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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.

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

Author's response to Review 1 - Handling Editor: Dr. Jim Freer, jim.freer@bristol.ac.uk

The authors would like to thank reviewer 1 for its constructive remarks on the paper. Response to the comments in this review are provided here.

1.In Section 2.2 (description of the BLUE method), Equations (2)-(4) and (6) are redefined on the next page with a time index (Eq. 7-10). This repetition can be safely omitted by keeping only one set of equations (e.g., that with a time index). I am not

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sure why it is stated (near the end of this section) that in the BLUE method, M(i-1,i) is assumed to be an identity matrix. Does this mean the model is kept unchanged over time? Please clarify.

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 review 1, a revised version of the manuscript describes the full Kalman Filter equations once for all . Special focus on the nature of the matrix M depending on the nature of the control vector is given in section 2.3.1 and 2.3.2.

The comment at the end of the session regarding the hypothesis M_(i-1,i) = I will be removed. It is then explained in session 2, how the Kalman Filter algorithm is implemented : when the control vector is the state variable, the propagation of the B matrix is too expensive as it requires the formulation and the use of the tangent linear of the MASCARET model. The approach is then to assume that the tangent linear of the model is kept unchanged over time (B is not explicitly propagated by the dynamics) but a specific study enabled the estimation of a B matrix that is coherent with the dynamics (session 3).

In the revised manuscript, the Kalman Filter without propagation of the covariance

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matrix is referred to as Invariant Kalman Filter (previously denoted by BLUE).

2.Since the correction of upstream flows is the first step of the two-step approach, it makes sense to describe this step first (instead of the correction of the states).

The authors totally agree. Section 2.3.1 was moved to 2.3.2 and 2.3.2 was moved to 2.3.1.

3.Equation (16): it would be desirable to briefly describe the physical meanings of the three parameters a, b, and c. If this equation was based on some previous work, the related reference(s) should be provided here.

The choice for the a,b,c parametric correction of the upstream flow forcing enables simple control (physically plausible) on the time series : a enables homothetic vertical transformation, b enables a shift in in amplitude (vertical translation), c enables a shift in amplitude (horizontal translation).

Typically, at the upstream station, the forcing is described as a discharge whereas water level are usually observed. A rating curve linking water level and discharge is the used and usually interpolated for high discharges. The coefficient a and c allow for a correction of the uncertainty related to the use of this rating curve. The b parameter allows for the estimation of an unknown intermediate input flow.

In the revised manuscript, the justification of the choice of this parametrization as well a the physical meaning of these coefficients were given in section 2.3.1 (previously 2.3.2).

4.Section 3: Modeling of background error covariance B. This is potentially an important section since in the BLUE approach B is kept constant instead of evolving with time. However, the organization/presentation of this section is particularly poor, making it very difficult to follow. First of all, while it is important to do so, the purpose of the model simplification and that of applying KF and BLUE to the 1-D advection-diffusion model are never explicitly stated. Although one could get the idea after reading this sec-

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tion and the next section a couple of times, the purpose of Section 3 should be explicitly stated upfront. Also, the description in 3.2 and 3.3 is pretty much fragmented with the results and interpretations from these experiments (including figs 5&6) presented in the appendix. The revised paper should focus on a better coordination between Sections 3.2 -3.3 and the appendix so that a complete story (short or in relevant detail) is provided in the body text.

The authors agree that this session is important and should be improved : the revised version of the manuscript aims at better presenting the purpose of the session and ease the reading of 3.2 and 3.3. In the revised version of the paper : - 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 parametrization of the covariance function at the observation point (previously 3.3), then to present the use of such parametrization 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.

The authors would rather keep the details for this study in the appendix A and B to ease the reading of the paper (as previously suggested by the editor).

5.The description of the two catchments in Section 4.1 can be improved and consolidated. For example, currently some location names mentioned in the text cannot be found on the schematic diagrams (Fig. 7&8). Another example is the second paragraph on page 9088, which is somewhat too wordy.

Figures 7 and 8 are modified accordingly to the locations mentioned in the text. Globally, the text was clarified, especially the Marne catchment description. See figures 5 and 6 attached for modifications.

In the revised manuscript, Section 4 was reorganized in 4.1 experiments set up, and 4.2 Flood event simulation with data assimilation. Section 4.1.1 describes the Adour and Marne catchments. Section 4.1.2 describes the criteria for the interpretation. Section 4.2.1 gives a detailed interpretation of the simulation of a flood even on the Adour catchment. Section 4.2.2 gives a detailed interpretation of the simulation of a flood even on the Marne catchment. Section 4.2.3 given a statistics interpretation for both catchments. The number of events for both catchments was increased.

