Earth System Dynamics Discussions

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Comment on esd-2022-32

Anonymous Referee #1

Referee comment on "Continental heat storage: Contributions from ground, inland waters, and permafrost thawing" by Francisco José Cuesta-Valero et al., Earth Syst. Dynam. Discuss., https://doi.org/10.5194/esd-2022-32-RC1, 2022

General Comments

The manuscript submitted by Cuesta-Valero et al. considers continental heat storage and determines the contribution from three components. The analysis is important as it contributes to better understanding of the overall global heat balance by ensuring that all components are accounted for in the calculation of continental heat storage. The subject area is therefore appropriate for publication in ESD and would be of interest to its readers. The MS is also relevant to better estimates of the impact of climate change on the landmass. The MS has clear objectives and is generally well written with results and interpretations presented clearly. I don't have any major concerns with the MS but I do have a number of comments that should be considered prior to acceptance for publication.

One of the key things that is done in the paper is the calculation of the heat in the ground that is utilized for phase change (latent heat) as ice in permafrost melts. However, the way the paper is written the authors seem to consider this separate from the subsurface (or ground) heat storage, which I found odd. Permafrost is a component of the ground (essentially a thermal condition of the ground) in cold environments so both the heat used to raise its temperature or for phase change when it thaws are components of the heat that is stored in the ground. It would seem that this is more an issue of the method that has been traditionally utilized to determine ground heat storage. Analysis utilizing subsurface temperature profiles only considers conduction in the estimate of ground heat fluxes. As ground temperatures approach 0°C in permafrost, heat is utilized for phase change of any ice in the ground rather than raising the temperature and little change in temperature over time is observed in ground temperature profiles (as discussed in Romanovksy et al. 2010; Smith et al. 2010). Lack of consideration of the latent heat effects therefore means that ground heat storage determined considering only conduction would be underestimated. It would make more sense for the authors to say that they are refining the estimates of ground heat storage by addressing a limitation of the method traditionally used by considering the latent heat utilized for phase change in the estimates.

The authors do not mention the role of other modes of heat flux in the ground such as convection. Heat transfer associated with water movement (advection) such as infiltration of precipitation and snow melt or subsurface water flow may also influence the ground thermal regime (see for eg. Douglas et al. 2020; Neumann et al. 2019; Phillips et al. 2016; review of Smith et al. 2022b also discusses this). As permafrost thawing occurs, subsurface water flow becomes more important. Is lack of consideration of this mechanism of heat flow also a limitation of the method used to determine ground heat storage?

I have a number of additional comments (see below) for the authors' consideration in preparing the revised manuscript. These comments identify where further clarification or information may be required. Suggestions for editorial revisions have also been provided.

Specific comments (keyed to line number)

L31 – See comment above – permafrost is the ground (earth material) so its thaw is a component of subsurface heat storage.

L32 – Suggested revision: " The ground accounts for ~90% of….."

L41 – What is included in "cryosphere"? Permafrost is a component of the cryosphere but it is treated separately in this paper.

L53 – Permafrost includes soil and rock. Since there can be water within rock, phase change can also occur in frozen rock (even if the amount is small compared to soils).

L55 – replace "underline" with "underlie"

L55 – Note Obu (2021) determines the equilibrium permafrost distribution so it does not consider permafrost that formed under a colder climate and still persists today. For example, permafrost in peatlands in the southern portion of the permafrost regions formed under colder conditions and is preserved due to the insulating properties of peat. Also, permafrost can be quite thick in the Arctic and it can take a century or more to completely thaw so that relict permafrost continues to exist as climate warms.

L56 – It is important to note that these are average values of warming based on several sites (I believe Biskaborn 2019 gives a range).

L59 – Misleading/incorrect statement. These simulations only consider the upper 2-3m of permafrost rather than its total vertical extent, which may be 10s to 100s m. These values therefore do not refer to complete loss of permafrost from this area (i.e. refer to thaw being more than 2-3m over this area).

L61 – Permafrost is frozen ground so permafrost heat uptake is ground heat uptake. Until it thaws, the heat storage would be accounted for by the methods (inversion of temperature profiles) utilized to determine ground heat storage.

L66 – What is meant by recent times? It would be clearer to give the time period over which this reduction occurred.

L67 – suggested revision: ' ….going to continue throughout the 21st century…:

L79 – should this be "deep subsurface temperature profiles"

L87 – replace "in" with "of"

L89 – revise to "slope of this regression line" (or best-fit line)

L99-100 – If the time for temperature changes at the surface to reach a given depth depends on the thermal properties, how does truncating to the same depth yield the same temporal reference if thermal properties are variable?

