Hydrology & Permafrost WG

WG co-Chairs: John Kimball (Univ. MT), Jennifer Watts (WHRC)

- >60 members representing university, international & multi-agency collaborators
- ~23 projects represented
- ~6 new Phase II projects with PF-Hydro emphasis
- HPWG sign-up available through Science Team link on the ABoVE webpage

HPWG Science Focus Area

Key Science [1]Questions:

- What processes control changes in PF distribution & properties; what are the impacts of these changes?
- What are the causes and consequences of hydrologic changes, Incl. amount, temporal distribution and discharge of surface & subsurface water?

[1]Objectives:

- Understand processes controlling changes in PF distribution and hydrology. Clarify feedbacks & consequences of these changes on flora, fauna, carbon biogeochemistry & ecosystem services.
- Quantify linkages, drivers & patterns of change in the surface non-frozen period, permafrost active layer conditions, snow cover, surface & sub-surface hydrology.
- Assess effects on vegetation greening/ browning, carbon exchange, animal habitats, ecosystem services, infrastructure, transportation & community resilience.

[1]ABoVE Implementation Plan

Linking Field Studies & Remote Sensing

ARCTIC BOREAL VULNERABILITY EXPERIMENT

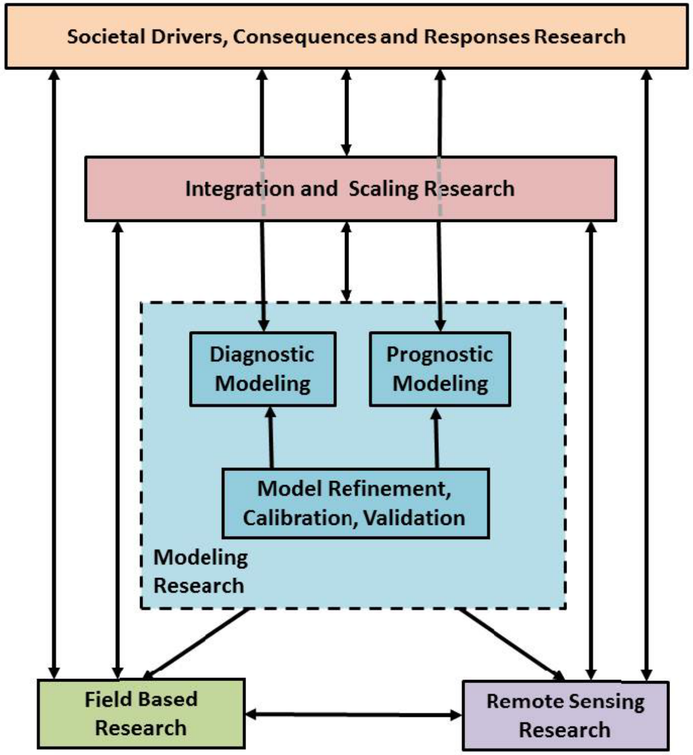
In situ field measurements:

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

Remote Sensing & model extrapolations:

- Development of local to landscape maps of surface conditions to assess hydrological patterns, drivers and linkages
- Interpolation, upscaling of sparse ground Obs.
- Lake elevations, surface inundation & soil moisture extrapolations for evaluating microtopography & thermokarst effects on water budgets & wetting/drying patterns
- Evaluating variability within coarser satellite & model footprints
- Consolidated data products to serve as drivers & benchmarks for modeling

