Yukon River Watershed Northern Watershed Change

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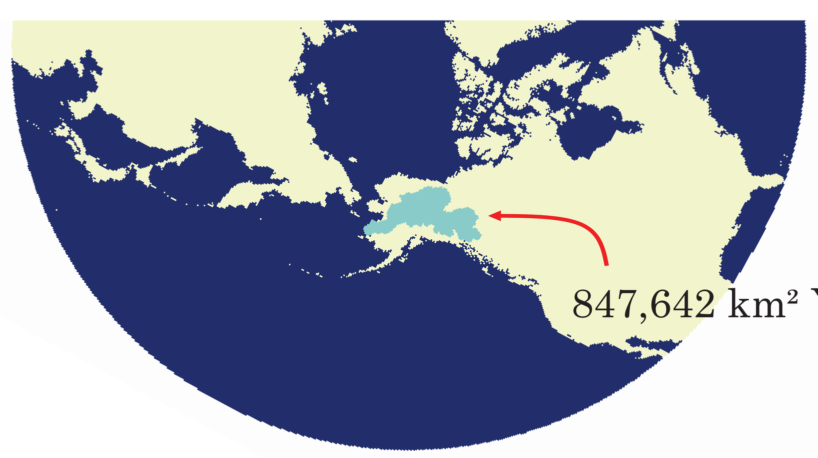
Abstract

Changes in the terrestrial hydrologic cycle in northern watersheds can be seen through permafrost warming. Furthermore, vegetation shifts occur with climate changes coupled with permafrost degradation. Permafrost warming is resultant from warming air temperatures and the accumulation of buffers between the atmosphere and the top of the permafrost: the active layer, snow, and vegetation. In this study, we apply the Temperature at the Top of the Permafrost model (TTOP) to examine the present and future thermal stability of permafrost and changing surface in 1 km² resolution in the 847,642 km² Yukon River watershed. In order to achieve this, we utilize output products from MicroMet and Snow Model. MicroMet is a quasi-physically based model for interpolating between air temperature measurement/ climate product point locations using known temperature-elevation, wind-topography, humidity-cloudiness, and radiation-cloud-topography relationships. SnowModel is a snow evolution model for generating, transporting, intercepting, sublimating, and melting snow. From these models, we generate 1 km² air temperature and snow depth rasters. The air temperature raster is then converted into freezing and thawing degree-day indices. We use the snow depth raster and a 1 km² vegetation product in conjunction with winter and summer n-factor literature values. We combined a 1 km² soils product indicating classification with a soil database indicating horizonation in order to calculate frozen and thawed thermal conductivity values. These values become the inputs into TTOP. In TTOP, **air temperature** is related to soil surface temperature, **buffered by vegetation and snow**, and the resultant heat is then propagated through **the horizons of the active layer**. Present compared with future top of the permafrost/ base of the active layer temperatures indicate areas of **vulnerable and degrading permafrost**. In future research, in order to study the **changing surface** we will focus on warming permafrost and groundwater discharge and recharge locations.

Location



Task

- **Calculate** top of the permafrost **temperature**
  - **in 1km² resolution**
  - for the 10-yr averaged periods: 1) **1997-2007** and 2) **2090-2100**

Future top of the permafrost temperatures are forced by ECHAM5-A1B GCM air temperature data.

Motivation

Climate warming, changes in vegetation, thicker snow cover, and lag time experienced from earlier climate warming have warmed continuous permafrost ~2-3 °C since about the 1980s in northern Alaska, 0.6-0.7 °C in northern Russia during 1970-1990, and discontinuous permafrost **1-1.5 °C** in the late 1980s-early 1990s in Interior Alaska (Hinzman et al, 2005; Romanovsky and Osterkamp, 1997; Osterkamp, 2003; Serreze et al, 2000; Romanovsky and Osterkamp, 1999). **The most thermally sensitive permafrost cases are warm and relic permafrost** (permafrost existing in areas where permafrost can not form under present climatic conditions) (Lunardini, 1996).

