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Hydrology and Earth System Sciences Discussions

Interactive comment on "Hydrological real-time modeling using remote sensing data" *by* P. Meier et al.

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We would like to thank the anonymous reviewer for the time spent for in reviewing our manuscript and appreciate the positive and constructive criticism.

The paper by Meier et al. is an interesting study of the application of coarse resolution soil moisture observations for hydrologic modelling. It is one of the first studies in this domain. The paper is of particular interest to the HESS audience considering the recent availability of SMOS, AMSR-E and ASCAT data and the foreseen launch of the SMAP mission. All four missions provide a similar type of observations which so far have not fully been exploited by the hydrologic community.

The results are encouraging as since 3 years data from the ASCAT mission is available. This data has a better temporal coverage and a higher quality. Especially the improved temporal sampling could have a significant positive impact. I therefore would like to encourage the authors to repeat the study with data from the ASCAT sensor in a follow up paper. A follow up study could also investigate if a local calibration of the parameters (on a pixel or subcatchment basis) could improve the results.

- We agree with the reviewer that the method presented in this paper is especially interesting when it is tailored towards the application of the recent satellite based soil moisture data sets.

Before publication in HESS following issues shall be clarified:

1. The setup of the Kalman Filter is not very clear to me. Which state variables are updated? If I understand correctly soil moisture and discharge is used. If both are used it would be interesting to see which of the two has the largest impact on the forecast. For example the model could be run with and without discharge updates.

- As requested by other referees the manuscripts structure will undergo major re-work. We hope the understandability of the article will be improved.

  On page 8819, L.3 we explain that the state variables updated are the surface storage volume S_S and the groundwater storage S_GW. The observation data used is only the discharge since soil moisture is already used as input data. We think that using satellite derived soil moisture to update a hydrological model is a highly interesting approach. However, in our opinion this implies that a much more complicated model which calculates the soil moisture explicitly has to be applied. For this purpose a detailed knowledge of the soil properties is necessary, which is not the case for simple conceptual models as we use.

2. Please give an explanation what deterministic and adaptive mode means.

- We agree that the definitions of the different modeling modes are weak in the present manuscript. We propose a consistent wording where (1) "hindcast" is defined as the application of the forecast model including the updating by the Ensmble Kalman Filter (EnKF) and (2) "deterministic mode" is defined as running the conceptual model itself without updating using EnKF.

3. What is the implication of using the SWI. The SWI is a measure of profile soil moisture which is derived from the remotely sensed surface observations using a simplified infiltration model which is characterised by the parameter T. Strictly speaking the T parameter should be calibrated like the k parameters. Also the question arises how the T parameter impacts the k parameters, clearly they are not independent. Especially in the Luangwa catchment characterised by steeper slopes and faster water flow the use of surface observation instead of the SWI could be beneficial. Also the observation that the model is not capable of correctly reproducing peak discharge could partly be explained by using the SWI. As the model to derive the SWI acts as low pass filter peaks are suppressed.

- We agree that the parameter T of the infiltration model is a model parameter in a strict sense. However, including it in the calibration is only useful if the parameter is sensitive and not or only weakly correlated with the other model parameters. In addition we think that a conceptual model should have as little parameters as possible.

  For the application of surface soil moisture (SSM) data as model input it has to be averaged in time over 10 days (the time step of the model is 10 days due to the availability of rainfall data) and in space to calculate the BWI. This averaging already leads to BWI values which are very similar to the BWI calculated from the soil water index (SWI). The BWI obtained by using the SSM data directly is therefore already a filtered time series.

  T can be considered as a parameter which drives the infiltration velocity. A low value of T corresponds to a quick response of the total soil moisture (SWI) to the SSM, a high value of T corresponds to a slow response of the SWI to the SSM. The influence of the parameter T on the model parameters k_i is shown in tables 1 and 2 below. While T correlates well with the two parameters k_2 and k_3, its influence on the other parameters is generally low. k_2 governs the surface runoff, which is slower with quicker infiltration rate. k_3, which relates the BWI to the total amount of water stored in the subsurface, is higher for slower infiltration.

  The influence on the quality of the fit is marginal even with the simple 10 days average good calibration results can be obtained.

  However, even for the Luangwa catchment the application of the SWI with $T = 20\,\mathrm{d}$ seems to be better than just using the averaged SSM. The concern that the use of SWI instead of SSM suppresses peaks in discharge was found to be not justified. The Nash-Sutcliffe efficiency which is sensitive to the predictive accuracy of peaks is slightly higher if the SWI ($T = 20\,\mathrm{d}$) is used.

