B53E-0715

EARTH SCIENCES DIVISION

# High Resolution Characterization of Heterogeneous Arctic Tundra Subsurface Properties using a Multiscale Bayesian Fusion Approach with Geophysical Datasets

HM Wainwright[1](hmwainwright@lbl.gov), SS Hubbard[1], C Gangodagamage[2], JC Rowland[2], A Liljedahl[3], A Gusmeroli[3], B Dafflon[1], C Ulrich[1], Y Wu[1], C Wilson[2], C. Tweedie[4] and S. Wullschleger[5]
[1]Lawrence Berkeley National Laboratory, [2]Los Alamos National Laboratory, [3]University of Alaska, Fairbanks, [4]University of Texas, El Paso, [5]Oak Ridge National Laboratory

## ABSTRACT

This work presents a data fusion method based on a hierarchical Bayesian model for integrating multiscale, multi-type datasets and prior knowledge to provide estimates of heterogeneous subsurface properties and their associated uncertainty in the artic tundra ground. The subsurface properties–such as thaw depth, soil moisture, snow depth and geochemical parameters–are key parameters for modeling the hydro-micro-geochemical processes to predict the future of carbon stored in permafrost. The surface geophysical data are non-invasive and spatially extensive, which increases the spatial coverage in subsurface and reveals the fine-scale variability. Remote sensing data can further increase the spatial coverage through the subsurface-surface property correlation. The model consists of two sub-models: data model and process model. First, the process model describes the heterogeneous field of each subsurface property mathematically. Second, the data model connects the heterogeneous field to multiscale datasets. Once we establish the data and process models, we estimate the heterogeneous fields using the Markov Chain Monte-Carlo method. We demonstrate our approach using co-located datasets collected at the Barrow Environmental Observatory, Alaska, including thaw depth, soil temperature, snow depth, ground penetrating radar data, electrical resistivity tomography, and airborne LIDAR. We obtain high-resolution estimates of thaw depth, soil water content, snow depth and other subsurface properties over a several hundred meter-scale domain.

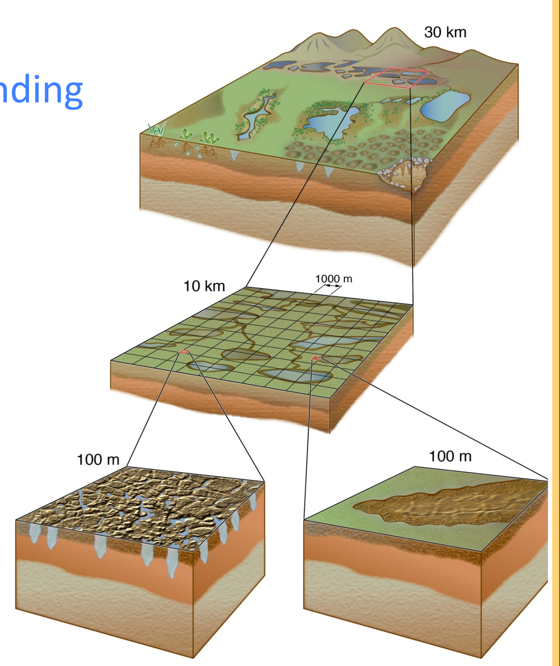
## OBJECTIVES

### Environmental controls on carbon decomposition in subsurface

→ Critical for modeling and predictive understanding

- Thaw depth
- Active layer thickness (ALT)
- Soil moisture
- Redox status
- Temperature
- Snow depth

