Hydrological Processes and Parameterization: Infiltration and Runoff

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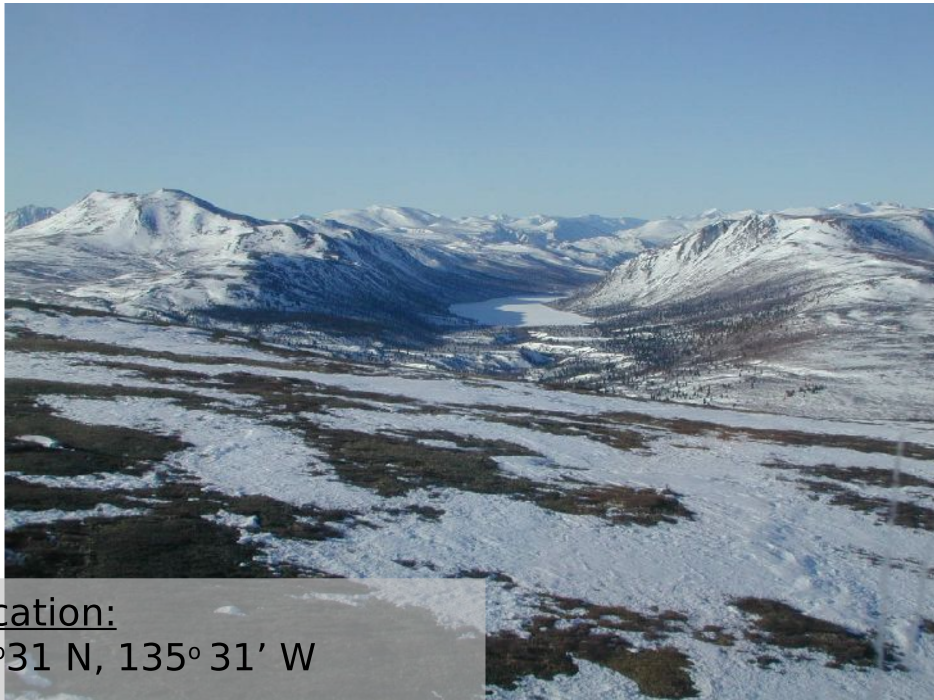
Overview

- Runoff
  - Ecosystem Controls
  - Transit Time Distributions
  - Channel Snow/Ice
- Infiltration
  - Parameterization/modelling activities
- HRU Classification

The Wolf Creek Research Basin



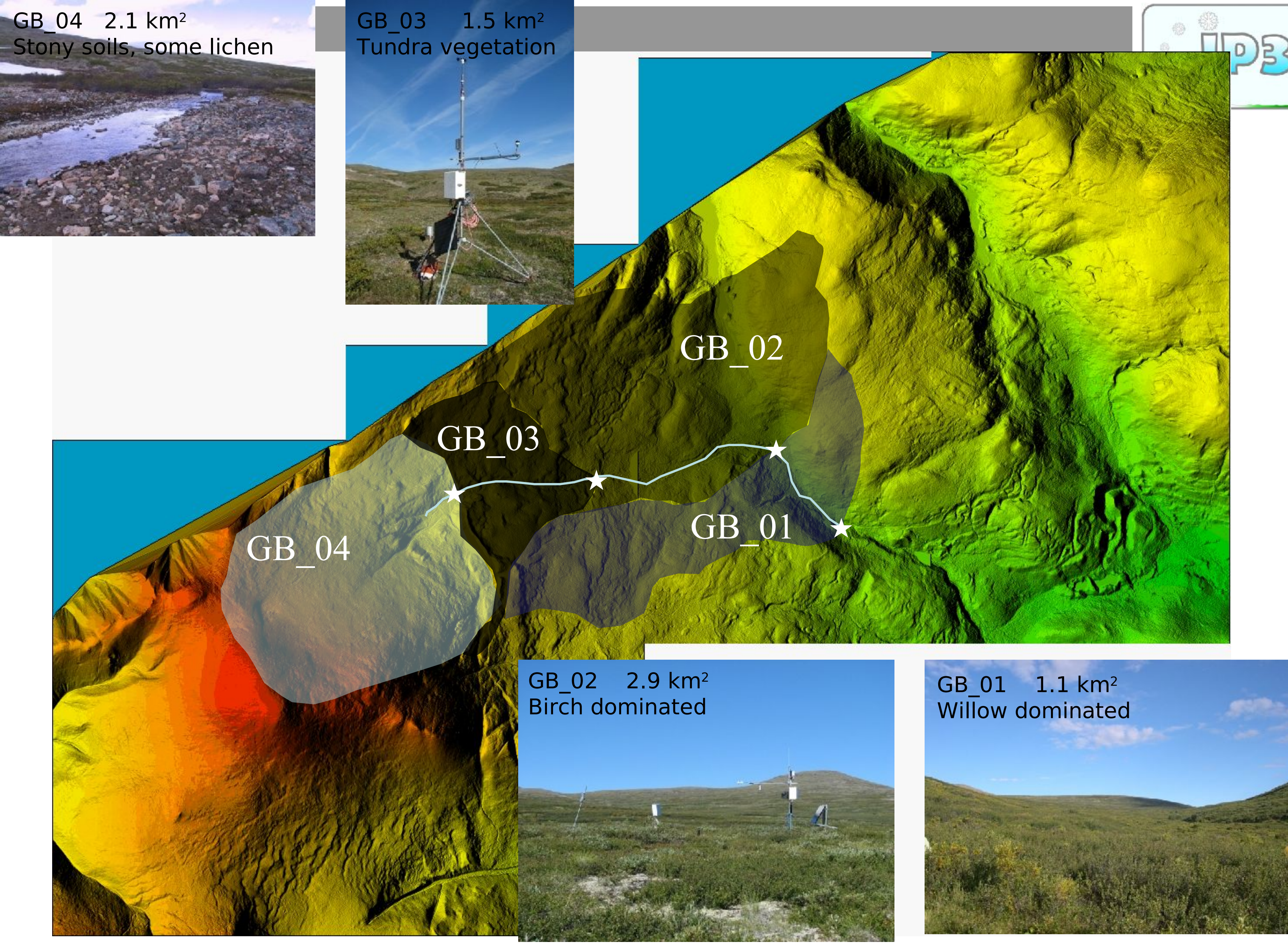
<u>Location:</u>
60^{o}31 N, 135^{o} 31’ W

<u>Area:</u>
Approx. 200 km^{2}

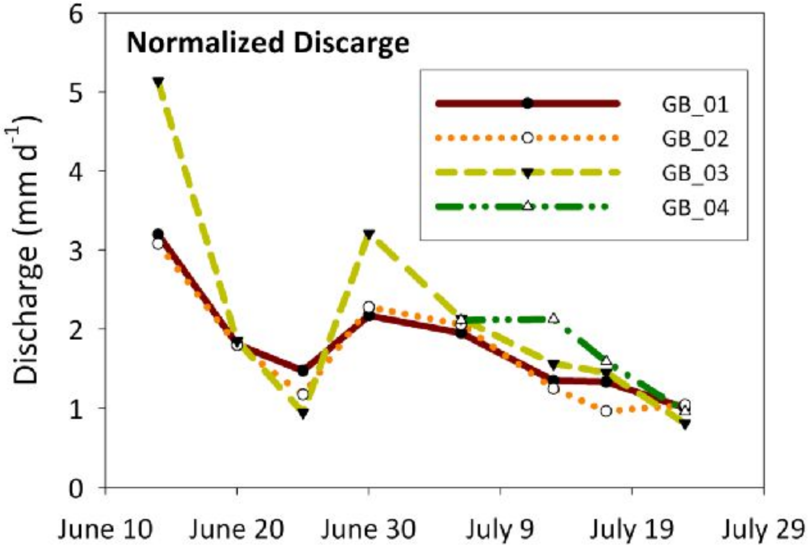
<u>Elevation Range:</u>
800 to 2250 m a.s.l.
(3 ecozones)

