Hydrol. Earth Syst. Sci. Discuss.,
https://doi.org/10.5194/hess-2017-678-AC1, 2018

Hydrology and Earth System Sciences
Open Access
Discussions

Interactive comment on "Seasonally frozen soil modifies patterns of boreal peatland wildfire vulnerability" *by* Simon J. Dixon et al.

Simon J. Dixon et al.

s.j.dixon@bham.ac.uk

Received and published: 9 March 2018

We thank the reviewer for their interest in this work and for their comment. We have addressed their concerns as to the modelling set up in detail below. In summary, many of the concerns they raise are do not map onto the specific aims of this study listed at the end of the introduction. This study is a reduced complexity, exploratory modelling exercise. The purpose of which is to evaluate how hydraulic properties and frost layer continuity (through their role as aquitards) interact to drive vertical and lateral transfers and induced heterogeneity in patterns of vulnerability to smouldering during prolonged rain free periods. We further reiterate this targeted aim in the methodology section (line 174) and discussion (line 484), highlighting that the modelling is only able to give insights into behaviour, not predictions.

Printer-friendly version

Discussion paper

We acknowledge that the reviewer has not recognised the aims of the study. Therefore we aim to minimise such a misunderstanding by emphasising our aims within the abstract, and adding a short section at the end of the introduction section (after the 3 aims are stated). In this added section, we will clearly state the areas which are beyond the scope of the study. We will also thoroughly check the manuscript to confirm all language is used clearly and directly map to these aims. A key point is that this study does not attempt to simulate or recreate detailed thermal and water balance calculations for a specific peatland, under specific measured conditions. This study is exploratory (or heuristic) modelling in which a simplified modelling framework and boundary conditions are used within in a verified numerical model to generate insights into the directionality and relative magnitude of system response to forcings.

To recap the modelling aims:

* explore how hydraulic properties and frost layer continuity interact to drive vertical and lateral transfers of water during prolonged rain free periods of high fire risk.

* explore how spatial variability in hydraulic properties, peatland microforms and frost layers interact to induce spatial variability in GWC and associated smouldering severity during the exceptionally dry periods which precede wildfires.

Here, we impose clear and tight limits on what we wish to explore. We examine two degrees of freedom – peat properties and frost layer (aquitard) continuity and only explore how changing these alters the degree of vertical and lateral water flow between scenarios. In the second aim above, we also introduce peatland microtopography. We are therefore only comparing relative changes in behaviour. Furthermore, we restrict our modelling to very dry periods.

Additional text to be added after the aims above (at line 91 in original manuscript):

"It is important to emphasise that the numerical modelling in aims ii and iii uses a heuristic modelling framework, in which a simplified representation of the system is used to explore relative differences between modelling scenarios (Bankes, 1993). The purpose is to illuminate the role of different controls on the study system, and not to provide explicit quantitative predictions. In this respect, the results of the modelling should be treated in a comparative sense."

Bankes, S 1993 Exploratory Modeling for Policy Analysis. Operations Research 41 435-49.

In numerical modelling a model set-up can be both verified (which means it has been established that the model accurately represents the processes it is designed to, i.e. the equations are faithfully represented), and validated (which means the set-up of the model has been compared to known input and output data to establish it can accurately recreate an observed event). In this study the verification of the model is accomplished by use of a widely used numerical model/software package for simulating water movement in the unsaturated zone. But the model is not validated, as the purpose is not to recreate or simulate a known event and then extrapolate from it. Many of the points the reviewer raises are relevant to a modelling exercise which aims to simulate, or recreate detailed water balance calculations for a specific peatland, under specific, measured conditions, i.e. to validation of the model. See also point 9 below where we link to a paper in Science which discusses the appropriateness of model validation and verification.