→ Highly heterogeneous
→ Difficult to characterize in a large scale




### Objective

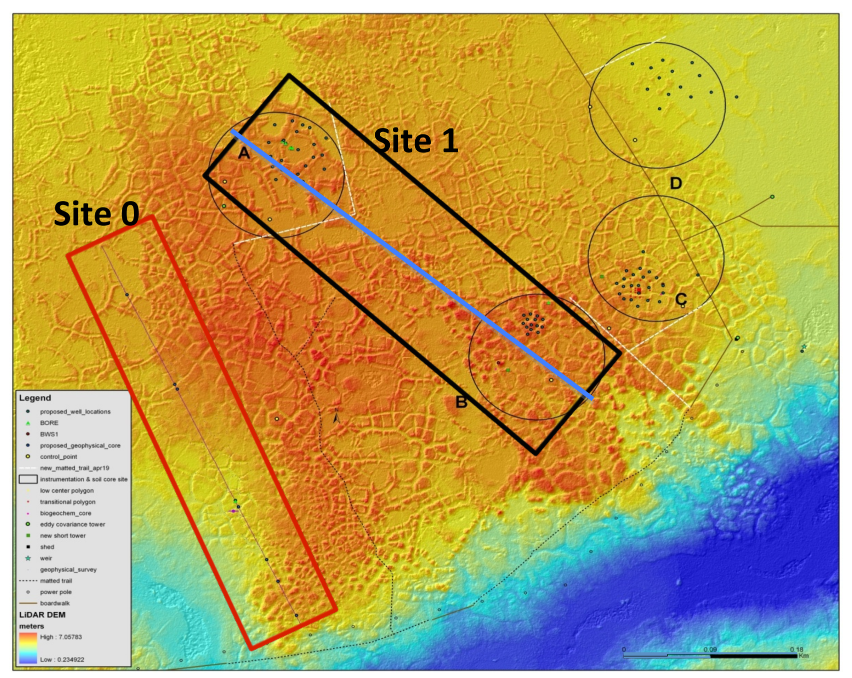
- Combine different types and scales of data and also prior knowledge to characterize the subsurface in a large-scale domain

→ Surface geophysics, remote sensing

- Develop a data fusion framework and apply it to the real datasets

## SITE AND DATA

### NGEE Arctic Site (Barrow, AK)




**Time slices**

- Sept 2011 (Freeze-up)
- May 2012 (Frozen)
- July 2012 (Thawed)
- Sept 2012 (Freeze-up)
- November 2012

