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Interactive comment on "Modelled present and future thaw lake area expansion/contraction trends throughout the continuous permafrost zone" *by* Y. Mi et al.

Anonymous Referee #3

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Readers of this review should note that the reviewer's field experience is limited to North America. None of what follows should be interpreted as an authoritative statement regarding the context of thaw lakes and thaw lake development in Eurasia.

Stochastic models describe environmental systems from two perspectives. First, they may simulate systems that have genuinely stochastic properties and behaviour. Second, they may represent a fiction of convenience. This latter approach may be adopted for several reasons, for example, a multivariate system may be more efficiently simulated as stochastic behaviour than as the deterministic behaviour of many, interrelated variables. Similarly, precise local conditions may not be known, and so the variability of field contexts may be simulated by stochastic functions.

In cases where a stochastic approach is being used to describe the outcome of a deterministic system, it is critical to examine the assumptions used to develop the stochastic variables. Commonly, the physical basis of the variable may be established, but possible results are specified over a range of outcomes with associated probabilities. In other cases, dummy variables may be used, which have limited physical basis, but significant correlation with the phenomena under investigation.

The paper under review requires examination in this context, because its title is breathtaking. It aims to assess present and future thaw lake expansion and contraction THROUGHOUT the continuous permafrost zone. In other words, the paper addresses the vast majority of the circumpolar region, through a range of sedimentary and geologic settings, a range of climatic regimes, and an area with a range of Quaternary histories. The climates, just in North America, range from the Arctic maritime environment of northern Alaska, through to conditions south of Hudson Bay. The sedimentary environments range from unglaciated terrain, of Beringia, through the land covered by the Cordilleran and Laurentide ice sheets, and the multitude of settings created during deglaciation. Of particular interest in this case is the legacy of ground ice residual from the ice cover, and the frost susceptibility of glacial soils that have created environments favourable to the presence of ground ice. Thaw lakes do not exist where there is no ground ice, because subsidence is required for impoundment of water.

The editors of the journal should also consider carefully the recognition by Lachenbruch et al. (1962) that in permafrost regions, the thermal regime of lakes represent the greatest local departure from conditions determined by climate. Thaw lakes expand because permafrost in their vicinity is no longer sustainable, due to the thermal effect of the water body. In some cases the expansion is enhanced by hydrodynamic effects. Lake development is not sensitive to climate, because lake temperatures vary little over a wide climate range. The statement is based on the small amount of data that is available on this topic, mostly from northwest Canada and Alaska, but throughout the permafrost zones of this region.

Thaw lakes in continuous permafrost are in many cases in equilibrium with their environment. Numerous lakes on the North Slope of Alaska, and in the Canadian western Arctic, have wide littoral terraces, beneath which permafrost is preserved. The area of the lake beneath which the talik develops is restricted to a central portion of the lake. Many of these lakes do not expand, unless terrestrial effects, such as thaw slumps, affect the shoreline. Drainage of such thaw lakes commonly occurs catastrophically. Catastrophic drainage has been described in some detail by Mackay (1988, 1992) (not Mackay et al. 1992, as cited in this paper), and the potential for drainage rates to increase or decrease has been considered. Of key importance to evaluation of the paper under discussion is the observation that few lakes drain as a result of proximity to a river. Drainage occurs by overtopping of an interfluve, normally during snow melt but sometimes after intense summer rain. Lakes commonly drain in isolation, and in the Canadian western Arctic, Mackay (1992) reports that about one or two have drained on average each year for the last 4000 years. Mackay did not report an increase in lake drainage following the Little Ice Age when the regional climate warmed significantly. In some cases, the discharge from a drained lake fills another, which in turn drains. The factors causing the second to drain are then quite different from those that simulated the first drainage. The second is not stimulated by climate, just by receipt of drainage water from above.

The paragraphs above indicate why I believe the editors should be extremely cautious about this paper. In short, I am not convinced that the variables selected to drive the simulation of thermokarst development are sufficiently physically associated with thaw lake development to be informative.

Some more detailed points are provided below. I have not pointed out the typographical errors and other matters of editorial significance.

p. 3604. Line 17. The statement that thaw lake cycles and expansion rates are comparable with data is taken to mean that the simulations are validated with respect to field evidence. This is not the case as far as data from Alaska are concerned, and will

be addressed below.

p. 3604, line 18. The text gives the impression that this paper is a preliminary progress report. It is an editorial matter to decide if the journal exists to publish work that can clearly be improved.

p. 3604, line 25. The authors state that the sediments are usually supersaturated with ice. What proportion of the time are these sediments not saturated with ice? It is not at all clear what the authors are attempting to convey. It would be appropriate to cite a report of permafrost sediments in which the ice content fluctuates over time.

p. 3604 line 26. Mackay et al. 1992 appears to have been cited using an automatic system. There is only one author of this paper. It is Professor J. R. Mackay. The correct citation is:

Mackay, J.R. 1992. Lake stability in an ice-rich permafrost environment: examples from the western Arctic coast. In Arctic ecosystems in semi-arid regions: Implications for resource management. Robarts R.D., Bothwell M.L. (eds). Environment Canada: Saskatoon, Sask.; NHRI Symposium Series 7, 1-25.

p. 3605, line 10. Citation for Lenz et al. 2013. This paper does not demonstrate cyclic behaviour of thaw lakes, in support of which it is cited. The paper documents the occurrence and existence through the Holocene of one lake. p. 3605, line 13. The authors state that thaw lakes form as a result of climate change, but provide no citations in support of this point, which is key to the argument. There are very few papers that demonstrate this, but there are some, and they should be cited here.

p. 3605, line 16-17. The authors state that “As lakes grow, they often coalesce or connect with surface or subsurface drainage system and eventually become drained lake basins.” As described above, drainage of lakes is the permafrost region is commonly catastrophic. Coalescence is one way in which lake levels may change, but when this occurs, the level is adjusted; it is uncommon for the lake to drain completely.

