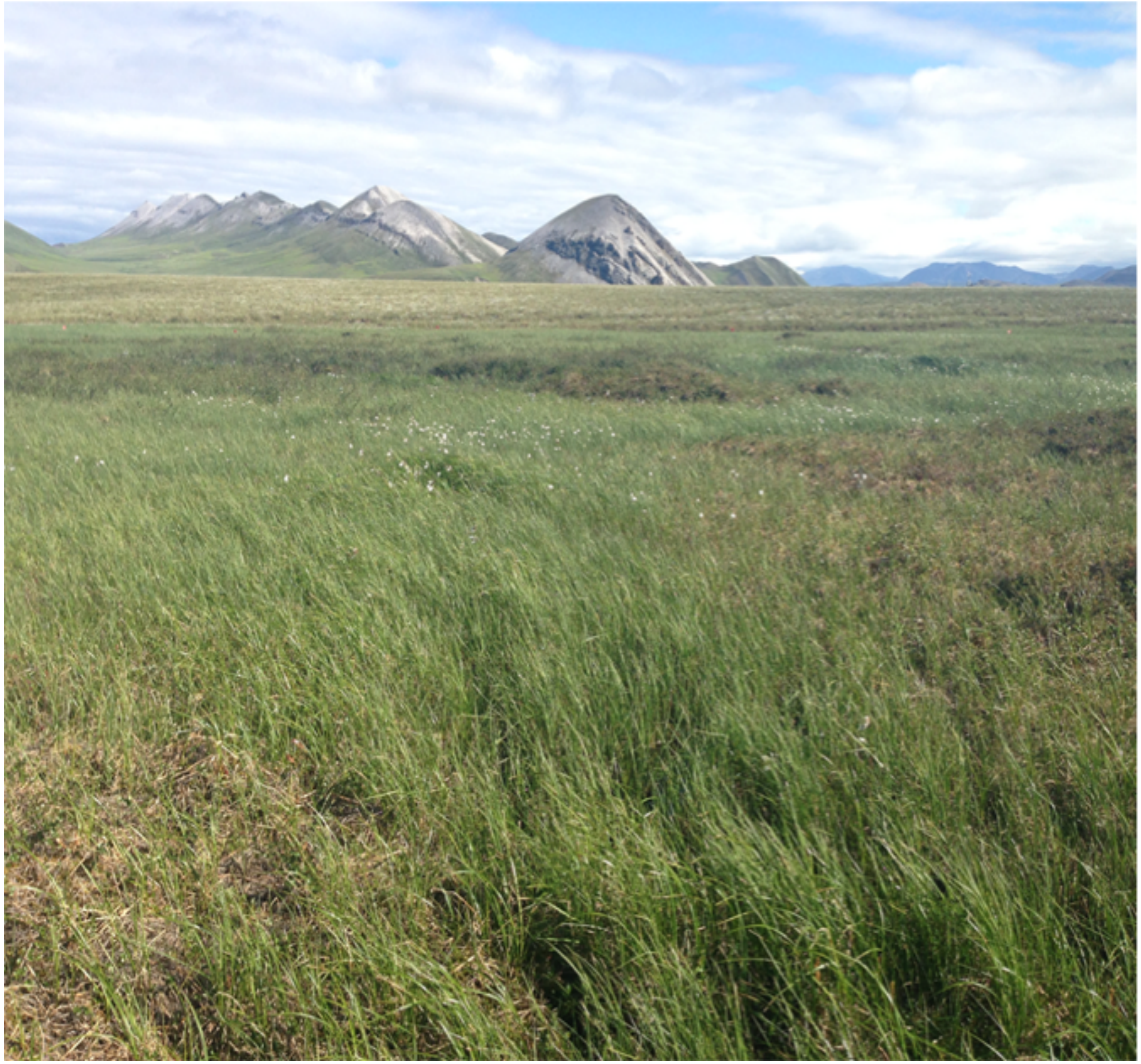
# Hydrology & Permafrost WG

John Kimball (UM, HPWG co-Chair)
Jennifer Watts (WHRC, HPWG co-Chair)
Mark Carroll (GSFC)
Chris Derksen (Environment CN)
Tom Douglas (USACE CRREL)
Mahta Moghaddam (USC)
Walt Oechel (SDSU)
Stan Wullschleger (DOE ORNL)
Cathy Wilson, Elchin Jafarov (DOE, LANL)
Franz Meyer (ASF, UAF)
Donald McLennan (CHARS)
Michelle Walvoord, Jen Rover, Burke Minsley;
Neal Pastick, Brian Ebel (USGS)
Peter Kirchner (NPS, SWAN)
Oliver Sonnentag (Montréal Univ.)
Phil Marsh (Wilfrid Laurier Univ.)
Kevin Schaefer (NSIDC)
Touzi Ridha (CCRS, NRCan)
Laura Bourgeau-Chavez, Liz Jenkins (Mich Tech)
Josh Rose (USFWS AK)
Go Iwahana, Torre Jorgenson, Matthew Whitley,
Mark Lara, Dmitry Nicolsky (UAF)
John Gamon (Univ. Alberta)



ARCTIC BOREAL VULNERABILITY EXPERIMENT

# Selected 2017-18 Project Activities and Accomplishments

ARCTIC BOREAL VULNERABILITY EXPERIMENT

## Hydrology & Permafrost Working Group

NASA

### Group Objectives

**Quantify linkages, drivers & patterns of change in surface *non-frozen period*, permafrost *active layer conditions, snow cover, surface & sub-surface hydrology*.** Assess effects on vegetation greening/ browning, carbon exchange, animal habitat, ecosystem services & community resilience

**Participation:** >30 members; representing university, international & multi-agency collaborators

### Education & Outreach

**Planning & initiation of science education and outreach for ABoVE projects** in remote North Central & North Slope Alaska in partnership with University of Alaska Fairbanks, Arctic Research Consortium of US (ARCUS), USGS.

**Coordination with NASA GLOBE Observer** to field test land cover change protocol app for citizen science (Holli Riebeek)

### Field Activities (2017)

**Ground truth supporting field studies, airborne campaign & modeling:**

**Flux Tower** EC data collections from 5 AK tundra towers (BRO, IVO, ATQ); tower relocation (IVO) and new soil sensor installations [Oechel-01, Kimball-03]. Contributions from other boreal/tundra sites [Marsh-01, Gamon-01, Wullschleger-01; Natali-01]

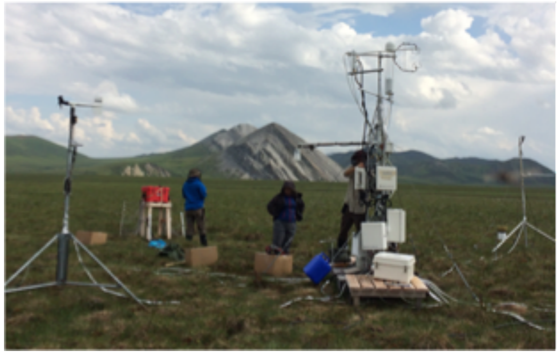
**Energy/water/gas fluxes** [*Oechel-01; Wullschleger-01; Marsh-01, Gamon-01; Natali-01*]

**USArray network enhancement** for active layer and permafrost temperatures [Nicolsky-01]

**ALT, soil dielectric and moisture/thermal profiles** [*Schaefer-03/05; Moghaddam-03; Natali-01; Rogers-01; Loboda-03; Oechel-01; Kimball-03; Frost-01; Bourgeau-Chavez-02/03/04; Striegl-01; Iwahana-01; Douglas-01; Wullschleger-01*]

High Res. **Snow depth and ablation** surveys [Wullschleger-01]

