Augmentation of the USArray sites with temperature profilers

GIPL[1] and USArray[2] Teams

1. Geophysical Institute, University of Alaska Fairbanks, AK 99775 2. USArray Alaska, IRIS, Anchorage, AK 99517

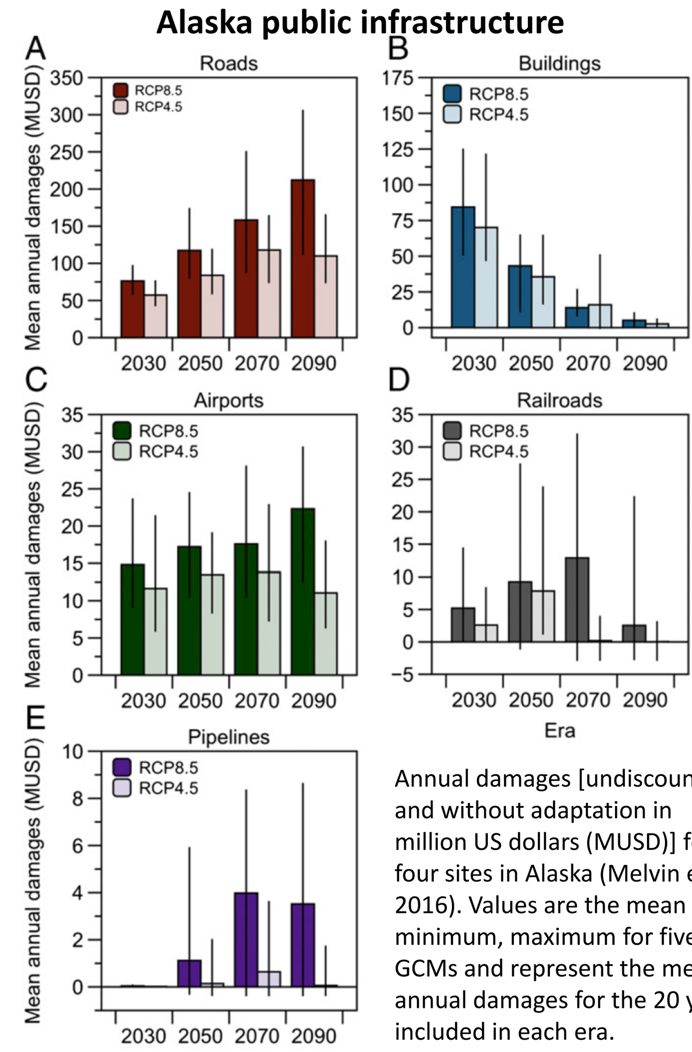
ABSRACT:

The ground temperature variability across the Arctic landscape depends on the air temperature, snow cover, moisture content, vegetation, terrain, soil properties, and related environmental variables. A juxtaposition of all these factors results in a highly heterogeneous distribution of the ground temperature, active layer thickness and permafrost conditions. As a result, prediction of subsurface temperature dynamics remains challenging, and mean temperatures for a study region may not account for "hot spots" of change, which alone could significantly contribute to thaw and associated carbon emissions. A solution is to sample (record) temperature regimes within different ecotypes, temperature and precipitation conditions, and build a portfolio of subsurface thermal regimes across various ground conditions. The proposed temperature profilers will supplement the existing data loggers and provide means to sample the ground temperature regime in currently underrepresented ecotypes and increase our knowledge of permafrost variability across Alaska and Northern Canada.

