**Response to comments by Anonymous Referee #1**

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General comments: The manuscript aims to demonstrate that a high resolution data-assimilation modelling framework allows improving soil moisture and runoff simulations at a continental scale. Thus, it addresses a question within the scopes of the journal. Aims of the work are overall clearly outlined and supported by references.

We would like to thank the anonymous reviewer for his/her comments and constructive suggestions, which we believe have led to an improved manuscript.

I suggest to better justify the choices of models and datasets and temporal domain (2000-2006).

RESPONSE: We selected CLM because it is one of the most complete land surface model at the moment and part of a large community effort (Community Earth System Model; http://www.cesm.ucar.edu/). It has been widely applied at continental and global scales to understand how land processes and anthropogenic impact on land states affect climate (e.g. Bonan et al., 2002; Dickinson et al., 2006). The CLM model parameterizes most of the land surface processes (such as infiltration, evaporation, surface runoff, subsurface drainage, canopy and snow processes) using the water and energy balance equations. In addition, CLM was designed for coupling with climate models and is also part of the fully coupled Terrestrial Systems Model Platform (TerrSysMP; Shrestha et al., 2014) that simulates the full terrestrial hydrologic cycle including feedbacks between atmosphere, land-surface and subsurface compartments of the water cycle. For upcoming studies, it is planned to use TerrSysMP including the parallel data assimilation framework (PDAF) to assess the impacts of satellite soil moisture assimilation on other water cycle variables across the soil-vegetation-atmosphere system and its effects on the accuracy of model simulations at the continental scale. Moreover, the CLM model can efficiently run for large model domains and at high spatial resolution. Since we performed our simulations at high spatial resolution and at continental scale, we selected the TerrSysMP -PDAF modeling framework which can be run on high performance computational infrastructure and can efficiently cope with the high computational burden of ensemble-based data assimilation framework.

With respect to the time span simulated, we used a high-resolution reanalysis system dataset (COSMO-REA6 from Hans-Ertel Centre for Weather Research (HErZ); Simmer et al., 2016), which is only now publicly available for a longer time period of 1995 – 2015. However, this recent dataset was not fully publicly available at the beginning of our study. We preferred to use this data over other datasets, because of its high spatial resolution in comparison to other commonly used forcing datasets such as E-OBS and ERA-Interim at 25 and 80km resolution, respectively. In addition, the COSMO-REA6 dataset was produced through the assimilation of observational meteorological data and showed good performance particularly for precipitation when compared to the observations (Wahl et al., 2017).

We now added additional motivation for the model selection, time period and forcings datasets in the revised manuscript.

Data-assimilation results are compared to open-loop simulations to quantitatively assess this improvement basing on root mean square error and mean bias error estimates with respect to CCI SM data. Overall results are well supported by figures and graphs. However, I would suggest the Authors to give a more detailed explanation for differences in overestimate and underestimate between the regions and between the seasons (particularly in par. 3.1.1). It seems that this part has been deepened more for runoff than for soil moisture.

RESPONSE: We included an extended discussion of the soil moisture differences with respect to other data assimilation studies over Europe. Please see our response below to the specific comment 2.

Besides I would suggest the Authors to better explain if and how results can be affected by spatial resolution differences in the data.

RESPONSE: See our response and Figure R1 below to the specific comment 6 on resolution and interpolation effects.

The advancements described in this study would benefit from a quantitative or qualitative comparison with other studies claiming the use of data assimilation for improving soil moisture and runoff simulations, to assess if the obtained results are satisfying. My recommendation is to accept the manuscript with minor review.

Specific comments

Page 2 Line 32 and Page 6 Line 2: I would suggest to add spatial resolution in km, as done is other sections of the text

RESPONSE: It has been modified in the revised manuscript.

Page 2 Lines 18-27: I think sentences here are a bit contradictory. I would suggest the Authors to better clarify what is commonly done in the state of the art and what is rarely done (and eventually why it is rarely done), in order to better highlight element of novelties of this work.

