

Author comments on:

Interactive comment on "A global analysis of satellite derived and DGVM surface soil moisture products" by K. T. Rebel et al.

Anonymous Referee #1

A global analysis of satellite derived and DGVM surface soil moisture products

General comments

An interesting study that compares the soil moisture simulations of a process-based vegetation model with soil moisture measured in-situ and derived from the AMSR-E radiometer. The study is original as, apart from classical metrics such as Pearson's R it also considers autocorrelation to compare the dynamics of the various data sets. The manuscript is well structured and written in fluent English. I would like to recommend it for publication in HESS after carefully addressing the issues raised in this review.

My major concern is the application of a 5 day moving average to the satellite-based soil moisture product prior to starting the analysis. Your motivation for doing this seems unjustified. In many cases the random noise of the signal is on average much smaller than the natural fluctuations of soil moisture. This means that you take out a lot of the soil moisture dynamics. First, the radiometric accuracy of AMSR-E is believed to be rather good, second, the revisit time of the satellite is far higher than every 16 days, so a global coverage is attained within ~2 days (You even contradict yourself in the next paragraph where you discuss the coverage...). I recommend to either repeating the analysis for non-convoluted data or to providing much stronger justification. Alternatively, you could use remote sensing-based profile soil moisture, such as the soil water index (Wagner et al., 1999).

Answer:

The revisit period of Aqua is 16 days, meaning that the satellite is on the exact same orbit every 16 days. However, the sensor has a global coverage of two days. AMSR-E observations are stored in a 0.25 degree grid using a nearest neighbor approach, but each gridded observation in time is based on a selection of footprint observations which represent a slightly different area at each time step. After 16 days the sensor sees more or less the same region. One part of the soil moisture noise is caused by this issue, which could be resolved with a low pass filter, as done previously by Draper et al., 2009, and Wagner et al., 2007.

In the revised manuscript, we redid all analyses without the 5-day moving average. In Table 2 of the revised manuscript, we show the results with and without the moving average. We calculated the r of AMSR-E (LPRM) with in-situ data with and without a 5-day moving average on AMSR-E (LPRM), to see the difference when accounting for the noise on AMSR-E (LPRM) and found that a 5-day moving average did not make a significant difference for these sites (average r AMRS_E without moving average = 0.55 ± 0.14 , average r AMRS-E with moving average = 0.62 ± 0.13). However, in the revised manuscript, all other analyses are performed without moving average, to avoid the damping effect of the filter on the autocorrelation analyses.

This text is added to the revised manuscript.

Related to this, I find your results difficult to interpret, as in most analyses you compare the surface soil moisture measured by AMSR-E with ROOT_SM (2m column?) of ORCHIDEE. Also in this context, using a remote sensing-based profile soil moisture instead of surface soil moisture would significantly increase the value of the similarities and differences observed in this study.

Answer:

The goal of this paper was to use the non-adjusted AMSR-E near surface soil moisture data and compare this with the different ORCHIDEE soil moisture variables (ROOT, TOTAL, DEEP and SHALLOW) with the goal to identify if this non-adjusted value could be used to assimilate soil moisture variables in ORCHIDEE in future modeling. Adjusting AMSR-E to a root-zone soil moisture would imply another simulation and parameterization step. This is beyond the scope of this paper

My second concern is the use of in-situ data. On the one hand, a clear description of the measurements is missing, even as a clear description of the measurement depths that were used for the comparison. In Section 2.3 you write that you selected sites with a reliable record of top-soil moisture record, whereas in Section 3.2.2 it seems that you used deeper in-situ measurements for the comparison. Or did you use surface measurements for the comparison with AMSR-E and deeper measurements for comparison with ROOT_SM? Otherwise I could not explain the differences in availability between AMSR-E and ORCHIDEE in Table 3. On the other hand, the sites selected do not seem to be very representative on a global level, especially not if half of the sites falls out in the in the analysis. They cover mainly grassland sites at mid-latitudes.

Answer:

AMSR-E and ORCHIDEE were both compared to the same FLUXNET data, taken at the same depth (top 30 cm soil). In our original analyses, we were limited to ORCHIDEE data-availability in 2003-2004, resulting in differences in availability in table 3. However, in the revised manuscript ORCHIDEE is available between 2002-2010, and AMSR-E and ORCHIDEE can use the same number of FLUXNET sites.

We re-analyzed all available FLUXNET sites and adjusted the revised manuscript to explain how we selected sites to be used:

'Of all available FLUXNET sites (253), 118 sites include soil moisture measurements in the top 30 cm of the soil. We applied a data selection methodology to ensure data quality. First we selected sites with more than 300 data-points between July 2002 and Jan 2007, which resulted in 35 sites. Next we ensured the sites were not located near coasts / waterbodies, ensuring that the AMSR-E (LPRM) soil moisture retrieval was not contaminated by radiofrequency interference, and that the sites were located in a region with not too high a vegetation density (optical depth < 0.8, see Parinussa et al 2011). Finally we visually assessed whether the sites had enough data in winter, and that the sites didn't include strange data-jumps due to e.g. change of instruments. This resulted in 15 sites available for this study. These selected sites have a variety of vegetation types and climates. Table 1 lists the selected FLUXNET sites, their coordinates and the vegetation type at the site.'

Specific comments

P4282.I5: "...to evaluate the results..." Please be more precise. What results? What do you mean with "evaluate"? Reading this the first time I expected a more comprehensive validation than the one presented in the manuscript.

Answer:

Original sentence: In this paper we assess the possibility of using remotely sensed soil moisture (AMSR-E) to evaluate the results of the process-based vegetation model ORCHIDEE during the period 2003-2004.

