Analysing Retrogressive Thaw Slump Activity using Elevation Models generated from TanDEM-X observations

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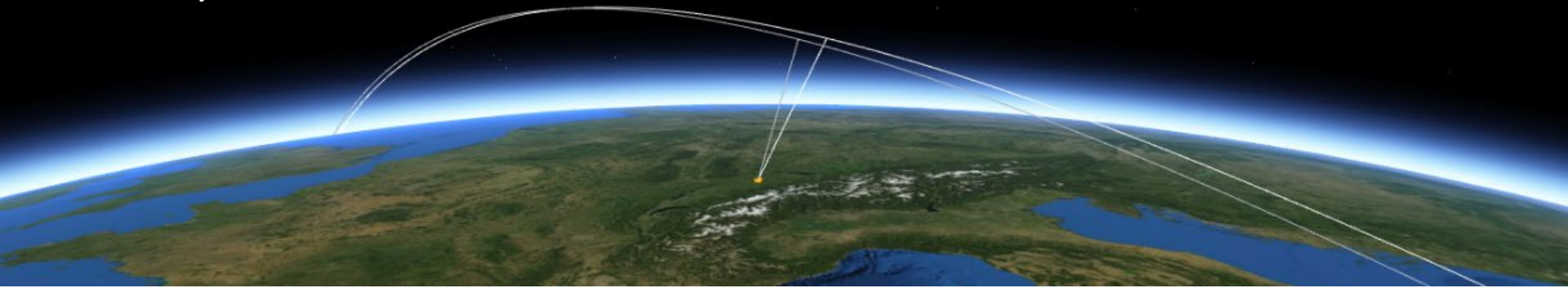

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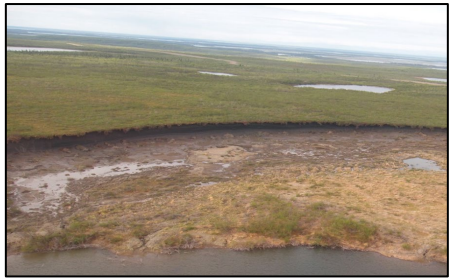
Earth Observation and Remote Sensing

Retrogressive Thaw Slumps (RTS)

one form of abrupt permafrost thaw

Initiation: Exposure of ice-rich permafrost
Growth: Melting of ice in the headwall, sediment transport downslope
Stabilization: Change in conditions (e.g. topography, ground ice content)

Headwall height

<1m | 5-10m | 10-20m | >20m

Retreat rate

<1m/yr | 5-10 m/yr | >20m/yr

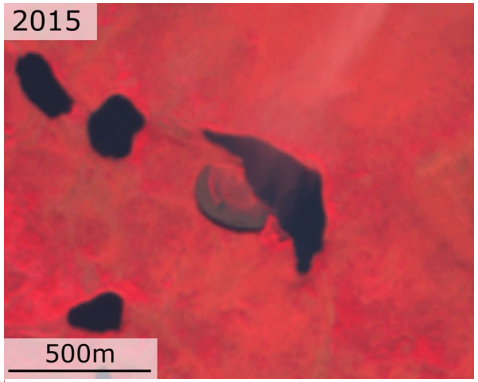
Large-scale mapping of RTSs

RTS in the Mackenzie River Delta, Canada

2D change/disturbances

Change detection or landcover classification

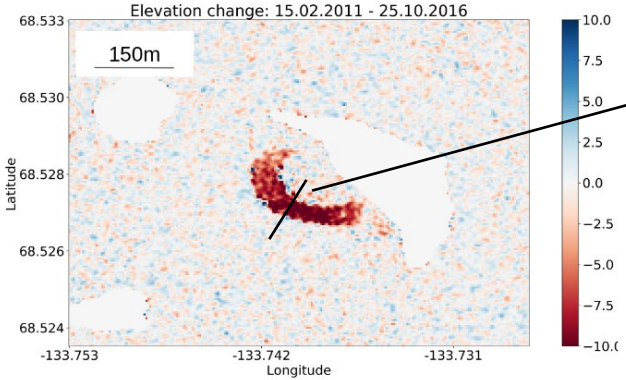
Sentinel-2



3D change

Elevation models differencing

TanDEM-X



Zink, et. al. 2014.

