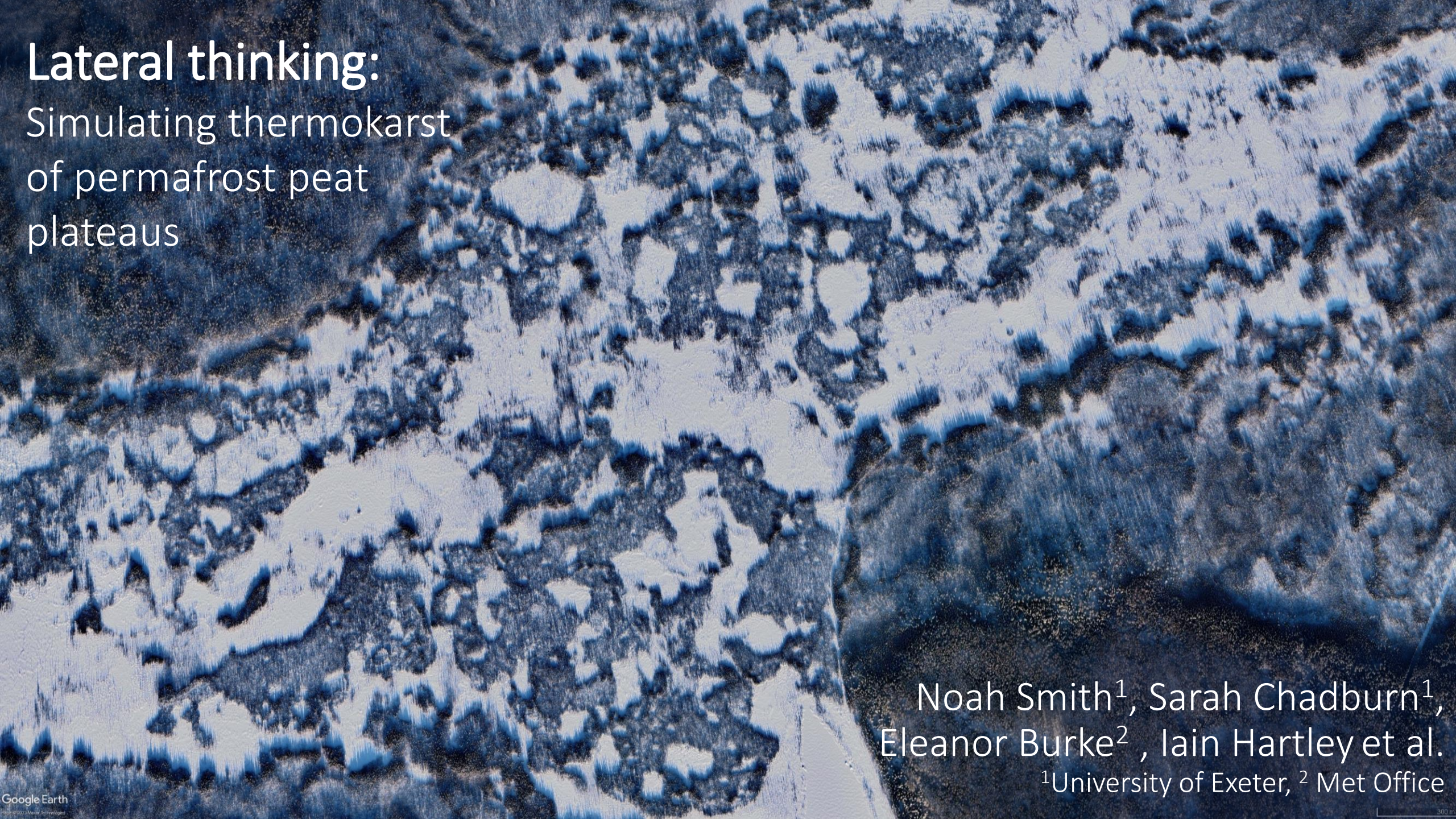
Lateral thinking:

Simulating thermokarst of permafrost peat plateaus



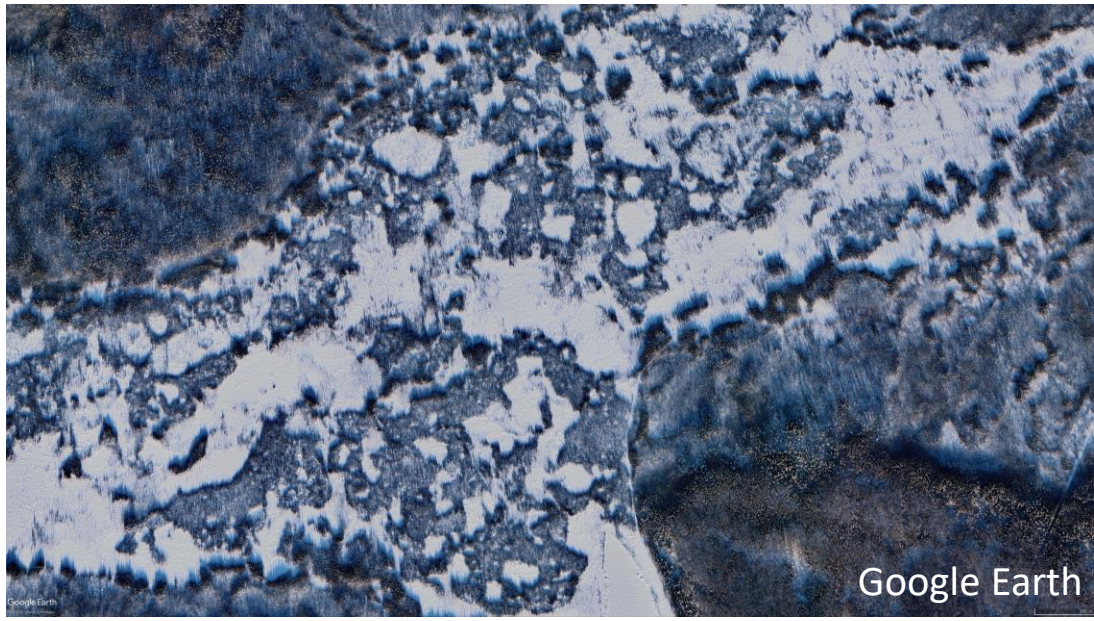
Noah Smith[1], Sarah Chadburn[1], Eleanor Burke[2] , Iain Hartley et al.

[1]University of Exeter, [2] Met Office

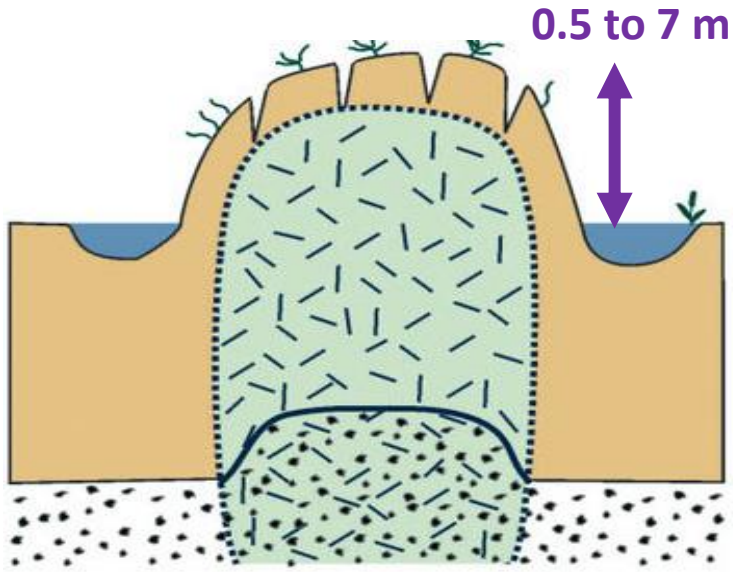
What are peat plateaus / palsas?

- Landforms in permafrost peatlands
- Formed by excess ice
- Bistable heterogeneity

Treed peat plateaus in winter, Canada



Ice lenses



Seppälä (2006)

Palsa mire Iškoras, Norway

Do they matter?

