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# Regional Mapping Of Soil Conditions In Northern Alaska Permafrost Landscapes Using AirMOSS And Land Model Data Assimilation, And Associated Impacts On Terrestrial Carbon Fluxes

IDS **(2014 start)**

Co-Investigators: Koster (GSFC), Kimball (U of MT), Oechel (SDSU), Reichle (GSFC), Zona (SDSU)
Collaborators: Goetz (WHRC), Miller (JPL), Romanovsky (UAF)

Special thanks to: R. Chen and A. Tabatabaeenejad (USC)

ARCTIC BOREAL VULNERABILITY EXPERIMENT

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# OVERVIEW
# "AND..BUT..THEREFORE"

- The depth of the active layer is expected to play a critical role in defining the landcover types in boreal/arctic north America
- Time-series measurements of permafrost soil temperatures in Alaska have shown pervasive warming trends within these systems; may be detrimental to infrastructure; may release large amount of stored soil organic Carbon
- Measurements on depth and spatial distribution of permafrost in Alaska are highly localized, are often inconsistent
- Hypothesis: long-wavelength radar can be used to retrieve soil moisture profile and active layer thickness in permafrost systems, on continuous and extensive spatial scales, with high resolution
- Retrievals will be used to inform a succession of land surface hydrology and terrestrial carbon flux simulations to investigate the impact of permafrost soil dynamics and surface hydrologic information on regional carbon fluxes

# MODELING APPROACHES

- Will use an integrated ecosystem process model combining a satellite data driven Terrestrial Carbon Flux (TCF) model with a coupled permafrost and water balance hydrology model that includes a detailed 1-D soil heat transfer representation

- Establish hydrologic model baseline maps using the Catchment-CN model and forcing from GMAO-GEOS-5

# SCIENCE QUESTIONS AND OBJECTIVES

- Tier 2 Science Questions addressed
  - *"What are the causes and consequences of changes in the hydrologic system, specifically the amount, temporal distribution, and discharge of surface and subsurface water"*
  - *"How are the magnitudes, fates, and land-atmosphere exchanges of carbon pools responding to environmental change, and what are the biogeochemical mechanisms driving these changes?"*

- Tier 2 Science Objectives
  - investigate societal vulnerability to environmental change by: *elucidating how climate change and disturbances interact and alter land-atmosphere carbon exchange*.

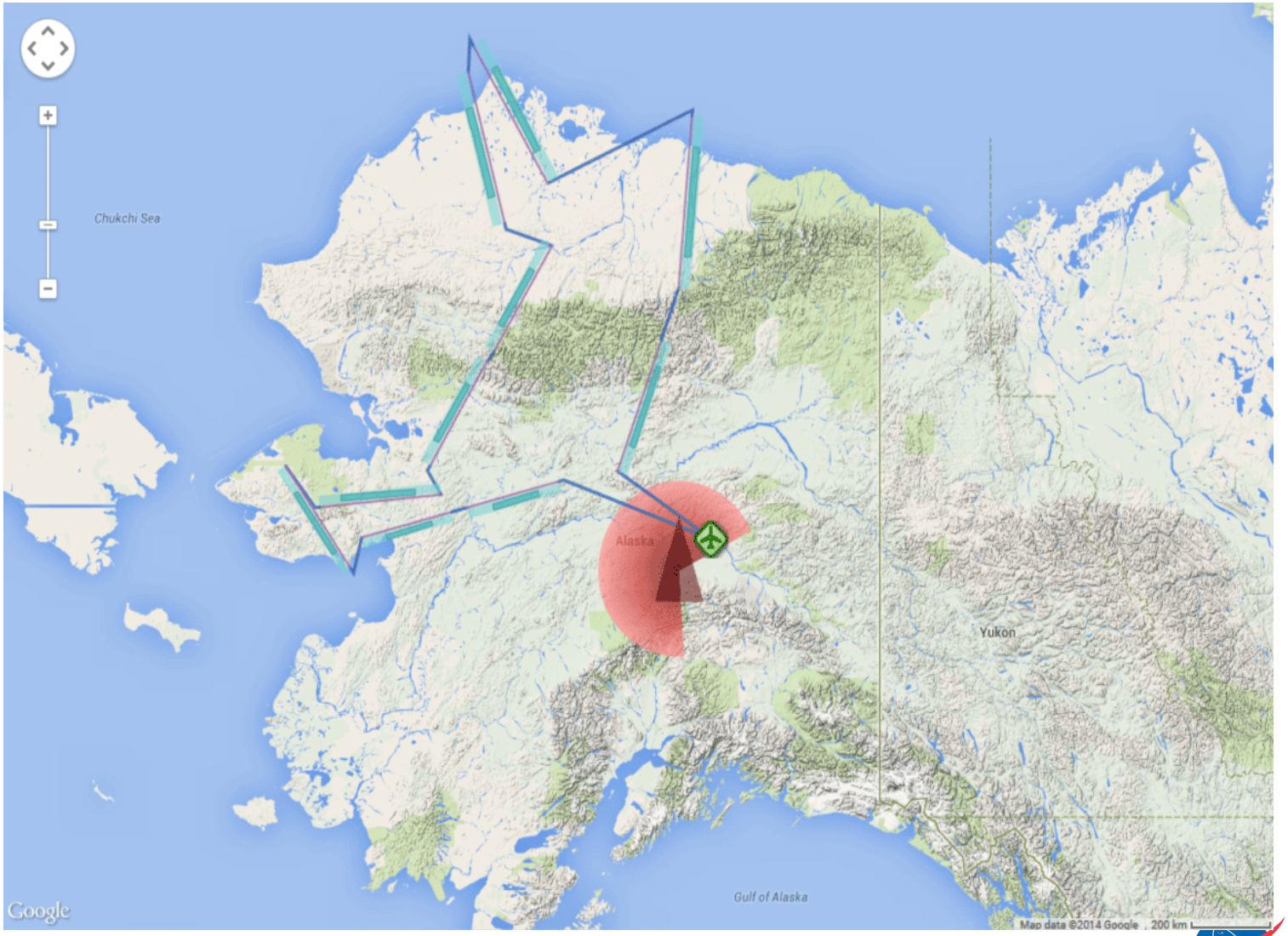
# AIRBORNE REMOTE SENSING OBSERVATIONS

- AirMOSS P-band SAR has been collecting data
  - ✓ Flew in August and October 2014, April and August 2015
  - ✓ Flight scheduled for tomorrow (10/1/15); another one in April 2016
  - ✓ Expect that adding L-band UAVSAR will increase retrieval accuracy and enable the inclusion of more near-surface (e.g., organic) layers in retrieval model: flying the L-band radar next week and again in April 2016

- Retrieval algorithms build on AirMOSS EVS-1
  - ✓ Explicit assumption that lower-most layer is frozen soil

- First time this has been done as a direct product of a remote sensing observation
  - ✓ Validation data are terse; validation is challenging

# AIRMOSS TRANSECT FLOWN FOR IDS TASK

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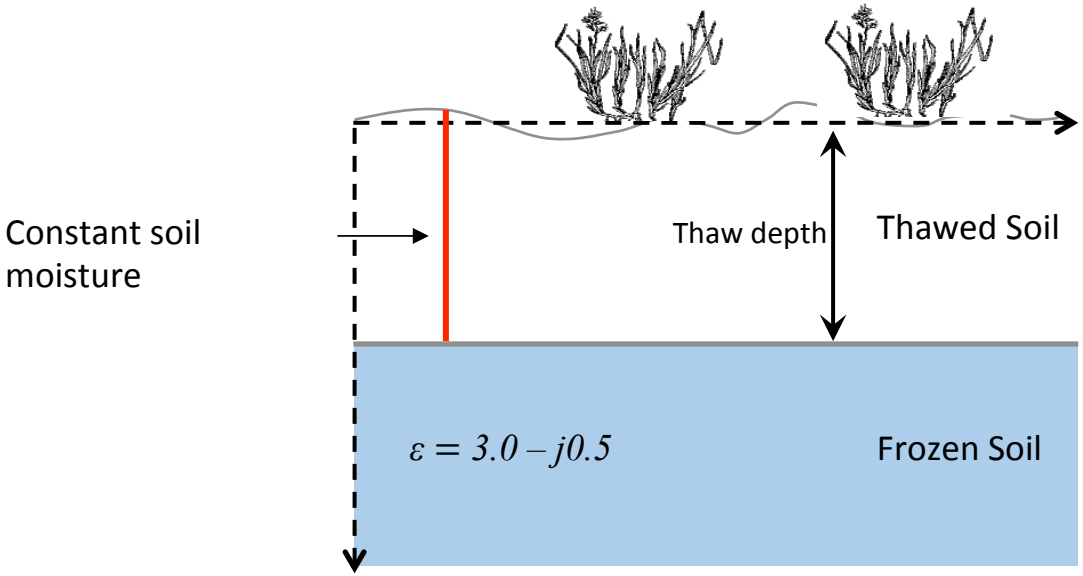
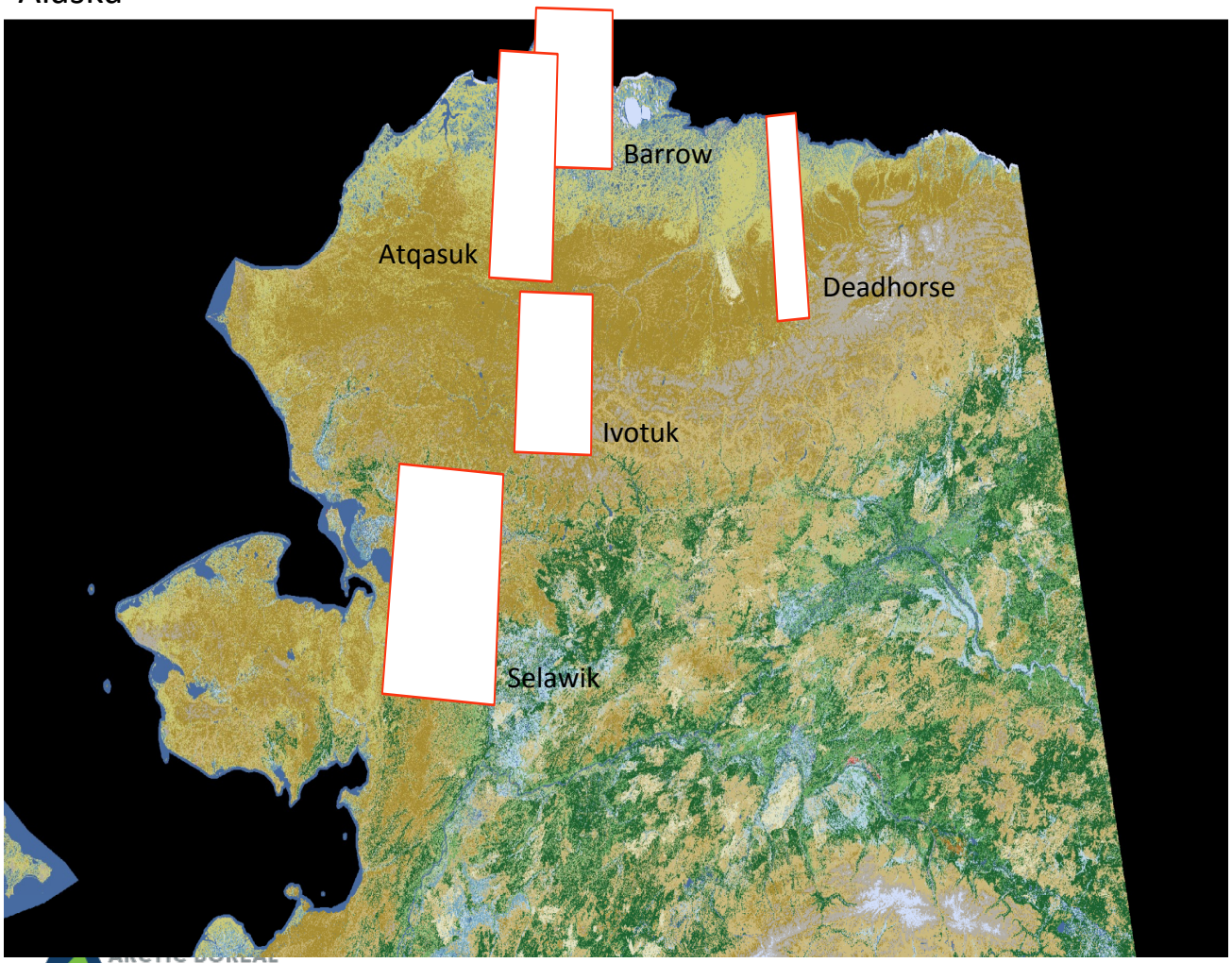
# THAW DEPTH AND SOIL MOISTURE RETRIEVAL EXAMPLES

- Sites: Barrow, Deadhorse, Ivotuk, Selawik, Atqasuk
- Flight dates: 2014-08-16 (max thaw) and 2014-10-09 (partially frozen)
- Two-layer soil structure (thawed soil layer + frozen soil layer), with vegetation on top
- Ancillary data
  - NLCD 2001 for land cover
  - HWSD for soil texture



