Response to Editor

Dear authors, Thank you very much for submitting your revision. In addition to the two reviews, there was a third one that also needs to be addressed. Please provide a point by point response and your revision thereafter.

I briefly checked some of your results and was puzzled by the ranges of values in r_{ss}. In Fig. 5, log(r_{ss}) is 0∼15, while in Fig. 13, r_{ss} is (0 ∼2)x10^4, or log(r_{ss})∼4. Please clarify these issues.

Thank you for pointing this out. In our case, we used the natural logarithm and not the decimal logarithm. For r_{ss} (0∼2)x10^4, the variation of ln(r_{ss}) is hence 0∼9.9. For clarity, “log” is systematically replaced by “ln” in the revised manuscript. Consistently, the values presented in the revised Fig. 13 (see below) correspond to the values obtained in figure 5.b. Note that few values are missing in Fig. 13 because of gaps in measured H/LE.

Another issue is related to the soil heat flux. Please add a sentence to explain how it was estimated.

The equation used to estimate the soil heat flux was added to the revised manuscript (Page 6 Lines 25-27):
“The surface soil heat flux is estimated as a fraction of $R_{n,soil}$:

$$G = c_g * R_{n,soil} \tag{1}$$

where cg ∼ 0.35” (Choudhury et al., 1987)

Please also pay attention to table 2, it seems the soil heat flux is the latent heat flux of soil surface (or soil latent heat).

The soil heat flux in Table 2 is changed by Soil latent heat flux

The eq. for r_{ss} is not complete.

Checked and corrected

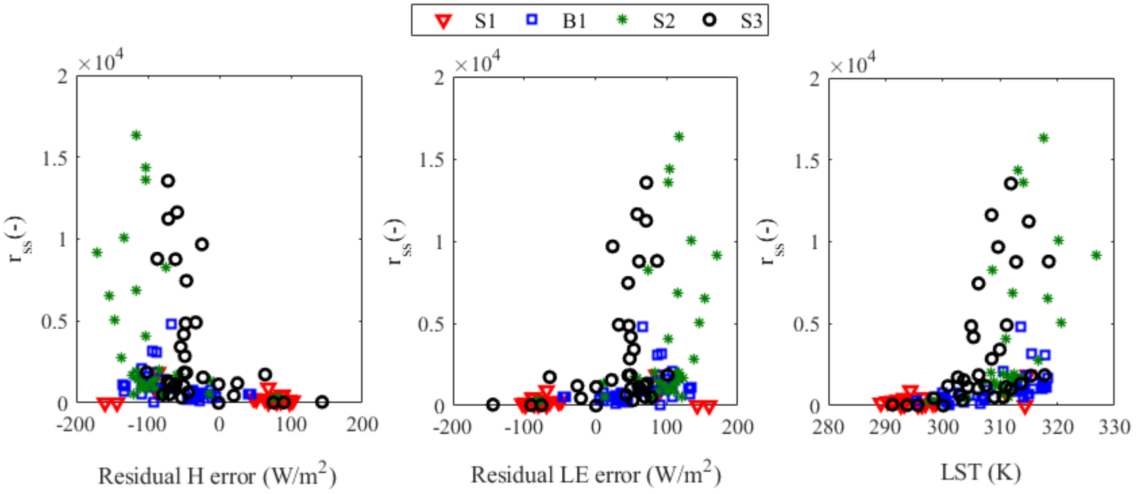

Figure 1. Previous version of fig.13 .