Permafrost peatlands currently:

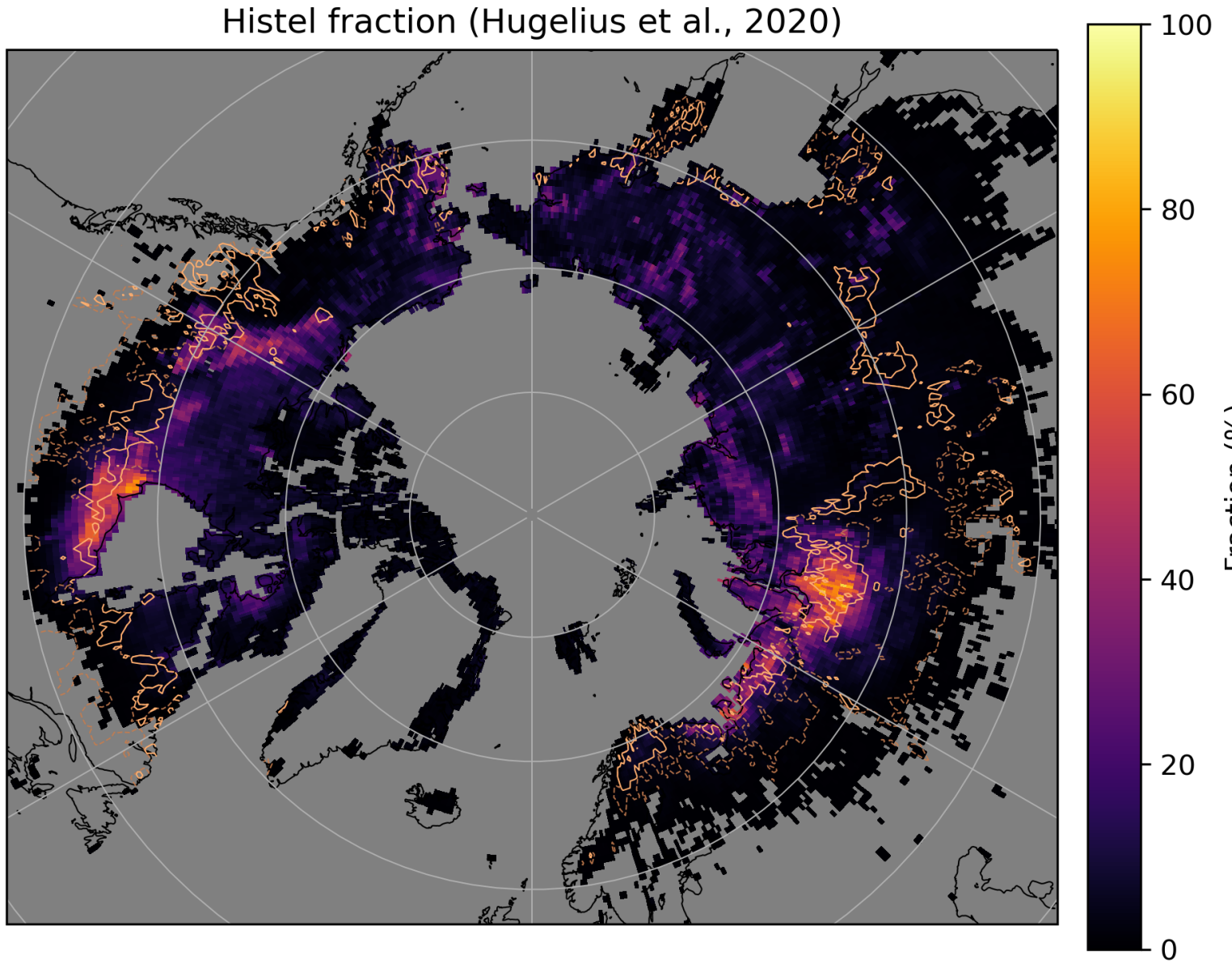
- Store 185 Gt carbon (¼ of atmospheric carbon)
- ½ northern peatland area
- Very small CO_2 sink 0.10 ± 0.02 PgC y^{-1}
- Methane source 26 ± 2 TgC y^{-1} (1/10 anthropogenic methane emissions, ≈coal mining)

With warming of 2◦C:

0.7 million km^2 (40 %) of peatland permafrost area could thaw

By 2100: across scenarios of +1.5 to 6◦C a cumulative 0.7 to 3 PgC of methane could be released (1% of projected anthropogenic emissions)

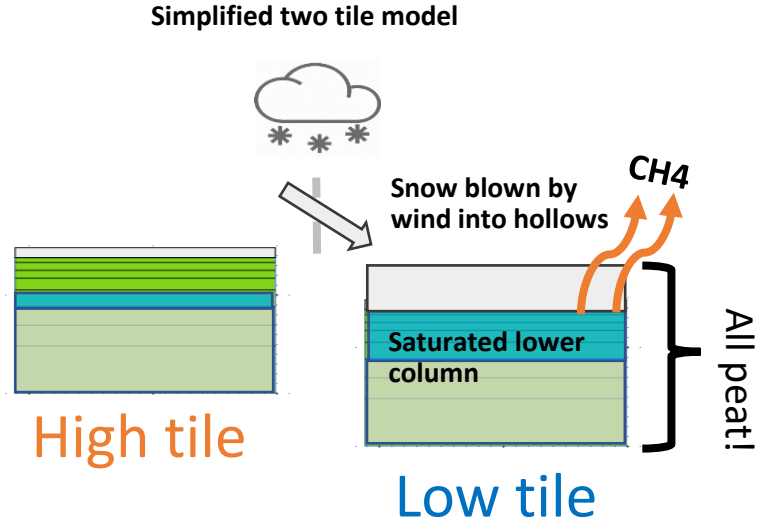
..but this is highly uncertain.



(Friedlingstein et al., 2022; Hugelius et al., 2020; Saunois et al., 2020; Walter et al., 2007)

