Improved Parameterisations for Organic-covered Permafrost Soil in Land Surface and Hydrological Models

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- Organic soil and thaw/freeze are two major headaches in LSMs and HMs, creating challenges in both energy and water simulations.

- Large diversity exists in the algorithms and parameterisations employed in current LSMs and HMs.

- Very little evaluation/validation using data from cold regions

Major Contributions

- Review algorithms and parameterisations currently employed in several key processes of LSMs and HMs.
- Select commonly used algorithms and parametrisations for comparison.
- Collect and compile datasets for model calibration and evaluation (IP3 sites)
- Evaluate selected algorithms and parametrisations using common datasets
- Employ improved algorithms and parameterizations in operational LSMs and HMs (on going)

Processes and Algorithms Examined

Thaw/Freeze

- ATIA
- TDSA
- HMSA
- FD-DECP
- FD-AHCP

Infiltration

- GA-SHAW
- ML-CLASS
- IT-TOPO
- GRAY-IN
- ZHAO-IN

Abbreviations

ATIA	Accumulated Thermal Index Algorithm
TDSA	Two Directional Stefan Algorithm
HMSA	Hayashi's Modified Stefan Algorithm
FD-DECP	Finite difference numerical scheme with the Decoupled Energy Conservation Parameterization
FD-AHCP	Finite difference numerical scheme with the Apparent Heat Capacity Parameterization
GA-SHAW	Modified Green and Ampt algorithm for non-uniform soils
ML-CLASS	Modified Mein and Larson algorithm for non-uniform soils
IT-TOPO	Instantaneous infiltration algorithm in Topoflow
GRAY-IN	Gray's empirical infiltration algorithm
ZHAO-IN	Zhao and Gray's parametric infiltration algorithm

Parameterisations Examined

Soil thermal conductivity

- Complete-Johansen
- Common-Johansen
- De Vries's Method

Soil hydraulic conductivity and retention curves

- Clapp and Hornberger (CH-Para)
- Brooks and Corey (BC-Para)
- van Genuchten (VG-Para)

Unfrozen water content

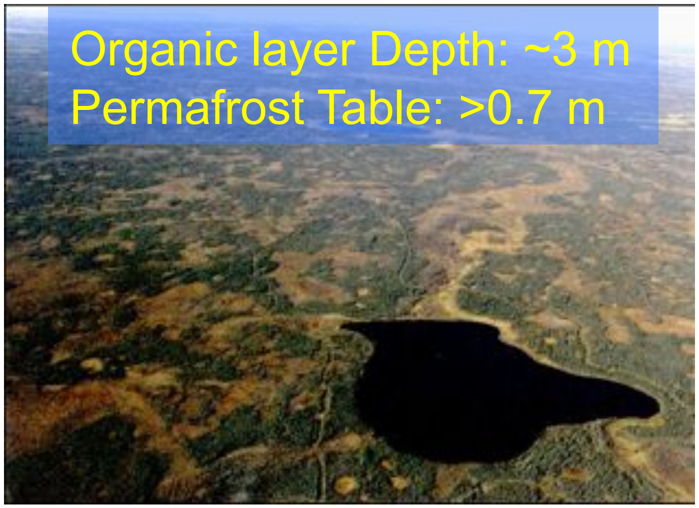
- Power function (UFW-PF)
- Segmented linear function (UFW-SL)
- Water potential-freezing point depression function (UFW-WP)

Ice impedance factors

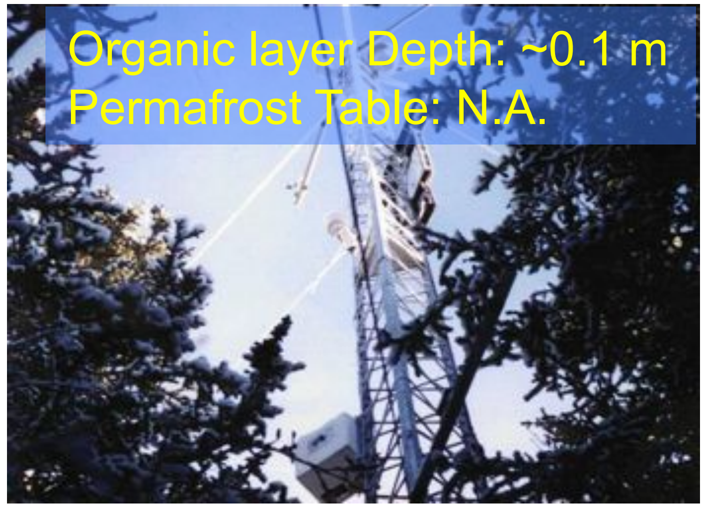
- Exponential function (EP-Ice)
- Squared function (SQ-Ice)
- Linear function (LN-Ice)
- None

Testing Sites

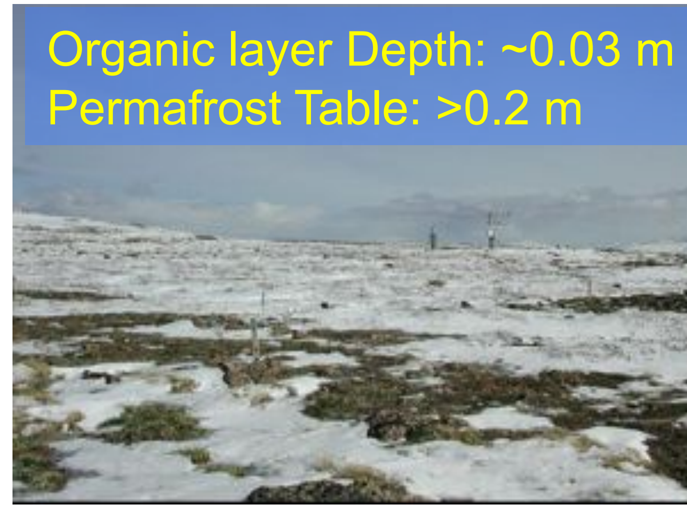
Scotty Creek Peat Plateau
61°18’N, 121°18’W, 280 m



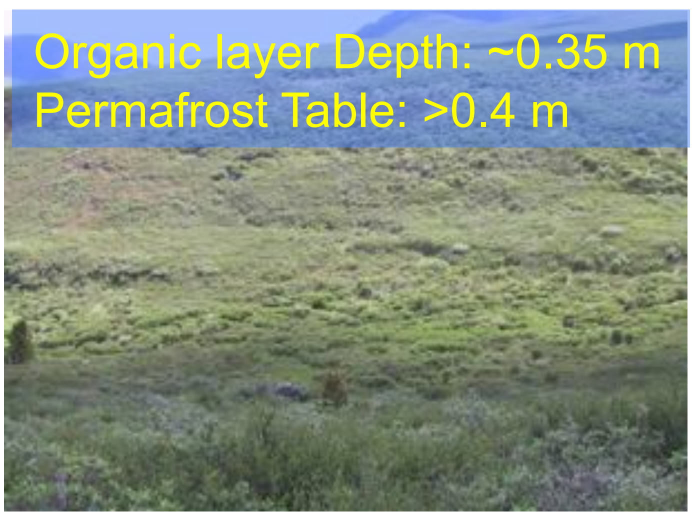
Wolf Creek Forest Site
60°36’N; 134°57’W, 750 m



