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Paper: HESS-2014-355
Title: Evaluation of land surface model simulations of evapotranspiration over a 12-year crop succession: impact of the soil hydraulic properties.
Status: Major revisions

Avignon, 20 February 2015,

Dear Editor,

We would like to thank you and the two anonymous referees for the review of our paper. We have carefully considered the reviews. They helped us to improve the clarity and the quality of the paper. Below, we describe the main modifications of the revised version of the paper. Then, we provide detailed answers to each of the referee's comment.

1 Major modifications

1.1 Uncertainty analysis

We incorporated an uncertainty analysis as suggested by the editor and the referees. The objective consists in evaluating the impact of uncertainties in the soil parameters on ET simulations. We question the representativeness of field average estimates of the soil parameters which can be temporally and spatially variable. We address the following questions:

- How the uncertainties in the soil parameters translate into uncertainties in simulated ET ?
- How the uncertainties triggered by the soil parameters compare with those generated by the mesophyll conductance which is a key vegetation parameter involved in the simulation of the stomatal conductance?

To address these questions, we conducted two Monte-Carlo analyses to generate two ensembles of 100 simulations. The Monte-Carlo was applied to the most accurate simulation case (Sd) which was achieved with the soil parameters estimated from the field measurements of soil moisture. We applied the Monte-Carlo scheme to the soil parameters tested in this work: the rooting depth, the soil moisture at saturation, the soil moisture at field capacity and the soil moisture at wilting point. We considered uncertainties related to their spatiotemporal variability at the field scale (quantified in Table 3&4). Then, we applied the Monte-Carlo scheme to the mesophyll conductance. The spatiotemporal variability of the soil parameters can generate large uncertainties in ET. The 95% percentile interval represents 866 mm (23%) of cumulative ET over 12 years. The uncertainties generated by variations in the mesophyll conductance are much lower. The uncertainty analysis methodology is explained in the new Section 4.2. The results are reported in the new Section 5.4 (Fig. 6) and discussed in Section 6.1.3.

We chose to discuss measurements uncertainties in a separate Section (Section 6.4). We quantified and discussed both random and systematic errors. The latter are discussed in relation with the non-closure of the energy balance. We quantified the possible impact of underestimation of ET by eddy-covariance measurements over 12 years.

1.2 Improvement of the structure of the paper

- We clearly re-stated the objectives of the paper in Introduction. The uncertainty analysis is a new objective.

- We improved the description of methodology (Section 4). The distinct simulation cases are clearly described in the new Section 4.1 We identified 4 distinct analyses which correspond to each objective of the paper. They are described in Section 4.2.
- We modified the structure of the result section to provide results for each analysis. We removed in all redundancies between the result section and the discussion section.
- We modified the discussion. It is mainly dedicated to the uncertainties in each type of estimate of the soil parameters and to their impact on simulated ET. The two last sections discuss other sources of modeling and measurement uncertainties.
- In the last paragraph of Conclusion, we acknowledge that accounting for uncertainties in soil hydrodynamic properties is of paramount importance for the spatial integration of land surface models. We provide future directions for this work that should capitalize on the use of Bayesian inverse modelling technique to calibrate the LSM at regional scale and propagate the uncertainties in soil parameters.

2 Response to referee-1

0/"*Many parts are redundant, and need to be shortened, simplified and well-stated." :*

We carefully reviewed the paper, removed redundancies and improved the structure of the text. This mainly concerns:
- the objectives of the work,
- the description of measurements in Section 2,
- the methodology in Section 4: we described each experiment and we explained each analysis that will be conducted,
- result and discussion sections: we removed redundancies and we improved the structure.

1/"*by referring to Table 4, all the different simulation cases have to be clearly explained one by one in Section 4.1" :*

We agree and we clearly described each simulation case in the new Section 4.1.

