Simulating Permafrost Hydrology for Cold Regions Mountains

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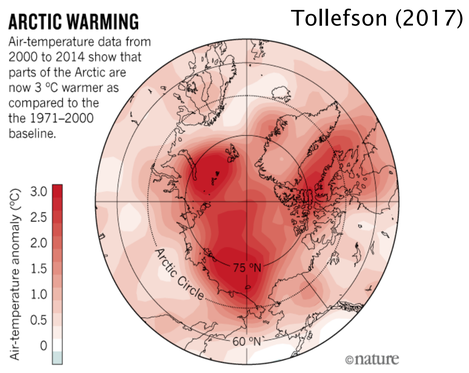
BACKGROUND

Rapid warming is thawing permafrost and driving vegetation expansion in the Arctic.

Robust and reliable hydrological models are required for prediction of hydrological responses of **ungauged basins** that are prevalent in the Arctic and for **all basins under future conditions** due to climate change.

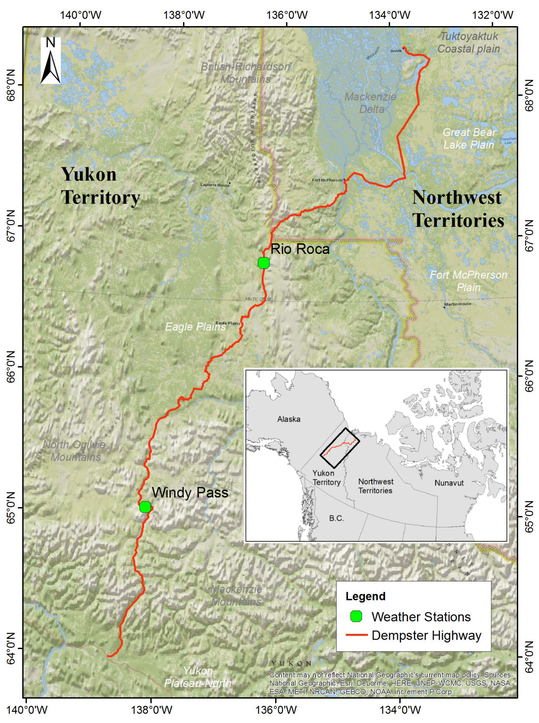
Thawing and freezing of ground are either unrepresented or calculated by simple and unreliable degree-day methods in hydrological models.

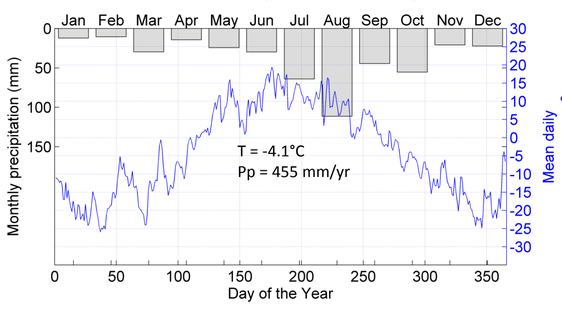


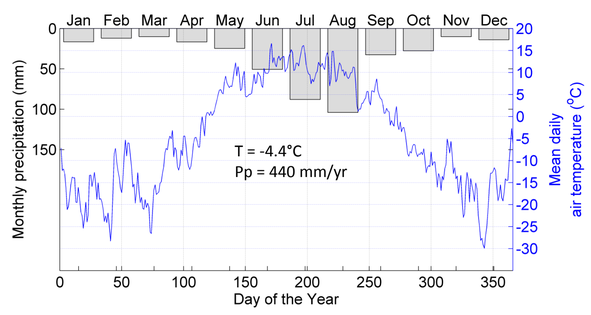
Tollefson (2017)