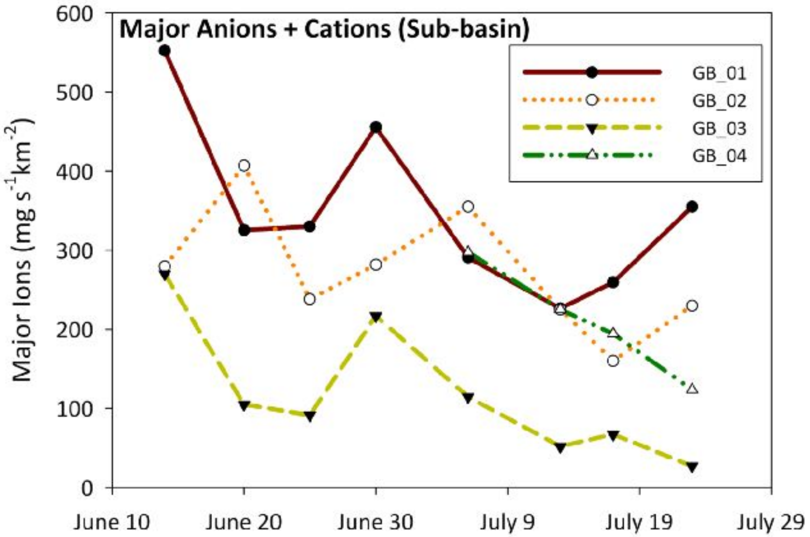
<u>Mean Annual Precipitation:</u>
300 to 400 mm (40% snow)

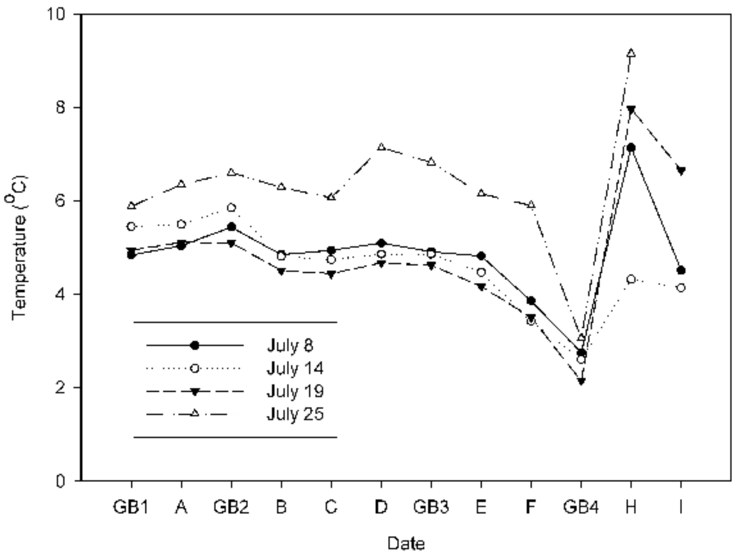
<u>Mean Annual Temperature:</u>
-3 ^{o}C

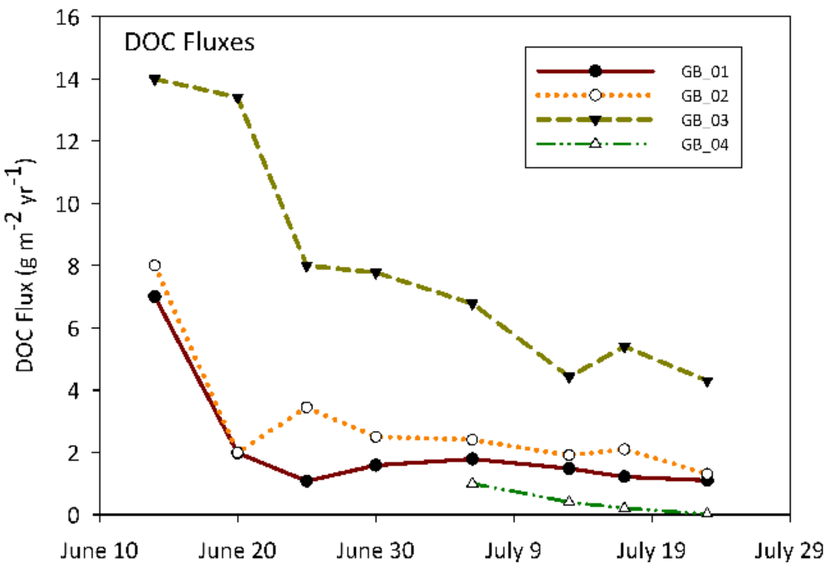

GB_04 2.1 km²
Stony soils, some lichen
GB_03 1.5 km²
Tundra vegetation
GB_02
GB_03
GB_04
GB_01
GB_02 2.9 km²
Birch dominated
GB_01 1.1 km²
Willow dominated

Data – Simple Hydrochemistry





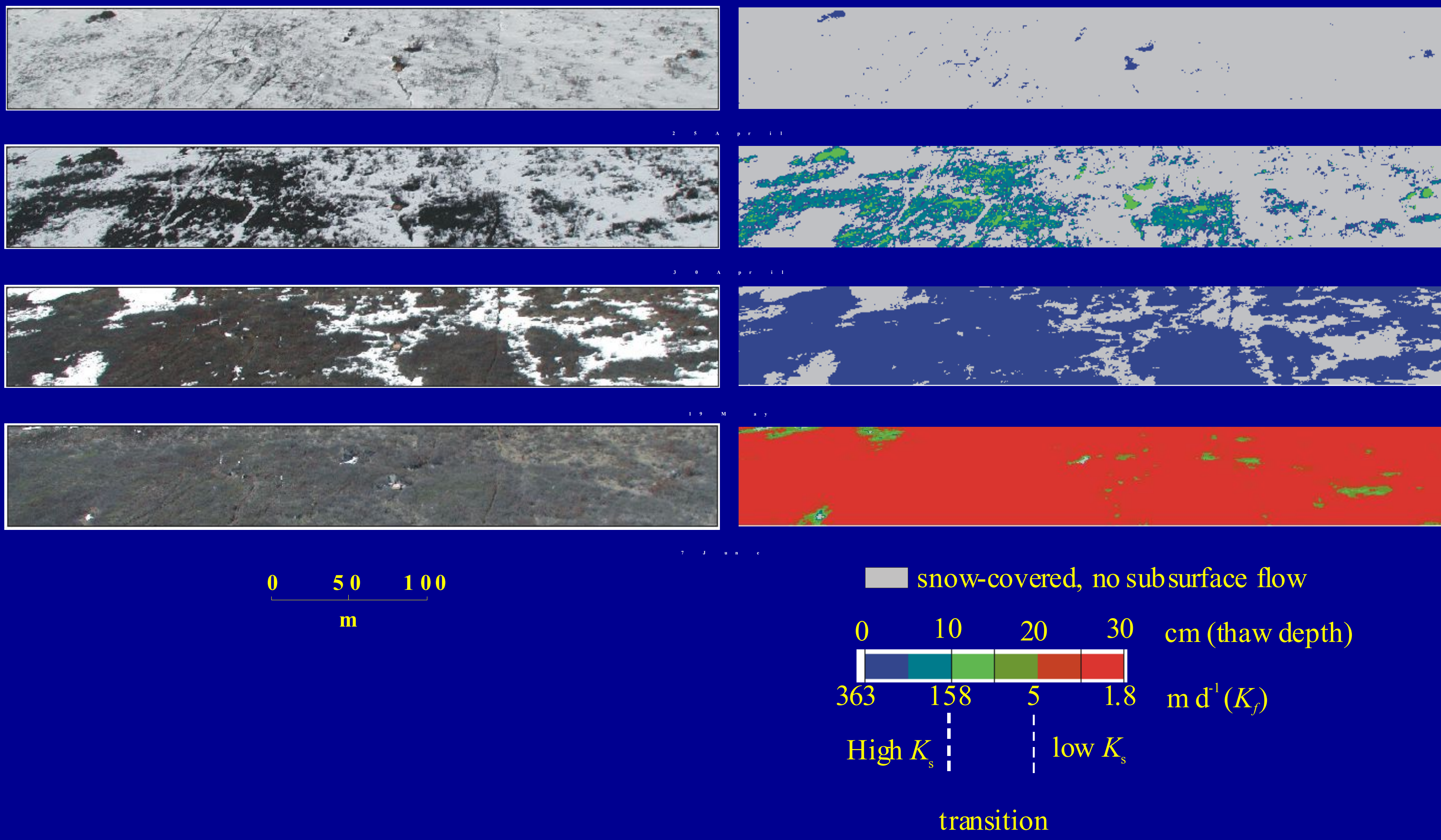




Last Year's summary

- All HRUs contribute water to the stream in approximately equal volume.
- Much greater deep groundwater flow than previously reported or anticipated.
- Work ongoing to assess seasonal dominance of HRUs (logistics).
- Role of channel ice/snow to be investigated