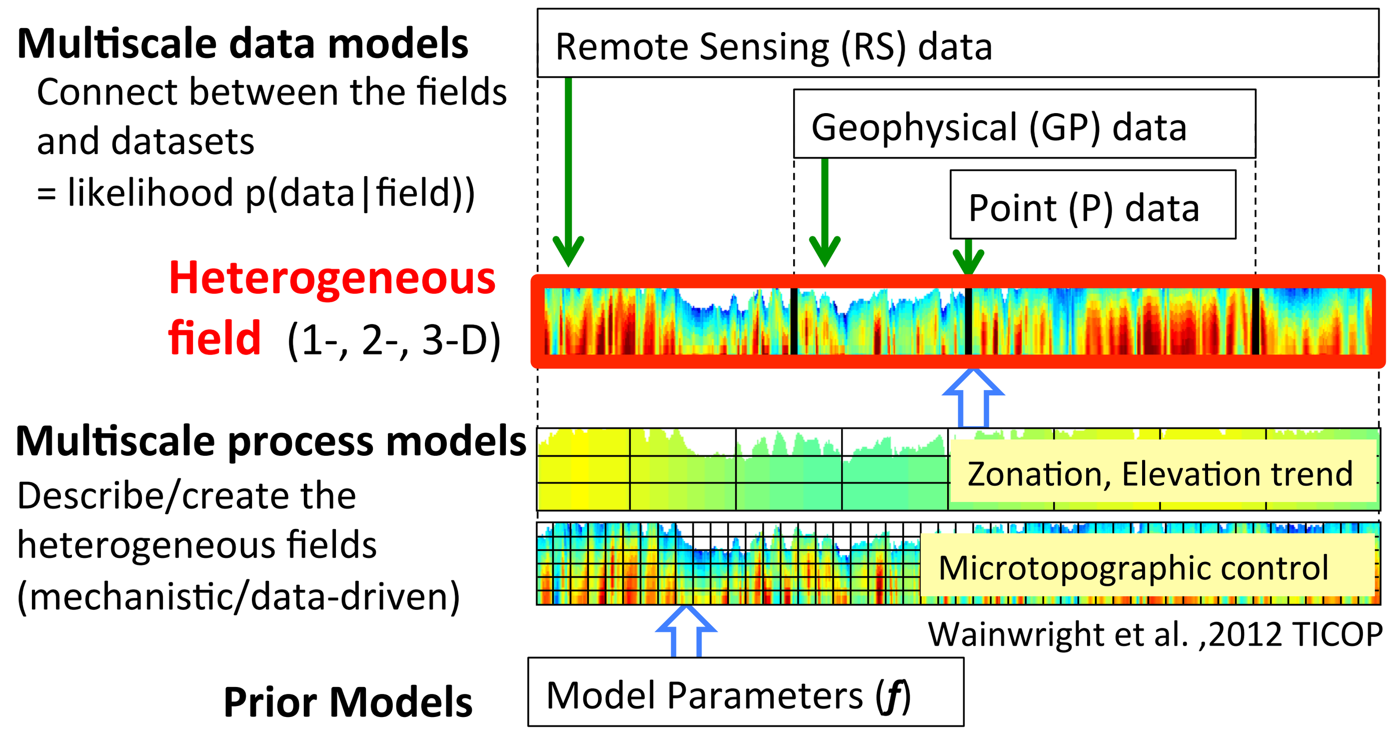
**Multi-data types**

- 2D & 3D ERT/GPR
- Soil texture, thaw depth
- Temperature
- Snow depth (and more)

## METHODS

### Multiscale Bayes Model

Integrate multiscale multi-type datasets for spatially variable properties that are created/described by multiscale processes




### Integration: Bayes Rule

$p(\text{field}|\text{data}) \propto p(\text{RSdata}|\text{field})\,p(\text{GPdata}|\text{field})\,p(\text{Pdata}|\text{field})\,p(\text{field}|f)\,p(f)$

→ Markov-Chain Monte-Carlo (MCMC) Sampling
→ Integrate the measurement errors/spatial variability/uncertainty consistently

### Data-driven Process Model Development

Identify key controls and correlations between surface and subsurface attributes (microtopography, base-line elevations etc)

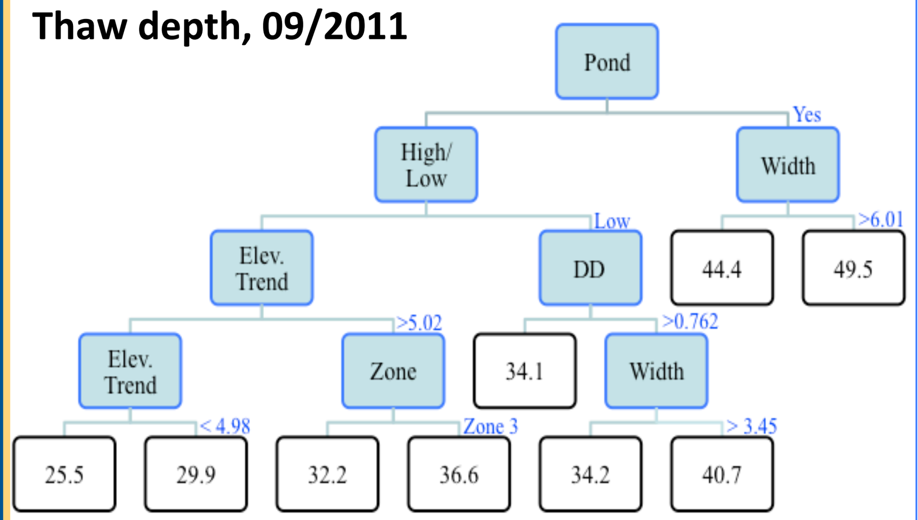
→ Data mining techniques: Regression tree method