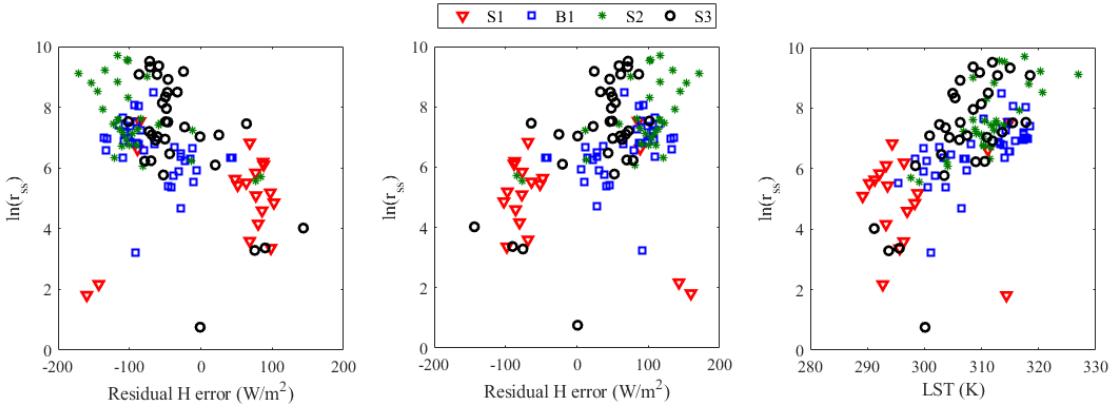

Figure 2. Revised fig.13 .

Response to Reviewer 1

Parameters in TSEB-SM were calibrated by using MODIS LST and SMOS SM observations. This gives us a solution on how to combine the use LST and SM for the ET simulation. This work is innovative and has a potential to be used by other studies. As an open access publication journal, I suggest the authors open the access to the model code and input data used in the paper, or published them with the paper on HESS.

First, we thank the reviewer for his/her interest in our work. Regarding the access to the model code, we would like to mention that the current version is in Matlab. We are planning to translate it into Python before the source code can be released under a license in which the copyright holder grants users the rights to study, change, and distribute the software to anyone and for any purpose. However, this step will be considered separately from the publication process of the HESS paper.

There are some minor mistakes in the manuscript, which are listed below:

In the same way, Li et al. (2006) indicated that the model performance is sensitive to these two coefficients, which two coefficients? SM and LST? Why SM and LST are called coefficients?

These two coefficients are a_{rss} and b_{rss}. To clarify this point, the following sentence (lines 5-6 page 3 of the previous version): “Moreover, the soil evaporation is constrained by the SM through soil-texture dependent coefficients reported in (Sellers et al., 1992). In the same way, Li et al. (2006) indicated that the model performance is sensitive to these two coefficients”.

Was replaced by (Page 3 Line 4-6 of the revised): “Moreover, the soil evaporation is constrained by the SM through its soil-texture dependent coefficients (a_{rss} and b_{rss}) reported in (Sellers et al., 1992). In the same way, Li et al. (2006) indicated that the model performance is sensitive to these two coefficients”.

Rewrite the sentence ”TSEB-SM is applied to 1 km resolution using MODIS LST/ fc data and to SMOS SM data is applied.”

The sentence was modified (Page 4 Line 7 of the revised) : “ TSEB-SM is applied at 1 km resolution using MODIS LST, MODIS fc and disaggregated SMOS SM data”.

Eq.7. When LST was simulated, what kind of input data were used and which values for the α_{PT}, r_{ah}, r_s were given? This information is important when you take LST as a simulation output. It‘s better to include this information.

For clarity, the details regarding the LST estimation were inserted in Page 7 Lines 21-27:

“The LST (noted $T_{surf,sim}$)) was simulated as follows:

$$(T_{surf,sim} = (f_c * (T_{veg})^4 + (1 - f_c) * (T_{soil})^4)^{0.25} \qquad (2)$$

where T_{veg} and T_{soil} are the vegetation and soil components of temperature (K). The LST is simulated each 30 min (between 11 am and 2 pm) and at Terra and Aqua overpass times for in-situ and satellite data, respectively.

The LST at first calibration step is simulated with a constant value of α_{PT} (average value of the α_{PT} retrieved for $f_c > 0.5$). Then, for the second calibration step, it is simulated using the daily retrieved α_{PT}."

The details regarding the resistances were inserted in Page 7 Lines 4-8:

“ r_{ah} the aerodynamic resistance is calculated from the adiabatically corrected logarithmic temperature profile equation (Brutsaert, 1982) and r_s the surface-soil resistance to transport of heat between the soil surface and a height representing the canopy, is estimated using (Sauer et al., 1995). Both resistances are simulated each 30 min (between 11 am and 2 pm) and at Terra and Aqua overpass times for in-situ and satellite data, respectively." A detailed description of TSEB model and the main equations used for the calibration strategy have been presented in our article published in AFM 2018 (Ait Hssaine et al., 2018).”

