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Comparing thaw probing, electrical resistivity tomography, and airborne lidar to quantify lateral and vertical thaw in rapidly degrading boreal permafrost

Thomas A. Douglas et al.

Correspondence to: Thomas A. Douglas (thomas.a.douglas@usace.army.mil)

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Sect. S1

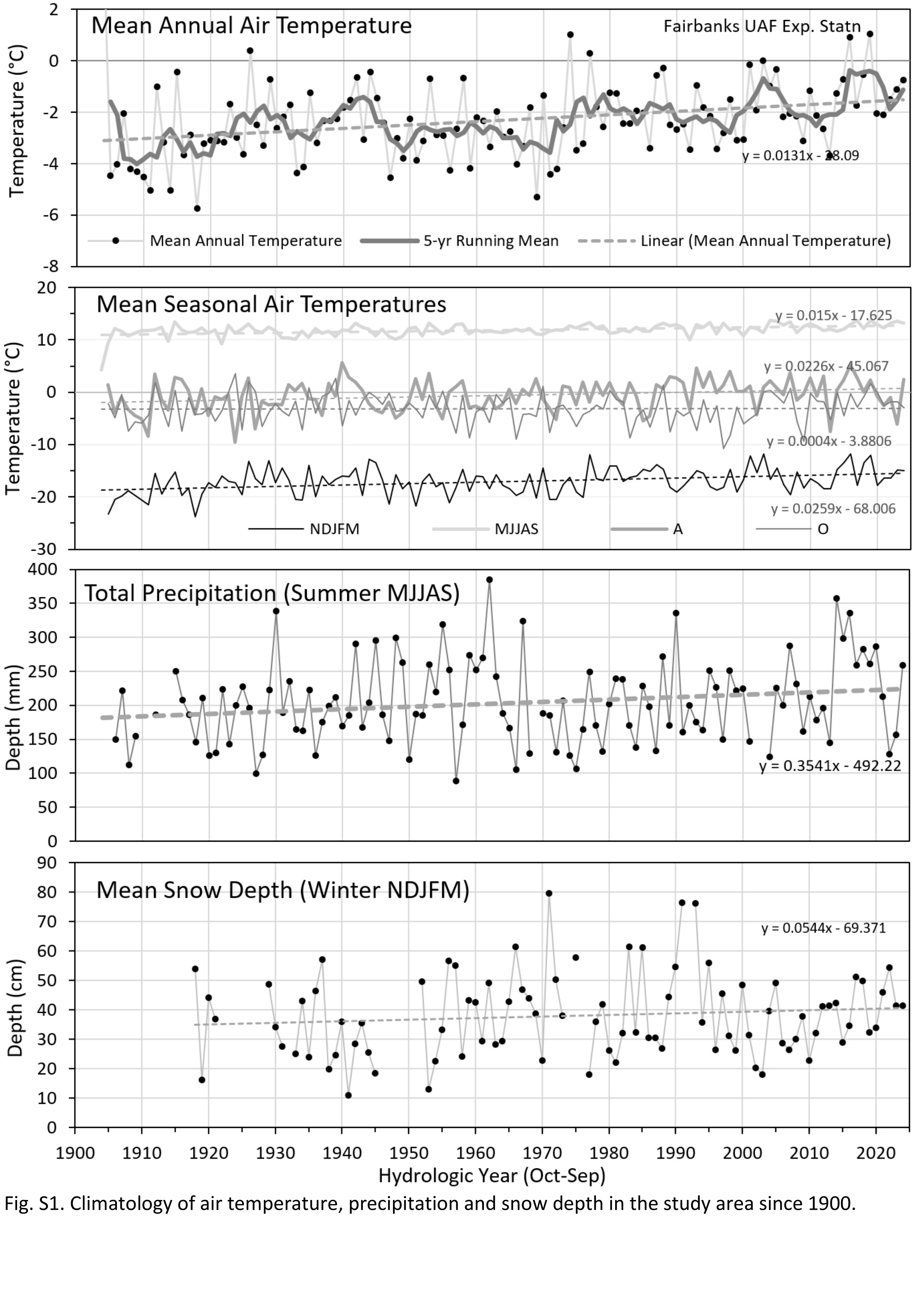

Fig. S1. Climatology of air temperature, precipitation and snow depth in the study area since 1900.