ABoVE Experiment Design

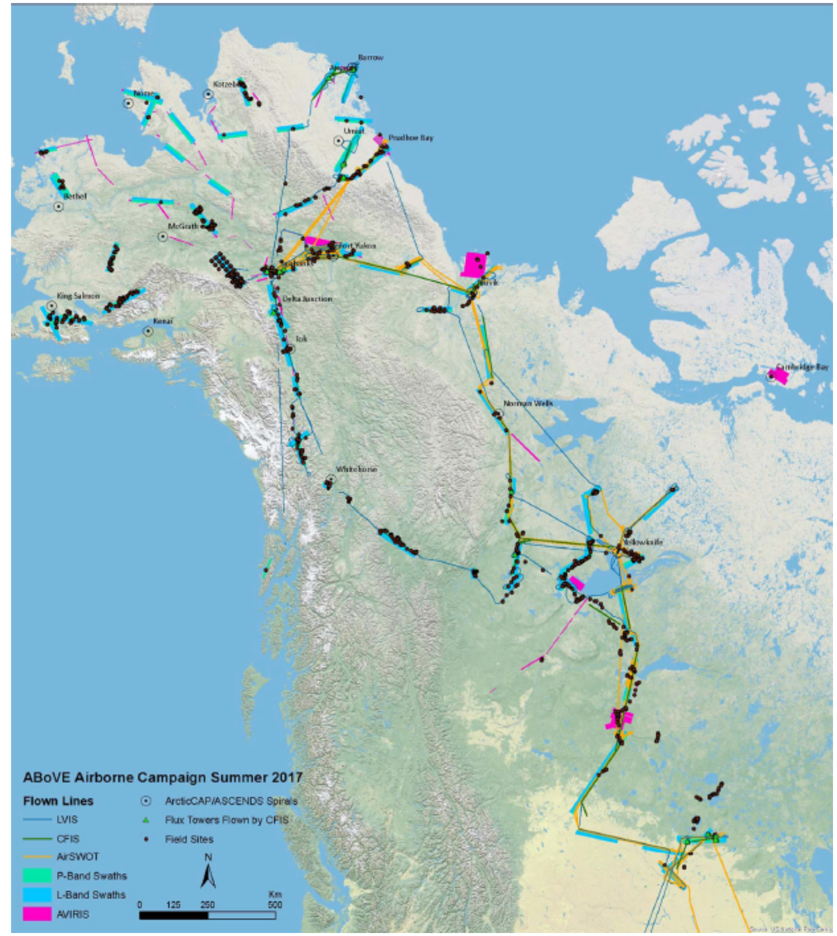


ABoVE Experiment Plan (Fig. 4.2)

Selected Phase I Accomplishments

- Extensive overlapping field, airborne & satellite data
  - **>20 HP project datasets archived**, incl. permafrost, active layer, surface water & snow properties from field studies, remote sensing & modeling
  - Tower EC & augmented USArray networks; vegetation, snow, permafrost, active layer and GPR/NMR/ERT surveys, water Chemistry surveys
  - >200 airborne flights & 4 million km^2 sampled in 2017 AAC: SAR (UAVSAR, AirMOSS), LIDAR (G-LiHT, LVIS), Altimetry/CIR (AirSWOT), AEM, hyperspec (AVIRIS-NG); additional pre-ABoVE campaign data (2014-2016).
- **~60 peer-reviewed HP publications** (2015-2019)
- Action plans & protocols developed with other WGs for soil moisture & active layer sampling, SAR validation, & geospatial data standards.
- Education & community outreach across AK & NW Canada, coordinating with regional universities (UAF), agencies (NPS, USGS, NASA, CHARS), communities & other stakeholders (GLOBE, ARCUS).

[1]2017 Summer airborne campaign (AAC)



[1]Miller et al., 2019. *ERL,* doi.org/10.1088/1748-9326/ab0d44

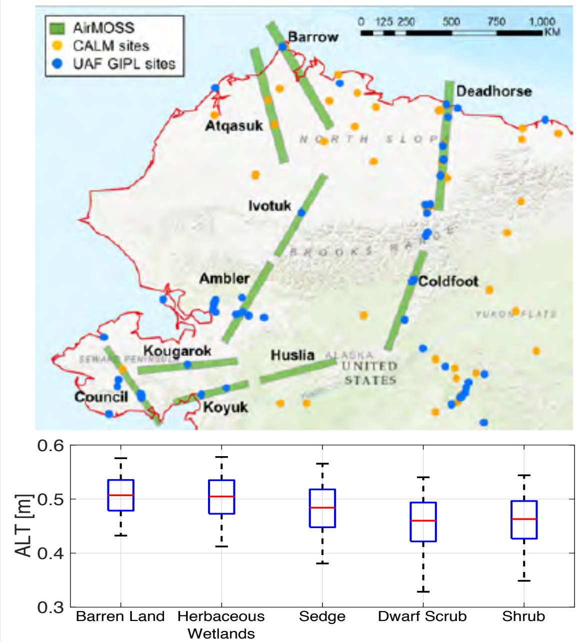
Retrieval of Permafrost Active Layer Properties Using Time-Series P-Band Radar Observations