Changed in revised manuscript to: In this paper we assess the possibility of using remotely sensed soil moisture (AMSR-E) to assimilate soil moisture dynamics of the process-based vegetation model ORCHIDEE by evaluating the correspondence between these two products using both correlation and autocorrelation analyses.

P4282.I6: why is only the period 2003-2004 considered? Including more years, e.g. until 2009 would make the observed findings more robust. For example, are the structural differences between 2003 and 2004 still present (or reversed) between 2004 and 2005?

Answer:

In the revised manuscript, we changed the analysis to include the years 2002 - 2010 for AMSR-E as well as ORCHIDEE. Rather than looking at the interannual variability as we did in the original manuscript, we adjusted our analysis to study anomalies, which we were unable to with only two years of data.

P4283.I15: "...difficult to observe..." Add "with in-situ measurements"

Answer:

Changed in the revised manuscript

P4283.I15: "Microwave remote sensing provides the capability for direct observation of soil moisture." This is wrong, remote sensing of soil moisture is an indirect measurement (radiation is measured) and a model is needed to convert measured radiation into soil moisture units.

Answer:

We agree, however, the same holds for other in situ measurement techniques, e.g. TDR, capacitance probes, etc.

We changed the phrase to: 'Microwave remote sensing provides the capability for spatial soil moisture observation'.

P4284.I4: "working at the same temporal and spatial resolution. This is not always true: several land surface models work at higher or lower temporal (e.g. 6h) and spatial (e.g. 0.5_) resolutions. Based on section 2.2 (p4287.L1) I even assume that the soil moisture state in ORCHIDEE is updated every 0.5 h.

Answer:

In the revised manuscript, changed to: 'working at similar spatial resolution'

P4284.I4: "... spatial correlation is lost at around 25 km...". This cannot be considered a general statement as it depends very much on the region and principle weather systems. In many areas spatial correlation may extend for 100s of kilometres whereas in others the correlation may get lost within a few kms. Anyway, this statement is not really needed to justify the use of satellite-based retrievals for LSM validation.

Answer:

In the revised manuscript, the sentence is eliminated

P4284.I9: Spend a few more words on ORCHIDEE, e.g., the input and output variables.

Answer:

In the revised manuscript, changed text to: ORCHIDEE simulates fluxes of CO₂, water and energy at a half-hourly time step, while the ecosystem carbon and water dynamics (allocation, plant respiration, growth, mortality, soil organic matter decomposition, water infiltration and runoff) are calculated at a daily time step (Krinner et al., 2005).

P4284.I23: Explain "comparison analysis". In this form it is too vague.

Answer:

In the revised manuscript, changed comparison to correlation

P4286.I3: see my comment on the 5 -day low-pass filter in general comments section

Answer:

See earlier answer (page 1, general comments) on the 5-day low-pass filter, changed in revised manuscript.

P4286.I16: define "sparse", "moderate", and "dense" vegetation cover. Please check and cite also (Parinussa et al., 2011) for uncertainty of LPRM product.

Answer:

In the revised manuscript, changed text to:

The uncertainty of soil moisture retrieval is a function of the vegetation density and sensor characteristics and was previously estimated to be 0.05 m³ m⁻³ for sites with sparse vegetation (LPRM vegetation optical depth < 0.4) to 0.1 m³ m⁻³ for regions with moderate to dense (optical depth > 0.4) vegetation cover (Parinussa et al., 2011).

P4286.I17: "This is relatively small number..." This statement does not hold: an error of 0.04 m³m⁻³ still leads to a very high relative error in dry conditions.

Answer:

In the revised manuscript, changed text to:

'The range of soil moisture between a dry and wet state is about 10 times higher ($\sim 0.4 \text{ m}^3 \text{ m}^{-3}$) than the uncertainty'

P4287.L15: What is the lower boundary of SHALLOW_SM?

Answer:

The lower boundary of SHALLOW_SM is zero, since it disappears when all soil moisture has either been lost by evapotranspiration or when SHALLOW_SM has merged with DEEP_SM. We clarified the SHALLOW_SM and DEEP_SM behavior in the revised manuscript.

P4287.L17-L23: too little information is give on the way how SHALLOW_SM fills up and loses water. At what speed? What mathematical description is used to percolate water to the deeper layer? How is "very dry" defined? How "wet"?

Answer:

SHALLOW_SM acts as a bucket. It only loses water by evapotranspiration. So the speed for water loss is related to the evapotranspiration rate. It is filled by precipitation that reaches the soil (e.g. precipitation that is not intercepted by leaves). So SHALLOW_SM will first fill up until it reaches the surface. Then its depth will increase. If its depth reaches the DEEP_SM pool the two pools will merge and SHALLOW_SM will disappear. This is clarified in revised manuscript.

P4287.L24: 300 mm: is this for the 2 m profile or per meter?

Answer:

300 mm is for the 2-meter profile, which is changed in the revised manuscript.

P4288.L4: To me it is not clear how ROOT_SM is related to SHALLOW_SM and DEEP_SM. Is this a different layer?

Answer:

In the revised manuscript, changed text to:

The variable HUMREL (in this study indicated as ROOT_SM) is defined as the soil moisture that is available in the root profile (which exponentially declines with depth). In ROOT_SM the soil moisture is weighted by the average fraction of roots at this level assuming that the total (sum) of roots fractions is 1 with the soil depth.

P4288.L15; how is increasing CO₂ accounted for? Using what scenario? How do you incorporate the increase in CO₂?

Answer:

In the revised manuscript, changed text to:

Then simulation is launched using climate from 1901 to 2010 taking into account increasing CO₂ which is prescribed as uniform in the atmosphere and varies each year according to ice core data and Mauna Loa observations after year 1957 (Keeling, 1960).

