Answers to REVIEW1

Interactive comment on "An improved perspective in the representation of soil moisture: potential added value of SMOS disaggregated 1km resolution product" by Samiro Khodayar et al.

Answers to Reviewer 1

We thank reviewer 1 for all his/her suggestions and comments. We considered all of them and will modify the manuscript accordingly. In the following, one may find a general description of the main changes to be applied and detail answers to his/her comments.

Kind regards,
Samiro Khodayar on behalf of all co-authors.

In the following a description of the main changes suggested is summarized,

- Proposed title change:
  An improved perspective in the representation of soil moisture: potential added value of SMOS disaggregated 1 km resolution "all weather" product

- Better definition of the objective, novelty and relevance of this study improving the structure, content and length of the publication accordingly:
  1. To examine the benefits of the SMOS L4 version 3.0 or "all weather" high resolution soil moisture disaggregated product (~ 1 km, SMOS_L4$^{3.0}$).
     - *The added value compared to SMOS-L3 (~ 25 km) and L2 (~15 km) is investigated.*
     - *High-temporal (every 10 min over several years) and spatial (7 stations in an area of about 10 x 10 km^2) soil moisture observations from the Valencia Anchor Station (VAS; SMOS Calibration/Validation (Cal/Val) site in Europe) are used for comparison and assessment of the spatio-temporal performance of the satellite derived soil moisture products.*
     - *The SURFEX-ISBA model is used to simulate point-scale surface SM (SSM) and, in combination with high-quality atmospheric information data, namely ECMWF and the SAFRAN meteorological analysis system, to obtain a representative SSM mapping over the VAS.*

  2. First study, to the authors knowledge, apart from the quality report, that makes use of the newly SMOS L4 3.0 "all weather" soil moisture product.

     - *Added value compared to Level 2 and 3 SMOS products*
     - *Validation of the SMOS_L4$^{3.0}$ product in a different climatic region than REMEDHUS (Quality Report, Piles et al 2015)*
     - *Temporal and spatial assessment of the performance of the SMOS_L4$^{3.0}$ product including a seasonal analysis*
     - *First examples of possible applications of this product for initialization of off-line Soil-Vegetation-Atmosphere Transfer models (in this case SURFEX-ISBA) in stand-alone or regional approaches.*

3. The comparison carried out helps drawing guidelines on best practices for the sensible use of these products. Currently, there is not a consensus about what is the “best” SMOS product. Different users utilize different products depending on their application rather than based on performance arguments. This study and the conclusions obtained on the comparison are important to provide information on the advantages and drawbacks of these datasets.
Furthermore, regional SM maps with high accuracy are needed for flood forecasting, crop monitoring and crop development strategies, among others. Correct initial conditions for model simulations of these SM maps are fundamental to obtain a good accuracy. SMOS-L4$^{3.0}$ could fill the actual information gap and fulfil this requirement.

- New references have been included following the reviewers suggestions:
    - Piles, M., Pou, X., Camps, A., Vall-llosera, M. (2015): Quality report: Validation of SMOS-BEC L4 high resolution soil moisture products, version 3.0 or “all-weather”. Technical report. Available at: http://bec.icm.csic.es/doc/BEC-SMOS-L4SMv3-QR.pdf
    - SMOS-BEC Team (2016): SMOS-BEC Ocean and Land Products Description. Technical report. Available at: http://bec.icm.csic.es/doc/BEC-SMOS-0001-PD.pdf
    - Malbéteau, Y., Merlin, O., Balsamo, G., Er-Raki, S., Khabba, S.,Walker, J. P., Jarlan, L. (2018). Toward a Surface Soil Moisture Product at High Spatiotemporal Resolution: Temporally Interpolated, Spatially Disaggregated SMOS Data. Journal of Hydrometeorology, 19(1), 183-200.
    - Djamai, N., Magagi, R., Goïta, K., Merlin, O., Kerr, Y., Roy, A. (2016). A combination of DISPATCH downscaling algorithm with CLASS land surface scheme for soil moisture estimation at fine scale during cloudy days. Remote Sensing of Environment, 184, 1-14.
    - Louvet, S., Thierry Pellarin, Ahmad al Bitar, Bernard Cappelaere, Sylvie Galle, Manuela Grippa, Claire Gruhier, Yann Kerr, Thierry Lebel, Arnaud Mialon, Eric Mougin, Guillaume Quantin, Philippe Richaume, Patricia de Rosnay (2015). SMOS soil moisture product evaluation over West-Africa from local to regional scale. Remote Sensing of Environment, Volume 156, Pages 383-394, ISSN 0034-4257, DOI: 10.1016/j.rse.2014.10.005.