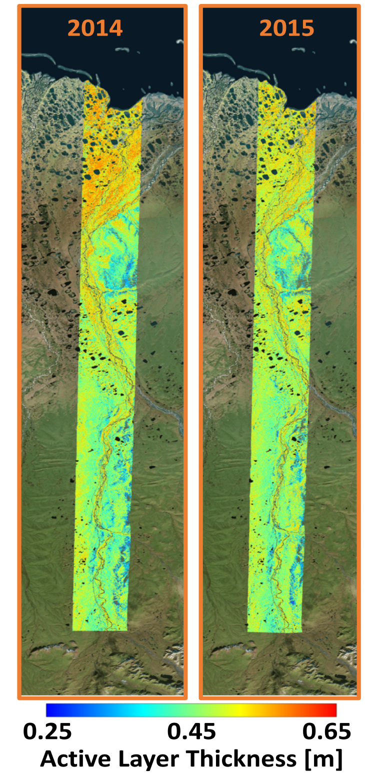
Richard H. Chen et al., 2019. *IEEE TGRS*, DOI: 10.1109/TGRS.2019.2903935
Data available via ORNL DAAC: https://doi.org/10.3334/ORNLDAAC/1657

Background: Long wavelength radar enables direct retrieval of permafrost soil properties and dynamics due to ability to penetrate soils. We developed a retrieval algorithm for permafrost active layer thickness (ALT) and soil moisture profiles from time-series AirMOSS P-band polarimetric SAR (PolSAR).

Analysis: Dielectric contrast between thawed active layer and frozen soil provides radar backscatter signature for ALT and soil moisture retrieval. This is accomplished using a computational electromagnetic inverse model. ALT retrievals validated from in-situ measurements.

Findings: **ALT retrieval error <10 cm** where ALT is within AirMOSS sensing depth (~0.55 m). Beyond the sensing depth, error increases, as expected, but retrieved ALT remains positively correlated with in-situ data. Retrieved dielectric profiles also provide soil moisture and F/T state and can inform organic matter content calculation. Results show active layer distribution & dynamics more controlled by land cover than the N-S temperature gradient.





Example of retrieved ALT is shown on right for the Deadhorse flight line. Bottom left panel shows retrieved ALT spatial distributions across different land covers.

Significance: Demonstrated P-band radar retrieval of active layer properties, incl. **ALT**, **soil moisture**, and **F/T profiles**. Insights into regional high-resolution active layer variability to improve soil process modeling for permafrost vulnerability assessment.

Changes in lake area in the Yukon Flats observed using novel CubeSat imagery

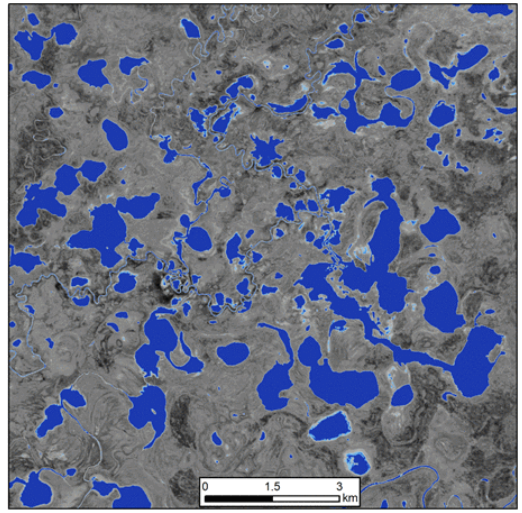
Sarah Cooley (Brown University), Laurence Smith (UCLA), Tamlin Pavelsky (UNC) and others

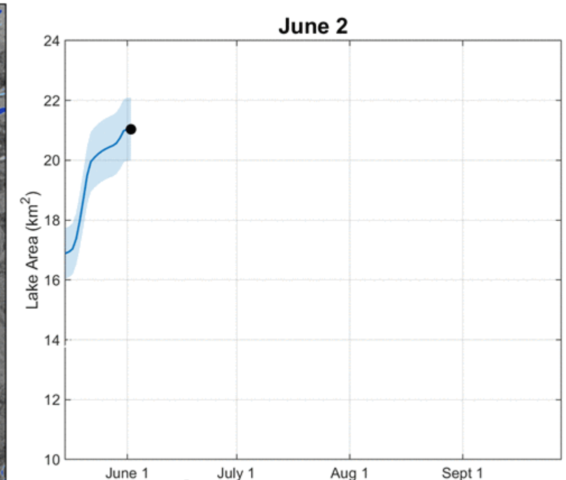
Background

- The seasonal fluctuation of lake area in the Yukon Flats impacts freshwater carbon emissions, wildlife habitat, and local access to cabins and hunting grounds.
- Mapping these changes across 1000s of km² has previously been prohibited by the coarse spatial (30 meter) and temporal (~biweekly) resolution of available satellite imagery.

