Hydrol. Earth Syst. Sci. Discuss., 10, C2432–C2434, 2013
www.hydrol-earth-syst-sci-discuss.net/10/C2432/2013/

Hydrology and Earth System Sciences
Discussions

Interactive comment on "Simultaneous estimation of model state variables and observation and forecast biases using a two-stage hybrid Kalman filter" *by* V. R. N. Pauwels et al.

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Received and published: 11 June 2013

This manuscript presents a hybrid Kalman filtering approach that incorporates both observation and simulation forecast bias and uncertainty. A two stage approach is used whereby the biases are estimated using a Discrete Kalman Filter, and the state variables are estimated using en Ensemble Kalman Filter. The new filtering approach was tested on both a synthetic hydrologic study and a real-world test case using a simple conceptual rainfall-runoff model. The results of the study indicate that the proposed bias aware version of the filter outperformed the bias unaware version for cases where both observation and forecast bias were incorporated simultaneously, and when only

observation bias was incorporated.

This manuscript was well written, well organized, and thorough in its technical content. There are two main contributions made by this study. The first is that this appears to be the first attempt at effectively incorporating both observation and simulation bias simultaneously within a Kalman filtering framework. The results of the study show a clear benefit in this regard. A second major contribution is that the two-stage filtering approach is less expensive computationally, and potentially easier to implement than traditional state augmentation approaches.

The authors do an excellent job of deriving the equations for the two stage Kalman filtering approach. Their detailed mathematical derivation should permit others to utilize their approach within future research and applications. Additionally, appendices are provided for additional details of the derivation. The notation used in deriving the filtering equations is consistent with prior established notation.

I believe that the manuscript should be accepted for publication, pending these minor revisions:

1) Page 5170, line 26: Suggest replacing "various" with perhaps "numerous".

2) Page 5171, line 22: Add "the" before "assimilation".

3) Page 5173, line 9: Change to "time step k by Eq. 1:".

4) Page 5173, line 11: Add "where" to beginning of sentence.

5) Page 5173, line 21: Add "where" to beginning of sentence.

6) Page 5174, line 1: Add "where" to beginning of sentence.

7) Page 5178, line 22-23: Place "on the one hand, the Kalman gains for the system state and forecast bias, and on the other hand the Kalman gain for the observation bias" between em dashes (-).

8) Page 5189, line 19: Need to justify the size of the ensemble chosen. I think you do this in the spread analysis but a sentence is needed here.

9) Page 5190, line 9: Change "It has been found that a too low value" to "It has been found that too low a value".

10) Page 5196, line 29: Change "distribued" to "distributed".

11) Figure 2: I would suggest better differentiating the observed and modeled discharge lines. Since this is an online Journal, I would use color and thickness. Then, when readers print in black and white, they can use thickness. However, having color to differentiate will be extremely helpful.

12) Additional Figure: I would really like to see an example discharge time series showing three lines: (1) Observations, (2) Simulation, and (3) KF forecasts and updates for experiment 2 where both observation and forecast bias were incorporated. While your current figure sequence does a very good job of showing the statistical performance of the approach, I would like to physically see its real-world performance so to speak. In other words, if you were to pick an interesting sub-period from your overall time series shown in Figure 2 (something on the scale of one or two interesting events), and zoom in, what is the KF actually doing over this time period. Where are the forecasts, and where are the updates going? I am very interested from an applications perspective in this approach and would like to see how your two-stage KF could improve forecast capabilities. I think providing a figure such as this would tie everything together very nicely at the end of the manuscript. In other words, you show its statistical performance is superior early on, and end by showing an example of its performance at the event scale.

This was an excellent manuscript and I thank the authors for their careful attention to detail.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 10, 5169, 2013.