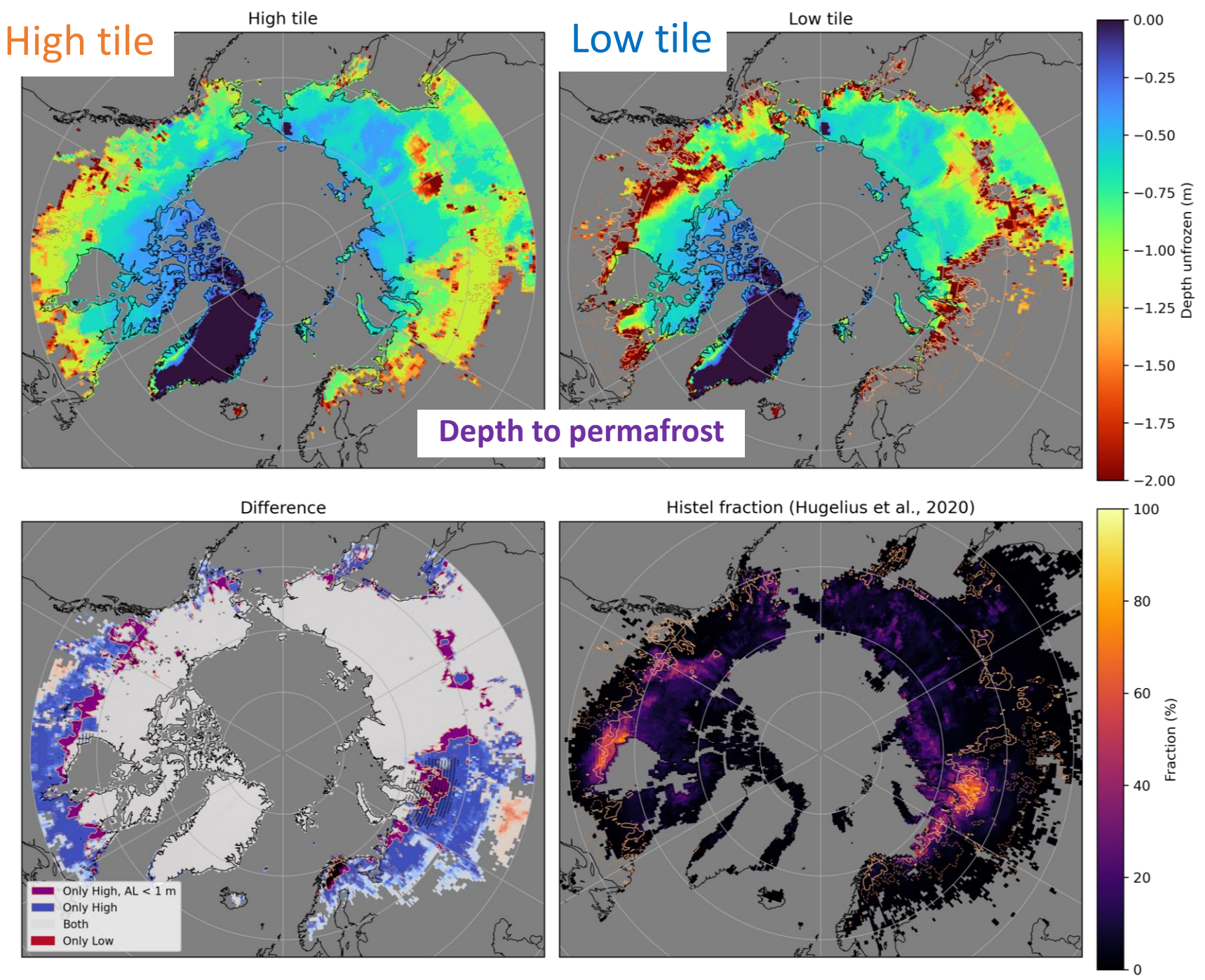
Previously…

Tiling approach to modelling peat plateau heterogeneity in JULES



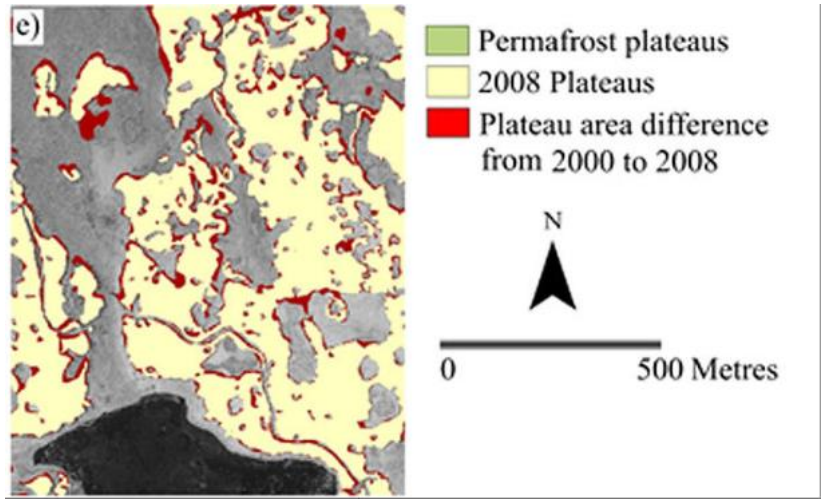
We can run this into the future,

But…

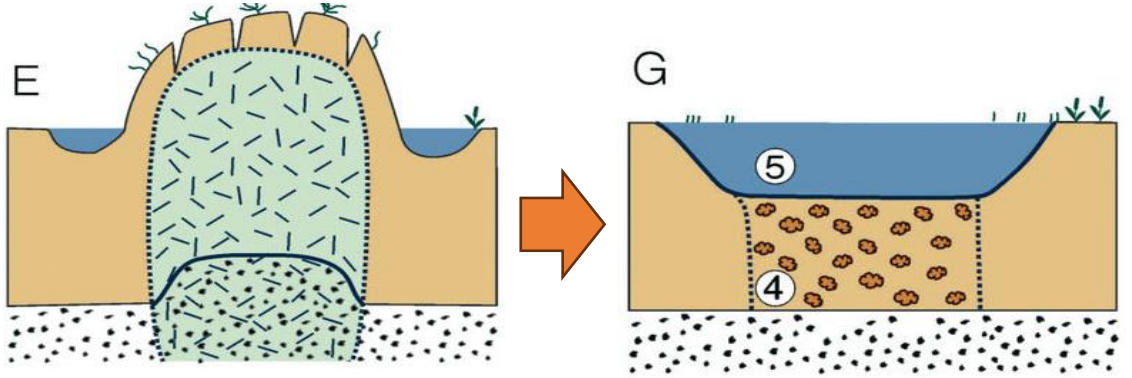


The key processes are missing:

- Most thawing of peat plateaus happens laterally



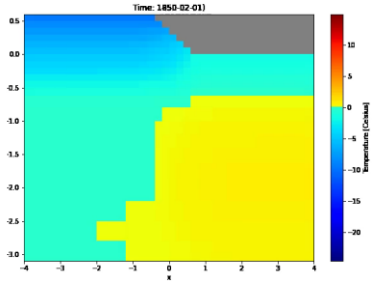
- JULES lacks a representation of excess ice thaw



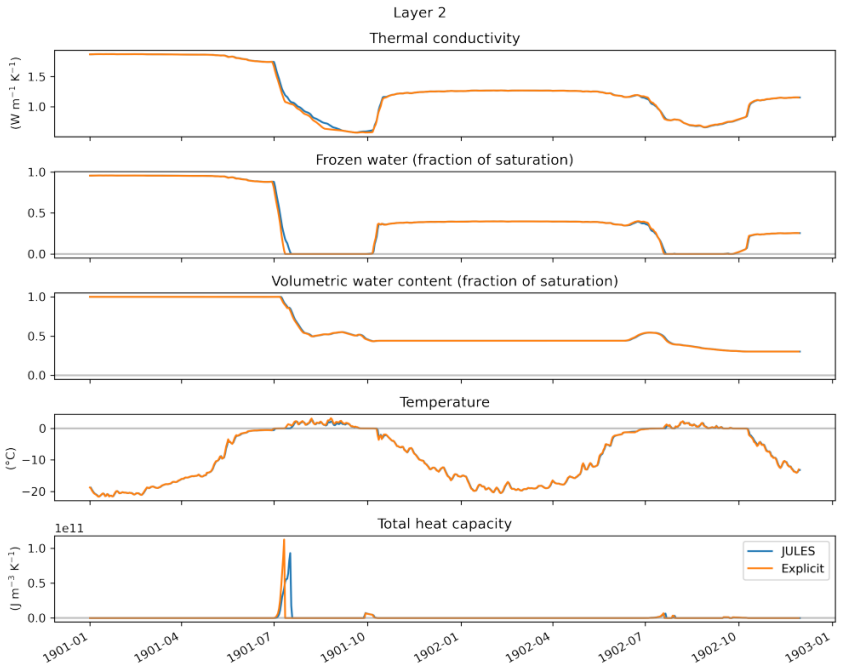
Introducing lateral thaw

- Most thawing of peat plateaus happens laterally

2D thermal model driven by surface temperatures of two-tile model



Explicit formulation vs JULES

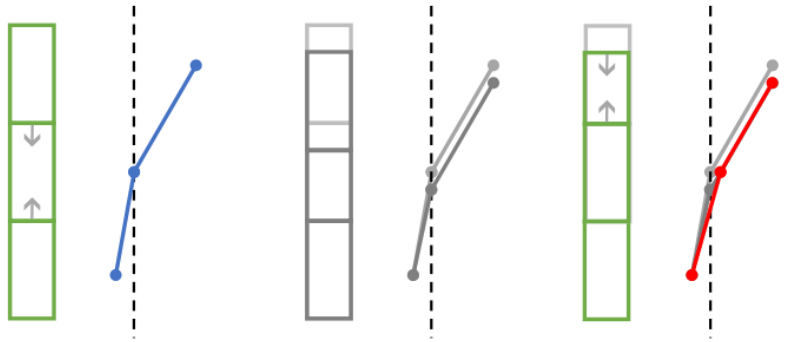


- JULES lacks a representation of excess ice thaw

Excess ice:

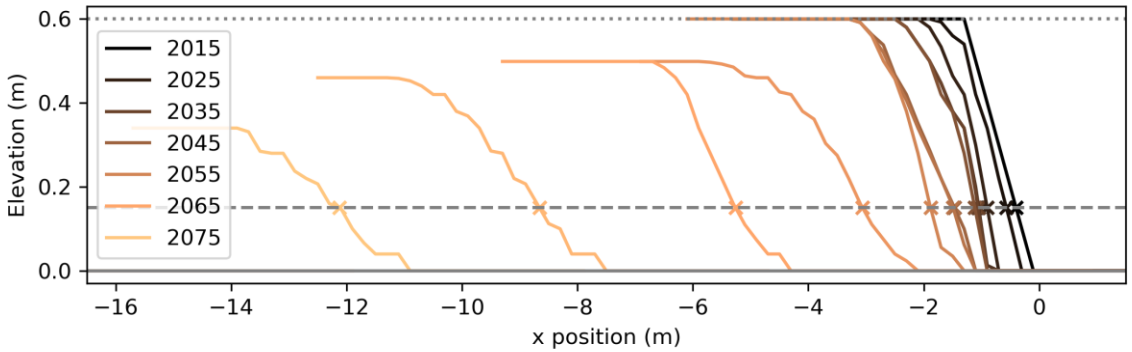
- Takes up space
- Modifies the average thermal properties
- Thaws after pore ice thaws

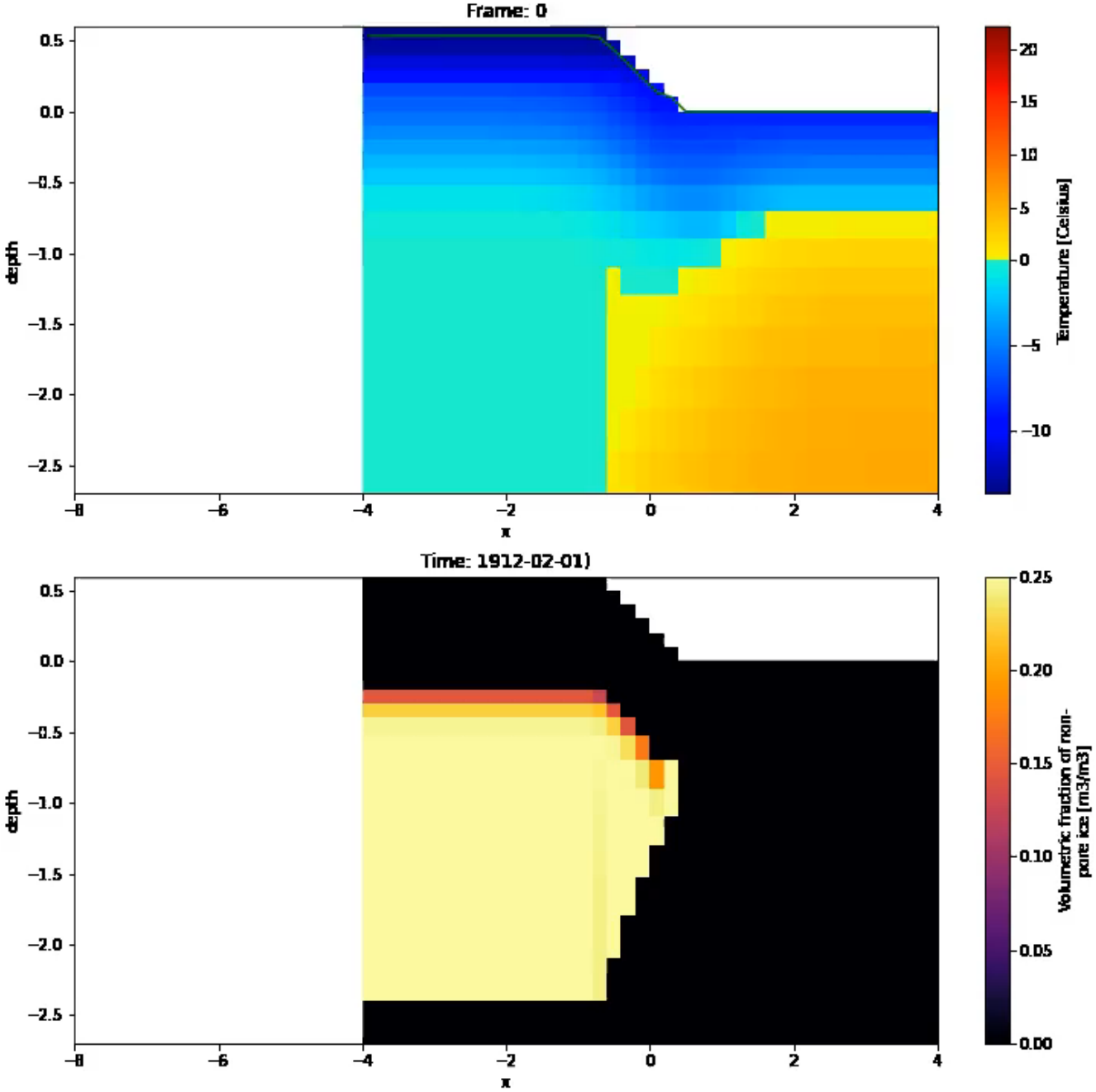
Subsidence: Soil variables are reinterpolated onto original layers