Arctic Issues:

1. **Degrading permafrost —** damaged infrastructure, relocation of settlements => social impact, medical and psychological impact, increased potential for higher unemployment and homeless people
2. **Easier access —** new sea transportation routes, more intensive onshore/offshore oil and gas development, increase in military presence
3. **Degradation of terrestrial and sub-sea permafrost —** potential increase in the greenhouse gases emissions, changes to biosphere

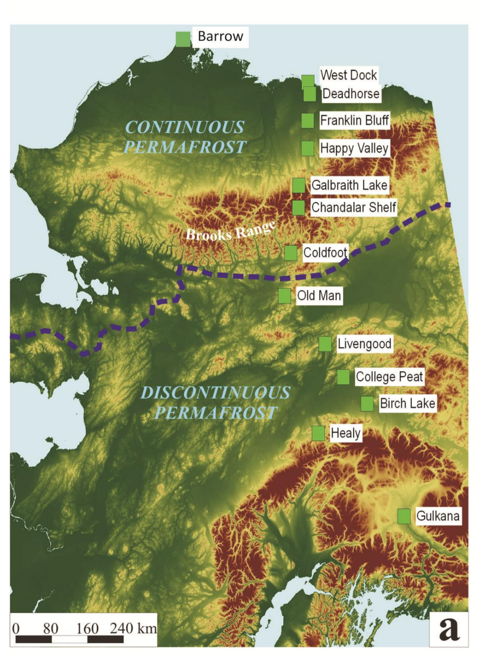
Climate change damages to Alaska public infrastructure

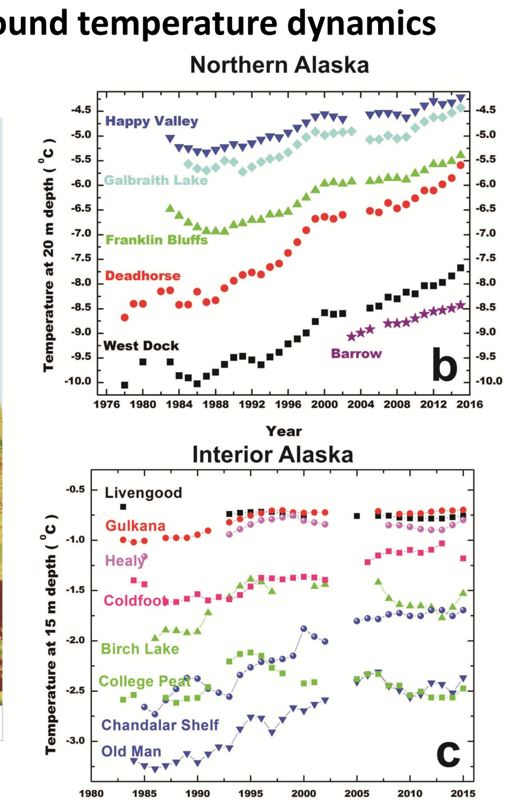


Annual damages [undiscounted and without adaptation in million US dollars (MUSD)] for four sites in Alaska (Melvin et al., 2016). Values are the mean ± minimum, maximum for five GCMs and represent the mean annual damages for the 20 yr included in each era.

How do we go from point-wise observations to the regional coverage?

