Spatial and temporal variability of active-layer thickness under changing climatic conditions in Northwest Siberia

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Outline

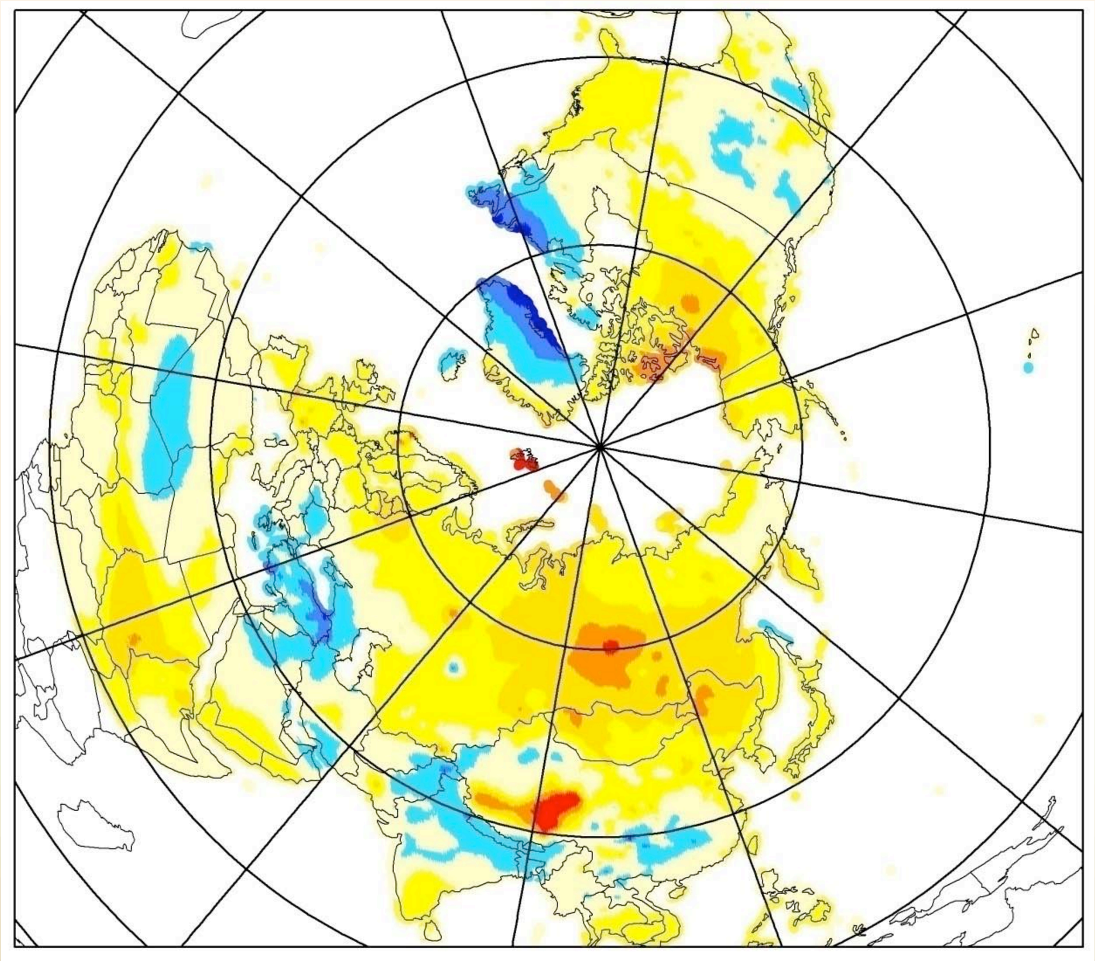
I. Observations

1. CALM network
2. Observed ALT trends
3. Observed trends in air temperature in WS
4. Role climatic and landscape-specific factors in ALT variability

II. Modeling of near-surface permafrost parameters

1. Local scale: example from Marre-Salle
2. Regional scale: Northwest Siberia
   - Uncertainties in input climate fields
   - Changes in air temp, TTOP, ALT
3. Applications: bearing capacity and subsidence risk

Mean Annual Air Temperature Difference (1960s -1990s)



dT (C)

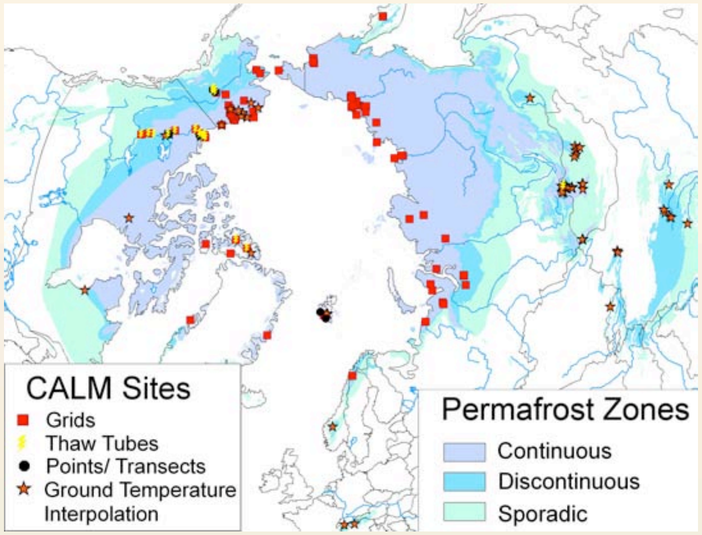
	<-1.0
	-1.0...-0.5
	-0.5...0.0
	0.0...0.5
	0.5...1.0
	1.0...1.5
	1.5...2.0
	>2.0

Composite ensemble from W&M, CRU, ERA40, NCEP
Spatial resolution: 25x25 km

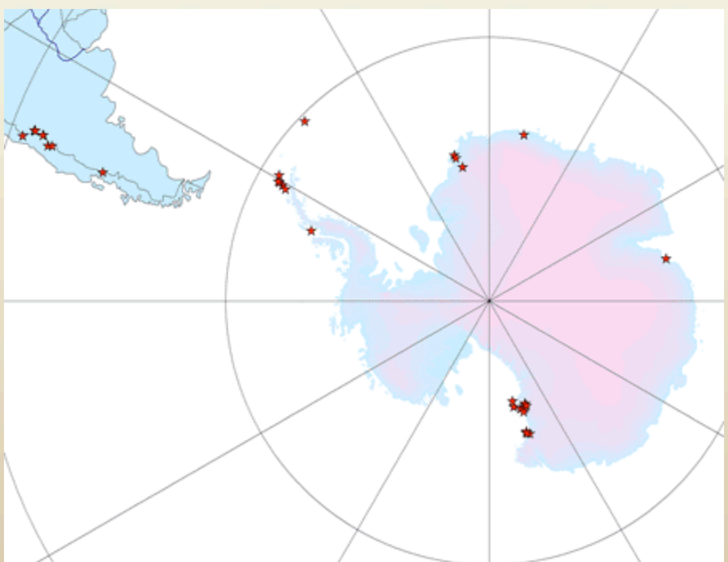
Observations

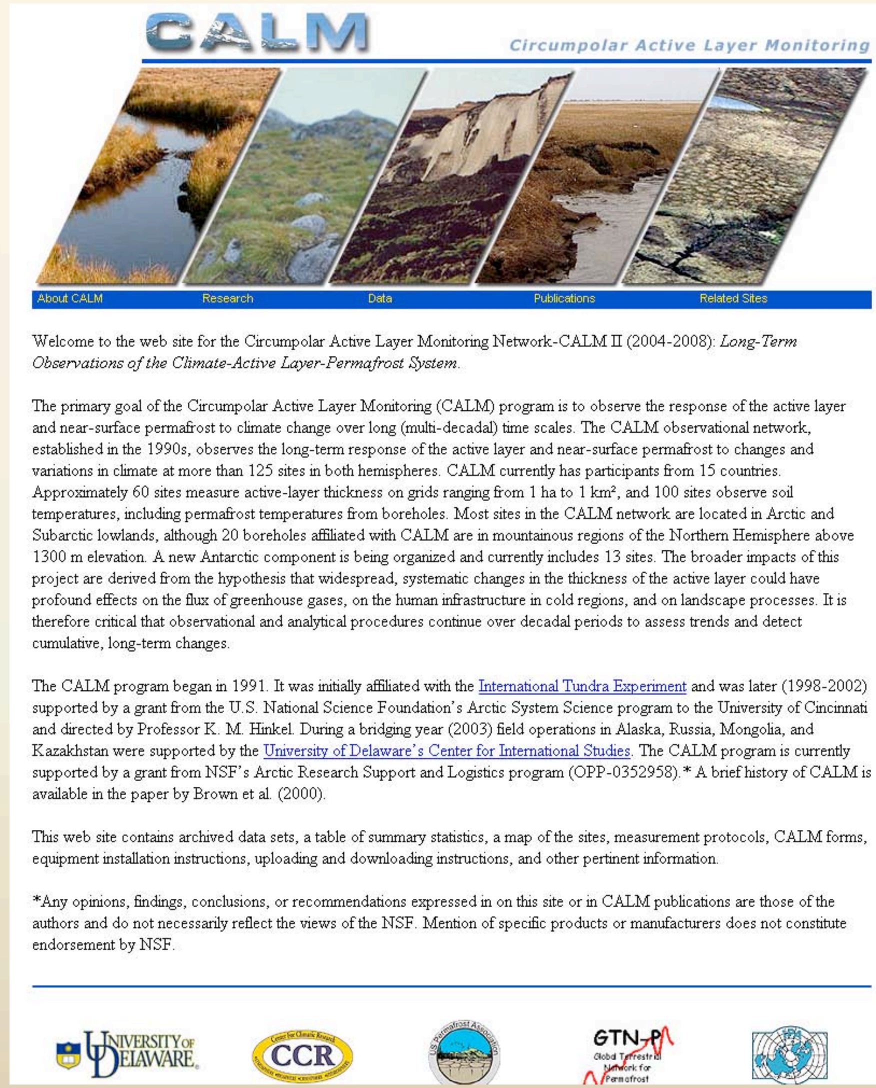
Circumpolar Active Layer Monitoring Program

CALM-North



CALM-South




CALM
Circumpolar Active Layer Monitoring

About CALM | Research | Data | Publications | Related Sites

Welcome to the web site for the Circumpolar Active Layer Monitoring Network-CALM II (2004-2008): *Long-Term Observations of the Climate-Active Layer-Permafrost System.*

The primary goal of the Circumpolar Active Layer Monitoring (CALM) program is to observe the response of the active layer and near-surface permafrost to climate change over long (multi-decadal) time scales. The CALM observational network, established in the 1990s, observes the long-term response of the active layer and near-surface permafrost to changes and variations in climate at more than 125 sites in both hemispheres. CALM currently has participants from 15 countries. Approximately 60 sites measure active-layer thickness on grids ranging from 1 ha to 1 km², and 100 sites observe soil temperatures, including permafrost temperatures from boreholes. Most sites in the CALM network are located in Arctic and Subarctic lowlands, although 20 boreholes affiliated with CALM are in mountainous regions of the Northern Hemisphere above 1300 m elevation. A new Antarctic component is being organized and currently includes 13 sites. The broader impacts of this project are derived from the hypothesis that widespread, systematic changes in the thickness of the active layer could have profound effects on the flux of greenhouse gases, on the human infrastructure in cold regions, and on landscape processes. It is therefore critical that observational and analytical procedures continue over decadal periods to assess trends and detect cumulative, long-term changes.

