installation / calibration
30/11/2017	Balaguer (flight)	T3 – C3	Aerial flight / validation (not reported in this document, still processing data)
12/12/2017	Parc Garraf	T2 – C5	Drone interference test

Test 1: Analysis of requirements and laboratory test

Rationale

This first test aimed: i) to have a modular mechanical interface which allows the easily use of the radiometer sensor inside a anechoic chamber, and its integration in an UAV, and ii) to measure the radiation pattern of the sensor's antenna and identify potential impacts on the electromagnetic propagation.

Facility

The use of an anechoic chamber located at the Department of Signal Theory and Communication of Polytechnic University of Catalonia (UPC) was initially planned. However, results of this test were finally retrieved using computing simulations. See comments in the Results section.

Equipment

Initial plan: Anechoic chamber (UPC), and Balamis' RF signal analyzer, and electronic devices.

Protocol

- To check anechoic chamber mechanical interfaces.

- To check UAV mechanical interfaces.

- To design and built a compatible structure for the sensor.

- To measure the new structure in the anechoic chamber.

- To analyze radiation pattern results.

Test 2: Interference tests between ARIEL and mobile platforms

Rationale

This test aims to analyze the optimal requirements for the right integration of ARIEL in mobile platforms, and to solve electronic interferences between ARIEL and the UAV.

Facility/ies

Experimental sites used during interference tests (test 2):

Testing site	Location (Longitude; Latitude)[1]	Altitude (m.a.s.l.)	Land cover
Can Cartró (Lleida, Spain)	394375; 4583783	186	Area 1. Field with herbaceous crops (20 cm. height) Area 2. Ploughed field
Mollerussa (Barcelona, Spain)	322829; 4609509	245	Agricultural field with apple trees.
Parc del Garraf (Barcelona, Spain)	4570644; 4570644	472	Road

[1] Projection system: ETRS89 - UTM Z31N

Equipment

UAV and airborne platforms; Calibrated radiometer onboard a quad or other platform for ground truth purposes.

UAV characteristics:

Type	Multicopter
Make / model	Drone Tools / Drone octo 8
Number of rotors	8
Electronics	DJI Wokong 2
Weight	4Kg
Autonomy (Batteries)	15 min. (2x 7000mAh - 4S 14.6V)
Frequencies used	2.4Ghz, 5.8Ghz

Protocol

The general protocol consisted in a testing phase and a post-processing phase. In each one, several tasks were performed, i.e.:

Testing phase:

- Integration of ARIEL with the drone.
- Checking of mechanical components.
- Retrieval of radiometer measurements (Sky/Abs) with the UAV electronics turned off.
- Retrieval of radiometer measurements (Sky/Abs) with the UAV electronics turned on.
- Retrieval of radiometer measurements (Abs) with the UAV electronics turned on and motors rotating at low speed.
- UAV flight with radiometer measurements and attitude data.

Post-processing phase:

- Quick parse of the measurements and quick check for interference.
- Check obtained attitude UAV data (PITCH, YAW, POSITION, HEIGHT, TIMESTAMP) during flight
- Check obtained radiometer data (TIMESTAMP, VOLTAGE DATA) for inconsistencies.
- Quick analysis of radiometer data for quick results.
- Integrate the radiometer parameters with the UAV data to obtain the antenna footprint
- Analyze antenna footprint with the measurements

Test 3: Analysis of requirements and laboratory test

Rationale

To calibrate and validate soil moisture measurements. ARIEL sensor can be combined with optical and thermal sensors (photodiodes or cameras) in order to remove vegetation interferences. If cameras are used, then it is possible to use disaggregation algorithms able to increase the spatial resolution of the soil moisture outputs.

Facility

Experimental sites for ARIEL testing:

Testing site	Location (Longitude; Latitude)[1]	Altitude (m.a.s.l.)	Land cover
Can Cartró (Lleida, Spain)	394375; 4583783	186	Ploughed field
ICGC hangar at the Barcelona airport (El Prat de Llobregat, Spain)	423510; 4573237	5	Industrial area - Airport

[1] Projection system: ETRS89 - UTM Z31N

Equipment

Airborne platform; Ground-based soil moisture measurements using bulk density drills and laboratory analyses.

Protocol

Testing tasks

- Integration of the radiometer with the optical sensors on-board the drone.
- Checking of mechanical components.
- UAV flight for retrieving radiometer measurements and GPS data.
- Ground truth measurements.

Post-processing tasks

- Integration of radiometer parameters with UAV data to retrieve the antenna footprint.
- Compensation of angles during the flight, and data georeferentiation with adjusted antenna footprint.
- Implementation of pixel disaggregation algorithms.

Test 4: Testing and validation of innovation in experimental agriculture fields

Rationale

The aim of this package is microwave technology validation in Agriculture. To do so, ARIEL will be tested in irrigation crops.

Facilities

Experimental sites for ARIEL testing:

Testing site	Location (Longitude; Latitude)[1]	Altitude (m.a.s.l.)	Land cover
Can Cartró (Lleida, Spain)	394375; 4583783	186	Area 1. Field with herbaceous vegetation (20 cm. height) Area 2. Ploughed field Area 3. Ploughed vineyard field.
Mollerussa - IRTA experimental site (Lleida, Spain)	322829; 4609509	245	Agricultural field with irrigated apple trees.
Parc del Garraf (Barcelona, Spain)	4570644; 4570644	472	Road
Port Ainé	352905; 4698882	1976	Terrain with paths and vegetation. Some areas covered with snow and ice.
Agramunt	341221; 4627371	328.2	Rough terrain with big sinkholes.

[1] Projection system: ETRS89 - UTM Z31N

Equipment

An ATV and an airborne platform were used. Soil core sampler and soil laboratory instruments for measuring soil moisture at field conditions.

Protocol

Pre-testing tasks

- Data information of study area.
- Meeting with users.

Testing tasks

- Integrate the radiometer with the drone.
- Check mechanical components.
- UAV flight with radiometer measurements and position data.
- Ground truth measurements.

Post-processing tasks

- Integrate the Radiometer parameters with the UAV data to obtain the antenna footprint.

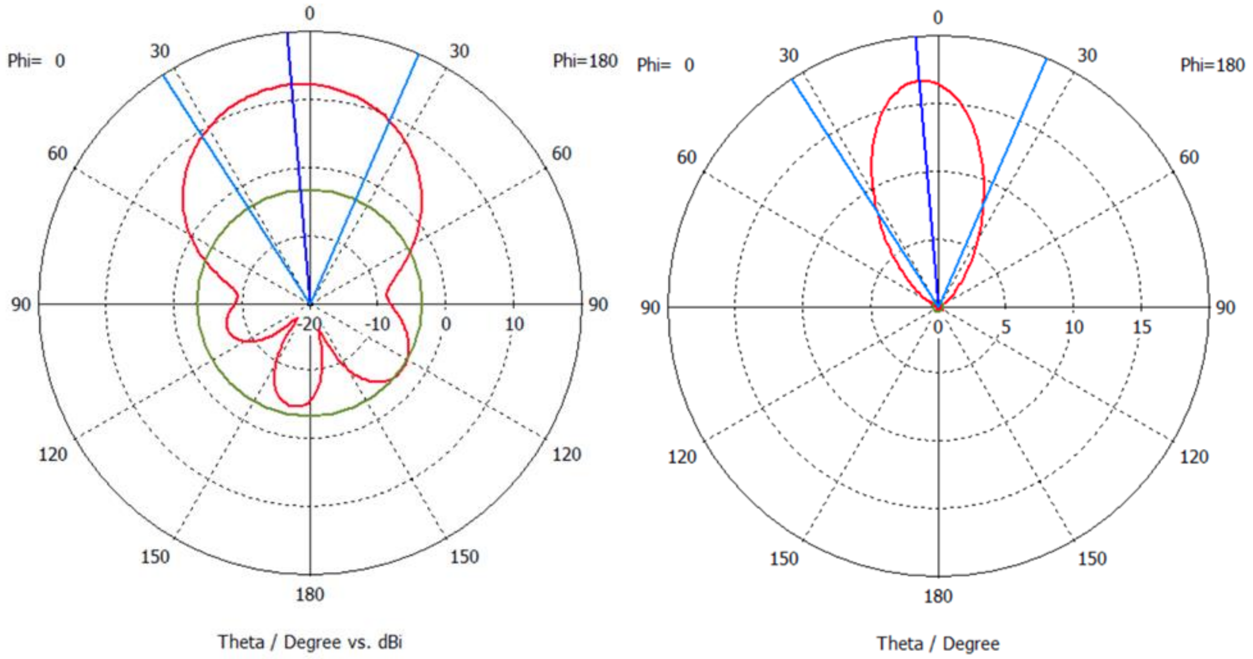
- Compensate angles during the flight and geo-reference the data acquired with the correct antenna footprint.
- Pixel disaggregation algorithms implementation.
- Viability study of microwave technology in irrigation systems.

Testing results

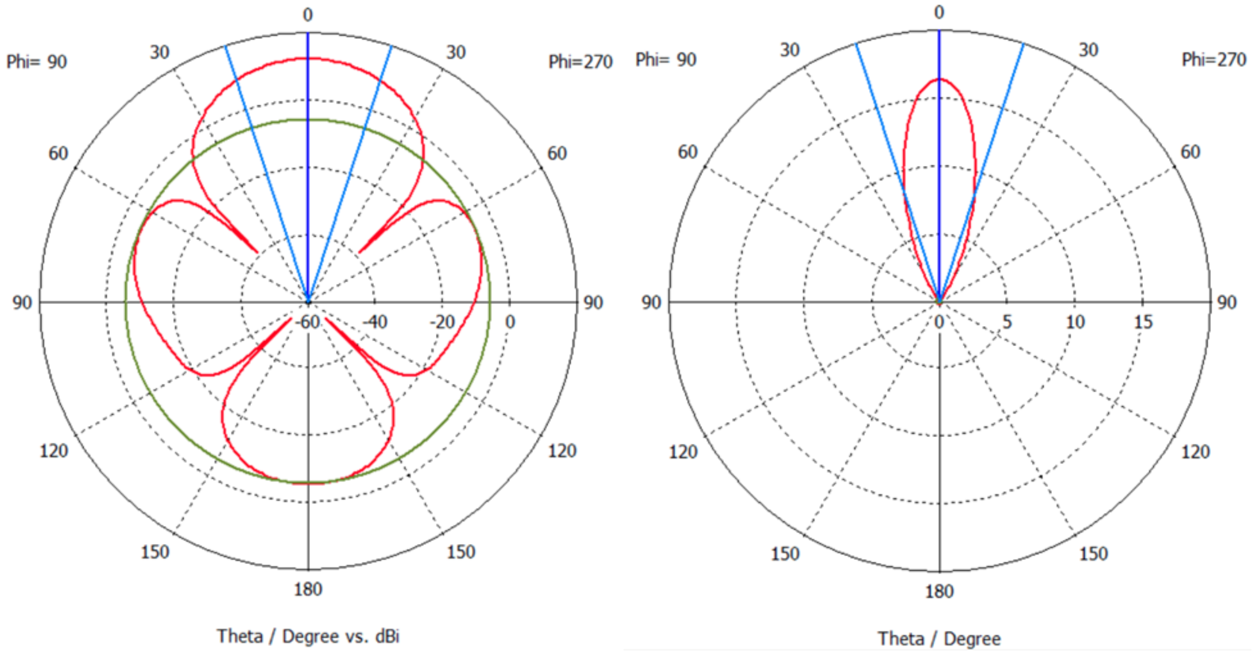
Test 1: Analysis of requirements and laboratory test

1 patch and 2x1 antenna patch arrays have been simulated and analyzed for the different ARIEL versions (aircraft, UAV, and ATS). Results on the antenna radiation pattern are shown next.

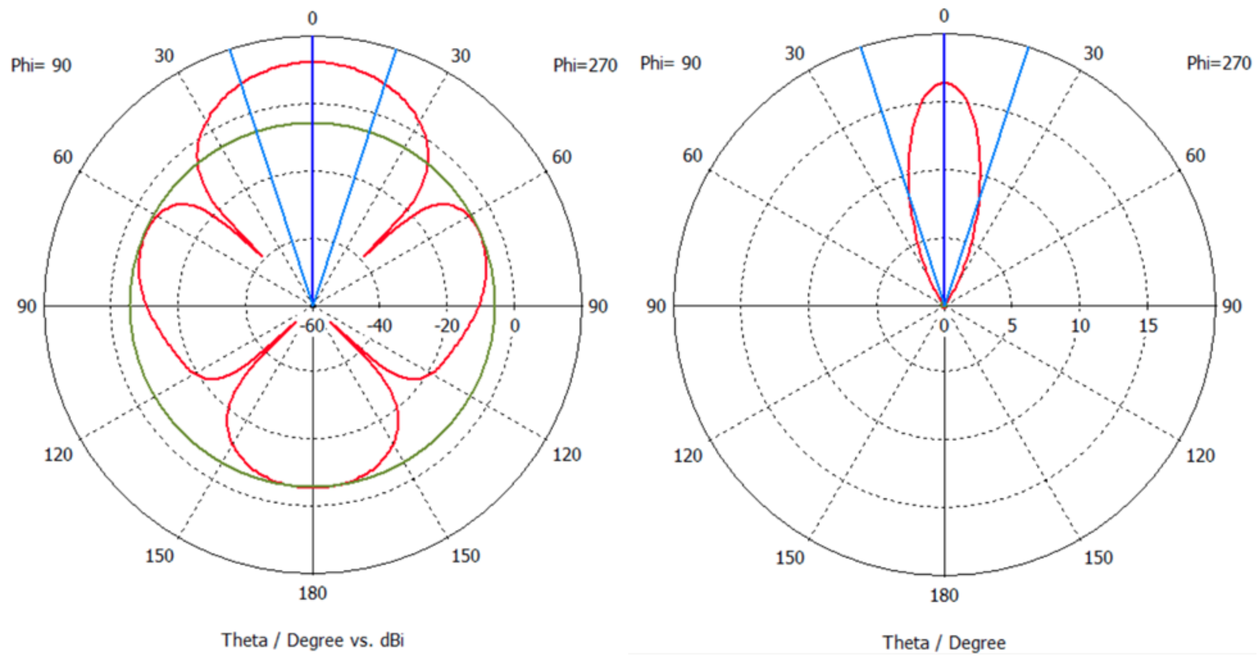
1 patch logarithmic (right) and linear (left) radiation diagrams. Frequency: 1.413 GHz; Main lobe: 12.2 dBi; Angular beam width (3dB): 56.3º:



2x1 patch array logarithmic (left) and linear (right) radiation diagrams. Frequency: 1.413 GHz; Main lobe: 12.1 dBi; Angular beam width (3dB): 36.1º:



2x1 patch array logarithmic (left) and linear (right) radiation diagrams. Frequency: 1.413 GHz; Main lobe: 12.1 dBi; Angular beam width (3dB): 36.1º:



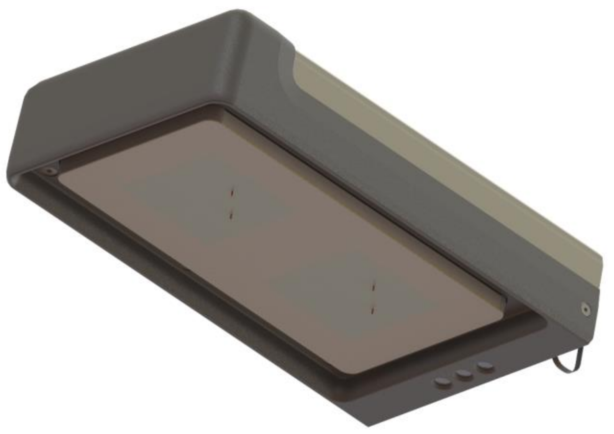
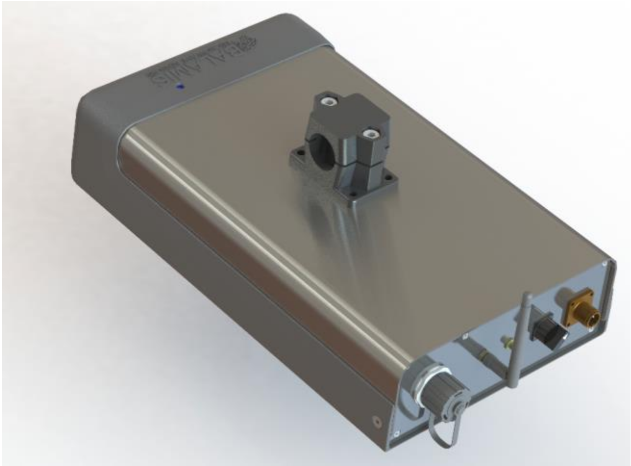
As consequence of the antenna radiation pattern, an upgrade of the antenna was performed for the ground vehicle version. The new antenna adopts the 2x1 patch. This antenna is more directive (narrower beam of view), and has a destructive interference at 50º. This destructive interference angle is used to cancel interferences coming from the environment (mostly with a horizon origin). Consequently, new ground version of ARIEL has the antenna pointing at 50º respect to the NADIR (hence, 40º respect to the horizon).

According to Prof. Camps from UPC, no significant differences in directivity should be expected between the computing simulations performed and the measurements that may be retrieved at an anechoic chamber. Because expert advised against the use of the anechoic chamber, Balamis finally decided to spend the budget reserved for this testing activity in the development of a new radiometer with a 2x1 patch antenna.

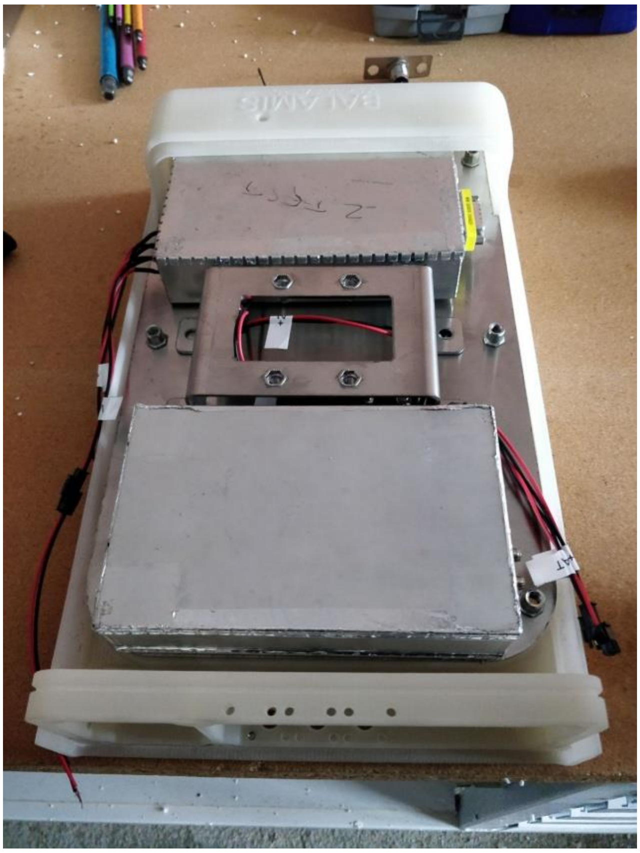
Because this change was a major technological adjustment of the system, a new structure had to be designed. Other adjustments and features were additionally included. These include:

- protected connector and cables to avoid impacts due to trees branches.
- protected antenna from lateral impacts of branches.
- switch button to start and stop the acquisition of measurements.
- LED light, rightly visible from the ATV driver, to indicate if the system is working.
- new mechanical joint, to make easier its use on other ground vehicles.

Upgraded sensor’s antenna structure and new features developed (simulated version):

	
Lower view: 2x1 antenna, lateral protection, rear connectors	Upper view. LED, new joint, and rear connectors

New ARIEL antenna under integration (current version). Left: Front side with the antenna, Right: Rear side with the electronics installed:



Test 2: Interference tests between ARIEL and mobile platforms

Campaign 1

Date: 30/03/2017

Participants: Balamis Team (Roger, Ricard, Adria, Esther)

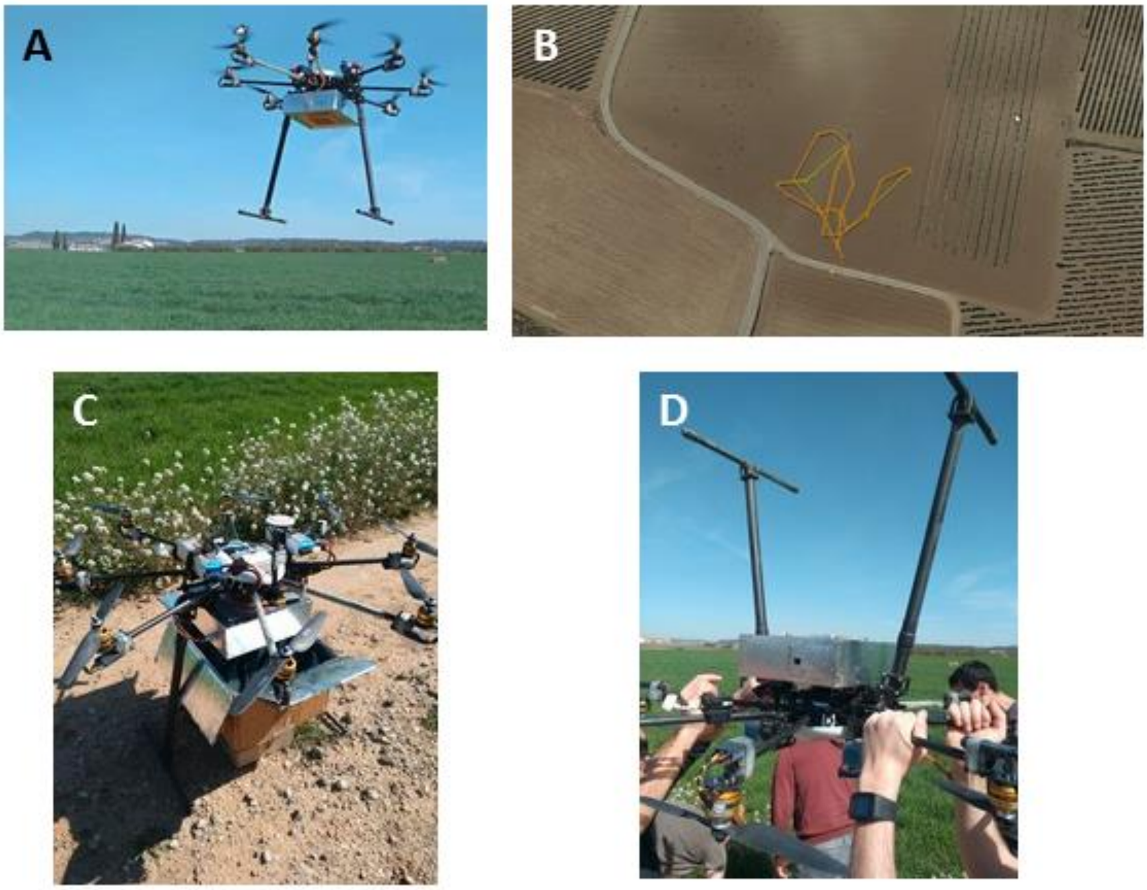
UAV company: M-Drone S.L.

Testing objectives: To analyze the optimal requirements for the right integration of ARIEL in mobile platforms, and to solve electronic interferences between ARIEL and the UAV.

Specific protocol: The radiometer is installed in a UAV (unmanned aircraft system). The UAV follows the path previously defined in a flight plan. Sensor is disassembled from the UAV when flight finishes, and raw data (.csv format) is downloaded into a PC. Raw data are finally post-processed using a GIS software (quality check, and spatial interpolation) to retrieve a soil moisture map.

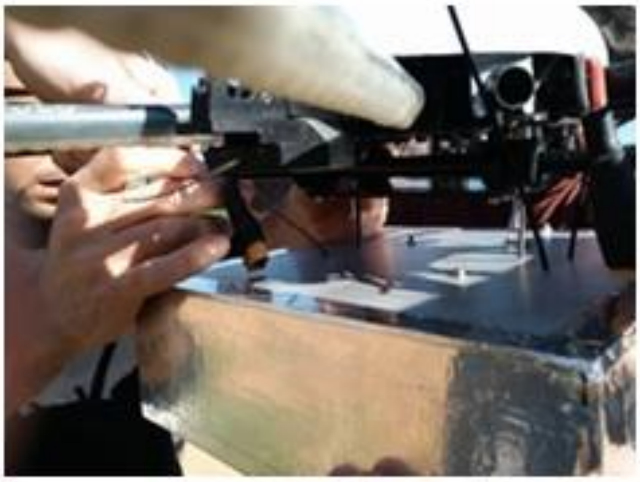
Experimental Site: Can Cartró - Area 1

(A) Radiometer onboard the UAV; (B) Flight path from UAV logs; (C) Radiometer absorber calibration; (D) Radiometer SKY calibration:



Despite the radiometer was successfully mounted to the UAV using nylon cable ties, the mechanical integration was not fully reached due to a misalignment between the screws placed in the radiometer and the holes of the UAV mounting.

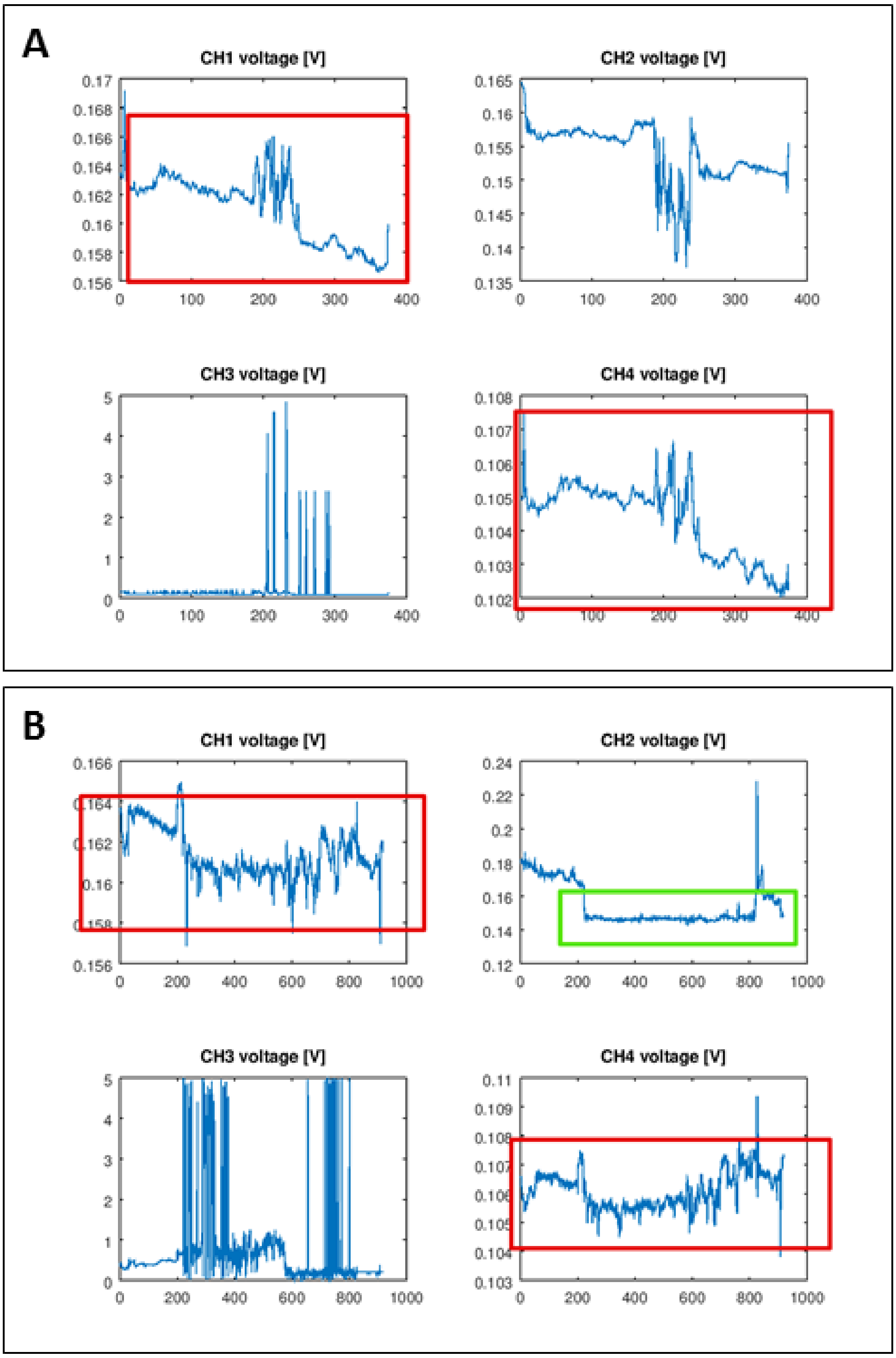
Left: Radiometer integration with nylon ties, Right: Drone coupling:



It was initially expected to use the UAV batteries to power the radiometer. However, the UAV and radiometer use different connectors (XT90 and XT60 respectively). To solve this problem, the UAV company provided a small battery with XT60 connectors.

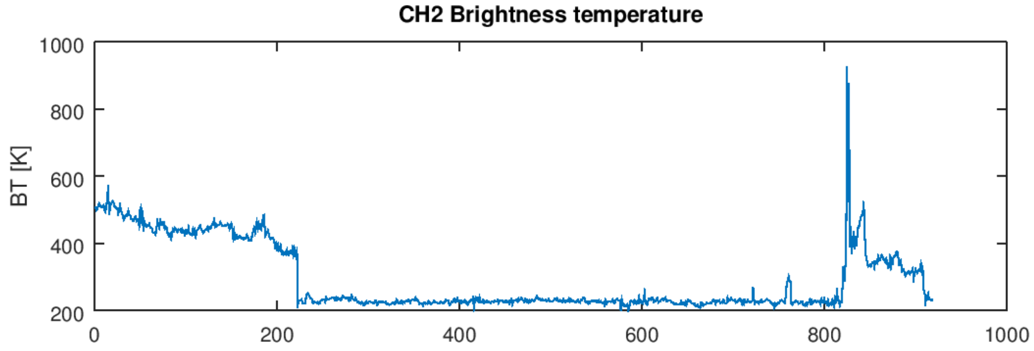
During the inspection and analysis of the data logs, interference noise was detected in the radiometer HOT (CH1) and COLD (CH4) loads channels even with the drone was off (red squares in next figures). These errors may be explained due to an unstable voltage or bad isolation of the radiometer.

UAV radiometer voltages (V) vs time, during (A) calibration (with the drone turn off) (B) flight. CH1: Hot channel; CH4: Cold channel:



Because the loads had interferences, the calibration factors could not be accurately computed. Nevertheless, some approximate factors were extracted and used to calibrate the radiometer and obtain brightness temperature values. Factors were computed by hand, with the aim of programming the algorithm in the radiometer itself.

Computed Brightness Temperature (Kelvin) in channel 2 vs time:

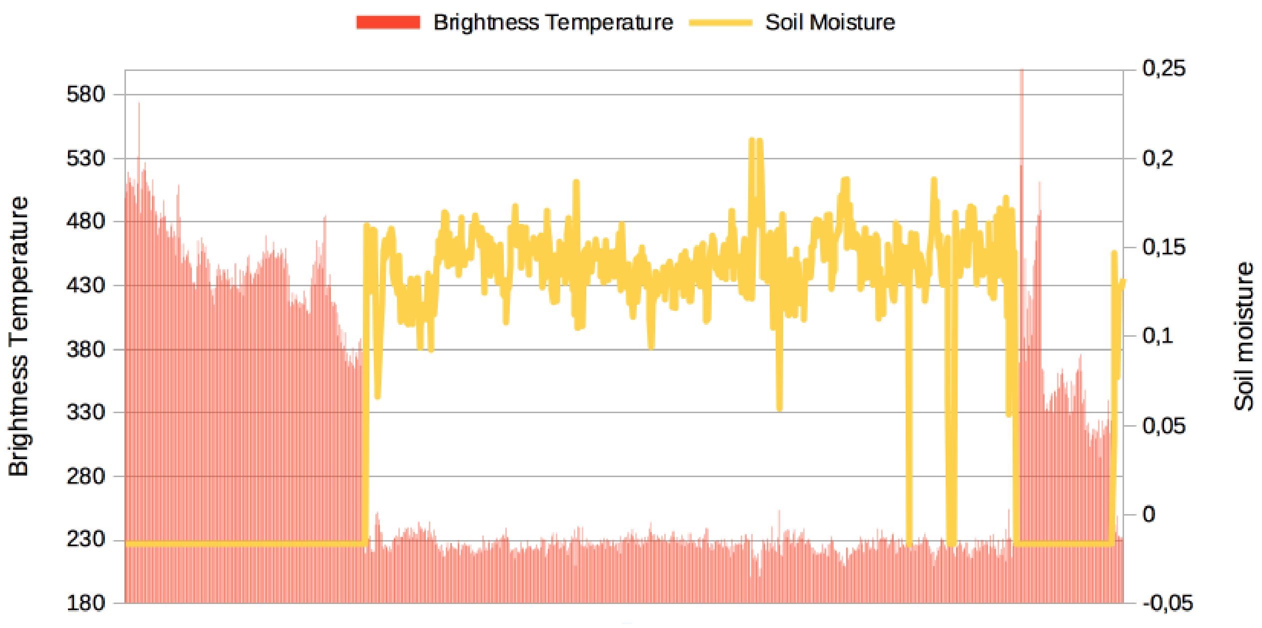


As expected, lowest brightness temperatures were associated to vegetated areas.

Calculation of soil moisture: Because GPS and attitude data from the UAV could not be synchronized with the radiometer measurements, the antenna incidence angle was assumed to be equal to the NADIR angle. To compute soil moisture values, soil temperature and sand/clay content percentages were also required as auxiliary data. Soil temperature was estimated and averaged for the whole area using ground temperature measurements. This data can also be retrieved if a thermal sensor is installed on the radiometer or by making a second UAV flight in which a thermal camera has been installed.

To obtain soil textural information a soil sample was collected and analyzed in the laboratory using standard procedures. Textural values from this single sample, i.e. clay:16%, sand: 50%, silt: 34%, were considered constant for the whole field. The rugosity parameter was averaged as 0.2 (usual value for a plough field). Alternatively, the availability of soil texture values from a detailed soil map may increase the accuracy of the soil moisture retrievals.

Erroneous computed brightness and soil moisture (m3/m3) vs time:



In this first test the GPS (Global Positioning System) and the IMU (Inertial Measurement Unit) were not connected to the radiometer, although the use of data from both devices was initially planned. In this test, the RTC (Real Time Clock) timestamp provided by the radiometer was thought to be enough to synchronize the radiometer measurements with the UAV data. However, and despite of retrieving the timestamp data from the radiometer, the UAV software was not able to store them in the logs. As consequence, it was decided that the radiometer will have its own GPS and IMU data during next testing campaigns.

Without GPS data it was not possible to evaluate the spatial consistency of the data. However, as the sampling rate was correct no problems are expected in future when the GPS is being used.

Failure matrix of the Campaign 1:

Failure	Description	Mitigation actions
Mechanical integration / installation	Misalignment between the coupling and the drone screws	For the next test the UAV mounting exact dimensions were asked to the provider and correct holes done in the radiometer structure.
Power connectors not matching	Different connectors in drone (XT60) and UAV (XT90).	For the next test the UAV mounting exact dimensions were asked to the provider and correct holes done in the radiometer structure.
External Interferences	In-flight and calibration measurements affected by the drone system. These interferences made the whole system inaccurate. Brightness and soil moisture values were weakly estimated.	Check the radiometer alone for self interferences, and improve the radiometer.
Attitude data not available	Unable to synchronize the attitude data from the UAV logs with the measurement logs	Install our own attitude/GPS logging system.

Conclusions:

The radiometer does not work correctly (very low performance) due to interference noise in the internal loads and in the antenna.

Due to the difficulties found to integrate UAV and radiometer data, it was concluded that the radiometer must gather its own GPS and attitude data.

The antenna orientation could not be computed due to the lack of GPS and attitude data, and hence the pointing algorithms could not be tested.

Campaign 2

Date: 08/05/2017

Participants: Balamis Team (Roger, Adria, y Esther)

UAV company: M-Drone S.L.

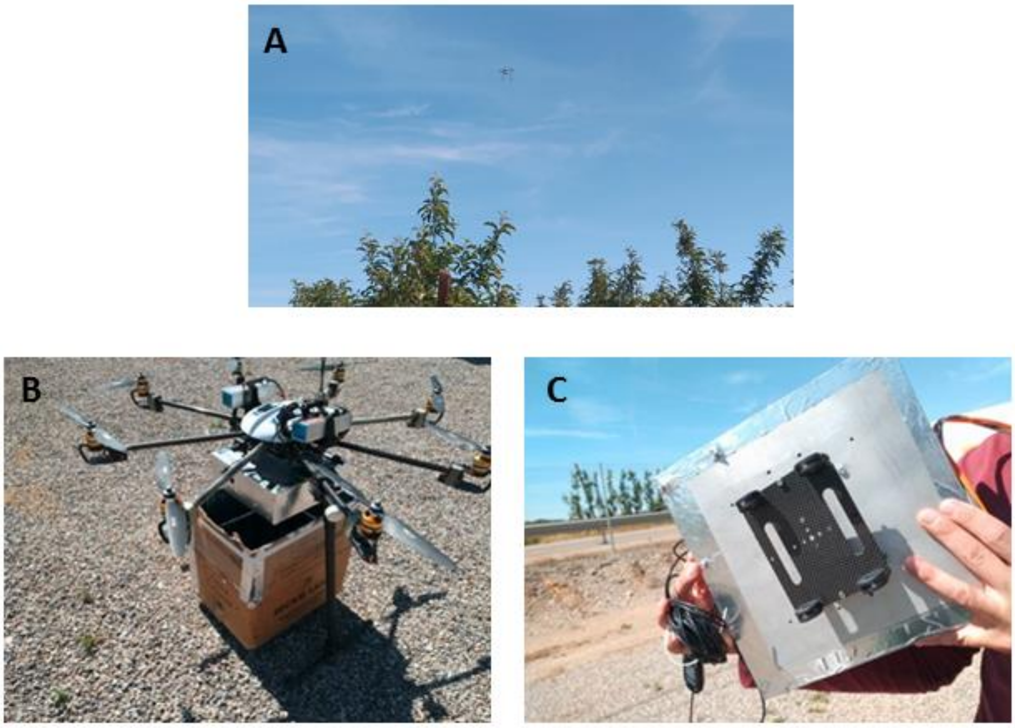
Testing objectives: Same than in campaign 1

Specific protocol: Same than in campaign 1

Experimental Site: Mollerussa

Background: After the first test a check was performed to the radiometer which revealed that it had a lot of self-interference. The shielding and the electronic isolation of the radiometer was improved, and this second campaign was planned in order to check again the behavior with the drone.

