Runoff Processes and Thermal Modelling in Subarctic Catchments

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Overview

- HRU runoff sources and pathways
- Evaluate existing numerical descriptions for frozen and organic soils
- HRU Classification
- Future Program

The Wolf Creek Research Basin

Location:
60º31 N, 135º 31' W

Area:
Approx. 200 km^2

Elevation Range:
800 to 2250 m a.s.l.
(3 ecozones)

Mean Annual Precipitation:
300 to 400 mm (40% snow)

Mean Annual Temperature:
-3 ºC

HRU Runoff Processes (conceptual model)

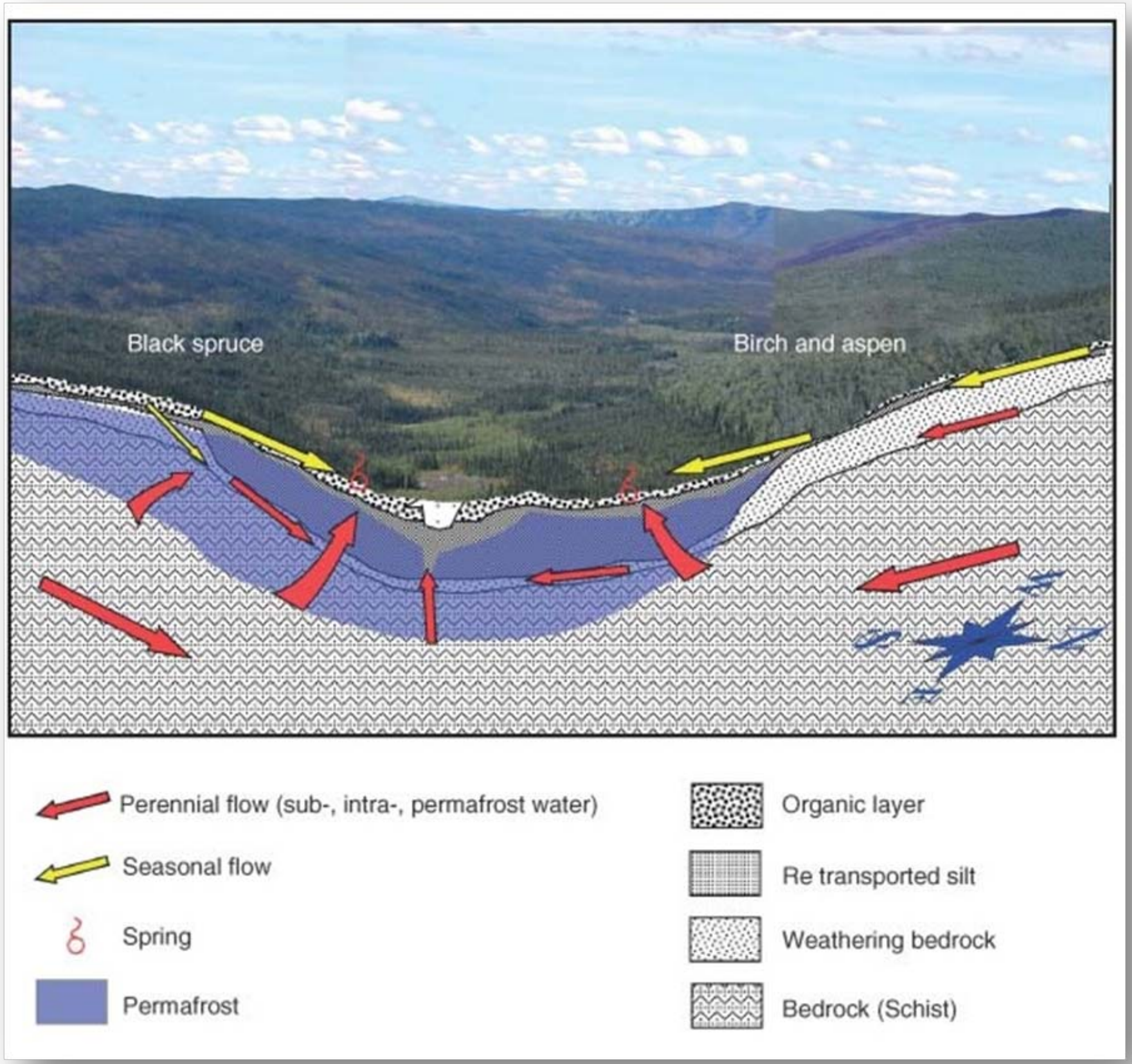
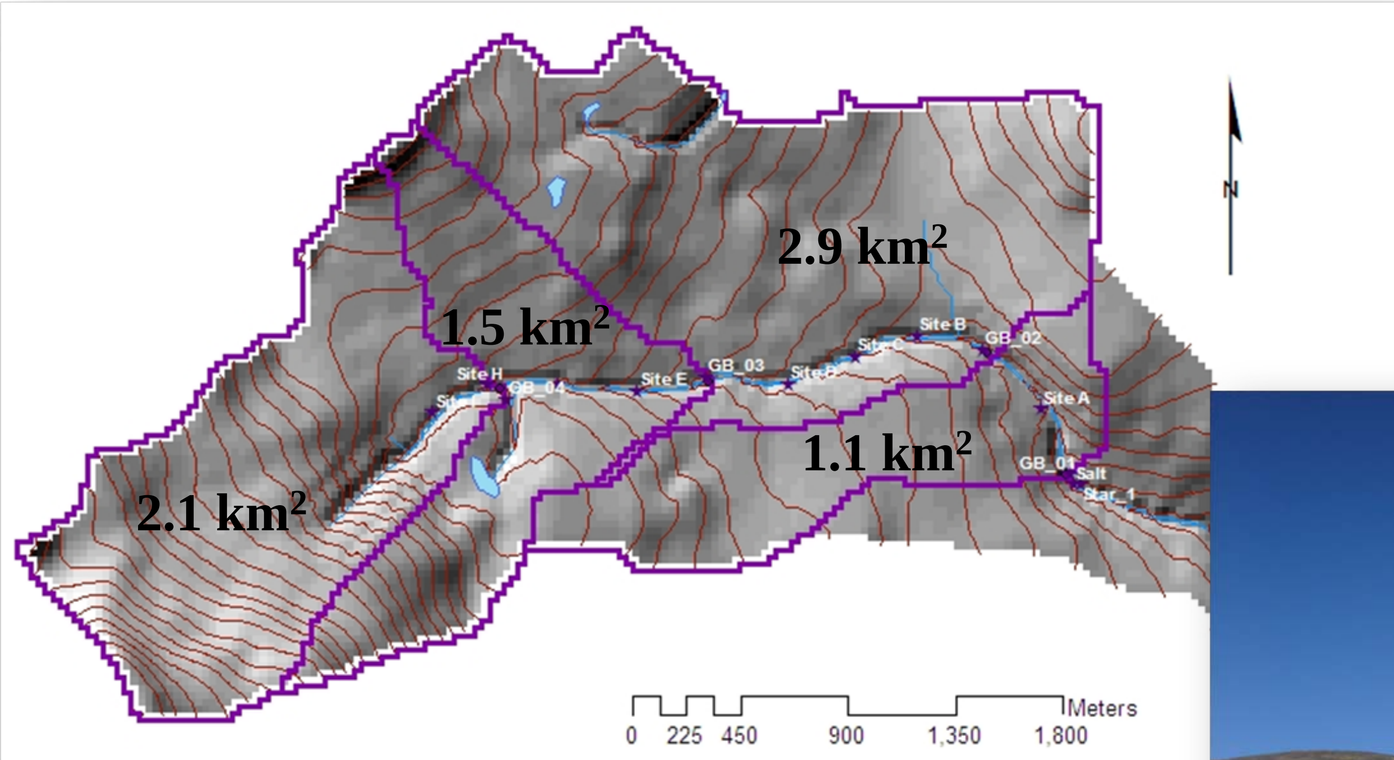