# ANCILLARY DATA: LAND COVER

NLCD 2011
Alaska



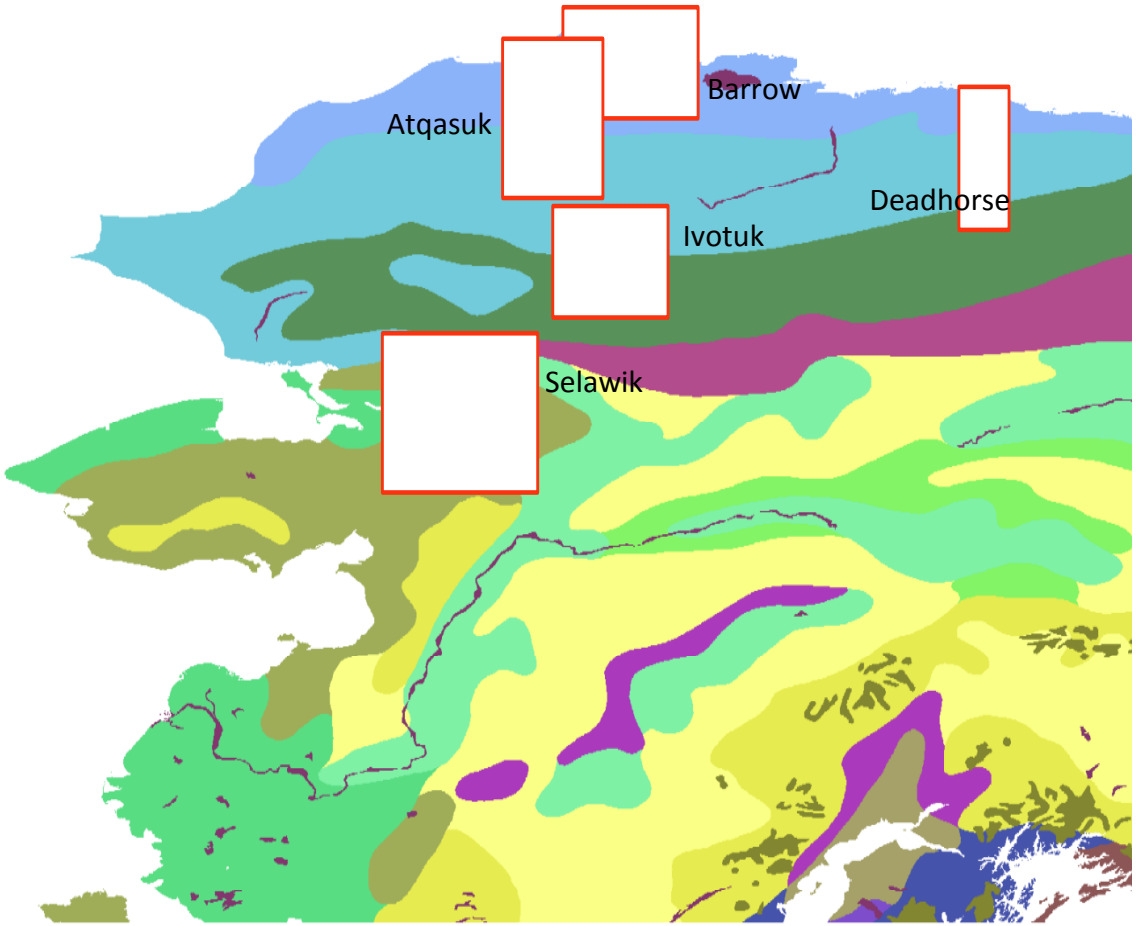

NLCD Land Cover Classification Legend

- 11 Open Water
- 12 Perennial Ice/ Snow
- 21 Developed, Open Space
- 22 Developed, Low Intensity
- 23 Developed, Medium Intensity
- 24 Developed, High Intensity
- 31 Barren Land (Rock/Sand/Clay)
- 41 Deciduous Forest
- 42 Evergreen Forest
- 43 Mixed Forest
- 51 Dwarf Scrub*
- 52 Shrub/Scrub
- 71 Grassland/Herbaceous
- 72 Sedge/Herbaceous*
- 73 Lichens*
- 74 Moss*
- 81 Pasture/Hay
- 82 Cultivated Crops
- 90 Woody Wetlands
- 95 Emergent Herbaceous Wetlands

* Alaska only

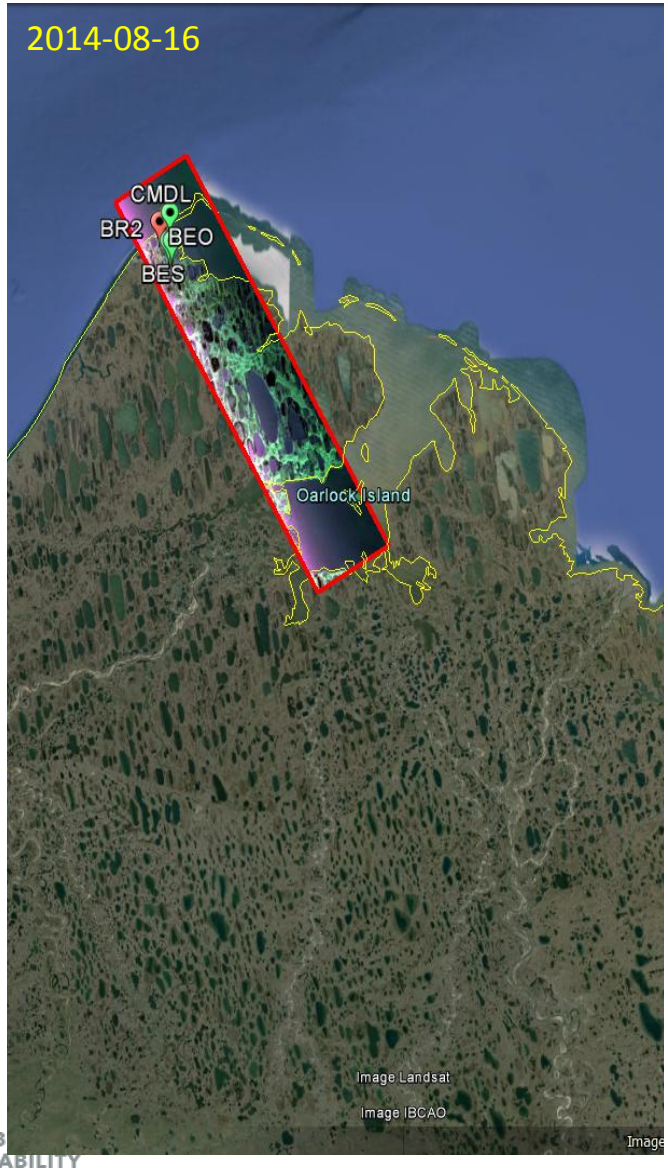
# ANCILLARY DATA: SOIL TEXTURE

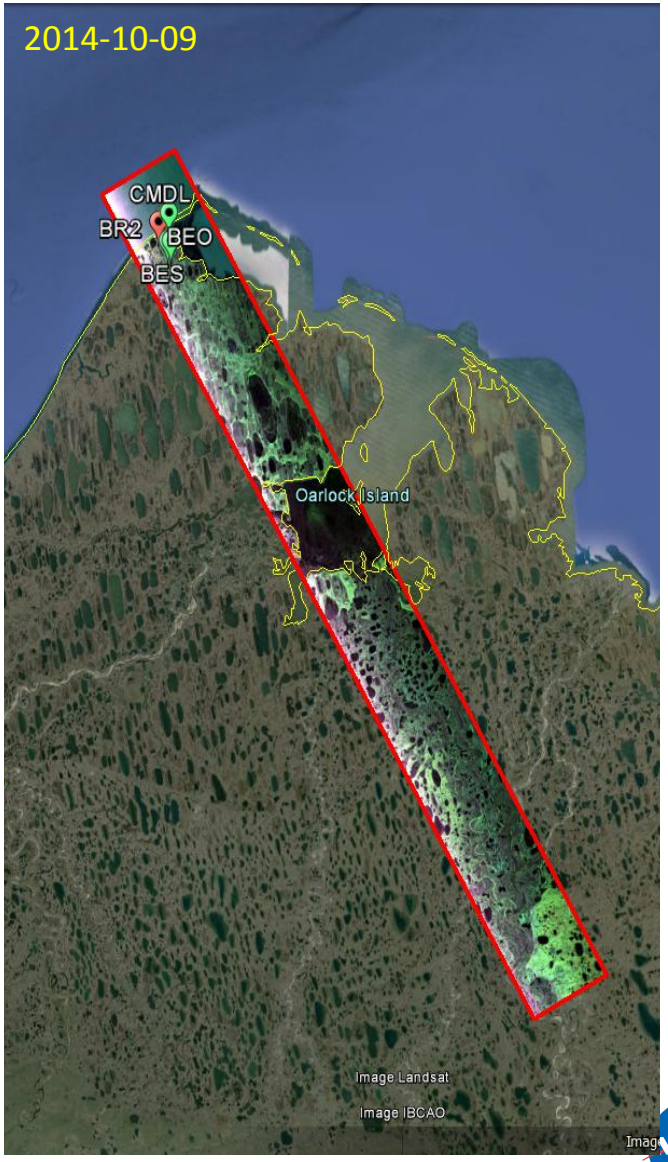
Harmonized World Soil Database (HWSD)




- FAO/IIASA/ISRIC/ISSCAS/JRC
- Resolution: 30” (~1 km)
- Two soil layers
  - topsoil (0 – 30 cm)
  - subsoil (30 – 100 cm)

# BARROW: P-BAND RADAR IMAGES

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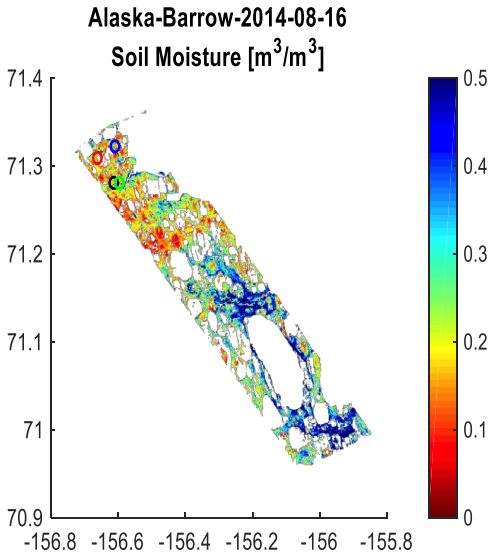
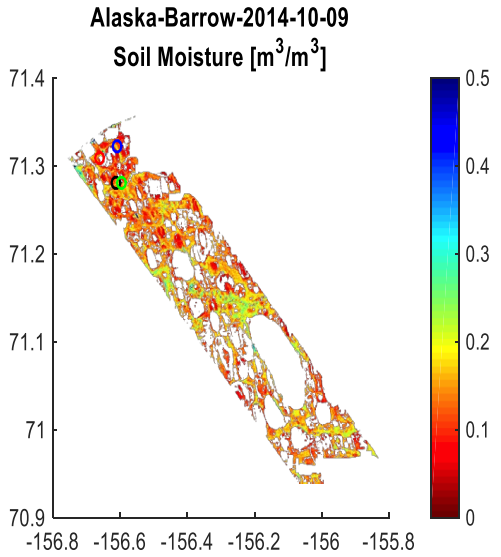
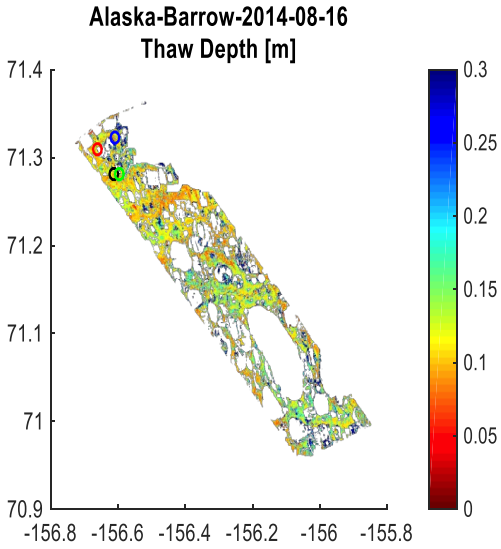
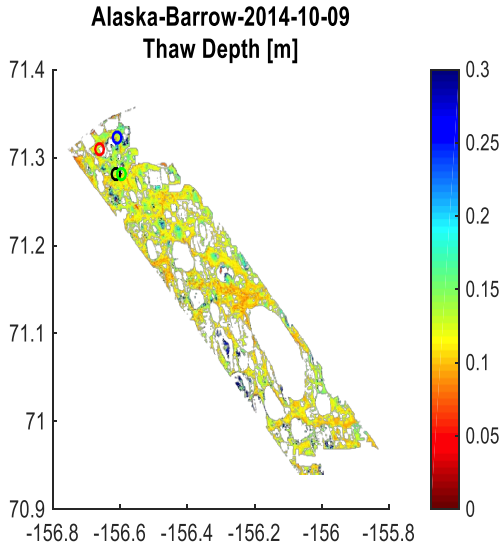
# BARROW: PRELIMINARY RADAR RETRIEVALS (1)