## RESULTS I: Data Mining

### Regression Tree Analysis (Data from Site 0)

Higher in the tree = more influential

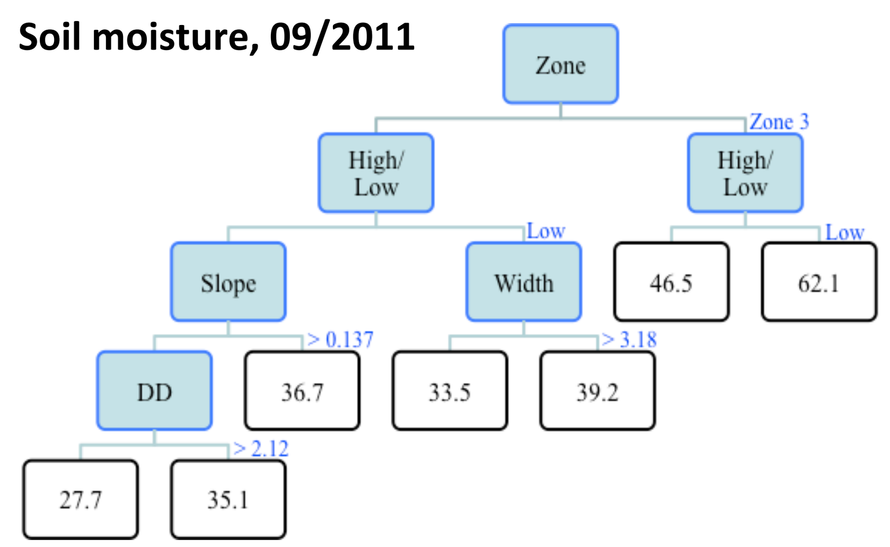
**Thaw depth, 09/2011**




**Thaw depth** is larger at
- surface inundated locations
- centers (high directed distance) of wide micro-topographic low.

At microtopographic high areas, it is larger at
- higher base-line elevation
- low-centered polygons.

**Soil moisture, 09/2011**




**Soil moisture** is higher at
- wide micro-topographic low
- low-centered polygons.

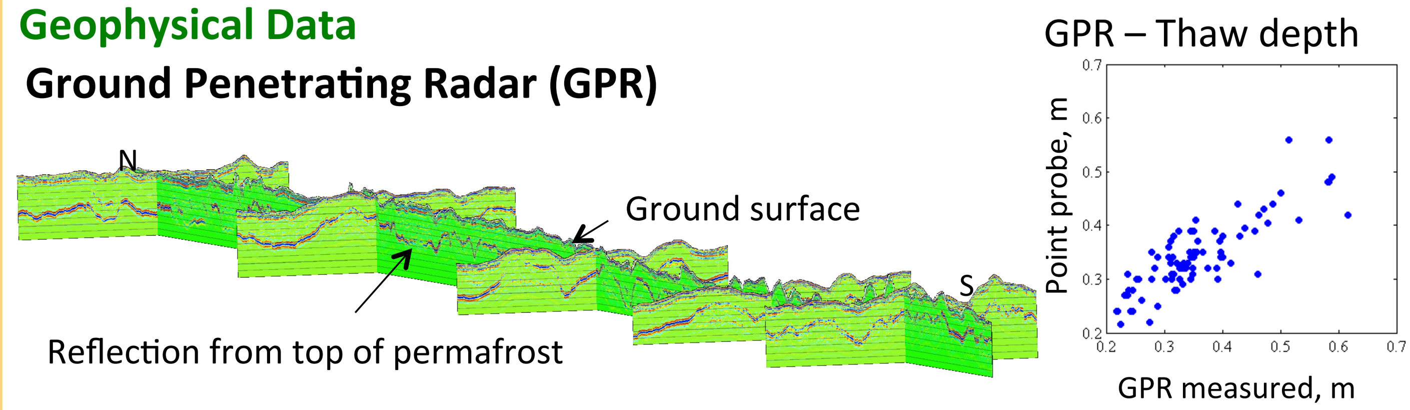
At microtopographic high, it is higher at
- lower base-line elevation

(Note: snow/vegetation effects might be confounded with microtopography)