**Permafrost structure, surface hydrology, water chem.** [Marsh-01, *Striegl-01, Turner-K-01*]



### Other Accomplishments

**Airborne campaign support**: coordinated field and RS data collections, Incl. AirMOSS, UAVSAR, AirSWOT, AEM, and G-LiHT sensors

**Remote sensing cal/val assessments:**

- AirMOSS, UAVSAR evaluated for detecting ALT, OLT, soil moisture and microtopography across AK and NWT [Moghaddam-03, Kimball-03, Schaefer-03/05, Marsh-01, Bourgeau-Chavez-03/04, Douglas-01, Loboda-03, Turner-K-01];
- Coordinated AEM and ground surveys to map deep permafrost structure over central AK [Striegl-01]
- GPR and mechanical probing surveys used to map fine scale ALT variations [Schaefer-03/05]

**Synthesis sub-groups organized:** Remote sensing hydrology; Arctic wetting/drying; snow properties; ALD distributions; outreach

HPWG collaborations with other ABoVE WGs: Airborne, Wildlife, Carbon, Vegetation, Disturbance, Modeling, Product standards

**Publications: >18** peer-reviewed publications (2017/18) from HPWG members

**New science data products:**

- Landsat 30-m lake map for ABoVE domain centered on yrs 1991, 2001, 2011[*Carroll-01*]
- AMSR-E/2 6-km polar-grid daily Freeze-Thaw & 5-km lake ice phenology records (2002-2016) [*Kimball-03*]
- Airborne EM survey and resistivity over western Yukon Flats, Alaska. USGS F7QC01P9. [*Striegl-01*]
- ~10 of 38 ABoVE datasets available through ORNL-DAAC relating to hydrology and permafrost

# Action Plans and Protocols Developed with other WGs

- Survey of ABoVE regional water products [Carroll-01]
- ABoVE protocol for ALT surveys [Schaefer-03/05]
- Soil Moisture sampling protocol update [Bourgeau-Chavez-03/04]
- Establishing field sites for studies using SAR data to analyze variations in permafrost, vegetation cover, and soil moisture [Bourgeau-Chavez-03/04]

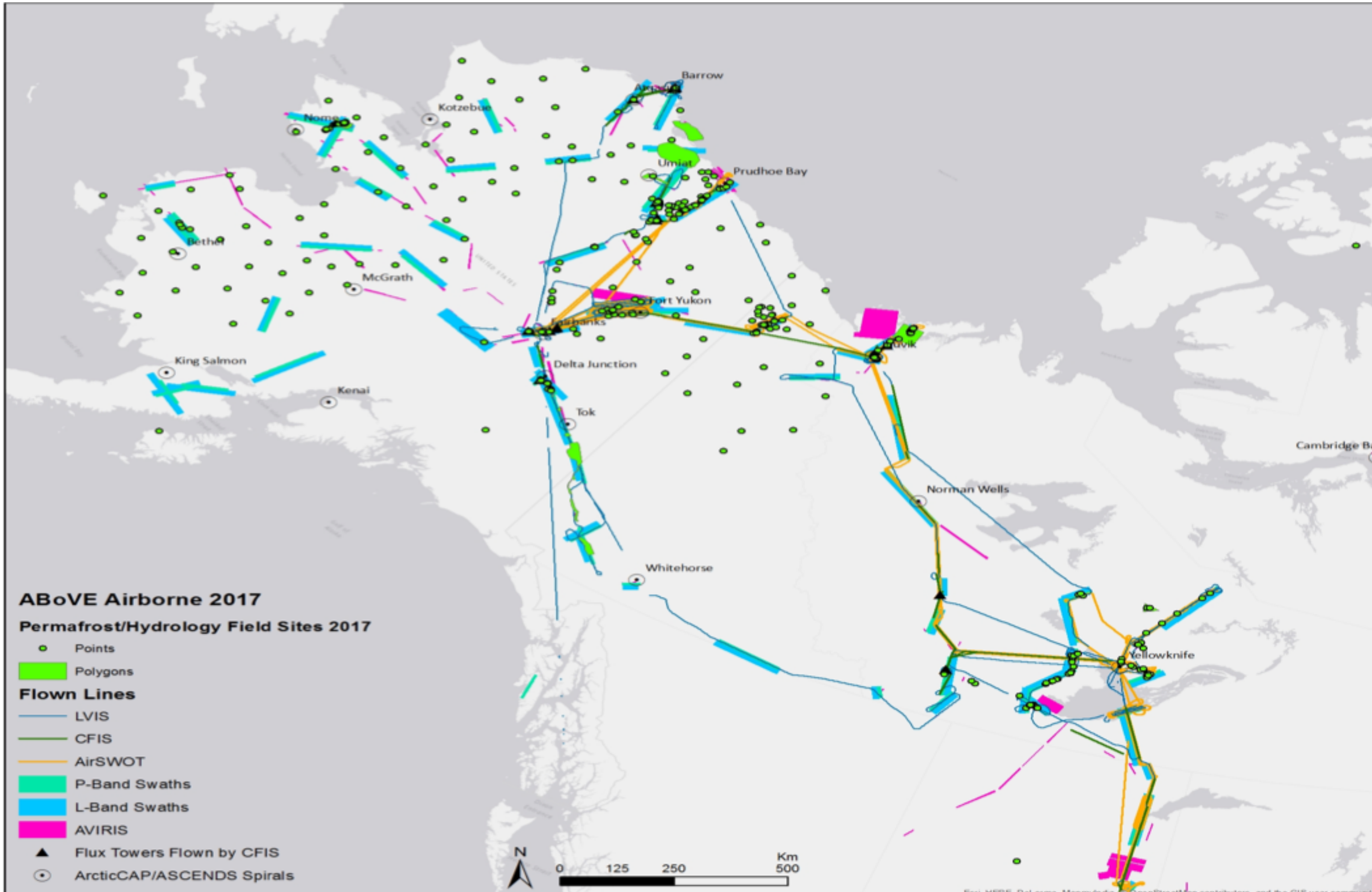
ARCTIC BOREAL VULNERABILITY EXPERIMENT

# Synthesis Activities

- Hydrology Synthesis Paper (Lead: Mark Carroll)
- Arctic Wetting/Drying (Elchin Jafarov/NGEE) **
- Snow Properties (Peter Kirchner)
- Active Layer Depth Distributions (Kevin Schaefer)
- HPWG Outreach (Merritt Turetsky)

ARCTIC BOREAL VULNERABILITY EXPERIMENT

# Field Study Locations + Airborne



# Linking Field Studies and Airborne Data Collections

## Field data collections:

| | | | |
|---|---|---|---|
| ALD, ALT | Relative Humidity | Precipitation | Organic Layer Thickness |
| Air Temperature | Stream Flow | Snow depth, density, SWE | $NO_3^-$ Isotopes |
| Soil Temperature | Stream/Lake Temp. | Surface Albedo | H2O Isotopes |
| Soil Moisture | pH/Salinity | Solar Radiation | Ground Penetrating Radar |
| Soil Matric Potential | DOC/DIC | Terrain deformation | Nuclear Magnetic Resonance |
| Pore Water Elec. Cond. | Aquatic $CH_4$ | | Electrical Resistivity Tomography |
| Water Table Depth | | | Soil thermal conductivity |