Observed trends in the ground temperature dynamics

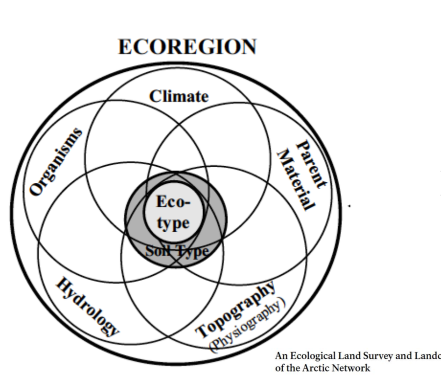


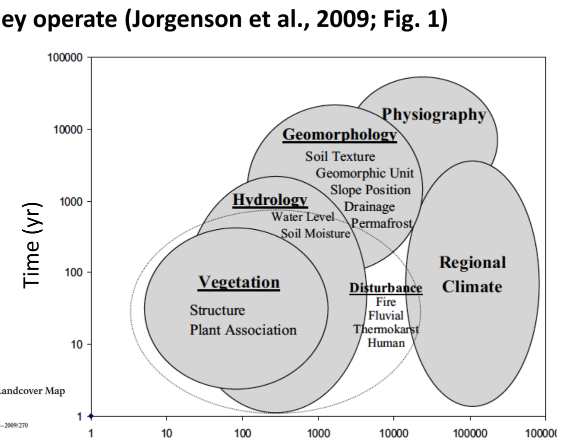


Sites with 40-m deep boreholes are marked by green squares

The ground temperature dynamics depends on the air temperature, snow cover, moisture content, vegetation, terrain, soil properties, and related environmental variables. A juxtaposition of all these factors results in a highly heterogeneous distribution of the ground temperature, active layer thickness, and permafrost conditions. At local scales, within several hundred meters, two ecotypes may co-exist and be characterized by a very different subsurface thermal regime. For example, for the same air and precipitation, observed permafrost temperature can differ by as much as 4°C if the vegetation cover is different. Therefore, an increase in the air temperature may lead to some warming of the ground material at one location, whereas at the neighboring site with a different ecotype, this warming may pass a thaw threshold and cause permafrost degradation. As a result, prediction of subsurface temperature dynamics remains challenging, and mean temperatures for a study region may not account for "hot spots" of change, which alone could significantly contribute to thaw and associated carbon emissions. A solution is to sample (record) temperature regimes within different ecotypes, temperature and precipitation conditions, and build a portfolio of subsurface thermal regimes across various ground conditions.

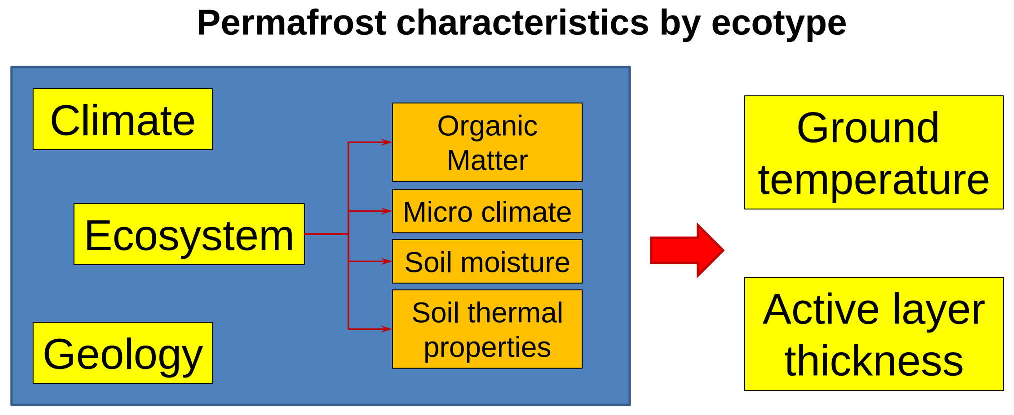
Interaction of interrelated state factors that control the structure and function of ecosystems and the scales at which they operate (Jorgenson et al., 2009; Fig. 1)



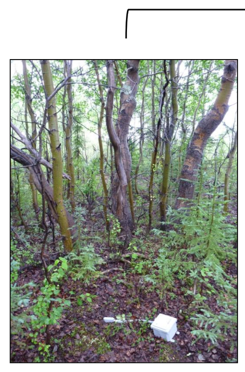


Above and below ground ecosystems co-evolve with their soils and have been "relatively" stable over centuries and millennia.

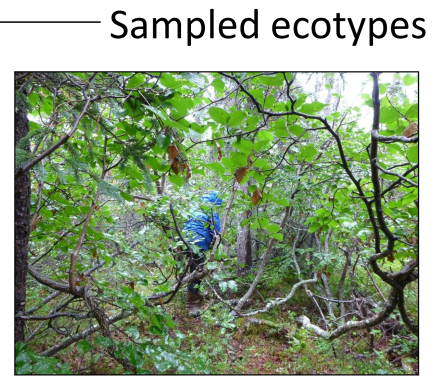
Permafrost characteristics by ecotype



Sampled ecotypes



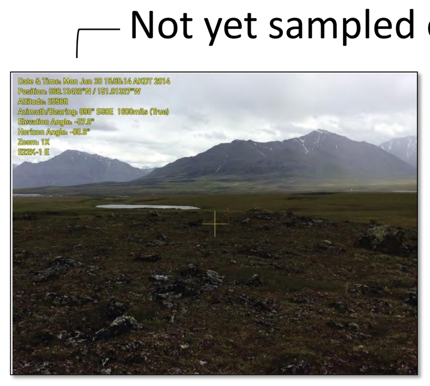
Upland Aspen Forest, $T_{1\ m\ depth}$ = +0.65°C