The CALM program began in 1991. It was initially affiliated with the International Tundra Experiment and was later (1998-2002) supported by a grant from the U.S. National Science Foundation's Arctic System Science program to the University of Cincinnati and directed by Professor K. M. Hinkel. During a bridging year (2003) field operations in Alaska, Russia, Mongolia, and Kazakhstan were supported by the University of Delaware's Center for International Studies. The CALM program is currently supported by a grant from NSF's Arctic Research Support and Logistics program (OPP-0352958).* A brief history of CALM is available in the paper by Brown et al. (2000).

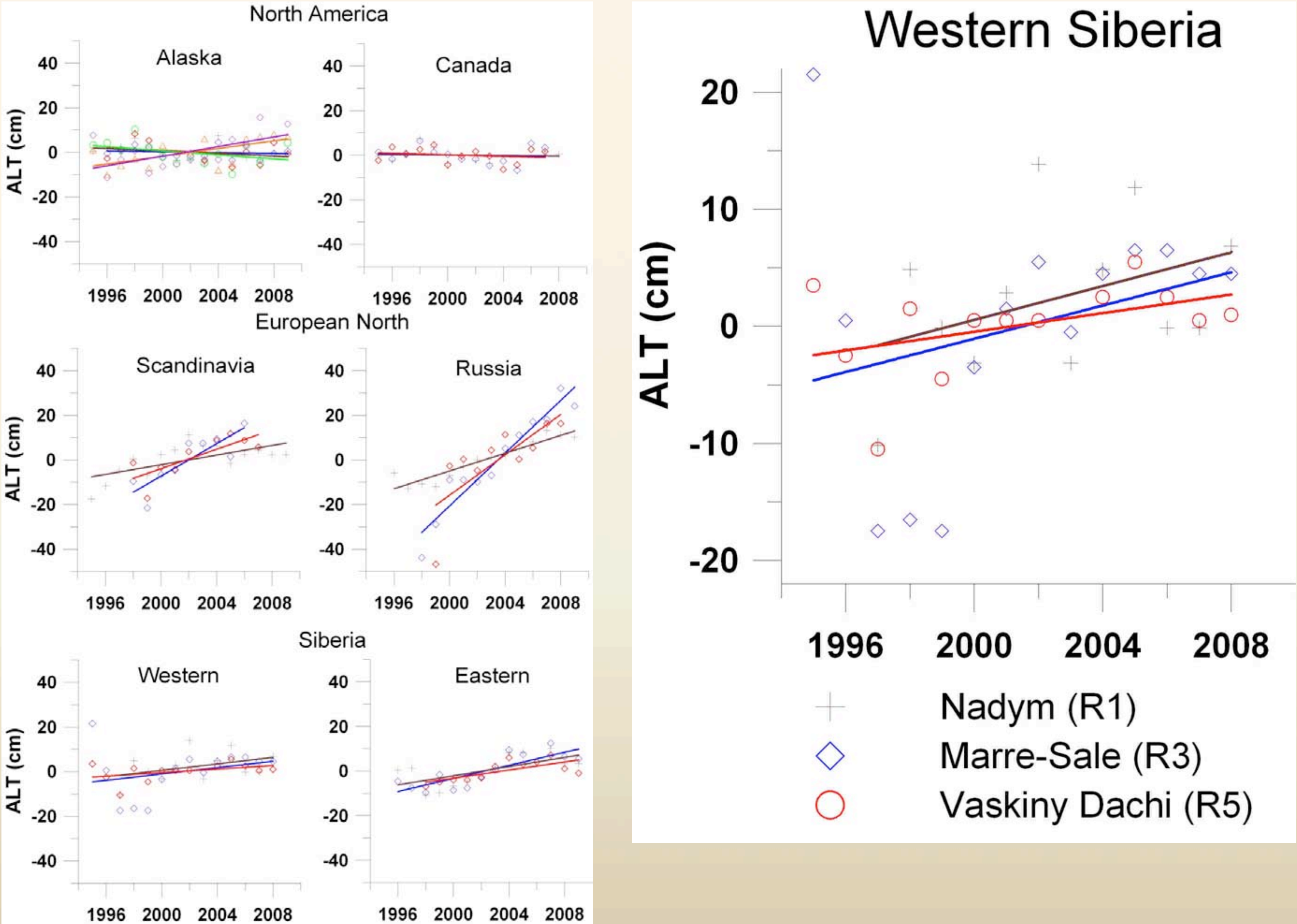
This web site contains archived data sets, a table of summary statistics, a map of the sites, measurement protocols, CALM forms, equipment installation instructions, uploading and downloading instructions, and other pertinent information.

*Any opinions, findings, conclusions, or recommendations expressed in on this site or in CALM publications are those of the authors and do not necessarily reflect the views of the NSF. Mention of specific products or manufacturers does not constitute endorsement by NSF.

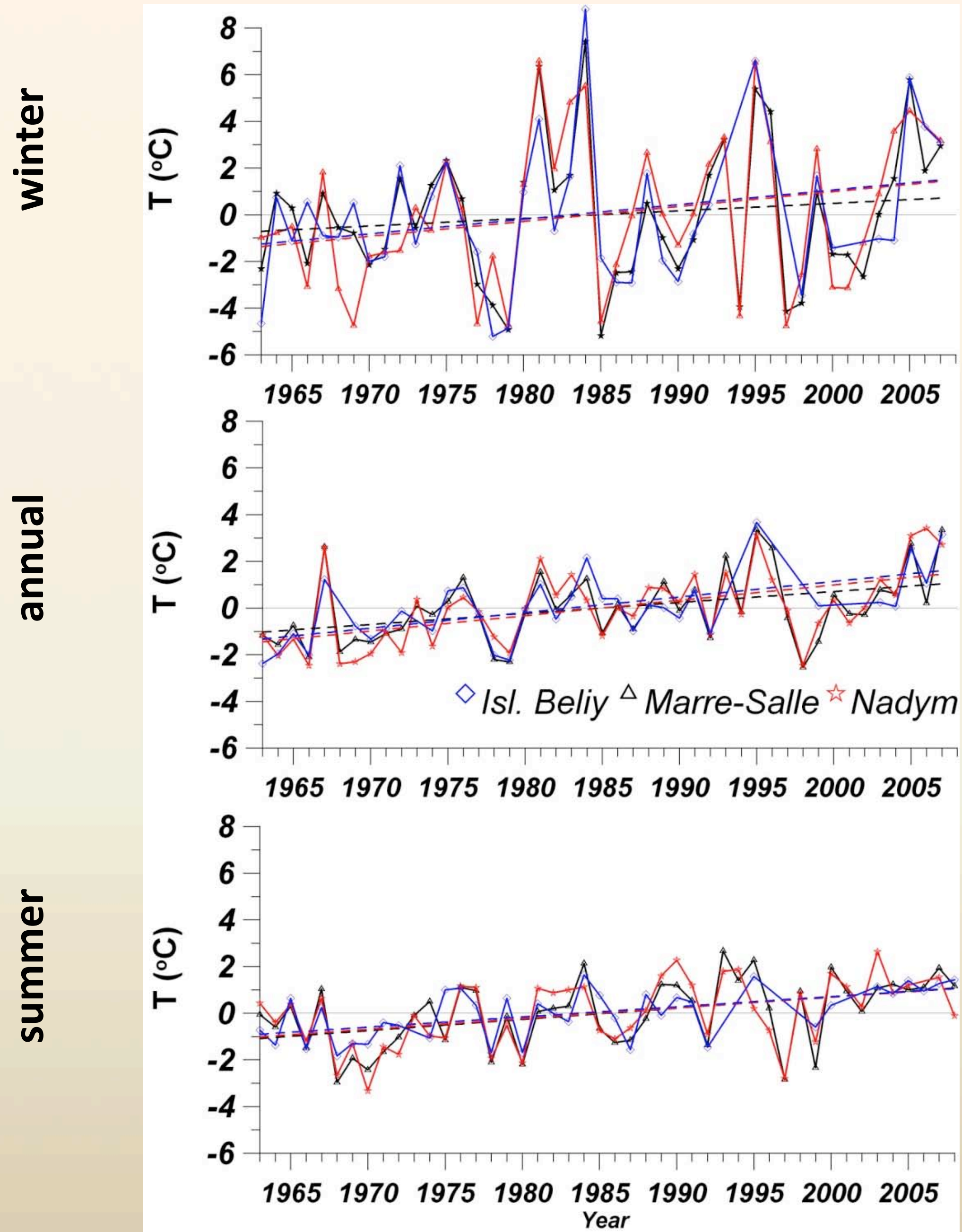
University of Delaware | CCR | GTN-P Global Terrestrial Network for Permafrost

www.udel.edu/Geography/calm

Regional trends in ALT (1995-2008)

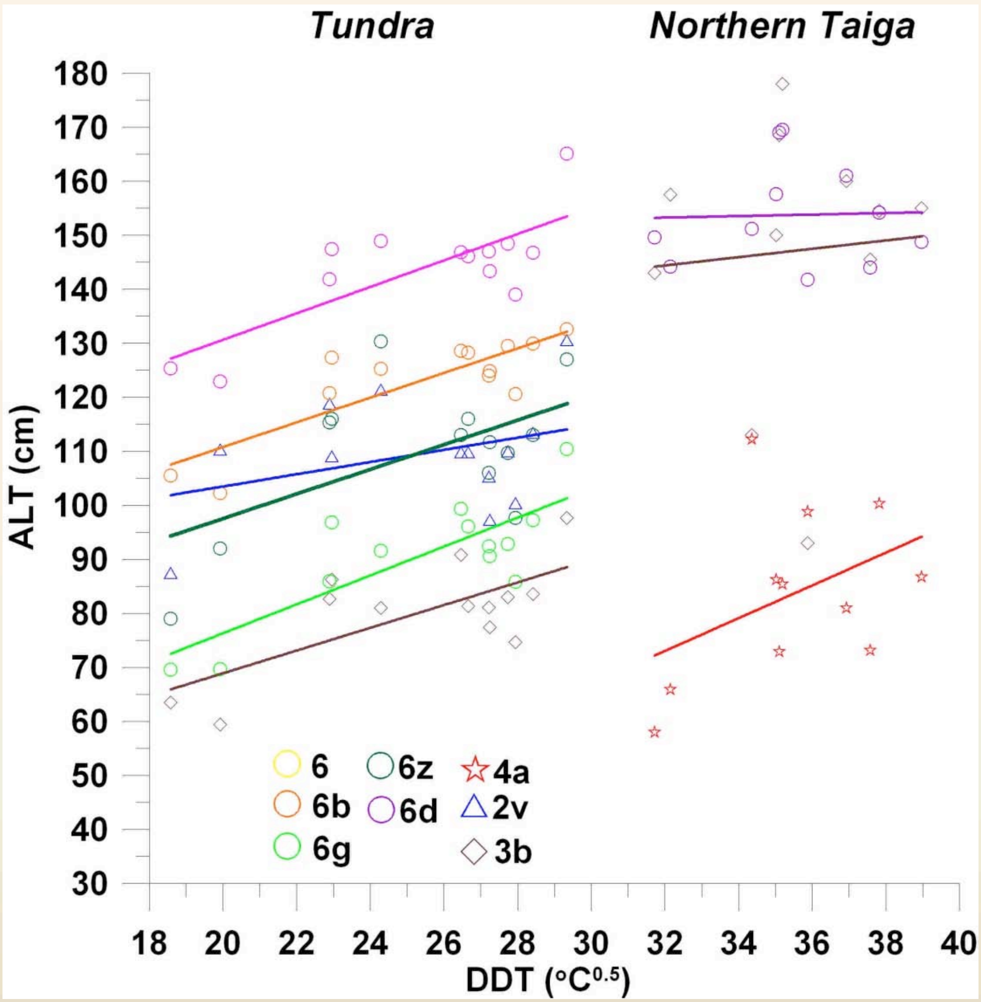


Air temperature anomalies in Northwest Siberia



Tair trends (C/100years)