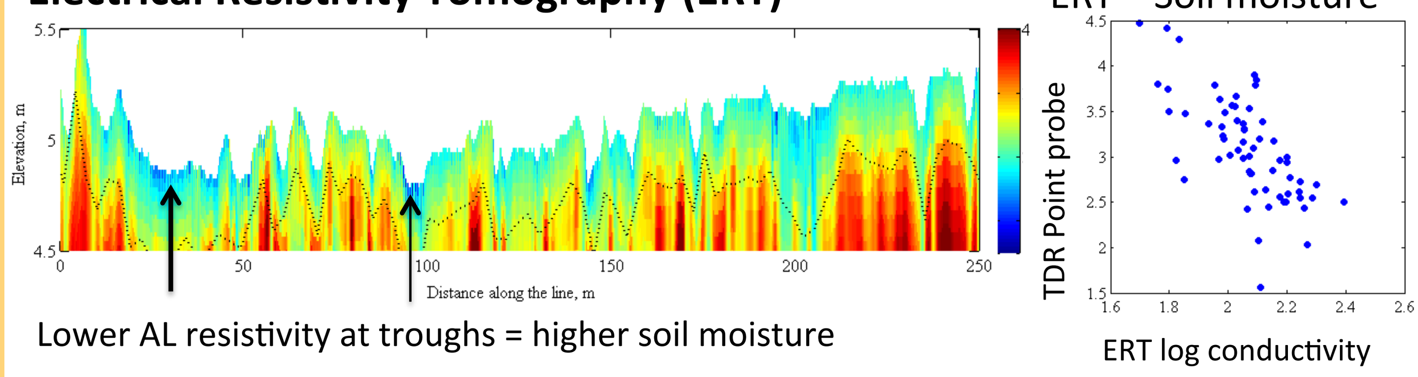
## RESULTS II: Data Integration

### Geophysical Data

**Ground Penetrating Radar (GPR)**



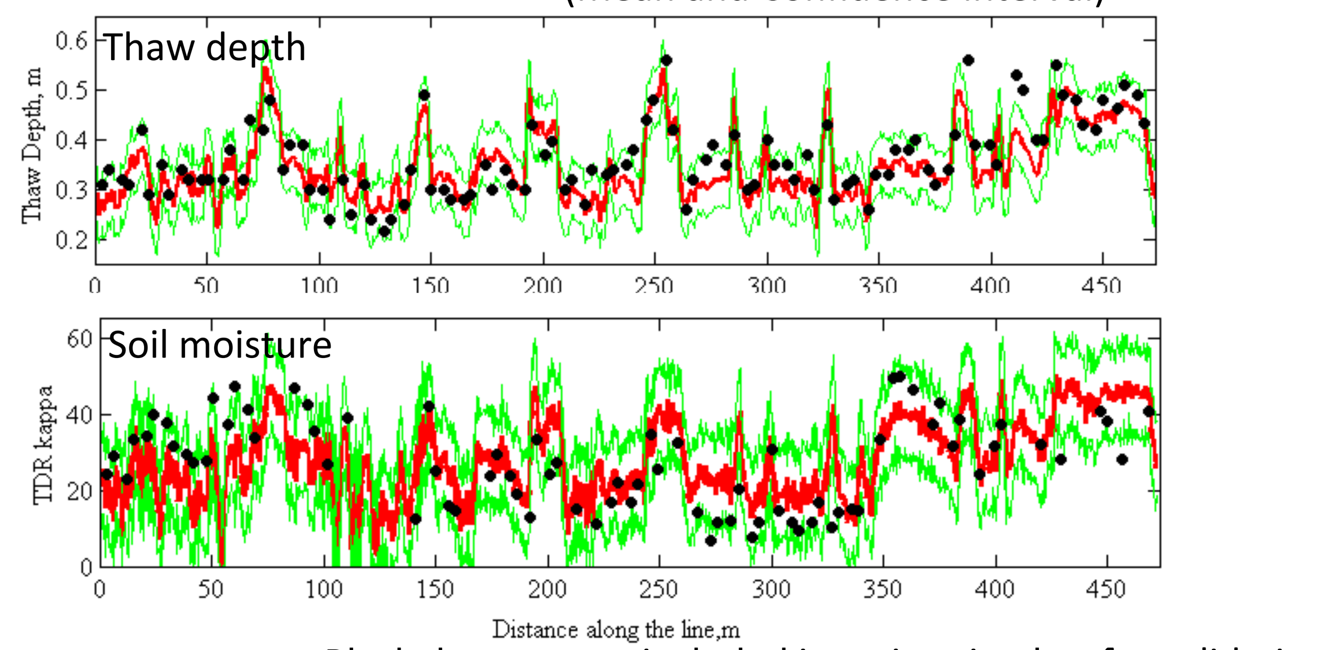

**Electrical Resistivity Tomography (ERT)**