Tools for the Job

1. Air
2. Snow
3. Vegetation

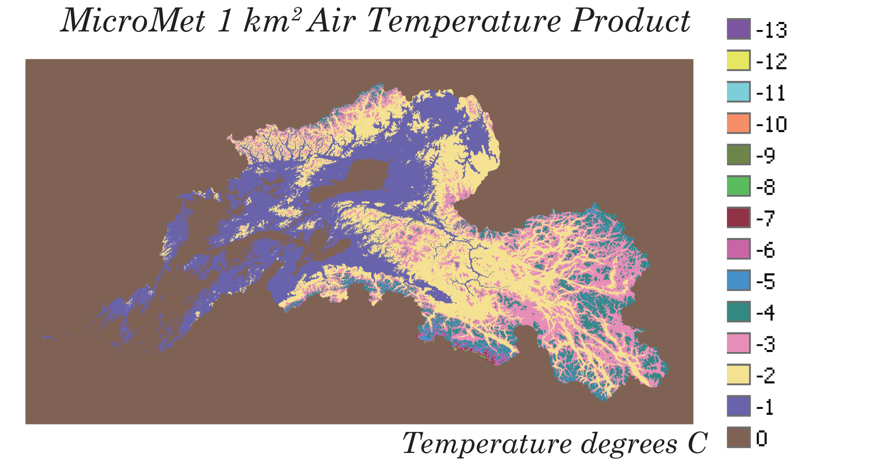
4. Active Layer

Permafrost

Photo Credits (Top to Bottom) ~ A. Hinzman, R. Bryan, A. Wagner

Fine Points

MicroMet 1 km² Air Temperature Product



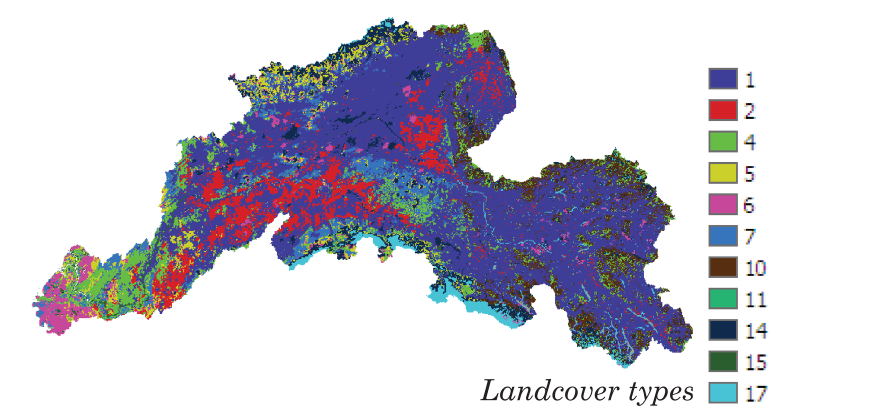
The air temperature raster is converted into freezing and thawing degree-day indices.

SnowModel 1 km² Snow Depth Product

The 1 km² snow depth raster (to come) is forced with MicroMet output and vegetation. SnowModel suggests and allows us to define vegetation snow holding depth/ capacities (veg_shc) (in meters). We have chosen Needleleaf Forest= 15.00, Broadleaf Forest= 12.00, Tall and Low Shrublands= 4.00, Dwarf Shrublands= 0.65, Dry Herbaceous= 0.15, Wet Herbaceous= 0.30, Lichens= 0.15, Closed Broadleaf and Closed Mixed Forest= 14.00, Barren= 0.01, Rivers, Streams and Lakes= 0.01, Ice and Snow=0.01.

We use the snow depth raster and a 1 km² vegetation product in conjunction with winter and summer n-factor literature values. Example winter n-factor: Wet Herbaceous & 8.4 cm of snow; n_F= 0.56 (Klene in Kuparuk). Example summer n-factor: Tall and Low Shrublands; n_T= 1.07 (Karunaratne & Burn in Mayo).