4. For the uncertainty of the BWI the authors used a number that comes from a comparison study of SWI and in-situ observations. What is the implication of doing this. The BWI is a different quantity. Mathematically it is a simple average (which should decrease the error), physically it represents a different measure (which could imply that the uncertainty measure can not directly be used). Also to my knowledge the uncertainty was derived using a different T value. Considering the criticality of uncertainty measures in the Kalman Filter I suggest to carry out a sensitivity analysis to investigate how the selected uncertainty influences the results.

- We agree that the uncertainty of the BWI is a quantity which is hard to estimate. Wagner et al. (2003) estimated the upper limit of the SWI measurement error to be 0.03 $m^3\,m^{-3}$ to 0.07 $m^3\,m^{-3}$. The more detailed analysis by Ceballos et al. (2005) found an error between ground measurements and the SWI around

$0.025\,\mathrm{m^3\,m^{-3}}$. Whether these uncertainties can be translated directly to the BWI is unclear indeed. They provide more like a worst case error.

We also agree that the uncertainty of the input data is a crucial parameter for the Ensemble Kalman Filter. However, the uncertainties of the rainfall data are always much bigger than the those of the BWI. With a mean rainfall in one time step of around 30 mm the uncertainty of the rainfall product is 50 mm (RMSE). This implies that the influence of the BWI uncertainty is limited.

The sensitivity analysis reveals that the uncertainty of the BWI has almost no effect on the accuracy of the forecast within an uncertainty range between $0.0\,\mathrm{m^3\,m^{-3}}$ and $0.07\,\mathrm{m^3\,m^{-3}}$(see Fig. 1 and 2).

There is some influence on the uncertainty of the forecast. An increase of the uncertainty by $0.01\,\mathrm{m^3\,m^{-3}}$ increases the standard error of the forecast by approximately 5%.

5. In the results and discussion section there are several statements without further proof. E.g. the authors state on p 8820, l 20 "...the soil properties in the two catchments are similar...", on p 8822, l 2 "...the flow is attenuated by the wetlands...". Although results of the study suggest that the statements are valid they are somewhat speculative without providing any other evidence. Either provide some evidence from an independent source or add a statement that these observations need further proof.

- We agree that the statements made on the soil properties are rather speculative. Since no detailed information on the soil properties is available we will change the sentence on page 8820 from

  "The Kafue River basin shows a very similar value of k_1 which leads to the conclusion that the soil properties in the two basins are similar and that the influence of the size of a watershed on the parameter is marginal."

  to

  "The Kafue River basin shows a very similar value of k_1 which suggests that the soil properties in the two basins are similar. However, due to the absence of detailed information on the soil properties in the area this statement can not be verified. The influence of the size of a watershed on the parameter k_1 is marginal."

- The attenuation of flow in the wetlands of the Zambezi River is described for example in Vörösmarty and Moore (1991) and in Winsemius et al. (2006). The wetlands in the Upper Zambezi basin and the Kafue basin, the Barotse Plains and the Lukanga Swamps, are not mentioned in the manuscript. To improve the structure of the article we will introduce a new section "2. Study area". In addition to the information on the physical properties of the watersheds provided in the manuscript, some geomorphological information will be included.

6. In the discussion the authors state that a better spatial and temporal resolution will greatly improve modelling efforts. I don't understand this statement in the context of this study. While the impact of a better temporal resolution is evident the impact of a better spatial resolution is not clear considering that the data is anyway average over the entire basin.

- Besides the obvious improvement of such models which can be achieved with data at a higher temporal resolution, higher spatial resolution could be beneficial for several reasons. The ERS scatterometer data have a resolution of $50 \times 50\,\mathrm{km^2}$ (with a pixel size of $12.5 \times 12.5\,\mathrm{km^2}$). This is relatively large, the Kafue River Basin for example is covered by around 900 pixels only. The averaging over a large area causes the model not to be able to capture peak discharges especially in areas where rainfall from thunderstorms dominate. In such areas small thunderstorm cells can cause high discharges if they hit an area with already high soils moisture. By averaging the rainfall and the soil moisture over the whole area this is not the case anymore.

A better model could therefore be built if one divides the whole catchment into sub-catchments. However, if one tries to apply the method to watersheds which are small compared to the pixel size of the soil moisture data, the single pixel values become more important. Thus a stable BWI can not be calculated anymore.

References

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Wagner, W., Scipal, K., Pathe, C., Gerten, D., Lucht, W., and Rudolf, B.: Evaluation of the agreement between the first global remotely sensed soil moisture data with model and precipitation data, J. Geophys. Res-A., 108, 4611–4626, 2003.

Winsemius, H. C., Savenije, H. H. G., Gerrits, A. M. J., Zapreeva, E. A., Klees, R.: Comparison of two model approaches in the Zambezi river basin with regard to model reliability and identifiability, Hydrol. Earth Syst. Sci., 10, 339-352, doi:10.5194/hess-10-339-2006, 2006.