(A) Radiometer installed in the UAV, (B) Radiometer calibration, (C) Sensor adapter:



Results:

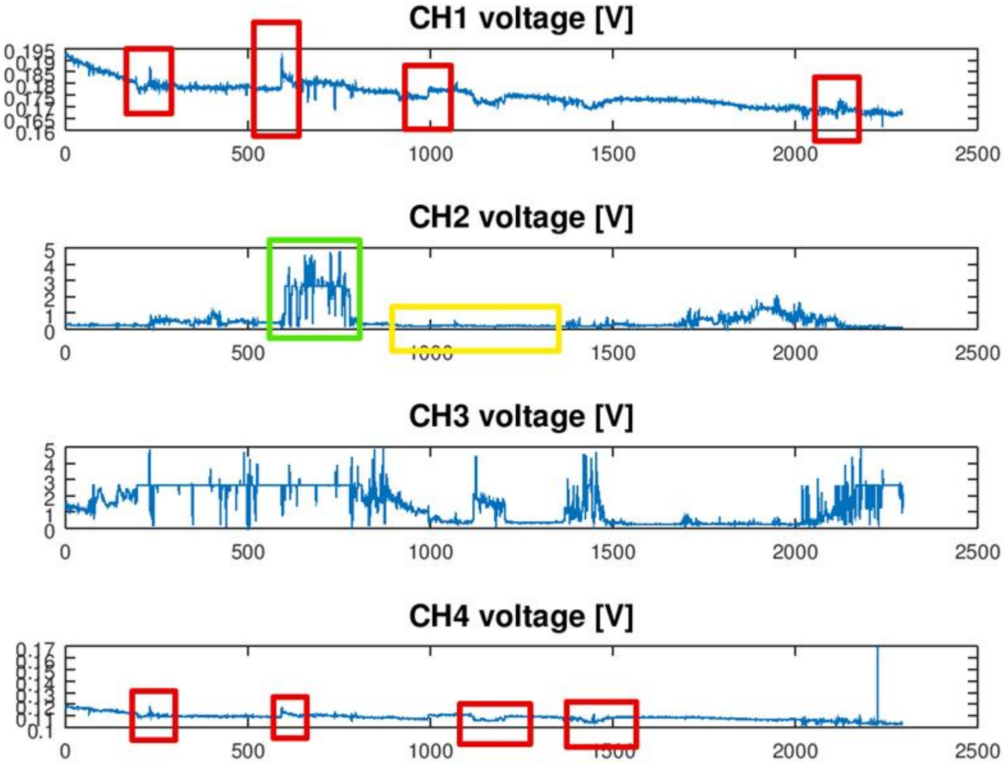
The sensor was integrated with UAV using large screws. Although the sensor was initially fixed, it oscillated and hence it was necessary to use thick paperboard to prevent large oscillations. Still, the mechanical integration was not optimal. Battery problems detected during the first campaign were solved using an own battery and its matching connectors. Battery problems detected during the first campaign were solved using an own battery and its matching connectors.

Detail of the integration and the cardboard to prevent oscillations:

During calibration, unstable measurements were detected in load voltages like in the first campaign (red squares in next figures). The reasons were unknown, although they may be explained by interferences with the newly installed GPS, self interferences or electronic interferences from UAV. CH3 was not connected.

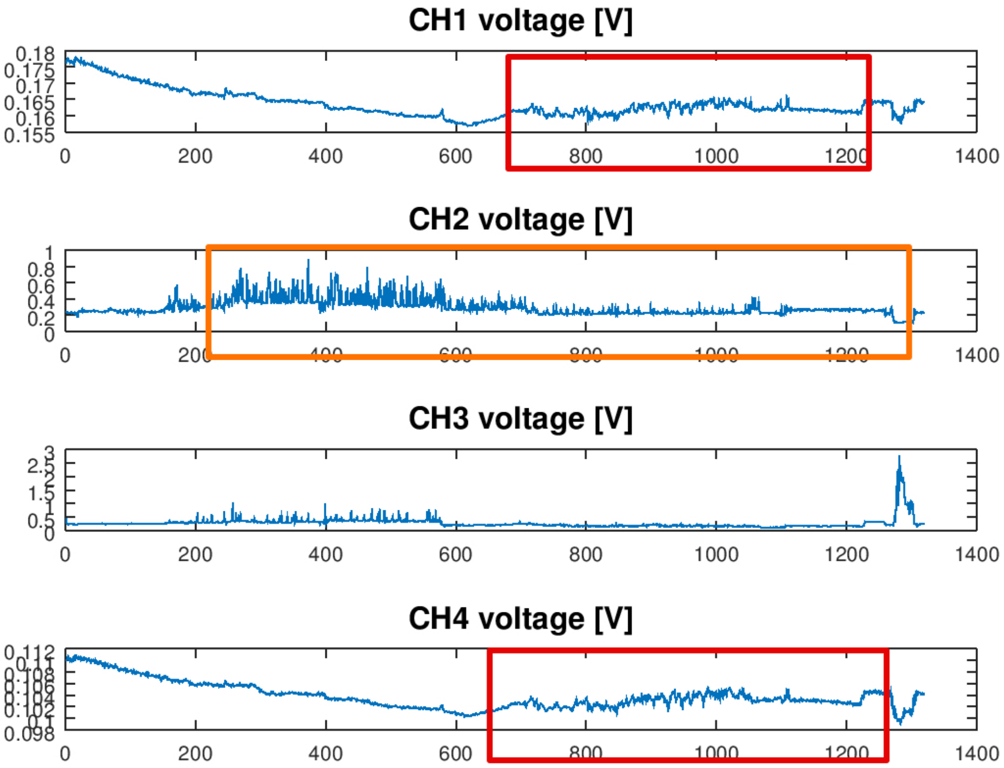
Interference increased when the antenna was pointed towards the absorbent which may be explained by the reflection of the emissions from the absorbent box to the antenna (green square in next figure). However, when the antenna was pointing to sky the emissions couldn't be reflected so they were not picked up by the antenna (yellow square in next figure). As consequence, it was concluded that the emissions may be generated by the UAV or by the radiometer itself.

Voltage measurements vs time during calibration of the sensor:



During the flight, interferences were also detected in the loads (red square in) and in the antenna channel (red and orange squares in **Error! Reference source not found.**, respectively). When the ntenna was affected with large interference spikes, the brightness temperature measurements were completely discarded and hence no moisture values were computed.

Radiometer voltages vs time during UAV flight:



During this campaign the GPS data were successfully retrieved with the radiometer GPS. The GPS log and the sampling frequency of the radiometer was correct. No failures were detected.

GPS track of the UAV flight:

Failure matrix of Campaign 2:

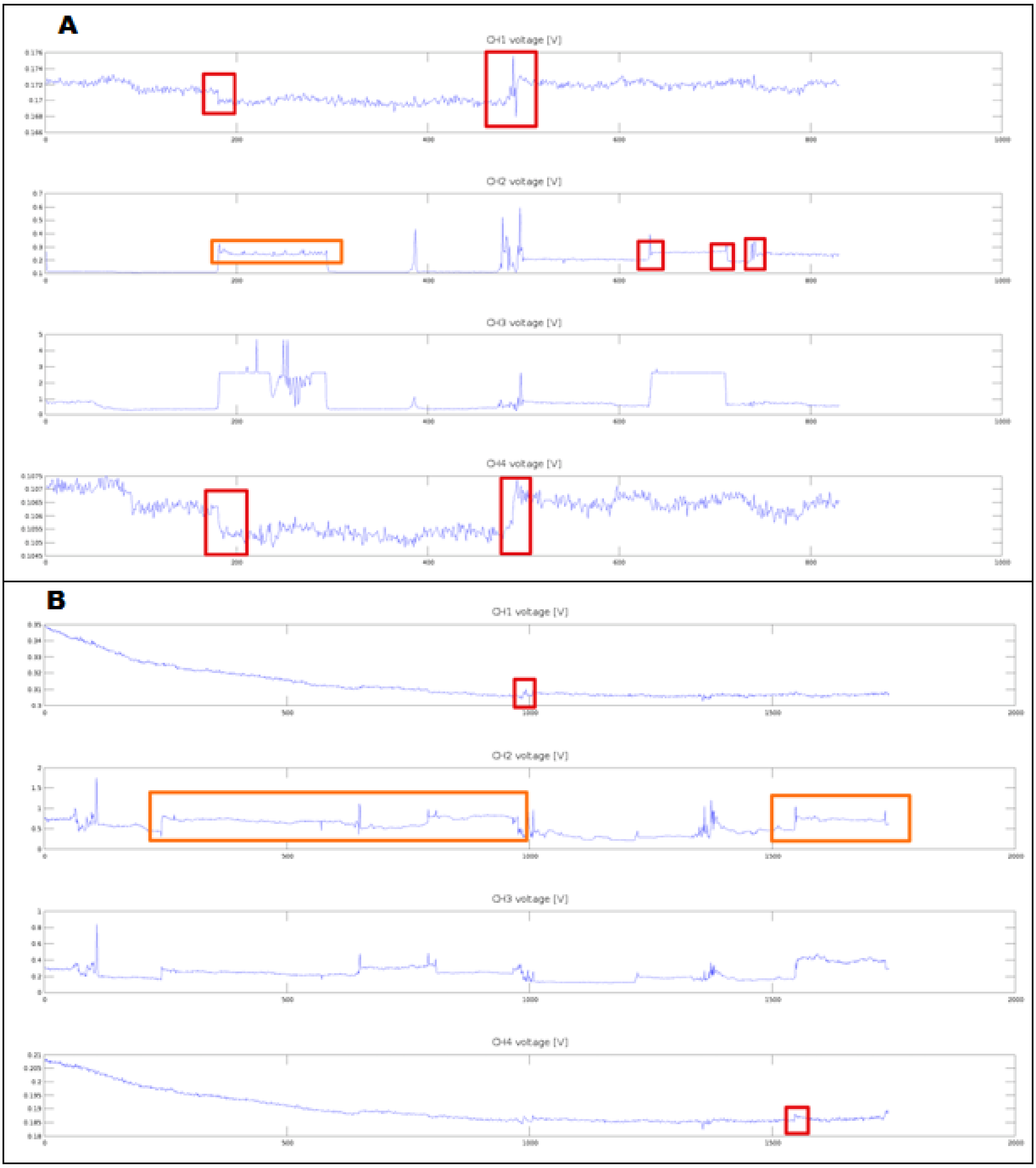
Failure	Description	**Mitigation actions**
Mechanical integration / installation	Integration not yet optimal, sensor oscillates a little bit	Find some structure to fix the radiometer properly and without oscillations.
External interferences	Same than in campaign 1. In-flight and calibration measurements affected by the drone system. These interferences made the whole system inaccurate. Brightness and soil moisture values were weakly estimated.	Test the reliability of the radiometer more strongly.

Conclusion and further testing:

Because the testing campaign was not completely successful, Balamis decided to proceed with an additional testing exercise (3 days campaign) at Can Cartró, a free-interference site location. To make sure the interference was not created by the radiometer itself, the test consisted in a series of absorbent-sky calibrations with the radiometer alone. Additional manual shake tests were also performed.

The additional test revealed that despite of the loads and the antenna measurements levels were correct, they showed some instability (orange boxes in next figure) and sudden changes of level (red boxes in next figure). This led to the decision of building a new radiometer with a better isolation, stability and mechanical stiffness.

Voltage vs time graphs during further testing:



Campaign 3

Date: 14/09/17

Participants: Balamis team (Roger, Ricard y Esther)

UAV company: M-Drone S.L.

Testing objectives:

- Test the NEW UAV radiometer for interferences.
- Test the NEW UAV radiometer and its new components (IMU and GPS) in a real operational campaign.
- Test the antenna footprint calculation algorithms, the gridding system and the raster outputs

Experimental Site: Mollerussa

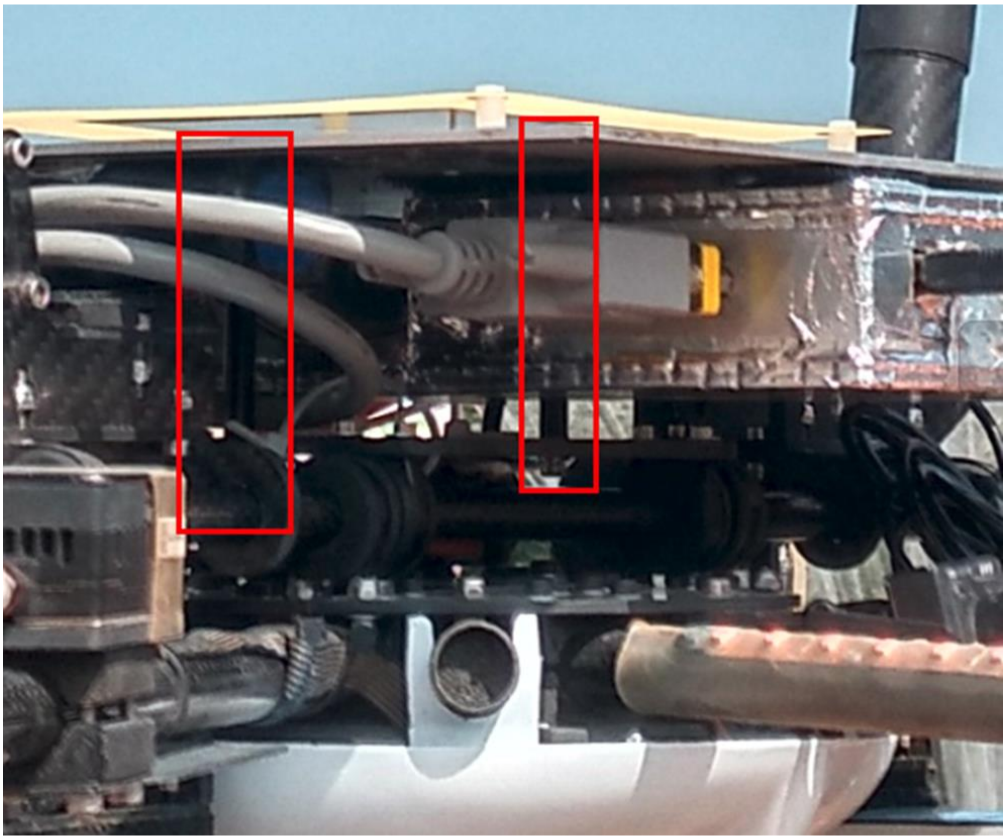
Background: This test was the first campaign realized with the new improved radiometer without self-interference.

Results:

Integration

The radiometer was integrated with the UAV using two aluminum solid extender screws between the UAV accessory board and the main aluminum plate of the radiometer. The integration was robust and did not oscillate.

Detail of the integration with the UAV:



Calibration and in-flight results

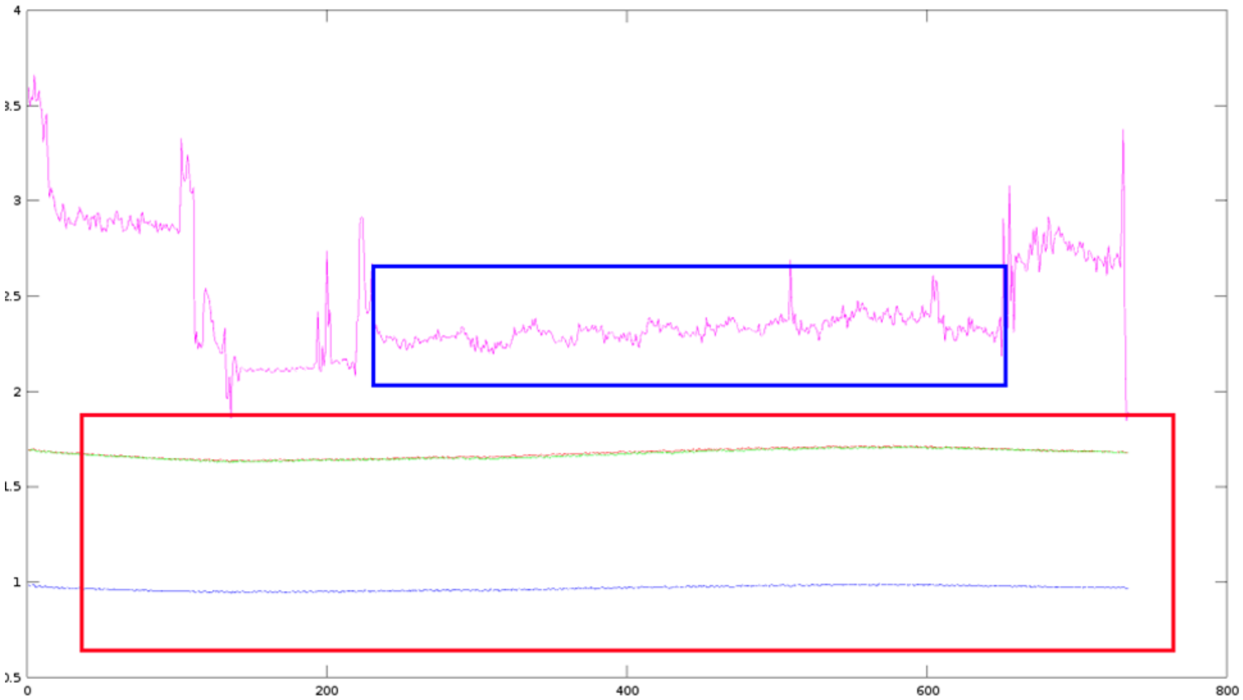
A large interference was again observed when the electronics of the UAV was turned on, but it disappeared when the electronics was turned off.

The temperature of the radiometer did not reach the optimum setpoint (40 ºC) and it was decreasing during the flight making the voltages too inaccurate and inconsistent over time. As consequence of the radiometer cooling, internal calibration loads moved during time (red box in next figure).

Many interferences were detected during the calibration phase (blue box in next figure). These increased significantly when the UAV was in the ground likely because signals were reflected on the absorber material and on the ground (start and end of the voltage graph).

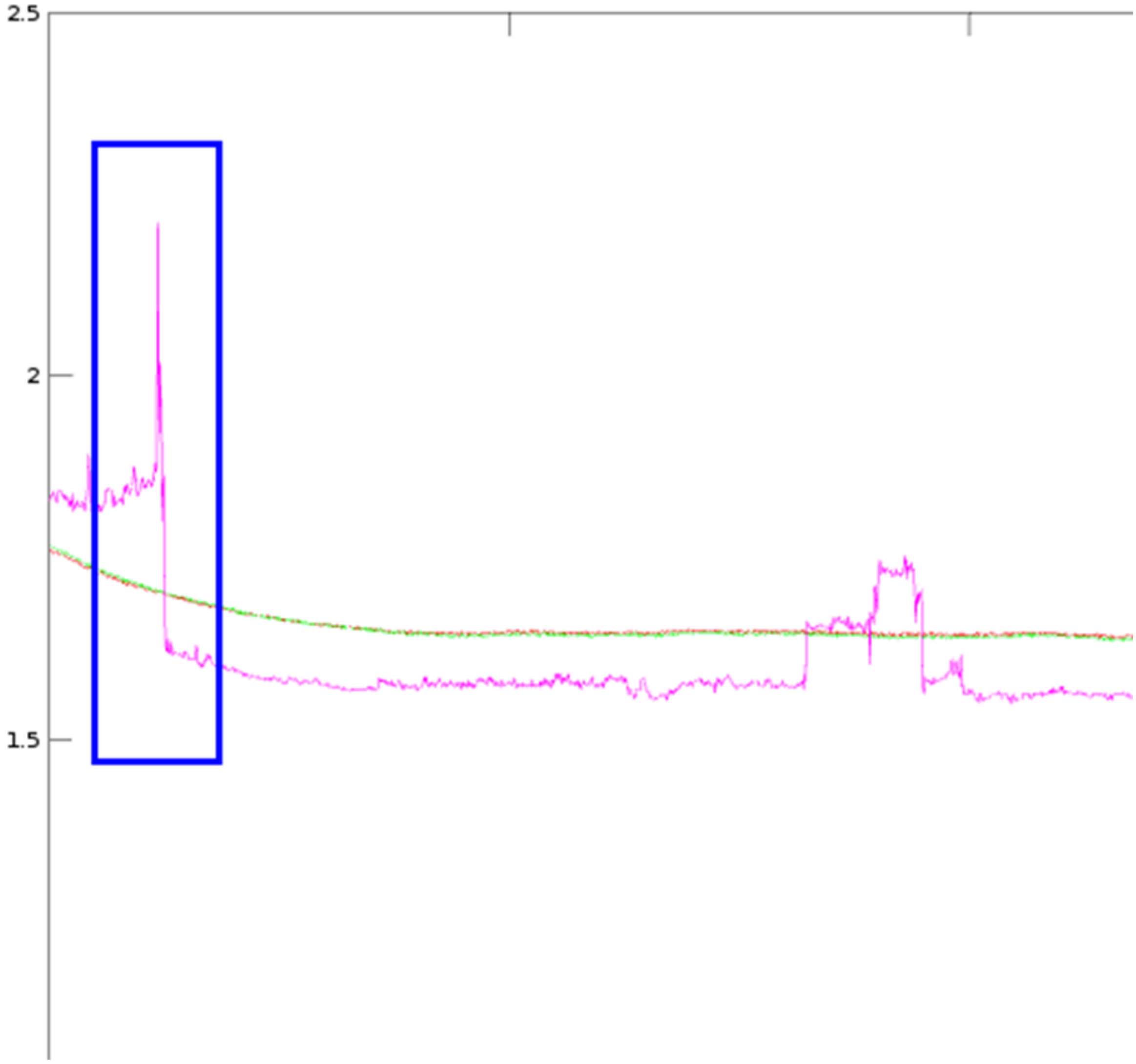
Only one antenna polarization (vertical) was connected, the other channel had a 50 ohm load connected (green line in next figure) which is equivalent to the HOT load (red line in next figure).

Radiometer voltages vs time during the flight. Channels: COLD load (blue line), HOT load (red line), Vertical polarization (purple line), 50 ohm load (green line):



After switching the UAV electronics off, interferences were eliminated (blue box in next figure). Because of these failures, brightness temperatures could not be accurately retrieved. However, IMU and GPS values were accurately and correctly measured, and hence these data could be used for testing the footprint algorithms.

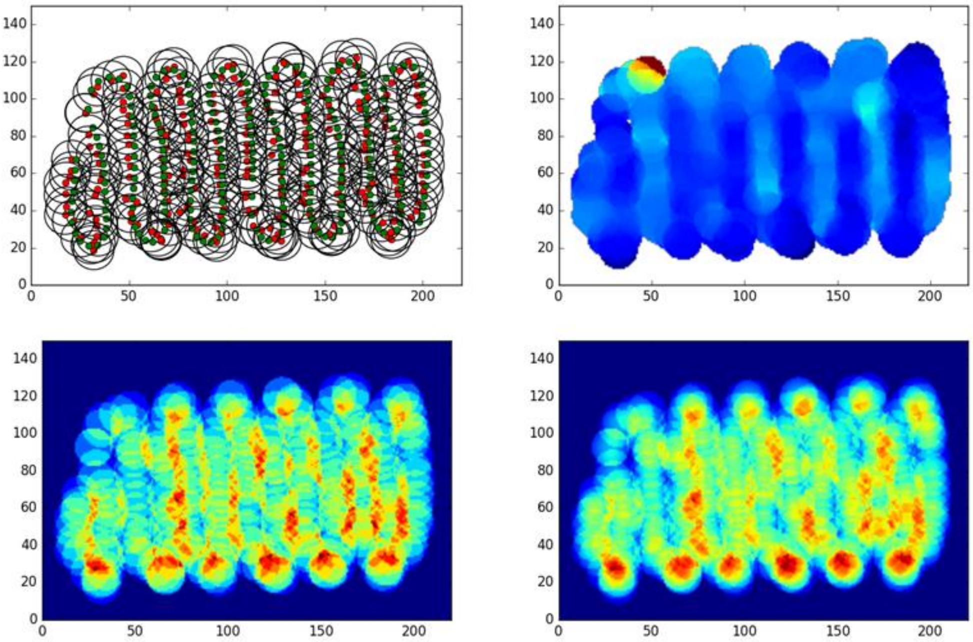
Radiometer voltages vs time. Effect of UAV switching off on the radiometer voltages. Channels: HOT load (red line), Vertical polarization (purple line), 50 ohm LOAD (green line):



Antenna footprint algorithm results

After correcting some initial errors, algorithms worked as expected. Intaking GPS, voltage and attitude angle values, maps of the corrected antenna footprints on the surface were generated at 1m spatial resolution which also included the contributions of each footprint for each point.

Results from the projection algorithm: GPS points with the corrected antenna footprints (upper-left), raster generated from the captured data (upper-right), number of contributing footprints for each point (lower-left), antenna weighing for each point (lower-right):



Failure matrix of the Campaign 3:

Failure	Description	Mitigation actions
Limited battery duration	During the assembly and heating phase of the radiometer the battery drained to 50%. To make sure it lasted the whole flight another one was borrowed for the UAV company.	Buy another battery so one is used during the assembly with the UAV and during heating, and another fully charged one is used only for in-flight measurements
Heating inconsistencies	During the in-flight measurements the internal temperature of the radiometer was not correct. This caused higher voltage values of the measurements and made the calibration fail.	After the flight another test was performed and the radiometer heated correctly. Vibrations could make a cold solder joint fail, so the whole heating circuit is going to be re soldered and checked.
External Interferences	In-flight and calibration measurements affected by the drone system.	Schedule another test with the UAV provider, disabling each electronic subsystem to identify which one interferes with the radiometer and seek for possible solutions. The new radiometer checked several times alone to confirm that self-interferences are not generated.

Other results:

A new set of algorithms that provide disaggregation of the data using Land Surface Temperature and the NDVI index are going to be tested when these data is being provided by the UAV company.

UAV during calibration (left) / steady (upper-right) / field measurement (bottom-right):

Campaign 4

Date: 14/11/17

Participants: Balamis team (Roger, Ricard, Adrià, Marc)

UAV company: M-Drone S.L.

Testing objectives:

- Test the NEW UAV radiometer for interferences.
- Test the NEW UAV radiometer and its new components (IMU and GPS) in a real measurement campaign.
- Test the antenna footprint calculation algorithms, the gridding system and the raster output
- Calibrate the aerial radiometer.

Experimental Site: Can Cartró - Area 2

During the testing phase, just before the UAV flight, the aerial radiometer was calibrated using a new technique based on SKY measurements while the antenna was heating up.

Results:

This test was done with the third version of the UAV radiometer, which included improvements in cabling and boxes to prevent the heating issues detected in the previous version.

Integration:

The radiometer is mechanically identical to the previous version, so the integration with the drone was identical to the previous test.

Left: Testing the UAV; Right: SKY measurements:

Calibration:

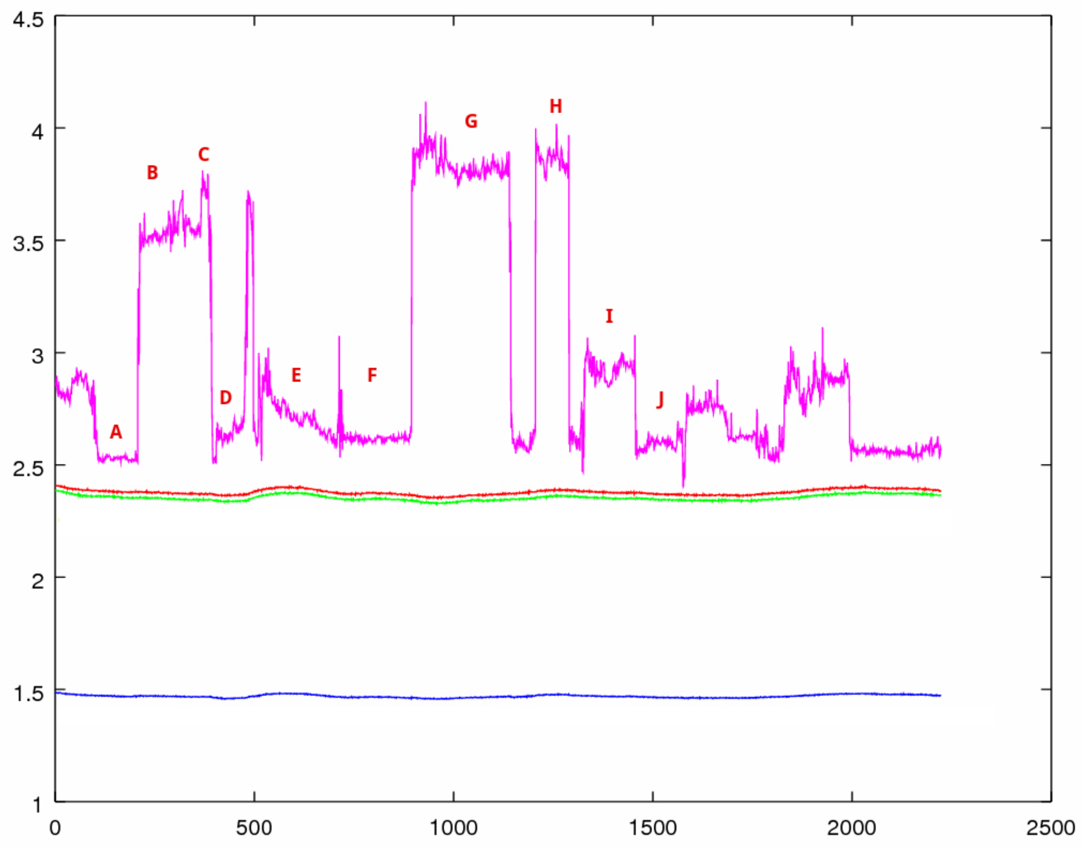
After doing the full calibration cycle the results were not correct (see next section).

The radiometer could be repaired in-site and did the full calibration again.

The radiometer internal loads were stable. The second channel had a 50 ohm load which means that the signal level was very similar to the hot load (confirmed by green and red lines in next figure, see previous test).

The Voltage vs Time graph indicates clearly that once the drone electronics was turned on a large interference appeared on the antenna. This high level of interference completely blinded the radiometer which made not possible to proceed with the flight campaign. The various points of the voltage graph in next figure are explained in next table.

Radiometer voltage vs time. COLD LOAD (blue line), HOT LOAD (red line), Vertical polarization (purple line), 50 ohm LOAD (green line):



Stage phases during the calibration process (as shown in previous figure):

Index	Situation
A	Drone electronics powered off with absorbent underneath. This can be used as a reference level.
B	Drone electronics powered on. The Interference increases dramatically. The level should have been as in A to be considered as interference free.
C	Drone electronics + Motors rotating. Interference increases
D	Moving the drone.
E	Drone pointing to SKY with electronics powered on. The reference level for SKY signal was near the blue line. In this case it was much higher.
F	Drone pointing to ABS with the electronics powered off, but the transmitter ON.
G	Drone electronics turned ON
H	Drone motors ON
I	Ethernet connection.
J	Drone pointing to ABS with the electronics powered off, but the transmitter

	ON.

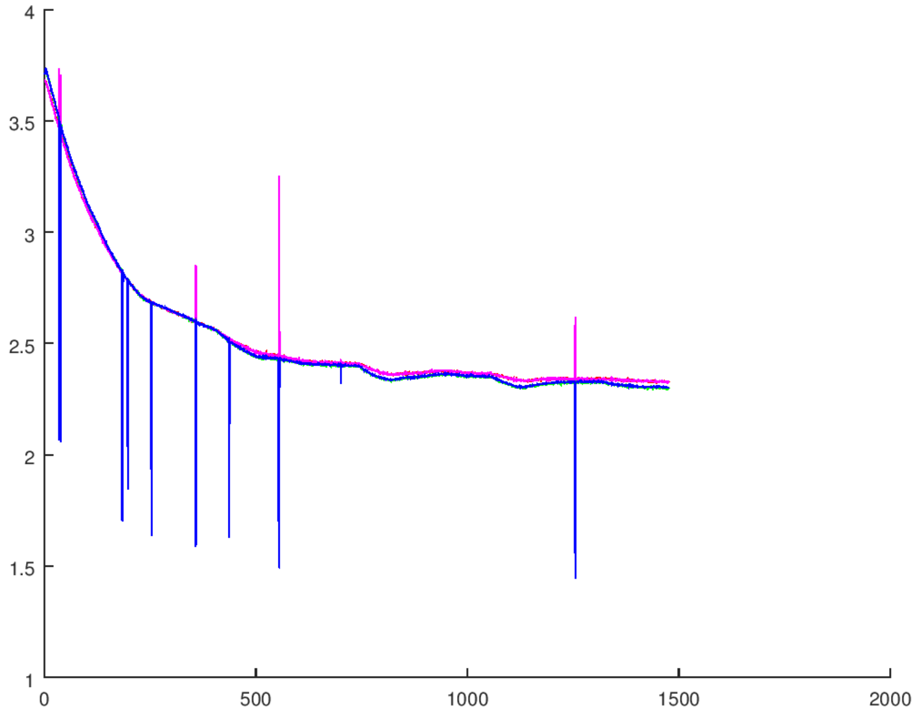
Antenna footprint algorithm results:

The drone did not fly, so the algorithms were not computed.

Failure matrix of the Campaign 4:

Failure	Description	Mitigation actions
Wrong voltage readings, electrical connection failure	During the test, several results were inaccurate because of a failed connection between the RF switching, and the control sections. This problem did not emerge previously during in-house tests. The radiometer was opened and checked. The failure was amended, and measurements were taken correctly.	Check the wiring and connections, and assure the problem does not happen again.
External Interferences	Measurements affected by the drone system	Schedule another test with the UAV provider, disabling each electronic subsystem to identify which one interferes with the radiometer and seek for possible solutions. The new radiometer checked several times alone to confirm that self-interferences are not generated.

Next graph shows that measurements did not change, while spikes indicate that the failure issue was related with the electronic switching. Channels: COLD load (blue line), HOT load (red line), Vertical polarization (purple line), 50 ohm load (green line). Note that the lines are overlapped.



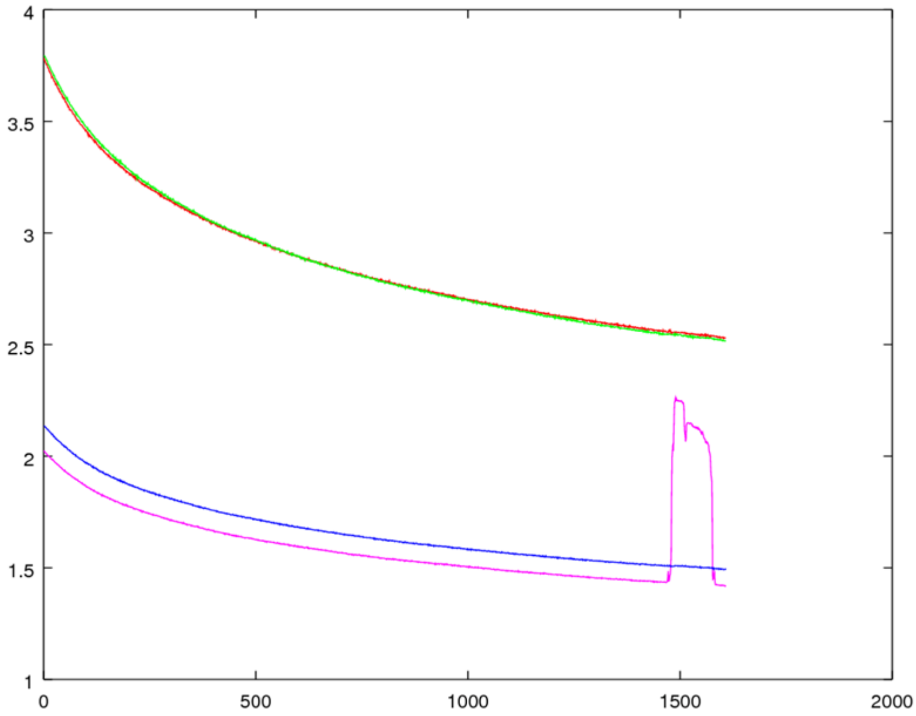
Aerial calibration:

The aerial radiometer was left apart pointing to SKY heating itself. The antenna temperature was measured at regular intervals. The results of the test are interference free, and the calibration data could be retrieved accurately.

