# Environmental controls on ground temperatures in Labrador, northeast Canada

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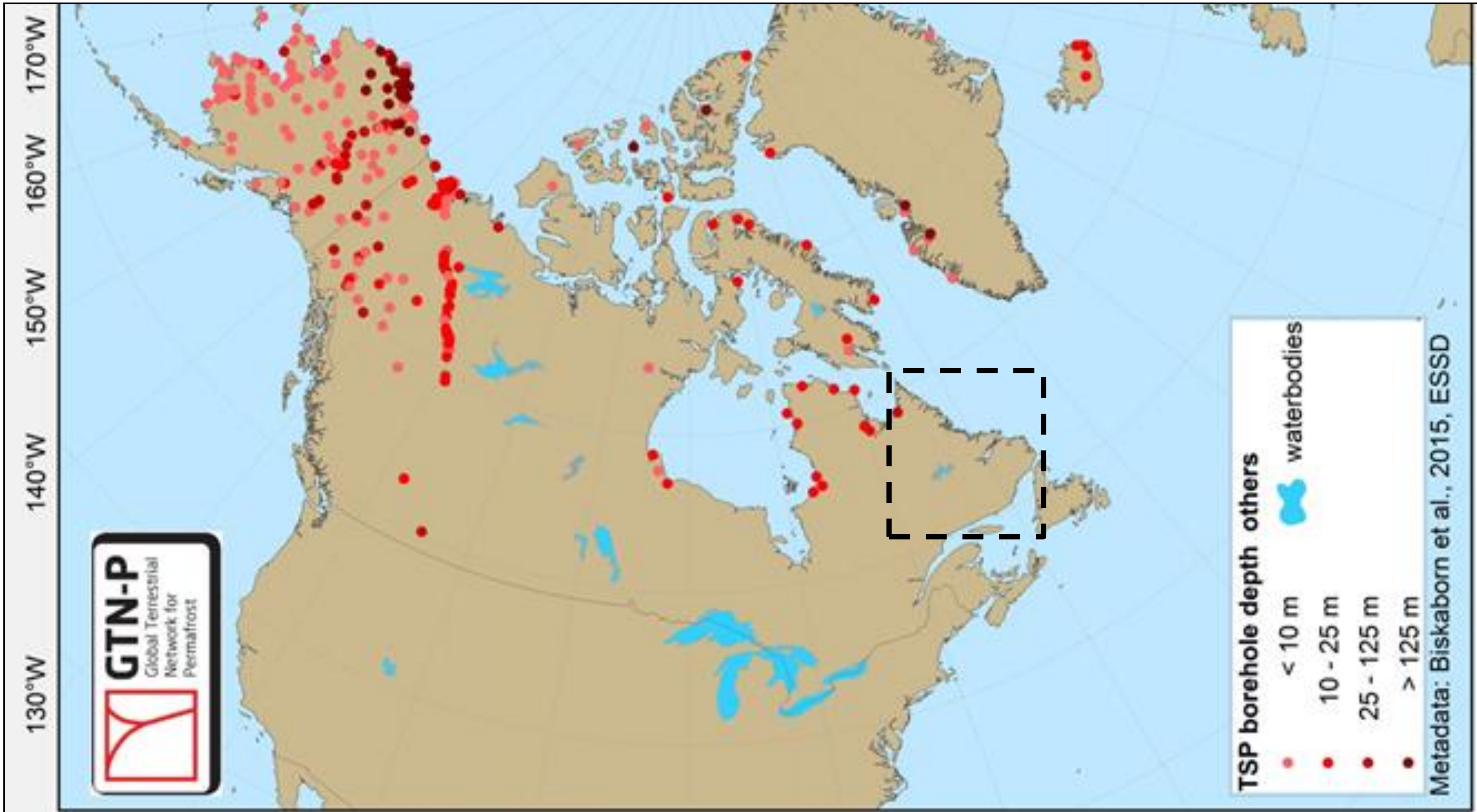
# Study area

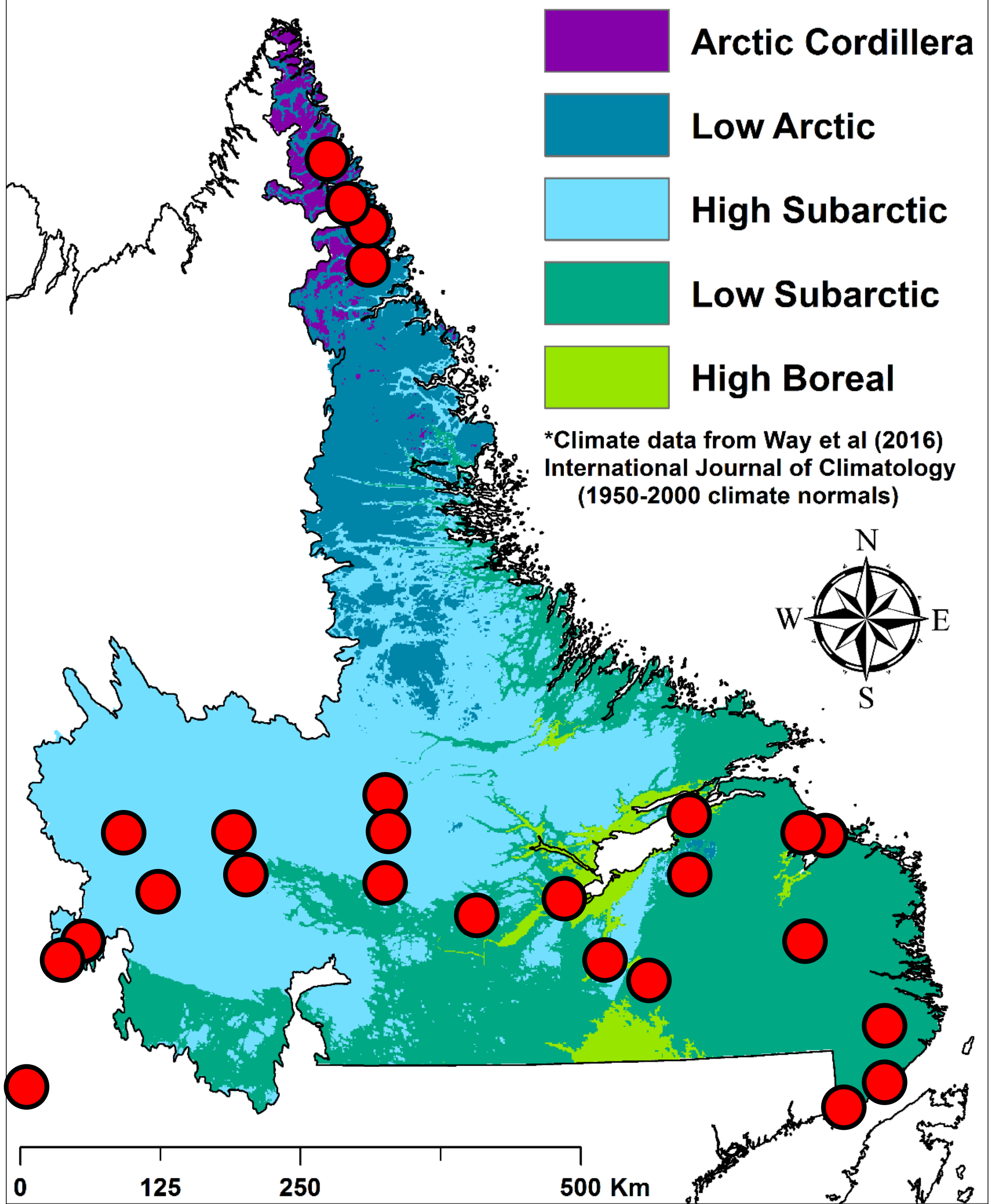


170°W
160°W
150°W
140°W
130°W
GTN-P
Global Terrestrial Network for Permafrost
TSP borehole depth
< 10 m
10 - 25 m
25 - 125 m
> 125 m
others
waterbodies
Metadata: Biskaborn et al., 2015, ESSD

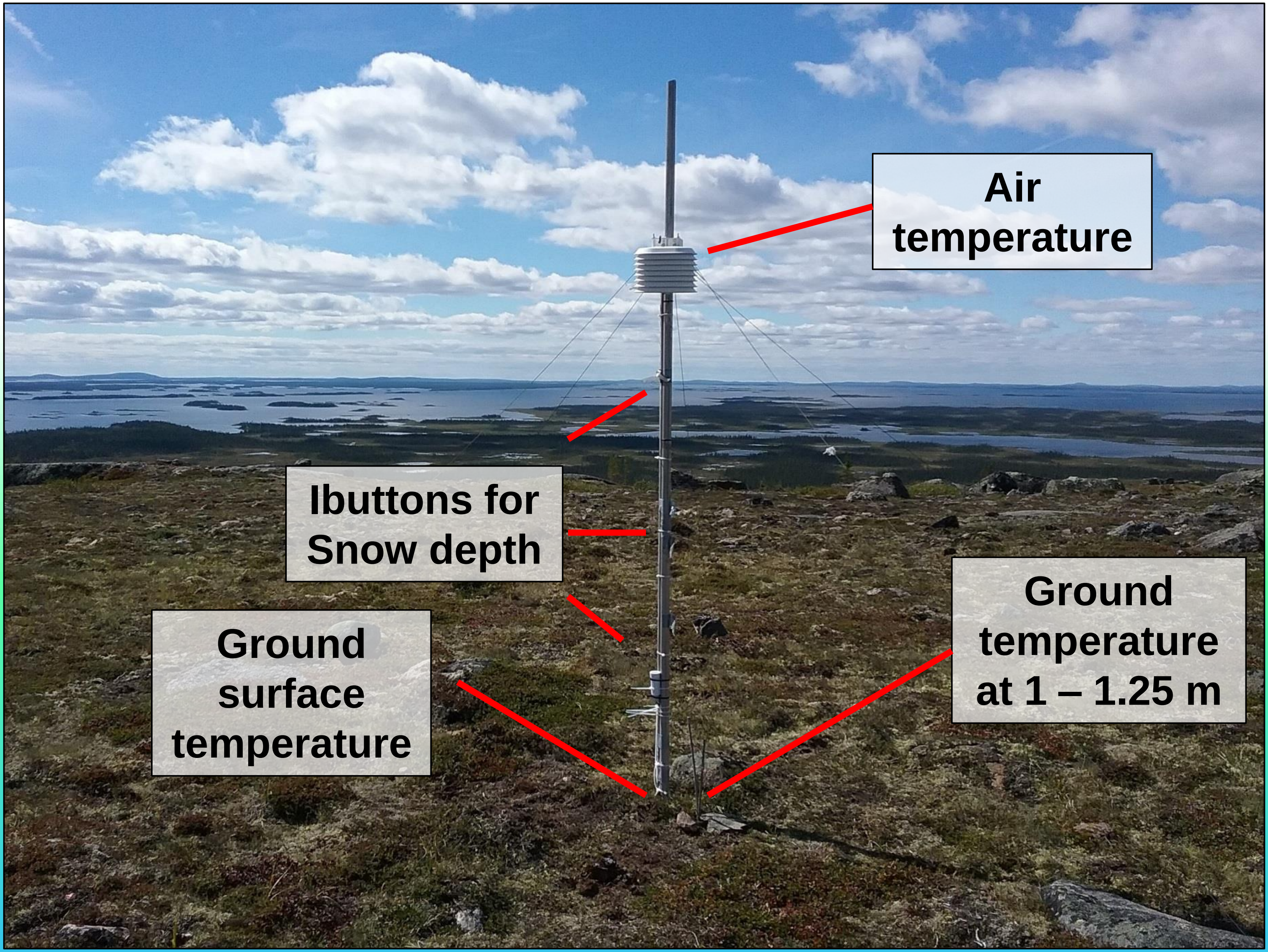
# Permafrost thaw in Nain, Nunatsiavut, Labrador