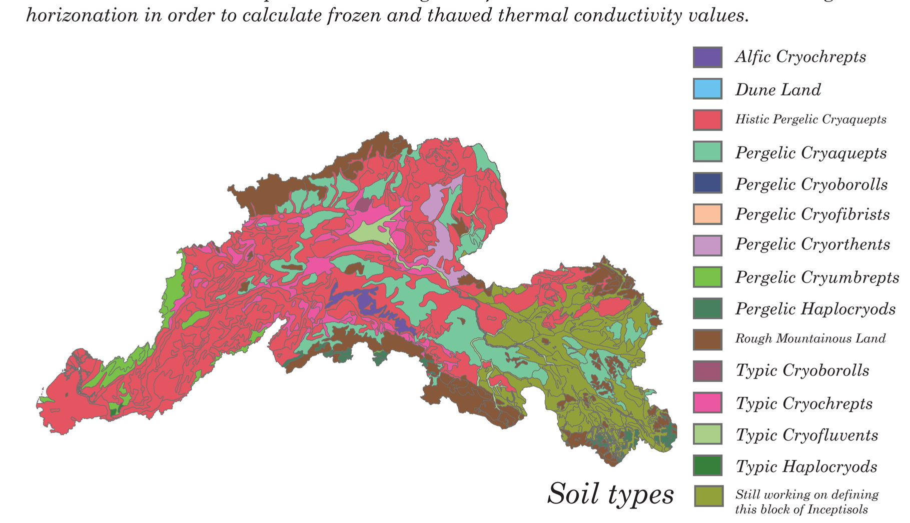
USGS 1 km² Landcover Product



1= Needleleaf Forest, 2= Broadleaf Forest, 4= Tall and Low Shrublands, 5= Dwarf Shrublands, 6= Dry Herbaceous, 7= Wet Herbaceous, 10= Lichens, 11=Closed Broadleaf and Closed Mixed Forest, 14= Barren, 15= Rivers, Streams and Lakes, 17= Ice and Snow

USGS Yukon Soil Polygons (to be converted into 1 km² raster)

We combined a 1 km² soils product indicating classification with a soil database indicating horizonation in order to calculate frozen and thawed thermal conductivity values.



Example- Histic Pergelic Cryaquepts, poorly aerated, poorly drained, permafrost affected soils in lowands (slightly to moderately decomposed organic matter that grades into silt loam). In the Alaska Soil Carbon Database many of the soils in this region had buried organic layers and/or were affected by fire.
Soil name, horizon names, depths, % OM/clay/sand/silt, drainage class, permafrost, and fire data will be considered when calculating kT & kF using the Côté & Konrad method.

The TTOP Equation for Temperatures at the Base of the Active layer/ Top of the Permafrost

The above values become the inputs into TTOP. In TTOP, air temperature is related to soil surface temperature, buffered by vegetation and snow, and the resultant heat is then propagated through the horizons of the active layer.

Soil thermal Conductivity (W/ m²K)

Landcover n-factor Ratio of I_s / I_a

Degree-day Index (°C*day)

$$T_T = \frac{n_T k_T I_{AT} - n_F k_F I_{AF}}{k_F P}, T_T < 0$$

Period (days)

$$T_T = \frac{n_T k_T I_{AT} - n_F k_F I_{AF}}{k_T P}, T_T > 0$$

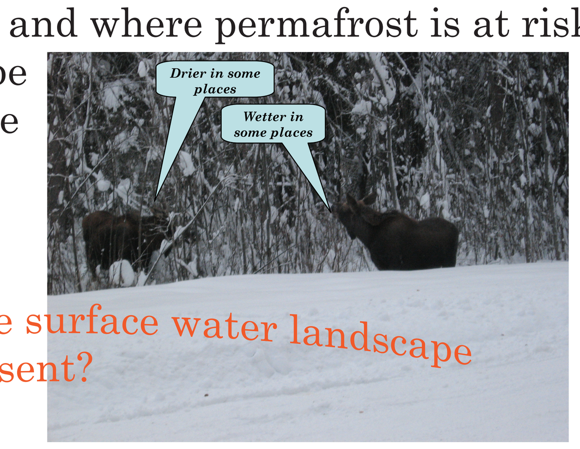
These temperature at the top of the permafrost results in 1 km² resolution in the Yukon River Watershed are calculated using present day (1997-2007) meteorological station forcing and the Max Planck GCM, ECHAM5- A1B future projection for the years 2090-2100. Comparison of results shows warming permafrost areas.

Expected Products

- Three 1 km² raster products:
  - **Present** (1997-2007) top of the permafrost temperatures
  - **Future** (2090-2100) top of the permafrost temperatures
  - Calculated, indexed temperature difference (**future-present**) showing a range of **stable to mild to severe risk permafrost**.

