Climate change and ecological interactions affecting permafrost temperature regime and ice-wedge activity in the Narsajuaq river valley, Nunavik, Canada

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Introduction

Problems:

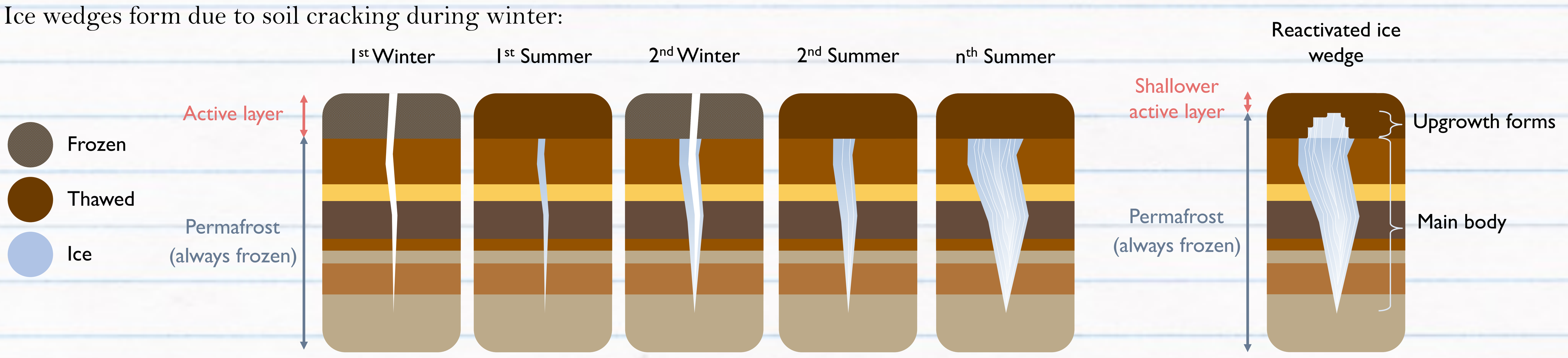
- Studies in the Arctic spanning multiple decades are rare and rarely based on direct measurements
- Ice wedges are widespread in the Arctic and very sensitive to climate warming

Questions:

- How did climate change affect active layer depth and dynamics, and ice-wedge activity over the past 25 years?
- Did the changes in the permafrost/vegetation interactions affect ice-wedge degradation and the permafrost thermal regime over the past decades?

Ice wedges

Ice wedges form due to soil cracking during winter:



Ice wedge are good climate indicators: They grow during cold periods, but are dormant or in degradation during warm periods.

In Nunavik, ice wedges were generally inactive during the first half of the 20th century, but a cooling period from 1946 to 1992 (Figure 2) led to the formation of upgrowth forms. Such forms were noted by Kasper and Allard (2001) in 1991 when ice wedges were very active.

