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 Angela Bowman for her feedback on the manuscript. Our detailed responses to the each comment are as follows.

Overview

Overall, the paper is well written and concise. The goals of the paper are outlined well and the results are presented in a clear manner.

The purpose of this manuscript is to understand the possible implications of anthropogenic climate change on watershed-scale water budget through a global sensitivity analysis of PET. Several scenarios were analyzed in which baseline (current) climatic conditions were subjected to changes in: temperature; relative humidity; solar radiation; and, wind speed. The methods in this paper appear sound.

Comments

Specific comments

1. LINE 72: List the references to "number of recent studies"

The references have been listed in L74-81 in the original manuscript, as:

- *"For example, Goyal (2004) found that … Tabari and Hosseinzadeh Talaee (2014) also looked at … Gong et al. (2006) found that …"*

2. LINES 72-86:
   (1) Were these analyses all specific to PET sensitivity? Which PET models did each use in their analysis?
   (2) How were they similar and different to this analysis?

(1) Yes, all of these analyses were specific to PET, although referred to as reference ET – which is the PET for a reference crop evaporative surface. All these studies were based on results from the Penman-Monteith model.
In the revised manuscript, we will add the following phrase (underlined) to the first sentence of this paragraph, to clarify the PET models used in these studies:

- *"Sensitivity analysis methods have been employed in a number of recent studies to assess the overall sensitivity of PET <u>estimated by the Penman-Monteith model</u> to potential changes in climate, as well as to better understand the relative importance of different climate variables on overall PET sensitivity."*

(2) We have highlighted the similarities/differences of these studies compared to our study in L81-86 of the original manuscript:

- *"However, most of these PET sensitivity analysis studies focused on a limited number of study sites and/or climatic zones, so that the specific causes for varying PET sensitivity at different locations, such as the roles of climatic and hydrological conditions, remain unclear. Consequently, it is difficult to extrapolate our existing knowledge of PET sensitivity and the relative importance of each climate variable to new locations, which is essential for assessing the water balance at regional scales."*

Similar to these studies, we focused on reference crop PET estimated with the Penman-Monteith model. However, to address the abovementioned limitations in the existing studies, we looked at a much broader range of climate zones. We also compared the results from the Penman-Monteith model with the Priestley-Taylor model, to understand the role of alternative model structures on climate sensitivity. Finally, to assess the sensitivity of PET, we conducted both one-at-a-time and global sensitivity analysis, which allowed us to not only assess the responses of PET to potential changes in each input climate variable, but also compare their relative importance in affected PET.

3. LINES 87-90:
   (1) How are baseline hydrologic and climatic conditions affected by PET? Aren't the baseline conditions used as the baseline for comparison?
   (2) How is "…and how these sensitivity estimates are affected by baseline hydrologic and climatic conditions" in (i) different than "…and how this changes with the baseline hydrologic and climatic conditions" in (ii)? I am unclear what the difference is. Wouldn't the baseline hydrologic and climatic conditions be the baseline?

Thank you for highlighting these issues.

(1) We would like to take this opportunity to clarify the use of 'baseline hydrologic and climatic conditions' in our manuscript, which refers to the historical status of hydrology and climate at different locations. It is important to investigate the impact of different baselines on the overall PET sensitivity results as identified from previous literature (L72-86 in the original manuscript), since this will affect the degree to which sensitivity values at one geographic location can be used to infer expected sensitivities for other locations. To clarify this, we will revise our study aims as follows (with changes underlined):

- *"…this study aims to gain an understanding of (i) the sensitivity of PET estimates to changes in the key climatic variables which influence PET, and how these sensitivity estimates are affected by <u>varying</u> baseline hydrologic and climatic conditions <u>at different locations</u>; and (ii) the relative importance of these climatic variables for PET, and how this changes with the baseline hydrologic and climatic conditions <u>at different locations</u>."*

(2) In both study aims we were interested in the impact of varying baseline hydro-climatic conditions at different locations. The difference is that in study aim (i) we were interested in how the sensitivity of PET varies as a function of baseline hydro-climatic conditions at different locations. In contrast, in study aim (ii) we were interested in how the relative importance of each climate variable for PET varies as a function of baseline hydro-climatic conditions at different locations.