Do you mean rss or a_{rss}, b_{rss} with “the soil resistance” by “Once the soil resistance has been calibrated”?

The soil resistance refers to r_{ss}. To clarify this point, the following explanation was inserted in the revised (Page 8 Line 2): "once both parameters a_{rss} and b_{rss} have been estimated"

What is the difference of both $T_{surf,mes}$ in eq.7 and 8? Both Terra and Aqua LST were used in eq. 8. How about eq. 7? Which LST were used in eq. 7? Or both were used in eq.7?

$T_{surf,mes}$ in eq.7 are instantaneous LST each 30 min (between 11 am and 2 pm) while using in-situ data and at Terra and Aqua overpass times when using satellite data. $T_{surf,mes}$ in eq.8 is daily LST (an average of such LST measurements for a given day).

There are some mistakes in table2. It is not Soil heat flux.

Thank you for pointing out this error. The error was corrected.

It might be interesting to show the time series of soil and canopy H, LE component against flux measurement to look at the influence of dynamic variation with the variational α_{PT} ,and a_{rss}, b_{rss}.

We fully agree with the Reviewer. The time series of soil and canopy H, LE component against flux measurement is of great interest for our work. However, our focus for this work is the validation of total H and LE. As we mentioned (Response to Reviewer 3), measurement devices of separate E/T were not present at the Sidi Rahal site. Note that an intensive experiment was recently undertaken in the same region (Rafi et al. 2019) to provide such E/T estimates over irrigated wheat crops. Our plan is to develop an approach to implement TSEB-SM at the 100 m resolution and to validate the E/T components over those fields. This will be the focus of future studies.

We point out that there is no dynamic variation of a_{rss} and b_{rss}, as we only retrieve a pair of values calculated for the entire study period.

To look at the influence of dynamic variation with the variational α_{PT}. We plot the time series of simulated and measured LE superimposed with daily retrieved α_{PT}. At the beginning of the season, the soil is almost bare meaning that the α_{PT} doesn't affect the LE variabilities. In the growing stage, both observed and simulated fluxes depict a similar behaviour. The maximum of LE_{sim} is reached after the peak of rainfall during the growing stage which coincides exactly with the maximum value of the retrieved α_{PT}. Afterward, LE_{sim} tends to decrease at the senescence stage because of the decrease in daily α_{PT}

