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POLITIQUE SCIENTIFIQUE FEDERALE - FEDERAAL WETENSCHAPSBELEID

RESEARCH PROGRAMME FOR EARTH OBSERVATION STEREO III

INITIAL REPORT

CONTRACT SR/00/302

HYDRAS+

Improving drought monitoring through assimilating multi-source remote sensing observations in hydrologic models

Date: 20/12/2014

For the partnership: Niko Verhoest / Hans Lievens

1 CONTENT

2 PARTNERSHIP INFORMATION

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2.4 PROMOTOR HARRY VEREECKEN / CARSTEN MONTZKA (FORSCHUNGSZENTRUM JÜLICH)

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3 PROJECT INFORMATION

PROJECT WEBSITE

http://www.hydrasplus.ugent.be/

(POTENTIAL) STAKEHOLDERS

Given the objective of the project to improve or to come up with alternative techniques for drought monitoring schemes (based on remote sensing, modelling and data assimilation), the stakeholders mainly consist of scientists involved in setting up such systems, or who have major interest in remote sensing products to be used in land surface models. Therefore, potential stakeholders could be:

- ECWMF (European Centre for Medium-Range Weather Forecasts)
- ESA (European Space Agency)
- NASA (National Aeronautics and Space Administration)
- JRC (Joint Research Centre)
- Developers of drought monitoring/forecasting systems (e.g. United States department of Agriculture (USDA), Princeton University, Terrestrial Hydrology Research Group, …)
- IPCC (Intergovernmental Panel on Climate Change)
- Specialist companies providing water management services (Deltares, Arcadis, DHI …)

Stakeholders which would profit from having improved drought monitoring and forecasting systems involve:

- Water managers responsible for e.g. irrigation scheduling
- FAO (Food and Agriculture Organization)
- UNESCO (United Nations Educational, Scientific and Cultural Organization)
- NGO's (e.g. PROTOS)

POTENTIAL SOCIETAL IMPACT

Given the expected increase in extreme events due to climate change, more drought events can be expected in the future. These events have often devastating impacts on the society and the environment. Therefore, adequate monitoring of these events is of utmost importance within disaster management.

Remote sensing data can provide important information, though does not allow for a complete assessment of droughts as (1) only measurements of the surface are obtained and (2) spatial and temporal resolutions are often too coarse. Combining remote sensing data with land surface models is generally opted for, and is already in place in many drought monitoring systems. However, several parts of these systems can be improved with respect to (1) the use of multiple sources of remote sensing data, (2) the modelling approach used and (3) the updating of models based on remotely-sensed observations. If any of these components can be improved, a more precise monitoring and modelling can be expected, and therefore enhanced predictions of droughts can be made.

HYDRAS+ works on these three domains and will demonstrate the benefits of the joint assimilation of several remote sensing sources in land surface models. It furthermore will investigate whether conceptual models can be used instead of complex and computation-expensive land surface models. Such simplified models will allow for a faster computation of droughts at very large scale.

HYDRAS+ does not foresee to develop an alternative drought monitoring system, but aims at developing methodologies that can improve many of the currently existing systems. Any improvement in the currently available systems will have important positive consequences with respect to disaster management as it will allow for an improved management of resources, reducing the number of casualties.

POTENTIALLY RELEVANT TREATIES, AGREEMENTS, DIRECTIVES, DECREES, ...

Currently, at the EU-level, policies and actions are being set up in order to prevent and to mitigate water scarcity and drought situations. The aim is to move towards a water-efficient and water-saving economy. In this policy, annual follow up reports are made, stakeholders get involved, … One of the measures concerns improving drought risk management, which includes the development of a European Drought Observatory and early warning system.

ESTIMATED DATE FIRST STAKEHOLDER MEETING

The consortium has not yet decided upon a date for a first stakeholder meeting. However, the project partners definitely wish to account for requirements of stakeholders and therefore propose prof. Siegfried Demuth to be member of the Steering Committee. Prof. Demuth is Chief of the Hydrological Systems and Global Change Section and one of the core members of the European Drought Center. Through his affiliation with UNESCO, he has many contacts with organizations that are involved in drought policy and humanitarian aid during drought events. We foresee that, through discussions with prof. Demuth, a protocol can be defined on the format of a stakeholder meeting or inquiry (through a questionnaire). One option includes coupling such meeting or inquiry with upcoming workshops or meetings dedicated to droughts.