Hillslope Runoff – Energy Dynamics



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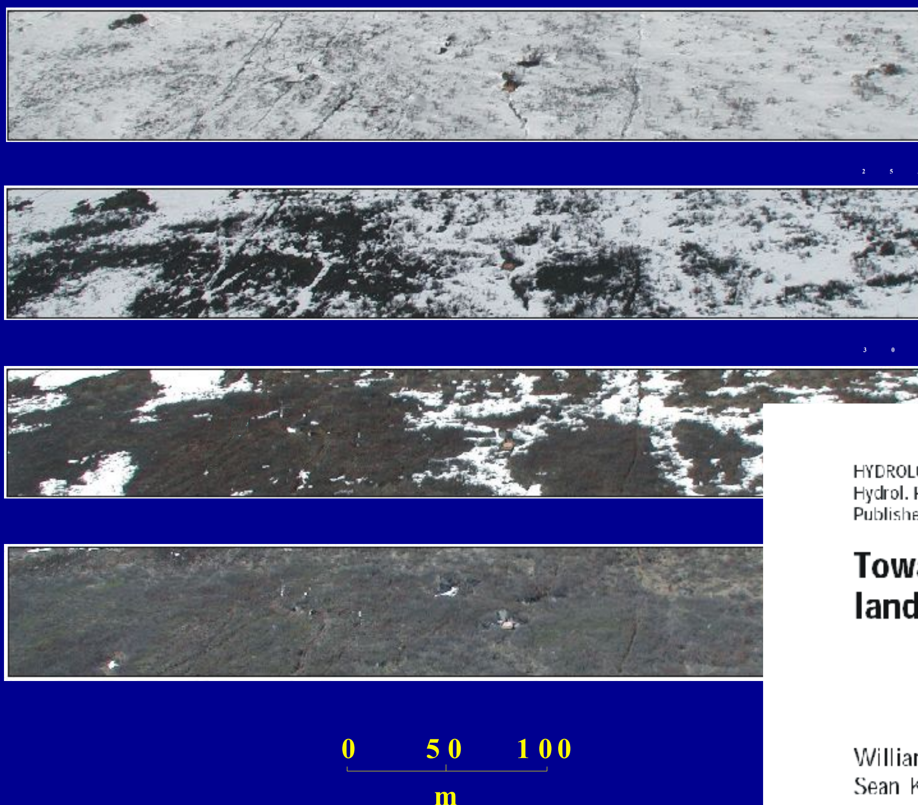

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Towards an energy-based runoff generation theory for tundra landscapes

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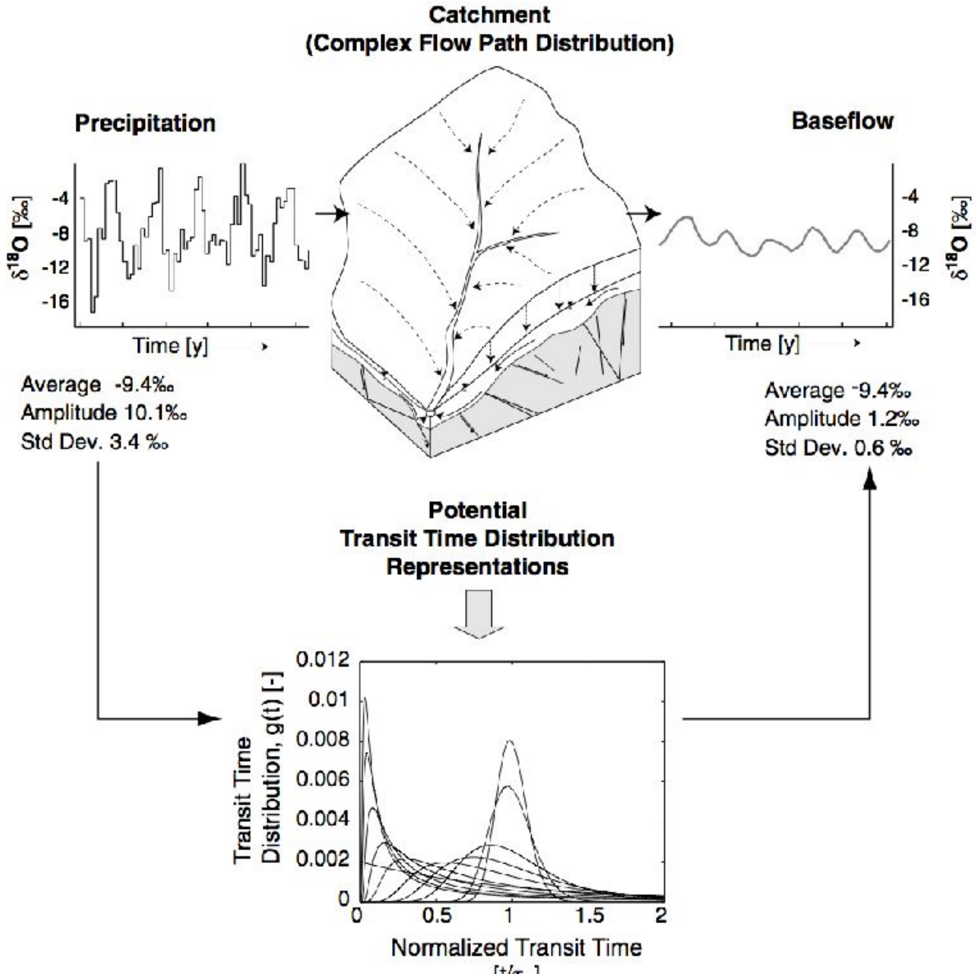
Abstract

Runoff hydrology has a large historical context concerned with the mechanisms and pathways of how water is transferred to the stream network. Despite this, there has been relatively little application of runoff generation theory to cold regions, particularly the expansive treeless environments where tundra vegetation, permafrost, and organic soils predominate. Here, the hydrological cycle is heavily influenced by 1) snow storage and release, 2) permafrost and frozen ground that restricts drainage, and 3) the water holding capacity of organic soils. While previous research has adapted temperate runoff generation concepts such as variable source area, transmissivity feedback, and fill-and-spill, there has been no runoff generation concept developed explicitly for tundra environments. Here, we propose an energy-based framework for delineating runoff contributing areas for tundra environments. Aerodynamic energy and roughness height control the end-of-winter snow water equivalent, which varies orders of magnitude across the landscape. Radiant energy in turn controls snowmelt and ground thaw rates. The combined spatial pattern of aerodynamic and radiant energy control flow pathways and the runoff contributing areas of the catchment, which are persistent

Transit/Residence Time Distribution

Residence Time: time (since entry) that a water molecule has spent inside a flow system



McGuire et al. 2005

Residence Time Assumptions

$$\delta_{out}(t) = \int_0^{\infty} g(\tau)\delta_{in}(t-\tau)d\tau$$

Convolution integral

$$\delta_{out}(t) = \frac{\int_0^{\infty} g(\tau)w(t-\tau)\delta_{in}(t-\tau)d\tau}{\int_0^{\infty} g(\tau)w(t-\tau)d\tau}$$

Weighed recharge (a must!)

Model	Residence Time Distribution g(τ)	Parameters	Mean Residence Time[a]
Exponential[b]	${\tau_m}^{-1}\exp(-\tau/\tau_m)$	τ_m	τ_m
Exponential-piston flow[b]	$\left(\frac{\tau_m}{\eta}\right)^{-1}\exp\left(-\frac{\eta\tau}{\tau_m}+\eta-1\right)$ for $\tau \geq \tau_m\,(1-\eta^{-1})$	τ_m, η	τ_m
	0 for $\tau < \tau_m\,(1-\eta^{-1})$		
Dispersion[b]	$\left(\frac{4\pi D_p\tau}{\tau_m}\right)^{-1/2}\tau^{-1}\times\exp\left[-\left(1-\frac{\tau}{\tau_m}\right)^2\left(\frac{\tau_m}{4D_p\tau}\right)\right]$	τ_m, D_p[c]	τ_m
Gamma[d]	$\frac{\tau^{\alpha-1}}{\beta^{\alpha}\Gamma(\alpha)}\exp(-\tau/\beta)$	α, β	$\alpha\beta$
Two parallel linear reservoirs[e]	$\frac{\phi}{\tau_f}\exp\left(-\frac{\tau}{\tau_f}\right)+\frac{1-\phi}{\tau_s}\exp\left(-\frac{\tau}{\tau_s}\right)$	τ_f, τ_s, ϕ	–
Power law[f]	$\frac{\tau^k}{\Gamma(1-k)}$	k	–