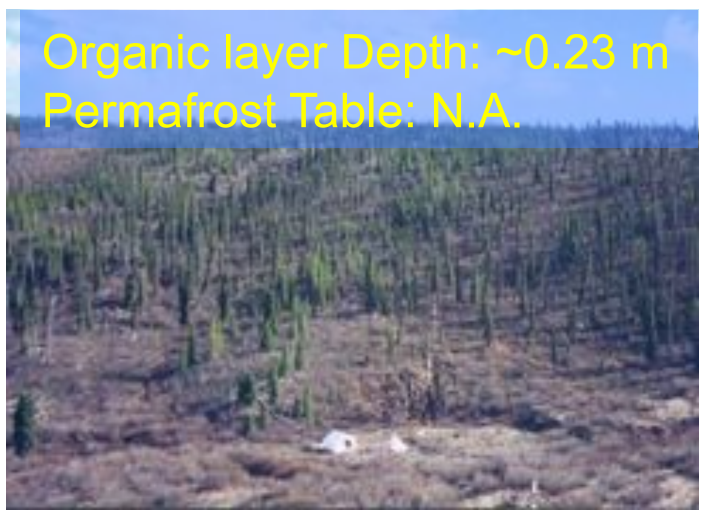
Wolf Creek Alpine Site
60°34’N; 134°09’W, 1615 m



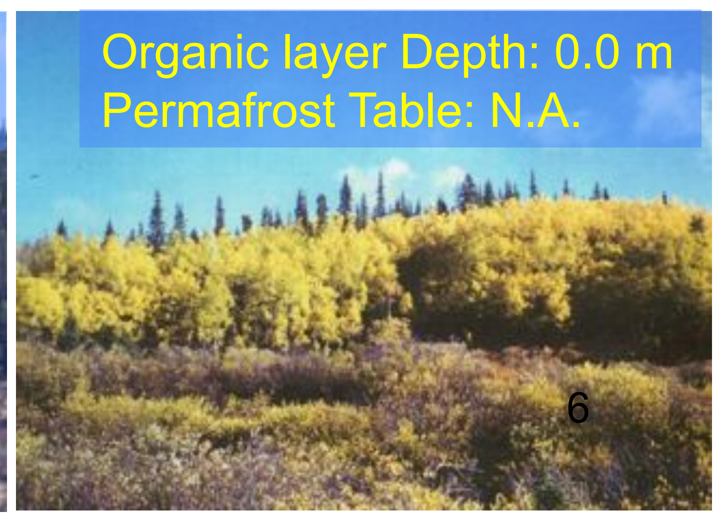
Granger Creek North Facing Slope
60°33’N, 135°11’W, 1338 m



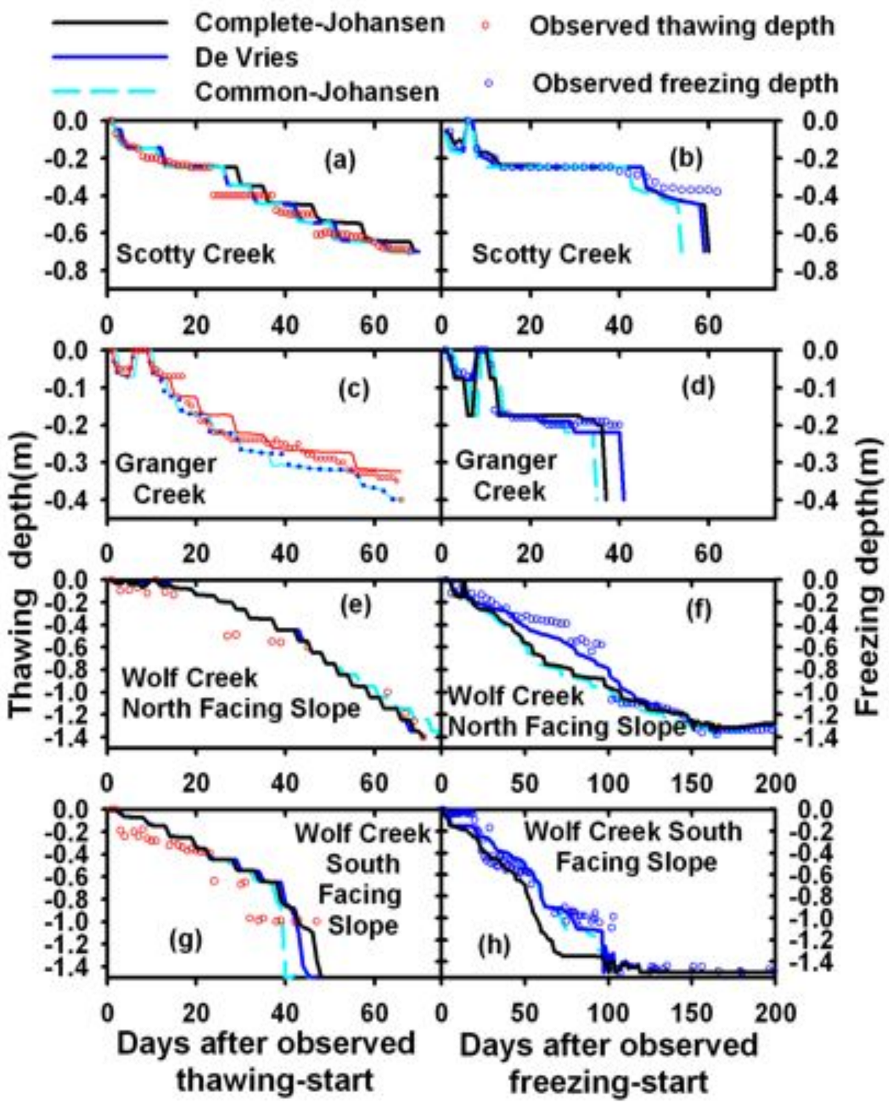
Wolf Creek North Facing Slope
61°31’N, 135°31’W, 1175 m