Lower AL resistivity at troughs = higher soil moisture

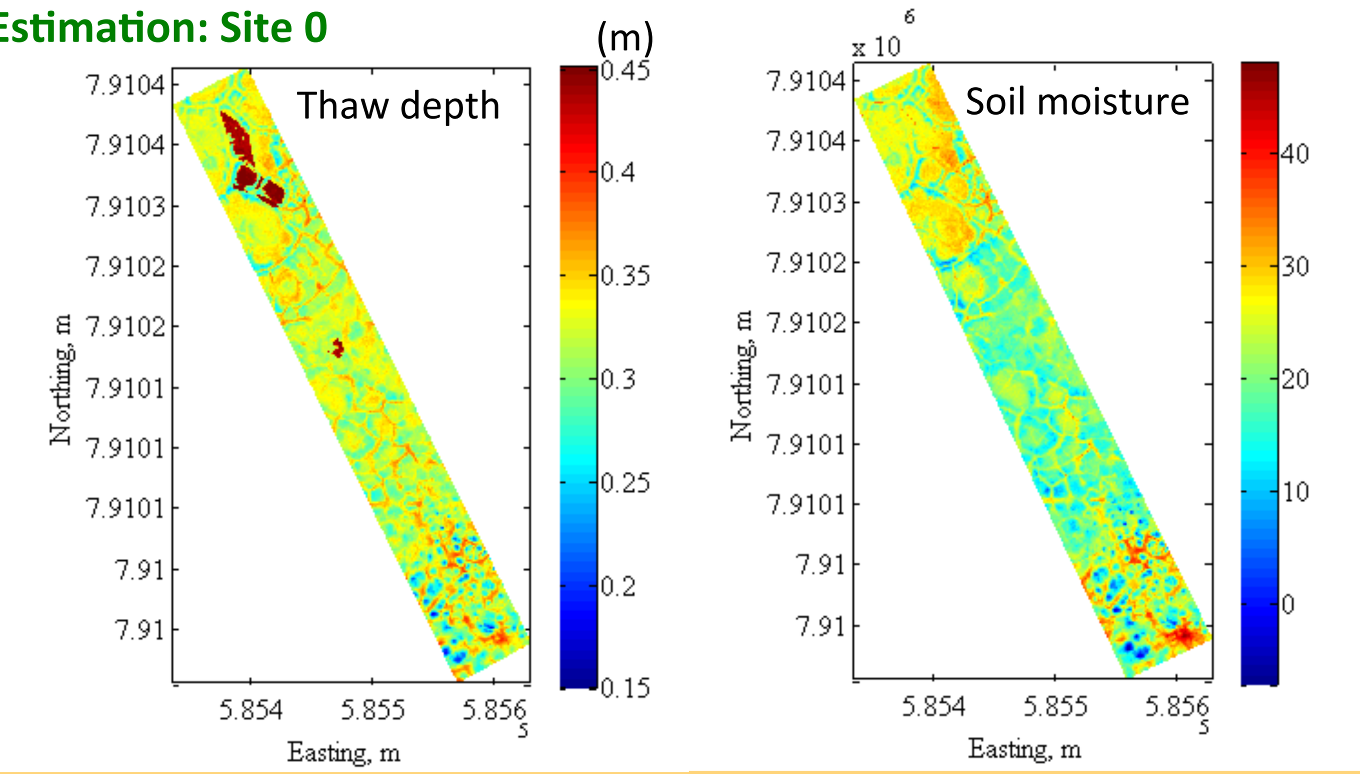
### Estimation: Site 0 Transect

(Mean and Confidence interval)




Black dots are not included in estimation but for validation.

