EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY

SHORT TERM SCIENTIFIC MISSION (STSM) – SCIENTIFIC REPORT

The STSM applicant submits this report for approval to the STSM coordinator

Action number: ES1404
STSM title: Multi-parametric Variational Data Assimilation of Satellite Snow Products through Hydrological Modelling
STSM start and end date: 02/11/2018 - 08/11/2018
Grantee name: Dr. Gökçen UYSAL

PURPOSE OF THE STSM/

Snow observations are valuable in the high altitude snow dominated basins in order to set a proper hydrological modelling as well as weather prediction and climatic models. Snow modelling studies include a wide range of application area using different numerical weather prediction data (both deterministic and ensemble) (Ertaş et al., 2016) and different estimation approaches (Şensoy and Uysal, 2012); novel modelling techniques using different observations such as ground measurements, satellite snow data (Uysal et al., 2016) and different modeling environments such as SRM and HBV (Uysal et al., 2015). In the modelling studies, Remote Sensing (RS) snow data are provided from different satellites having different temporal and spatial resolutions.

Nowadays, integration of RS snow data and ground snow measurements into Data Assimilation (DA) applications for an operational system receives growing attention. DA methods are useful techniques that help model developers in many disciplines as a result of decreasing the uncertainties by updating the model states and improving initial conditions. Besides, RS data are very valuable for data sparse regions like Turkey, thus studying and practicing DA techniques with snow observations will contribute for better representation of models in this region. Most of the existing implementations of DA in hydrology have focused on the assimilation of streamflow data and DA becomes very important process in hydrological modelling due to its ability to correct the model estimates of the snow state by using observations.

Dr. G. Uysal, the applicant, is currently a researcher within the Department of Civil Engineering in Eskişehir, Turkey. He is eager to extend his background throughout snow DA methods, to improve our model results with state-of-art techniques and understand the snow modelling processes in deeply. Mr. R. Alvarado-Montero has extensive experience in these topics and the host institution, Deltares, located in Delft (Netherland), is a non-profit institute for applied research in the field of water.

There are different sources of uncertainty in hydrological forecasting such as: model input data, initial conditions and model structure (due to parametric and structural uncertainty). The uncertainties of the initial conditions are mainly tackled with DA methods. Concerning the importance of snowmelt in the mountainous Eastern Turkey and the limited availability of data, incorporating different DA techniques with different snow data sources is very crucial in the runoff predictions over the region. Considering these, the applicant and the host had proposed and applied a Short Term Scientific Mission (STSM) on conceptual hydrological model (HBV) with variational DA techniques using satellite snow products as a case study in the Upper Euphrates

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Basin (Karasu), Turkey. Preliminary results showed that there is an improvement in terms of discharge forecast in comparison with no DA model results. Since Snow Cover Area (SCA) is one of the important element of snow melting process, the accuracy of SCA play important role to have a reliable model. Therefore, the model outperform in SCA statistics when SCA becomes an additional assimilation variable. In general, the performances were improved with variational DA (VarDA) technique by assimilating both discharge and SCA. Moreover, a joint work together with other colleagues (Aynur Şensoy and Antonio Collados) and a comparative assessment of the model results with different methods (sequential methods) and different snow dominated basins (Karasu Basin from Turkey and Canales Basin from Spain) was done during this study. A joint scientific paper is being prepared considering different methods and implementations from STMSs (Alvarado et al., in preparation).

On the other hand, the developed hydrological forecasting system can still be improved in terms of the other uncertainties. Among them, the uncertainty of the model structure is very important since in each implementation same model and same parameter sets are used. Generally this uncertainty is considered using multi-modelling methods. In order to make use of this approach, a follow-up study is intended to implement a novel approach (Alvarado-Montero et al., 2017) that generates a probabilistic estimate of initial states using a multi-parametric modelling method based on the VarDA. It is very convenient to conduct this new study considering previously dedicated data and VarDA model implementation in the same area of interest. At the end, several purposes are targeted in this STSM as:

i. The visit has contributed to applicant’s useful knowledge on model uncertainty of hydrological models with an expected better prediction by multi-modelling approach.
ii. The important piece of knowledge on model uncertainty is shared by implementing a novel multi-parametric variational DA (which has been developed by Alvarado-Montero et al. 2017) for hydrological forecasting in a mountainous catchment in Turkey.
iii. The outcomes of this visit provide a detailed comparison of different advanced techniques using snow observations such as single (deterministic) VarDA and multi-parameteric (probabilistic) VarDA.
iv. The follow-up STSM has a great impact on the improvement (quality) of the scientific paper which is being prepared. Therefore, the results are elaborately investigated from the point of view of initial conditions and structural uncertainty in terms of parametric way. Thus, the DA method becomes more robust against different sources of uncertainties.

