POLITIQUE SCIENTIFIQUE FEDERALE - FEDERAAL WETENSCHAPSBELEID

RESEARCH PROGRAMME FOR EARTH OBSERVATION STEREO III

ACTIVITY REPORT

CONTRACT SR/00/302

HYDRAS+

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

Date: 12/11/2015

For the partnership: Niko Verhoest

PARTNERSHIP INFORMATION

1.1 CHANGES IN PROJECT STAFF

Due to personal reasons Renaud Hostache asked for a leave period at LIST and will continue working on HYDRAS+ in April 2016. In order to not create any long-term delays he will then be working full-time on the project for the necessary time to synchronise all activities of the project consortium. For the short-term planning a formal request has been submitted to BELSPO to postpone the steering committee meeting, due in April, to July.

PROJECT INFORMATION

2.1 PROJECT PROGRESS AND RESULTS

Work packages as defined in the accepted project proposal. Only work packages which are relevant within year one are mentioned.

WP 0 – Project Management (months 1 - 48)

- In May the first steering committee meeting took place in Brussels. Feedback from the steering committee and comments on this feedback from the project members is included in this annual report (see section 5).

WP 1 – Data set assembly (months 1 – 48)

- An FTP site was set up on the LHWM lab server for easy sharing of project data between the partner organizations.

WP 2 – Remote Sensing Data Processing (months 1 – 36)

- SMOS brightness temperatures, SMOS soil moisture values and the first available SMAP brightness temperature products were preprocessed.

WP 3 – Model Integration (months 1 – 36)

- The WFDEI forcing dataset was processed globally for use in the model simulations

- A mix of ERA-Interim analysis and forecast fields was processed globally enabling the assimilation of present sensors (e.g. SMAP / Sentinel 1). In-situ corrected reanalysis products such as WFDEI are only available within a lag of 1-2 years.

- The CLM (Community Land Model) was set up for the Murray-Darling basin at 0.125 degrees resolution both on the LHWM cluster (2 nodes with 32 CPU's each, 128 GB RAM), specifically installed for the project, and on the Jülich supercomputer JUROPA and its successor JURECA.

- A number of model runs were performed to test the performance of the CLM Land Surface Model by comparing the soil moisture outputs to in-situ validation sites. For the years 2000 – 2012 model outputs at 22 in-situ stations within the Murray-Darling basin correlated well (R=0.76) running the model with the global WFDEI forcing dataset.

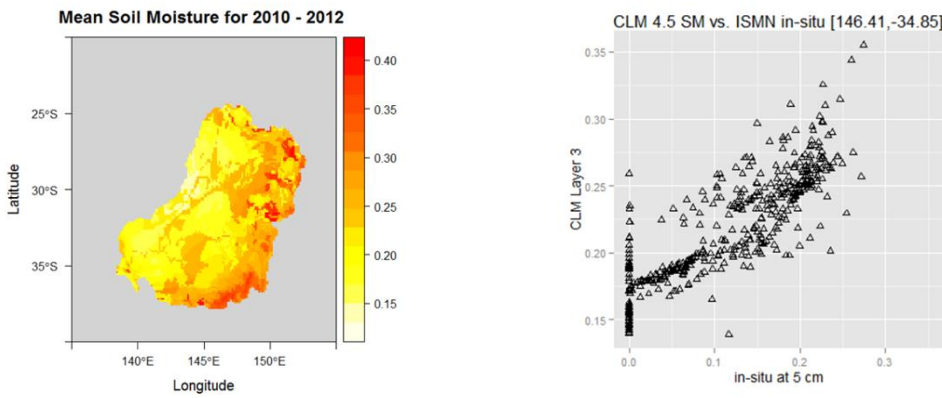

Figure 1: Mean soil moisture for 2010 – 2012 period for CLM 4.5 using WFDEI forcing for the Murray-Darling basin at 0.125 degrees resolution (left). 2D-Scatterplot of modelled and observed Soil Moisture values for one in-situ station (right).

- CLM was set up for the entire Australian continent on a 0.25x0.25 degree grid.