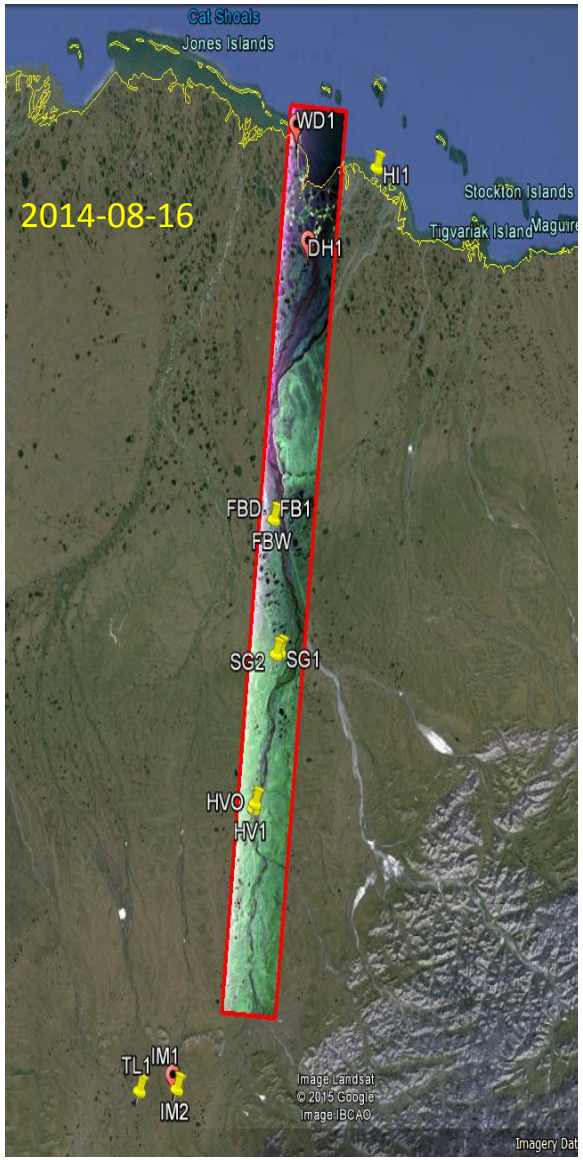



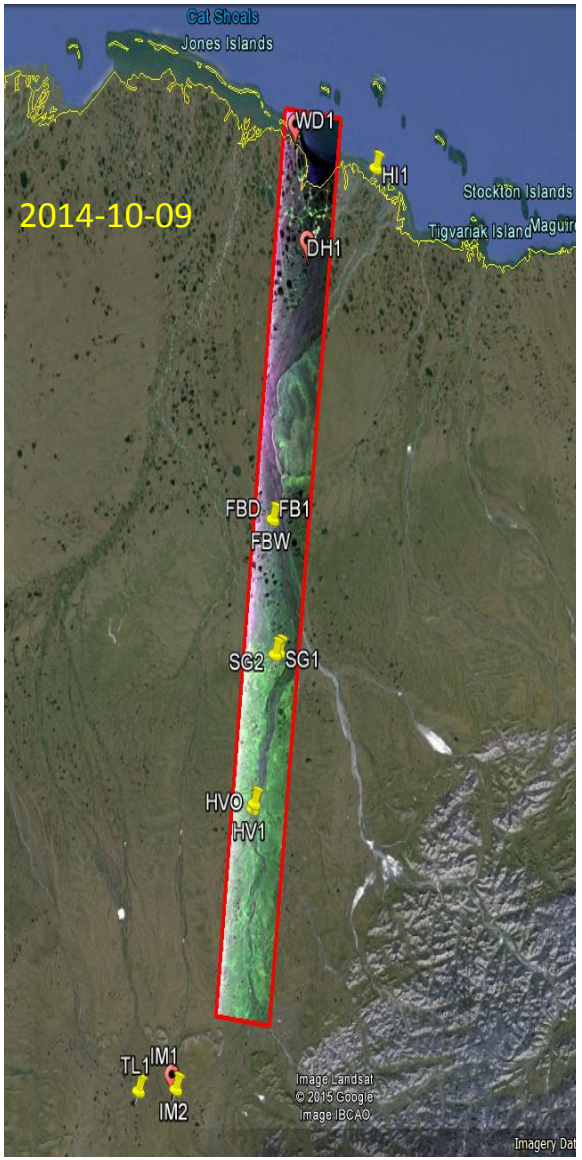




- SDSU-BEO
- SDSU-BES
- SDSU-CMDL
- UAF-BR2

ARCTIC BOREAL VULNERABILITY EXPERIMENT

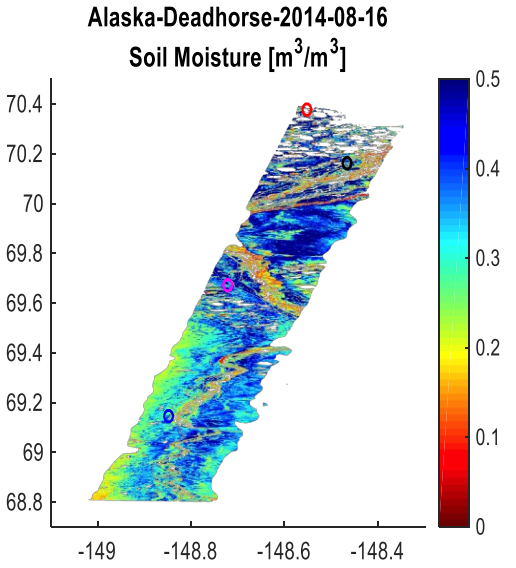
# DEADHORSE: P-BAND RADAR IMAGES

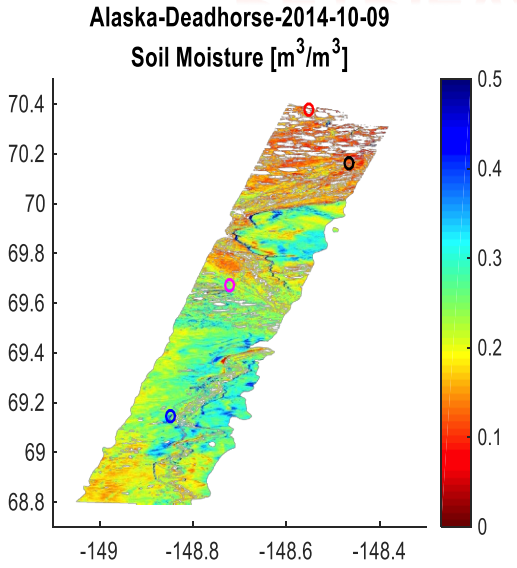


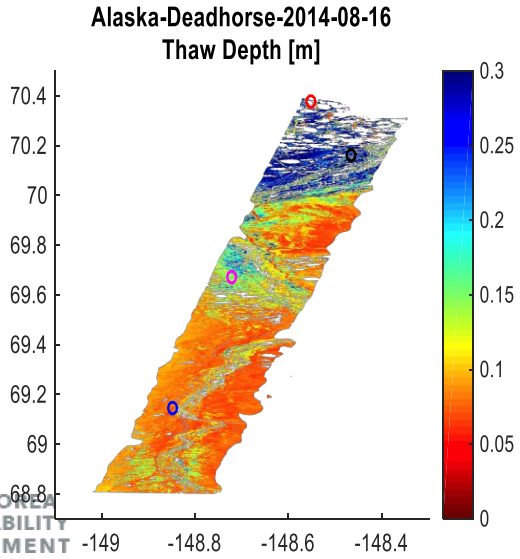



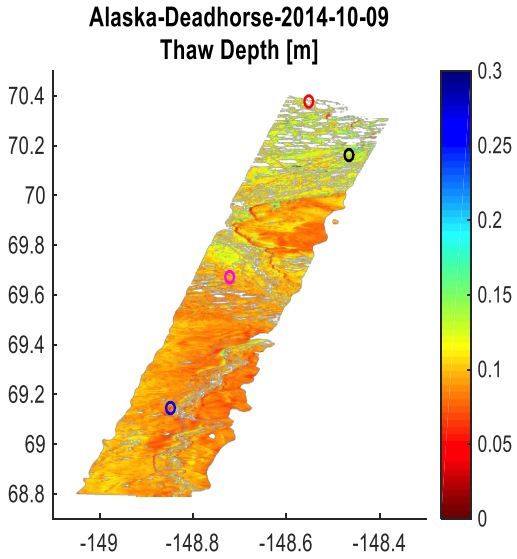

ARCTIC BOREAL VULNERABILITY EXPERIMENT

# DEADHORSE: RETRIEVAL RESULTS (1)



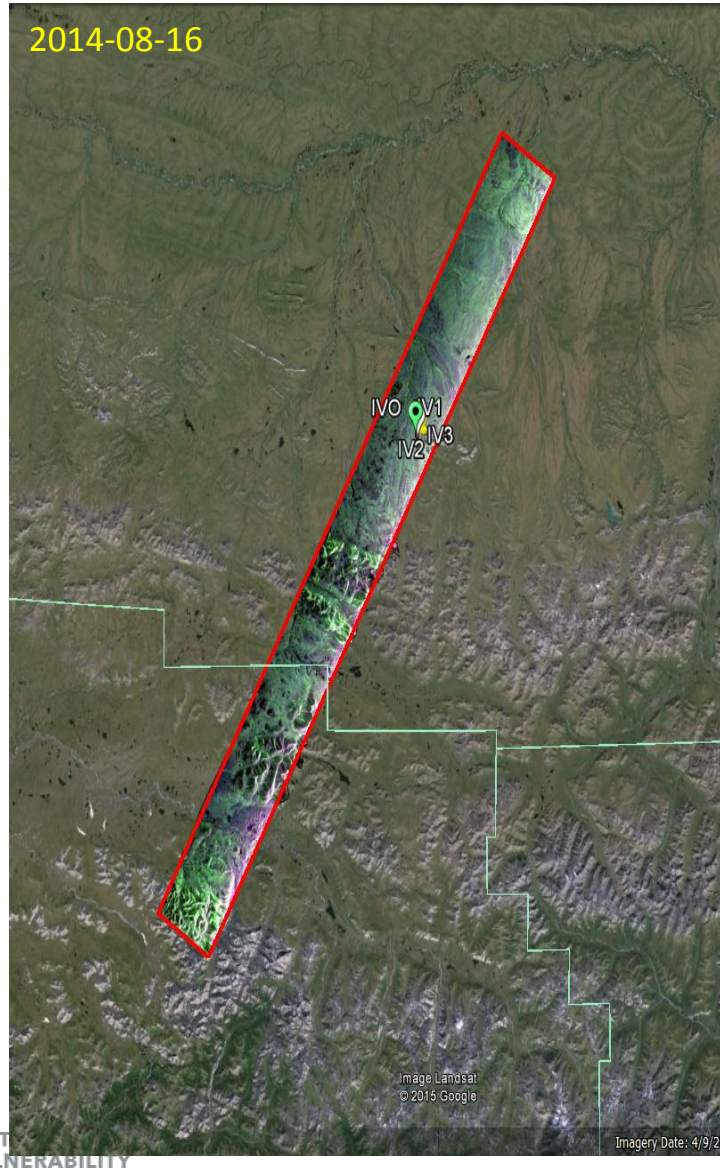



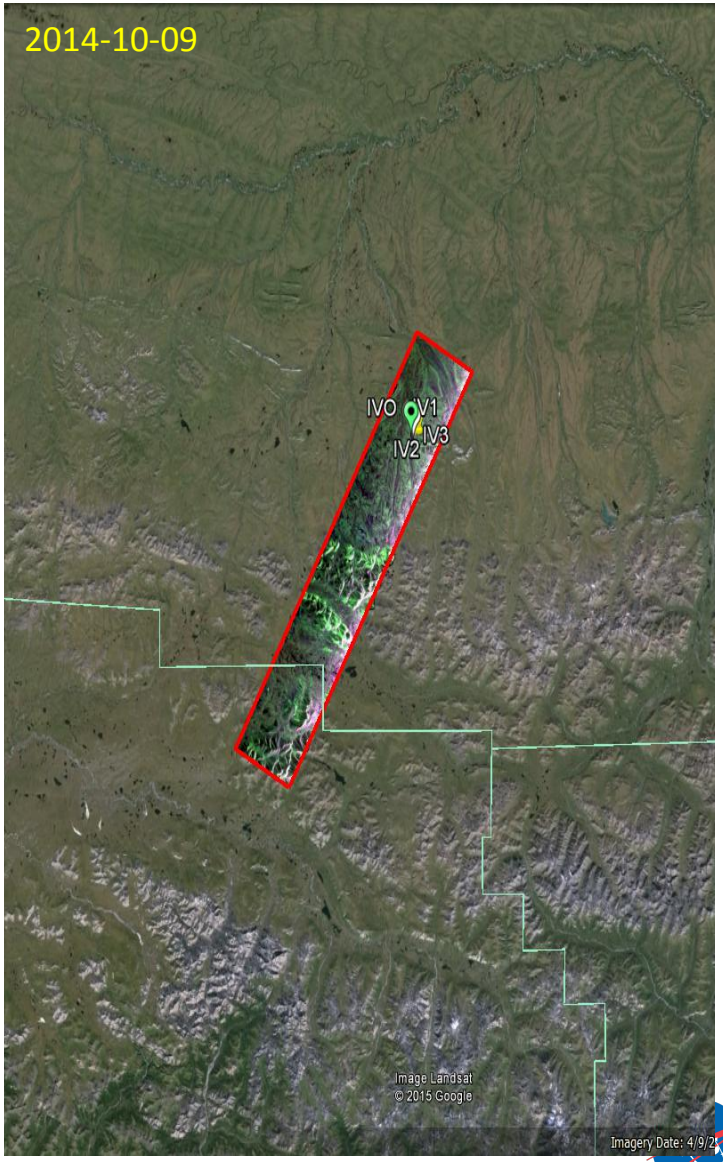




- UAF-DH1 (Deadhorse)
- UAF-WD1 (West Dock)
- UAF-FB1
- UAF-HV1

ARCTIC BOREAL VULNERABILITY EXPERIMENT

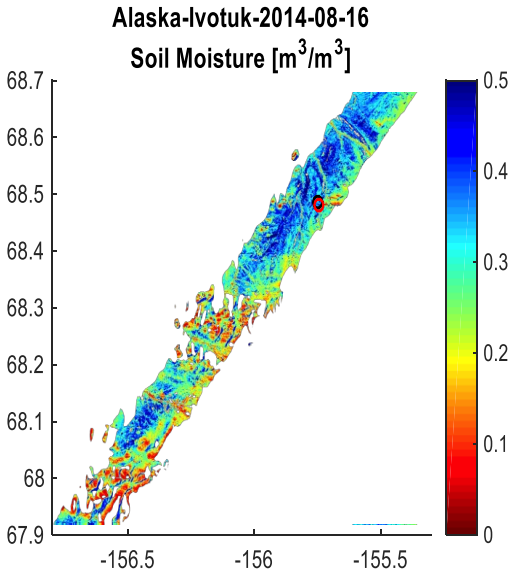
# IVOTUK: P-BAND RADAR IMAGES

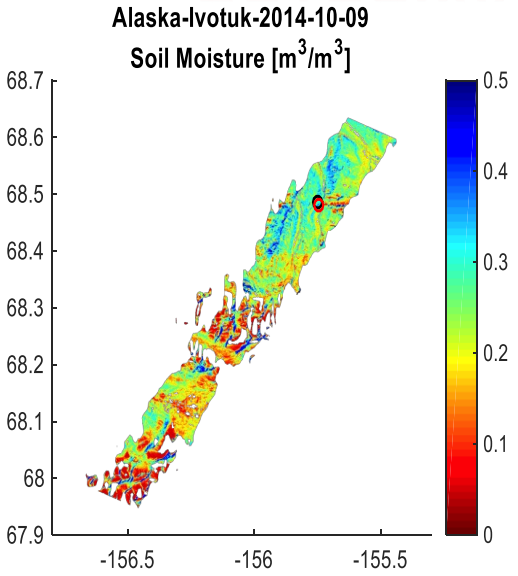