P4288.L21: aren't there more than 500 FLUXNET sites?

Answer:

The total FLUXNET dataset we used consisted of 253 eddy covariance measurement sites (<http://www.fluxdata.org>). We changed the text to explain the selection and quality control that resulted in the number of FLUXNET sites we used (see page 2, answer 2, reviewer 1, just above 'specific comments').

P4288.L27: Information should be provided about the measurement depths (this can be done in Table 1) as this will determine to a large extent the results in Section 3.2.2. How are in-situ data processed? Do you average over all depths to obtain a value for the root zone which in Section 3.2.2. you use for comparison with ROOT_SM?

Answer:

Soil moisture data at the FLUXNET sites at taken between 0 and 30 cm soil depth. We changed the text in the revised manuscript.

P4289.L1: is optical depth <0.8 considered as "low" vegetation density?

Answer:

We consider the optical depth of 0.8 as a threshold. Beyond this value we don't feel confident to derive reliable soil moisture values. This is also shown by Parinussa et al., 2011. We changed the text in the revised manuscript into: 'the sites were located in a region with not too high a vegetation density (optical depth < 0.8 , see Parinussa et al 2011)'.

P4290.L1: equation requires appropriate formatting, using variable names instead of numbers. And where does 2003/2004 stand for? Average soil moisture content for the year 2003/4?

Answer:

We omitted this part of the analysis in the revised manuscript

P4291.L2: What is the time unit of k? Days?

Answer:

Time unit of k is days, changed in revised manuscript

P4291.I17: You write that you masked cells with less than 100 data points per year. For me it is difficult to believe that for large parts of the Sahara and the entire Arabian Peninsula the top layer bucket is filled more than 100 days / year. Please check if this is correct.

Answer:

We checked this over an extreme dry desert site in Libya (25 N 20E) and there we found 923 observations over a total of 3650 days for ORCHIDEE in GQSB. It is correct that we have often more than 100 days observations per year in the shallow soil moisture layer in ORCHIDEE. This could indeed appear to be strange but the reason of this behavior is that we have in these dry regions a dew deposition during the night and this dew goes into the soil. So even if it is evaporated rapidly during the day it allows the creation of the SHALLOW_SM that is then counted as a day with SHALLOW_SM, but in fact the layer has negligible soil moisture available.

P4291.I21: "the correlation coefficient is difficult to calculate at dry times of the year". But you don't do this: You calculate R for the entire year, not for parts of the year

Answer:

We calculate r over the daily values of both AMSR-E and ORCHIDEE for the entire simulation period.

We adjusted the text in section 3.1.1 in the revised manuscript to: 'we first calculated the correlation coefficient (r) between the daily output values of AMSR-E and the daily state variables of ORCHIDEE over 2002-2010.'

P4291.L21: I miss a discussion on the differences we see in Fig. 1 between SHALLOW_SM and DEEP_SM. They almost perfectly behave like each other's negative (See e.g., northern America, SE and SW Australia). Where does this behaviour come from? Why are correlations for SHALLOW_SM higher for many dry areas than for other areas?

Answer:

For dry areas the DEEP_SM is very small and in fact interacts little with the surface since there is never the possibility of a merge between SHALLOW_SM and DEEP_SM. For this reason, in this case the model behaves like a single bucket model represented by the SHALLOW_SM. This explains why we have a relatively good correlation between SHALLOW_SM and AMSR-E and a poor correlation between DEEP_SM and AMSR-E. For others regions, the behavior of SHALLOW_SM is more complex and can appear of disappear when merging with DEEP_SM in a relatively random way which explains the poor correlation between SHALLOW_SM and AMSR-E and the good correlation between DEEP_SM and AMSR-E. We added this explanation to the revised manuscript.

P4192.L3: frozen soils should be masked out entirely for the AMSR-E product. The analysis should be redone using a snow and frozen soil mask.

Answer:

We did mask out frozen soil, see P 4291, l14-17:

In the northern latitudes, AMSR-E is frequently not receiving a good signal because there is often snow on the ground, which leads to few reliable data points for the comparison. Therefore we applied a mask to select cells that have at least 100 (daily) data points per year.

We changed the last sentence in the revised manuscript into:

Therefore we applied a simple Land Surface Temperature algorithm to mask all cells with $T < 273K$ (Holmes et al., 2009), and masked all cells with less than 100 (daily) data points per year.

P4292.l7: I'd suggest to also have a look at Fig.4 in (Liu et al., 2011) where correlations are shown between AMSR-E and the Noah model. This would provide you a more direct comparison.

Answer:

We changed the text in the revised manuscript to:

The regions where ORCHIDEE and AMSR-E are closely related (r close to 1), correspond to a comparison of the European Remote Sensing Satellites (ERS) soil moisture products with soil moisture output by the global dynamic vegetation model LPJ (Wagner et al., 2003), as well as the comparison of AMSR-E with the global NOAH shallow soil moisture output (Liu et al, 2011).

P4292.l10: ". . . results in low r-values, comprised between 0 and 1." Remove "low", 1 is not really a low r-value... Or do you mean the globally averaged r-value?

Answer:

'low' is removed in revised manuscript

P4292.l17: "correlation between AMSR-E and ORCHIDEE": which soil moisture layer are you referring to? Same for caption table 2.

Answer:

We removed this part of the text in revised manuscript and have been more careful referring to the different ORCHIDEE parameters.

P4292.l20; "Figure 3c shows. . .": how significant are these differences? Or is it just a " $\geq$ "?