4 STEERING COMMITTEE

4.1 COMPOSITION

MATTHIAS DRUSCH

Dr. Matthias Drusch was with Princeton University, Princeton, NJ, and Bonn University before joining the European Centre for Medium-Range Weather Forecasts from 2002 to 2008. Since 2008, he has been with the European Space Agency (ESA) as the Land Surfaces Principal Scientist in the Mission Science Division. His fields of interest are in remote sensing and radiative transfer modelling, data assimilation, hydrological modelling, and weather forecasting. He is currently the Mission Scientist for Sentinel-2, the Fluorescence Explorer Earth Explorer 8 candidate mission, and ESA's Soil Moisture and Ocean Salinity Science and applications representative.

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JOAQUIN MUÑOZ SABATER

Dr Joaquín Muñoz Sabater was born in Valencia, Spain. He received his Ph.D degree from the Paul Sabatier University (Toulouse III, France) in April 2007. In 2008 he joined the European Centre for Medium-Range Weather Forecasts (ECMWF), where he is currently working. His research focuses mainly on the assimilation of passive remote sensing data (with special emphasis on SMOS data), for soil moisture analysis and the impact in the weather forecast. Before his Ph.D Joaquín Muñoz Sabater worked firstly at the European Space Agency, where he was involved in feasibility studies for the EARTHcare mission, and secondly at the Delft University of Technology, where he carried out research within the radar interferometry group. His thesis was done entirely at Météo France and it was focused on the assimilation of remote sensing data for the characterization of land surfaces. Before joining the ECMWF, he worked at The European Centre for Research and Advanced Training in Scientific Computation (CERFACS). There, he was responsible for a project of the French National Hydro-meteorological and Flood Forecasting Centre, where he studied the impact of assimilating streamflow observations for flood forecasting applications.

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SIEGFRIED DEMUTH

Prof. Siegfried Demuth is Chief of the Hydrological Systems and Global Change Section at the Division of Water Sciences in UNESCO, Paris. He obtained his Diploma (Physical Geography), his Doctoral Degree (Natural Sciences), his Habilitation and his Professorship in Hydrology at the University of Freiburg, Germany. Prof Demuth served as officer on various committees of the International Association of Hydrological Sciences (IAHS), particularly as Secretary of the International Commission of Surface Water (ICSW) and later as the President of the International Commission of Surface Water. He served on the IHP Bureau as Vice-Chairperson representing UNESCO Member States from Europe and North America. He was member of the Advisory Working Group of the Commission for Hydrology (Chy) of WMO. Prof. Demuth received the CSIRO Medal for Research Achievements for advances in sustainable management of Australia's water resources and was awarded the UNESCO Team Award for the Natural Science Sector of UNESCO addressing water hazards through an integrated approach. He is core group member of the European Drought Center (http://www.geo.uio.no/edc/).

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4.2 ESTIMATED DATE OF MEETINGS

04/2015

04/2016

04/2017

06/2018

5 FEEDBACK ON THE EVALUATION OF PROJECT PROPOSAL

Generally, the project was well perceived by the different evaluators and the members of the jury of the oral defence. Yet, some comments/suggestions were raised that require some feedback.

EVALUATOR 1

1. *Relevant time scale of interest not specified*

The time scale at which will be modelled is probably the hourly level, though, for assessing drought characteristics, a coarser temporal resolution of 1 day can be allowed.

2. *Validation strategy and metrics not indicated*

The validation will mainly be done by comparing model results with soil moisture observations available from different continuously monitoring soil moisture networks, but also with discharge observations. The metrics used will be based on classical measures such as Root-Mean-Square Errors (RMSE), determination coefficients, Nash-Sutcliffe efficiencies, Kling-Gupta efficiencies, …

EVALUATOR 2

1. *Uncertainties in success of satellite missions and appropriateness of data*

There are indeed uncertainties in data from new satellite missions. However, if these missions would fail, there are still several data sources that can be used for the project. These include SMOS (which is foreseen to remain operational for the coming 5 years), ASCAT and RADARSAT.