2/*"the experiments are not well described. More details have to be added. "At which depth did you install the 4 neutron probes? Why do you average soil moisture at saturation (wsat) for different field locations if the model refers to an experimental soil profile? Not clear at all. How many samples (and which depth) were collected for the Richard plate apparatus? Explain better point 2 at page 11695: how do you retrieve rooting depth (d2), wilting point (wwp) and field capacity (wfc) from the measurements of the water content values? Can you show a graph where you point wwp and wfc in each growing season (to integrate Table 3)"*

We improved the description of soil measurements in Section 2.2. We clarified the following points:

- The simulations were designed to be representative of the field. They were not conducted for a particular experimental soil profile. This is the reason why we used soil and vegetation parameter values which were spatially averaged over the field. We clarified this point in the text (Section 3.2)

- Neutron probe was used to retrieve volumetric soil moisture over a 0–1.90 m soil profile with a vertical resolution of 10 cm. To implement the measurements, 3 to 6 neutron probe access tubes were installed at the centre of the field along a north-south transect. A calibration was done for every access tube and soil layer by relating neutron count rates to soil moisture measured by gravimetric method. The average soil moistures at given depth were then used.

- the soil moisture at saturation was derived from soil bulk density measurements, performed within the 0-1.2 m soil layer, at different field locations and times. We used the spatiotemporal average value to be representative of the soil structure at the field scale at which the simulations were conducted. The impact of the spatiotemporal variability of soil moisture at saturation which can be large due to occurrence of macroporosity is now analyzed using the Monte Carlo analysis (see point 3).

- The measurements done with the Richard plate apparatus cover water potentials of −1, −2, −3, −5, −10, −30, −50, −100, and −150 m. 3 samples were collected at depths of 0-0.4 m, 0.4-0.8 m and 0.8-1.2 m. These measurements are described in Bruckler et al., (2004). A retention curve model from Brooks and Corey (1964) was adjusted for each soil layer. It was used to retrieve the soil moisture at field capacity (θ_{fc}) and the soil moisture at wilting point (θ_{wp}) for each soil layer. θ_{wp} and θ_{fc} were averaged over the 0-1.2m soil profile and were used in the experiment.

- We clarified how the rooting depth, the wilting point and the field capacity were retrieved from the analysis of the evolution in time of the vertical profiles of soil moisture measurements over each crop cycle.
  - The rooting depth ($Z_{root-zone}$) was estimated for each crop cycle from the analysis of the time evolution of the vertical profiles of soil moisture measurements over the growing season. $Z_{root-zone}$ was approximated by the depth at which the soil moisture change in time vanished. We assumed that at a given depth, the time variations in soil moisture due to the vertical diffusion and gravitational drainage were smaller than those generated by the plant water uptake. This is a reasonable hypothesis for low hydraulic conductivity soil as the one under study.

  - Regarding θ_{wp} and θ_{fc}, we considered typical evolution cycle of the root-zone soil moisture under Mediterranean climate. Soil moisture generally starts from a upper-level which approximates θ_{fc}. It generally reaches a lower-level at the end of the growing season which often approaches θ_{wp}. To be consistent with the Richard plate measurements, we integrated soil moisture measurements over the 0-0.4 m, 0.4-0.8 m and 0.8-1.2 m soil layers. θ_{wp} and θ_{fc} were estimated for each soil layer as the maximum and minimum soil moisture value over the growing season. The mean values of θ_{wp} and θ_{fc} over the 0-1.2m profile were computed and reported in Table 3. The evolution of the measured root-zone soil moisture over each growing season is displayed in the new Fig. 2 (old Fig 1). For clarity reason, we did not point θ_{wp} and θ_{fc} for each crop cycle. We refer to Fig. 3b to illustrate how the wilting point and the field capacity were retrieved from the analysis of measurements of water content over the growing season.

3/"uncertainty is not properly addressed. It is just qualitative in Section 6. It is mandatory to quantify the uncertainty propagation on ET by running a Monte-Carlo analysis (for example 100 simulations for each case) and plot it (grey lines for all, black lines for the average ET-values). Same for the measured ET through the eddy-covariance. I understand this suggestion requires numerical effort, but the paper would be optimal by presenting this analysis."