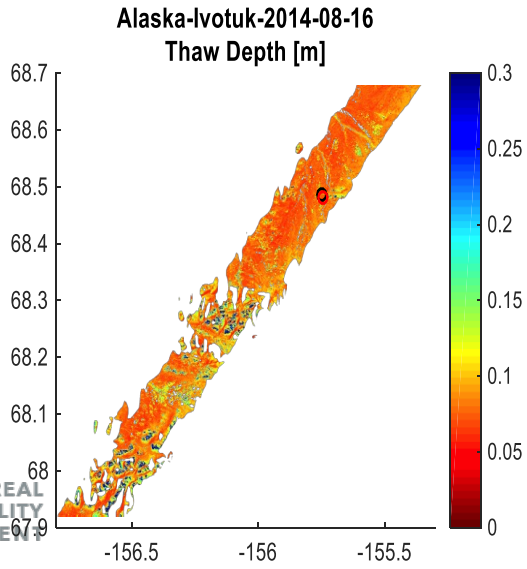



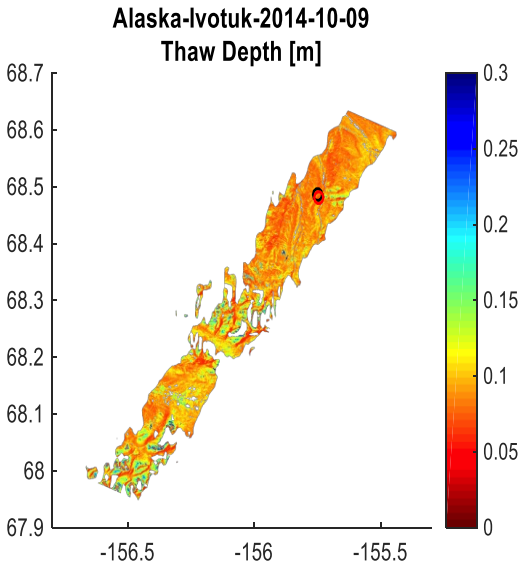

ARCTIC VULNERABILITY EXPERIMENT

# IVOTUK: RETREIVAL RESULTS (1)



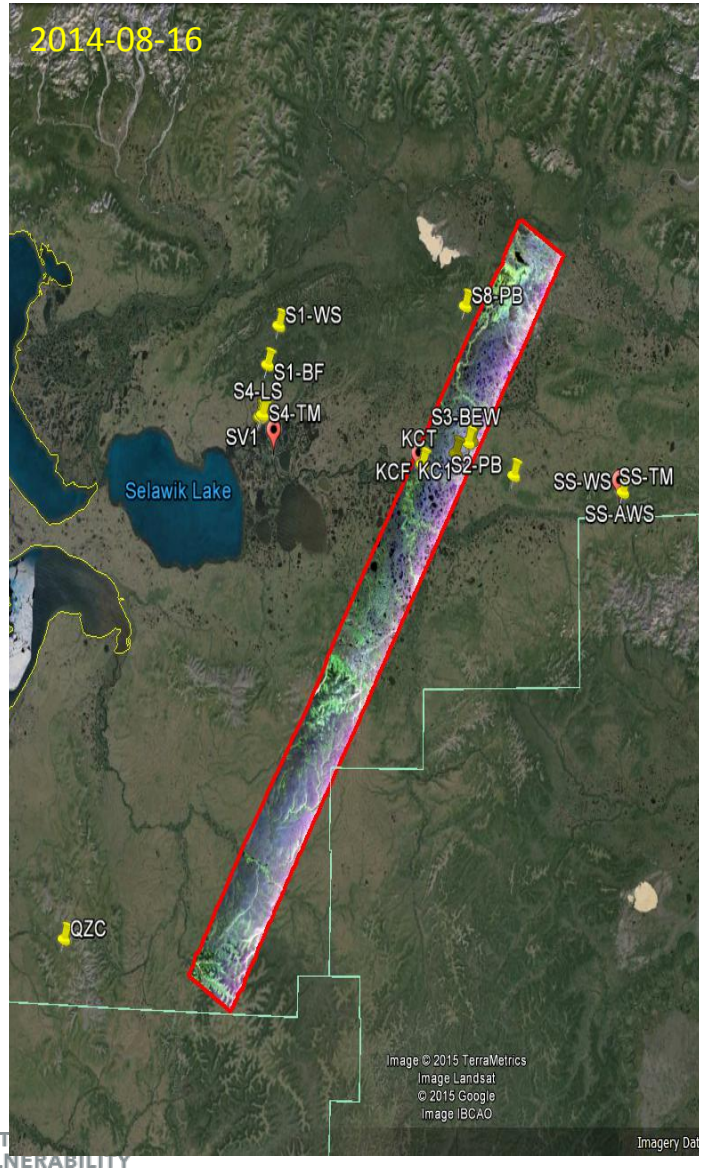



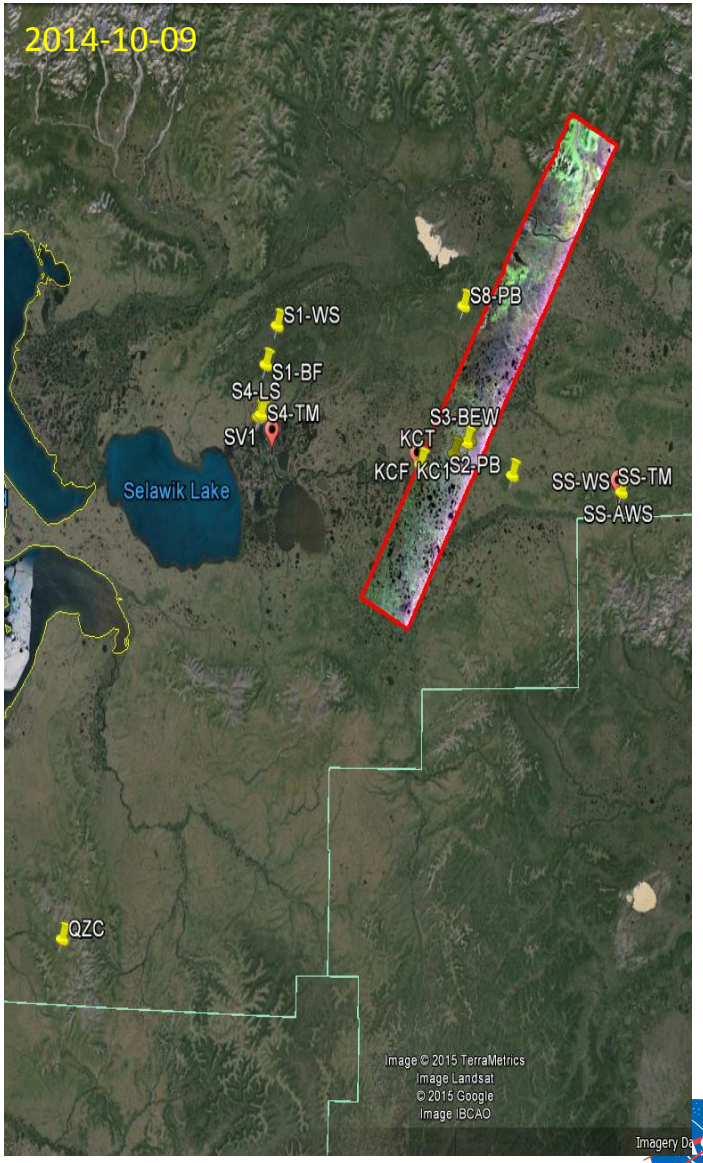




- SDSU-IVO
- UAF-IV4

ARCTIC BOREAL VULNERABILITY EXPERIMENT

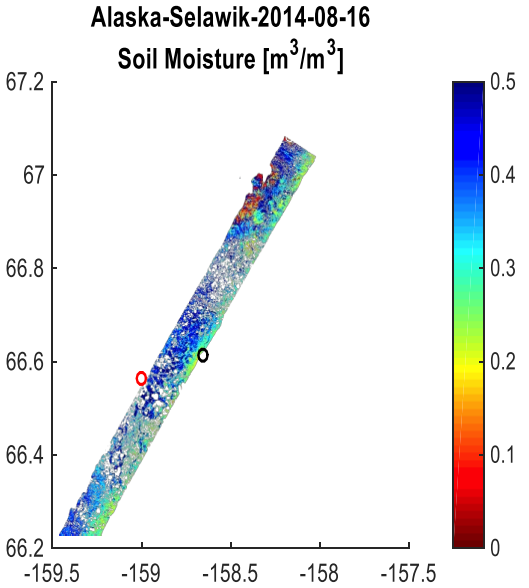
# SELAWIK: P-BAND RADAR IMAGES

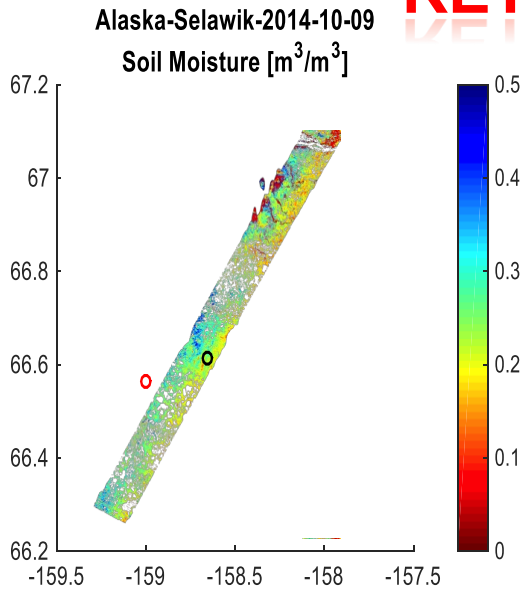


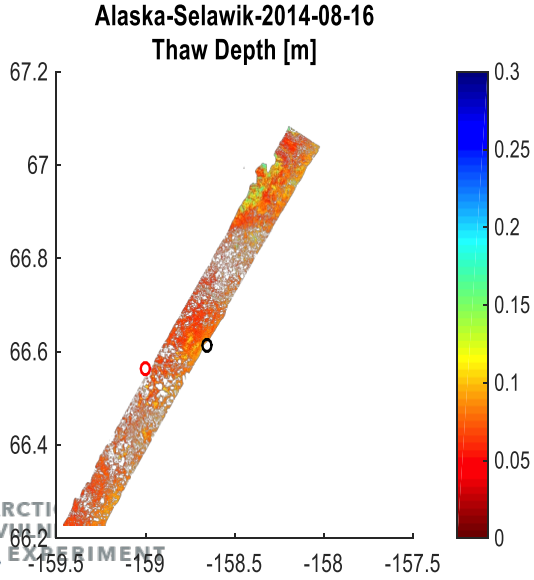



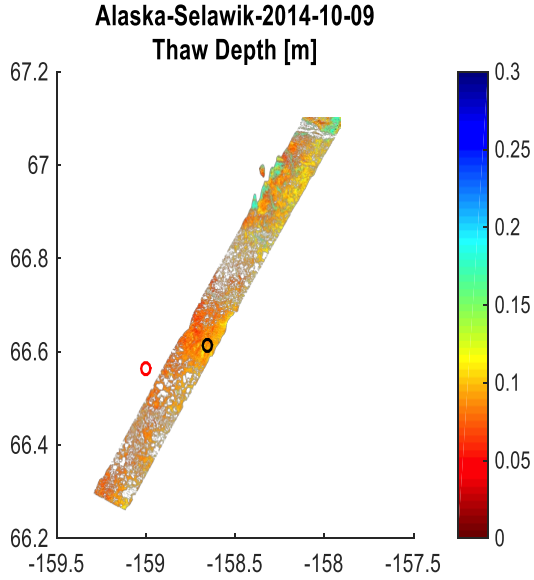

ARCTIC VULNERABILITY EXPERIMENT

# SELAWIK: RETRIEVAL RESULTS



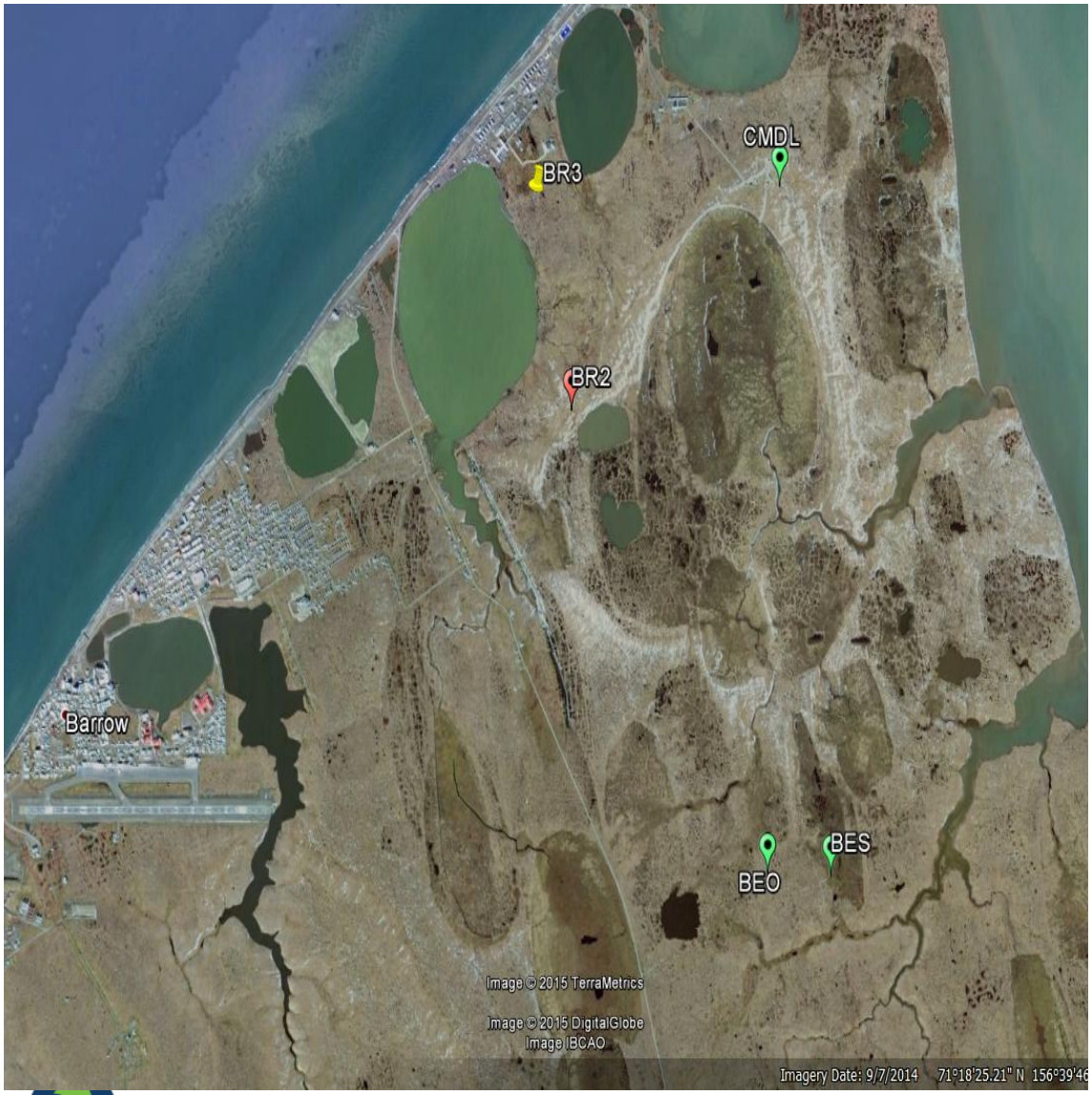




- UAF-S3-TM (Selawik)
- UAF-KC1 (Kugurak Cabin)