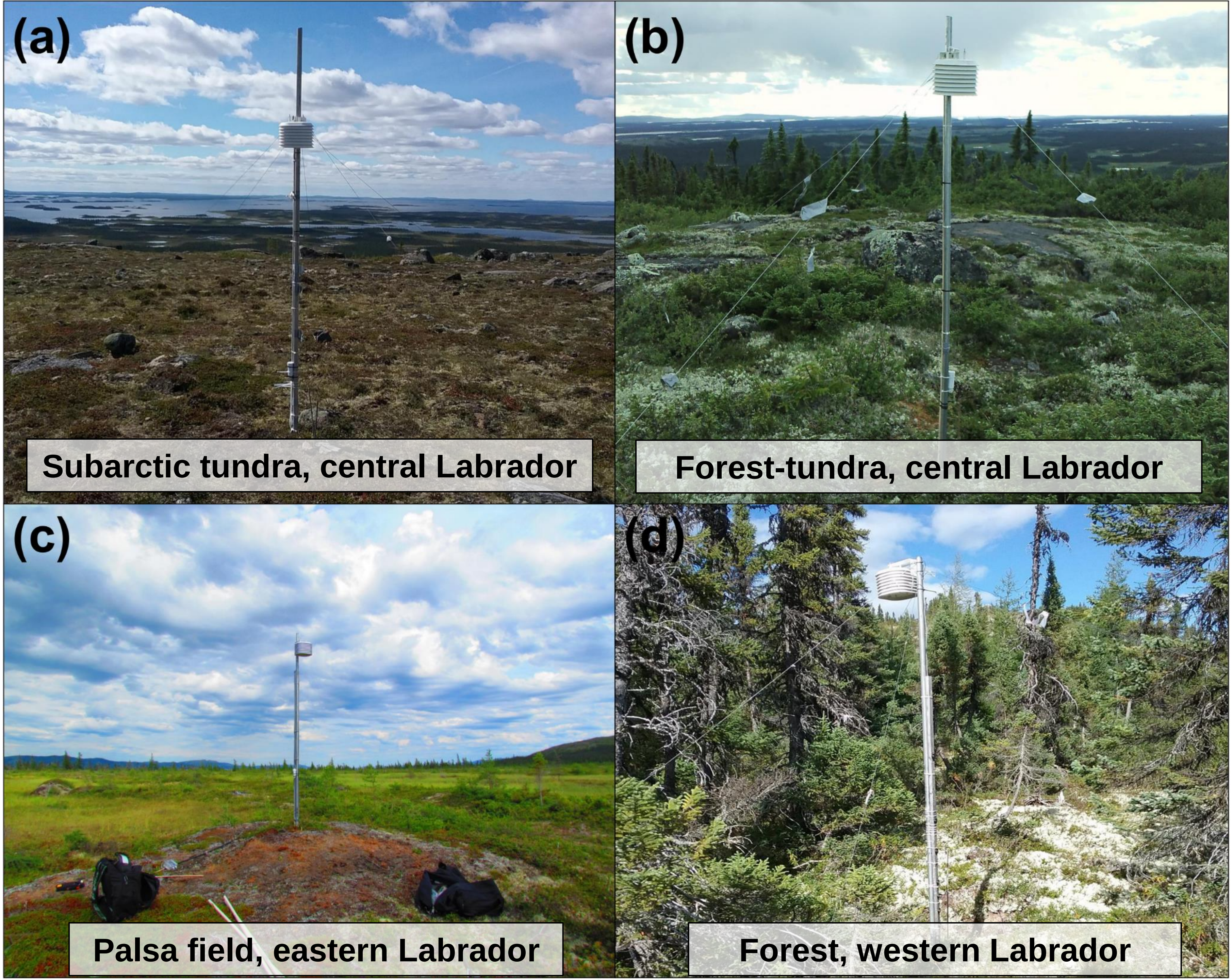

*Allard et al. (2012)

# Temperature zones in Labrador



# Climate and permafrost monitoring




(a)
Subarctic tundra, central Labrador
(b)
Forest-tundra, central Labrador
(c)
Palsa field, eastern Labrador
(d)
Forest, western Labrador

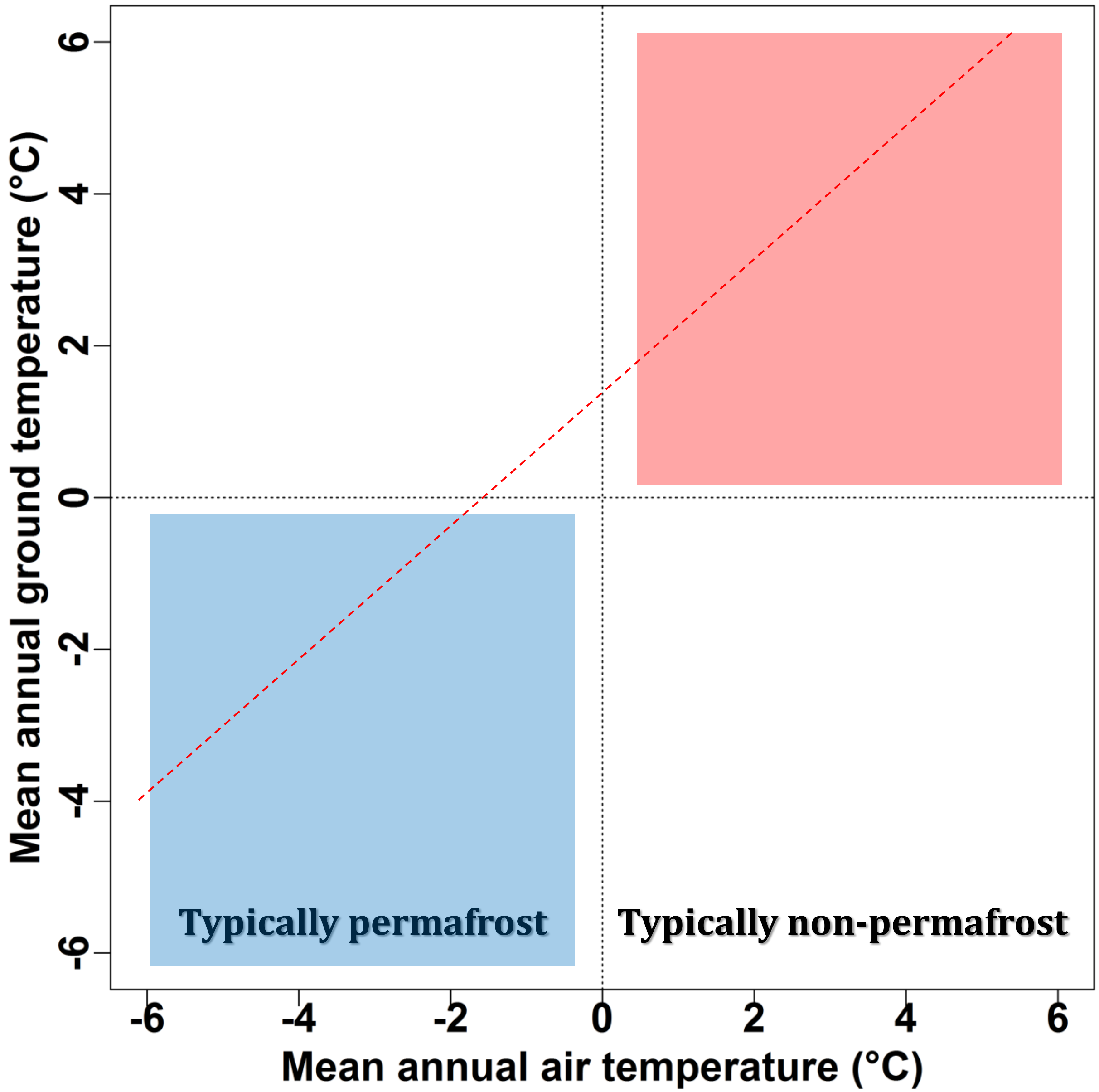
# Measured and derived parameters

Table 1: Field-measured or derived parameters.

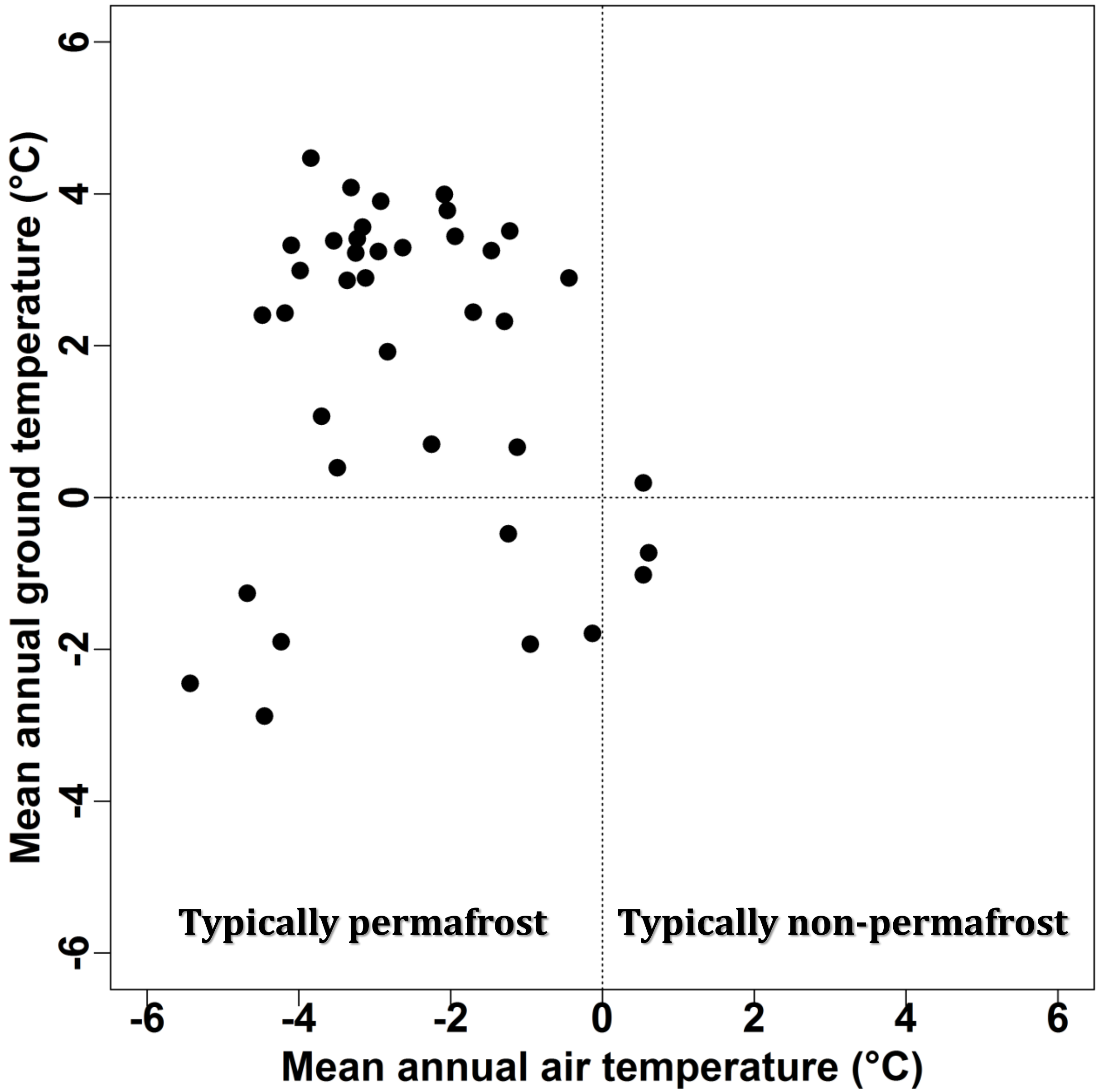
| Parameter | Acronym | Units | Calculation method |
|---|---|---|---|
| Mean annual air temperature | MAAT | °C | (TDDa - FDDa) ÷ 365 |
| Freezing n-factor | nf | unitless | FDDs ÷ FDDa |
| Mean annual ground temperature | MAGT | °C | Mean annual ground temperature at the top of the perennially frozen or unfrozen ground |