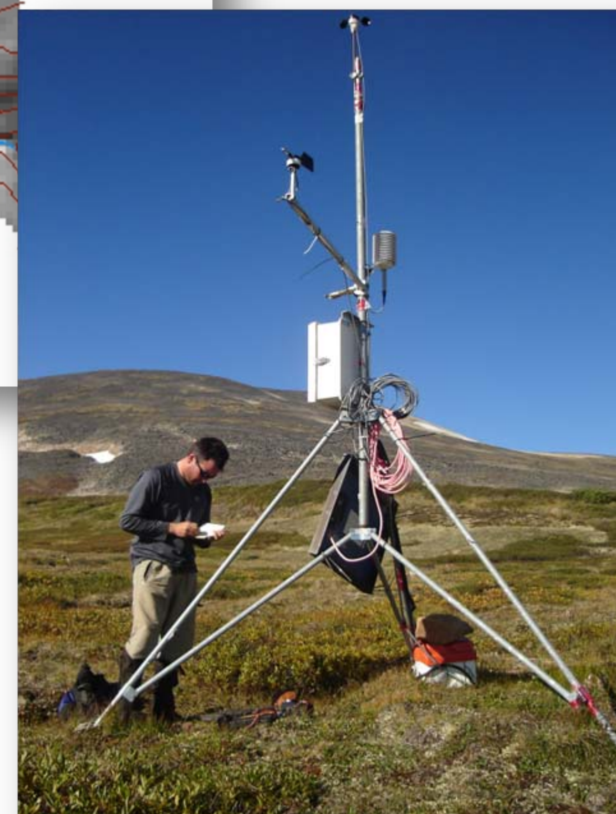
Figure Source: Encyclopedia of Hydrological Sciences, John Wiley & Sons, Ltd.