For example, one of the findings related to study aim (i) is as L266-273 in the original manuscript, in which the sensitivity of PET at each study site was represented by the percentage change in PET in responses to plausible changes in the four climate variables:

- *"… with the Penman-Monteith model (Fig. 3), it is clear that the PET sensitivity displays clear association with the baseline levels of climate variables, with higher sensitivity values for locations that are cooler (low T), more humid (high RH), and receiving less solar radiation (low Rs). The highest associations can be found with T (Fig. 3a), with the monthly changes in PET ranging from -30.2% to +98.3 % for the lowest baseline T value of 5.0 °C, compared to a range of -13.3 % to +46.6 % for the highest baseline T of 30.3 °C. Similarly, the range of Penman-Monteith PET sensitivity values also shows clear decreases with baseline R_s (Fig. 3c), and increases with baseline RH (Fig. 3b). The baseline uz (Fig. 3d) levels show no obvious impact on the PET sensitivity."*

And one of the findings related to study aim (ii) is as L365-376 in the original manuscript, in which the relative importance of each climate variable for PET at each study site was represented with the Sobol' first-order sensitivity index:

- *"… for the Penman-Monteith model …the Sobol' indices in the figure show that T is generally the most important variable for PET, with index values ranging from 0.46 to 0.62. Since the Sobol' indices suggest the partitioning of the total variance in PET, these results are consistent with Fig. 5a, which suggests that perturbations in T contribute to at least 45 % of the variation in the estimated changes in PET. The role of wind and humidity in affecting the sensitivity values is also evident, with wind being the second-most important variable (with Sobol' indices up to 0.42) for sites with low baseline humidity, and humdity being the second-most important variable (with Sobol' indices up to 0.47) for sites that have high humidity (Fig. 7b). Solar radiation is generally the variable with the lowest Sobol' indices, although the largest contributions (up to 18 %) can be observed for warm catchments (Fig. 7a)."*

4. LINE 96: What is meant by "climate-induced changes"?

We will remove this phrase and revise the sentence as follows:

- *"…the potential changes in one climate variable can be amplified or offset by changes in another variable…"*

5. LINE 97: Provide examples of how climate variables have been amplified or offset in the referenced literature.

A good example of these interactions is the 'evaporation paradox' which has been summarised in L58-61 of the original manuscript:

- *"…potential compensating effects between temperature and wind that may explain the paradox that decreasing pan evaporation (which is closely related to PET) has been observed with increasing temperatures for many locations worldwide (Roderick et al., 2007;McVicar et al., 2008;Lu et al., 2016)."*

To enable easier reference to this example, we will update L58-61 to include the term 'evaporation paradox', as:

- *"<u>For example, the Penman-Monteith model can account for the effects of wind, and thus can assist with explaining at least part of the observed decreases in pan evaporation with an increasing in temperature in many locations globally due to the observed decreases in wind speed (this is sometimes referred to as the 'pan evaporation paradox; see Roderick et al., 2007;McVicar et al., 2012;Lu et al., 2016)</u>."*

And L97 will be updated accordingly (with changes underlined), as:

- *"It is worth noting that the potential changes in one climate variable can be amplified or offset by changes in another variable (for examples see the discussion on the 'evaporation paradox' in Lu et al., 2016;Roderick and Farquhar, 2002) which can affect the relative importance of each variable."*

6. LINES 99-101: What is meant by the term "successful"? This sentence is unclear. Which environmental models is the author referring to?