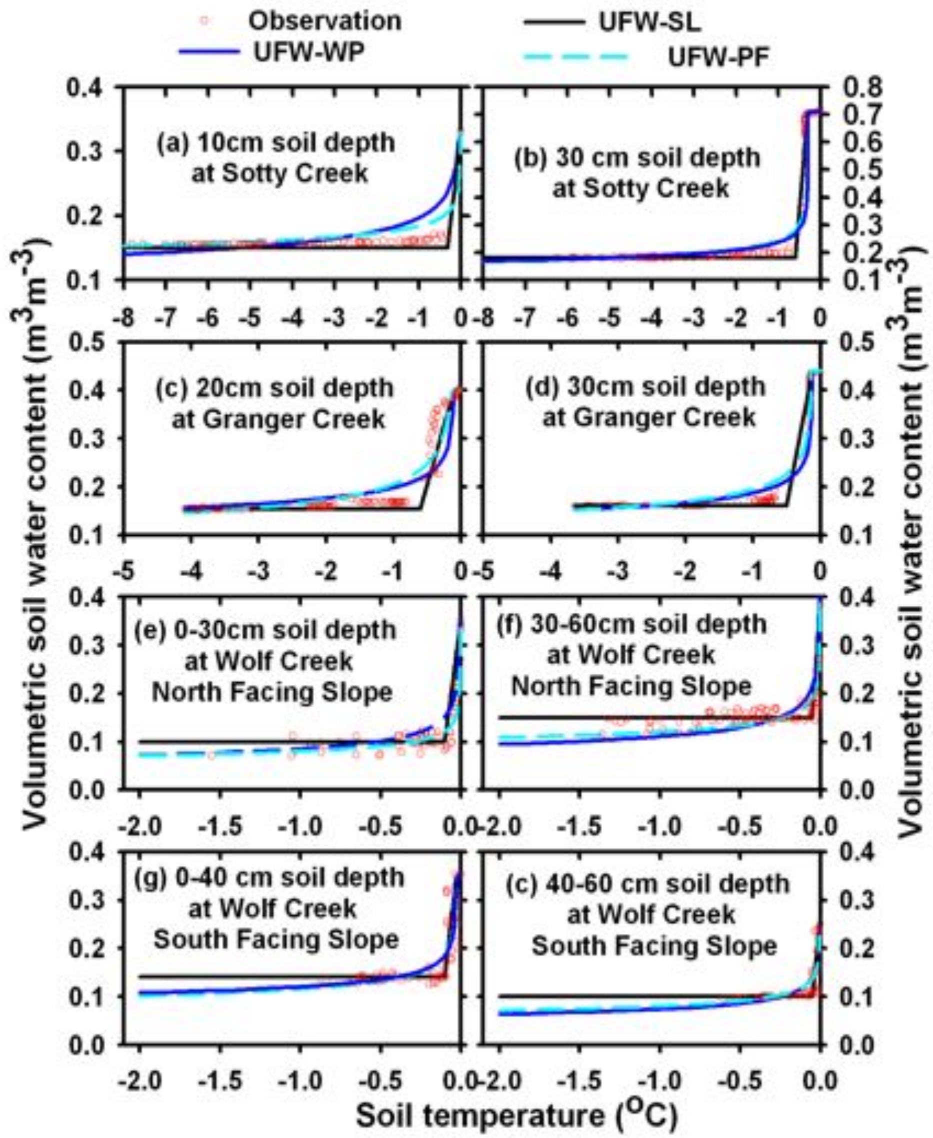


Wolf Creek South Facing Slope
61°18’N, 121°18’W, 280 m



Results-thermal conductivity and unfrozen water content

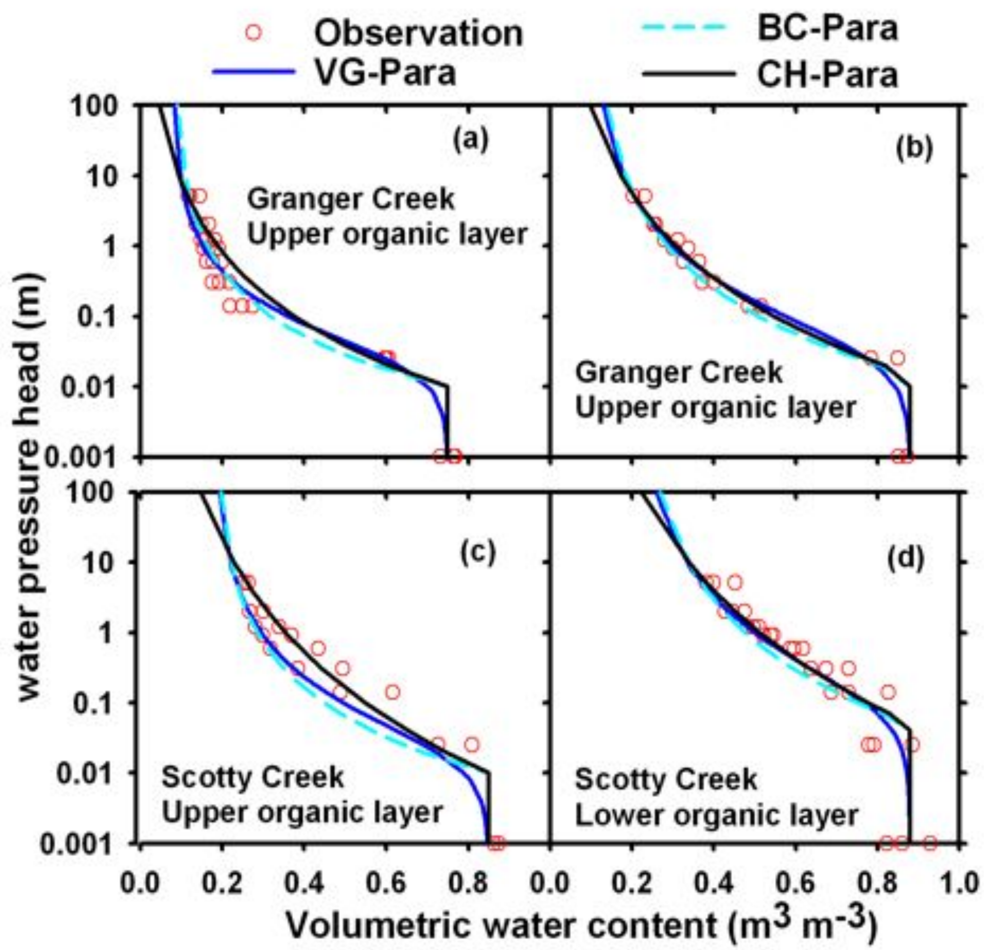




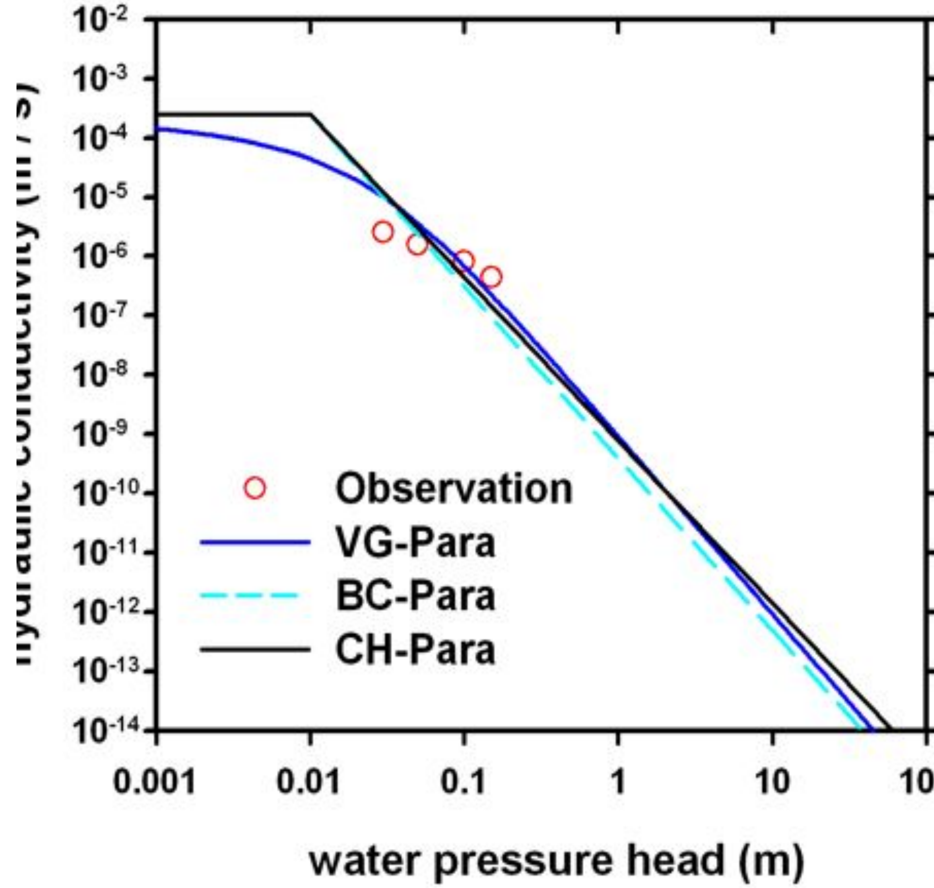
Comparison of three thermal conductivity parameterisations