- CLM uses a percentage of Plant Functional Types per grid cell compared to a discrete land cover map with one value per pixel and these model inputs are aggregated from a 3x3 min raw dataset to the model resolution and corresponding LAI and SAI values are disaggregated from a 0.5x0.5 degree raw dataset. We replaced the CLM standard Plant Functional Type dataset with MODIS MOD12Q1 Plant Functional Type dataset at 500 m which is reclassified to CLM Plant Functional Types using WorldClim temperature and precipitation data. MODIS monthly LAI products are computed based on the MODIS MOD15A2 8-daily 500m LAI values. The CLM source code was changed and now supports these non-climatological monthly LAI values.

- The optimal configuration for the conceptual hydrologic model SUPERFLEX, which will be compared to the fully-physical CLM land surface model, was identified and a four reservoir structure will be used.

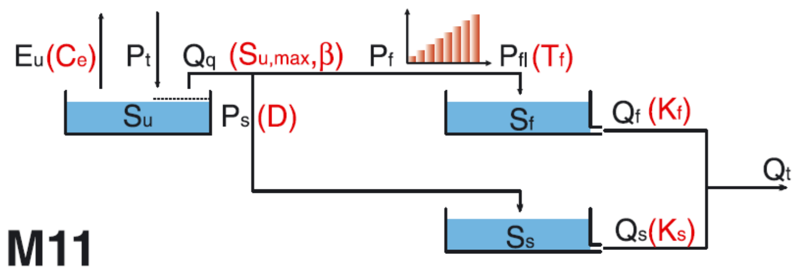

Figure 2: SUPERFLEX model structure selected for the Hydras+ experiments

WP 4 – Data Assimilation Integration (months 12 – 36)

- On the LHWM cluster and the supercomputer the data assimilation system, DasPy is installed and is operational for the Murray-Darling basin for which some code adaptations were necessary. DasPy was also extended and now includes an implementation of the WCM (Water Cloud Model) as an operation operator for backscatter assimilations (e.g. ASCAT, Sentinel 1) in addition to the already coupled CMEM (Community Microwave Emission Model) observation operator for the assimilation of brightness temperatures.

- For the CMEM observation operator a number of offline brightness temperature simulations were performed to develop a good understanding of the parameters involved and simulation results were compared to SMOS brightness temperatures at 42.5 degree incidence angle.

Table 1: Exemplary RMSE values between brightness temperatures observed by SMOS ascending orbit and CMEM simulated brightness temperatures both at 42.5 incidence angle for 2010 – 2012 horizontal and vertical polarisation before and after quantile mapping in order to account for differences in the cumulative distribution functions of modelled and simulated data.

	RMSE 2010	RMSE 2011	RMSE2012	RMSE	Pol
original	23.30 K	22.15 K	21.43 K	22.20 K	H
	27.51 K	25.50 K	23.34 K	25.30 K	V
quantile mapping	10.61 K	12.42 K	11.23 K	11.56 K	H
	10.59 K	12.08 K	10.93 K	11.28 K	V

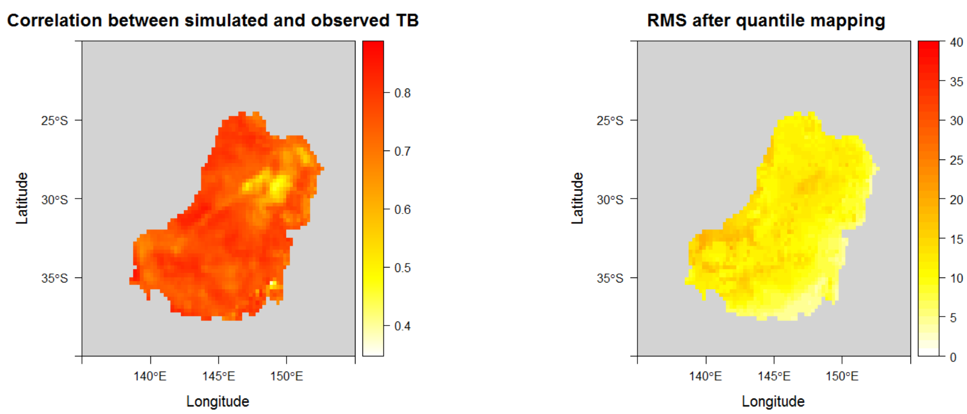

Figure 3: Correlation between observed and simulated brightness temperatures at H polarisation and 42.5 incidence angle (left). RMSE map after per pixel quantile mapping