TanDEM-X

Purpose:
Generation of global digital elevation model (DEM) using single-pass Interferometric SAR

Properties:

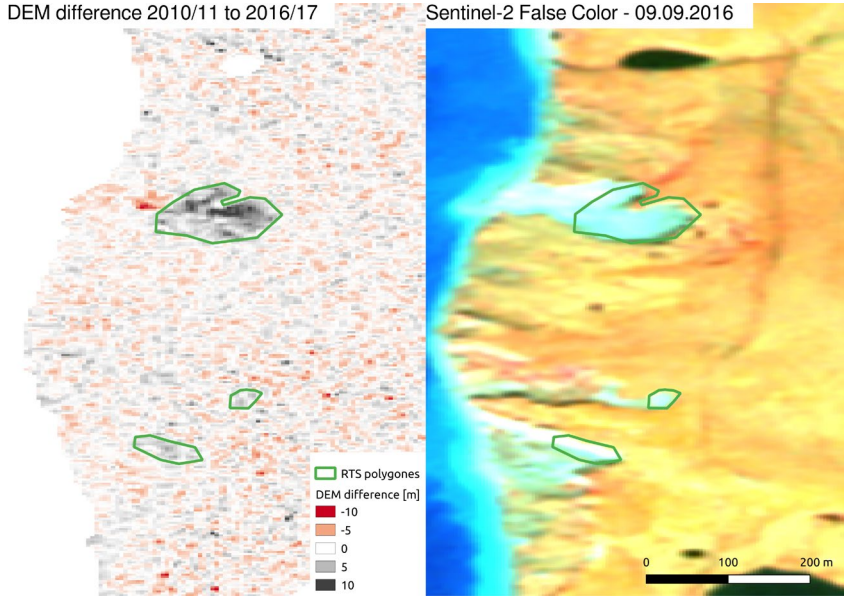
- Active (X-Band) radar: incentive to cloud cover/ no solar irradiation needed
- Single pass: low atmospheric errors, high temporal coherence

Resolution:
Spatial resolution: ~ 10-12 m
Height resolution: ~ 1-2m

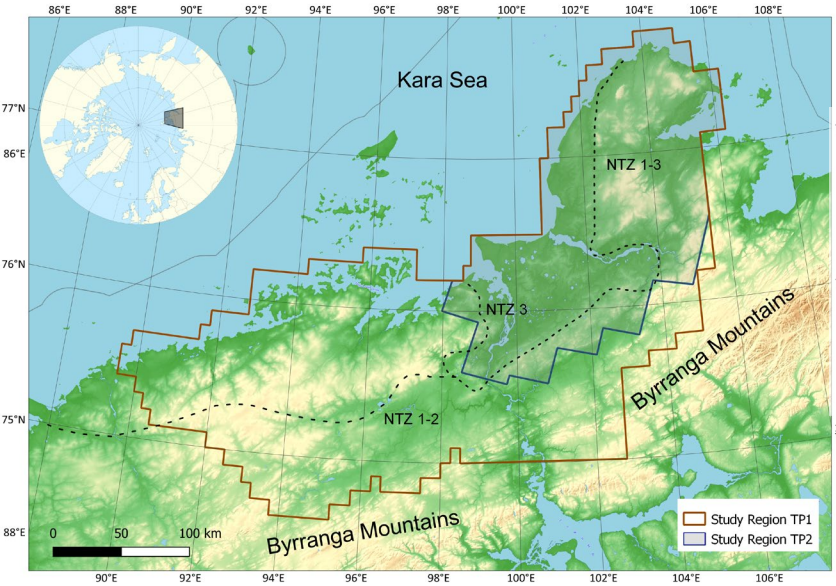
Temporal coverage:
observation time: ~ 2010-today
> 3 observations of the whole Arctic

Mapping Thaw Slump activity from TanDEM-X DEMs

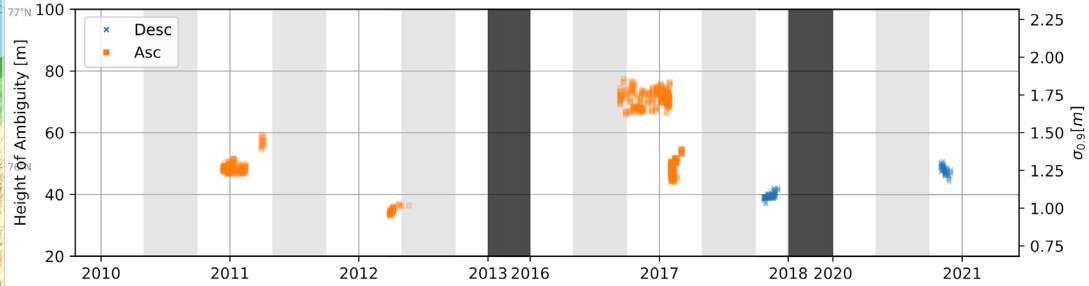
DEM difference images → Significant elevation change detection → Manual classication and RTS outline → RTS property extraction