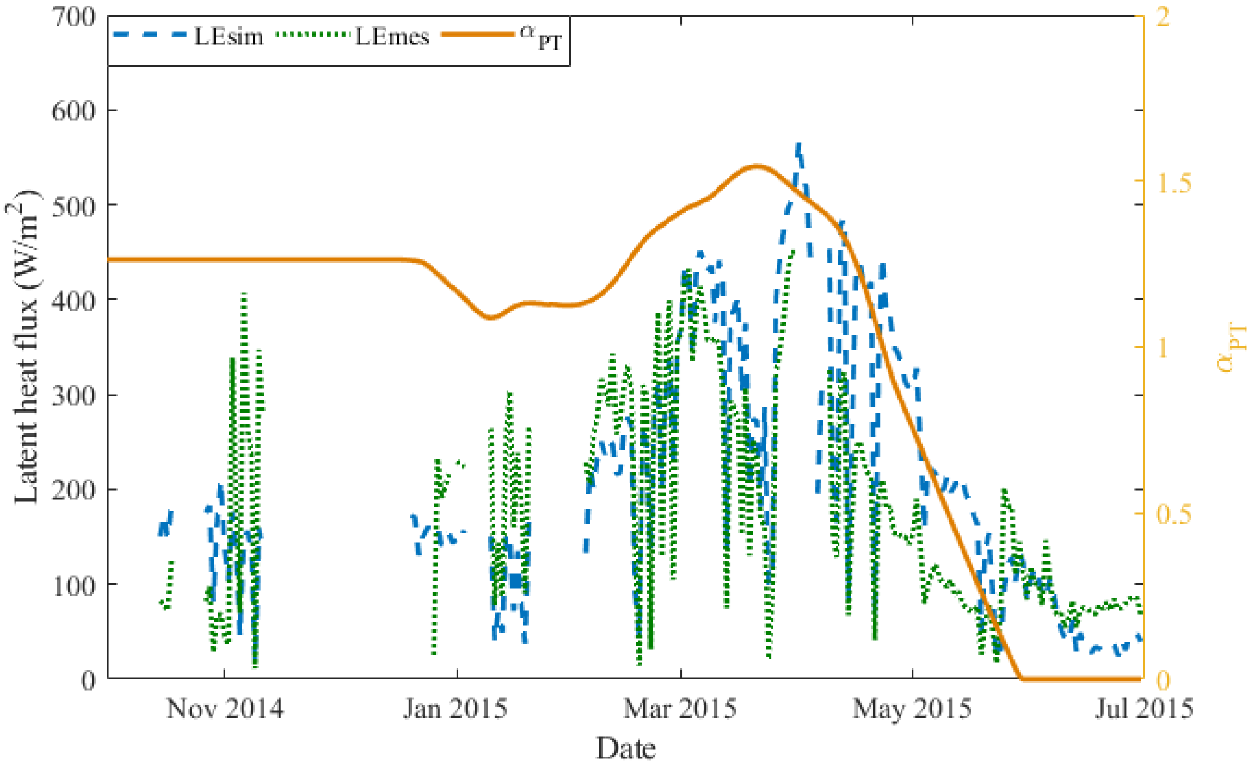

Figure 3. Time series of simulated and measured LE superimposed with daily retrieved α_{PT} .

Response to Reviewer 2

The revised 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 have substantially improved as compared to the initial version. However, couple of points need to be addressed after which it can be accepted for publication.

Introduction: The first paragraph should be written as follows (some references need to be added): Evapotranspiration (ET) is a crucial water flux for drought monitoring (Bhattarai et al., 2019; Gerhards et al., 2019; Mallick et al., 2014, 2016, 2018), water resource management (Please add references related to METRIC model applications in water resources management) and climate simulation (Littell et al., 2016; Molden et al., 2010) in the semi-arid ecosystems. A precise estimate of ET determines the crop water requirements, which subsequently allows the optimization of irrigation water applications (Allen et al., 1998). Reference: 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.

We thank the reviewer for the precise review of our paper. The paragraph in the previous manuscript was changed according to the above suggestions.

Page 2 L13-14 (Introduction): Please correct it as, (iii) other categories of models that integrate LST into water balance models (Olivera-Guerra et al., 2018) or into the Penman-Monteith Energy Balance (PMEB) equation to directly estimate ET (Amazirh et al., 2017; Mallick et al., 2015, 2018).

The sentence in Page 2 L13-14 (Introduction) was corrected.

Page 2 L24 – 28 (Introduction): Please correct as follows: Recently, Boulet et al. (2015) have developed the Soil-Plant-Atmosphere and Remote Sensing Evapotranspiration (SPARSE) model, which is similar to the TSEB model in its basic assumption, but, with additional constraints to improve the ET model performance in heterogeneous vegetation.

Lines L24-28 in page 2 (Introduction) were corrected in the revised manuscript.

P4 L5 – 10: Calling it cutting edge capability is an overstatement. Please correct it as follows:

Although TSEB-SM has the capability to calibrate its main parameters from remotely sensed data, however, the real-life application needs extensive evaluation and testing. The objective of this paper is thus to demonstrate for the first time this capacity using disaggregated SMOS and MODIS (Moderate resolution imaging spectroradiometer) data.

Line 5-10 in page 4 were corrected in the revised version.

Conclusions: Some insightful conclusions are expected. Better to give the significant conclusions in bullet points The conclusion is rewritten in bullet point as suggested by the Reviewer.

The microwave-derived near-surface soil moisture (SM) from SMOS and the thermal-derived land surface temperature (LST) from MODIS are integrated simultaneously in the TSEB formalism within a calibration procedure to invert both the soil resistance to evaporation (constant parameters) and the PT coefficient based on a threshold on f_c. The TSEB-SM model is applied during a four-year period (2014-2018) over a rainfed wheat field in the Tensift basin, central Morocco. Significant conclusions are given below.

The constraint applied on the soil evaporation represented explicitly as a function of SM via a soil resistance term reduces the errors when using TSEB-SM instead of TSEB.

