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Hydrology and Earth System Sciences
Discussions

Interactive comment on "Integrating ASCAT surface soil moisture and GEOV1 leaf area index into the SURFEX modelling platform: a land data assimilation application over France" *by* A. L. Barbu et al.

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The authors thank the anonymous referee #1 for his/her comments that will help to improve the quality of the manuscript.

Major comment #1

The author emphasized several places about the advantage of joint assimilation of RS SSM and LAI, and even highlighted that these two observation data are somehow con-

flicting. However, in the manuscript, there is no discussion on the difference between the assimilation results calculated by jointly assimilating both observations and the results calculated by assimilating only one of these two observation. To convince readers on this point, such kind of comparison is needed.

RESPONSE 1

There is a large interest in using a multivariate data assimilation system as a unifying context in which various types of observations from different sources are integrated in a complex model. From a theoretical point of view, the more information a system gets, the better the resulting analysis. In practice, due to the inherent uncertainties in the observations as well as in the models, the analysis is often not optimal. The multivariate approach imposes additional constraints on the system to fit the observations and prevents it from being too close to the observations for wrong reasons (such as an underestimation of the observation uncertainty).

As mentioned in the Introduction, a joint assimilation is designed to better exploit the close link between soil moisture and vegetation variables. The off-diagonal elements (dLAI/dWG2 and dSSM/dLAI) of the Jacobian matrix H reflect how this link is directly used by the multivariate analysis. The joint assimilation is effective when the values of these Jacobian terms are non-zero. Through the Jacobian terms of the observation operator, an observation of LAI can produce an increment of WG2 or an observation of SSM can correct the LAI.

As pointed out by Reichle (2008), a data assimilation system can organize and join potentially redundant or conflicting data into a single best estimate. As it has been highlighted in the literature (Barbu et al., 2011; Kato et al., 2013), the multivariate assimilation of possible conflicting data streams is a valuable method that permits the identification of biases in the observations and of shortcomings in the model parametrisation. Figure S1 (see supplement) shows a grid cell where such problems occur in the period of vegetation senescence. The joint assimilation of LAI and SSM data is com-

pared with univariate assimilation cases (only LAI and only SSM). During the growing period and at wintertime, the LAI observations mainly correct the vegetation state, whereas SSM observations correct the root-zone soil moisture. Also since the error covariance matrix B is static (not cycled) and diagonal, the errors of a variable do not project on the corrections of another variable. In Fig. 1 (below), one notes that these analyses are almost independent in the growing phase and at the end of the annual cycle. During the senescence, it is generally found that the analysed LAI from the multivariate assimilation lies between the two univariate assimilation cases. Limitations in the model physics (uncertainties in the relation between soil moisture and photosynthesis activity) or in the assimilation scheme (bias correction of SSMsat via the CDF matching) are more difficult to detect when only one set of observations is assimilated. Therefore, univariate analysis experiments are considered as being less informative. Based on the recommendations from the literature cited in our manuscript (Kato et al., 2013 ; Nearing et al., 2013 ; Kaminski et al., 2012 ; Barbu et al., 2011 ; Sabater et al., 2008 ; Pauwels et al., 2007) our interest was motivated in combining the two data streams in an unified assimilation scheme.

Figure 1: The LAI annual evolution for the year 2009 at a location (43.35°N, 1.30°E) in France for the model, the multivariate assimilation (LAI and SSM), and two univariate assimilation cases (LAI only and SSM only). The LAI evolution at the grid scale is shown at the same location for the model (blue curve) and the three assimilation cases: both LAI and SSM (in red), only LAI (in black), and only SSM (in cyan), respectively. The LAIsat values are depicted by green dots.

Major comment #2

The determination of the weighting factor is not discussed in details. It is understood that the cover fraction occupied by each patch is adopted as the weighting factor. However, the correctness of such method is not clarified. The paper used one observation per grid box for a number of land covers inside this grid box. In terms of soil moisture observation, the response of soil moisture in the bare soil, the crop and the grass to

the wetting-drying cycle is expected to be different. Such kind of response in the bare soil is expected to be quicker than the other two land covers. The differences in such responses from different land covers should be considered into the weighting factor as well. Although it is understandable that bigger cover fraction will contribute more to the analysis, there is a necessity in explaining the effect of soil moisture response on the determination of the weighting factor, in a way, to verify the exclusion of such consideration.

RESPONSE 2

In the original ISBA scheme, surface and soil parameter aggregation laws were defined by Noilhan et al. (1997) and Noilhan and Lacarrere (1995). However, more advanced schemes simulating the carbon cycle such as the ISBA-A-gs model employed in this study, are run several times for the same grid cell, using patches, as the definition of aggregated effective parameters for such models is not straightforward.