- In its current state SUPERFLEX does not model soil temperature thus the relationship between in-situ measured soil temperature and measured air temperature as well the relationship between reanalysis air temperature and soil temperature were studied both yielding high correlations of 0.78 enabling the use of near-surface air temperature as a proxy. This simplification suits the framework of Hydras+ well comparing a highly complex fully physical based land surface model and a more simple conceptual model. Brightness temperature simulations based on SUPERFLEX soil moisture and MERRA reanalysis soil temperature showed a slightly reduced RMSE compared to simulated brightness temperatures based on SUPERFLEX soil moisture and MERRA air temperature as a soil temperature proxy compared to brightness temperature simulations performed with in-situ soil moisture and soil temperature. However, calibrating the linear relationship between air temperature and soil temperature based on satellite based brightness temperatures can overcome possible inherent errors of the MERRA soil temperature product.

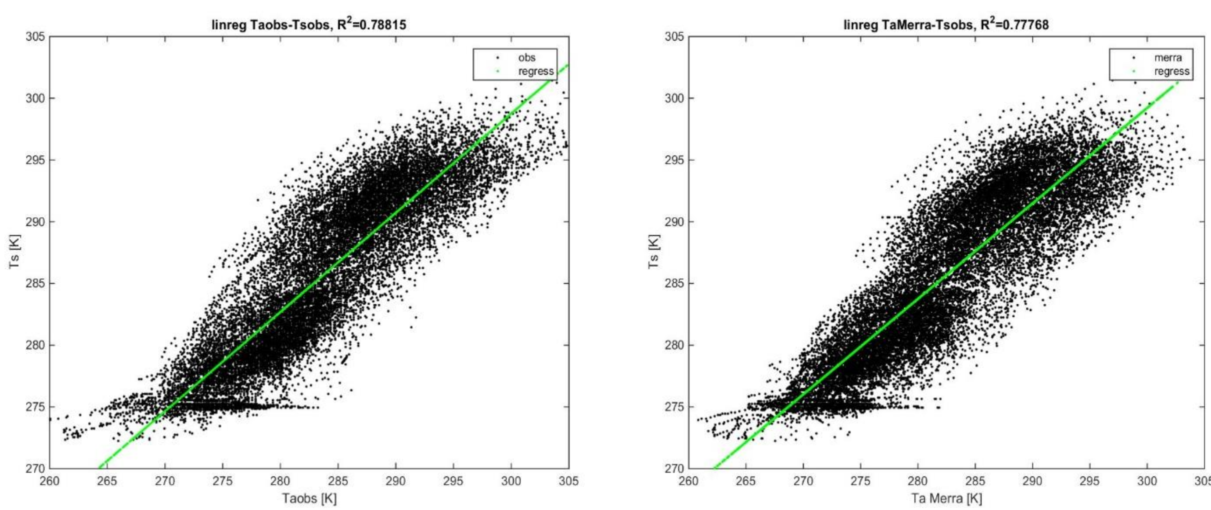

Figure 4: Relationship between in situ measured soil temperature and air temperature (left) and relationship between MERRA-Land air temperature and in situ measured soil temperature (right).