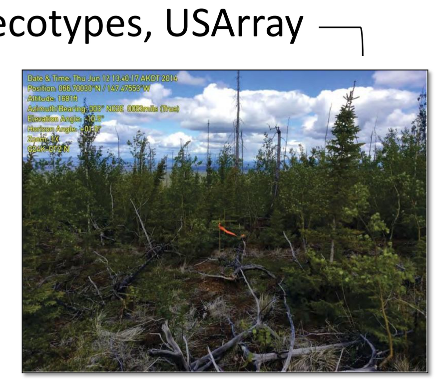


Upland White Spruce Forest with Alder Temperature at 1 m depth: +0.17°C

Upland and Lowland Tussock Meadows, $T_{1\ m\ depth}$ = from -3.6°C to -4.55°C

Not yet sampled ecotypes, USArray

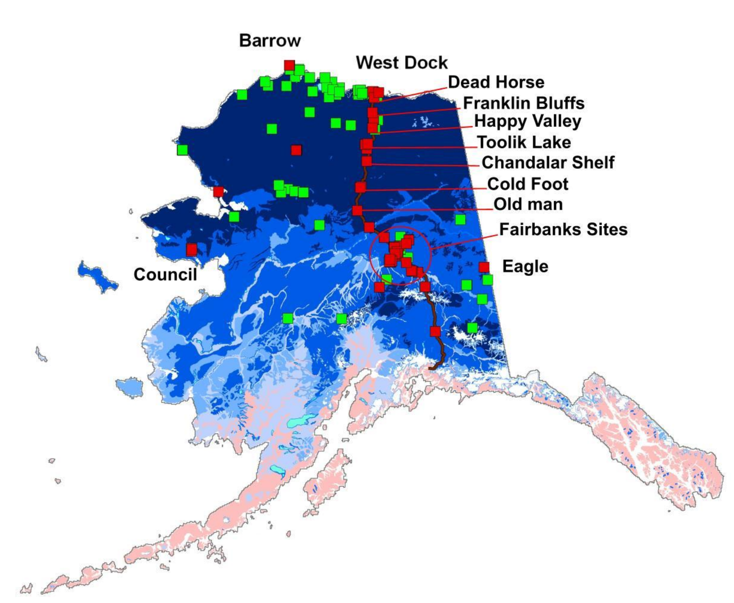




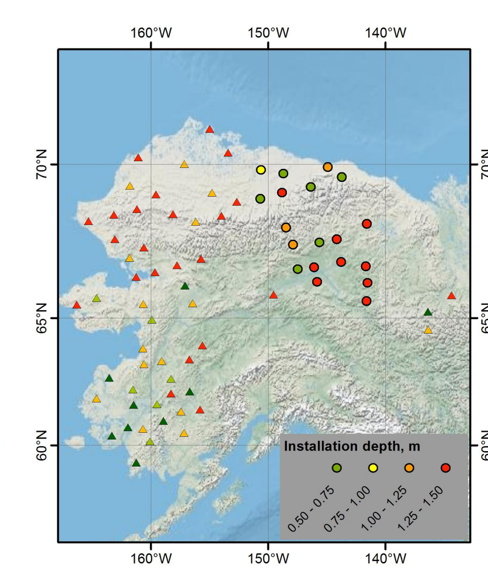
<u>Project Goal:</u> To measure active layer and permafrost temperature distribution and dynamics across the ABoVE domain

<u>Objective 1</u>: Supplement the US Array sites with temperature profilers in remote areas of Alaska and western Canada to augment the current permafrost borehole network.
<u>Objective 2</u>: Sample US Array sites to capture spatial heterogeneity across the landscape and the domain.
<u>Objective 3</u>: Increase sampling density and provide a consistent dataset of ground temperature measurements.
<u>Objective 4</u>: Provide permafrost temperature profile data sets for calibration and validation of remote sensing algorithms and modeling efforts.