- UAF-KC1 was excluded in the inversion since incidence angle is out of 25°-50° range
- Can relax the incidence angle range to include UAF-KC1 or have access to in-situ data at UAF-S3-TM for validation
- No comparison possible currently

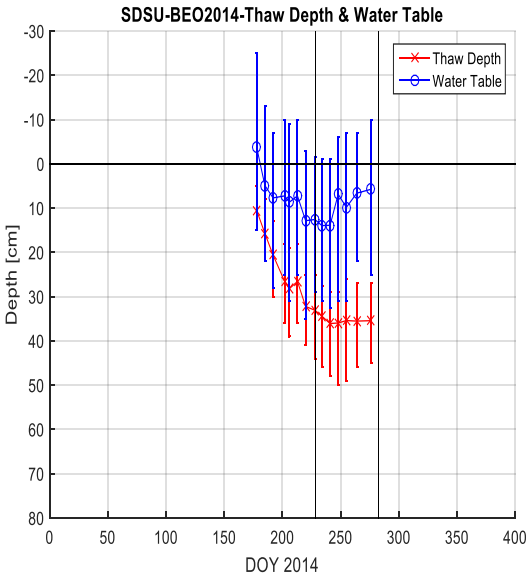
# BARROW:
# IN-SITU TEMPERATURE AND SOIL MOSITURE SITES

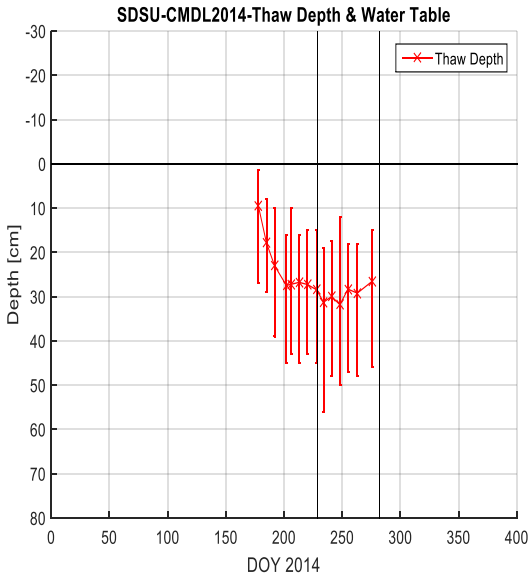


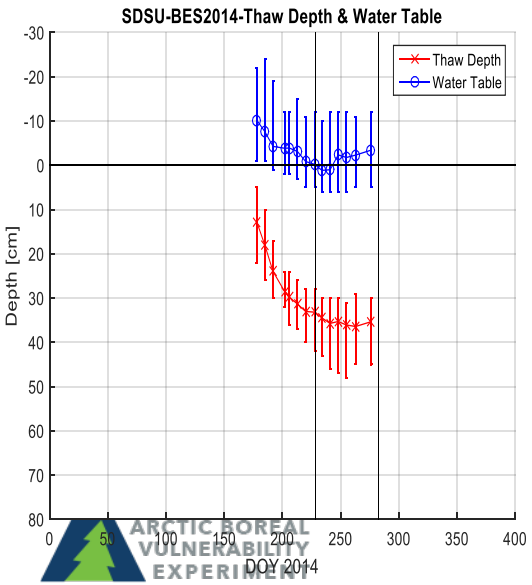

- SDSU: BEO, BES, CMDL
- UAF: BR2
- No real-time data from UAF-BR3

# BARROW: SDSU SITES AND DATA

SDSU sites



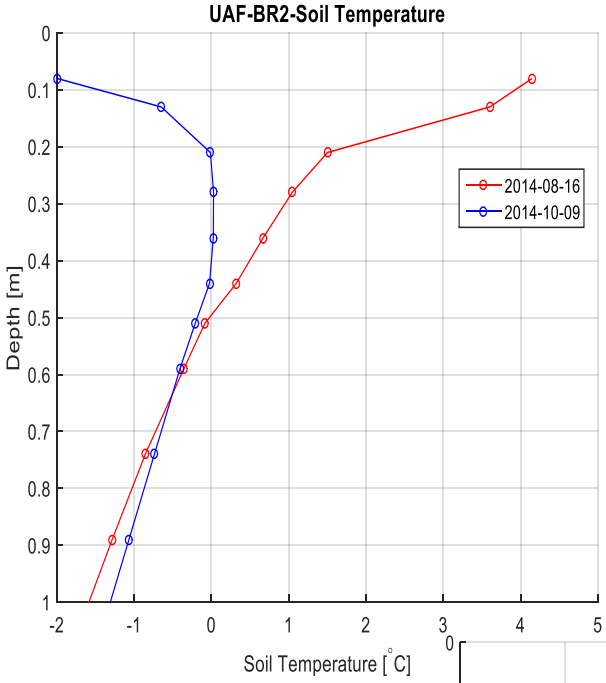


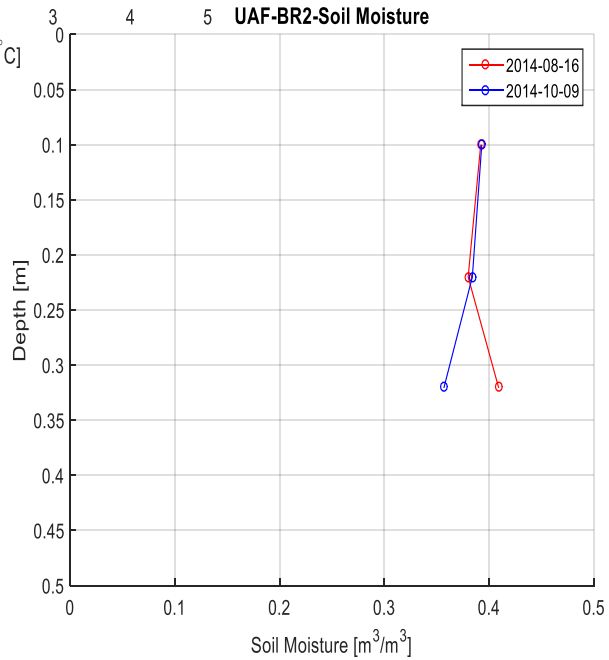
- Thaw depth was about 28-33 cm during summer 2014
- Water table often above ground
- Soil is often nearly saturated
- Don't expect good radar retrievals