## Demand and utility for airborne remote sensing data includes:

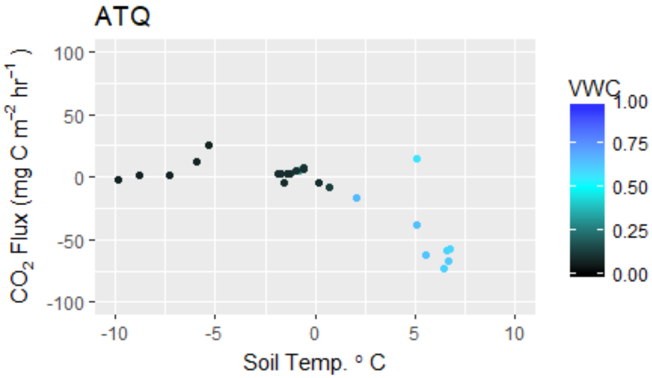
- Developing local to **landscape maps of land cover** (new vegetation map for ABoVE-Jon Wang), **land surface & soil conditions** (temperature, moisture) to assess hydrological patterns and drivers
- **Upscaling** of sparse ground observations
- **Lake elevation change, surface inundation and soil moisture extrapolations** allowing evaluations of climatic vs. microtopography and thermokarst effects on water budgets and wetting/drying patterns
- **Evaluating sub-grid variability** within coarser satellite and modeling footprints
- Consolidated data products that can serve as **drivers and benchmarks for modeling**

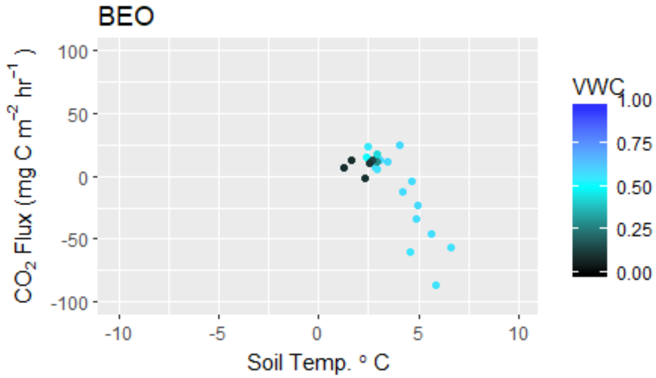
ARCTIC BOREAL VULNERABILITY EXPERIMENT

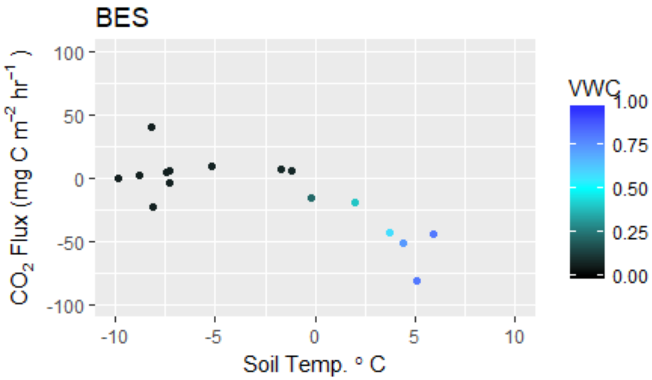
NASA

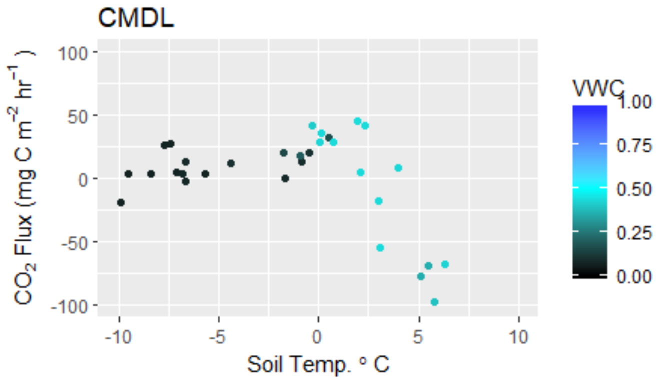
# Measuring GHG fluxes and controls at the Alaska Tundra Tower Sites

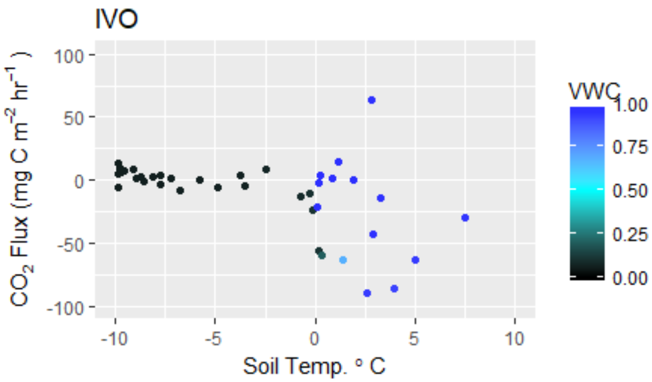
W. Oechel, D. Zona, K. Arndt et al. SDSU




Soil temperature and volumetric water content (VWC) controls on $CH_4$ fluxes from 5 AK tundra eddy flux towers. All data is the weekly mean of half-hourly averages. ***$CH_4$ fluxes positively correlated with soil temperature when unfrozen; wetter sites show generally higher fluxes.*** Soil T and VWC measured in situ at 15-20 cm depth