Table 1. Influence of the parameter T on the model parameters k_i in the Kafue river basin. To give an estimate on the goodness of the fit the root mean square error (RMSE) and the Nash-Sutcliffe efficiency (E) are calculated. For the 10 day average the arithmetic mean was calculated from the SSM measurements available within the time step.

	k_1 ($\times10^{-5}$)	k_2	k_3 ($\times10^{3}$)	k_4	RMSE	E
10 days average	6.66	0.19	3.01	0.12	111.0	0.78
$T = 5\,\mathrm{d}$	6.33	0.21	3.55	0.12	108.0	0.79
$T = 10\,\mathrm{d}$	5.80	0.22	4.47	0.12	104.8	0.80
$T = 20\,\mathrm{d}$	5.00	0.29	5.61	0.13	99.2	0.82
$T = 30\,\mathrm{d}$	4.82	0.34	6.03	0.14	97.8	0.83

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 7, 8809, 2010.

Table 2. Influence of the parameter T on the model parameters k_i in the Luangwa watershed. To give an estimate on the goodness of the fit the root mean square error (RMSE) and the Nash-Sutcliffe efficiency (E) are calculated. For the 10 day average the arithmetic mean was calculated from the SSM measurements available within the time step.

	k_1 ($\times 10^{-5}$)	k_2	k_3 ($\times 10^{3}$)	k_4	RMSE	E
10 days average	17.6	0.34	7.36	0.28	550.9	0.71
$T = 5\,\mathrm{d}$	16.3	0.39	8.67	0.30	561.5	0.69
$T = 10\,\mathrm{d}$	12.1	0.47	15.2	0.29	526.6	0.73
$T = 20\,\mathrm{d}$	10.4	0.68	18.1	0.35	513.7	0.74
$T = 30\,\mathrm{d}$	13.6	0.73	13.5	0.43	523.8	0.73

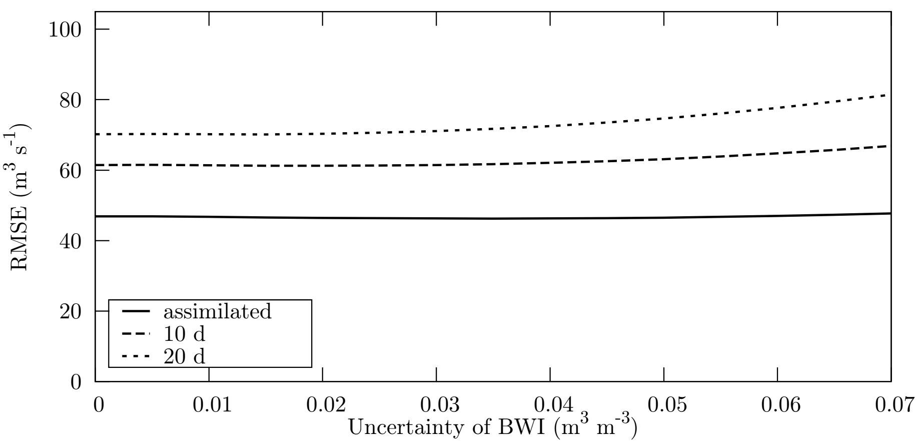

Fig. 1. Effect of the uncertainty of the BWI on the RMSE of the predicted discharge in the Kafue River basin (10 d and 20 d) and of the model error at the time of data assimilation.

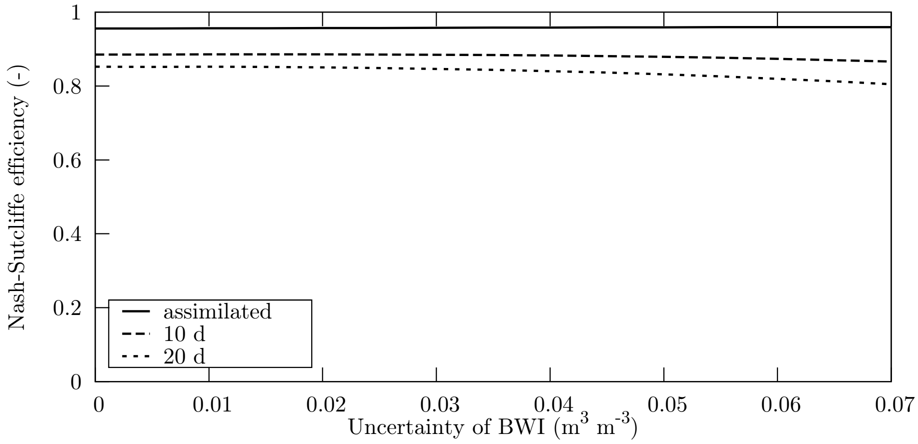

Fig. 2. Effect of the uncertainty of the BWI on the Nash-Sutcliffe efficiency of the predicted discharge in the Kafue River basin (10 d and 20 d) and at the time of data assimilation.