McGuire et al. 2005

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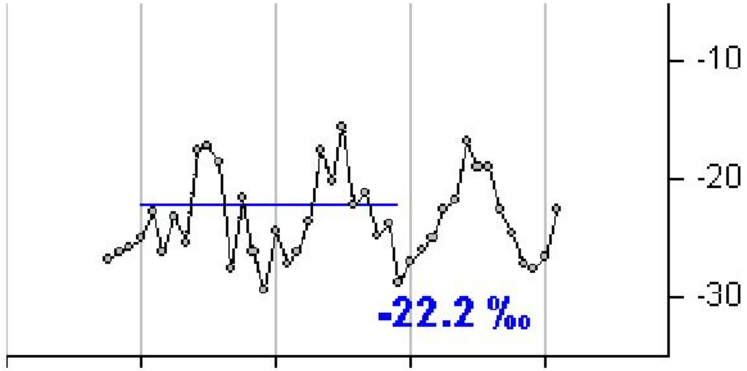
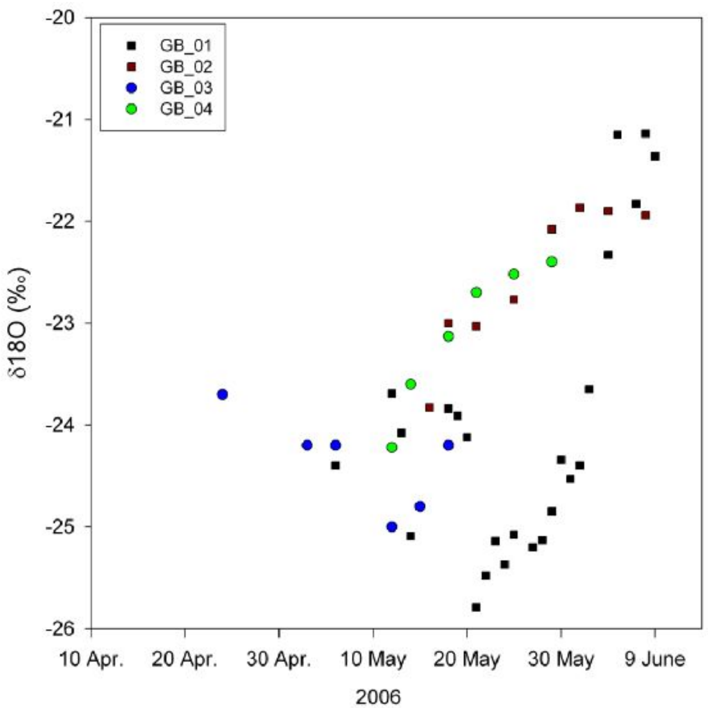
Power law[f]	$\frac{\tau^k}{\Gamma(1-k)}$	k	–

Inputs – tough with lots of assumptions





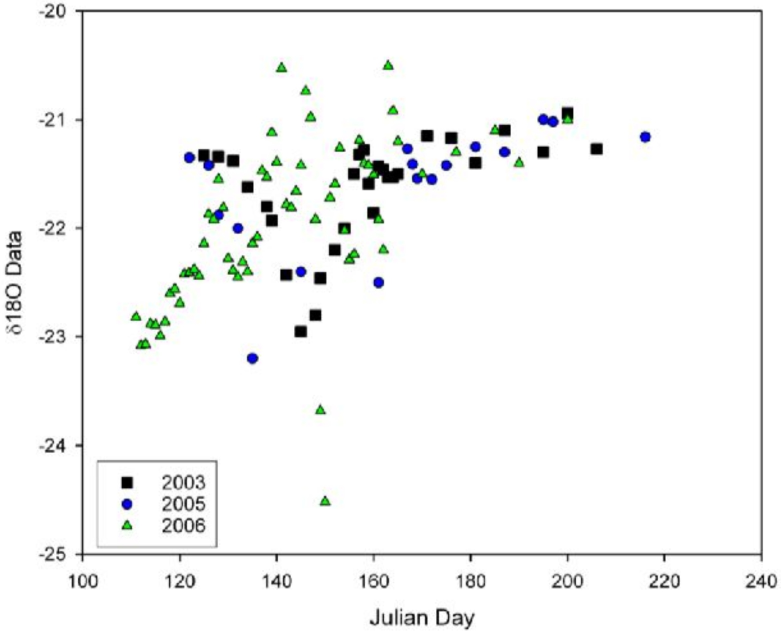
- Use Whitehorse δ ^{18}O curve for post-melt period
- No input after October to melt
- Observed meltwater δ ^{18}O and volume
- “flow weighted”

Outputs - messy!

- Lag times need to be adjusted if considering rainfall versus snowmelt (may want to consider only melt signatures or rain/melt separately)

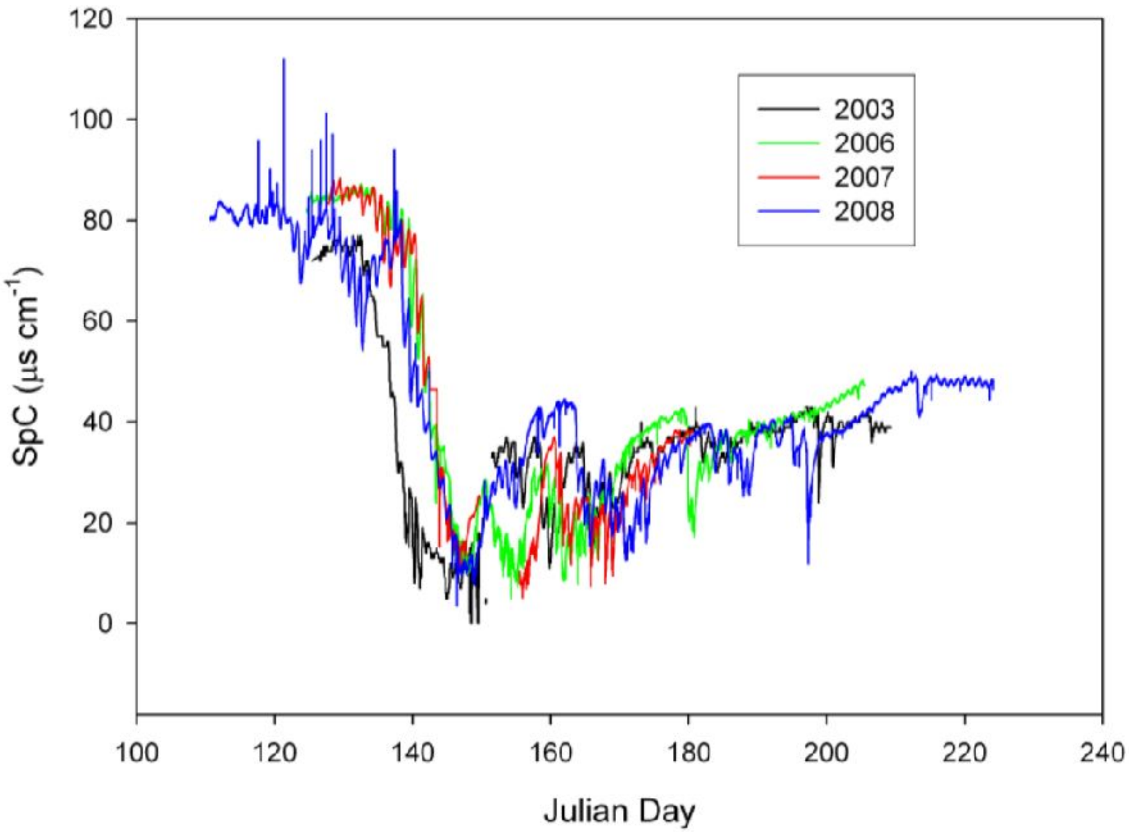
- Parameter converge does occur (GLUE), yet N-S goodness of fit “mediocre” ~0.6 to 0.7

- Mean Residence Times fast compared with temperate catchments (<2 months) – the melt signature strongly influences the result.