It is assumed that the SSM observations represent different sub-grid dynamics of soil moisture in a 8 km grid cell, and the predicted model equivalent of the observation consists of a patch-aggregation in this grid cell. The LAI and WG2 values of the grid cell represent the linear combinations of LAI and WG2 from each patch weighted with their cover fraction (Eq. (7)).

The cover fraction and also the Jacobian terms impact the analysis increments (defined by Eq. (2)), as a result of the two generic equations Eq. (3) and Eq. (5). For example, the Jacobian term dSSM/dWG2 of the Jacobian matrix H is used to calculate the Kalman gain (Eq. (3)) and then the increments (Eq. (2)). This Jacobian term represents the sensitivity of SSM to changes in WG2. The effect of different soil moisture responses in bare soil and in vegetated ground conditions is taken into account through this Jacobian term. Indeed, its behaviour over bare soil and over a vegetated surface is significantly different, as demonstrated by several authors (Calvet and Noilhan, 2000 ; Draper et al., 2009 ; Mahfouf, 2010). The influence of WG2 on SSM is mainly de-

termined by the surface soil evaporation process. The dSSM/dWG2 Jacobian element has higher values over vegetated areas due to an increased coupling between the two layers in the ISBA force-restore scheme. Conversely, over bare soil, a reduced sensitivity of SSM to WG2 is noticed at daytime, when high evaporation rates occur. Finally, the analysis differs from one patch to another because of (1) different land cover fractions (Eq. 7), and (2) contrasting water fluxes in the soil depending upon soil texture and vegetation cover (as shown in Mahfouf (2010) through an analytical expression of the Jacobians).

Major comment #3

The state vector for the analysis consists of two prognostic variables, root-zone soil moisture (WG2) and LAI, corresponding to two observations SSMsat and LAIsat. The SSMsat represents the first 5cm soil moisture content, while the WG2 represents the soil moisture at rooting depths depending on the vegetation type, with a maximum thickness of 2.5m. Does it mean that the assimilation of SSMsat refers to the simple replacement of the SSM in the ISBA-A-gs LSM with the SSMsat? If this is the case, please specify clearly in the manuscript. Does it mean the SSM is not a prognostic variable in the ISBA-A-gs LSM in this study?

RESPONSE 3

In this study, the vector of observations includes two elements: SSMsat and LAIsat at each grid cell. The control state vector for the analysis consists of two prognostic variables, root-zone soil moisture (WG2) and LAI, each of them containing 12 values that correspond to the twelve patches. The SSM does not belong to the control state vector, but it is a prognostic variable in the ISBA-A-gs LSM. As mentioned in the manuscript, the pragmatic reason for excluding the SSM variable from the control state vector was to reduce the number of additional perturbed runs needed to compute the Jacobians. Moreover, the Kalman filter is particularly useful for correcting system variables presenting a slow temporal evolution such as LAI and WG2. Due to the small capacity of

the superficial soil water reservoir, the SSM is rapidly influenced by the atmospheric forcing and by the capillarity rises from the deep reservoir. Therefore, a dedicated initialization of the SSM is less critical than for WG2, which is associated with soil depths up to 2.5 m. The modelled SSM is used to calculate the innovation and is linked to the control variable WG2 via the prognostic equations of the ISBA force-restore scheme. The SSM variable is not simply replaced by the satellite value as in this case, one would consider the observations as perfect. The error associated to the observations would be equal to zero which is not the case in our scheme. The SSM variable is indirectly corrected through the changes made by the assimilation in the deep reservoir.

Minor comment #1

Line 2-7, Page 9074, can the authors detail the issue related to this part of description?

RESPONSE 4

In summer, in water-limited conditions, the temporal evolution of LAI per patch shows a complex picture due to the combined effect of LAI and WG2 analysis, and also, due to possible conflicting information from the assimilated observations. This is illustrated by Fig. 5 (a and b). In June/July the SSMsat observations are generally below the model at this location (not shown). Since in a moisture-limited regime (close to the wilting point) the dSSM/dWG2 Jacobian has large positive values (caused by strong non-linearities in the description of the water diffusion in the ISBA force-restore scheme), large negative WG2 increments are generated. In this way, the reduction in WG2 in June/July due to the assimilation of SSM observations contributes to a more rapid decrease of LAI towards the low LAIsat values. Simultaneously assimilating the two data streams converges to a bias reduction in LAI. On the other hand, after this period, the SSMsat data are consistently above model values and then the analysis accumulates positive increments in the root zone. This results in a slightly enhanced WG2 that allows a vegetation regrowth for both croplands and grasslands. The vegetation regrowth is related to sufficient water availability only, as this behaviour is not

confirmed by LAIsat observations.

