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Hydrology and Earth System Sciences Discussions

Interactive comment on "Assimilation of ASCAT near-surface soil moisture into the French SIM hydrological model" *by* C. Draper et al.

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We appreciate Dr Agashe's interest in our paper. Dr Agashe's comments are reproduced below, with our response to each comment provided as a bullet point.

This is an interesting study that has attempted to correct the SIM model random errors and biases by assimilating the surface soil moisture observations. Authors have substantially examined the effect of the assimilation experiments over the model performance; specifically over the water balance elements. However, there is still room to improve the manuscript further. These points include:

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Interactive Discussion

Discussion Paper

1) In the past, many studies have attempted to perform on-line and off-line corrections of biases during the assimilation of the observations. As Dee and Da Silva (1998; Data Assimilation in the Presence of Forecast Bias) have performed, bias corrections are generally done to correct "short-term forecast" biases. Furthermore, as Dee and Da Silva (1998) says, "unless bias is explicitly accounted for, it can be reduced only at the expense of increasing the noisiness of the analysis" (shown in their fig. 1). Hence, it is expectedly a better way to first correct the anticipated long-term bias in the system and then perform the assimilation of observations to reduce the random errors of the system. However, in this study, the goal of the study is setup over the use of observations to reduce the long-term bias rather than the random errors of the system. Could authors elaborate the performance gain and loss of this assimilation system due to the setup selection in this study in the context of the bias and the random errors?

- In this instance a bias-aware assimilation will not be useful, since the principle variable that is being analysed (root-zone soil moisture) is not observed, and a bias aware assimilation of soil moisture cannot estimate the bias in layers for which no observations or knowledge of the truth is available (de Lannoy et al, 2006). However, the original submission did not sufficiently deal with the issues surrounding biases in these experiments, and the paper has now been substantially rewritten to better deal with the implications for data assimilation of i) the biases between the SIM_NRT and SIM_DEL soil moisture, and ii) the finding that a bias-blind assimilation of CDF-matched (unbiased relative to the model) soil moisture influenced the model biases. Please see the response to Wade Crow's comments.

2) In general, in a forecasting system, every bit of information should be incorporated in the system to obtain the best model forecast. Given the awareness of the dry bias, can authors tell why a forcing bias correction before the assimilation was not performed? There are so many precipitation observations obtained from rain gauges, radars, and

satellites exist; a potential bias correction can be done in many different and much simpler ways, without performing complicated data assimilation techniques. Following the above comment, correcting the bias before the assimilation of observations could potentially further reduce the noisiness of the system too. Without the bias correction, the question, would replacing the existing forcing with an unbiased forcing without the assimilation of the observations give better results than biased forcing simulations with assimilation, would always remain. Hence, it is recommended that authors would also include some simulations (open loop and assimilation) that uses forcing that is corrected for bias.

- We agree that addressing the precipitation bias will improve the performance of SIM_NRT, and that this is an important direction for research. However, the SAFRAN precipitation used in the NRT SIM model is already a sophisticated analysis, utilising all relevant observations available at the time of the analysis (including data from > 1000 rain gauges). The errors in these estimates have been diagnosed only by reference to the delayed cut off SAFRAN analysis, which utilises additional data that are reported once monthly (and so are not available to the NRT SIM). The bias in the NRT precipitation are not constant in time, and it is not straight forward to design a bias model with which to correct it. However, there are several current projects which explore methods that could be used to improve the precipitation in the NRT SAFRAN analysis. One option being explored is to replace the precipitation analysis currently used in SAFRAN with one based on the CANARI OI scheme (Taillefer, 2002), which could eventually provide improved near real time precipitation fields. Additionally, Mahfouf and Bliznak (2011) present a method for applying innovations, derived from radar precipitation observations, directly to the land surface state variables (rather than updating the precipitation field itself).