	North	Central	South
season	**Beliy**	**Marre-Sale**	**Nadym**
winter	6.3	3.2	6.3
summer	4.4	4.8	4.6
annual	6.7	4.7	6.6

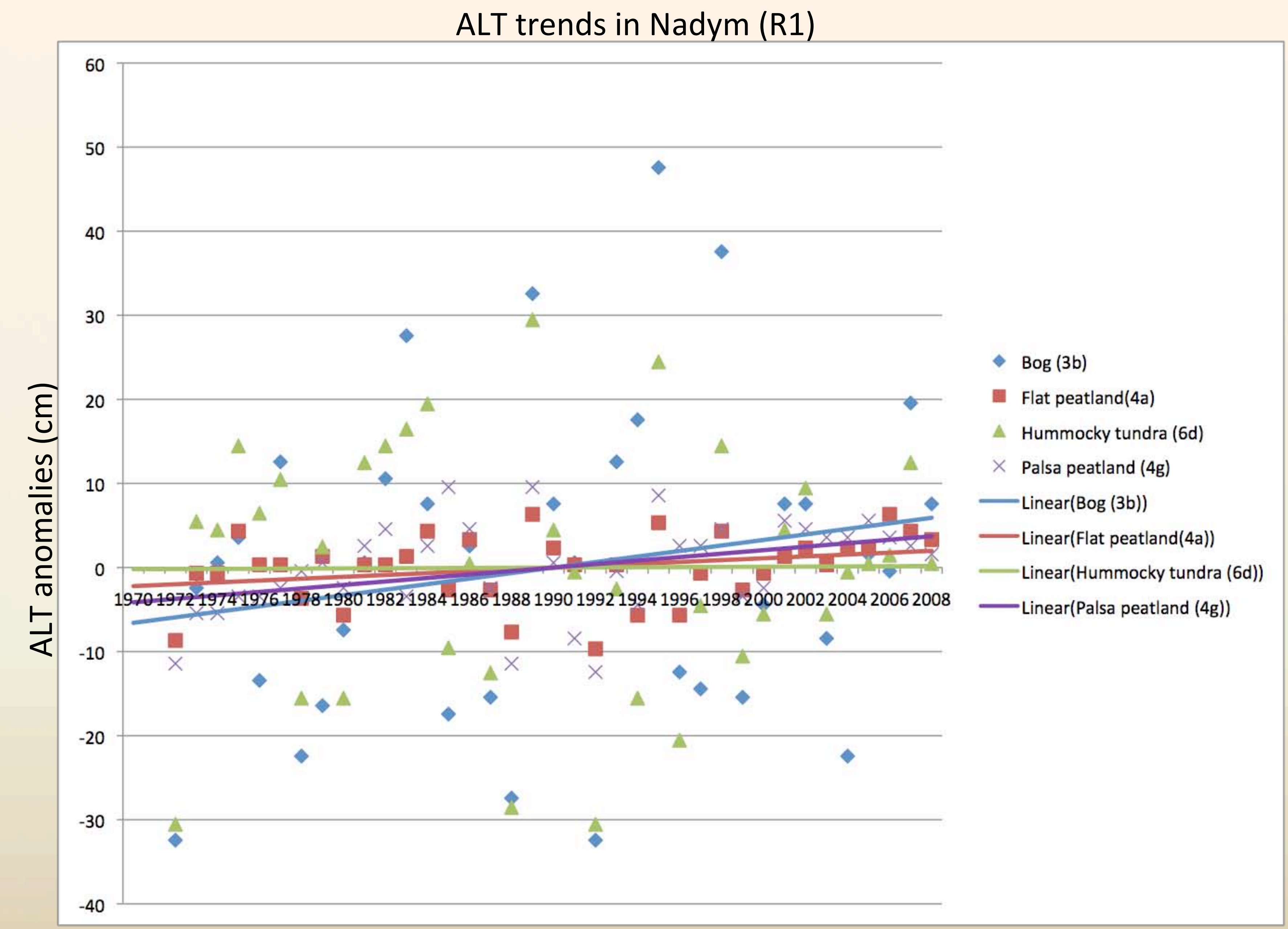


2v: gullies and watertracks
3b: bogs

4a: dwarf-shrub-moss-lichen peatland
4g: palsa peatland

6: Blowouts with little tundra vegetation (sandy tundra)
6b: Polygonal dwarf-shrub tundra DRY
6g: Polygonal dwarf-shrub tundra WET
6d: Hummocky tundra
6z: peatlands

Data provided by N. Moscalenko and A. Vasilev

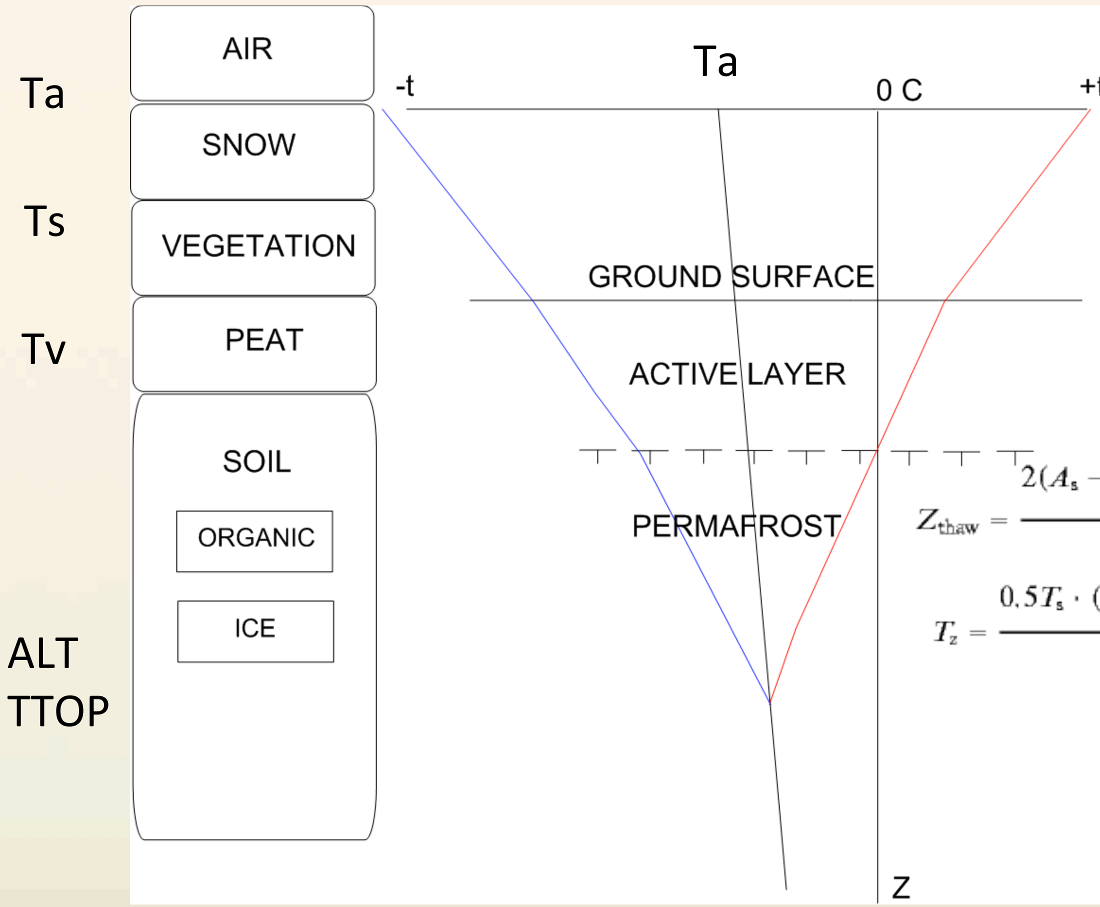


Variability: Bogs > Hummocky Tundra > Peatland

Trend: Bogs > Peatland > Hummocky Tundra

Data provided by N. Moscalenko

Modeling



Monthly air temp. and precip

Simple transfer functions/parameters to account for isolation properties of buffer layers.

analytical solution of heat conduction equation

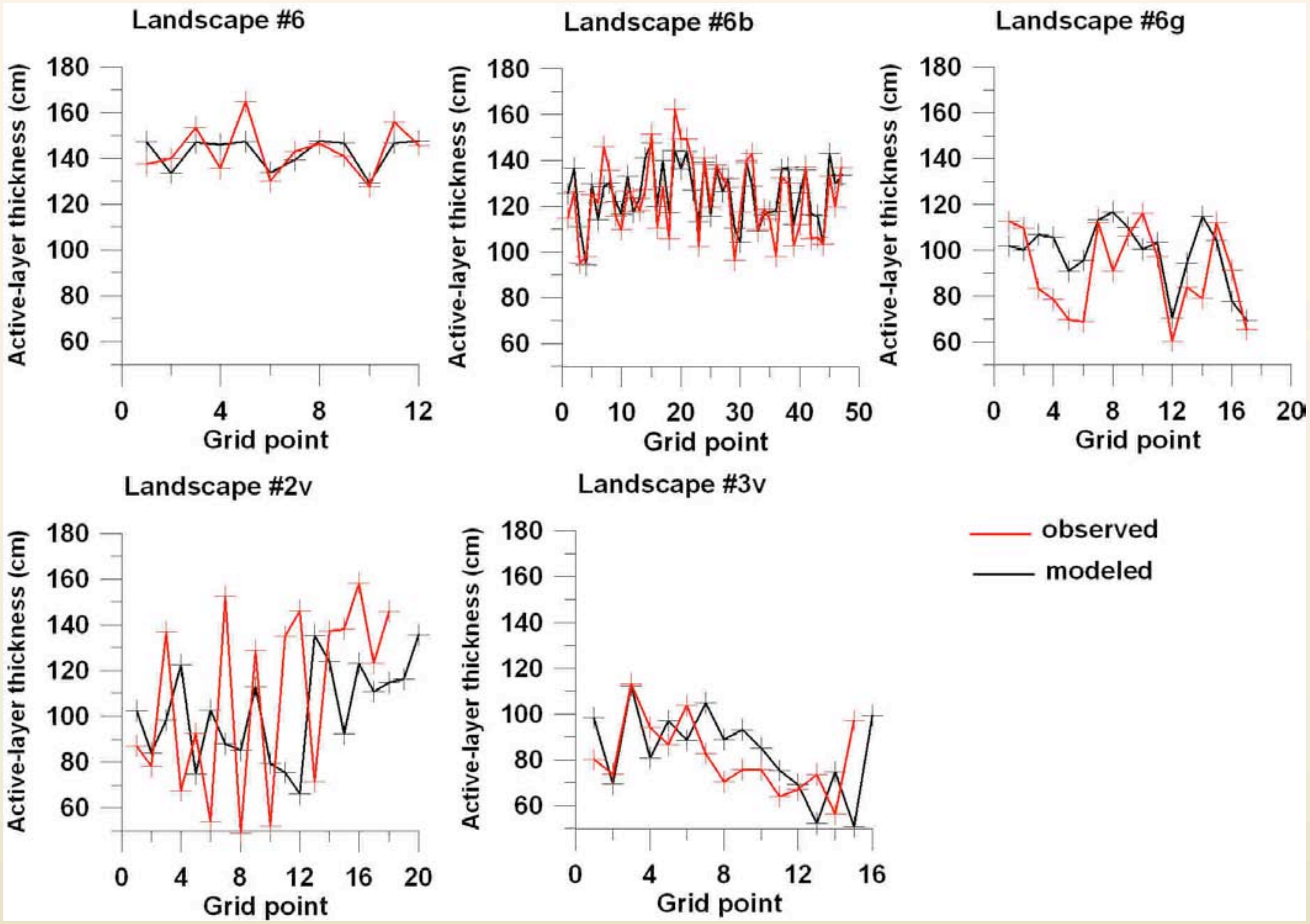
$$Z_{\text{thaw}} = \frac{2(A_s - T_z)\cdot\left[\frac{\lambda\cdot P_{sn}\cdot C}{\pi}\right]^{1/2} + \frac{(2A_z\cdot C\cdot Z_c + Q_{ph}\cdot Z_c)\cdot Q_{ph}\left[\frac{\lambda\cdot P_{sn}}{\pi\cdot C}\right]^{1/2}}{2A_z\cdot C\cdot Z_c + Q_{ph}\cdot Z + (2A_z\cdot C + Q_{ph})\cdot\left[\frac{\lambda\cdot P_{sn}}{\pi\cdot C}\right]^{1/2}}}{2A_z\cdot C + Q_{ph}}$$

$$T_z = \frac{0{,}5T_s\cdot(\lambda_f + \lambda_t) + A_s\frac{\lambda_f - \lambda_t}{\pi}\cdot\left[\frac{T_s}{A_s}\arcsin\frac{T_s}{A_s} + \left[1 - \frac{\pi^2}{A_s^2}\right]^{1/2}\right]}{\lambda^*}$$