ARCTIC BOREAL VULNERABILITY EXPERIMENT

UAF sites

# BARROW: UAF SITES AND DATA

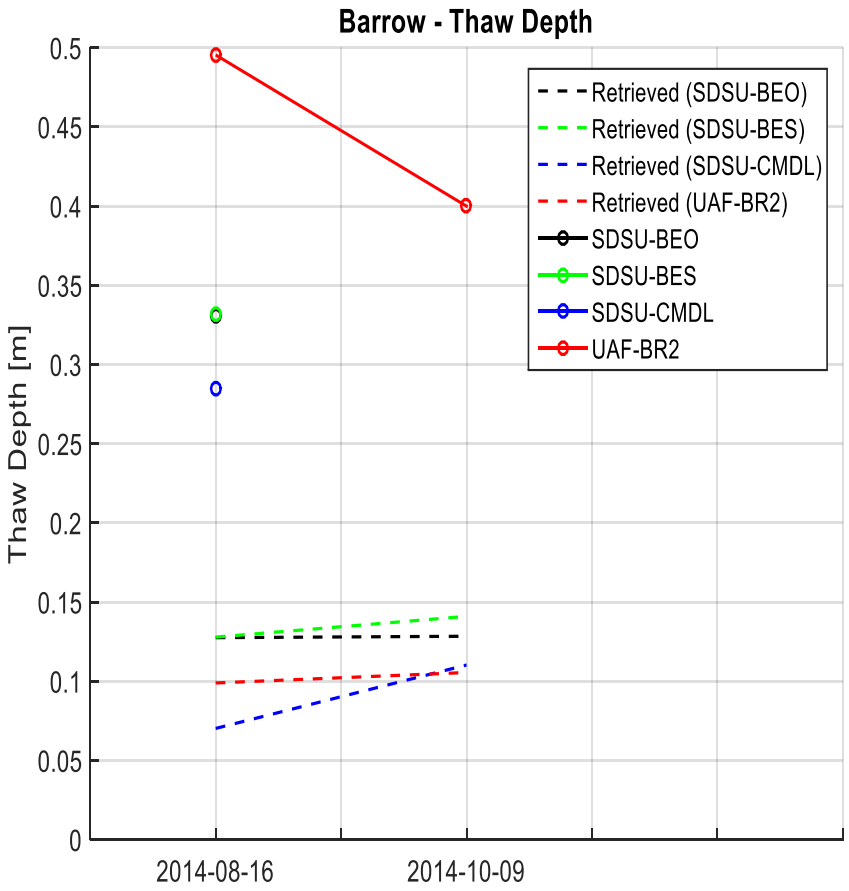


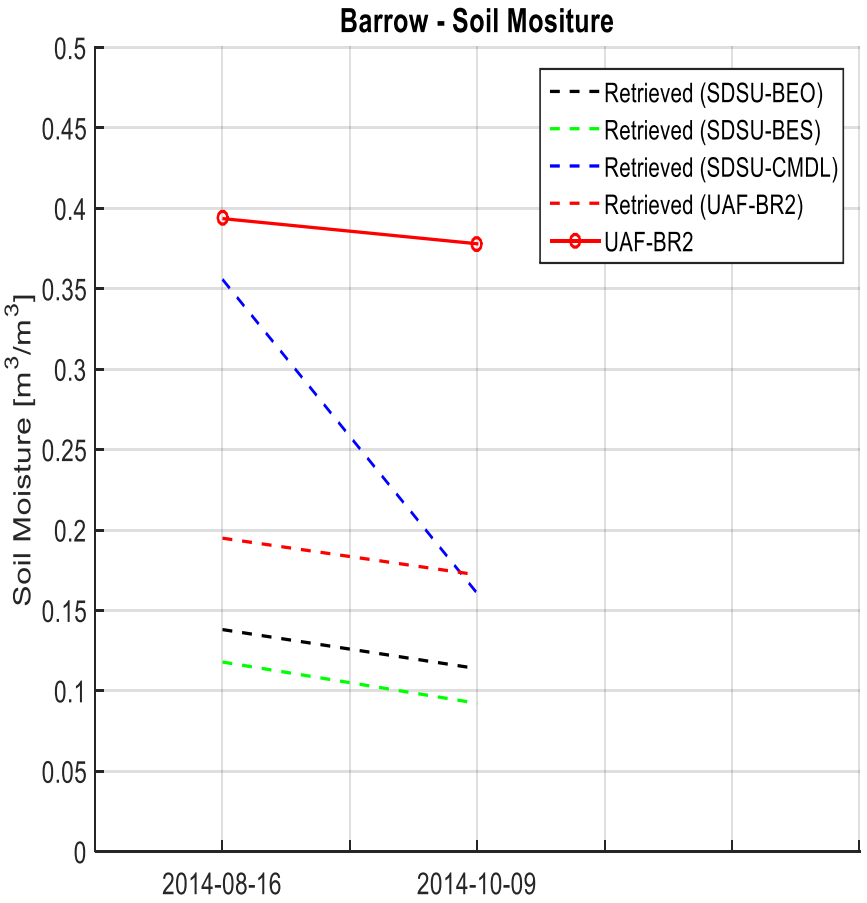




- Thaw depth about 50 cm during summer 2014
- In October, soil freezes from the surface (max thaw -> partially frozen)
- Data show that soil moisture decreases very slowly as soil freezes


ARCTIC BOREAL VULNERABILITY EXPERIMENT

# BARROW: PRELIMINARY RADAR RETRIEVALS (2)




Looks like water table depth is retrieved instead of depth of thaw

Soil moisture trend is correct

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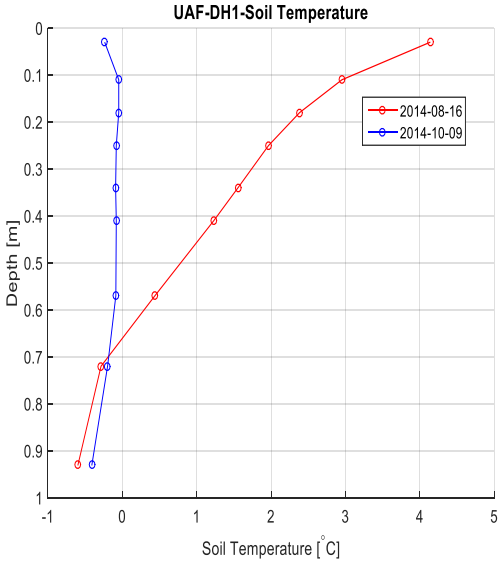
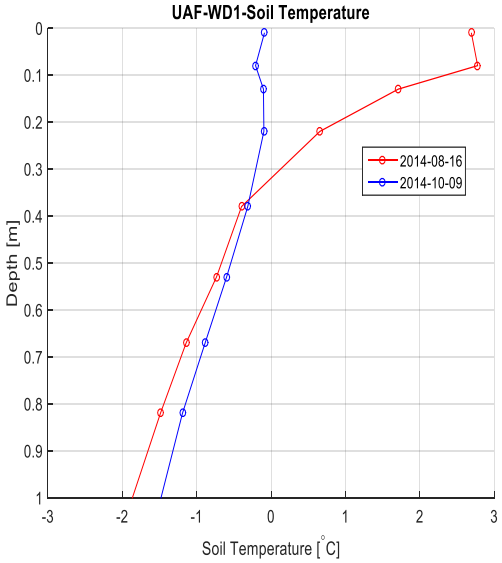
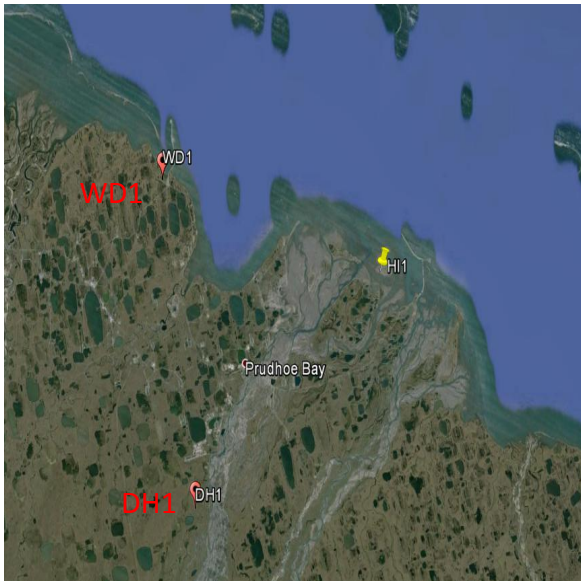
# DEADHORSE: IN-SITU TEMPERATURE AND SOIL MOISTURE SITES


- UAF: DH1 (Deadhorse), WD1 (West Dock)
- Other UAF sites don't have real-time data available

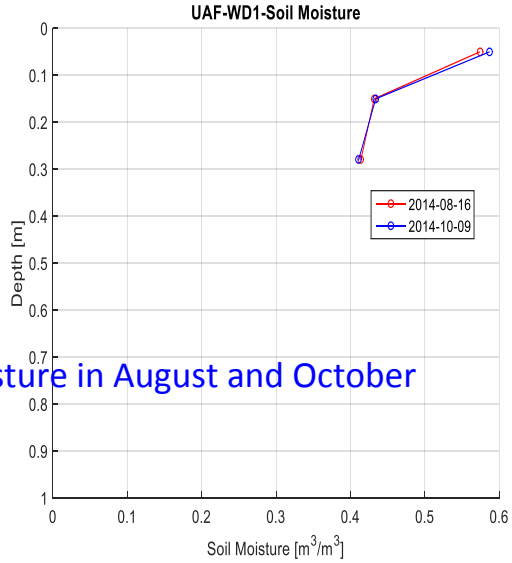
# DEADHORSE: UAF SITES








Wasn't expecting same soil moisture in August and October

- Max thaw depth is about 66 cm at Deadhorse and 32 cm at West Dock
- It's difficult to tell if soil is fully frozen in October – can be a mixture of soil, water, and ice, which make the temperature hover around 0 °C from surface downward

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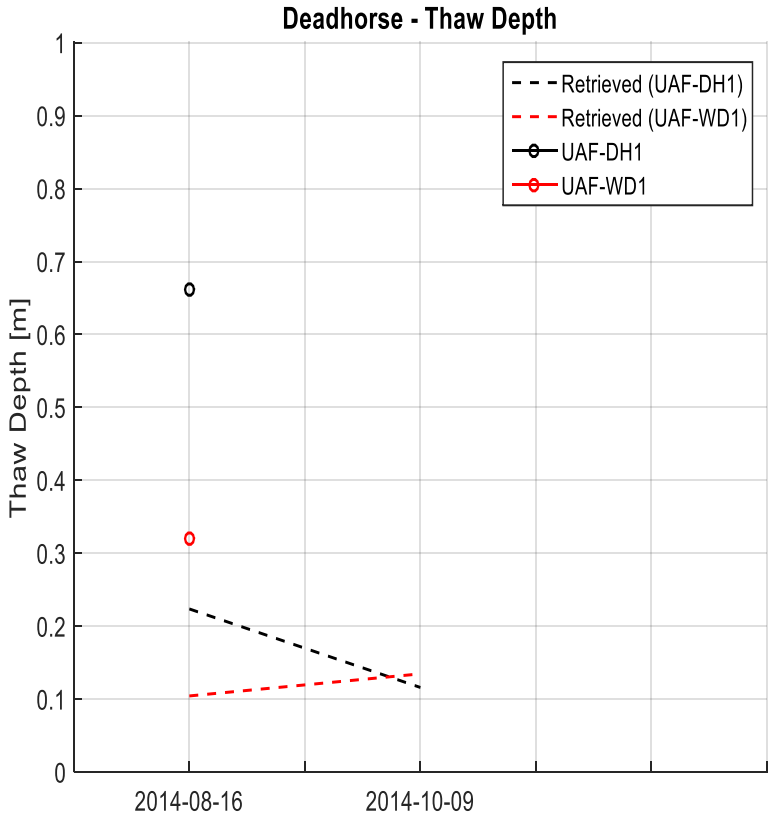
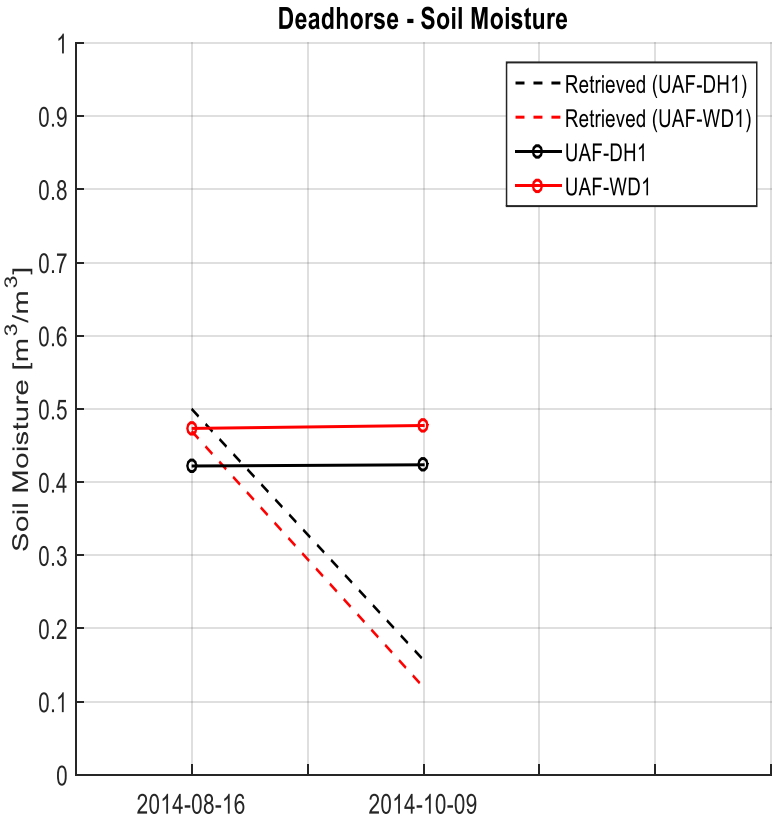
# DEADHORSE: RETRIEVAL RESULTS (2)