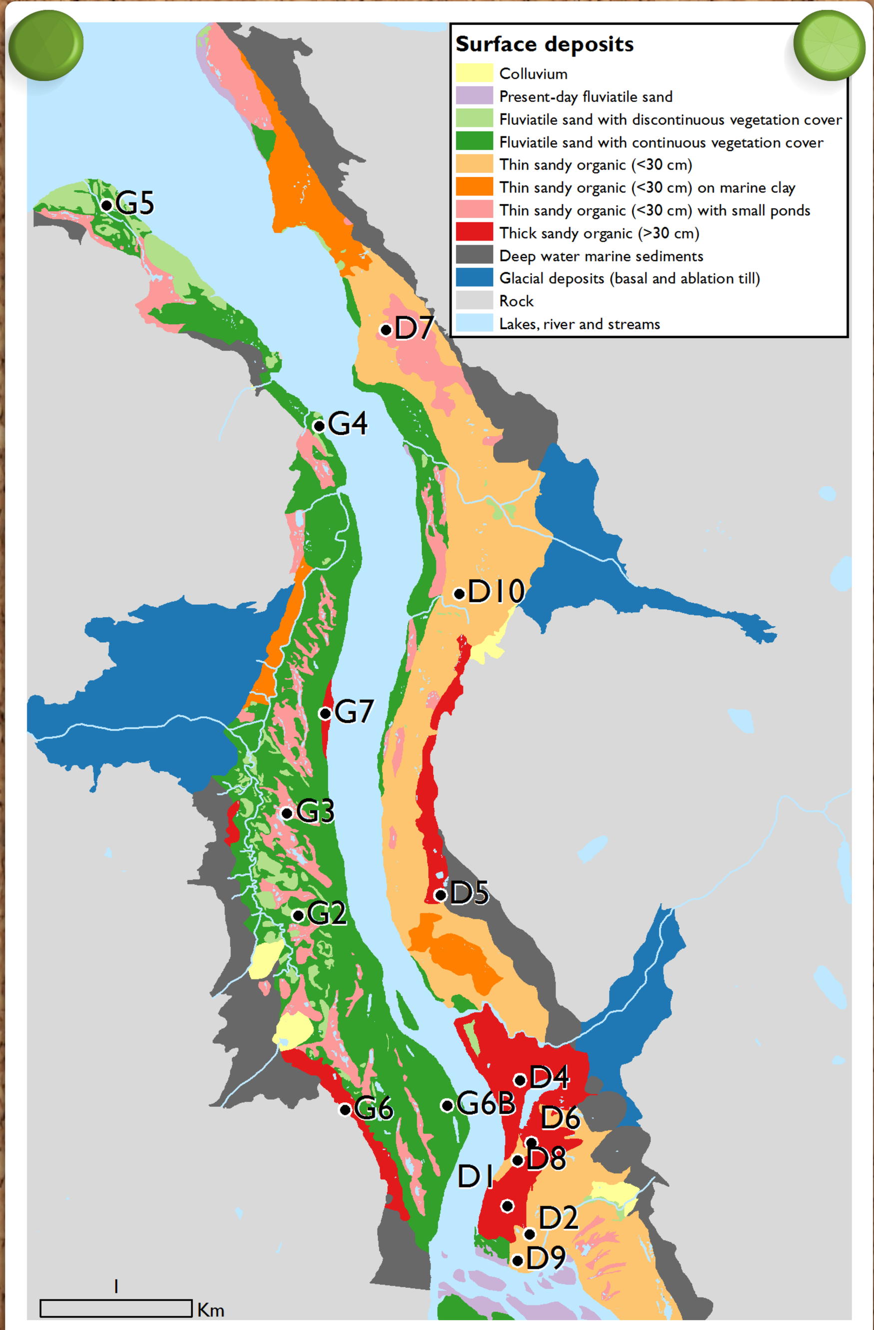
Materials and methods

16 sites revisited:

- Description of polygonal networks
- Comparison of photos (1991 vs 2017)
- Vegetation survey on each site
- Characterization of erosion gullies to investigate the effect of ice wedge degradation on the landscape

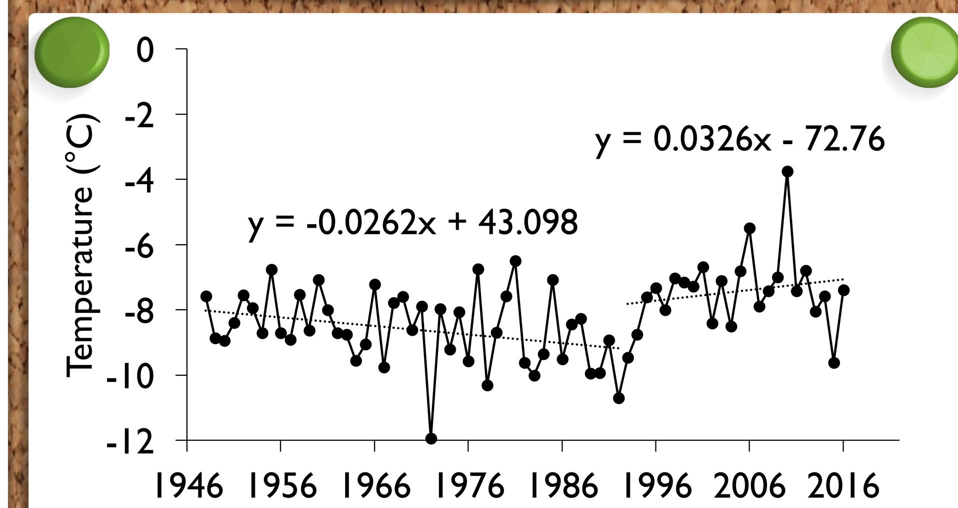
Ice wedges:

- Over 100 holes dug and 260 holes with a soil auger to note surface deposits
- Excavation of ice wedges to note shape, width, depth, color, and upgrowth forms
- Ice wedge activity measured with extensometers



Study site

◀ **Figure 1.** Surface deposit map of the Narsajuaq river valley near Salluit (Nunavik, Canada). We revisited 16 sites that vary in soil type, vegetation, water saturation and terrace level, and that were extensively studied between 1989 and 1991 (Kasper, 1995).