6.The first paragraph of Section 4.2 seems to be out of place since this section should be focus on "data assimilation set up". This paragraph can be removed.

The first paragraph was removed. Detailed on the simulated events are given in the following sessions.

7.Section 4.3 is more about illustration of data assimilation "results" instead of method. Hence the section title should be rephrased.

The title was modified as the section was re-organized.

8.It is mentioned on page 9091 (Line 21-22) that similar performance was observed for shorter and longer range forecasts (as compared to six-hour forecasts). I am curious to see whether this is really true as normally one would expect to see forecast skill decreases with lead time (especially when the forecast is persistence based). As a recommendation, the authors could evaluate the skill as a function of time within both the analysis and forecast periods, i.e., evaluating the skill at every hour from the beginning of the assimilation window to the end of the forecast window (as oppose to only examining the performance at -24 hr and +6 hr). This would provide a more complete investigation/evaluation of the gain from data assimilation and how it changes with lead time.

The presentation of the criteria was improved to clearly state that the Precision (eq. 23) evaluates the cumulative skill over a time period (in reanalysis 24 h before the lead time or in forecast after the lead time). However, the distance between the simulation and the observations (FmO and AmO) are computed at a given time.

Note : the notation FmO and AmO was replaced by MmO (Model minus Observation), the model integration being either the free run or the assimilation run. The mean(MmO) criteria is noted C1, the std(MmO) criteria is noted C2 and the cumulative criteria (previously denoted by Precision) is noted C1 .

As suggested for page 9091, statistics over the events were computed to illustrate how the forecast skill decreases with lead time. 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 (C1, C2, C3) 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 3 stations of the Adour catchment as well as for the Marne catchment to illustrate that : the behavior seen on figure 12 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.

9.As a suggestion, the authors could compare the DA results to another baseline scenario where the most recent water level observation is used to directly initialize the

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model to make a forecast, in addition to a free run starting from several days earlier in the past, not using recent observations that are already available. One would argue that such a baseline is expected to perform better than the free run defined in the paper, making it more difficult to demonstrate the value of data assimilation.

As suggested by reviewer 1, the DA results where compared to another baseline scenario presented in 4.1.2. Initializing the model to the observation state at the last observed time (as suggested) was not possible since this I.C is not coherent with the model equations (spatial discontinuity, inconsistency between water level and discharge since only water level is observed). 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.Currently the paper focuses on the results from the Adour basin only, while it is desirable to also provide results from the other basin with proper interpretations. For example, Table 1 and 2 can be extended to include some statistics for the Marne Vallage basin.

See response for point 8.

11.Other minor issues/typos (note this is not a complete list; a thorough proofreading is necessary)

A thorough proofreading of the manuscript was achieved.

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

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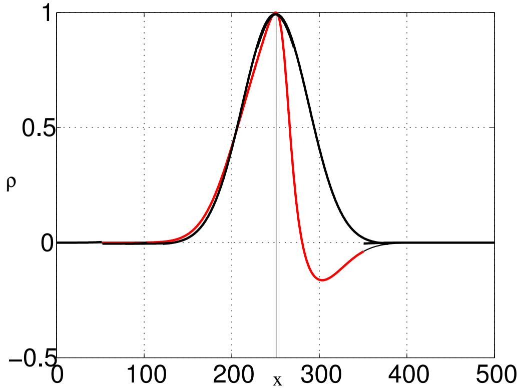

Fig. 4. Initial Gaussian background error covariance function (black curve) and anisotropic background error covariance function (red curve) from KF, at observation point.

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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.

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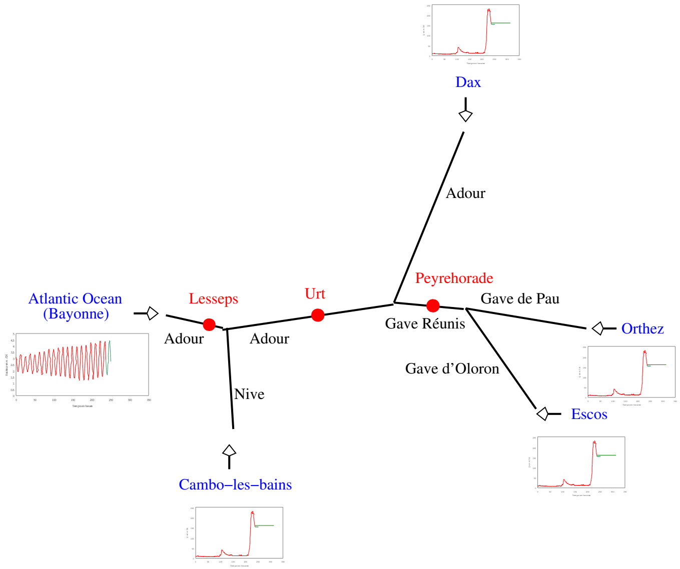

Fig. 5. The Adour catchment with the measurement stations in red and the upstream stations in blue.