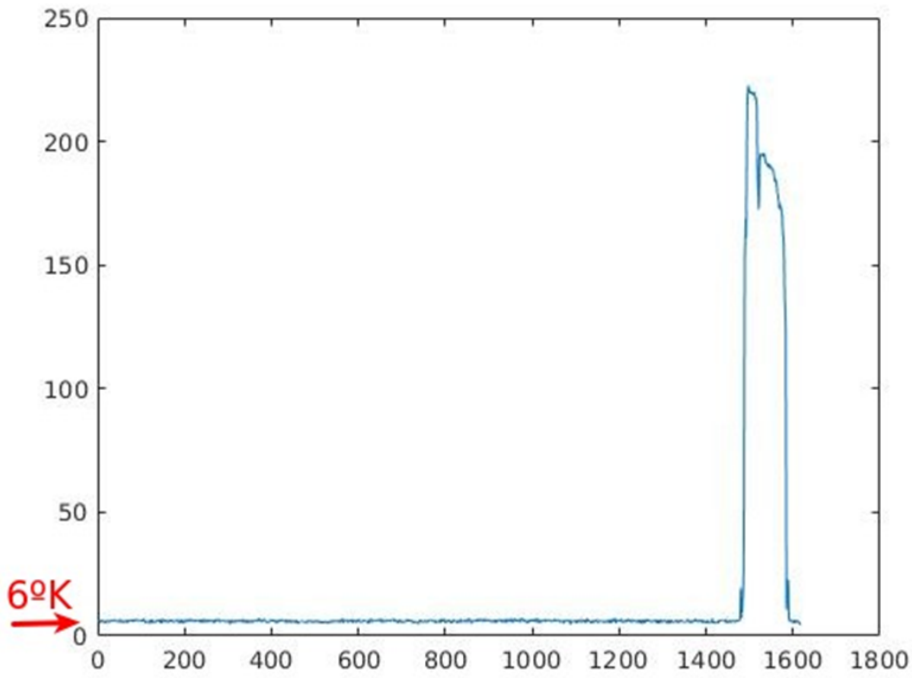
The new calibration method was proved to be accurate below a calibrated brightness temperature obtained from the voltage plotted above. We can clearly see that when the antenna was pointed to the SKY the brightness temperature was 6 Kelvin.

Aerial radiometer SKY calibration:

Aerial radiometer free of interferences (voltage readings vs time):



Calibration converted to brightness temperature (ºK) vs time:



Other results:

The electronics of the drone cannot be changed or modified, and tests suggest that it is the only source of interferences. Different control systems need to be tested. The drone company does not have a drone with a different electronic system for testing, but the drone manufacturer has been contacted and they can allow us to test with different control electronics (these tests are planned for the next testing phase).

Campaign 5

Date: 12/12/17

Participants: Balamis Team (Ricard, Marc)

UAV company: M-Drone S.L.

Testing objectives: Test a new UAV model for interferences with the radiometer.

UAV Characteristics:

Type	Multicopter
Manufacturer / model	Drone Tools / Drone hexa 6
Number of rotors	6
Electronics	Zerotech GEMINI dual
Weight	4Kg
Autonomy (Batteries)	15 min. (2x 7000mAh - 4S 14.6V)
Frequencies used	2.4Ghz, 5.8Ghz

Experimental Site: Parc del Garraf

Test description:

Testing phases

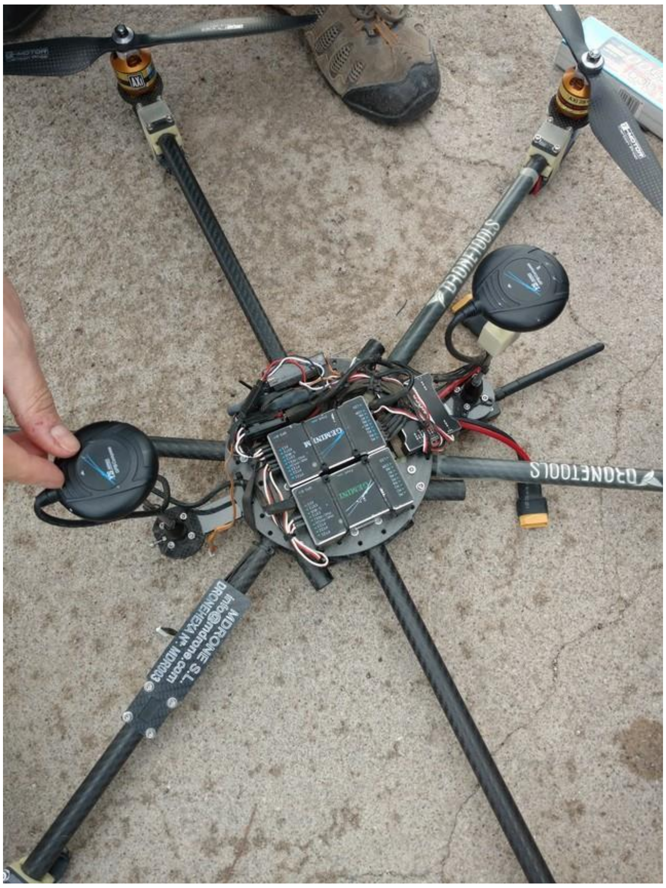
- Heat up the radiometer
- Radiometer measurement (SKY/ABS) with the UAV electronics turned off.
- Radiometer measurement (SKY/ABS) with the UAV electronics turned on.
- Test other radiometer positions.

Post processing phases

- Quick analysis of the measurements and quick check for interference.

Results:

This test was done with the third version of the aerial radiometer. In this case, the test was performed with a completely different UAV control electronics provided by the UAV company.



Drone with alternative control electronics:

Integration:

The radiometer was not integrated into the drone because a flight was not planned.

Calibration results:

In next figure the results of this test are shown. The first part of the graph corresponds with the radiometer heating.

The text in green indicates that the UAV electronics were turned off and the text in red indicate the UAV electronics are turned on. From what we can see from the voltage graph, when the drone electronics are turned on there are still interferences in the antenna measurements.

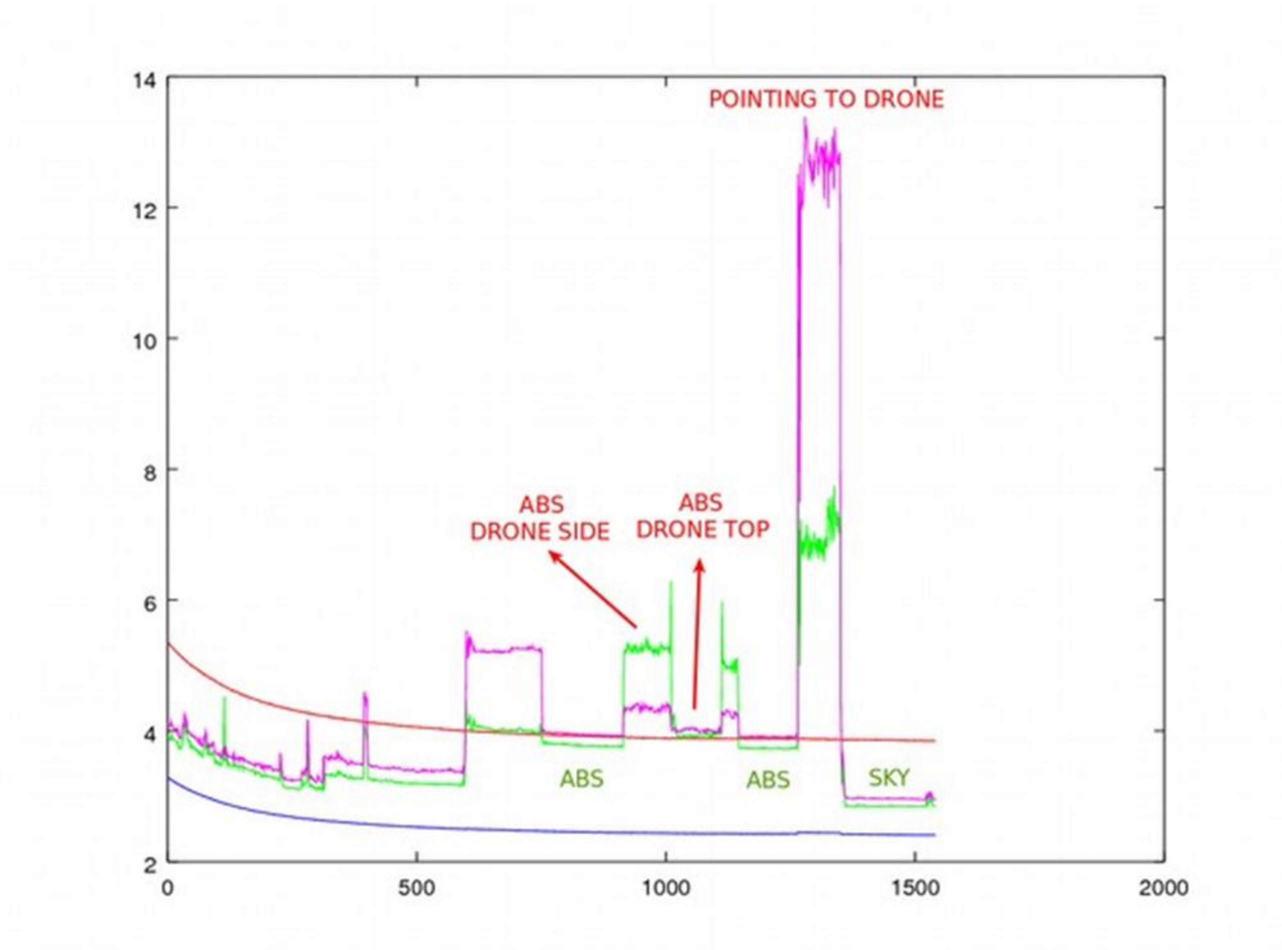
The HOT load and COLD load graphs (red and blue lines) are interference free which indicate that the radiometer is well isolated and it’s not an internal problem.

When the drone is on the side the interference is higher than with the drone on top, this is due the antenna pattern which has a side lobe bigger than a rear one. With the drone on top of the radiometer the interference is smaller, but it is still present.

When the antenna is fully pointing to the drone the interference increases drastically which is the expected result.

During the time when the drone was turned off, the interference disappeared completely (periods with green text).

Radiometer voltages vs time during the test; COLD LOAD (blue line), HOT LOAD (red line), Vertical polarization (purple line), Horizontal polarization (green line):



Antenna footprint algorithm results:

The drone did not fly, so the algorithms were not computed

Failure matrix of the Campaign 4:

Failure	Description	Mitigation actions

Failure	Description	Mitigation actions
External Interferences	Measurements affected by the drone system.	From the previous section we can see that the UAV system still interferes with the radiometer. Another test will be scheduled in order to test another UAV electronics system

Test 3: Calibration and accuracy tests

This test consisted in the building, calibration and flight of an aerial radiometer on board a Cessna Caravan owned by ICGC (http://www.icgc.cat/).

The test consisted of 4 phases:

- Radiometer calibration
- Radiometer installation
- Flight
- Data processing

The radiometer had the latest version of the electronics developed by Balamis and an antenna specifically designed for the ICGC airplane and developed by the UPC RSLab.

Antenna specifications:

- 7 Patch Antenna
- Beam width: 22º
- V Polarization
- Self heating

ARIEL is able to measure two polarizations, but only one was connected because during the flight the antenna was always in the NADIR position, which make both polarizations identical. The H channel of the radiometer was plugged to a load, so measurements were very similar to the hot load inside the radiometer.

The flight path was provided by ICGC. Soil samples at different types of crops were collected at some sites covered by the airplane track. All soil samples were analyzed and were adopted as ground truth measurements for the calibration/validation.

ICGC will fly a multispectral and a thermal infrared camera at the same time and will provide the LST and NDVI data to test and enhance the data disaggregation algorithms.

A pass over the sea during landing provided some data to test the radiometer calibration.

Campaign 1

Date: 26/11/2017

Participants: Balamis team (Roger Jové, Ricard Gonzalvez)

Testing objectives:

- Test the complete aerial radiometer for interferences
- Perform a heating calibration
- Perform SKY/ABS Calibration

Experimental Site: Can Cartró - Area 2

Test description: The first part of the test was done simultaneously with the campaign 4 of test plan 2.

The aim of this test was to perform a full calibration of the whole system flying on board the airplane, using SKY and the heating of the antenna. This test was made to guarantee that the calibration can be repeated accurately, and that the new components do not add any type of noise.

A traditional calibration using SKY and ABS measurements was also made.

Finally, a measurement of the soil brightness was retrieved and compared against values measured with a terrestrial radiometer.

Testing tasks

- Heat up the radiometer measuring SKY
- Measure ABS
- Quick measurement of the soil brightness temperature

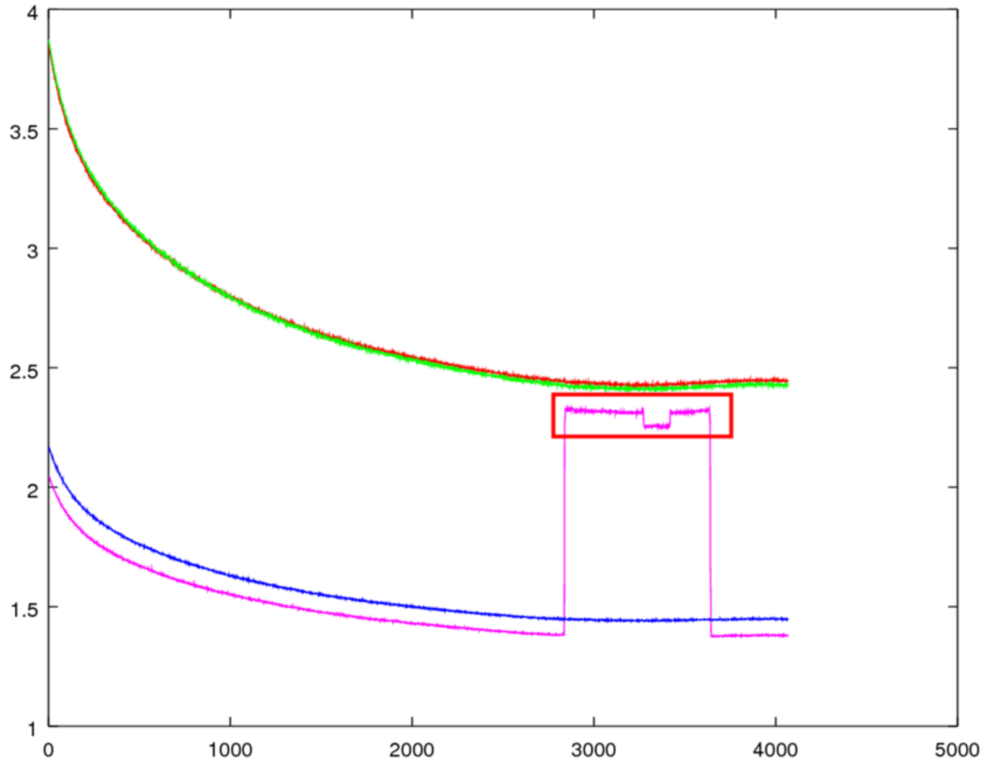
Post processing tasks

- Quick analysis of measurements and quick check for interference noise.
- Radiometer calibration with heating data
- Quick analysis of radiometer data for quick results.

Results:

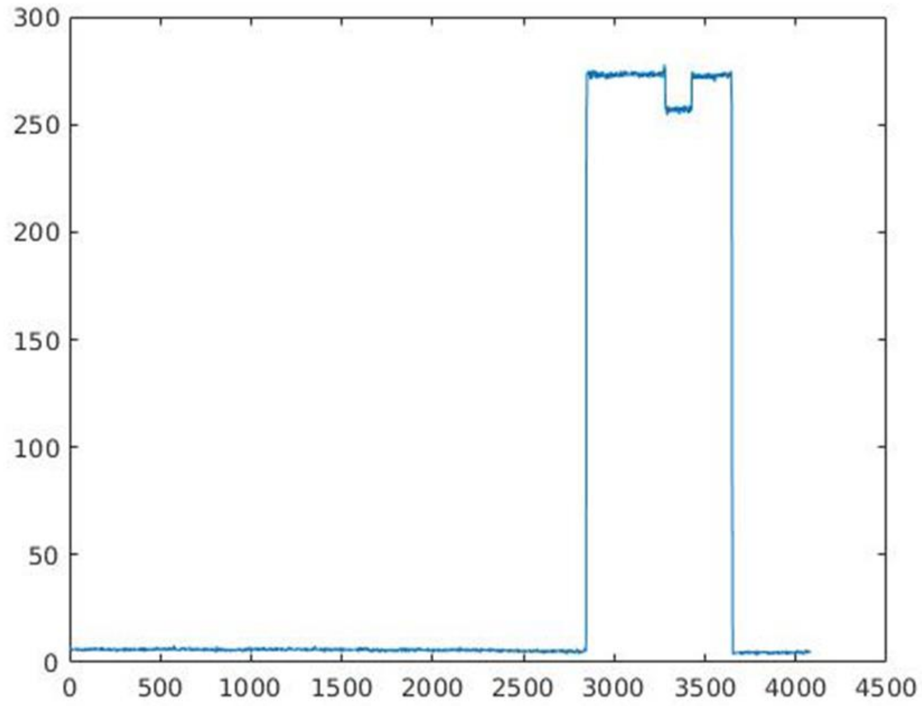
The calibration performed with the heating of the antenna is nearly identical to the previous campaign. The voltage graph showed no interferences. The channel not used had a 50 ohm load connected.

Radiometer voltages vs time during antenna heat-up and absorber measurement; The purple channel is that one connected to the antenna. Channels: COLD load (blue line), HOT load (red line), Vertical polarization (purple line), 50 ohm load (green line):



The measured brightness for the SKY is correct (6 Kelvin aprox.), although it was too low for the absorber, likely because its small size. Consequently, soil is expected to be a source of noise in this measure.

Measured brightness temperature (K) vs time after calibration:



Drawn measurement cone (red) showing the small size of the absorber:

Aerial radiometer during the sky / soil measurements:

Failure matrix of the Campaign 1:

Failure	Description	Mitigation actions
Absorbent measurements	The absorbent surface is too small and the measured brightness was not accurate	From the image it can be seen that the microwave absorbent for this type of antenna is too small and soil noise was observed in the voltage graph (red square in **Error! eference source not found.**). Standard calibration is not fully accurate. A new and larger absorbent is required (it is being bought with a case to move it).

Campaign 2

Date: 28/11/2017

Participants: Adria Amézaga, Ricard Gonzalvez

Testing objectives: Integrate the aerial radiometer with the ICGC airplane and to perform a heating calibration.

Experimental site: ICGC hangar at Barcelona airport

Test description:

Testing phase

- Integrate the radiometer with the airplane.
- Check mechanical and electrical connections.

- Check for interferences.
- Heat up the radiometer to obtain a heating calibration.

Post processing phases

- Quick analysis of the measurements and quick check for interference.
- Quick analysis of radiometer data to check if the calibration matches the previous one.

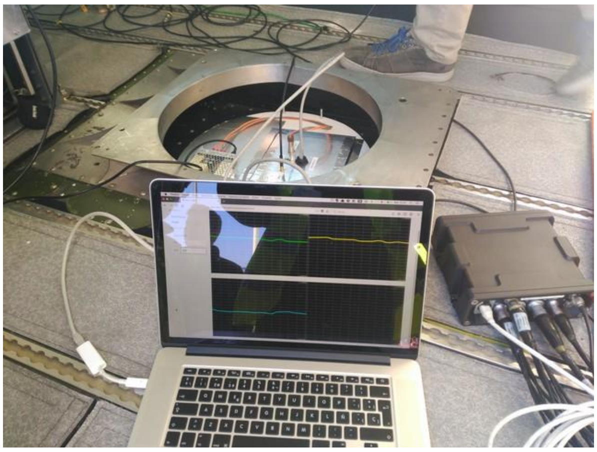
Installation:

The radiometer was installed in a hole present in the Cessna caravan airplane. This hole is usually unused or used by other type of sensors (e.g. LIDAR). The antenna was designed and built by UPC RSLab specially for the same aircraft. The antenna was tightly installed in the correct position by 13 screws.

Installation procedure of the ARIEL antenna in the Cessna airplane:

After the installation the radiometer operation was checked. The new larger microwave absorber was used to check the calibration and check for interferences. The airport provided a large interference-free zone in the protected L-band region for the calibration process. The GPS signal was also checked at open air.

Aerial radiometer in-place calibration procedure:

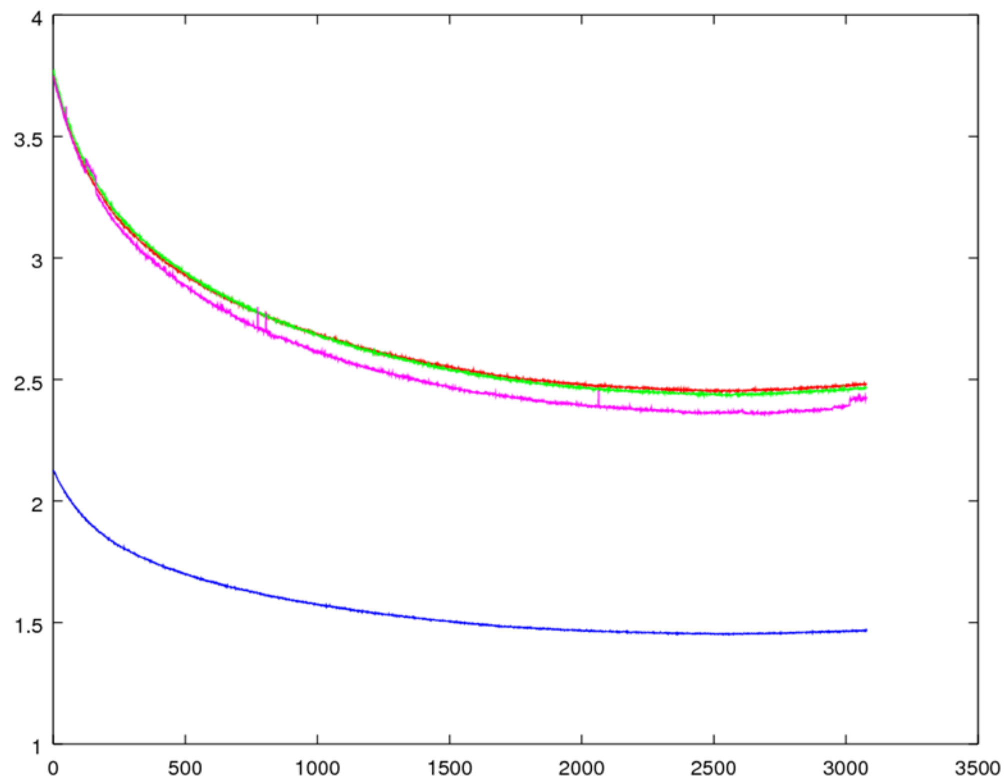


Cessna airplane outside the hangar for GPS testing:

Results:

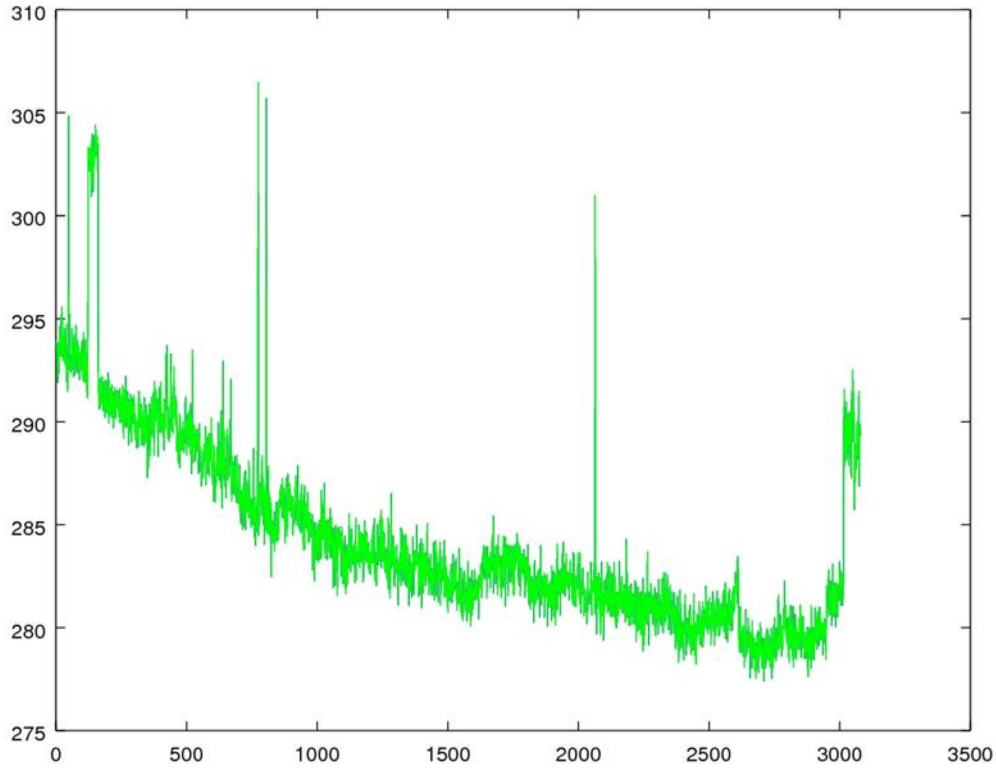
The loads voltages are interference free. The spikes seen in the antenna channel (purple line) were associated to the presence of people in front of the antenna. The rise that can be seen at the back of the graph is due to the absorber being removed. The down slope on the brightness temperature is due to the microwave absorber cooling down as it was in an open-air area.

Aerial radiometer under calibration with the microwave absorber; The purple voltage is that one connected to the antenna. COLD load (blue line), HOT load (red line), Vertical polarization (purple line), 50 ohm load (green line):



By definition, brightness temperature of the absorber once calibrated corresponds to its physical temperature. The brightness temperature at sample 2500 was 281K (approx. 8 ºC) which fitted with air temperature during the test. This proved that the calibration was accurately done and the radiometer was ready for the flight campaign.

Computed brightness temperature during calibration; Values retrieved using the coefficients from previous calibrations. (Test 3-Campaign 1 and Test 2-Campaign 4):



Test 4: Analysis of requirements and laboratory test

This test consisted of a set of different test campaigns on the experimental fields.

Since the UAV radiometer had many interferences (as stated before), the campaigns were done using the radiometer mounted on the ground vehicle (ATV radiometer).

Campaign 1

Date: 25/04/2017

Participants: Balamis team (Roger Jové, Esther López)

Testing objectives:

- To generate a raster of soil moisture map for a large area.
- Check the radiometer strength and operations.

Experimental site: Agramunt

Test description:

Testing tasks

- Integrate the radiometer with the vehicle.
- Check mechanical components.
- Heat the radiometer
- Microwave absorber measurement.
- Sky measurement
- Radiometric measurement of the soil.

Post-processing tasks

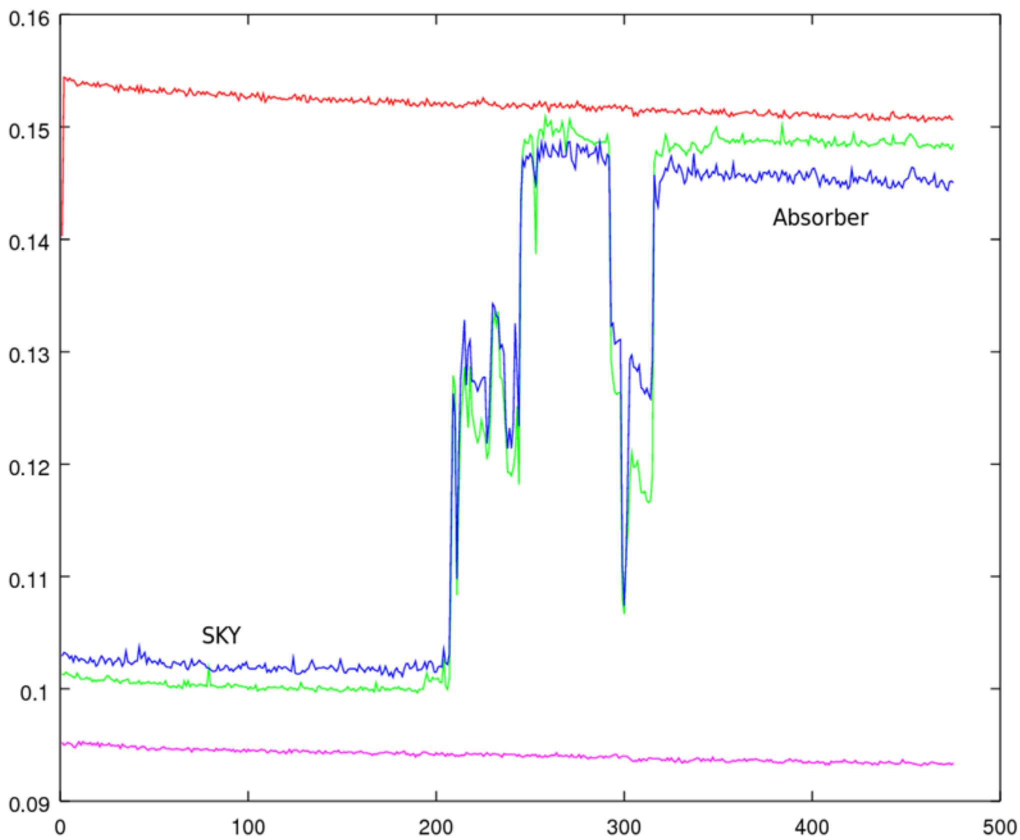
- Calibrate the radiometer with the Absorber – SKY measurements.
- Quick analysis of the measurements and quick check for interference.
- Check obtained radiometer data (TIMESTAMP, VOLTAGE DATA) for inconsistencies.
- Analysis of data to obtain moisture rasters.
- Data analysis and interpretation

Results:

Calibration:

Overall, the calibration process was consistent and similar to previous calibration campaigns.

Voltage vs time during calibration; COLD LOAD (pink line), HOT LOAD (red line), Vertical polarization (purple line), Horizontal polarization (green line):



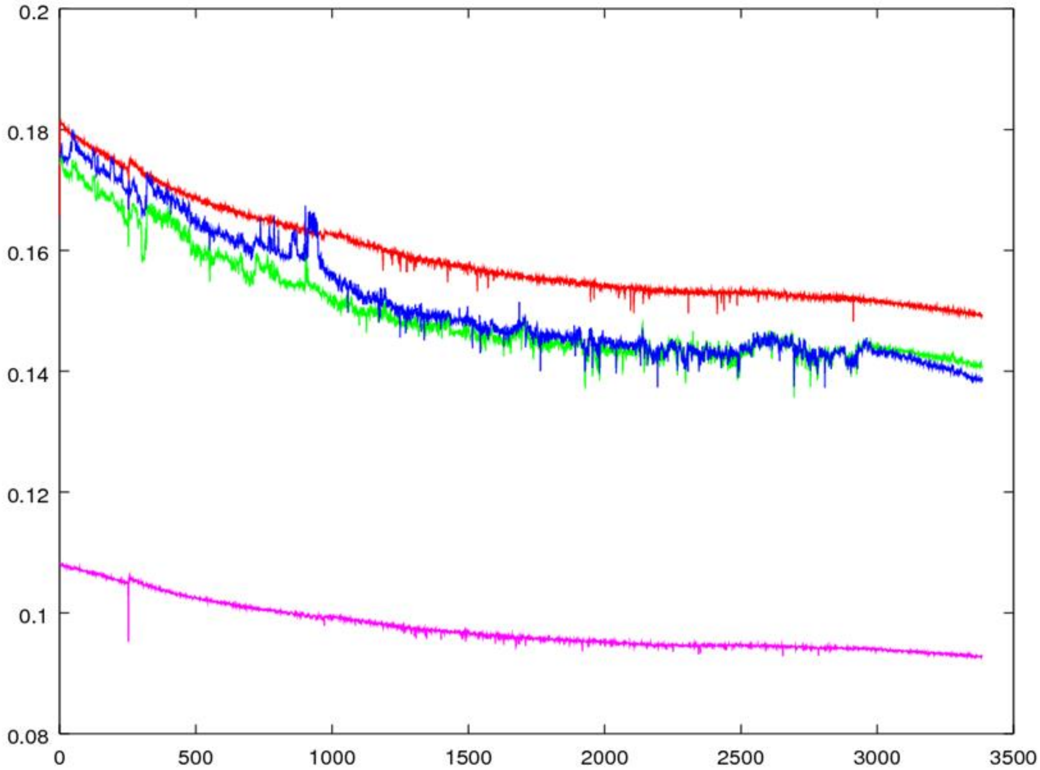
Field testing:

Some overlapping (inaccurate GPS measurements) issues were detected during the tracking process.

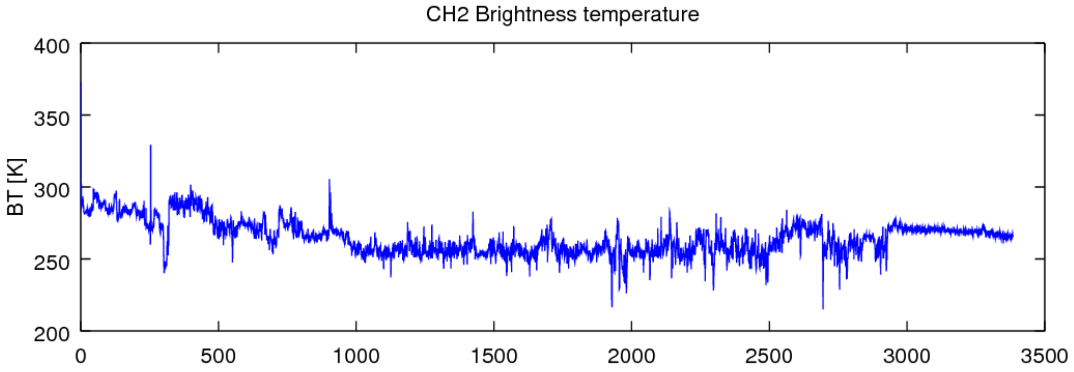
GPS track for field ARIEL measurements:

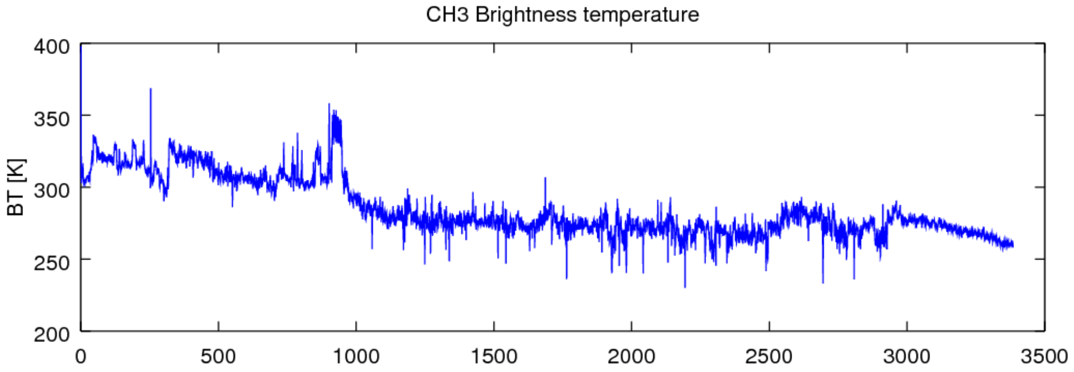
The voltage graph during the measurements show some interfering peaks even in the internal loads. They also appear on the brightness graphs obtained after the calibration.

Radiometer voltage vs time. Showing some noise interferences (peaks); Channels: COLD load (purple line), HOT load (red line), Vertical polarization (purple line), Horizontal polarization (green line):



Brightness temperature (ºK) vs time measurements during the field testing campaign:

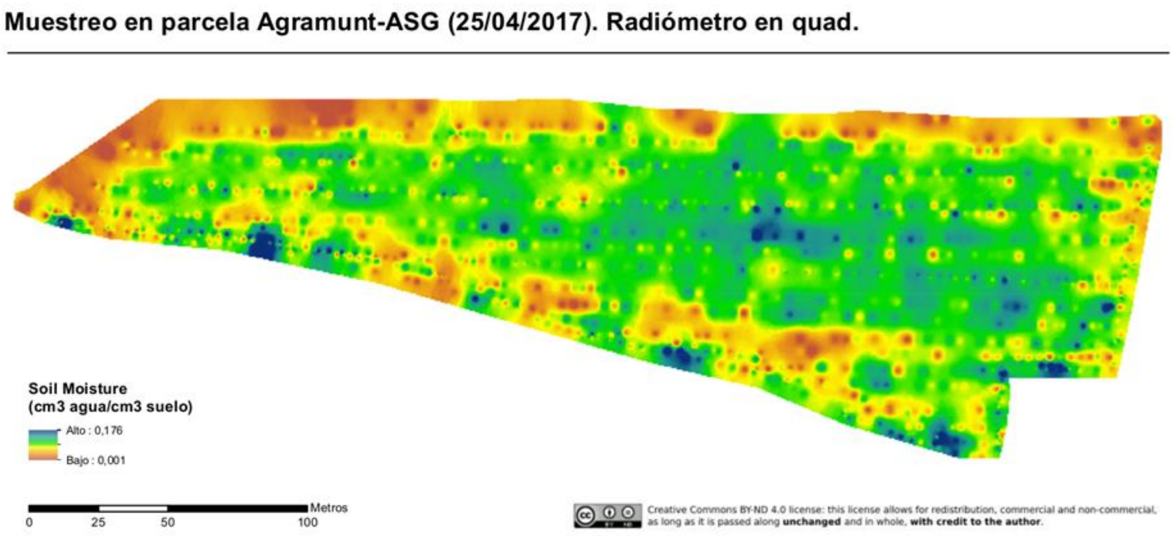




Finally, ARIEL point measurements were spatially interpolated using an IDW (Inverse distance weighing) algorithm to retrieve a soil moisture map for the whole study area.