▲ **Figure 2.** Mean annual temperature in Salluit, from 1948 to 2017. Climate warming only started around 1992 whence mean annual air temperatures started to rise from -10 °C then to about -7 °C nowadays.

Results

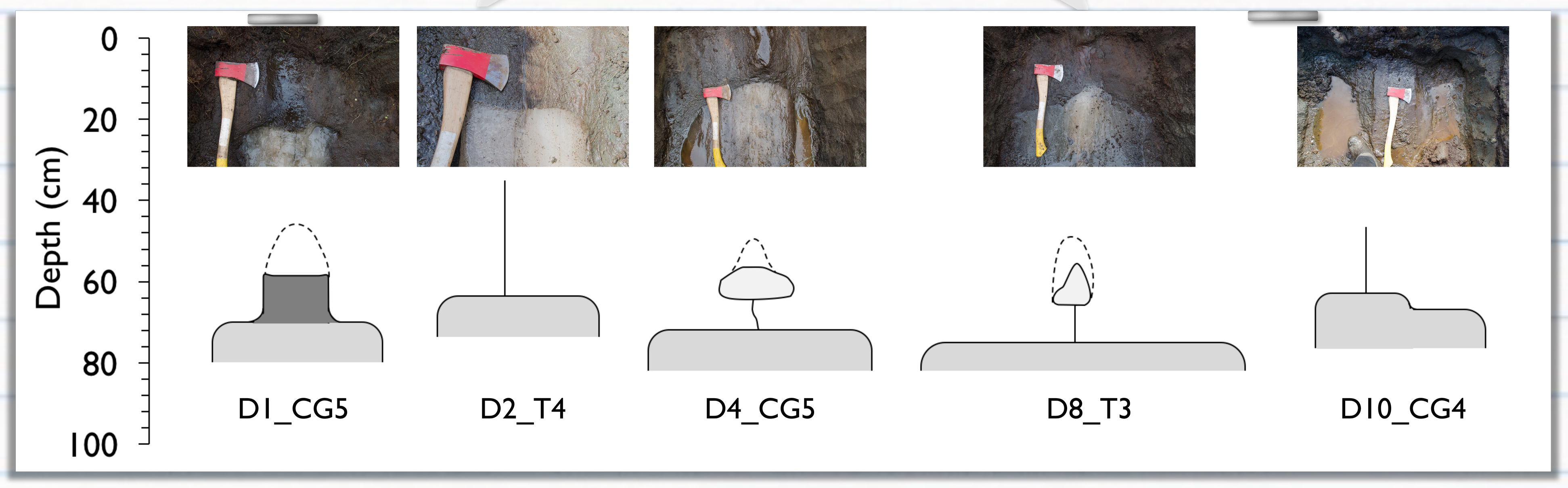


Figure 3. Photos taken from above and cross-sections of ice wedges.

- 94% of the wedges excavated in 1991 had upgrowth forms, less than 10% in 2017 (Figure 3)
- Mostly one-stage wedges with melted tops pre-dating the cooling period of 1946-1992 (Table 1)
- Recently formed ice veins were visible in 75% of the pits with ice wedges
- Underground tunnels in 58% of the pits with ice wedges
- Formation of erosion gullies in some areas (Figure 4)
- More shrubs and drier conditions in 2017 (Figure 5)

Stage	Site					
	D1	D2	D4	D9	D10	G5
1991	Depth (cm)					
A	50	40	55	55	63	85-87
B	40	32	45	50	50	75-77
C	35	27-28	35-37	45	47	70
D	30	21-22	29-32		44	63-65
E	25	18	27		41-42	60
F	20		25			52
G	13		21			
2017						
A	53	61	71	59	74	>110

Table 1. Average depth of the ice-wedge stages measured in 1990-1991 and in 2017 on the same sites.