L131-134 – I may have missed something here - how are the results from point-based measurements applied to the entire area considered. In figure 2a, heat storage is shown for points that are not uniformly distributed with very large areas not represented. It isn't clear how the point-based data are extrapolated to the larger area or what other information may be utilized especially give the large areas with no data.

L136 – Isn't it more correct to say that the heat input to the subsurface is utilized to melt ground ice as permafrost temperatures approaches 0°C?

L140 – Do you mean the surface offset which is the difference between mean annual air and ground surface temperatures and is influenced by snow cover. The thermal offset refers to the difference in temperature between the ground surface and the top of permafrost, which (if equilibrium conditions exist) depends on difference between frozen and unfrozen thermal conductivity (See for e.g. Riseborough et al. 2008).

L143 – What about rock – permafrost includes rock which can contain ice.

L179 – How is depth determined?

L165-199 – Lakes can form or drain in the Arctic due to permafrost thaw. Is the change in surface water distribution due to thermokarst processes considered or is this a limitation to heat storage estimates?

L220 (also elsewhere in paper including L223) – See earlier comments. Permafrost heat flux, if thaw is not is not occurring (this will be the case where temperature below melting point of ice in the ground) will be considered in the estimates of subsurface storage determined utilizing subsurface temperature records. It is only when thaw occurs in warmer permafrost at temperatures near 0°C that latent heat needs to be considered in addition to conduction.

L235 – Where around Hudson Bay? There was cooling in the eastern Arctic including northern Quebec into the 1990s – is this the reason for the lack of heat gain in this area?

L267 – Why isn’t the Tibetan Plateau included given it is a fairly significant area. Permafrost in this region is generally warm so latent heat effects are important.

L275-276 – It is important to indicate here that the estimate of ground heat flux needs to consider non conductive heat flow (i.e. address limitations) to improve estimates. The MS makes progress in addressing this limitation by considering the latent heat associated with phase change as permafrost thaws.

L280-300 – This section is OK but most of this has been well covered in other publications so nothing really new here.

L280-285 –Other implications of ground warming and permafrost thaw are impacts on landscape processes and stability, changes to surface water distribution and increase in subsurface water flow. These impacts can also have feedbacks to the ground thermal regime with further impacts on carbon feedback.

L288-290 – This is really an issue of landscape change associated with thawing of ice-rich permafrost (such as subsidence, thaw slumps), which is abrupt or sudden, exacerbating permafrost thaw – with geomorphic change such as slumps and other slope failures the upper boundary changes as material is removed (also lateral heat flow).

L293 – Do you mean "surpassing" rather than "trespassing"

L295-300 – Other impacts related to permafrost thaw (especially if ice-rich) include loss of bearing strength and ground settlement/subsidence with impacts on infrastructure; landscape instability including slope failures which can release sediment into water bodies with implications for water quality; impacts on integrity of contaminant containment facilities.

L301-303 – more evaporation?

L325-335 – There are several recent ground temperature records in the permafrost regions (some results included in Smith et al. 2022b, Noetzli et al. 2022, Biskaborn et al. 2019 and other papers). These are generally at shallower depths (usually upper 20 m) than would be utilized for the inversion of ground temperature profiles that is utilized in the MS. However, these provide information at depths where latent heat effects are important.

L337 – This is not a new observation and the lack of ground ice information has been identified as a limitation in permafrost modelling in other papers (e.g. Smith et al. 2022b; O'Neill et al. 2020).

L347 – With respect to latent heat effects related to permafrost thaw, including the Tibetan Plateau is probably more important than permafrost zones of Antarctica given the rather dry conditions and the geology.

L358-359 – While the deeper subsurface is an improvement, the LSMs still have limitations with respect to representation of subsurface conditions including ground ice distribution.

L382 – As mentioned in previous comment there are borehole temperature measurements in permafrost and at some sites, there are moisture content measurements. There are also often observations of excess ice content when boreholes are drilled.

L385 – One of the issues in areas such as the Canadian Arctic is the remoteness and significant cost of drilling boreholes, especially deeper ones where specialized equipment needs to be transported to the site (see for e.g. Smith et al. 2022b). Most permafrost monitoring sites therefore are often located near communities, existing infrastructure, associated with resource development (hydrocarbon, mining) etc.

L392 – This is also discussed in Smith et al. (2022b) and O'Neill et al. (2020). There are also efforts to improve ground ice potential modelling and mapping – see for e.g. O'Neill et al. (2019)

Figure 5 – See previous comments regarding other implications of permafrost thaw such as impacts on infrastructure integrity. Landscape instability is a more inclusive term than ground subsidence.

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