



## ***Interactive comment on “Spatial and temporal variability of biophysical variables in Southwestern France from airborne L-band radiometry” by E. Zakharova et al.***

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Reviewer #2 – Richard de Jeu

The authors thank Richard de Jeu, reviewer #2, for his review of the manuscript and for the fruitful comments.

2.1 [The introduction is too short and does not have a clear rationale. Furthermore it needs more information about the vegetation optical depth because not a lot of readers know what a vegetation optical depth is. The results and discussion need a more thorough comparison analysis between the modeled and remotely sensed retrievals

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(for example a discussion on the changing spatial correlation over time was missing). In addition, a discussion on the b factor should be reconsidered because LAI is not always directly related to vegetation water content and the changes in b could easily be related to a wrong approximation of VWC.]

#### RESPONSE 2.1

Yes, we agree that the Introduction and Discussion Sections need to be improved. Detailed responses are given below.

2.2 [Page 897 Line 4: please explain why it is important for ecohydrology, hydrometeorology: give an example.]

#### RESPONSE 2.2

This is particularly true in regions affected by droughts, where water is a limiting factor of plant growth (Porporato and Rodriguez-Iturbe, 2002).

#### ADDITIONAL REFERENCE

Porporato, A. and Rodriguez-Iturbe, I.: Ecohydrology - a challenging multidisciplinary research perspective, Hydrol. Sci. J., 47(2), 811-821, 2002.

2.3 [Page 897 Line 7: please give a reference here]

#### RESPONSE 2.3

The study of Mohr et al. (2000) is a good example illustrating the importance of soil moisture in land surface models.

#### ADDITIONAL REFERENCE

Mohr, K.I., Famiglietti, J.S., Boone, A., and Starks, P.J.: Modeling soil moisture and surface flux variability with an untuned land surface scheme: A case study from the Southern Great Plains 1997 Hydrology Experiment, J. Hydrometeorol., 1, 154-169, 2000.

Full Screen / Esc

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2.4 [Page 897 Line 17 to end. Please explain the relevance of this part first by a few lines. Now it is not clear for the reader how this section is related to your work.]

#### RESPONSE 2.4

The CAROLS campaign was performed in the framework of the calibration/validation of the SMOS (Soil Moisture and Ocean Salinity) spaceborne instrument operating at L-band (Kerr et al., 2001). Over land, the main product of SMOS is surface soil moisture (SSM). The multi-angular, bipolarized observations of SMOS permit the retrieval of the vegetation optical depth (VOD), in addition to SSM (Wigneron et al., 1995 ; Lee et al., 2002 ; Pellarin et al., 2003).

#### ADDITIONAL REFERENCE

Lee, K., Burke, E.J., Shuttleworth, W.J., and Harlow, R.C.: Influence of vegetation on SMOS mission retrievals, *Hydrol. Earth Syst. Sci.*, 6(2), 153–166, 2002.

2.5 [Page 898 line 4: First ground based.... Jackson et al., 1986. This is not true Njoku and Kong were one of the first in 1977 (JGR paper). Please change.]

#### RESPONSE 2.5

Yes. The sentence could be reworded as:

“The first ground-based studies dedicated to soil moisture measurement at L-band started in the 1970s (Njoku and Kong, 1977).”.

#### ADDITIONAL REFERENCE

Njoku, E.G. and Kong, J.-A.: Theory for passive microwave remote sensing of near-surface soil moisture, *J. Geophys. Res.*, 82(20), 3108-3118, doi:10.1029/jb082i020p03108, 1977.

2.6 [Page 898 Line 11, the BARC experiments were done in the early eighties and not carried out for SMOS: please change.]

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## RESPONSE 2.6

Yes, BARC is not relevant in this context. Thanks for the detection of this typo.

2.7 [Page 898, line 21, please explain why an additional validation is still needed.]

## RESPONSE 2.7

The sentence could be reworded as:

“After the launch of SMOS, there is now a need to assess the accuracy of SSM retrievals for various ground properties and vegetation types in the framework of the calibration/validation of the instrument.”.