We agree with your remark. We quantified the impact of uncertainties in soil parameters on ET by conducting a Monte-Carlo analysis for the most accurate simulation Sd. The Monte-Carlo process is applied to the soil parameters investigated in this work (rooting depth, soil moisture at saturation, field capacity and wilting point). The uncertainties in these parameters are represented by their spatiotemporal variability given in Table 3 and 4. We showed the propagation of uncertainties over the crop succession in Fig 6. The results are reported in the new Section 5.4 and discussed in Section 6.1.3. The spatiotemporal variability of the soil parameters can generate large uncertainties in ET. The 95% percentile interval represents 866 mm (23%) of cumulative ET over 12 years.
We chose to discuss measurements uncertainties in a separate Section (Section 6.4). We quantified and discussed both random and systematic errors. Random errors in measurement explain a large part of the unresolved scattering between simulations and measurements at half-hourly time scale. The likely underestimation of ET by eddy-covariance measurements could represent between 310 mm (5%) and 727 mm (12%) of cumulative ET over 12 years.

MINOR COMMENTS

1) "Please use simple (or standard) symbols to avoid confusion: for example LH for latent heat, E for soil evaporation, T for transpiration, for soil volumetric water content (w is soil gravimetric water content), s for saturated water content, Ks for saturated conductivity, Zr for rooting depth (why the subscript 2?)"

We agree and we used the appropriate symbols. For Latent Heat flux, we used LE which is largely used in the land surface model community. LE stands for L (latent heat of vaporization)*E (evapotranspiration).

2) "use same units throughout the manuscript. Be consistent. If the fluxes are in mm d-1, K has to be set in mm d-1 as well. The unit day is set with the letter d."

We checked that the same units are consistently used. For K, we used mm d^{-1} in the text. We replaced $m.s^{-1}$ by mm d^{-1} in Table A1.

3) "enlarge fonts in the figures, thicken the lines, enlarge the legend"

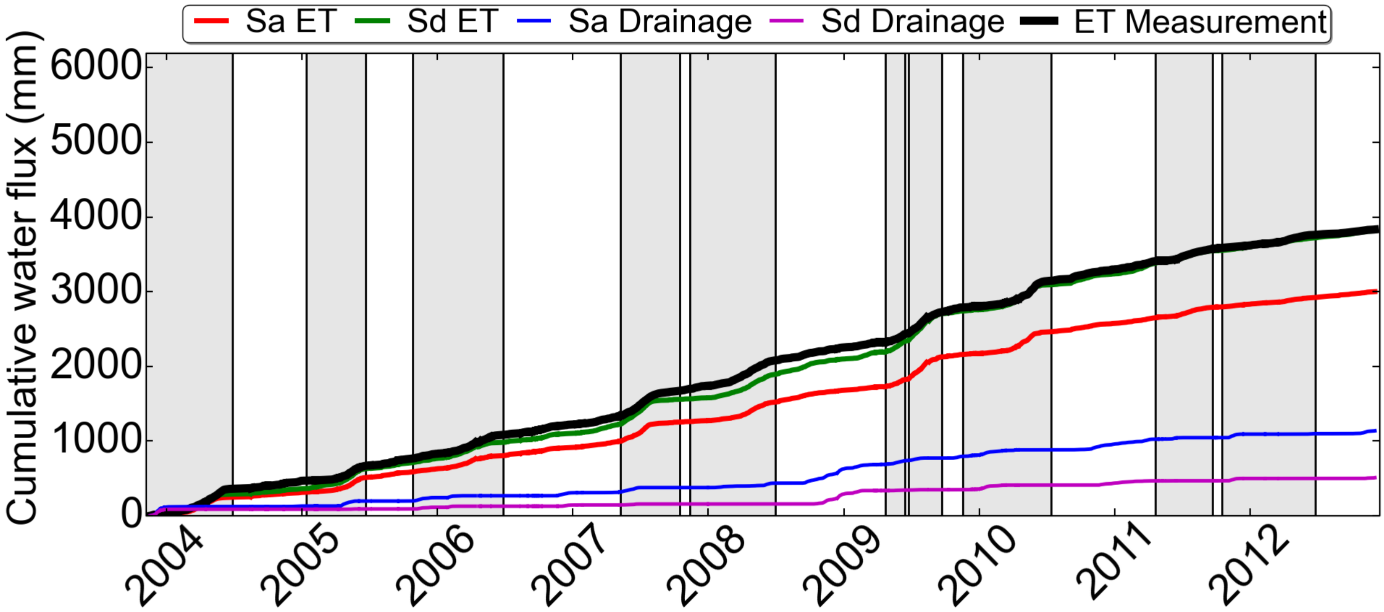
We improved the presentation of Figures.