An incoherent soil moisture spatial pattern was detected mainly due to the high influence of the peaks which were probably caused by the mechanical failure of the radiometer resulting from the breakage of the electromagnetic sealing and the generation of extra-large vibrations on the system electronics.

Soil moisture map in the Agramunt experimental site:



Failure matrix of the 5th operational testing campaign:

Failure	Description	Mitigation actions
Mechanical integrity. Case problems.	The outer shell of the case was broken and opened due to strong ATV vibrations caused by large sinkholes in the field.	Strengthen the mechanical structure.
Regular noise-interferences	Regular interferences in the loads and measurements (in all lines of the voltage, see **Error! Reference ource not found.**) caused by large ATV vibrations or self-interferences.	To detect the source of noise and try to mitigate it using post-processing. Reinforce the mechanical structure of the radiometer.

Other results:

The mechanical robustness of the whole system has been increased by adding metallic angles inside the case to strengthen the outer case and to reduce mechanical vibrations.

Campaign 2

Date: 02/05/2017

Participants: Balamis team (Adrià Amezàga, Roger Jové, Esther López)

Testing objectives: Check the behavior of the radiometer in snow and ice.

Experimental site: Port Ainé

Test description:

Testing tasks

- Integrate the radiometer with the vehicle.
- Check mechanical components.
- Heat the radiometer
- Microwave absorber measurement.
- Sky measurement
- Radiometric measurement of the soil.

Post-processing tasks

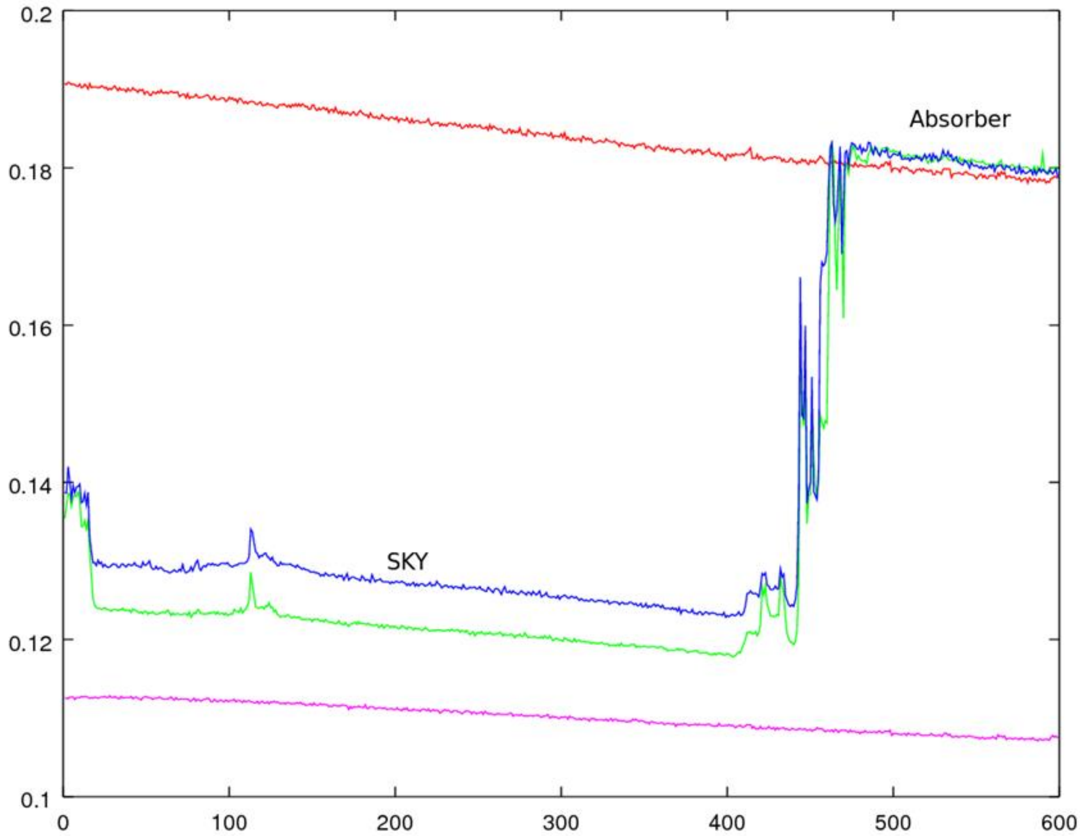
- Calibrate the radiometer with the Absorber – SKY measurements.
- Quick parse of the measurements and quick check for interference.
- Check obtained radiometer data (TIMESTAMP, VOLTAGE DATA) for inconsistencies.
- Parse data to obtain moisture rasters.
- Data analysis and interpretation

Results:

Calibration Voltages:

The calibration data is consistent with previous calibrations. The observed slope is due to the radiometer heating.

Voltage vs time of radiometer during calibration:

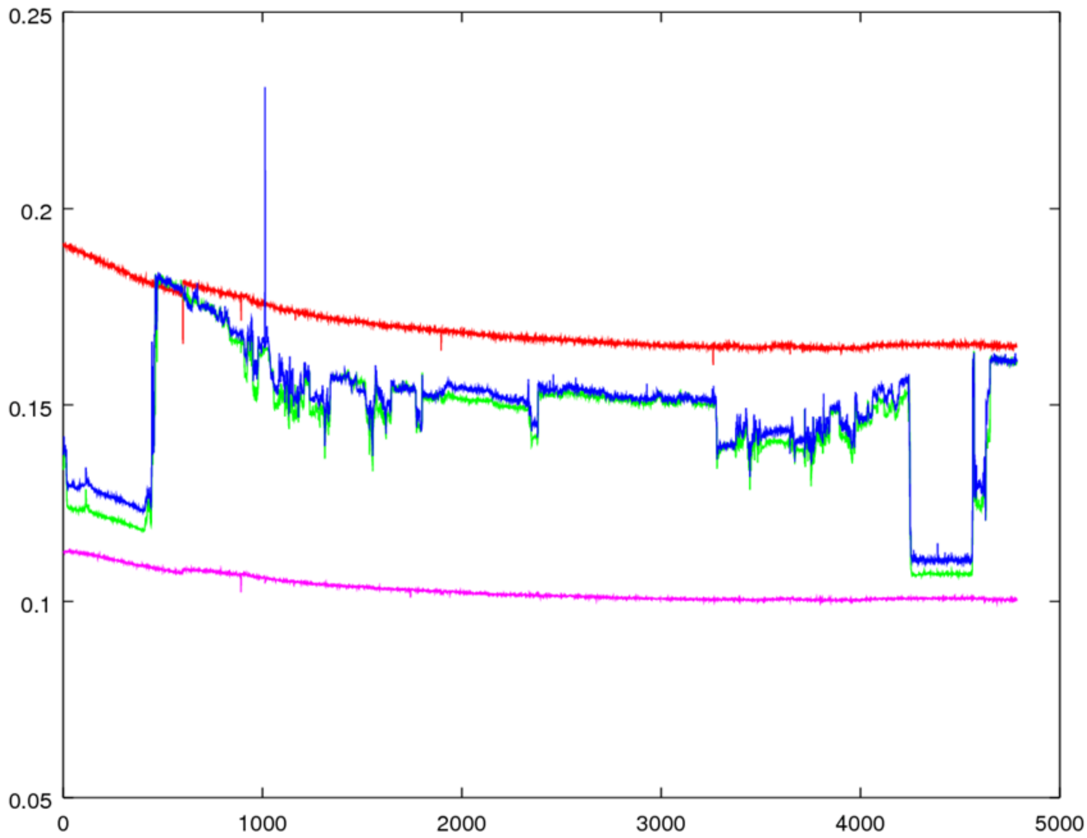


The loads were stable when they heat up, and the overall voltages were coherent and with no large interferences.

Field testing:

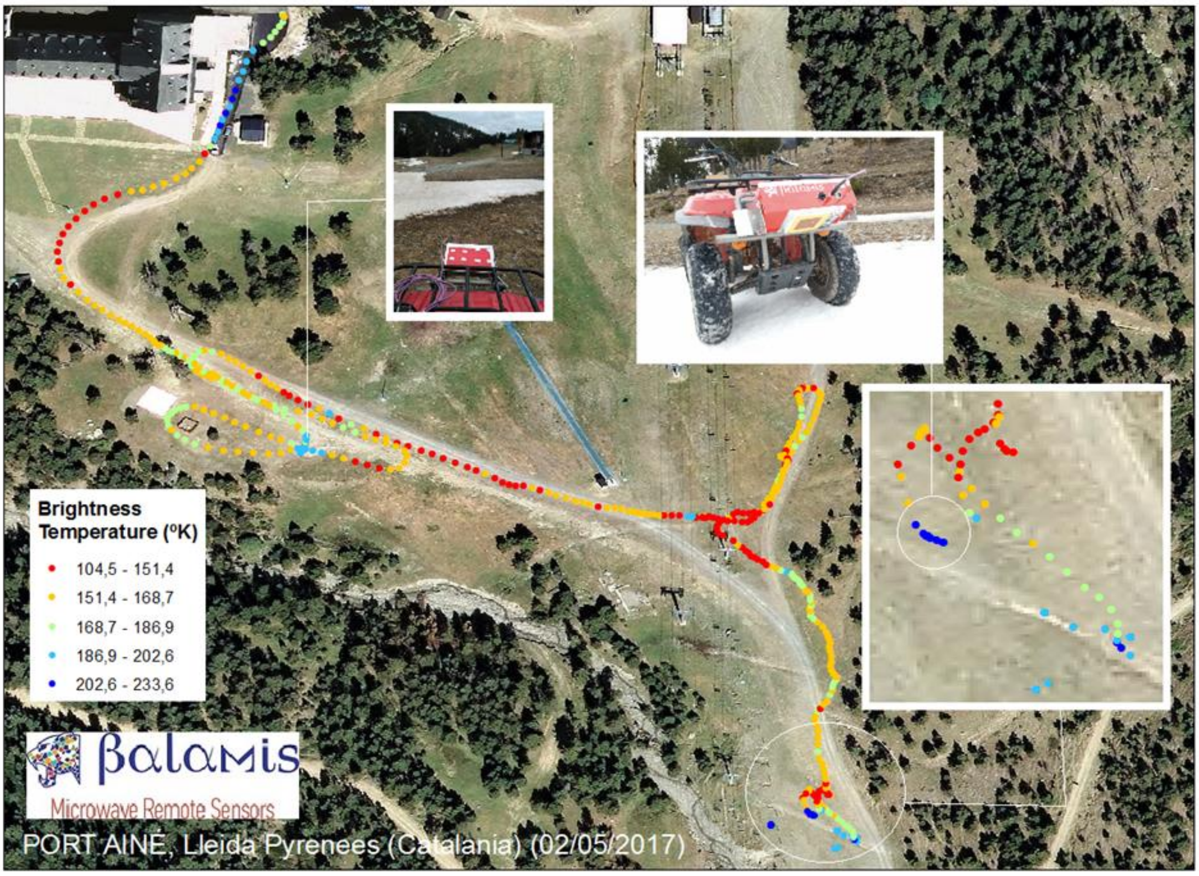
GPS track of the measurements:

Voltage vs time of radiometer measurements; Channels: COLD load (purple line), HOT load (red line), Vertical polarization (blue line), Horizontal polarization (green line):



Because snow and ice have greater emissivity than the bare soil, measured brightness temperature in snow/ice are expected to be higher than that measured in the bare soil or asphalt even when they are colder (intuitively one may think that colder areas may produce lower brightness temperatures). Vegetation has even a lower emissivity so its brightness temperature is even smaller. We clearly observed this behavior in the following illustration where the points were the radiometer measurements - snow and frozen snow produced higher brightness temperatures despite being colder than the rest of the area.

Detail of the measurements:

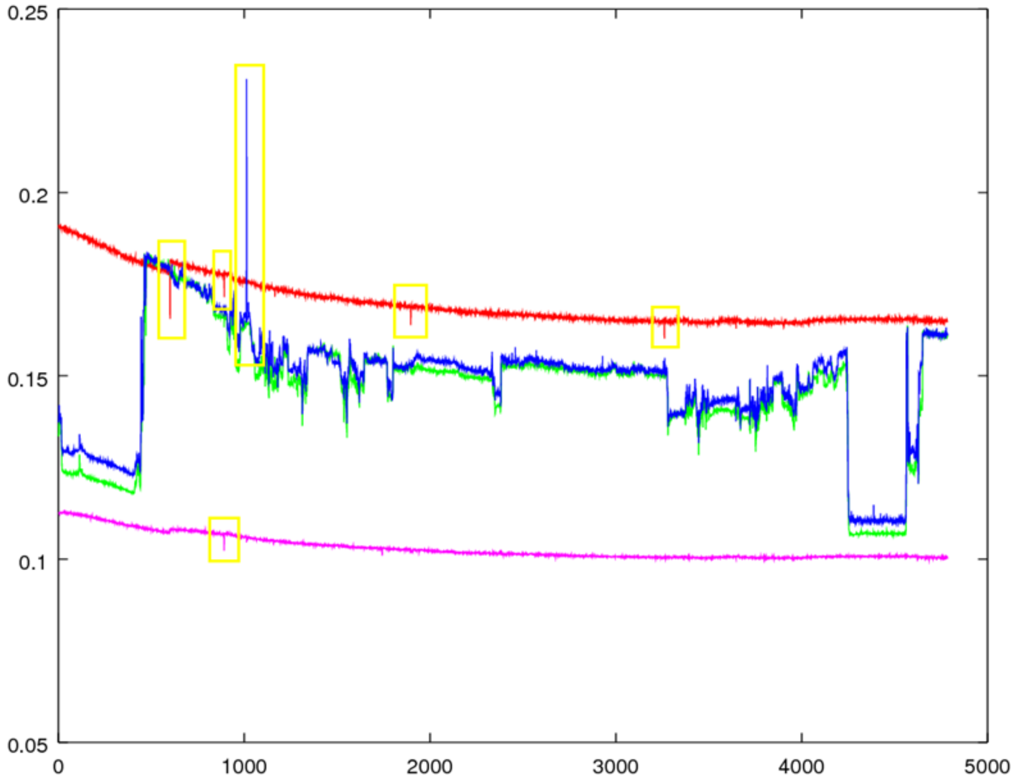


The data of interest are punctual measurements, so a brightness temperature raster was not generated.

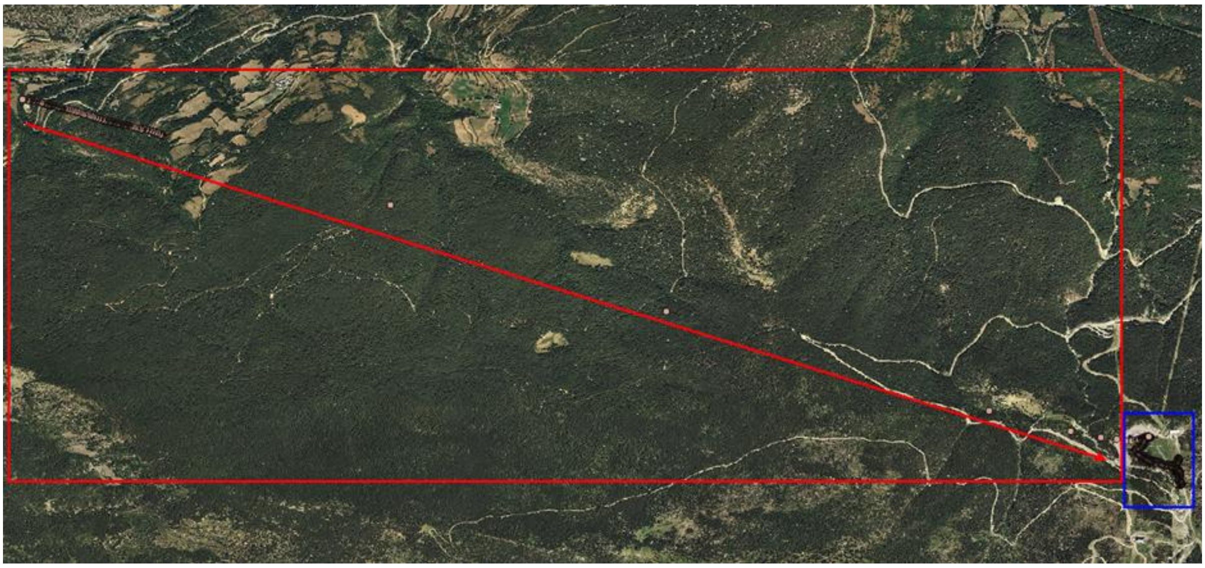
Failure matrix of the 2nd operational testing campaign:

Failure	Description	Mitigation actions
Punctual interferences	There have been punctual interferences (yellow square in next figure), but they don't affect the measurement since they are very localized.	Can't be mitigated.
GPS Lock not stable	Description: At the beginning the GPS Lock is not stable (red square in next figure), the points are not in the actual location (blue in next figure), it does not affect the measures since it was the heating phase of the radiometer.	Wait longer for the GPS lock. Improve the GPS hardware.
Heating inconsistencies	Due to the stacked radiometer topology the temperature sensor does not sense correctly all the stages. So some stages are not fully up to temperature when the radiometer thinks they are.	Let the radiometer heat up for more time. For a new version of the radiometer the heating system and the temperature system are going to be improved.

Voltage vs time of radiometer including calibration and measurements; Channels: COLD load (purple line), HOT load (red line), Vertical polarization (blue line), Horizontal polarization (green line):



Full GPS track. Bad initial lock. COLD LOAD (pink line), HOT LOAD (red line), Vertical polarization (purple line), Horizontal polarization (green line):



Campaign 3

Date: 08/05/2017

Participants: Balamis team (Roger Jové, Esther Lopez, Adrià Amézaga)

Testing objectives:

- Test ARIEL radiometer on the field
- Calibration of ARIEL
- Retrieval of soil moisture maps
- Comparison of radiometer soil moisture outputs against neutron probes and lab measurements at control sites.

Experimental Site: Mollerussa

Field view during the measurement campaign:

Test description:

Testing tasks

- Integration of the radiometer with the vehicle.
- Checking of mechanical components.
- Radiometer calibration
- Measuring soil moisture at the field with the ARIEL radiometer
- Measuring soil moisture with neutron probes at control (ground-truth) sites

Post-processing tasks

- Quick analysis of the measurements and quick check for interference.
- Checking of radiometer data (TIMESTAMP, VOLTAGE DATA) to evaluate potential inconsistencies.
- Quick analysis of radiometer data for quick results.
- Retrieval of soil moisture map.

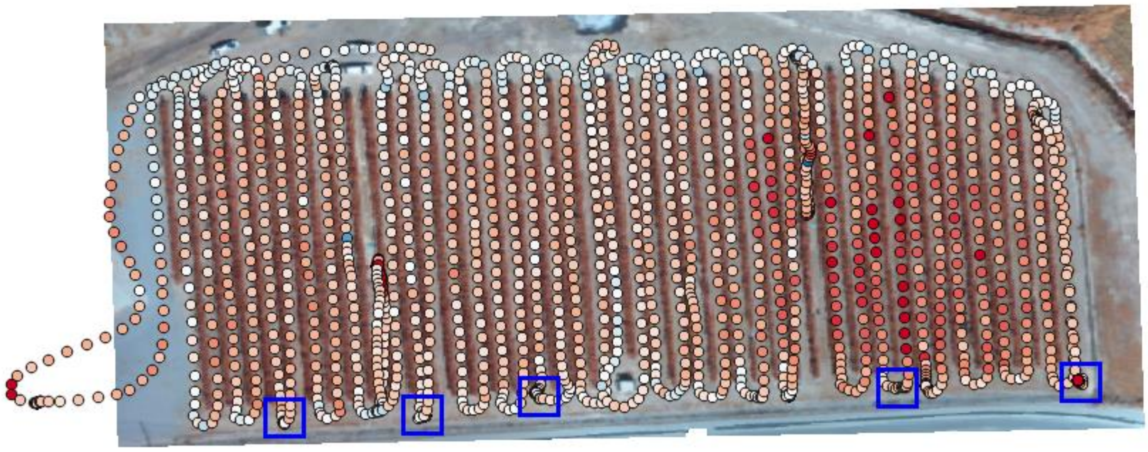
Track and voltage patterns:

Despite the radiometer was previously calibrated, a second calibration was performed to check the consistency of the first one. This second calibration was done before the first passage and using a microwave absorber at some points of the field.

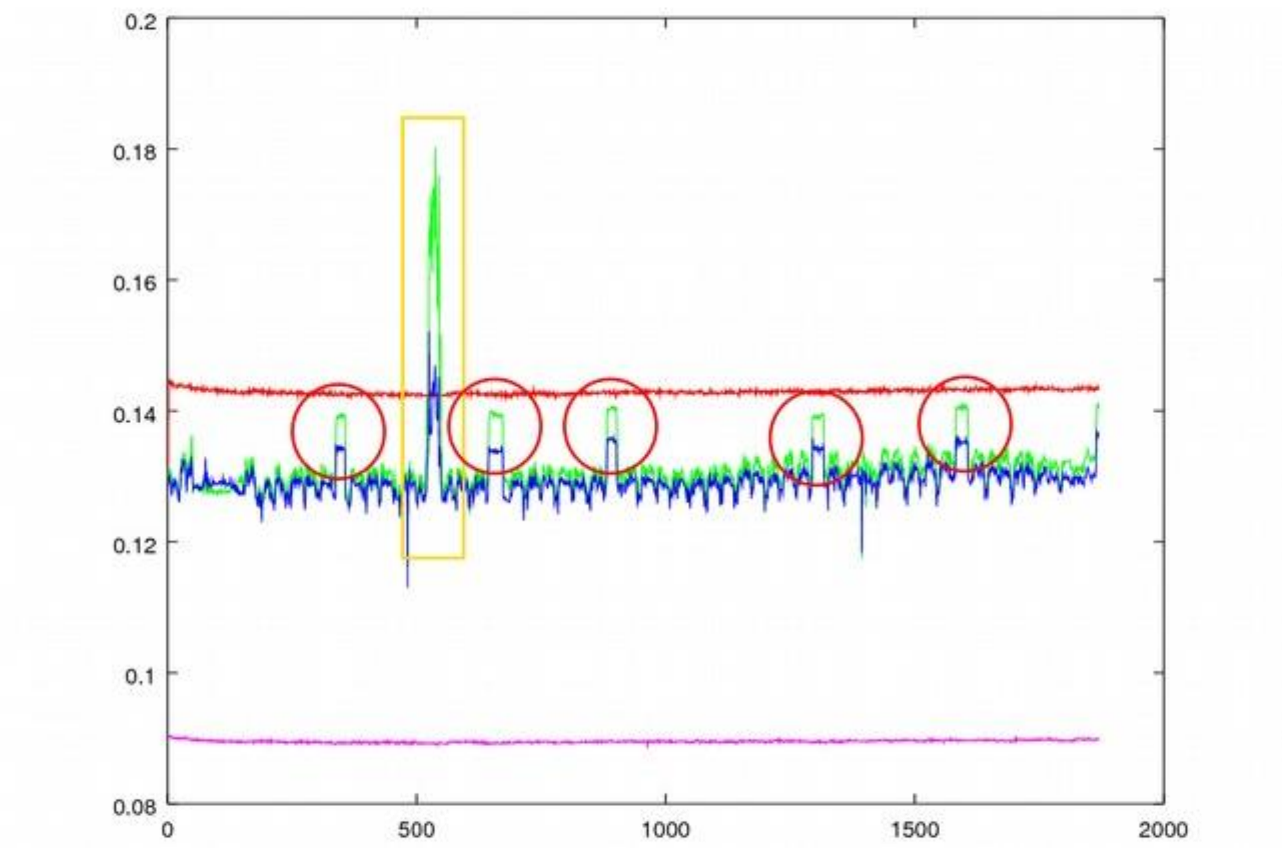
First pass:

The GPS track is shown in next figure. Voltage values were consistent during all the path and in the whole field. Lower spikes in the figure are associated to the edges of the field where the terrain had lower emissivity. Calibration points are clearly identified in the track log (blue squares in next figure) and the voltage graph (red circles in next figure). The voltage values were consistent with the calibration and did not change.

GPS track of the first pass measurements where red is drier:



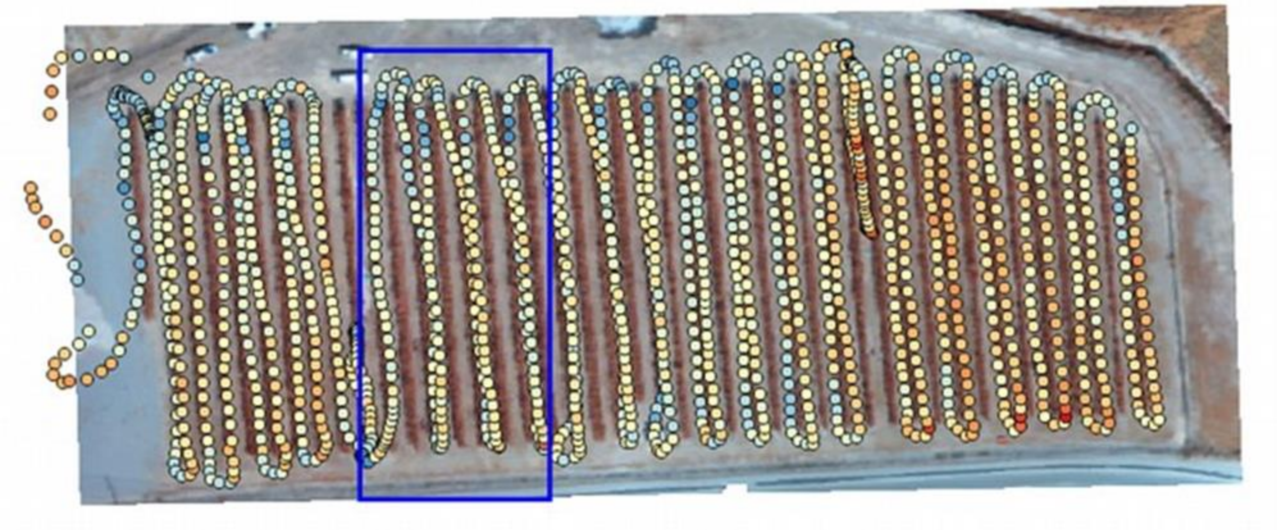
Voltage vs time during the measurement (first pass); COLD LOAD (pink line), HOT LOAD (red line), Vertical polarization (blue line), Horizontal polarization (green line):



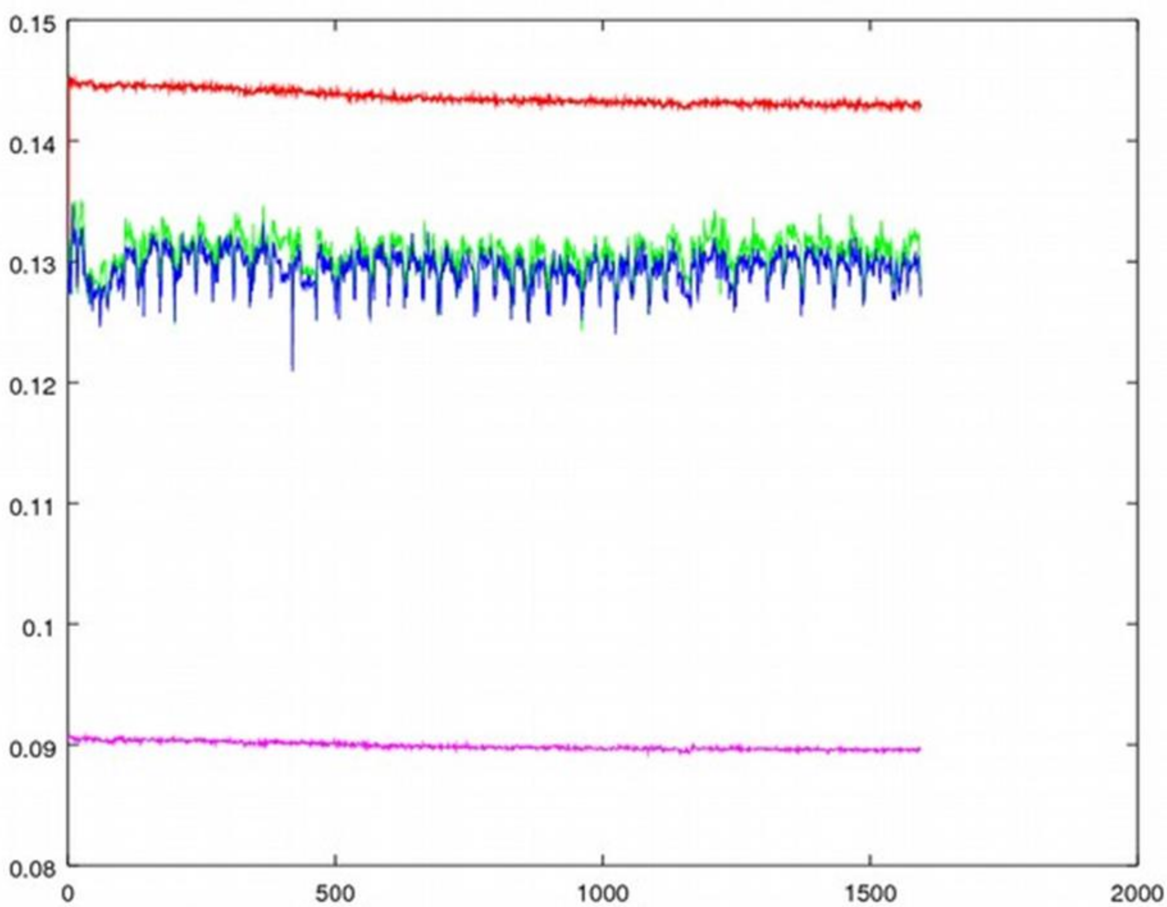
Second pass:

Voltages were again considered normal and consistent. Like in the first pass the voltage low spikes correspond to the edges of the field. There is a small inconsistency in the GPS position (blue).

GPS Track for the second pass where red is drier:



Voltage measurement vs time of the whole field using ATV (second pass); Channels: COLD load (purple line), HOT LOAD (red line), Vertical polarization (blue line), Horizontal polarization (green line):



Results:

The soil moisture algorithm was computed for each point (the soil composition values were obtained using a lab analysis (clay 0.25 – sand 0.37) and an average rugosity of 0.2 was used). Also an IDW (Inverse Distance Weight) algorithm was used to interpolate point values. The calibrated brightness temperature map was also retrieved by interpolation.

Interpolated calibrated brightness temperature maps for the first (up) and second (below) passes:

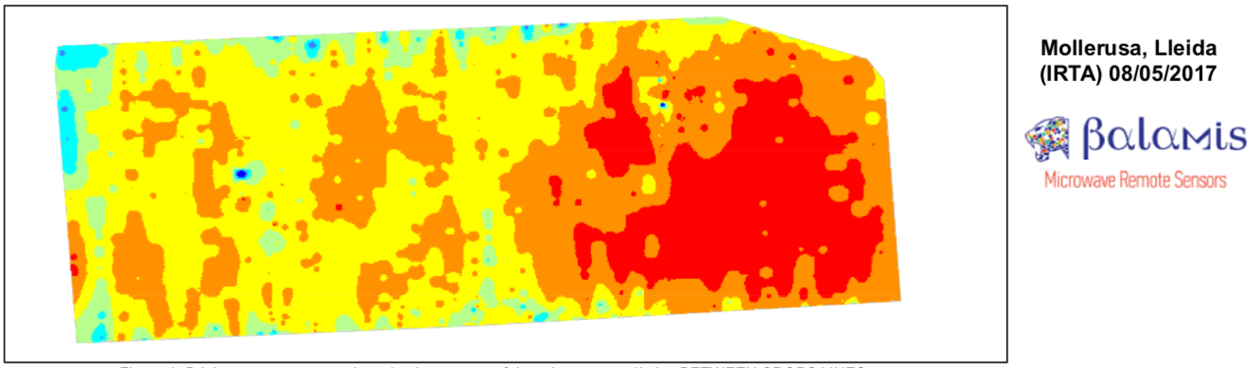


Figure 1. Brightness temperature (raw data), measure of the microwave radiation BETWEEN CROPS LINES.
Radiometer on-board a Quad, Time: 10.00 -10.30 h

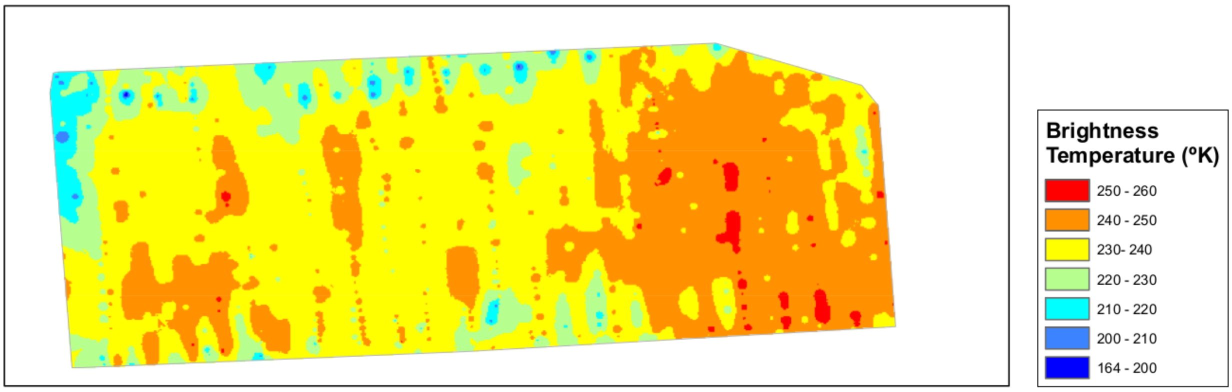
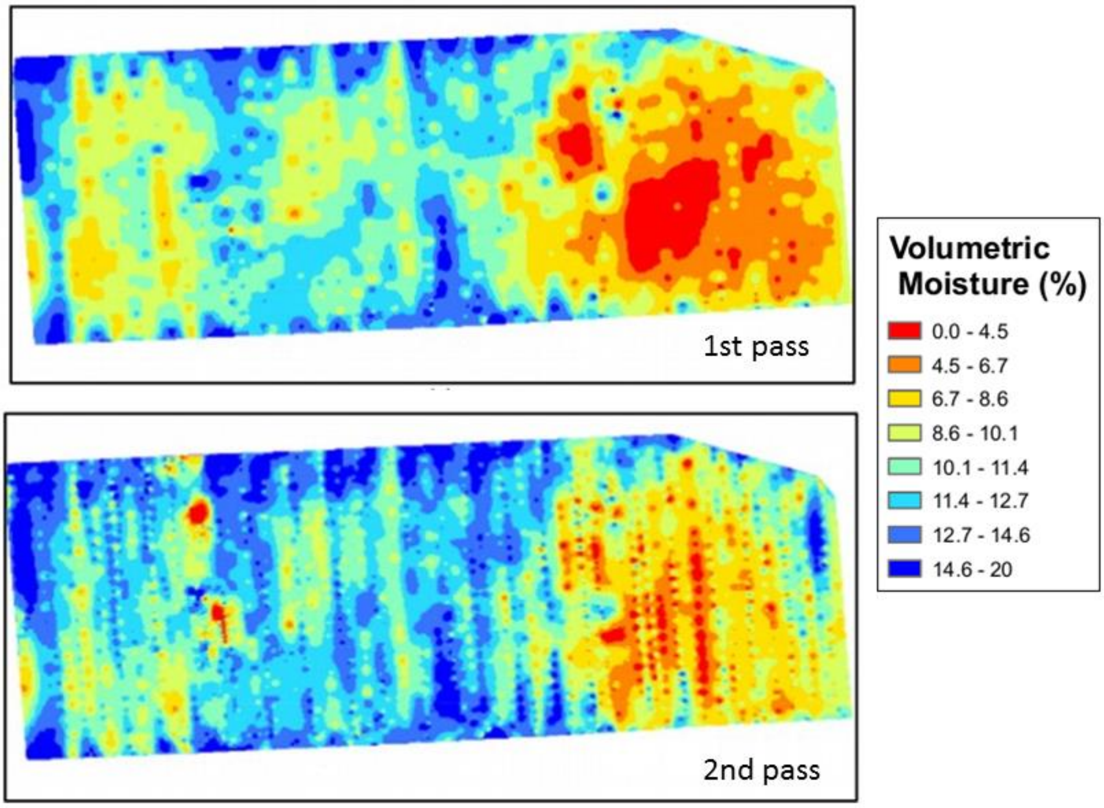
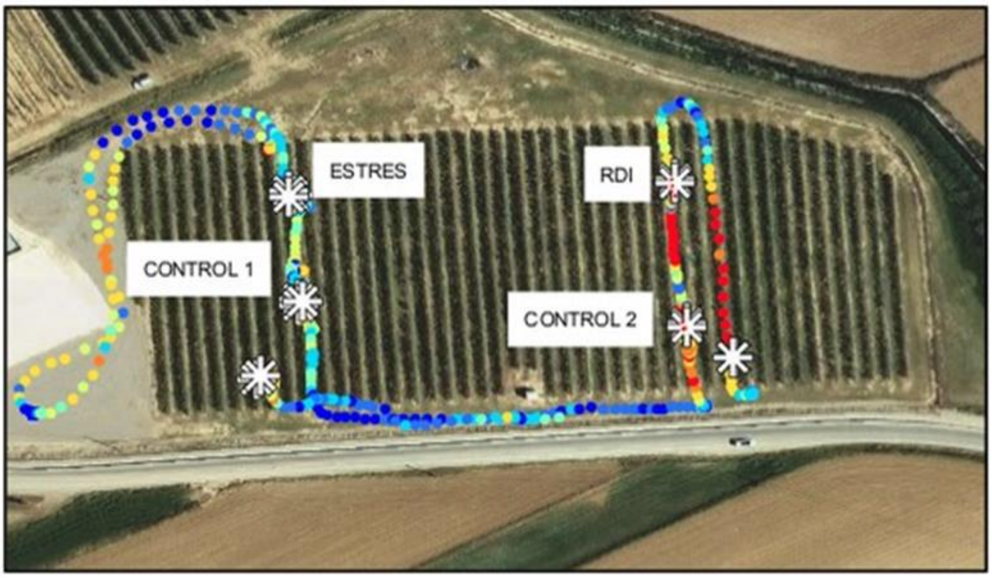


Figura 2. Brightness temperature (raw data), measure of the microwave radiation CLOSE TO TREES LINES.
Radiometer on-board a Quad, Time: 10.30 -11.00 h

Maps of soil moisture retrieved from the first and second pass:



GPS track of the ATV with the measuring points locations:



Detail of the measurement points with the ATV:

Soil moisture values measured at lab (SM_Lab), in the field -20cm in depth- with neutron probes (SM_NP) and with the ARIEL ATV radiometer (SM_ARIEL) are shown in next table. It is concluded that ARIEL provides enough accurately soil moisture when are compared against neutron probe values. Lab soil moisture measurements were a bit different maybe because the sampling process was too inaccurate due to the soil characteristics.