(inspired by JULES-peat)

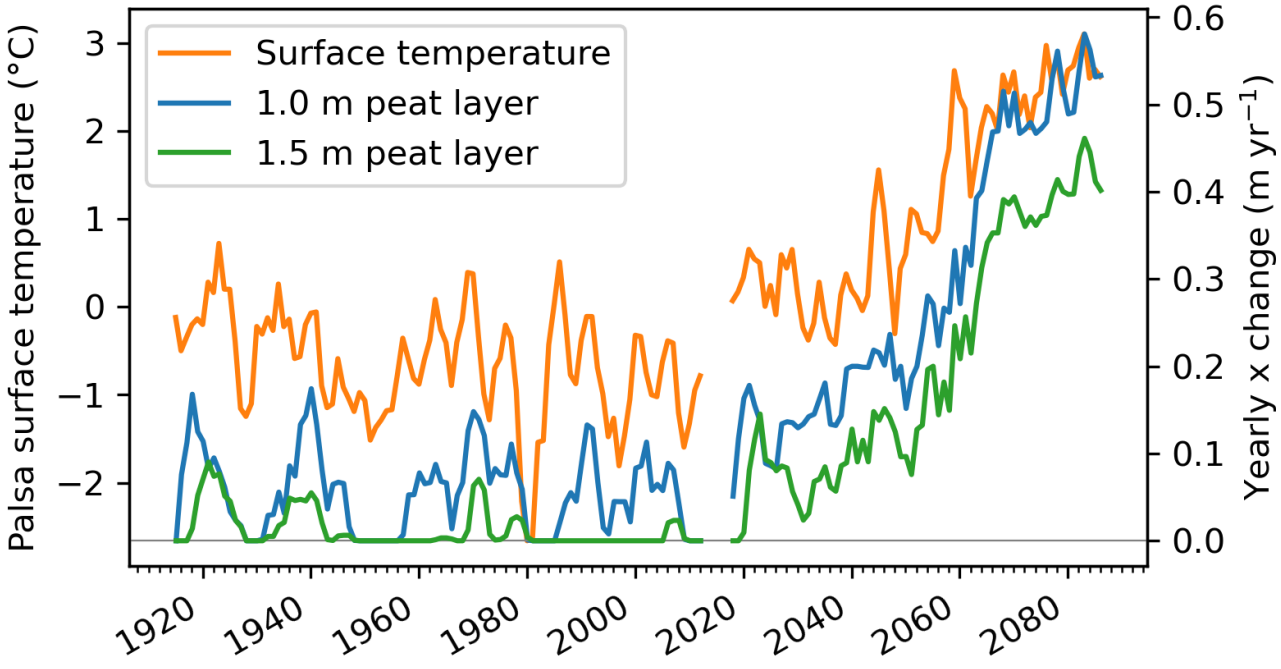
Introducing lateral thaw

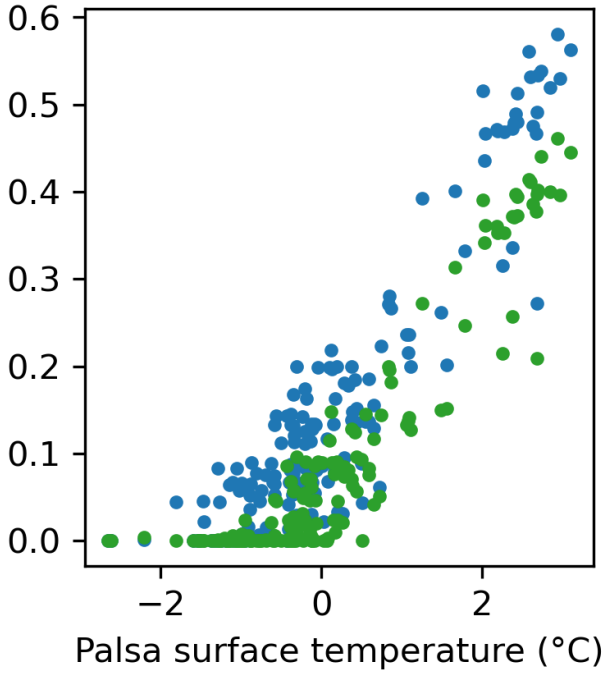




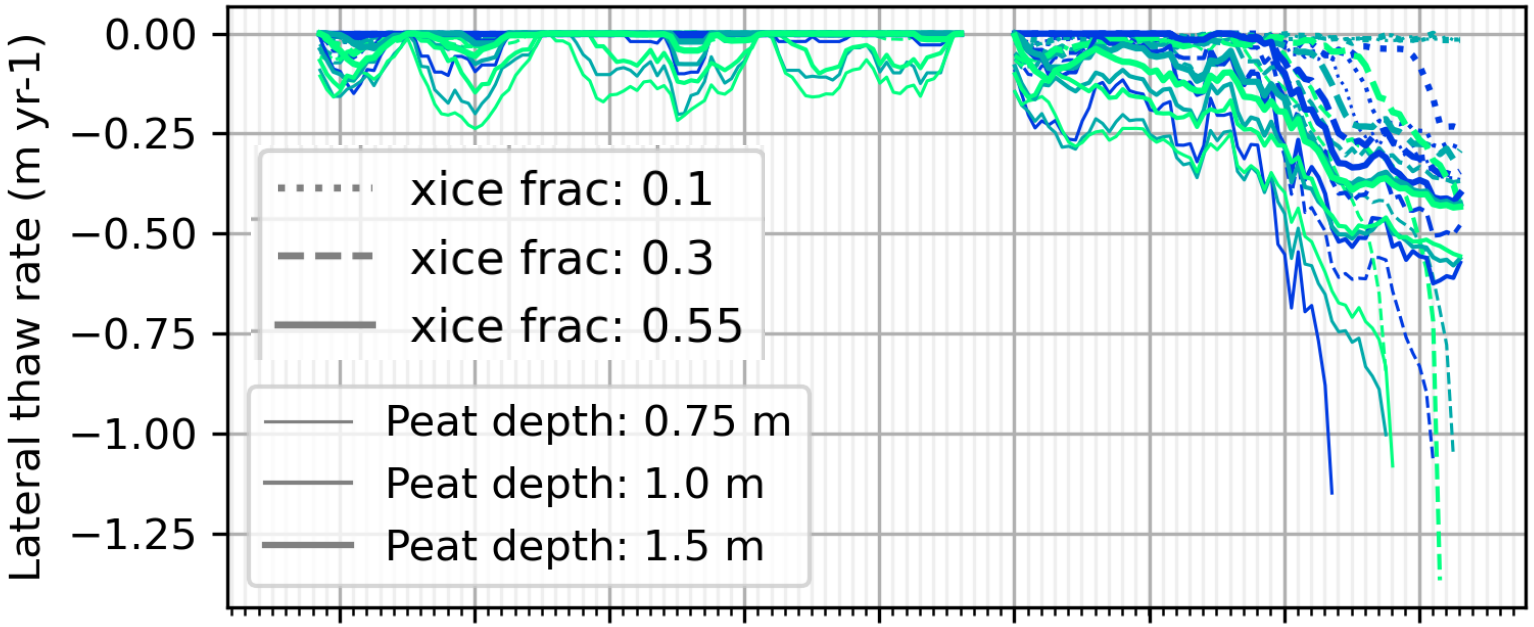
What do we see?