***Following Smith and Riseborough (2002) and Way and Lewkowicz (2018)**

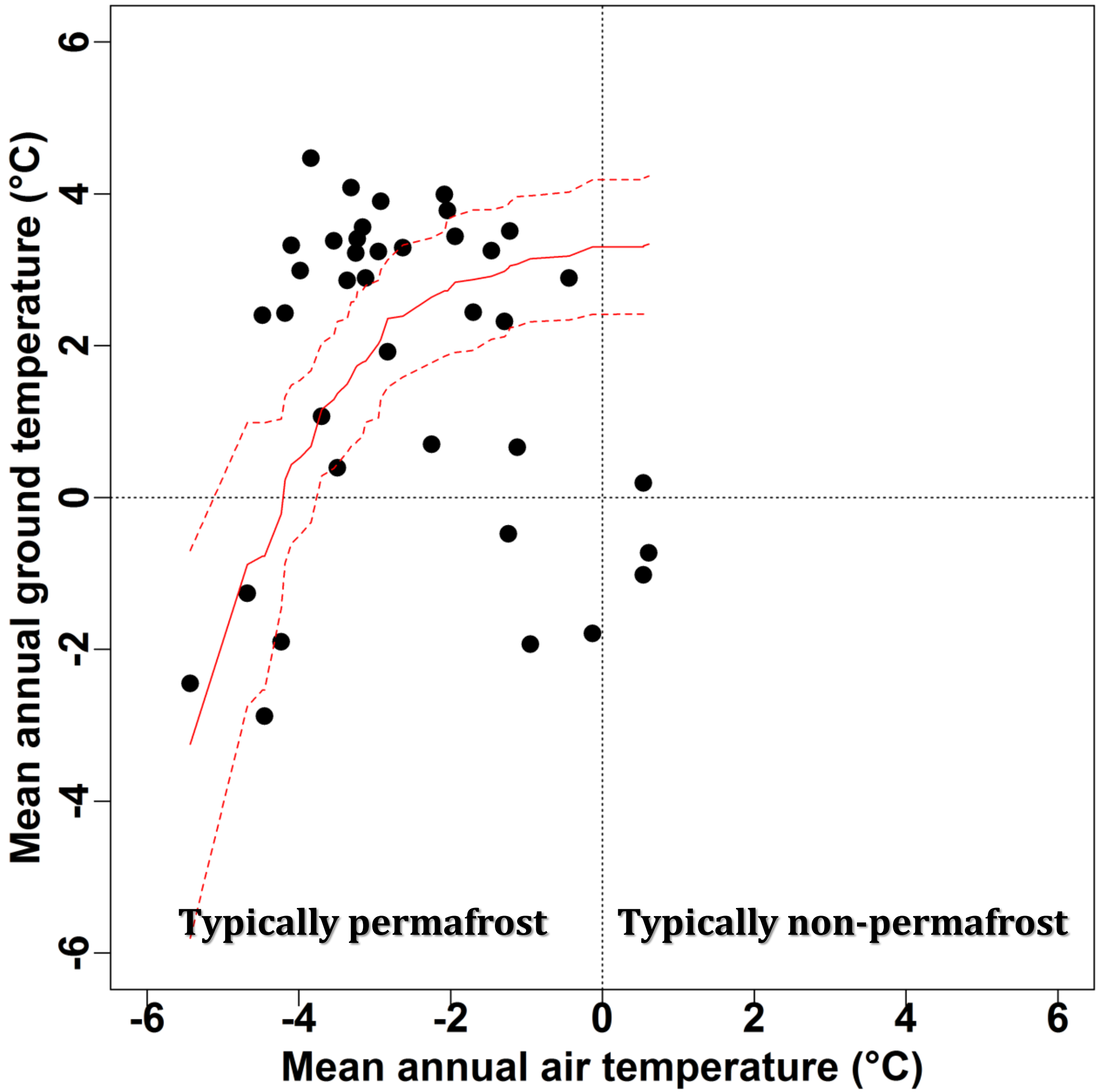
# MAAT vs MAGT at field sites



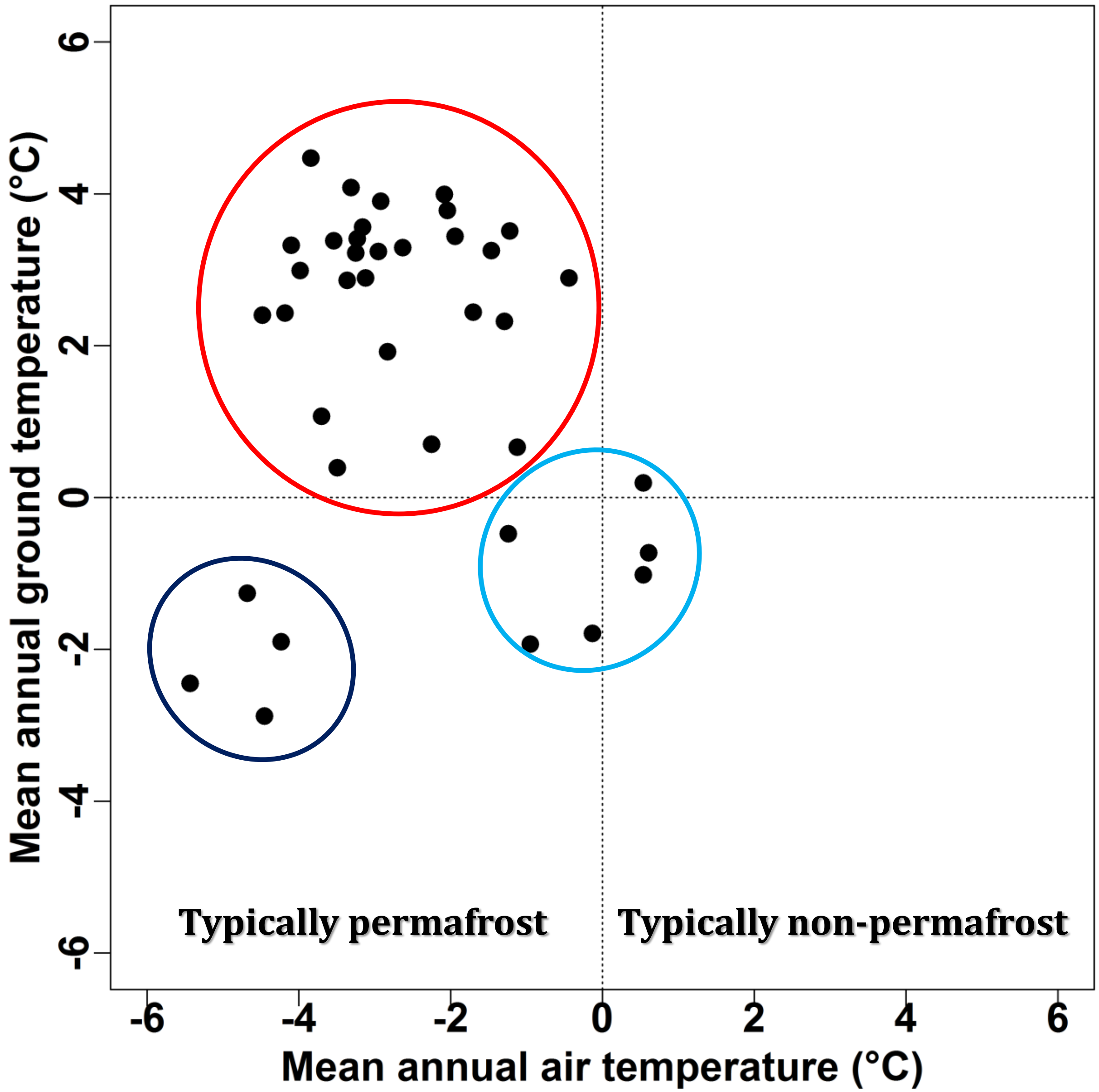
# MAAT vs MAGT at field sites

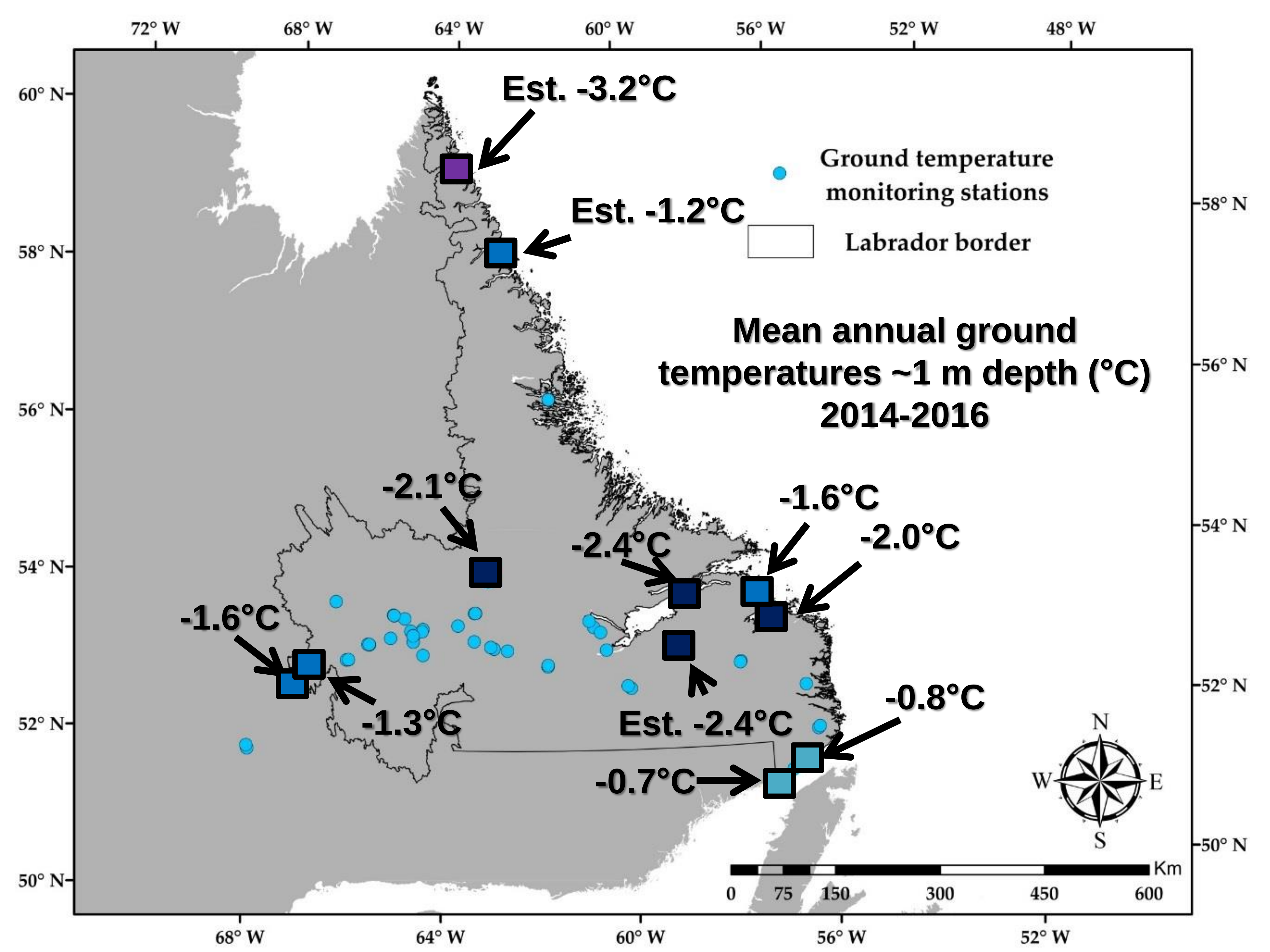


# MAAT vs MAGT at field sites



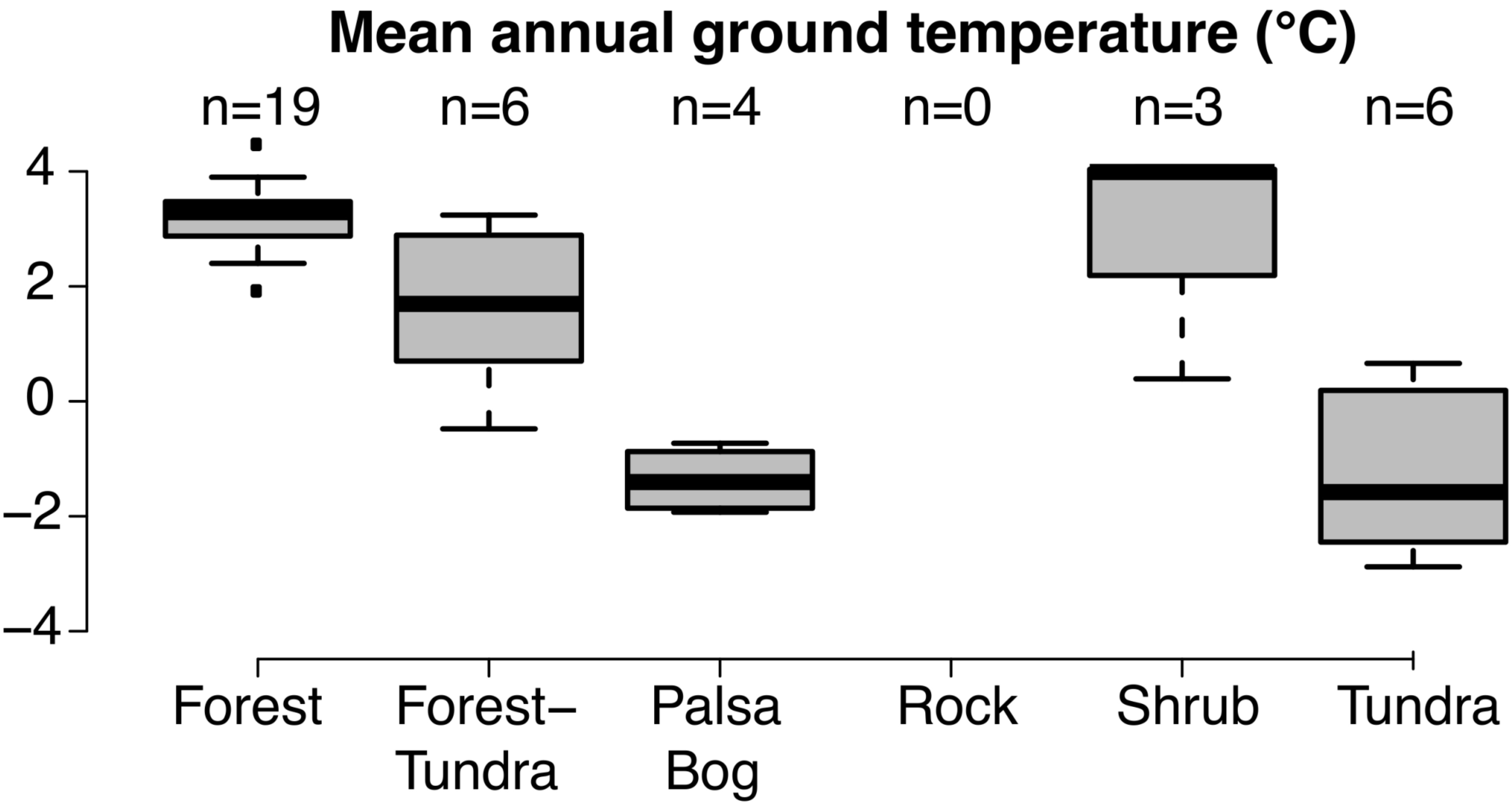
# MAAT vs MAGT at field sites



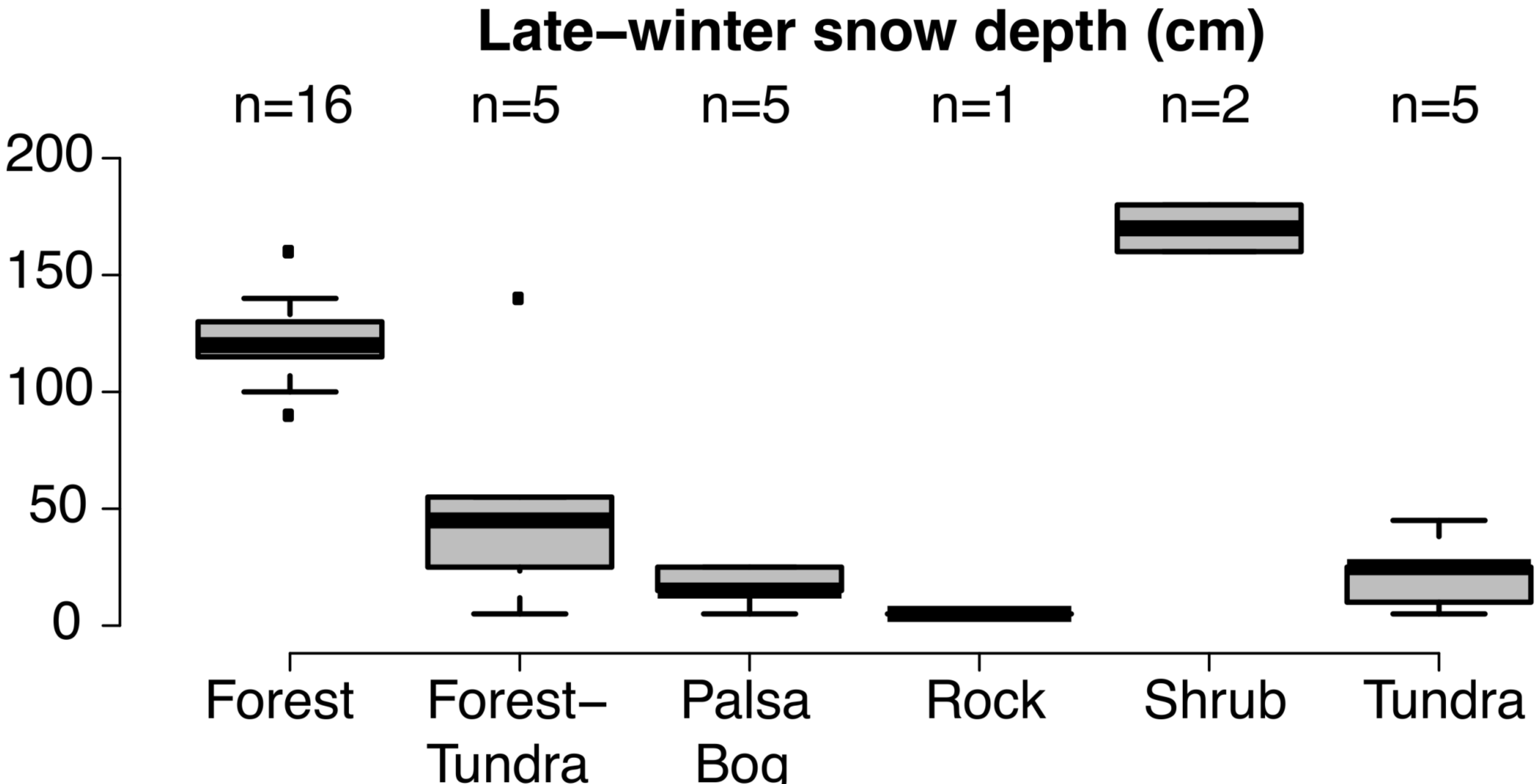


Est. -3.2°C
Est. -1.2°C