DESCRIPTION OF WORK CARRIED OUT DURING THE STSMS

For this study, the variational data assimilation (VarDA) approach is based on the Moving Horizon Estimation (MHE) formulation described in Alvarado-Montero et al. (2017). Therein, the hydrological model can be described in a time discretization according to:

$$x^k = f(x^{k-1}, u^k, d^k, p) \quad (1)$$
$$y^k = g(x^k, v^k, d^k, p) \quad (2)$$

where x, y, d are the state, output and external forcing vectors, respectively, u, v are noise terms, p is the model parameters vector, $f()$ and $g()$ are functions representing arbitrary linear or non-linear components of the model, and k is the time step index.

This study is conducted by extended version of deterministic VarDA (referred to the multi-parametric variational data assimilation, MP-VarDA) to assimilate information into a pool of M number of model instances, according to:

$$\min_{u,v} \sum_{m=1}^{M} \left(p_m \sum_{k=-N+1}^{0} \left(w_x \left\| \hat{x}^k - x^{k,m}(u) \right\| + w_y \left\| \hat{y}^k - y^{k,m}(u,v) \right\| + w_u \left\| u^k \right\| + w_v \left\| v^k \right\| \right) \right) \quad (3)$$

Subject to:

$$u_L \leq u^k \leq u_U \quad (4)$$
$$v_L \leq v^k \leq v_U \quad (5)$$

where $\hat{x}$ and $\hat{y}$ are observations of the state and the dependent variable vectors, respectively, w_x, w_y, w_v are weighting coefficients to define the trade-off between different penalties, ||.|| is a suitable norm penalizing the deviation between observed and simulated quantities as well as the amount of noise introduced by the data assimilation procedure. Note that the optimization setup modifies the noise variables u^k and v^k to find the minimum value of the objective function. Furthermore, the noise terms get bounded by inequality constraints which consider constant lower and upper bounds during the complete assimilation period.

Generalized Likelihood Uncertainty Estimation (GLUE) (Beven, 2009) is used to create a model pool based on previously calibrated model.

$$-p_{i,cal} * F_{var} \leq p_{i,m} \leq p_{i,cal} * F_{var} \quad (6)$$
$$p_{i,L} \leq p_{i,m} \leq p_{i,U} \quad (7)$$

where $p_{i,cal}$ is the parameter i of the calibrated set, F_{var} is a variation factor, $p_{i,m}$ is the modified parameter bounded to the lower and upper bounds $p_{i,L}$ and $p_{i,U}$ respectively. The parameters $p_{i,m}$ are generated using the Monte-Carlo method.

The produced models include large set of parameters sets, thus it is also critical to have a representative set of number in the VarDA implementation. In this study two different methods (Fast-Forward, FF, (Gröwe-Kuska et al., 2003**)** and Aggregated Distance, AD, are used to establish a reduced number of parameter sets while keeping the maximum amount of parametric uncertainty in the remaining sets.

Since the variational methods use optimization algorithms to minimize an objective function, the trade-off is done in between the amount of noise introduced into the model and the distance between simulated and observed variables. Different than single VarDA, MP-VarDA optimize the function using multiple model instances. To that end, discharge and satellite SCA data are assimilated by using noise terms of states and forcings such as precipitation and temperature as indicated in Table 1. The probabilistic initial values are produced by MP-VarDA, and ensemble forecasts are produced with probabilistic initial states and multi-model structure.