Answer:

This is ' $\geq$ ', but we removed this figure from the revised manuscript

P4293.l10: In Table 3 half of the comparisons are missing for ORCHIDEE, which really is a pity and bases the evaluations made in this section only on 8 stations. I would suggest that you look for some more sites where also ROOT_SM is available for 2003-2004. Apart from the FLUXNET sites you could have a look at the International Soil Moisture network (<http://www.ipf.tuwien.ac.at/insitu>) to see if you find something suitable (e.g. OzNet). To me it is not clear what in-situ measurements (which depths) you use for the comparison with ROOT_SM (see my comment above).

Answer:

We changed this in the revised manuscript, where we use ORCHIDEE data from 2002-2010.

P4293.l15: What do you mean by "correlation coefficient rank"?

Answer:

The value of the correlation coefficient and its order, we changed this in the text

P4293.I17: "The correlation coefficients for ORCHIDEE are generally higher than for AMSR-E". I am not entirely satisfied with the explanation you give in the following lines. Are you sure that you compare the same things? Can the explanation also be sought in the fact that AMSR-E represents surface soil moisture and ROOT_SM root zone soil moisture?

Answer:

ORCHIDEE has indeed on average a higher correlation coefficient than AMSR (although not significant, average correlation coefficient values are for ORCHIDEE and AMSR-E respectively: 0.67 ± 0.23 and 0.55 ± 0.15).

We changed the text in the revised manuscript to:

The correlation coefficients for ORCHIDEE are generally higher than for AMSR-E (LPRM) (on average 0.67 and 0.55 respectively), which may indicate that the FLUXNET measurements, which are taken in the top 30 cm, are more comparable to the depth of the ORCHIDEE root zone soil moisture than to the 2-5 cm surface soil moisture of AMSR-E.

P4294.I9: Why do you use this cut-off value? Is there any physical meaning for this? A reference or plausible explanation should be provided for this.

Answer:

Changed in revised manuscript:

The characteristic lag-time is the lag at which the autocorrelation function (r_k) reduces to $1/e$ (0.37) (Maurer et al., 2001; Delworth and Manabe, 1988)

P4294.I17: "ORCHIDEE always overestimates the auto-correlation". Two things: 1) avoid the use of "overestimates" as you are not sure if the other ones are correct (notice that this also depends on the threshold r_k that you use). 2) Can you convince me that you are not comparing apples with oranges as you compare the time lags of surface SM with the time lags of root-zone SM? I therefore think that reason number 3 (p4294.I25) is THE reason for the differences encountered between AMSR-E and ROOT_SM.

Answer:

- 1) Text in revised manuscript is changed into 'higher or lower characteristic lag-times than FLUXNET', rather than 'over- or underestimation'.
- 2) It is part of the autocorrelation analyses to determine if these variables can be compared with each other, and therefore we cannot omit the first two explanations.

P4295.I12: "... showing a too slow temporal dynamics. . ." Based on your analysis you can only conclude that they are different, but not which one is correct, as you correct surface soil moisture with root-zone soil moisture. Unless you want to use ROOT_SM to describe your surface soil moisture characteristics, but I don't think that this is the case.

Answer:

We agree and changed this in revised manuscript into 'showing a lower temporal dynamics'.

P4295.I17: "...overestimates..." see remark above.

Answer:

Changed text in revised manuscript into 'has always higher characteristic lag-times'

P4295.I21: provide support for choosing " $1/e$ " as threshold for being significant.

Answer:

Changed in revised manuscript:

The characteristic lag-time is the lag at which the autocorrelation function (r_k) reduces to $1/e$ (0.37) (Maurer et al., 2001; Delworth and Manabe, 1988)

P4295.I23ff: Fig. 6 This comparison would be even more interesting if you would include a soil map. Fig 6c suggests that high differences correspond to areas with relatively impermeable soils (clay) and peat land (Siberia).

Answer:

We used the soil map FAO 2000. Digital soil map of the world and derived soil properties, Ref 1. (CD Rom), 1, FAO land and water digital media series. When comparing this map to Figure 6, we do not see a large correspondence, neither to the maps in the revised manuscript.

Technical corrections

Title: the term DGVM is not explained in the text: spell out entirely in title and explain somewhere in manuscript

Answer:

We removed the term DGVM from the revised manuscript

P4284.l11: "...point locations, and in..." remove ", and"

Answer:

Changed text in revised manuscript

P4285.l11: "swatted" is used incorrectly here.

Answer:

Changed text in revised manuscript

P4286.l16: "0.1" what unit?

Answer:

Changed revised manuscript to include '0.01 m³/m³'.

P4292.l6-9: this part should move to previous paragraph. New paragraph should start with: "Correlating the precipitation..."

Answer:

Changed text in revised manuscript

P4292.l29: I would not use the term "climate" for yearly variations

Answer:

Changed text in revised manuscript

P4295.l18: "this may suggests" Remove "s"

Answer:

Changed text in revised manuscript

Fig.4.: legend cannot be read entirely: Root_SM falls off. Use same formatting of variables as in text, i.e. "ROOT_SM" instead of "Root_SM". Does rk have a unit? You only show grassland sites. I would suggest to show at least one other land cover type. ". . . calculated foUr different sites: remove "u"

Answer:

We adjusted the legend in the revised manuscript.

Rk is the lag-k autocorrelation coefficient, which is dimensionless and has a value between -1 and 1.

We changed the sites shown in figure 3 in the revised manuscript, which now show the land cover types Savannah, Evergreen Needleleaf Forest, grassland, Deciduous Broadleaf Forest and pine forest.

We removed the 'u' in the revised manuscript

Fig.5.:Use different symbols for AMSR-E and ROOT_SM which makes the distinction easier in a black and white print. What do labels indicate? The plot numbers? Some labels overlap.