2.8 [Page 898, line 22: This introduction part needs a more thorough description on VOD because a lot of readers don't know what VOD means. Vegetation studies with microwave observations already have a nice history; for example Choudhury was one of the first who demonstrated a global vegetation application in a desertification study(Choudhury, 1993). In addition a few of the coauthors of this paper wrote already an excellent review on vegetation optical depth in 1994 (Kerr and Wigneron, 1994). And now, eighteen years later, different researchers have been using VOD for different applications. Liu et al (2011) detected deforestation and agricultural intensification in VOD records, Miralles et al. (2011) used VOD records to estimate vegetation stress and in 2007 Liu et al. (2007) used VOD to show the impact of ENSO on vegetation in Australia. By addressing a few of these studies, you will put your work more in perspective and give the VOD more value.]

## RESPONSE 2.8

We agree that more insight is needed regarding the vegetation optical thickness (VOD) retrieval at L-band.

In this study, VOD is defined as the effective zenith (i.e. nadir) opacity of the vegetation (“Tau”, dimensionless) in the microwave domain. This quantity can be produced by the

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inversion of the simplified “Tau-Omega” approach used in the L-MEB model (Wigneron et al., 2007). When  $VOD = 0$ , there is no vegetation attenuation of the soil microwave emission. The VOD value tends to increase with the vegetation water content (VWC, in  $\text{kg m}^{-2}$ ). From L-band to X-band, VOD is proportional to VWC and to frequency ( $f$ ) (Jackson and Schmugge, 1991 ; Schmugge and Jackson, 1992 ; Kerr and Wigneron, 1995 ; Njoku and Chan, 2006). The VOD value is often expressed as  $VOD = b \cdot VWC$ , with  $b = A \cdot \text{epss} \cdot f$  (Kirdyashev et al., 1979), where the value of  $A$  is related to the canopy structure, and  $\text{epss}$  is the imaginary part of the dielectric constant of saline water in the vegetation. The latter depends only slightly on temperature, at the low salinity levels generally observed in plants. At low frequencies, it is often assumed that the  $A \cdot \text{epss}$  product does not vary much from one vegetation type to another and across frequency values, and that  $b$  is proportional to  $f$ . For example, the frequency used by the SMOS radiometer is 1.42 GHz (L-band) and the C-band and X-band channels of AMSR-E correspond to 6.925 GHz and 10.65 GHz, respectively. Therefore, if one assumes that  $f$  dominates the VOD response to VWC, VOD is about 5 times more sensitive to VWC at C-band than at L-band, even more at X-band.

Using ground multi-frequency passive microwave observations, Calvet et al. (2011) have shown that C-band and X-band are more appropriate than L-band to monitor the VWC of a wheat field, with VWC values close to  $3 \text{ kg m}^{-2}$  at the end of May. This is consistent with the lower sensitivity of VOD to changes in VWC (i.e. the lower  $b$  value) at L-band. A number of studies have shown the usefulness of VOD values retrieved from C-band or X-band satellite microwave brightness temperatures (Liu et al., 2007, 2011 ; Jones et al., 2011 ; Miralles et al., 2011).

This study tends to confirm that the L-band VOD relationship with vegetation characteristics is less straightforward than at C-band or X-band. In addition to the reduced sensitivity to VWC, the L-band  $b$  value is found to present a seasonal variability for low vegetation canopies. This finding is consistent with the microwave observations over a wheat field analysed by Wigneron et al. (1996) and could be explained by changes in

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the value of the A coefficient.

## ADDITIONAL REFERENCES

Jackson, T. J. and Schmugge, T. J.: Vegetation effects on the microwave emission of soils, *Remote Sensing of Environment*, 36, 203– 212, 1991.

Kerr, Y.H. and Wigneron, J.-P.: Vegetation models and observations, a review, in *Passive Microwave Remote Sensing of Land-Atmosphere Interactions*, Eds. Choudhury, B.J., Kerr, Y.H., Njoku, E.G., and Pampaloni, P., VSP, Utrecht, the Netherlands, 317-344, 1995.

Kirdyashev, K.P., Chukhlantsev, A.A., and Shutko, A.M.: Microwave radiation of the Earth's surface in the presence of vegetation cover, *Radio Eng. Electron. Phys.*, 24, 256-264, 1979.

Liu, Y., De Jeu, R.A.M., McCabe, M.F., Evans, J.P., and Van Dijk, A.I.J.M.: Global long-term passive microwave satellite based retrievals of vegetation optical depth, *Geophys. Res. Lett.*, 38, L18402, doi: 10.1029/2011GL048684, 2012.