Thaw Slump activity on the Northern Taymyr Peninsula



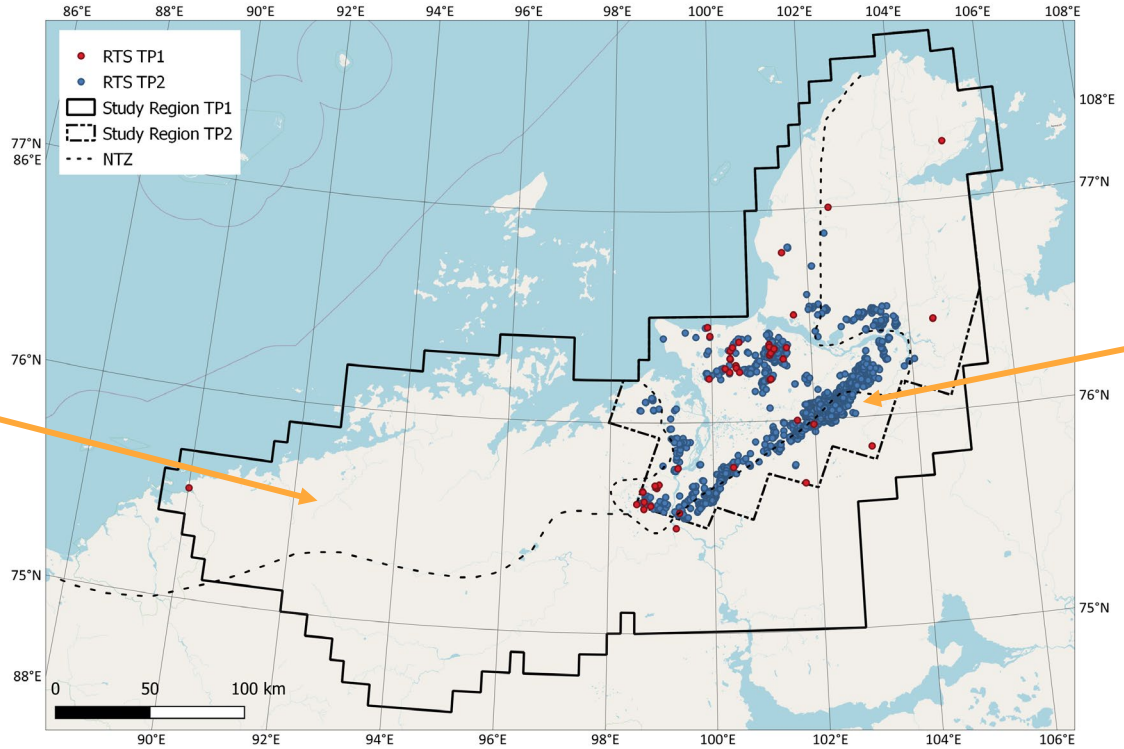
TanDEM-X data availibility



TP1: 2010/11/12 to 2016/17 (Ascending)
TP2: 2018/19 to 2020/21 (Descending)

DEM difference images → Significant elevation change detection → Manual classication and RTS outline → RTS property extraction → Comparison of TP1 and TP2; Quantify carbon mobilization