Answer:

We changed the symbols of Figure 5 in the revised manuscript; ORCHIDEE has red open circles and AMSR-E has closed blue circles. The labels indicate the plot numbers, which is added in the legend of Figure 5 in the revised manuscript.

References

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Extra references reply:

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Anonymous Referee #2

Manuscript is well written and structured. Authors perform a global evaluation of the LPRM derived AMSR-E product against a modeled soil moisture output generated using the ORCHIDEE vegetation model. However, there are several issues that need to be addressed, including the fact that ORCHIDEE is a root-zone "single-layer" model and AMSR-E provides an estimated of the top few cm, the impact of the 5-days smoothing filter that was applied to the AMSR-E data and value of the in situ observations used here.

What does the "DGVW" abbreviation in the title mean? It is not a common abbreviation. Please either define it or re-word the title. AMSR-E is available since 2002 until present and section 2.2. explains that the model was run between 2000 and 2008. Why the analyses focus on only two years and why were exactly these two years selected (2003 and 2004)?

Answer:

These same issues were raised by Reviewer 1, and hopefully have been answered adequately above.

pp. 4283, last paragraph: authors explained that the LPRM model provides a "global soil moisture product" where the retrieval is based on the radiative transfer equation, which is true; however, all of the available passive microwave techniques are based on this same equation. It will be more useful if the statement reflects on what makes the LPRM retrieval different than the rest of the existing approaches.

Answer:

A special characteristic of LPRM is the internal analytical approach to solve for the vegetation optical depth, τ_v (Meesters et al., 2005). This unique feature reduces the required vegetation parameters to one, the single scattering albedo. Additionally LPRM also uses Ka band observations to estimate the temperature of the emitting layer. These two features make LPRM different than the other algorithms. We changed the text in the revised manuscript.

pp. 4285, last paragraph – the supreme performance of descending C-band data set used here, is it relative to the ascending C-band retrieval, to X-band, to the alternative global soil moisture data sets? Is this the justification for choosing LPMR over the rest of the available global products? Please, clarify.

Answer:

In this study we only used soil moisture retrievals acquired by night-time overpasses (descending occurring between 0030 and 0230 local time), as near surface land surface temperature gradients are less at night and more robust retrievals are obtained (Owe et al. 2008).

The choice for LPRM was based on the following criteria:

- Satellite soil moisture data should be public available
- Data record should have a long record to study inter annual variations (> 5 years)
- Satellite soil moisture data already been used by different independent research groups and shown a proven quality.

Based on these criteria, LPRM is the only choice.

pp. 4286, line 13: "These satellite . . . products" – assume the sentence describes the C-band LPRM product as not other products have been mentioned previously. Please, re-word. Justification for the 5-days moving average filter should be provided, i.e. AMSR-E revisit time is 16 days, why a 5-days moving window was selected? More importantly, given that the analysis are based on "the dynamics of the soil moisture depletion processes after rainfall events" (pp. 4284, lines 10-15), the filter will actually dampened down the AMSR-E response to rainfall events and possibly remove spikes caused by small events.

Answer:

We changed the text in the revised manuscript to: These satellite derived soil moisture products at the frequencies used here (C and X band) are representative of soil moisture of approximately the first centimeters.

In the revised manuscript, we did the analysis both with and without the 5-day moving average (see Table 2), and found no significant different for the correlation values. We did continue our analyses without a 5-day moving average, since it may influence the autocorrelation values as well as the anomaly values.

Can you please elaborate a little bit on the implications of the smoothing step, i.e. were any analyses performed to assess how this moving filter impacts the AMSR-E response to rainfall events?

Answer:

See answer to comment pp. 4286, line 13

How exactly does the ORCHIDEE model do the water transfer through the soil medium? Is it a simple bucket model? There is no info on the actual depths of the model soil layers. Description if the ORCHIDEE should be improved.

Answer:

ORCHIDEE water transfer is clarified in the revised manuscript by including: SHALLOW_SM acts as a bucket. It only loses water by evapotranspiration. So the speed for water loss is related to the evapotranspiration rate. It is filled by precipitation that reaches the soil (e.g. precipitation that is not intercepted by leaves). So SHALLOW_SM will first fill up until it reaches the surface. Then its depth will increase. If its depth reaches the DEEP_SM pool the two pools will merge and SHALLOW_SM will disappear.

Can you please elaborate on the fact that the top layer disappears during dry periods. Why?

Answer:

Please see reply above, on ORCHIDEE water transfer, which also explains why and when the top layer disappears.

Why was not the model soil moisture recalculated into m^3/m^3 – 20 mm of water within 5 cm deep layer is different than 20 mm within 1 m or 2 m layer!

Answer:

We agree with the remark, However, as the soil is represented as 2 buckets a volumetric representation of the soil is not relevant as the vertical discrimination of the soil is not precisely represented. For this reason we prefer to only represent a total amount.

What is the difference between deep (DEEP_SM), total (TOT_SM) and root zone (ROOT_SM) layers? Please, explain.

Answer:

DEEP_SM is the second bucket (below SHALLOW_SM, as explained above), which will always exist. DEEP_SM has a maximum depth of 2 m. TOT_SM is the sum of SHALLOW_SM and DEEP_SM. The variable ROOT_SM is defined as the soil moisture that is available in the root profile (which exponentially declines with depth). In ROOT_SM the soil moisture is weighted by the average fraction of roots at this level assuming that the total (sum) of roots fractions is 1 with soil depth.

Authors explained that the modeled soil moisture is a daily product; if the precip data are available on an hourly time step why the model was archived on a daily basis? AMSR-E is an instantaneous observation in time. Since AMSR-E estimates are representative of only a very shallow soil depth – the response to a rainfall event that was let's say 8 hours before the overpass will be rather small or not evident at all depending on the rainfall amount, but will be present in the model's response.

