Referee #3 Wade Crow

The authors would like to thank Dr Crow for making a valuable contribution to the interactive discussion and for his supportive comments.

Comments

1) I would suggest that the author's rethink the title – there isn't any formal "data assimilation" in the manuscript and the potential impact of this research goes beyond the use of LPRM retrievals in data assimilation systems.

Reply: In line with suggestions made by other referees, the term 'data assimilation' has been removed from the paper title.

2) The paper would be greatly-improved by a "back-of-the-envelope" sensitivity calculations tion that demonstrates the feasibility of < 3-5 percent uncertainty in sub-footprint-scale surface water inducing (up to) 30 percent biases in remotely-sensed surface soil moisture retrievals. Even if based on very simplistic assumptions (e.g., surface temperature = air temperature, fixed water emissivity, constant VWC and b, the omega-tau model) this analysis would really help the credibility of the paper. Is the magnitude of bias attributed to variations in (sub-footprint-scale) surface water area variations credible? Lacking this – I don't feel the key manuscript conclusion "The comparison indicates seasonally varying biases of up to 30 percent (relative) soil water content can be attributed to the presence of relatively small areas (< 5 percent) of open water in the (nominal) footprint." is fully justified.

Reply: The authors agree with the suggestion made by the referee. In fact, an earlier draft of the paper included a similar, though inversed calculation. Here, the LPRM was inverted to calculate the open water fraction needed to account for the difference between observed satellite brightness temperature and the brightness temperature calculated from non-satellite derived soil moisture estimates (modelled and ground-observed), if these were smaller than the LPRM-derived product. This was done by reinserting the satellite-retrieved land surface temperature (with the simplistic assumption of equal LST for land surface and open water) and optical density. To calculate the brightness temperature of water the absolute value of the dielectric constant of water (80) was used. The authors have reinserted this section into the paper, as a third method to assess an open water fraction within the satellite footprint:

P7,L18-23:With regard to (3), the effect of the open water fraction (OWF) in the passive microwave footprint was assessed in three ways, *viz.* (a) using 1 km 16-day composite MODIS reflectance data; (b) from an open water fraction estimate, based on 18.7 GHz H and V polarized AMSR-E brightness temperature (Jones *et al.*, 2010), made available by the University of Montana (hereafter referred to as $\mathrm{OWF}_{\mathrm{UoM}}$); and (c) the difference between satellite-observed and modelled brightness temperature, inverting LPRM.

P8,L7 and onward: The third method calculates an open water fraction by solving the following equation for $\mathrm{OWF}_{\mathrm{LPRM}}$, which apportions the overall observed satellite brightness temperature proportionately between the open water and the land surface:

$$T_{b\,sat} = (1-\mathrm{OWF}_{\mathrm{LPRM}})*T_{b\,obs/LSM} + \mathrm{OWF}_{\mathrm{LPRM}} * T_{b\,water} \qquad [1]$$

where $T_{b\,sat}$ is the satellite-observed brightness temperature, $T_{b\,obs/LSM}$ is the brightness temperature calculated from LSM simulated or ground-observed soil moisture and $T_{b\,water}$ is the brightness temperature of water.

Both $T_{b\ obs/LSM}$ and $T_{b\ water}$ are calculated by inverting the LPRM and re-inserting retrieved LST and optical density values. To calculate $T_{b\ water}$ the absolute value of the dielectric constant of water (80) is inserted into the model. Thus, the product of $\mathrm{OWF}_{\mathrm{LPRM}}$ and $T_{b\ water}$ is used to account for the difference between $T_{b\ \mathrm{sat}}$ and $T_{b\ obs/LSM}$, where $T_{b\ obs/LSM}$ exceeds $T_{b\ \mathrm{sat}}$.

Newly inserted section 3 in Chapter 4 Results (just before Chapter 5 Discussion (P10,L16 and onward):

Estimation of OWF by inversion of LPRM 5 Discussion

Figure 5 shows $\mathrm{OWF}_{\mathrm{LPRM}}$ calculated for the grid cells shown in Figure 2 and 4, in case the AMSR-E VUA products exceeds the modelled or ground-observed soil moisture estimate. As a result, it is calculated for the drier CLM2 simulations in the Western area only, reflecting an alternating pattern of dry down and wetting up in the shallow 2 cm model top soil layer. In the Eastern and South-Central area, the alternating $\mathrm{OWF}_{\mathrm{LPRM}}$ pattern is set on top of a more seasonal variation of $\mathrm{OWF}_{\mathrm{LPRM}}$. As discussed above, the computed open water fraction in the South-Central area is presumably the result of an artefact, caused by signal smearing of the relatively large 6.9 GHz satellite footprint over a 0.25 degree grid. The $\mathrm{OWF}_{\mathrm{UoM}}$ in the Eastern area corresponds remarkably well to $\mathrm{OWF}_{\mathrm{LPRM}}$, especially the fraction calculated for CLM2. In summer, $\mathrm{OWF}_{\mathrm{LPRM}}$ (Mesonet, Noah) is lower than or out of phase with $\mathrm{OWF}_{\mathrm{UoM}}$. This could indicate additional bias due to another source, e.g. dense vegetation. In the Eastern area, however, the computed $\mathrm{OWF}_{\mathrm{LPRM}}$ indicates a small fraction (< 0.05) of open water in the satellite observation footprint alone may cause a large positive bias in the soil moisture product (> 0.2 m^3m^{-3})