Major comments:

1) Few information about the SMOS L4 version 3.0 (section 2.2) are given and the reference Piles et al. 2015 (Quality report) could not be found in the reference list.

The quality report reference Piles et al. (2015) has been included in the reference list, thanks for noticing. Additionally, we included another reference to a document from the Barcelona Expert Center (BEC) with detailed information about all the products generated by BEC (SMOS-BEC Team (2016)). Unfortunately, after careful literature review no more references or information related to this product could be found. Nevertheless, some additional useful information has been included in the text, which can be found in the following question-answer. For further details regarding this product the SMOS BEC team should be contacted directly using the email address that is made available in the quality report. This information has been included in the manuscript.

When looking at SMOS L4 data maps (Figures 2 and 4), one question arises strikingly: what is the actual spatial resolution of the downscaled SSM? The spatial resolution of SMOS L4 seems to be much larger than that of L2 and L3. Has the meteorological forcing used to derive ERA Interim LST anything to do with the apparent resolution of L4 product? What is the spatial resolution of ERA-Interim LST?

The Level 4 SM, SMOS-L4 2.0 data (SMOS-L4$^{2.0}$), with 1 km spatial resolution results from the application of a downscaling method that combines highly accurate, but low-resolution SMOS radiometric information (SMOS L2 data) with high-resolution (brightness temperature measurements), but low sensitivity, visible-to-infrared imagery (MODIS) to SSM across spatial scales (Piles et al 2010, 2014; Sanchez-Ruiz et al. 2014). Brightness temperature measurements from SMOS were combined with NDVI (Normalized Difference vegetation Index) and LST (Land Surface Temperature) from Aqua MODIS. Since MODIS does not measure under cloudy conditions, the SMOS-L4$^{2.0}$ product was affected by the presence of clouds. In the new version 3.0, ERA-Interim LST data is introduced in the MODIS LST/NDVI space, thus, providing soil moisture measurements independently of the cloud conditions. ERA-Interim provides a resolution of about 0.125°, whereas MODIS is a ~ 1 km product. This information has been added in section 2.2.

2) Another concern with the use of ERA-Interim LST data for downscaling SMOS data. As the LST is derived numerically from the ERA-Interim soil moisture data via the energy budget model of TESSEL, would it be equivalent to use the ERA-Interim soil moisture data directly?

The methodology used to derive the SMOS-L4 2.0 and 3.0 products has been developed at the Barcelona Expertise Center (BEC). All references provided in this manuscript define the methodology followed and present the results obtained by the multiple validation exercises performed evidencing the quality of the data and supporting the use of the 3.0 product, as we do in this investigation. We are just users of these products and it is out of our scope and the scope of this paper to discuss the methodology applied for the derivation of the products. In any case, we understand that ERA-Interim LST data are used just to extend the downscaling SMOS L4 data to all weather conditions.

3) Evaluation of the SSM product:
Line 366: “the higher resolution SMOS L4 showing lower standard deviation”.

Line 415: “The CVs of the spatially averaged SMOS L4 is lower than those of SMOS L3 and L2 and in situ observations indicating that this data are less scattered.”
In my opinion, a lower variability for the downscaled SSM product is unexpected. It should be the opposite: higher variability for the downscaled SSM.