  Until better precipitation forcing is available (and since there will likely always be errors in precipitation forcing), this paper sought to test whether assimilation of

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ASCAT data might also be useful for correcting SIM. A discussion of how the soil moisture assimilation approach relates to that of correcting the precipitation forcing has been added to the introduction. Additionally, given the difficulties that were encountered in this study related to the non-linear response of the model to the biased precipitation forcing, it is recommended in the paper that approaches based on correcting precipitation biases are likely to be more effective than soil moisture assimilation for preventing the development of root-zone soil moisture biases. Ultimately, the best option will likely be to combine both of these approaches. For example Reichle et al (2011) found that assimilating satellite soil moisture observation and correcting precipitation together generated greater improvements in their model soil moisture skill than applying either of these techniques separately. Also, Mahfouf and Bliznak (2011) show that combining the use of precipitation-based innovations with innovations from a more traditional land surface analysis (based on screen-level observations) can improve the model forecasts.

3) In this study, observations added water into the system even though they were CDF matched and unbiased when compared to the forecasts. The results are intriguing that the observations effected the system in a particular direction (they increased the wetness). This implies that the observations were more correct than the forecast when observations were wetter; and the reverse is also true that observations were less correct when they are drier than model forecast (=higher Kalman gain when observations are wetter and vice versa; so that on average observations would increase the moisture content of the system). This has to be the case, otherwise if the correctness of observations is equally distributed when the observations are wetter or drier than the forecasts, then the cumulative innovation would cancel each other; and eventually, on average, the assimilation system would not get drier or wetter (there wouldn't have been any bias). Given a CDF match is already performed (observations are not biased in any direction), could authors tell why this mechanism exists? (observations are

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more correct when they are wetter than forecasts). Does it exist in other observation systems? Could this mechanism be a reliable mechanism to improve the assimilation studies in general?

- The observation errors used in $\mathbf{R}$ were estimated by calculating the sensitivity of the retrieval algorithm to noise in the ASCAT backscatter observations. Scatter-plots of these error values values show a clear tendency to decrease as the AS-CAT observation becomes wetter (at least within the range of most of the ASCAT data used here), resulting in higher $\mathbf{K}_2$ for wetter ASCAT observations. However, the impact on $\mathbf{K}_2$ of the variability in $\mathbf{R}$ was much less than the impact of the relationship between the observation operator and the model soil moisture. Please see the response to Wade Crow's comments for a more detailed discussion of this.

Lastly, adding the innovation time-series in the same panel with the analysis increments (Figure 7f) could be very helpful in the interpretation of the effect of the observations.

- This Figure is intended to demonstrate how the water balance of the model is affected by the assimilation. We feel that adding in information relating to the ASCAT data would be confusing. We have carefully examined the observation departures for evidence of seasonal behaviour that could have caused the assimilation to favour adding moisture (which is perhaps what the reviewer is looking for here). However, we have found no such relation, and a sentence has been added to the paper to state this.

4) The goal of the study can be clarified, specifically the definition of "benefit". Do authors mean "reducing the random errors of soil moisture analysis of SIM model", or "reducing the bias of the soil moisture analysis of SIM model", or both, "or including other water balance elements"?

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- The aim of the study is described clearly on page 5430. Currently, the initial conditions in the NRT SIM must be periodically reset, and this study "is motivated by the possibility that the near-real time SIM land surface states could be more effectively constrained by assimilating the ASCAT near-surface soil moisture observations". Specifically, "to establish the impact of the assimilation on the modeled hydrological cycle and surface moisture storage; and (ii) to determine whether the assimilation corrected the SIM forecasts for the errors in the near-real time SAFRAN forcing." The SIM forecasts of soil moisture, and also water balance terms that depend on soil moisture are all relevant to this aim, and so have been considered.

5) It is not very easy to get the details of some plots in Figure 7 & 8. Using a scale consistent with the max/min values could help greatly.

- Within each of these Figures, the same resolution has been used for the vertical axes to allow direct inter-comparison between the different panels. Scaling each term between its min and max would exaggerate the importance of the less variable terms, and has not been done. However, sub-panel 7c was not scaled consistently in the initial submission, and this has been amended.

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