Answer:

The model calculates soil moisture every half an hour, however, we only used the daily output because global hourly output from the model would be very large and in fact not relevant since the climate forcing is 6 hourly, so within the 6 hours we don't know the real precipitation distribution. Moreover we know that precipitation distribution coming from an initial NCEP reanalysis at 2.5° is probably not realistic for representing synoptic events.

Furthermore, it is expected that the satellite product will correlated better with the top layer model estimate; however, this is not the case here. Authors' explanation for this is the fact that the shallow layer "disappears" under dry conditions and the results from the AMSRESHALLOW_SM comparisons are omitted in the end. If the shallow model layer is so unstable, it may be less confusing if the satellite comparisons against the shallow soil moisture layer are not included.

Answer:

In theory it would be the most obvious choice to use the shallow soil moisture layer of ORCHIDEE for soil moisture assimilation with satellite soil moisture. However, this paper clearly shows this is not a good choice. This is important information for future researcher, and therefore we think it should be presented in this paper.

At what depth do the in situ stations measure soil moisture? Better/more detailed description of the soil moisture instruments at the Fluxnet sites should be provided.

Answer:

Soil moisture data at the FLUXNET sites at taken between 0 and 30 cm soil depth. We changed the text in the revised MS.

Why were the Fluxnet sites selected considering that there are alternative, well instrumented watersheds that provide more than one observation per footprint? 15 stations out of 300(?) available seem like a very small subset! Also, given the multiple reasons provided by the authors, why the in situ data are expected to behave differently

than the other two products (i.e. scale, not representative footprint average, etc.), not convinced that the analyses against the station data really provide additional info on the performance of the model/satellite or help “learn more about the inter-annual differences”.

Answer:

Instrumented watersheds do not have the same global coverage as the FLUXNET sites, and furthermore, data from instrumented watersheds is not always publicly available. Also, one of the underlying aims of this paper is to show the availability of the new and freely available soil moisture source of FLUXNET.

The selection of 15 out of 253 FLUXNET sites is better explained in the revised manuscript:

‘Of all available FLUXNET sites (253), 118 sites include soil moisture measurements in the top 30 cm of the soil. We applied a data selection methodology to ensure data quality. First we selected sites with more than 300 data-points between July 2002 and Jan 2007, which resulted in 35 sites. Next we ensured the sites were not located near coasts / waterbodies, ensuring that the AMSR-E (LPRM) soil moisture retrieval was not contaminated by radiofrequency interference, and that the sites were located in a region with not too high a vegetation density (optical depth < 0.8, see Parinussa et al 2011). Finally we visually assessed whether the sites had enough data in winter, and that the sites didn’t include strange data-jumps due to e.g. change of instruments. This resulted in 15 sites available for this study. These selected sites have a variety of vegetation types and climates. Table 1 lists the selected FLUXNET sites, their coordinates and the vegetation type at the site.’

Is 0.8 optical depth indicative of low vegetation density?

Answer:

An optical depth of 0.8 is the threshold, beyond 0.8 there are no reliable values

Authors use correlation coefficient, lag correlation coefficient, rank coefficient – do the authors compute and discuss diff. statistical parameter or the three are used interchangeably? Please, clarify.

Answer:

The correlation coefficient is the Pearson product-moment correlation coefficient (Eq 1), which is equal to the lag-k autocorrelation coefficient (r_k). The rank coefficient is the order of the lag-k autocorrelation coefficient. This is better explained in the revised manuscript.

pp. 4290, line 7-8 – The modeled, satellite and in situ may differ in terms of absolute value, but should agree in terms temporal dynamics.

Answer:

We agree, changed in revised manuscript

pp. 4291, line 9 – “the significant ($p < 0.05$) correlation coefficients” – it appears that the corr. values shown in Fig. 1 are not all significant.

Answer:

In Fig 1, only the significant values are shown, which have a $p < 0.05$.

pp. 4291, line 13-14 – not clear: “since the precipitation input in these years was different in each region”;

Answer:

This analysis is removed from the revised manuscript

pp. 4292, line 11-12 – certainly precipitation is the dominant input when it comes to calculating the soil moisture state; however, the more significant issue here is the simplicity of the hydrologic component of the vegetation model;

Answer:

We agree with the reviewer that both precipitation and the hydrologic component of the vegetation model are important for the analyses in this manuscript. In the revised version of the manuscript, we also emphasize the simplicity of the hydrologic component of ORCHIDEE.

Not clear why $1/e$ was selected as a threshold.

Answer:

Changed in new version manuscript:

The characteristic lag-time is the lag at which the autocorrelation function (r_k) reduces to $1/e$ (0.37) (maurer et al., 2001; Delworth and Manabe, 1988)

Table 2 is not needed – authors can add a color bar with the percentages next to each category next to Fig. 3c

Answer:

Table 2 is removed in the revised manuscript, since we do not compare two years anymore, but multiple years

Figure 5: What are the numbers shown in the plot? Station number (corresponding to the numbers listed in Table 1)?

Answer:

These are station numbers, changed in revised manuscript

References:

- Delworth, T. L. and Manabe, S.: The influence of potential evaporation on the variabilities of simulated soil wetness and climate, *J. of Climate*, 1 (5), 523-547, 1988.
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Anonymous Referee #3

The authors performed a global analysis of a microwave-based soil moisture retrieval based on the LPRM model (using AMSR-E Tb) and modeled soil moisture provided by the ORCHIDEE model. The article is well written, however, several issues are present which need to be addressed.