We provide comments to the reviewer's numbered points below:

1) The parameters and boundary conditions that the reviewer has mentioned are stated in the methods, so we are clear and up front about this limitation throughout. In the case of the frost layer, and the lack of dynamics, this is inherently a simplification of the system. However, the aims of the study states that we are only looking to explore the effects of the frost layer on vertical and lateral transfer of water during extreme drying events. While the role of aquitards is well understood, interactions between a seasonal frost layer and different peat hydraulic properties have not been demonstrated. This

issue cuts to the heart of how complex a model needs to be in order to generate new insights. To date, simplified one and two-dimensional models have provided key insights in the fields of hydrology and ecohydrology. Indeed, Benscoter et al, 2008 show with a simple peat smouldering model that the most important variables are moisture content and peat properties. Even though a model does not directly represent all of the complexity in an uncertain and unknown system, it is still able to teach us something about the system. In the discussion section, we address the recharge effect from melting ice (and other assumptions) at line 463 and show it is of the same order of magnitude as other assumptions. Most importantly, our results can very broadly be divided into those for which the water table recession reaches the aquitard, and those it does not. In very simple terms it is only those simulations in which the water table drops to the depth of the aquitard that would be markedly influenced by its recession and/or melt recharge. In these cases, the overall relative behaviour of the system in this reduced complexity model wouldn't appreciably change with ice recession dynamics (the drier simulations would still be drier than the wetter ones), but timing when the system reaches specific states would change – taking longer to reach a specific point in the event of melt water recharge. This is discussed at line 484

2) Although we agree with the reviewer that questions of heat/mass balance in peatlands are interesting and would be worthy of future study, that is not within the aims or scope of this study. In the context of this study, we highlight that the thawing of ice from the frost table represents a small change in store. Relative to evapotranspiration occurring, this is only a maximum of 1.8 mm/day assuming the soil was frozen whilst saturated. In this study we are not trying to replicate the smouldering process, or conduct detailed water balance simulations.

3) We parameterise peat properties based on a summary from one of our own papers. However, this paper also contains data from extensive field data collection from other studies, (at a site where the modelling is based) and utilizes peat properties from field samples at other sites (n$\sim$300). Although these results show weak depth dependence

with peat hydraulic properties over the top ~60cm, depth explains only a small proportion of variance, we have attached a basic sketch plot of alpha vs depth for hummock samples using the data from the aforementioned paper for example (alpha on the X axis, depth in cm on the Y axis).

Furthermore, the relationship between depth and properties is not unidirectional; in some cases the average properties (for example alpha) of a depth layer across all samples do not linearly decrease but fluctuate up and down as one moves down the "average" depth core. Given the substantial uncertainty in the precise numeric relationship between depth and peat properties, the use of uniform values for different micro-topographic features, reflecting the range of variability in peat properties, is a justifiable simplification. As an aside, more extensive, critical inter and intra site investigation into the relationship between depth and peat properties in the near surface represents an exciting area for future study, both in the field and in modelling.

We will reword the Quinton reference, as we believe the reviewer has read that the whole sentence refers to the reference. Rather, the first part before the comma is intended to talk about the Quinton study, while the subsequent clause places their findings into the context of our argument. We will reword for clarity as follows:

Quinton et al [2008] also showed that Ks is dependent on the degree of compaction and decomposition; however, compaction and decomposition does not necessarily show a linear relationship with depth.

4) The section detailing evaporation is poorly worded, as the rate is for PET not AET, (which will be lower than 4.5mm/day), and we propose amending the start to read:

"We assume a fixed daily Potential Evaporation Rate (PET) of 4.5mm/day; this is a fairly high. . .."

As stated in the aims, the purpose of the modelling is to explore systems behaviour during exceptionally dry, rain-free periods. As stated a line 470: "..this is a fairly high rate, however, Sphagnum evapotranspiration rates can reach an average of 0.47 mm/hr, and unlike systems which show highest ET rates coincident with highest air temperatures, Alberta peatlands show peak ET rates during the early growing season as frozen soil is thawing (Brown et al., 2010), which is the period being modelled". This means that the AET.