Table 1. Set up of MP-VarDA models

MP-VarDA model pool	Weight of Observations		Range of Noise Terms (weight at 1.0)				
	Q	SCA	P (%)	T (°C)	SM (mm)	UZ (mm)	LZ (mm)
5 model instances	10	1	1.3, 0.7	2.0, -2.0	5.0, -5.0	5.0, -5.0	5.0, -5.0

where Q, SCA, P, T, SM, UZ and LZ stand for discharge, snow cover area, precipitation, temperature, soil moisture, upper zone, lower zone, respectively.

DESCRIPTION OF THE MAIN RESULTS OBTAINED

The developed methodology is applied to Upper Euphrates (Karasu) Basin which is located in the eastern part of Turkey and forming the headwaters of the Euphrates River Figure 1. The basin with a drainage area of 10,275 km^2 has an elevation range from 1125 m to 3500 m and a hypsometric mean elevation of 1983 m. The main land cover types are pasture, cultivated and bare land. Snowmelt runoff in the mountainous eastern part of Turkey is of great importance as it constitutes approximately 2/3 in volume of the total yearly runoff during spring and early summer months. Long term studies indicate that around 60-70% of the total annual volume of water comes during the snowmelt season (March-June). Furthermore, Karasu Basin is divided into 10 elevation zones between 1125-3500 m.

The required input data for HBV model are Precipitation (P), Temperature (T) and Potential Evaporation (PE). In this study, P and T data are provided from zone based areal distributed values whilst PE data are given as same to all zones.

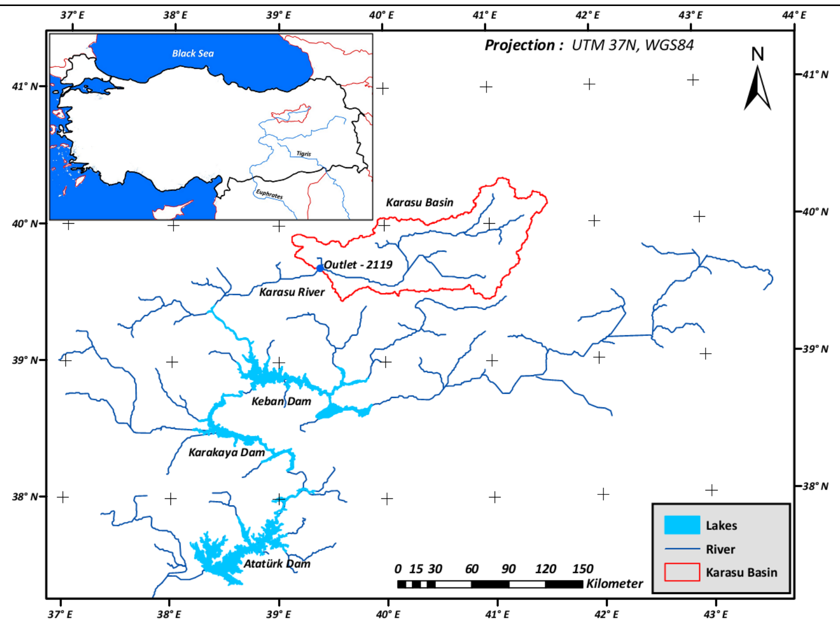

Figure 1. Location of Karasu Basin and Euphrates River

Preliminary results from the STSM work are presented in this part in accordance with description of the work. Previously calibrated HBV model and parameters having 0.84 of Nash-Sutcliff model efficiency is used as a basis. The first task is to find multiple parameters sets which are above the performance obtained during calibration period. The variable model parameters $p_{i,m}$ are generated using the Monte-Carlo method based on Generalized Likelihood Uncertainty Estimation (GLUE) (Beven, 2009) and previously calibrated parameters (deterministic case). To that end, the model pool is using F_{var} of 30 % with respected to calibrated parameter set generate 1,000 Monte Carlo generations. Only 800 of the produced models having different parametrization from all simulations has been selected considering performance threshold (with model performance above 98 % of the calibrated model for each of the model pools obtained from different variation factor). Later, the parameters are reduced to five instances based on two different (FF and AD) reduction techniques. The average distances are presented in comparison with three random selections (Figure 2).

