Authors response to reviewer 2

Manuscript review for HESS-2013-444:"Irrigated plantations and their effect on energy fluxes in a semi-arid region of Israel a validated 3D model simulation" by Oliver Branch et al.

Comments:

This paper simulated irrigated plantations and their effect on regional climate in a semi-arid region, with comparisons between plant areas and desert. The work is valuable and interesting.

The authors thank the reviewer for his/her expertise and for the acknowledgement of the importance of this submission. Please note that any line numbers referred to here correspond to the original submitted manuscript (as suggested by the reviewers) and not the proofread online version.

Major comments:

1. The major comment is about the evapotranspiration. It may be not very convincing if ET are estimated using Penman-Monteith or FAO methods without calibration. There are many other methods on ET estimates, such as complementary relationship model with only meteorological data, method using remote sensing data, etc. If possible, please pay more attention on ET estimates, or even give direct measure in the future.

The P-M model, to the best of our knowledge, is a full solution of the energy balance, with the only compromise being the linearity of the vapor pressure to temperature relationship, which is accurate as long as crop surface temperature is within a few degrees of air temperature. Used with local climate data, soil heat flux and appropriate resistances it is a theoretically sound model of evaporation (Brutsaert, 1981; Monteith and Unsworth, 1990).

The FAO56 P-M model was selected by the FAO committee from available models and developed specifically to predict crop water use based on solution of the model for a reference grass surface, for which it has been calibrated in a number of climates (Allen et al., 1998). Applying an empirical crop coefficient specifically for Jojoba gives a rough estimate of actual crop water use. Crop coefficients are used without calibration, for example, in the FAO CROPWAT software to predict crop water use and determine irrigation requirements. Where local extension services have the possibility for field trials they will calibrate for the particular location in order to improve accuracy, as you have noted. In our case, unfortunately, we were unable to make direct measurements of crop water use and are not familiar with any methods that would give better estimates of actual crop water use.

Brutsaert (1981) does discuss the use of Bouchet's elegant complementary hypothesis to derive an equation for local ET, which might be interesting to compare. However we think that although the complementary approach is of interest in climatological studies, it would be difficult to apply in our case, and would not outperform the "uncalibrated" FAO56 approach for predicting crop water use.

2. "low Bowen ratios should not necessarily be assumed when irrigated plantations are implemented in" is a major conclusion. However, only latent heat and sensible heat are presented. Why not give the Bowen ratio results directly? This was only concluded from that the HFX over the plantations is higher than over desert surface. Please compare the bowen ratio directly. If it is possible, please compare the Bowen ratio over the plantations during the irrigated and non-irrigated periods. If so, the conclusions on lower Bowen ratios or not would be more convincing.

On reflection, the authors see that the use of "Bowen ratio" may be surplus to requirements so we have removed all uses of it and re-stated each instance of it in terms of fluxes instead, as follows:

"For the latter land use type, higher Bowen ratios would result from less water availability." (line 70)

to

"For the latter land use type, higher HFX and lower latent heat (LH) magnitudes would result from less water availability"

and

"Regarding fluxes, an expectation is that a freely transpiring canopy would result in low Bowen ratios in contrast to bare desert surfaces, where latent heat (LH) is likely to be almost zero." (line 88)

to

"*Regarding fluxes, an expectation is that a freely transpiring canopy would result in low HFX and higher LH, in contrast to bare desert surfaces where LH is likely to be almost zero.*"

and

"Plantation evapotranspiration (ET) could therefore be limited, resulting in higher Bowen ratios than a freely transpiring canopy implies." (line 100)

to

"Plantation evapotranspiration (ET) could therefore be limited, resulting in higher HFX magnitudes than a freely transpiring canopy implies."

and

"These predictions of large plantation T2 and HFX magnitudes appear to differ with conclusions from regional irrigation impact studies (e.g. Qian et al., 2013 and Kueppers et al., 2007) which diagnose cooler (daily mean) T2 and lower Bowen ratios over irrigated plantations." (line 713)

to

“These predictions of large plantation T2 and HFX magnitudes appear to differ with conclusions from regional irrigation impact studies (e.g. Qian et al., 2013 and Kueppers et al., 2007) which diagnose cooler (daily mean) T2 and high ET over irrigated plantations.”