Granger Basin

- Intra-basin variability:
  - Vegetation, soils, frozen ground, climate

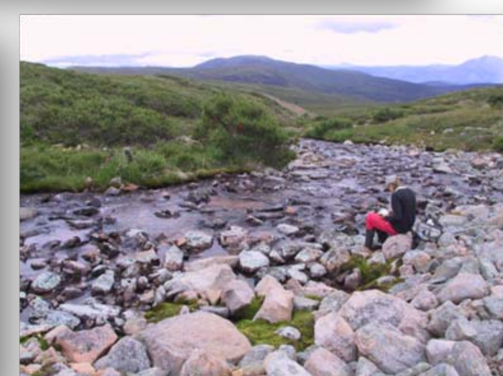
Granger Sub-basins



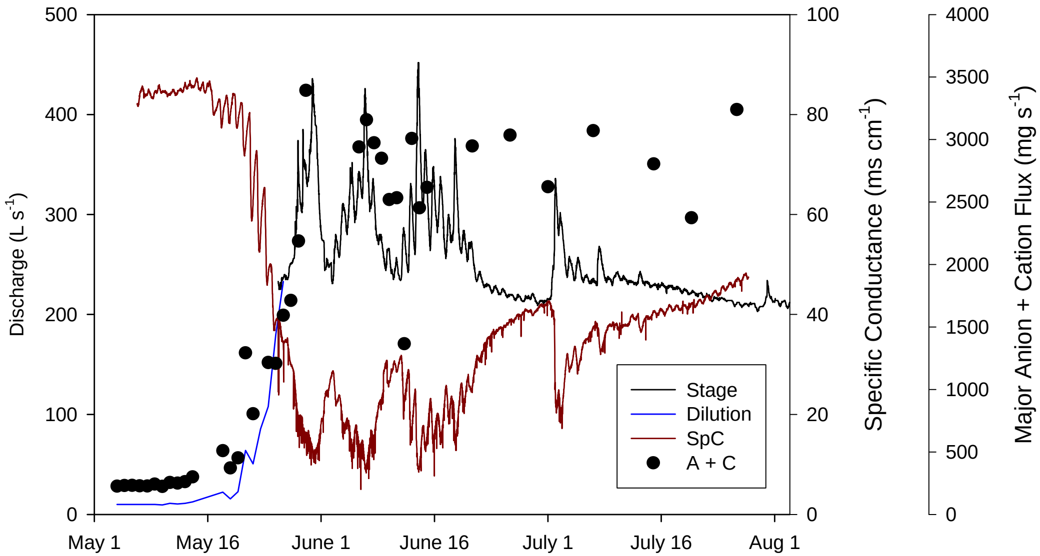


Techniques

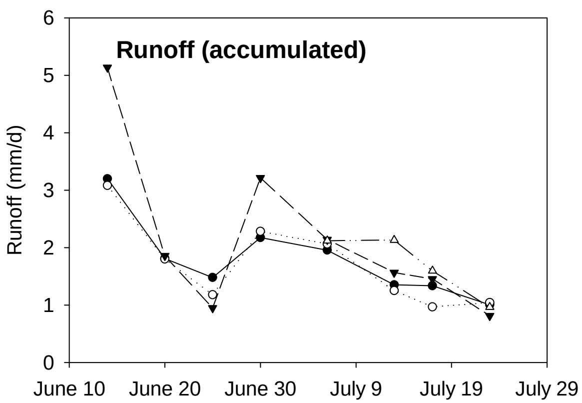
- High-frequency Sampling
- Synoptic Sampling
- Hydrometric
- Hydrochemical

