Hydrol. Earth Syst. Sci. Discuss., 7, C5329–C5343, 2011
www.hydrol-earth-syst-sci-discuss.net/7/C5329/2011/

Hydrology and Earth System Sciences Discussions

Interactive comment on "Correction of upstream flow and hydraulic state with data assimilation in the context of flood forecasting" *by* S. Ricci et al.

S. Ricci et al.

ricci@cerfacs.fr

Received and published: 15 April 2011

Correction of upstream flow and hydraulic state with data assimilation in the context of flood forecasting.

Author's response to Review 2 - Handling Editor: Dr. Jim Freer, jim.freer@bristol.ac.uk

The authors would like to thank reviewer 2 for its constructive remarks on the paper. Response to the comments in this review are provided here.

1- From Eq. 2 and Eq. 11, there are many redundant mathematical expressions. BLUE is basically a special case of the Kalman filter and thus this reviewer does not see any clear reason why the authors use the specific term 'BLUE' to describe the

methodology. There are redundant descriptions of the hydraulic model used in the work. Overall, chapters 2 and 3 can be restructured more concisely to describe the model and KF.

The BLUE equations (2-4-6) are those of the "analysis equations " of the Kalman Filter algorithm (8-9-10) for a given time index and any control vector x (state variables or parameters). The full Kalman filter algorithm also describes the "propagation equation" (equations 7 and 11) for the control vector and the background error covariance matrix. When the control vector is composed of the state variable, these equations are applied at a given observation time i-1. The propagation of the state (eq 7 from i-1 to i) is done with the non linear model M_(i-1,i) (the Saint Venant equations) and the propagation of the B matrix (equation 11) is done with the tangent linear approximation of the model M_(i-1,i). When the control vector is a set of parameters, these equations are applied over a time window (several observation time steps). It is assumed that the parameters as well as their errors are constant over this window thus equations 7 and 11 are irrelevant.

As suggested by reviewer 2, a revised version of the manuscript describes the full Kalman Filter equations once for all with special focus on the nature of the matrix M depending on the nature of the control vector. In the revised manuscript, the Kalman Filter without propagation of the covariance matrix is referred to as Invariant Kalman Filter (previously denoted by BLUE).

MASCARET is the hydraulic model for the Saint-Venant equations used for the simulations on the Adour and Marne catchment. The 1D advection-diffusion model is only used for purpose of estimating the background error covariance matrix. Session 2 and 3 were restructured to explain why these two models are used : - Session 2 introduces the idea that the KF algorithm can not be implemented on top of the MASCARET model (regarding the propagation of B) and that a model for B should be provided. - An introduction at beginning of Session 3 describes that the purpose of the session is to provide such a model for B. The major steps for the determination of such model are given : description of the simplified model, application of the full Kalman Filter to the simple model that leads to the parametrization of B and then the use of this B matrix with the Invariant Kalman Filter on the simplified model. - In 3.1 the advection-diffusion model is described. - Section 3.2 and 3.3 are organized to first described the background error covariance matrix with a KF (on the 1-D advection-diffusion eq.) leading to the parametrisation of the covariance function at the observation point (previously 3.3), then to present the use of such parametrisation with the BLUE (on the 1-D advection-diffusion eq.) and finally the assumption that this parametrisation is also used on the Saint Venant model MASCARET. A new figure (Figure 4 attached) was added for Section 3.2.

2- Observation error R and error covariance terms are not described in detail even though they form the essence of the Kalman-filter based data assimilation. Please add quantitative descriptions of the terms used in the simulations.

The observation error matrix is assumed to be diagonal as the observation points are far from each other (so the spatial errors are weakly correlated). The variances for water level observations are estimated to 0.1m. This choice is based on statistics on sets of measurements on both catchments.

3- In the formula for Hsel on page 9074 (not numbered), are the locations of 1's chosen just randomly for illustration? I wonder what the columns of all zeros (first and last) represent.

The Hsel operator is a selection process operator. The observed water level is compared to the water level at the closest grid point. The locations of the 1's are chosen randomly for illustration. As pointed out by reviewer 2, the first and last columns are irrelevant.

4- Equations 14 and 15 need a sound justification. What is the relationship between the Z vs. Q in the manuscript and the conventional rating curves linking Z to Q?