Ground temperature monitoring stations
Labrador border
Mean annual ground temperatures ~1 m depth (°C) 2014-2016
-2.1°C
-1.6°C
-2.4°C
-2.0°C
-1.6°C
-1.3°C
Est. -2.4°C
-0.8°C
-0.7°C
72° W
68° W
64° W
60° W
56° W
52° W
48° W
60° N
58° N
56° N
54° N
52° N
50° N
N
S
E
W
Km
0
75
150
300
450
600

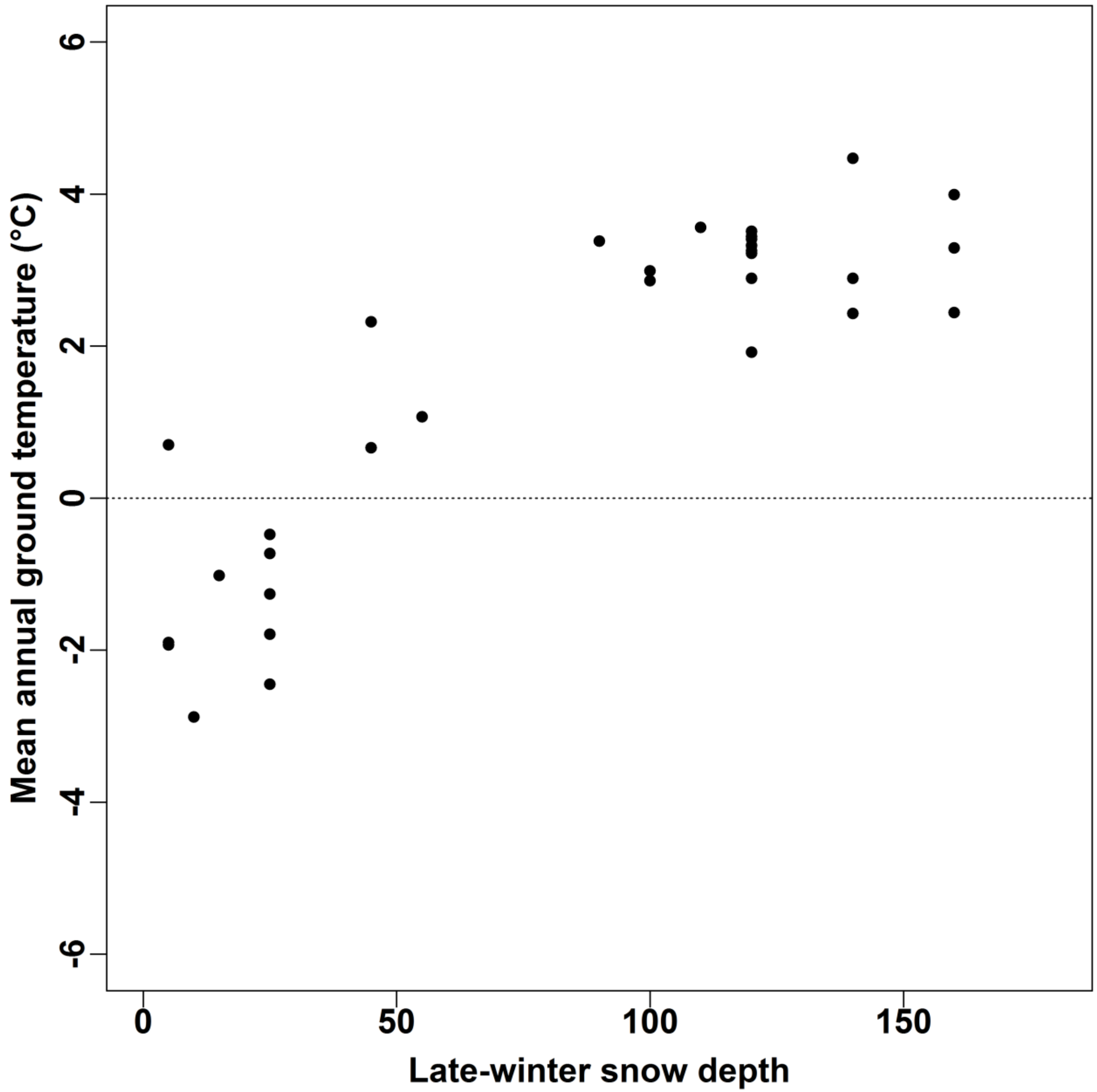
# Land cover class and MAGT at field sites



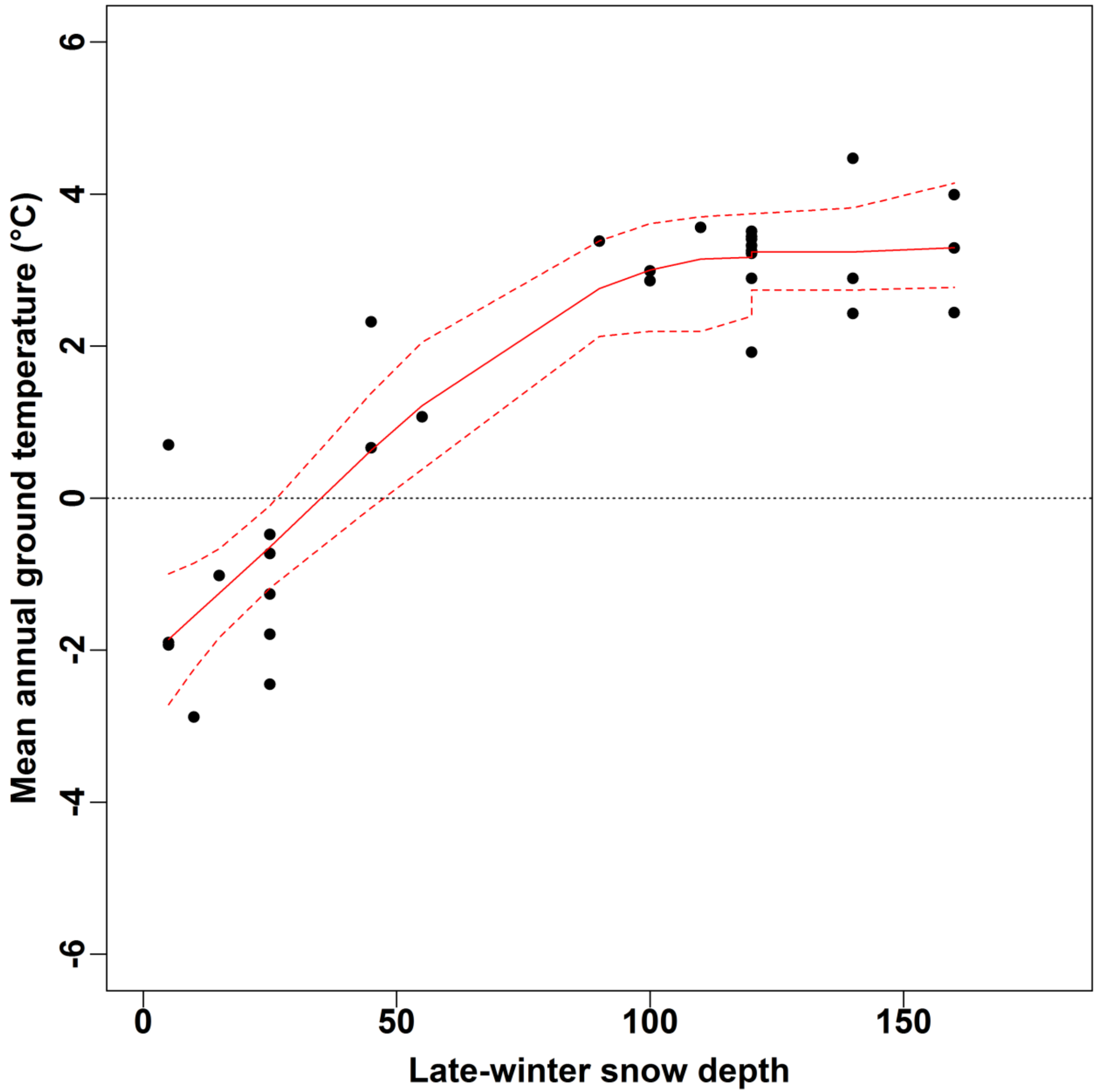
# Land cover class and LWSD at field sites