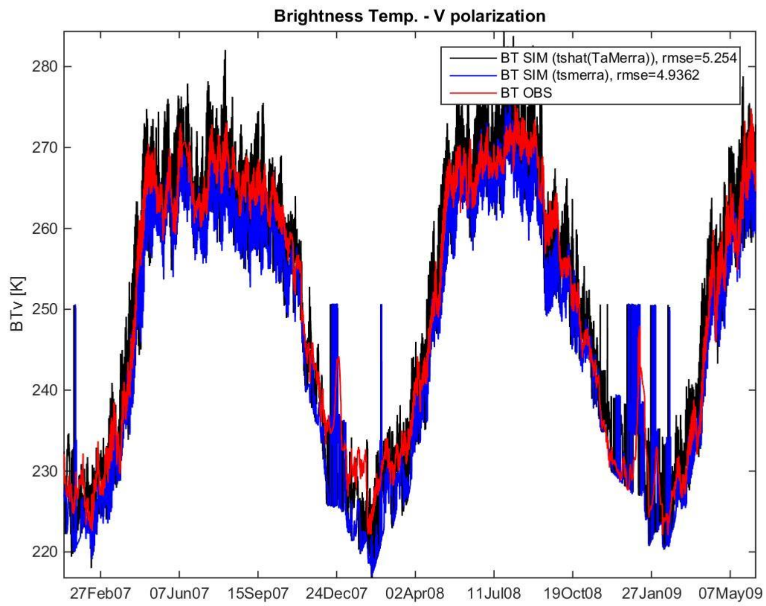

Figure 5: Simulated brightness temperatures at V polarization based on the linear relationship between reanalysis air temperature and soil temperature and SUPERFLEX soil moisture, reanalysis soil temperature and SUPERFLEX soil moisture as well as in-situ soil temperature and soil moisture.

2.2 WORK PLAN FOR NEXT YEAR

Within the first year the data assimilation system for CLM has been set up and is operational in order to carry out a number of data assimilation experiments both with active and passive sensors within 2016.

The first experiments will be performed using data from the SMOS and SMAP satellites after which the assimilation of backscatter data from active systems such as ASCAT will be tested.

The SUPERFLEX modelling framework was analyzed and a fixed model structure to be used for the Hydras+ experiments identified. The lack of soil temperature simulation can be substituted by using air temperature from the forcing data as analyzed in a number of experiments allowing the assimilation of SMOS and SMAP brightness temperatures in the coming year and comparing the results to CLM assimilation experiments.

The existing copula-based downscaling framework (WP 2) will be made more flexible w.r.t. the choice of marginal distributions and copulas per pixel. This framework will be applied to CLM-modeled soil moisture values and SMOS data acquired for the Murrumbidgee catchment. Next, the framework will be extended such that the uncertainty on the coarse-scale observations can be incorporated in order to estimate the uncertainty on the downscaled remote-sensing data. Near the end of 2016, the robustness of framework will be further assessed with respect to downscaling the coarse-scale remote sensing data based on fine-scale remotely-sensed data. If necessary, the framework will be adapted to ensure the preservation of the statistics of the hydrologic model simulations.

DESSIMINATION ACTIVITIES

3.1 MISCALLENEOUS MISSIONS: STAYS AT PARTNER'S ORGANISATION, MEETINGS, CONFERENCES, ...

Dominik Rains, LHWM Ghent
Research visit at FZ Jülich for setting up the data assimilation system DasPy
4.2.2015 – 11.2.2015

European Geoscience Union General Assembly
Poster presentation
12.4.2015 – 17.4.2015

2nd SMOS Science Conference, ESA-ESAC, Madrid
25.5.2015 – 29.5.2015

Earth Observation for Water Cycle Science, ESA-ESRIN, Frascati
Poster presentation
20.10.2015 - 23.10.2015

Several courses on high-performance computing in Ghent / Leuven organised by the Flemish Supercomputing Centre

Carsten Montzka, Jülich

Helmholtz Alliance on Remote sensing and earth system dynamics, Alliance Week, Garmisch-Partenkirchen, Germany

Poster Presentation
22.6.2015 – 26.6. 2015

ESA-NRSCC Dragon Conference, Interlaken, Switzerland
Oral and Poster Pesentation
22.6.2015 – 26.6. 2015

3.2 SCIENTIFIC PAPERS

PUBLISHED

none

SUBMITTED

Rötzer, K., C. Montzka, D. Entekhabi, A. G. Konings, K. A. McColl, M. Piles, and H.Vereecken (submitted): Relationship Between Vegetation Optical Depth and HV backscatter from the Aquarius mission. IEEE Transactions on Geoscience and Remote Sensing

IN PROGRESS

On the Assimilation of SMOS / SMAP Soil Moisture and Brightness Temperatures over Australia using the CLM Land Surface Model and Parameter Estimation (planned submission 03/2016)

3.3 COLLABORATION WITH OTHER PROJECTS

A questionnaire is being prepared and will be distributed to relevant stakeholders (environmental agencies, research institutes, re-insurance …) in order to get feedback on which final products should be disseminated and what the requirements are on drought information.

