H45I: Evaluating Soil Freeze Thaw Approaches for Hydrologic Models Using the Next Generation Water Resources Modeling Framework

Ahmad Jan[1,2], *Fred L. Ogden*[2], *Luciana Kindl da Cunha*[3], *Rachel McDaniel*[2], *Trey Flowers*[2], *Keith Jennings*[1]

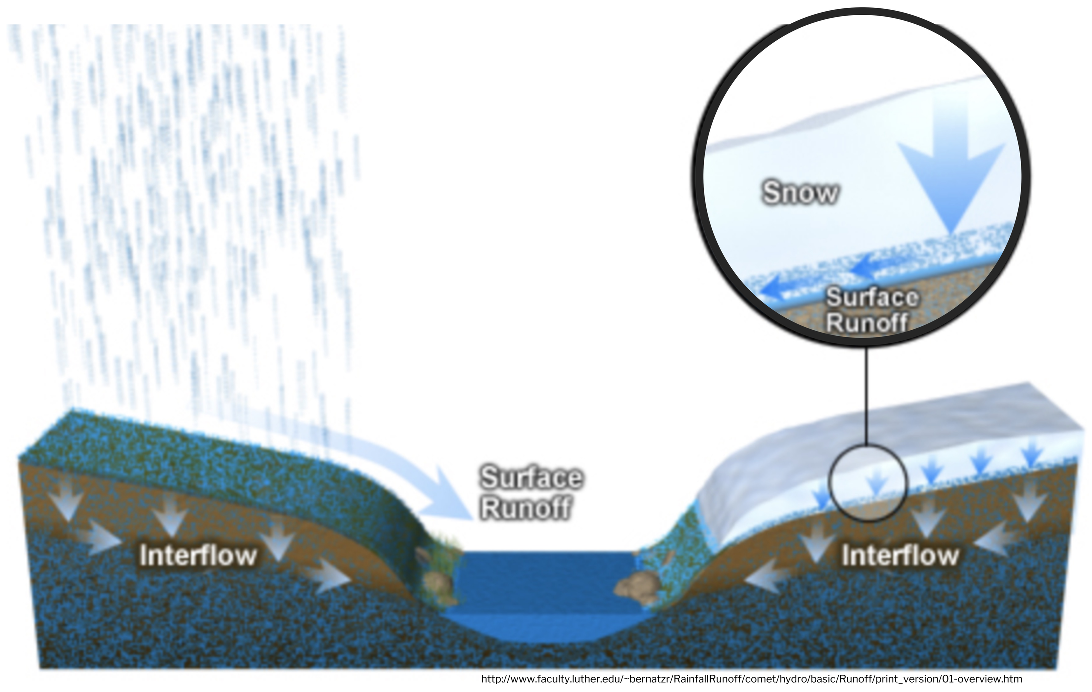
Presenting author's email: ahmad.jan@noaa.gov

[1]Lynker Technologies, LLC, [2]NOAA Office of Water Prediction, National Water Center, [3]WEST Consultants

OWP OFFICE OF WATER PREDICTION

I. Seasonally Frozen Soil

- Thermal seasonality (frozen/unfrozen state of the soil) strongly controls the partitioning of precipitation between runoff and infiltratio.



- Frozen soils prevent vertical movement of water, which increases the potential for high runoff

II. Heat Diffusion Equation

A physically based energy equation is implemented to model the vertical transport of heat in soil[1].

$$C(\theta)\frac{\partial T}{\partial t} = \frac{\partial}{\partial z}\left(K(\theta)\frac{\partial T}{\partial z}\right) + \rho_{ice} L_f \frac{\partial \theta_{ice}}{\partial t}$$

$C(\theta)$: Effective volumetric heat capacity [J/(m³ K)]
$K(\theta)$: Soil thermal conductivity[2] [W/(m K)]
L_f : Latent heat of fusion [J/kg]