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

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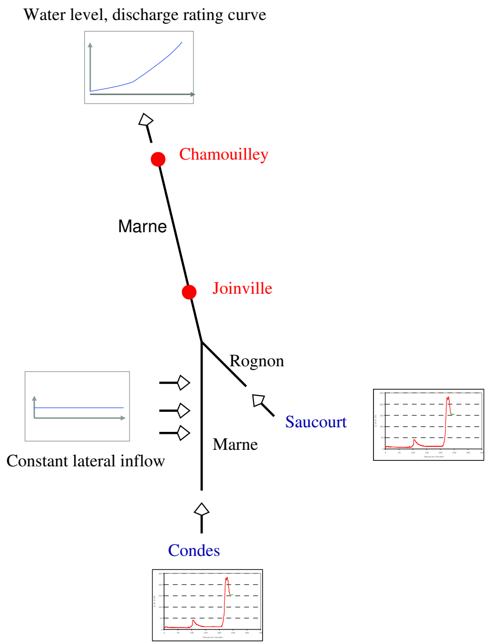

Fig. 6. The Marne Vallage catchment with the measurement stations in red and the upstream stations in blue.

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

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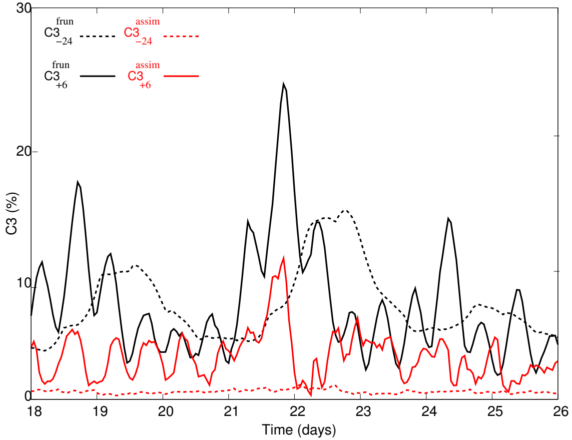

Fig. 9. November 2002 event, Adour catchment. C3 for the Free run (in black) and Assim run (in red) computed over 24 h before T_r (dashed curves) and over six hours after T_r (solid curves) at Peyrehorade.

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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

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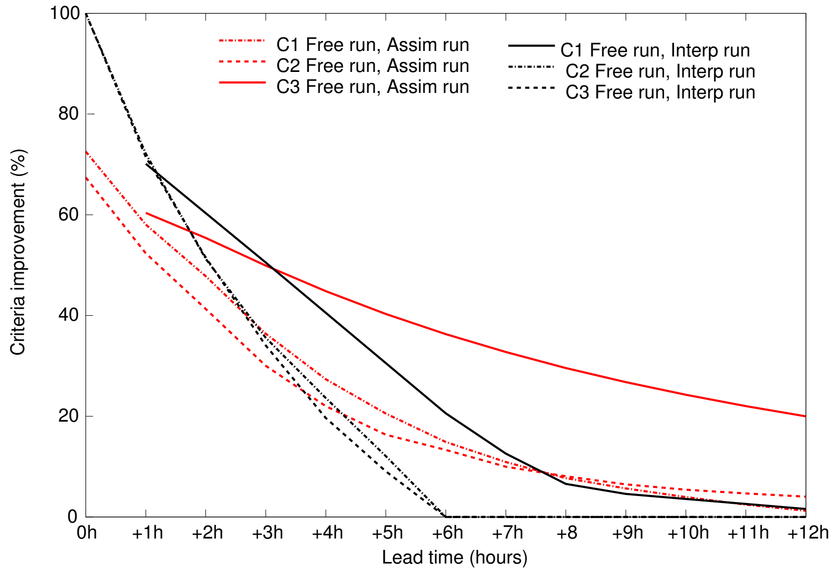

Fig. 12. C1 (dashed-dotted),C2 (dashed) and C3 (solid) improvement en % between Assim run and Free run (red curves) and between Interp run and Free run (black curves). Average over seven flood events, at Peyrehorade (Adour).

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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

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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.

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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

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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.

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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

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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.

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