Hydrology & Permafrost WG

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Selected 2017-18 Project Activities and Accomplishments

Hydrology & Permafrost Working Group

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

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]
- USAir array 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]

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)

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 F7Q01P9. [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]
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)
Field Study Locations + Airborne
Linking Field Studies and Airborne Data Collections

**Field data collections:**

<table>
<thead>
<tr>
<th>ALD, ALT</th>
<th>Relative Humidity</th>
<th>Precipitation</th>
<th>Organic Layer Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Temperature</td>
<td>Stream Flow</td>
<td>Snow depth, density, SWE</td>
<td>NO₃ Isotopes</td>
</tr>
<tr>
<td>Soil Temperature</td>
<td>Stream/Lake Temp.</td>
<td>Surface Albedo</td>
<td>H₂O Isotopes</td>
</tr>
<tr>
<td>Soil Moisture</td>
<td>pH/Salinity</td>
<td>Solar Radiation</td>
<td>Ground Penetrating Radar</td>
</tr>
<tr>
<td>Soil Matric Potential</td>
<td>DOC/DIC</td>
<td>Terrain deformation</td>
<td>Nuclear Magnetic Resonance</td>
</tr>
<tr>
<td>Pore Water Elec. Cond.</td>
<td>Aquatic CH₄</td>
<td></td>
<td>Electrical Resistivity Tomography</td>
</tr>
<tr>
<td>Water Table Depth</td>
<td></td>
<td></td>
<td>Soil thermal conductivity</td>
</tr>
</tbody>
</table>

**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**
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.
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:
  - Prudhoe Meadow (70°13′47″ N, 148°25′19″ W) with 5 sensor nodes
  - Happy Valley (69°09′11″ N, 148°50′31″ W) with 8 sensor nodes

- 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:
  - Soil moisture
  - Freeze/thaw state

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

**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.

**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


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.

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


- 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.
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.
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
Recent Publications


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.


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


Thank You WG Members