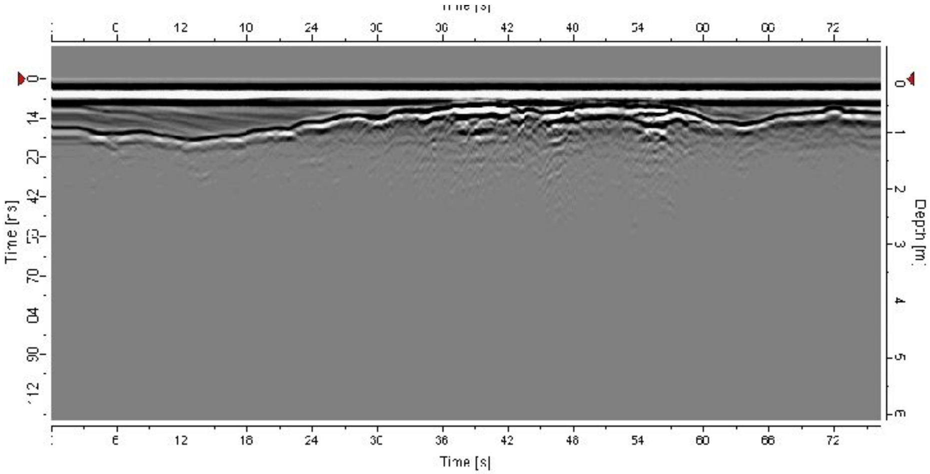
Utility of SpC and other high-frequency data

- Development of a SpC budget as a way forward (stronger and cleaner signal)
- SpC, while not conservative, has a strongly weighted snowmelt signature
- RTD can be further assessed using runoff models at event-scale and tracer data
- Off to Aberdeen in February for advice.



The Role of Channel Ice and Snow

- What is the role of icing and channel ice?


Time [s]




Simulation of infiltration into organic-covered permafrost soils

- Evaluate several commonly used infiltration algorithms using filed measurements at several organic covered permafrost sites

- Identify the key parameters/processes in infiltration simulations at organic covered permafrost soil.

- Provide guidelines for the implementation of appropriate infiltration algorithms/parameters in hydrological and land surface models

Tested ( ) Infiltration Algorithms

Empirical & analytical

- Gray et al. (1985) SWE based empirical relation

$$INF = ٥(١ - S_I)SWE^{٠.٥٨٤}$$

- Zhao and Gray (1999) parametric relation

$$INF = CS_{٠}^{٢.٩٢}(١ - S_I)^{١.٦٤}\left(\frac{٢٧٣.١٥ - T_I}{٢٧٣.١٥}\right)^{-٠.٤٥} t^{٠.٤٤}$$

- Green_Ampt (1911) and various modifications

$$INF_r = K_s\left[1 + \frac{(\theta_0 - \theta_i)\psi_w}{F}\right]$$

Numerical

- Numerical solvers of Richard’s equation or coupled heat and water transfer equations with water flux as surface boundary
- e.g. HYDRUS1D (Šimůnek et al., 2005), HAWTS (Zhao et al., 1997) etc.

Mixed (analytical+ numerical)

- ARHYTHM Instantaneous Infiltration model (Zhang et al., 2000) (TopoFlow)
- SHAW infiltration - modified Green_Ampt Approach for Muti-layered soil (Flerchinger and Saxton, 1989)

Determination of input/output variables from field observations

Ground surface temperature (T_0)

-- Observed surface or near surface temperature

Snow-melt (M_{sn}) and rainfall (R)

--Scotty Creek: daily SWE observation and tipping-bucket rain gauge

--Wolf Creek: daily snow depth with in situ snow density samples and tipping-bucket rain gauge

Evapotranspiration (ET) --Site calibrated Priestley- Taylor (1972)

Infiltration ($\Delta SW_{liq}/\Delta SW_{total}$: liquid / total soil water changes; SW_{melt} : soil ice melt)

--Scotty Creek: $INF_{est} = \Delta SW_{liq} - SW_{melt} + ET$ *(if positive)*

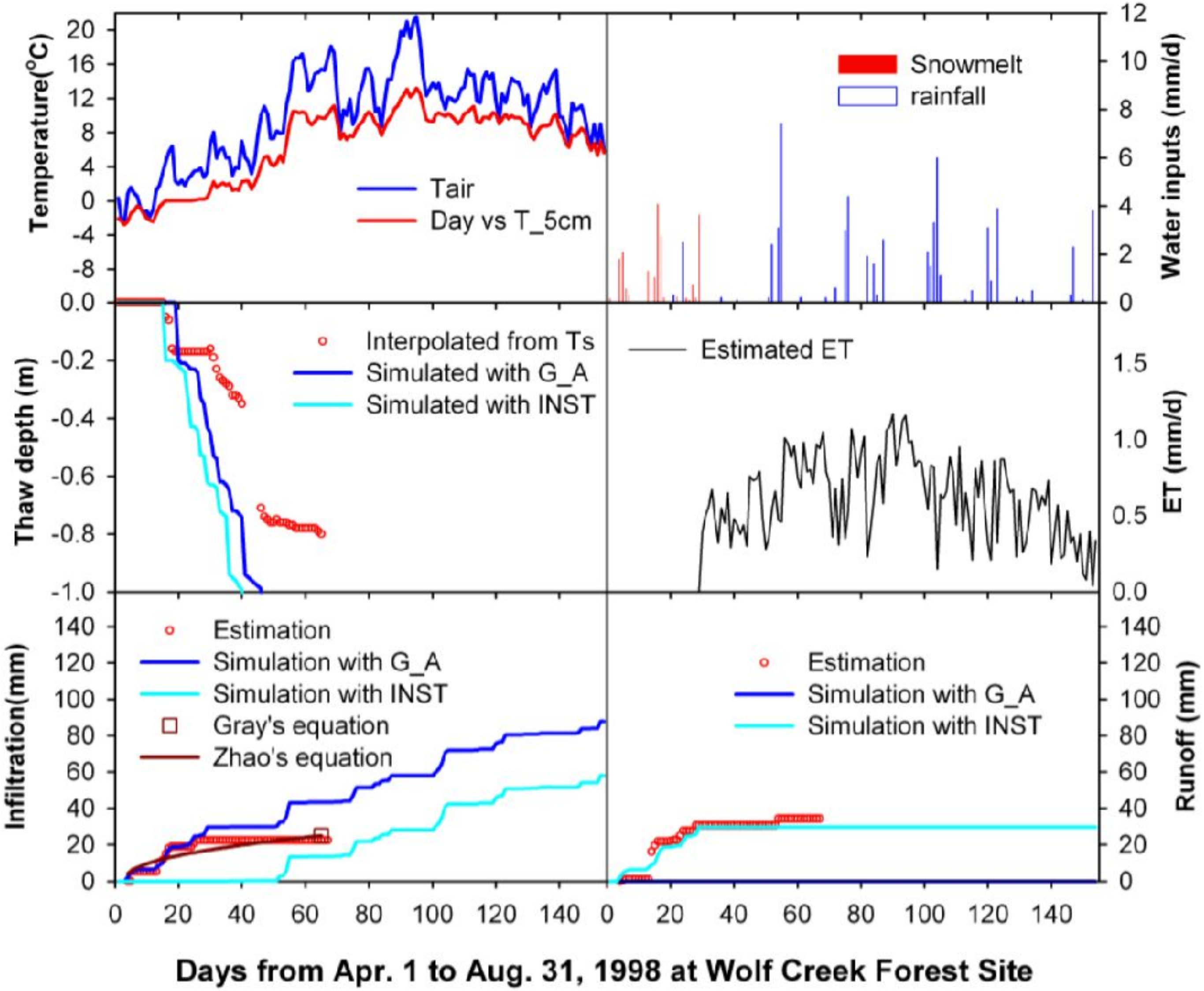
--Wolf Creek: $INF_{est} = \Delta SW_{total} + ET$ *(if positive)*

Runoff

--Scotty Creek: $Runoff_{est} = R + M_{sn} + SW_{melt} - \Delta SW_{liq} - ET$ *(if positive)*

--Wolf Creek: $Runoff_{est} = R + M_{sn} - \Delta SW_{total} - ET$ *(if positive)*

