Ref: gmd-2014-171

Dear Reviewer 1,
We would like to thank you for your careful and constructive review of our paper. We have tried to follow all your requests as best as we could and believe that it helped to substantially improve the manuscript. A point by point explanation follows below for your comments:

Comments

- *Page 7153, line 16: please correct: "observations measurements"*

Reply: corrected

- *Page 7157: It is not clear the difference between ALARO and ALADIN. Please be more explicit*

Reply: In the revised manuscript the description of ALARO and ALADIN was adapted to make this difference more explicit.
The ALADIN model is the LAM version of the Action de Recherche Peite Echelle Grande Echelle Integrated Forecast System (ARPEGE-IFS) (Bubnová et al., 1995), developed by MétéoFrance and the ECMWF. In the ALARO model, ALADIN is updated with the ALARO-0 physics package. This parameterisation has been designed to run at resolutions from the mesoscale to the cloud-resolving scales in a scale-aware manner, based on the modeling approach of the Modular Multiscale Microphysics and Transport (3MT) cloud and precipitation scheme of Gerard and Geleyn (2005); Gerard (2007); Gerard et al. (2009) and has been validated up to a spatial resolution of 4 km for NWP (Gerard et al., 2009, De Meutter et al. 2015) and climate (Hamdi et al., 2012, 2014b; De Troch et al., 2013). The ALARO-0 physics package is coupled to the dynamics via a physic-dynamics interface based on a flux-conservative formulation of the equations proposed by Catry et al. (2007). The ALARO model is running operationally at the Royal Meteorological Institute (RMI) of Belgium as well as in a number of other countries of the ALADIN and HIRLAM consortia.

- *Page 7159, line 7* $(y_0^t - H(x_b^0) \rightarrow [y_0^t - H(x_b^0)]$ *it is not clear the meaning of the subscript 0 in the y vector*

Reply: the subscript o stands for observation, as a stands for analysis and b for background. To avoid confusion the superscript 0 was changed to t0. The text is adapted to make this more clear:
"… where subscripts a, b, o indicate the analysis, background and observations, such that the analysis model state ..."

- *Page 7160, line 24: Why this values: "1 K for 2 m temperature and 10 % for 2 m relative humidity" and for : "2 K for the background errors of Ts and T2 and 0.1 × (wfc − w wilt) for Wg and W2"*

Reply: These values are the same as in Mahfouf et al. (2009). The text is adapted to make this more clear: **The EKF for soil analysis has been tested using the same setup and covariance values as in Mahfouf et al. (2009).**

- *Page 7162, lines 12/13: “runs from 12:00 to 18:00 UTC”, every days?*

Reply: We have checked the presence of oscillations on five random days throughout the month and found oscillations on each of these days in various locations. However, it is not feasible to check this for every day of the month, due to a lack of storage resources. In order to check for oscillations the output fields should be stored at each timestep, which requires a lot of storage.

- *Page 7163, paragraph lines 5-20: Question: The noisy signal in the Jacobian values appear only in the therms related to the soil water content or also in the terms related to the soil temperature? The figure 4 only show the noisy signal for the derivatives with respect to wg and w2, but for the terms with respect to Ts and T2 the period shown is outside the window were the noisy signal appear. In my opinion the authors should clarify this question in the text.*

Reply: The noisy signal in the Jacobian values appears in terms related to soil water content as well as terms related to the soil temperature. Figures 1 and 2 added here below show the noisy Jacobians related to soil temperature to the reviewer. The following was added to the revised manuscript to clarify this: **Similar oscillations occur for the Jacobian values related to soil temperature (not shown) for this case.**

- *Page 7163, line 20: The expression “(not shown)” should come after “the coupled case”*

Reply: corrected

- *Page 7165, line 16: The aim of the filter is to cured only the impact of the oscillations that occurred at Ri critical values or also the oscillations that are due to non-linearities for SWI-values close to 0?*

Reply: The filter does not differentiate between oscillations initiated by different mechanisms, therefore it will filter oscillations that occur at the Ri critical values as well as oscillations due to SWI-values close to 0. In addition it might even filter oscillations caused by other mechanisms, like the oscillations due to rainy conditions for the coupled approach as described by Balsamo et al. (2004). In the revised manuscript a sentence about this was added to the explanation of the filter:
The filter does not differentiate between oscillations initiated by different mechanisms. Therefore it will filter oscillations due to the critical RI values and SWI-values close to zero but also for example oscillations due to rainy conditions for the coupled approach as described by Balsamo et al. (2004).