Table of soil moisture values of the control points using various methods:

Control Point	SM_Lab	SM_NP20	SM_ARIEL
CONTROL1	20,83	12,38	12,42
CONTROL2	17,89	10,99	10,26
ESTRES	10,77	11,43	13,18
RDI	10,07	11,93	10,49

Failure matrix of the Campaign 3:

Failure	Description	Mitigation actions
Interference noise	The large interference detected in the first pass (yellow box in figure) was due to people passing in front of the radiometer.	None

Failure	Description	Mitigation actions
	From the track log it is clear that the vehicle was stopped.	
Negative soil moisture measurements (9% of the total)	The algorithm is not enough accurate when certain conditions are met (high difference between both polarizations). Negative values were masked and set to 0.	Further efforts are required to check and improve the soil moisture algorithm and solve the inconsistency.
Overlapped GPS positions	During the second pass several GPS positioning values were overlapped (blue box in figure) despite quad moved through different tracks. It was demonstrated that the accuracy of the GPS was not enough to distinguish between track too close.	A new system is proposed with a better GPS device and the possibility to include RTK corrections.

Campaign 4

Date: 03/07/2017

Participants: Esther Lopez, Ricard Gonzalvez

Testing objectives:

- Test the radiometer on field
- Radiometer calibration
- Retrieval of soil moisture map
- Comparison of radiometer soil moisture results with neutron probes and lab measurements.

Experimental site: Mollerussa

Field view (left) and soil sampling at the Mollerusa experimental site (right):


Test description: Same than in Campaign 1.

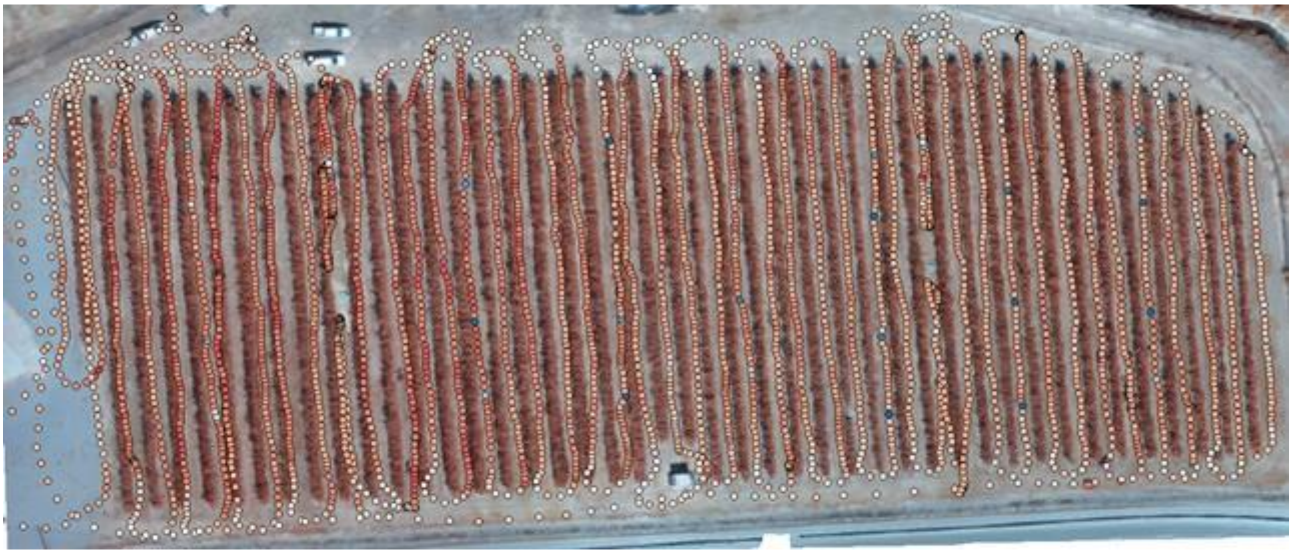
Results:

For this test a new mechanical support was designed to bring the radiometer closer to the trees.

At this time, the proposed RTK system was not still ready, so spatial inconsistencies detected during the campaign 1 may emerge. Also, the new soil moisture algorithm developed to correct the post-processing inconsistencies detected in the previous test was not ready for this test.

Detail of the new lateral positioning of the radiometer:


GPS Track with the whole field measured with the radiometer centered in the ATV:

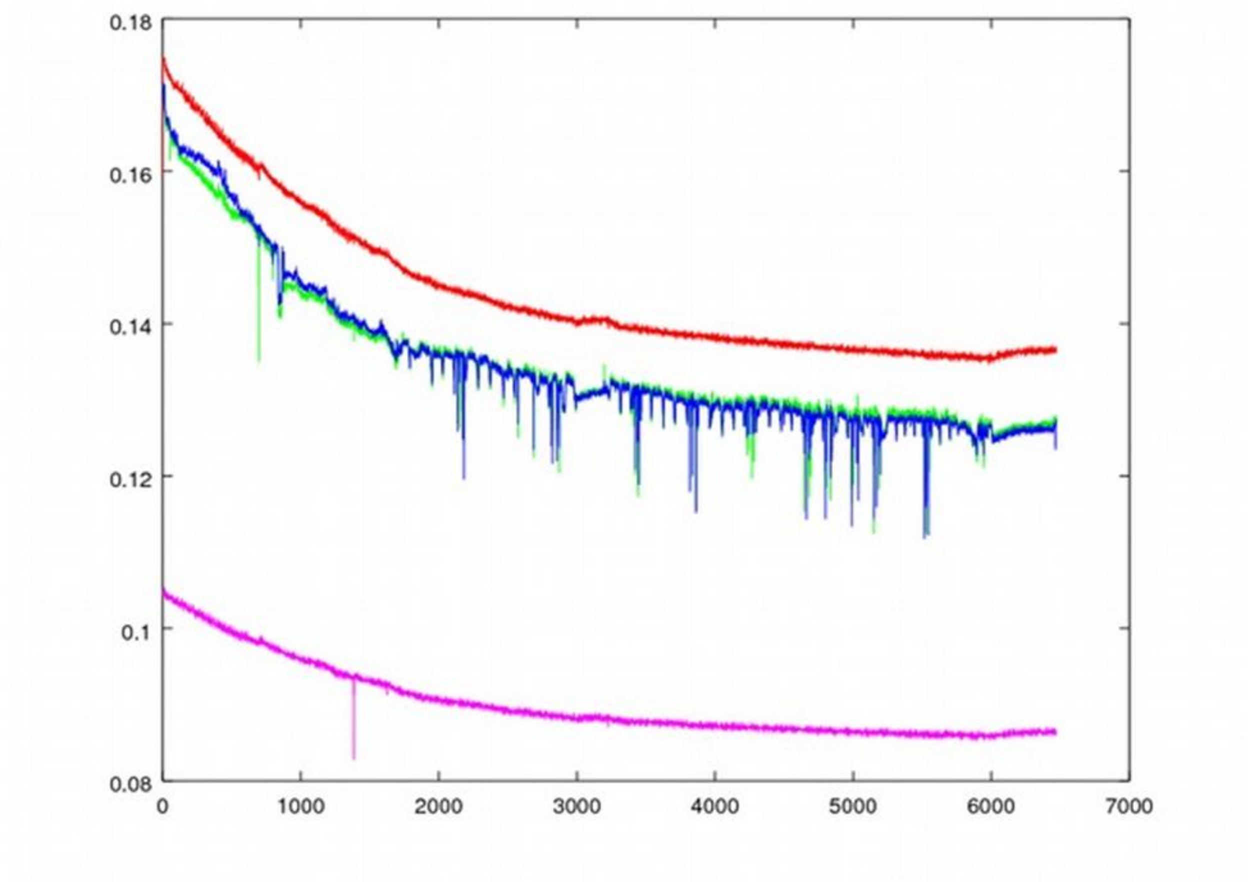


The voltage graph values were coherent and no interferences were observed. The low peaks in the graph correlated with the extremes of the field where the soil type has lower emissivity.

The lowest peaks were related with a set of calibration materials placed in the middle of the tree lanes that were used to calibrate the multi-spectral cameras of the drones and airplanes used during the campaign and are unrelated to the radiometer. These peaks are identified in the track figure as the blue points located in some lanes and equidistant to each other.

There were also other punctual interferences not related with relevant phenomena or materials. This noise could be corrected by deleting that points in the post processing phase.

Voltage vs time from ARIEL measurements (centered in the ATV Channels: COLD load (purple line), HOT LOAD (red line), Vertical polarization (blue line), Horizontal polarization (green line). The slope is due to the radiometer heating:

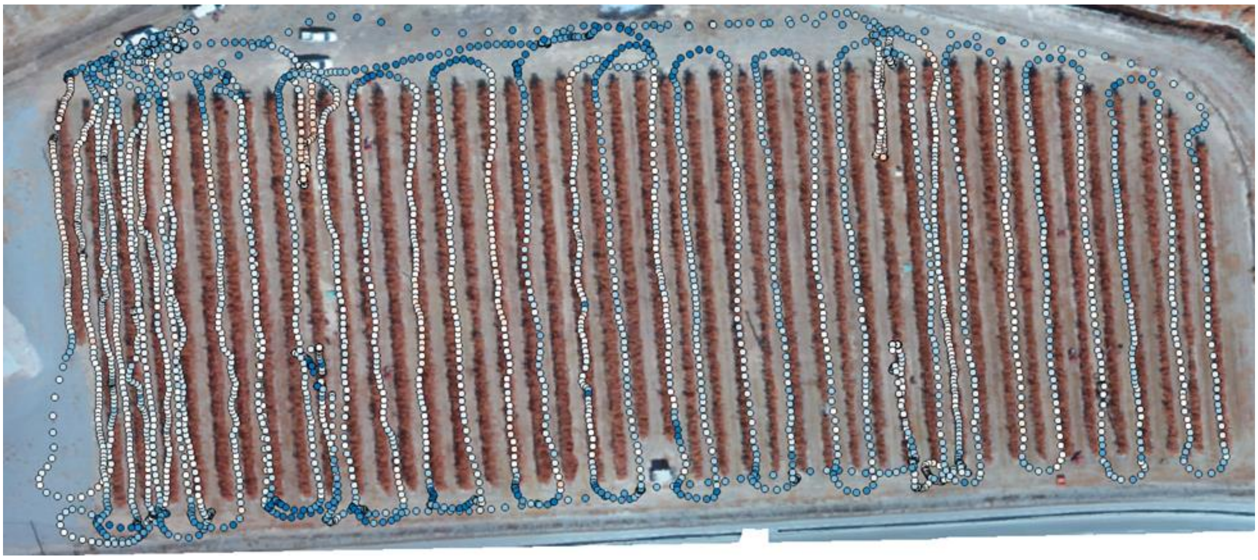


Second pass:

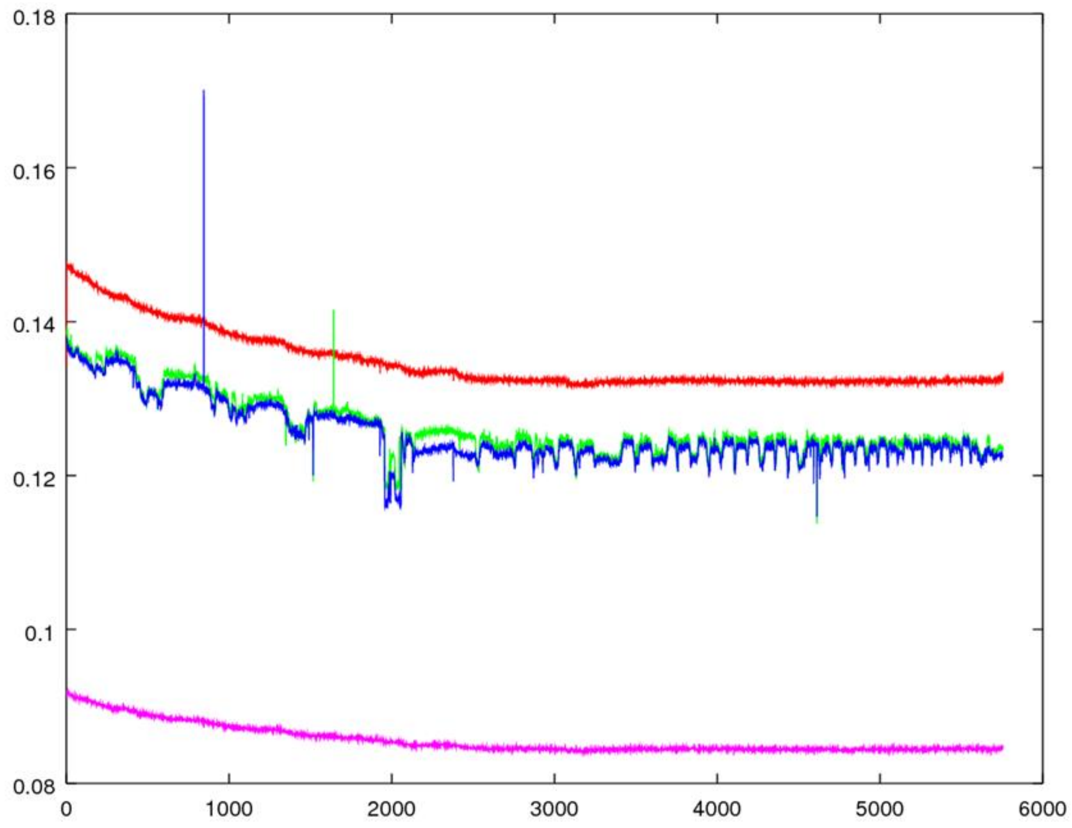
In this second pass the radiometer was placed at the new structure near the trees and did not pass over the calibration material.

A 30 s (approx.) stop was made in each probe measurement point. As it was observed in the previous voltage graph, the lowest peaks correspond to changes of terrain properties at the limits of the field.

GPS track of the measurements near the trees with the ATV:



Voltage vs time of measurements near the trees with the ATV; Channels: COLD load (purple line), HOT LOAD (red line), Vertical polarization (blue line), Horizontal polarization (green line):



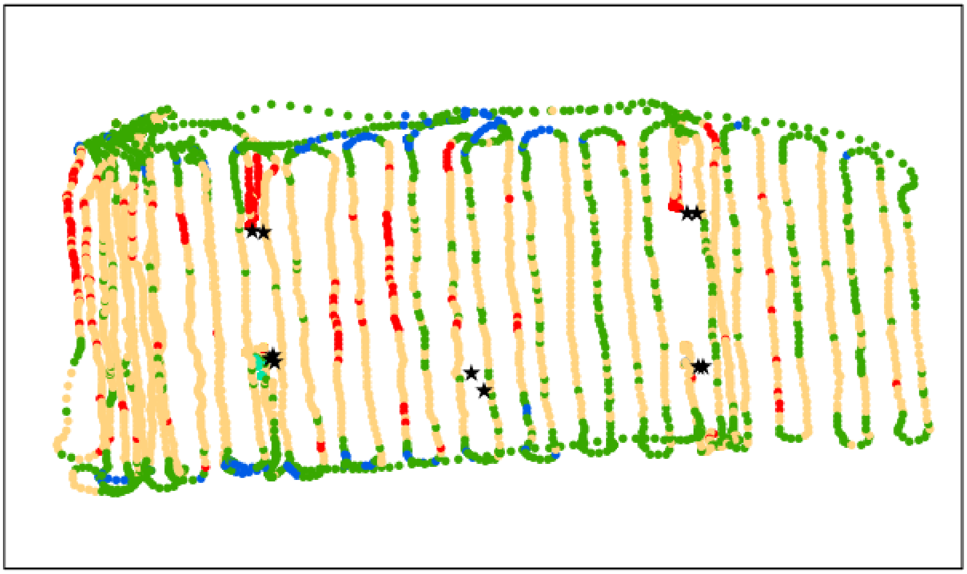
Results:

Spatial patterns of soil moisture values measured by the ARIEL radiometer are shown in next figure, while their comparison against neutron probes measurements in the control sites are in next table. Overall, an important bias between neutron and radiometer measurements was found.

Detail of the radiometer soil moisture measurements in the field and in the control points:

2º TEST. Mollerusa, Lleida 03/07/2017

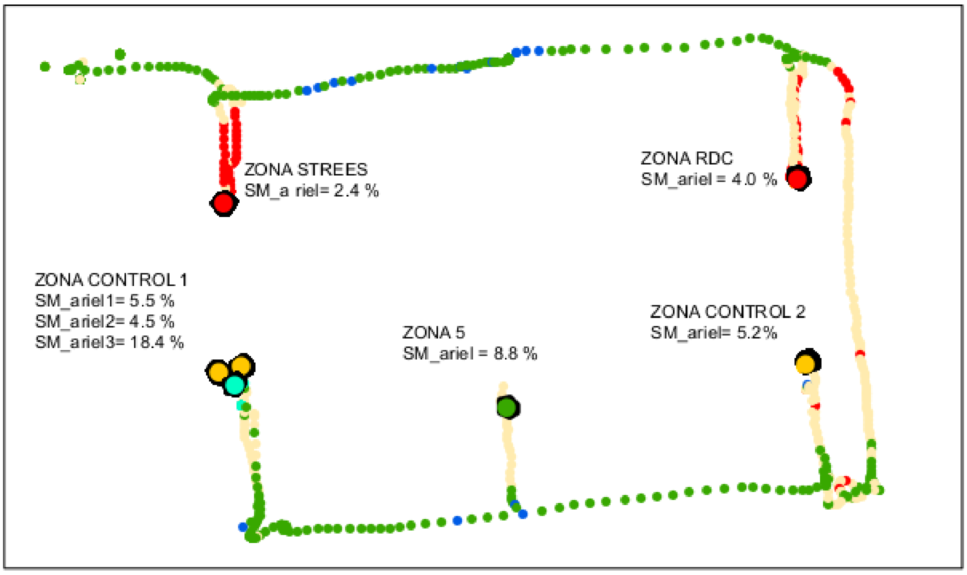
Recerca i Tecnologia Agroalimentaries (IRTA)



Surface Soil Moisture CLOSE TO TREE LINES.

Volumetric Moisture (%)

0 - 4 | 0,4 - 0,8 | 0,8 - 12 | 12 - 16 | 16 - 20 | ★ PROBES



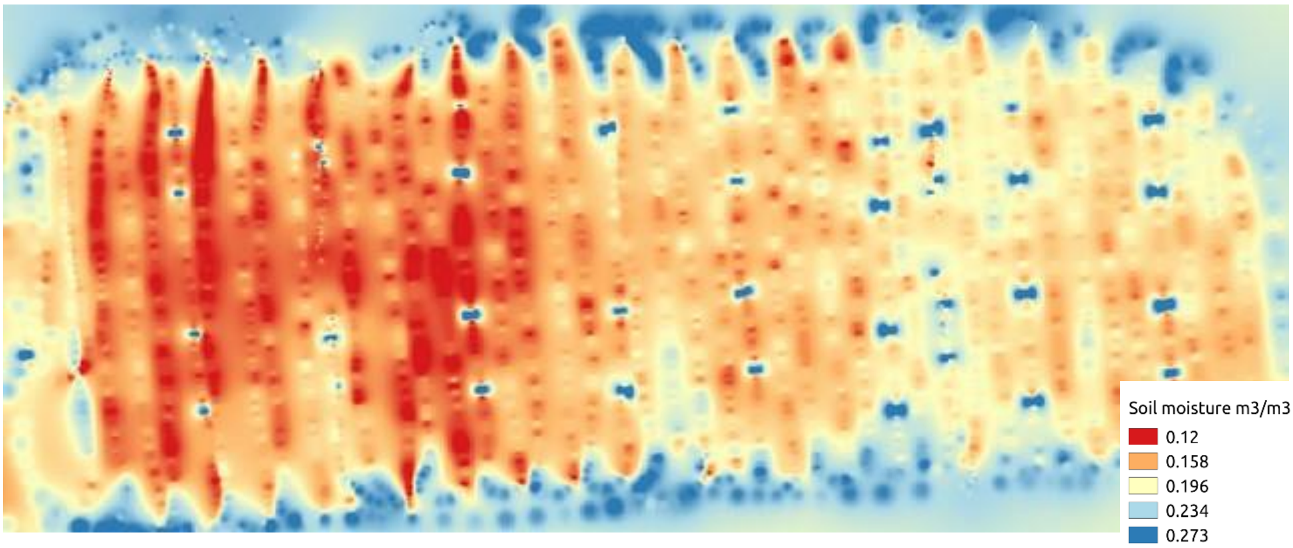
Surface Soil Moisture CLOSE TO NEUTRONS PROBES

Comparison of soil moistures values retrieved with neutron probes at 20 and 10 cm. depth, and ARIEL radiometer:

Control Point	SM_ARIEL	SM_NP10	SM_NP20	Bias (%) vs SM_NP10	Bias (%) vs SM_NP20
CONTROL1_1	18.04	10.98	11.53	64.30	56.46
CONTROL1_2	5.50	9.66	11.24	-43.06	-51.07
CONTROL1_3	4.40	10.29	11.67	-57.24	-62.30
CONTROL2	5.20	8.06	10.22	-35.48	-49.12
ESTRES	2.40	6.68	8.88	-64.07	-72.97
RDC	4.00	7.73	9.43	-48.25	-57.58
PARCELA_5	8.80	9.12		-3.51	

The soil moisture map retrieved from ARIEL point measurements using an IDW interpolation showed clearly the after mentioned (previous section) imagery calibration points and a drier soil surface in the left section of the field.

Map of interpolated (IDW) soil moisture of whole field measured using ATV:



Failure matrix of campaign 4:

Failure	Description	Mitigation actions
Soil moisture bias	Soil moisture values from radiometer did not match the neutron probe (ground-truth) ones. After analyzing the general procedure, it	To follow the measuring protocol strictly, taking the measurements more accurately.

Failure	Description	Mitigation actions
	was concluded that the radiometric values of the test points were not correctly measured due to a human error. The radiometer's antenna was not pointed directly to the neutron probe spots (however it was pointed to vegetated traits in the surroundings which yielded lower emissivity and soil moisture values)	
Inaccurate GPS	The GPS used was still the old one, and hence some GPS inconsistencies / overlapping was present	A new GPS is being worked on for the next test

Campaign 5

Date: 14/09/2017

Participants: Roger Jové, Ricard Gonzalvez, Esther Lopez

Testing objectives:

- Test the radiometer on field
- Test a new RTK GPS system
- Obtain a soil moisture map
- Compare radiometer moisture results with neutron probes and lab measurements.
- Test the new improved soil moisture algorithm.

Experimental site: Mollerussa

Test description:

Testing tasks

- Integration of the radiometer with the vehicle.
- Checking of mechanical components.
- Heating of the radiometer.
- Calibration with microwave absorber measurements.
- Radiometric measurement of the soil.

Post-processing tasks

- Same than in campaigns 1 and 2.

Results:

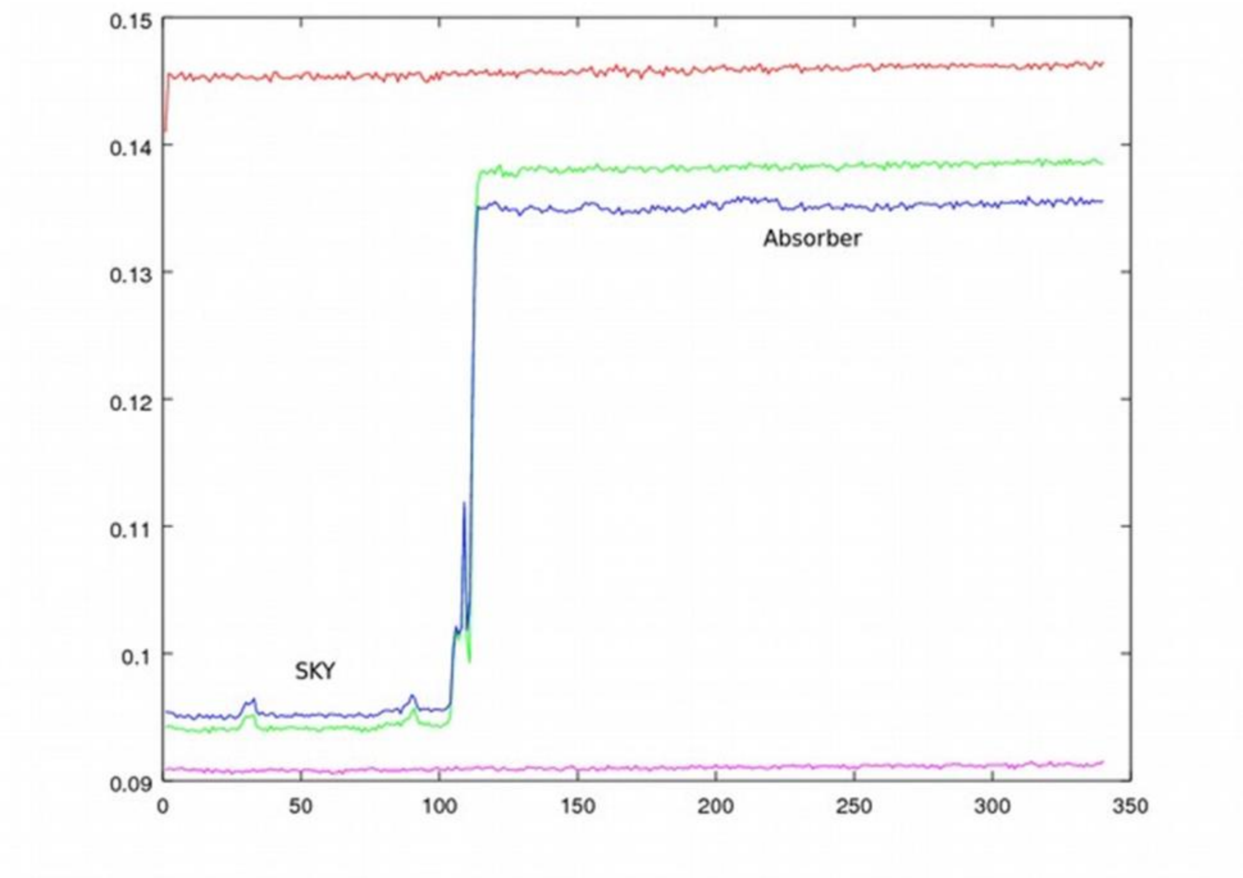
A new trolley was acquired in order to get the radiometer closer to the soil and tree roots and hence retrieve more accurate soil moisture measurements without the interference of the tree leaves. The radiometer used in the trolley was the same that that used in the ATV but with a mechanical adapter.

Details of the new measurement trolley:

<u>*Calibration:*</u>

The calibration voltages was coherent.

Voltage vs time during calibration; Channels: COLD load (purple line), HOT LOAD (red line), Vertical polarization (blue line), Horizontal polarization (green line):

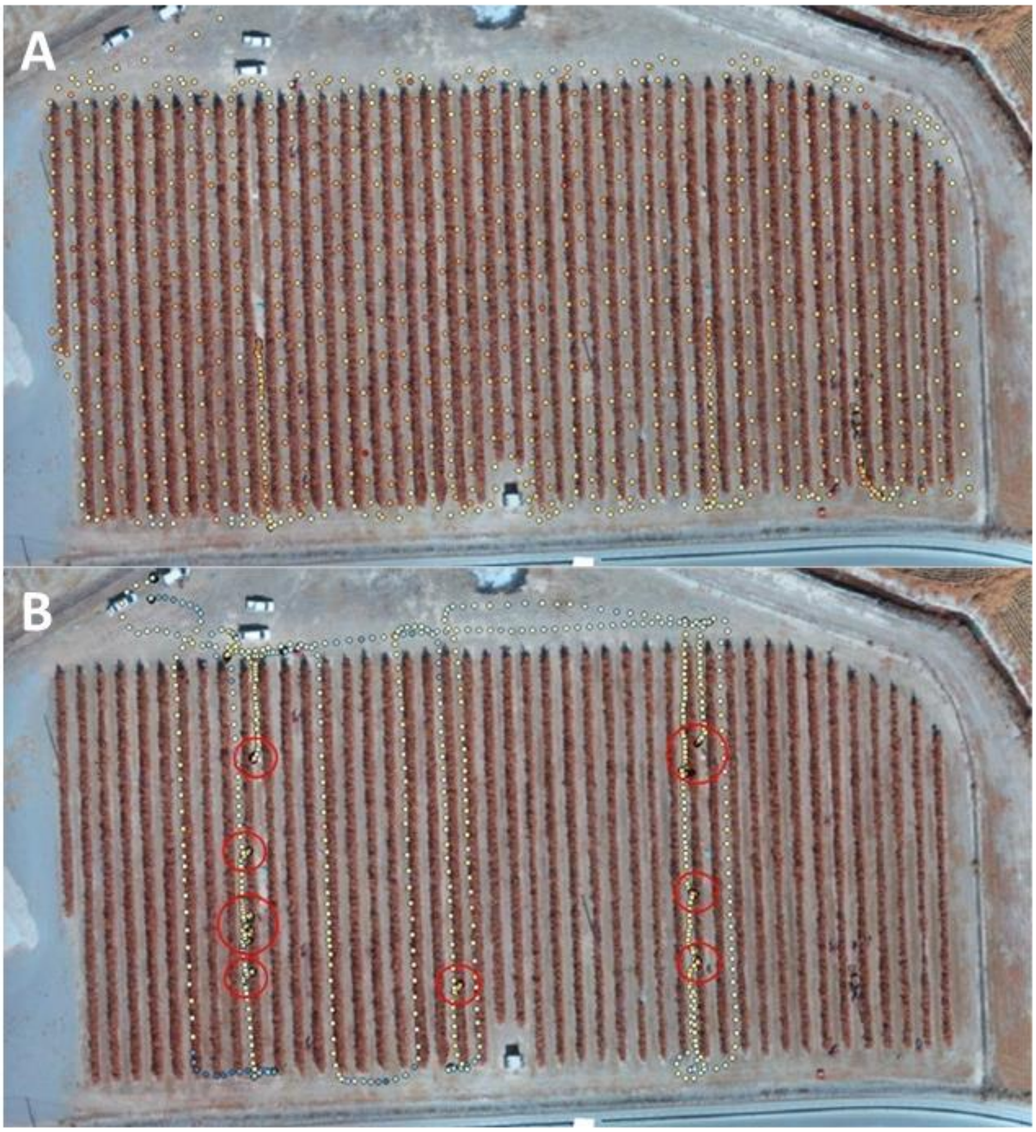


Measurements with the ATV:

Two passes were performed : the first one covered the whole field through the center of the paths, while the second one was done only for validation purposes measuring in the sites with the netron probes. In these validation points, the ATV the radiometer pointed more accurately to the neutron probe spot in order to avoid the mistakes made during the previous campaign.

The new GPS positioning is very good with no overlapping paths.

GPS tracks for discrete point measurements with the ATV: (A) whole field area (1st pass), (B) discrete measurement points (2nd pass):

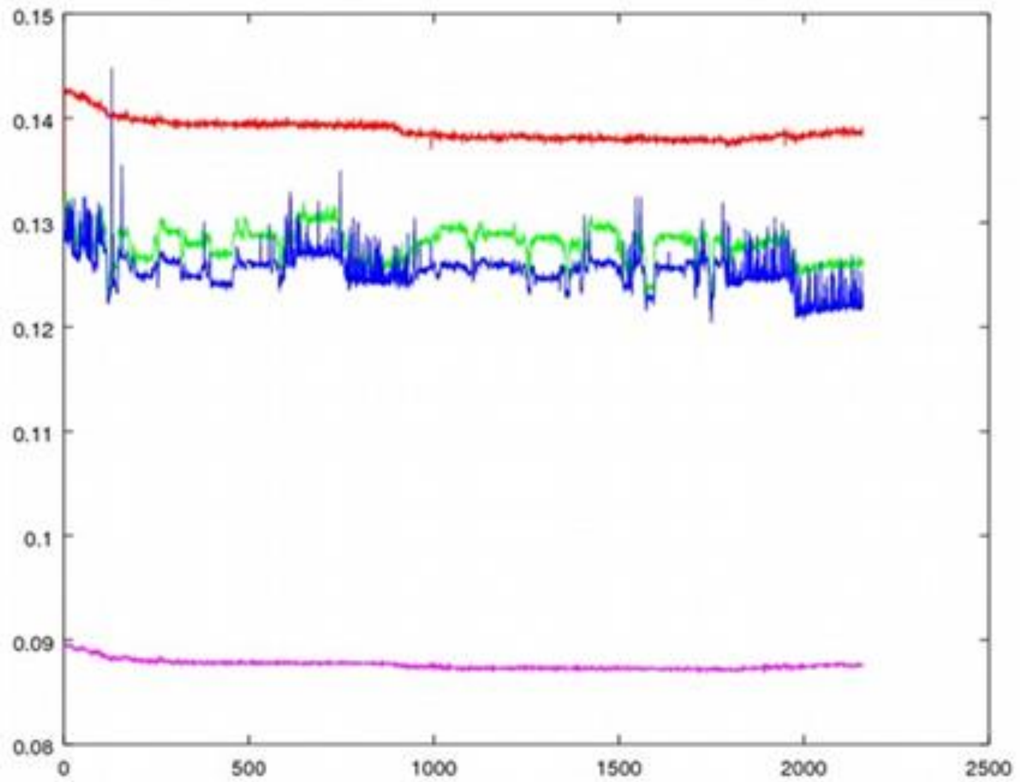


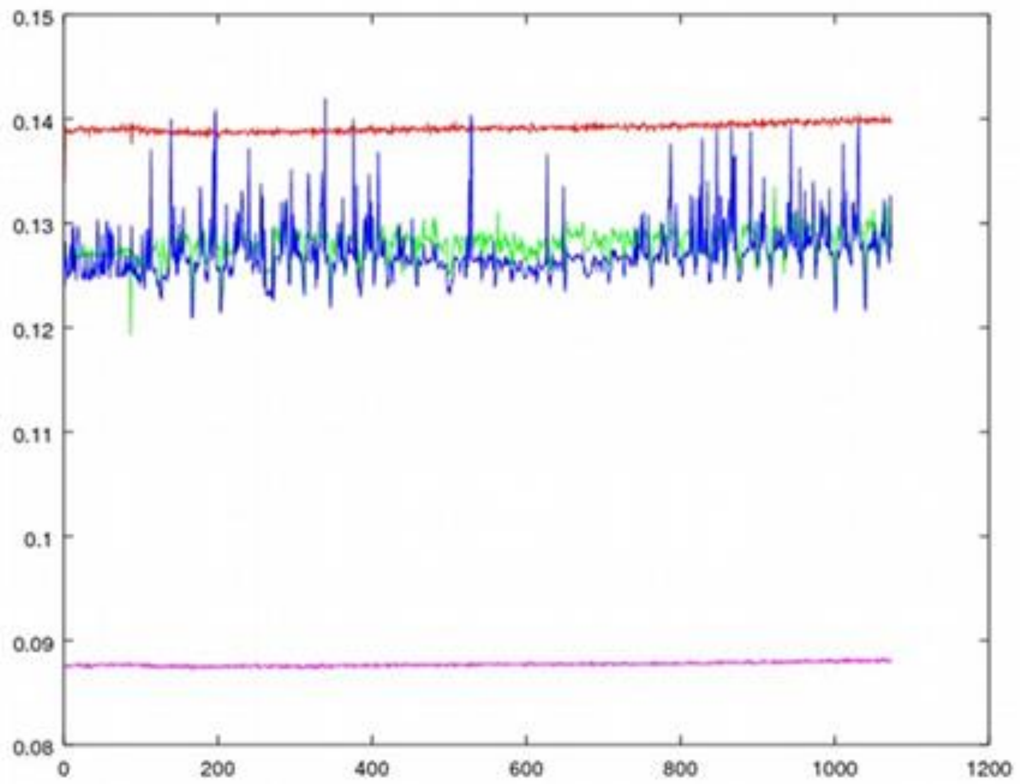
Several interferences in the H (blue) channel are identified in both voltage graphs. The number of interferences was lower in the V channel (green), so data from this channel were those ones finally used for computing soil moisture values.

Some interfering features were identified at some points located along the track (red circles in next figure). The low voltages observed in the graph were related to changes in the characteristics of the soil at the beginning and end of each tree lane.

In the second pass, the interference level was even higher in the V channel which would yield inaccurate soil moisture estimates.