Comparison of three unfrozen water parameterisations

Results-soil hydraulic property parameterisations



Comparison of three parameterisations for soil water retention curves

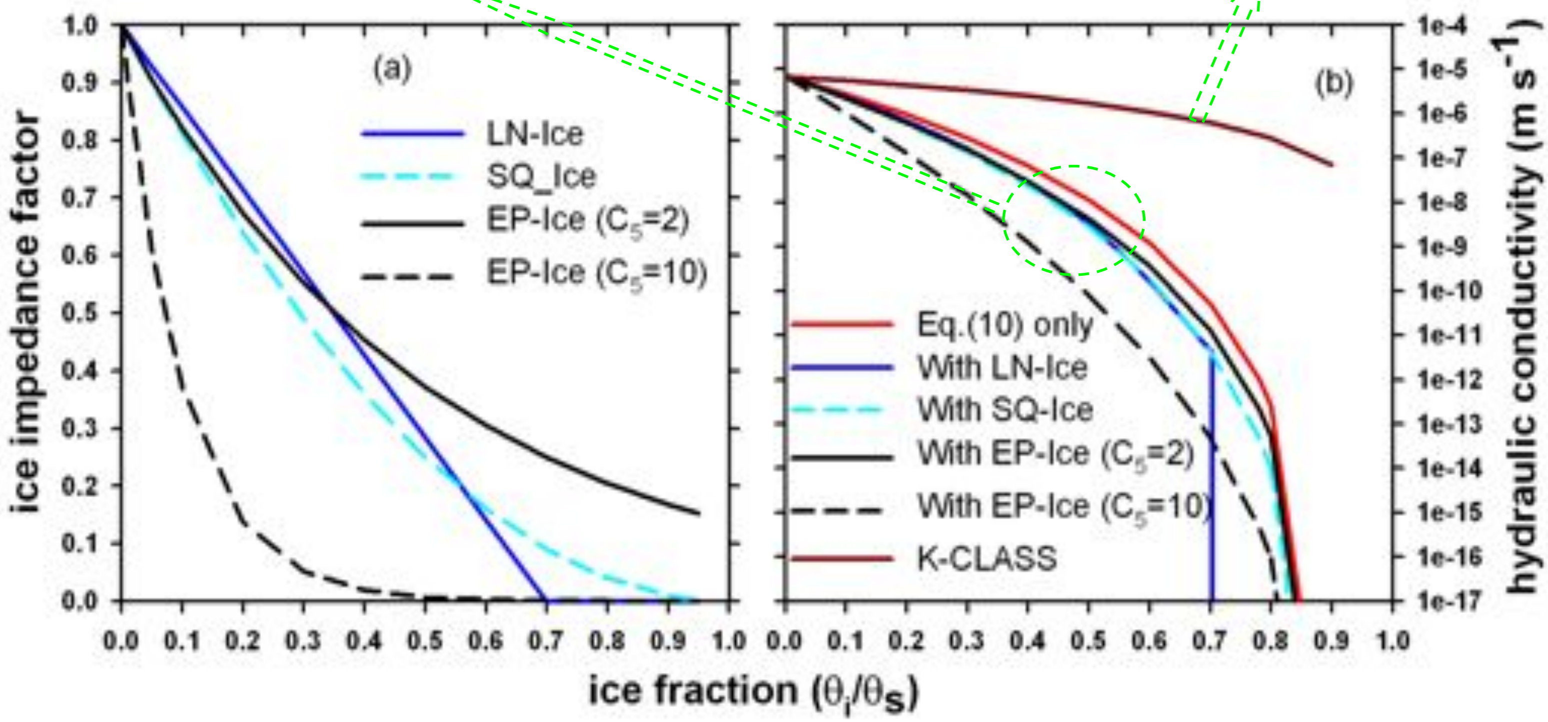


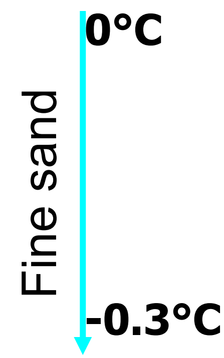
Comparison of three parameterisations for soil hydraulic conductivity

Results-ice impedance to hydraulic conductivity

$$S_e = (\theta_l - \theta_r)/(\theta_s - \theta_r)$$

$$S_e = (\theta_l - \theta_r)/(\theta_0 - \theta_i - \theta_r)$$





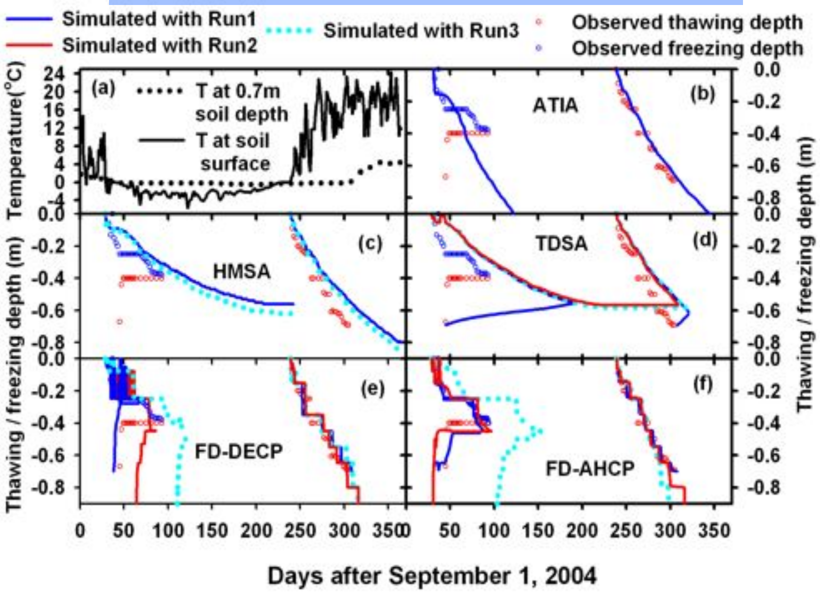
Reported frozen soil K reduction (Burt and Williams, 1976)