2. *Lack of involvement of international (external to Europe) investigators (even if unfunded)*

There will be other researchers involved in this project, though not mentioned in the project proposal, who will at first be contacted with respect to data acquisition. For the Murray Darling basin, we can rely on Prof. Jeffrey Walker and prof. Valentijn Pauwels (Monash University, Australia). For the second basin, the Red Arkansas River (United States) (if approved by the Steering Committee) we can involve dr. Gabriëlle De Lannoy (NASA), dr. Thomas Jackson (USDA) and prof. Eric Wood (Princeton University). With all persons mentioned, there have been collaborations in the near past.

EVALUATOR 3

1. *Handling large amount of satellite data and ensemble model simulations can be a challenge, especially for a team over distributed locations*

This is true and will deserve a special attention. Specifically, a server will be purchased at Ghent University for data sharing. During the first months of the project, this server will be set up and together with the different partners, a protocol on the database will be established and implemented.

2. *Temporal and spatial extent of experiments and validation can be larger*

The main objective of the project is to come up with new methodological techniques that can be applied on a large scale. Therefore, we opt for testing, validating and demonstrating these techniques on two large catchments. Additional tests to alternative catchments would of course be beneficial, though, we believe that gathering data and setting up a model for these new sites would take too much time to ensure that the intended methodological progresses cannot be reached at full, given the budget foreseen for this ambitious project.

3. *Some specific techniques are less proven*

We agree that this is true, but see this rather as an asset then a drawback. In this project we wish to make scientific progress, therefore, we opt for (further) developing some concepts that have shown in some preliminary results to have interesting potential, rather than to stick with proven concepts. The proven concepts will be used to assess the merit of the newly developed techniques.

4. *Better if an example monitoring system for limited area could be established at the end*

Though it would be tempting to aim for this, we did not foresee to build a monitoring system within this project, as first of all we wish to make advances in several parts of such systems, rather than to focus on the complete system itself. We rather see such a monitoring system, based on 'proven new concepts' developed in this project as a follow-up project that aims at making theoretical concepts operational applicable.

5. *Some suggestions: (1) try to include past satellite sensors so that the experiments and validations can be conducted over a longer period (more reliable); (2) make use of as many as possible ground sensor networks in the world; (3) stay well communicated and collaborated with researchers in the same field for new emerging techniques.*

We welcome all of these suggestions, as all of them were already foreseen within the project (but maybe insufficiently stressed in the proposal).

EVALUATOR 4

1. *Dependence on future missions*

As explained in a comment to a remark of evaluator 2, there are indeed uncertainties in data from new satellite missions and the project (partly) depends on them. However, there are still several data sources of existing missions that can be used for the project. These include SMOS (which is foreseen to remain operational for the coming 5 years) and RADARSAT or even successful previous missions (Envisat, ASCAT,…). Furthermore, one important uncertainty was related to SENTINEL-1, which has meanwhile been successfully launched. The only remaining uncertainty is therefore the launch and operation of the SMAP mission.

2. Unclear definition of drought index

We agree with this comment and suggest to put a larger focus on different drought indices, including also vegetation-based drought indices which can be determined from additional remote sensing data such as NDVI. Work package 6 can therefore be extended with development of a drought monitoring framework based on multiple drought indices, derived from remote sensing or (updated) hydrological model results. Important will be to assess whether the onset and the ending of a drought can be predicted. An extensive literature review, conducted at an earlier stage within the project, should compare the different drought monitoring indices, their applicability with respect to this project, their potential for assessing severity, onset and ending of drought events and how different indices can be combined in order to improved early-warning systems.

3. Unclear definition of drought detection technique

Based on the literature study, a selection of drought indices to be used will be defined. Once a selection is made, a drought detection technique will be developed that makes use of these indices.

4. Unclear plan how the results will be communicated to end users especially the format and the content of the early warning system

One task that is taken up in the contract concerns the communication with end users. However, as the project does not aim at developing an early warning system and make it available on the web, its end users are to be sought in agencies developing and/or maintaining existing drought monitoring and drought warning systems. During the first months of the project these people will be identified, and a framework will be developed that ensures their involvement within the project.

5. The use of another model rather than in situ observation to validate the outcome of the drought monitoring system is also a weakness that should be considered. The investigators could have selected others basins that are heavily instrumented. In addition, the authors selected two watersheds in a similar climate conditions i.e. semi-arid to develop and verify the anticipated early warning system. A stringer assessment could have been done over basins in diverse climate systems e.g. those in the US in mid latitude regions could be excellent candidate.