-The first step of the TSEB-SM approach is to calibrate r_{ss} for ($f_c \leq f_{c,thres}$) at Terra and Aqua overpass times. Despite the scale difference between the MODIS/DisPATCh resolution data and the footprint size of in-situ measurements, the parameters (a_{rss}, b_{rss}) calculated for the entire study period using satellite data are relatively close to those derived from in-situ measurements.

-The second step of the TSEB-SM approach is to invert the α_{PT} on a daily basis for f_c> $f_{c,thres}$ by using LST and SM data. The maximum of daily calibrated α_{PT} are 1.38, 1.25 and 0.87, when using satellite data, for S1, S2 and S3, respectively. Those values are in accordance with the total rainfall amounts, which were about 608, 214 and 421mm/wheat season for S1, S2 and S3 respectively. S1 and S2 have the same distribution of daily calibrated α_{PT} when comparing with the α_{PT} retrieved using in-situ data, while the retrieved α_{PT} remains at a mostly constant value (0.7) throughout the study period S3 because of the non-availability of MODIS products during cloudy days.

-Finaly, an analysis of the spatial distributions and the magnitude of the turbulent fluxes using remotely sensing data produced from the two models were conducted. TSEB exhibits larger errors on H and LE estimates. These uncertainties can be linked to the theoretical value of α_{PT}, which is fixed to 1.26 for the whole study period, as well as to the scale mismatch between the 1 km resolution of MODIS LST and the footprint size (approximately 1 m) of the ground-based radiometer.

As a short term prospect, the use of high-resolution products from active sensors (Sentinel-1) would allow applying the TSEB-SM approach at the field scale over heterogeneous (e.g. irrigated) landscapes. Also the robustness of TSEB-SM in terms of evaporation/transpiration partitioning will be tested by using independent flux measurements derived from lysimeters and sap flow sensors (Rafi et al., 2019). In addition, the evaluation of ET at large scale is missing. Spatialized measurements that could be collected by scintillometers installed at various points in the region would be a solution for that purpose.

Response to Reviewer 3

Two-source energy balance (TSEB) model based on remotely sensed land surface temperature is an important modelling approach for estimating evapotranspiration (ET) and its components of E and T. This study aimed to use disaggregated soil moisture from SMOS to constrain the soil evaporation in TSEB and to further improve ET estimation. I do agree this is a good start point. However, the disaggregated soil moisture data should be reliable to calibrate the TSEB-SM model. If the authors failed to prove the reliability of the disaggregated soil moisture, this manuscript is just like the Ait Hssaine et al. AFM 2018b and should not be published again. After carefully read this manuscript, I think the "proof" provided in the current manuscript is not strong enough.

It is true that the accuracy in the disaggregated soil moisture data fosters the possibility to efficiently constrain the soil evaporation in TSEB. However, we do not agree with the reviewer that the accuracy in DisPATCh data is not sufficient to show the strength of the approach. In this paper, we show that the use of DisPATCh soil moisture improves the TSEB results (See results in Tables 4 and5 and Figures 8, 9, 10 and 11). In addition, the DisPATCh products have been extensively evaluated, especially over semi-arid areas like the Marrakech region (Bandara et al., 2015; Colliander et al., 2017; Escorihuela et al., 2018; Escorihuela and Quintana-Seguí, 2016; Lievens et al., 2015; Malbéteau et al., 2016, 2018; Merlin et al., 2012, 2013, 2015; Molero et al., 2016; Ojha et al., 2019; Peng et al., 2017; Sabaghy et al., 2020). In our opinion, both arguments 1) improved TSEB results by including DisPATCh soil moisture and 2) extensive validation of DisPATCh data over semi-arid areas) are sufficiently strong to prove that the approach using DisPATCh is reliable.

(1) The DisPATCh algorithm was applied to disaggregated 1km resolution soil moisture from SMOS soil moisture products. The DisPATCh algorithm is actually based on a contextual method to estimate soil and vegetation evaporative fraction. The question is whether it is reliable to apply the contextual method to such as heterogeneous farmland (See Figures 1 and 4)?