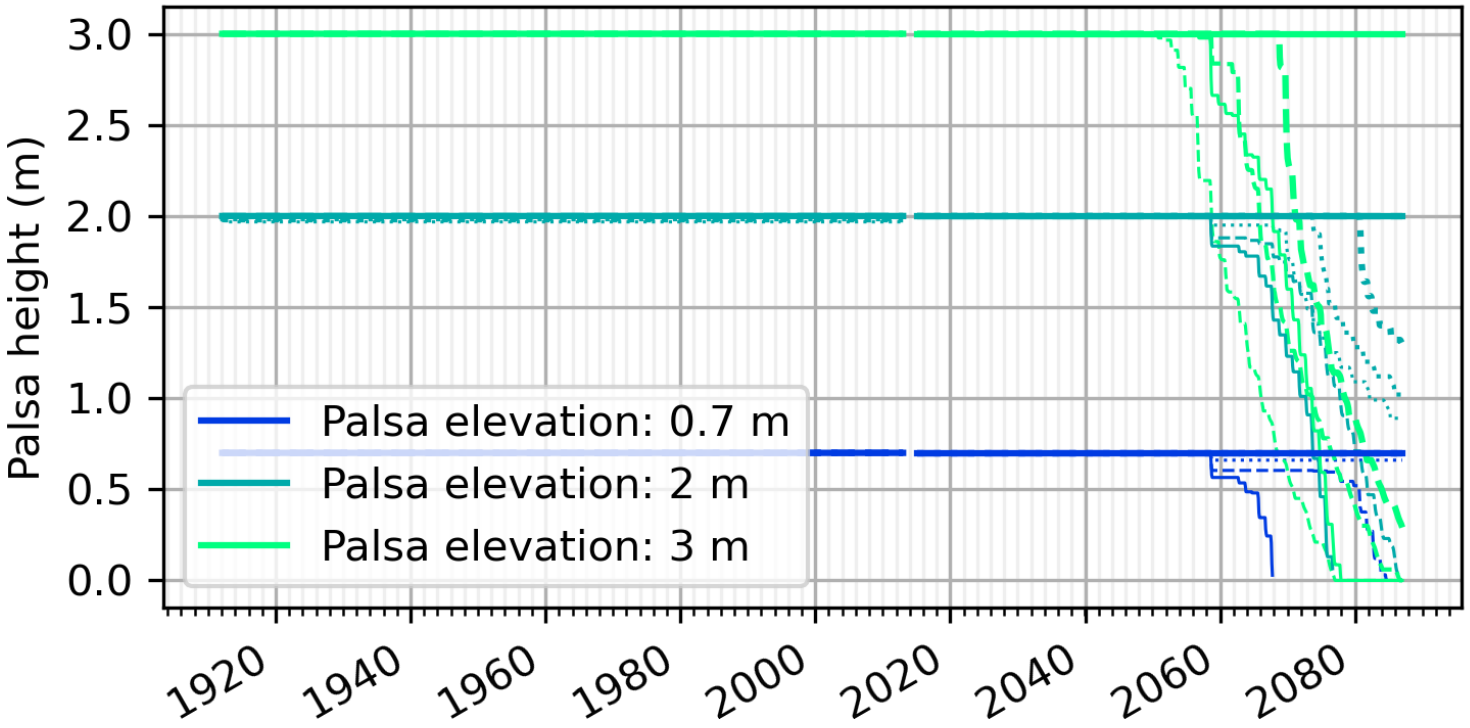
The rate of lateral thaw is correlated with palsa surface temperature





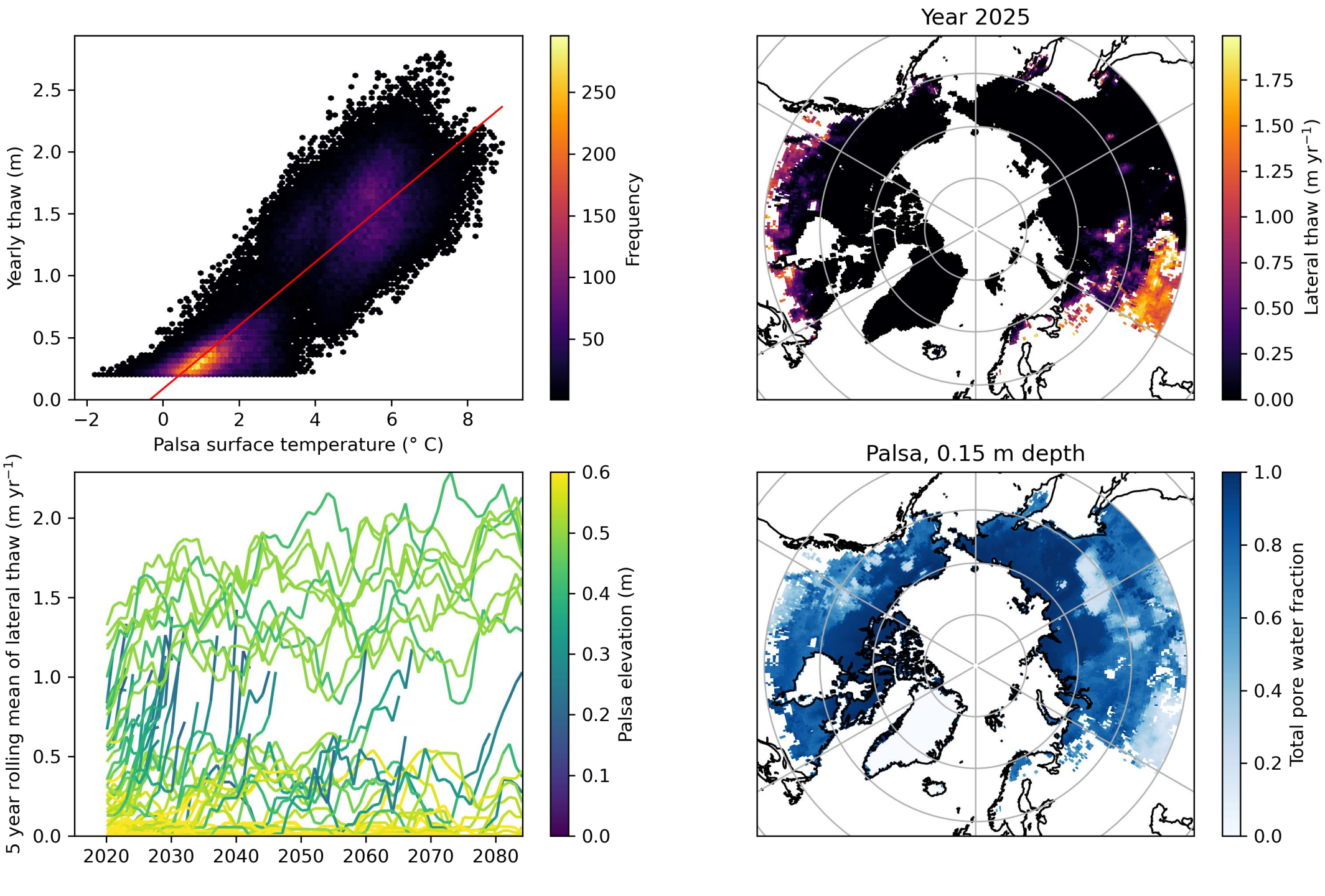
There is a threshold response to thaw



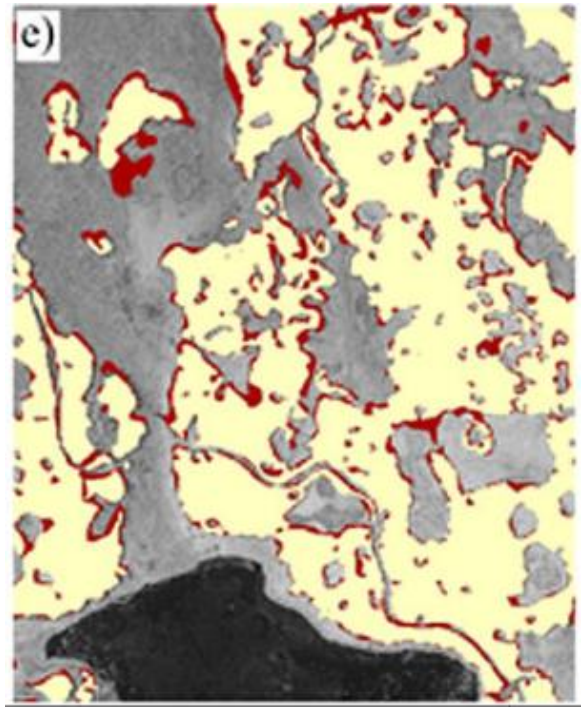


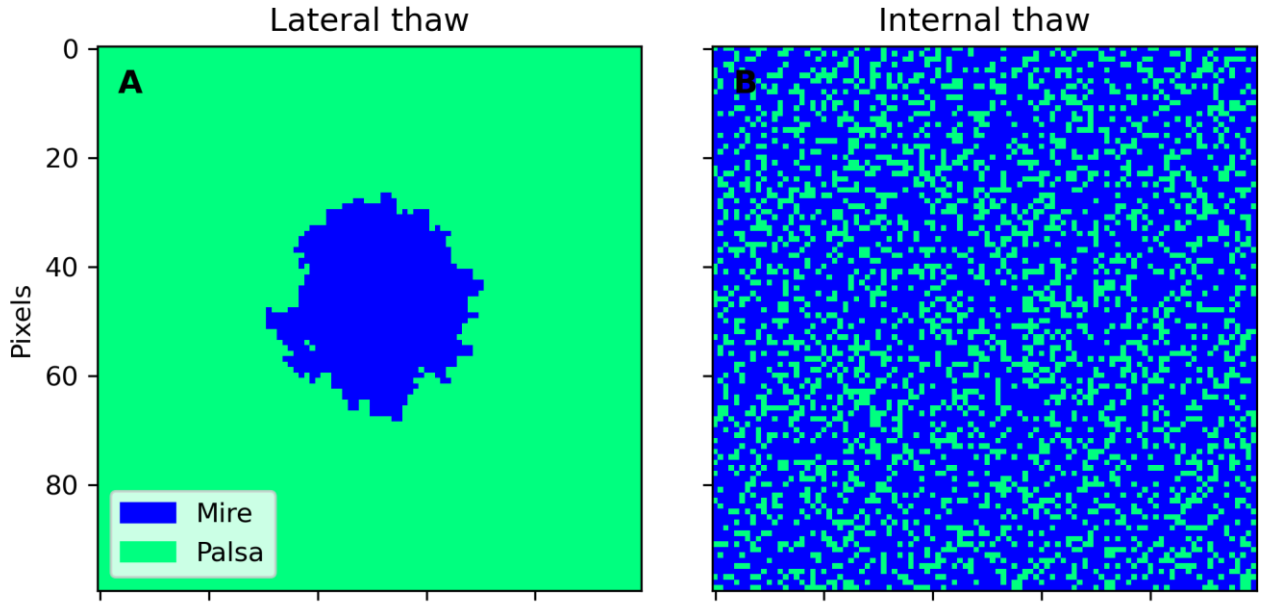
There is a limit to how much lateral thaw rates increase with temperature…