We agree with this comment. Of course, in situ data will be used to assess model performance. However, the idea behind comparing with another model (and early warning system) consists of evaluating the methodologies used. It is even foreseen for one researcher to visit Princeton University to learn to work with their methodology and to implement some of the new concepts developed in this project in order to assess the merit of the proposed techniques for currently operational systems. Furthermore, as suggested by the reviewer, the study will include the Red Arkansas river basin, which is a extensively monitored basin in the US. The large amount of in situ soil moisture measurements that are continuously assembled in this basin will be of high value for validating the study results.

6. *putting a stronger emphasis on WP7 should enhance the visibility of the outcome of the research, especially if the investigators find a way to communicate their results to local end- users in the study sites*

We agree on this and will take great care of this when involving potential end users.

COMMENTS AFTER ORAL DEFENCE

Based on the questions during the oral defence of the HYDRAS+ proposal, the panel had three major concerns with respect to the project, which can be summarized as:

(1) More attention should go to remote sensing and advances in remote sensing
(2) More emphasis should be put on droughts
(3) Less emphasis should go to the mathematical development of techniques

These perceptions of mainly focussing on mathematical developments of techniques and less on remote sensing and droughts are probably caused by the fact that we attempted to highlight and clarify the scientific novelties with respect to the assimilation of coarse-scale remote sensing data in hydrologic models, which have been identified as an important shortcoming in current modelling systems. Unfortunately, by doing so, we failed to stress the drought component and the potential benefits of the research for operational hydrology with respect to drought monitoring and prediction. Yet, the advances with respect to remote sensing applications for drought monitoring clearly lie in this field as several shortcomings and challenges for the current drought monitoring systems can be identified. The majority of these shortcomings are being addressed in the HYDRAS+ proposal.

For each of the concerns, we can briefly summarize how HYDRAS+ will address them.

(1) More attention to remote sensing and advances in remote sensing

Much research in the HYDRAS+ project is devoted to advances in remote sensing. These involve:

- *Combination radar and radiometer measurements*: (1) we foresee an alternative and innovative technique for merging radar and radiometer data (but can be other type of data as well) within a framework that is to be further developed. (2) We also foresee to assimilate Level-1 data (i.e. brightness temperature and backscattering coefficient as this circumvents the need of higher level data (such as retrieved soil moisture). Assimilation of Level-1 data is of high interest to ESA as (i) consistent model inputs (e.g. land cover, LAI, texture, etc.) can be used in both the land surface and radiative transfer models, (ii) the delivery of the data is faster than compared to Level-2 data, and (iii) ESA does not foresee to freely provide Level-2 (or higher level) data for the upcoming Sentinel missions, but will only make Level-1 data accessible to the end users.
- *Downscaling and bias correction*: This is a key item in the HYDRAS+ proposal: how should coarse-scale remote sensing data be rescaled to the model scale such that it can be assimilated? This question truly requires to be investigated as much data are being acquired at coarse scale. Resolving this problem will meet the users' needs, and therefore, space agencies, in particular ESA, show large interest in downscaling approaches as most sensors provide observations at a coarser scale than what is needed. Besides downscaling, another major problem needs to be overcome, i.e. the bias-problem: this is a typical problem that also starts to get attention in the international community: even though given the same name, soil moisture from observations

(being *in situ* or remotely sensed) is not the same as that used as a state variable in a hydrologic model. The reason therefore is that due to simplifications in the model physics and the model structure, the model state variable (called soil moisture) may deviate from the 'true' soil moisture to compensate for the shortcomings in the model. Data assimilation however requires that bias is accounted for. In this project, different bias correction techniques will be evaluated, while the downscaling framework proposed in the project inherently accounts for bias which therefore circumvents the estimation and correction of bias.

- *Use of multiple data sets*: In HYDRAS+, we aim at using data from different platforms. These data have to be scaled to the resolution of the model. Therefore, the proposed downscaling framework can be used. This will allow for applying multiple data sets in a data assimilation framework, as all data have the same spatial resolution and are bias-corrected with respect to the model climatology.