### Estimation: Site 0



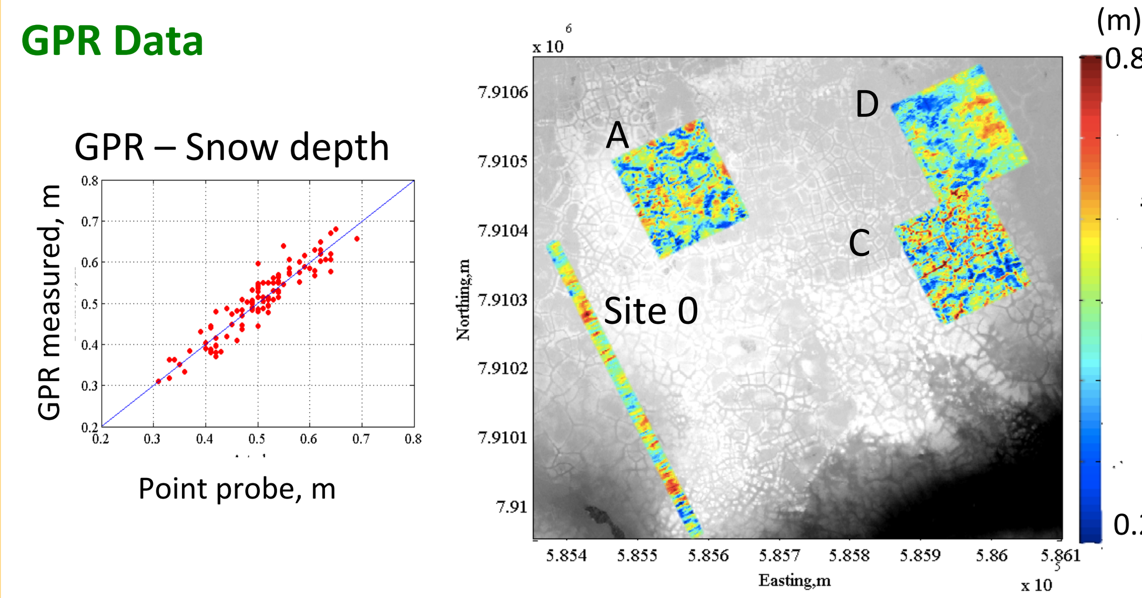

## REFERENCES

Hubbard, SS, C Gangodagamage, B Dafflon, H Wainwright, JE Peterson, A Gusmeroli, C Ulrich, Y Wu, C Wilson, J Rowland, C Tweedie and SD Wullschleger, Quantifying and relating land-surface and sub-surface variability in permafrost environments using LiDAR and surface geophysical datasets, in press, Hydrogeology.

Wainwright, HM, S Hubbard, B Dafflon, C Ulrich, Y Wu, C Gangodagamage, J Rowland, C Wilson, C Tweedie, S Wullschleger, Multiscale bayesian fusion approach using geophysical and remote sensing data for characterizing arctic tundra hydrogeochemical properties, TICOP 2012.

