

Response to Reviewer 1

The paper titled 'An evapotranspiration model self-calibrated from remotely sensed surface soil moisture, land surface temperature and vegetation cover fraction: application to disaggregated SMOS and MODIS data' by Ait Hssaine aimed to use LST and disaggregated soil moisture to better constrain the soil evaporation of TSEB model. This is a good idea; however, the presentation of the manuscript needs substantial improvement before being published in HESS. Here are my suggestions and comments, which need to be considered before being approved for publications.

(1) The abstract is poorly written and does not give a clear message about the novelty of the work. Rework is necessary.

In order to give a clear message about the novelty of the work, an effort was made to re-write the abstract. The revised abstract reads as follows:

Thermal-based two-source energy balance modeling is essential to estimate the land evapotranspiration (ET) in a wide range of spatial and temporal scales. However, the use of thermal-derived land surface temperature (LST) is not sufficient to simultaneously constrain both soil and vegetation flux components. Therefore, assumptions (on either soil or vegetation fluxes) are commonly required. To avoid such assumptions, a new energy balance model (TSEB-SM) was recently developed in Ait Hssaine et al. (2018a) in order to consider the microwave-derived near-surface soil moisture (SM), in addition to the thermal-derived LST and vegetation cover fraction (f_c) normally used. While TSEB-SM has been successfully tested using in-situ measurements, this paper represents its first evaluation in real-life using 1 km resolution satellite data, comprised of MODIS (Moderate resolution imaging spectroradiometer) for LST and f_c data and 1 km resolution SM data disaggregated from SMOS (Soil Moisture and Ocean Salinity) observations. The approach is applied during a four-year period (2014-2018) over a rainfed wheat field in the Tensift basin in central Morocco. The field used was seeded for the 2014-2015 (S1), 2016-2017 (S2) and 2017-2018 (S3) agricultural seasons, while it remained not ploughed (as bare soil) during the 2015-2016 (B1) agricultural season. Firstly, the classical TSEB model, which is driven only by LST and f_c data, significantly overestimates latent heat fluxes (LE) and underestimates sensible heat fluxes (H) for the four seasons. The overall mean bias values are 119, 94, 128 and 181 W/m^2 for LE and -104, -71, -128 and -181 W/m^2 for H, for S1, S2, S3 and B1 respectively. Meanwhile, when using TSEB-SM (SM and LST combined data), these errors are significantly reduced, resulting in mean bias values estimated as 39, 4, 7 and 62 W/m^2 for LE and -10, 24, 7, and -59 W/m^2 for H, for S1, S2, S3 and B1 respectively. Consequently, this funding confirms again the robustness of the TSEB-SM to estimate latent/sensible heat fluxes at large scale by using satellites data. In addition, the TSEB-SM approach has the original feature to allow for calibrating its main parameters (soil resistance and Priestley-Taylor coefficient) from satellite data uniquely, without relying neither on in situ measurements nor on a priori parameter values.

(2) Introduction: The flow should be logical. Since the objective of the manuscript is to improve the soil evaporation in TSEB to meet up field-scale ET mapping challenges, I do not see any need of line 5 – 10 in page 2.

We agree with the reviewer proposition. The lines 5-10 in page 2 were deleted.

(3) Introduction: 'Evapotranspiration (ET) is a crucial water flux in semi-arid areas'; should be supported by recent literature. The authors should be aware about some recently published ET modeling and mapping studies that particularly addressed the challenges semi-arid and arid ecosystems (that deserves to be cited here); for example, Mallick et al. (2015). Reintroducing radiometric surface temperature into the Penman-Monteith formulation, *Water Resources Research*, 51, 6214–6243, <http://doi.org/10.1002/2014WR016106>. Mallick et al. (2014). A surface temperature initiated closure (STIC) for surface energy balance fluxes, *Remote Sensing of Environment*, 141, 243 - 261. Bhattarai et al. (2019). An automated multi-model evapotranspiration mapping framework using remote sensing and reanalysis data. *Remote Sensing of Environment*, 229, 69 - 92. Gerhards et al. (2019). Challenges and Future Perspectives of Multi-/Hyperspectral Thermal Remote Sensing for Crop Water Stress Detection: A Review, *Remote Sensing*, 11(10), 1240; <https://doi.org/10.3390/rs11101240>. Bhattarai et al (2018). Regional evapotranspiration from image-based implementation of the Surface Temperature Initiated Closure (STIC1.2) model and its validation across an aridity gradient in the conterminous United States, *Hydrology and Earth System Sciences*, 22, 2311-2341, <https://doi.org/10.5194/hess-22-2311-2018>. Mallick et al. (2018). Bridging Thermal Infrared Sensing and Physically-Based Evapotranspiration Modeling: From Theoretical Implementation to Validation Across an Aridity Gradient in Australian Ecosystems, *Water Resources Research*, 54, 3409–3435. <https://doi.org/10.1029/2017WR021357>. Garcia et al. (2013); <https://www.sciencedirect.com/science/article/abs/pii/S0034425712004828>. Morillas et al. (2013); <https://agupubs.onlinelibrary.wiley.com>