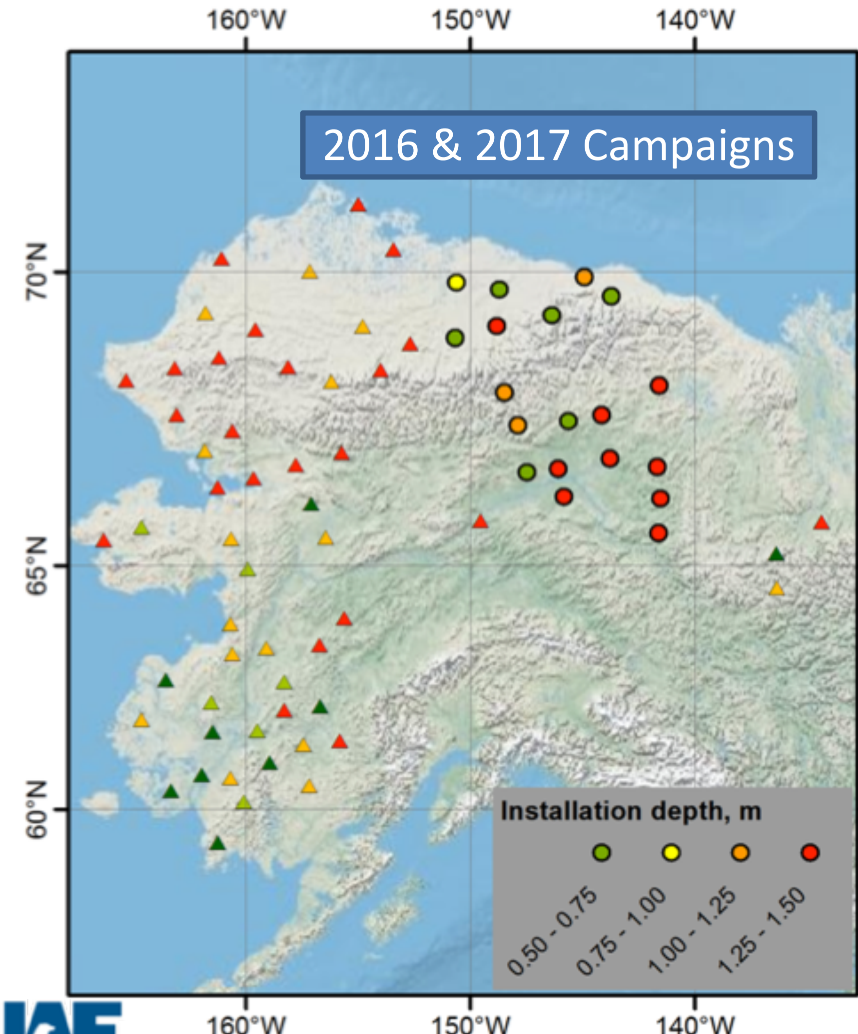
ARCTIC BOREAL VULNERABILITY EXPERIMENT

NASA

# Augmentation of the USArray sites with temperature profilers

Dmitry Nicolsky, Alexander Kholodov, and Vladimir Romanovsky

Many thanks to the USArray installation teams



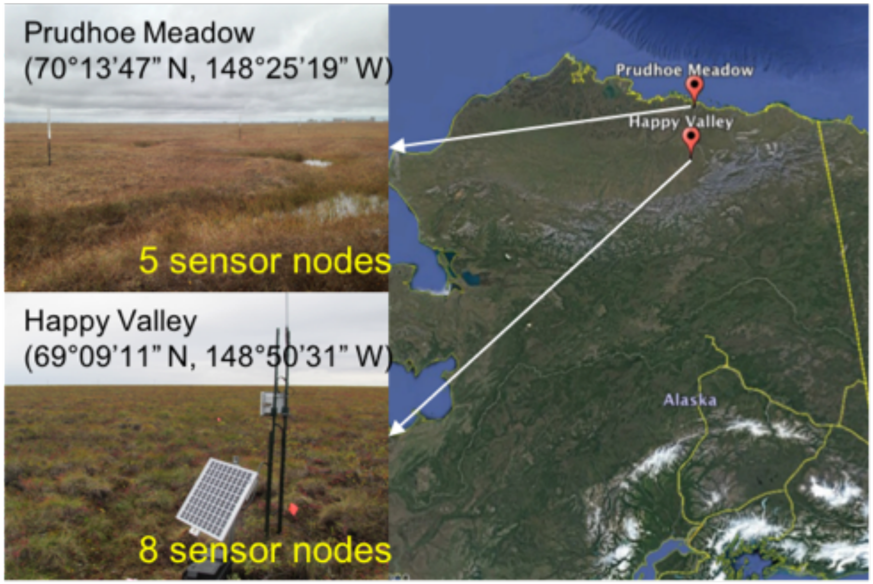

**Project Goal:** ***To measure active layer and permafrost temperature distribution and dynamics across the ABoVE domain***

- During 2016 campaign - **19 USArray sites**
- During 2017 campaign - **55 USArray sites**
- Currently the plan is to upload temperature data and distribute it to the public
- 4-8 sensors to measure temperature at and below the ground surface

# Alaska SoilSCAPE Sensor Network Installations

M. Moghaddam, R. Chen, et al. (USC)

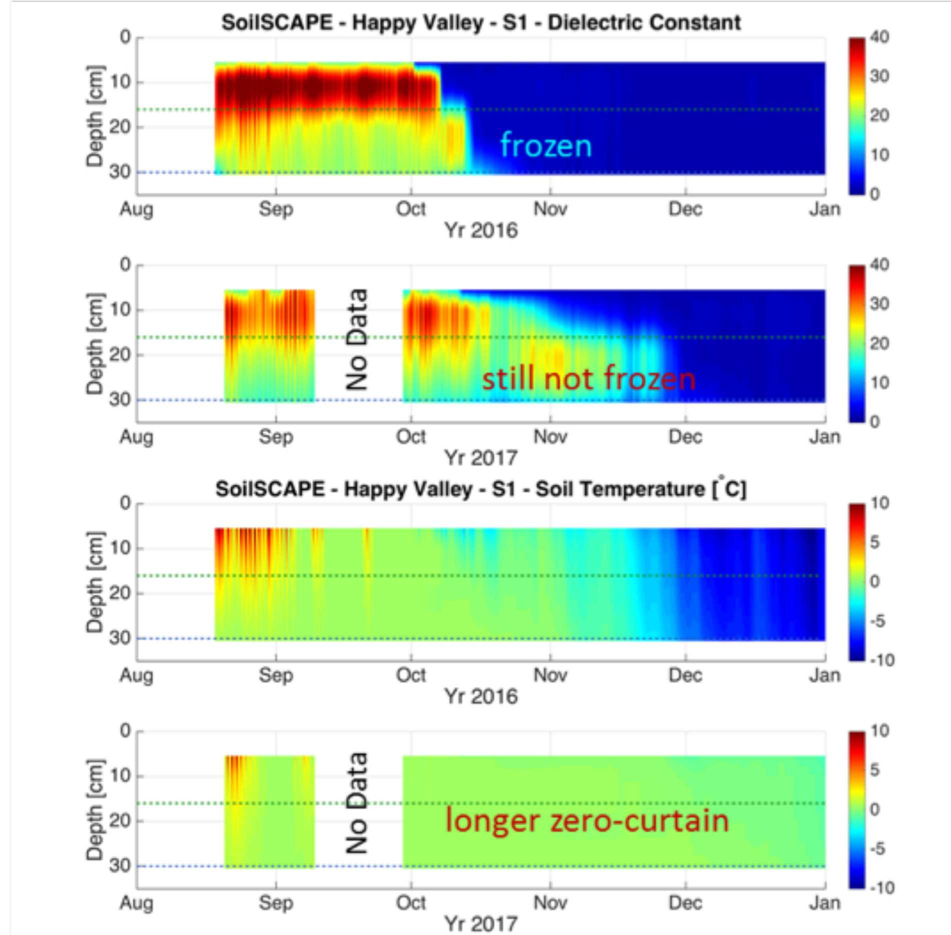
- Two wireless sensor networks (13 nodes) in Alaska North Slope:




- At each node, soil sensors installed at 4 depths to measure:
  - Soil temperature
  - Dielectric constant
  - Electrical conductivity

  ⟷ Soil moisture, Freeze/thaw state
- Data transmission via 4G/LTE or satellite (Iridium) links for real-time monitoring

- Fall 2017 was observed to be much warmer than Fall 2016:

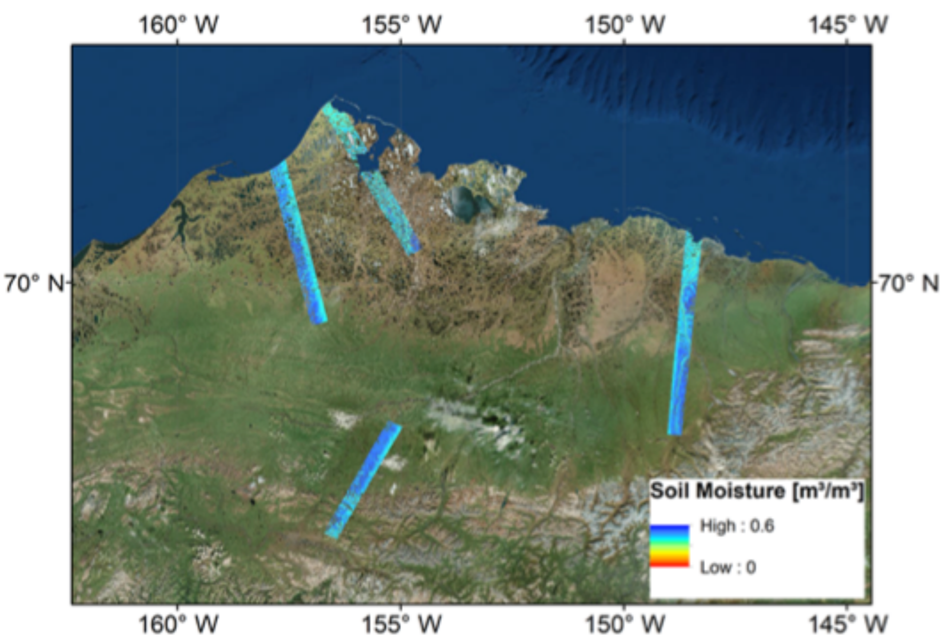



- Freeze/thaw state transitions can be detected by dielectric constant and conductivity measurements