We will remove the term 'successful', and also specify the 'environmental models' used in literature to L99-101, as follows (with changes underlined):

- *"... a global sensitivity analysis method was used, with similar methods being applied to account for the impact of joint variations in the input variables on the output from a variety of environmental models, ranging from conceptual rainfall-runoff models (e.g. Tang et al., 2007a;Tang et al., 2007c) to complex models which consider a number of surface-groundwater processes (e.g. Guillevic et al., 2002;van Griensven et al., 2006;Nossent et al., 2011)."*

7. LINES 101-102:
   (1) Which results? The analysis presented in this paper or the past studies referenced in this paragraph? Clarify which results are presented.
   (2) What does the author mean by "elucidate the specific roles of the baseline hydro-climatic condition on the PET sensitivity"? Earlier in the Introduction, the goal of the paper was stated to present how PET sensitivity changes with the baseline condition. Clarify this statement.

Thank you for highlighting these confusions.

(1) 'The results' in L101-102 referred to the results from the global sensitivity analysis of this study. We will update L101-102 in the revised manuscript to clearly specify the purpose and the expected outcomes from this sensitivity analysis, as follows (with changes underlined):

- *"The results of the global sensitivity analysis in this study will be presented in terms of both absolute sensitivity and relative sensitivity indices of each climate variable..."*

(2) The global sensitivity analysis employed in this study was only used to address research objective (ii) for analyzing the relative importance of each climate variable for the PET, and then comparing these values across different case studies with varying baseline climatic conditions. We will clarify this by updating L96 as follows (with changes underlined), where the global sensitivity analysis was first introduced:

- *"It is worth noting that the potential changes in one climate variable can be amplified or offset by changes in another variable (for examples see the discussions on the 'evaporation paradox' in Lu et al., 2016;Roderick and Farquhar, 2002) which can affect the relative importance of each variable. Therefore, to address study aim (ii), a global sensitivity analysis method was used ..."*

We will also re-emphasize the purposes of the global sensitivity analyses in L101-102, as follows (with changes underlined):

- *"The results of the global sensitivity analysis in this study will be presented in terms of both absolute sensitivity and relative sensitivity indices of each climate variable, and presented to* *elucidate the specific roles of varying baseline hydro-climatic conditions on influencing these sensitivity measures."*

8. LINES 105-107: Do these two sets of results coincide with the study aims from LINES 87-90?

Yes. To highlight this alignment, we will modify the wording of L105-107 (with changes underlined), as:

- *"Section 4 presents and discusses two sets of results which address the two study aims respectively, as: (i) the estimated PET sensitivity to potential changes in temperature, solar radiation, humidity and wind, and how this changes with location; and (ii) the relative importance of the four climate variables for estimating PET, and how this changes with location."*

9. LINES 123-124: This data period seems to be pretty old. Can you provide explanation as to why more recent data was not selected?

The data period was selected according to the availability of high-quality climate observations in Australia (released by BoM 2013), which was mainly constrained by wind data that 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.

10. LINE 128: Instead of sunshine hour, sunrise-sunset?

The original data we obtained to calculate the solar radiation was in the form of sunshine hours, and were in the required format for the Ångström-Prescott equation in McMahon et al. (2013).

11. LINE 136: Instead of level, use elevation for land surface elevation, and values for the meteorological values listed in the table.

Thank you for the recommendation and we will replace 'level' with 'value' here.

12. LINE 140: What are the water-limited and energy-limited ratios based on? Provide a reference.

We will add the following references discussing the relevance of PET/P ratio and the water-/energy-limited status of catchments:

- *Gerrits, A., et al. (2009). "Analytical derivation of the Budyko curve based on rainfall characteristics and a simple evaporation model." Water Resources Research 45(4).'*
- *McVicar, T. R., et al. (2010). "The effects of climatic changes on plant physiological and catchment ecohydrological processes in the high-rainfall catchments of the Murray-Darling Basin: A scoping study." Prepared for the Murray-Darling Basin Authority (MDBA) by the Commonwealth Scientific and Industrial Research Organization (CSIRO) Water for a Healthy Country National Research Flagship, MDBA, Canberra, ACT, Australia.*

13. LINES 142-144: Penman and P-T estimates of PET can vary significantly, especially if wind is a factor and the P-T alpha-parameter is under- or over-estimated. Provide an example of the range of differences (i.e. uncertainty) between these two models for the climatic conditions you are presenting. In LINES 22-25 the authors mention there may be a need to select a different PET model based on the climatic conditions. I think the statements need to be revised to be more in line with the overall message.