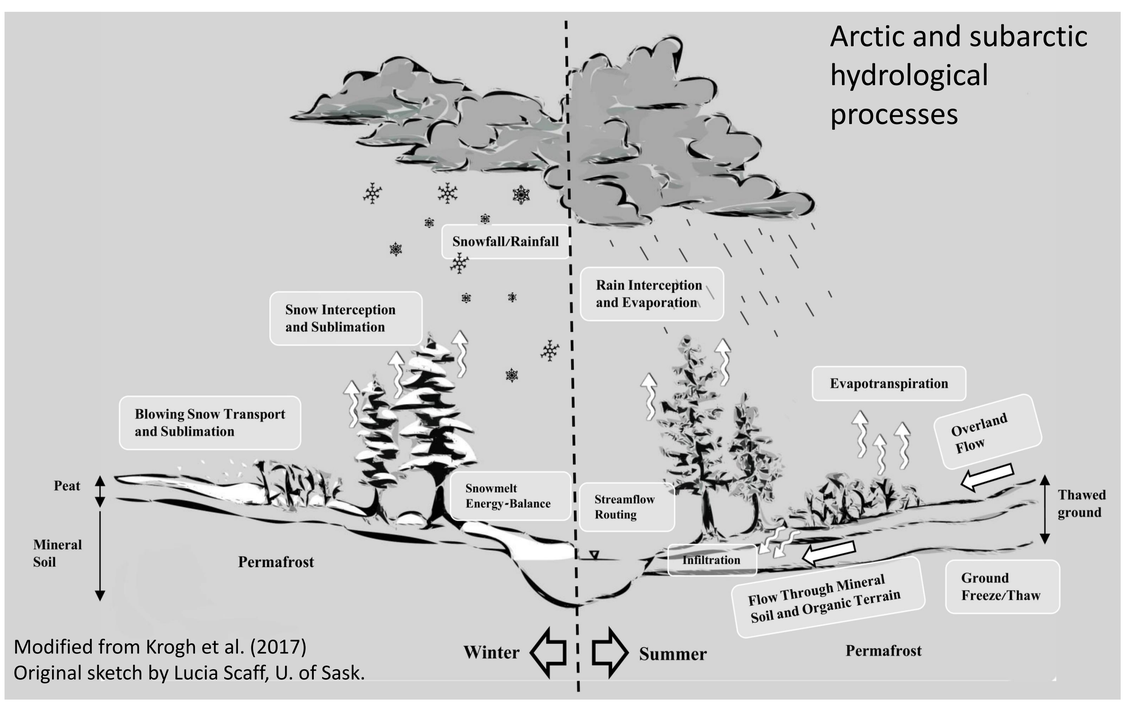
This study demonstrates the successful coupling of a robust, uncalibrated **ground freeze/thaw algorithm into the Cold Regions Hydrological Modelling platform (CRHM)** at two, cold, remote mountainous sites in northern Yukon, Canada.

STUDY SITE AND METHODS







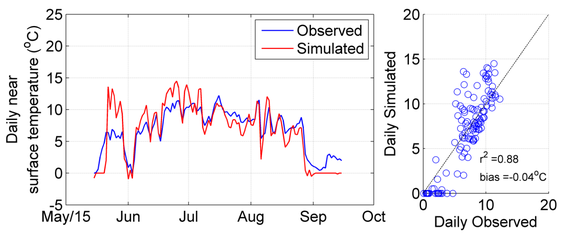


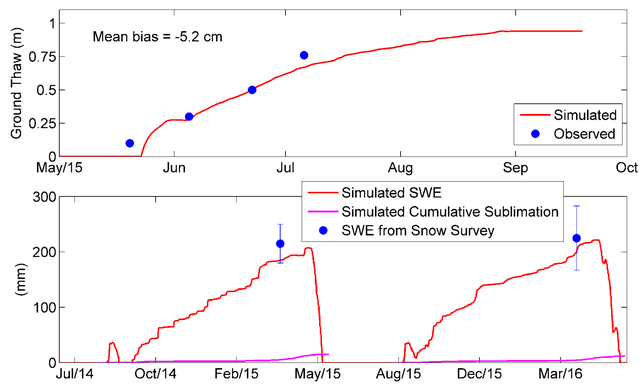
Modified from Krogh et al. (2017)
Original sketch by Lucia Scaff, U. of Sask.

- Arctic Hydrology Model (AHM; Krogh et al., 2017) developed in CRHM includes blowing snow, snowmelt, evapotranspiration, ground freeze/thaw.
- Physically based representation for most hydrological processes.
- Hourly inputs: precipitation, air temperature, wind speed, relative humidity and short- and long-wave irradiance.
- Single control volume (hydrological response unit) point modelling does not include streamflow routing.
- Ground surface temperature estimating using the Radiation-Convection-Conduction approach (Williams et al., 2015)
- Ground freeze and thaw using the XG-algorithm (Changwei and Guo, 2013)

RESULTS

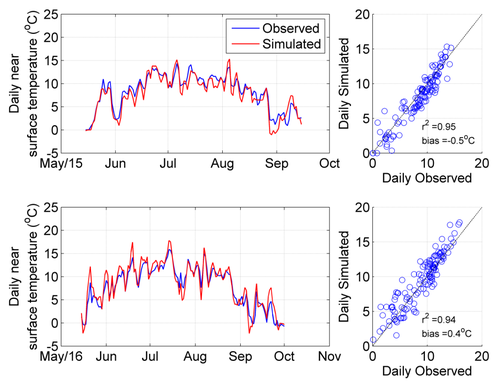
Rio Roca

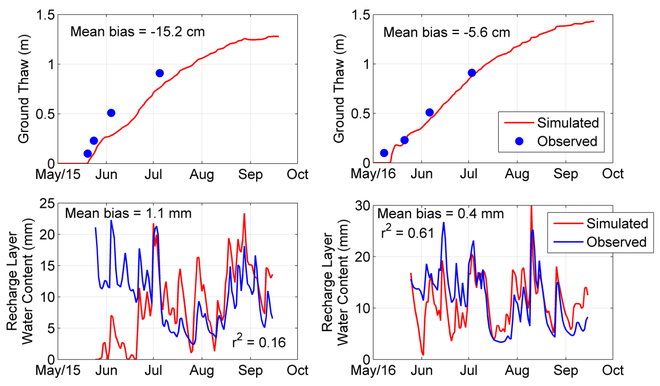


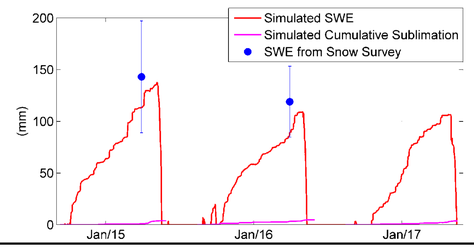


- Ground surface temperature: bias = 0.04 °C and r^2 = 0.88
- Ground thaw: bias = -5.2 cm
- SWE: bias = -27 mm