RESPONSE: We appreciate the suggestion. We added several references of other assimilation/modeling studies over Europe in the introduction section of the revised manuscript. For instance, many studies have explored the role of soil moisture assimilation in different modeling frameworks over Europe (e.g. Albergel et al., 2017; de Rosnay et al., 2013; Brocca et al., 2010; Draper et al., 2009; Ni-Meister et al., 2006). Albergel et al. (2017) applied a global land data assimilation system at 0.5° over Europe and Mediterranean domain to sequentially assimilate ESA CCI satellite-derived soil moisture data and leaf-area index product into the ISBA (Interactions between Soil, Biosphere and Atmosphere) land surface model. They found more improvements in the surface soil moisture and particularly in the summer and autumn than in the winter and spring but found little improvements to the discharge when compared to the open loop (i.e. no assimilation) simulations.

In our study, we highlighted the added value of merging coarse resolution satellite observations through data assimilation with a land surface model to generate higher spatial resolution, downscaled estimates of the surface soil moisture profile with complete spatio-temporal coverage and with a higher accuracy than that of the open loop model estimates. To the best of our knowledge, this is the first study of its kind to provide a downscaled daily soil moisture product at 3km resolution over Europe

We discuss the added value of our data assimilation experiment in the introduction section of the revised manuscript to clarify the objectives of the study.

Figure 1b: I would suggest to use a discretized legend as it represents different classes

RESPONSE: We appreciate this comment. The figure has been modified in the revised manuscript.

Page 4 Lines 2-3: the Authors state that "CLM3.5 was used in this study, instead of its most recent version, to keep the modelling framework consistent to Kurtz et al. (2016)." Would it be possible to hypothesize some advantages or disadvantages in using CLM most recent versions?

RESPONSE: We added the following text to highlight the differences in different versions of the CLM model.

"The early version of CLM used a simplified bucket runoff model. While the saturated and unsaturated runoff assumptions based on the TOPMODEL concept were later introduced into the runoff scheme in CLM 2.0 (Bonan et al., 2002) and the Common Land Model (Dai et al., 2003), these models used a constant value to describe topography. In an ensuing step, a simplified topography representation, the SIMTOP scheme, was employed in CLM 3.5 (Niu et al., 2005). Previous studies showed that CLM 3.5 produces higher soil moisture and lower variability than observations in the root zone (e.g. Lawrence et al., 2011 and Niu et al., 2011). In order to reduce these biases, Li and Ma (2015) introduced a factor to describe soil porosity and increase recharge water from the soil column to the aquifer in the newer CLM versions (4.0 and 4.5) which offer improved solutions related to soil moisture and biogeochemical processes. However, Lawrence et al. 2011 showed that the differences between CLM3.5 and new versions of CLM with respect to soil moisture variability remain low when compared with observations (Lawrence et al. 2011). Based on assessment of the applicability of CLM 3.5 across the observation-based datasets in other studies (Li and Ma 2010; Li et al., 2011) and its coupling with current PDAF setup, we decided to use CLM 3.5 in this study."

Page 5 Line 9: I would suggest to briefly explain how this conversion is done or at least provide a reference?

RESPONSE: We prescribed vegetation as the fractional coverage of different vegetation types according to the MODIS land cover dataset for the year 2001, which contains 21 land cover types defined by the International Geosphere-Biosphere Program (IGBP) (Friedl et al., 2002). This information is added in the revised manuscript.

Page 6 Lines 12-15: Would it be possible to perform the inverse resampling (from 0.0275° to 0.25°) and compare results with the one from 0.0275° to 0.25°? The same could be said for runoff rates (paragraph 2.3.3)

RESPONSE: We compared the original 0.25° against 0.0275° ESA CCI soil moisture. Only small differences between the two resolutions were visible particular for the time period of 2003 – 2006 (Fig. R1). However, we do see some differences in the first two years and the regions where the temporal coverage of the ESA CCI data is less than 30%. However, for the time period and regions with a good coverage of ESA CCI soil moisture data, we believe that our results are not significantly affected by the difference in the resolution. Similarly, for the model outputs, we don't see any significant difference (e.g. R-squared value in both cases is 0.56) in our results between 0.0275° and 0.25° when compared to the original CCI data at 0.25° resolution as shown in Fig. R2 as an example for one region.

