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Hydrology and
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Discussions

Interactive comment on “From near-surface to root-zone soil moisture using an exponential filter: an assessment of the method based on in-situ observations and model simulations” *by* C. Albergel et al.

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Response to the editor

The authors response to the comments of the four anonymous referees was published on the HESSD web site.

The authors have prepared a revised version of the paper, addressing the reviewers comments.

In the revised manuscript, the soil moisture definitions are now detailed in the material and methods section and the figures titles and legends are consistent with the used units. The effect of climate, season and soil texture on T is addressed more carefully. The discussion section was enhanced (new Fig. 12) in order to demonstrate the added value of the filter.

The changes relative to the HESSD paper are detailed below. The page numbering of the HESSD paper is used to track the changes.

Figures

p.1631: y-label on Fig.2 was modified: #Soil Moisture [m3m-3]#

p.1632: y-label on Fig.3 was modified: #Soil Moisture [m3m-3]#

p.1633: Fig.4 was modified, the left y-label is referring to w2, #w2 [-]#, the right y-label is referring to the retrieved SWI, #SWI [-]#. Dimensions were added in the legend.

p.1634: Fig.5 was modified, y-label is now #Nash-Sutcliff score [-]# and the correspondence between symbols and stations was added in the caption: #SBR, open circles and full line, SMX, open circles, URG, +, CRD, + and full line, PRG, *, CDM, * and full line, LHS, dots, SVN, triangles and full line, SFL, diamonds, LZC, triangles, NBN, solid circles and full line, MNT, diamonds and full line, N values for MTM station are negative (see table II).#

p.1635: Fig.6 was modified, the left y-label is referring to w2, #w2 [-]#, the right y-label is referring to the retrieved SWI, #Soil water index [-]#. Dimensions were added in the legend.

p.1636: Fig.7 was modified, a zoom was made on France only.

p.1637: Fig.8 was modified, the left y-label is referring to w2, #w2 [-]#, the right y-label is referring to the retrieved SWI, #Soil water index [-]#.

p.1638: Fig.9 was modified, the right side of Fig.9 presents Topt as a function of soil thickness for SIM and SMOSREX, its caption is now: #Optimised characteristic time

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length of the recursive formulation of the exponential filter (Topt) versus the corresponding (left) depth of the reference root-zone observations of SMOSREX, (right) thickness of the root-zone soil layer of SIM (open circles) and of SMOSREX (full circles). In the case of SIM, average Topt values are plotted.#

p.1639: Fig 10 was modified, the mean and the standard deviation (errors bars) of clay and sand fraction are presented versus Topt.

A new figure, Fig.12 was added to the manuscript. Fig.12 illustrates the added value of the filter applied to the SIM data base over France. Its caption is #Performance of the recursive formulation of the exponential filter over France based on modelled soil moisture (SIM) for a 2-year period: statistical distribution of the Nash-Sutcliffe coefficient N of the SWIm derived from wg (scaled surface soil moisture simulations), for different values of the characteristic time length (T) of the filter, optimised value Topt, single median value of 15 days, and T=0 day. Note that positive values of N are presented, only.#

Tables

p.1268: A new column with the bias was introduced in Table 2.

p.1269: A new column with the bias was introduced in Table 3.

References

A new reference used in the discussion was included in the manuscript.

p.1624 L.2: Escorihuela, M.J, de Rosnay, P., Kerr, Y. and Calvet, J.-C.: Influence of bound water relaxation frequency on soil moisture measurements, IEEE Trans. Geosc. Remote Sens., 45 (12), 4067-4076, doi:10.1109/TGRS.2007.906090, 2007.

Abstract

p.1604 L. 17-18: #the modelled spatial variability and the observed inter-annual variability of T suggest that a climate effect exist.# was replaced by: #the modelled spatial variability and the observed inter-annual variability of T suggest that a weak climate effect may exist.#

Introduction

p.1605 L. 12-14: #Moreover, the [. . .] (Sabater et al., 2007)# was replaced by: #The chosen assimilation method may also affect the results (Sabater et al., 2007).#

p.1605 L. 15-16: this sentence was removed.