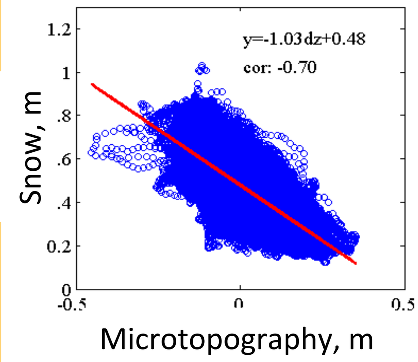
## RESULTS III: Snow Depth

### GPR Data

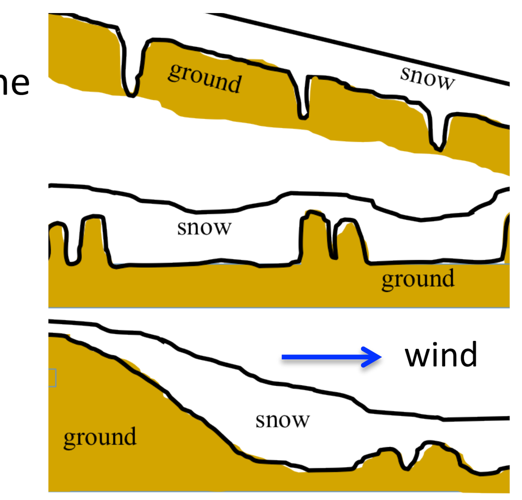



Av. snow dep.
A: 0.47m
B: 0.48m
C: 0.47m
S0: 0.52m

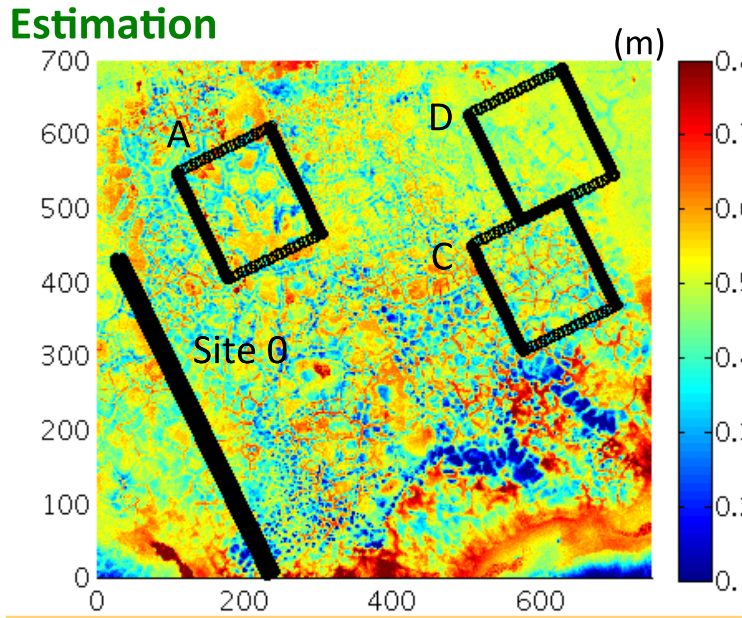
### Microtopography – Snow depth




In "general", the snow surface follows the base-line elevation. Exceptions:
- large depressions
- before/behind slopes in the wind direction (predominantly ENE)




### Estimation




Snow ~ a function of microtopography and slope

Wind direction will be considered in the future work.

More on snow including snow water equivalent →Gusmeroli (C33C-0668)

## SUMMARY AND CONCLUSIONS

- Developed a multiscale estimation framework to combine point/geophysical/remote-sensing data for estimating subsurface properties in the Arctic tundra ground based on hierarchical Bayes models:
  - Integrate complex correlations/dependencies between data and subsurface processes
  - Integrate measurement errors and spatial variability consistently
- Identified key controls on subsurface properties:
  - Microtopography of the tundra ground influences hydrological (soil moisture), thermal processes (thaw depth) and snow distribution.
  - Not only microtopographic high/low in the polygons, width of troughs and drainage features (directed distance) affect soil moisture and thaw depth.
  - Large-scale features (high/low-centered polygon zones, base-line elevation) would be another key for a large-scale estimation
- Established correlations between thaw depth/soil moisture/snow depth and geophysical data/surface topography
- Applied the framework to the actual datasets at Barrow and estimated thaw depth, soil moisture and snow depth

## ACKNOWLEDGMENTS

The Next-Generation Ecosystem Experiments (NGEE Arctic) project is supported by the Office of Biological and Environmental Research in the DOE Office of Science. This NGEE-Arctic research is supported through contract number DE-AC0205CH11231 to Lawrence Berkeley National Laboratory and through contract DE-AC05-00OR22725 to Oak Ridge National Laboratory.