(2) More emphasis should be put on droughts

Drought identification and monitoring will get a key role in the project:

- *Soil moisture versus drought monitoring*: Assessing droughts based on remotely sensed soil moisture is not straightforward as generally, only the top few centimetres of the soil are observed, whereas agricultural drought (defined by deficits in soil moisture) is greatly influenced by the total soil moisture content of the root zone. It is thus required to foresee a mechanism that allows for estimating the root zone soil moisture given remote sensing observations of the surface soil moisture. This can be done through involving a hydrological model that allows for simulating the soil moisture content in different sub-layers of the soil and which is constrained by remote sensing observations through data assimilation. Within the HYDRAS+ project, we intend to assess droughts through analysing time series of root zone soil moisture as modelled by the hydrologic models that are updated with top layer soil moisture observations from different remote sensing platforms.
- *Satellite-based soil moisture observations for drought monitoring*: In the HYDRAS+ proposal, we aim at demonstrating the benefits of assimilating different soil moisture products, and also level-1 products (brightness temperature and backscattering coefficient) into hydrologic models with the aim to improve drought monitoring. This type of applications have not been performed up till now, and it is likely that different international groups will also move in this direction, making this topic very relevant for the near future. With this proposal, the HYDRAS+ team members wish to ensure to be on the forefront of any developments in this respect.
- *Put a larger focus on different drought indices*: therefore, vegetation-based drought indices could also be selected which can be determined from additional remote sensing data such as NDVI. Work package 6 can be extended with development of a drought monitoring framework based on multiple drought indices, derived from remote sensing or (updated) hydrological model results. Important will be to investigate whether the onset and the ending of a drought can be predicted. Based on an extensive literature review, conducted at an earlier stage within the project, different drought monitoring indices will be compared with respect to their applicability, their potential for assessing severity, onset and ending of drought events and how different indices can be combined in order to improved early-warning systems.

(3) Less emphasis should go to the mathematical development of techniques

Given this comment, we intend to decrease the research on mathematical developments by putting less focus on downscaling using 3D or higher dimensional copulas, but to further develop a 2D framework. Given the significant reduction in research in this respect, the budget of Prof. B. De Baets was considerably reduced. With respect to data assimilation and dual state-parameter estimation, no significant developments are needed as these techniques are currently used by different partners within the consortium.

6 PROJECT SHEET

HYDRAS+ (SR/00/302)

Project type:	Thematic networks projects
Duration:	4 year (2014 – 2018)
Composition partnership:	Niko Verhoest/Hans Lievens (UGent)
	Bernard De Baets (UGent)
	Laurent Pfister/Patrick Matgen (Centre de Recherche Public-Gabriel Lippmann, Luxembourg)
	Harry Vereecken/Carsten Montzka (Forschungszentrum Jülich, Germany)
Study area:	Murray Darling Basin (Australia) and Red Arkansas River (USA)
RS data used:	microwave based sensors (SMOS, SMAP, ASCAT, Sentinel-1, Radarsat, …)
Website:	http://www.hydrasplus.ugent.be/

CONTEXT AND OBJECTIVES

Given the expected increase in extreme events due to climate change, more drought events can be expected in the future. These events have often devastating impacts on society and the environment. Therefore, adequate monitoring of these events is of utmost importance within disaster management. Remote sensing can provide important information, though does not allow for a complete assessment of droughts as (1) only measurements of the surface are obtained and (2) the spatial and temporal resolutions are often too coarse. Combining remote sensing with land surface models is generally opted for, and is already in place in many drought monitoring systems. However, several parts of these systems can be improved with respect to (1) the use of multiple sources of remote sensing data, (2) the modelling approach used and (3) the updating of models based on remotely sensed observations. If any of these components can be improved, a more precise monitoring and modelling can be expected, and therefore enhanced predictions of droughts can be made.

The objective of HYDRAS+ is to work on these three domains and to demonstrate the benefits of the joint assimilation of several remote sensing sources in land surface models. It furthermore aims at assessing whether conceptual models can be used instead of complex and computation-expensive land surface models. If such models can be used, a faster computation of droughts at very large scale becomes possible.

HYDRAS+ does not foresee to develop an alternative drought monitoring system, but aims at developing methodologies that can improve many of the currently existing systems. Any improvement in the currently available systems will have important positive consequences with respect to disaster management as it will allow for an improved management of resources, reducing the number of casualties.

