EGUsphere, referee comment RC1
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Comment on egusphere-2022-630

Anonymous Referee #1

Referee comment on "Investigating the thermal state of permafrost with Bayesian inverse modeling of heat transfer" by Brian Groenke et al., EGUsphere, https://doi.org/10.5194/egusphere-2022-630-RC1, 2022

This manuscript investigates the thermal states of permafrost using a recently developed Bayesian inverse method, Ensemble Kalman Sampling (EKS). The study uses borehole and meteorological data from four sites in different regions with continuous permafrost and performs Bayesian trend analysis and inversion to investigate (1) the long-term trend from 2000 to 2020 of air and soil temperature and their relationship using available meteorological and borehole data; (2) modeled ground temperature and its annual variability compared with borehole data; (3) the relationship between change in latent heat (and thaw depth) and change in temperature; (4) the modeled trend of energy change partitioned into latent heat (permafrost), latent heat (active layer) and sensible heat. The results show the two colder sites (Samoylov and Barrow) have substantially different thermal states from the two warmer sites (Bayelva and Parson’s Lake), which are attributed to different historical climatology and soil types determining the contribution of latent heat. The authors highlight the importance of considering the latent heat (and therefore the soil characteristics) and climatology when interpreting the warming trends of permafrost. They conclude the thawing status of areas with warmer permafrost or higher silt/clay content soils has larger uncertainties in response to the ground temperature trend compared to areas with colder permafrost or low silt/clay content soils.

The research topic falls in the interests of the Cryosphere Journal. The manuscript is well-written and presented. However, the manuscript has three substantial issues that need to be addressed.

(1) The research design has some issues making it unclear if the main conclusions are attributed to the physical processes or the modeling uncertainties.

First, the available depths of borehole data are not the same. At the two colder sites (Samoylov and Barrow, Fig 4b and 4c), both sites have deep borehole data although

Barrow does not have shallow borehole data. In contrast, neither of the two warmer sites (Fig 4d and 4e) has deep borehole data. This could be the main reason causing the much larger temperature variability (Fig 4d and 4e), more scattered relationships in Fig 5, and more observed uncertainties in Fig 6. Therefore, the majority of conclusions made by comparing colder and warmer sites are not convincing. One or more warm sites with deep borehole data are needed to validate this study's conclusions. It is also worth performing the inverse modeling again on the Smoylov site excluding its deep borehole data to see if its thermal behavior stays the same or changes toward the warm sites. Line 374 seems to demonstrate depth alone cannot explain the variability. However, the statement is not strong because 82 cm is too small on a 10 m scale. Also, the observations of Bayelva also have less variability than those of Parson's Lake, which likely explains the less variability in the modeled temperature at Bayelva. The authors do have a full section 5.6 to discuss the limitations. While these limitations are definitely important, the current research design is not strong enough to support the conclusions even neglecting other uncertainties.

Secondly, section 5.3 discusses the role of surface conditions on ground warming based on the n-factor change before and after 2005. Again, uncertainties can be the main driver because no borehole observations are available to constrain the model before 2005. This is another key point made based on the comparison of two data not having the same conditions.

(2) The manuscript has a large space describing the modeling method but most contents are too technical and not accessible to people who are in the cryosphere community but do not have expertise in numerical modeling, inversion, and Bayesian method, etc. The authors focus too much on the advanced topics of the method but completely missed the information on the basic idea of the applied method. Also, in many cases, the authors only cite some references without explicitly describing the methods, which makes the readers difficult to follow or understand. Below, I list the locations where I think additional explanations and clarifications are necessary.

Section 3.1. The introduction of Bayesian inference involves too many technical terminologies. Please consider adding supporting sentences to make it easier for people not familiar with the Bayesian method to understand it.

Lines 140-144. Need to briefly explain the bias correction procedure.

Line 150. Need to briefly explain the numerical procedures and parameterizations of CryoGrid.

Section 3.6 This section introduces a key methodology EKS. It presents the advantages of EKS over MCMC and EKI without explaining the basic theory/idea of EKS in the first place. Again, this makes researchers not familiar with EKS very difficult to follow and understand it.

Line 250. Need briefly explain what a mean vector from Garbuno-Inigo et al. 2020 is.

(3) The discussion needs more quantitative and specific analysis. When interpreting the results, the authors only briefly propose possible factors without explaining how would these factors impact the results. Below are some examples.

Paragraph 255. I may miss something but I did not get the purpose of this paragraph. It states that the prior distribution over model parameters is important but does not explain what was done to improve performance.

Line 356. This sentence does not explain why Samoylov has deep soil temperature warming faster than the air temperature. Factors other than air temperature should be included here.

Paragraph 360. Besides only presenting the potential factors impacting the soil thermal states, I would include how they impact the thermal states. For example, how does the ground temperature change with air temperature giving increasing (or decreasing) snow thickness and soil thermal diffusivity?

Line 390. Please explain more about why latent heat is lost so that the temperature is warmer. Please also explain why drainage and evapotranspiration cause latent heat loss.

Section 5.6. It would be helpful if include some discussion about the expected changes after addressing each limitation.

Minor comments:

Line 345 information about site location is needed for Biskaborn et al. 2019.

Line 386. This may be due ‘to’ the thermal…

Line 445. The second point. Warm permafrost could have slow refreezing when warming due to the effects of latent heat.

Fig B1. In my opinion, this figure is important as it shows the basic settings of forward modeling. Please consider moving it into the main text.

Line 170. The depth information of each layer is missing.