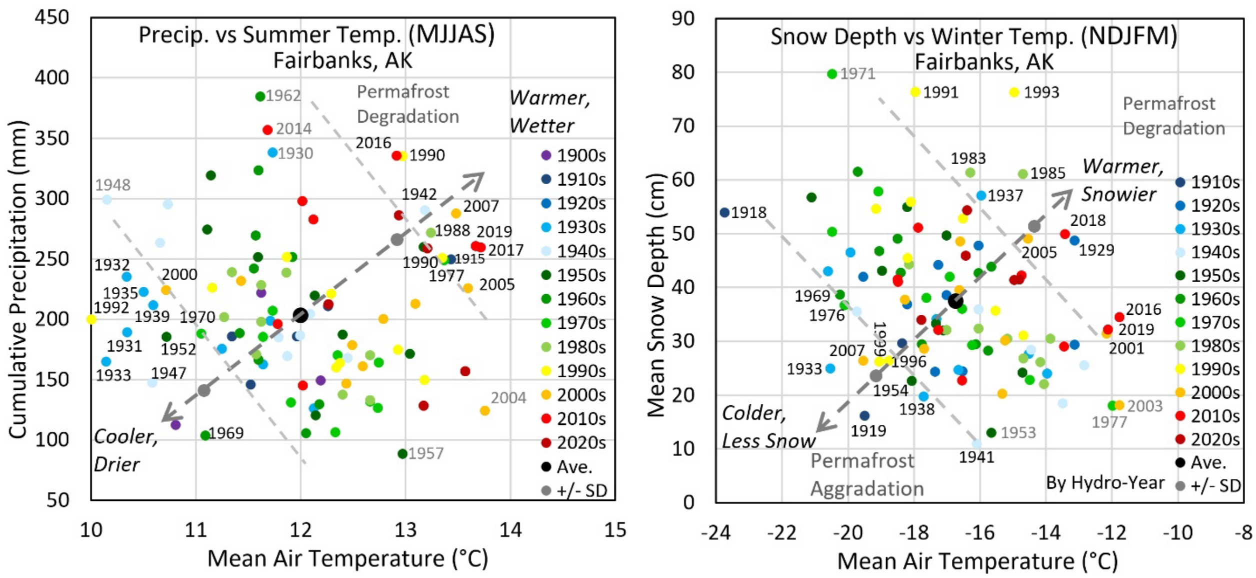

Fig. S2. Summaries of (left) mean temperature with cumulative summer (May-September; MJJAS) precipitation and (right) average end of winter (November-March; NDJFM) snow depths on the ground. In each plot color values represent decades, the overall average value is identified by the black dot, and ±1 standard deviation from the mean is shown by the grey dots. The dark grey dashed line with arrows bisects standard deviations of precipitation and snow on the ground and this represents the gradient between warmer/wetter and cooler/drier conditions. The light grey dashed lines perpendicular from the gradient are constrain the 10% most extreme years at the end of each gradient which are labeled in black. Extreme values for only one given condition are in grey text. Permafrost is vulnerable to thaw during warm and wet summers and warm and snowy winters. Colder and less snowier conditions and cooler drier summers favor permafrost stability or aggradation. Updated from Jorgenson et al. (2020).