Estimates of “average” geocryological parameters (permafrost extent, thickness, annual ALT, Annual soil/permafrost temperature) which are in equilibrium with climate conditions.

Model based on earlier works by Kudryavtsev et al., 1974; Ansimov and Nelson (1997); Shiklomanov and Nelson, 1999; Anisimov et al, 2002; Sazonova and Romanovsky, 2003 with parameterization from Construction Norms and Regulartions (1990), Feldman (1988)

Model validation at Marre-Salle grid (R3), Central Yamal



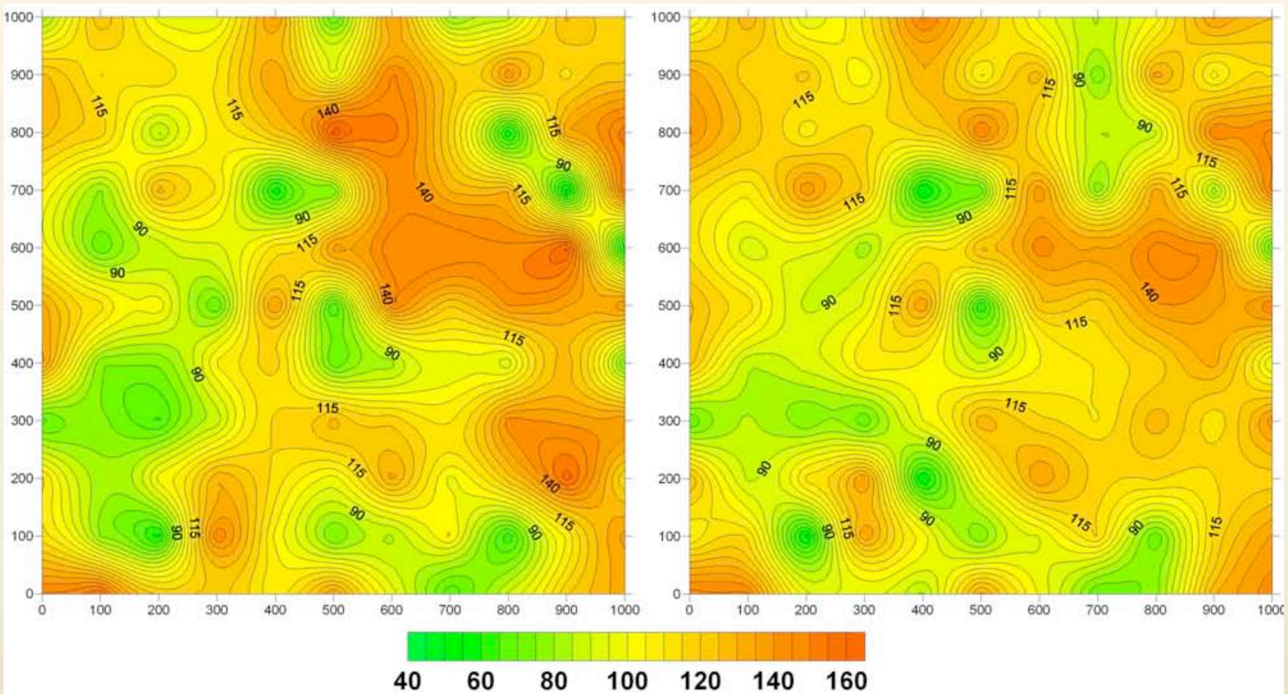
6: Blowouts with little tundra vegetation (sandy tundra)
6b: Polygonal dwarf-shrub tundra DRY
6g: Polygonal dwarf-shrub tundra WET
2v: Gullies and water tracks
3b: Bogs

Data provided by A. Vasilev

Marre-Salle Grid
(ALT for 1995-2008)

Predicted

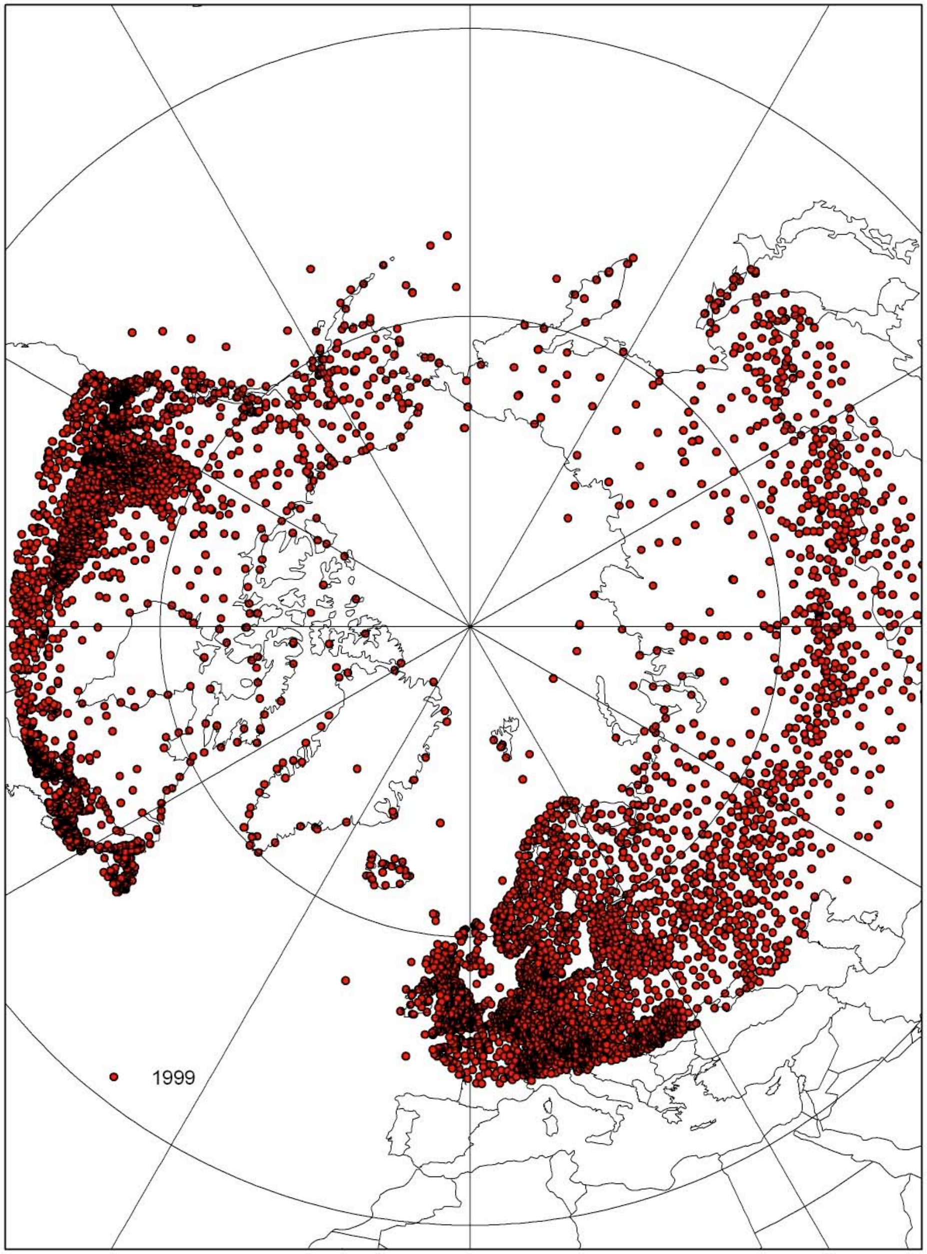
Observed



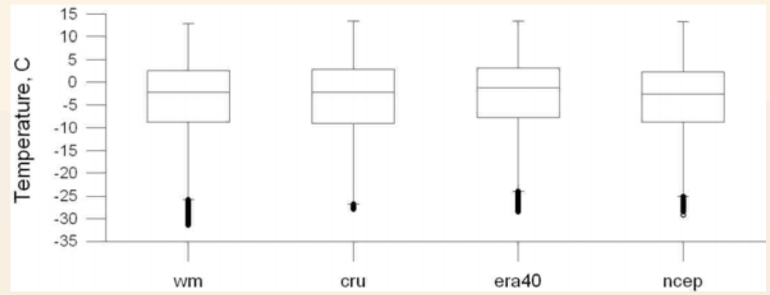
ALT (cm)