In lines 368 to 384, we describe the reasons behind the lower variability obtained when temporal means (seasonal) of SMOS L4 are evaluated, which is in relation with the limited temporal availability of the product dictated by the revisit period of the satellite. Furthermore, in the new version 3.0 the use of the coarse resolution ERA-Interim LST in the high-resolution MODIS LST/NDVI space to provide soil moisture measurements independently of the cloud conditions could explain the reduced spatial variability of the SMOS L4 3.0 soil moisture product.
In lines 411 to 415, we discuss that the averaged SMOS-L2 and -L4 3.0 data over the IP are much more variable than the SMOS-L3, showing a more extreme daily index (SMOS-L2: -1 to 2; SMOS-L43.0: -0.7 to 412 1.45). Over the VAS, SMOS-L2 is more variable than the higher resolution SMOS-L4 3.0. But, the last one shows a wider range of values as well as more extreme daily index values when compared to the averaged in situ soil moisture measurements.

Line 393: “L4 product shows SSM mean and variability in the same range of the SMOS L2 and L3 products, but with a finer-improved resolution representation of the spatial distribution”.
L398: “the potential added value of the 1 km product is manifest”.
The SMOS L4 has a spatial variability much lower than that of both L2 and L3 products. How to demonstrate that the slight 1 km variability is real information and not an artefact (oversampling)?

In lines 395 to 398, we discuss that at sub-seasonal (event) scales “comparisons with the mean ground-based SSM at the VAS (OBS area: *0.25 ±0.0002*) show better agreement with the mean SSM from the SMOS-L4 3.0-1 km disaggregated product (*0.23±0.002*) and poorer correlation with SMOS-L2 (*0.20±0.002*). The problematic of SMOS-L4 3.0 on seasonal time scales vanishes at sub-seasonal (event) scales where the potential added value of the 1 km product is manifest.”
Individual comparisons with single in situ measurements from the VAS network (covering a 10 x 10 km^2 area with a temporal resolution of 10 min) reveal correlation coefficients higher than 0.7 (e.g. Table 3, Figure 7 and 8).

Line 633: “consistent with the finer resolution of this product which better captures local information on the 1 km x 1 km pixel, whereas coarser products smooth out this vital information”.
To me, there is no information in this paper supporting the hypothesis that the downscaled product improves the spatial representation of SMOS L2 and L3 products. To really evaluate the SMOS L4 product, one should compare (in Table 3 for instance) the SMOS L4 versus in situ and SMOS L2 (or L3) versus in situ for each station separately, that is at a scale finer than the L2/L3 spatial resolution. Are statistics better for L4 than for L2 or L3?

Bottom sub-table of Table 3 is unclear. In addition errors are identified in the right column (OBS), which does not always correspond to the mean for all stations (?).

The spatio-temporal correlations are analysed through comparison with point-scale observations over the VAS region. Section 4.2, lines 438 to 477, is devoted to the comparison of SMOS L4 and –L2 products to the in situ measurements from the VAS network. Statistics for individual comparisons at all stations are summarized in Table 3. Figures 7, 8 and even 9 are devoted to these comparisons, although it is not possible to always show all stations due to space issues. In the description, details are given about the better accuracy of the –L4 product. Comparisons with -L3 product are similarly performed but no included in the manuscript because of space issues and not significant results. But following the reviewer suggestion we have included in this section the following paragraph: "Comparisons between SMOS-L3 and ground measurements were similarly performed evidencing the expected bad correlations (R^2 ~ 0,002, not shown)".

The legend in Table 3 has been improved to better the reader's understanding about the information provided. The names of the individual stations in the VAS network have been defined for clarification. We have explained relevant calculation methodologies and the content of the table. Also errors in the OBS column have been corrected.