The contextual method in DisPATCh is implemented at 1 km resolution within a SMOS pixel i.e. within a 40 km by 40 km area (Merlin et al., 2012). Over the study area, the heterogeneity of the surface (in terms of vegetation cover and soil moisture conditions) is large due to the presence of both dry land and irrigated areas near Marrakech. In such heterogeneous conditions, the contextual approach is very well adapted as the dry and wet boundaries can be well estimated all along the agricultural season.

It seems the authors only use one soil moisture site to do the validation. Although the authors provide a scatter in Figure 3, this is not sufficient.

We fully agree with the reviewer that one single soil moisture site is not sufficient to assess the accuracy of the DisPATCh products. Instead our choice to use the DisPATCh product is supported by the numerous evaluation studies of this product (Bandara et al., 2015; Colliander et al., 2017; Djamai et al., 2015; Escorihuela et al., 2018; Escorihuela and Quintana-Seguí, 2016; Lievens et al., 2015; Malbéteau et al., 2016, 2018; Merlin et al., 2012, 2013, 2015; Molero et al., 2016; Ojha et al., 2019; Peng et al., 2017; Sabaghy et al., 2020) . Actually the scatterplots of Figure 3 aim to simply verify that the DisPATCh soil moisture is consistent, during four agricultural seasons, at the site level where the comparison between TSEB and TSEB-SM is undertaken.

To further emphasize this point, the following sentence was inserted (Page 9 Lines 14-19 of the revised) : " The DisPATCh products have been extensively evaluated, especially over semi-arid areas like the Marrakech region (Bandara et al., 2015; Colliander et al., 2017; Djamai et al., 2015; Escorihuela et al., 2018; Escorihuela and Quintana-Seguí, 2016; Lievens et al., 2015; Malbéteau et al., 2016, 2018; Merlin et al., 2012, 2013, 2015; Molero et al., 2016; Ojha et al., 2019; Peng et al., 2017; Sabaghy et al., 2020). Actually the scatterplots of Figure 3 aim to verify that the DisPATCh soil moisture is consistent, during four agricultural seasons, at the site level where the comparison between TSEB and TSEB-SM is undertaken".

(2) The manuscript failed to provide related information to the DisPATCh algorithm when applying the algorithm to the study

area. How the dry and wet edge associated with the DisPATCh algorithm been determined in this study?

The description of the DisPATCh algorithm is out of the scope of this paper. Instead we are using the DisPATCh product as input to TSEB formalism. As a short reminder of the edge determination in DisPATCh, the following information were inserted in the revised manuscript (Page 6 Lines 4-7): "Soil ($T_{s,min}$, $T_{s,max}$) and vegetation ($T_{v,min}$, $T_{v,max}$) temperature endmembers are estimated from the polygon obtained by plotting MODIS LST against MODIS NDVI, where the LST is partitioned into its soil and vegetation components according to the trapezoid method of Moran et al. (1994) (Moran et al., 1994). Details on the DisPATCh algorithm and the methodology to determine dry and wet edges can be found in Merlin et al. (2012). The aim of this work is to use the disaggregated SM to feed our model TSEB-SM."

The EFs derived from empirical contextual based DisPATCh algorithm is applied to disaggregated SMOS soil moisture, and the soil moisture is applied to constraint a more physically based TSEB ET model. What is the difference between EFs derived from DisPATCh and TSEB? Which model is more reliable?

The evaporative fractions derived from DisPATCh and from TSEB are not the same quantity. DisPATCh is based on the soil evaporative efficiency (SEE, ratio of actual to potential soil evaporation), which is used as a proxy for the 0–5 cm (microwave-derived) soil moisture variability. While in TSEB-SM we use the surface evaporative fraction (EF, defined as the ratio of latent heat to available energy) to normalize the output fluxes using the LST-derived available energy.

EF and SEE are both indicators of SM. However, the comparison of EF and SEE proxies indicates that SEE is more directly related to SM, especially for the higher range of SM values. The diurnal variability of EF, due to variations in incident radiation and relative humidity, seems to explain the superiority of the SEE-based approach for SM disaggregation purposes compared to EF-based approach (Merlin et al., 2008). For clarity, we plot the EF versus in-situ SM and the DisPATCh SM (linked to SEE) versus in-situ SM (The figure below). The figure shows the good agreement between DisPATCh SM and in-situ SM (R^2=0.59) compared to EF versus in-situ SM (R^2=0.31). EF is more scattered for higher SM values.