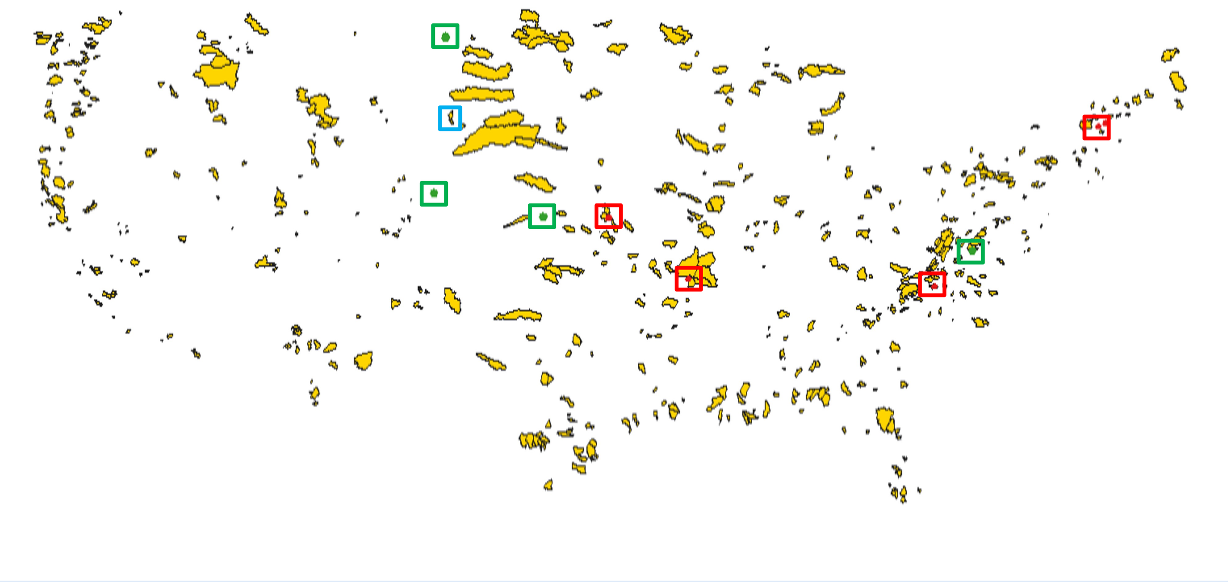
The model uses a freezing-point depression equation for phase partitioning between water and ice.

The last term on the right side represents the latent heat released/consumed during the phase change.

Soil freeze-thaw processes can be effectively simulated in a 6 m computational domain using the NextGen Framework

V. Field sites

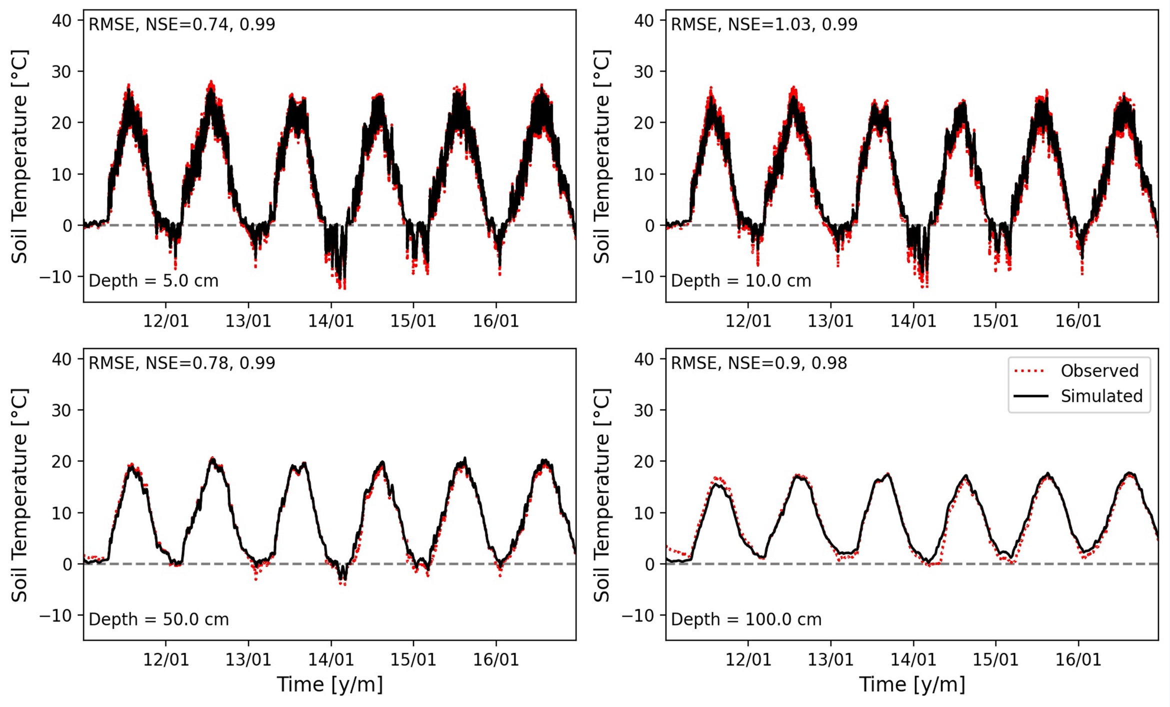
- *CAMELS basins (in yellow),
- **SCAN sites (in red) that overlap with CAMELS basins
- Selected SCAN sites (in green) for the evaluation of freeze-thaw model against observed soil temperatures
- Sites in red are not well suited for evaluation as soil hardly freezes there
- The CAMELS basin in the blue box is used for analysis and in the sensitivity study