Discussion

Locations where groundwater is discharging or recharging and where permafrost is at risk for thawing are potential locations where the surface will be wetter or drier in the future. We have seen examples on the landscape where increased ponding or drying has occured due to permafrost degradation. Other intensifications/ reductions of the northern hydrologic cycle should also be considered to evaluate land surface change.



How will the future surface water landscape compare to the present?

~ R. Bryan

Changing Surface

~ T. Jorgenson

In the Tanana Flats, near Fairbanks, Alaska, birch and spruce forests are being converted into minerotrophic floating mat fens with open water corridors. Permafrost was estimated to underlie 84% of the 260,000 ha area a century or more ago. The Tanana Flats, now described as **groundwater-discharge** wetlands, are fed by **springs that upwell through taliks or unfrozen areas in the permafrost.** This is evidenced by cold (less than 5 °C) water (mud volcanoes) and winter icing (aufeis). Similar areas have been observed by Kane and Slaughter (1973) (Isabella Creek Lake near Fairbanks) and Van Everdingen (1988) (perennial (present all seasons of the year) springs in peatlands on alluvial and glacio-fluvial fans near the Alaska-Yukon border) (Racine and Walters, 1994; Hinzman, 2005).
Although, Racine and Walters (1994) observe that most wetlands documented in the discontinuous permafrost regions of Alaska are ombrotrophic peatlands (bogs) whose water source is solely precipitation.

References

Côté & Konrad, 2005. A Generalized Thermal Conductivity for Soils and Construction Materials, Canadian Geotechnical Journal, 42, 443–458.
Hinzman et al., 2005. Evidence and Implications of Recent Climate Change in Northern Alaska and other Arctic Regions, Climatic Change, 72, 251-298.
Johnson, 2009. An Alaska Soil Carbon Database, EOS, Transactions, American Geophysical Union, 90(21), 184.
Kane & Slaughter, 1973. Recharge of a Central Alaska Lake by Subpermafrost Groundwater, North American Contribution to the Second International Conference on Permafrost, 458-462.
Karunaratne & Burn, 2004. Relations between Air and Surface Temperatures in Discontinuous Permafrost Terrain near Mayo, Yukon Territory, Canadian Journal of Earth Sciences, 41, 1437-1451.
Klene et al., 2008. Interannual Variability of Winter N-Factors in the Kuparuk River Basin, Alaska, Proceedings of the Ninth International Conference on Permafrost, 953-958.
Liston & Elder, 2006a. A Meteorological Distribution System for High-Resolution Terrestrial Modeling (MicroMet), Journal of Hydrometeorology, 7(2), 217-234.
Liston & Elder, 2006b. A Distributed Snow-Evolution Modeling System (SnowModel), Journal of Hydrometeorology, 7(6), 1259-1276
Lunardini, 1996. Climatic Warming and the Degradation of Warm Permafrost, Permafrost and Periglacial Processes, 7, 311-320.
Osterkamp, 2003. A Thermal History of Permafrost in Alaska, Proceedings of the Eighth International Conference on Permafrost, 863-868.
Racine & Walters, 1994. Groundwater-Discharge Fens in the Tanana Lowlands, Interior Alaska, U.S.A., Arctic andAlpine Research, 26(4), 418-426.
Romanovsky & Osterkamp, 1997. Thawing Active Layer on the Coastal Plain of the Alaskan Arctic, Permafrost and Periglacial Processes, 8, 1-22.
Romanovsky & Osterkamp, 1999. Evidence for Warming and Thawing of Discontinuous Permafrost in Alaska, Permafrost and Periglacial Processes, 10, 17-37.
Serreze et al., 2000. Observational Evidence of Recent Change in the Northern High-Latitude Environment, Climatic Change, 46, 159-207.
Smith & Riseborough, 1996. Permafrost Monitoring and Detection of Climate Change, Permafrost and PeriglacialProcesses, 7(4), 301-309.
Van Everdingen, 1988. Perennial Discharge of Subpermafrost Groundwater in Two Small Drainage Basins, Yukon, Canada, Proceedings of the Fifth International Conference on Permafrost, 639-643.