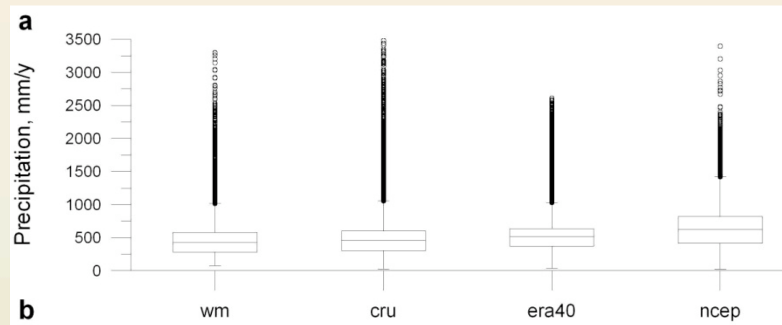
METEOROLOGICAL NETWORK

GRIDDED CLIMATE FILELDS
25 x 25 km, 0.5 x 0.5 degree

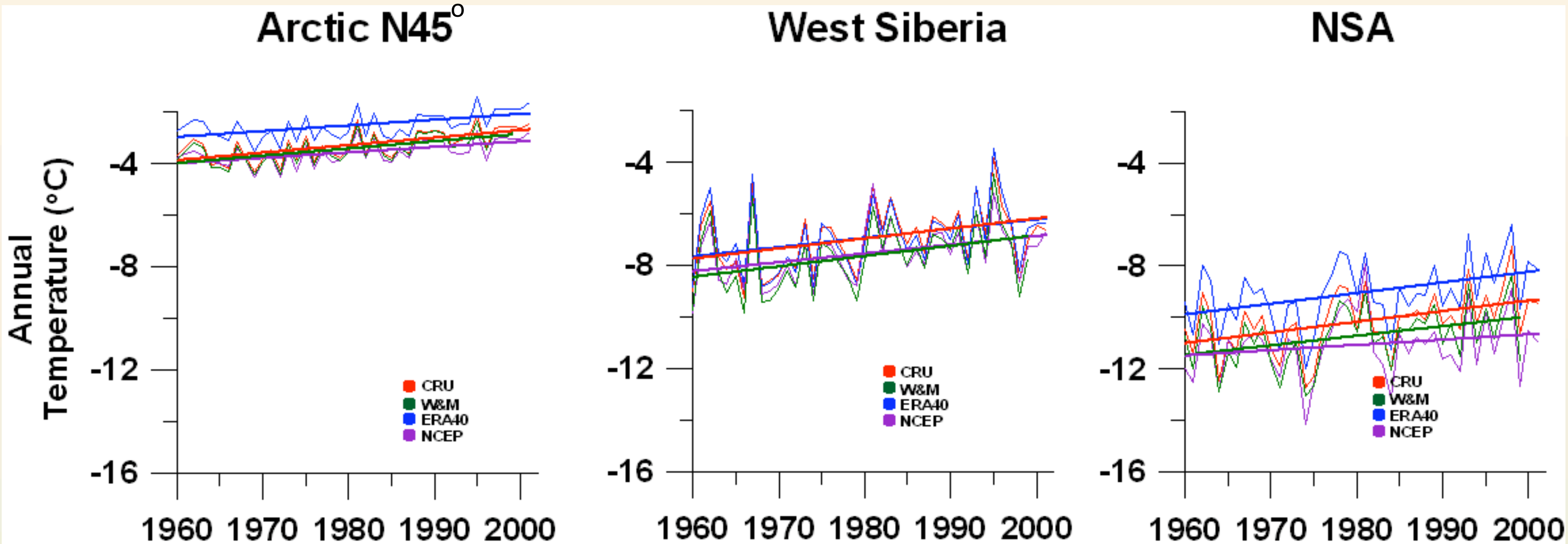


Differences in interpolation and validation create differences in climatic fields





Uncertainties in air temp and regional trends



Arctic: 45-90°N, Area: 39.375 million km^2

West Siberia: 63-74°N and 63-87°E. Area: 0.969 million km^2.

North Slope of Alaska: 67 - 71°N and 140 - 167°W. Area: 0.368 million km^2

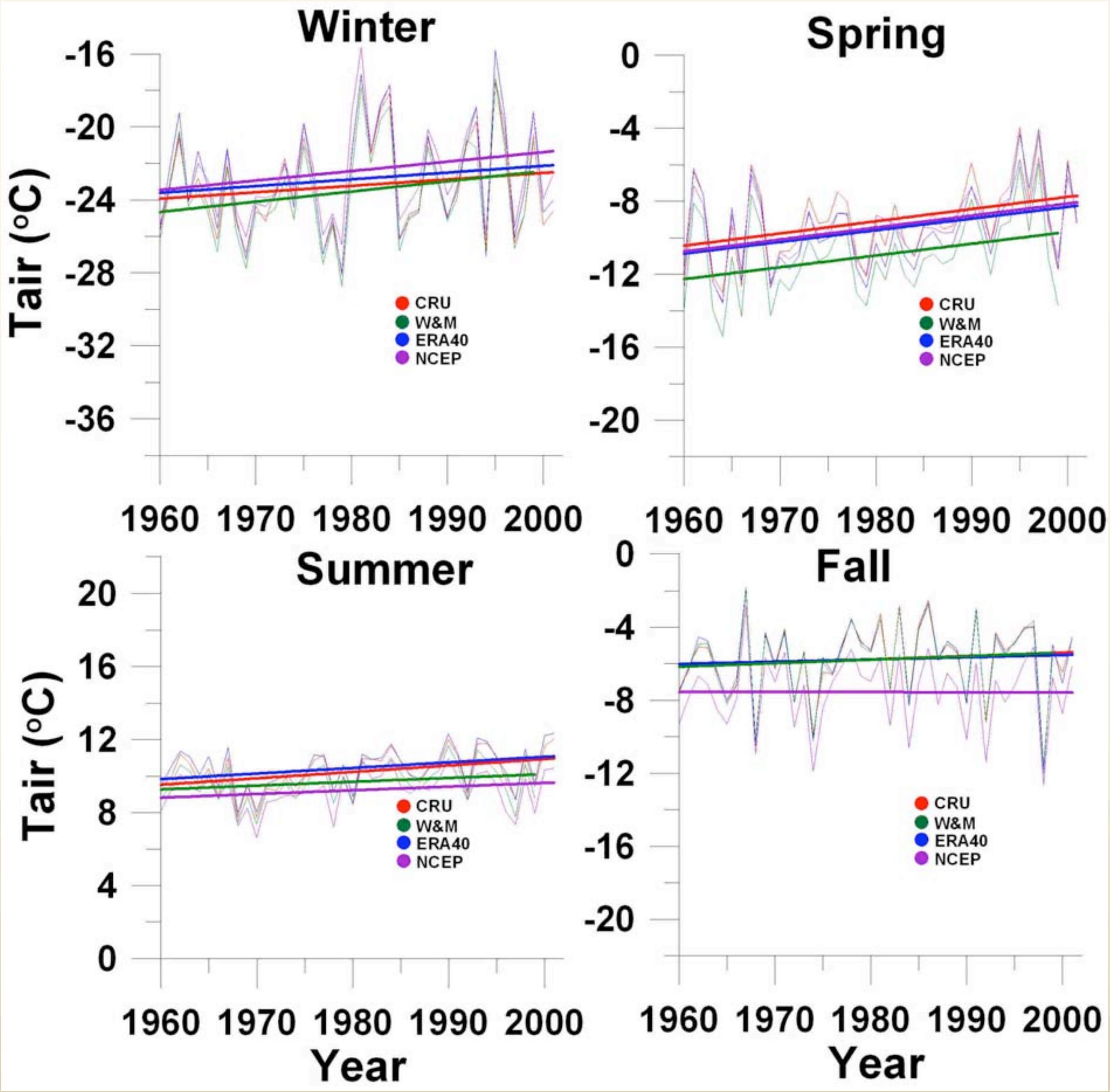
CRU: UK Climate Research Unit Dataset

W&M: Willmott and Matsuura Dataset

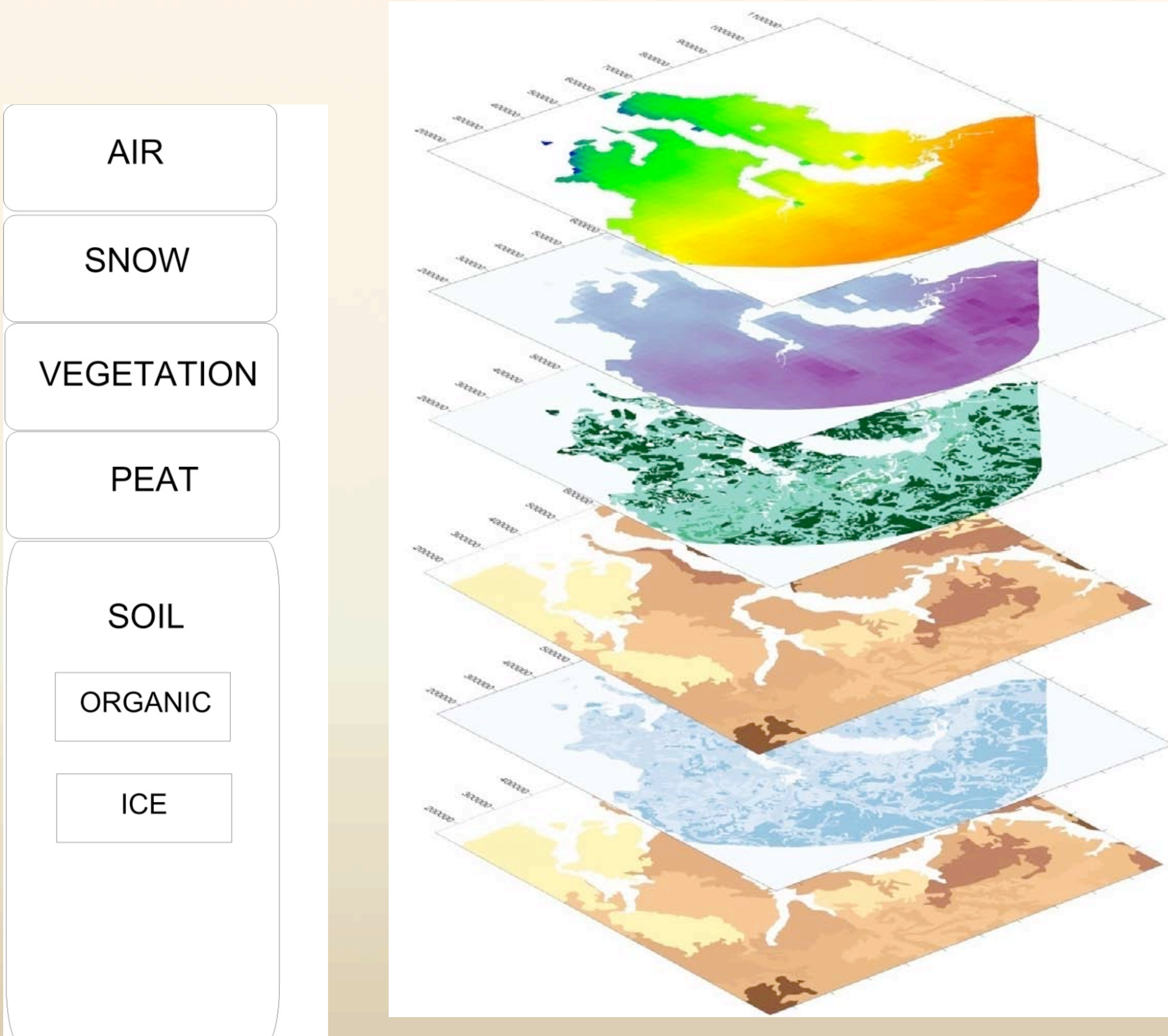
ERA40: European Center for Medium-Range Weather Forecast 40-year Re-Analysis

NCEP: National Center for Environmental Prediction – National Center for Atmospheric Research