Equations and Applications

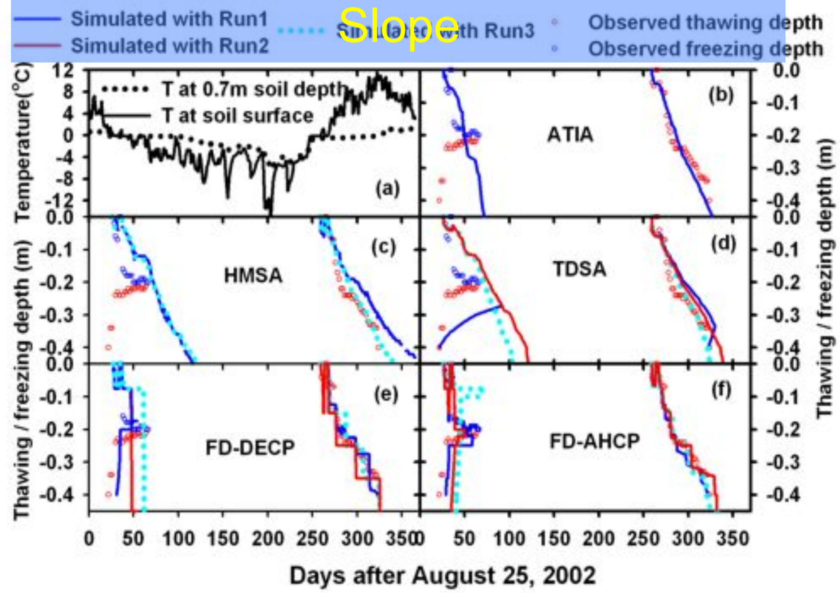
K-*ψ* relation (Eq. 10)	$K = K_s S_e^{2/\lambda+3} = K_s(\psi/\psi_0)^{-(2+3\lambda)}$	CLASS;SHAW
EP-Ice	$f_{imp,1} = 10^{-C_5\theta_i}$	CHRM
SQ-Ice	$f_{imp,2} = (1.0 - \theta_i/\theta_s)^2$	CLASS
LN-Ice	$f_{imp,3} = \begin{cases} (\theta_0 - \theta_i - 0.13)/(\theta_0 - 0.13) & \theta_0 - \theta_i > 0.13 \\ 0 & \theta_0 - \theta_i \le 0.13 \end{cases}$	SHAW