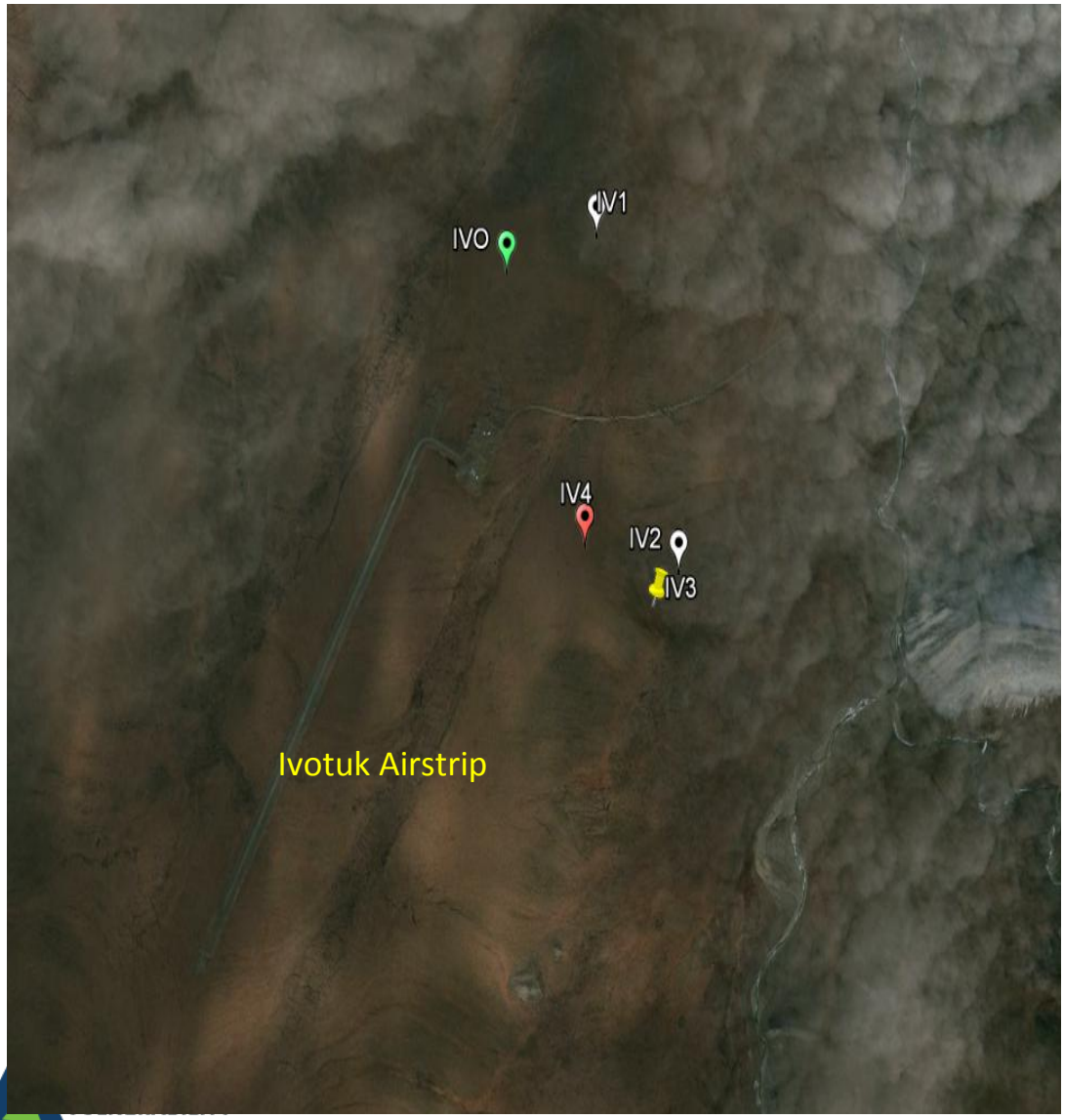




Don't have water table info, so don't know if this is bias or water table

Soil moisture retrieval very good for August and trend is as expected for October; in-situ data to be checked

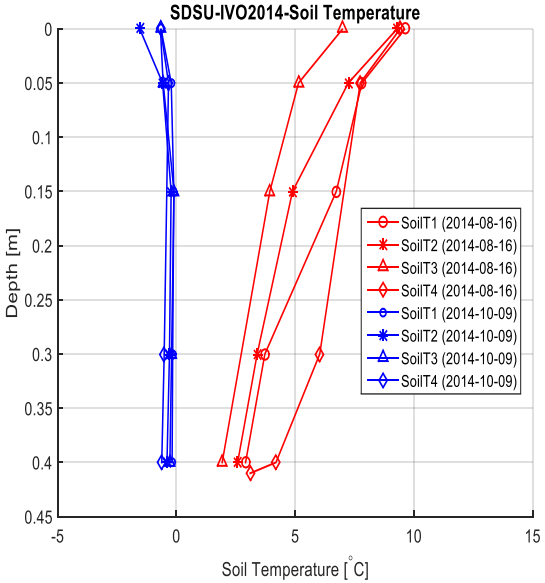
ARCTIC BOREAL VULNERABILITY EXPERIMENT

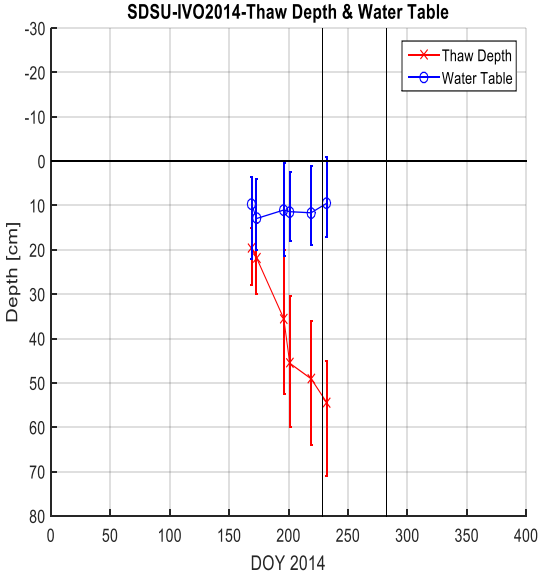
# IVOTUK:
# IN-SITU SOIL MOISTURE AND TEMPERATURE SITES

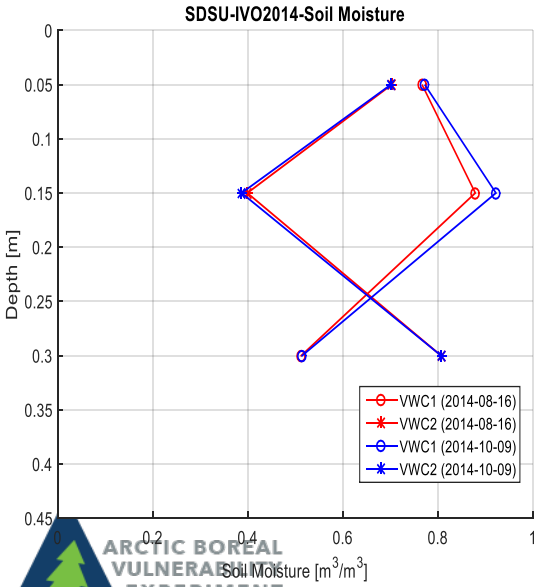


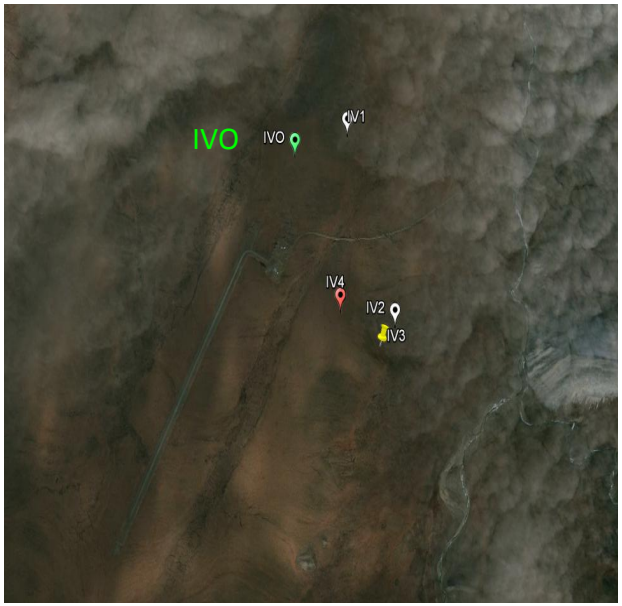

- SDSU: IVO
- UAF: IV4
- No real-time data from UAF-IV3
- UAF-IV1 and UAF-IV2 are not operational

# IVOTUK: SDSU SITES




- Thaw depth is about 53 cm in August at SDSU-IVO
- Soil is nearly saturated
- Not a big difference in in-situ soil moisture between August and October

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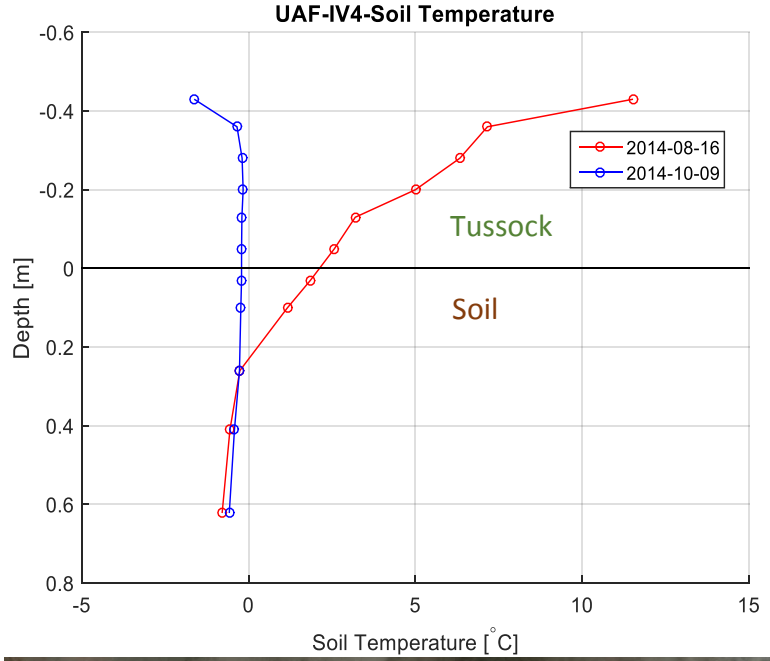
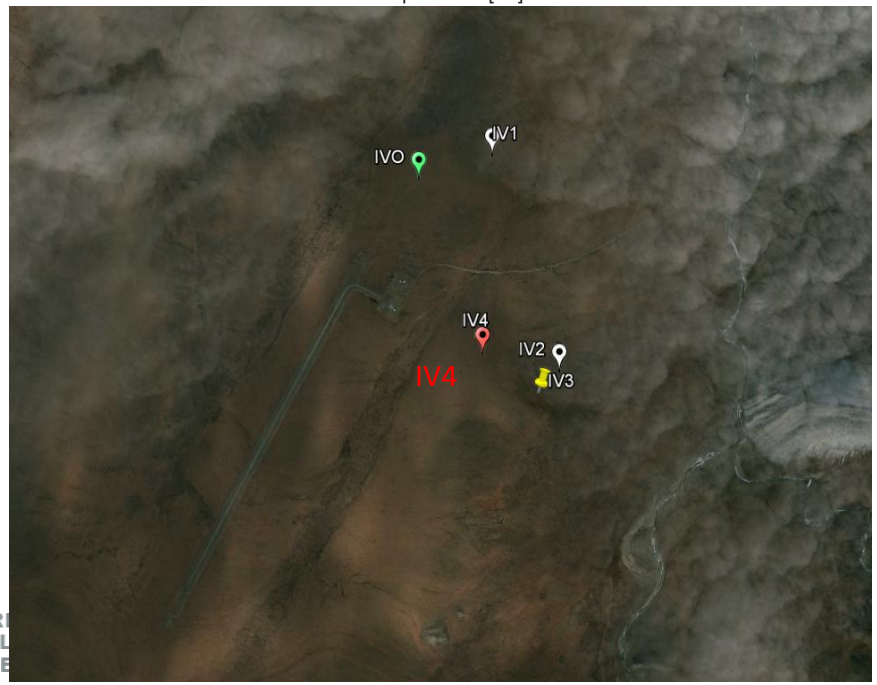
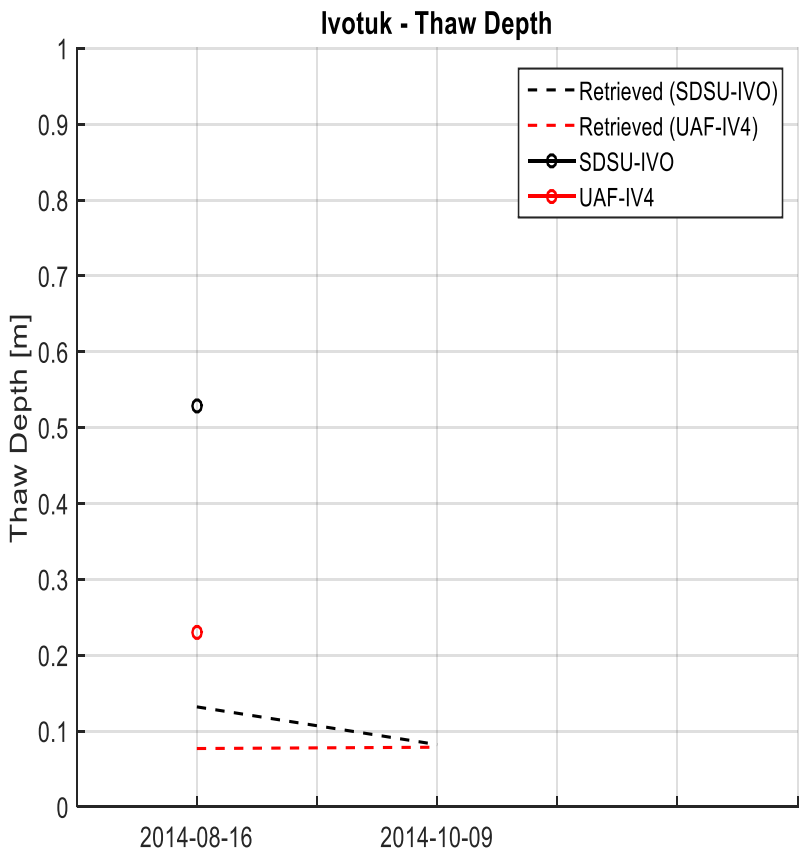
# IVOTUK: UAF SITES