- *Page 7166, line 6: Which case? The period, as well the time-steps of the runs should be given.*

Reply: we did not intend a particular case, but rather the comparison between the reference approach and the filtered approach for the same periods, which are indicated each time in the text. We now write in the revised manuscript: **In the following part, the filtering approach FIL is compared to the reference approach without filtering ...**

- *Page 7167, line 12/13: 6 July or 2 July? In the figure caption it is indicated the 2 July.*

Reply: corrected, it should be 2 July

- *Page 7168, line 10: parturbation → perturbation*

Reply: corrected

- *Page 7168, lines 18 and 19: should be Figure 9*

Reply: corrected

- *Page 7168, line 23/24: the following conclusion: "(...) a Jacobian calculated with a positive perturbation has the same size but an opposite sign as the Jacobian value calculated with a negative perturbation." seems to me a little bit strange and in contradiction against the values of H+ - H- shown in figure 8. Please confirm the result and if it so, try to explain it.*

Reply: We agree that this conclusion is a bit too strong. The results shown in figure 10b as well as figure 8 have been verified and are correct. However for most points in this plot there is still a large deviation from the diagonal, resulting in the larger values for H+ - H- than would be expected if the points are all on the diagonal. To try to explain why the points follow more or less the opposite diagonal would be a research in itself. It could point to the presence of non-linear effects that are triggered in the case of too small perturbations, but this is outside the scope of this paper. For other perturbation sizes (like in figure 10d) the results are as expected, so the results 10b are an artefact of this particular perturbation size. The conclusion mentioned above was removed in the revised manuscript and replaced by the following:

The points of the coupled EKF follow slightly the opposite diagonal. It cannot be excluded that some non-linear feedback effects between the surface and the atmosphere are triggered here but this is out of scope of the present paper.

- *Page 7169, line 11: Should be Figure 10*

Reply: corrected

- *Page 7172, line 26. Do you have testes some values for the B components?*

Reply: We used the values for the B components that were suggested in Mahfouf et al. (2009). The hypothesis that other values for these B components could reduce the larger increment values, has not been tested yet. Therefore we remove this sentence in the revised manuscript and add a sentence about this in the conclusions:

The results also depend on the choice of the background and error covariance matrices values. In this paper we used the values proposed by Mahfouf et al.(2009). It could be interesting to compare the increments and forecast scores for different values of these covariance matrices.

- *Page 7173, line 4/5: "The larger increment for FIL on 14 July corresponds to a heavy precipitation event in the region". The authors should try to justify why sometimes occur such strongly differences between REF and FIL.*

Reply: An explanation was added to the revised manuscript: **The large increment for FIL on 14 July corresponds to a heavy precipitation event in the region. In the second half of the month the increments for FIL are often larger than those for REF. It is easily explained by the evolution of the SWI values for W2 (not shown). On the 9th of July the negative increment of REF is much larger than that of FIL. In FIL the noise filtering in the Jacobian prevents the large negative increment. This results in a negative SWI-value for REF, while the SWI value of FIL is just above zero. As a consequence FIL remains sensitive to increments, while in REF the increments for W2 remain near zero as long as the SWI value is negative. The heavy precipitation event of 14 July brings the SWI value of REF above zero again, but on 16 and 19 July this results in a strong negative W2 increment. After that the SWI value of REF remains below zero most of the time, while the SWI value of FIL is positive and thus FIL has larger increments in this period.**

The corresponding figure (Fig. 3) is added below for the reviewer.

- *line 18/19: "We tested this EKF with the assimilation of T 2 m and RH 2 m observations to correct errors in soil moisture and soil temperature". This comment should also have been spelled out previously, may be in the §3.*

Reply: A sentence about this was added in §3: **Observations of T2m and RH2m are assimilated to correct errors in soil moisture and soil temperature.**

References

- *Page 7175: the two first references are equal.*

Reply: corrected

Figures

- *Figure 1. As I understand in the offline set-up the runs of the ALORO Model were coupled to the surfex. If so, the figure may be changed.*