Liu, Y., De Jeu, R.A.M., Van Dijk, A.I.J.M., and Owe, M.: TRMM-TMI satellite observed soil moisture and vegetation density (1998–2005) show strong connection with El Nino in eastern Australia, *Geophys. Res. Lett.*, 34, L15401, doi:10.1029/2007GL030311, 2007.

Miralles, D.G., Holmes, T.R.H., De Jeu, R.A.M., Gash, J.H., Meesters, A.G.C.A., and Dolman, A.J.: Global land-surface evaporation estimated from satellite-based observations, *Hydrol. Earth Syst. Sci*, 15, 453-469, doi:10.5194/hess-15-453-2011, 2011.

Njoku, E.G. and Chan, S.K.: Vegetation and surface roughness effects on AMSR-E land observations, *Remote Sensing of Environment*, 100, 190-199, 2006.

Schmugge, T.J. and Jackson, T.J.: A dielectric model of the vegetation effects on the microwave emission from soils, *IEEE Transactions on Geoscience and Remote Sens-*

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ing, 30(4), 757-760, doi:10.1109/36.158870, 1992.

2.9 [Page 903 : Please explain the letters A to D in the Figure 3 caption.]

#### RESPONSE 2.9

The A-D letters correspond to data clusters in the TbH-TbV space. The main cluster A (except for TbH < 220 K) corresponds to the data analyzed in Sects. 3-4. Clusters B-D correspond to observations excluded from the dataset: B and C are related to unmitigated RFI perturbations close to urban areas, D is related to a high density of water bodies.

2.10 [Page 906: in the 2.3 Section: Please make a clear note here that the assumption to describe LAI as a function of VWC is not always true. A leafless tree does have a VWC but no LAI. An interesting example on this can be found in the FOSMEX study where Guglielmetti et al., (2008) found a small variation in transmissivity over the season for a beech forest in Germany. In this study the seasonal variation of VWC for this forest was probably different than the seasonal LAI variation.]

#### RESPONSE 2.10

Yes. As shown by Eq. (3b), VWChigh does not depend on LAI and does not present seasonal variations. This is coherent with ground observations of the L-band microwave emission of forest canopies showing little or no change across seasons (e.g. Guglielmetti et al., 2008 ; Grant et al., 2008).

#### ADDITIONAL REFERENCE

Guglielmetti, M., Schwank, M., Mätzler, C., Oberdörster, C., Vanderborght, J., and Flühler, H.: FOSMEX: Forest soil moisture experiments with microwave radiometry, IEEE, TGARS, 46(3), 727-735, doi:10.1109/TGRS.2007.914797, 2008.

2.11 [Page 907: Line 25: Please quantify good correlation ( $r > 0.5$ ) and explain what kind of correlation you use (Spearman or Pearson).]

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## RESPONSE 2.11

Yes, “Good correlation” refers to p-values lower than 0.05. The Pearson correlation coefficient was used.

2.12 [Page 908: Line 7: please describe how you obtain the standard deviation of differences. This statistical is not so common and needs a bit more explanation.]

## RESPONSE 2.12

In Tables 1-2, SDD is the standard deviation of differences between two independent estimates of the same quantity. If the two estimates present the same mean value, then SDD is equal to RMSD. Otherwise, SDD is lower than RMSD as the latter is impacted by the bias.

2.13 [Page 908: Within this section a more thorough description of the soil moisture retrieval skills based on correlations is lacking and is now mostly focused on SDD. I would recommend to describe the differences in correlation between the models, and in situ in more detail, because they will give you more info on the retrieval skill than for example the SDD.]

## RESPONSE 2.13

Yes. In Table 1, the lower average SDD between the model and in situ observations is associated to a better average correlation (0.62, against 0.57 for CAROLS).

2.14 [Page 909: Figure 5 is hard to read. I would recommend to make time series for the different regions (including LAI, precip and soil moisture.)]

## RESPONSE 2.14

Yes, time series can be plotted in Fig. 5 instead of the present Hovmoller diagram, for the Atlantic, Garonne, and Mediterranean regions described at the end of Sect. 2.1.2. A new Fig. 5 could also include the MODIS climatology.

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2.15 [Page 910: Table 2 is very interesting especially the information on the change in spatial correspondence over time. It would be really nice if you could describe (and explain) this behavior. So when is there a good/bad spatial correlation between the model and the remote sensing product and why?]

#### RESPONSE 2.15

Table 2 is described in Sect. 3.2.1 for SSM and in Sect. 3.2.2 for VOD.

