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Interactive comment on "Global joint assimilation of GRACE and SMOS for improved estimation of root-zone soil moisture and vegetation response" *by* Siyuan Tian et al.

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Anonymous Referee #2

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The submitted manuscript by Siyuan Tian et al investigated the impacts of assimilating satellite water content retrievals on the estimation of surface and root-zone soil moisture over the globe and across different land cover types. The authors aimed at improving the accuracy of root-zone soil moisture prediction by jointly assimilating satellite-observed soil moisture from SMOS and total water storage changes from

GRACE into a global ecohydrological model. They then evaluated the performance of the joint assimilation by comparing against the open-loop model and alternative assimilation methods with ground-based soil moisture measurements and vegetation index.

This paper is well written, properly structured and presented, with interesting results being thoroughly interpreted by a good discussion. I believe this manuscript will be interesting to future HESS readers and contribute to the international literature. There are two major concerns that I would like the authors to address before the publication of this manuscript.

1. While GRACE-derived TWSA provides an integrated measurement of water storage changes above and underneath the earth surface, why would near-surface soil moisture derived from SMOS still be required? Don't SMOS and GRACE monitor overlap water content at near-surface? This has not been fully justified and explained in the Introduction or in the ecohydrological modelling method.

We thank the reviewer for the opportunity to clarify. The SMOS and GRACE did both include the water content at near-surface. However, the near-surface soil moisture content is highly variable both spatially and temporally. The assimilation of monthly GRACE data alone has little impact on the estimation of near-surface soil moisture (Zaitchik et al., 2008, Tangdamrongsub et al., 2018; Li et al., 2012; Girotto et al., 2017). The assimilation of daily SMOS observation with higher spatial resolution together with monthly coarse GRACE data can better disaggregate the vertical distribution of water storage into different components. As demonstrated in Tian et al., (2017), the joint assimilation of SMOS and GRACE provides constraints on both the total water storage estimates and surface soil moisture estimate, as a result providing more accurate root-zone soil moisture and groundwater storage estimates.

In our revised manuscript, we will include the following justification in the introduction: "Conversely, GRACE-observed total water storage anomalies were successfully assimilated or otherwise combined with model simulations for improved deep soil and

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groundwater estimation (Zaitchik et al., 2008; Khaki et al., 2017; Schumacher et al., 2018; Tangdamrongsub et al., 2015; Girotto et al., 2017; van Dijk et al., 2014; Tangdamrongsub et al., 2018), but with typically marginal improvements for surface and shallow soil moisture (Tangdamrongsub et al., 2018; Li et al., 2012; Girotto et al., 2017; Tian et al., 2017). This is due to the highly variable nature of near-surface and shallow soil moisture in space and time, which has little influence on the GRACE signal. Recently, near-surface soil moisture and total water storage observations were jointly assimilated into a water balance model over Australia and demonstrated consistently improved water storage profile estimates, especially in the root-zone soil moisture estimates (Tian et al., 2017). The use of satellite-observed daily near-surface soil moisture has been demonstrated to better disaggregate shallow soil moisture and groundwater change from GRACE-observed total water storage change because of the different temporal dynamics."

2. Following up Reviewer#1's major comment on assessing assimilated soil moisture using NDVI, I do agree Reviewer#1 that extra experiments of correlation analyses based on de-seasonalized times series of all data are required. Although I agree with the authors that the improvements of the modelled root-zone soil moisture over only ET limited regions are likely due to increased seasonality, authors may need to show how the methods proposed in this study could improve root-zone soil moisture in the long run without the effect of seasonality.

We agree. We will show the improvements on anomalies in revising the manuscript to address the concerns from both reviewers.

My specific comments are as follows: 1). Page1, Line 4:Do you have references to confirm this? Some people believe GRACE-derived TWSA is mainly dominated by soil moisture variation over many places.

We agree with the reviewer that GRACE-derived TWSA can be dominated with snow and/or soil moisture at different locations. However, there are studies that show that the changes in GRACE TWSA mainly come from changes in groundwater such as Rodell, Velicogna and Famiglietti (2009), Famiglietti et al. (2011) and Voss et al. (2013). To be more precise in the abstract, we will modify this as follow:

“In contrast, GRACE (Gravity Recovery and Climate Experiment) mission detected the variability in storage within the total water column, with no vertical resolution. Root-zone soil moisture, often the main interest in agriculture and ecology, cannot be separated from GRACE observed total water storage anomalies without ancillary information on surface soil moisture or groundwater changes.”