5) As stated in the aims, we are modelling an exceptional rain-free period. Furthermore, we do not report and/or discuss results solely from the perspective of the system after 50 days. We look at how the system response changes throughout the drying period; the bulk of our discussions focus on 2 weeks and 5 weeks (35 days) from the start of the model simulations. It is important to emphasise that the results at 2, 3, 5 weeks, etc., will be the same regardless of whether the total model run time is 5 weeks, 50 days, or even longer. Lastly, it is important to reiterate again, this is not intended to be a simulation of a measured event. The purpose is to explore how the system responds, both in the presence and absence of the frost layer, to a sustained drying event.

6) We will included a brief explanation in the methods of the reasons for different peat properties. Currently reads (line 244)

"..the model domain was parameterised as; a water conserving hummock, a water conserving hollow, a productive hummock, a productive hollow, and a water conserving hummock. The sequence ensures all four possible transitions between hummock and hollow properties are represented in the model domain."

We will add following this:

"These peat types are based on the work in Dixon et al, 2017 and Kettridge et al, 2015; these previous studies showed that despite a wide range of possible peat hydraulic properties water balance responses to evaporative stress are bimodal. Peat tends to either be able to maintain low near surface tensions under evaporative stress and thus is able to remain productive and sustain evaporation through vertical movement

Printer-friendly version

Discussion paper

of water from deeper in the peat profile, or alternatively, peat will rapidly experience high near surface tensions, restricting evaporation and conserving water. This bimodal response to evaporative stress is observed in both hummock and hollow microforms. By alternating the peat types along a microtopographical transect, the model will allow us to explore how peat microforms with different representative hydraulic property types interact to alter local water balance at their interfaces"

7) The water recharge rate of 1.8 mm/d is calculated from the field work and explained at line 280-281, it is important to emphasise this is a maximum possible rate, based on the assumption that the peat is frozen in saturated conditions; the actual recharge rate may well be lower. We have then restated the maximum recharge figure in the discussion of model limitations/assumptions at line 469. However, we believe the way this is stated is not clear enough and has led to the reviewer's confusion. We will change to:

"We also assume the frost layer does not thaw during the model runs and thus does not provide water recharge in the model; for context, from the above field results such a recharge would be a maximum of approximately 1.8 mm/day, depending if the peat was saturated prior to freezing."

8) In exploratory (and indeed computational/contributive) numerical modelling all results and conclusions are directly derived from the model set-up decisions. The peat properties are parameterised from field measurements, and based on other studies are divided into representative "types" which represent the two broad types of responses to evaporative stress in peatlands. Naturally, as one type of peat is able to maintain evaporation whilst minimising tensions, whilst the other type cannot, the first type loses more water to evaporation. So whilst we have chosen to represent these two types of peat in our modelling, and from that respect the model set up informs our results, this peat parameterisation is grounded in the results and conclusions of other studies. It is also important to emphasise that the gaps in the ice lens/aquitard are below both a productive hollow and a water conserving hollow, so where we find the productive

hollow is sensitive to the continuity of the ice lens, this is in comparison to the water conserving hollow. The key is that the continuity of the lens, in terms of effects on water flow, is most important in this location/this combination, in comparison to the other combinations/locations we have modelled.

9) No model validation is performed, as this is an exploratory, not a predictive piece of modelling. With an exploratory modelling approach, concepts such as model validation and sensitivity analysis can be seen as nonsequiters (see Bankes, 1993). Because the initial model set and the scenarios used in exploratory modelling are not simulations of specific times and places there is nothing to validate model output to. This also relates to general concepts of verification and validation as discussed in the hydrology literature (and more widely – see Oreskes, N, Shrader-Frechette, K & Belitz, K 1994 Verification, validation, and confirmation of numerical models in the earth sciences. Science 263 641-46. for example). In the respect of exploratory hydrological modelling the key principle is that the model used is verified, that is to say there is confidence that the model is mathematically representing the processes it is designed to do (which is the case with Hydrus as an established hydrological model)

10) The in-line figures for the review are .png files imbedded within the pdf document as requested by the journal. The final figures for journal production we have as separate .TIF files at 900dpi. However, should a further review copy of the paper be needed we will endeavour to improve the resolution of the imbedded .png files for the reviewers/editors.