3 Response to referee-2

1.1/ "The simulated cumulative ET is more than 20% lower than the measurement, then, where has the input precipitation/irrigation gone? "

The deficit in simulated ET obtained with the standard implementation of the model triggers an increase of simulated drainage that is probably overestimated. We added this sentence in Section 6.1.1 (first paragraph).

The large deficit in simulated ET reported in Fig 2 (old Fig 1) corresponds to the standard simulation Sa achieved with the pedotransfer estimates of the soil parameters. The deficit in cumulative ET over the 2004-2012 period amounts to 22% for Sa. The simulation Sd was achieved with the in situ values of the soil parameters derived from the analysis of soil moisture measurements over each crop cycle. The deficit in simulated ET is reduced to 0.45 % for Sd. The increase in simulated ET from the simulation Sa to the simulation Sd is 1025mm. The decrease in simulated drainage is 1070 mm. This is illustrated in the following Figure. We focus on the 2004-2012 period for which direct eddy-covariance measurements of ET are available.



1.2/ "The eddy covariance ET is usually lower than the real ET value. On this aspect, the predicted ET is much lower than the measurement. "

We agree that the deficits in simulated ET reported in this work are probably larger due to likely underestimation of ET by eddy-covariance measurements. We discussed this aspect in Section 6.4. To assess the uncertainties in eddy-covariance measurements, we computed two other estimates of ET. The first one is the residue of the energy balance. The second one is computed from the bowen ratio. The mean deviation in cumulative ET over 12 years between the bowen ratio estimate of ET and the direct measurement represents 727 mm (12%). It is 310 mm (5%) between the estimate derived from the residue of the energy balance and the direct measurement.

1.3/ "The time series of water balance components should be presented to justify the period the model failing. As shown in Fig.1, in some crop growth periods, the predicted and measured soil moistures are greatly and unreasonably deviated. It is seemed that there is some inconsistency between the precipitation input and soil moisture measurements."

We added time series of rainfall+irrigation in Fig. 2 (old Fig.1).
The underestimation of ET by the model is mainly related to errors in the values of the soil parameters which are derived from the ISBA pedotransfer functions (simulation Sa):

- The overestimation of the soil moisture at wilting point triggers the underestimation of the water stock available for the crop which conducts to the underestimation of the simulated plant transpiration at the end of the crop cycle.
- The overestimation of the soil moisture at saturation triggers an underestimation of the water diffusivity in the superficial layer which reduces the soil evaporation during wet periods.

We showed that the bias in simulated ET is mostly removed when the soil parameters are derived from the analysis of the vertical profiles of soil moisture measurements. This corresponds to the Simulation Sd which is the most accurate simulation (see new Fig . 6 and the Figure above)

2/"Soil hydraulic conductivity and its curve shape parameters are also important to soil water dynamic.

Their effects on soil moisture should be considered”

We agree with this remark. The ISBA model used in this work relies on a force-restore reservoir model (Noilhan and Planton, 1989). Darcy and Richards laws are not explicitly simulated. The force-restore scheme is based on effective soil parameters derived from pedotransfer functions embedded in the model (Noilhan and Laccarere, 1995). The coefficients of the force-restore scheme were calibrated using a detailed water transfer model and the soil hydraulic conductivity/retention models from Brooks and Corey, (1964). They were calibrated for various types of soil considering various curve shapes of the soil hydraulic model. However, we were not able to modify the curve shape parameter of the soil hydraulic model for this experiment. This would require the use of a multi-layer diffusion scheme where the Richard Equation and the hydraulic conductivity model are explicitly used. A multi-layer diffusion model is being tested for ISBA and could be used in future works. However, Olioso et al., 2002 showed that the performances of such detailed models rely on accurate parametrization of the root profile and soil vertical heterogeneity which may not be available at large-scale. Further works are needed to evaluate whether such model improves the simulation of ET dynamic over a crop succession.