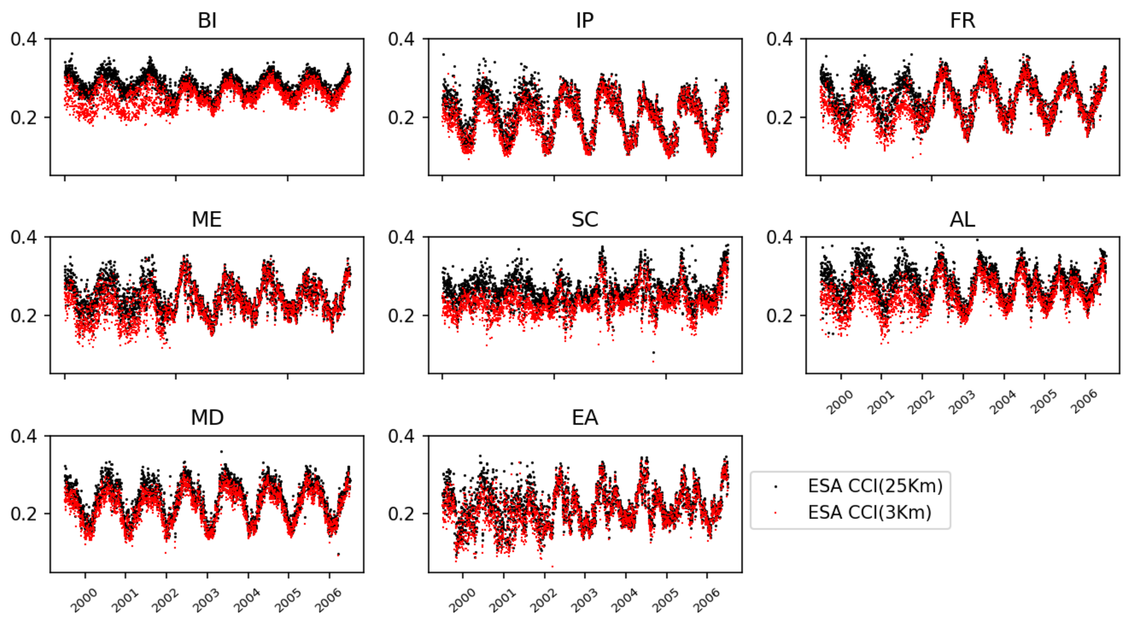


Figure R1: Comparison of spatially averaged 2000 – 2006 daily ESA CCI soil moisture data between original 0.25° (black) and interpolated 0.0275° (red) over PRUDENCE regions.

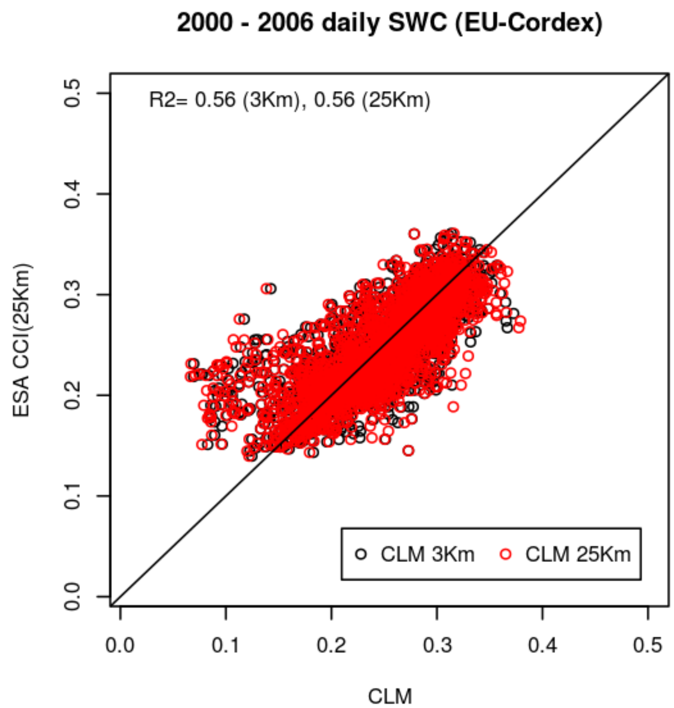


Figure R2: Scatter plot showing the comparison of spatially averaged daily soil moisture between ESA CCI (0.25°) and CLM at 0.25° and 0.0275° resolution over the PRUDENCE region France.