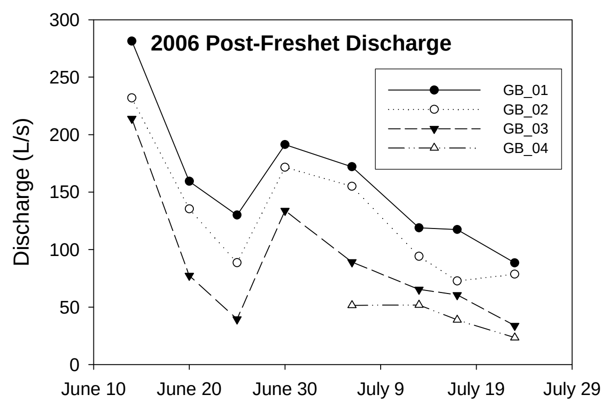


Data - Streamflow

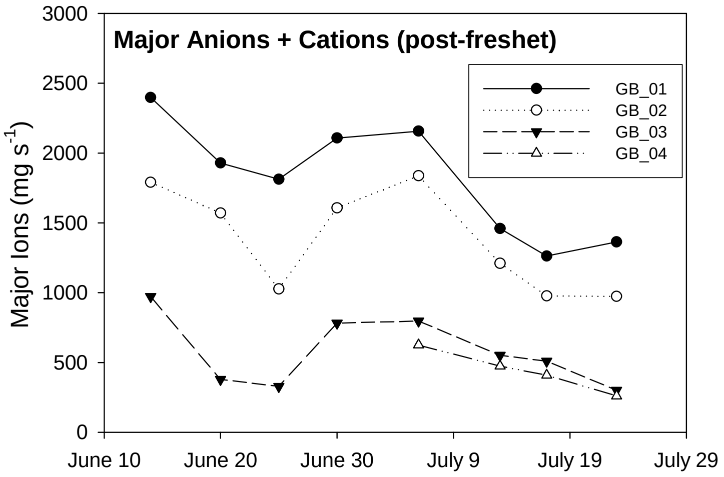


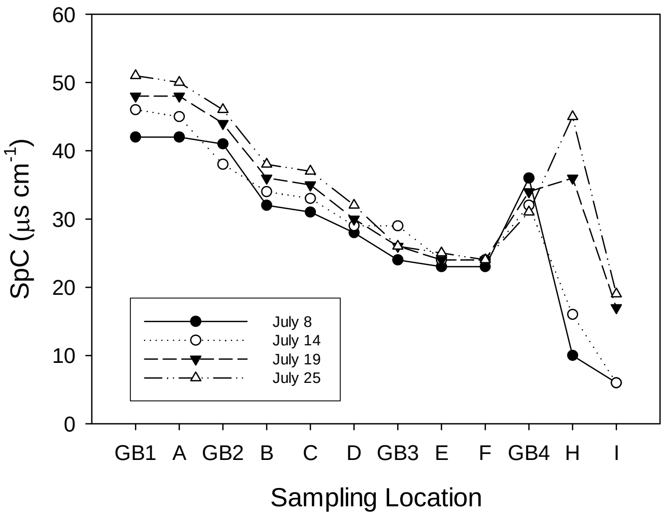
- Each HRU contributes approximately equal amounts of flow per unit-area.
- Areas with limited permafrost extent are important sources of baseflow.

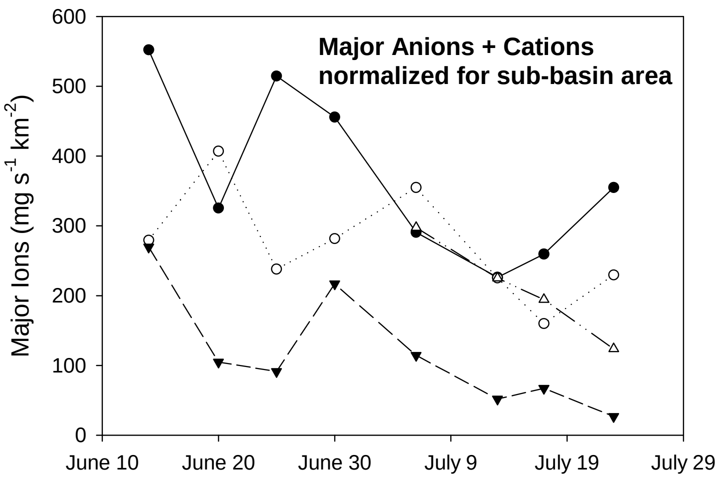




Data – Simple Hydrochemistry

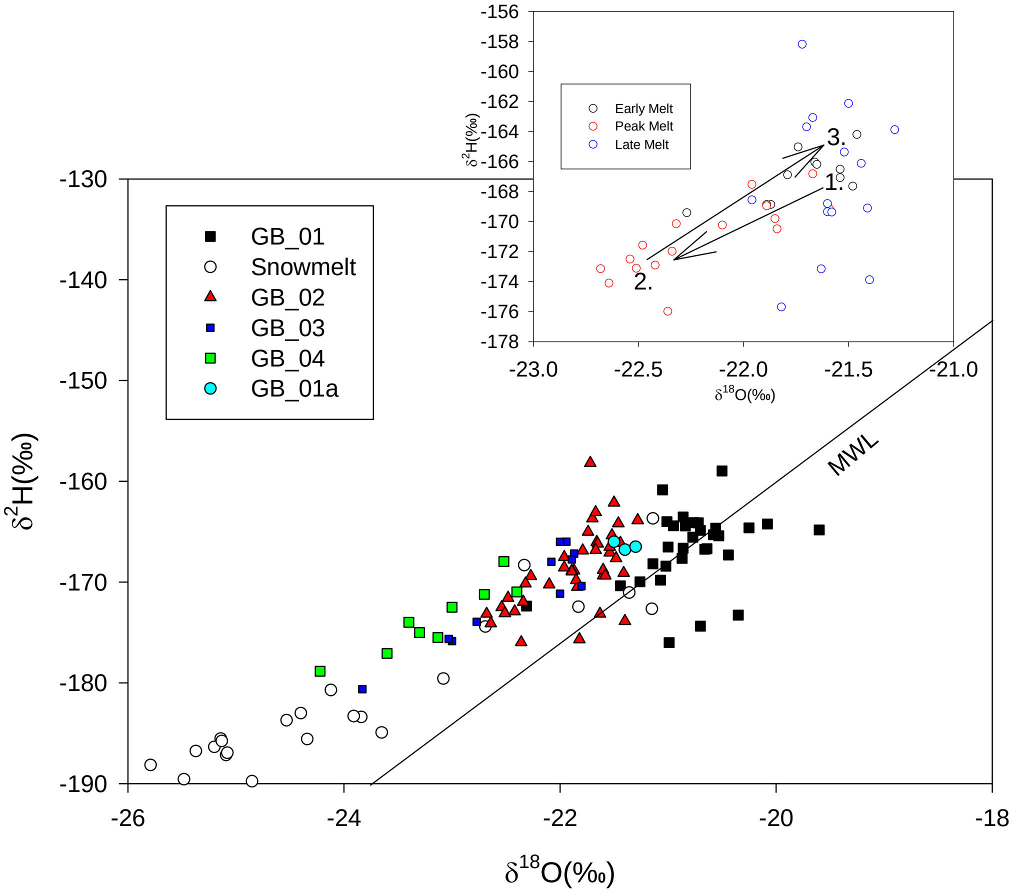






- Each HRU has a (mostly) unique hydrochemistry.
- Areas underlain with permafrost have dilute supra-permafrost signatures compared with more ionic deep (sub permafrost) groundwater

Stable Isotopes



- Results ongoing. Data from 2006 being supplemented with 2007 and historical data.
- δ^{18}O/ δ^2H show unique water signatures.