To address the reviewer’s comment regarding the direct comparison of flux gradients a new 2D plot (Fig. 12) has been added to compare the plantation and surrounding desert LH and HFX in WRF-Impact:

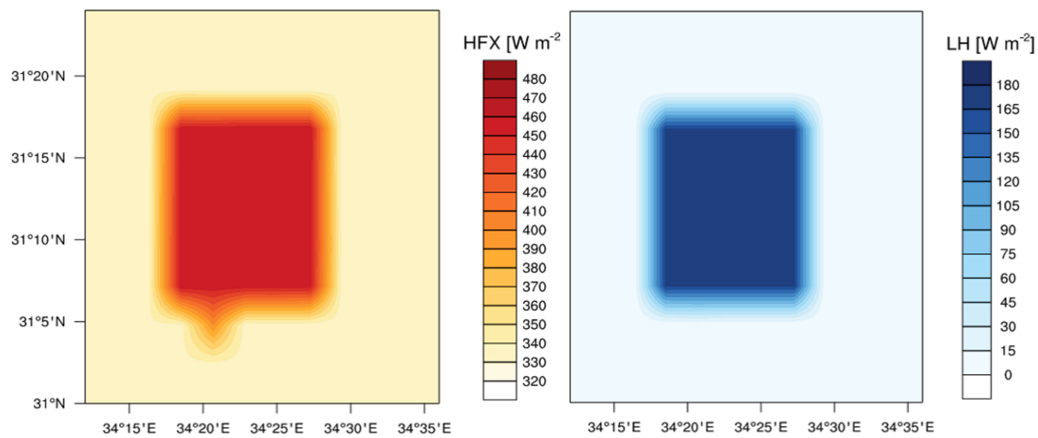

Figure 12. Mean daily maximum of sensible and latent heat flux (JJA) in WRF Impact to show the spatial gradient between the plantation and the surrounding desert. Values of HFX over plantation and desert are around 460 and 330 Wm^{-2} respectively (a 130 Wm^{-2} gradient). Values of LH over plantation and desert are around 165 and 0 Wm^{-2} respectively (165 Wm^{-2} gradient).

3. The comparisons were conducted on the mean diurnal cycle. Why not give some results on the daily variation of ETc, HFX, Bowen ratios? Because the irrigation may be different, some results about the comparison between the irrigated or non-irrigated periods may be more interesting.

The authors agree with the reviewer and Figure. 11 has now been re-plotted showing the diurnal standard deviation for the ET estimates and also for WRF Impact.

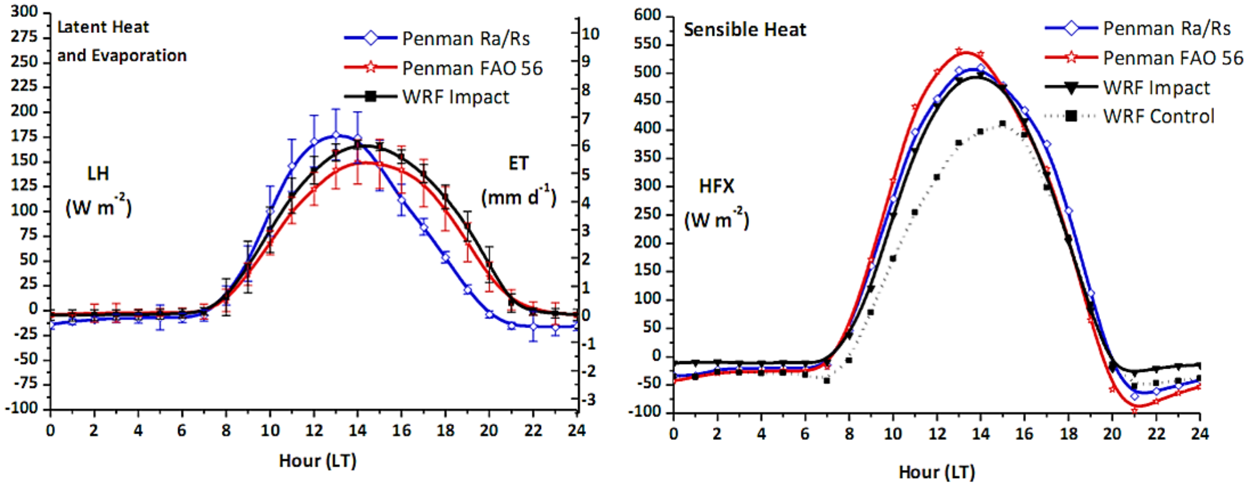

Figure 11. Mean summer diurnal cycles of LH and HFX from WRF Impact (solid lines). Also indicated are the estimates from Penman-Monteith with R_a/R_s and Penman-Monteith FAO 56 (dashed lines). The left hand plot shows ET expressed in W m^{-2} (left Y axis) and mm d^{-1} (right axis) along with the standard deviation. The right hand plot shows the HFX fluxes from WRF Impact and also the implied HFX based on the Penman estimates [calculated as the residual of the energy balance R_n (Obs) – G (Obs) – LH (Estimation)]. HFX from WRF Control is also plotted to assess the diurnal differences between HFX from desert and from irrigated plantations