The above recent papers about the modeling and mapping ET are now cited in the revised version.

(4) P2: L15-L20 (Introduction). The authors mentioned that LST based ET models fall into two categories. It is worth mentioning other categories where LST is integrated into Penman-Monteith energy balance (PMEB) equation to directly estimate ET.

To address this issue, the following paragraph was inserted to replace the Lines 15-20 of the revised: In this context, numerous models based on land surface temperature (LST) data have been developed such as : (i) residual balance methods that consider ET as the residual term of the energy balance like TSEB (Two-Source Energy Balance, (Norman et al., 1995)) and SEBS (Surface Energy Balance System (Su, 2002)), (ii) contextual methods that estimate ET as the potential ET times the evaporative efficiency (Moran et al., 1994) or as the available energy times the evaporative fraction (Merlin et al., 2013; Roerink et al., 2000) and (iii) other categories of models that integrate LST into a water balance model (Olivera et al., 2018) or into Penman-Monteith energy balance (PMEB) equation to directly estimate ET (Mallick et al., 2015; Amazirh et al., 2017).

(5) P3: L12 – L20: I do not see the necessity of such texts. This paper talks about TSEB model improvement and constraining soil evaporation. Yao et al. (2017); Purdy et al. (2018) only used soil moisture data into empirical PT model. I do not see any relevance of these sentences here. The current study is LST based, and the authors should mention why the additional use of SM along with LST can produce good ET estimates.

We agree with the reviewer's opinion, and accordingly the texts on page 3 Lines 12-30 were removed.

(6) P3: L25-L30: This is very significant. Therefore, the texts 'One difficulty lies in developing a consistent representation of the soil evaporation (as constrained by SM, (Chanzy and Bruckler, 1993)), the total ET (as constrained by LST, (Norman et al., 1995)): : ...' should replace the texts in P3 L12 – L20.

Agreed and done.

(7) Site description: Please provide a table describing the characteristics of S1, S2 etc.

According to the Reviewer's suggestion a table describing the characteristics of the 4 agricultural seasons was presented (Table 4 in the revised manuscript).

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(8) Suggesting to provide a Table on main equations of TSEB-SM and sub-equations related to LE_{soil}; the parameters involved in LE_{soil} model, their significance, what parameters did you calibrate, what are their value range etc. This would improve the readability of the manuscript.

According to the Reviewer's suggestion, a new Table (Table 5) was inserted to present the main equations of TSEB-SM and the sub-equations related to LE_{soil} and LE_{veg}.

(9) Section 2.3: There should be a separate sub-section on Retrieval and calibration of r_{ss} , $a_{r_{ss}}$, $b_{r_{ss}}$. The current description is unclear. How the parameters were calibrated? With respect to which observation they were calibrated? All these aspects should be crystallized in the methods section.

A detailed description and the main equations used for the calibration of the two soil parameters $a_{r_{ss}}$ and $b_{r_{ss}}$ as well as α_{PT} have been presented in our article published in AFM 2018 (Ait Hssaine et al., 2018b). For clarity, the lines 14-18 in page 9 have been restructured as follows:

'In Ait Hssaine et al. (2018b), an innovative calibration approach of α_{PT} , $a_{r_{ss}}$ and $b_{r_{ss}}$ is developed from in-situ SM, LST and f_c data (Ait Hssaine et al., 2018b). The calibration methodology is briefly reminded below.