Results-ground thaw/freeze algorithms

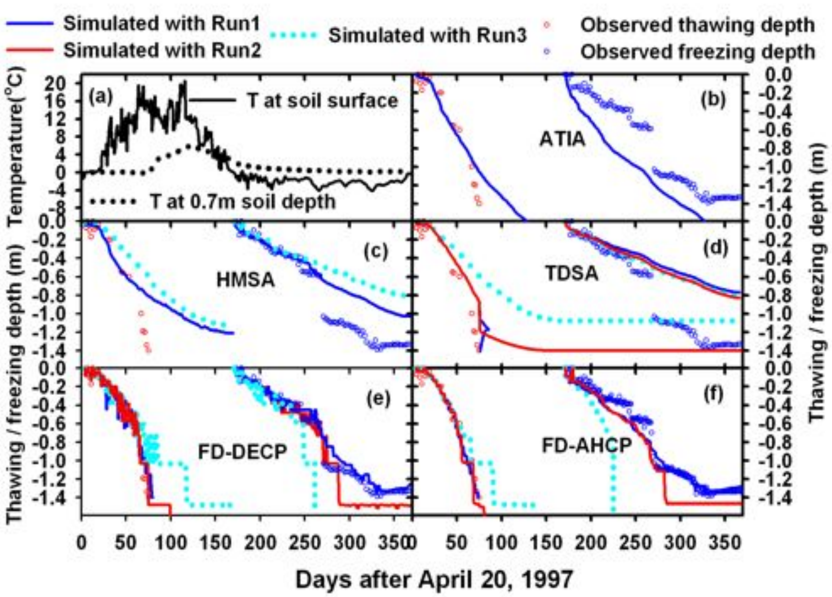
Scotty Creek Peat Plateau



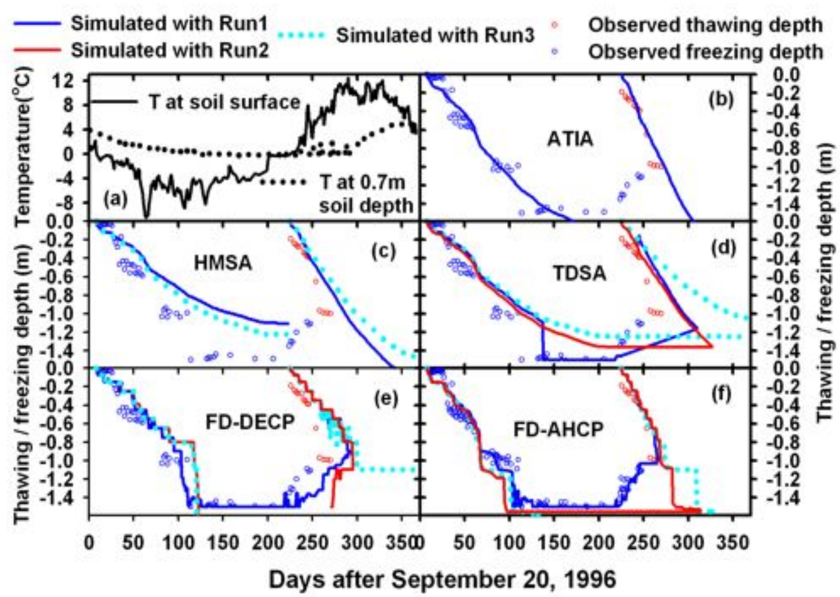
Granger Creek North-Facing Slope



Wolf Creek North-Facing Slope

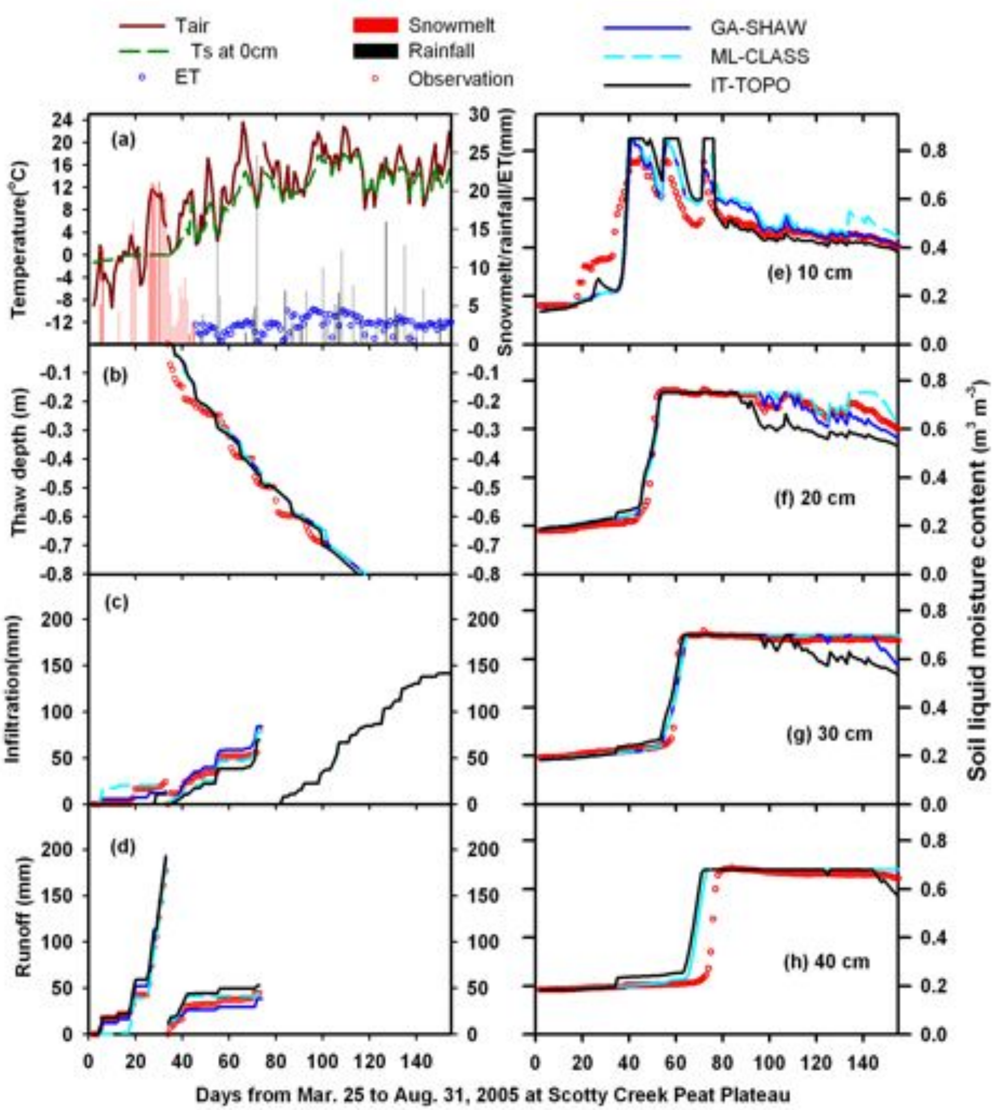


Wolf Creek South-Facing Slope

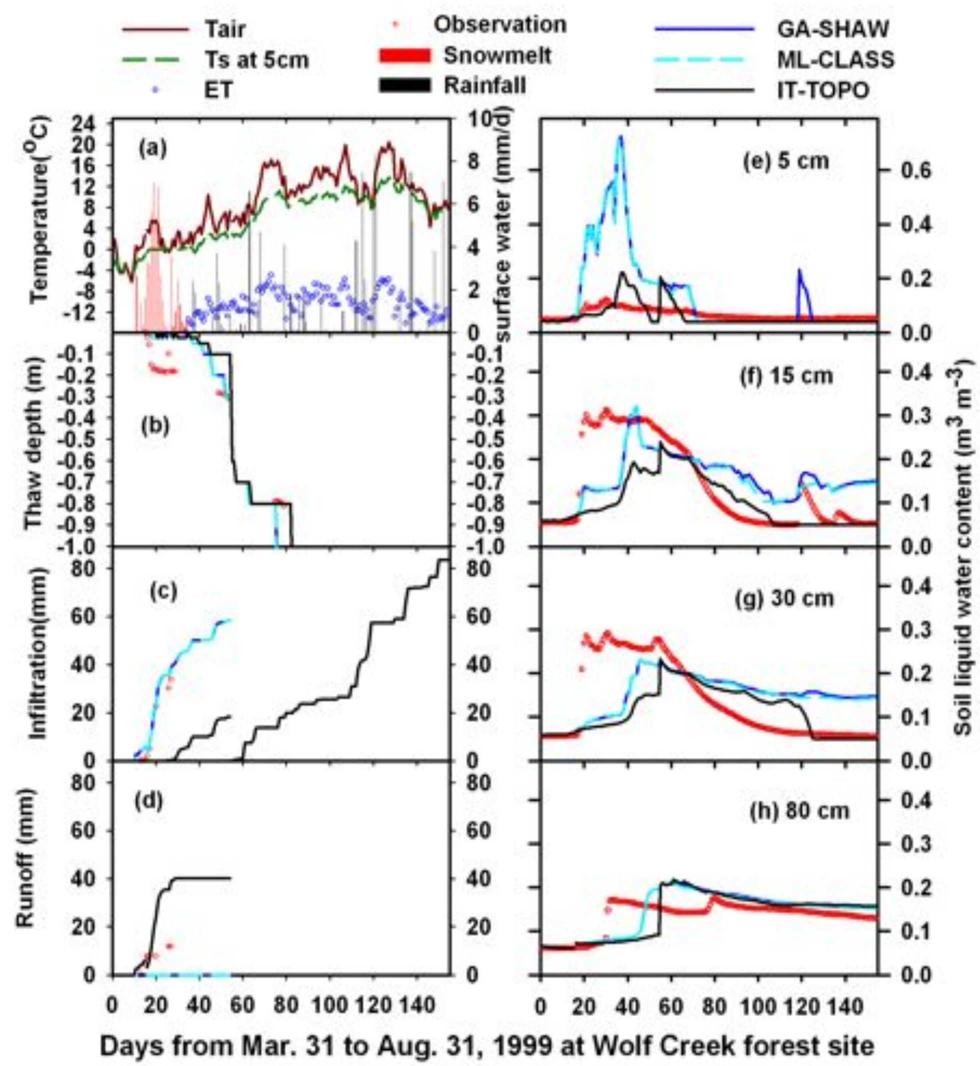


Results-surface water infiltration algorithms (I)