Existing GIPL and USGS sites in Alaska



USArray sites in Alaska



Survey of ABoVE science team projects who will make use of US Array borehole temperature profile data

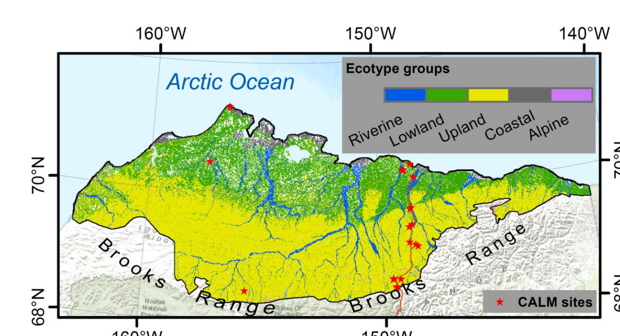
PI	Project name	Utility of temperature profile data	Priority
Kimball	Environmental variability & controls on carbon fluxes	Soil thermal profile measurements are required across the ABoVE domain to characterize spatial & seasonal variability in permafrost active layer depth, to validate NASA remote sensing (e.g. for use of SMAP products for ABoVE), and to inform & calibrate models.	Essential
Natali	Winter respiration	Highly relevant measurements of variables that influence winter respiration rates. Soil thermal properties essential for spatial up-scaling of CO2 flux measurements.	Essential
Fisher	Model-Data Integration	With measurements of quantified uncertainty of soil temperature, stratified by vertical layer, that are dynamic and robust through time, these measurements would be highly useful to our large-scale modeling activities. Terrestrial Biosphere Models are highly uncertain in soil energetics, which propagates through to critical biogeochemical cycling and permafrost activity. Having a benchmark with which to improve models for this component will lead to improvements in modeled terrestrial processes, stocks, and fluxes.	Highly Useful
Mack	Legacy carbon	These data sets would be valuable for validation of soil thermal models and the distributed nature of the measurements will help determine the spatial scaling of factors controlling the potential loss of legacy carbon.	Highly useful
Moghaddam	Regional Mapping of Soil Conditions in Northern Alaska Permafrost Landscapes	Soil temperature profile measurements are required within the footprint of radar remote sensing measurements in the ABoVE domain to validate retrieved high-resolution (50-100 m) active layer products and to calibrate physics-based radar model parameters to make them reliably applicable to larger heterogeneous domains.	Highly Useful
Striegl / Walford	Vulnerability of the carbon cycle to changing permafrost	Borehole temperature data will provide valuable information for geophysical data interpretation and calibration of permafrost hydrology model simulations.	Highly useful
Wilson	Characterizing Thawing Permafrost Carbon Emissions	These measurements would be extremely useful for validating our project's ground penetrating radar data to identify the water/ice layer in the subsurface structure	Highly useful

Preparation of the temperature profilers

HOBO UX120 4-Channel Analog Data Loggers with two Lithium batteries to support multi-year data collection efforts

- During 2016 campaign we supplemented **19 USArray sites** with temperature profilers
- During 2017 campaign we supplemented **55 USArray sites** with temperature profilers
- Currently the plan is to location and instrument interesting sites in the Interior Alaska
- Besides the ground temperature sensors each USArray station is supplemented by an air temperature measurement sensor, **wind speed** and **air pressure** sensor

USArray sites capture heterogeneity and compliment existing data collection efforts



The 30-m resolution ecotype map based on the remote sensing product.