Reply: This is a good remark. The difference between the *coupled* and the *offline* approach only relates to the way the Jacobian is calculated, not the actual forecast. In what we call the *coupled* approach, there is a two-way coupling between ALARO and SURFEX (at each timestep the two models exchange atmospheric forcing and surface fluxes) while in the *offline* approach there is only a one-way coupling between ALARO and SURFEX (ALARO provides the forcing to SURFEX, but there is no feedback from SURFEX to ALARO). In practice the *offline* approach uses atmospheric forcing that was calculated in a coupled ALARO-SURFEX forecast from the previous assimilation cycle. During the *offline run* only the SURFEX model is run and the previously stored atmospheric forcing is used as input for the SURFEX run. Since SURFEX is run without ALARO in the *offline* case, there can be no feedback from SURFEX to ALARO. Figure 1 has been changed in the revised manuscript to explain this more clearly. The text at the beginning of section 2 was adapted in the revised manuscript:
When SURFEX is coupled to the atmospheric model, they exchange fluxes and forcing at every timestep. SURFEX can also be used in offline mode, i.e. without coupling to an atmospheric run. In offline mode ALARO provides hourly forcing for SURFEX, but there is no feedback from SURFEX to ALARO. The difference between the coupled and offline approach is shown in figure 1.
Also the caption of figure 1 was adapted:
Schematic overview of the coupled and offline set-ups, used for the perturbed runs of the EKF.

- *Figure 2. Figure 2 might be more informative (countries, lat / long)*

Reply: Lat, lon and country for each location have been added to the figure caption: **The operational 4km ALARO-Belgium domain. The indicated locations will be used in the following sections. Beitem: 50.905°N, 3.123°E (Belgium). Location A: 50.534°N, 4.497°E (Belgium). Location B: 52.092°N, 9.488°E (Germany). Location C: 52.082°N, 9.722°E (Germany)**

- *Figure 6 : about the colour-scale: for the analysis in the text, the 0.0 should be in the centre of a class. The label does not indicate it, but maybe it's just a label error. If so, please correct it, if not it will be better to redo the figure.*

Reply: the coulour-scale was adapted so that the 0.0 is in the centre of the class

- *Figure 8 The conclusion: "The offline approach has a smaller optimal perturbation size (black lines) and smaller jacobian values (red lines)" should not be indicated in the figure caption. on the other hand, the caption may indicates the differences between the top and the bottom figures*

Reply: corrected. The sentence has been removed. The difference between the top and bottom figures was added: **Comparison of the optimal perturbation size for the offline (top) and coupled (bottom) approach.**

- *Figure 10 ↔ Figure 9 (Figure 9 is first refereed in page 7169, Figure 10 in page 7168)*

Reply: corrected

- *Figure 10 The last sentence: "The linearity assumption is better approximated for the offline approach" should no appear in a figure caption.*

Reply: corrected. The sentence has been removed.

- *Figure 11 The final sentence: ", i.e these are the optimal perturbation sizes." is not clear and not needed*

Reply: corrected. The sentence has been removed.