Scotty Creek Peat Plateau

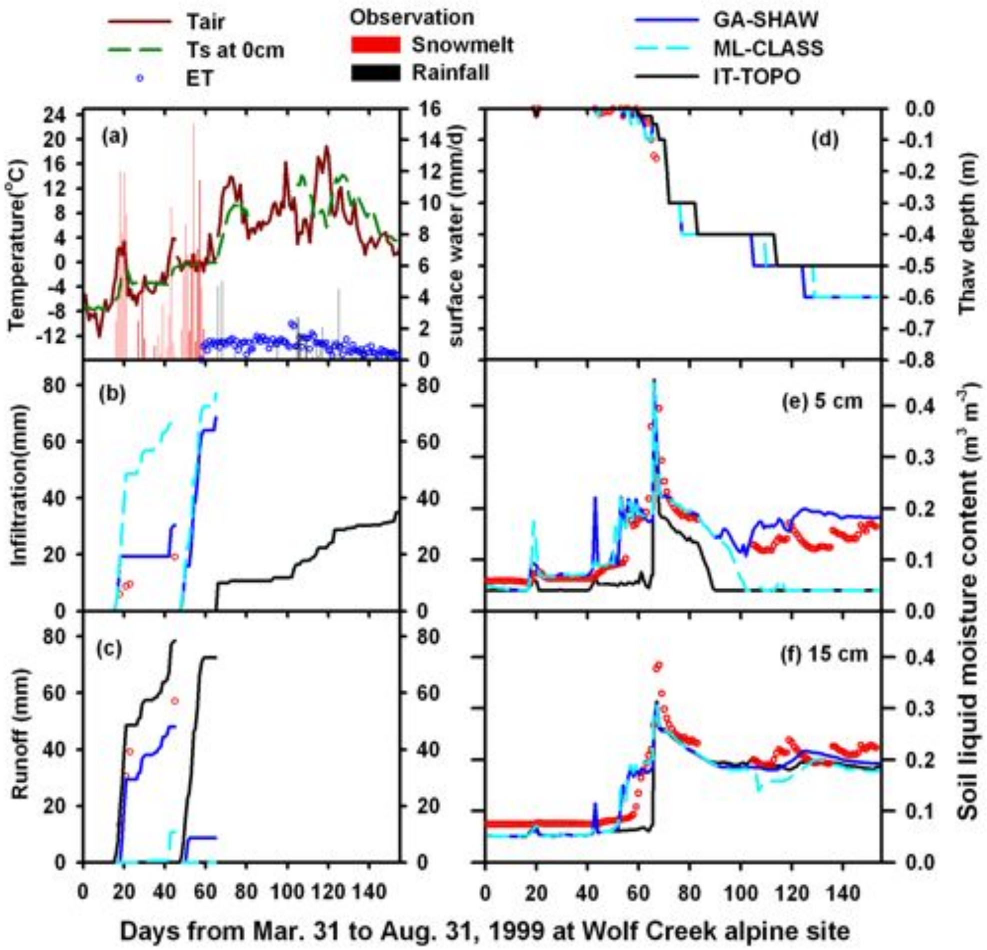


Wolf Creek Forest Site



Results-surface water infiltration algorithms (II)

Wolf Creek Alpine Site



Comparisons of infiltration (mm) by observation and simulations during three ground thawing stages

Site	Method	Frozen	Thawing	Thawed
Scotty Creek	Observation	24.0	80.0	--
	GRAY-IN	16.8		--
	ZHAO-IN	44.8	--	--
	GA-SHAW	14.1	84.0	170.0
	ML-CLASS	23.0	78.0	170.0
	IT-TOPO	11.2	69.6	170.0
WC Forest Site	Observation	-	>33.8	-
	GRAY-IN	38.8		--
	ZHAO-IN	10.1	41.0	--
	GA-SHAW	4.5	59.8	83.5
	ML-CLASS	4.5	59.8	83.5
	IT-TOPO	0	18.2	83.5
WC Alpine Site	Observation	19.1	--	--
	GRAY-IN	49.6		--
	ZHAO-IN	29.7	7.7	--
	GA-SHAW	30.5	68.7	34.9
	ML-CLASS	67.9	77.3	34.9

Conclusions (I)

- All the empirical and semi-empirical algorithms are subject to site specific parameter calibration, thus are not suitable for LSMs and HMs that normally operate across various site conditions.

- Numerical models with an apparent heat capacity treatment gives the most accurate thaw/freeze simulation, yet requires:
  - -- appropriate time and spatial resolutions.
  - -- accurate ground surface temperature inputs.

Conclusions (II)

- Both analytical algorithms modified for non-uniform soil from Green-Ampt and Mein-Larson are recommended for simulation in infiltration into organic covered permafrost soils, yet requires:
  -- appropriate parameterisation of soil thermal and hydraulic properties
  -- accurate representation of ground thawing depth

- For unfrozen water parameterisation, the segmented linear function is the easiest to be parameterised, while the water potential–freezing point depression relation is the best choice for coupled numerical simulation of soil thermal and moisture transfers.

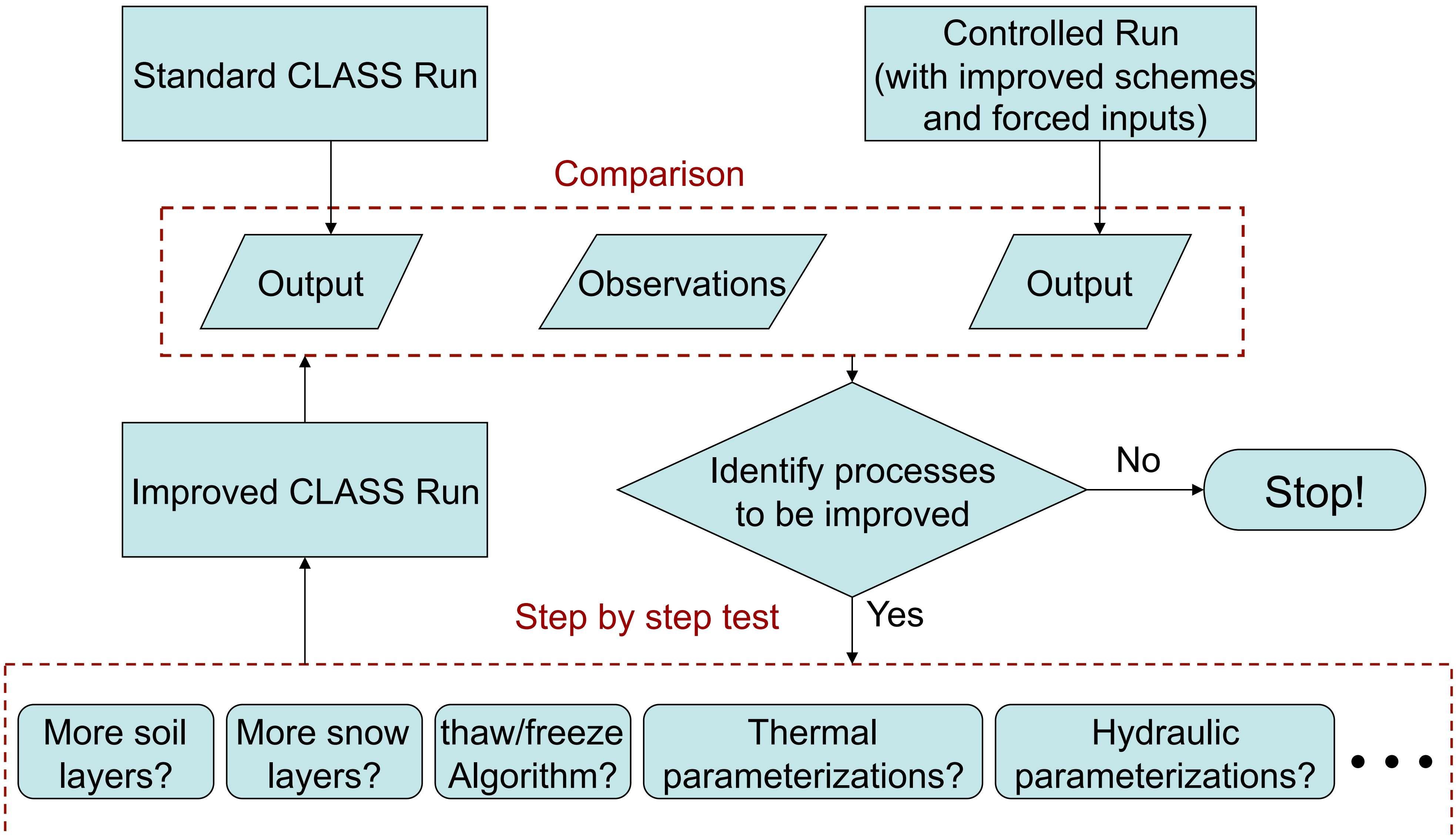
Conclusions (III)

- For soil thermal conductivity parameterization, the De Vries' method is recommended.