Strong increase in RTS activity: 82 RTSs → 1404 RTSs

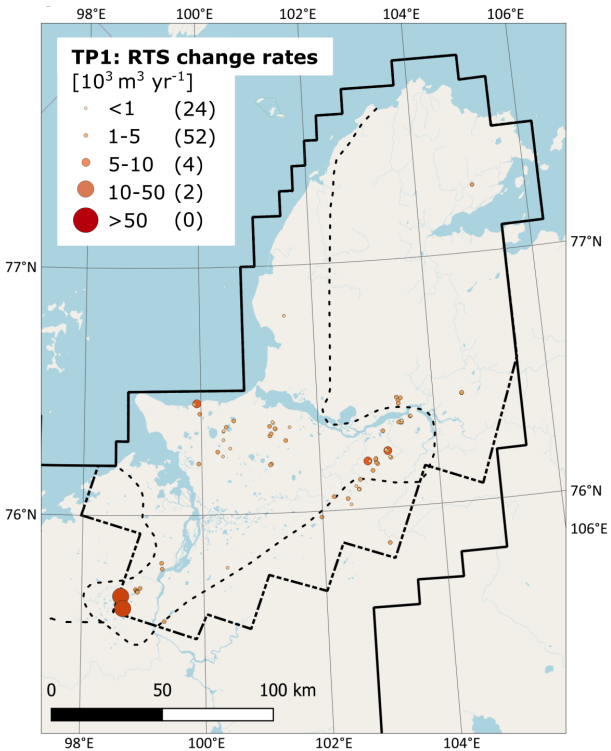


Small amount of RTS activity outside TP2 study region

RTS activity along northern Taymyr Ice-Marginal Zone

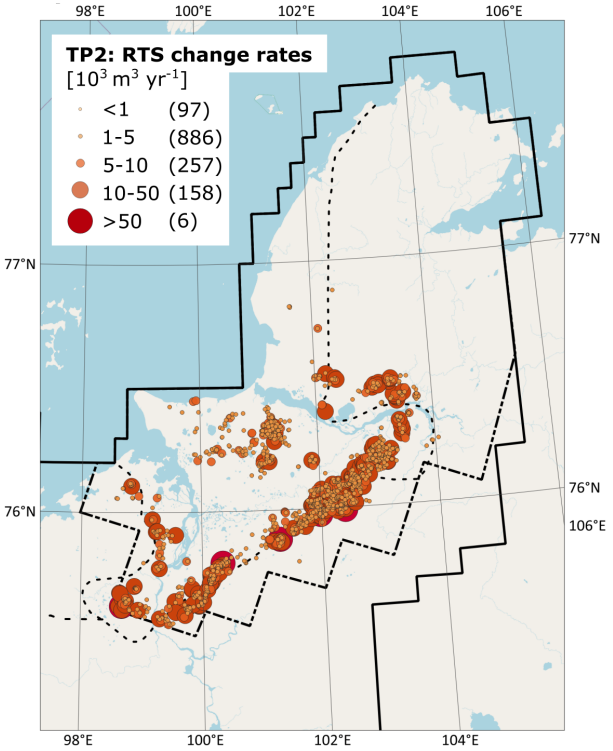
TP1: 2010/11/12 to 2016/17
TP2: 2018/19 to 2020/21

Strong increase in RTS activity:
82 RTSs → 1404 RTSs



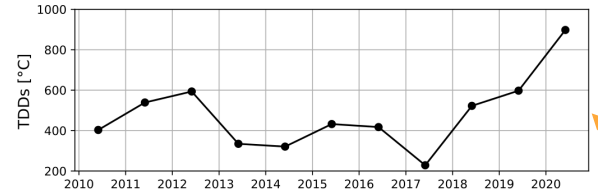
42-fold increase in volumetric change rates

