

## Reply to reviewer 1

*We would like to thank the reviewer for providing these valuable comments that helped us to significantly improve the quality of our publication. We provide below the detailed reply letter with our answers in italic.*

Comments on “Growth of a young pingo in the Canadian Arctic observed by RADARSAT-2 interferometric satellite radar”

The authors observe and analyze the growth of previously unknown and relatively large pingo in Northwestern Canada. While the observational dataset includes historic aerial photos and some field measurements, the bulk of the observations are focused on high-resolution InSAR data collected with RADARSAT-2 over about 3 years from ascending and descending orbits. Using all available, high-coherence InSAR data, the authors infer the deformation time-series over the pingo of interest. The authors use elastic plate and permafrost aggradation models to support their claim that the observed deformation signal is a pingo.

I am not an expert in permafrost morphology or the MSBAS methodology used in this study, but my overall impression of the paper is very positive. The authors applied cutting-edge observational methods and simple physical models to perform a reasonably detailed phenomenological study that at least advances InSAR time-series methodology, if not also our understanding of permafrost morphology. This is my first review of this manuscript, which has already undergone one round of review and revision, and I have no major concerns about its form or substance. I think it will make a fine addition to the literature and recommend it for publication in TC. I only have a few minor comments.

*Reply: Thank you very much for a favorable evaluation of our manuscript.*

Minor comments (numbers given as page.line):

1.15: The phrase “permafrost aggradation is resulting in the freezing a sub-pingo water lens” is awkward and grammatically incorrect.

*Reply: the sentence was rephrased.*

1.18: In the phrase “can successfully contribute,” the word “successfully” is redundant.

*Reply: The word was deleted.*

1.20-1.24: I think the authors are being overly critical of their work and unnecessarily give the

reader the impression that the modeling results are a poor fit to the observations (at least that was my impression on first reading). Given the apparent simplicity of the models, the modeled results and the InSAR observations match quite well. While there are discrepancies in the modeled and observed rates, I advise to authors to rephrase this part of the abstract and to cast this mismatch in a more positive light as an opportunity to further develop (not “define limitations of”) the observational methodology and to develop more sophisticated pingo models. The authors do a decent job in the text of noting that the lack of observed deformation in the surrounding pingos is due to limitations in satellite resolution, not in processing methodology, as is suggested in this part of the abstract (at least as I read it initially). Furthermore, if this misfit between modeled and observed rates is important enough to be mentioned in the abstract, then it merits a bit more discussion in the text.

*Reply: We corrected abstract as suggested.*

3.71: It appears as though there is a missed reference, as indicted by the question mark in “... pingos by Mackay (1977); ? has shown...”

*Reply: Corrected.*

Sections 2.1 and 2.3: Ensure that any available references and/or websites for these data and software are cited.

*Reply: We have added relevant URLs and citations to the text to provide the reader with more information on the software (and equipment) used.*

Section 2.2: This is just nit-picky, but since one of the main points of this paper is to look at the InSAR results, the authors might consider making this section 2.1.

*Reply: Corrected as suggested.*

4.111: “The 3x3 spatial...” is not a complete sentence.

*Reply: Corrected.*

4.112: Do the authors mean geocoded or radar geometry?

*Reply: Radar geometry, now it is clear from a following sentence “Then, ascending and descending interferograms were geocoded and resampled to a common lat/long grid...”*

5.128: Since data from ascending and descending orbits are being used, shouldn't matrix A (hat) also contain line-of-sight vectors in addition to the time intervals?

*Reply: It is now clarified in a caption of the equation.*

5.130: Again, please be clear about whether these data are in radar or geocoded coordinates.

*Reply: Corrected. It now reads “geocoded and resampled to a common grid, DInSAR data”.*

5.146: Fig 2 and Fig 3 are out of order. Fig 3 is referenced in the text before Fig 2.

*Reply: To correct the order and the logic of presentation we now introduce Fig 2 for the first time in the third paragraph of introduction.*

7.192: E is Young’s modulus (not module).

*Reply: Corrected.*

7.195: I don’t think Fig. 3 shows the schematic of an elastic pingo model.

*Reply: We meant to say in Fig 3 of Mackay 1987.*

7.199: Check the units on  $\Delta q/D$ . If  $\Delta q$  has units of Pa/year and D has units of Pa m<sup>3</sup>, how do the authors end up with units of  $\Delta q/D$  being m<sup>-2</sup>?