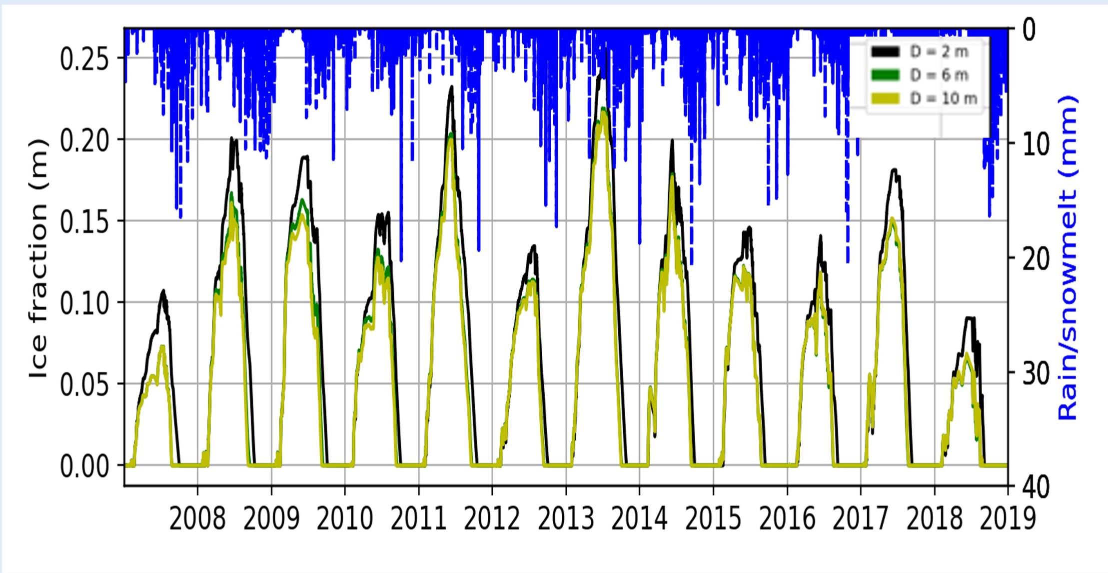
* CAMELS: Catchment Attributes and Meteorology for Large-Sample Studies
** USDA Soil Climate Analysis Network (SCAN)

VI. Results

- The figure compares observed and simulated soil temperatures at several depths for the USDA SCAN site in Montana.
- Diffusion equation can accurately simulate the transport of energy in soils provided accurate boundary conditions and soil moisture profiles
- Resolution: Top 10 cm in 5 cm cells, and the rest of the domain in 10 cm
- Nash-Sutcliffe efficiency (NSE) for the four depths is greater than 0.93, which indicates a good match between the observed and simulated data