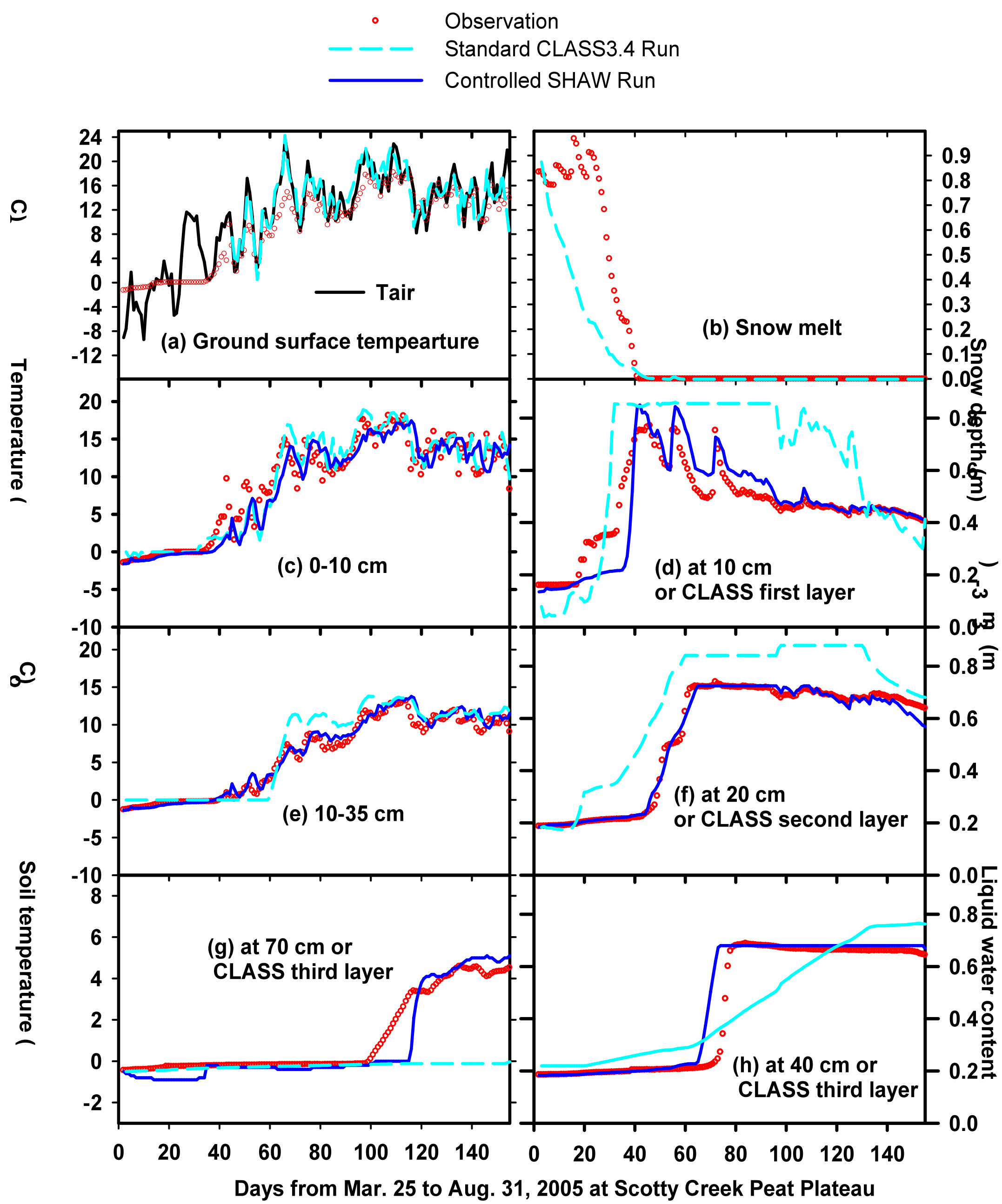
- For soil hydraulic parameterization, van Genuchten's is applicable over all soil moisture ranges, but its application was restricted by parameter availability. Brooks-Corey and Clapp-Hornberger's have better parameter availability, yet special treatment must be arranged for saturated, extremely dry or frozen soil conditions.

- The various ice impedance factors currently employed in many LSMs and HMs may not be necessary once the water potential, soil temperature and hydraulic conductivity relationships were applied.

Preliminary investigations in implementation of the improved algorithms/parameterisations into CLASS/MESH



Preliminary investigations



Standard CLASS3.4 Run

- --Standard CLASS inputs
- --Surface temperature and snow melt is simulated
- --3 soil layers (0.1m, 0.25m, 3.75m) to 4.1 m soil depth

Controlled SHAW Run

- --Forced inputs
- --Observed surface temperature and snow melt is used
- --16 soil layers to 5 m soil depth

Some preliminary results and problems faced

- The CLASS thermal simulation were good for upper two layers, but the thermal responses below 0.35m were much delayed. More and finer soil layers suggested.

- More snow layers might be needed in order to improve snowmelt simulation, which is crucial for soil water simulations.

- Major problems encountered in running CLASS3.4 were frequent unusual stops of model run due to failures in canopy or ground surface energy solvers: “TSOLVC” and “TSOLVE”, more expertise in setting the initial file “*.ini” is required.

References and Acknowledgement

- More information could be found in the following publications:

--Zhang, Y., Carey, S. K., Quinton, W. L., Janowicz, J. R. and Flerchinger, G. N., 2009. Comparison of algorithms and parameterisations for infiltration into organic-covered permafrost soils, Hydrology and Earth System Sciences Discussions, 6, 5705-5752.

-- Zhang Y., Carey, S. and Quinton, W., 2008. Evaluation of the algorithms and parameterizations for ground thawing and freezing simulation in permafrost regions. Journal of Geophysical Research, 113, D17116, doi: 10.1029/2007JD009343.

-- Quinton, W. L., Bemrose, R. K., Zhang, Y. and Carey, S. K., 2009. The influence of spatial variability in snowmelt and active layer thaw on hillslope drainage for an Alpine tundra hillslope, Hydrological Processes, DOI: 10.1002/hyp. 7327.

- Please also see the poster in this workshop entitled "Parameterizations of organic-covered permafrost soils in land surface and hydrological models"

- We acknowledge the following who contributed to this work with data, models and ideas (alphabetically): **C.R. Burn, B. Davison, G.N. Flerchinger, L.E. Goodrich, M. Hayashi, J.R. Janowicz, M. MacDonald, M. Mollinga, C. Marsh, J. Pomeroy, F. Seglenieks, R. Soulis, W.L. Quinton, D. Verseghy, M-K. Woo, N. Wright, S. Yi and Yu Zhang ….**