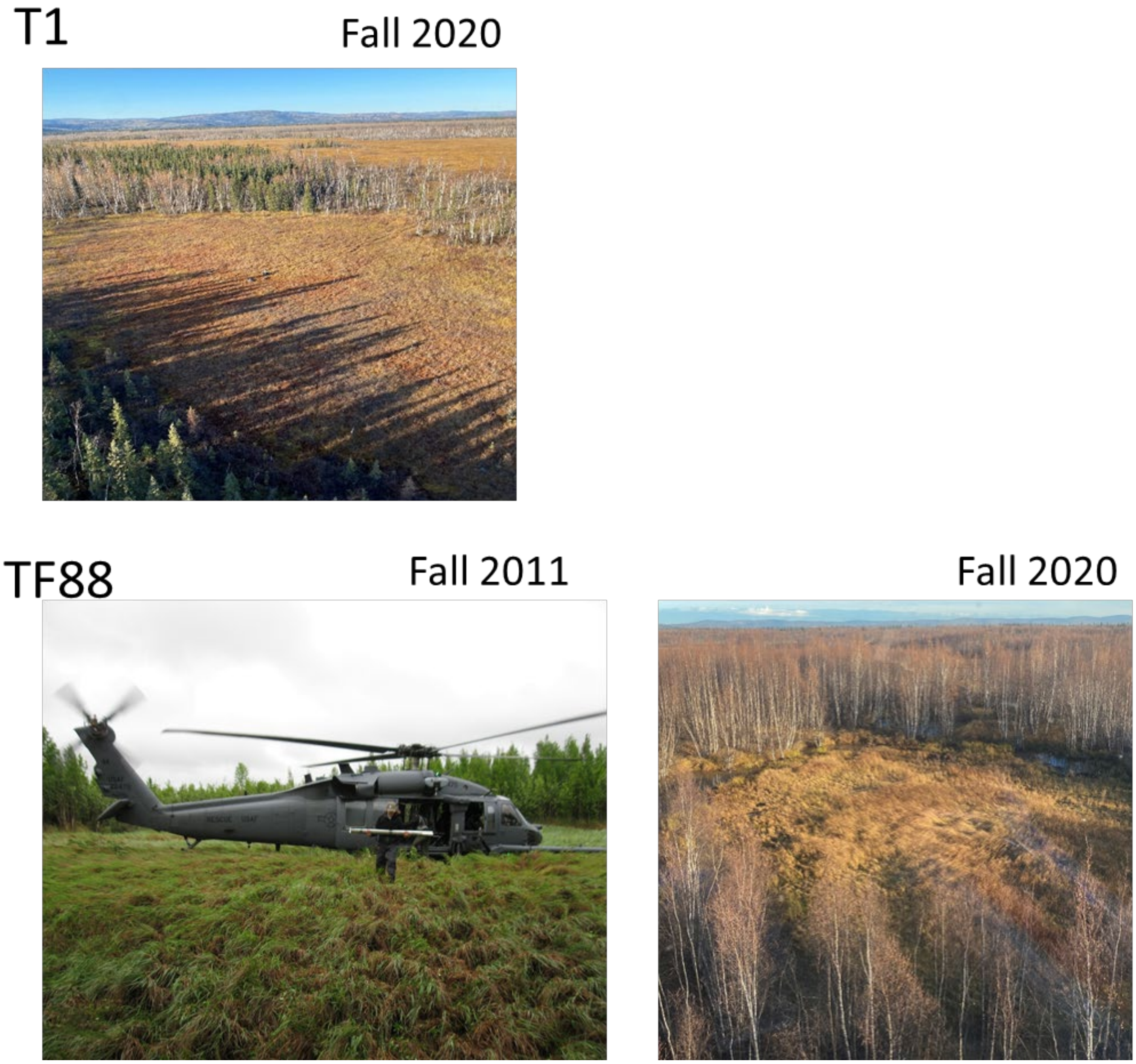

Fig. S3. Example photos from sites T1 and TF88.

TF01 Fall 2011 Fall 2020

TF10 Fall 2011 Fall 2020

Fig. S4. A summary of photos from sites TF01 and TF10.

Fig. S5. Photographs of the different permafrost types from our study sites.

Table S1. A summary of the permafrost stages.

Degradation stage		**Code**	**Description**
Undegraded		UD	Stable permafrost with thaw depths within the range of normal variation. In the mid-boreal region with fine-grained soils, thaw depths typically are <0.8 m
Degradation-initial		DI	The initial stage of permafrost degradation that exceeds the normal variation of stable permafrost, but does not yet create a closed talik, the thin unfrozen zone between the active layer and permafrost table. Thaw depths increased over time to >1.1 m. This stage is more applicable to arctic regions, where permafrost causes shallow depressions. It is particularly useful for situations where the active layer has increased sufficiently to thaw underlying ice wedges.
Degradation-progressive	Degradation-progressive-shallow	DPS	The progressive increase in thaw depths below the zone of seasonal freezing and thawing, resulting in the expansion of a closed talik. Depths to the permafrost table can still be measured, but different from DPD where thaw probing no longer encounters the permafrost table. This is useful because increases in thaw depths for DPS can still be calculated. For warm permafrost in mid-boreal regions, thaw depths >1.1 m typically indicate a closed talik. Thaw probing to depths of 3 m in fine-grained soils typically is reliable.
	Degradation-progressive-deep	DPD	Similar to above, except thawing probing does not encounter the top of permafrost. This stage typically is limited to small surface depressions <10 m across. Large features may be Degradation-Complete
Degradation-lateral		DL	Lateral degradation is used to define permafrost thaw that occurs along margins of permafrost plateaus and thermokarst features. The lateral thaw can cause a sloping boundary near the top of permafrost or a thermal niche well below the permafrost table due to warm subsurface water temperatures. This stage can occur even under cold climates.
Degradation-complete		DCO	This stage is associated with open taliks where permafrost has thawed completely through the permafrost zone. It can sometimes be detected with electrical resistivity tomography when permafrost is relatively thin (<30 m thick). More typically, DC is assumed to be present under large thermokarst bogs and fens.

Table S2. Thaw extent (m^2) and volumetric settlement loss (m^3) due to lateral and vertical thaw derived from repeat LiDAR DEMs for a 300 m by 500 m buffered area around each transect.

Transect		Percent	Extent	Volume
T1	Lateral	16.1	24097	1595
	Vertical	37.2	55806	4381
TF01	Lateral	18.2	27297	2125
	Vertical	29.7	44509	3447
TF10	Lateral	17.7	26555	5015
	Vertical	46.1	69125	9755
TF88	Lateral	10.5	15732	374
	Vertical	60.8	91206	3350