Windy Pass





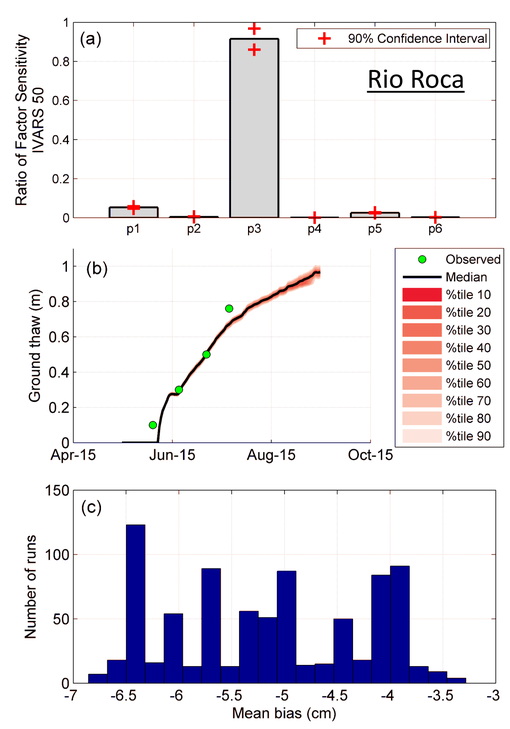


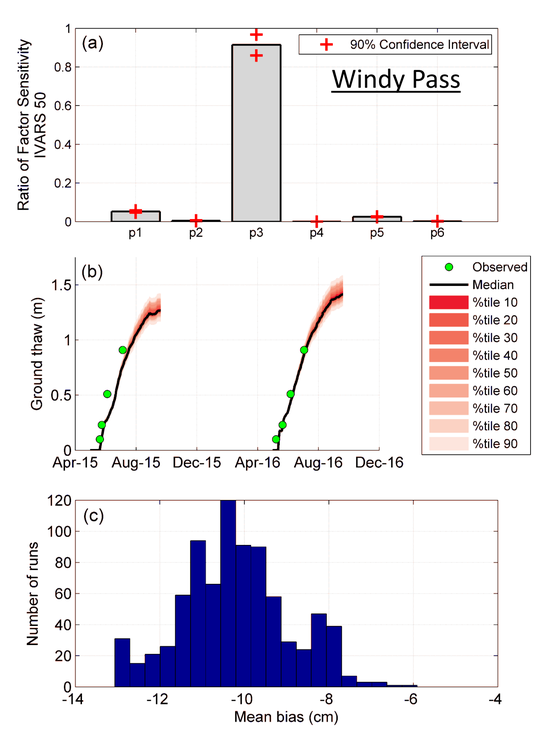
- Ground surface temperature: bias = 0.02 °C and r^2 = 0.94
- Ground thaw: bias = -11 cm
- Water content: bias = 0.8 mm and r^2 = 0.4
- SWE: bias = -30 mm

Ground thaw sensitivity of uncertain parameters

p1: Organic soil porosity ()
p2: Mineral soil porosity ()
p3: Organic soil dry thermal conductivity (W/m/K)
p4: Mineral soil dry thermal conductivity (W/m/K)
p5: Organic soil saturated thermal conductivity (W/m/K)
p6: Mineral soil saturated thermal conductivity (W/m/K)

Parameter (Woo, 2012)	Organic soil layer	Mineral soil layer
Porosity	0.7 – 0.9	0.3 – 0.5
Soil dry thermal conductivity	0.06 – 0.15	0.2 – 0.3
Soil saturated unfrozen thermal conductivity	0.25 – 0.75	2.0 – 3.0





CONCLUSIONS

- The model **underestimated snow accumulation** at both sites, likely due to uncertainty in the snowfall wind-undercatch equation used or errors in parameterizing the blowing snow transport calculation, or both.
- The model **successfully represented the ground surface temperature.** The mean biases at Windy Pass and Rio Roca were 0.02 and 0.04 °C, and the correlation coefficients were 0.94 and 0.88, respectively.
- The model **adequately estimated the dynamics of soil liquid content** in summer at Windy Pass.
- The model **slightly underestimated ground thaw** at both sites, with mean biases of 11 and 5 cm at Windy Pass and Rio Roca, respectively. This could be due to errors in simulating the **initiation of ground thaw**, **parameter selection** or **modelling assumptions/implementation**.
- Sensitivity analysis of parameter selection impact on thaw demonstrated the **robust representation of ground thaw** using standard physically identifiable parameters from the literature, encouraging **model transferability** to other regions and model **implementation under future climate conditions**.

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