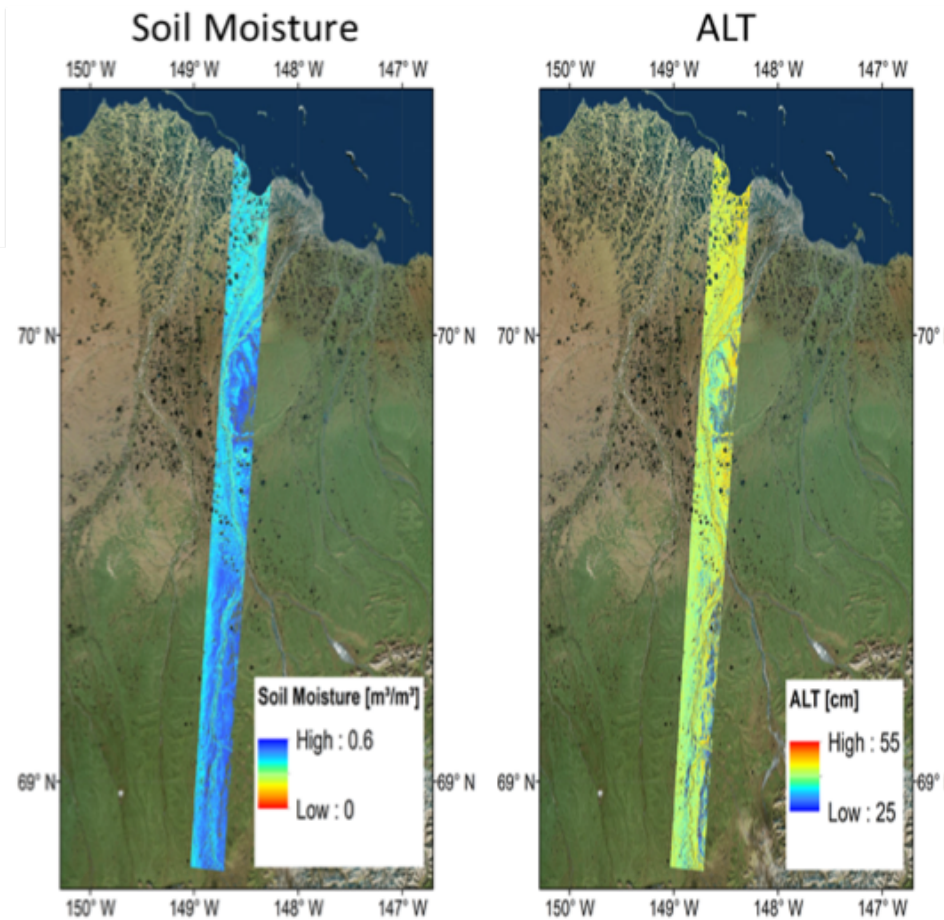
# Retrieval of active layer properties using time-series airborne P-band polarimetric SAR

M. Moghaddam, R. Chen, et al. (USC)

- P-band AirMOSS flights (legacy lines in Alaska) in August and October 2015 used to retrieve soil moisture and ALT 2 arcsec (20 m x 60 m) resolution
- Active layer and permafrost modeled as layered dielectric structure, where dielectric constants converted to soil moisture using soil dielectric models (Engstrom's equation)



Soil moisture retrievals of AirMOSS legacy lines in Alaska North Slope

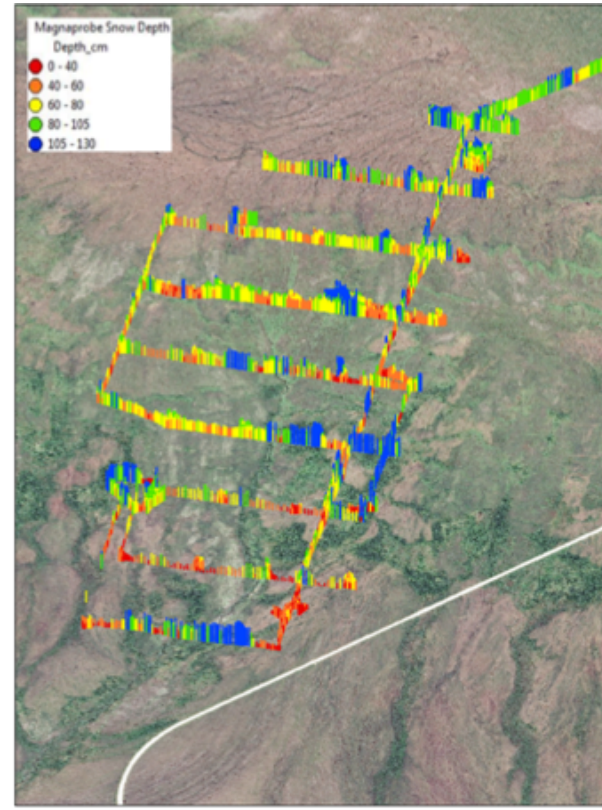


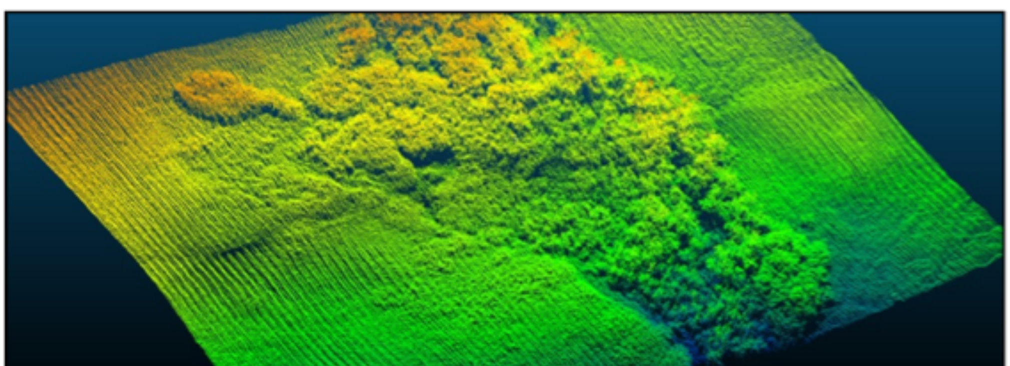
Dalton Highway flight line (dhorse)

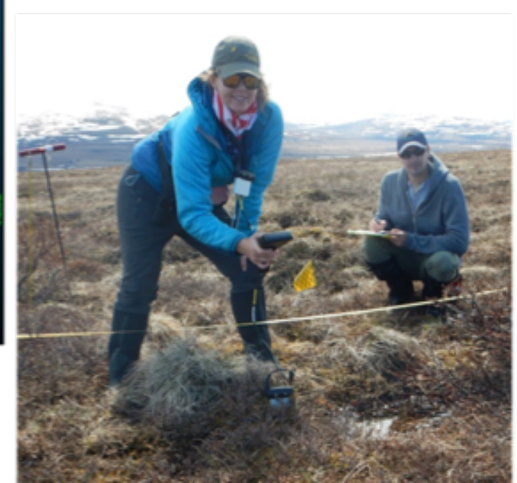
# NGEE-Arctic Hydrology Highlights
# Quantifying controls on permafrost hydrology