p.1605 L. 18: After the sentence #[. . .] soil moisture time series#, the following sentences were added: #A single parameter (T) has to be determined, which implicitly takes many physical parameters into account. The rationale for retrieving a SWI, instead of root-zone soil moisture values is that over a large footprint, the variability of soil characteristics may be very high and may not be represented accurately. In this context, only the relative dynamic range of the soil water content can be represented (Rüdiger et al., 2008). Data assimilation methods are based on unbiased observations. In the case of soil moisture, this is tantamount to using SWI values.#

p.1605 L. 25: #and a ground resolution of 50km# was added before the reference to Kerr et al, 2001.

p.1606 L.24-25: #The exponential filter equation uses a single tuning parameter: a time constant, T.# was replaced by: #The exponential filter equation, which is the operational filtering method for ERS and ASCAT data, uses a single tuning parameter: a time constant, T.#

Material and methods

p.1607 L.8: A new paragraph #2.1 Definition of soil moisture variables# was added: #2.1 Definition of soil moisture variables Different soil moisture variables are used in this study: wg is the water content (m3m-3) of a surface soil layer, 5 cm for SMOSMANIA stations, 0-6 cm for SMOSREX, a few mm for SIM. w2 is the root-zone soil moisture content (m3m-3), measured at 30 cm (SMOSMANIA), at various depths (SMOSREX),

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or integrated over the root-zone profile (SIM and SMOSREX). Prior to filtering, surface soil moisture wg observations or simulations are scaled between [0,1] using maximum and minimum values of each time series (ms, dimensionless). The dimensionless root-zone SWIobs used in Sect. 3.1, Eq.(7), to assess the quality of the results is the reference w2 (either observed in situ or simulated by SIM) scaled to [0,1] using maximum and minimum values of each time series. SWIm is the result of the exponential filter and of its recursive formulation. It is dimensionless and ranges from 0 to 1. A scaled SWI allows to combine the different dynamic ranges of surface soil moisture and profile soil moisture. This is essential, as the surface may show soil moisture values below the wilting point and above field capacity, while the profile soil moisture is generally bound by those two parameters.#

p.1607 L.8: #2.1 SMOSMANIA# is now #2.2#.

p.1608-1609 L.28-L.1: #Figures 2 and 3 show the 5 cm and 30 cm volumetric soil moisture content for the 12 SMOSMANIA stations, respectively, over a period of 14 months (January 2007-February 2008) and at 12 minutes time intervals.# is now: #Figures 2 and 3 show the 5 cm (wg) and 30 cm (w2) volumetric soil moisture content (m3m-3) for the 12 SMOSMANIA stations, respectively, over a period of 14 months (January 2007-February 2008) and at 12 min time intervals. Except for the stations of LHS, MTM and LZC, there is a good agreement between surface soil moisture and deepest soil moisture. The squared correlation coefficient (r^2) between wg and w2 is greater than 0.5.#

p.1609 L.5: #2.2 SMOSREX# is now #2.3#.

p.1609 L.15: after sentence #[. . .] time step#, a new sentence was added: #Soil moisture is automatically measured by impedance sensors (ML2X ThetaProbes).#

p.1609 L.18: #2.3 SIM# is now #2.4#.

p.1610 L.13: a new sentence was added: #The ISBA model simulations were performed at this resolution.#

p.1610 L.24-25: the sentence #In Sect. 4, the retrieved SWI is compared with the reference w2 # is now: #In Sect. 4, the retrieved SWIm is compared to the reference w2, scaled to [0,1] using maximum and minimum values of the time series.#

p.1610 L.26: #2.4 The exponential filter# is now #2.5#.

p.1612 L.14: A new sentence was added after #[. . .] at time ti #: #The scaled and therefore dimensionless surface soil moisture content is retrieved in Wagner et al. (1999) by first extrapolating the observed backscatter to a reference angle of 40 degrees and then scaling this observation between the maximum and minimum values observed during the instrument_s lifetime.#

p.1612 L. 18-21: the last paragraph of sect. 2.5 was modified: #SWIm is a trend indicator ranging from 0 to 1. For estimating the water in deeper layer, auxiliary information like soil physical properties are required. In Wagner et al (1999) a plant available water (PAW) content is derived from the SWIm by using auxiliary information about the soil physical properties (wilting point, field capacity and total water capacity), and thus converting relative values into absolute soil moisture content. Equation (3) was validated against in situ measurements by Ceballos et al. (2005) in the semi-arid region of the Duero Basin in Spain. They found a statistically significant coefficient of determination (r2=0.75) and a RMSE of 0.022 m3m-3 when comparing the PAW values derived from scatterometer and area-averaged field measurements (0-100 cm).#

p.1612 L.22: #2.5 Recursive formulation of the exponential filter# is now #2.6# and the first sentence of this section was modified, reference to Kalman (1960) was removed: #In contrast to Wagner et al. (1999), Stroud (1999) presents a recursive formulation of the exponential filter.#

p.1613 L.16-19: the last paragraph of sect.2.6 was modified: #In this study, the recursive formulation of the exponential filter, as proposed by Stroud (1999), was used. Both