"**Table 3:** Statistics of the comparisons between SMOS-L2 and SMOS-$L4^{3.0}$ soil moisture versus ground-based measurements in the VAS network (the area covering the ground-based network has been called OBS, Figure 1). SMOS descendent orbits are selected for the comparison. Characteristics of the individual stations are given in Table 1. The acronyms for the names of the stations are as follows: (M-I: Melbex_I, M_II: Melbex_II, VAS: VAS, NIC: Nicolas, EZ: Ezpeleta, LC: La Cubera). The period December 2011 to December 2012 is evaluated. The seasonal analysis follows the hydrological cycle. OBS stands for the average of (i) SMOS-L2 and/or SMOS-$L4^{3.0}$ soil moisture values within the 10x10 km^2 where the ground-based network is placed, and (ii) in the case of the in situ observations it refers to the mean of all stations. In Table (a) a seasonal comparison between the mean of all in situ stations and the corresponding mean of SMOS-L2 and/or SMOS-$L4^{3.0}$ soil moisture values within the 10x10 km^2 area is presented. In (b) SMOS-L2 and SMOS-$L4^{3.0}$ soil moisture observations are compared to point-like ground measurements using the closest grid point. The column on the right shows the mean of all stations."

4) In the present form, the paper is a bit lengthy. The description of approaches is sometimes repetitive. The structure of the manuscript could be improved. For instance: lines 334-335 (and lines 507 to 512) three to four initialization experiments are presented, but the initialization using SMOS data is not mentioned, although claimed as the main objective of the paper. Conclusions are confusing as well. The authors should better highlight their findings by selecting few key results.

The objective with the different initialization experiments described in lines 334-335 was to demonstrate the impact of initialization on the simulation of SSM. Commonly used initialization values are employed in this perturbation experiment to assess the consequent variability that could be expected in the evolution of the simulated SSM. In lines 340 to 344, the experiments using SMOS L4 3.0 for initialization are introduced.

This part will be reduced and improved to better reflect our purposes. Conclusions will be also rewritten to highlight our findings instead of summarizing our results.

5) As the study focuses on SMOS derived SSM at high spatial temporal resolution including all weather conditions, I suggest two recent references to complement the state-of-the-art presented in the introduction:

Malbéteau, Y., Merlin, O., Balsamo, G., Er-Raki, S., Khabba, S.,Walker, J. P., Jarlan, L. (2018). Toward a Surface Soil Moisture Product at High Spatiotemporal Resolution: Temporally Interpolated, Spatially Disaggregated SMOS Data. Journal of Hydrometeorology, 19(1), 183-200.

Djamai, N., Magagi,R., Goïta, K., Merlin, O., Kerr, Y., Roy, A. (2016). A combination of DISPATCH downscaling algorithm with CLASS land surface scheme for soil moisture estimation at fine scale during cloudy days. Remote Sensing of Environment, 184, 1-14.

Thank you for the additional references both will be included in the manuscript. This will also give us the opportunity to point out relevant differences between the investigated products:
"Recently, complementary studies have produced similar high-resolution SMOS-L4 products such as those of Malbéteau, Y., et al (2018) and Djamai, N., et al (2016). Being similar, however, the algorithms originating them are totally different from those of SMOS-L4$^{3.0}$ used in our study. Whereas SMOS-L4$^{3.0}$ products proceed from the original SMOS-L2 (15 km resolution soil moisture) disaggregated by 1-km MODIS LST and NDVI and modulated with 0.125°-resolution ERA-Interim LST for all-weather conditions, Malbéteau, Y., et al (2018) and Djamai, N., et al (2016) products proceed from the original SMOS-L1 (15 km resolution brightness temperature)."

6) Line 529: "soil moisture initialization in spatialized SURFEX simulations requires a single representative value for the whole simulation area. In this case, we use as input the SMOS L4 1 km disaggregated soil moisture mean over the whole simulation area for the initialization day". Why not initializing the model at 1 km resolution if 1 km resolution data are available? What is the point of disaggregating SMOS L2/L3 data then?