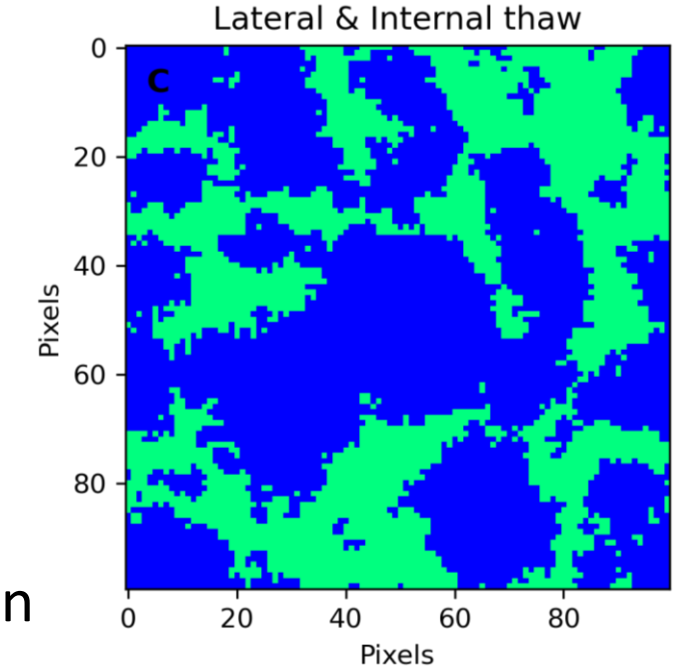
…as at some point the whole palsa thaws from the top down.


Yearly thaw (m)
Palsa surface temperature (° C)
Frequency
Year 2025
Lateral thaw (m yr^{-1})
5 year rolling mean of lateral thaw (m yr^{-1})
Palsa elevation (m)
Palsa, 0.15 m depth
Total pore water fraction

Lateral thaw rate
→ areal thaw rate?







$$\frac{dp_{frac}}{dt} \approx -\frac{r_l}{d} e_{frac} - P_p p_{frac}$$

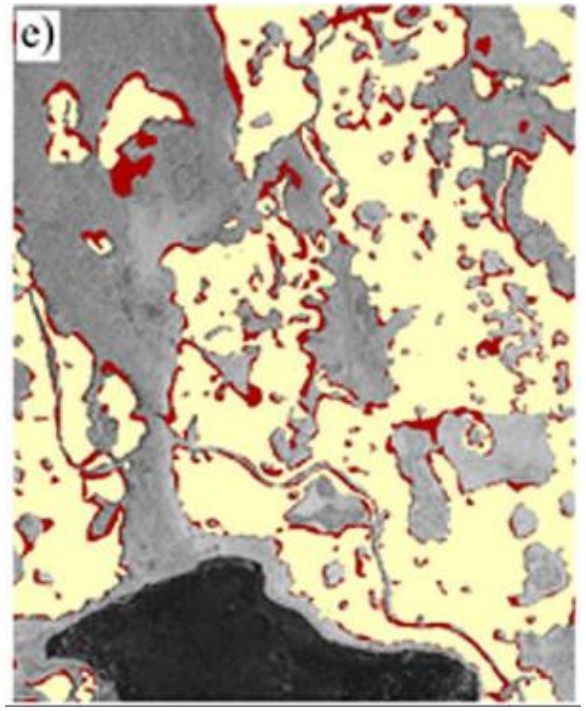
Lateral thaw rate

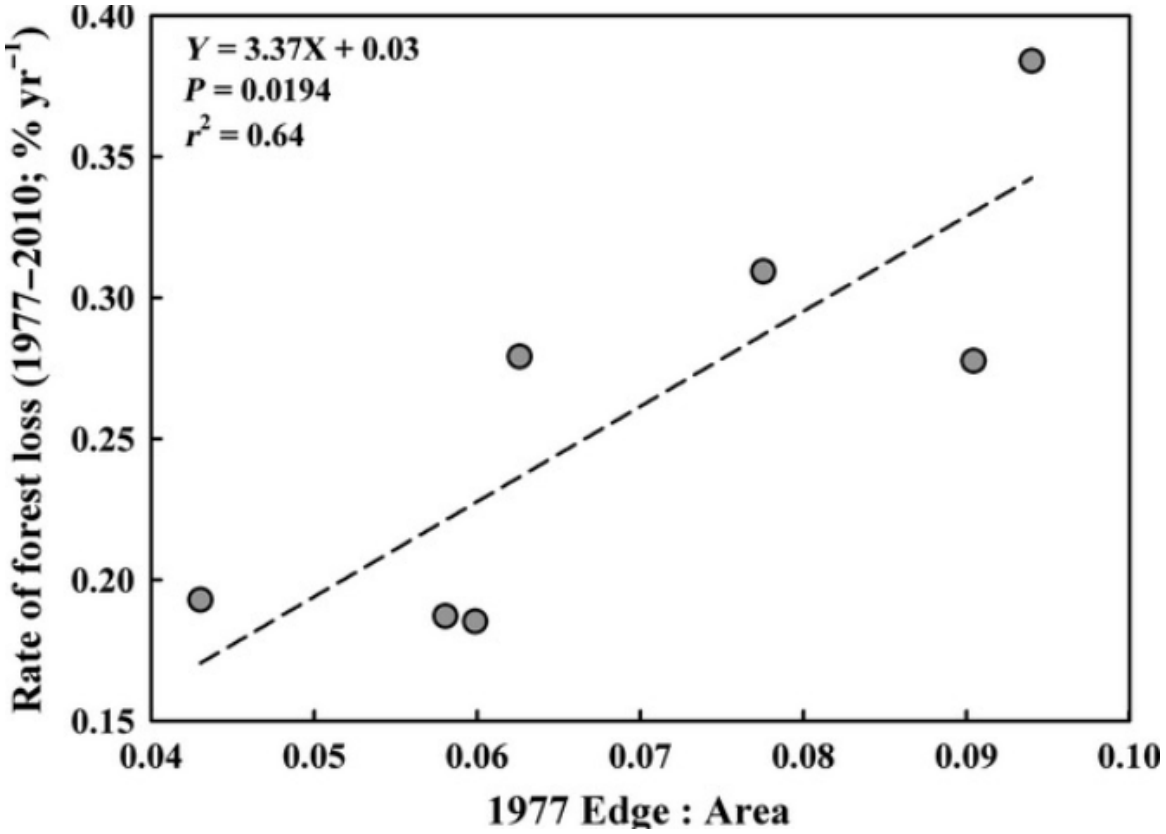
Internal thaw rate

Edge length

Palsa fraction

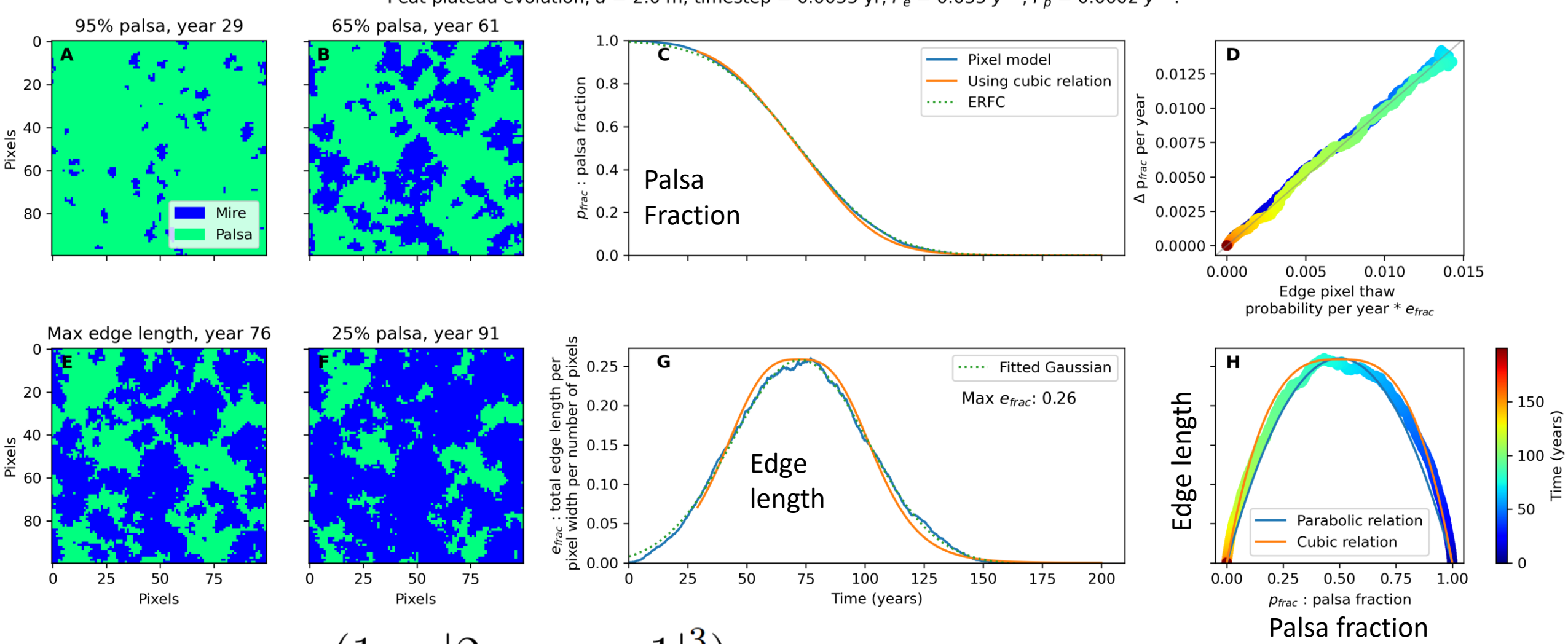
Lateral thaw rate
→ areal thaw rate?