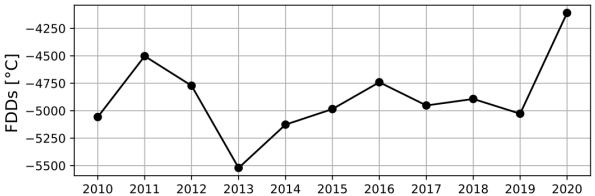
54-fold increase in area change rates



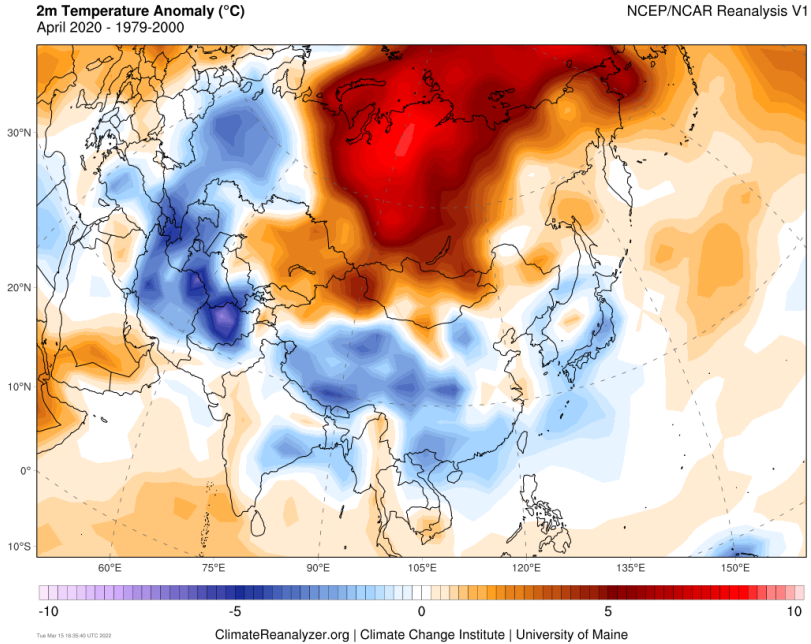
TP1: 2010/11/12 to 2016/17
TP2: 2018/19 to 2020/21