Voltages logs measured with the ATV for the whole area (top), and discrete points; Channels: COLD load (purple line), HOT LOAD (red line), Vertical polarization (blue line), Horizontal polarization (green line):





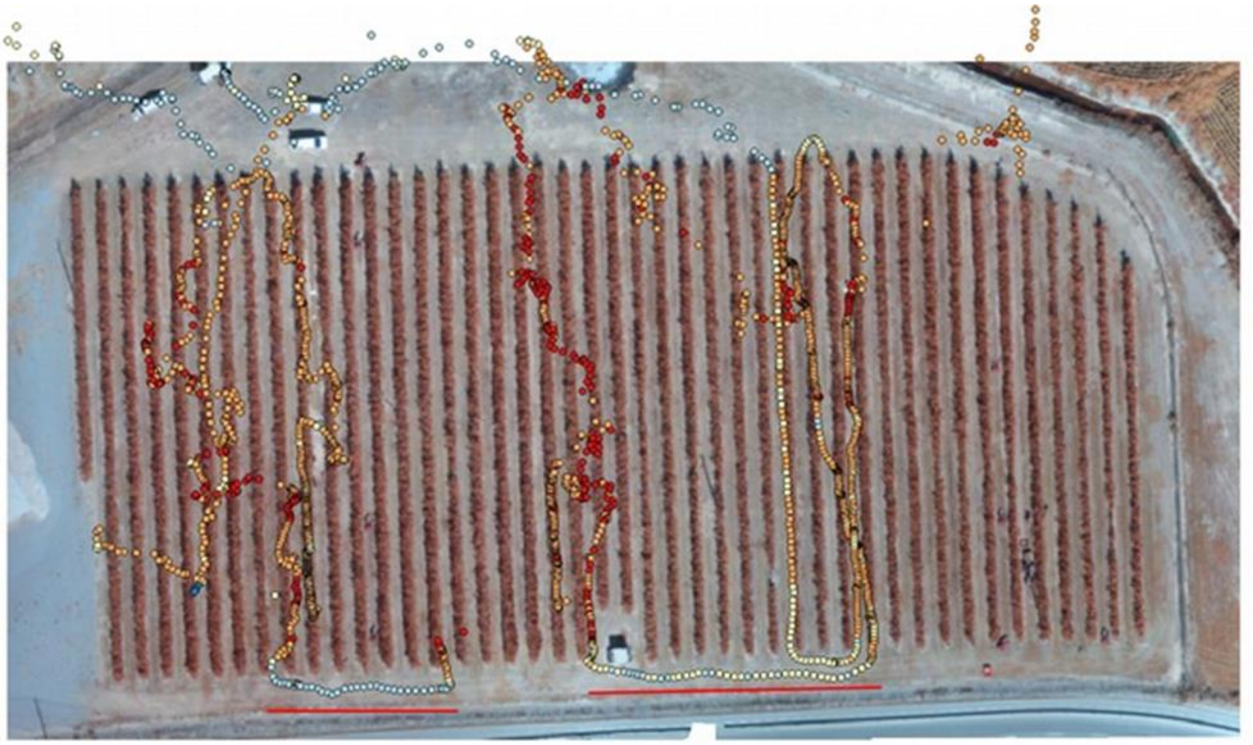
Measurements with the manual trolley:

Because the time consumed for retrieving measurements with the manual trolley is much higher than using the ATV, only a few lanes were measured.

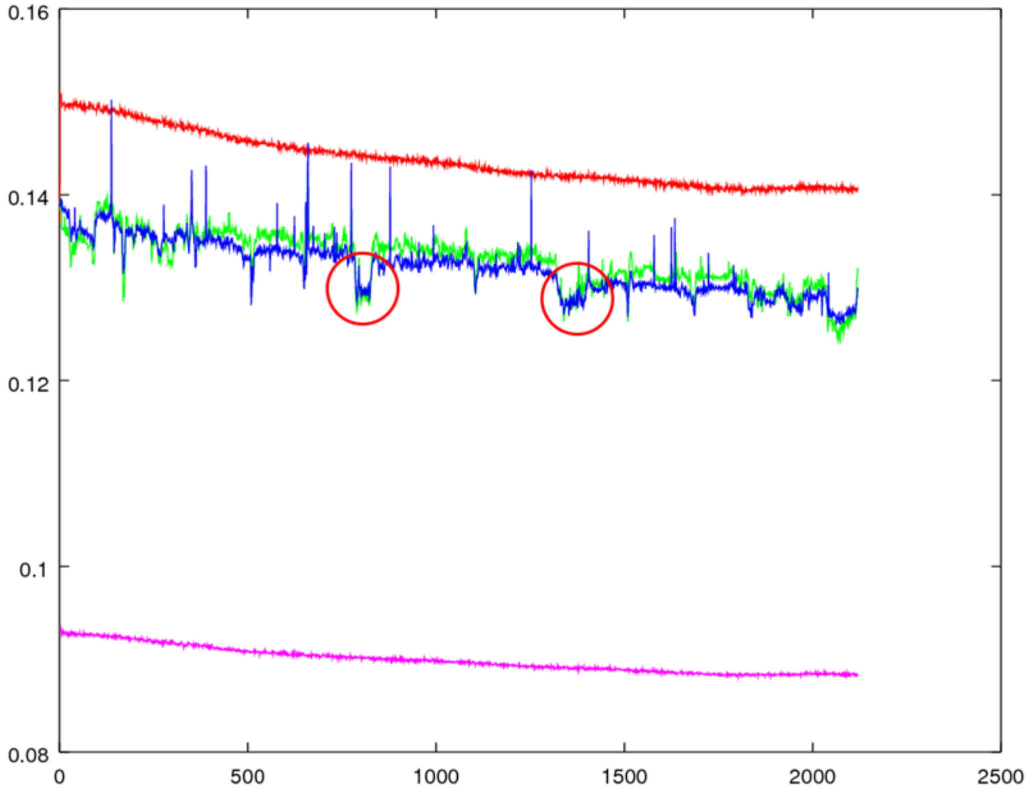
Some spatial inconsistencies in the GPS positioning were observed (a more detailed explanation is provided in the failure matrix). Data with wrong GPS measurements were finally discarded.

Except some interferences, the voltages observed and the radiometer behavior were within the expected range and well correlated with the terrain characteristics: the soils in the non-irrigated outer area (red lines in next figure, and red circles in the figure) had less emissivity than soils in the irrigated cropping area.

GPS track of radiometer measurements taken with the manual trolley:



Voltage of the measurements using the manual trolley; Channels: COLD load (purple line), HOT LOAD (red line), Vertical polarization (blue line), Horizontal polarization (green line):



Post processing results:

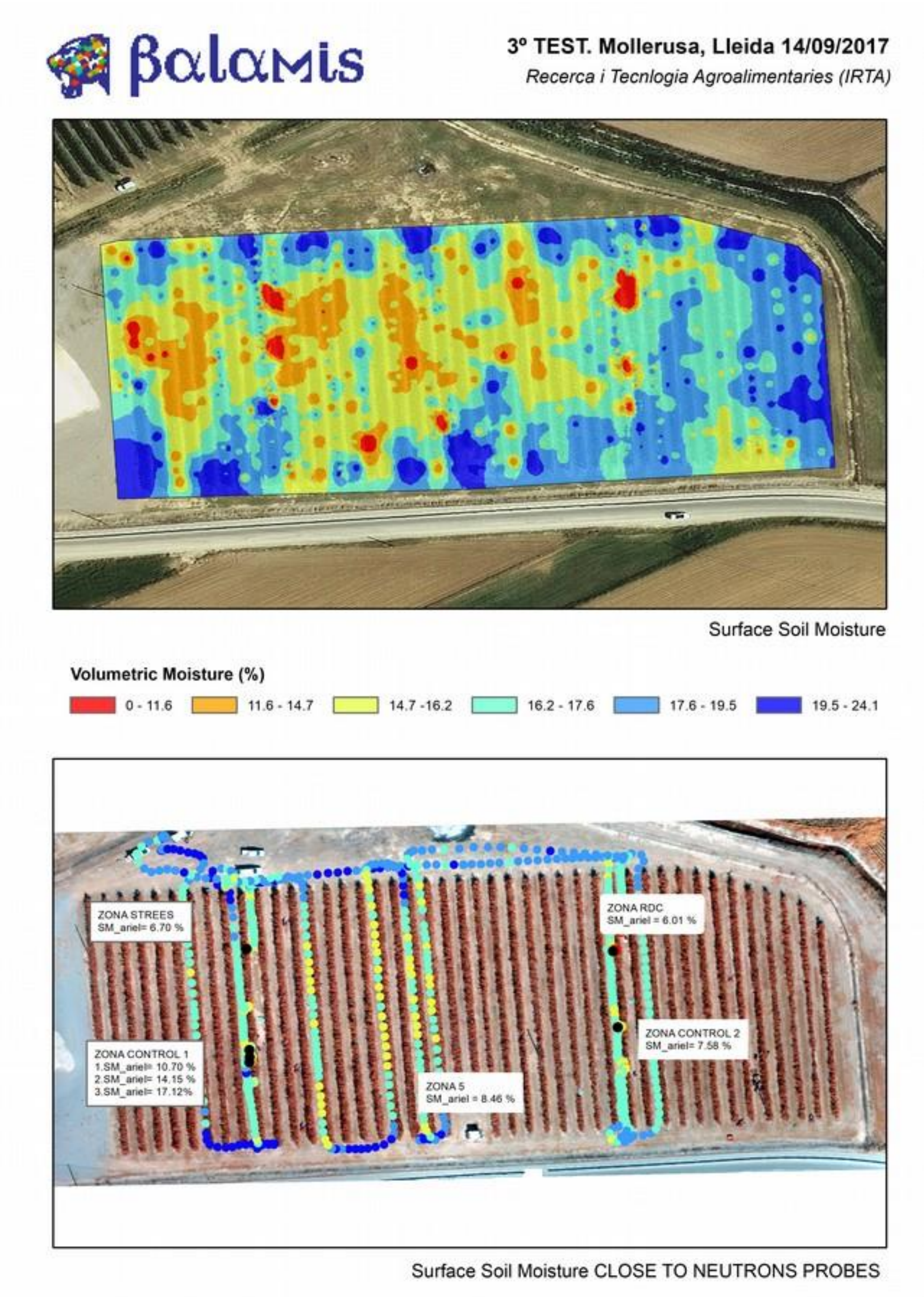
The channel used for this phase was the V one (green line in previous figure) because this had the less interferences.

At this time, a new algorithm was implemented to compute soil moisture values. The first algorithm was a simplified version which only runs with real coefficients, while the new one take into account both the real and imaginary parts of these coefficients in order to improve the accuracy of the outputs. The old algorithm yielded under some circumstances negative values of the moisture in some cases between 10% and 20% of the samples. The new one solves the negative moisture values problem (0%).

For the generation of soil moisture maps, soil moisture values at the point level were firstly retrieved from the radiometer raw data, and after spatially interpolated using an IDW (inverse distance weighing) algorithm. This soil moisture map has been computed using the data collected with the ATV during the first pass.

For the calibration process with the neutron probe point moisture measurements, radiometer data from the second track were selected because they were better and more accurately positioned towards the site control measurements.

Soil moisture values and maps from the calibration/validation campaign:



The results of the radiometer soil moisture are generally a little bit lower than the neuron probes, due to the interferences present in the V channel.

Comparison of soil moistures values retrieved at control points with neutron probes at 20 and 10 cm. depth, laboratory measurements, and ARIEL measurements:

Control Point	SM_ARIEL	SM_NP10	SM_NP20	SM_Lab	Bias (%) vs SM_NP10	Bias (%) vs SM_NP20	Bias (%) vs SM_Lab
CONTROL1_1	10.70	10.91	11.88	10.28	-1.91	-9.90	4.09
CONTROL1_2	14.15	9.84	11.24	8.60	43.86	25.84	64.53
CONTROL1_3	17.12	10.98	11.96	6.07	55.99	43.14	182.04
CONTROL2	7.58	8.10	9.37	5.72	-6.41	-19.06	32.52
ESTRES	6.70	5.90	8.75	9.65	13.50	-23.39	-30.57
RDC	6.01	7.02	9.50	5.69	-14.35	-36.70	5.62

Failure matrix of campaign 5:

Failure	Description	Mitigation actions
Interference noise	Large spikes in H channel in both ATV and trolley voltage graphs. The source of those spikes could not be identified despite several tests were performed to get it. It is thought that may be associated to noise with a field origin or produced by the GPS RTK system used in this test. The noise was also well identified in the V channel (green) during the first pass, so inaccurate points could be deleted before the post-processing phase. In the H channel and during the second pass, noise could not be deleted and hence, soil moisture estimates were of low accuracy.	Detection and removal of noise measurements during the post-processing phase.

Failure	Description	Mitigation actions
Underestimation of soil moisture estimates by ARIEL radiometer	Lower soil moisture values than neutron probes measurements (ground-truth) due to interferences (high voltage values yield lower soil moisture values)	To detect the source of noise and try to mitigate it using post-processing.
Positioning failures (incoherences) in trolley track log	The antenna in the trolley was positioned lower than the antenna in the ATV. Vegetation traits (leaves) interfered the GPS signal making difficult an accurate positioning.	A proposed solution is to increase the height of the antenna with a pole.

Campaign 6

Date: 11/09/2017 – 12/09/2017

Participants: Balamis team (Roger Jové, Esther López)

Testing objectives:

- To retrieve a large dataset of radiometer measurements
- To test the radiometer during operational conditions,
- To evaluate the overall performance of the post-processing algorithms and the reliability of soil moisture maps.

Experimental Site: Can Cartró - Área 3

Test description:

Testing tasks

- Integration of ARIEL radiometer with the UAV.
- Checking of mechanical components.
- Retrieval of field measurements.

Post processing tasks

- Quick analysis of the measurements and quick check for interferences.
- Checking radiometer data inconsistences (for TIMESTAMP and VOLTAGE DATA) f
- Analyze data from different fields.
- Retrieval of soil moisture data
- Generation of soil moisture maps
- Joining soil moisture maps and Google Earth outputs.

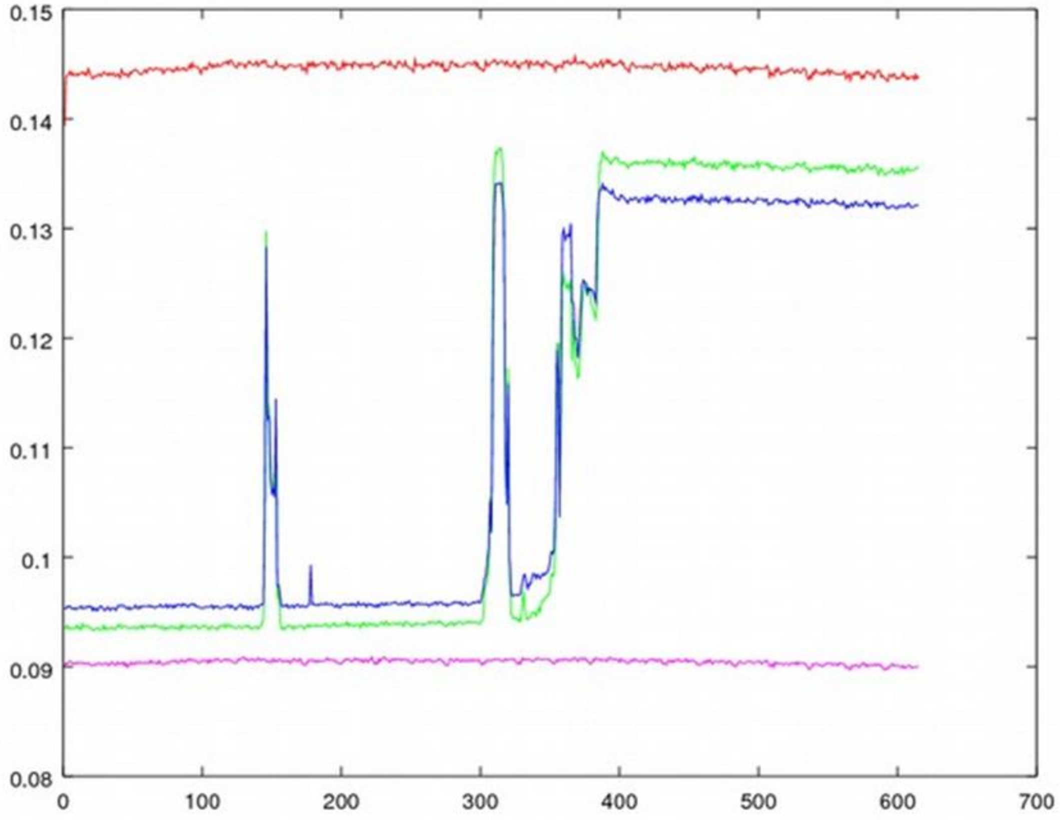
Permissions for doing these tests were accordingly granted by land owners. Before the measurements at the different farms, the radiometer was previously calibrated.

Results:

Calibration

The calibration was correctly done. Coherent and stable outputs were retrieved, low antenna values for the sky absorber (from time/sample 300 in next figure) and high values for the microwave absorber (from time/sample 400 in next figure).

Voltage vs time during the calibration phase (before starting the field measurements); COLD LOAD (pink line), HOT LOAD (red line), Vertical polarization (purple line), Horizontal polarization (green line):



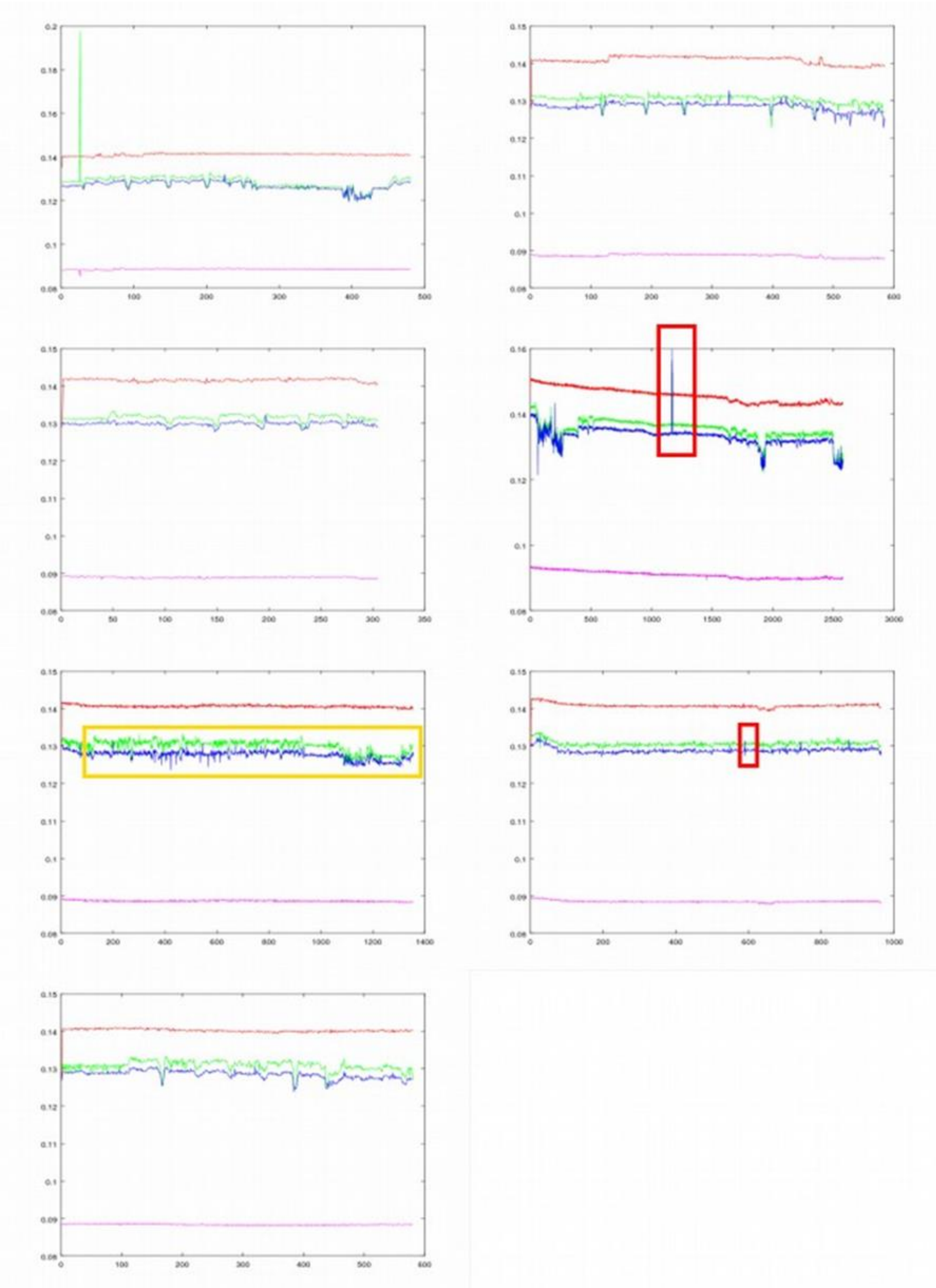
Field testing

Next figure shows the ATV tracks performed during this testing campaign.

GPS tracks of field measurements; each track in a different color:

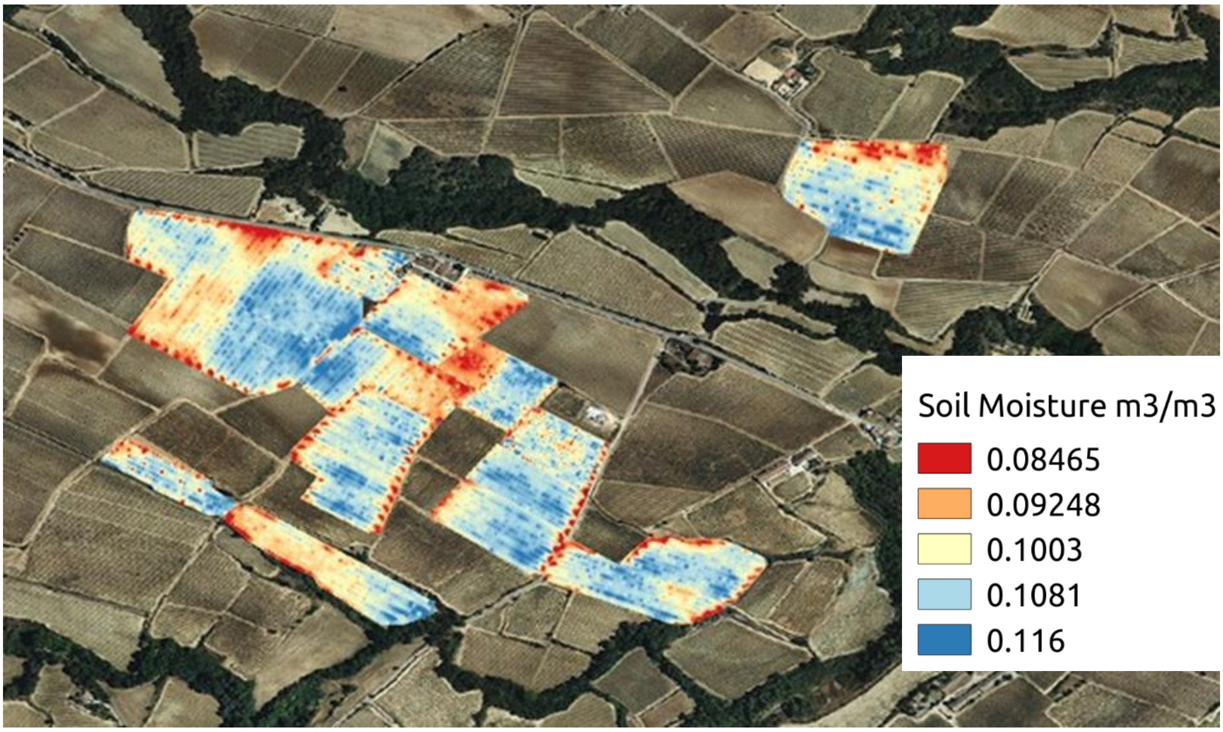
Voltage plots for some of tracks performed are shown in next figure. Overall, voltage values from the different fields were coherent. Several issues related with vibration effects (yellow box in figure) and discrete interferences (red box in figure) were observed. Vibration effects could be minimized by increasing the vibration dampening of the radiometer and increasing the electronics mechanical strength. These effects were only noticeable and relevant when ATV reached high speed values (>20 km/h).

Some random voltage vs time measurements of different tracks; Channels: COLD load (purple line), HOT LOAD (red line), Vertical polarization (blue line), Horizontal polarization (green line):



Finally, a soil moisture map for the region of interest were generated from the ARIEL point measurements and their spatial interpolation using a IDW algorithm. The soil values are averaged for all the zones from other tests in the same regions (Test 2 – Campaign 1).

Soil moisture map generated from ARIEL measurements at different vineyards:

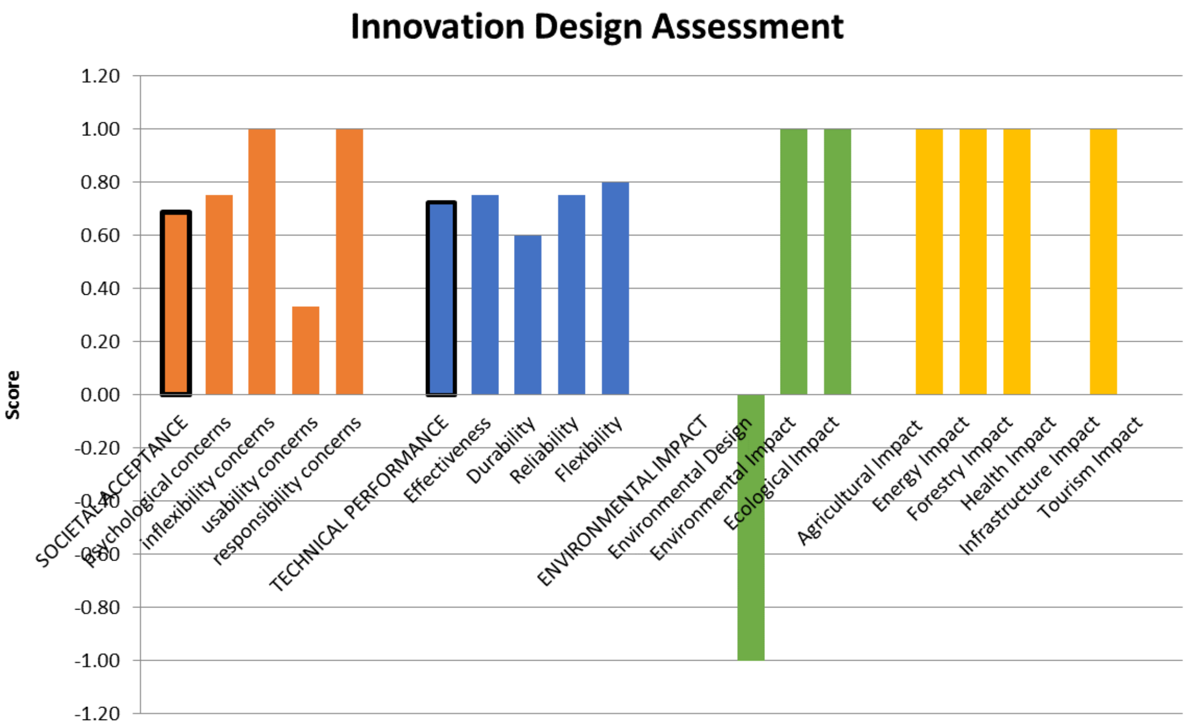


Other results:

No noticeable failures were detected except the minor ones resulting due to vibration effects and some occasional discrete interferences.

TIF Tool results

Overall assessment of ARIEL using the BRIGAID's TIF Tool:



Overall results of the TIF Tool assessment:

1	Your innovation raises	few	societal concerns overall, having scored	11	out of a possible	16	and is	close	from/to SOCIETAL READINESS.
1.1	Your innovation raises	few	psychological concerns, having scored	3	out of a possible	4	and is	close	from/to societal readiness.
1.2	Your innovation raises	few	inflexibility concerns, having scored	5	out of a possible	5	and is	close	from/to societal readiness.
1.3	Your innovation raises	many	usability concerns, having scored	2	out of a possible	6	and is	far	from/to societal readiness.
1.4	Your innovation raises	few	responsibility concerns, having scored	1	out of a possible	1	and is	close	from/to societal readiness.
2	Your innovation raises	few	technical concerns overall, having scored	13	out of a possible	18	and is	close	from/to being ready in terms of its TECHNICAL DESIGN.
2.1	Your innovation raises	few	concerns related to its technical effectiveness, having scored	3	out of a possible	4	and is	close	from/to being ready/effective in terms of its technical design.
2.2	Your innovation raises	few	concerns related to its durability, having scored	3	out of a possible	5	and is	close	from/to being ready/effective in terms of its technical design.
2.3	Your innovation raises	few	concerns related to its reliability, having scored	3	out of a possible	4	and is	close	from/to being ready/effective in terms of its technical design.
2.4	Your innovation raises	few	concerns related to its flexibility, having scored	4	out of a possible	5	and is	close	from/to being ready/effective in terms of its technical design.
3	Your innovation raises	many	environmental concerns overall, having scored	0	out of a possible	6	and is	far	from/to being ready in terms of its ENVIRONMENTAL DESIGN.
3.1	Your innovation raises	many	concerns related to its Environmental Design having scored	-3	out of a possible	3	criteria. Your innovation may have a	negative	on the environment.
3.2	Your innovation raises	many	concerns related to its Environmental Impact, having scored	1	out of a possible	1	criteria. Your innovation is may have a	positive	on the environment.
3.3	Your innovation raises	no	concerns related to its Ecological Impact, having scored	2	out of a possible	2	criteria. Your innovation is may have a	positive	on the environment.
4.1	Your innovation raises	no	concerns related to Agricultural Impacts, having scored positively on	2	out of	2	criteria Your innovation may have a	positive	impact on the Agricultural Sector.
4.2	Your innovation raises	no	concerns related to Energy Impacts, having scored positively on	1	out of	1	criteria Your innovation may have a	positive	impact on the Energy Sector.
4.3	Your innovation raises	no	concerns related to Forestry Impacts, having scored positively on	2	out of	2	criteria Your innovation may have a	positive	impact on the Forestry Sector.
4.4	Your innovation raises	ERROR	concerns related to Health Impacts, having scored positively on	0	out of	0	criteria Your innovation may have a	ERROR	impact on the Health Sector.
4.5	Your innovation raises	no	concerns related to Infrastructure Impacts, having scored positively on	3	out of	3	criteria Your innovation may have a	positive	impact on the Infrastructure Sector.
4.6	Your innovation raises	ERROR	concerns related to Tourism Impacts, having scored positively on	0	out of	0	criteria Your innovation may have a	ERROR	impact on the Tourism Sector.

The responses for each section of the TIF Tool are detailed hereafter:

Societal acceptance assessment

1	Societal acceptance assessment	
Answer the following 16 questions by writing Yes or No in the corresponding cells.		**Yes or No?**
1	Does your innovation use any materials that might be considered unfamiliar (such as nanomaterials or genetically modified mat	NO
2	Will members of the public affected by your innovation be the ones to decide whether or when to use it?	NO
3	Does your innovation involve visible infrastructure (such as physical barriers) or visible land use changes (such as woodland ren	NO
4	Could the deployment of your innovation disrupt daily activities, for example through road closures?	NO
5	Does your innovation require large amounts of capital investment?	NO
6	Does your innovation require a long lead time between users placing an order and it becoming operational?	NO
7	Does your innovation require new infrastructure or significant changes to existing infrastructure?	NO
8	Does your innovation involve releasing any materials into the environment (such as sprays or coatings)?	NO
9	Are your potential users likely to have a single mission, for example to protect ecosystems?	NO
10	Does your innovation take less time to deploy than incumbent alternatives (such as sand bags for floods or fire nozzles for wildl	NO
11	Would the use of your innovation require special training?	YES
12	Will help and support be available to users of your innovation?	YES
13	Innovations can either reinforce or change users' existing ways of working. Does your innovation reinforce existing ways of work	YES
14	Are the effects of your innovation directly publicly tangible (such as seeing flood defences working or hearing a warning alert sy	NO
15	Adaptations can either be deployed permanently or temporarily. Is your innovation deployed permanently?	NO
16	Are members of the public involved in shaping the research, development, demonstration and deployment of your innovation?	YES
Answer the following 4 questions by writing A, B or C in the corresponding cells.		**A, B or C?**
17	What would your innovation primarily protect? (A) public infrastructure, (B) private properties or (C) the environment	n/a
18	Who would pay for your innovation? (A) government authorities, (B) private companies or (C) local communities	B
19	Who would implement your innovation? (A) government authorities, (B) private companies or (C) local communities	B
20	How would compensation be made in the event of your innovation failing? Through (A) government compensation, (B) project insurance or (C) responsible parties	B

Technical design

2	Technical Design	
Answer the following questions by writing Yes or No in the corresponding cells.		**Yes or No?**
1	Does the innovation provide significant technical advantage(s) relative to a traditional/conventional measures?	YES
2	Does your innovation physically prevent a hazard from occurring?	YES
3	Does your innovation require combination with other interventions and/or activities in order to reduce risk (e.g, flood warning system in combination with a flood barrier or a fire warning system in combination with controlled burning)?	YES
4	Will the innovation require additional testing and/or substantial upgrades when considering future hazard conditions (i.e., considering climate change)?	NO
5	Is the lifetime of the innovation limited by climate change? (i.e., will climate change affect the estimated life(time) of the innovation?)	NO
6	Does the innovation require frequent inspection and maintainence to reach its intended lifetime?	YES
7	Are the materials or software needed for maintanence and/or repair easily obtained and can they be integrated by the end-user?	NO
8	Is the innovation designed to be used repetitively or continuously operated over its lifetime?	YES
9	Can the innovation be operated without repair and/or replacement of components during a hazard event?	YES
10	Does the innovation exhibit vulnerabilities during testing and/or demonstration (e.g., structural: sliding or rotation, or technological: errors)?	YES
11	Is there a critical component in the innovation's structural or technological design that could lead to catastrophic failure?	NO
12	Does your innovation rely on the delivery of services or materials (e.g., structural components, data) outside of your control to be successfully operated during a hazard event?	NO
13	Does your innovation require the execution of tasks by humans to be successfully operated during a hazard event?	N/A
14	Can the vulnerability of your innovation to human error be easily reduced through improvements in operational protocols and/or end-user training?	YES
15	Is the innovation modular (opposite: monolithic) and can it be easily installed or applied at different sites across Europe without adjustment?	YES
16	Does the innovation require additional testing and/or substantial upgrades (e.g., new components) if used at different sites across Europe?	NO
17	Will the size of the market for the innovation (in Europe) will significantly decrease (>50%) due to future hazard conditions (i.e., considering climate change)?	NO
18	Have relevant end-users been identified and contacted and has a need for this innovation observed?	NO
19	Are the advantages of the innovation derived from its multi-functionality (e.g., reduction of carbon emissions or enhanced recreational activities)?	YES

Environmental characteristics

3	Environmental Characteristics	
Answer the following questions by writing A, B, or C, in the corresponding cells.		A, B or C?
3.1	Environmental Design	
3.1.1	Does the innovation deliberately use ecosystems and their services, or mimic or preserve natural processes? (A) Yes (B) No	B
3.1.2	How does the change in footprint (area) required for implementation on-site compare to conventional measures or the present situation? (A) Increase space required (B) Decrease space required (C) No Impact on space required	C
3.1.3	How does the construction or operation of the innovation affect the quantity of greenhouse gases in the environment (e.g., as CO_2 or CH_4)? (A) Increase (B) Decrease (C) No Impact	C
3.1.4	Is the innovation made from recycled or recyclable materials? (A) Yes (B) No	B
3.1.5	Does the innovation include specific design features or components which preserve or enhance ecosystem services? (A) Yes (B) No	B
3.2	Environmental Impact	
3.2.1	How does the innovation impact the quality of surface water? (A) Improve (B) Worsen (C) No Impact	C
3.2.2	How does the innovation impact the quantity of available surface water? (A) Increase (B) Decrease (C) No Impact	C
3.2.3	How does the innovation impact the quality of ground water? (A) Improve (B) Worsen (C) No Impact	C
3.2.4	How does the innovation impact the quantity of available ground water? (A) Increase (B) Decrease (C) No Impact	C
3.2.5	How does the innovation impact the quality of the sea water? (A) Improve (B) Worsen (C) No Impact	C
3.2.6	How does the innovation impact soil quality? (A) Improve (B) Worsen (C) No Impact	C
3.2.7	How does the innovation impact air quality? (A) Improve (B) Worsen (C) No Impact	C
3.2.8	Does the implementation (or construction) of the innovation generate debris? (A) Yes (B) No	B
3.2.9	Does the implementation (or construction) of the innovation generate noise or vibration? (A) Yes (B) No	B
3.2.10	How does the innovation impact landscape quality? (A) Improve (B) Worsen (C) No Impact	C
3.3	Ecological Impact	
3.3.1	How does the innovation impact the spatial extent of protected nature area? (A) Increase (B) Decrease (C) No Impact	C
3.3.2	How does the innovation impact the quality of protected habitats? (A) Improve (B) Worsen (C) No Impact	C
3.3.3	How does the innovation impact the number protected species (e.g., birds, vegetation, fish, mammals)? (A) Increase (B) Decrease (C) No Impact	C
3.3.4	How does the innovation impact the spatial extent of non-protected nature area? (A) Increase (B) Decrease (C) No Impact	A
3.3.5	How does the innovation impact the quality of non-protected habitats? (A) Improve (B) Worsen (C) No Impact	C
3.3.6	How does the innovation impact the number non-protected species (e.g., birds, vegetation, fish, mammals)? (A) Increase (B) Decrease (C) No Impact	C