If areal thaw rate is proportional to edge length,

…how does edge length change with areal thaw?



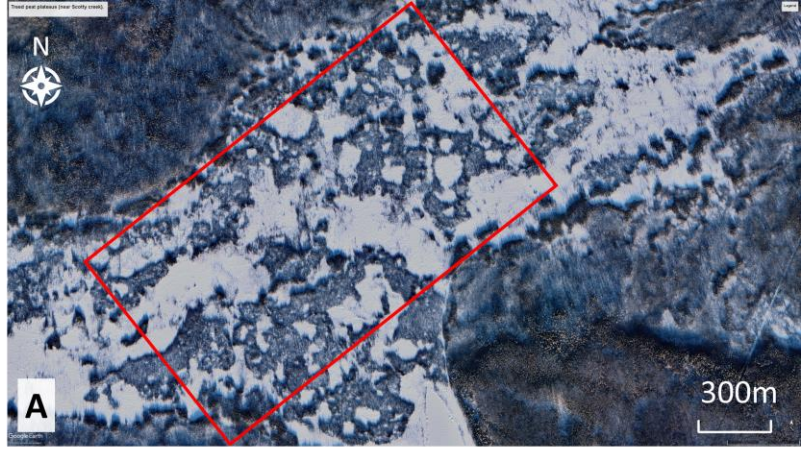
$$e_{frac} = e_{max}(1 - |2p_{frac} - 1|^3)$$

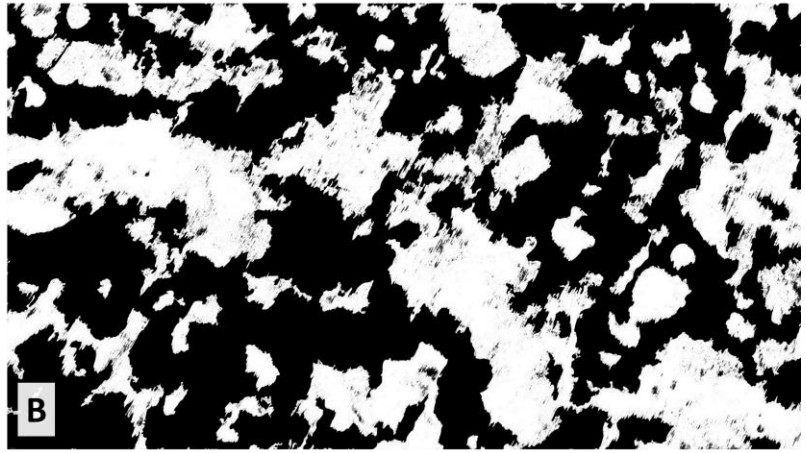
Edge length

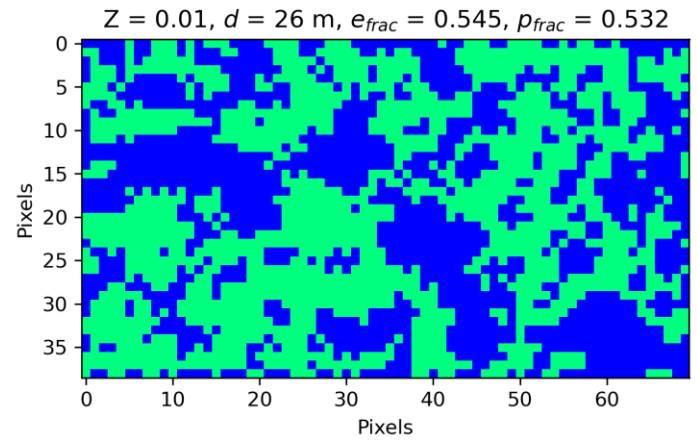
Max edge length

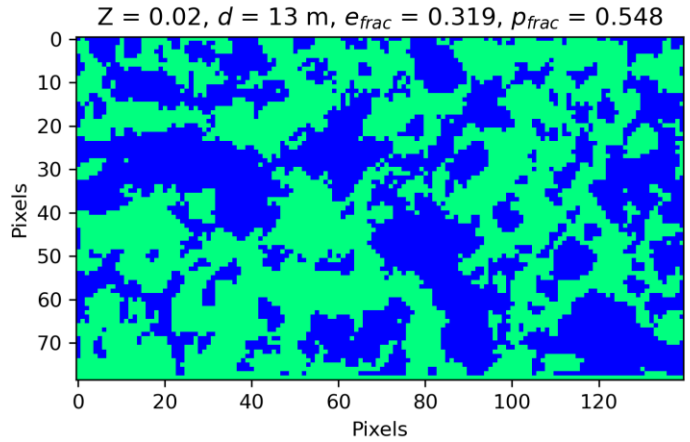
Palsa fraction

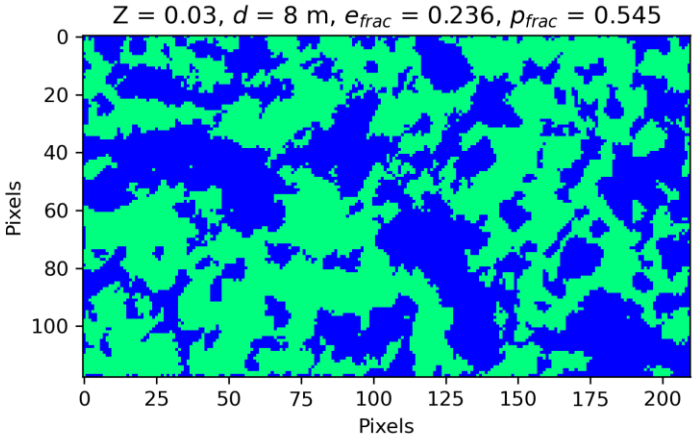
$$\frac{dp_{frac}}{dt} \approx -\frac{fr_l}{d} e_{frac} - P_p p_{frac}$$

