Responses to interactive comment on "Sensitivity of potential evapotranspiration to changes in climate variables for different climatic zones"

by Danlu Guo et al.

Black text – Reviewer's comments

Green text – Authors' responses

We would like to thank the feedback from the anonymous reviewer on the manuscript. Our detailed responses to the each comment are as follows.

Comments

General comments

1. The manuscript presents a sensitivity analysis of potential evaporation (PE) estimates to changes in climate variables by using two different PE formulations. This issue is clearly not novel but to my opinion, the wide range of climatic settings of the studied sites and the fact that no clear consensus emerged from the literature on this issue justify the proposed manuscript. The paper is easy to follow and the discussion is interesting and nicely put into perspective with other related recent studies. My main concern is on the likelihood of the way the authors dealt with sampling the climate perturbations and on the potential impact of these choices on the proposed sensitivity analysis. In principle, Sobol analyses should be applied on models with non-correlated inputs, which is not the case of PE climate inputs. This does not mean that the analysis proposed is wrong but that a careful attention should be paid on these correlations and on the way they can be reduced/ taken into account. To shed light on this issue, I suggest the authors show the correlations between variables on the studied sites. The other related major comment is on the way the authors sampled the climate perturbations. As far as I understand, they sample individually the perturbation for each climate variable by ignoring the interactions between variables. This is a strong assumption since some perturbations are likely to be interdependent. For instance, RH is often estimated on the basis of dew-point and air temperatures. Consequently, the perturbations should concern dew-point temperature (or water vapour pressure) and air temperature rather than relative humidity and air temperature. Besides, the range of possible might be criticized since some perturbations might not be realistic (e.g. an increase of Rs will likely not be possible with a decrease in temperature).

Thank you for raising these issues. Our responses to each of your three concerns are as follows:

(1) ***Concern:*** *Sobol' method assumes independent inputs so it is not suitable for the PET-related variables as they are correlated.*
Response: *Our input variables for the Sobol' analysis in this study were actually the annual average changes in each climate variable (i.e. climate perturbations), rather than the daily data of each variable (where correlations can exist). These perturbations have been sampled with Latin hypercube sampling, which resulted in samples which ensured independence among the average changes of the four climate variables (see the figure below, which shows the average*

perturbation determined by the first 1000 samples – to allow easier visualization). Therefore, Sobol' was a suitable method for analysing the sensitivity of output PET to these average changes in each climate variable.

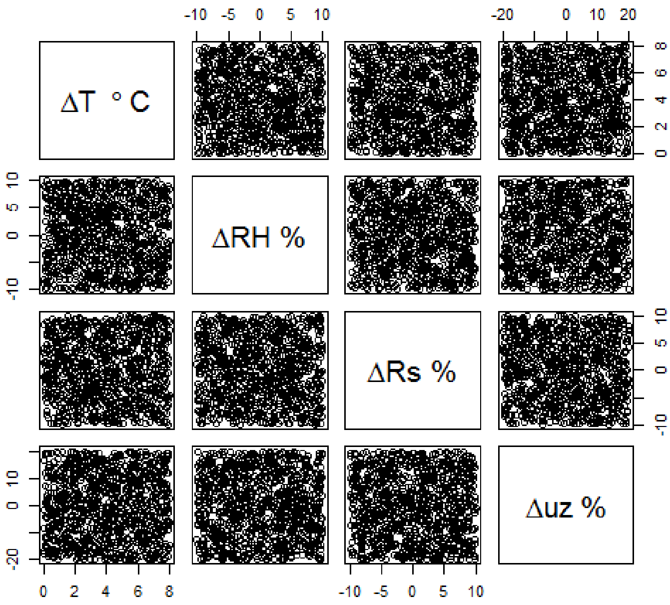
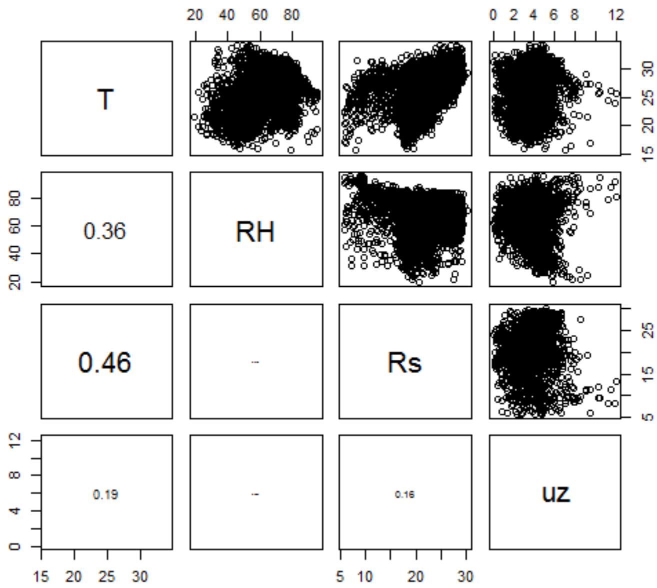


Figure 1. The first 1000 sets of perturbations in each of the four climate variables relative to the corresponding historical annual average levels, as used for the Sobol' analysis in this study. These perturbations were determined by Latin hypercube sampling and thus ensured the independence among the average changes in the four climate variables.