Runoff 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).
- Will extended to entire Wolf Creek, although problems in methodology arise.

Ground thermal modelling (organic soils)

- Ground thaw/freeze processes have a large influence on the land surface energy balance and hydrology in permafrost regions.
- Large diversity exists in current simulation algorithms and parameterisation methods.

- Objectives:
  - Evaluate the performance of commonly used simulation algorithms in permafrost regions
  - Evaluate commonly used soil parameterisation schemes for both mineral and organic soil
  - Provide guidelines for the implementation of appropriate ground thermal models

Ground Thermal Modelling

Site name	Coordinates	Vegetation	Organic layer depth	Permafrost table
Scotty Creek	61°18'N 121°18'W	Black Spruce	3 m	>0.7m
Granger Creek	60°32'N 135°18'W	Willow Shrub	0.35m	>0.4m
Wolf Creek NFS	61°31'N 135°31'W	Black-Spruce	0.23m	>1.4m
Wolf Creek SFS	61°31'N 135°31'W	Aspen Forest	No	No

Simulation Algorithms

Semi-empirical → **Accumulated Temperature Index Algorithm (ATIA)**

$$Z = \beta F^{0.5}$$

Analytical

- **Two Directional Stefan Algorithm (TDSA)**

$$Z = [2KF/(\rho L\theta)]^{0.5}$$

- **Hayashi's Modification to Stefan Algorithm (HMSA)**

$$Z = [2/(\rho L\theta)]^{0.5}[86400\sum(K_b T_s)]^{0.5}$$

Numerical

- **Finite Difference Thermal Conduction Method with DECP (FD_DECP)**
- **Finite Difference Thermal Conduction Method with AHCP (FD_AHCP)**
- **Finite Element Thermal Conduction Method with AHCP (FE_TONE)**

Latent Heat Parameterisation

DECP: Decoupled Energy Conservation Parameterisation

AHCP: Apparent Heat Capacity Parameterisation

Parameter tests

Tests of soil thermal conductivity parameterisation

- --Johansen'formulation
- --De Vries's formulation

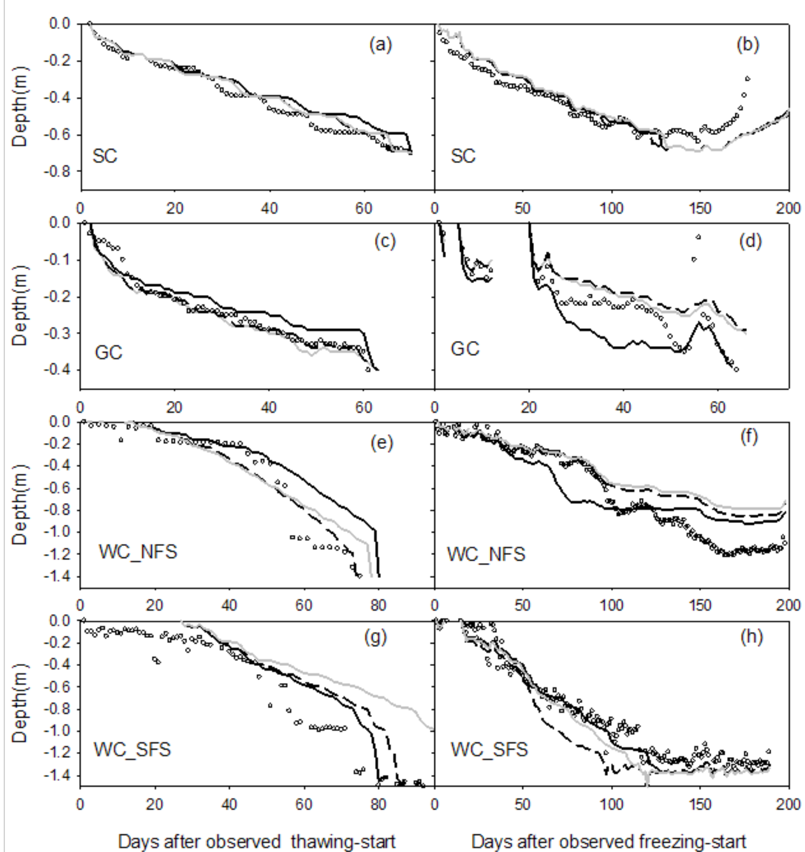
Test of unfrozen water parameterisation

- --Segmented linear functions
- --Power function
- --Water potential-freezing point depression formulation