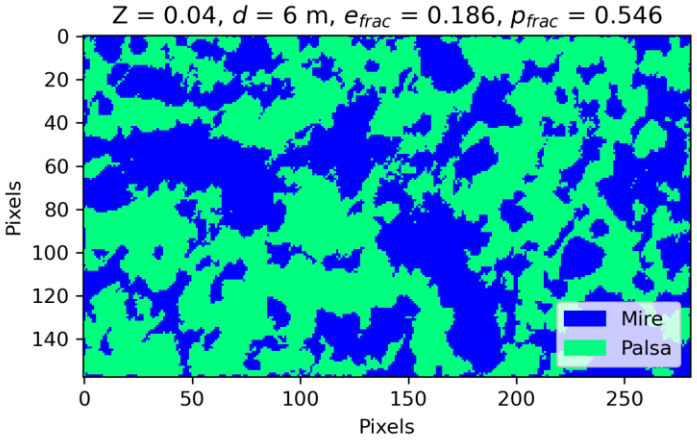

N
A
300m

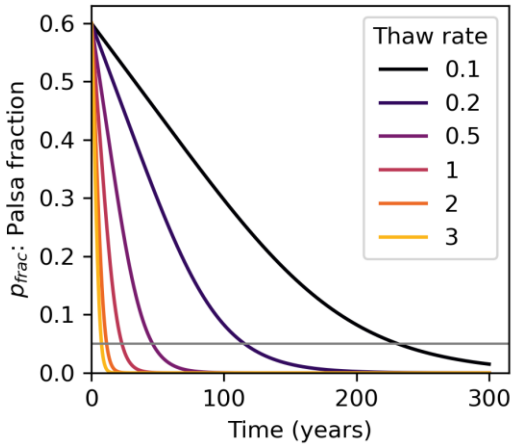

B

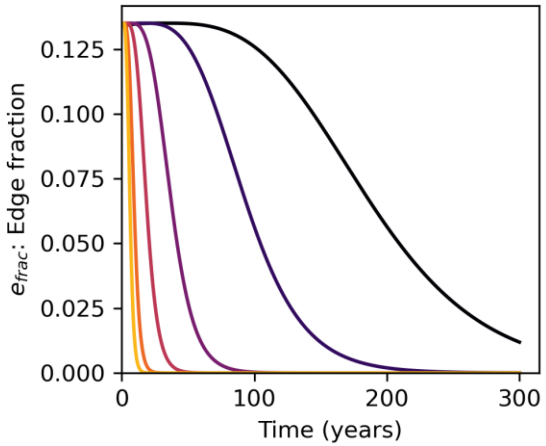

Z = 0.01, d = 26 m, e_frac = 0.545, p_frac = 0.532
Pixels
Pixels

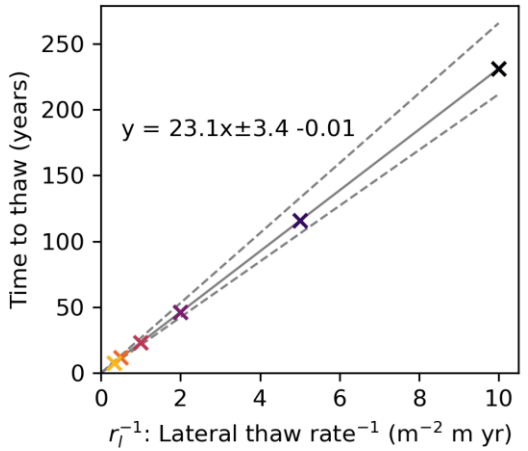

Z = 0.02, d = 13 m, e_frac = 0.319, p_frac = 0.548
Pixels
Pixels


Z = 0.03, d = 8 m, e_frac = 0.236, p_frac = 0.545
Pixels
Pixels


Z = 0.04, d = 6 m, e_frac = 0.186, p_frac = 0.546
Mire
Palsa
Pixels
Pixels


Thaw rate
0.1
0.2
0.5
1
2
3
p_frac: Palsa fraction
Time (years)


e_frac: Edge fraction
Time (years)

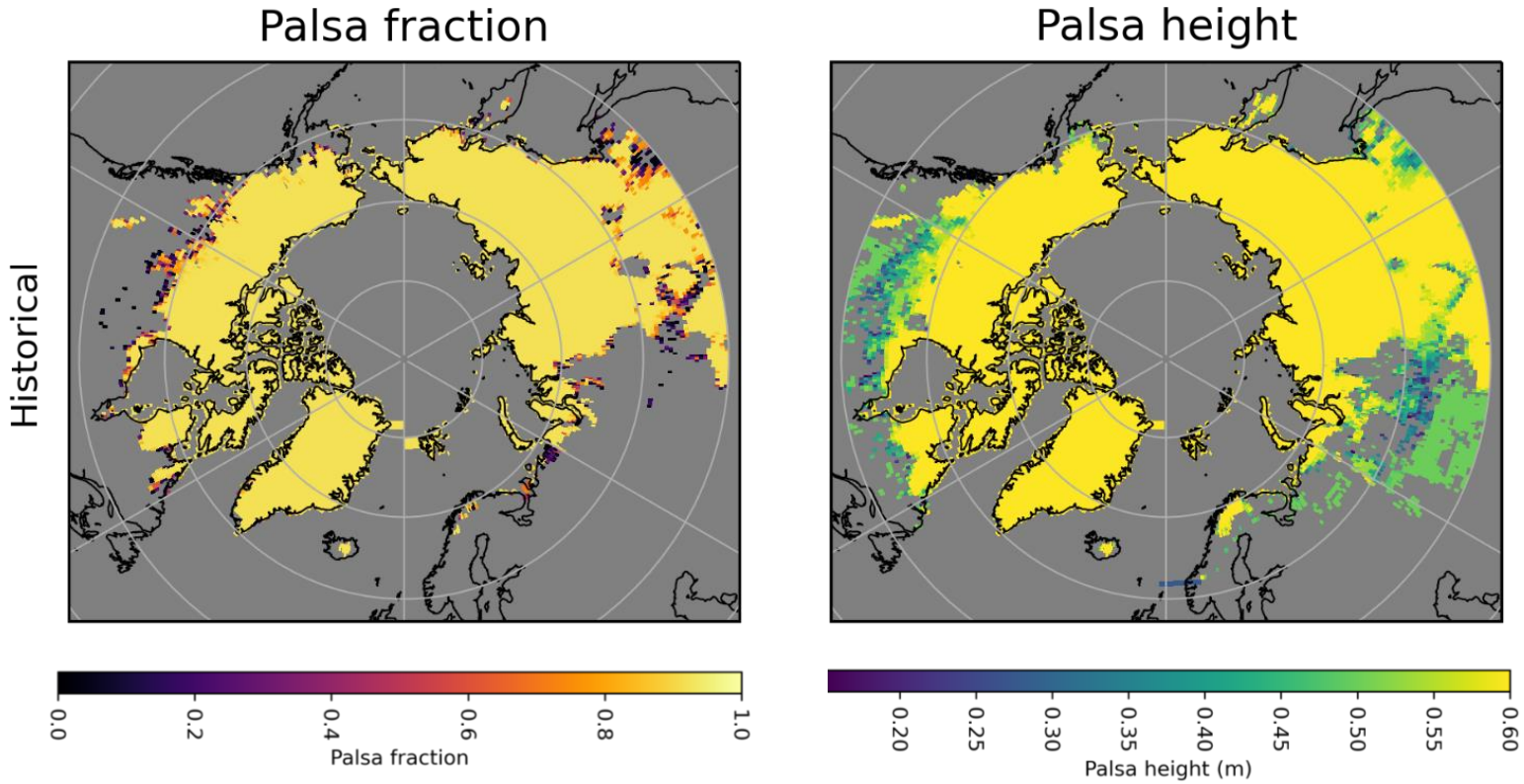

y = 23.1x±3.4 -0.01
Time to thaw (years)
r_l^-1: Lateral thaw rate^-1 (m^-2 m yr)

Altogether

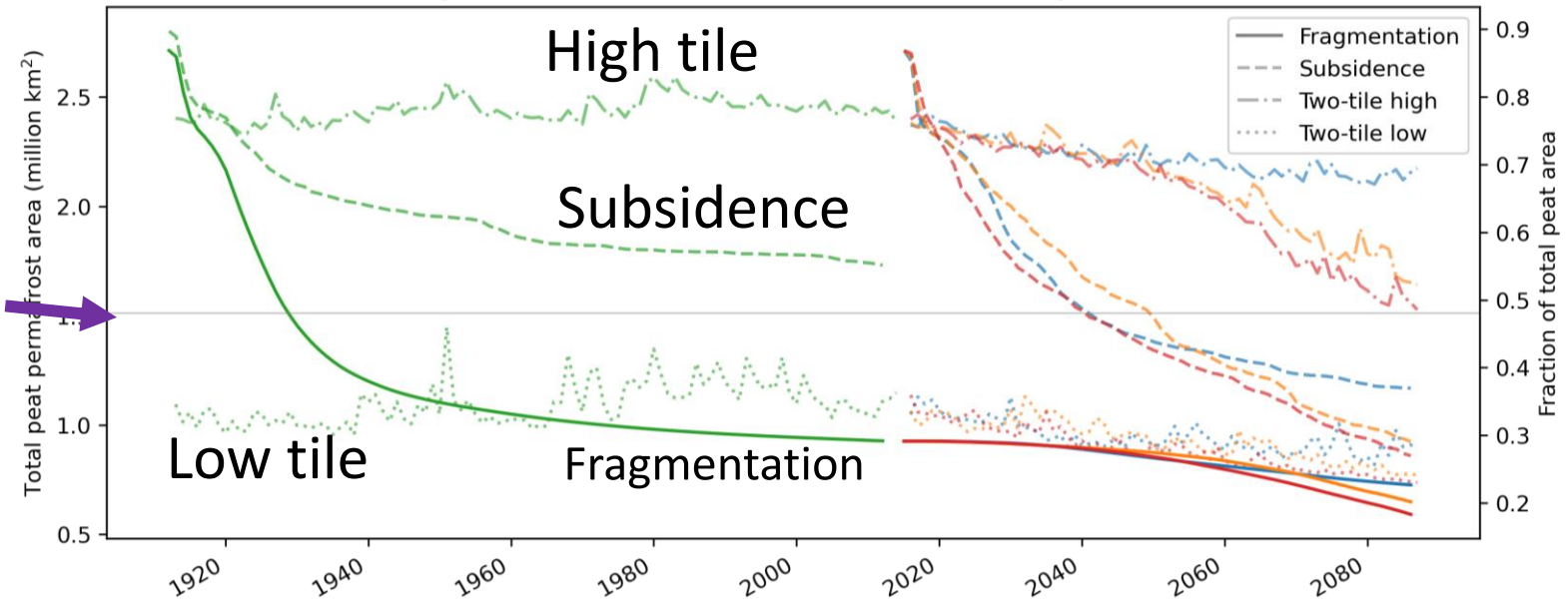
- Thaw rates too large

-> Peat depth probably too small?

- Is restoration of palsas needed?
- Distribution of thaw rates?



Current observed



Summary

- Peat plateaus thaw laterally
- By taking JULES 2D and adding thaw subsidence we can predict lateral thaw rates
- Lateral thaw rates increase with temperature, up to a point
- Fragmentation could be simple
- More testing needed

→ Dynamic tiling in JULES?

The problem of perimeter