Locations of the temperature monitoring sites by GIPL and USGS are marked with black triangles and squares, respectively. Location of the CALM sites are marked by red stars.

Ecotypes covered by permafrost boreholes

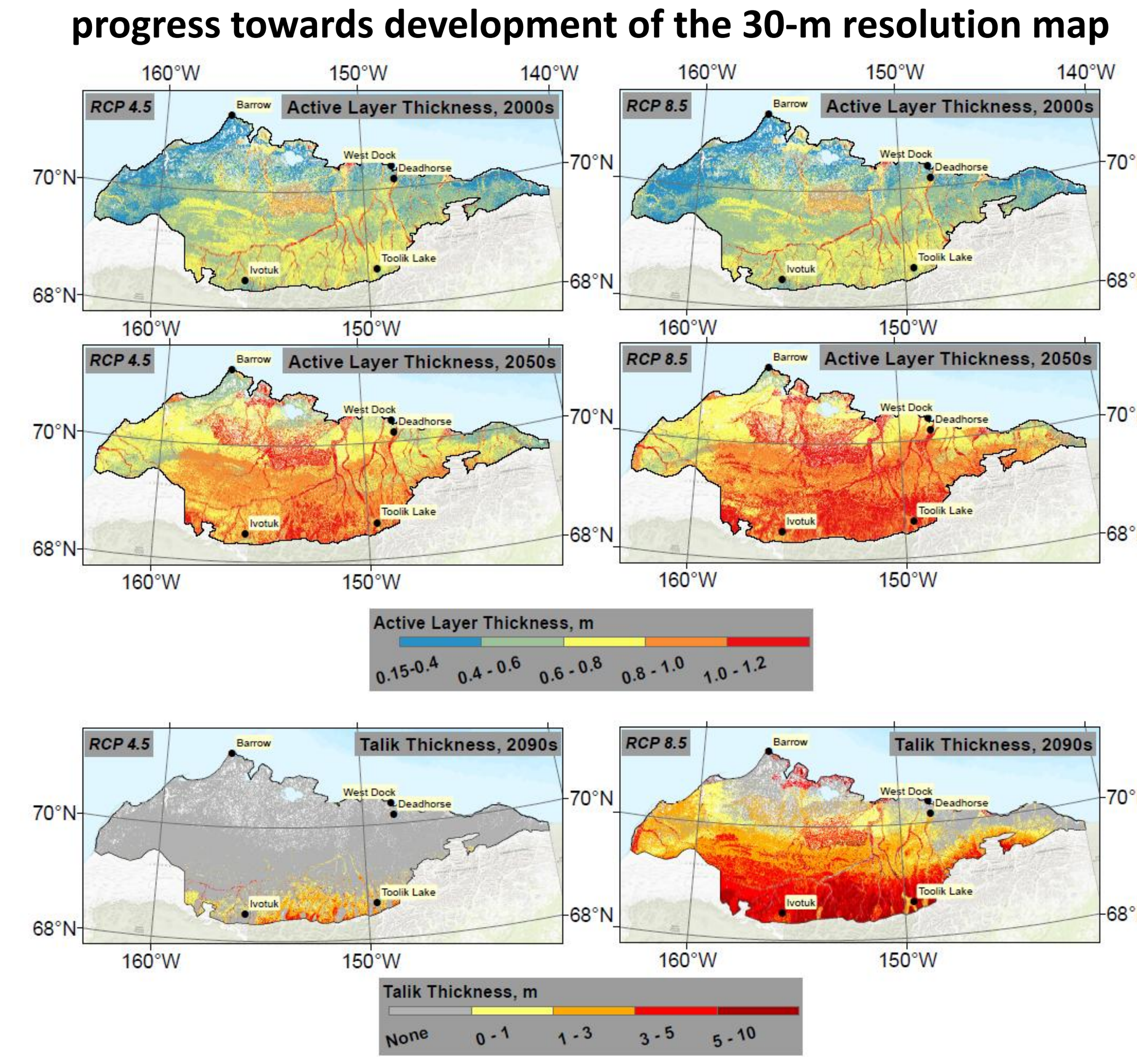
Ecotypes	% Cover
Coastal grass & dwarf shrub tundra	0.8
Riverine wet sedge tundra	1.1
Lowland wet sedge tundra	11.2
Lowland moist sedge-shrub tundra	13.4
Upland tussock tundra	11.3
Upland shrubby tussock tundra	24.7
Upland low birch-willow shrub tundra	14.2
Upland moist sedge-shrub tundra	5.3
Total cover	82.0