2.3.1.1. Retrieval and calibration of r_{ss} , $a_{r_{ss}}$ and $b_{r_{ss}}$

The r_{ss} is first adjusted by minimizing a cost function defined by:

$$F_{inst} = (T_{surf,sim} - T_{surf,mes})^2 \quad (1)$$

With $T_{surf,sim}$ and $T_{surf,mes}$ being the simulated and measured LST, respectively. The inverted r_{ss} is then correlated to the SM (in-situ or DisPATCh) to determine the $a_{r_{ss}}$ and $b_{r_{ss}}$ parameters by considering that, when f_c is lower than a given threshold ($f_{c,thres}$), the dynamics of total LE is mainly controlled by the temporal variation of soil evaporation. Meaning that both soil parameters are estimated when the PT coefficient can be set to a constant value.'

(10) There should also be a sub-section on daily ALFApt (Priestley-Taylor parameter) retrieval.

The P7: L18-L21 was replaced by a sub-section

2.3.1.2. Daily α_{PT} retrieval

Once the soil resistance has been calibrated, the PT coefficient is retrieved on a daily basis when f_c is larger than $f_{c,thres}$, by minimizing a cost function at the Terra and Aqua-MODIS overpass times:

$$F_{inst} = \sum (T_{surf,sim} - T_{surf,mes})^2 \quad (2)$$

In fact, an iterative loop is run on soil (r_{ss}) and vegetation (α_{PT}) parameters to reach convergence of all parameters.

5 (11) Results and discussion: I am surprised to see the use of old reference (e.g., Sellers et al., 1992). There should be huge amount of literature on soil resistance and soil moisture that deserved citation.

According to Reviewer's suggestion, the following papers were cited in the revised version: Gentine et al., 2007; Chirouze et al., 2014; Oleson et al., 2008.

10 (12) Scatterplot of ALFApt (Priestley-Taylor parameter) versus residual ET and H errors (TSEB-SM – observed) should be shown to reveal the importance of this variable.

1

15 The Figure 1 shows that the scatterplot of α_{PT} is poorly correlated to residual H ($R=-0.27$) and ET ($R=0.27$) errors especially for the seasons S1 and S2. For season S3, few retrieved α_{PT} values were available because of the non-availability of MODIS products during cloudy days. It is well shown that the trend between α_{PT} and residual H error is negative for S1 while it is positive for S2. According to these results, no information linked to the variability of α_{PT} versus residual ET and H errors can be derived.

(13) How the retrieved soil resistance is related to the residual ET and H errors (TSEB-SM – observed)? What is the magnitude of variability of r_{ss} with LST? Such analysis would look excellent.

2

20 The r_{ss} is negatively correlated ($R=-0.33$) with residual H error (predicted–observed) for the four seasons, while it is negatively correlated ($R=0.33$) with residual LE error. The residual error covers a wide range (between -150 and 150 W/m²) for lower r_{ss} , while it varies with the increase of r_{ss} LST is positively correlated to r_{ss} ($R=0.45$). This is very coherent since r_{ss} decreases with the increase of SM. Since SM decreases with the increase of LST, the LST increases with the increase of LST.

25 (14) Residual error analysis should be done to show how the errors in ET and H estimates (TSEB-SM – observed) are related to both DisPATCH soil moisture and observed soil moisture.

3

The SM is positively correlated with residual H error for the entire study period, while it is negatively correlated with residual LE error. The correlation coefficient is about 0.29 when using DisPATCH SM while it is about 0.41 when using in-situ SM. This can be explained by the bias between DisPATCH and in-situ SM

30 For S2, B1 and S3, the residual H error ranges between -150 and 50 W/m² for SM between 0-10

I believe the authors put major emphasis to improve the ET and sensible heat flux simulation. But the intermediate parameters should be thoroughly analyzed to give it good scientific quality.