The variability is significantly higher in the estimates than in WRF, which is to be expected given that the simulated spatiotemporal variability in soil moisture is likely to be much lower than in reality. The reasons for this have been mentioned in section 4.2 (line 376-387), but this section of text has now been expanded further in view of the comments made and now reads:

"Because the entire volume of each soil layer was wetted, the drainage over time is very slow, despite losses to uptake and deep percolation, and therefore after the first day of irrigation, Θ remains almost constant even over the seven day irrigation intervals (0.18 ± 0.002).

The reproduction of soil drainage characteristics over time therefore remains a problem, because in reality the Θ fluctuation would be larger and more rapid from a smaller wetted volume. Therefore, the variability in canopy ET at short time scales of e.g. a few days, may not be well represented by the model because in reality the soil may dry before the sensors activate new irrigation and higher resistances are likely to occur briefly. In this simulation therefore, ET is limited by Θ, but only in terms of the target level applied and not by varying levels of moisture due to soil moisture spatial heterogeneity, as may happen in reality. Well-reproduced daily variability therefore, might not always be expected but representative diurnal ET magnitudes based on target Θ levels and the environmental conditions are assumed."

We have also added some text in section 5.2. 'Comparison with evapotranspiration estimates' from line 588 the following text to discuss the variability:

"Both estimates vary more than WRF-NOAH especially during the morning up until midday. There could be many reasons for this. Biophysical factors not accounted for by WRF-NOAH

are spatiotemporal heterogeneity in soil moisture and stomatal resistances. The influence of these factors are unquantifiable though without detailed hydrological measurements. In terms of atmospheric demand, for which we do have sufficient data, we know that R_n varies by 80 Wm^{-2} during this time of day (Fig. 4) and decreases in mean daily values over the season by around 20 Wm^{-2} (Fig. 3). From Figure 9, G varies very little at this time (<10 Wm^{-2}) so is not likely to influence ET significantly. T2 in Jojoba also varies by 2° C during these hours (Fig.4) which is explained mostly by the seasonal peak in July (Fig. 3). U varies only by around 0.5 ms^{-1} diurnally and with little drift over the season, therefore aerodynamics do not seem to play a large role. VPD varies diurnally by around 0.4 hPa and from (Fig. 3) we can surmise that there is a peak of humidity during July because it remains constant whilst there is T2 peak at this time. Visually it appears that R_n is the most variable during the morning hours which corresponds most closely with ET variability. Given the size of the 80 Wm^{-2} fluctuation it is likely then that ET_0 variability is driven predominantly by that of R_n."

A more detailed irrigation simulation and finer resolution could improve representation of variability, and would ideally account for subgrid scale processes. This could mean that canopy resistances become much greater on some days and very large HFX magnitudes would occur. This study can be seen as an idealized scenario where water is always available, up to a maximum/optimal stress point, and ET is only dependent on atmospheric demand. This is valuable in any case because the mean values are representative (to 0.5 mm) even if the variance is less so.

Specific comments to the authors: Ln3, please give the meaning of HFX when it first appears.

This has been amended.

2. Please introduce the observations about the meteorological data, albedo, etc.

This text has been extended.

3. Fig. 8, "the model wind speeds are at 10m height, whilst the observations are measured at 6 m." The model or observed wind speeds can be transformed to the same height using the boundary layer method.

Both reviewers have mentioned this. The authors agree with the reviewers and the U raw data has now been height extrapolated from 6m to 10m using the following neutral stability log profile method from WMO:

$$\frac{\overline{U_1}}{U_{ref}} = ln\left(\frac{Z_1 - d}{Z_{0m}}\right) \Big/ ln\left(\frac{Z_{ref}}{Z_{0m}}\right)$$

The Desert diurnal mean curve does not alter significantly from the uncorrected data, due to the low roughness and still agrees with the WRF estimates to within approximately 0.5 ms^{-1} over 24 hours. The Jojoba curve is shifted upward significantly and now matches the WRF curve more closely, to around 0.5 ms^{-1}. This method and reference has now been included in the manuscript in a new appendix (Appendix C) and the validation plot and caption has been amended (Fig. 8).