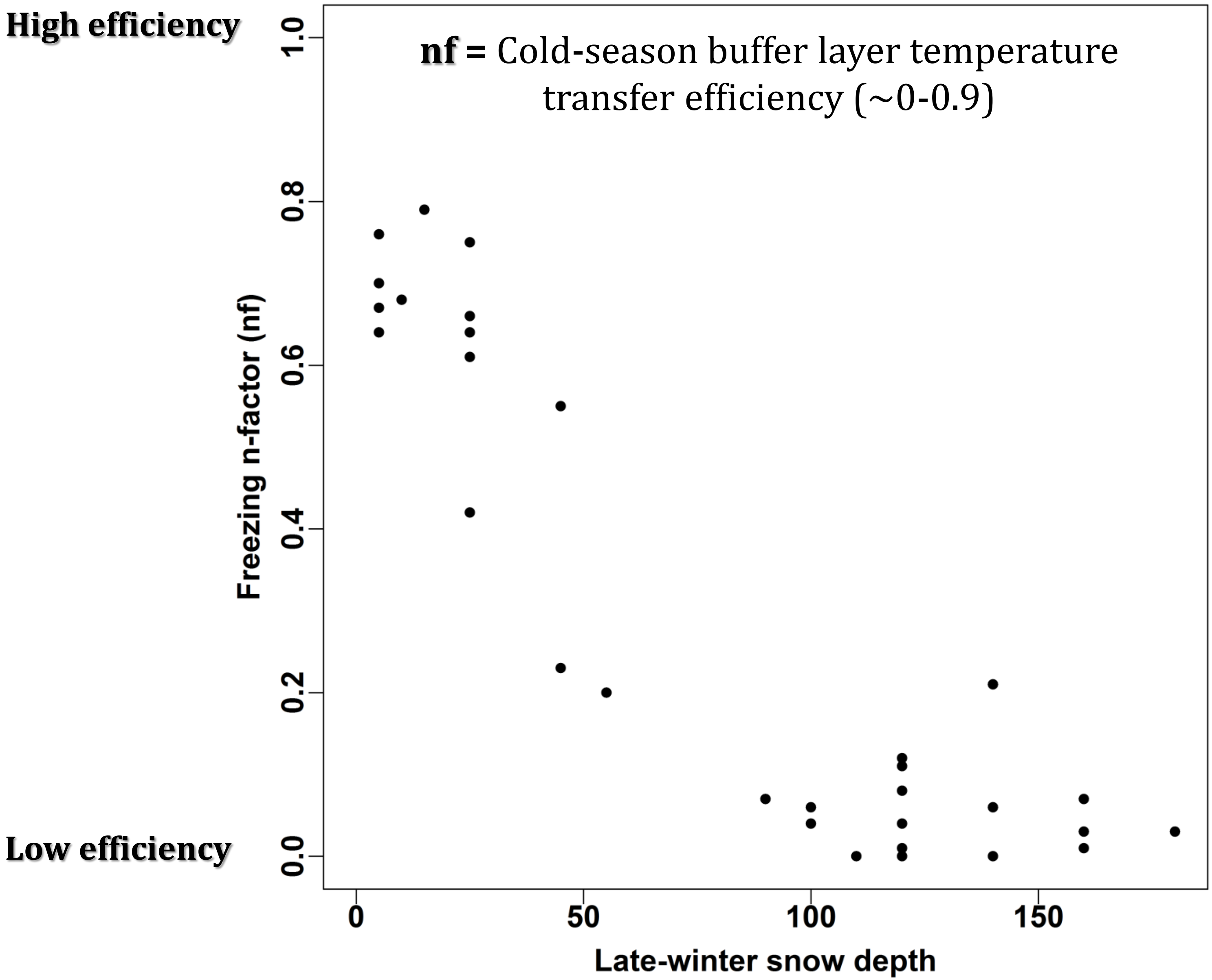
# LWSD vs MAGT at field sites

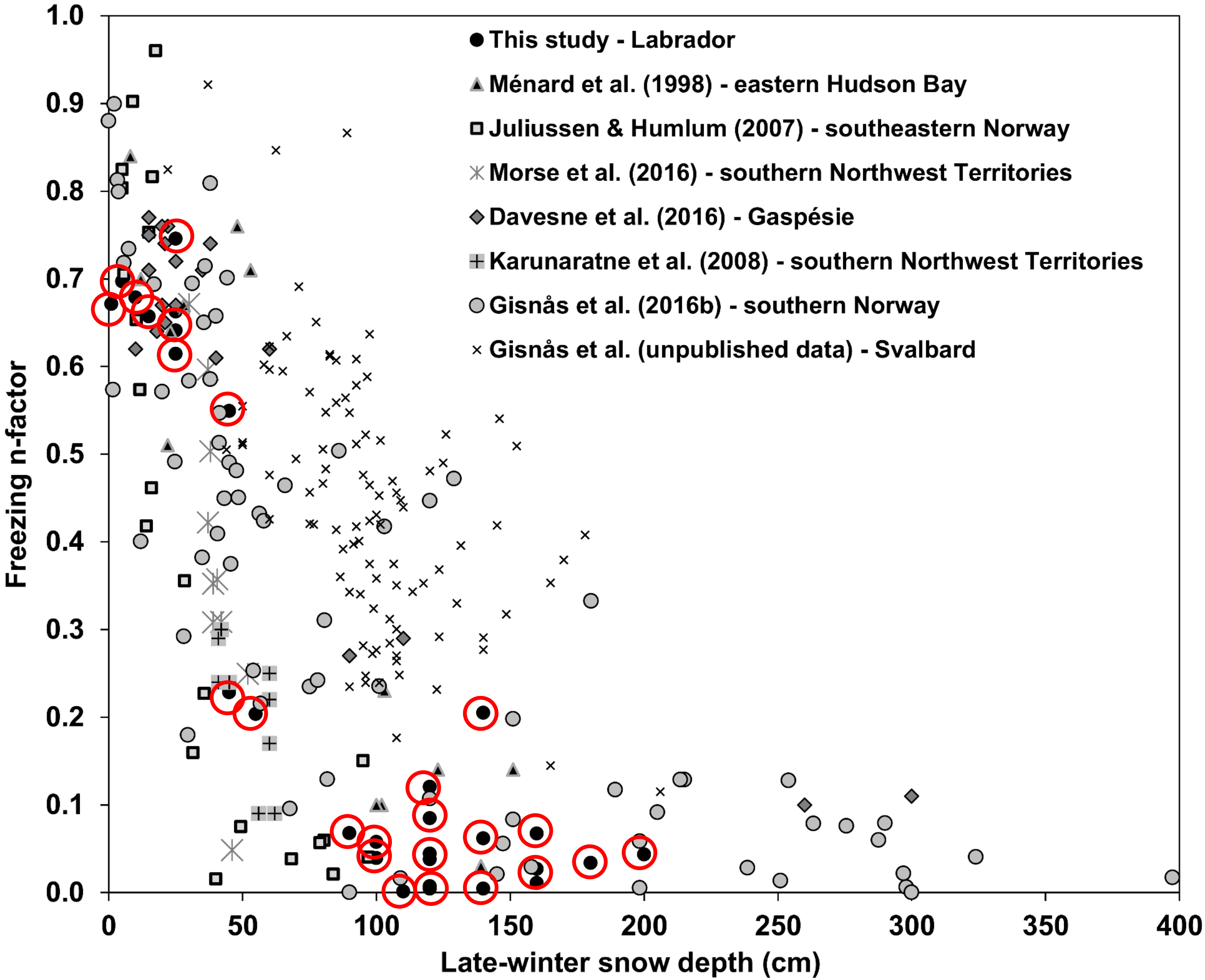


# LWSD vs MAGT at field sites

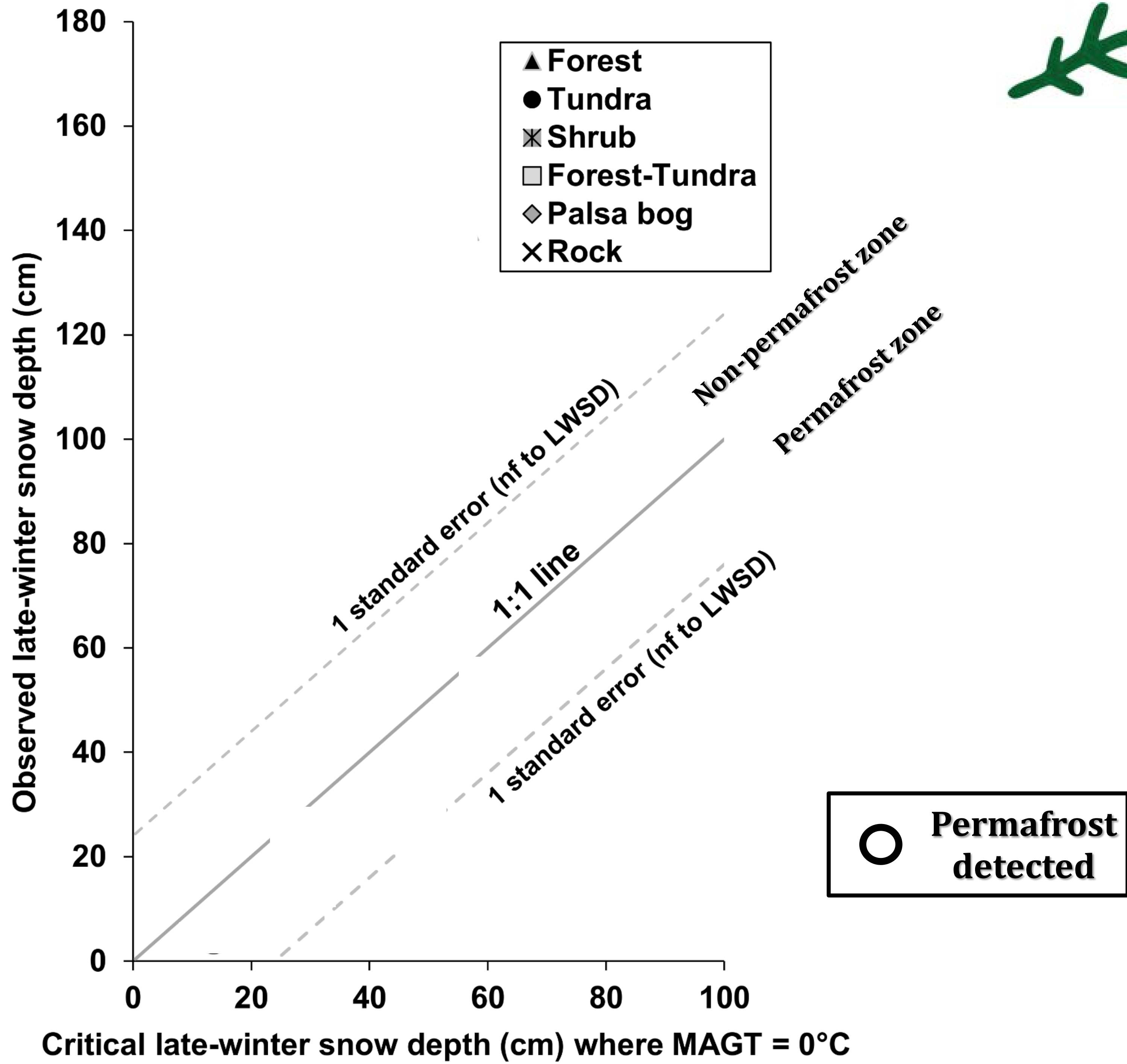


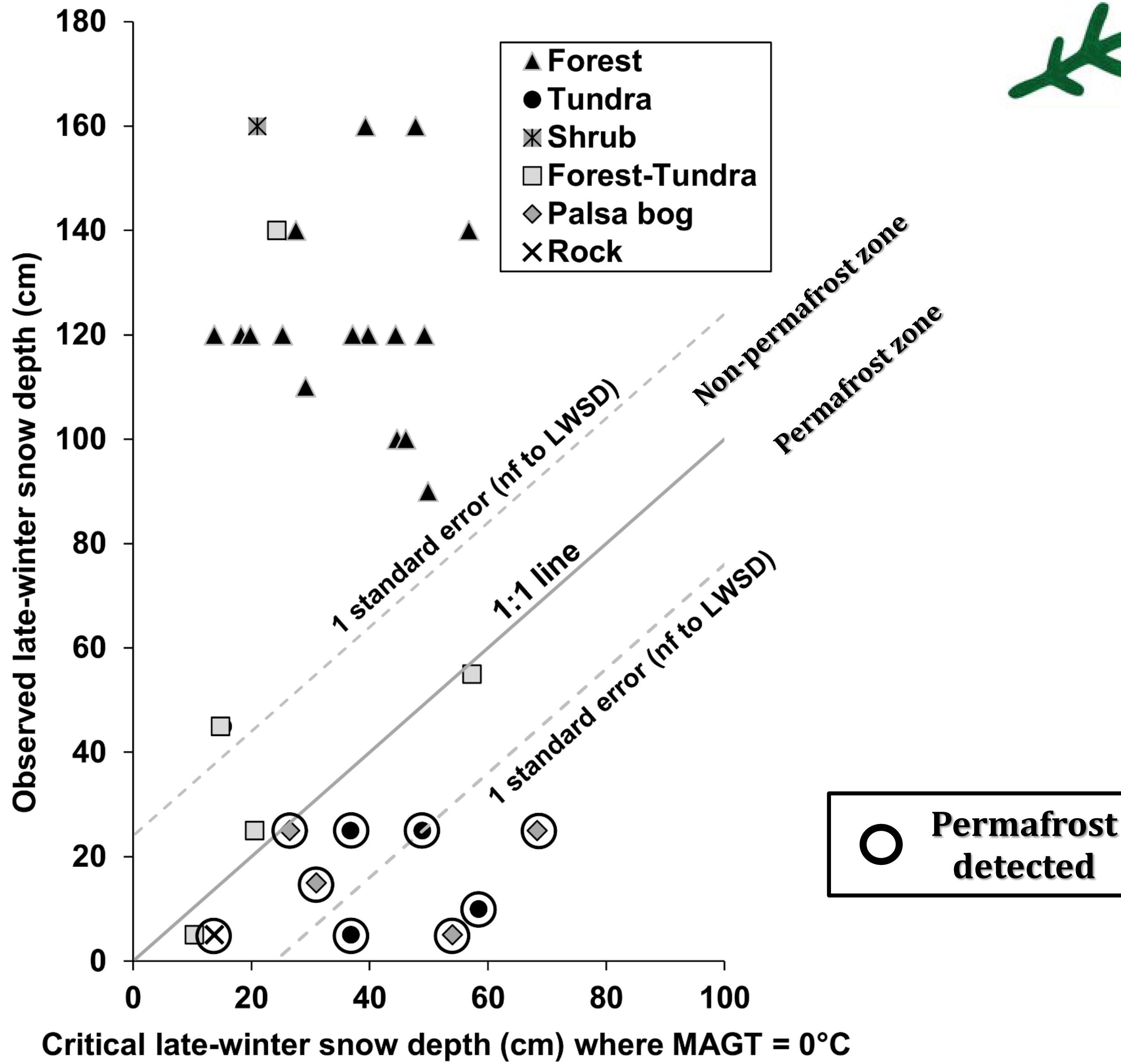
# LWSD and nf

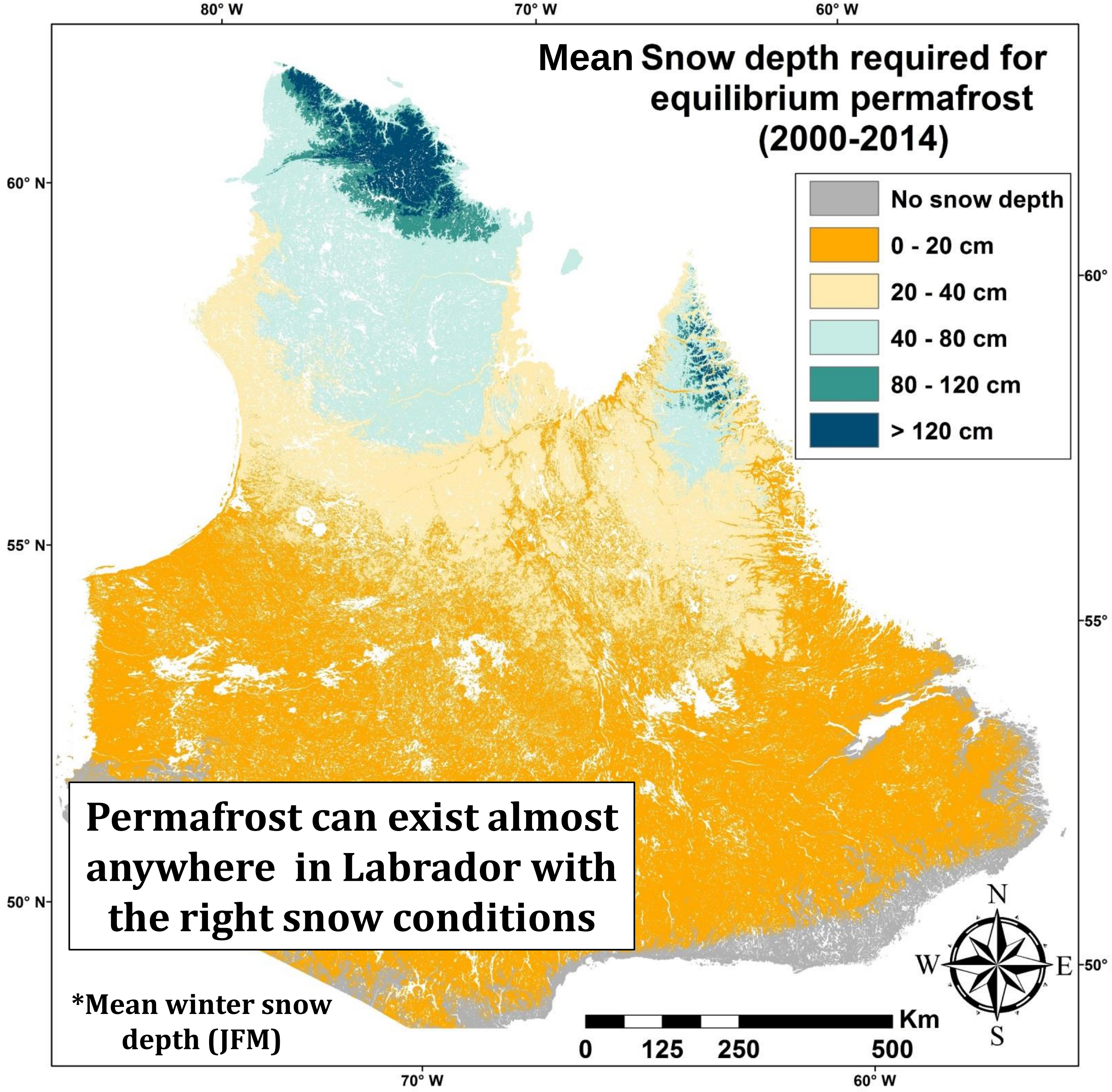

High efficiency
Low efficiency
**nf =** Cold-season buffer layer temperature transfer efficiency (~0-0.9)
Freezing n-factor (nf)
Late-winter snow depth
0.0
0.2
0.4
0.6
0.8
1.0
0
50
100
150



This study - Labrador
Ménard et al. (1998) - eastern Hudson Bay
Juliussen & Humlum (2007) - southeastern Norway
Morse et al. (2016) - southern Northwest Territories
Davesne et al. (2016) - Gaspésie
Karunaratne et al. (2008) - southern Northwest Territories
Gisnås et al. (2016b) - southern Norway
Gisnås et al. (unpublished data) - Svalbard
Freezing n-factor
Late-winter snow depth (cm)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