We now discussed the effects of resolution and interpolation on the results in the discussion section of the revised manuscript.

Page 7 Line 27: Is it possible that Authors refer to another figure?

RESPONSE: This has been now corrected in the revised manuscript.

Page 10 Line 3: "CLM-DA reduces the runoff bias compared to CLM-OL". Evidence of this is in Figure 9, not in Figure 7. It would suggest the author to better clarify this point or remove it (as it is already stated in line 20) I suggest to add a table similar to Table 1 also for soil moisture.

RESPONSE: We appreciate this comment. We removed this sentence and added a table for soil moisture (similar to Table 1) in the revised manuscript.

Technical corrections

Page 1 Line 31: Western et al., 2002 has to be changed with Western et al., 2004 according to references

RESPONSE: We appreciate this comment. This has been now corrected in the revised manuscript.

Page 2 Line 16: bracket missing after ". . .Clark et al., 2011)"

RESPONSE: This has been corrected in the revised manuscript.

Page 2 Line 25: López et al., 2016 is missing in the references and there is a repetition of the name in the text

RESPONSE: We appreciate this comment. This has been corrected in the revised manuscript.

Page 2 Line 28: Rains et al., 2017 is missing in the references

RESPONSE: The missing reference has been added in the revised manuscript.

Page 3 Line 28: remove comma before brackets Page 4 Line 9: remove the semicolon before bracket

RESPONSE: This has been corrected in the revised manuscript.

Page 4 Lines 12-27: I think this sentence is too long, thus I would split it into different sentences maybe one for each formula

RESPONSE: This has been modified in the revised manuscript for clarity.

Page 5 Lines 30-31: Wahl et al. 2017 is missing in the references

RESPONSE: The missing reference has been added in the revised manuscript.

Page 6 Line 13: Jones, 1999 is missing in the references

RESPONSE: The missing reference has been added in the revised manuscript.

Page 6 Line 19: remove full stop after brackets

RESPONSE: This has been corrected in the revised manuscript.

Page 9 Line 28: replace Decker and Zeng, 2009 with Zeng and Decker, 2009, as for references

RESPONSE: This has been corrected in the revised manuscript.

Page 11 Lines 32-33: I think that Authors mean "it is preferable to account for additional model parameter uncertainties that shows a high sensitivity towards runoff" instead of "it is preferable to account for additional model parameter uncertainties towards runoff that shows a high sensitivity"

RESPONSE: We appreciate this comment. This has been modified in the revised manuscript for clarity.

Page 12 Line 12: Remove “This study showed that”, as it is a repetition of the above line

RESPONSE: This has been modified in the revised manuscript for clarity.

Page 12 Line 30: “The improvement in peak runoff could be OF particular importance in the management of extreme events such as flooding”

RESPONSE: This has been modified in the revised manuscript for clarity.

Page 14 Line 7: reference missing in the text

RESPONSE: The missing reference has been corrected in the revised manuscript.

Page 15 Line 9: reference missing in the text

RESPONSE: The missing reference has been corrected in the revised manuscript.

Page 17 Line 18: reference missing in the text

RESPONSE: The missing reference has been corrected in the revised manuscript.

Page 19 Line 31: replace 998 with 1998

RESPONSE: We appreciate this comment. This has been corrected in the revised manuscript.

Page 20 Line 34: year of publication should be after doi, as for the other references

RESPONSE: This has been corrected in the revised manuscript.

Page 21 Line 8: reference missing in the text

RESPONSE: The missing reference has been corrected in the revised manuscript.

Figure 2c: better if months initials are in English

RESPONSE: This has been modified in the revised manuscript.

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