Sectoral impacts

4	Sectoral Impacts	
Answer the following questions by writing A, B or C in the corresponding cells.		A, B or C?
4.1	Agriculture	
4.1.1	How does the innovation impact the total area available for agricultural production? (A) Increase (B) Decrease (C) No Impact	C
4.1.2	How does the innovation impact agricultural production conditions (e.g., by increasing soil quality or water availability)? (A) Improve (B) Worsen (C) No Impact	A
4.1.3	How does the innovation impact the variety of agricultural products (e.g., crops, dairy, meat, fruit, fish, aquaculture) that can be produced or are available? (A) Increase (B) Decrease (C) No Impact	C
4.1.4	How does the innovation impact the total yield of one or more agricultural products? (A) Increase (B) Decrease (C) No Impact	A
4.2	Energy	
4.2.1	How does the innovation impact the energy production capacity (e.g., by generating energy or increasing energy distribution)? (A) Increase (B) Decrease (C) No Impact	C
4.2.2	How does the innovation impact the reliability of energy production (e.g. by improving cooling water conditions for energy plants)? (A) Increase (B) Decrease (C) No Impact	C
4.2.3	How does the innovation impact the efficiency of energy production? (A) Increase (B) Decrease (C) No Impact	C
4.2.4	How does the innovation impact the carbon footprint of the end-user? (A) Increase (B) Decrease (C) No Impact	B
4.3	Forestry	
4.3.1	How does the innovation impact the total area available for wood production (including timber and biomass)? (A) Increase (B) Decrease (C) No Impact	C
4.3.2	How does the innovation impact wood production conditions (e.g., by increasing forest resilience or water availability)? (A) Improve (B) Worsen (C) No Impact	A
4.3.3	How does the innovation impact the total area available for non-wood production (including cork, fruit, honey, mushrooms, pastures, game and fishing)? (A) Increase (B) Decrease (C) No Impact	C
4.3.4	How does the innovation impact non-wood production conditions (e.g., by increasing forest resilience or water availability)? (A) Improve (B) Worsen (C) No Impact	A
4.4	Health	
4.4.1	How does the innovation impact the number of fatalities in the area exposed to the hazard? (A) Increase (B) Decrease (C) No Impact	C
4.4.2	How does the innovation impact the number of people affected by the hazard in their physical health (i.e., number of people injured)? (A) Increase (B) Decrease (C) No Impact	C
4.4.3	How does the innovation impact the number of people affected by the hazard in their mental/physo-social health? (A) Increase (B) Decrease (C) No Impact	C
4.4.4	Does the innovation emit or release chemicals or products that are harmful to humans? (A) Yes (B) No	C

4.5	**Infrastructure**	
4.5.1	How does the innovation impact the quality of the built environment (I.e., residential, commercial, and industrial)? (A) Improve (B) Worsen (C) No Impact	C
4.5.2	How does the innovation impact the total area available for urban development? (A) Increase (B) Decrease (C) No Impact	C
4.5.3	How does the innovation impact the capacity of existing transportation systems (e.g., roads, railways, waterways, and airports) or create new capacities? (A) Increase (B) Decrease (C) No Impact	C
4.5.4	How does the innovation impact the reliability of existing transportation systems (e.g., roads, railways, waterways, and airports)? (A) Increase (B) Decrease (C) No Impact	A
4.5.5	How does the innovation impact the transport capacity of critical infrastructure networks (e.g., power, water, waste management)? (A) Increase (B) Decrease	A
4.5.6	How does the innovation impact the reliability of critical infrastructure networks (e.g., power, water, waste management)? (A) Increase (B) Decrease (C) No Impact	A
4.6	**Tourism**	
4.6.1	How does the innovation impact the total area available for recreational activities? (A) Increase (B) Decrease (C) No Impact	C
4.6.2	How does the innovation impact the attractiveness of the area for recreational activities? (A) Increase (B) Decrease (C) No Impact	C
4.6.3	How does the innovation impact the length of the tourist season? (A) Increase (B) Decrease (C) No Impact	C

Conclusions and upcoming activities

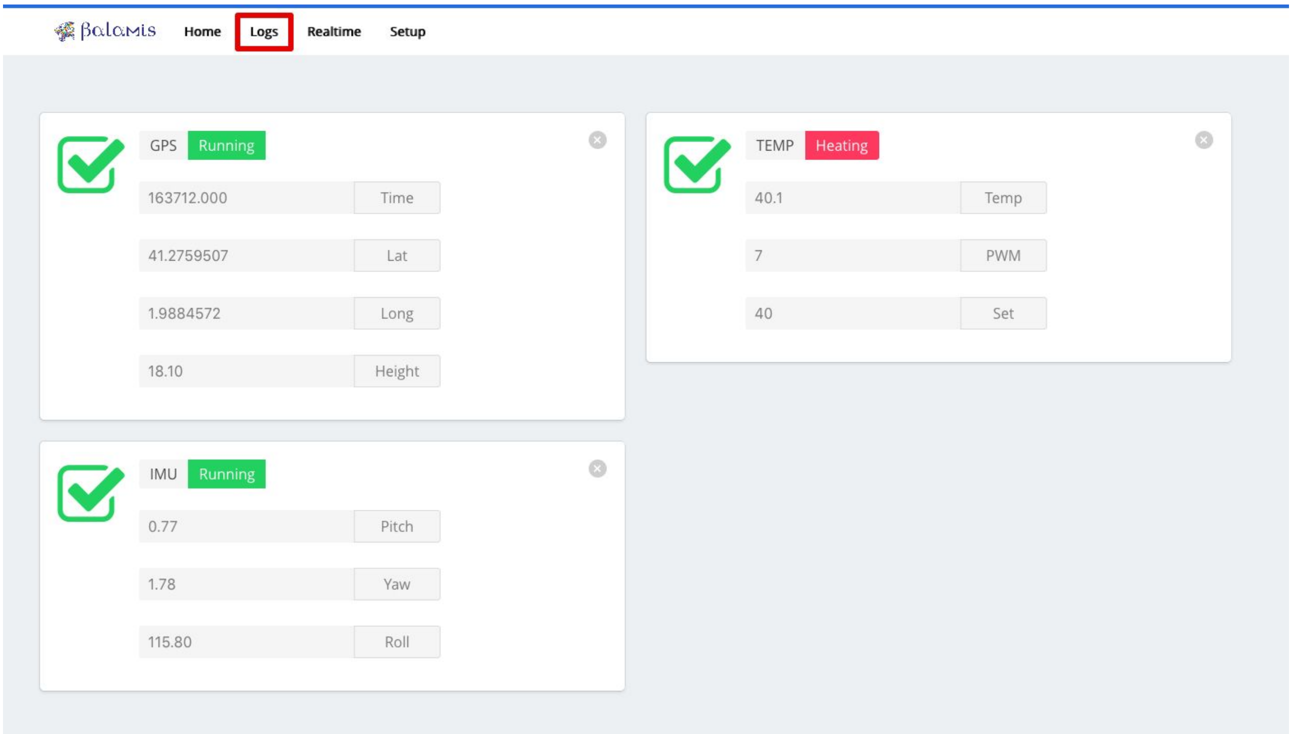
By the time of joining BRIGAID, Balamis had only a failed (non-optimal) ground prototype of ARIEL and none drone or aircraft version. The TRL of ARIEL was set at 5.

With the support of BRIGAD, Balamis has:

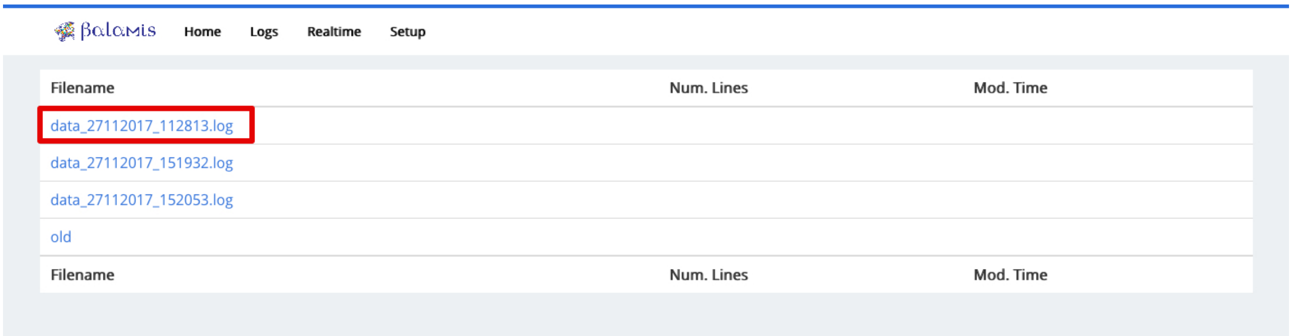
- improved the antenna of ARIEL in all its versions,
- developed a new ground, drone, and aircraft ARIEL versions,
- improved post-processing algorithms,
- tested the ground and aircraft versions systems in operational environment.
- identified strong electromagnetic interferences with drone platforms.

Although not mentioned in the presentation of the results, Balamis has additionally simplified the operation of ARIEL by writing a user guide, and developing a Graphic User Interface (GUI) which can be accessed using a web browser. These user guide and GUI were successfully tested in operational environment by the operators of ICGC on board its Cessna Caravan aircraft.

ARIEL GUI status panel:



ARIEL GUI download data stored files panel:



After the 2017 testing campaigns, ARIEL is close to reach a TRL7 for the ground and the aircraft versions. The drone version needs still technological improvements to reach the TRL aim set at the beginning of the testing phase.

TRL status at the end of the project for each version of ARIEL:

TRL 7 Criteria	Ground	Drone	Aircraft
Have all interfaces been tested individually under stressed and anomalous conditions?	System fully integrated and tested.	System mechanically integrated, but did not succeed with the electromagnetics interferences.	System fully integrated and tested.
Has technology or system been tested in a representative operational environment and shown to withstand the expected hazard loads?	System tested on multiple fields successfully.		System tested on board Cessna Caravan.
Has the reliability of the prototype been quantified and validated in a representative operational environment?	Yes, since May 2017 no failures were due to the system.		Working properly since its first test.
Are available components representative of production components (i.e., will the innovation be ultimately produced using the same materials as used in testing; is the prototype to-scale)?	Yes	No	Yes
Have vulnerabilities to human error been effectively minimized?	Yes, plug and play system. Graphic user interface developed. The user does not have to open the system for any reason.		
Has fully integrated prototype been demonstrated in actual or simulated operational environment?	System tested on multiple fields successfully.	No	System tested on board Cessna Caravan.

Upcoming activities:

During the upcoming months, Balamis will:

- test the new ground radiometer in vineyards,
- merge data from optical sensors with ARIEL radiometer in order to validate the data fusion algorithms.
- prepare a communication and marketing campaign to properly target potential customers,
- prepare the company for presentation in front of private investors.

With the upcoming testing activities, we expect to completely reach the TRL7 stage.

5. Innovation: HYDROVENTIV - The Hydroactive Smart Roof System

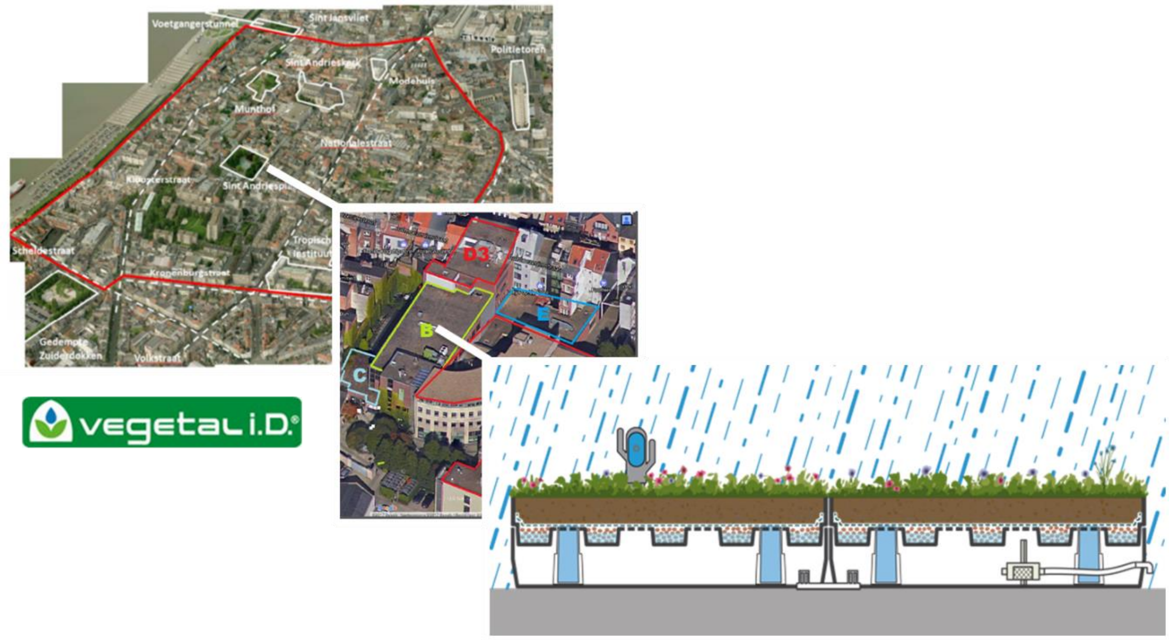
Innovator: Le Prieuré / vegetal i.D. (external innovator)

Contributing authors: Jean-Christophe Grimard (Le Prieuré / vegetal i.D.)

Innovation description

The description of HYDROVENTIV below is also available from the Climate Innovation Window, http://climateinnovationwindow.eu/innovations/hydroventiv

Name
Hydroactive Smart Roof System : HYDROVENTIV
Short description
The Hydroactive Smart Roof System (HYDROVENTIV) innovation consists of modular trays device for retaining and dissipating rain water on a roof, with outflow control delayed, piloted by a remote system control for optimizing water resources. The system aims to both reduce the urban flood hazard (probability that sewer surcharge will happen) due to the more efficient and regulated rain water storage on the roof. The second benefit is that the vegetation on the roof can survive much longer during long dry periods (due to the longer time that water will be stored on the roof). This has a clear benefit on the biodiversity / green in the city. The third benefit is the thermal cooling effect the water storage and vegetated roof has on the surroundings. Of course, the effect is minor for a single roof but the effect is expected to be significant and potentially important when the system is installed on many roofs in a city.
Sketch/Photograph of the Innovation



Which hazard(s) is the innovation designed to mitigate?
Heavy precipitation / pluvial floods: rainfall events that result in 1) (urban) floods due to exceedance of: drainage capacity, and 2) flash floods, defined as rapid flooding of low-lying areas, generally within a few hours after heavy rainfall events such as thunderstorms. Other: - StormWater Management and Monitoring - Reuse rainwater for irrigation - Cool down the building and the surrounding area - Promote urban Biodiversity
How does the innovation work?
Overlaid plastic trays assembled on roof capture and store rainfalls, regulate the outflow slowly to sewer and dissipate water by evapotranspiration of plants through capillarity wicks, sucked from the reservoir tray.
Added value / main differentiating element from conventional approach
There are 4-5 European and American competitors but with less functionalities on the product.
Critical success factors / Limitations
Need to prove the benefits and the interests and enlarge the HYDROVENTIV local visibility Need to facilitate the business contacts and the entrance on the local market

Technology Readiness Level (TRL)

The basic system has just been validated on experimental sites in France after 1 year of real-time measurements (hydric characterisation) and analysis program. Some real projects has been installed and are still monitored in view of the integrated control system. Further extensions are being investigated by the BRIGAID project such as real-time regulations taken rainfall forecasts into account.

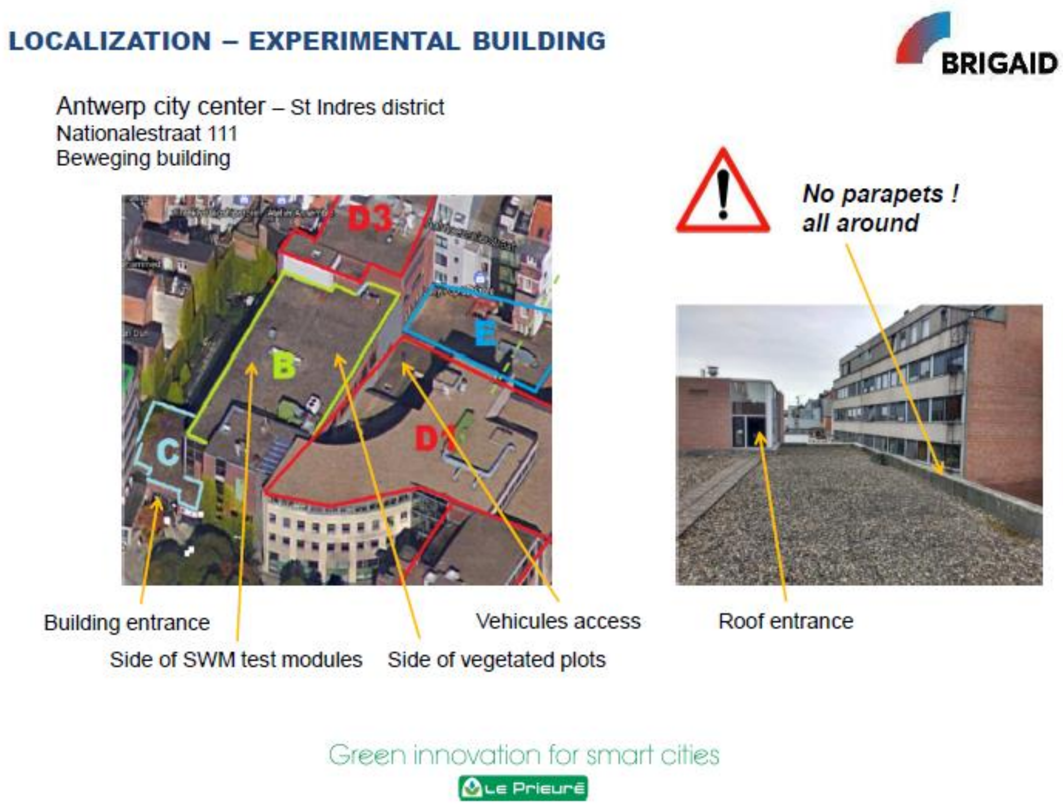
Test plan

Rational

In real conditions, to test on a roof where we can compare hydric performances of instrumented green roof solutions including HYDROVENTIV during at least 1 year (up to 2 years) under local climate conditions.

Facility

The test site is the roof of the Beweging.net building at Nationalestraat 111, Antwerp:



Equipment

The test roof will be used in 2 parts:

- One dedicated to the testing of 3 or 4 single modules with instrumented Aluminum Modules.
- The other dedicated to demonstration, examples of 2 real hydroactive plots where we will show to be able to manage both stormwater and preserve wide choice of plants.

This requires the following equipment: Material to install the instrumented aluminum modules and the hydroactive plots Remote control devices : • Weather station with remote control (for input control) • Flow meters (for output control) installed at the outlet of each system • Water level ultrasonic autonomous sensor • Temperature sensors under and below the systems
Protocol
Automatic and continuous monitoring will be done to evaluate the rainfall (input) and the water release (output) of the systems to characterize instantaneous and cumulative runoff behavior. For the hydroactive vegetated plots, 2 plots of an area of about 30 m² will be installed onsite surrounded by a wooden deck allowing access and larger surface of rain collection. The vegetation choice will be based on biodiversity and landscape design (wide choice of plants). The vegetal behaviour of plants will be inspected visually. Comparison of the water performance with conventional systems will be made. The optimal performance of the water resource will be evaluated in terms of the benefits for the vegetation and the plants preservation. Also the thermal benefits will be studied (reduction of heat stress problem, as a complementary benefit to the stormwater retention and plant preservation).

The installation is planned for this summer such that the testing can start shortly after summer

(September 2017) during a period of at least 1 year, probably 2 full years. The decision on the prolongation will be made in consultation with the BRIGAID team (WP4 coordinator) after year 1, and will depend on the test results after year 1.
Expected Results
The expected results from the tests are: • Results on the comparison of the water performance with conventional systems. • Results on the evaluation of the optimal performance of the water resource in terms of the benefits for the vegetation and the plants preservation • Results on the thermal benefits (reduction of heat stress problem, as a complementary benefit to the stormwater retention and plant preservation)

Budget request

Please specify the *eligible costs* for which budget is requested from BRIGAID.
Budget allocated for : • Testing equipment (weather station, flow meters, water level ultrasonic autonomous sensor, temperature sensors) • Remote control devices (datalogger, monitoring software) • Experimental structure/design, green roof and hydroactive systems installed in separate compartments; parapets around the roof for safety reasons This involves the following costs: • Installation and maintenance costs (plants + systems + instrumentation) : around 34 k€ • Project management cost (design, following, analyzing, reporting…) : around 26 k€
If applicable, please describe any resources that have already been acquired or additional external budget that is available (or being requested from other sources) for testing.
-
Any other comments:
Note that KU Leuven / Sumaqua will conduct the upscaling from the test results on one single roof to many roofs and evaluate the cumulative effect at the scale of a larger city area at Antwerp. This upscaling will be done based on Sumaqua's SCAN tool.

Testing results

KU Leuven & City of Antwerp announced a call to citizens of the living lab area of Sint-Andries in the city of Antwerp to make their roof available for the BRIGAID testing. At the end, 11 local people/organisations were interested to have the green roof installed and tested on their roof. On 24 April, these buildings were visited, the feasibility was checked in terms of roof area, accessibility, weight it can handle, and interest of the location for reasons of promoting the innovation. Two best options were selected. One of these was under negotiation, as there was an interesting plan to have the green roof combined with a sports & playing garden from the nearby building. Finally, the decision was made to have the system installed on the roof of Beweging.net. A concrete installation plan has been prepared, negotiated and revised.

The materials were put on the roof with a crane on November 3; the impact on the traffic and parking places has been discussed and agreed upon with the city authorities. The actual installation of the roof was done on 6-10 November. Because this was the same week as the BRIGAID Venice workshop, we planned to have a “lifestream” connection during the Venice workshop with the site at Antwerp. The WEBEX connection was tested on beforehand and a video prepared as backup, which was finally shown due to the unstable connection. In the video, the innovator showed the system being installed and explained the tests that will be conducted; followed by persons from the city of Antwerp and the building owner explaining why such innovation is so important for the city.

Material to be transported to Antwerp:

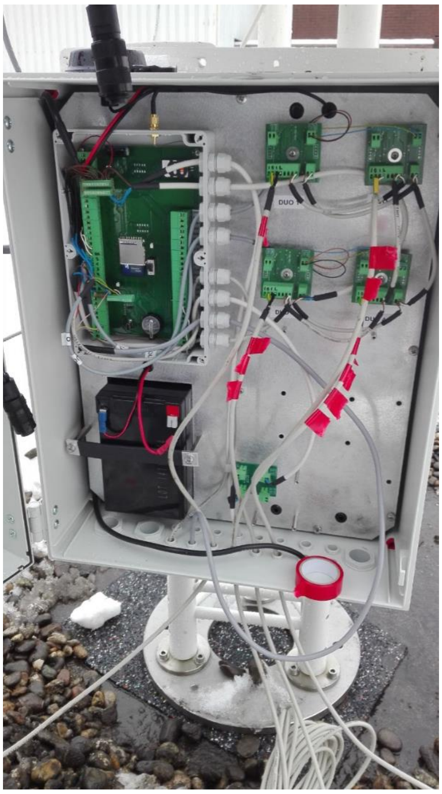

Photos of the installation at Antwerp:

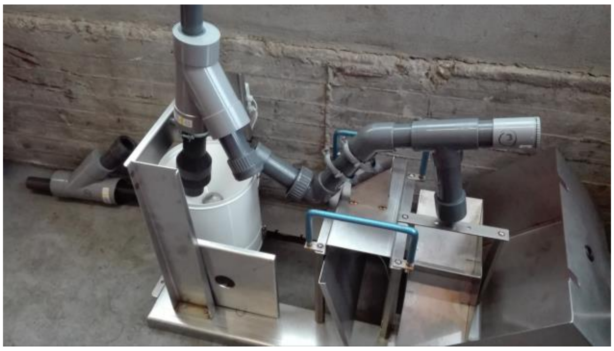




Additional protection elements (parapets) had to be installed around the roof for safety reasons:

Installation of the measuring equipment:





There are currently five devices that collect data centrally: the weather station and the four flow measurement devices (and their datalogger). Each flow measurement device makes registrations per minute. The flow measurement device is a dual tipping-bucket installation, with one bucket of 1 liter, and a smaller bucket of 10 ml. This unique approach enables the registration of both high and low intensity rainfall events. Note that we do not have access to the tipping count of each bucket. Instead, the station automatically calculates the combination of the 10 ml and 1 liter buckets.

The weather station is measuring:

- Air temperature (°C, 1 measure / min)
- Relative air humidity (%, 1 measure / min)
- Wind speed (m/min, 1 measure / min)
- Rain (mm/min, resolution 0.2mm, 1 measure / min)

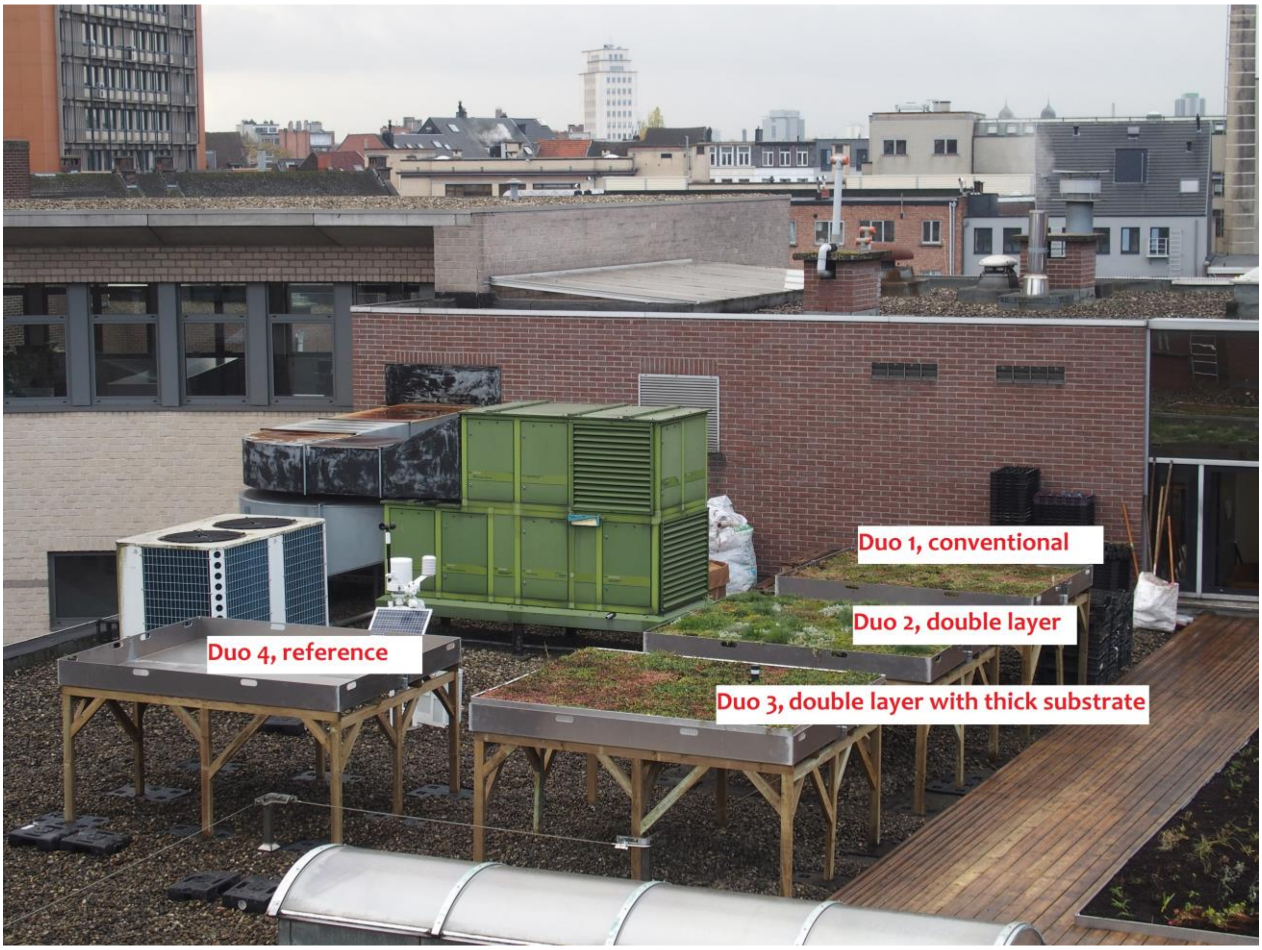
Data is sent via GPRS on a distant server every hour. Data is also stored locally on an industrial grade SD card.

Note that the measuring span is much longer than the one on the weather station : we've experienced on our previous sites that having a short measuring frequency does not significantly increase data precision (water processes are slow enough in the trays), and leads to more maintenance needs on the sensors (battery consumption + components such as memory unit tends to be less resistant if we are that demanding).

Unfortunately, there were some initial problems to trigger the GPRS forwarding for both systems (station + flowmeters and US sensors). This delayed the start of the measurements.

Promotion photo showing the green roof together with the designed weather station:

Final configuration of the test roof in 2 parts: one dedicated to the testing of 4 single modules with instrumented aluminum modules; the other dedicated to demonstration, examples of 2 real hydroactive plots where we will show to be able to manage both stormwater and preserve wide choice of plants:



As for the modules, these are composed as follows:
- Module 1 : Conventional,

- Module 2 : HYDROVENTIV 1 (Trays) double layers
- Module 3 : HYDROVENTIV 2 (Plate) double layers with thick substrate

Videos about the installation can be found on:

https://www.youtube.com/watch?v=3fNAMMGQIUw&feature=youtu.be

https://www.youtube.com/watch?v=NWZSk0qawTE

See also the following promotion videos and press items:

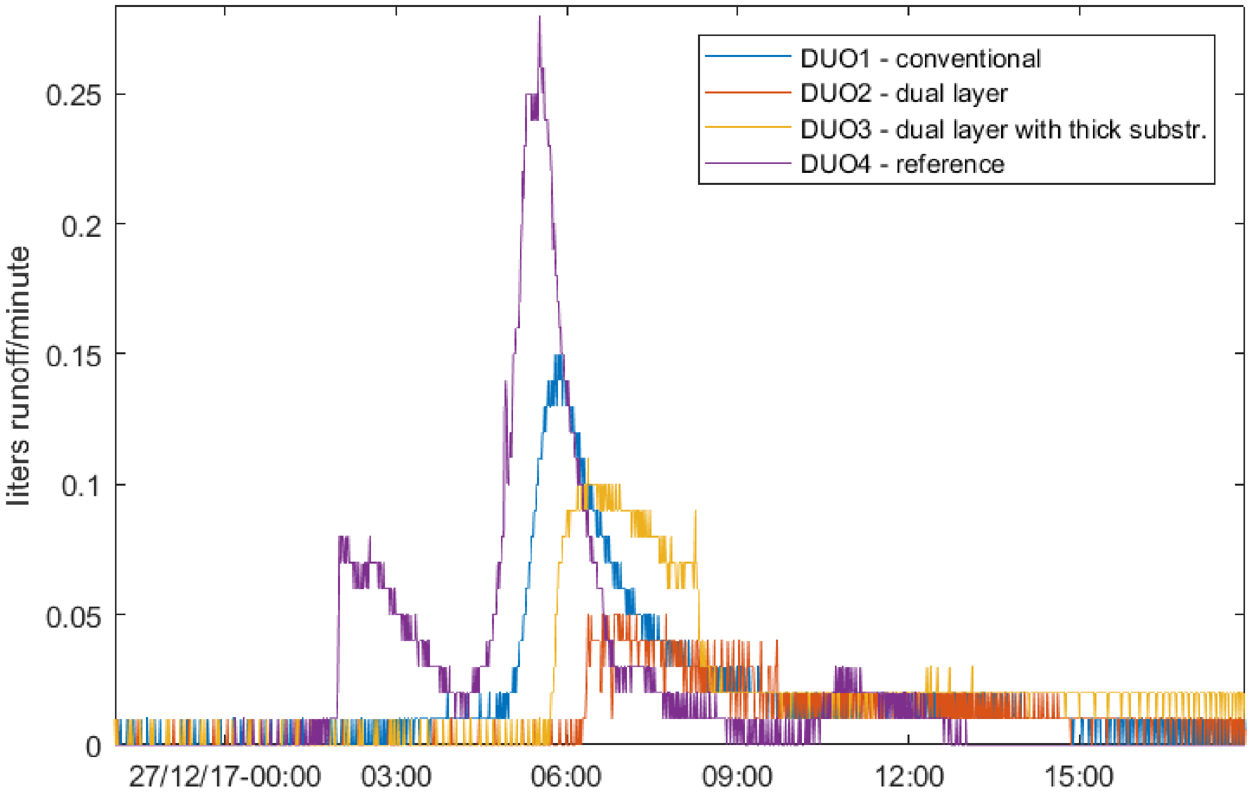
VRT Flanders' television News: https://www.vrt.be/vrtnws/nl/2017/11/09/maak-kennis-met-het-intelligente----groendak/

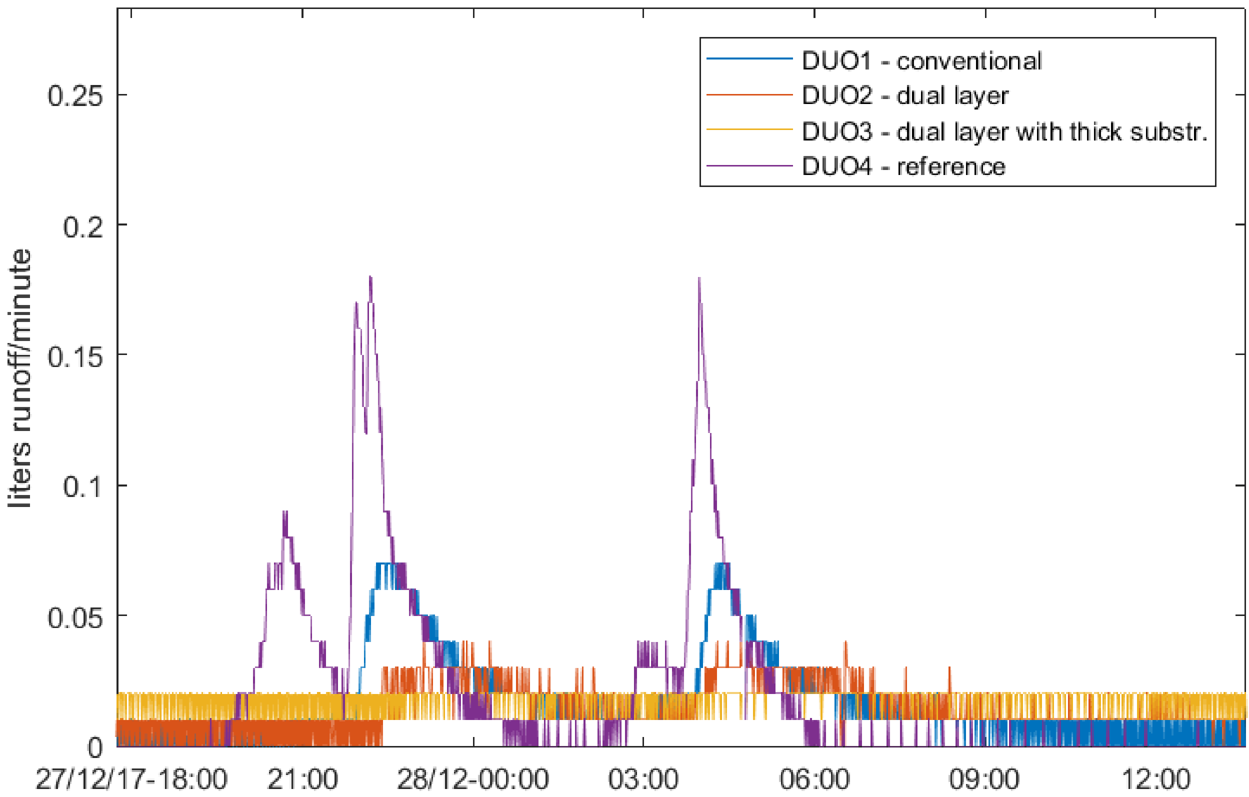
Regional TV of Antwerp: https://atv.be/nieuws/video-eerste-intelligente-groendak-van-het-land-ligt-in-antwerpen-51526?utm_content=buffer5c259&utm_medium=social&utm_source=twitter.com&utm_campaign=buffer

Nice infographic by VRT news: https://www.vrt.be/vrtnws/nl/2017/11/09/wat-is-een-slim-groendak-/

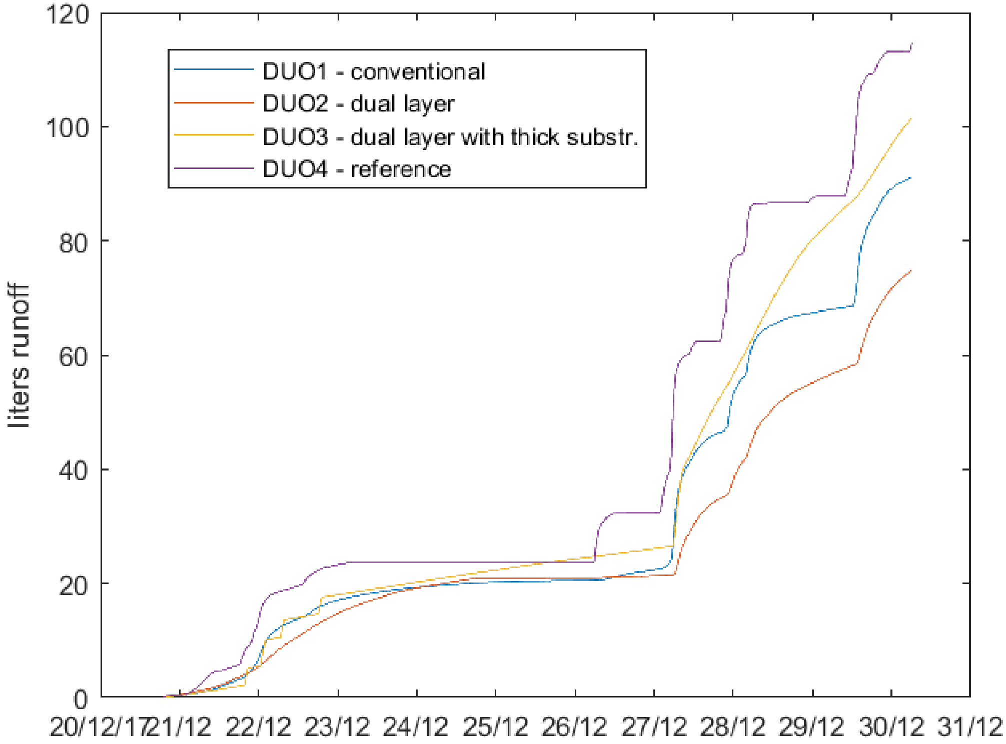
Testing results so far:

The figures below show some of the first measurement results. Here, we can clearly see that the reference installation (i.e. without green roof) yields, as expected, the highest runoff rates. The reference installation if followed by the conventional green roof. The runoff of such conventional green roof (i.e. a single layer installation, thus without storage tray) is faster than the HYDROVENTIV green roofs. One figure below shows a faster runoff from DUO2 (i.e. dual layer) compared to DUO3 (i.e. dual layer with thicker substrate), while another measurement period shows this vice versa. This will be examined on site, as it is expected that DUO3 would yield a more delayed runoff compared to DUO2.