Mackay (1988) described in detail how lakes drain, and this explanation is reiterated in the incorrectly cited paper Mackay (et al.) (1992). Mackay emphasized catastrophic drainage by breaching of a snow dam, or along ice wedges, in the vast majority of cases for which we have field data. Neither of these mechanisms is cited by the authors, probably because neither of these is amenable to simulation with the variables presented.

p. 3605, line 17. Climate is but one of the variables required to re-establish permafrost in a drained lake basin. Jorgenson and Shur have also made clear the need for appropriate ecological conditions in many cases.

p. 3606, line 24-25. In 1962, Lachenbruch et al. indicated that lakes provide the greatest local departure of ground temperature from patterns determined by climate. This statement was reiterated recently on p. 333 of the excellent review of thermokarst lakes published in 2013 by Grosse et al., and can be found in several other publications. It should make the authors wonder whether their premise that there is a linear relation between lake expansion and climate variables is valid. Lake temperatures are insensitive to climate variation because (a) in winter the water body is disconnected from the atmosphere by the ice cover; (b) in summer, evaporation influences the surface energy balance. In a long-term reconstruction of lake development in central Yukon Territory, Burn and Smith (1990) indicated that the rate of growth of the thermokarst lakes they were studying was constant over a period of about 100 years.

p. 3607, line 2. It is not clear why permafrost that is today at a mean annual ground temperature of -6 C or below is not stable. Pleistocene permafrost may have been stable, but much of it is stable at present.

p. 3607, line 5. Drainage in the model is a stochastic function of the distance to the drainage system. In the field, the work of Mackay has shown drainage unrelated to a stream network. All of the field data we have on lake drainage points to other variables being important; none of it has cited the distance to the drainage system, unless the

coastline is considered a drainage system.

p. 3608, line 22. Statistical significance of time series is a mystery to this reviewer. The time series are not samples, they are documentation of past conditions. It is not possible to resample the record and obtain different coordinates. Therefore whatever change in temperature or precipitation is observed over time is what it is.

p. 3608, line 21 and p. 3609, line 1. Mackay (1992) discussed lake stability and climate change in pp. 19-21 of his paper. It is not clear why the authors have decided to offer a different version of the relations between thaw lake area and climate. There are several points: (1) If thaw lakes are a disturbance, because the annual mean temperature in the lake is above 0 C, then they are expected to thaw the permafrost around them and expand, whether or not the climate is changing. In other words, what rate of expansion of lake area do the authors anticipate without climate change? How do we know that the rates cited here are anything other than what would be expected without climate change? (2) The model indicates the average lake expansion rate in Alaska is 0.15% per year. If the radius is expanding at a constant rate, due to thaw of adjacent permafrost, then the areal expansion will increase with time as the circumference of lakes increases. Is this, in fact the case? (3) The model indicates the average lake expansion rate in Alaska is 0.15% per year. However, on the same page, the authors cite Riordan et al. (2006), who indicate no change in area; Hinkel et al. (2007) conclude the same; and Labrecque et al. (2009) in the adjacent Old Crow Flats of northwest Canada find a reduction in surface area. Only Jorgenson et al. (2006) show an increase in area of ponds. How such varied field information can be used to state that “thaw lake cycles and expansion rates are comparable with data” as on p. 3604, line 17 is not clear. The same phrase is repeated on p. 3613, lines 14-15.

p. 3610, line 25. The authors state that “the model can model thaw lake dynamics on a landscape scale”. For the case of Alaska, the data presented do not justify this statement.

The following papers that are not included in the original submission have been cited in this review:

Burn, C.R., and Smith, M.W. 1990. Development of thermokarst lakes during the Holocene at Mayo, Yukon Territory. Permafrost and Periglacial Processes, 1: 161-176.

Grosse, G., Jones, B., Arp, C. 2013. Thermokarst lakes, drainage, and drained lake basins. In Treatise on Geomorphology. Shroder, J., Giardino, R., Harbor, J. (eds). Academic Press: San Diego; Vol. 8, 325-353.

Lachenbruch, A.H., Brewer, M.C., Greene, G.W., and Marshall, B.V. 1962. Temperatures in permafrost. In Temperature: its measurement and control in science and industry. Herzfeld, C.M. (ed.). reinhold: New York; Vol. 3, 791-803.

Mackay, J.R. 1988. Catastrophic lake drainage, Tuktoyaktuk Peninsula area, District of Mackenzie. Geological Survey of Canada, Paper 88-1D, 83-90.

Mackay, J.R. 1992. Lake stability in an ice-rich permafrost environment: examples from the western Arctic coast. In Arctic ecosystems in semi-arid regions: Implications for resource management. Robarts R.D., Bothwell M.L. (eds). Environment Canada: Saskatoon, Sask.; NHRI Symposium Series 7, 1-25.

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