Analysis

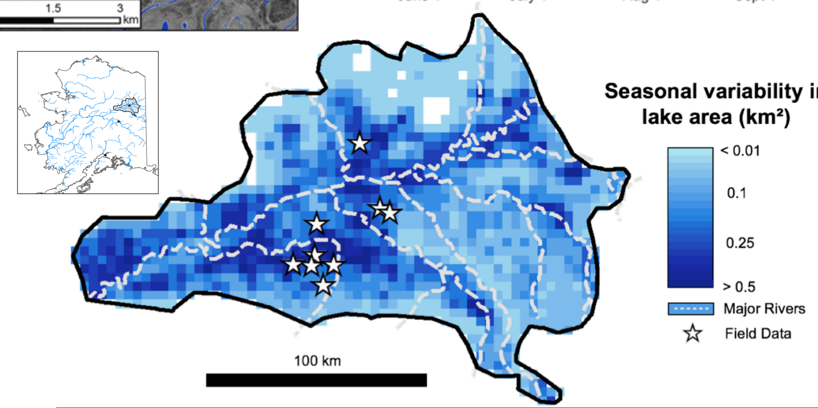
- A new constellation of tiny satellites known as CubeSats and operated by Planet Labs now take pictures of the entire world at 3 meter resolution every day.
- We developed a new method for mapping changes in lake area using CubeSat imagery, and applied it to the entire Yukon Flats Basin.
- We compared our lake area time series to field data collected in the Yukon Flats in summer 2017.





Results

- We quantified changes in lake area for ~9,000 lakes in the Yukon Flats and identified regions which experienced the greatest seasonal declines in lake area.
- On average, lakes in the Yukon Flats lost 39% of their area during summer 2017.



Significance

- Many of the most variable lakes are located near rivers, particularly in the Christian River and Birch Creek basins.
- The largest and most rapid changes in lake area occur in mid-June following ice-breakup and snowmelt, although lake area rebounds in some basins in late-August.
- These findings may be useful for navigating waterways and access to cabins in the Yukon Flats, and also may affect estimates of freshwater greenhouse gas emissions.

Cooley et al. (2019), Arctic-Boreal Lake Dynamics Observed using CubeSat Imagery, *Geophysical Research Letters*, doi:10.1029/2018GL081584

Airborne Electromagnetic Surveys and Landsat Time-series Clustering Inform Lake-area Dynamics

Rey, D, Walvoord, M., B. Minsley, Rover, J., and Singha, K. (2019), *ERL*. DOI: 10.1088/1748-9326/aaf06f.

Goals:

- Elucidate mechanisms driving lake-area dynamics in regions of variable permafrost and lake talik conditions.

Analysis:

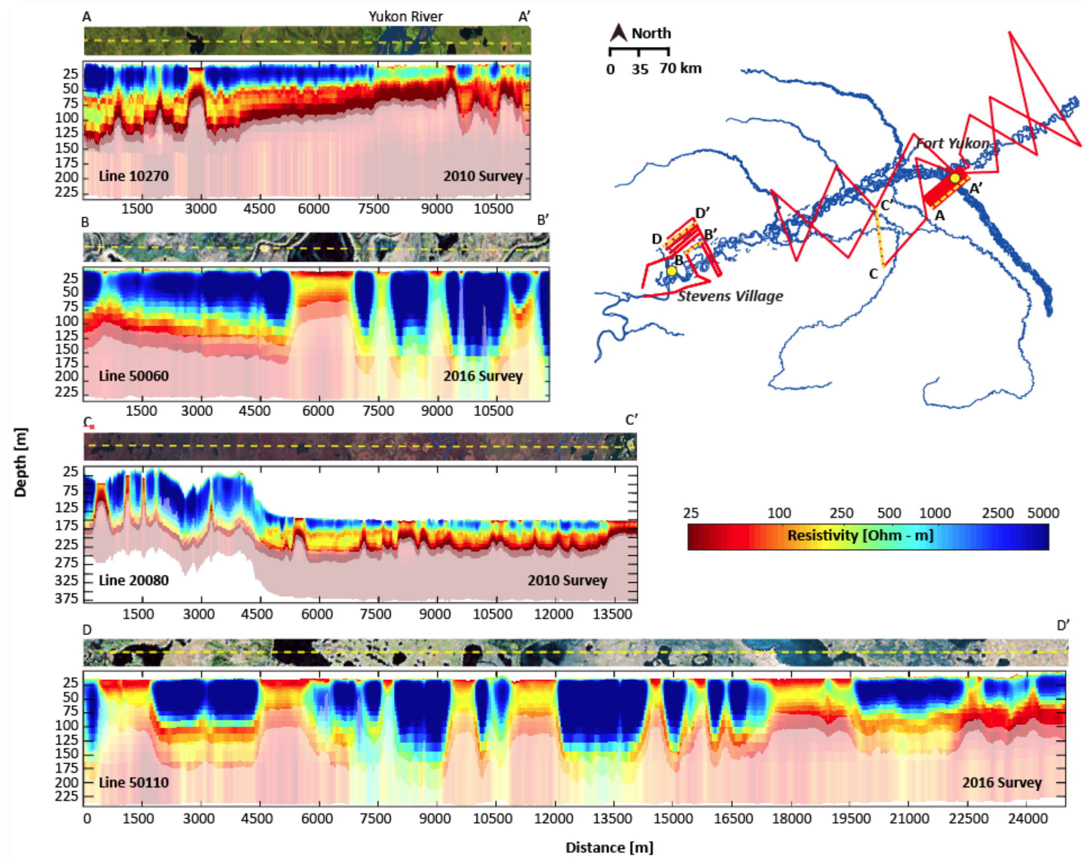
- 2010 and 2016 AEM surveys constrain permafrost distribution, statistical clustering of Landsat derived lake surface-area time-series highlight mechanisms driving lake behavior.