C. Wilson, S. Wullschleger E. Jafarov, et al. (DOE ORNL, LANL)

- **NGEE sites:**
  - Barrow Environmental Observatory
  - Three sites on Seward Peninsula: Teller, Kougarok and Council
- **Role of landscape structure:** Macro to micro topographic controls on inundation, soil moisture (coordinated with ABoVE SAR campaign), and flow paths
- **Snow-vegetation-permafrost interactions:** Ultra-high resolution LiDAR datasets, high resolution snow depth and ablation surveys, micro-meteorology, ground temperature surveys, geophysical data
- **Lateral and vertical fluxes of water:** Applied tracer experiments, natural soil water, groundwater and stream aqueous and isotope geochemistry**,** instrumented shallow bore holes





# Airborne Geophysics Maps Deep Permafrost Structure in the Western Yukon Flats

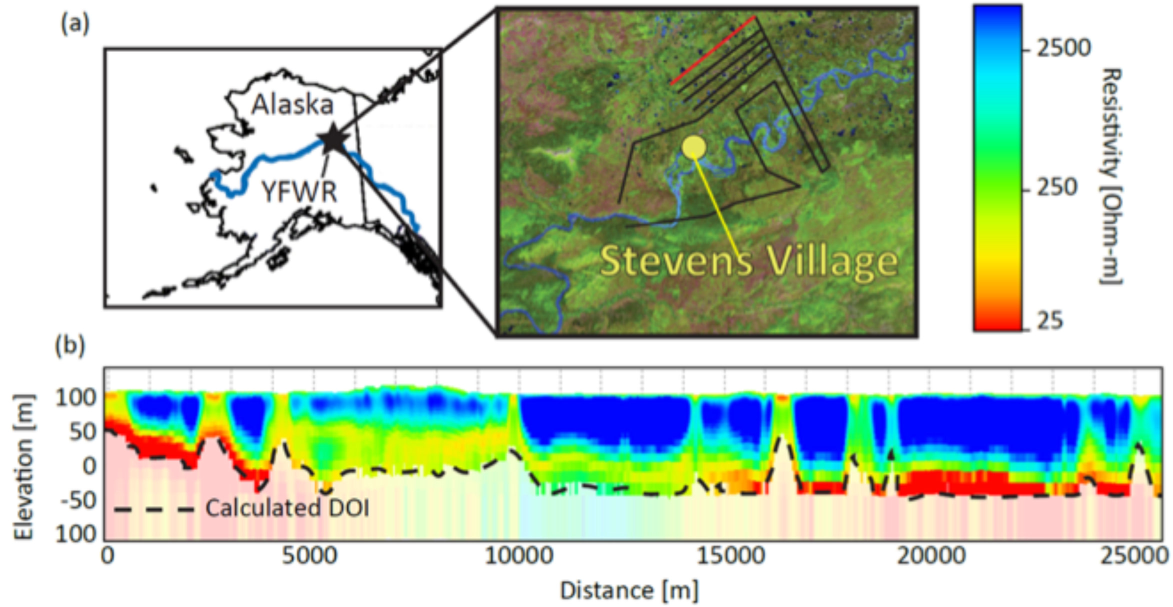
Minsley, B.J., A. M. Emond, and D. M. Rey, 2017, U.S. Geological Survey data release, https://doi.org/10.5066/F7QC01P9.

## Background:

- Airborne geophysics is only way to effectively **map deep (1-100+ m) permafrost** over large areas and with high spatial resolution.
- **300 line-kilometers of new data** were acquired in March 2016 in cooperation with AK DGGS, and complement an earlier USGS Yukon Flats survey from 2010.

## Analysis:

- Acquisition of this small survey was possible by coordinating efforts with an existing DGGS survey in the region.
- Data were acquired using commercial instrumentation, but ABoVE project support allowed us to coordinate this survey and perform geophysical data analysis and interpretation.




(a) Location of new airborne geophysical survey lines in the western Yukon Flats near Stevens Village, AK. (b) 25 km-long cross-section of inverted resistivity models indicate the complex distribution of permafrost at depths of ~1 – 150m belowground. High resistivity (blue colors) areas indicate permafrost, which is discontinuous beneath the many lakes and surface water features characteristic of the Yukon Flats. The DOI (dotted black line) indicates the maximum depth of investigation along the transect.

## Findings:

- **Permafrost in the western Yukon Flats appears to be thicker and potentially more ice-rich.**
- Impacts on the distribution of permafrost related to **historical fires and hydrological processes** are evident
- Investigation on relations between permafrost distribution and historical lake trends is ongoing.

## Significance:

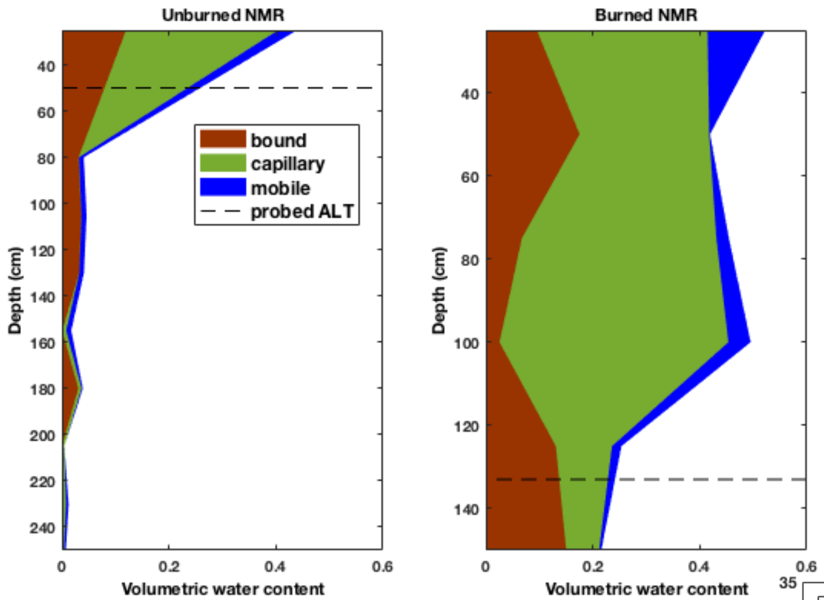
- Airborne geophysics extends our view of regional permafrost distributions at depth far beyond the reach of other remote sensing methods.

# Downhole nuclear magnetic resonance (NMR) quantifies unfrozen water in permafrost soils

Kass, Irons, Minsley, Pastick, Brown, and Wylie, 2017. *The Cryosphere* 11, 6, 2943-2955.

## Background:

- Measurements of shallow soil moisture commonly made in the unfrozen layer above permafrost, but **distribution of water with depth into the permafrost table difficult to measure in the field**.
- 'Warm' transitional permafrost can contain **significant amounts of unfrozen water** and that may contribute to degradation of carbon.




NMR measurements of unfrozen water content as a function of depth at (left) a unburned site and (right) a burned site. Total water content is partitioned into bound, capillary, and mobile fractions that reflect the relative pore size distribution in which the water is held. Manually probed depths to permafrost are indicated by the dashed line.

## Analysis:

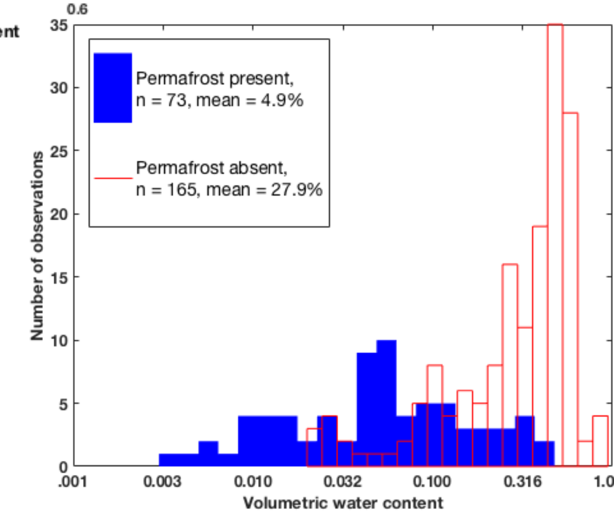
- A new commercially available portable downhole NMR tool facilitates *in situ* measures of unfrozen water.
- **>200 NMR measurements made at 52 locations** over four field seasons including both ABoVE and USGS LandCarbon project support.