#### SSM:

For fourteen flights there is a very good agreement ( $p$ -value  $< 0.001$ ) between the CAROLS and ISBA-A-gs SSM spatial distribution, with Pearson correlation coefficients ranging from 0.43 to 0.85 (Table 2). For these flights, the mean SDD value is 0.062 m3m-3. The six remaining CAROLS SSM transects do not correlate very well with the simulated SSM and present higher  $p$ -values: 28 April 2009, 20 May 2009, 26 May 2009, 15 April 2010, 28 April 2010, and 3 May 2010. Figure 6 illustrates the disagreement between the simulated and observed SSM spatial patterns on 28 April 2009 and 28 April 2010. For these dates, the CAROLS retrievals present a more pronounced spatial variability than the simulations. This discrepancy can be caused by uncertainties in both retrievals and simulations.

#### VOD:

The spatial correlation between the CAROLS VOD and the aggregated model-derived VOD is highly significant ( $p$ -value  $< 0.001$ ) for thirteen flights, with Pearson correlation coefficients ranging from 0.38 to 0.61 (Fig. 8 and Table 2). For these flights, the mean SDD value is 0.057. Seven CAROLS VOD transects do not correlate very well with the simulated VOD and present higher  $p$ -values: 20 May 2009, 3 May 2010, 26 May 2010, 8 June 2010, 13 June 2010, 18 June 2010, 26 June 2010. Among them, only two are associated to rather poor SSM spatial correlations: 20 May 2009 and 3 May 2010. For these two flights, the CAROLS observations were markedly affected by RFI along the

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whole transect, and it is likely that the filtering technique described in Sect. 2.1.4 was not able to screen out all the perturbations. On 8 June 2010, the RFI affected two zones in the middle of the transect. They were not that strong and did not stop the retrieval of either SSM or VOD values, but they affected the retrieval accuracy, especially for VOD. On 26 June 2010, only 22 CAROLS VOD retrievals were successful, mainly at the westernmost and easternmost parts of the transect.

Overall, SSM SDD values and to a lesser extent VOD SDD values tend to increase in wet conditions (not shown). This is consistent with the findings of Pellarin et al. (2003) regarding the L-MEB retrievals. They showed that (1) for VOD values higher than 0.1, the value of SSM impacts the success of the SSM retrievals, (2) the retrieval performance is lower in wet conditions. Indeed, the weaker L-band emission of a wet soil is more easily attenuated by the vegetation. This study confirms that surface conditions have to be accounted for in assessing the uncertainty of the SMOS SSM and VOD retrievals (Wigneron et al., 2000).

#### ADDITIONAL REFERENCE

Wigneron, J.-P., Waldteufel, P., Chanzy, A., Calvet, J.-C., and Kerr, Y.: Two-Dimensional Microwave Interferometer Retrieval Capabilities over Land Surfaces (SMOS Mission), *Remote Sens. Environ.*, 73(3), 270-282, 2000.

2.16 [Page 911 Line 11: please be careful here. LAI is not always a good indicator for VWC and this can be the reason why you find changes in b (see comment above).]

#### RESPONSE 2.16

Yes. As explained in Sect. 2.3 (Eq. 3), LAI is not expected to correlate to VWC over forested areas. Figure 10 shows that the forest fraction can be high along the CAROLS transect. This is why Fig. 8 shows the modelled VOD in addition to the modelled LAI and that Fig. 9 focuses on VOD values.

2.17 [Page 912 see comment on Page 908. I would rather see a discussion on the cor-

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relation than on the bias because of the representativeness of the in situ observations. The in situ observations have a support of just a few centimeters and they most likely don't represent the true absolute soil moisture value at model/remote sensing scale (which has a support of about 1 km). Therefore you have to be careful with an analysis on bias.]

#### RESPONSE 2.17

Yes, the use of the SDD and Pearson correlation coefficient scores permit to cope with the bias problem caused by the representativeness of the in situ observations (see Response 2.12). More emphasis will be put on SDD (instead of RMSD) in the Conclusions section.

2.18 [Page 914: again, it is important to realize that you cannot always use LAI to estimate VWC (especially at seasonal scale). This is probably the reason why you see a variation in the b parameter.]

#### RESPONSE 2.18

Again, it must be emphasized that LAI is used for low vegetation, only (see Eq. (3)).

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Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 9, 895, 2012.

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