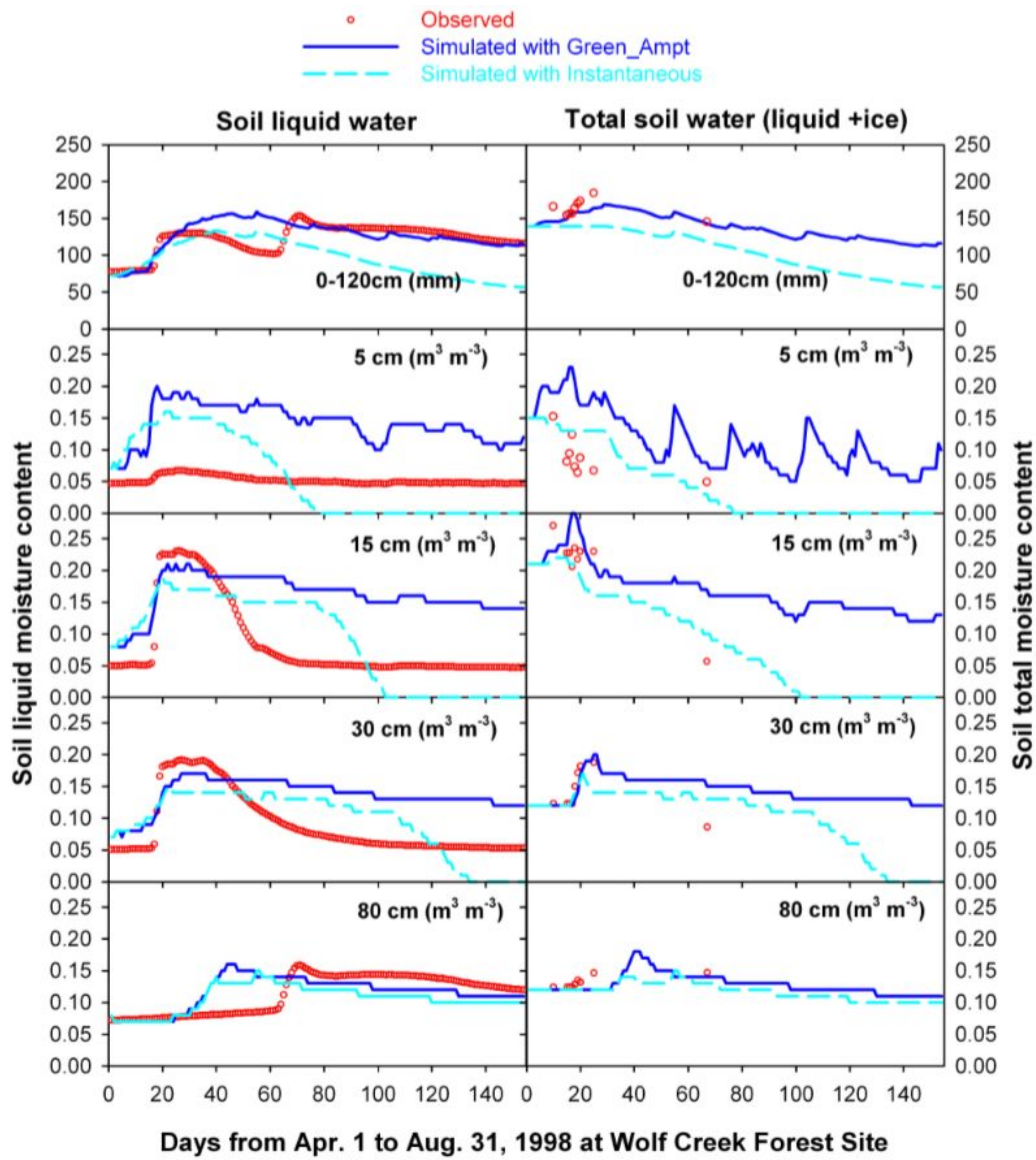
Wolf Creek Simulations: control variables, thaw depth, infiltration and runoff



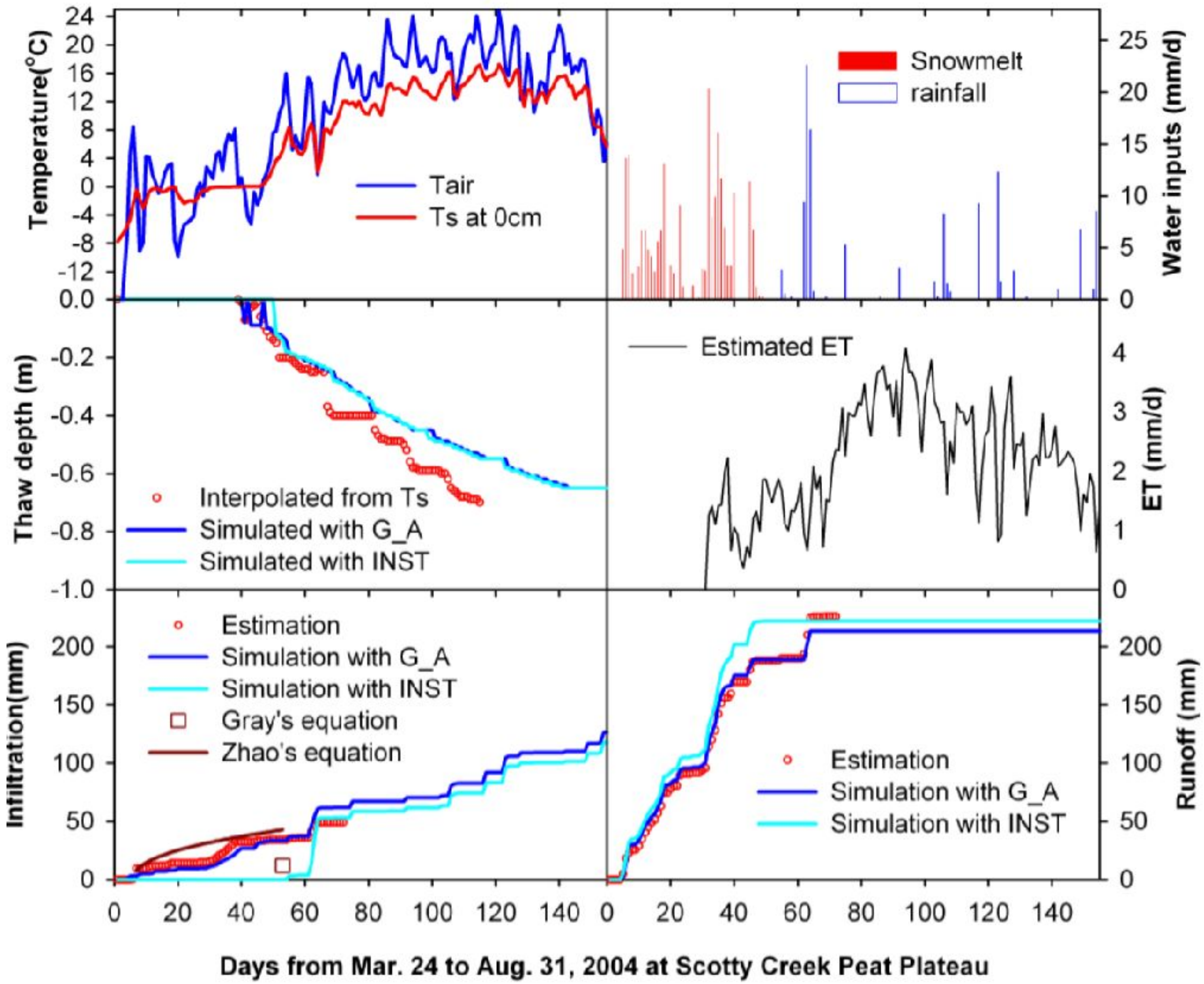
Wolf Creek: Soil Moisture Simulations and Observations