## Findings:

- **Significant unfrozen water, up to 10-30 %, can exist in shallow 'warm' permafrost soils.**

## Significance:

- Airborne geophysics extends view of regional permafrost distributions at depth far beyond reach of other remote sensing methods.

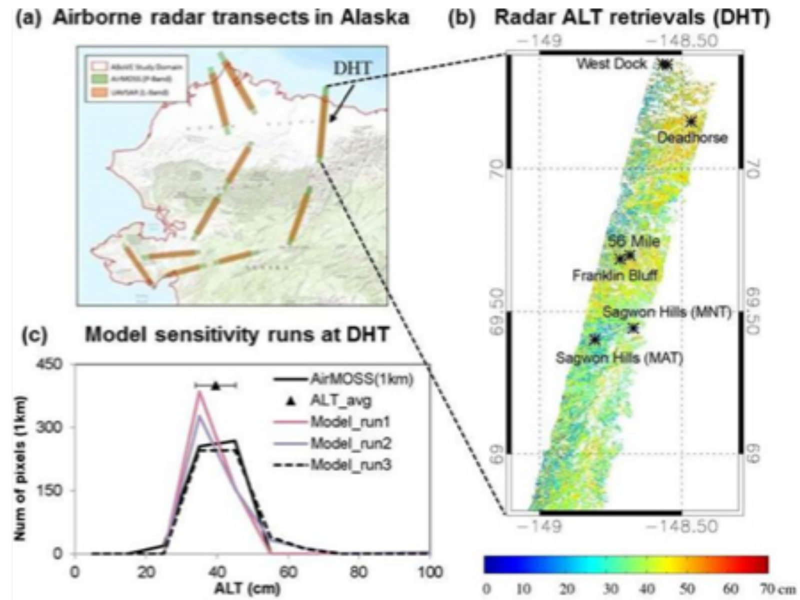


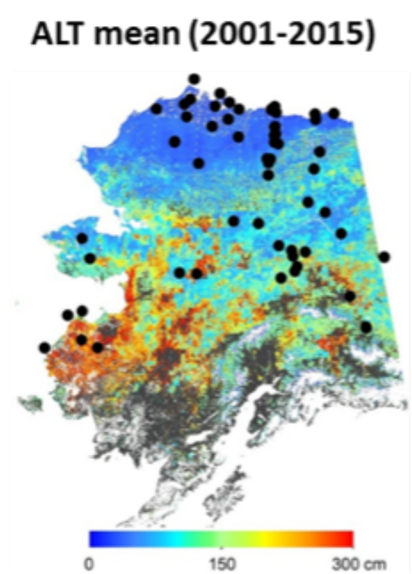

Total unfrozen water content at locations with (blue) and without (red) permafrost

# Characterizing Permafrost Active Layer Dynamics and Sensitivity to Landscape Heterogeneity and Regional Warming in Alaska

Yi, Kimball, Chen, Moghaddam, Reichle, Mishra, Zona and Oechel, 2017. *The Cryosphere* 12, 145-161.

- Satellite data-driven heat transfer modeling of AK (1-km Res.) permafrost extent and ALT trends (2001-2015)
- Local scale (50-m) SM, ALT retrievals from UAVSAR, AirMOSS (L+P-band) used for model Cal/Val
- Model drivers: SMAP L4 SM; MODIS SCE, LST; MERRA-2 snow depth, density
- Results:
  - Regional warming and longer snow-free season promoting widespread ALT deepening, esp. in western AK.
  - **SOC distribution was largest uncertainty factor affecting model ALT accuracy**.
  - Advances in SOC and SM mapping will enable largest improvements in model ALT predictions.



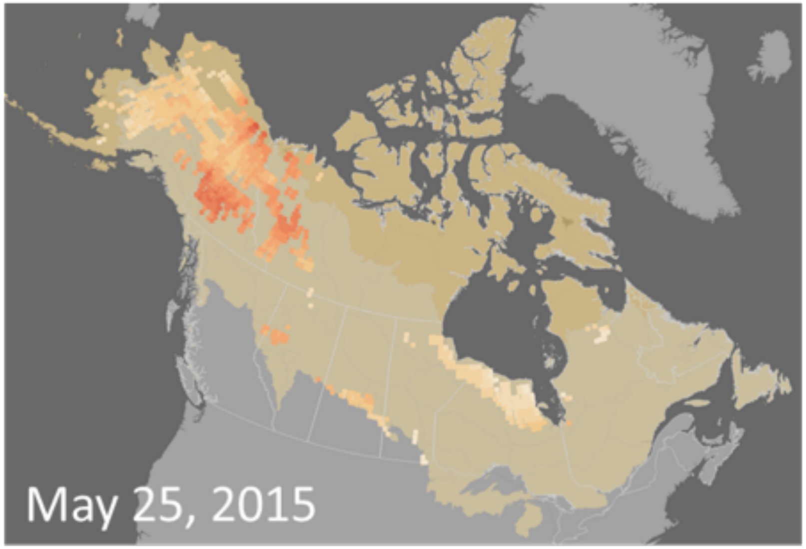


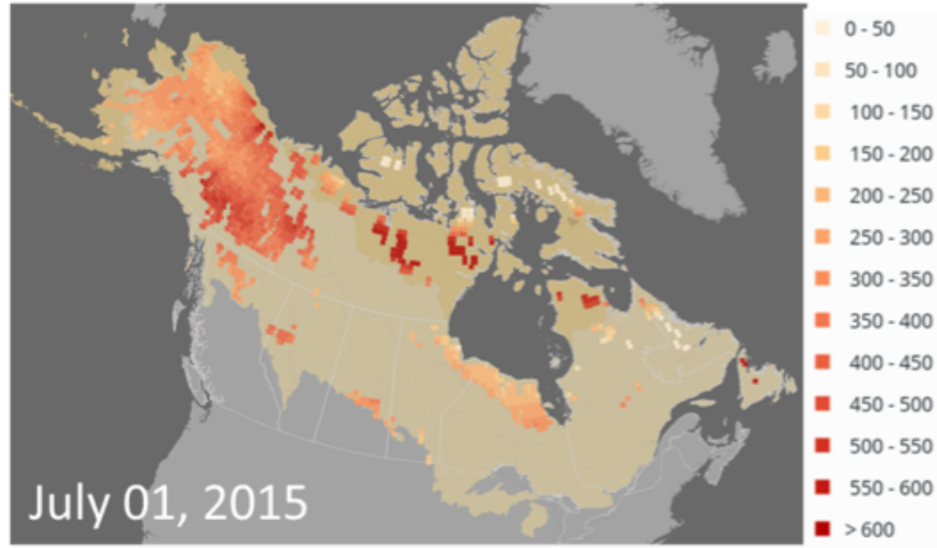
NTSG Numerical Terradynamic Simulation Group

