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Hydrology and Earth System Sciences
Discussions

Interactive comment on "The challenges of an in situ validation of a non-equilibrium model of soil heat and moisture dynamics during fires" *by* William J. Massman

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Response to Comments from Anonymous Referee #2 dated 8 June 2020

My thanks to the Referee for his/her comments. They were helpful. Below is my response to the referee's major comments along with my response to two of the reviewer's technical comments. Otherwise I accepted all the reviewer's minor technical corrections so I will not respond to those. My response to the reviewer's comments are in italics and follow a restatement of his/her comment.

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Referee - 0a) This manuscript makes novel and useful contributions toward an improved understanding of how soils are impacted by wildfire. But the contributions are actually much broader than that. This work addresses a number of key issues relevant to general topic of coupled heat and water flow in soils. As such, the work most certainly falls within the scope of Hydrology and Earth System Sciences.

RESPONSE - 0a) *Thank you and I hope this paper does reach a larger audience than just the fire science community.*

Referee - 0b) The manuscript is well written, the experimental work is described in sufficient detail, and the changes made to the HMV model are described clearly and with appropriate mathematical notation. The comparisons between the modified HMV model and the experimental data provide sufficient support for the interpretations and conclusions of this study. Although this manuscript is in excellent shape, the following issues need to be addressed before this manuscript is in suitable form for publication:

RESPONSE - 0b) *Thank you. The following should address your concerns.*

Referee - 1) The Abstract needs to be revised to include a description of the changes made to the forcing function and the parameterization of the surface energy balance. This is a major component of the study, yet receives no mention in the Abstract.

RESPONSE - 1) *A Change was made. I added the following sentence (in red) to lines 10-12 more of the absract:*
... "Improvements to the model eliminate two important (but heretofore universally overlooked) inconsistencies: one that describes the relationship between evaporation and condensation in the parameterization of the non-equilibrium vapor source term and the other, is the incorrect use of the apparent thermal conductivity in the soil heat flow equation. The first of these enhanced the stability and performance of the model. The second is an important improvement in the model's physical realism, but had less

of an impact on the model's performance and stability than the first. This study also (a) develops a general heating function that describes the energy input to the soil surface by the fire and (b) discusses the complexities and difficulties of formulating the upper boundary condition from a surface energy balance approach. The model validation uses (in-situ temperature, soil moisture, and heat flux) data obtained in a 2004 experimental slash pile burn." ...

Referee - 2) Lines 60-63: It is not clear how the parameterization of the surface energy balance was improved. On lines 243-244 we read that the surface energy balance formulation is slightly different than in the previous work, but it is not clear how this improved the parameterization of the surface energy balance. This requires clarification.

RESPONSE - 2) *A Change was made. Lines 244-252 of the revised text now reads as follows:*
The energy balance at the soil surface used with the present study formulates the net infrared radiation loss at the surface as a balance between the outgoing and incoming infrared radiation. This is different from either Massman (2012) or Massman (2015), neither of which included the possibility of incoming environmental infrared radiation being absorbed by the soil's surface. Here the surface energy balance is expressed as

EQUATION (16)

where the '0' subscript refers to soil surface and the term on the left hand side of this equation is the energy absorbed by the soil (and assumes that absorptivity and emissivity of the soil are the same) and the first term on the right hand side is the net infrared heat loss (where the term $\propto \epsilon_a(\rho_{va})T_{Ka}^4$ *was not included in either Massman (2012) or Massman (2015))*, ...

Referee - 3) Lines 195-196: It would be appropriate to point out here that this observation differs from what Massman (2012) concluded regarding the effects of infrared radiation on soil thermal conductivity.

RESPONSE - 3) *A Minor change was made.*
I believe that the reviewer is really referring to Massman (2015) because Massman (2012) does not include R_p or the infrared component of λ_s (the Bauer term) to which it is essential. So I will address the results of Massman (2015). Massman (2015) does not really conclude anything definitive about R_p except that the model did a better job at reproducing the Campbell et al. (1995) Quincy sand soil temperature observations if R_p were increased to 4000 μm = 4 mm, which is much greater than the default value of 1000 μm = 1 mm (see figure 1 of Massman (2015)). Otherwise even at $R_p = 1000$ μm Massman (2015) suggests that the Bauer term does not impact λ_s or the soil temperatures very much. So at this point there is really nothing to justify revising the paper. Nevertheless, the following sentence now appears on Line 197: Massman (2015) reached a similar conclusion.

Referee - 4) Lines 533-534: The thermal conductivity model contains no explicit dependency on bulk density, but it does include porosity. Why not incorporate the effect of bulk density on conductivity via the effect it has on porosity, as was done for the WRC, hydraulic function, and the source term? This seems rather odd to me. Is there a reason why such an approach would not (or perhaps did not)? If so, that certainly needs to be addressed in the text of the manuscript.

RESPONSE - 4) *A Change was made. The change in porosity was included in the chance in thermal conductivity. My original wording was did not clearly state this to have been the case. I have altered the manuscript to indicate that the thermal conductivity also changed with the change in bulk density. And the referee is correct*

that it is the soil porosity that changed with the change in bulk density. The manuscript now reads:
"The following model parameters were changed for this sensitivity analysis to feedbacks: soil bulk density increases from 1.30 Mgm^{-3} to 1.46 Mgm^{-3} (a 12% increase as per figure 1); simultaneously the thermal conductivity of the mineral fraction, λ_{m0}, increases from 4.42 WmK^{-1} to 8 WmK^{-1}, the de Vries shape factor, g_a, decreased from 0.123 to 0.06, the Campbell et al. (1994) parameter q_{w0} (which determines when water content starts to influence the soil's thermal conductivity) decreased from 0.03 to 0.02, the soil's volumetric specific heat increases by 10% (in accordance with the observations made by Butters (2009)), the overall soil thermal conductivity, λ_s, increases by 15%, and finally the source term coefficient, S_*, decreases from 0.1 to 0.08 (specifically chosen to be a 20% decrease). This increase in bulk density yields a concomitant decrease in soil porosity, η, which is simply carried over in a purely linear fashion to the soil thermal conductivity, the WRC, the hydraulic function, and the source term, S_v."

Technical corrections:

Referee - Line 228: What does BFD stand for?
RESPONSE - Line 228 *Yijian Zeng also asked the same question. My response to him is: A Minor Change was made. The revised manuscript now places quotes around the term BFD curve. Barnett (2002) gives no explanation of what the "BFD" actually means. Nor could I find any thing in any of his subsequent papers or any papers citing his original 2002 paper that provided any explanation.*

Referee - Lines 452-453: This sentence requires clarification. To understand the context of this statement, it would useful to how much vertical structure in lambda-sub-s is included in the model.

RESPONSE - Lines 452-453 *A Change was made. The following sentence was added (Lines 458-460): This could easily be the case for MEF soils because the present model of λ_s does not include any of the observed vertical structure in soil bulk density or its relationship to the vertical structure of the soil's thermal conductivity (Massman et al., 2008).*

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