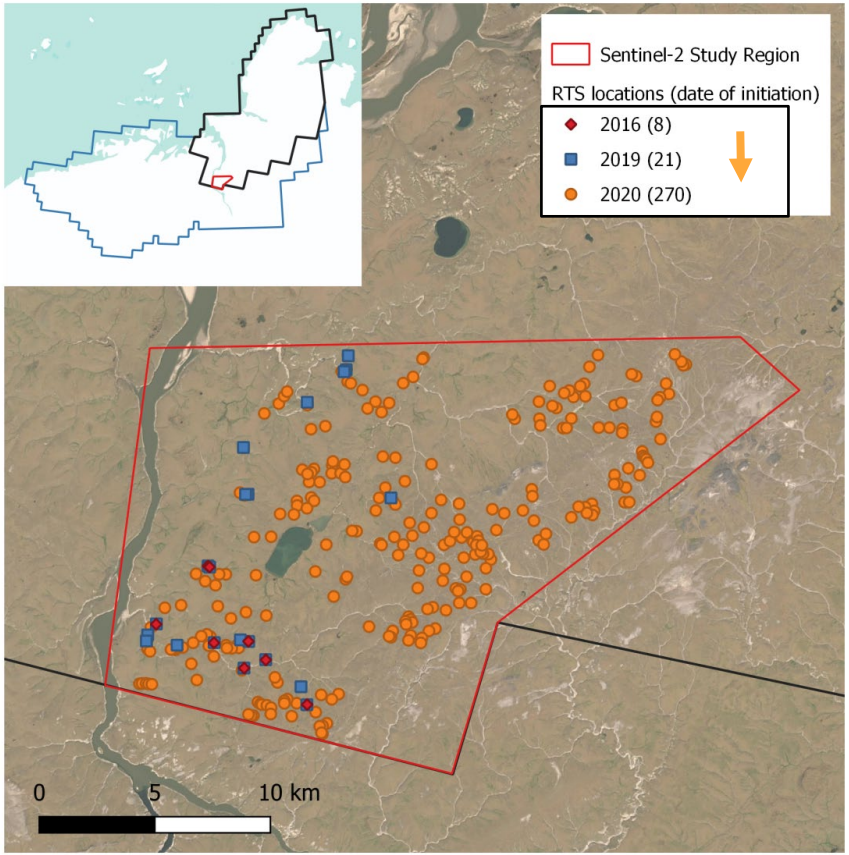
High spring/summer temperatures in 2020





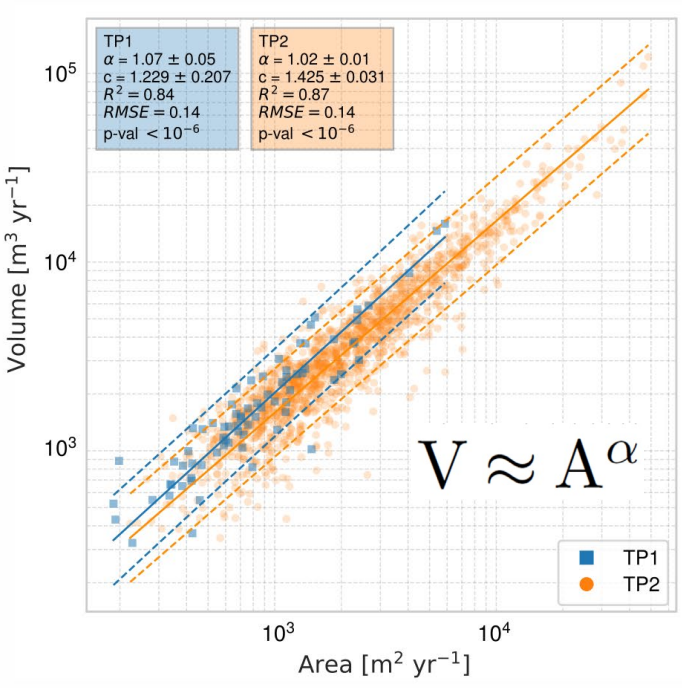
Heatwave in first half of 2020



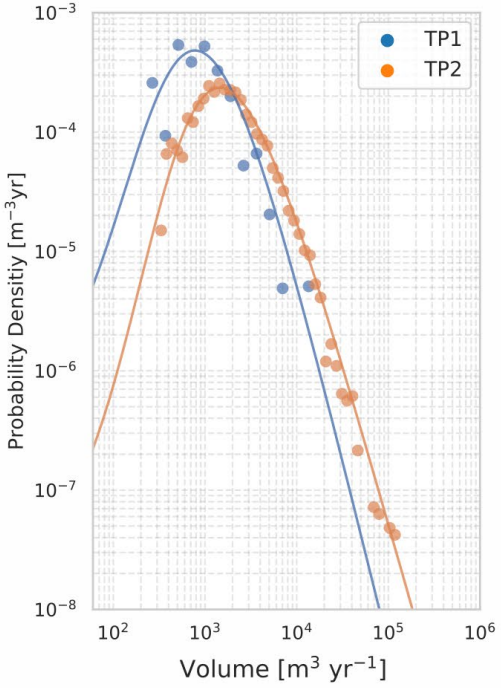


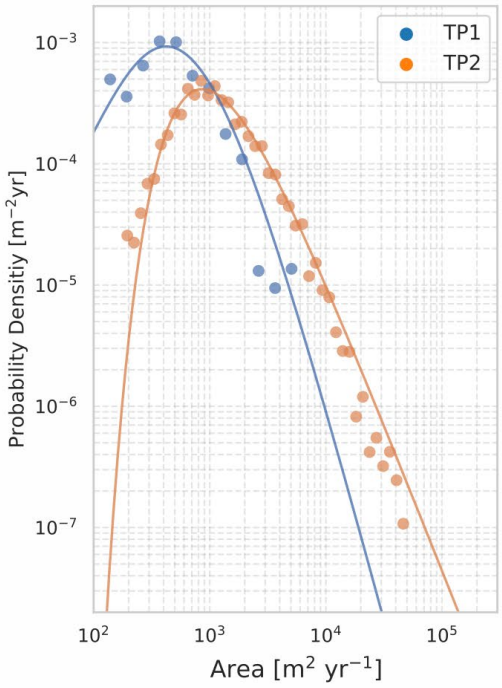
RTS scaling laws

Area-to-Volume scaling



Area and volume change **probability density distributions**

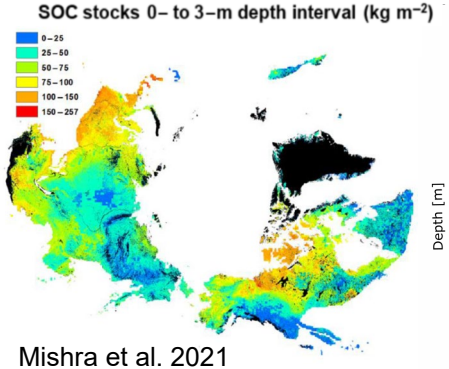




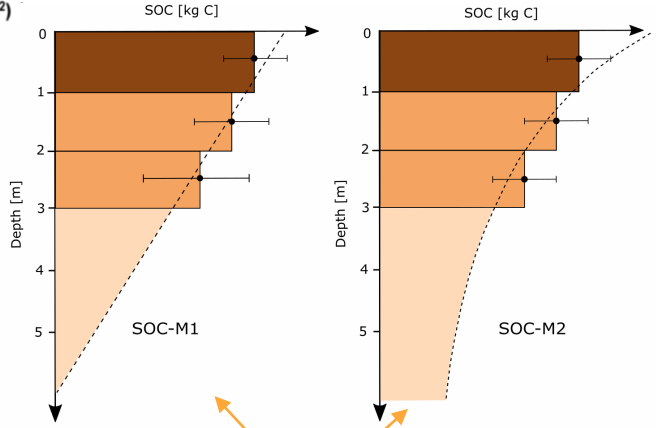
Quantification of the organic carbon mobilization by RTSs