3/”The authors claimed that the soil vertical profile is sensitive to the moisture simulation, but only the averaged parameters from field measurements are used. I am concerned how you derive these parameters representing the soil heterogeneity at field scale”

The simulations were conducted at the field scale. The most accurate simulation (Sd case) was achieved using the field averages of the soil rooting depth, the soil moisture at saturation, the soil moisture at field capacity and the soil moisture at wilting point. In in Section 2.3 of the revised manuscript, we clarified how these parameters are derived from field measurements.

- The soil moisture at saturation was derived from soil bulk density measurements performed within the 0-1.2 m layer at different field locations and times over the 12-year period. We used the average value to be representative of the soil structure at the field scale.
- The rooting depth, the soil moisture at field capacity and the soil moisture at wilting point are derived from the analysis of the evolution in time of the vertical profiles of soil moisture over each crop cycle. Field measurements of soil moisture better resolve the intra-field spatial variability through 4 neutron probes compared to the laboratory measurements.
    - The rooting depth was approximated by the depth at which the soil moisture change in time vanished (Table 4). We assumed that at a given depth, the time variations in soil moisture due to the vertical diffusion and gravitational drainage were smaller than those generated by the plant water uptake (Olioso, et al 2002).
    - Under Mediterranean climate, the root-zone soil moisture generally starts from a upper-level which approximates the field capacity. It generally reaches a lower-level at the end of the growing season which often approaches the wilting point. The wilting point and the field capacity were estimated for various soil layers as the maximum and the minimum, respectively, soil moisture over the growing season. We used the values averaged over the 0-1.2m soil profile.

Finally, we questioned the representativeness of field average estimates of the soil parameters which can be temporally and spatially variable. We evaluated the impact of such uncertainties in soil parameters on ET simulations using a Monte-Carlo analysis. These new results are given in Section 5.4 and are discussed in Section 6.1.3.

4/”The model uncertainty should be carried out to discern the contribution of soil hydraulic parameters to the model prediction deviation comparing with the above ground energy partitioning parameters, such as stomatal conductance, canopy extinction coefficients.”

We agree. We performed a Monte Carlo analysis to evaluate the uncertainties triggered by the spatiotemporal variability in the soil parameters. We compare them to uncertainties generated by the mesophyll conductance which is s a key parameter involved in the simulation of the stomatal conductance (Calvet et al;, 2012).

We discussed in Section 6.2 (last paragraph) possible shortcomings in the model related to inaccurate partitioning between soil evaporation and transpiration at low LAI. This could be related to unrealistic decrease of the vegetation cover which is a function of LAI in the model while the senescent crop is covering a non negligible soil fraction. The use of a single source energy balance can also impact ET partitioning (Olioso et al., 2002).

The canopy extinction coefficient should not play a key role for cropland. The radiative transfer in the canopy is based on a spherical angular distribution of leaves which should be accurate enough for most of the crops studied in this work.

5/"The section about eddy covariance uncertainty is not relevant to the model prediction, should be removed"

The simulations are evaluated using eddy-covariance estimates of ET. In Section 6.3, we quantified and discussed both random and systematic errors related to the eddy-covariance measurements. We showed that random errors may explain a large part of the unresolved scattering between simulations and measurements at half-hourly time scale. We highlighted that the deficits in simulated ET reported in this work are probably larger due to likely underestimation of ET by eddy-covariance measurements. We think that such discussion is essential to put into perspectives the evaluation of the model performances.

5 Other modifications

- We moved Appendix A.1 (List of symbols) to a new Table 1
- We improved the text of Appendix B. We clarified how random errors in eddy covariance measurements are computed.
- We added a new Figure 1 describing how the crop rotation is implemented in the simulations.
- We removed the experiment Sd_{Ks} where an exponential profile was used for the hydraulic conductivity at saturation Ks. This brought little results to the paper. We removed the result from Table 7 (old Table 6) to simplify the paper. We mentioned in Discussion that the use of an exponential profile does not change the performances of ET simulations. A multi-layer scheme is required to properly represent the soil vertical heterogeneity.
- New Table 7 (old Table 6): we changed the scores for the root-zone soil moisture. The scores in the previous version were computed over the full 2001-2012 period. The new scores are computing over the 20 November 2003-18 December 2012 period to be consistent with the scores for LE and daily ET. The new scores slightly change. This does not affect the interpretation of results.