1) Why was the ORCHIDEE model chosen for this analysis? Although it is a well received LSM, the authors make a special point that this analysis is necessary before a full assimilation methodology can be implemented, a point that is correct. However, the structure of the soil layers in ORCHIDEE may present a very difficult implementation of a soil moisture data assimilation system because of the dynamic surface layer in ORCHIDEE. The authors make this point in the conclusions, yet I believe it may need to be addressed earlier in the paper and also the authors should provide an opinion on how these necessary structural changes may affect the findings in this study.

Answer:

We choose the ORCHIDEE model because it is a widely used Dynamic Global Vegetation Model (DGVM) and has a relatively simple, albeit, unique parameterization of soil moisture. The purpose is not to specifically test or validate ORCHIDEE, but rather to

derive a methodology to validate any DGVM. While we expect other DGVMs to show (minor) differences, our way of comparing the satellite data with model estimates should be applicable to all. This is simply put, the first attempt to globally compare soil moisture from a DGVM with satellite data. Particularly our comparison of dynamic behavior should stimulate other DGVM groups to execute a similar study. For ORCHIDEE, a new hydrological scheme is under development that will represent the soil within 11 layers with an explicit representation of diffusion and percolation of water. So we expect that it will improve the results found in this study in particular because it will be easier to really explore the surface soil layer. However it is difficult to anticipate what would be the result. A more detailed model is not necessarily a guarantee of improved results.

2) The references to AMSR-E in the analysis should probably be changed to LPRM, while still making it clear that the LPRM is based on AMSR-E Tb in this study (for example, in Sec 2. 1).

Answer:

We agree and changed AMSR-E to AMSR-E (LPRM) in the revised manuscript.

3) What is the reasoning for the application of the low pass filter? The filter is going to act to dampen the soil moisture signal from LPRM, which when C- or X-band is used has an effective sensing depth of around 1 to possibly 2 cm. The use of the filter needs to be better justified.

Answer:

In the revised manuscript, we did the analysis both with and without the 5-day moving average (see Table 2), and found no significant difference for the correlation values. We did continue our analyses without a 5-day moving average, since it may influence the autocorrelation values as well as the anomaly values.

The revisit time of AMSR-E is more on the order of 1 to 2 days (dependent on latitude), not 16 days.

Answer:

Adjusted the manuscript to include the following text:

'The revisit period of Aqua is 16 days meaning that the satellite will be on the exact same orbit after 16 days. However, the sensor will have a global coverage within two days. AMSR-E observations are stored in a 0.25 degree grid using a nearest neighbor approach, but each gridded observation in time is based on a selection of footprint observations which represent a slightly different area each time step. After 16 days they will see more or less the same region. One part of the soil moisture noise is caused by this issue, which could be resolved with a low pass filter, as done previously by Draper et al., 2009, and Wagner et al., 2007'.

4) The manuscript cites the availability of 300 FLUXNET sites, why are only 15 chosen for the analysis? If it is a data availability issue (i.e. some sites do not measure soil moisture), I still think it would help the reader accept the decision of 15 sites. I think it may also be helpful to provide information about the depth of the soil moisture observations at the sites which were included in the analysis.

Answer:

We re-analyzed all available FLUXNET sites and adjusted the text to explain how we selected sites to be used in this manuscript:

'Of all available FLUXNET sites (253), 118 sites include soil moisture measurements in the top 30 cm of the soil. We applied a data selection methodology to ensure data quality. First we selected sites with more than 300 data-points between July 2002 and Jan 2007, which resulted in 35 sites. Next we ensured the sites were not located near coasts / waterbodies, ensuring that the AMSR-E (LPRM) soil moisture retrieval was not contaminated by radiofrequency interference, and that the sites were located in a region with not too high a vegetation density (optical depth < 0.8, see Parinussa et al 2011). Finally we visually assessed whether the sites had enough data in winter, and that the sites didn't include strange data-jumps due to e.g. change of instruments. This resulted in 15 sites available for this study. These selected sites have a variety of

vegetation types and climates. Table 1 lists the selected FLUXNET sites, their coordinates and the vegetation type at the site.'

5) The manuscript appears to reference several different time periods of available observations: ORCHIDEE – 2000 to 2008 AMSR-E (LPRM) – 2002 to 2008 FLUXNET – 2000 to 2008 Considering that this analysis would have benefited from using all available years, why was the analysis only performed for 2003/2004? The reasoning needs to be addressed in the manuscript.

Answer:

We changed the time period of study in the revised manuscript to include 2002-2010, rather than 2003-2004. Fluxnet site soil moisture data were only available to us up to 2008.

6) How is the monthly precipitation interpolated to daily values from the CRU dataset? Why was this dataset chosen during the analysis periods, were better precipitation datasets not available? Was any attempt made to temporally correct the monthly precipitation, so that the model was forced with precipitation at a given grid point on days in which precipitation was actually observed? This would seem to be an important consideration especially in the case of comparing the ability of ORCHIDEE and LPRM to react to precipitation events. This could potentially be done with a dataset such as TRMM or CMORPH, using a satellite precipitation dataset to temporally disaggregate the CRU precipitation forcing.

Answer:

The monthly precipitation is interpolated to 6h value using the NCEP precipitation variability. So each 6h the precipitation is calculated from monthly CRU value multiplied by the fraction of total NCEP precipitation simulation for this 6h. We agree that there is space for improving the global meteorological forcing, however, the CRU dataset has been available for us. Temporally correcting the monthly precipitation would be a study by itself, and is beyond the scope of this paper.