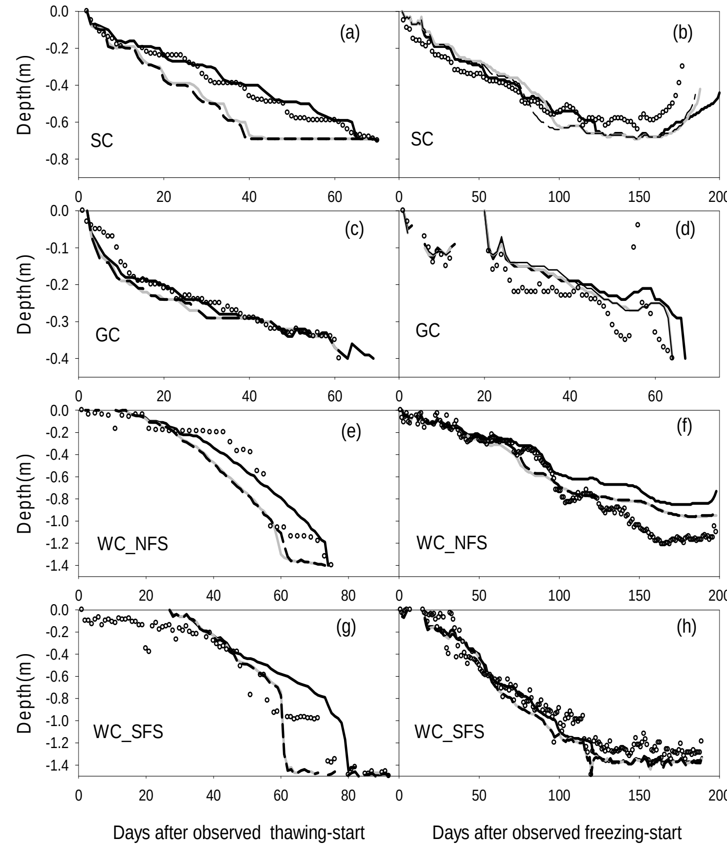
Tests of simulation algorithms (best parameterisation)

- --Run1: All the available inputs (T_{top}, T_{bot}, θ_w, θ_{ice},$T_{s,ini}$)
- --Run2: Without T_{bot}, lower boundary conditions and θ_w, θ_{ice},$T_{s,ini}$ have to be assumed.
- --Run3: Only T_{top} was supplied. Soil water assumed to be saturated at all times.