We thank the reviewer again for taking the time to comment on the manuscript, and to help us try and improve it for publication. We trust that our more extensive descriptions of exploratory modelling concepts has put their mind at rest that we are not trying to quantitatively simulate or provide predictions (nor have we claimed to). It is also important to emphasise that this work is not, and does not claim to be, providing definitive answers. Rather, we hope to provide some insights into system behaviour that can then be critically explored in the field, and in more computationally complex predictive numerical models. We feel that the ability of exploratory modelling to show that frost lenses can be important to seasonal water balance, but that this is not universal, and depends heavily on peat hydraulic properties is a useful insight, which advances our understanding of system behaviour and can inform future, more complex, hydrological water and mass balance modelling.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., https://doi.org/10.5194/hess-2017-678, 2018.

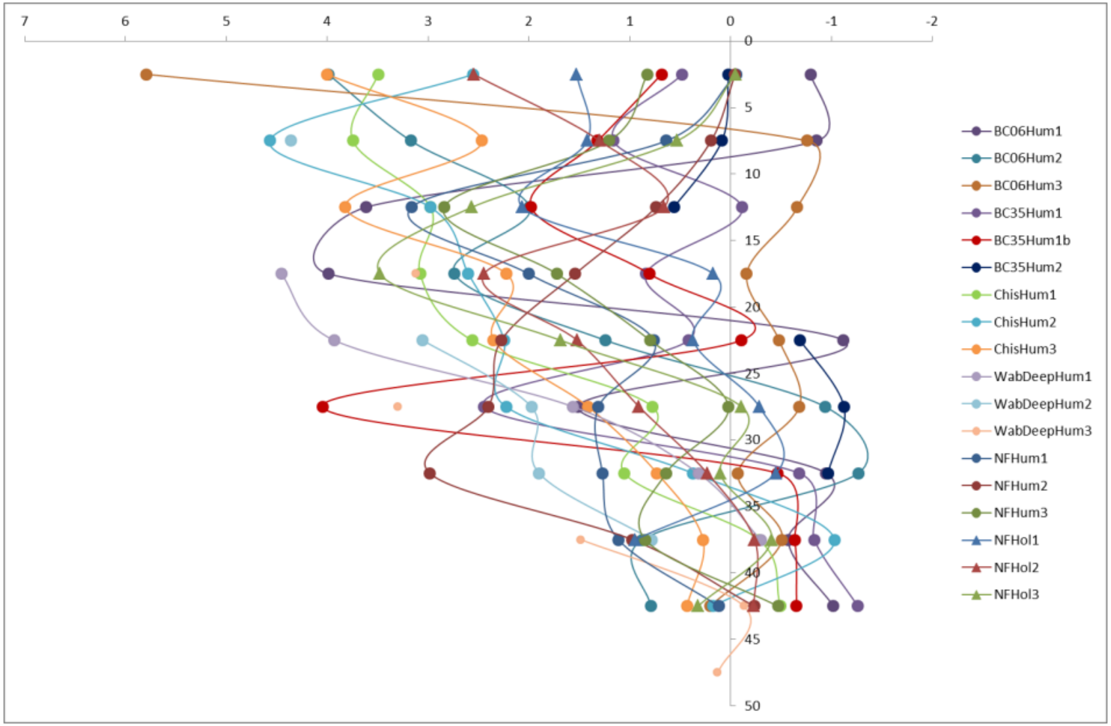
7
6
5
4
3
2
1
0
-1
-2
0
5
10
15
20
25
30
35
40
45
50
BC06Hum1
BC06Hum2
BC06Hum3
BC35Hum1
BC35Hum1b
BC35Hum2
ChisHum1
ChisHum2
ChisHum3
WabDeepHum1
WabDeepHum2
WabDeepHum3
NFHum1
NFHum2
NFHum3
NFHol1
NFHol2
NFHol3

Fig. 1.