Volumetric change rate + Carbon content + Massive ice content ⇨ Carbon mobilization rate

1) Carbon content



Mishra et al. 2021



Carbon estimate in depths:

- 0m - 1m
- 1m - 2m
- 2m - 3m

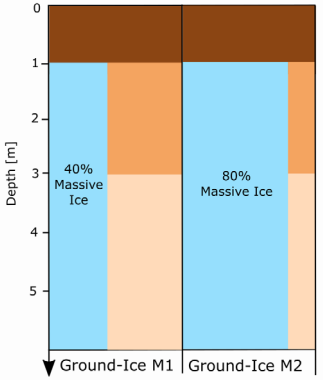
Two models for deep carbon

2) Massive ice content

Alexanderson et al. 2002

Active layer thickness of 0.5m - 1m with remnant glacier ice to a depth of 8m

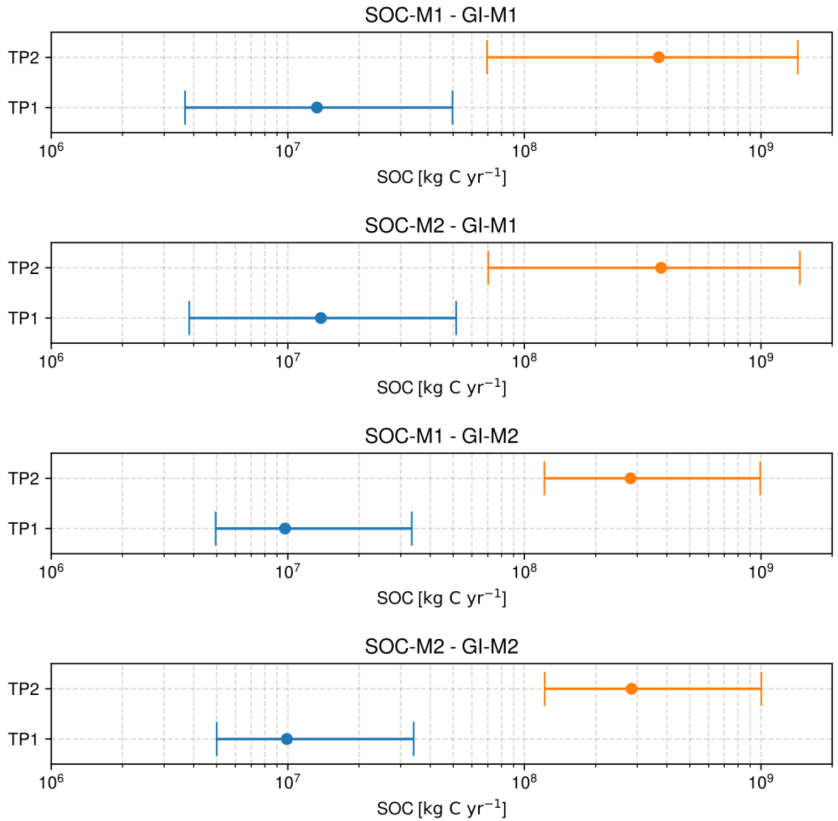
Geocryology of the USSR: 30%-70% massive ice



