Hydrol. Earth Syst. Sci. Discuss.,
https://doi.org/10.5194/hess-2020-343-RC2, 2021

Hydrology and Earth System Sciences
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Interactive comment on "Statistical Characterization of Environmental Hot Spots and Hot Moments and Applications in Groundwater Hydrology" *by* Jiancong Chen et al.

Anonymous Referee #2

Received and published: 27 February 2021

This study focuses on a very important and difficult topic (i.e., hot spots and hot moments: HSHMs). All progress in this domain is appreciated and important. They develop a statistical approach for characterizing HSHMs and work through some demonstration cases. As they state, "...clear statistical conventions of HSHMs are missing, which significantly limits the transferability of these approaches." I agree, and the topic of this contribution is relevant to a broad range of researchers and other practitioners due to the generality of the framework. After reading the manuscript I am left conflicted, however. While I appreciate the topic, I don't have a strong grasp of why this framework is needed. In some cases the framework seems based on straightforward 'if else' conditions that depend on already knowing what governs HSHMs. I also worry about the

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focus on defining places in space and time as either being or not being a HSHM. Rates are binary like that, and I am worried we are making arbitrary cutoffs of what counts as a HSHM instead of embracing the more continuous nature of natural systems. The proposed framework in based squarely on a binary view of HSHMs, which to me is limiting. There were many times in the manuscript that I did not understand how this framework would be used to advance understanding, and after reading the whole thing I am still mostly unclear. There are a couple examples in the end showing how it could be used, but I think those examples could by sampling spatial and temporal dynamics of physically based simulations. I don't understand why the statistical framework is needed or how to put into practice. I am willing to believe that I am just missing something and am willing to be convinced. I would highly recommend the authors make the applications more real world relevant. Speak to the average field person that is interested in HSHMs and tell them how they can use this framework and why it is better than other approaches. I think without plain language connections to the center of mass of researchers, the framework will go mostly unused. Below I provide more comments, many of them related to the above summary points.

Line 40: I am having a hard time with the definition used for HSHMs as it depends on the event having a negative effect on something (health or environment). But what if a HSHM does something beneficial like remove a pollutant. Is that not considered here? Maybe a slight modification of the definition is all that's needed.

Line 90: Here again the focus is on the negative side of HSHMs, I suggest taking a more balanced view that includes their benefits as well.

Line 100: I would suggest adding 1 sentence providing a non-jargon definition of indicator statistics. It will make the work more accessible.

Line 135: While I appreciate the development of a rigorous statistical framework, I question the utility of the binary definition of whether a place in space/time is or is not a HSHM. Do we care more about the definition or its influence? The influence

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is some continuous function of the magnitude to which it deviates from background conditions. It would be more powerful to define a statistical framework that captured this more continuous perspective. At a minimum, I think the authors should discuss this limitation of their framework and provide ideas for developing a more continuous approach. For example, maybe one could continuously vary the Cth and Rth from equation 1 to examine outcomes across a continuum of thresholds?

Line 145-150: All examples are for concentrations (Cth). It would be good to provide some examples for rates (Rth).

Line 160: Please briefly explain why type B includes the spatial component instead of only including the temporal.

Equation 3: This seems a big circular to me. It seems like this says that a location is a hot spot because it has the conditions (e.g., concentration) needed to be a hot spot given our defined threshold of what counts as a hot spot. So it's a hot spot because it's a hot spot. Maybe this can be clarified in terms of how this isn't circular? In other words, explain further why it is useful to call some place a hot spot based on defined criteria. Why don't we just define the location based on it's levels of continuous variables relevant to a given situation? This goes back to my comment above about the very binary nature of this approach. I am not yet convinced that this is really moving us forward a great deal. Though I am keeping an open mind as I read.

Line 225: I like the statistical framework here, though it presumes that we have complete (or very good) knowledge of the spatial and temporal factors governing HSHM 'activation' and I wonder if that makes this framework difficult to use? That is, if we already know the conditions that lead to HSHM behavior, then we already know that, and I am not clear on what we are learning from this framework.

Line 265: Again I am not understanding what we are learning here. The hot spots have been defined as NRZ with specific quantitative conditions. So what more is equation 10 telling us? I was expecting to see a figure or analysis here that went to the next

level of understanding through the use of eq 10.

Line 340: Unless I am missing something, the examples are based around meeting specific conditions in space and/or time, and saying that if all conditions are met, then a HSHM should occur. That's all fine, but again, what are we learning from that? It seems like this boils down to an if-else statement that is built around previous analyses of a given system. That seems really straightforward to the point that I feel like I am missing something. Maybe more of the implications can be drawn out through these sections?

Section 4.2.3: To be honest, I am not savvy enough to follow the math in this section. I can only assume that is it correct, and maybe other reviewers can go through it. Regardless of whether it is correct or not, however, I do not understand the purpose of the formulations. Maybe they come clear further into the paper. At this point this section and the previous two seem esoteric, and I am not sure what the work is really driving towards.

Section 4.3: Not clear on what 'w' is in this case. More generally, I continue to struggle to understand what we are learning. I really want to get on board and I feel strongly about HSHMs as important features, I just am struggling to connect the conceptual dots.

Line 515: can you show a figure of this? pretty hard to understand as is.

Line 520-540: Okay, so now we start to see some results from the framework, in which the time course of HSHM development is linked to variation in conductivity. This is nice, though I must wonder whether the formal statistical framework is necessary. Could this be done just as well with a Monte Carlo approach? What I am missing is a convincing argument that the formal framework is needed. Could one not just run a simulation and sample it to characterize the spatial distribution of biogeochemical rates, use that to determine the frequency and magnitude of hot spots and then do that through time to show the time course?

Line 595: I don't recall seeing any results showing how the framework can be used to study uncertainty. This seems important, but not presented.

Line 605: I think it would be useful to expand on the discussion through the manuscript in terms of how the framework provides understanding of mechanisms. Through much the paper it seemed that the mechanisms were known a priori and were actually used to define conditions that result in HSHMs. I don't fully understand how we are gaining more mechanistic understanding, but I am open to hearing more.

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