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methods are mathematically equal. However, the initialisation and the implementation of the recursive and non-recursive filters differ (the recursive formulation suppresses the need to prescribe an integration interval and to store past time series). It was verified that the two methods yield similar results for the SMOSMANIA network and at the SMOSREX station.#

Application of the exponential filter

p.1614 L.2-4: the sentence #Moreover undesired effects [. . .] therefore avoided# is now: #Moreover, even though measurements obtained with the ThetaProbe impedance soil moisture probes used in the SMOSREX and SMOSMANIA experiments are moderately sensitive to temperature, this effect may interfere with soil moisture measurements in dry conditions, when bound-water fraction is important (Escorihuela et al, 2007). As this effect may vary from one soil type to another, it cannot be accounted for easily. This undesired effect is more pronounced in the afternoon (more frequent dryer and warmer conditions at the top soil layer).#

p.1614 L.9: after #(RMSE)# it is now mentioned that the bias is calculated.

p.1614-1615 L.19-L.6: the first paragraph of sect.3.2 was modified: #For each SMOSMANIA station, the wg soil moisture observations at a depth of 5 cm, scaled between [0,1] using the minimum and maximum values of each time series, are used to calculate SWIm. The calculated SWIm is then compared to w2 (soil moisture observations at 30 cm, the deepest observation at the SMOSMANIA stations) scaled to [0,1] using the minimum and maximum values of each time series, for different values of T (up to 40 days). At SMOSREX, soil moisture observations are available from the surface down to 90 cm, and a SWIobs representing the fully integrated scaled root-zone soil moisture can be computed. The analysis of SMOSREX data (not shown) indicates that local soil moisture observations at depths ranging from 20 cm to 50 cm are significantly correlated to the root-zone soil moisture integrated over the whole profile. The r2 values over a period of three years (2001-2003) exceed 0.9. For the SMOSMANIA network, it is assumed that scaled soil moisture observations at 30 cm are a good proxy of the scaled root-zone soil moisture.#

Analysis of the results

p.1618 L.11-15: the paragraph #At wintertime [. . .] 7 year period# was replaced by: #In order to assess the impact of the interannual variability on the method, wg is scaled between [0,1] using the minimum and maximum values of the whole 7 year period. At wintertime, while the observations reach saturation, a saturation of the retrieved SWIm is not achieved every year. However this condition is obtained if wg is scaled separately on a year by year basis.#

p.1618 L.20: a new paragraph was added after L.20 at the end of sect. 4.1.2: #A possible seasonal impact on the T parameter for the 7 year period of SMOSREX was investigated. Instead of applying the filter with T=6 days to the whole period, the filter was applied season by season (winter, spring, summer, autumn, with T values optimised for each season pooled over the 7 year period, of 2, 3, 4, 6 days, respectively). The seasonal SWIm values were then aggregated and compared to the scaled observations at 30 cm. The obtained N value (0.717) is lower than for the standard method (0.858).#

p.1619 L.18-26: the last paragraph of sect. 4.2 (the description of Fig. 9) was reworded: #Figure 9 (left) presents the retrieved Topt for the individual sensors installed at different depths within the SMOSREX soil moisture profile (from 10 cm to 90 cm). As expected, it is found that Topt increases with the considered soil depth. In Fig. 9 (right) the Topt values are presented as a function of the soil thickness, for SMOSREX (integrated from the surface to 10 cm and up to 90 cm deep), and for SIM. In the case of SIM, binned and averaged values of Topt are presented, for different soil thickness values (19 classes of soil thickness are used, from 22 cm to 197 cm). The Topt derived from the simulated profiles are consistent with the observed ones.#

p.1620 L.6-9: this paragraph was modified: #In the case of SMOSMANIA, despite the results discussed in Sect. 4.1.1 where it was shown that sandy soils tended to have the lowest N values, a detailed analysis of correlation of particle size distribution with N did not present any conclusive results.#