Figure 4. Photos of underground tunnels (a-b) and of a collapsed tunnel (c) on D4.

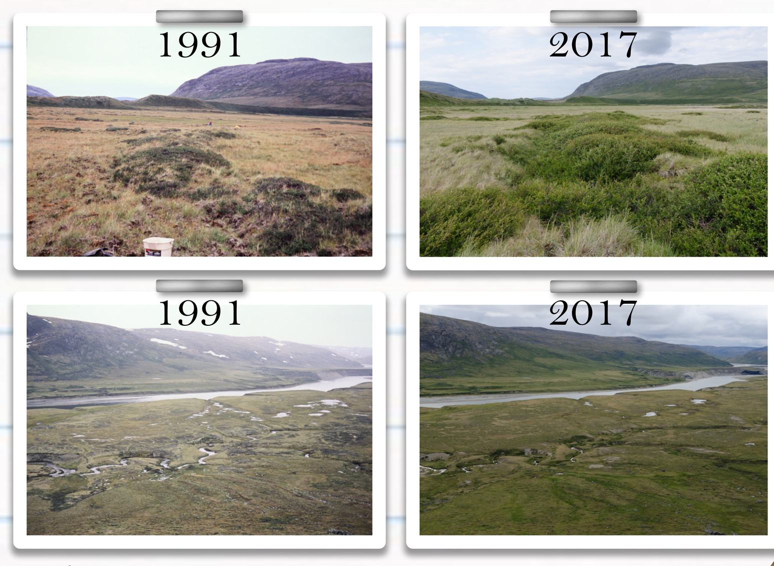


Figure 5. Comparison 1991 vs 2017.

Discussion

- Melting of the ice-wedge upgrowth forms was twice as fast as their formation
- Ice wedges were active due to recent cooling, but this will become increasingly rare as temperatures are expected to increase rapidly over the next decade
- Underground tunnels form above ice wedges when ice melts, but collapse from below because deeper mineral soil layers are not as cohesive as top organic layers and deeper layers are subject to more pressure (Figure 6)
- If the surface deposits are mostly organic, the tunnels can grow in size on the wedges and eventually collapse, forming erosion gullies and thus changing the landscape (Figure 4)
- The increased shrub cover might be accumulating more snow in zones of depression and decreasing ice-wedge activity in some areas due to a better insulation of the ground

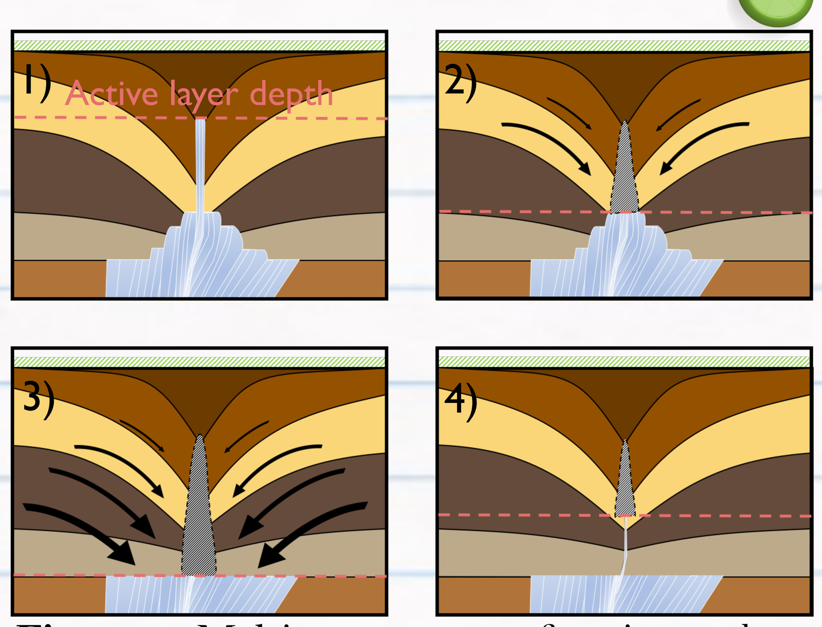


Figure 6. Melting sequence of an ice wedge with upgrowth forms leading to the formation of an underground tunnel above the wedge.

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