- Liquid: TDR

- Total: Gamma



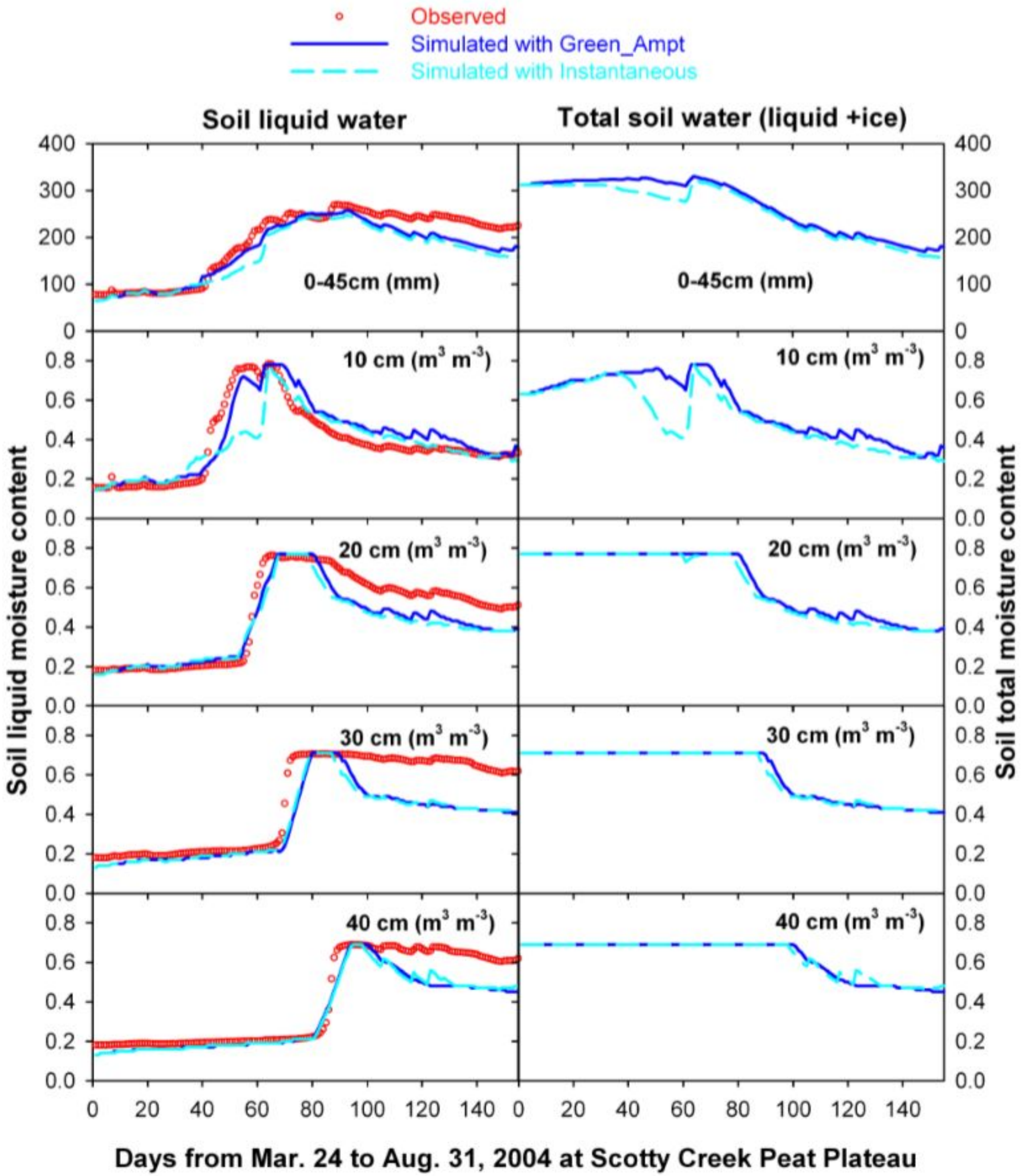
Scotty Creek Simulations: control variables, thaw depth, infiltration and runoff



Scotty Creek: Soil Moisture Simulations and Observations

- Liquid: TDR

- Total: None



Preliminary results and ongoing works

- Gray's empirical estimation gave an acceptable estimation for cumulative end-season snow-melt infiltration at Wolf Creek, but largely underestimated the infiltration at Scotty Creek, due to the near saturated soil condition.

- The parametric method (Zhao et al.) worked at both sites in terms of cumulative end-season snow-melt infiltration, however it power-shaped curve did not follow the actual daily infiltration course.

•Pure numerical solutions for infiltration problems require very fine time and soil layer resolutions (~minute / ~cm), hence very difficult to be applied in field applications.

- Mixed methods with coupled thermal and water transfer equations have the capacity to simulate the details of infiltration progresses and soil moisture dynamics in. However appropriate algorithms / parameters have to be identified for organic – covered permafrost soils.

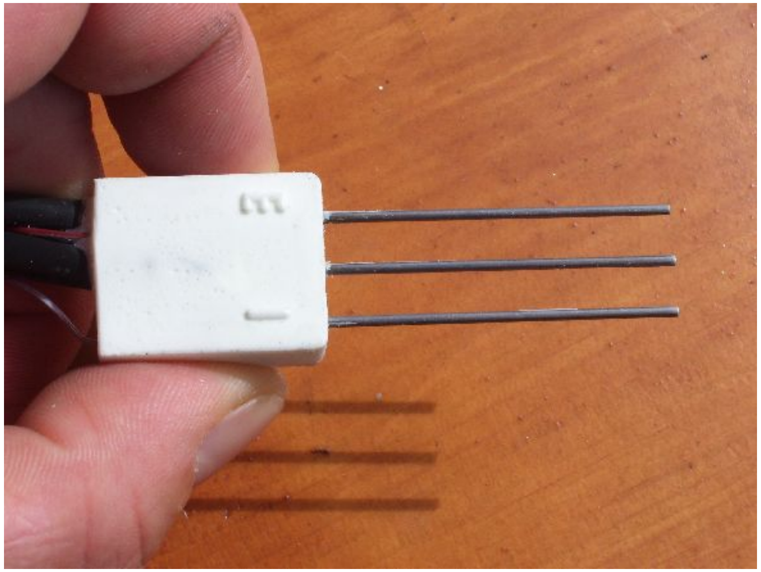
•Ongoing works for this study:

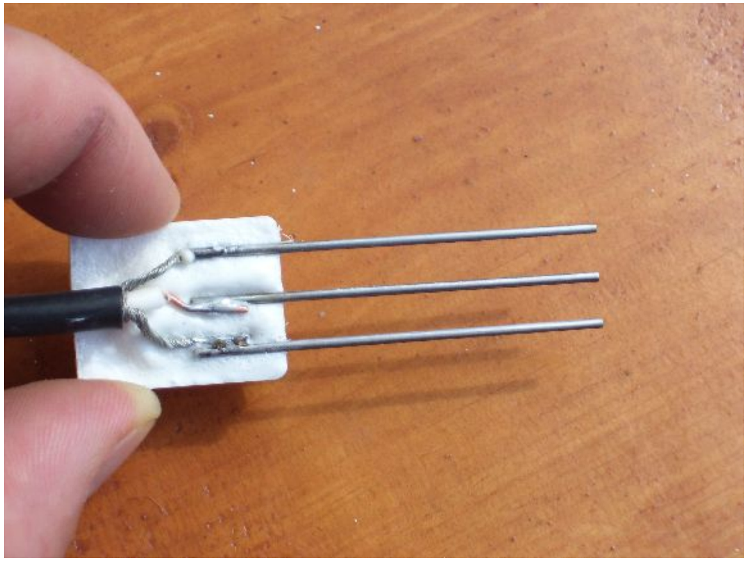
--more expertise is needed in quantifying the inputs/outs from limited observations

--evaluate the parameterization methods/parameters for thermal and hydraulic properties of those soils at the two sites.

--Improve the current tested infiltration algorithms for organic –covered permafrost soil.

Multi-Function Heat-Pulse Probes (MFHPP)





- Central probe is a heater
- Outer probes are thermocouples & Reflectometers

- Total water is unknown, liquid is known, all other k and C values known
- Inverse procedure allows determination of ice fraction

- Install vertically and horizontally (to measure infiltration similar to sapflow)

Multi-Function Heat-Pulse Probes (MFHPP)