The rating curve linking Z to Q can be written as Q_rc = α Zˆγ + β, where the subscript rc stands for "rating curve". The coefficients α, γ, β are identified at each observation station.

The discharge increment at observation points is formulated as a fraction of the background discharge value Qˆb : dQ = f * Qˆb with f = [Q_rc(Zb+ dZ) -Q_rc(Zb)] /Q_rc(Zb).

Assuming that Qˆb is a good approximation of Q_rc(Zb) leads to dQ = Q_rc(Zb+ dZ) -Q_rc(Zb), this is the increment in discharge corresponding to the increment in water level, via the rating curve.

When the rating curve can't be formulated as Q_rc = α Zˆγ + β (for example, wit the tide influence, the rating curve is not a bijective function), the a crude approximation is made and the rating curve is approximated by the identity function. This eads to dQ = Qˆb/Zˆb * dZ.

5- Justification for the asymmetric error correlation is made based on the simulation of a simple model. Is the 1-to-10 asymmetric ratio made integrating the correlation function on either side of Xobs or just chosen arbitrarily by trial and error. It is not clear from the manuscript.

The anisotropy is diagnosed from the Kalman Filter integration of the AD advection-diffusion equation. The ration between the upstream and downstream correlation length was carefully estimated for this simple model as a function of the ratio between the background error and observation error variance. This gave an estimate of a proper ratio for the MASCARET case. This ratio was then adjusted by trial and error.

6- In the last paragraph of page 9093, the numerical problem described is very hard to understand. Please elaborate on it.

The calibration of various parameters (topography, Strickler coefficient...) for the Adour and Marne model could be improved (especially for the Marne catchment). Without assimilation, the integration of the free run leads to nonphysical states for some flood events. In these cases, in order to perform the free run, the initial water level state had to be constrained to a previously computed state.

7- In Fig. 14, the assimilated runs look worse than the free run. Are the descriptions in the legend incorrect?

The blue line displays the observed water level (vertical axis on the left) where as the other lines (red and black) display the Precision criteria (vertical axis on the right) that should be small if the integration is close to the observation. The blue line is only shown here to visualize when the flood peak arises and should not be compared to the red and blakc lines.

In the revised version of the manuscript, the blue line was removed, only the precision (criteria C3) lines are plotted. From day 18 to 26, the precision computed in reanalysis (dotted line) and in forecast (solid line) for the assimilation (red) is lower than for the free run (black). The assimilation performs better than the free run. Please note that in the revised manuscript, this figure is now numbered figure 9 (see attached).

8- In the results summarized in the figures 12 and 13, the assim runs merges to the free runs at the end of the recessions. Does this originate from the increase impact of the base flow in the recession period?

When the water level observations are smaller than threshold, they are not assimilated. When the assimilation integration merges with the free run, it means that all the observations were rejected, this usually happens before and after the flooding period. These explanation was added in the revised manuscript. Please note that, in the revised manuscript, these figures are now numbered figure 10 and 11.

9- Much of the performance evaluation is based on somewhat qualitative descriptions, such as “significant” and “impressive”. Please provide quantitative measures to avoid the confusions in interpreting the results. In fact, it is hard to agree that the forecasting capability of the assim runs are significantly improved based on the results in Table 1.

The described approach needs to be applied to more cases, preferably separately to groups of similar rainfall-runoff events to be more convincing.

The forecasting capability of the assimilation was quantitatively assessed deriving statistics on the flood events for catchments (then number of events for increased for both catchments).

- Statistics over the events were computed to illustrate how the forecast skill decreases with lead time (see figure 12 attached). The statistics were computed for the Adour catchment (over 7 events instead of 5) and the Marne catchment (over 4 events) in re-analysis mode (24h before the lead time) and in forecast mode (hourly, up to a 12h forecast). The improvement between the free run and the assimilation run, for the 3 criteria is plotted in % as a function of the lead time (see figure 12) for the Peyrehorade station on the Adour catchment. - These skills are presented (see Tables 1, 2 and 3 attached) at (-24h and +6h) for the 2 other stations of the Adour catchment as well as for the Marne catchment to illustrate that : the behavior seen on figure A is valid at other stations. In the text, details are given regarding the poor improvement at the Lesseps station (Adour). Note : the quality of the Marne model (topography, strickler coefficient...) is not totally satisfactory, for that reason, the integration of the free run leads to nonphysical states for some flood events. This explains why the statistics over the Marne catchments are computed over only 4 events and also why the DA results are not good at Joinville. - the DA results where compared to another baseline scenario. The new baseline scenario consists in a post treatment of the free run integration for the forecast period. The difference between observation and free run at observation point is computed. The free run simulation is corrected over a 6h forecast period, the correction at lea d time is equal to the increment, the correction at +6h is zero, in between, the results are interpolated linearly. This scenario has a 100% improvement skill at lead time and 0% at +6h. The improvement for the 3 criteria between free run and the interpolation scenario are also presented on figure 12.