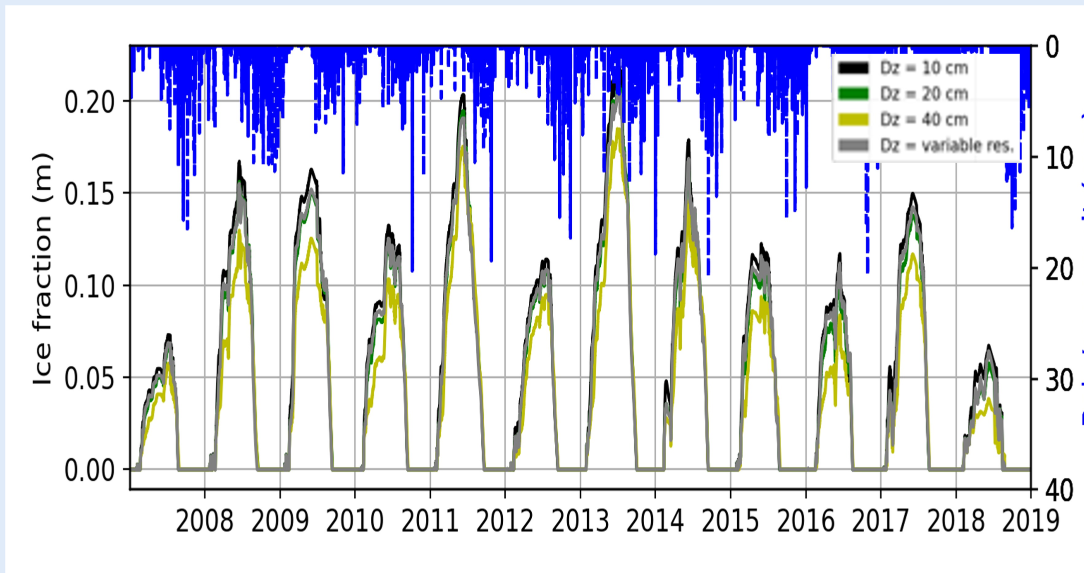


Sensitivity of ice content to the depth of model domain



The figure shows that shallow domains predict more ice content and may lead to bottom boundary artifacts. Shallower domains may overestimate runoff due to more ice content caused by colder soil conditions in winters

Sensitivity of ice content to soil discretization



The figure shows that coarser resolutions predict less soil ice and thus causing reduction in the direct surface runoff. This sensitivity decreases for drier soil conditions.

Conclusion: 6 m computational domain with variable resolution[3] can accurately simulate processes in seasonally frozen soils using the NextGen Framework

III) Model setup

Boundary conditions

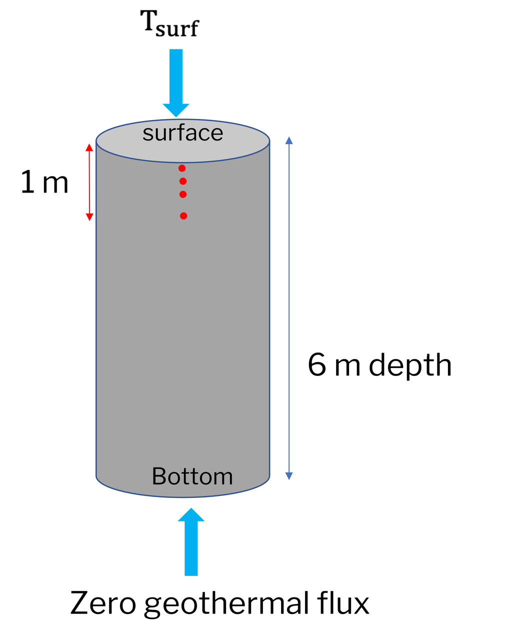
The land surface and lower soil column at 6 m depth are subject to hourly ground temperature and zero geothermal flux boundary conditions, respectively.