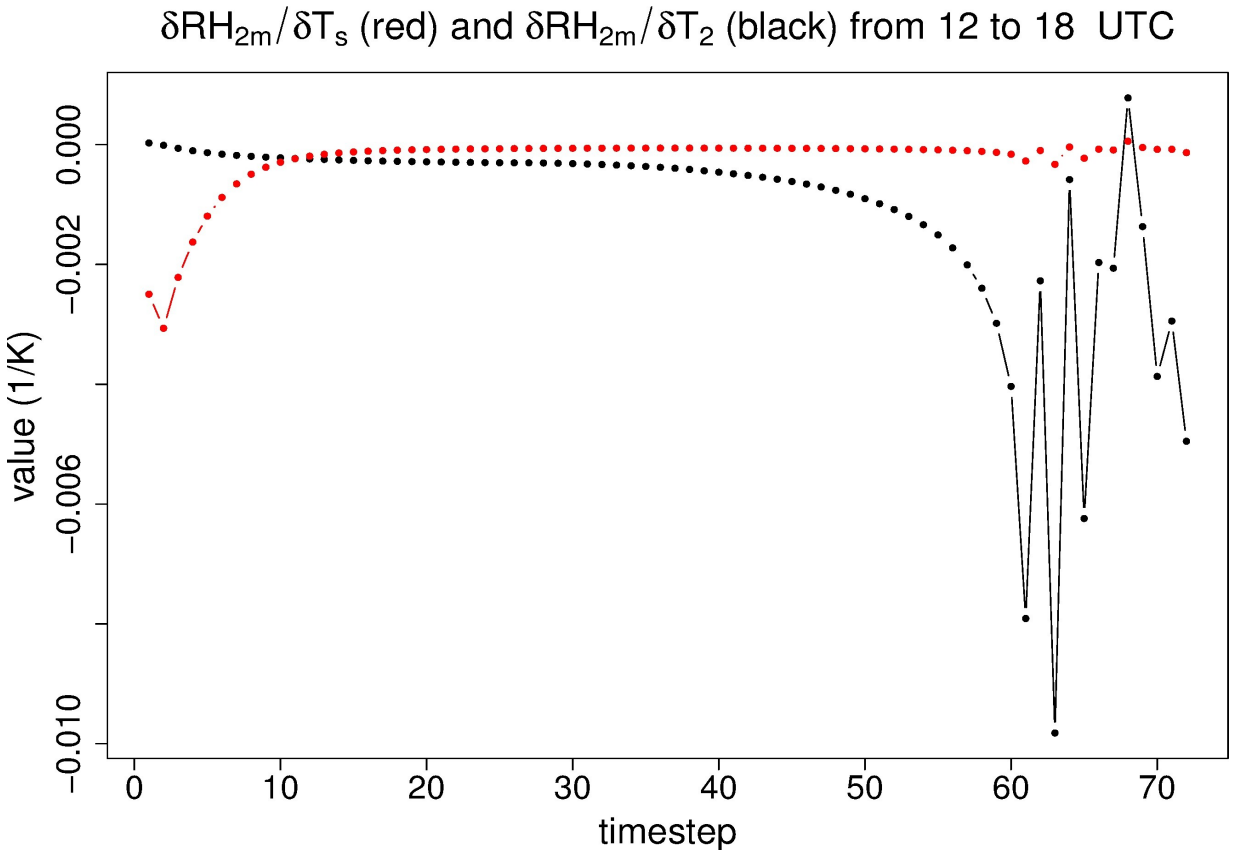

Figure 1: Evolution of the Jacobian value from 12UTC until 18 UTC for an offline SURFEX run on 2 July 2010 in location A (output plotted every timestep). Perturbation for the initial perturbed states is 1e-04.