The questionnaire is being developed in collaboration with the BELSPO funded SAT-EX project (http://www.sat-ex.ugent.be/).

3.4 OTHER TYPES OF OUTREACH

PRESS

None

SOCIAL MEDIA

Relevant results will be spread via social media (e.g. Linkedin)

PHD

PhD students involved did not complete their thesis.

OTHER (AWARDS, GUEST LECTURES, WEBINAR, …)

Verhoest N.E.C., Using remote sensing for detecting the global impact of climate extremes on vegetation and improving drought monitoring programs, Space4Food, World Exposition, Milano, Italy, June 11, 2015.

Montzka, C., Mikrowellenfernerkundung zur Bodenfeuchtebestimmung. Indikatorgestütztes Bodenfeuchte Monitoring (InBoMo) Workshop, Potsdam, Germany, November 3, 2015 (Invited Presentation)

STEERING COMMITTEE

4.1 COMPOSITION / CHANGES IN COMPOSITION

none

4.2 REPORT OF STEERING COMMITTEE

Below text was disseminated to the project partners by BELSPO in May 2015 on behalf of the steering committee as the initial steering committee report.

Overall Assessment

First of all, we coincide that the consortium is dealing with very relevant and interesting research questions, which will add a good value to the scientific community in the domain of hydrology. There is indeed some very interesting work going on within the groups that should make great strides towards optimal methods for assimilating multi-sensor data for improved monitoring.

Recommendations

There is a concern that the workload imposed and project objectives are too ambitious, which may endanger successfully reaching the four main objectives of the project. The models proposed, data assimilation techniques and methodologies to process remote sensing data involve a great number of parameters and configurations. They cannot all be tested within the project duration, for which different choices/decisions will have to be made. In this sense, it is recommended that the HYDRAS+ consortium set intermediate specific objectives/selections (choice of a model with a defined configuration, choice of data sets to work with, etc.) at earlier stages of the project (every six months for example), which will help to steer the direction of research.

Coordination between the different groups is essential to avoid substantial difference in the progress of each group individually and to avoid bottlenecks. The Steering Committee had the impression that the link between the work of the different teams was not clear. Visits of the key members between the different institutions are encouraged. A set of short-term, intermediate objectives as mentioned in #1 will help with coordination.

Test catchment site and necessity of a different validation site

The choice of the Arkansas-Red as a successful test basin depends a great deal on the availability of data, and we recommend that the group explores this as soon as possible. There are several potential sources of data, including the OK Mesonet network of measurement sites.

There are also many choices for the forcing data for the Arkansas-Red basin. Recommendations of forcing datasets that the group should consider include:

1) the NLDAS-2 1979-present (1hourly, 0.125-deg, full forcing data)
2) Livneh et al (2015) precipitation, tmin, tmax, windspeed only.
3) Other surface climate datasets, such as PRISM, which provide monthly data for precipitation and temperature only.

Other datasets that should be considered for the M-D include:
1) PGF (Sheffield et al., 2006) http://hydrology.princeton.edu
2) WATCH forcing data
3) Australian datasets (e.g. suggest contacting Albert van Dijk at ANU in Australia for details of high-resolution Australian climate datasets)

Long-term time series

Long-term time series of soil moisture and other hydrological variables are needed to understand the usefulness of the products for drought monitoring. For example, to calculate drought indices and evaluate the products and indices for particular drought events requires perhaps 10 years of data and preferable 30+ years. This suggests that products are developed with legacy sensor datasets (e.g. ASCAT, AMSR-E, …) in addition to the focus on more recently launched sensors.

End-users / Stakeholders

Fluent contact with the end-users/stakeholders is necessary in order to produce beneficial products for them. The current idea of using different drought indexes to monitor drought alerts is very vague and they should be agreed with end-users, with a likely more operational vision of what is needed.

Project Deliverables

Project deliverables should be more specific. For example, "comparison between the SUPERFLEX and CLM model" is a very wide deliverable and this could mean many different things. More specific items should help the members of HYDRAS+ to focus their research.