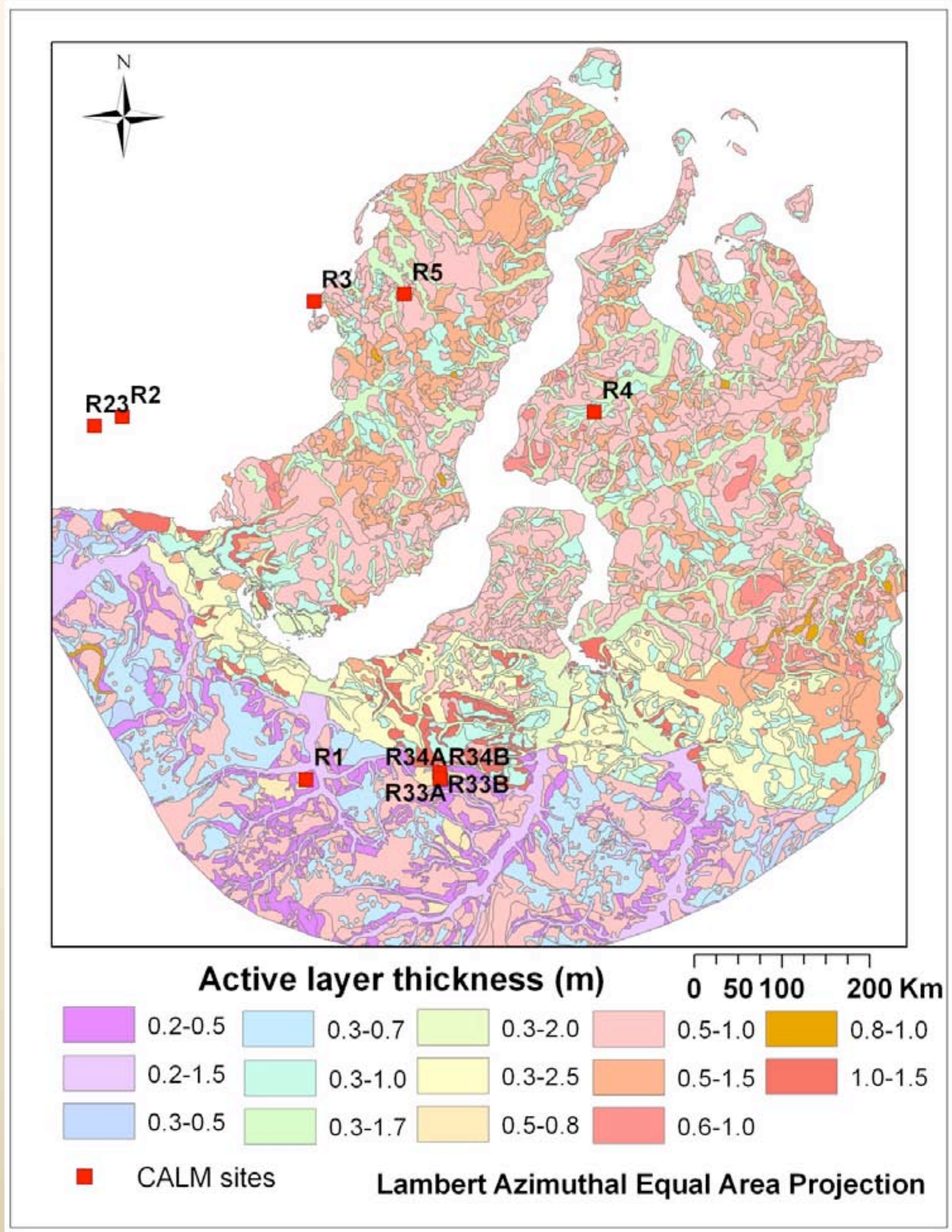
Seasonal trends in air temp in Northwest Siberia



Modeling near-surface-permafrost parameters in Northwest Siberia



Active Layer map of Northwest Siberia*

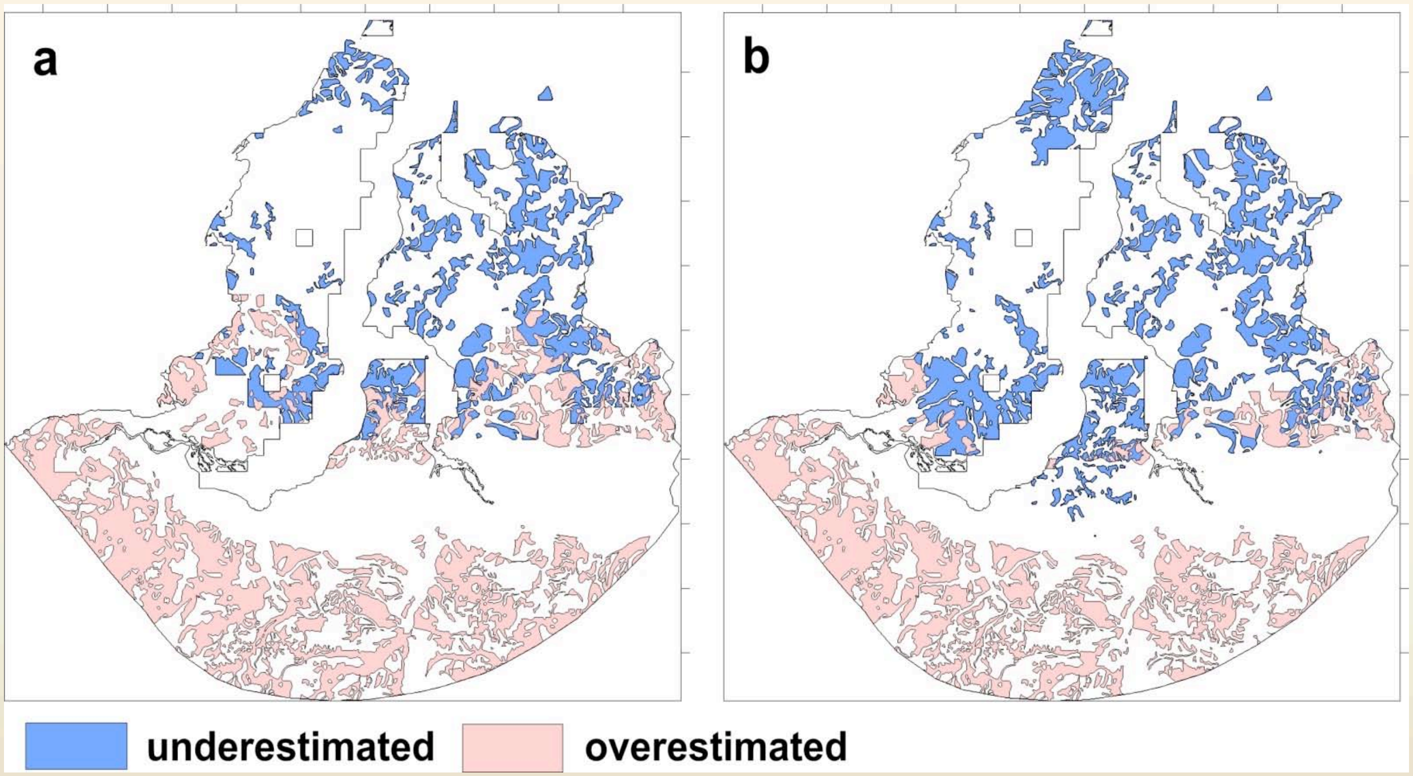


Based on data collected during 1962–1989 period

Data provided by D. Drozdov

Comparison of modeled ALT vs. "Active Layer map of Northwest Siberia"

"Warmest" climatic data set (a) "Coldest" climatic data set (b)

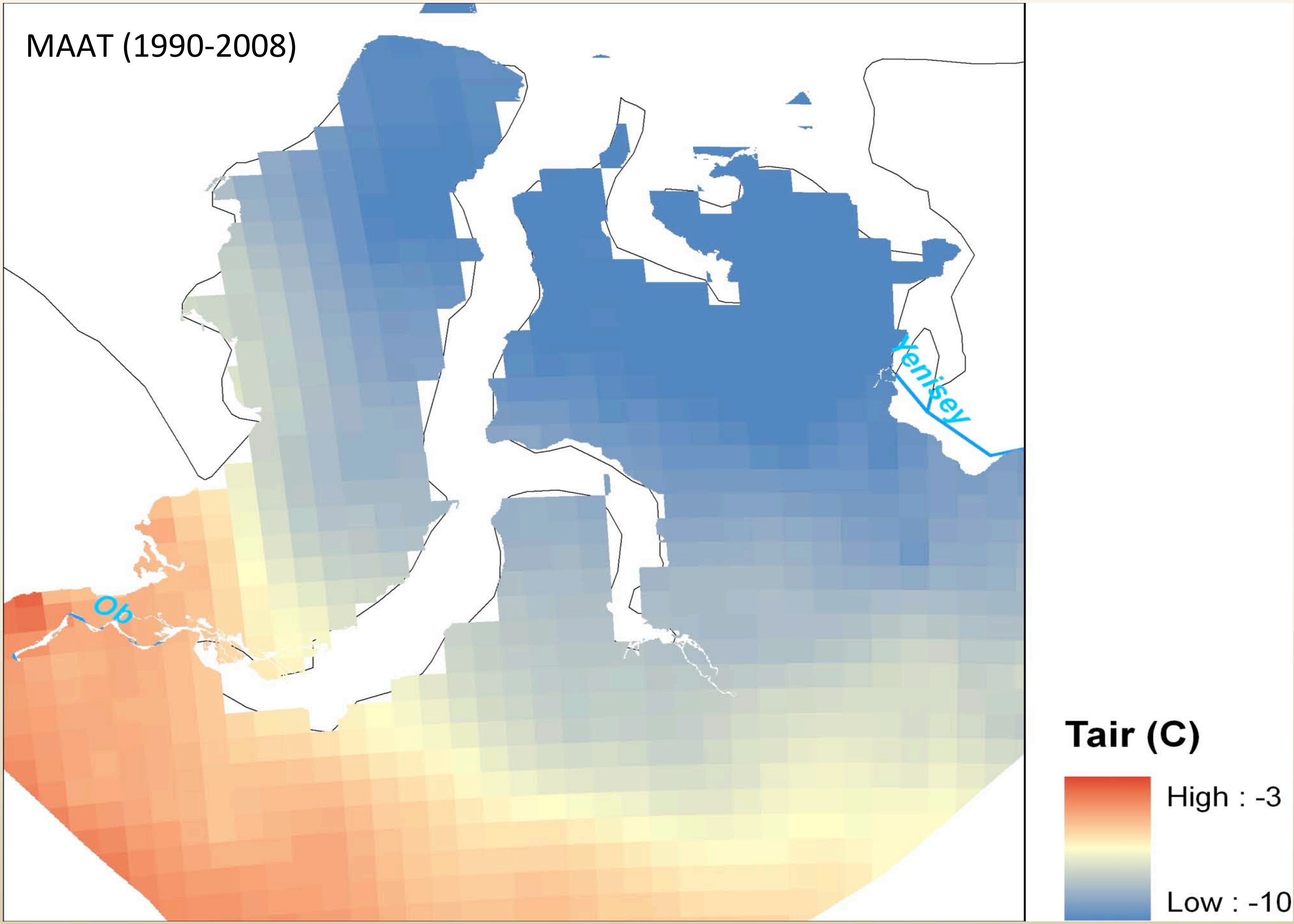


Comparison is based on climatic averages calculated for 1962–1989 period:

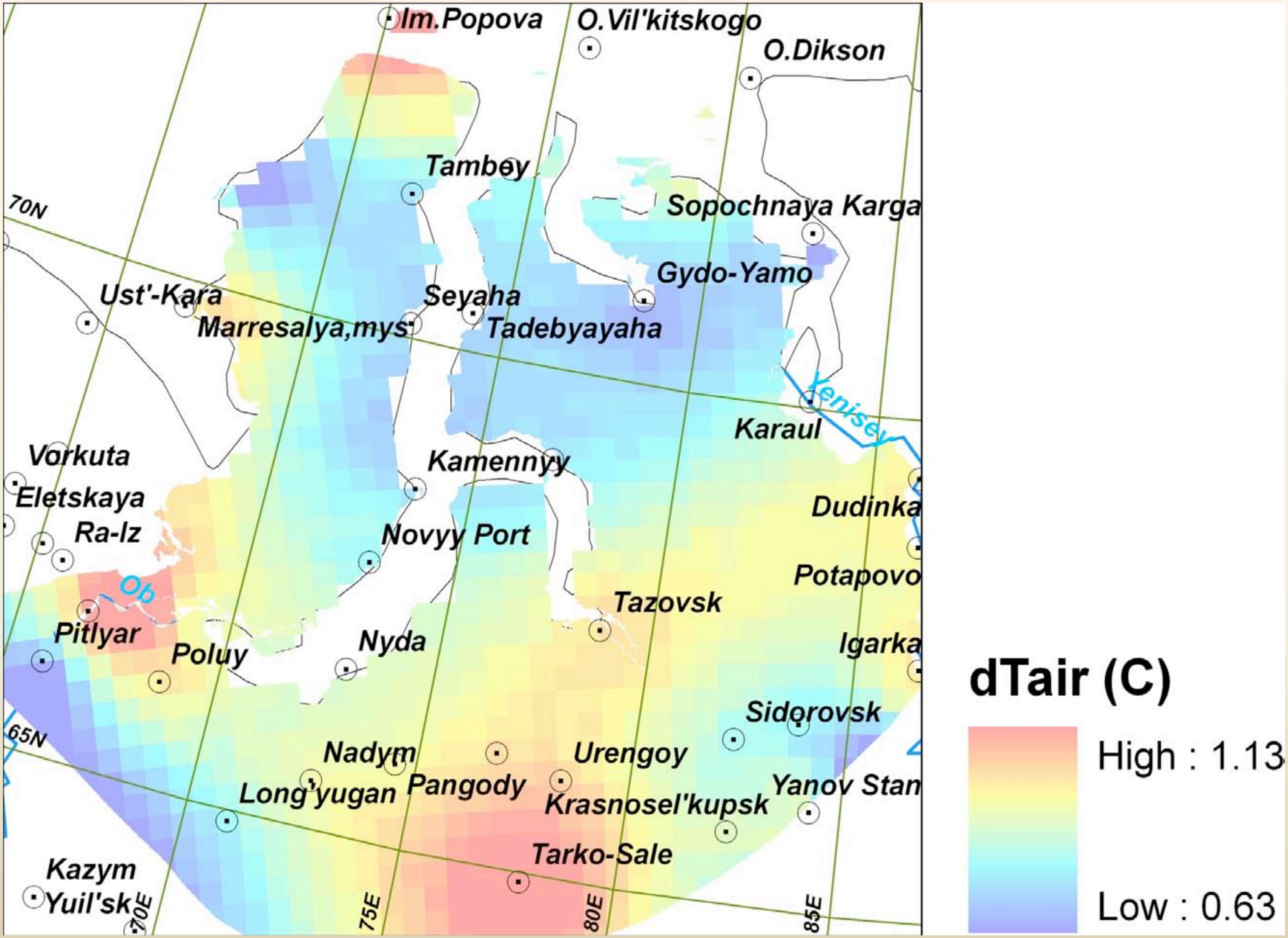
a. Model input from W&M data set (19% higher, 16% lower)

b. Model input from ERA40 data set (23% higher, 11% lower)