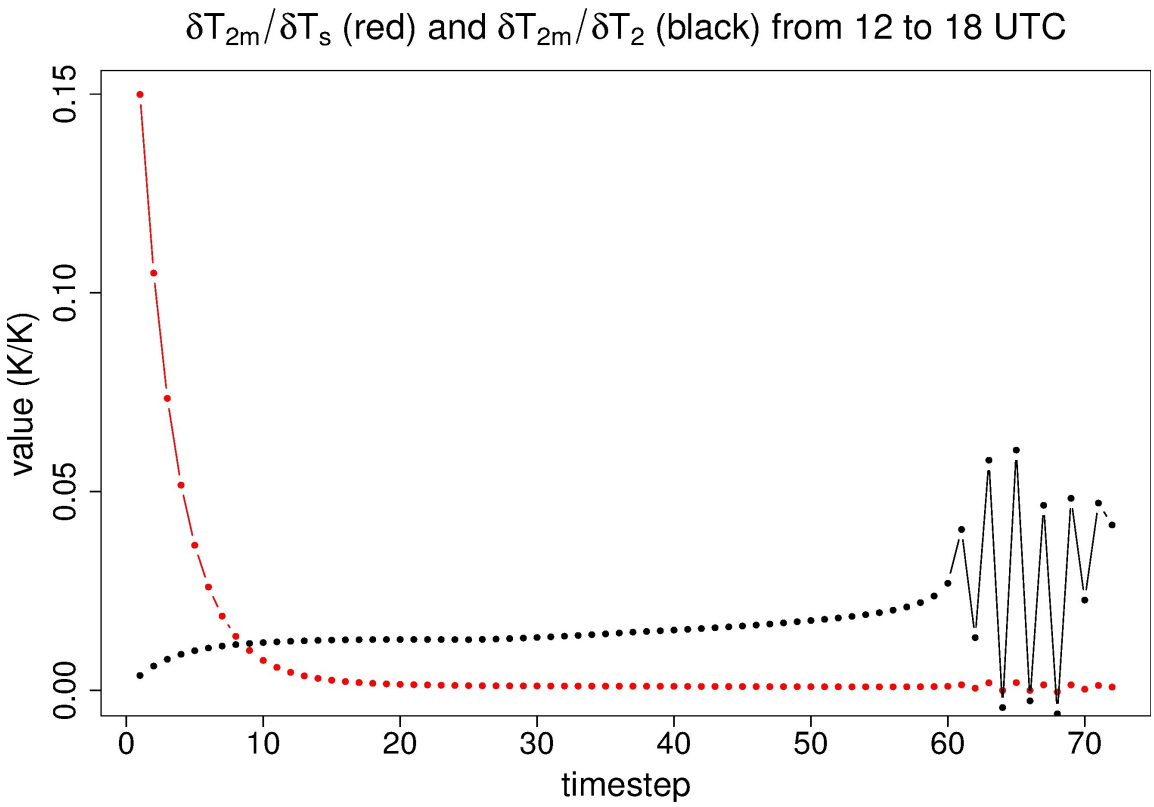

Figure 2: Evolution of the Jacobian value from 12UTC until 18 UTC for an offline SURFEX run on 2 July 2010 in location A (output plotted every timestep). Perturbation for the initial perturbed states is 1e-04.

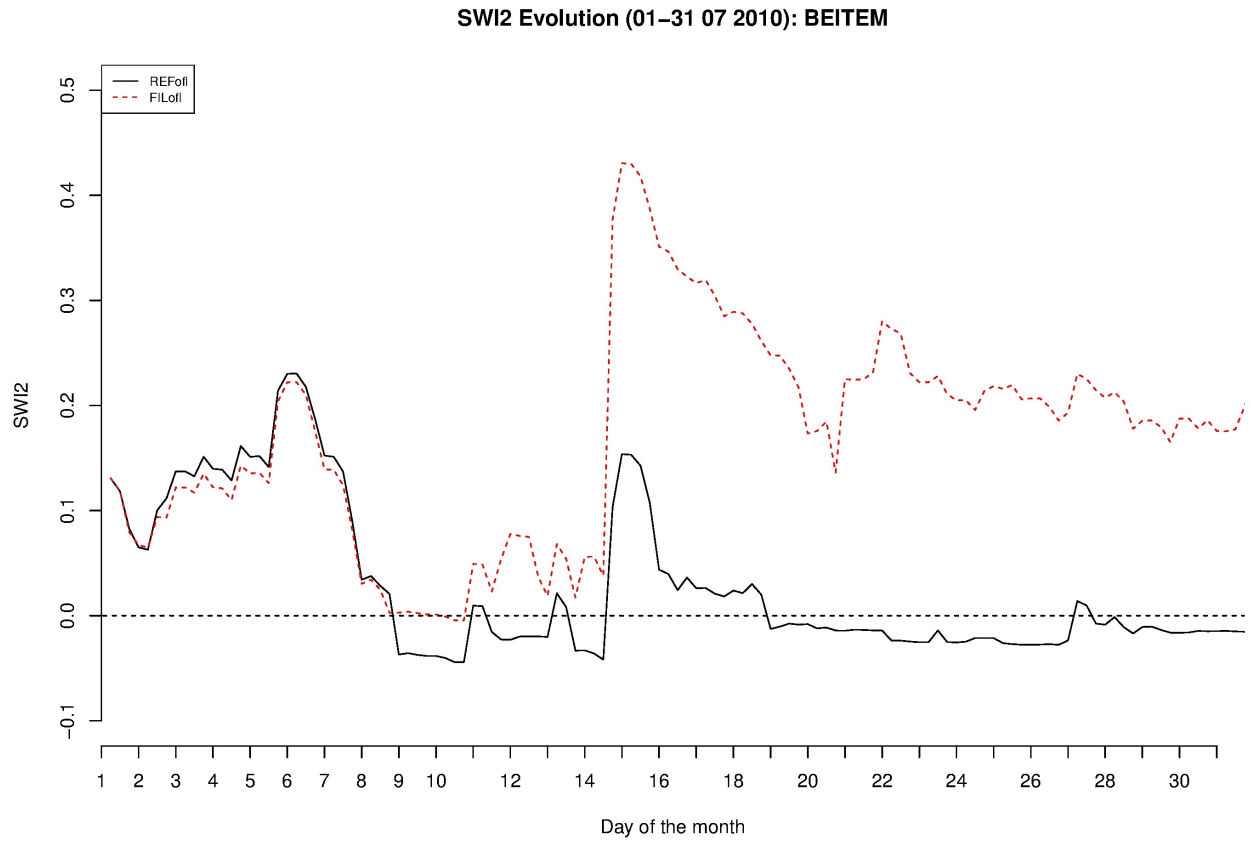

Figure 3: Evolution of the Soil Wetness Index of layer 2 (SWI2) for Beitem for REF(black line) and FIL(red line).