The approach proposed by the reviewer would be the ideal to demonstrate the potential of the SMOS L4 3.0 product. However, this is not possible with the SURFEX-ISBA model which requires a single representative soil moisture value for the simulations. We wanted to demonstrate that even when a single upscaled value is used results better reflect the evolution of SSM.
In a new study of the first author, which is about to be submitted to HESS, the suggestion of the reviewer is explored, in which we assess the benefit of using the SMOS-L4 product for the initialization of high-resolution convective-permitting simulations to improve the predictability of extreme weather phenomena such as heavy precipitation.

7) On the usefulness of surface soil moisture data to initialize ISBA. Line 229: "Particularly relevant for this study is the specific definition of the soil hydraulic parameters which they made for the VAS area, since most of the hydrological parameters are site dependent". Does the approach require in situ measurements for the calibration? Since the objective is to initialize ISBA using SMOS L4 data, I am wondering whether the site specific calibration could be done using SMOS L4 data solely (without relying on in situ measurements for ISBA simulations).

For the initialization of the model additional soil information, namely, texture (silt, sand and clay percentages), runoff, root-zone soil moisture and other hydraulic parameters in addition to SSM are needed, and those are not provided by SMOS. Most of these parameters were taken from a previous study carried out over the same area (Juglea et al. 2010a and b)

Juglea, S., Kerr, Y., Mialon, A., Wigneron, J.-P., Lopez-Baeza, E., Cano, A., Albitar, A., Millan-Scheiding, C., Carmen Antolin, M., and Delwart, S.: Modelling soil moisture at SMOS scale by use of a SVAT model over the Valencia Anchor Station (2010a). Hydrol. Earth Syst. Sci., 14, 831–846, doi:10.5194/hess-14-831-2010

Juglea, S., Y. Kerr, A. Mialon, E. Lopez-Baeza, D. Braithwaite, and K. Hsu (2010b). Soil moisture modelling of a SMOS pixel: interest of using the PERSIANN database over the Valencia Anchor Station. Hydrol. Earth Syst. Sci., 14, 1509–1525, doi:10.5194/hess-14-1509-2010

Line 488: “Initialization of land surface models is a crucial issue and its impact on the accuracy of model estimation is widely recognized to be significant”. What about the initialization of the root-zone soil moisture, which has supposedly more weight in the initialization than the SSM?

As above described, root-zone soil moisture has been used from previous studies/observations in the area (Juglea et al., 2010a), however, we did not used this variable in our analysis since SMOS only provides ~ 3-5 com SSM. We included this information in the paper for clarification.

Specific points:

- It is unclear at which spatial resolution ISBA model is run over the VAS?

The simulations are at 1 km resolution. This has been better clarified in the text.

- Confusion is often made between observation and sampling grid resolution. Ex. Line 10: 25 km and 15 km are the resolutions of sampling grids, the actual spatial resolution for both products being about 40 km.

This will be properly clarified in the text.

- Figure 2 (and Figure 4): Image at the middle is not correctly georeferenced compared to the left (top) and right (bottom) images.

This has been corrected

- Units in m3/m3 are sometimes missing the text and the figures.

This will be corrected

- Line 306: “SMOS L4 soil moisture grid cells are averaged over the 10x10 km2 area and compared to the mean from the soil moisture network stations to address the issue related to spatial averaging”. Please clarify the issue to be addressed?

Due to the high spatial and temporal variability of the upper 5 cm SSM the sampling of observations is a critical issue. We perform comparison between SMOS and in situ measurements at single locations/stations as well as using the averaged values over the area covered to address this issue.

- Notations: SURFEX-SAFRAN (SURFEX forced by SAFRAN), SURFEX-ECMWF (SURFEX forced by ERA-Interim) and SURFEX-ISBA are used. The terminology SURFEX-ISBA is confusing as it corresponds to SURFEX (ISBA) forced by station based meteorological measurements. For clarity, I suggest to replace SURFEX-ISBA by (for instance) SURFEX-VAS

This could be modified for clarity. We propose SURFEX (ISBA) instead

- Some references are missing in the reference list: I have noted Louvet et al. 2015; Piles et al. 2015; and maybe others.

The list of references has been revised and necessary corrections have been made.