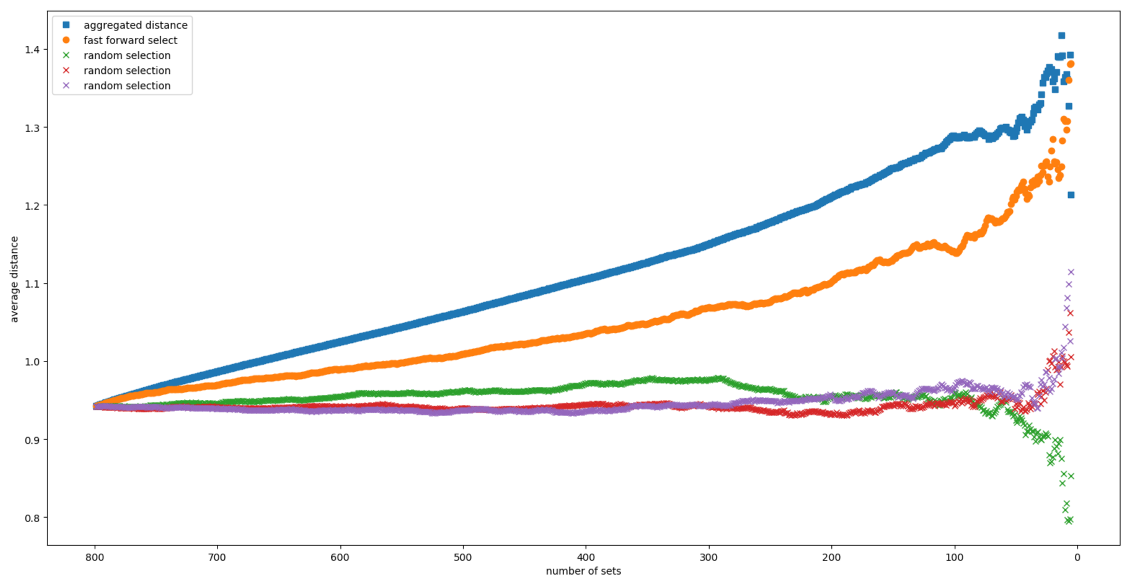

Figure 2. Comparison of different reduction techniques in terms of average distances

Later, the parameter sets (5 different) are implemented into HBV model to end up with multi-model hydrological model results. The first configuration is intended to have a multi-model ensemble streamflows in FEWS. Figure 3 shows 5 multi-model ensemble streamflows which are produced for 2007 water year. Here, there is no updated for initial states and the whole period is simulated with multi-model parametrization. The purple line indicates the observations, while the remaining are produced with selected parameter sets. This part is critical for both VarDA and also forecasting part.