4.3 FEEDBACK TO STEERING COMMITTEE

Below text was communicated to BELSPO in October 2015 by the project partners.

Overall Assessment and Recommendations

The project consortium is aware of the project being ambitious in its nature but we believe all proposed objectives are manageable within the 4 years, since also a substantial amount of knowledge on hydrologic modelling and data assimilation exists for all team members. We agree on having to limit model configurations and parameters tested and accept the proposal of deciding in regular intervals on which specific future analysis should be carried out and which not, always in respect to the current project progress. Decisions taking place every 6 months is reasonable, but might change depending on the workload associated to each individual research goal. In the near future, we will come up with a more detailed project plan including specifically the experiments we wish to perform, the expected time required for each experiment as well as decision points.

The tasks for which each of the project groups are responsible are well defined in the project proposal. One two-week exchange between UGent and FZ Jülich has already taken place and more exchange visits should follow during the project lifetime. This is supported by the fact that all project partners are geographically close to each other. Table 1 gives an overview of already carried out and future research visits. To further help to synchronize progress between all partners we will additionally have a bi-monthly teleconference and for larger milestones in person meetings.

Table 2: Overview of research visits

Guest	Host	Duration	**Timeframe**	Reasoning
UGent	FZ Jülich	1 week	February 2015	Data Assimilation introduction & installation
LIST	FZ Jülich	1 week	Spring 2016	Data Assimilation introduction & installation
UGent	FZ Jülich	1 week	Fall 2015	Data Assimilation details
LIST	FZ Jülich	1 week	Spring 2016	Data Assimilation details
LIST	UGent	1 week	2016	Synchronization of modelling activities
UGent	LIST	1 week	2016	Synchronization of modelling activities
UGent	TU Vienna	1 – 3 months	mid 2016	ASCAT, Sentinel 1
UGent	ESA/ESRIN	max. 3 months	2016/2017	Dissemination, SMOS/SMAP fusion, S1
UGent	Princeton	max. 6 months	2016/2017	Test of usefulness for existing drought monitoring systems, identification of optimal assimilation methodology for practical applications

It is correct that UGent has some experience with hydrologic modelling in the Murray Darling basin and the project partners need to catch up on this. Since the distributed CLM model used by UGent computes on a pixel level it is of no difference if the entire M-D basin or a sub-catchment is modelled, with the exception of required computational power. Therefore, the initial model setup could as well include the entire basin making it unnecessary to set up the CLM model again at a later project stage for the entire basin once the sub-catchment has been tested. Validation is easily performed on sub-catchment or full catchment level once CLM has finished execution and in fact all soil moisture validation data is focused on the Murrumbidgee sub-basin. Project members also participated in the SMAPex campaiain giving access to a range of in-situ data on larger scales.

Test catchment site and necessity of a different validation site

Although the Arkansas-Red basin is described in the project proposal it is still under evaluation if this basin will be actually used within the project. It is very well suited for validation purposes, since a number of in-situ soil moisture and runoff gauges are available. However, within the overall project context a basin might still be selected with prevalent droughts which have a larger impact on society (e.g. in Africa). In the submitted proposal we planned to work on the Zambezi basin, where large impact of our model results might be achieved without duplication of studies already conducted for the US (e.g. US drought monitor). The evaluation committee proposed the use of a US basin because of data availability. Our first concept using one site for validation of our methods and another basin for high societal impact can still be discussed. For the decision on which basin might be ideal in these terms we wish to have an in-depth discussion with the steering committee member Siegfried Demuth from UNESCO.

As a forcing dataset we choose the WFDEI forcing (currently available until 2012), since it is an updated version of the WATCH forcing proposed as one possible dataset by the steering committee. WFDEI is based on ERA-Interim with corrections applied by using the CRU dataset, which is generated from in-situ observations. ERA-Interim is believed to be the currently best reanalysis product available and thus we favor the WFDEI forcing to other in-situ corrected products based on other reanalysis datasets, e.g. NCEP. For more present data assimilation experiments, it is possible to use the original ERA-Interim reanalysis but we hope and think it is realistic that within the project lifetime the WFDEI forcing will be updated although no guarantee can be given. Since both WFDEI and ERA-Interim are global datasets the decision on which second basin to include within the project will have no influence. This was another reason for choosing an in-situ corrected global reanalysis forcing over locally available forcing datasets.