0
50
100
150
200
250
300
350
400


Forest
Tundra
Shrub
Forest-Tundra
Palsa bog
Rock
Non-permafrost zone
Permafrost zone
1 standard error (nf to LWSD)
1:1 line
1 standard error (nf to LWSD)
Permafrost detected
Observed late-winter snow depth (cm)
Critical late-winter snow depth (cm) where MAGT = 0°C
0
20
40
60
80
100
120
140
160
180


Forest
Tundra
Shrub
Forest-Tundra
Palsa bog
Rock
Non-permafrost zone
Permafrost zone
1 standard error (nf to LWSD)
1:1 line
1 standard error (nf to LWSD)
Permafrost detected
Observed late-winter snow depth (cm)
Critical late-winter snow depth (cm) where MAGT = 0°C
0
20
40
60
80
100
120
140
160
180
0
20
40
60
80
100




**Permafrost can exist almost anywhere in Labrador with the right snow conditions**

*Mean winter snow depth (JFM)

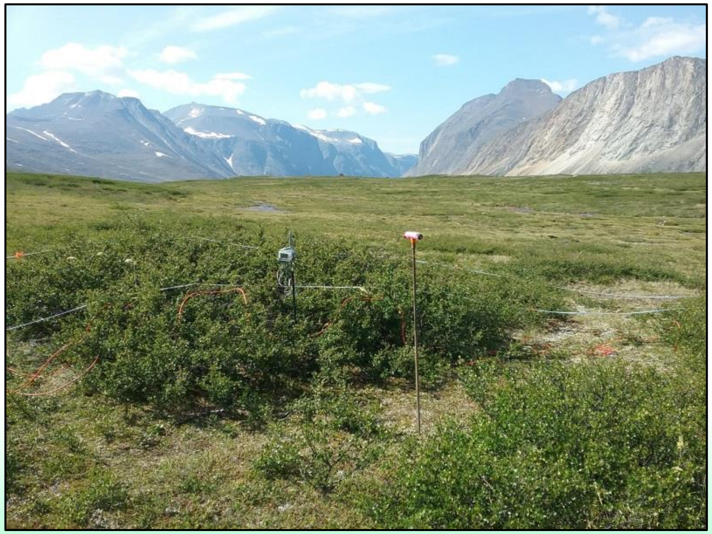
# Northern Labrador

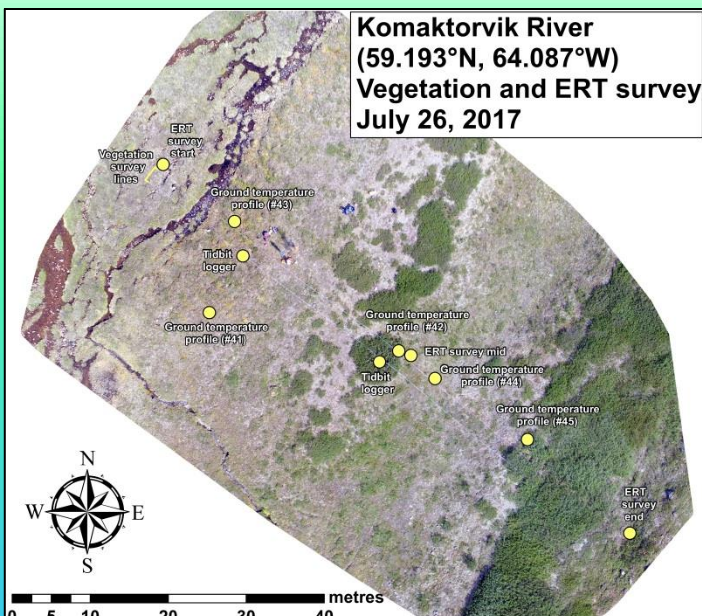
- **What happens if we change land cover?**