10- Specific Comments There are several acronyms that are used without explanations (e.g., MASCARET, BLUE, EDF). Please explain them when they first appear in the manuscript. Some of the errors in words and expressions are listed below. This is only a part of it, so please revise the manuscript thoroughly.

A thorough proofreading of the manuscript was achieved.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 7, 9067, 2010.

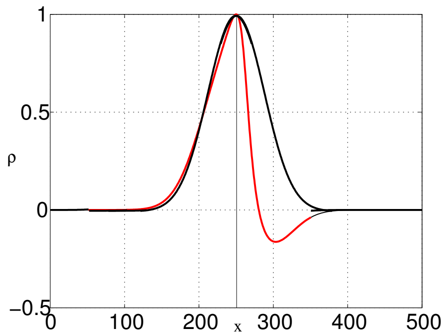

Fig. 4. Initial Gaussian background error covariance function (black curve) and anisotropic background error covariance function (red curve) from KF, at observation point.

41

Fig. 1. Fig. 4. Initial Gaussian background error covariance function (black curve) and anisotropic background error covariance function (red curve) from KF, at observation point.

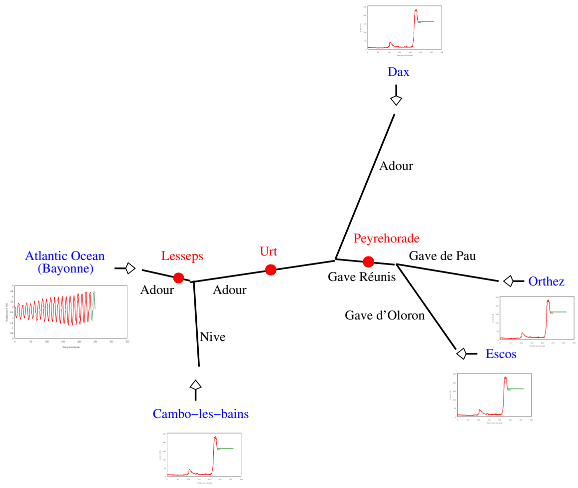

Fig. 5. The Adour catchment with the measurement stations in red and the upstream stations in blue.

42

Fig. 2. Fig 5. The Adour catchment with the measurement stations in red and the upstream stations in blue.

C5337

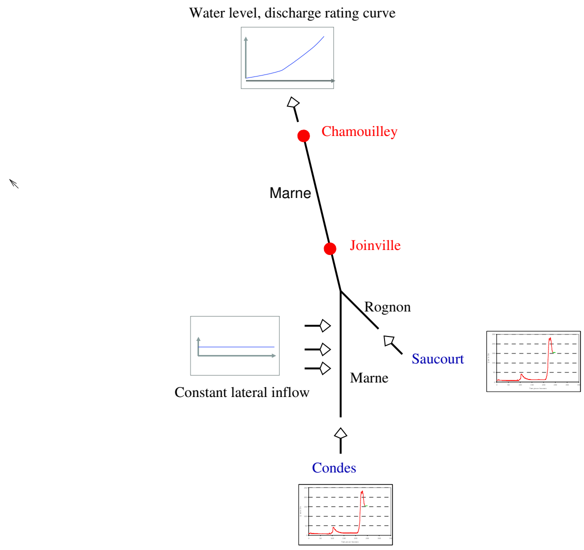

Fig. 6. The Marne Vallage catchment with the measurement stations in red and the upstream stations in blue.

43

Fig. 3. Fig. 6. The Marne Vallage catchment with the measurement stations in red and the upstream stations in blue.