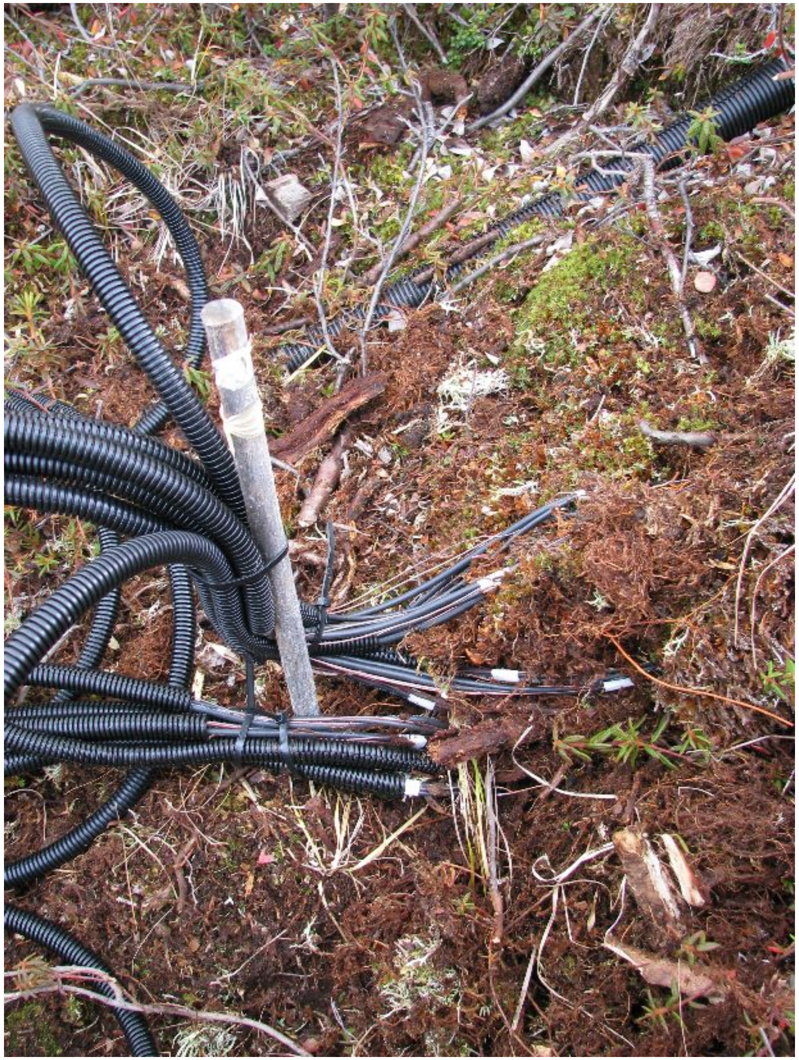
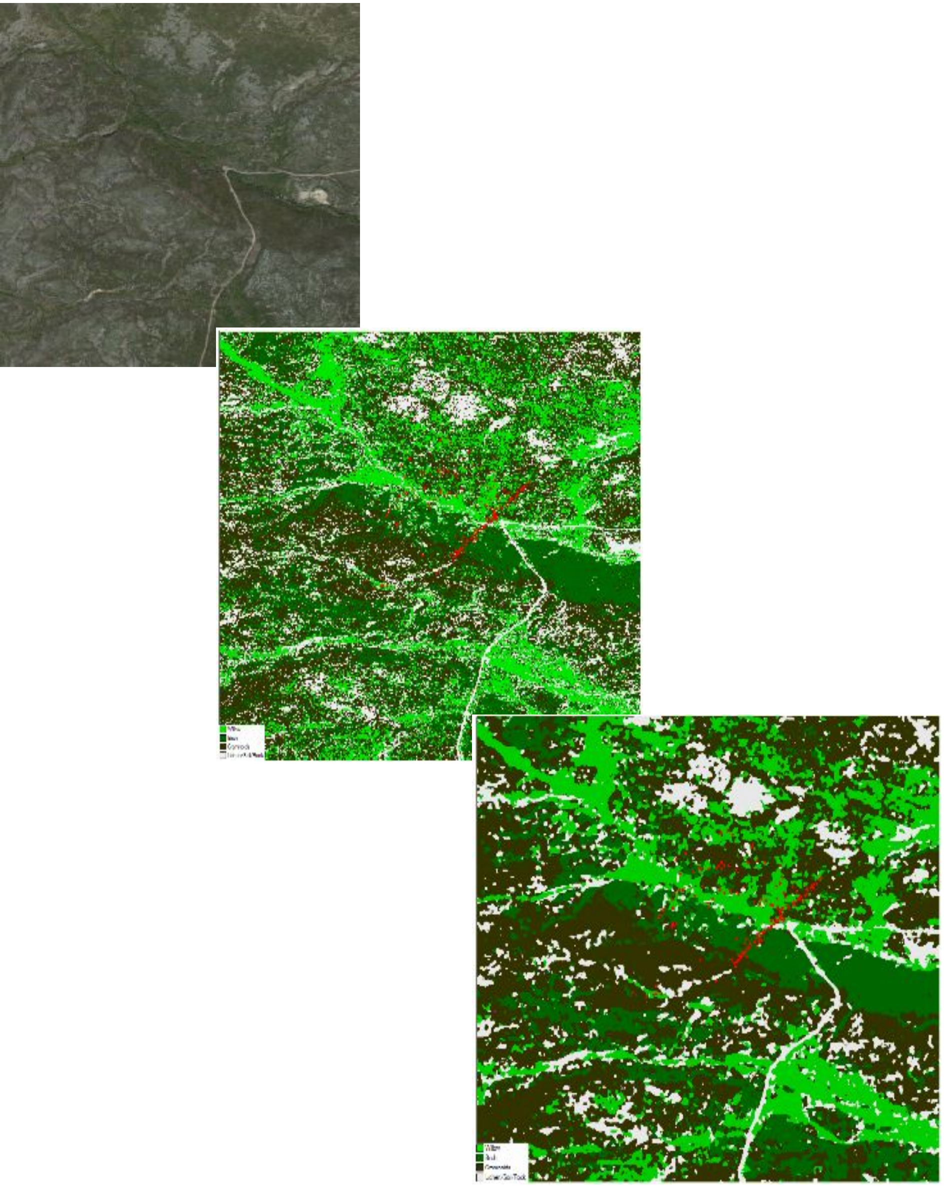
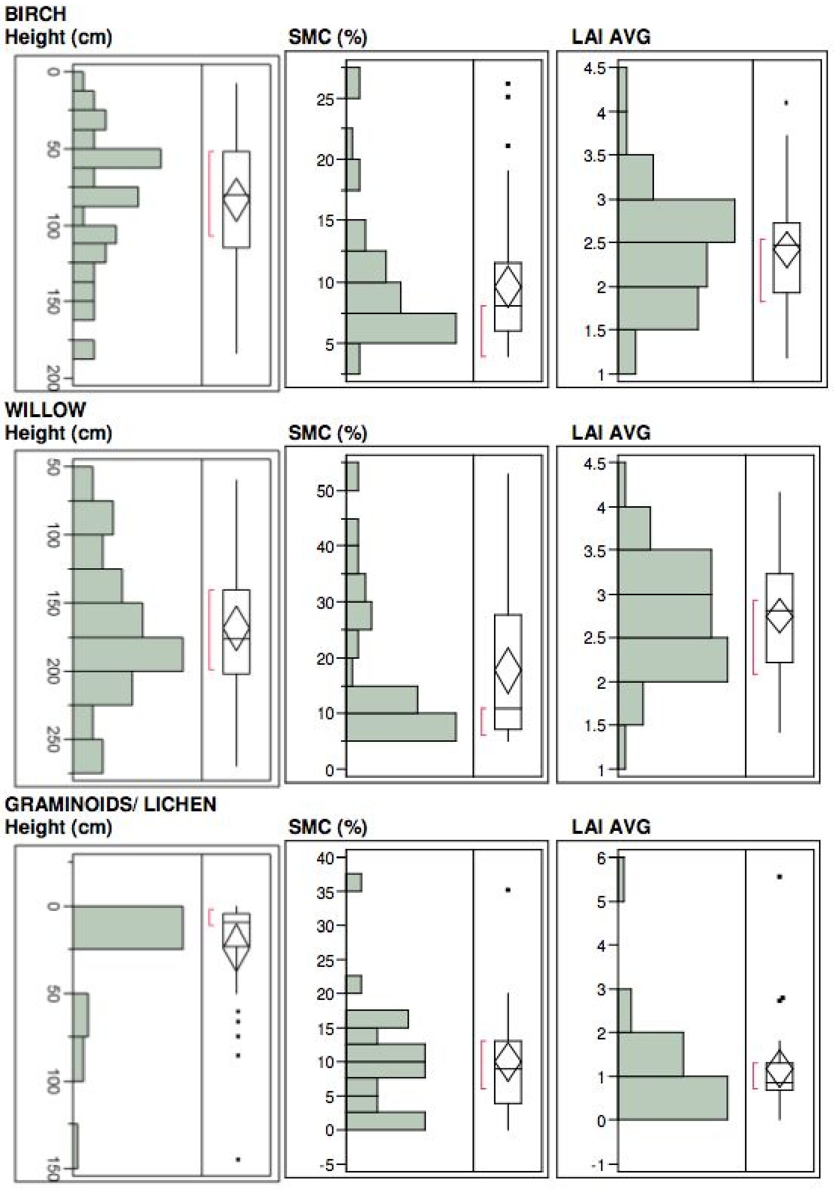


Image Classification





Ongoing Work