Land surface boundary condition

$$T_{surf} = ST_5 + \begin{cases} \alpha\,\Delta T, & \text{if } \Delta T \geq 0 \\ \beta\,\Delta T, & \text{if } \Delta T < 0. \end{cases}$$

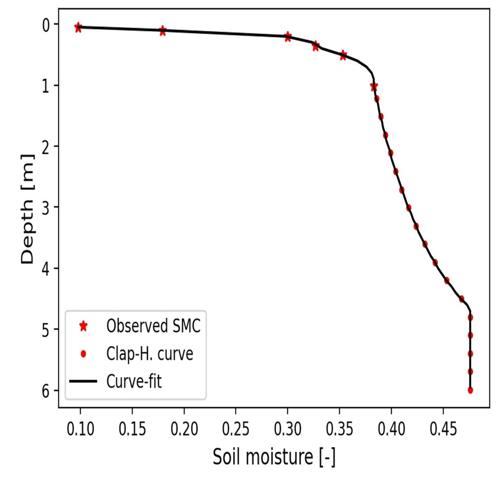
$$\Delta T = ST_5 - ST_{10}$$

- Observed soil temperature and moisture content



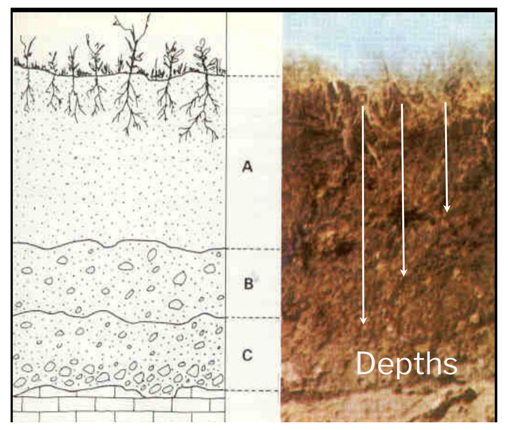
Soil moisture characterization

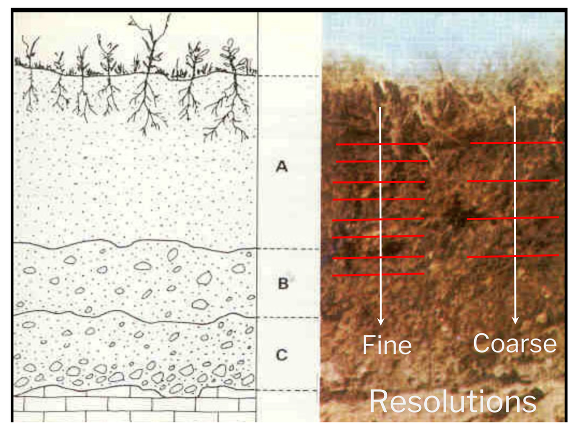
- Get observed soil moisture values for the top 1 m soil from SCAN sites
- Assuming continuity of soil moisture at 1 m depth, for the rest of the soil, we extend the soil moisture curve using the Clapp-Hornberger water retention function
- For high-resolution simulations, a spline curve is used to fit the soil moisture data



IV) Sensitivity study

A sensitivity study of soil ice content to computational domain depth and soil discretization is performed to determine an appropriate choice for domain depth and discretization





REFERENCES:
[1]https://github.com/NOAA-OWP/SoilFreezeThaw
[2]Peters-Lidard, C. D., Blackburn, E., Liang, X., & Wood, E. F. (1998). The Effect of Soil Thermal Conductivity Parameterization on Surface Energy Fluxes and Temperatures, *Journal of the Atmospheric Sciences*, *55*(7), 1209-1224
[3]Hermoso de Mendoza, I., Beltrami, H., MacDougall, A. H., and Mareschal, J.-C.: Lower boundary conditions in land surface models – effects on the permafrost and the carbon pools: a case study with CLM4.5, Geosci. Model Dev., 13, 1663–1683, https://doi.org/10.5194/gmd-13-1663-2020, 2020.

CONTACT
Website: https://water.noaa.gov
Email: nws.nwc@noaa.gov

View my poster, GitHub repository and other AGU materials

Poster Repository