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EFFECT OF DIFFERENT HYDROLOGICAL MODEL STRUCTURES ON THE ASSIMILATION OF DISTRIBUTED UNCERTAIN OBSERVATIONS OF DISCHARGE

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The reliable evaluation of the flood forecasting is a crucial problem for assessing flood risk and consequent damages. Different hydrological models (distributed, semi-distributed or lumped) have been proposed in order to deal with this issue. The choice of the proper model structure has been investigated by many authors and it is one of the main sources of uncertainty for a correct evaluation of the outflow hydrograph. In addition, the recent increasing of data availability makes possible to update hydrological models as response of real-time observations. For these reasons, the aim of this work it is to evaluate the effect of different structure of a semi-distributed hydrological model in the assimilation of distributed uncertain discharge observations. The study is applied in the Brue catchment, located in UK. The first methodological step is to divide the basin in different sub-basins according to topographic characteristics. Secondly, two different structures of the semi-distributed hydrological model are implemented in order to estimate the outflow hydrograph. Then, synthetic observations of uncertain value of discharge are generated as a function of the observed and simulated value of flow at the basin outlet, and assimilated in the semi-distributed models using a Kalman Filter. Finally, different spatial patterns of sensors location are assumed to update the model state as response of the uncertain discharge observations. The results of this work pointed out that different model structures can provide different improvements of model performances, and, different optimal location of the sensors.

INTRODUCTION

Regarding to uncertainty in hydrological modeling, data assimilation methods are an important tool used to integrate real time observations of hydrological variable, (such as soil moisture, discharge, water level, etc.) into hydrological models to reduce model uncertainty. Several studies were carried out to assimilate hydrological observations using different types of hydrological models, as lumped (Weerts and El Serafy [10]), semi-distributed (Chen et al. [1]) or distributed (Clark et al. [2], Rakovec et al. [8]). Lee et al. [5] used a variational assimilation method to assimilate streamflow observations and update the state of a lumped, semi-distributed and distributed model. They found out that the best results are obtained in case of distributed model with the updating frequency of one hour. On the other hand, the influence of different model structure on the assimilation of real-time observations was barely treated in hydrologic research. For these reasons, the main objective of this work it is to evaluate the effect of two different structures of a semi-distributed hydrological model on the assimilation of synthetic uncertain observations of discharge. The results of this work pointed out that, overall, the assimilation of uncertain observations can improve the hydrologic model performance. In particular, it is found that the model structure is an important factor, of difficult characterization, since can induce different forecasts in terms of outflow discharge.

STUDY AREA AND HYDROLOGICAL MODEL

The case study is located in the Brue catchment, in Somerset, South West of England. The streamflow network is derived from a SRTM 90m resolution. For this study, the average precipitation value in each sub-basin is estimated using the Ordinary Kriging, which allows for optimal interpolation of point data from the rainfall station information (Matheron [6]).

The flow hydrograph at the outlet section of the basin is estimated using a semi-distributed hydrological model (average drainage are of the sub-basins around 2 km^2) in order to take into account the spatial variability of the uncertain distributed observations. The first step in the estimation of the discharge hydrograph at the outlet point of each sub-basin is the assessment of the direct runoff which is estimated using the Soil Conservation Service Curve Number (SCS-CN) method. Then, this information is used as input into the lumped conceptual model of the single sub-basin. For this purpose, a Discrete Kalinin-Milyukov-Nash (KMN) Cascade model (Szilagyi and Szollosi-Nagi [9]) is implemented to estimate the outflow discharge. The model has two parameters, n, the number of storage elements in each sub-basin, and k, the storage constant. Finally, the discharge of the sub-basin is propagated, using the Muskingum channel routing method (Cunge [3]).

Two different model structures are assumed in this study. The first model structure can be thought as a series of sub-basins. In such structure, the output from an upstream sub-basin is used as input, in addition to the rainfall observations, in the downstream sub-basins. In the second model structure, which is a common structure in case of semi-distributed and distributed hydrological model, the output of the upstream sub-basins is propagated at the downstream section and sum up with the discharge estimated for the downstream sub-basin. In this case, the sequence of sub-basins is connected in parallel.

DATA ASSIMILATION METHOD

Among the Data Assimilation methods, the Ensemble Kalman Filter (EnKF) (Evensen [4]) is implemented in this study to assimilate the synthetic distributed observations of discharge coming into the model.

In the EnKF the ensemble size has to be chosen carefully since it is closely related to the model error and consequent efficiency of the EnKF (Pauwels and De Lannoy [7]). In this study the ensemble is estimated perturbing the forcing data and the parameters using a uniform distribution with standard distribution function of two parameters ε_I and ε_p. The approach proposed by Pauwels and De Lannoy [7] is used to evaluate the quality of the ensemble spread and estimate the value of ε_p and model realization n_{ens} for the two model structures. As a result of this analysis it is decided to set n_{ens} to 65 while ε_p is equal to 0.9 and 0.5 for the model structure 1 and 2, respectively.

Synthetic distributed observations of discharge are used in order to update the model states and consequent outflow hydrograph. In case of EnKF, these observations are assumed perturbing the vector $\mathbf{Q}_{true}$ with a normal distribution with mean 0 and standard deviation $\alpha\mathbf{Q}_{true}$, with α equal to 0.1 (Weerts and El Serafy [10]).

METHODOLOGY

In order to analyze the effect of model structure in the assimilation of distributed discharge observations, the following methodology is proposed:

A. The NSI of each sub-basin is estimated assuming discharge observations coming only from a given sub-basin per time.
B. Assume only 2 sensor locations in the sub-basin with higher NSI in a main river branch;
C. Assume only 2 sensor location in the sub-basin with higher NSI in an opposite main river branch;
D. Consider only two opposite sub-basins, with higher NSI, located in different branch;
E. Join the sub-basins considered in point 1 and 2;
F. Add, to the point 4, sub-basins having lower Nash value towards downstream;
G. Consider all the sub-basins having higher NSI classes (3 and 4);

RESULTS

The results of step A pointed out how the spatial pattern of NSI is similar in both the model structures. In particular, the higher values of NSI are coming from sub-basins located in the main river channel (order 3 in the Horton classification). In the model structure 1, sub-basins at the outlet section of the Brue basin tends to improve the model performance while the contribution of the same sub-basins in model structure 2 seems negligible. Similar results are obtained by Rakovec et al [8] and Lee et al. [5] in case of distributed hydrological model. It can be observed how, in both the model structures, the assimilation of observations from sub-basins of order 1 provide low value of NSI and consequent irrelevant contribution for the improvement of model performances.

Following the proposed methodology, different sensors locations are obtained for the two model structures. In particular, in both the cases, the sensors locations that provide the best model performance are the ones described in steps 5 and 6. Poor model performances are obtained considering only few sub-basins in one or two river branch (step 1, 2 and 4).

CONCLUSIONS

The main goal of this study is to evaluate the influence of different hydrological model structures in the assimilation of distributed observations of discharge. A semi-distributed hydrological model of the Brue basin, based on the Discrete Kalinin-Milyukov-Nash model, is implemented. Following the proposed methodology, it is possible to define different model improvements according to different spatial patterns of discharge observations. From the results of this study it can be observed that the assimilation of distributed observations using model structure 1 and 2 provide comparable results in terms of forecasting improvement. Different location of optimal sensors locations are obtained according to the different used model structure. In general, it can be concluded that integration of synthetic observations in both the proposed model structures provides a significant improvement of the model performances and a reduction in the flood prediction uncertainty.

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