Table 3: Forcings and validation data (Australian basin)

Geophysical variable	Dataset
Meteorological Forcings	WFDEI (until 2012) / ERA-Interim (- present)
Soil moisture validation data	OzNET
Streamflow validation data	BOM (Bureau of Meteorology, Australia)

Long-term time series

The project consortium will perform data assimilation experiments based on long-term ASCAT observations in order to test drought indices. Within this scope a research visit to the Technical University of Vienna is planned, which is the prime data provider for ASCAT based soil moisture data.

End-users / Stakeholders

HYDRAS+ does not attempt to setup a new drought monitoring system but aims at improving methods for satellite data assimilation, which then can be integrated into existing drought monitoring systems, which were setup with specific end-user requirements in mind. The project consortium actually has a link to Princeton University with a research visit taking place at Princeton once methods have reached a useful degree of maturity. An in-depth review of the benefits of the different data-assimilation schemes developed should be carried out evaluating the usefulness within a drought-monitoring context. The development of the methodologies, e.g. the resolution to which coarse-scale satellite observations should be rescaled to, is influenced by end-users and therefore we would like to establish a strong link to UNESCO via Siegfried Demuth who is an ideal partner for collecting end-user requirements in drought-prone areas.

Project Deliverables

The main project deliverables should be disseminated via a set of key publications summarizing the carried out experiments and their results. Table 3 gives an overview of possible key publications spanning the research areas although experiments, e.g. specific sensor combinations, might change during the project lifetime. The due date corresponds to the date of submission and are no guarantee, although they are realistically chosen. To keep the key publications on track, intermediate results are frequently presented at conferences via oral or poster presentations. All developed datasets and algorithms/methods are archived and made available to ensure full transparency.

Table 4: Project deliverables

Nr.	Deliverable	Due Date
1	CLM data assimilation using dual-state parameter optimization with SMOS	03/2016
2	Assimilation of brightness temperatures into a conceptual model for improved drought monitoring	08/2016
3	CLM long term assimilation using ASCAT and the Water Cloud Model, comparison to Vienna product, (extract droughts using existing indices?, maybe in second paper)	09/2016
4	Inter-comparison of soil moisture and brightness temperature data assimilation into a conceptual model for improved hydrological predictions	02/2017
5	Uncertainty propagation of coarse-scale remote sensing data through the copula-based downscaling algorithm	12/2016
6	CLM Sentinel 1 and SMOS assimilation (active / passive, downscaling)	04/2017
7	CLM SMAP assimilation (active? / passive, downscaling)	12/2017
8	Evaluation of methods developed within the project and analysis to which extent the inclusion of these methods into existing early warning is feasible and of great use. Comparison of CLM and SUPERFLEX for drought characterization (probably material for 2-3 papers)	06/2018

ILLUSTRATIVE MATERIAL

Relevant results will be presented as scientific posters and on the project website. Results might also be disseminated in a form more suitable for the general public / stakeholders.

ADDITIONAL INFORMATION

None

ABBREVIATIONS

FTP	File Transfer Protocol
LHWM	Laboratory of Hydrology and Water Management, University of Ghent
SMOS	Soil Moisture and Ocean Salinity Mission
SMAP	Soil Moisture Active and Passive Mission
WFDEI	Watch Forcing Data ERA-Interim
ERA	Extended Reanalysis (provided by ECMWF)
CLM	Community Land Model
CPU	Central Processing Unit
RAM	Random Access Memory
JUROPA	Jülich Research on Petaflop Architecture
JURECA	Jülich Research on Exascale Cluster Architecture
LAI	Leaf Area Index
SAI	Stem Area Index
MODIS	Moderate Resolution Imaging Spectroradiometer
DasPy	Python Multivariate Land Data Assimilation Framework with High Performance
WCM	Water Cloud Model
ASCAT	Advanced Scatterometer
CMEM	Community Microwave Emission Model