Model Results

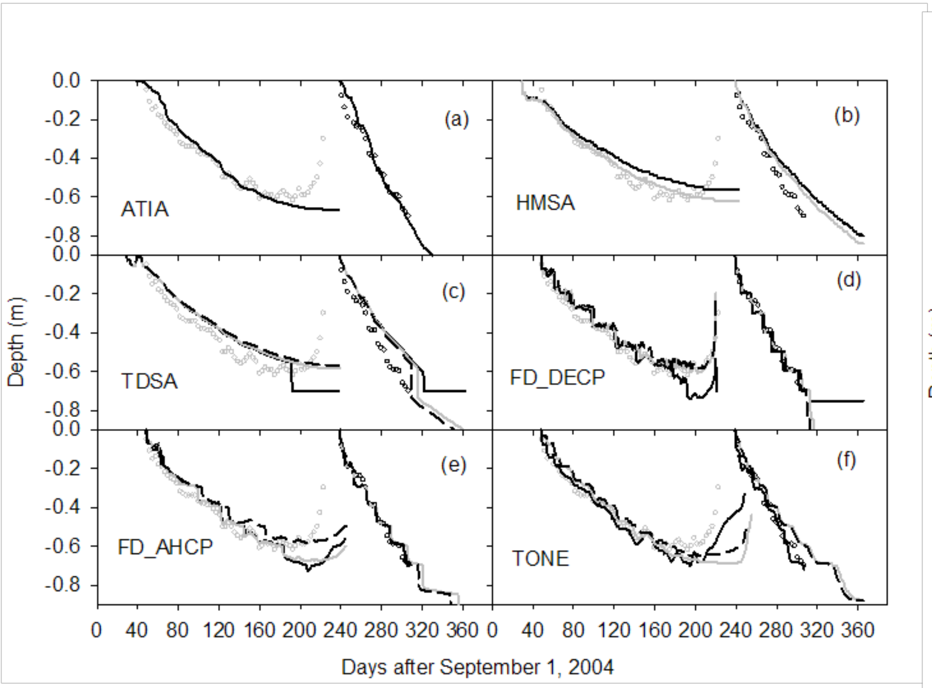


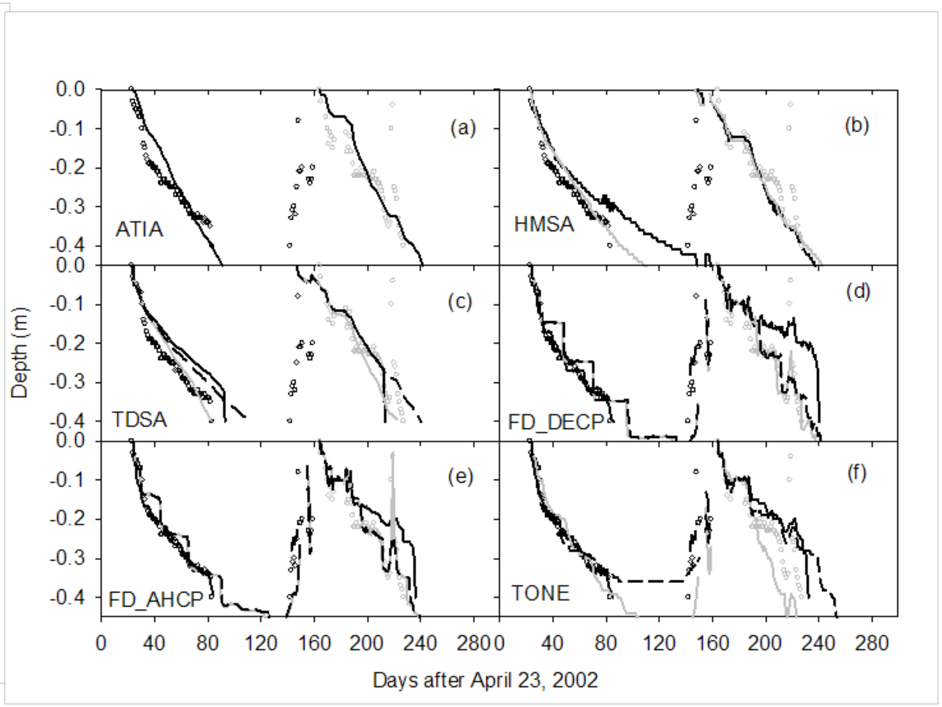
Tests of different soil thermal conductivity parameterisation methods, *i.e.* Complete Johansen's equations (dark solid lines), Commonly used Johansen's equations (grey solid lines), and a simplified de Vries's method (dashed lines). Open circles are observations.



Test of unfrozen water parameterisation methods, *i.e.* segmented linear function (dark solid lines), power function (grey solid lines) and water potential-freezing point depression

Model Results





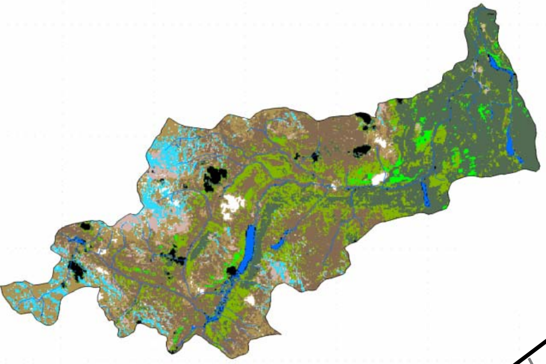
Comparisons of observed (symbols) and simulated (lines) thawing (dark circles for observation) and freezing (grey circles for observation) depths at Scotty Greek with six algorithms and three sets of model runs, *i.e.*, Run1 (dark solid lines), Run2 (dark dashed lines) and Run3 (grey solid lines).

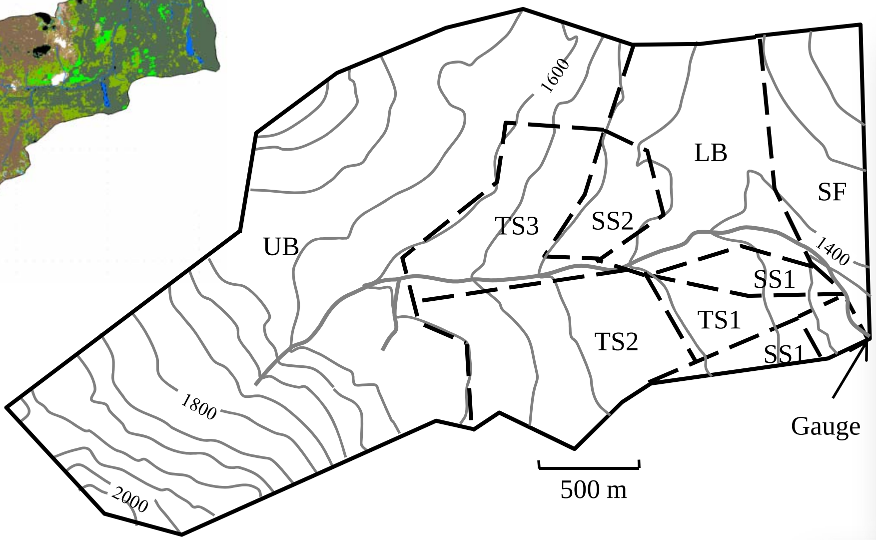
Comparisons of observed (symbols) and simulated (lines) thawing (dark circles for observation) and freezing (grey circles for observation) depths at Granger Greek with six algorithms and three sets of model runs, *i.e.*, Run1 (dark solid lines), Run2 (dark dashed lines) and Run3 (grey solid lines).