2). Page3, Line 9-18: Introduction is well presented, however, this paragraph of objectives could be improved by clearly numbering each objective such as 1). . .. 2). . ..3). . .. This will make it easier for future readers to get straight to the points.

We thank reviewer for the suggestion and we will clearly define the objectives of this study at the end of Introduction section in revision:

3). Page3, Line 27: includes aÌĆA ÌĘTËĞ> including, and these .

We are not entirely sure what was originally shown in this comment, but suspect the suggestion was to modify this sentence into:

“The 0.5$\times$0.5 WFDEI (WATCH Forcing Data methodology applied to ERA-Interim) meteorological forcing data set (Weedon et al., 2014) used in this study including radiation, air temperature, wind speed, and surface pressure, and these were resampled to be consistent with the resolution of precipitation at 0.25.”

4). Page3, Line 21-30: More details of the ecohydrological model (W3) is needed to show how exactly it works.

We agree. While the W3 model has been described in numerous other studies, we will include in our revisions the following additional explanation in revision at Section 2.1 Line 28:

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“Precipitation is assumed to be the only water input into the system. The precipitation enters the grid cell through the vegetation and soil moisture stores and exits the grid cell through evapotranspiration, run-off or groundwater discharge. Each grid cell contains a mix of land cover classes (Hydrological Response Units; HRUs) and is conceptualized as a catchment that does not laterally exchange water with neighbouring cells. Different vegetation has different degrees of access to soil water. Soil and vegetation water and energy fluxes were simulated separately for deep-rooted and shallow-rooted vegetation to consider different rooting and water uptake behaviour. The soil water store was partitioned into three layers, namely, top, shallow and deep soil to describe the plant available water, approximately 0–5cm, 0.05–1m, and 1–10m in depth respectively. The unconfined groundwater and surface water stores were simulated comprising the evaporation, discharge and runoff at grid cell level.”

5). Page7, Line 18-19: Please move API to Materials.

Agreed. We will move API to the data section in revision.

6). Page8, Line 9-11:How can these two statements be justified from Fig.3d? What do R0 and Ra stand for? I assumed they represent correlations for open-loop and joint assimilation? You need to indicate it at least in the Figures.

Thank you. Yes, the Ro and Ra are the correlation for open-loop and joint assimilation, respectively. We will improve the figure caption to specify this.

7). Figure 5 : I suggest authors to label these sample sites on Figure 2.

Thank you. We take the reviewer’s suggestion and we will label these sites on Figure 2.

8). Page8, Line 15: "marginally better than SMOS-only results", which is hard to tell from the figure.

Agreed. We will include the averaged statistics in the revision.

9). Page9, Result-4.2: This section needs extra experiments using de-seasonalized data as mentioned in the major concern 2.

Agreed. We understand reviewer's concern and we will include the de-seasonalized experiment in the revision.

10). Page12, Line 26-27: There is a recent study very relevant to this statement that used GRACE-derived TWSA for Australia. Xie, Z., Huete, A., Restrepo-Coupe, N., Ma, X., Devadas, R., Caprarelli, G., 2016. Spatial partitioning and temporal evolution of Australia's total water storage under extreme hydroclimatic impacts. Remote Sensing of Environment. 183, 43–52.

We thank reviewer for this reference and we will include the citation in the manuscript as follow: "After a sharp recovery from the Millennium drought with an extremely wet period from 2010 to 2011 (Leblanc et al., 2009; van Dijk et al., 2013a, Xie et al., 2016), drought returned to eastern Australia with a decrease in soil water over 15 mm/yr estimated from both model open-loop and joint assimilation (Fig. 8a and 8b)."

11). Page12, Line 28-29: This is likely to be attributed to 2015 El NinÌČo impact.

We thank reviewer for the suggestion. We will include the following statement in the manuscript as:

"A decline in NDVI of more than 0.025 units per year was observed for the majority of middle and eastern Australia due to the developing soil water deficit (Fig. 8d), which is likely due to the widespread rainfall deficits caused by the El NinÌČo 2014-16 and further amplified by the Indian Ocean Dipole 2015."

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