Thank you. With regard to PET, the Priestley-Taylor model did suggest consistently lower estimates compared with the Penman-Monteith model. Please see the figure below, which summarizes the model uncertainty for the daily average PET estimates at the 30 sites:

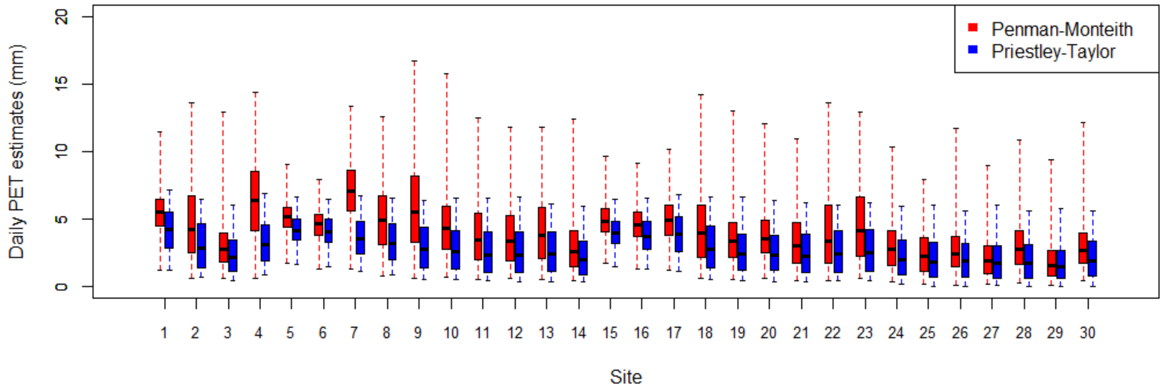

Figure 1. Ranges of estimates of average daily PET at each of the 30 study sites, with results from both the Penman-Monteith model and the Priestley-Taylor model

The figure above illustrates that the impact of model choice is substantial on estimating PET, which justifies the significance of PET model selection, and is consistent with L22-25.

We would like to clarify that in Line 142-144, we were focusing on the categorization of case studies into water- or energy-limited catchments, for which the PET model choice had minor effects, with only four sites showing different categorizations from Penman-Monteith and Priestley-Taylor models (i.e. sites 6, 19, 20, 27).

We will clarify the uncertainty from using the Priestley-Taylor model with the following addition to the revised manuscript after L144:

- *"Although use of the Priestley-Taylor model resulted in different PET estimates at each site, the categorization of water- and energy-limited catchments was generally consistent with that obtained from Penman-Monteith, with different categories only shown at four out of the 30 study sites (sites 6, 19, 20 and 27)."*

Technical corrections/comments

1. Lines 67, 93, 144, etc.: Correct spelling throughout text: Priestley-Taylor, not Priestly-Taylor

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

2. LINE 108: spell out Section

This abbreviation was used according to the formatting requirement for manuscript preparation for HESS (available from: http://www.hydrology-and-earth-system-sciences.net/for_authors/manuscript_preparation.html), which specified that: "the abbreviation "Sect." should be used when it appears in running text and should be followed by a number unless it comes at the beginning of a sentence."

3. LINE 166: remove extra "the"

We will correct this in the revised manuscript.

Further references

Gerrits, A., et al. (2009). "Analytical derivation of the Budyko curve based on rainfall characteristics and a simple evaporation model." *Water Resources Research* 45(4).'

McVicar, T. R., et al. (2010). "The effects of climatic changes on plant physiological and catchment ecohydrological processes in the high-rainfall catchments of the Murray-Darling Basin: A scoping study." Prepared for the *Murray-Darling Basin Authority (MDBA) by the Commonwealth Scientific and Industrial Research Organization (CSIRO) Water for a Healthy Country National Research Flagship*, MDBA, Canberra, ACT, Australia.