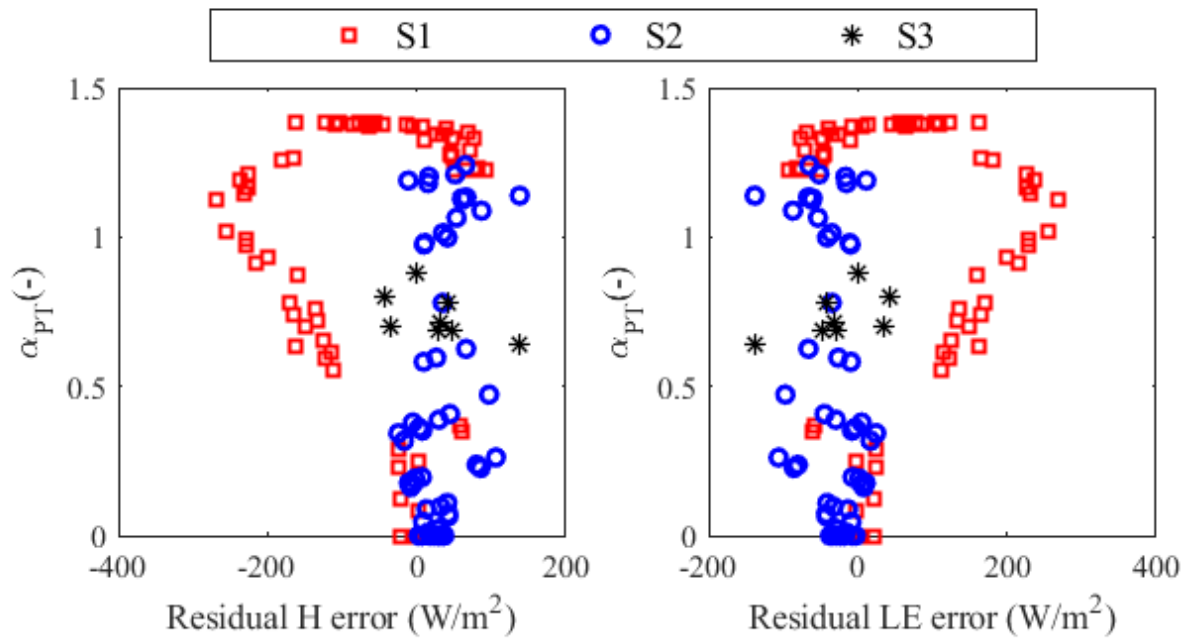


Figure 1. α_{PT} vs Residual H and LE error .

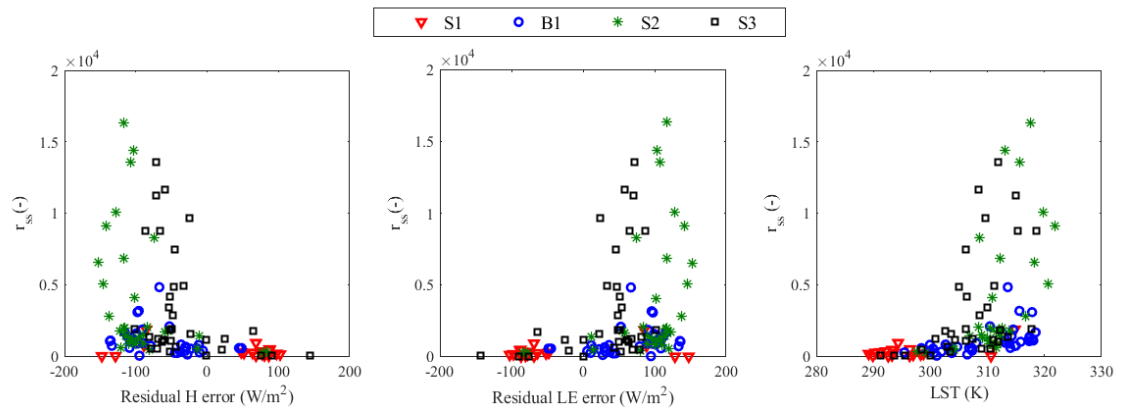


Figure 2. r_{ss} vs Residual H and LE error and LST for the four study periods .