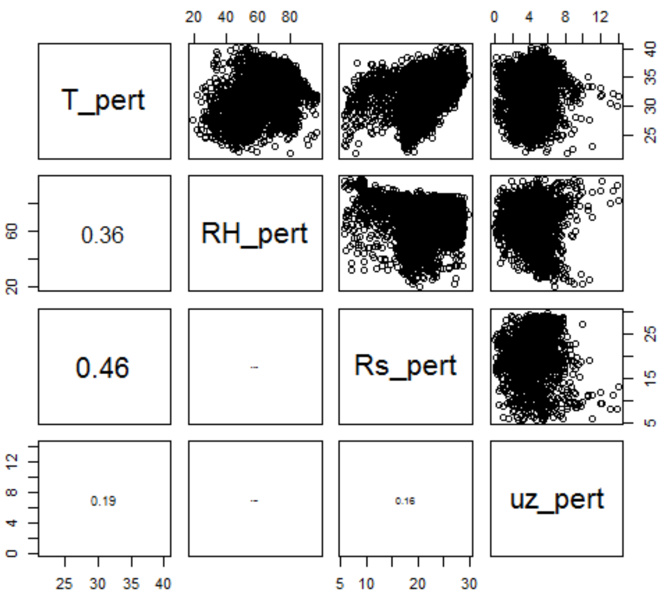
(2) ***Concern:*** *The perturbations of climate variables did not consider the historical correlation structures in the climate data.*

Response: *As we highlighted in the previous response, each of the climate perturbations in this study was applied to each climate variable as an overall annual average change factor, rather than being partitioned into daily variations. The resultant perturbed time-series of climate variables, therefore, were still able to preserve the historical correlation structures at the daily scale within historical data. For example, please refer to the two figures below, which show (i) pairwise correlation between the historical daily time-series of T, RH, R_s and u_z, for study site #1; and (ii) pairwise correlation between the perturbed daily time-series of T, RH, R_s and u_z, for study site #1, with the first perturbation used for Sobol' analysis, which was: +6.05 ºC, 1.14%, -1.74% and 16.9% for T, RH, R_s and u_z, respectively.*

It is evident from the figures that although our perturbation method may change the annual average values of these variables, they do not alter the correlation structures among the four climate variables at the daily scale.



(i)



(ii)

Figure 2. Pairwise correlation between (i) the historical daily time-series of T, RH, R_s and u_z, for study site #1; and (ii) the perturbed daily time-series of T, RH, R_s and u_z, for study site #1, with the first perturbation used for Sobol' analysis as: +6.05 ºC, 1.14%, -1.74% and 16.9% for T, RH, R_s and u_z, respectively.

(3) Concern: *The perturbations of climate variables might yield physically infeasible climate condition.*

Response: *The climate perturbations (i.e. sampling) was designed to serve the sensitivity analysis which aimed to test the sensitivity to all possible climate conditions. Therefore, although some perturbations might reflect climate conditions that are unlikely to occur in the future, they are still physically plausible. For example, although an increase in temperature is likely to lead to increasing R_s, both an increase or decrease in R_s are possible, as this is also related to cloud cover (e.g. Cubasch et al., 2013). Similarly, for all other pairs of climate variables, although some* *combinations of potential changes are more likely to happen than others, all combinations are physically plausible and thus should be considered in the sensitivity analysis.*

Note that although the above discussion concerns plausibility of different combinations of annual change factors applied as part of the sensitivity analysis, it is possible that application of such change factors can lead to physically implausible data points at the daily scale. For example, increasing annual average humidity in the sensitivity analysis may lead to daily values that exceed 100%. To avoid these changes, we have imposed an upper limit of 100%, and this issue is also the reason that we focus on changes in RH instead of Tdew.

Specific comments

1. - I suggest the authors change the term potential evapotranspiration into potential evaporation that is more consensual.

We decided to keep the term 'potential evapotranspiration' ('PET') as this is a more widely used term in the literature assessing the hydrological impacts of climate change (e.g. New et al., 2007; Chiew et al., 2009; Prudhomme et al., 2010;), which is more relevant to the context of this study.

2. - There are some typos in the text, e.g. Priestly-Taylor is often used instead of PriestleyTaylor and Figure 1 includes many typos (equatorial, temperate).

Thank you. We will correct these throughout the revised manuscript.

3. - I suggest the authors include in the manuscript the equations of the two PE equations.

We agree with your suggestion and will add the main equation for each model, as well as other equations used to estimate the intermediate variables to Appendix A.2. and Appendix A.3. in the revised manuscript.

