The Cryosphere Discussions

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Reply on RC1

Philipp Bernhard et al.

Author comment on "Accelerated mobilization of organic carbon from retrogressive thaw slumps on the northern Taymyr Peninsula" by Philipp Bernhard et al., The Cryosphere Discuss., https://doi.org/10.5194/tc-2022-36-AC1, 2022

We thank the reviewer for the detailed and constructive comments. We considered each comment carefully and address them point by point below. We hope that our modifications will make the manuscript clearer and more complete.

In the following we abbreviate: **RC1** (Reviewer 1 Comment), **RC2** (Reviewer 2 Comment) and **AC** (Author Comment)

Introduction

RC1: L34: Ramage et al., 2017 is the wrong reference. I guess you want to refer to Ramage, J.L., Irrgang, A.M., Morgenstern, A. and Lantuit, H., 2018. Increasing coastal slump activity impacts the release of sediment and organic carbon into the Arctic Ocean. Biogeosciences, 15(5), pp.1483-1495.

AC: We changed the reference to Ramage et al. 2018

RC1: L38-39: I would suggest expending on a few more reasons explaining their expansion

AC: We expanded the paragraphs and added more details:

In this work, we will focus on one form of hillslope thermokarst, namely retrogressive thaw slumps (RTS) also termed thermocirques or cryogenic landslides (Lantuit and Pollard, 2005; Leibman et al., 2014). They are characterized by a steep headwall and a scare zone where the thawed material from the headwall is transported downslope. RTSs initiate through the exposure of ice-rich permafrost by the removal of the protective active layer. The reason for this can be manifold and depend on the landscape settings and processes. Along coasts or rivers, mechanical erosion is the main driver of RTS initiation (Burn and Lewkowicz, 1990; Kokelj et al., 2015). On hillslopes, high summer temperatures and strong precipitation events can lead to active layer detachments due to high pore water pressure resulting from low hydraulic conductivity and which can then further develop into RTSs (Jorgenson and Osterkamp, 2005; Lewkowicz, 2007; Lamoureux and Lafreniere, 2009; Lewkowicz and Way, 2019; Jones et al., 2019). RTSs expand upslope due to the continual exposure and melt of ground ice at a headwall, thus mobilizing thawed materials which are transported downslope through the scar zone (Kokelj and Jorgenson, 2013; Zwieback et al., 2020). RTSs can grow where ground ice

content and topographic settings allows for a continued instability and removal of thawed soils (Burn and Lewkowicz, 1990; Lacelle et al., 2010; Kokelj and Jorgenson, 2013).

RC1: L43-44: this sentence is unclear and needs to be rewritten

AC: We rewrote the sentence to:

Past RTS studies have shown that the prevalence, geomorphic characteristics and carbon mobilization are related to soil properties, ice contents and topography which vary across the pan-Arctic landscape, highlighting the need for large-scale satellite-based monitoring (Lantz and Kokelj, 2008; Kokelj and Jorgenson, 2013; Zwieback et al.,2020).

RC1: L47: please add reference: Ramage, J. L., Irrgang, A. M., Herzschuh, U., Morgenstern, A., Couture, N., and Lantuit, H. (2017), Terrain controls on the occurrence of coastal retrogressive thaw slumps along the Yukon Coast, Canada, J. Geophys. Res. Earth Surf., 122, 1619– 1634, doi:10.1002/2017JF004231.

AC: We added the reference

RC1: L57: Do you mean "between Arctic regions"? Or did you forget to mention the region with which RTSs from the arctic region can be compared?

AC: We mean "between Arctic regions", for example the scaling coefficients relating the area change to the volumetric change vary between Arctic regions (e.g. Banks Island vs Yamal/Gydan).

RC1: L62: please provide references to "a region that is known to be susceptible to thaw slumping".

AC: We added the reference and slightly rewrote the sentence:

In this work our goal is to map and investigate RTSs on the northern Taymyr Peninsula, a region containing massive ground ice, remnant from the Kara Ice-Sheet and which is known to be susceptible to thaw slumping (Grosval'd et al., 1986; Yershov, E.D., 1989; Alexanderson et al., 2002).

RC1: L69: please repeat which periods are considered

AC: We added the time periods

RC1: L71-72: I find this terminology quite complex and I do not understand what you mean by "probability density function". I suggest you to simplify the methodology e.g "measure the change in RTSs areas and volumes"

AC: We changes item two of the objectives to:

- *Measure the change in RTSs areas and volumes including the RTS scaling relations and its change over time*

RC1: L73: replace "an estimation" by "estimate"

AC: Corrected

RC1: L77: change "our study region" by "the study region"

AC: Corrected

RC1: Technical -- Figure 7. a) show the Area to volume scaling relation and obtained fitting parameter.

AC: Corrected

Discussion:

Substantial organic carbon mobilization from RTSs: you mention that the landscape change is mostly driven by RTSs were re-initiating. The sediments that are remobilizing might have lower carbon content since part of it was already mobilized. How do you think that this re-initiation affects your estimates of carbon mobilization? I suggest adding a few sentences on this. There are a few studies on carbon mobilization on stabilized and re-initialized RTS that you could use:

Cassidy, A.E., Christen, A. and Henry, G.H., 2017. Impacts of active retrogressive thaw slumps on vegetation, soil, and net ecosystem exchange of carbon dioxide in the Canadian High Arctic. *Arctic Science*, *3*(2), pp.179-202.

Bröder, L., Keskitalo, K., Zolkos, S., Shakil, S., Tank, S.E., Kokelj, S.V., Tesi, T., Van Dongen, B.E., Haghipour, N., Eglinton, T.I. and Vonk, J.E., 2021. Preferential export of permafrost-derived organic matter as retrogressive thaw slumping intensifies. *Environmental Research Letters*, *16*(5), p.054059.

Abbott, B.W. and Jones, J.B., 2015. Permafrost collapse alters soil carbon stocks, respiration, CH 4, and N2O in upland tundra. *Global Change Biology*, *21*(12), pp.4570-4587.

AC: We addressed the points mentioned in the discussion:

The comparison the Sentinel-2 mapped RTSs has shown, that about 50\% of RTSs are missed in the TanDEM-X mapping approach. This is likely due to small headwall heights and relative recent initiations in summer 2020. But the missed RTSs can potentially mobilize a significant amount of organic carbon, due to typically larger soil organic carbon contents in the upper soil layer. Furthermore, RTS re-initiation can lead to an overestimation of the amount of mobilized carbon, since the upper soil layer with high carbon contents has already been mobilized. [...]

Our mobilization estimates show that RTSs are an important part of the carbon cycle on regional scales. The mobilized organic carbon is of at least the same order of magnitude as the NEE, when normalized by the total area. It is to note, that in this study we only estimated the amount mobilized carbon. The fate of this mobilized carbon is unknown and depends strongly on its decomposability and the general landscape setting. The timing and amount of greenhouse gases released from RTS mobilized organic carbon is thus difficult to quantify (Vonk and Gustafsson, 2013; Abbott and Jones, 2015; Turetsky et al.,2020). Slump-induced mobilization can nevertheless greatly affect the overall carbon balance of a region, even if only a part of the mobilized carbon becomes part of the ecosystem carbon fluxes (Cassidy et al., 2017; Bröder et al., 2021). Our estimations of large scale carbon mobilization rates is a first step to better quantify the impact of degrading permafrost on the permafrost carbon feedback.