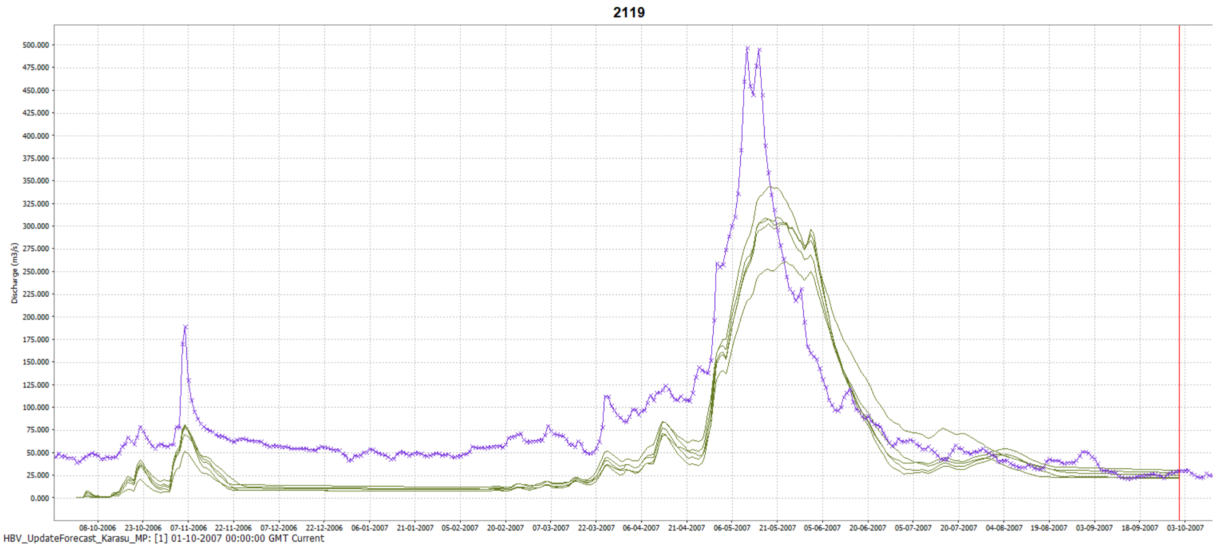

Figure 3. Multi-parametric modelling method application using model pool parametrization (example from 2007 water year)

In the final part of the study, both discharge and satellite snow data are assimilated in Multi-parametric VarDA that generates a probabilistic estimate of initial states using a multi-parametric modelling approach based on the MHE variational data assimilation. In each time step (daily), the execution is repeated by 180 days of assimilation windows and 10 days of forecast horizon. Figure 4 represents different time step ensemble discharge forecasts based on MP-VarDA updates for the initial states. Multi-parametric VarDA can provide more robust results by having probabilistic initial states (covering initial state uncertainty) and ensemble forecasts (covering model based uncertainty) rather than single VarDA method.

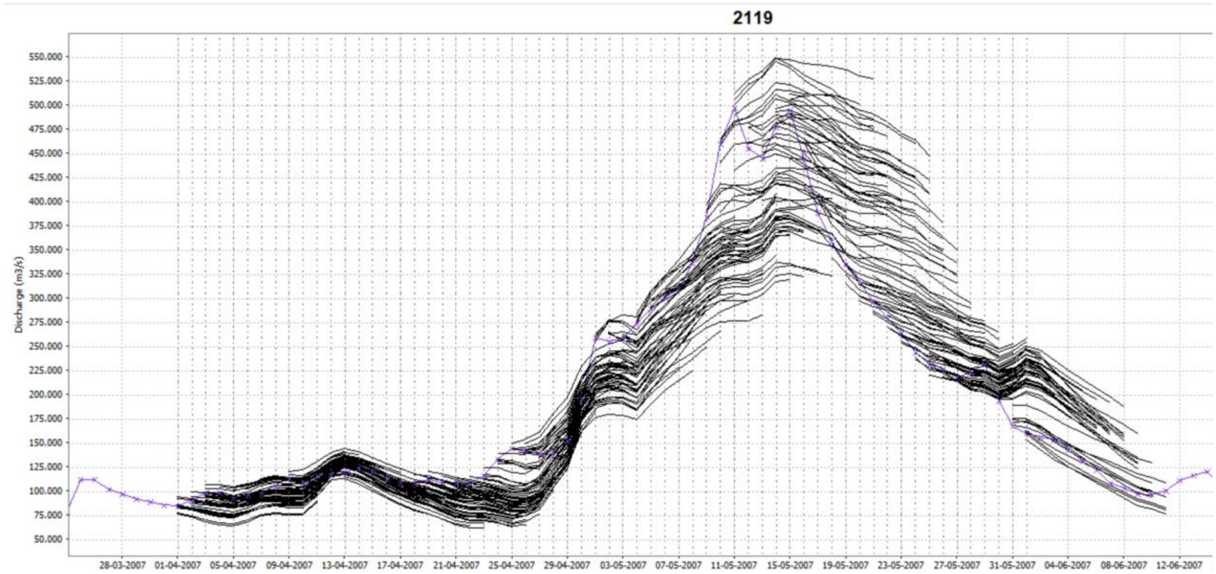

Figure 4. Multi-model forecasts having updated initial states by MP-VarDA for different days with 10 days leadtime (example from 2007 water year)

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FUTURE COLLABORATIONS (if applicable)

The joint work is resulted with possible further activities as summarized below:

1. The model results will be compared with previous STSM results having deterministic VarDA under hindcasting experiment.
2. The possible future work of testing different model pool sets which might lead to a new scientific paper is discussed.
3. It is also expected to growth ongoing international cooperation between the institutes for future studies with new project proposals.