4. Please give more introductions on the irrigation, such as irrigation amount.

Information on the irrigation methods at the Israel plantation are based on data obtained from the plantation agronomists and engineers. The actual quantitites fed to the plantations are quoted in Section 5.2:

…."….In Israel on the other hand, agronomists quote an annual input of 700 mm for Jojoba (650 mm for Jatropha). The average 200 mm of winter rain in Beer'sheva can be added to that." (line 544-545)

The following are further quotes from Section 2 (line 170-177):

….."The "Jatropha" case study (2) is a 2 ha irrigated Jatropha curcas plantation and the "Jojoba" case study (3) is a 400 ha plantation of irrigated Jojoba with a canopy height of around 3 – 3.5m. Both plantations are irrigated with secondary treated waste water from Beer'sheva, with low water salinity, i.e. the plantation's managers report that mean electrical conductivity (EC) of the irrigation water is ~1 dS m^{-1} (see Appendix B for more information about salinity)"….

…."The Jojoba plantation is fully mature and watered all year round" (line 186):

"…….. the Jojoba plantation is fed by a sophisticated, sub-surface deficit irrigation system configured to maximize water use efficiency and yield. Water requirements are estimated by agronomists using meteorology data and standard methods. The irrigation flow rates, duration and dripper spacing are optimized to minimize losses to percolation, runoff and direct evaporation. Given that a) there is little precipitation, b) the irrigation is sub-surface and c) the dosage is carefully calibrated, these losses are assumed to be negligible. Therefore, based on these assumptions, only the potential and transpired evaporation terms would play a role within the NOAH evaporation equation (Appendix A). The plants are watered directly at the root ball (35 cm deep) in alternate crop rows. Soil moisture (Θ) is monitored by a sensor network, and constrained to a fraction of between 0.16 and 0.30 so that the plant is neither water-stressed nor over-watered. This means that the frequency of watering can be irregular depending on environmental conditions such as radiation magnitudes, phenological stage and so on. The stem spacing of the Jojoba plantation also means that soil moisture is highly heterogeneous spatially. Irrigation information comes from the Jojoba plantation agronomists." (line 193-209):

In the model simulation, the irrigation is determined by the water stress/soil moisture requirement, rather than by adding a given amount and mass balances were not calculated. However this method has the advantage of accounting for differences in soil characteristics and transport between the model and reality, and it maintains the soil at a level where the plant experiences no more than a critical stress level. This is reasonable because the sophistication of the Israel irrigation system means allows for the following assumptions:

- No significant losses to drainage (all water added is taken up by the roots)
- No losses to direct evaporation (sub-surface and minimal capillary rise to surface)
- All ET comes from transpiration

In that case, we can make an estimate of the amount of water that is transpired i.e. the plant water requirement from the model output latent heat. Such estimates are reinforced by the Penman estimates. As well as the atmospheric demand this estimate will be based largely around the assumptions we have discussed in the paper on: optimal plant stress, the stomatal resistance.

These estimates can be seen in Figure. 11. Summer daily mean ET is equal to 4.56 mm d^{-1} (Penman Ra/Rs) and 4.33 mm (Penman FAO 56) and for WRF also 4.42 mm d^{-1}. This is now mentioned in the text in Section 5.2:

"ET from the Penman Monteith ET estimates and from the WRF-NOAH model, are compared in Fig. 11 (left plot), and are expressed in both W m^{-2} and mm d^{-1}. Given that we assume no losses to drainage or direct evaporation, the transpiration also represents an approximation of the plant water requirement. Therefore the (JJA) total requirement based on the WRF value of 4.42 mm d^{-1} would yield 406 mm over the 92 days of JJA (419 mm for Penman Ra/Rs and 398 mm for Penman FAO 56)."

We sincerely thank the reviewer for the useful expertise given and hope that we have addressed and clarified the main points and made all changes required to make the manuscript suitable for publication in HESS.

References used in the response to reviewer 2

Brutsaert, W. 1982. Evaporation Into the Atmosphere. Theory, History and Applications. D. Reidel Publ., London.

Monteith, J.L. and Unsworth, M. 1990. Principles of Environmental Physics. Second Edition. Arnold Publ., London