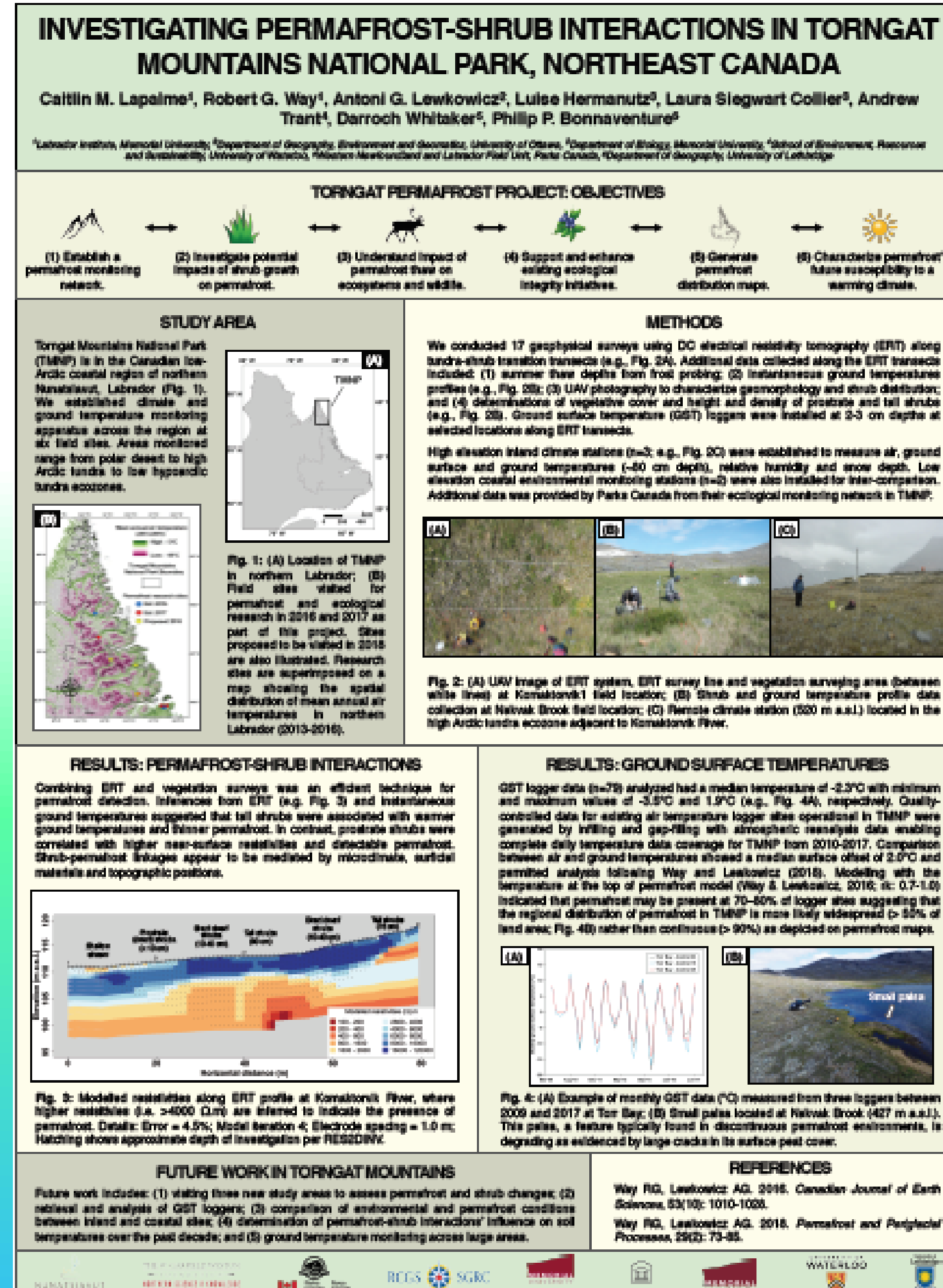

**Fraser et al (2011) – Environmental Research Letters**

# Shrub-permafrost interactions

# Poster section C, session 5, #27





## INVESTIGATING PERMAFROST-SHRUB INTERACTIONS IN TORNGAT MOUNTAINS NATIONAL PARK, NORTHEAST CANADA


Caitlin M. Lapalme[1], Robert G. Way[1], Antoni G. Lewkowicz[2], Luise Hermanutz[3], Laura Siegwart Collier[3], Andrew Trant[4], Darroch Whitaker[5], Philip P. Bonnaventure[6]


### TORNGAT PERMAFROST PROJECT: OBJECTIVES

(1) Establish a permafrost monitoring network. ⟷ (2) Investigate potential impacts of shrub growth on permafrost. ⟷ (3) Understand impact of permafrost thaw on ecosystems and wildlife. ⟷ (4) Support and enhance existing ecological integrity initiatives. ⟷ (5) Generate permafrost distribution maps. ⟷ (6) Characterize permafrost's future susceptibility to a warming climate.

### STUDY AREA

Torngat Mountains National Park (TMNP) is in the Canadian low-Arctic coastal region of northern Nunatsiavut, Labrador (Fig. 1). We established climate and ground temperature monitoring apparatus across the region at six field sites. Areas monitored range from polar desert to high Arctic tundra to low hypoarctic tundra ecozones.

Fig. 1: (A) Location of TMNP in northern Labrador; (B) Field sites visited for permafrost and ecological research in 2016 and 2017 as part of this project. Sites proposed to be visited in 2018 are also illustrated. Research sites are superimposed on a map showing the spatial distribution of mean annual air temperatures in northern Labrador (2013-2016).

### METHODS

We conducted 17 geophysical surveys using DC electrical resistivity tomography (ERT) along tundra-shrub transition transects (e.g., Fig. 2A). Additional data collected along the ERT transects included: (1) summer thaw depths from frost probing; (2) instantaneous ground temperatures profiles (e.g., Fig. 2B); (3) UAV photography to characterize geomorphology and shrub distribution; and (4) determinations of vegetative cover and height and density of prostrate and tall shrubs (e.g., Fig. 2B). Ground surface temperature (GST) loggers were installed at 2-3 cm depths at selected locations along ERT transects.

High elevation inland climate stations (n=3; e.g., Fig. 2C) were established to measure air, ground surface and ground temperatures (~80 cm depth), relative humidity and snow depth. Low elevation coastal environmental monitoring stations (n=2) were also installed for inter-comparison. Additional data was provided by Parks Canada from their ecological monitoring network in TMNP.

Fig. 2: (A) UAV image of ERT system, ERT survey line and vegetation surveying area (between white lines) at Komaktorvik1 field location; (B) Shrub and ground temperature profile data collection at Nakvak Brook field location; (C) Remote climate station (520 m a.s.l.) located in the high Arctic tundra ecozone adjacent to Komaktorvik River.

### RESULTS: PERMAFROST-SHRUB INTERACTIONS

Combining ERT and vegetation surveys was an efficient technique for permafrost detection. Inferences from ERT (e.g. Fig. 3) and instantaneous ground temperatures suggested that tall shrubs were associated with warmer ground temperatures and thinner permafrost. In contrast, prostrate shrubs were correlated with higher near-surface resistivities and detectable permafrost. Shrub-permafrost linkages appear to be mediated by microclimate, surficial materials and topographic positions.

Fig. 3: Modelled resistivities along ERT profile at Komaktorvik River, where higher resistivities (i.e. >4000 Ω.m) are inferred to indicate the presence of permafrost. Details: Error = 4.5%; Model iteration 4; Electrode spacing = 1.0 m; Hatching shows approximate depth of investigation per RES2DINV.

### RESULTS: GROUND SURFACE TEMPERATURES

GST logger data (n=79) analyzed had a median temperature of -2.3°C with minimum and maximum values of -3.5°C and 1.9°C (e.g., Fig. 4A), respectively. Quality-controlled data for existing air temperature logger sites operational in TMNP were generated by infilling and gap-filling with atmospheric reanalysis data enabling complete daily temperature data coverage for TMNP from 2010-2017. Comparison between air and ground temperatures showed a median surface offset of 2.0°C and permitted analysis following Way and Lewkowicz (2016). Modelling with the temperature at the top of permafrost model (Way & Lewkowicz, 2016; rk: 0.7-1.0) indicated that permafrost may be present at 70–80% of logger sites suggesting that the regional distribution of permafrost in TMNP is more likely widespread (> 50% of land area; Fig. 4B) rather than continuous (> 90%) as depicted on permafrost maps.

Fig. 4: (A) Example of monthly GST data (°C) measured from three loggers between 2009 and 2017 at Torr Bay; (B) Small palsa located at Nakvak Brook (427 m a.s.l.). This palsa, a feature typically found in discontinuous permafrost environments, is degrading as evidenced by large cracks in its surface peat cover.

### FUTURE WORK IN TORNGAT MOUNTAINS

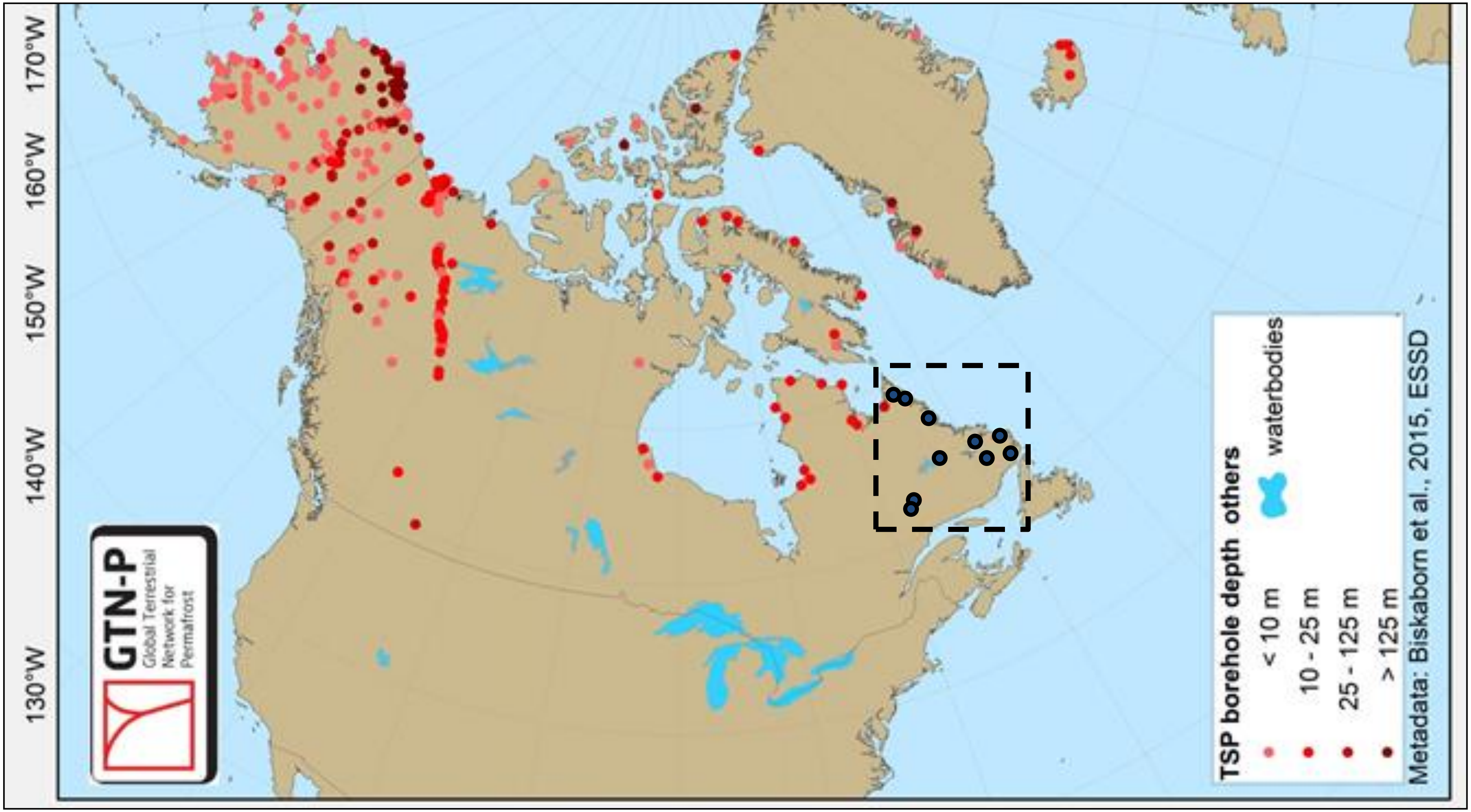
Future work includes: (1) visiting three new study areas to assess permafrost and shrub changes; (2) retrieval and analysis of GST loggers; (3) comparison of environmental and permafrost conditions between inland and coastal sites; (4) determination of permafrost-shrub interactions' influence on soil temperatures over the past decade; and (5) ground temperature monitoring across large areas.

### REFERENCES


Way RG, Lewkowicz AG. 2016. *Canadian Journal of Earth Sciences*, 53(10): 1010-1028.

Way RG, Lewkowicz AG. 2018. *Permafrost and Periglacial Processes*, 29(2): 73-85.