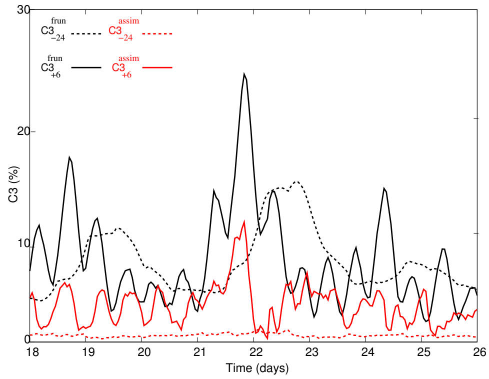

Fig. 9. November 2002 event, Adour catchment. C3 for the Free run (in black) and Assim run (in red) computed over 24 h before T_r (dashed curves) and over six hours after T_r (solid curves) at Peyrehorade.

46

Fig. 4. Fig. 9. November 2002 event, Adour catchment. C3 for the Free run (in black) and Assim run (in red) computed over 24 h before Tr (dashed curves) and ovesix hours after Tr (solid curves) at Peyrehorade

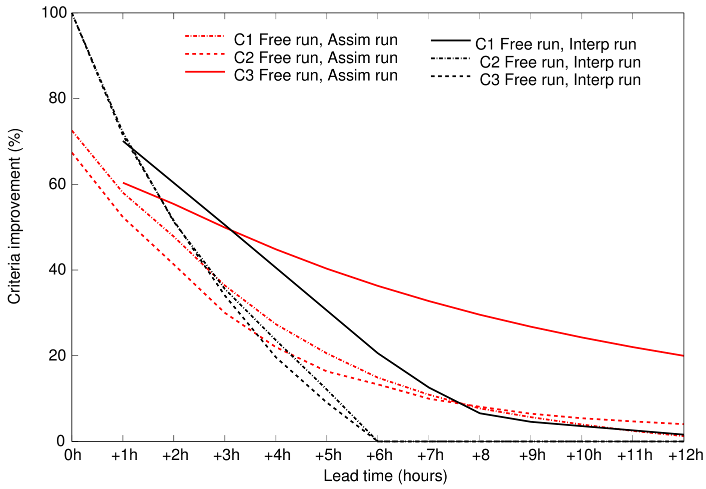

Fig. 12. C1 (dashed-dotted),C2 (dashed) and C3 (solid) improvement en % between Assim run and Free run (red curves) and between Interp run and Free run (black curves). Average over seven flood events, at Peyrehorade (Adour).

49

Fig. 5. Fig. 12. C1 (dashed-dotted),C2 (dashed) and C3 (solid) improvement en % between Assim run and Free run (red curves) and between Interp run and Free run (black curves). Average over seven flood events.

Table 1. C1,C2,C3 improvement between Free run and Assim run over twenty four hours before the reference time. Average on seven flood events for the Adour catchment, at Peyrehorade, Urt and Lesseps.

-24h re-analysis (Adour)	Peyrehorade	Urt	Lesseps
C1 improvement (%)	72	60	54
C2 improvement (%)	67	58	50
C3 improvement (%)	80	65	54

35

Fig. 6. Table 1. C1, C2,C3 improvement between Free run and Assim run over twenty four hours before the reference time. Average on seven flood events for the Adour catchment, at Peyrehorade, Urt and Lesseps.

Table 2. C1,C2,C3 improvement between Free run and Assim run over six hours after the reference time. Average on seven flood events for the Adour catchment, at Peyrehorade, Urt and Lesseps.

+6h forecast (Adour)	Peyrehorade	Urt	Lesseps
C1 improvement (%)	15	15	0.5
C2 improvement (%)	13	11	0
C3 improvement (%)	36	25	3

36

Fig. 7. Table 2. C1, C2,C3 improvement between Free run and Assim run over six hours after the reference time. Average on seven flood events for the Adour catchment, at Peyrehorade, Urt and Lesseps.

Table 3. C3 improvement between Free run and Assim run over twenty four hours before the reference times and six hours after the reference time. Average on four flood events for the Marne catchment, at Joinville and Chamouilley.

C3 improvement (%)	Chamouilley	Joinville
-24h re-analysis	41	24
+6h forecast	24	10

37

Fig. 8. Table 3. C3 improvement between Free run and Assim run over twenty four hours before the reference times and six hours after the reference time. Average on four flood events for the Marne catchment.