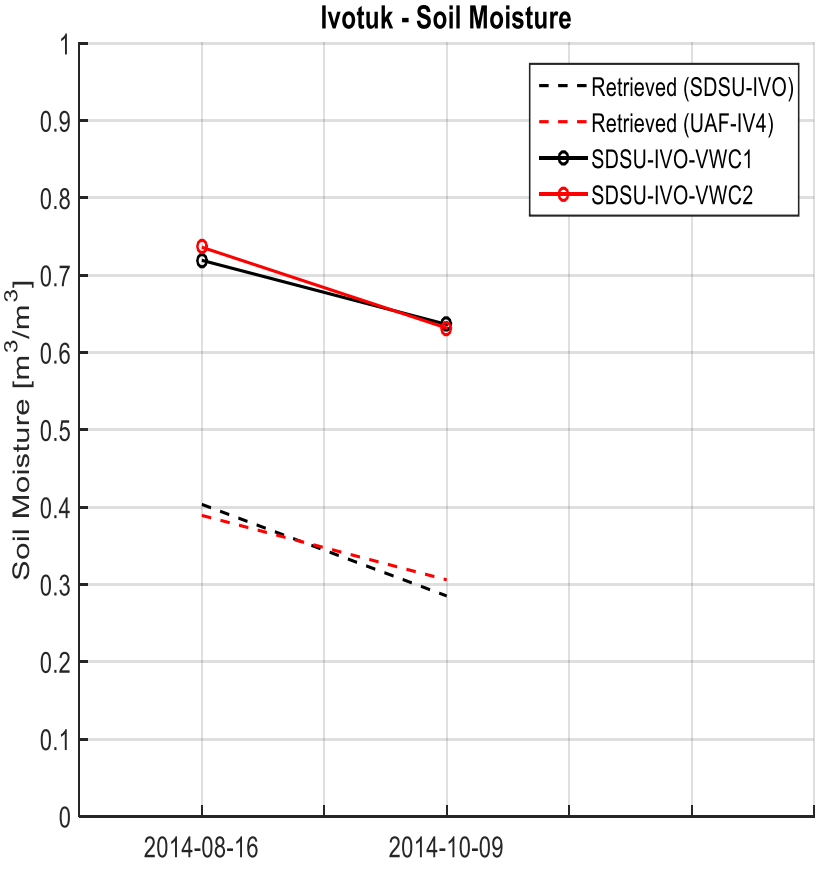



- Vegetation cover at UAF-IV4 is moss (tussock) dominated
- Thaw depth is about 23 cm in August, different from the one from SDSU-IVO (53 cm)
- No soil moisture data available from UAF site

# IVOTUK: RETRIEVAL RESULTS (2)

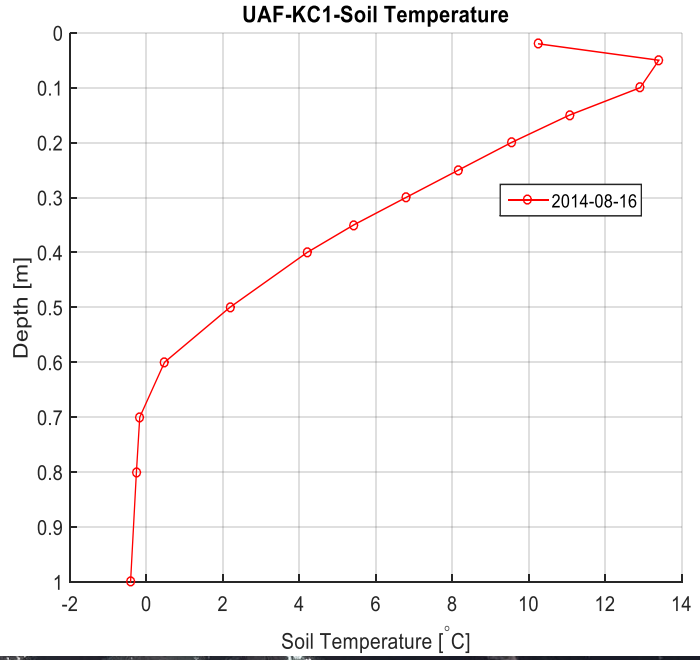


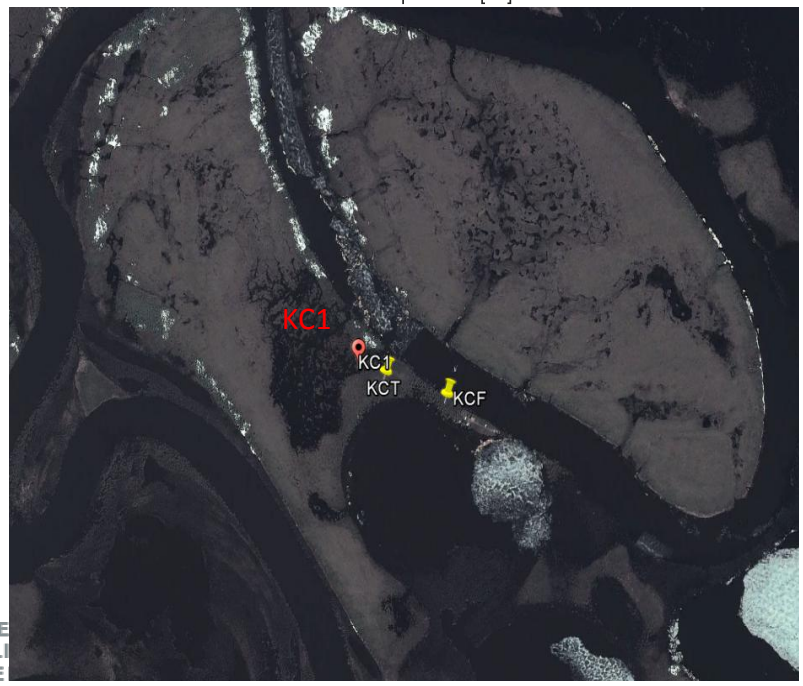




Looks like water table depth is retrieved instead of depth of thaw

Soil moisture trend is correct

# SELAWIK: IN-SITU DATA



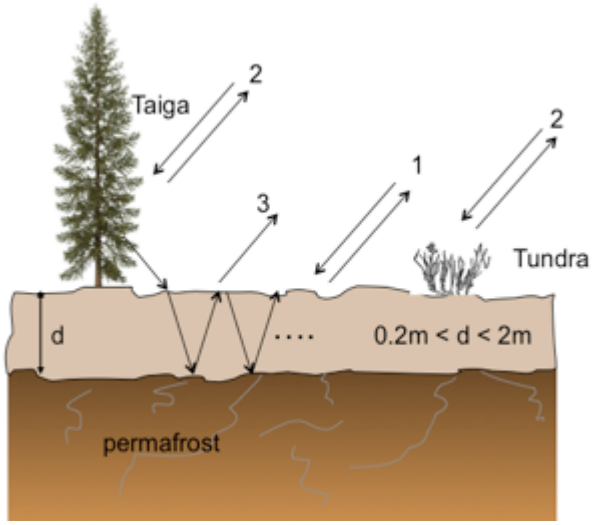



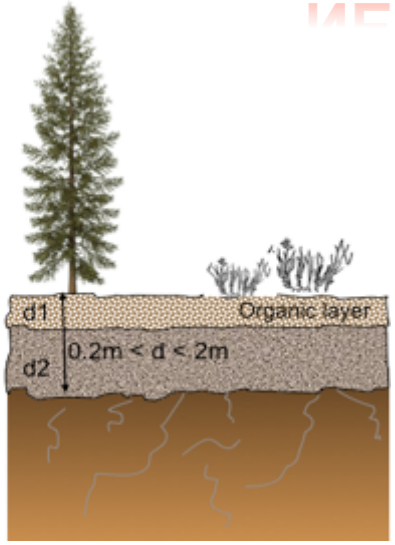

- Soil temperature data only available for the date of August flight
- Thaw depth is about 68 cm in August
- UAF: KC1
- No real-time data from KCT, KCF

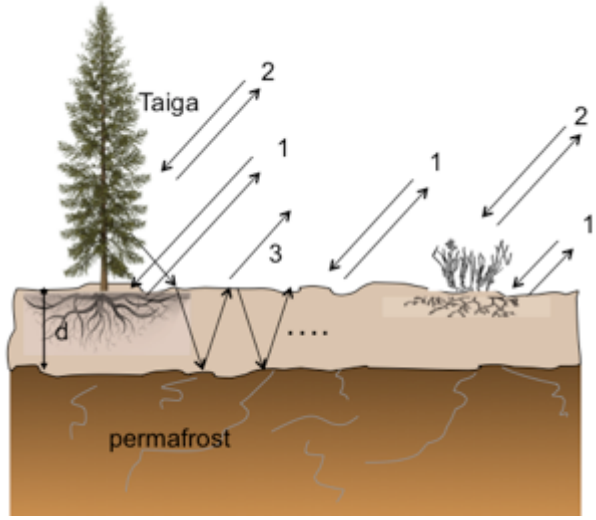
# SUMMARY

- Retrievals underestimate thaw depth in August for all four sites; could be retrieving water table depth
- In October, soil starts to freeze from the surface: soil-water-ice mixture
  - Difficult to define "thaw depth" from in-situ soil temperature in October
  - Two-layer structure may not be accurate to model partially frozen soil and/or organic layer
- Retrieved soil moisture shows decreasing trend for all four sites
  - Expected; could also be due to soil-water-ice mixture, which has much lower dielectric constant
- Next steps:
  - Update soil texture data – from HWSD to HWSD+STATSGO2 or SoilGrids-1km
  - Include organic soil model
  - Make radar forward model more realistic – different soil structures needed for different seasons (max thaw, partially frozen, fully frozen)
  - ***Need more field data***: in-situ validation data are sparse and/or inconsistent
  - Coordinate with ABoVE!

# RADAR MODELING ENHANCEMENTS: NEED DUAL-FREQUENCY




Current model

Enhancements to include organic layer and roots; will be enabled by **two frequencies**

Combination of P-band and L-band:

- Twice as much independent data
- Need two frequencies of polarimetric radar to retrieve unknowns to characterize more realistic subsurface structures
- Numerical simulations show good retrieval for both soil moisture and active/thaw layer thickness with two frequencies
- Will test the idea shortly with actual data

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