Minor comment #2

Figure 4. There is no detailed discussion on Figure 4.

RESPONSE 5

The Jacobian dLAI/dWG2 represents the sensitivity of LAI to water perturbations in the rooting layer. It reflects how the link between soil moisture and vegetation variables becomes effective when assimilating LAI observations. Generally, this Jacobian term has positive values since an increase in water content directly enhances photosynthesis and plant growth. This behaviour is common to all patches with one noticeable exception: the occurrence of negative values for the C3 crop patch (blue curve in Fig. 4) in spring and early summer. For normalized soil moisture values ranging between a given critical limit of 0.3 and 1, a moderate water stress is defined. In these conditions, a drought-avoiding strategy which characterises the crop vegetation takes place. A decrease in soil moisture is characterized by an increase in the water use efficiency, which enhances photosynthesis. Therefore, between these limits, negative water perturbations can lead to an increase in photosynthesis and therefore to negative Jacobian values. As illustrated in Fig. 4, during the senescence phase, large Jacobian values (above 1) correspond to advanced stages of water stress. When the normalized soil moisture approaches zero, small increases in WG2 cause large increases in biomass production which reveals a specific non-linear behaviour of the ISBA-A-gs scheme. This behaviour is common to all patches. Null Jacobian values, indicating no sensitivity of LAI to soil moisture changes, occur when the water content is below the wilting point (September-October) or above the volumetric field capacity (January-February). In these cases the plant is not sensitive to water perturbations and therefore LAI observations are not informative about the soil water content.

Minor comment #3

Line 29 Page 9077 - line 3 Page 9078, where are the results to support this statement?

RESPONSE 6

ASCAT is the main contributor to the changes in WG2 since, in general, the assimilation of SSM impacts WG2 more than the assimilation of LAI. Also, the assimilation of SSM is more frequent than the assimilation of LAI. This estimation was obtained by calculating the contribution of ASCAT to the increments when no LAI data were available.

Minor comment #4

Figure 2. It would be illuminating to include the original ASCAT data before rescaling in this figure.

RESPONSE 7

Yes, Fig. 2 will be improved.

Minor comment #5

Figure 6. The results for soil moisture should be shown.

RESPONSE 8

Yes, Fig. 6 will be improved.

Minor comment #6

Figure 7. The results for soil moisture should be shown.

RESPONSE 9

The information required for the monthly map of the posterior WG2 when compared to the prior WG2 is contained in Fig. 10, where the WG2 increments are presented in terms of monthly averages. Therefore monthly maps for WG2 would be redundant. The monthly averages were depicted for LAI in order to compare the LAI observations with the model and the analysis.

Minor comment #7

Figure 8. The results for soil moisture should be shown.

RESPONSE 10

Figure 8 illustrates intrinsic diagnostics (such as innovations and residuals) of the assimilation scheme. We have used these diagnostics for LAI only since the simulated LAI variable was also the observed variable. Concerning soil moisture, the innovations would be calculated by using the observed surface soil moisture, while the residuals would be computed for the unobserved root-zone soil moisture, making the comparison less useful.

Minor comment #8

Figure 11. The results for soil moisture should be shown.

RESPONSE 11

Yes, Fig. 11 will be improved.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 10, 9057, 2013.

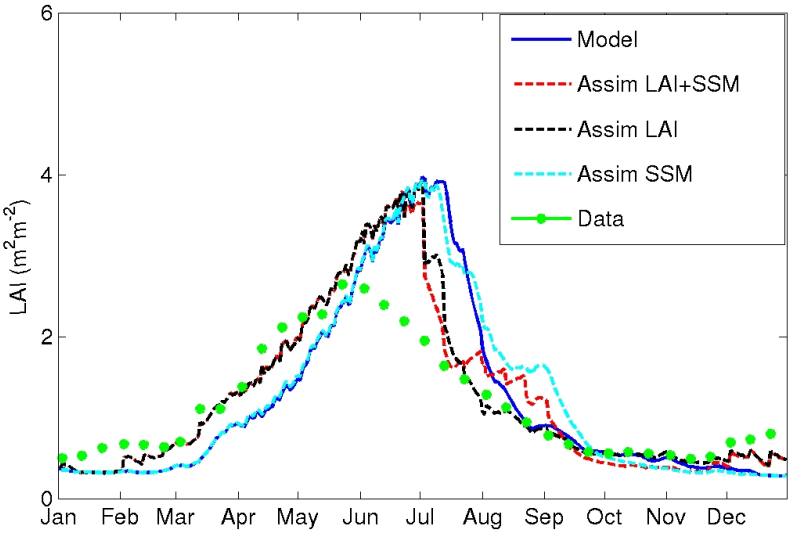

Fig. 1.