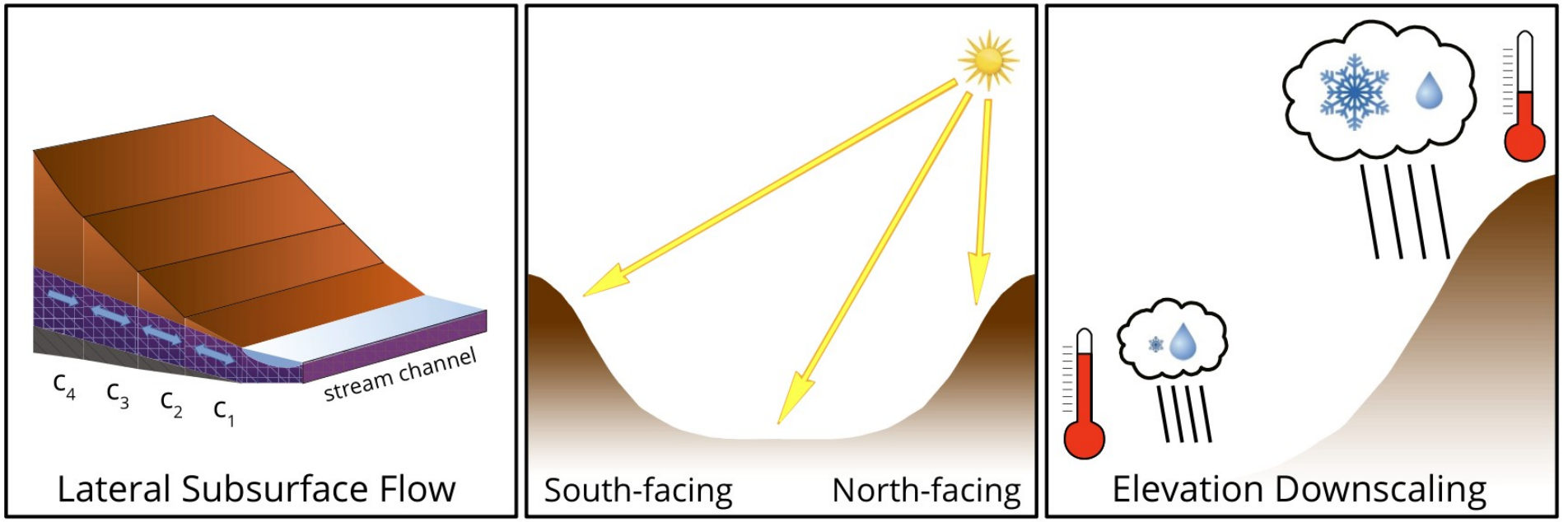
Update of the "Hillslope Hydrology" Configuration of CTSM

Some key features of the Hillslope Hydrology configuration

- A multi-column instantiation of CTSM
- Based on the concept of representative hillslopes
- Subsurface runoff is passed between columns
- Bidirectional stream – soil column interactions
- Slope, aspect, and elevation -based meteorological downscaling

Topography-informed processes



Update: Global hillslope dataset now available

A global dataset of hillslope geomorphic properties has been created based on MERIT 90m DEM data