Results:

- Continuous (Discontinuous) PF areas show synchronous (asynchronous) lake-area dynamics.
- Lakes ~37% ephemeral and ~63% perennial surface-water features. ~66% driven primarily by surface-water connectivity, ~19% driven primarily by shallow subsurface connectivity, ~15% appear to have no connectivity.

Significance:

- Space-for-time proxy of lake area/permafrost change.
- AEM deep subsurface Info. co-located with ABoVE data collections in Yukon Flats, AK.



Comparison of two AEM lines from the 2010 and 2016 surveys. Cross-sections display log(resistivity) vs. depth for each flight line. The resistive blue zones are interpreted as permafrost. Location map of the Yukon Flats, AK with AEM flight lines (in red) shown in the upper right.

Wet Snow Reinforces Arctic Springtime Warming

Y. Kim, J.S. Kimball, J. Du, C.L.B. Schaaf, and P.B. Kirchner. 2018. *ERL. 13, 075009*.

Motivation:

The Arctic albedo transition during spring snowmelt has strong climate impacts, but better process understanding is constrained by lack of reliable methods for regional monitoring.

Methods:

Fusion of synergistic satellite data used to quantify spring (Mar-Jun) transition from cold dry to warmer wet snow conditions over Alaska and NW Canada. Satellite data used: **AMSR** Freeze/Thaw (FT) status; **MODIS** Snow Cover Extent (SCE), surface temperature (LST) and shortwave albedo; Net solar radiation (**AVHRR**, MODIS).

Findings:

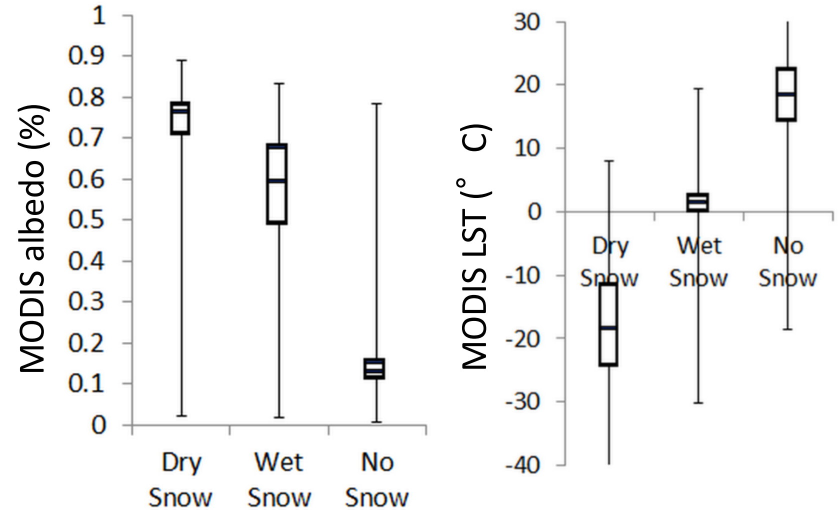
Onset of spring wet snow conditions coincides with ~19% albedo decline, extending over a 7-21 week snowpack depletion period;

Lower snow albedo enhances surface net radiation by ~82% (9-10 MJ m^{-2} d^{-1}) relative to dry snow conditions, reinforcing snowmelt and surface warming.