The figure below shows the cumulative runoff during the last 10 days of 2018. Firstly, one can see that all measurements follow the same trend, which is a first indication that the measurement devices function correctly/realistically. Secondly, the reference installation (DUO4) shows the highest and fastest cumulative runoff as expected. However, the dual layer with thick substrate (DUO3) seems to yield a slightly higher runoff than both the conventional green roof (DUO1) and the regular dual layer HYDROVENTIV (DUO2). This is caused by an apparently constant (although very low) flow from DUO3 (see also the figure above). This leads to a more or less constantly rising cumulative runoff volume in wet periods (see the figure below). These dynamics will also be examined closer on site.



The next steps include more detailed analyses on much longer time spans. Also, the actual evapotranspiration will be estimated and linked to temperature. At this moment, evapotranspiration is negligible (the months December 2017 and January 2018 are both amongst the months with the fewest hours of sunshine in the past 50 years).

Through the experimental set up, we will be able to gain unique insights into the (long term) functioning of the HYDROVENTIV green roofs and the effect of adding a thicker substrate layer. This will allow us to adjust and improve the design of the HYDROVENTIV further. In addition, we will gain knowledge about the types of vegetation that flourish on the green roof, and might even originate spontaneously. The analyses will also result in a simplified model that captures the most important dynamics of the green roof (water retention capacity, evaporation, throughflow vs. storage relationship, etc.). These results will then be upscaled through the innovation “SCAN” (also part of the BRIGAID test cycle) by KU Leuven/Sumaqua to the level of the city of Antwerp. Such analysis will quantify the impact of widespread use of these green roofs on flood probabilities and risks in Antwerp.

6. Tubebarrier

Innovator: Tubebarrier (external innovator)

Contributing authors: Robert Alt (Tuberbarrier), Michiel Linsen (TU Delft)

Innovation description

The description of Tubebarrier below is also available from the Climate Innovation Window, http://climateinnovationwindow.eu/innovations/tubebarrier

Name
Tubebarrier
Short description
The Tubebarrier (TB) is a temporary flood defense; quick and easy to deploy to prevent flooding of water in urban and rural environments. As well in case of industrial leakage/seepage or temporary water storage.
Sketch/Photograph of the Innovation
 *Figure 1: Demonstration TB in Flood Proof Holland (Delft, The Netherlands)*
Which hazard(s) is the innovation designed to mitigate?
Temporary flooding: - Fluvial floods: resulting from discharges that exceed flood protection levels; the high-river discharges are caused by heavy precipitation in the river basin. - Heavy local precipitation (rainfall events): results in 1) (urban) floods due to exceedance of drainage capacity, and 2) flash floods, defined as rapid flooding of low-lying areas, generally within a few hours after heavy rainfall events such as thunderstorms.
How does the innovation work?
At times of (anticipated) floods of vulnerable terrains the TB can be installed to temporarily retain water levels

to prevent flooding of the area behind it. The TB prevent flood by using the water itself as a barrier, due to an ingenious construction. Overall, it is used in areas where a permanent flood barrier is not preferred due to, for example, public resistance against barriers that block the view of the river or coast. The relative easy storage and handling makes it possible to install hundreds of meters by just two persons. The maximum design capacity height is currently 70 cm. The TB is capable for overflow (not turning over once the water reaches a level higher than its capacity), which increases the safeguarding properties. The TB is stored like an accordion (compact) and installed quick with a short installation guideline. The barrier is fixed into the ground by a skirt with ground plates or anchors (depends on the surface), and operates independent from electricity. After usage, the TB can be folded back together in the box and easily be transported to a storage facility for reusing.
Added value / main differentiating element from conventional approach(es)
Quickly to deploy (100 m/hr with 4 people) and to remove. Cheap, efficient and secure. Alternatives are slower, more difficult to organize during times of floods and less flexible for different surface conditions.
Critical success factors / Limitations
Success factors: - Quick to place; installation doesn't need much people and equipment. - Relatively cheap; for installation of a permanent flood defense is more complex. - Reusable; can be used more than once. - Multi-use on different locations; one TB can be used at multiple locations. Limitations: - Reality conditions differs always; no location is more or less the same. - Transportation possibilities (available time); sometimes, time pressure makes transportation difficult.

Desk study

Technical description		
Which of the following characteristics does the innovation have?	☐	structural/physical components that are engineered and built at a fixed location
	☐	software or IT-product/components to process or present information
	☐	ecosystem/nature-based aspects (inspired and supported by nature)
	☑	**mobile (deployable) object/components that require human action**
	☐	informational and education aspects to increase knowledge and awareness
	☐	encourages changes in human behavior or insist on immediate action
	☐	provides economic and financial incentives
	☐	methodology to identify and quantify risks and/or evaluate adaptation strategies
	☐	changes in laws, regulations and government policy to reduce risk
Technical specs of the innovation and its functionality. Provide a reference to documents if available.	The TB is a modular system based on linked segements: • One segment: 10 meter wide, 70 cm high and 2 meter depth. • Is made from PVC Cloth 670 grams and aluminium bows. • Segements can connected with waterproof zippers and protective flaps with Velcro. • Universal anchors made from aluminium (for different types of underground). • Storing and transported in a box of 100 kg (100 cm x 120 cm x 120 cm) • Installation of 100 meter/hour, with 4 people.	

Figure 2: Picture of one segment

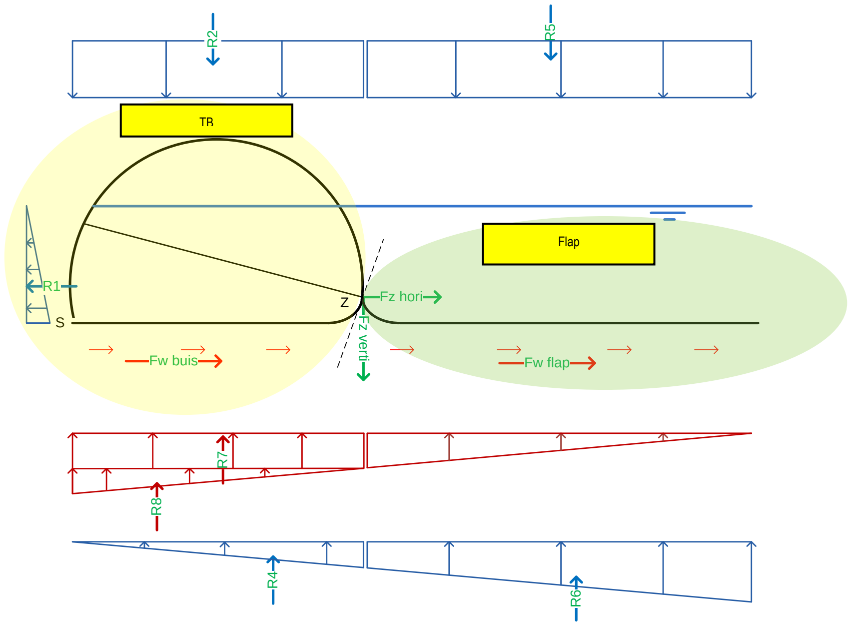
Figure 3: Zipper

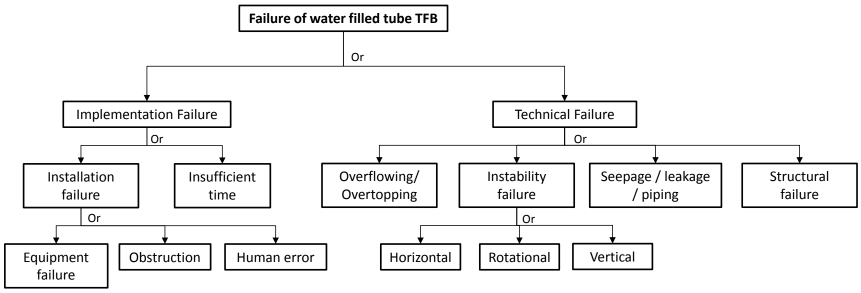
Figure 4: Anchor

Figure 5: Storage and transport box

Qualitative assessment of technical KPIs		
Reusability		
Nature of the innovation	☐	permanent
	☑	**semi-permanent**, fastening material (for installation) already available in urban environments

	☑	**temporary,** with a operation protocol: guideline and/or instruction.
Percent of the innovation needed to be repaired after each operation	0 % (no reparation needed after usage). No damage would occur under design conditions. In those cases the TB can reused.	
Expected lifetime of structural and/or material components	If the TB is used on a daily basis, under heavy circumstances the lifetime will be shorter, as well it is depending on storage and maintenance). For individual materials the lifetimes are: • PVC segments: At least 15 years. • Anchors: Around 25 years. • Zippers: Around 15 years.	
Inspection and maintenance requirements to maximize lifetime	Requirements: • Yearly visual inspection on damage and checkpoints of the TB itself. • After usage a check on leakage/seepage and damage. • Additional operation and maintenance documents: becoming available.	
Storage requirements when the innovation is not in use	One segment of 10 meter is stored in a plastic box: 100 cm x120 cm x120 cm, with a weight of 100 kg.	
Technical performance	How will the innovation reduce the risk of [hazard]?	
Decrease probability of occurrence	☐	reduction in load(ing)
	☑	**others: (temporary) increase of flood protection level**
Decrease exposure	☐	reduction in the area affected
	☑	**other(s): not applicable**
Decrease vulnerability	☐	increase in lead time
	☐	increase in adaptive capacity
	☐	increase in knowledge and/or awareness
	☐	changes in human behavior
	☑	**other(s): not applicable**
Intended (quantitative) level of risk reduction	☐	reduce water level by ____ (units)
	☐	reduce flow velocities by ____ (units)
	☐	increase lead time by ____ (units)
	☐	increase water quality by ____ (units)
	☐	decrease water evaporation by ____ (units)
	☐	decrease temperature by ____ (units)
	☑	**other(s): water levels up to 70 cm are blocked. This means a reduction in flood probability.**
Reliability		

Draw a diagram showing the operation of the innovation and the design loads acting on the innovation	 These design loads are used for one segment: $q_{water} = \rho \times g \times h = 8829\ N/m$ $R1 = \frac{1}{2} \times \rho \times g \times h^2 = 3973\ N$ $R2 = q_{water} \times b = 7504.6\ N$ $R3 = R2$ $M_s = \frac{1}{3} h \times R1 - \frac{1}{2} b \times R2 - b \times F_{z,vertical}$ $= 1191.9 - 0.85 \times F_{z,vertical}$ $F_{z,vertical} = 1402.2\ N$ $F_{w,TB} = f \times R2 = 1801.1\ N$ $F_{Z,horizontal} = R1 - F_{w,TB} = 2171.9\ N$ $R4 = b_{flap} \times q_{water} = 10594.8\ N$ $F_{w,flap} = R4 \times f = 2542.75$ $F_{resistant} = 0{,}85 \times F_{w,flap} + F_{w,anchor} = 2259.3\ N$
Fault tree	The fault tree is based on one flood event.

		
Technical failure modes	Height:	
	☑	**overtopping/overflowing**: The TB is designed to block 70 cm of water.
	Instability:	
	☑	**vertical:** The vertical waterload on the TB is counteracted by the ground pressure and water pressure below the TB. Beside of that, the internal reinforcement construction should prevent this.
	☑	**horizontal**: The anchors should prevent horizontal displacement (sliding). Three types of anchors are available for different surfaces. During the tests a new designed anchor will be used and should prevent for sliding.
	☑	**rotational**: This can occur due to air bubble formation under the front flap causing the front flap to be raised. Special drainagepipes in the TB should prevent this.
	☑	**seepage/leakage/piping**: Water may run underneath the TB. Drainagepipes (at every 70 cm) should control this process.
	Structural failure:	
	☑	**debris impacts**: Debris may cause damage such as cuts in the PVC.
	☑	**components fail**: Zippers connecting the segments are relatively new, and can damage.
	☑	**other(s):** Over time, oldness of the material can cause failure.
Implementation failure modes	Installation:	
	☑	**equipment missing/malfunction**: Not the correct installation material for the surface is used.
	☑	**obstruction**: Like all temporary flood barriers the location has to be cleared (e.g., remove parked cars). Installation requires enough space for a small car/van that brings the transport box. Total width needed is around 3 meters.
	☑	**human error**: • Groundplates are not correctly installed. • Units are not correctly connected to each other.
	Others:	
	☑	**insufficient time:** It is estimated that 4 people can install 100 metres in one hour. Transportation time depends also on distance between storage and emergency location.
	☐	other(s):
Ranking of most important failure modes	4. **Piping:** This occurs when the waterload on top of the flap is insufficient. This failure mechanism can be overcome with ground anchors and drainagepipes. The TB is designed with three types of ground anchors for different surfaces. A new universal ground anchor has been designed. 5. **Structural failure:** Debris impacts can cause a hole in the PVC. 6. **Human errors:** Installation of multiple segments by uninstructed people.	
Tests performed in the past		

Describe any tests that have been performed on the prototype or on its individual components	Until now, the TB did several experiments, for further development of the product. Also some Bachelor students of the Delft University of Technology have done some (theoretical) desk research. Only qualitative results of the field experiments are noted. The following tests have been carried out so far: 1. Overflowing of two days. **Result:** no damage on the TB occured. *(October 2013, Flood Proof Holland, Delft, the Netherlands).*  *Figure 6: Overflowing* 2. Water level maintained at a level of approximately 40 cm for 30 minutes, in an unprepared grassland. **Result:** no significant leakage. *(November 2016, Buren, the Netherlands).*  *Figure 7: Field-test in rural environment* 3. Installation of the TB under time pressure. Heavy precipitation and temperatures below 0^0C. The TB has placed in a 90-meter section on one piece (see illustration) and a number of sections to close off passageways. **Result:** Four people installed 90 meter in 1 hour correctly. Finally, no flood occured. *(Januari 2015, Hull, United Kingdom).*

	 *Figure 8: Installation TB in the United Kingdom* 4. A field test for debris impact and overtopping. After 2 hours of testing it appeared that floating objects such as a tree trunk and pallet had no impact on the TB. The overtopping gave no indication of failure. Obstacles were also built under the Barrier where the TB had to be laid over. **Result:** no damage of the TB. *(September 2016, Flood Proof Holland, the Netherlands).*  *Figure 9: Testing of failure mechanisms* 5. Installation test with employees of Water board Delfand. Beforehand, only a short instruction was given. **Result:** Within 15 minutes, one segment of 10 meter was installed correctly. *(June 2016, Flood Proof Holland, Delft, the Netherlands).*  *Figure 10: installation with employees of Water board Delfland* 6. Student installation of the TB. A group of 6 students of UNESCO-IHE installed after a short briefing the TB on a weak surface. **Result:** Within 10 minutes, one segment of 10 meter was installed correctly. One hour resistance against 40 cm water height. *(July 2016, Flood Proof Holland,*

Delft, the Netherlands).

Figure 11: Installation of the TB between two walls

7. Installation under urban circumstances during a competition for temporary bariers. Quays and an urban area was simluated by placing several objects and walls in the basins. The assignment was to turn water with the TB against a wall and over a pavement. **Result:** No significant leakage for 3 hours with 70 cm water height. *(May 2016, Flood Proof Holland, Delft, the Netherlands).*

Figure 12: Simulation of a quay

8. Drainage hoses. To ensure better drainage of ground water underneath the TB and to prevent air bubble formation under the flap. **Result:** this seemed to work well based on the data collection/analysis. *(October 2016, Flood Proof Holland, Delft, the Netherlands).*

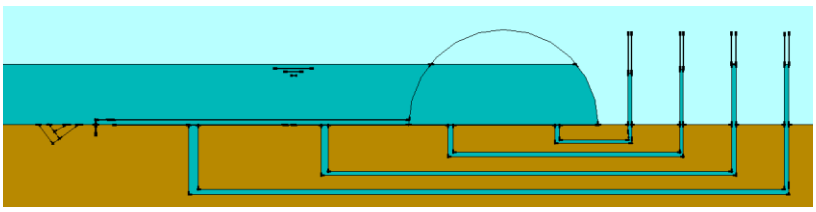


Figure 13: Pressure gauges installed

9. Installation in an urban area of universal anchors. Fout employees of the maintenance and . Beforehand, only a short instruction was given by the TB

	crew. **Result:** correct instalation of 50 meters TB *(October 2016, Steenbergen, the Netherlands).*  *Figure 14: Installation of the TB on vowels*	
Technology Readiness Level (TRL)		
	☐	1. Basic Principles Observed. Basic principles are observed and reported. Lowest level of technical readiness. Scientific research begins to be translated into applied research and development. Examples might include fundamental investigations and paper studies.
	☐	2. Technology Concept Formulated. Innovation concept and/or application formulated. Once basic principles are observed, practical applications can be formulated. Examples are limited to analytic studies and experimentation.
	☐	3. Experimental Proof of Concept. Active research and development is initiated. Laboratory studies aim to validate analytical predictions of separate components of the innovation. Examples include components that are not yet integrated or representative.
	☐	4. Technology Validated in Lab. Design, development and lab testing of innovation components are performed. Here, basic innovation components are integrated to establish that they will work together. This is a relatively “low fidelity” prototype in comparison with the eventual system.
Evaluate the current TRL level of the innovation	☑	**5. Technology Validated in a Simulated Environment. The basic innovation components are integrated together with realistic supporting elements to be tested in a simulated environment. This is a “high fidelity” prototype compared to the eventual system.**
	☐	6. Technology Demonstrated in an Operational Environment. The prototype, which is well beyond that of level 5, is tested in a relevant environment. The system or process demonstration is carried out in an operational environment.
	☐	7. System Prototype Demonstration in an Operational Environment. Prototype is near, or at, planned operational system level. The final design is virtually complete. The goal of this stage is to remove engineering and manufacturing risk.
	☐	8. System Complete and Qualified. Innovation has been proven to work in its final form under the expected conditions. In most of the cases, this level represents the end of true system development.
	☐	9. Actual System Proven in an Operational Environment. Here, the innovation in its final form is ready for commercial deployment.

Test Plan

Test Plan: laboratory tests	
Objectives of lab tests	
Overall test objective	Several practice (field)tests and demonstrations with the TB has been done. With the TIF-protocol from BRIGAID it's becomming possible to give (potential) users a more complete overview of the capabilities of the TB. With laboratory tests the validation of the technology can be endorsed, both in a laboratory environment (low-fidelity) as in a relevant environment (high-fidelity). If no failure is occured, the TB can proceed to the operational testing stage (TRL 6-8).
Prototype improvements prior to testing	At the same time, innnovations like the updated zippers and a new universal anchor will be tested. Originally, the TB is designed with three types of ground anchors for different surfaces. The use of three different ground anchors is too complex during a flood event, and increases the chances of human errors. The design is developed in CAD and strength calculations have been performed.
Design citeria	
Intended (quantitative) level of risk reduction	Water-filled tubes are designed to reduce risk of flooding by retaining water. The risk reduction capacity is expressed as a water level, wave height and/or flow velocity that the structure is able to resist. Based on the design height, the TB should resist a water level of 70 cm.
Intended Safety Factor or Reliability	Based on prior development of the TB, the intended reliability for these laboratorium tests is 100%. Which means no failure or insufficient leakage during the tests.
Test 1: Endurance tests	
Rationale	The period of flooding is often a long time event. Than it's needed that the TB can resist water or a longer period. Also some floodconditions can influence the capacity of resistance, such as (wind)waves. Summarized, this results in hydrostatic and hydrodynamic loads.
Facility	A test facility with a concrete bottom, and one with grassland ground. *(Delft, the Netherlands)*
Test equipment	These test equipments are needed: • Two TB segments with (new) zipper and anchor plates. In case of failure(s) more segments are needed. • Wave-generating machine. • Waterlevel gauge.
Protocol	The purpose of the National Flood Barrier Testing and Certification Program for temporary water-retaining structures, is to provide an unbiased process of evaluating products in terms of resistance to water forces, material properties, and consistency of product manufacturing. This will be accomplished by testing the product against water related forces in a laboratory setting and testing the product against material forces in a laboratory setting. The other reputable testing protocol, the BSI (Britisch Standards), tests also for comparable loads. The PAS process enables a specification to be rapidly developed in order to fulfil an immediate need in industry. A PAS may be considered for further development as a British Standard, or constitute part of the UK input into the development of a European or International Standard. However, this is

	more a standard in development. Therefore the test protocol for the TB is in accordance with the NFBTCP (in particular USACE) and the paper from Wibowo and Ward (2016). This test protocol for hydrostatic conditions is initiated (with H = design height for the temporary structure). All tests are performed on both concrete floor and in grassland.

Hydrostatic impact	Test condition	Allowed repair
Low water level	33% · H, 22 hours (24 hours*)	After test
Medium water level	66% · H, 22 hours (24 hours*)	After test
High water level	95% · H, 22 hours (24 hours*)	After test

* TÜV Nederland Q.A. B.V. test condition.

This test protocol for hydrodynamic conditions is initiated (with H = design height of the temporary structure):

Hydrodynamic impact	Test condition	Allowed repair
Low waves	66% · H, 7 hours	After test
Medium waves	66% · H, 3 x 10 minutes	-
High waves	66% · H, 3 x 10 minutes	After test
Low waves	80% · H, 7 hours	After test
Medium waves	80% · H, 3 x 10 minutes	-
High waves	80% · H, 3 x 10 minutes	After test

This test protocol for overflowing is initiated:

Hydrodynamic impact	Test condition	Allowed repair
Overflowing	2,5 cm, 1 hour	Major repair or rebuild after test

Measurements	• Measurement for hydrostatic impact: - Instability: rotational, horizontal and vertical instability is tested during

	hydrostatic load tests. These tests are performed by raising the water level until the maximum retaining height and assessing whether instability occurs. If no instability occurs after 22 hours, the testing is considered successful. - Seepage/leakage/piping: Measure the amount of seepage flow under the water-filled tube during hydrostatic impact tests and record the occurrence of piping (if any). (Conduct these tests using different subsoils (concrete and grassland). Minor leaks where not measured. - Structural failure: Measure whether elements of the water-filled tube fail when subject to the design criteria for a certain duration. • Measurement for hydrostatic impact: - Instability: rotational, horizontal and vertical instability is tested during hydrodynamic load tests. These tests are performed by raising the water level until the maximum retaining height and assessing whether instability occurs. At the same time, waves are generated. - Seepage/leakage/piping: Measure the amount of seepage flow under the water-filled tube during hydrodynamic impact tests and record the occurrence of piping (if any). (Conduct these tests using different subsoils (concrete and grassland). Minor leaks where not measured. - Overtopping/overflowing: Allow the structure to overtop/overflow to test its stability. Note that for water-filled tubes, overflowing may be allowed (and can be part of the intended functionality of the innovation) as long as the barrier is not breached (i.e., move or topple over). In this phase, testing for overtopping/overflow is considered successful if no breaching occurs during overtopping/overflow. - Structural failure: Measure whether elements of the water-filled tube fail when subject to the design criteria for a certain duration. • Measuring equipment: visual observation, and a camera for recording the results.
Expected relibablity	Based on the expectations no significant failure.
Expected reusability	Based on the reusaility expectation 0% cannot be reused (in case without any failure(s)). After installation the TB can reuse again without any waste.
Test 2: Incidental impact tests	
Rationale	During flood events, also debris from different resources can cause some damage on the TB. Therefore also some incidental impact tests are needed. The material of the TB (PVC), should resist the impact of floating objects, such as trees and branches. Summarized, a test for incidental loads is needed.
Facility	A test facility with a concrete basin is needed.

<table>
<tr><td></td><td>(Delft, the Netherlands)</td></tr>
<tr><td>Test equipment</td><td>These test equipments are needed:

One segment of the TB with new zipper and anchor plates.
Waterlevel gauge.
Measurement equipment: visual observation, camera.
A debris impact testing instrument (similar to the equipment wich is used in the National Flood Barrier Testing and Certification Program).

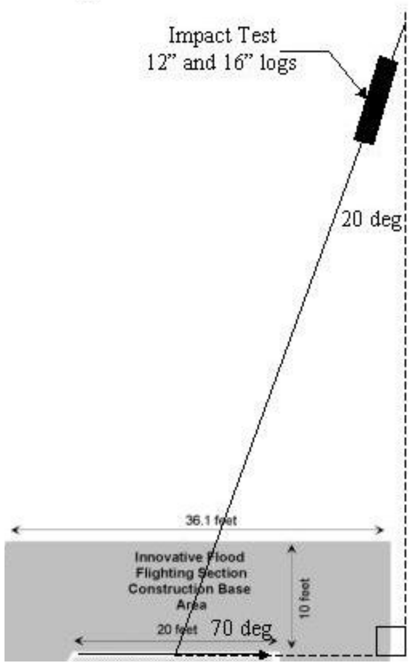


Figure 15: Example debris impact instrument</td></tr>
<tr><td>Protocol</td><td>The test protocol for the debris impact test is in accordance with the tests of the National Flood Barrier Testing and Certification Program (particular FM Approvals) (with H = design height for the temporary structure):
<table>
<tr><th>Debris impact</th><th>Test condition</th><th>Allowed repair</th></tr>
<tr><td>Impact load</td><td>0.3 m log, 8 km/hour, at 33% · H</td><td>Removal of all material</td></tr>
<tr><td>Impact load</td><td>0.4 m log, 8 km/hour, at 33% · H</td><td>Removal of all material</td></tr>
</table></td></tr>
</table>

<table>
<tr><td>Measurements</td><td>

- Measurement for debris impact:
  - Seepage/leakage/piping: Measure the amount of seepage flow under the water-filled tube during the impact load tests and record the occurrence of piping (if any). (Conduct these tests using different subsoils (concrete and grassland). Minor leaks where not measured.
  - Structural failure: Measure whether elements of the water-filled tube fail when subject to the design criteria for a certain duration.

Figure 16: Damage qualification

- Measuring equipment: visual observation, and a camera for recording the results.

</td></tr>
<tr><td>Expected relibablity</td><td>Based on the expectations, no significant failure.</td></tr>
<tr><td>Expected reusability</td><td>Based on the reusaility expectation 0% cannot be reused (in case without failure(s)). If the segment needs repairing during after the test, just maybe the segment of PVC will require a complete replacement.</td></tr>
<tr><td colspan="2">Test 3: Riverine current tests</td></tr>
<tr><td>Rationale</td><td>During flood events, also currents can cause some damage on the TB. Than some floodconditions can influence the capacity of resistance, such as currents. Therefore, a test for riverine current loads is needed.</td></tr>
<tr><td>Facility</td><td>A test facility with a concrete basin is needed.
FLOODPROOF HOLLAND (Delft, the Netherlands)</td></tr>
<tr><td>Test equipment</td><td>

These test equipments are needed:

- One segment of the TB with new zipper and anchor plates.
- Waterlevel gauge.
- A pump.
- Some tubes for defelcting the water in the right direction.
- Measuring equipment: water velocity meter, visual observation, camera.

</td></tr>
<tr><td>Protocol</td><td>The test protocol for the riverine current test is in accordance with the tests of the National Flood Barrier Testing and Certification Program (particular FM Approvals) (with H = design height for the temporary structure):
<table>
<tr><th>Hydrodynamic impact</th><th>Test condition</th><th>Allowed repair</th></tr>
<tr><td>Current</td><td>2.1 m/s, 1 hour at 66% · H</td><td>After test</td></tr>
</table>
</td></tr>
</table>

Measurements	• Measurement for riverine current impact: - Instability: rotational, horizontal and vertical instability is tested during riverine current tests. These tests are performed by raising the water level until the maximum retaining height and assessing whether instability occurs. At the same time, waves are generated. - Seepage/leakage/piping: Measure the amount of seepage flow under the water-filled tube during the impact load tests and record the occurrence of piping (if any). (Conduct these tests using different subsoils (concrete and grassland). Minor leaks where not measured. - Structural failure: Measure whether elements of the water-filled tube fail when subject to the design criteria for a certain duration. • Measuring equipment: visual observation, and a camera for recording the results.
Expected relibablity	Based on the expectations, no significant failure.
Expected reusability	Based on the reusaility expectation 0% cannot be reused (in case without failure(s)).
Ethical checks	
	No ethical issues arise during testing.

Test plan: operational tests	
Objectives of field tests	
Overall test objective	The field tests are done for a better understanding of the failure mechanisms (and probably fatalities) of the TB. Now, in this part of the test plan it's possible to get some insight of the resistance in various environments. The focus of the testing will be on TRL 6 and partly on 7. TRL 8 will be open for follow-up research. Due to the absence of a 'real' test environment (governmental organizations are hesitant for the probability of failure and its consequences), we try to simulate a relevant operational environment in a high-fidelity laboratory environment. However, the facility of Flood Proof Holland makes it, due to its features, useful as a relevant environment for these tests. Based on field observations some changes in the test facility are made, in order to create a more irregular environment. Validation of the stability of the TB in various field settings for fluvial and pluvial floods are possible due to these changes. Also a test with the new installation protocol and the failure probability due to human errors can be made transparent.
Prototype improvements prior to testing	This depends on the results of the laboratory testing. However we don't expect to make significant improvements. Only development of a new installation protocol for governmental organizations.
Design Criteria (i.e., Required Technical Effectiveness)	
Required level of risk reduction	A quick and correct installation of the TB is needed for a good water resistance. Based on the design height, which has been validated in the laboratory tests, the TB should resist a water level of 70 cm.
Required Safety Factor or Reliability	The required reliabily is 100%, no significant leakage/seepage or incorrect installation.

(External) Operating Conditions	No specific operational conditions affected/needed for the tests.
Test 4: Installation test	
Rationale	Installation tests with the TB have not been performed yet. Therefore the implementation of the interconnected units will be assessed in this field tests With this test evaluation of the behavior of multiple (e.g., 10) connected units will perform.. The units are connected with special zippers (YKK of Japan). These zipper-connections has not been tested yet. Verifying whether any human errors made during installation.
Facility	A test facility with a grassland basin is needed. FLOODPROOF HOLLAND *(Delft, the Netherlands)*
Test equipment	These test equipments are needed: • At least eight TB segments. • Equipment for transport from storage to testlocation. • Several (uninstructed) people who could be responsible for installation. • Measuring equipment: visual observation, and a camera for recording the results.
Protocol	The installation test protocol is a: • Transport from storage to test locatrion according to protocol. • Installation at location according to protocol. • Evaluation of required vs. available time. • Evaluation of human errors. • When the barrier is installed, loading conditions will be applied (e.g. install at low tide and wait for high tide).
Measurements	• Try to get an overview of the errors/extra improvements for a correct installation. • Measurement equipment: visual observation, and a camera for recording the results.
Expected relibablity	Based on prior experiments and the results of the field tests, for the installation test no extra instruction should be needed for a correct installation.
Expected reusability	Based on prior experiments 0% cannot be reused. After installation the TB can reuse again without any waste.
Test 5: Endurance test	
Rationale	To test the TB in a irregular environment is fundamental for a further development and demonstration as described in TRL 7 and 8. In order to create some insight in the behavior of the barrier in a relevant environment, this test is more in line with TRL 6. In this test, water retaining function of two segements of the TB can be validated for stability and leakage/seepage during usage. In the follow-up research (TRL 7) it's maybe possible to test the TB on the 'real' operating location, with a special focus on the behaviour of more connected segments that have been placed on irregular surface.
Facility	A test facility with a grassland basin is needed. FLOODPROOF HOLLAND *(Delft, the Netherlands)*

<table>
<tr>
<td>Test equipment</td>
<td>These test equipments are needed:

Two TB segments with (new) zipper and anchor plates. In case of failure(s) more segments are needed.
Wave-generating machine.
Waterlevel gauge.
Measuring equipment: visual observation, and a camera for recording the results.

</td>
</tr>
<tr>
<td>Protocol</td>
<td>The tests are comparable with the endurance test in the laboratory phase. Therefore, the test protocol of the National Flood Barrier Testing and Certification Program (in particular USACE) and the paper from Wibowo and Ward (2016) for hydrodynamic tests, can be used again.

This test protocol for hydrodynamic conditions is initiated (with H = design height of the temporary structure):
<table>
<tr><th>Hydrodynamic impact</th><th>Test condition</th><th>Allowed repair</th></tr>
<tr><td>Low waves</td><td>66% · H, 7 hours</td><td>After test</td></tr>
<tr><td>Medium waves</td><td>66% · H, 3 x 10 minutes</td><td>-</td></tr>
<tr><td>High waves</td><td>66% · H, 3 x 10 minutes</td><td>After test</td></tr>
<tr><td>Low waves</td><td>80% · H, 7 hours</td><td>After test</td></tr>
<tr><td>Medium waves</td><td>80% · H, 3 x 10 minutes</td><td>-</td></tr>
<tr><td>High waves</td><td>80% · H, 3 x 10 minutes</td><td>After test</td></tr>
</table>
This test protocol for overflowing is initiated:
<table>
<tr><th>Hydrodynamic impact</th><th>Test condition</th><th>Allowed repair</th></tr>
<tr><td>Overflowing</td><td>2,5 cm, 1 hour</td><td>Major repair or rebuild after test</td></tr>
</table>
</td>
</tr>
<tr>
<td>Measurements</td>
<td>Measurements for the endurance test:

Instability: rotational, horizontal and vertical instability is tested during endurance tests. These tests are performed by raising the water level until the maximum retaining height and assessing whether instability occurs. At the same time, waves are generated.
Seepage/leakage/piping: Measure the amount of seepage flow under the water-filled tube during hydrodynamic impact tests and record the occurrence of piping (if any). Minor leaks where not measured.
Structural failure: Measure whether elements of the water-filled tube fail when subject to the design criteria for a certain duration.

</td>
</tr>
</table>

	Measurement equipment: visual observation, and a camera for recording the results.
Expected relibablity	Based on the laboratory tests, no significant failure occurs.
Expected reusability	Based on the laboratory tests 0% cannot be reused (in case without failure(s)).
Ethical checks	
	No ethical issues arise during testing.

Test results

The testing of the Tubebarrier was delayed due to production of the ground anchors and the hiring of additional expertise (a TU Delft student). Tests are planned in Q1 of 2018 and will be reported in the tables below.

Laboratory Test 1 Summary	
Test results	*(After tests; to be continued…….)*
Is there a need to adjust the prototype based on the tests?	*(After tests; to be continued…….)*
Evaluate the TRL that has been reached after testing.	*(After tests; to be continued…….)*
Additional Tests Required/Proposed Future Tests	*(After tests; to be continued…….)*

Laboratory Test 2 Summary	
Test results	*(After tests; to be continued…….)*
Is there a need to adjust the prototype based on the tests?	*(After tests; to be continued…….)*
Evaluate the TRL that has been reached after testing.	*(After tests; to be continued…….)*
Additional Tests Required/Proposed Future Tests	*(After tests; to be continued…….)*

Laboratory Test 3 Summary	
Test results	*(After tests; to be continued…….)*
Is there a need to adjust the prototype	*(After tests; to be continued…….)*

based on the tests?	
Evaluate the TRL that has been reached after testing.	*(After tests; to be continued…….)*
Additional Tests Required/Proposed Future Tests	*(After tests; to be continued…….)*

Operational Test 4 Summary	
Test results	*(After tests; to be continued…….)*
Is there a need to adjust the prototype based on the tests?	*(After tests; to be continued…….)*
Evaluate the TRL that has been reached after testing.	*(After tests; to be continued…….)*
Additional Tests Required/Proposed Future Tests	*(After tests; to be continued…….)*

Operational Test 5 Summary	
Test results	*(After tests; to be continued…….)*
Is there a need to adjust the prototype based on the tests?	*(After tests; to be continued…….)*
Evaluate the TRL that has been reached after testing.	*(After tests; to be continued…….)*
Additional Tests Required/Proposed Future Tests	*(After tests; to be continued…….)*