No massive ice

Two models with 40% and 80% massive ice content

Accelerated carbon mobilization



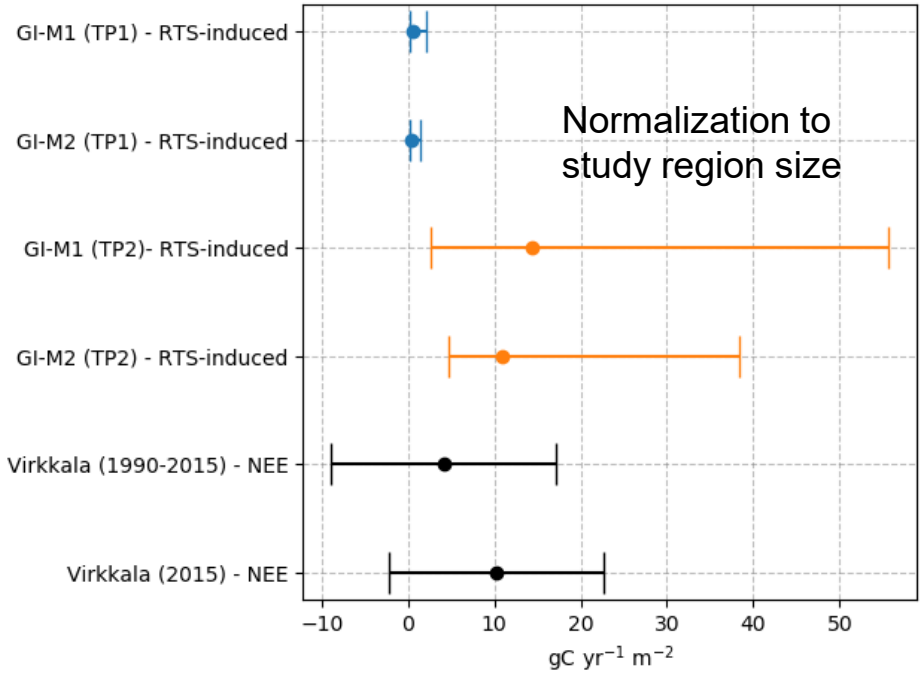
- 27-29 fold increase in carbon mobilization
- GI-M1 (40% massive ice) mobilizes 50% more carbon than GI-M2 (80% massive ice)
- SOC-M1 and SOC-M2 are very similar

Rapid increase of carbon mobilization from TP1 to TP2

TP1: 2010/11/12 to 2016/17
TP2: 2018/19 to 2020/21

Accelerated carbon mobilization

Net Ecosystem Exchange (NEE)
(overall carbon balance between land and athmosphere)



Carbon mobilization due to RTS activity in the same range as general NEE

Caveats:

- Fate of carbon after mobilization (deposition, decomposition)?
- Model assumptions?
- RTS re-initiation?
- Importance of missed RTSs with small headwall heights?

TP1: 2010/11/12 to 2016/17
TP2: 2018/19 to 2020/21

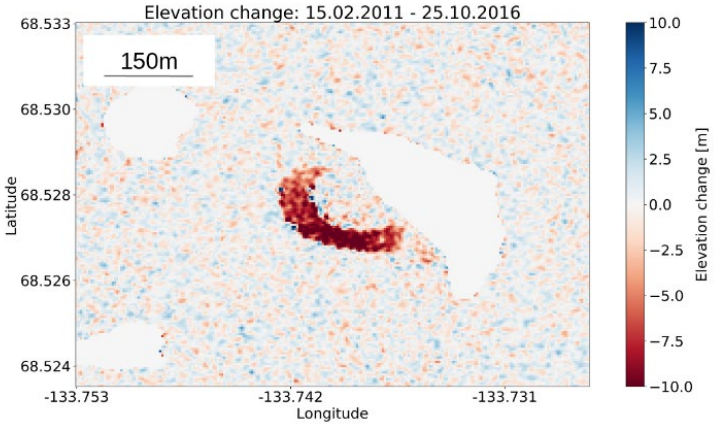
Virkkala et al. 2021 Statistical upscaling of ecosystem CO_2 fluxes across the terrestrial tundra and boreal domain: Regional patterns and uncertainties. Glob. Change Biol., 27: 4040-4059

Conclusions

- RTSs activity is most dominant along the **North-Taymyr Ice-Marginal Zone**
- RTSs activity on the Taymyr Peninsula **intensified in response to a heatwave**
- RTSs activity mobilizes large quantities of organic carbon which responded **sharply and non-linearly** to warming

Bernhard, P., Zwieback, S., Bergner, N., and Hajnsek, I.: **Assessing volumetric change distributions and scaling relations of retrogressive thaw slumps across the Arctic**, The Cryosphere, 16, 1–15, https://doi.org/10.5194/tc-16-1-2022, 2022.

Bernhard, P., Zwieback, S., and Hajnsek, I.: **Accelerated Mobilization of Organic Carbon from Retrogressive Thaw Slumps on the Northern Taymyr Peninsula**, The Cryosphere Discuss. [preprint], https://doi.org/10.5194/tc-2022-36, in review, 2022.



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