# Keep filling data gaps!



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NUNATSIAVUT
kavamanga Government

Association of Canadian Universities for Northern Studies

RCGS SGRC

Fisheries and Oceans Canada
Pêches et Océans Canada

NunatuKavut
our ancient land

PYRN
Permafrost Young Researchers Network

THE W. GARFIELD WESTON FOUNDATION

NSERC CRSNG

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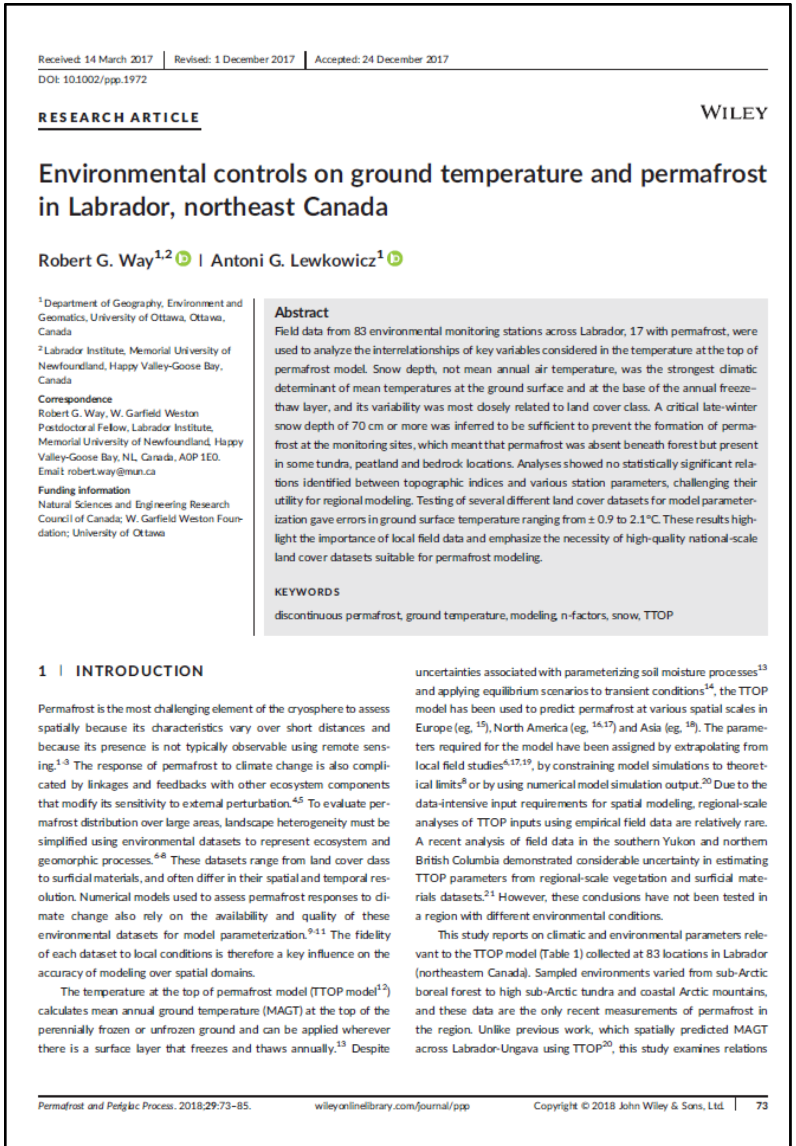

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RESEARCH ARTICLE

WILEY

## Environmental controls on ground temperature and permafrost in Labrador, northeast Canada

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Natural Sciences and Engineering Research Council of Canada; W. Garfield Weston Foundation; University of Ottawa

**Abstract**

Field data from 83 environmental monitoring stations across Labrador, 17 with permafrost, were used to analyze the interrelationships of key variables considered in the temperature at the top of permafrost model. Snow depth, not mean annual air temperature, was the strongest climatic determinant of mean temperatures at the ground surface and at the base of the annual freeze–thaw layer, and its variability was most closely related to land cover class. A critical late-winter snow depth of 70 cm or more was inferred to be sufficient to prevent the formation of permafrost at the monitoring sites, which meant that permafrost was absent beneath forest but present in some tundra, peatland and bedrock locations. Analyses showed no statistically significant relations identified between topographic indices and various station parameters, challenging their utility for regional modeling. Testing of several different land cover datasets for model parameterization gave errors in ground surface temperature ranging from ± 0.9 to 2.1°C. These results highlight the importance of local field data and emphasize the necessity of high-quality national-scale land cover datasets suitable for permafrost modeling.

KEYWORDS

discontinuous permafrost, ground temperature, modeling, n-factors, snow, TTOP

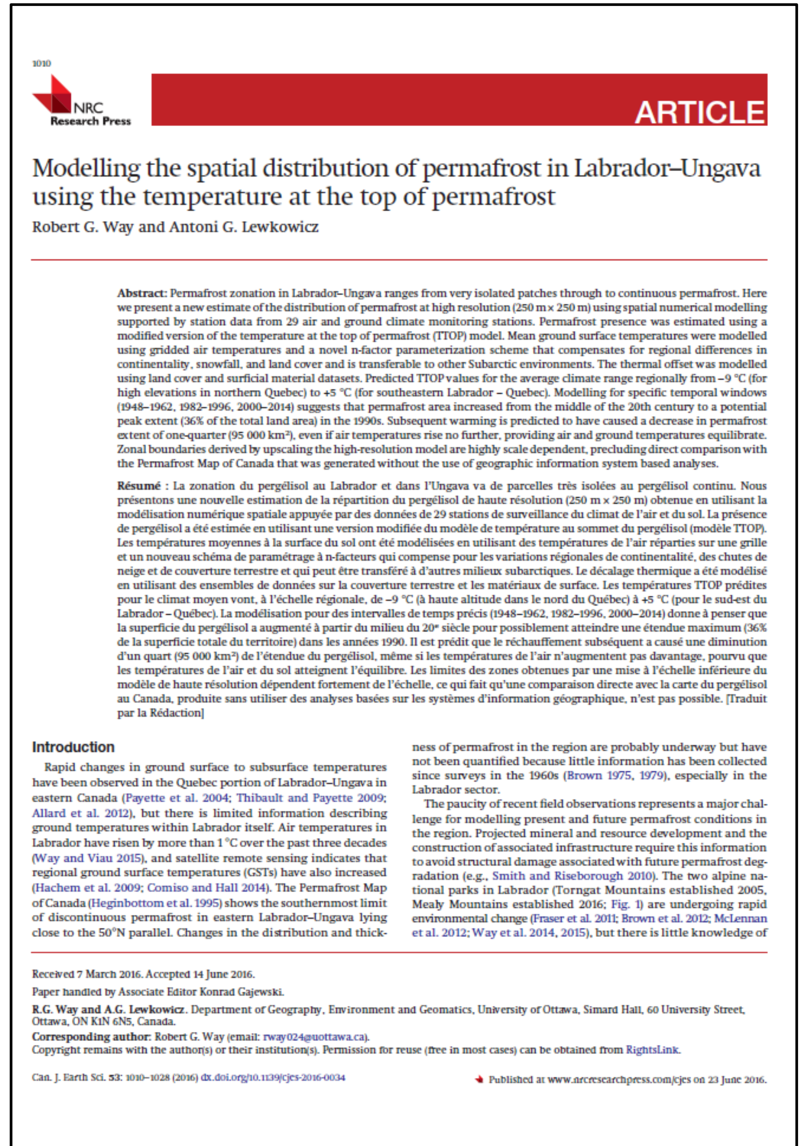
### 1 | INTRODUCTION

Permafrost is the most challenging element of the cryosphere to assess spatially because its characteristics vary over short distances and because its presence is not typically observable using remote sensing.[1-3] The response of permafrost to climate change is also complicated by linkages and feedbacks with other ecosystem components that modify its sensitivity to external perturbation.[4,5] To evaluate permafrost distribution over large areas, landscape heterogeneity must be simplified using environmental datasets to represent ecosystem and geomorphic processes.[6-8] These datasets range from land cover class to surficial materials, and often differ in their spatial and temporal resolution. Numerical models used to assess permafrost responses to climate change also rely on the availability and quality of these environmental datasets for model parameterization.[9-11] The fidelity of each dataset to local conditions is therefore a key influence on the accuracy of modeling over spatial domains.

The temperature at the top of permafrost model (TTOP model[12]) calculates mean annual ground temperature (MAGT) at the top of the perennially frozen or unfrozen ground and can be applied wherever there is a surface layer that freezes and thaws annually.[13] Despite uncertainties associated with parameterizing soil moisture processes[13] and applying equilibrium scenarios to transient conditions[14], the TTOP model has been used to predict permafrost at various spatial scales in Europe (eg, [15]), North America (eg, [16,17]) and Asia (eg, [18]). The parameters required for the model have been assigned by extrapolating from local field studies[6,17,19], by constraining model simulations to theoretical limits[8] or by using numerical model simulation output.[20] Due to the data-intensive input requirements for spatial modeling, regional-scale analyses of TTOP inputs using empirical field data are relatively rare. A recent analysis of field data in the southern Yukon and northern British Columbia demonstrated considerable uncertainty in estimating TTOP parameters from regional-scale vegetation and surficial materials datasets.[21] However, these conclusions have not been tested in a region with different environmental conditions.

This study reports on climatic and environmental parameters relevant to the TTOP model (Table 1) collected at 83 locations in Labrador (northeastern Canada). Sampled environments varied from sub-Arctic boreal forest to high sub-Arctic tundra and coastal Arctic mountains, and these data are the only recent measurements of permafrost in the region. Unlike previous work, which spatially predicted MAGT across Labrador-Ungava using TTOP[20], this study examines relations





NRC Research Press

ARTICLE

## Modelling the spatial distribution of permafrost in Labrador–Ungava using the temperature at the top of permafrost

Robert G. Way and Antoni G. Lewkowicz

**Abstract:** Permafrost zonation in Labrador–Ungava ranges from very isolated patches through to continuous permafrost. Here we present a new estimate of the distribution of permafrost at high resolution (250 m × 250 m) using spatial numerical modelling supported by station data from 29 air and ground climate monitoring stations. Permafrost presence was estimated using a modified version of the temperature at the top of permafrost (TTOP) model. Mean ground surface temperatures were modelled using gridded air temperatures and a novel n-factor parameterization scheme that compensates for regional differences in continentality, snowfall, and land cover and is transferable to other Subarctic environments. The thermal offset was modelled using land cover and surficial material datasets. Predicted TTOP values for the average climate range regionally from −9 °C (for high elevations in northern Quebec) to +5 °C (for southeastern Labrador – Quebec). Modelling for specific temporal windows (1948–1962, 1982–1996, 2000–2014) suggests that permafrost area increased from the middle of the 20th century to a potential peak extent (36% of the total land area) in the 1990s. Subsequent warming is predicted to have caused a decrease in permafrost extent of one-quarter (95 000 km²), even if air temperatures rise no further, providing air and ground temperatures equilibrate. Zonal boundaries derived by upscaling the high-resolution model are highly scale dependent, precluding direct comparison with the Permafrost Map of Canada that was generated without the use of geographic information system based analyses.

**Résumé :** La zonation du pergélisol au Labrador et dans l'Ungava va de parcelles très isolées au pergélisol continu. Nous présentons une nouvelle estimation de la répartition du pergélisol de haute résolution (250 m × 250 m) obtenue en utilisant la modélisation numérique spatiale appuyée par des données de 29 stations de surveillance du climat de l'air et du sol. La présence de pergélisol a été estimée en utilisant une version modifiée du modèle de température au sommet du pergélisol (modèle TTOP). Les températures moyennes à la surface du sol ont été modélisées en utilisant des températures de l'air réparties sur une grille et un nouveau schéma de paramétrage à n-facteurs qui compense pour les variations régionales de continentalité, des chutes de neige et de couverture terrestre et qui peut être transféré à d'autres milieux subarctiques. Le décalage thermique a été modélisé en utilisant des ensembles de données sur la couverture terrestre et les matériaux de surface. Les températures TTOP prédites pour le climat moyen vont, à l'échelle régionale, de −9 °C (à haute altitude dans le nord du Québec) à +5 °C (pour le sud-est du Labrador – Québec). La modélisation pour des intervalles de temps précis (1948–1962, 1982–1996, 2000–2014) donne à penser que la superficie du pergélisol a augmenté à partir du milieu du 20e siècle pour possiblement atteindre une étendue maximum (36% de la superficie totale du territoire) dans les années 1990. Il est prédit que le réchauffement subséquent a causé une diminution d'un quart (95 000 km²) de l'étendue du pergélisol, même si les températures de l'air n'augmentent pas davantage, pourvu que les températures de l'air et du sol atteignent l'équilibre. Les limites des zones obtenues par une mise à l'échelle inférieure du modèle de haute résolution dépendent fortement de l'échelle, ce qui fait qu'une comparaison directe avec la carte du pergélisol au Canada, produite sans utiliser des analyses basées sur les systèmes d'information géographique, n'est pas possible. [Traduit par la Rédaction]

### Introduction

Rapid changes in ground surface to subsurface temperatures have been observed in the Quebec portion of Labrador–Ungava in eastern Canada (Payette et al. 2004; Thibault and Payette 2009; Allard et al. 2012), but there is limited information describing ground temperatures within Labrador itself. Air temperatures in Labrador have risen by more than 1 °C over the past three decades (Way and Viau 2015), and satellite remote sensing indicates that regional ground surface temperatures (GSTs) have also increased (Hachem et al. 2009; Comiso and Hall 2014). The Permafrost Map of Canada (Heginbottom et al. 1995) shows the southernmost limit of discontinuous permafrost in eastern Labrador–Ungava lying close to the 50°N parallel. Changes in the distribution and thickness of permafrost in the region are probably underway but have not been quantified because little information has been collected since surveys in the 1960s (Brown 1975, 1979), especially in the Labrador sector.

The paucity of recent field observations represents a major challenge for modelling present and future permafrost conditions in the region. Projected mineral and resource development and the construction of associated infrastructure require this information to avoid structural damage associated with future permafrost degradation (e.g., Smith and Riseborough 2010). The two alpine national parks in Labrador (Torngat Mountains established 2005, Mealy Mountains established 2016; Fig. 1) are undergoing rapid environmental change (Fraser et al. 2011; Brown et al. 2012; McLennan et al. 2012; Way et al. 2014, 2015), but there is little knowledge of

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# Thank you and Nakummek!