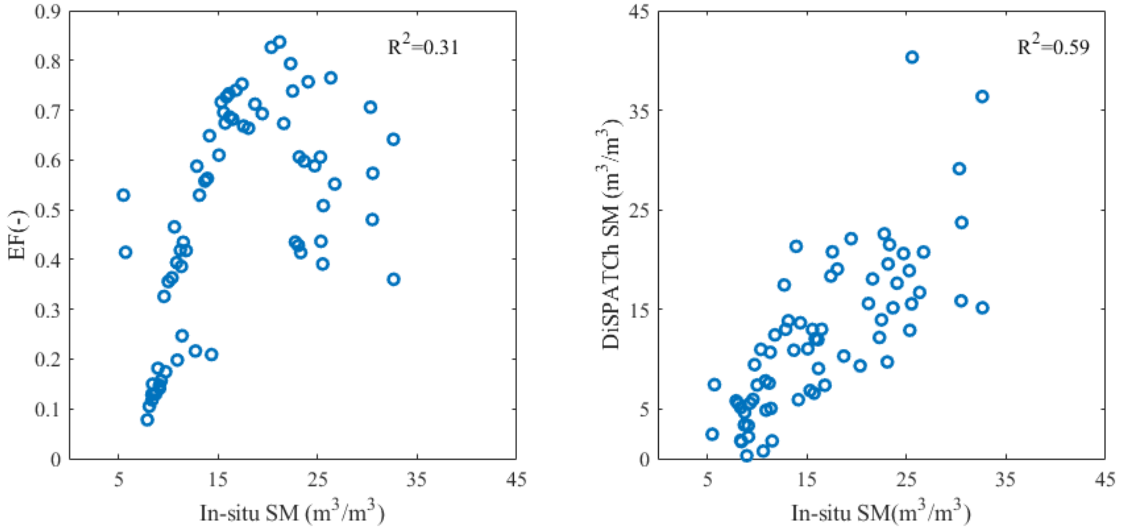

Figure 4. DiSPATCh SM (linked to SEE) versus in situ SM and TSEB EF versus in situ SM .

(3) It is clear the study area is very small from the Map scale in Figure 1, and the MODIS products with coarse resolution may not be a good choice in this area. I should recommend the authors try to use other high-resolution satellite images.

We agree with the reviewer that the study area is small compared to the 1 km resolution MODIS pixel. However, our choice was not arbitrary, because the field is located within a larger area occupied, quite uniformly, by rainfed wheat ‘Bour’. This field was chosen to be representative at a scale larger than 1 km, thus enabling the comparison between 1 km resolution satellite-derived and localized in-situ measurements. The use of high-resolution (Landsat) satellite images, compatible with the land use of the irrigated agricultural zone around Marrakech will be the focus of another separate paper. Note that another SM product should be used in this case (e.g. Ojha et al. 2019).

(4) As a two-source model, TSEB can provide ET components (E and T) as well. The authors only provide validation results for H and LE. It should be very interesting if the E/T partition can be provided for the original TSEB and the calibrated one.

We fully agree with the Reviewer. The validation of the E/T partition estimated by the original TSEB and by the calibrated one (TSEB-SM) is of great interest for our work. However, measurement devices of separate E/T were not present at the Sidi Rahal site. Note that an intensive experiment was recently undertaken in the same region (Rafi et al. 2019) to provide such E/T estimates over irrigated wheat crops. Our plan is to develop an approach to implement TSEB-SM at the 100 m resolution and to validate the E/T components over those fields and compare the results of partition with those of original TSEB. This will be the focus of future studies.

(6) More consideration should be taken to the smoothed PT coefficient in Figure 6. It seems the points are quite scatter.

It is true that the retrieved PT coefficients are quite scattered. A particular care was given to reduce uncertainties. To remove outliers and to reduce uncertainties on the daily inverted α_{PT}, these values were smoothed by using weighted linear least squares and a 1st degree polynomial model while taking a 30-day sliding average over the entire season.

Other specific comments (1) P6 Line 6, “the revised soil temperature” –may be retrieved?

Corrected.

(2) Table 2. The variable for the first equation should be soil latent heat flux. Soil heat flux should be G

Done.

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