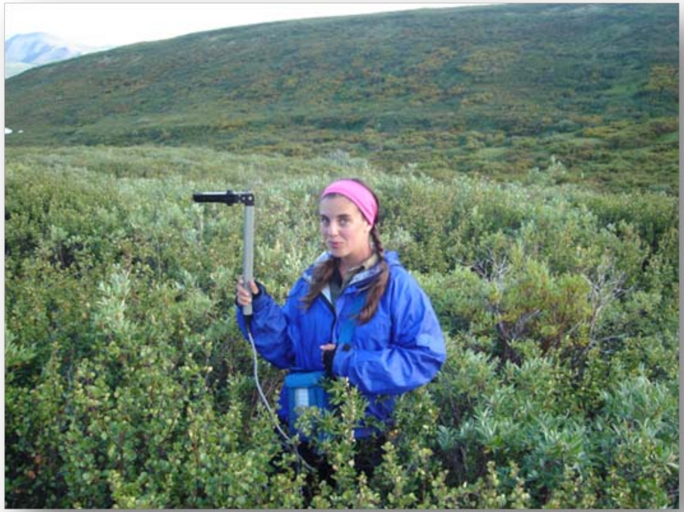
Some Key Findings

- A simplified de Vries's formulation generated reasonable GTFD simulations at all the four tested sites, while a commonly used Johansen's formulation only achieved good results at the three organic covered permafrost sites. The formulations originally designed by Johansen for peat did not work at the organic soils of the tested sites.
- The analytical algorithms are less sensitive to resolution of soil layers than the numerical models. A six-layer resolution worked well for both HMSA and TDSA, while at least nine soil layers were needed in the 5-m soil column for the three numerical models, in order to simulate the GTFD with acceptable accuracy.
- The semi-empirical algorithm ATIA worked well at all the four tested sites when site-calibrated coefficients (β) were used. However, due to the large variations of the β values from thawing to freezing, from site to site and from year to year, it is not recommended to apply this method to dynamic analyses of GTFD.
- All three numerical algorithms (FD_DECP, FD_AHCP and TONE) traced GTFD evolutions more precisely than other algorithms at all sites, particularly when observed and best estimated soil moisture was supplied .

Landscape Classification

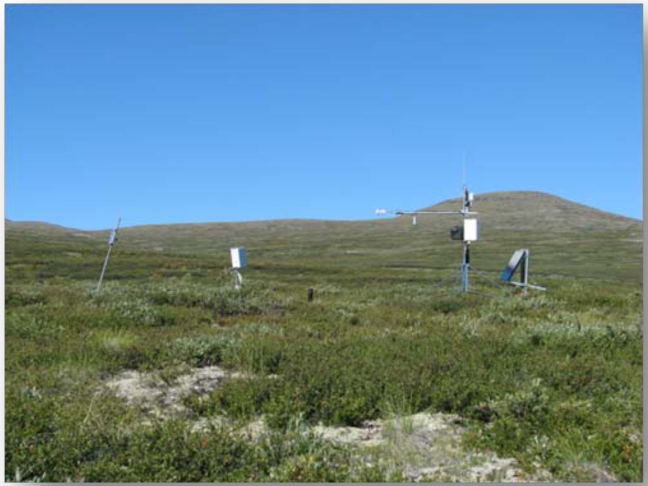


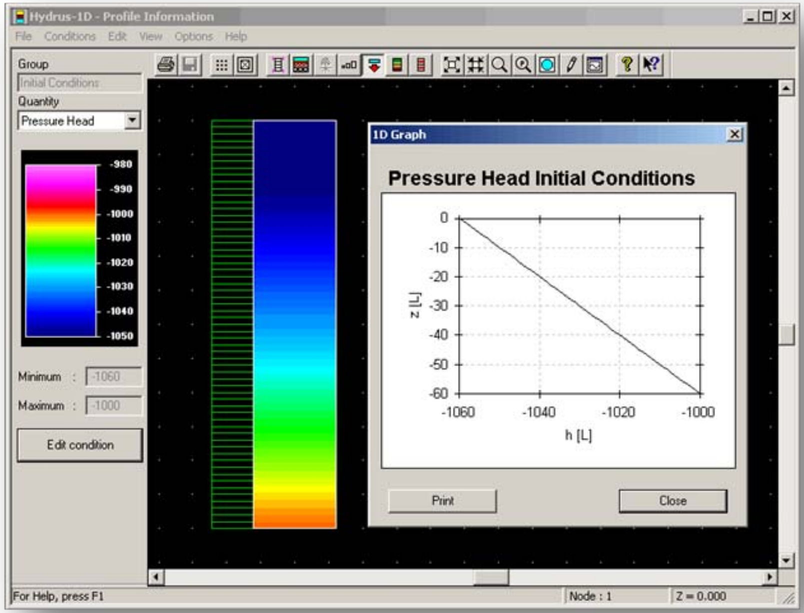




Ongoing Work

- Infiltration into frozen soils
  - New Field Experiments
  - New Instrumentation (MFHPP)
  - New Modelling
    - Modify Hydrus 1-D
      - Simplify and C++ coding
      - Incorporate frozen ground parameterizations
      - Test at a variety of sites





Ongoing Work

- Role of Channel Snow and Ice
  - What is the role of icing and channel ice?
  - GPR to establish volume, overlay on DEM
  - Measure decay through time, geochemical signature, establish contribution to flow

Ongoing Work

- Snowmelt processes
  - Test SNAP and existing snow melt/percolation routines in CRHM.
  - Isotopic evolution of snowpack, snowmelt, and its relation to soil water and runoff