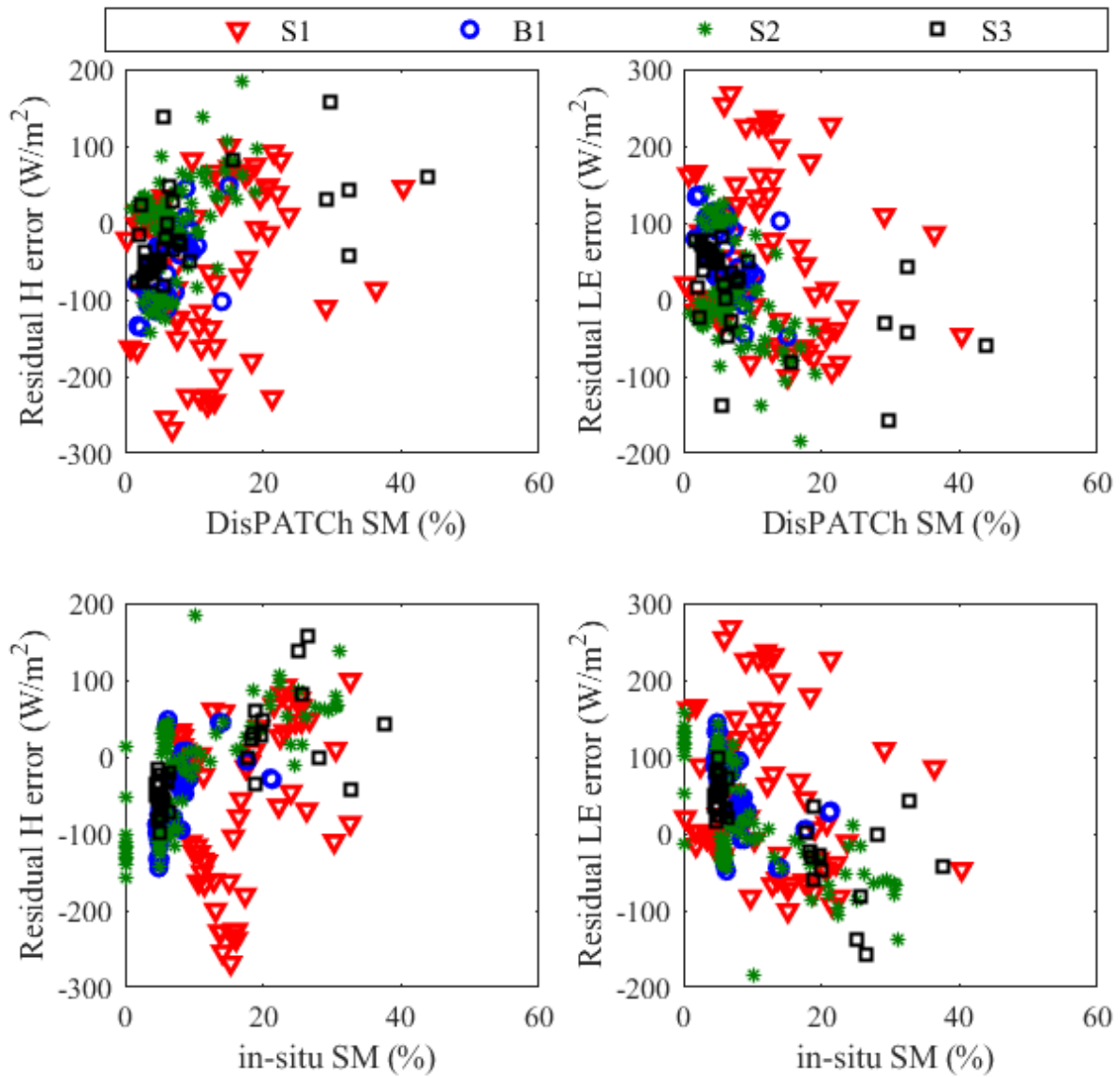


Figure 3. Residual H and LE error vs SM .

Table 1. Characteristics of the study site.

Study period	R ainfall amount (mm)	Field status
Oct 2014- Jun 2015 (S1)	608	Cultivated
Aug 2015- Sep 2016 (B1)	157	Bare soil
Sep 2016- Jun 2017 (S2)	214	Cultivated
Oct 2017- Jun 2018 (S3)	481	Cultivated

Table 2. Mean equations of TSEB-SM.

Variable	E	quation	Value range
Soil heat flux		$LE_{soil} = \frac{\rho c_p}{\gamma} \frac{e_s - e_a}{r_{ah} + r_s + r_{ss}}$	0-600 W/m ²
Resistance to vapor diffusion in the soil		$r_{ss} = \exp(a_{rss} - b_{rss} \times \frac{SM}{SM_{sat}})$	a_{rss} and b_{rss} : (1-13)
Soil moisture at saturation		$SM_{sat} = 0.1 \times (-108 \times f_{sand} + 49.305)$	0,47m ³ /m ³
Cost function for minimizing r_{ss}		$F_{inst} = (T_{surf,sim} - T_{surf,mes})$	$F_{inst} = 5$ K
Vegetation latent heat flux		$\alpha_{PT} \cdot f_g \cdot \frac{\Delta}{\Delta + \gamma} \cdot R_{n,veg}$	α_{PT} (0-2) $f_g = 1$