Coastal, river, and lake water bodies cover 9.3% of the study area excluded from permafrost modeling.

Ecotypes <u>NOT covered</u> by permafrost boreholes

Ecotypes	% Cover
Coastal barrens	0.3
Coastal wet sedge tundra	0.9
Riverine barrens	1.2
Riverine low willow shrub tundra	0.8
Riverine moist sedge-shrub tundra	3.1
Riverine dryas dwarf shrub tundra	0.0
Lowland low birch-willow shrub tundra	1.3
Upland dryas dwarf shrub tundra	0.6
Upland tall alder scrub	0.0
Alpine non-carbonate barrens	0.0
Alpine carbonate barrens	0.0
Alpine non-carbonate dryas dwarf shrub	0.2
Alpine carbonate dryas dwarf shrub	0.0
Total cover	8.7

High-resolution modeling of permafrost dynamics in Alaska progress towards development of the 30-m resolution map



Data assimilation and model parameterization

GIPL 2 Model:
1-D heat equation with phase change, no convective heat transport, and no interval sources or sinks of heat.

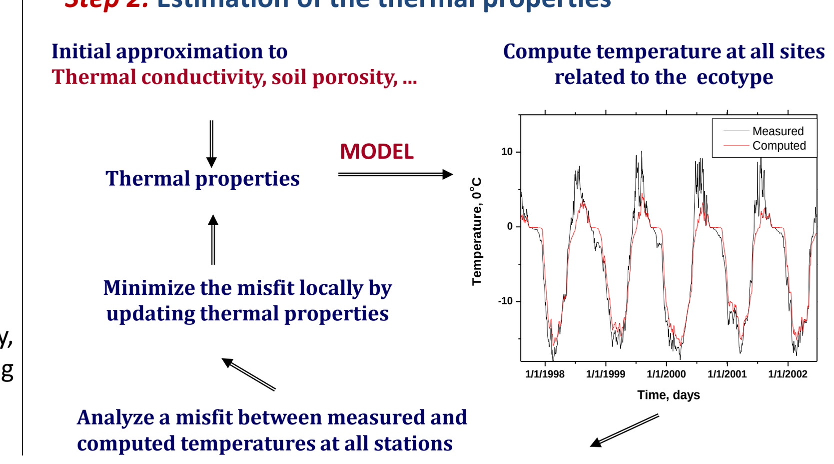
Assumptions:
fully saturated soil, thermal properties do not vary with depth within each layer.

Parameters:
thermal conductivity, soil porosity, freezing point depression, etc.

Step 1: Estimation of the snow properties

- **Initial approximation to the thermal ground properties**
- **Calibrate the snow viscosity at the borehole sites using the ground temperature measurements**

Step 2: Estimation of the thermal properties



CONCLUSIONS:

1. To mitigate all possible impacts of permafrost degradation, an accurate and timely forecast of changes in permafrost based on reliable permafrost observation system should be established
2. Despite our accumulating knowledge of changing permafrost, future permafrost dynamics and its impacts remain poorly quantified especially on local scales
3. Including observations of permafrost temperatures in the EarthScope set of instrumentation in Alaska will dramatically improve our ability to monitor and to predict near-term changes in permafrost
4. Successful implementation of this project will double the number of Permafrost Observatories in Alaska
5. It will lead to much better ability to predict the consequences of permafrost thaw to the earth natural systems and to foresee their societal impacts on the communities and infrastructure in Alaska

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