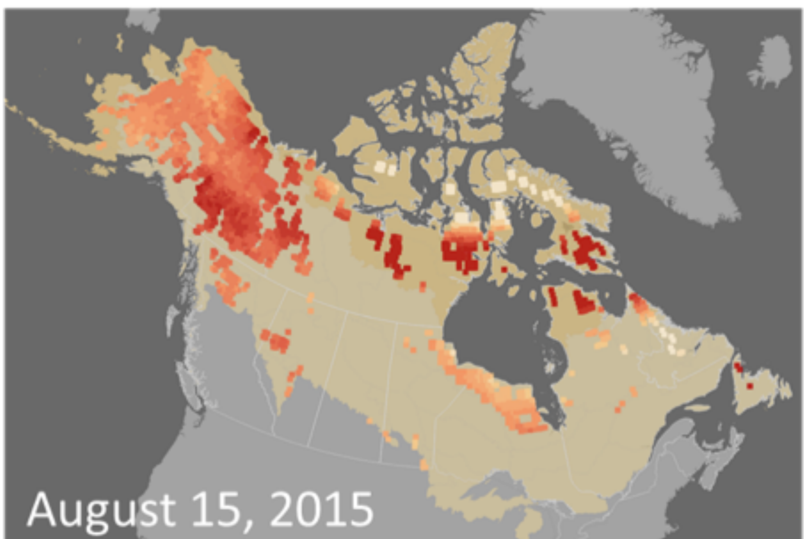
ABoVE ARCTIC - BOREAL VULNERABILITY EXPERIMENT

# Predicting Drought Code (DC) using SMAP

Bourgeau-Chavez and Billmire




- Drought Code (DC) is a weather index used by managers to help predict wildfire location and severity
- Here, SMAP satellite surface soil moisture retrievals used for regional DC mapping
- DC ranges from relatively moist (0) conditions to extreme drought (600) levels
- SMAP results explain 62% of station network based DC assessments

ARCTIC BOREAL VULNERABILITY EXPERIMENT

NASA

# Summary

- New field data collections, remote sensing and geospatial products produced during the 2016/17 project phase, and available through ABoVE project page, ASC, ORNL-DAAC or project teams.
- Detailed action plans and protocols developed to organize field data collections and establish consistent definitions and sampling methods.
- >18 peer-reviewed publications resulting from recent project science activities.
- **HPWG sub-groups organized and progressing on five science synthesis topics: Remote sensing hydrology; Arctic wetting/drying; Snow properties; ALD distributions; and Outreach.**
- Initial progress and plans developed for exploiting airborne data collections, including upscaling of sparse ground observations; characterizing surface water budgets and wetting/drying patterns; evaluating sub-grid heterogeneity, and developing consolidated data products needed for model drivers and assessments.
- **Several science gaps and research priorities identified including:**
  - **Quantifying and projecting permafrost landscape wetting/drying dynamics and lateral fluxes**
  - **Quantifying deeper (1-10m) bedrock-permafrost-hydrology interactions**
  - **Characterizing surface water extent changes especially in smaller to medium sized water bodies for water budget and BGC assessments**
  - ***Linking C fluxes with hydrology & permafrost active layer* characteristics; transitional littoral zones**

ARCTIC BOREAL VULNERABILITY EXPERIMENT

# Recent Publications


Balabubramaniam AM, AS Medeiros, KW Turner, RI Hall, BB Wolfe. 2017. Biotic responses to multiple aquatic and terrestrial gradients in shallow subarctic lakes (Old Crow Flats, Yukon Territory, Canada). Arctic Science: 3: 277-300, dx.doi.org/10.1139/as-2016-0021

Bouchard F, LA MacDonald, KW Turner, JR Thienpont, AS Medeiros, BK Biskaborn, J Korosi, RI Hall, R Pienitz, BB Wolfe. 2017. Paleolimnology of thermokarst lakes: a window into permafrost landscape evolution. Arctic Science: 91-117, dx.doi.org/10.1139/as-2016-0022

Carroll, M.L., and T.V. Loboda, 2017. Multi-decadal surface water dynamics in north American tundra. *Remote Sensing*, 9, 5, 497.

Cooley, S.W., L.C. Smith, L. Stepan, and J. Mascaro, 2017. Tracking dynamic northern surface water changes with high-frequency Planet CubeSat imagery. *Remote Sensing* 9, 12, 1306.

Davidson, S.J., M.J. Santos, V.L. Sloan, et al. 2017. Upscaling CH4 fluxes using high-resolution imagery in arctic tundra ecosystems. *Remote Sensing* 9, 12.

Derksen, C., X. Xu, R.S. Dunbar, A. Colliander, et al., 2017. Retrieving landscape freeze/thaw state from Soil Moisture Active Passive (SMAP) radar and radiometer measurements. *Remote Sensing of Environment* 194, 48-62.

Du, J., J.S. Kimball, C. Duguay, Y. Kim, and J.D. Watts, 2017. Satellite microwave assessment of northern hemisphere lake ice phenology from 2002 to 2015. *The Cryosphere*, 11, 47-63.

Kass, M.A., Irons, T.P., Minsley, B.J., Pastick, N.J., Brown, D.R.N., Wylie, B.K., In situ nuclear magnetic resonance response of permafrost and active layer soil in boreal and tundra ecosystems. The Cryosphere, 11, 2943-2955.

Kim, Y., J.S. Kimball, J. Glassy, and J. Du, 2017. An extended global earth system data record on daily landscape freeze-thaw status determined from satellite passive microwave remote sensing. *Earth System Science Data*, 9, 133-147.

Krogh, S.A., J.W. Pomeroy, and P. Marsh, 2017. Diagnosis of the hydrology of a small arctic basin at the tundra-taiga transition using a physically based hydrologic model. *J. Hydrology* 550, 685-703.

MacDonald LA, BB Wolfe, KW Turner, L Anderson, CD Arp, SJ Birks, F Bouchard, TWD Edwards, N Farquharson, RI Hall, I McDonald, B Narancic, C Ouimet, R Pienitz, J Tondu, H White. 2017. A synthesis of thermokarst lake water balance in high-latitude regions of North America from isotope tracers. Arctic Science:  118-149, dx.doi.org/10.1139/as-2016-0019

Minsley, B.J., Emond, A.M., and Rey, D.M., 2017, Airborne electromagnetic and magnetic survey data and inverted resistivity models, western Yukon Flats, Alaska, February 2016: U.S. Geological Survey data release, https://doi.org/10.5066/F7QC01P9.

Pastick, N.J., P. Duffy, H. Genet, T.S. Rupp, et al., 2017. Historical and projected trends in landscape drivers affecting carbon dynamics in Alaska. *Ecological Applications* 27, 5, 1383-1402.

Stackpoole, S.M., D.E. Butman, D.W. Clow, K.L. Verdin, B.V. Gaglioti, H. Genet, and R.G. Striegl, 2017. Inland waters and their role in the carbon cycle of Alaska. *Ecological Applications* 27, 5, 1403-1420.

Tondu JM, KW Turner, JA Wiklund, BB Wolfe, RI Hall, I McDonald.  2017.  Limnological evolution of Zelma Lake, a recently drained thermokarst lake in Old Crow Flats (Yukon, Canada). Arctic Science 220-236, dx.doi.org/10.1139/as-2016-0012

Wagner, R., D. Zona, W. Oechel, and D. Lipson, 2017. Microbial community structure and soil pH correspond to methane production in Arctic Alaska soils. *Environmental Microbiology* 19, 8.

Wrona, E., T.L. Rowlandson, M. Nambiar, A.A. Berg, A. Colliander, and P. Marsh, 2017. Validation of the soil moisture active passive (SMAP) satellite soil moisture retrieval in an arctic tundra environment. *GRL* 44, 9.

Yi, Y., J.S. Kimball, R. Chen, M. Moghaddam, R.H. Reichle, U. Mishra, D. Zona, and W.C. Oechel, 2017. Characterizing permafrost soil active layer dynamics and sensitivity to landscape spatial heterogeneity in Alaska, *The Cryosphere* (In press).


ARCTIC BOREAL VULNERABILITY EXPERIMENT

# Thank You WG Members

ARCTIC BOREAL VULNERABILITY EXPERIMENT

NASA