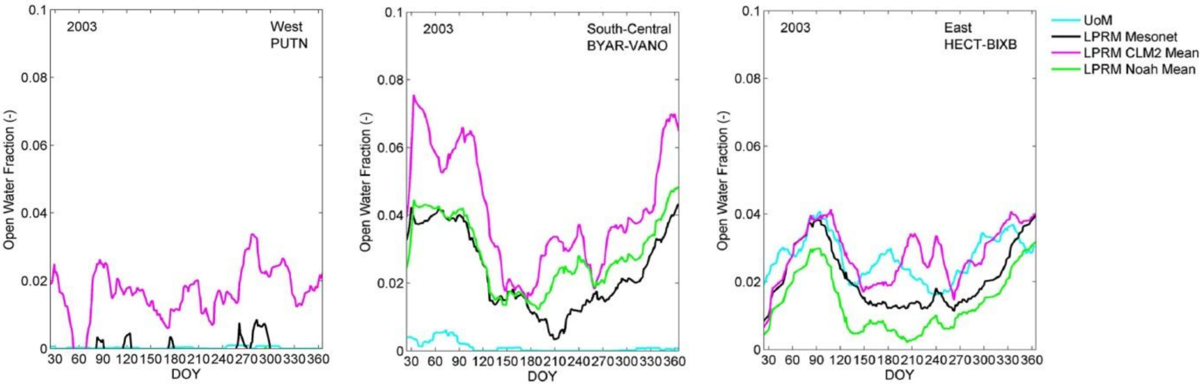

Figure 5. Time series of the Open Water Fraction calculated with the LPRM, together with the $\mathrm{OWF}_{\mathrm{UoM}}$, for the 0.25° grids cells in the Western, South-Central and Eastern Oklahoma area (low pass filter 14 days).

3) In Figure 3, seasonally-varying biases are observed in the “South-Central” Oklahoma domain WITHOUT a corresponding seasonal variation in open water fraction for the same domain (Figure 5). This would seems to contradict the author’s assertion that seasonal soil moisture biases arise directly from ignoring seasonality in open water content. If this is true – what causes the observed biases in the “South Central” domain? More discussion on this point would be helpful.

Reply: The authors believe the positive bias observed in the South-Central area is the result of an artefact, caused by signal smearing of the relatively large 6.9 GHz satellite footprint over a 0.25 degree grid. The smaller 18 GHz satellite footprint, which is used to compute the UoM open water fraction, is hardly affected by signal smearing, as it fits entirely in the 0.25 degree grid.This is discussed in some detail in Chapter 4 Results, Section Independent estimation of OWF using MODIS imagery, P10, L6-16.

4) The author's argue that the observed seasonality cannot be attributed (at least not completely) to seasonality vegetation optical (VOD) because the seasonal trend of the biases does not align with the seasonal trend of VOD. But it seems like the real issues is the seasonal trend of ERRORS in VOD (and not VOD itself). From this point of the view, the argument concerning the (potential) role of VOD seems slightly off-target. Can the seasonality of VOD errors be assessed somehow?

Reply: Following Parinussa *et al.* (2011), the higher bias retrieval error occurs at higher VOD values. From this it would follow the size of the retrieval error tracks the seasonal trend, i.e. higher in spring/summer and lower in autumn/winter.

5) Most of the large water bodies in Eastern Oklahoma are reservoirs – obviously there is some draw-down in these during the summer but Figure 5 seems to suggest there is (at least) a 50 percent reduction in the surface area of these reservoirs within a single year. This seems like a lot and suggests that the seasonal signal is tied to smaller water courses (e.g., farm diversion ponds) that dry up completely in the summer. Some discussion (even if it's speculative) on this point would help. At present the magnitude of required season variations seems a little implausible. Could the authors show a histogram of water body sizes during summer and winter? Variations in this histogram might clarify where this seasonality is coming from (i.e., what size of water bodies are appearing and disappearing).

Reply: The authors thank the referee for offering this interesting perspective. Given the 1km MODIS data resolution used to compute the open water fraction, it seems unlikely the smaller farm dams are picked up by the sensor. The application of this MODIS-based open water monitoring technique over continental Australia confirms this (Guerschman *et al.*, 2009; Ticehurst *et al*, 2009). As such, it would seem only the larger water bodies, the reservoirs, are registered, as shown in Figure 4 (now Figure 3). Although barely visible with the naked eye, a slight reduction in open water extent may be discerned going from spring to summer. The authors speculate a small fraction may only require a relatively small reduction to have a large impact.

6) Figure 7 is good – it would also help to assure the reader that seasonal variations seen in open water fraction shown in Figure 5 are also repeated for other AMSR-E years.

Reply: The authors appreciate the referee's compliment. Figure 7 shows the UoM open water fraction for all other AMSR-E years, together with the VUA and UoM soil moisture and VOD products. The MODIS-derived open water fraction is not shown for all years, due to the labour-intensive nature of retrieving, collecting and processing the MODIS data. Figure 5 shows, however, the MODIS-derived and UoM open water fraction correspond quite well in the Eastern area in 2003. Hence, the UoM open water fraction may be considered indicative of the MODIS-derived fraction through means of extrapolation for the other AMSR-E years.