Discussion

p.1621 L.7-20: the first paragraph of the discussion is now: #This study provides several insights into the use of the semi-empirical approach developed by Wagner et al. (1999) to retrieve the root-zone soil moisture from remote sensing surface soil moisture estimates. It is shown that the main factor impacting on the retrieval is soil depth (Topt increases with soil depth). The Topt values vs. soil thickness as derived from the simulated profiles or from the observed ones at SMOSREX are consistent. This study does not permit to establish a link between Topt and soil texture (fraction of clay or sand). The dominant climatic conditions within a region may influence Topt. The data on Fig. 11, are obtained from model simulations throughout the Rhône valley, which suggests that a climate factor may exist. However, it is difficult to find a climate effect on Topt derived from the full SIM data set. The Rhône valley example is a rather extreme case. The Rhône gradient found on Topt from model simulations only suggests that a climate factor may exist. Further investigation is needed to consolidate this result.#

p.1622 L.6: two more paragraphs were added to the discussion part in order to show the added value of the filter, with comments on the new Fig.12: #In order to assess the added value of the filter, the scores were calculated for T=0 day, which is the equivalent of a direct replacement of the modelled root-zone soil moisture data with the surface soil moisture observations, without filtering. At the SMOSMANIA stations and at SMOSREX, the comparison of the two time series shows high correlations ($r2>0.5$), except for three stations (LHS, MTM, LZC). It is interesting to note that for these stations, the filter score N (Table 2) is rather low, also. This is not a general rule: although N is low for SBR, the 5 cm vs. 30 cm correlation is high (r2=0.66). Regarding the correlation between the surface soil moisture and deeper layers simulated by ISBA, a number of factors (soil texture, vegetation coverage, time) were investigated by Calvet and Noilhan (2000). A decoupling between the two layers may occur for low vegetation coverage (favouring direct soil evaporation). The decoupling is more pronounced before dusk, and for sandy soils. Figure 12 shows the distribution of SIM N values for T= Topt, T= 0 day, and T= 15 days (i.e. the median Topt value) over France. Very similar distributions are obtained for T= 15 days and for T= Topt. Indeed, the soil thickness (the main driver of Topt, as discussed in section 4.2) used in SIM is predominantly (65 %) distributed between 1.35 m and 1.65 m. The comparison of the simulated surface vs. deep scaled soil moisture (i.e. T= 0 day) shows that surface values may be fair estimates of root-zone values: $N>0.5$ for 32 % of the grid cells. On the other hand, good estimates ($N>0.7$) are never achieved with this method. For T= 15 days, the proportions of fair and good estimates reach 49 % and 37 %, respectively. An attempt (not shown) was made to assess the SIM N values for T= 6 days, i.e. for the median Topt for SMOSMANIA and SMOSREX. The proportions of fair and good estimates reach 56 % and 29 %, respectively. This shows that while the proportion of good estimates is sensitive to T, the proportion of acceptable estimates (either fair or good) does not vary much with T (86 % and 85 % for T= 15 days and T = 6 days, respectively).#

Conclusions

p.1622 L.8-11: The two first sentences of the conclusion were rewritten: #In this paper, the use of an exponential filter to retrieve the scaled root-zone soil moisture (SWIm) from surface soil moisture observations or simulations, was assessed using modelled and real data over France.#

p.1622 L.14: A new sentence was added at the end of the first paragraph: #Generally, the use of this method was satisfactory, after the characteristic time length of the filter (T) was optimised (Topt). The main features of the seasonal and interannual variability of SWIm were captured by the filtering method.#

p.1622 L.18-24: the third paragraph of the conclusion was rewritten: # Topt was found to vary with the soil depth (soil thickness) at (over) which SWIm was considered. No clear link between Topt and soil and climate properties was found. The exponential filter was not very sensitive to interannual or spatial variations of Topt, and the application of a constant average value of T did not significantly affect the quality of the retrievals. Over France, the proportion of acceptable estimates (either fair or good) did not vary much with T. However, the area extent of good estimates varied with T. #

p.1622-1623 L.26-L.3: the last paragraph of the conclusion was rewritten: #No land surface model or meteorological observations (like precipitation) are needed to retrieve SWIm and the discussed method relies solely on surface soil moisture estimates. As surface soil moisture can be observed from space by remote sensing techniques, the performance of the exponential filter is particularly interesting in areas with atmospheric information of poor quality.#

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