Mean annual air temperature

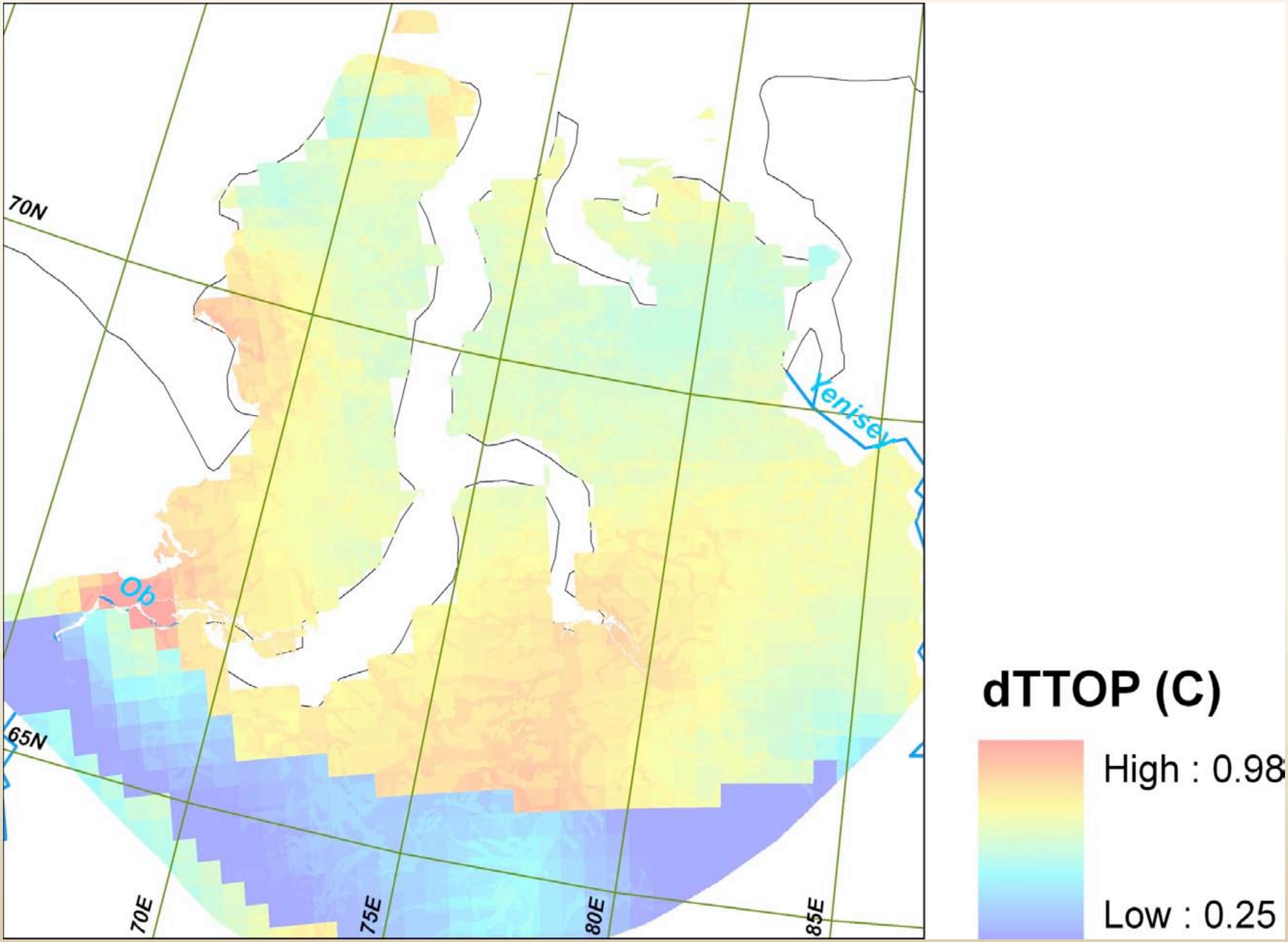


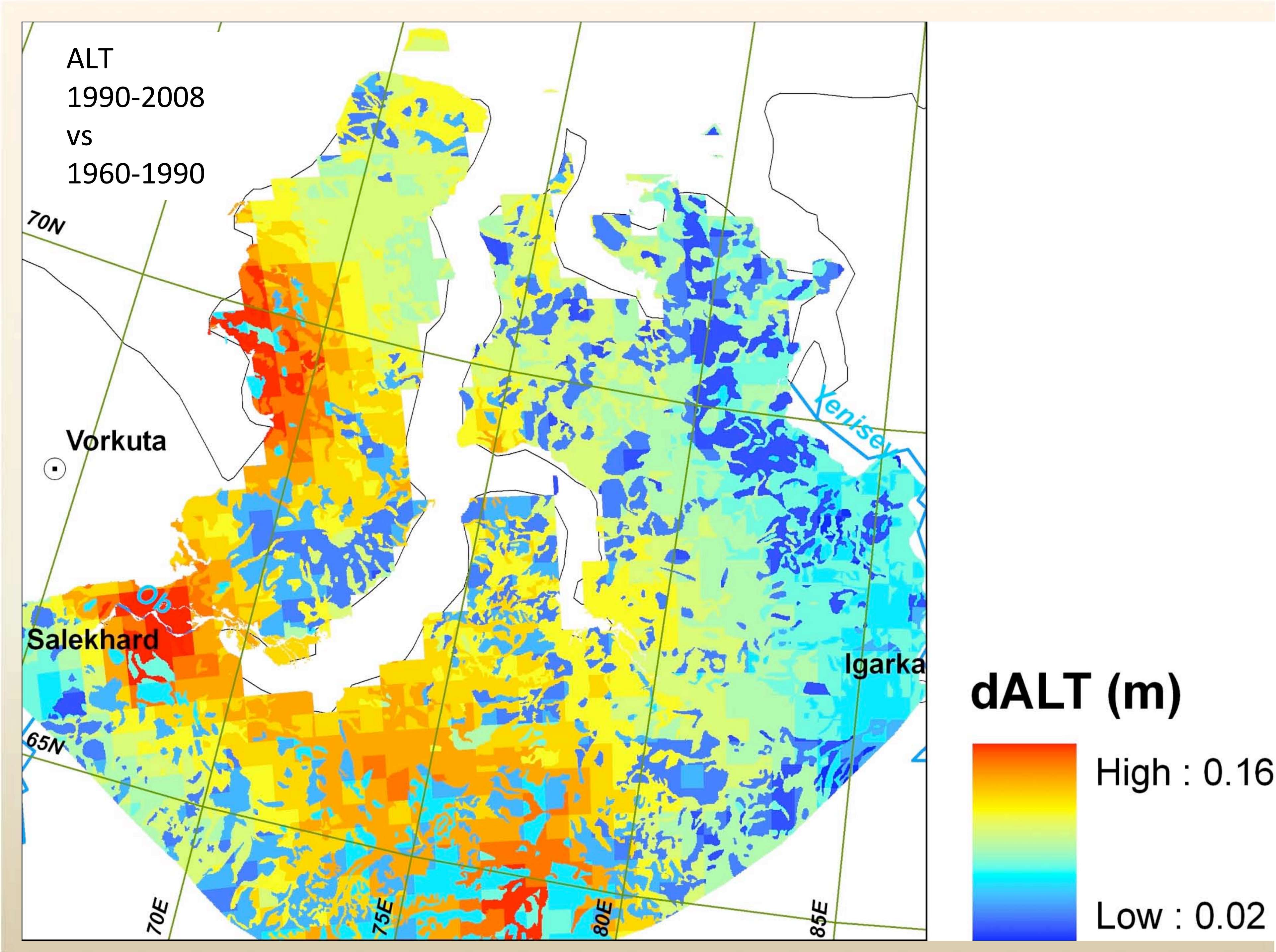
Mean annual air temperature change*

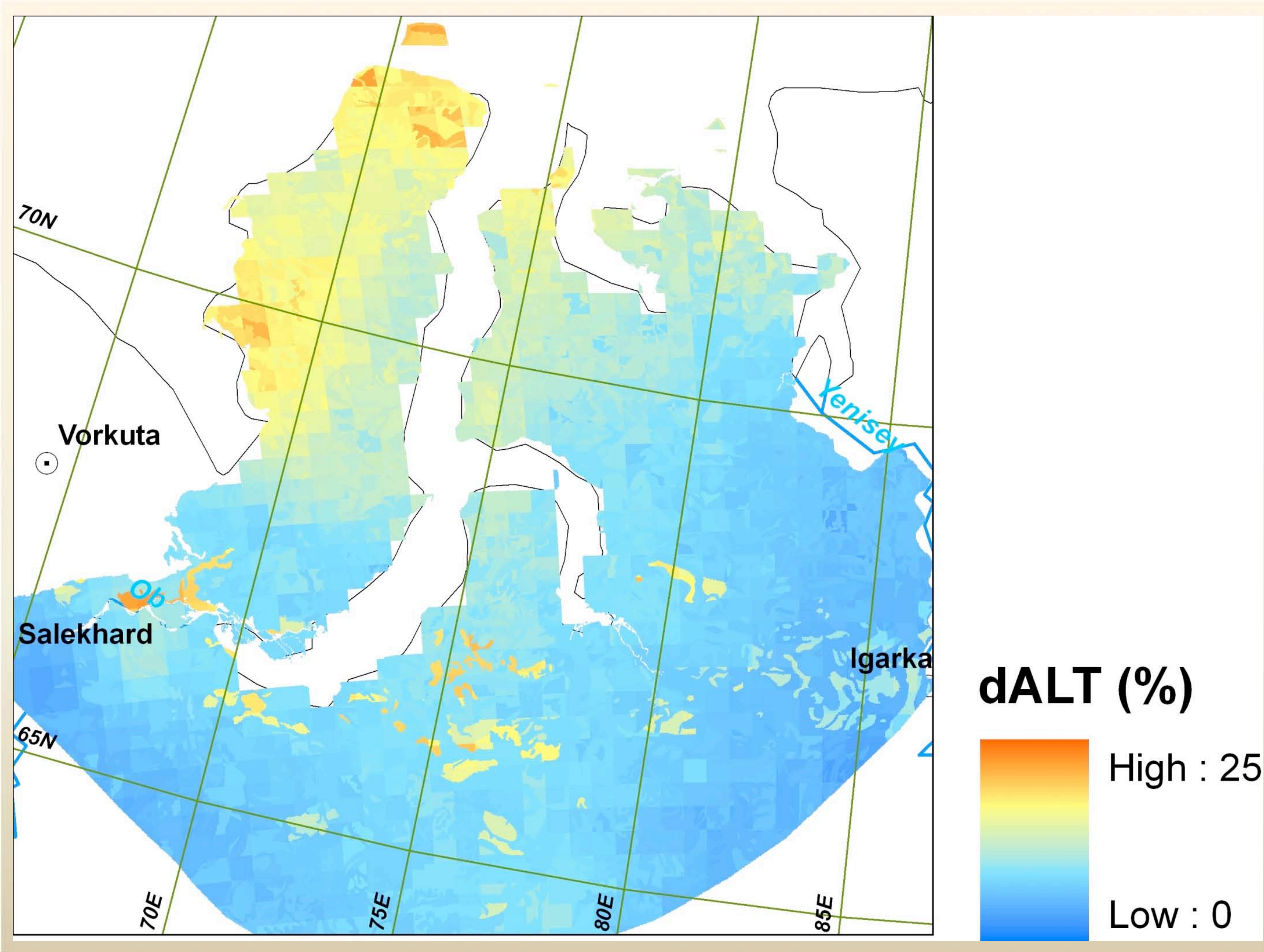


*climatic averages for 1960-1990 vs 1990-2008

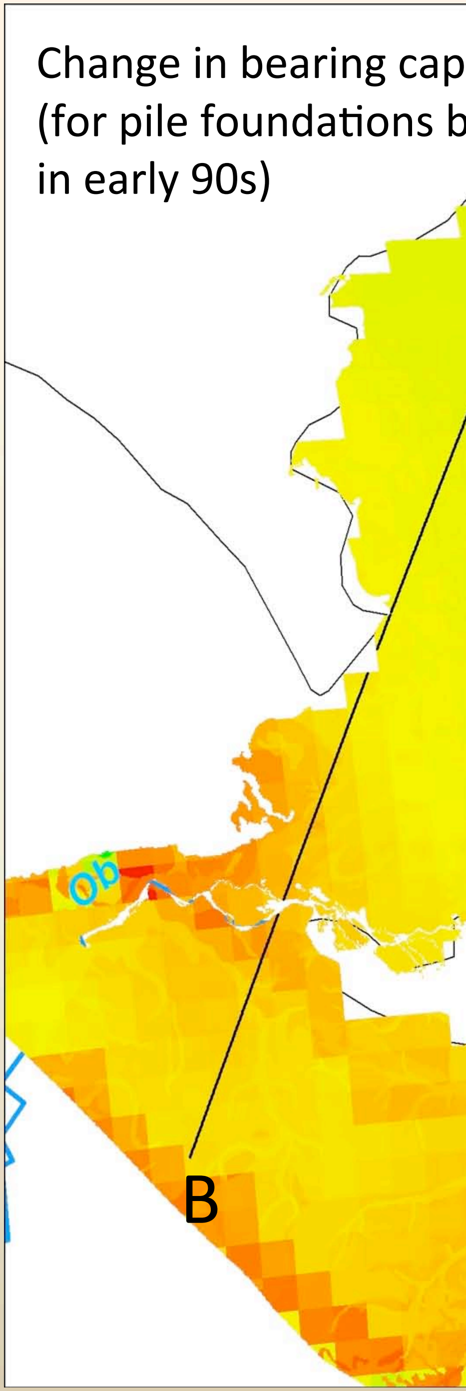
Temperature of the Permafrost Top (TTOP)

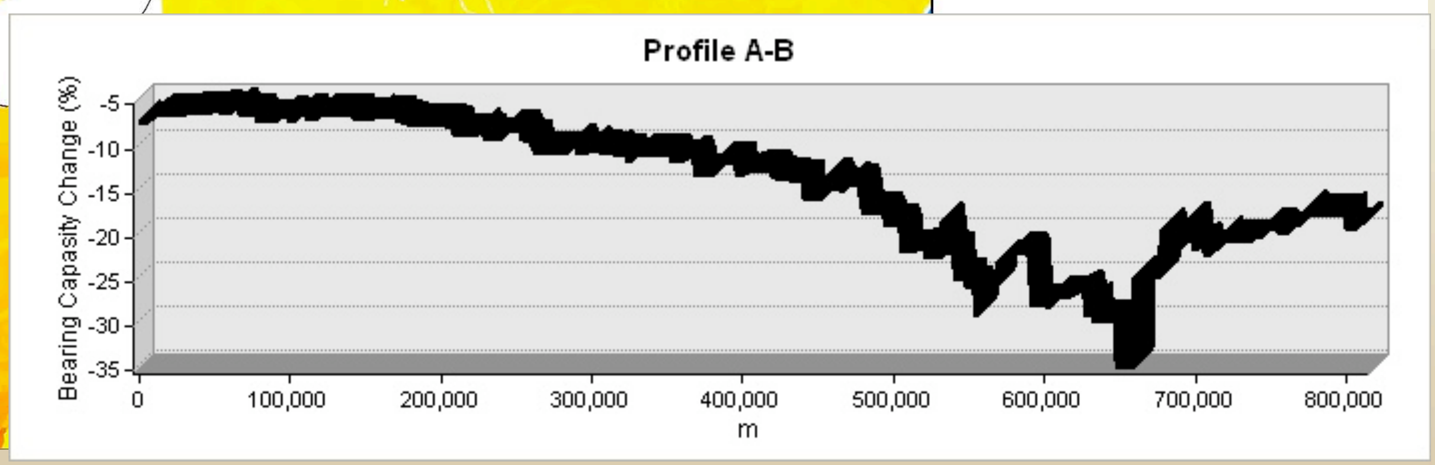



ALT
1990-2008
vs
1960-1990
70N
Vorkuta
Yenisey
Ob
Salekhard
Igarka
65N
70E
75E
80E
85E
dALT (m)
High : 0.16
Low : 0.02

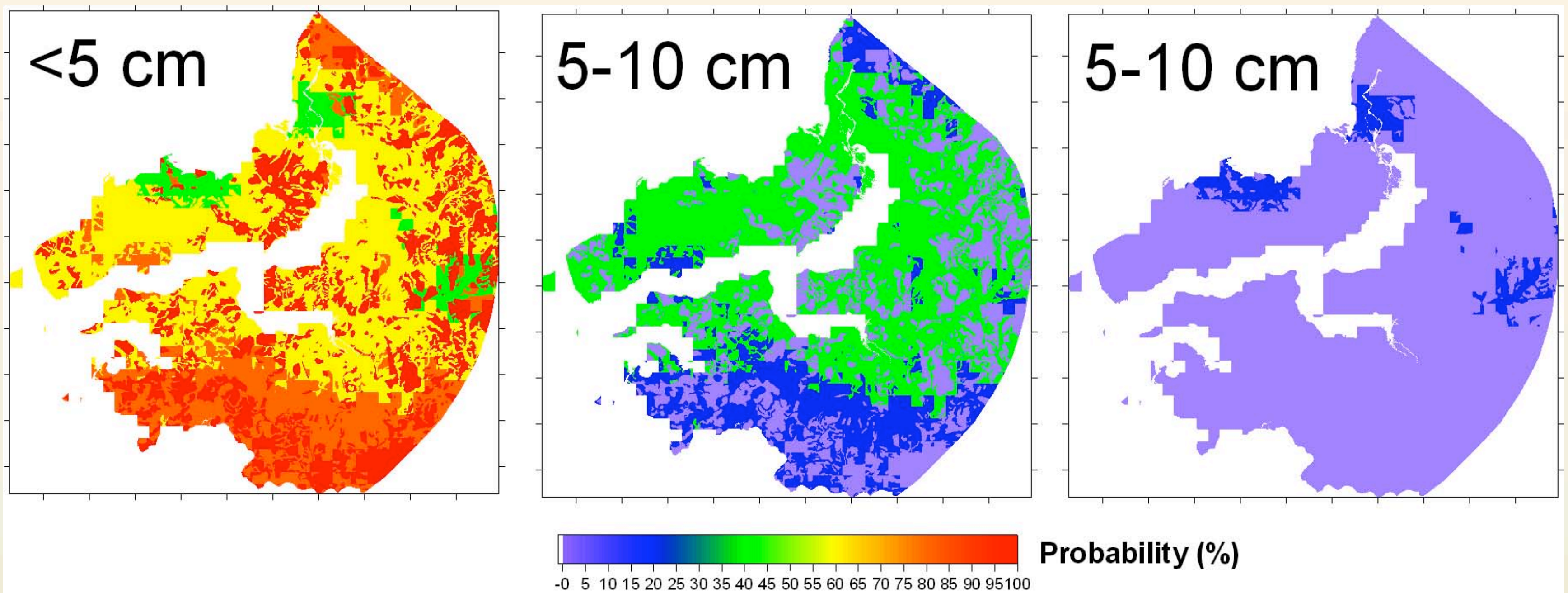

70N
65N
70E
75E
80E
85E
Vorkuta
Salekhard
Ob
Yenisey
Igarka
dALT (%)
High : 25
Low : 0

Change in bearing capacity (for pile foundations built in early 90s)





Maps of ground subsidence probability



S = δALT * I, where

S : subsidence (cm),
δ ALT: active-layer thickness change (cm)
I: volumetric ice content

Conclusions

- Landscapes with well-developed organic horizons show substantially lower dependence on climate compared to those with less developed vegetation and peat layers.
- Increases in vegetation cover and, especially, peat thickness in taiga relative to the tundra zone requires higher values of DDT to reach the same maximum thawing in northern taiga than in tundra.
- Climate warming in Northwest Siberia is mostly attributed to winter and spring seasons with less to the summer. Fall season temperatures shows no – to negative trend.
- Increase in air temperature lead to increase of TTOP by 0.3-1 C compare to reference climatology of 1960-90s with a corresponding increase in ALT from 2 to 15 cm. The highest increase in ALT (up to 25% from the reference climatology) corresponds with areas with the highest increase in continentality of climate.