METHODOLOGY

HYDRAS+ will focus on three main aspects: (1) remote sensing imagery, (2) land surface modelling and (3) data assimilation. The methodologies used in each of these aspects involve:

a. *Downscaling, bias correction and uncertainty characterization of the remote sensing data*
   Different sensors provide data at different resolutions. In order to use these data, two options are possible: assimilation at the scale of the observations, or assimilation at the scale used by the model. In this project, the second approach will be investigated in detail, where a new framework, based on copulas, will be developed and optimized for scaling and/or merging data at the model resolution. Major attention will be paid to bias-correction, as assimilation requires bias-free estimates of model states, and to the assessment of the uncertainty in downscaled products, as the latter information is of crucial importance in data assimilation systems.
b. *Hydrologic model integration*
   The hydrologic model integration involves the integration of a radiative transfer model and a land surface model, being both a physically-based model and a conceptual model. Such coupled system is necessary for assimilating level-1 products (backscatter and brightness temperatures).
c. *Data assimilation integration*
   Different data assimilation algorithms will be implemented, based on the Kalman Filter. Major attention will go to the implementation of a dual state-parameter estimation technique that should allow to update model parameters every time observations become available. It is hypothesised that such approach is necessary when simplified conceptual models are used instead of physically-based land surface models.
d. *Data assimilation experiments*
   The model framework is going to be used for a set of dedicated assimilation experiments, which should demonstrate the benefit of this approach for water managers, and organizations dedicated to climate research and/or reporting such as ECMWF, JRC, or IPCC. The assimilation experiments will enable to provide recommendations on which algorithms of current early-warning systems may potentially be improved by implementing the developed algorithms within the project.
e. *Analysis of extreme events and development of an early-warning system*
   The developed framework that optimally makes use of remotely sensed observations will be assessed with respect to currently available drought monitoring/forecasting systems in order to make recommendations for improving these operational systems. Therefore, an existing drought monitoring/forecasting system will be used as benchmark and methodologies developed in the

framework of HYDRAS+ will be implemented in this system in order to validate the merit of the proposed methodologies.

EXPECTED SCIENTIFIC RESULTS

Several scientific results are expected with respect to:

- Downscaling remote sensing data to the model resolution
- Conceptual modelling of the mass and energy balance at large scale
- Data assimilation of a suite of remote sensing observations
- Merging of data from different sensors
- Dual state-parameter estimation
- Recommendations with respect to the use of remote sensing data in land surface models
- Recommendations with respect to improving operational drought monitoring/forecast systems

EXPECTED PRODUCTS AND SERVICES

The main products that can be expected are new methodologies and insights in the application of remotely sensed observations in land surface models in order to improve drought monitoring. The products that will initially be delivered will be contributions to workshops/conferences/symposia and publications in peer-reviewed journals. However, end users (mainly organizations that provide drought forecasts and space agencies) will be informed on the advances made through this project, and how these may benefit their services.

POTENTIAL USERS

- ECWMF (European Centre for Medium-Range Weather Forecasts)
- ESA (European Space Agency)
- NASA (National Aeronautics and Space Administration)
- JRC (Joint Research Centre)
- Developers of drought monitoring/forecasting systems (e.g. United States department of Agriculture (USDA), Princeton University, Terrestrial Hydrology Research Group, …)
- IPCC (Intergovernmental Panel on Climate Change)
- Specialist companies providing water management services (Deltares, Arcadis, DHI …)

Stakeholders which would profit from having improved drought monitoring and forecasting systems involve:

- Water managers responsible for e.g. irrigation scheduling
- FAO (Food and Agriculture Organization)
- UNESCO (United Nations Educational, Scientific and Cultural Organization)
- NGO's (e.g. PROTOS)

7 COPY OF THE INTERNAL AGREEMENT (SIGNED BY ALL PARTNERS)

An internal agreement is being developed, but has not yet been approved by the different partners. Once this agreement is accepted by all parties, a copy will be sent to Belspo.

8 COPY OF THE AGREEMENT SIGNED WITH THE INTERNATIONAL PARTNER(S)

An agreement with the international partner is being developed, but has not yet been approved by the different partners. Once this agreement is accepted by all parties, a copy will be sent to Belspo.