

Response to Reviewer 3

Review of “Exploring how groundwater buffers the influence of heatwaves on vegetation function during multi-year droughts”, by Mu et al.

In this study, the authors analyze the influence on groundwater dynamics on land surface conditions during hot-dry compound events using dedicated land surface model simulations. The authors discover that groundwater can help maintain transpiration during the initial phase of a multi-year drought, and thereby dampen canopy temperatures during heatwave condition, but that this effect diminished beyond two years into the drought as the groundwater gets depleted.

The paper uses model simulations to assess an understudied process in land-atmosphere interactions, that is, groundwater-induced dampening of extreme heatwaves. The skill of the GW experiment regarding TWSA is quite impressive, especially since it appears that there has been no tuning. Moreover, the manuscript is well written, and the figures are generally clear. Also, the introduction reads very well.

This study thus overall demonstrates the potential to make a substantial contribution to the scientific literature. However, I have some concerns, which require minor revisions of the manuscript. In general, I could recommend publication of this study if the comments specified below are sufficiently addressed.

We thank the reviewer for the positive summary of our work and we address the reviewer's concerns below. Comments are shown in black, with our response below in blue in each case.

General Comments

1. My main concern relates to terminology and definitions: It appears that the paper is using inconsistent variable names, for instance in eq. 2 it uses q_{re} for groundwater recharge while figure 2 uses Q_{rec} for denoting apparently the same term. It is also not clear to me what is meant with ‘vertical drainage’ in fig. 2 (panel d): is this the vertical downward transport of water from the soil column to the aquifer to the soil column (what would normally be called groundwater recharge)? In that case ‘recharge’ represents the vertical upward transport of water from the aquifer to the soil column (as suggested in L270)? Overall, I'm confused by the terminology used in this context (recharge is normally used to denote the downward flux from soil to aquifer). Please carefully check throughout and make sure to use consistent and well-defined terms and variables throughout the manuscript and figures. Perhaps a schematic showing these fluxes across a vertical atmosphere+soil+aquifer profile could help as well (potentially with one panel per experiment).

We thank the reviewer for this comment. As we pointed out in Line 105-106, q_{re} is the water flux between the aquifer and the bottom soil layer. The positive q_{re} refers to the downward water flow from soil column to aquifer (i.e. vertical drainage, Dr), and the negative q_{re} is the upward water movement from aquifer to soil column (i.e. recharge, Qrec). Recharge in our paper is not groundwater recharge but the recharge from the aquifer to the soil column. We will explicate this point in the manuscript,

“The positive q_{re} refers to the downward water flow from soil column to aquifer (i.e. vertical drainage, Dr), and the negative q_{re} is the upward water movement from aquifer to soil column (i.e. recharge, Qrec)”.

To avoid the confusion, we will also clarify that ‘recharge’ in this paper is the recharge from aquifer to the soil column throughout the manuscript and figures.

We like the idea of a schematic and will endeavour to include this in a revised paper.

Specific comments

1. L134: Also with the time-evolving meteorological forcing, right?

Yes, the simulation from 1970-2019 is with time-evolving meteorological forcing. We will mention this point in the experiment design section.

2. L136: As we currently are in the CMIP6 era, I feel it could be more relevant to comment (also) on the status of groundwater modules in this generation of models.

We will try to find this information out for the CMIP 6 models and include a revised sentence in the revised manuscript if we can.

3. L209: In the case of water fluxes, a conservative remapping would be more appropriate. It’s ok to leave it like this now, but please keep this in mind for future research.

We thank the reviewer for this suggestion, and we will explore this in future work.

4. L123: From the context it appears that the simulations are run at 0.05° spatial resolution and 3h time step, but I suggest mentioning this somewhere explicitly in the method section, for instance in L124-127.

Agree. We will edit this sentence as:

“To explore how groundwater influences droughts and heatwaves, we designed two experiments, with and without groundwater dynamics, driven by the same 3-hour meteorology forcing and land surface properties (see section 2.5 for datasets) for the period 1970-2019 at a 0.05° spatial resolution with a 3-hour time step.”

5. Fig3a: the underscore in the right y-axis label can be omitted. How did you define forested area? All pixels in the model domain with 100% tree fraction? Please clarify in the caption.

Agree. We will remove the underscore in Figure 3.

In our simulations, there is only one vegetation type in each pixel, the dominant vegetation type (Figure S2a). For our study region, the forested area is the region is dominated by evergreen broadleaf forest (green area in Figure S2a). We will clarify the location in the caption of Figure 3:

“Groundwater-induced differences in (a) Tcanopy-Tair (ΔT), (b) evaporative fraction (EF), (c) transpiration (E_t), and (d) water stress factor (β) during 2000-2019 summer heatwaves over forested areas (the green region in Figure S2a)”.

Textual comments

1. L248, caption figure 2 and elsewhere: replace ‘(total) evaporation’ by ‘evapotranspiration’, whenever you are referring to the sum of transpiration and soil evaporation. Likewise, replace ‘recharge’ by ‘groundwater recharge’ if that is what you mean (though it looks like you mean something like ‘soil moisture recharge’ with this term, which appears odd to me).

We thank the reviewer for this comment but we do not agree. Indeed, one of us was in a room when John Monteith complained bitterly about the word “evapotranspiration”. The suggestion by the reviewer to add a schematic helps us clarify what “total evaporation” means which we hope will suffice but the term “evapotranspiration” may not be an appropriate way to express our fluxes.

As noted above, ‘recharge’ in our paper is not ‘groundwater recharge’ but ‘recharge from the aquifer to the soil column’. We will clarify the recharge is the recharge from aquifer to soil column throughout the paper.

2. L346: ‘estimated’ > ‘estimates’.

Thanks. This will be fixed as,

“Figure 7 shows the diurnal cycles of ΔT for the two selected regions (red boxes in Figure 6) compared with the MODIS LST estimates”.