4. - Priestley-Taylor equation is simple and some results might be discussed on the basis of the equation directly (e.g. by deriving analytically sensitivity coefficients).

We have explained the zero-sensitivity of Priestley-Taylor PET to wind in L350-351 of the original manuscript, as:

- *"…wind is shown to have no impact as expected, since wind is not an input into the Priestley-Taylor model (Fig. 6d)."*

We will add the following explanation to the sensitivity of Priestley-Taylor PET to relative humidity to L347-349 as follows (with changes underlined):

- *"…the role of relative humidity does not appear to increase significantly with increasing baseline humidity (Fig. 6b) and in general contributes less than 33 % of the overall variability. <u>The lower impact of RH on Priestley-Taylor PET compared to the impact on Penman-Monteith PET can be related to the structure of the Priestley-Taylor model, which does not consider the aero-dynamic processes, so that the impact of RH on PET through these processes is not accounted for (see Eqn. 2.7, 2.15 and 2.16 in Appendix A.2.).</u>"*

The other two input variables, temperature and solar radiation, are incorporated into the Priestley-Taylor model in a highly non-linear manner, so it would be difficult to infer the corresponding sensitivity directly from the model equation. For the same reason, it is difficult to explain the magnitude of PET sensitivity to these two variables with reference to the model structure.

5. - The time period used as the baseline is relatively short and this might be helpful to give some information on the climatic specificity of the time period.

The selected study period aimed to reflect baseline near-recent climate conditions in Australia, and was selected according to the availability of high-quality climate observations in Australia (released by BoM 2013). The data period was mainly constrained by wind data, which were only available up to the year 2005. In addition, the data period was also determined so that climate data were available for a consistent period at a number of case study locations within different climate zones in Australia, which is another factor limiting the data period that could be considered.

As summarized in Table 1, the baseline included various climate conditions, with a wide range of values for each climate variable. Any uncertainty in specifying the baseline at individual locations due to the data length are therefore likely to be overshadowed by the wide ranges of each climate variable across the different study locations, as indicated by the variable ranges given below:

- *T: 9.95 °C (Lake Leake) – 27.4 °C (Darwin)*
- *RH: 37.2 % (Tennant Creek) – 78.0 % (Strathgordon village)*
- *R_s: 11.7 MJ $m^{-2}day^{-1}$ (Strathgordon village)– 21.6 MJ $m^{-2}day^{-1}$ (Tennant Creek)*
- *u_z: 2.34 ms^{-1} (Alice Springs) – 6.40 ms^{-1} (Flinders Island)*

6. - Are wind speed and air temperature measured at 2m for all locations?

Air temperature data were measured at a height of approximately 1.2 metres above the ground, and wind speed data were normally measured at a height of 10 metres above the surface (http://www.bom.gov.au/climate/cdo/about/faq-data.shtml). The temperature observations were assumed to be close to the evaporative surface, while the height of wind speed measurements has been incorporated in the estimation of Penman-Monteith model to convert to a 2m height (as discussed, the Priestley-Taylor model does not use wind as an input so this effect was not relevant).

7. - P.8 l.136 ET-related -> PET-related?

We agree with your suggestion and will reflect this change in the revised manuscript.

8. -P.14 l.260 “,.” -> “.”

This will be updated in the revised manuscript.

9. - The distinction between ‘energy-limited’ and ‘water-limited’ sites is interesting but not clearly defined: from the legends of Fig. 3-6, it appears that a studied site might be energy-limited for some months AND water-limited on some other month, which is non sense. From Fig 1, it appears that a given site is water-limited OR energy-limited. This need clarification and the threshold of aridity index value between the two classes should be defined.

Thank you for highlighting this confusion. We would like to take this opportunity to clarify that the water-/energy-limited status for each catchment presented in Fig. 1 was based on the long-term ratio of PET/P from the 10 years of data (as the PET/P ratios presented in Table 1), which was used to categorize the overall hydrological condition at the 30 case studies.

Due to the seasonal variation of PET and P, a catchment can switch between water- and energy-limited conditions for different months. Therefore, estimating the monthly PET/P ratios allowed us to discover more on how the PET sensitivities vary with these seasonal changes in hydrological conditions. The status shown in Fig. 3-6 was therefore based on monthly PET/T.

In the revised manuscript, we will update L291-293 (where the monthly PET/P ratio is first introduced) to clarify the monthly scale for estimating this ratio and differentiate these with the ratios presented in Table 1, as following (with changes underlined):

- *"In addition to the impact of baseline climatic conditions, we are also interested in the role of baseline hydrological conditions (represented by the PET/P ratio at each study site) on PET sensitivity. Since the hydrological conditions can vary substantially over the course of a year for each study site, for this analysis we focused on the PET/P ratios estimated on a monthly basis, which therefore differ from the long-term PET/P ratios presented in Table 1."*

Further references

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