*Reply: Corrected. We now use “m<sup>-3</sup> year<sup>-1</sup>” units.*

Fig 3: This plot could be clarified by adding markers to indicate the SAR acquisitions.

*Reply: Corrected as suggested.*

*Reply to reviewer 2*

*We would like to thank the reviewer for providing these valuable comments that helped us to significantly improve the quality of our publication. Please see attached the detailed reply letter.*

I asked for clarifications in my previous review on this interesting paper by Samsonov et al. They did a good job in addressing my comments (and from another reviewer) in the response letter. But some of the points, including (1) the significance of this work, (2) the possible reasons for the differences between the modeled permafrost growth (7.4 cm/year) and the InSAR-measured maximum uplift rate (2.7 cm/year), (3) the effects of the seasonal thaw settlement on the observed uplift (line 277), (4) and the relationship between downward migration of freezing front and pingo uplift, are not explicitly explained or clarified in the revised manuscript. The authors could incorporate the reply comments into the manuscript. I believe this would be of great help for readers to understand this work.

*Reply: Please see below for details.*

*(1) We addressed this comment in Introduction section and throughout the entire manuscript, for example: “Seminal work by Dr J.R. Mackay on genesis and growth of pingos has provided tremendous insight into the landscape forming processes associated with permafrost*

*aggradation and ground ice development ( e.g. Mackay, 1977, 1979, 1987, 1990, 1992, 1997, 1998). This research has provided context for our work, which explores the potential of SAR technology and processing techniques to describe surface deformation that would arise from processes associated with pingo growth.”*

*(2) We addressed this comment in Introduction section:”The long-term monitoring of numerous pingos by Mackay, (1977, 1998) has shown that growth rates can vary significantly through time in response to changes in: 1) rates of ground water flow to the sub-pingo water lens, 2) release of pressurized water along hydraulic fractures and 3) variation in rates of downward freezing. Pingo growth may continue as long as ground water continues to be supplied to the area beneath a pingo. It may take more than a thousand years for a talik to refreeze, so a pingo in the Tukotyaktuk coastlands may continue to grow for hundreds to thousands of years.*

*(3) We addressed this comment in Modeling results section: “The satellite observed seasonal uplift rate reaches peak values in late July (red dashed line in Fig 9), which coincides with the annual maximum rate of downward permafrost growth as predicted by the NEST model for the pingo scenario. Active-layer thaw in summer typically yields surface settlement in areas of permafrost terrain. These DInSAR results suggest that the seasonal pattern of satellite observed land uplift is likely driven by increased water pressure beneath the pingo and subsequent freezing of the water lens.*

*(4) We addressed this comment in Permafrost aggradation modeling section “The growth of a pingo is due to downward freezing of a pressurized sub-pingo water lens (Mackay, 1979). Permafrost aggradation into the sub-adjacent lake bottom sediments and pore water expulsion continue to feed the sub-pingo water lens. The process of permafrost aggradation both maintains a pressurized water lens and, beneath the pingo, converts the water into ice. Thus, we can estimate the growth rate of a pingo based on the downward freezing of the water in the sub-pingo water lens. An increase in thickness of the pingo ice corresponds to its uplift, and in turn increases the lag between seasonal cooling cycles, permafrost aggradation at depth and pingo growth.”*

Still I have some minor comments:

Unit vectors for the line-of-sight directions are missing from Equation (1).

*Reply: Corrected, we now provide additional details for equation 1 in the caption.*

Line 71: ‘?’ should be a citation

*Reply: Corrected.*

Line 172, units for 'B' should be cm/year

*Reply: Corrected.*

Line 173, at first sight, I found  $C = -5190.6$  cm is odd. Then I realized that the authors defined  $t$  in years, since 0 AD. This is minor, but a clarification is helpful.

*Reply: Corrected as suggested.*

Line 199, the units of  $\Delta q$  over  $D$  are wrong. By unit analysis on equation (3),  $q/D$  should be in SI units of  $m^{-3} s^{-1}$

*Reply: Corrected. We now use " $m^{-3} year^{-1}$ " units.*

Table 1, first row, put degree symbols into parentheses. They appear as superscripts for  $\theta$  and  $\phi$ .

*Reply: Corrected.*

Fig 8 caption: data 'are' plotted

*Reply: Corrected.*

Fig 9 caption: uplift should be uplift

*Reply: Corrected.*