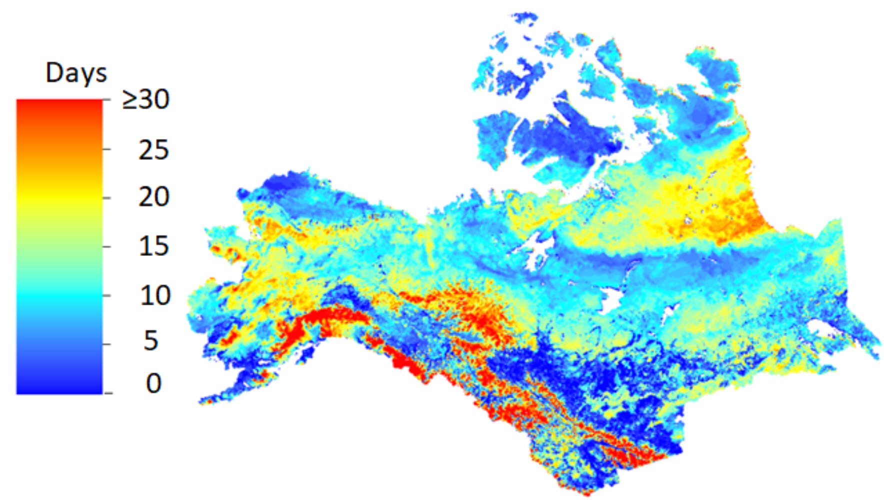
Significance:

Better understanding and monitoring of snow albedo feedbacks driving Arctic amplification of global warming.

MODIS LST and albedo variations during Arctic spring snowmelt transition



Spring wet snow period derived from AMSR FT and MODIS SCE records:

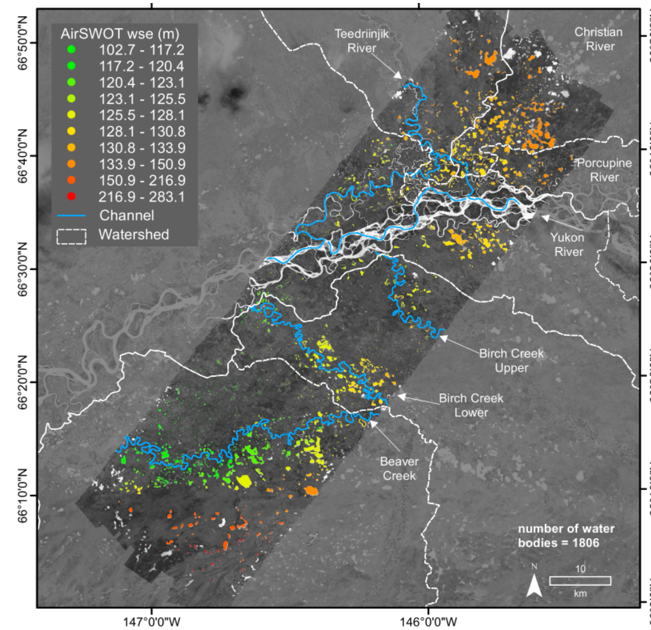


Looking ahead: Potential Phase II WG Focus Areas

ARCTIC BOREAL VULNERABILITY EXPERIMENT

- Protocols for spatial/temporal extrapolation & upscaling of hydrologic variables (e.g. surface water, PF & active layer properties);
- Enhanced algorithms & products from integrated observations;
- Knowledge gaps & new opportunities (e.g. SnowEx, Arctic-COLORS, NISAR, SWOT);
- Cross-cutting WG synthesis activities:
  - ✓ Cryosphere change impacts on ecosystems & society
  - ✓ Linking GHG fluxes & lateral materials transport with PF active layer changes & disturbance
  - ✓ Evidence & impacts of water cycle intensification
  - ✓ Impacts from recent climate anomalies (e.g. ENSO)
  - ✓ ABoVE relevance & implications to the broader pan-boreal/arctic

Yukon Flats water flow gradient (AirSWOT)



Pitcher et al., 2018. *WRR 55, 2.*