7) In section 3.2.1, the manuscript states that TOT_SM and ROOT_SM show the best correlation with LPRM (or AMSR-E), and in large areas of Europe, east Europe, North America, and South America, the correlation between LPRM and ROOT_SM is close to one. Can the authors provide a potential reasoning for such a high correlation between LPRM (0 – 1 or 0 – 2 cm soil moisture retrieval, which is very sensitive to precipitation events) and ORCHIDEE TOT_SM and ROOT_SM (essentially 0 – 2000 cm, forced with a monthly, low resolution precipitation dataset)?

Answer:

SHALLOW_SM does not always exist, which explains the poor relationship with AMSR-E, and top soil moisture is coupled to rootzone soil moisture. We also see that seasonality dominates the correlation, which is visible when comparing the correlation maps with the anomaly maps that have lower correlation values. We explained this better in the revised manuscript.

Was any attempt made to remove the seasonal cycle of SM which is potentially dominating the correlation signal, while not providing much information about the interannual skill of LPRM or ORCHIDEE? For example, when the seasonal cycle of SM is not removed, the analysis is potentially only showing that LPRM has very high skill (r near 1) of denoting wet vs. dry seasons, not denoting daily changes in SM (from precipitation events).

Answer:

In the revised version of the manuscript, we also show the anomalies, with removal of seasonal cycle.

Furthermore, in this section it is shown that while LPRM and ORCHIDEE have very high correlation in TOT_SM and ROOT_SM, the correlation between LPRM and the CRU precipitation forcing is not very high? As a reader, I had trouble rectifying how LPRM and ORCHIDEE TOT_SM/ROOT_SM can have a correlation near 1, while LPRM and the CRU precipitation forcing shows very low correlation. The SM evolution of ORCHIDEE is dominantly driven by the precipitation forcing, so I would expect poor precipitation forcing

would lead to poor soil moisture predictions (i.e. better agreement between the correlation of LPRM and ORCHIDEE SM and the correlation of LPRM and CRU precipitation).

Answer:

The evolution of soil water is related not to precipitation itself but to its integral. Moreover, it also depends on other processes like evapotranspiration, interception loss, runoff, etc. We changed the text in the revised manuscript to better explain this behavior.

8) What does DVGM stand for? Please specify at its first reference in the manuscript.

Answer:

We omitted the word 'DGVM' in the revised manuscript.

pp. 4283, line 17 – should not be considered a direct observation, soil moisture is retrieved through application a radiative transfer model, radiance (or brightness temperature) is directly observed.

Answer:

We agree, however, the same holds for other in situ measurement techniques, e.g. TDR, capacitance probes, etc.

We changed the phrase to: 'Microwave remote sensing provides the capacity for spatial soil moisture observation'.

pp. 4283, line 21 – should provided a quantitative measure of "significant" vegetation

Answer:

Significant vegetation has a vegetation optical depth of 0.8, we added this information to the revised manuscript.

pp. 4285, line 14 – please make it clear that microwave satellite soil moisture covers on the first few centimeters, indirect soil moisture estimation using thermal wavelengths have been shown to potentially provide a root-zone soil moisture signal over moderate to dense vegetation.

Answer:

Microwave energy originates from within the soil and the magnitude of anyone soil layers contribution decreases with depth. The sampling depth is influenced mainly by the total complex dielectric constant discontinuity at the surface and the near surface dielectric constant gradient. The sampling depth is only several tenths of the wavelength, which is 1-2 cm (Schmugge, 1983). We added this text to the revised manuscript.

pp. 4285, line 27 – provide the reader with the reasoning that descending retrievals are more reliable.

Answer:

See comment reviewer 2, pp. 4285, last paragraph

pp. 4291, line 7 – it is a bit confusing what correlation you are referring to in the heading of 3.2.1, please specify

Answer:

We changed the text in the revised manuscript to 'Global correlation between AMSR-E and ORCHIDEE soil moisture'

pp. 4297, line 8 – should be more like 1 to 2 cm when retrieval is based on C- or X-band, L-band sensors are more on the order of 3 to 5 cm

Answer:

See comment reviewer 3, pp. 4285, line 14. We would like to add that the total dielectric constant discontinuity at the surface and the near surface dielectric constant

gradient varies between a dry soil and a wet soil, causing the sampling depth to vary over time (de Jeu, 2003).

References:

- De Jeu, R. A. M.: Retrieval of Land Surface Parameters using Passive Microwave Remote Sensing, Phd dissertation VU University Amsterdam, NL, 122 pages, 2003.
- Draper, C. S., Walker, J. R., Steinle, P. J., De Jeu, R. A. M., and Holmes, T. R. H.: Evaluation of AMSR-E derived soil moisture over Australia, *Remote Sens. Environ.*, 113, 703-710, doi: 10.1016/j.rse.2008.11.011, 2009.
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I would like to discuss about the preprocessing of microwave data, why is 5 day moving average to the satellite-based data applied? In application, moving average seems to blur the contrast before and after rainfall events. In addition, the time series of AMSR-E data are not continuous (with few days missing), and in some software, moving average are not recommended for series with missing data. It seems other smooth method, like 'loess' can more accurate approximate the curve, why isn't that being used?

Answer:

In the revised manuscript, we redid all analyses without the 5-day moving average. In Table 2 of the revised manuscript, we show the results with and without the moving average. We calculated the r of AMSR-E (LPRM) with in-situ data with and without a 5-day moving average on AMSR-E (LPRM), to see the difference when accounting for the noise on AMSR-E (LPRM) and found that a 5-day moving average did not make a significant difference for these sites (average r AMRS_E without moving average = 0.55 ± 0.14 , average r AMRS-E with moving average = 0.62 ± 0.13). However, in the revised manuscript, all other analyses are performed without moving average, to avoid the damping effect of the filter on the autocorrelation analyses. This text is added to the revised manuscript.