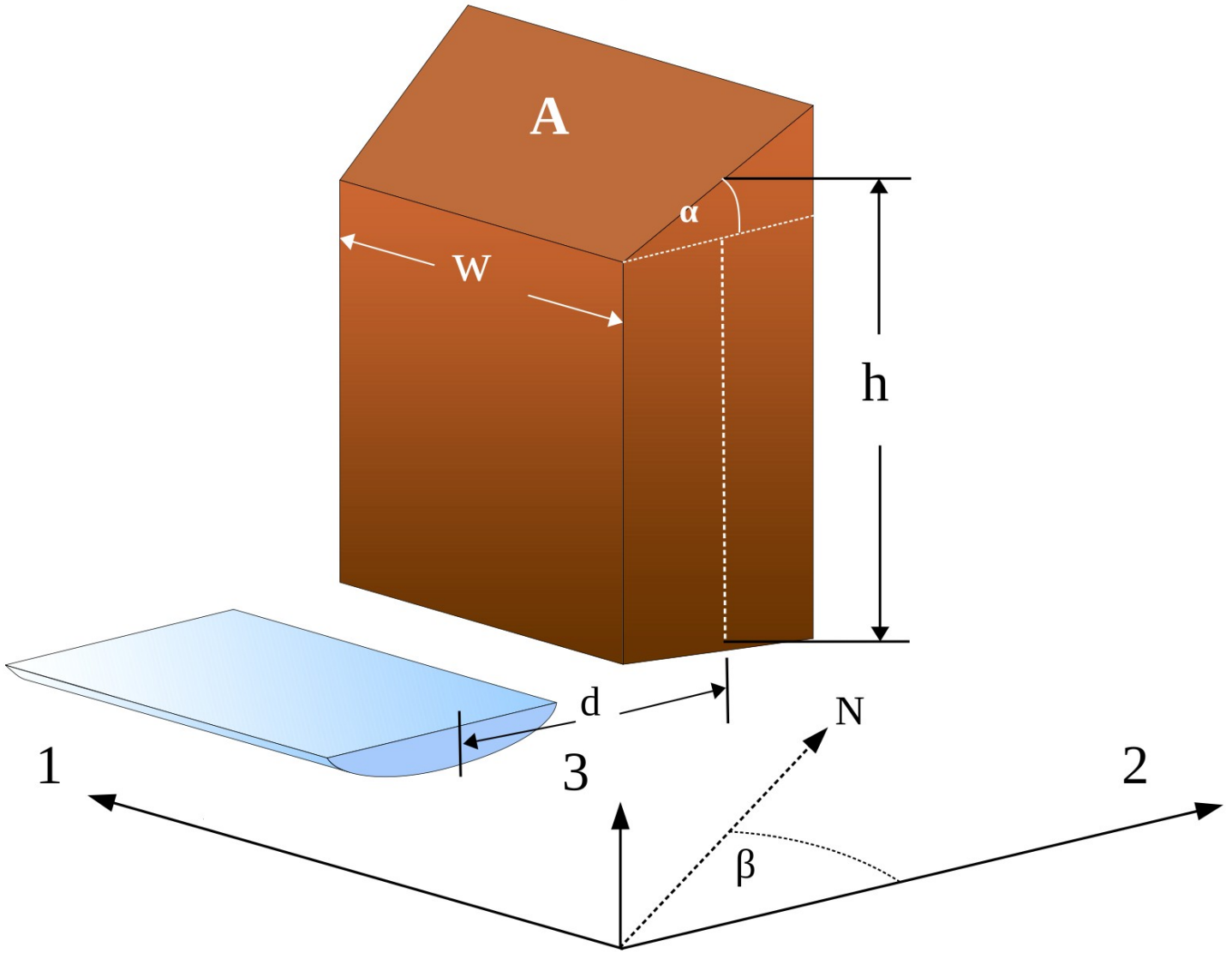
Properties include: height, distance, slope, aspect, width, and area

Method published:

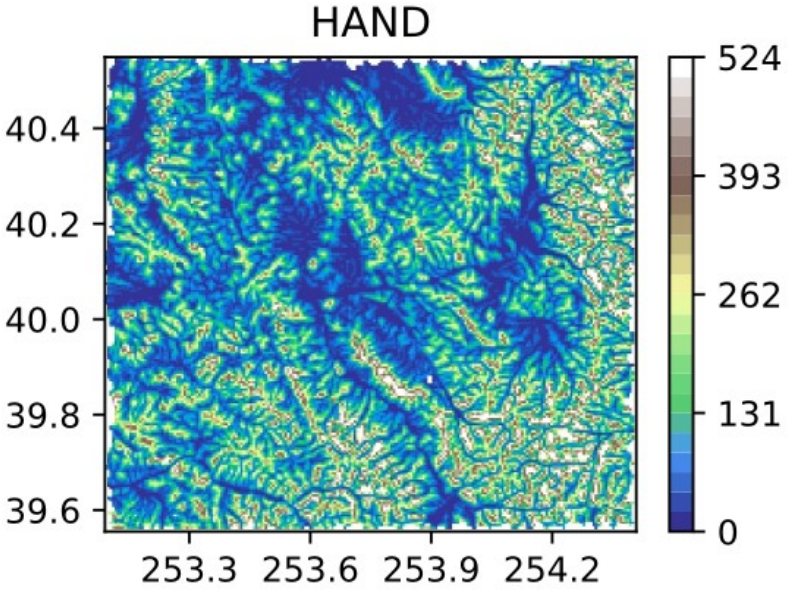
Swenson & Lawrence, 2025

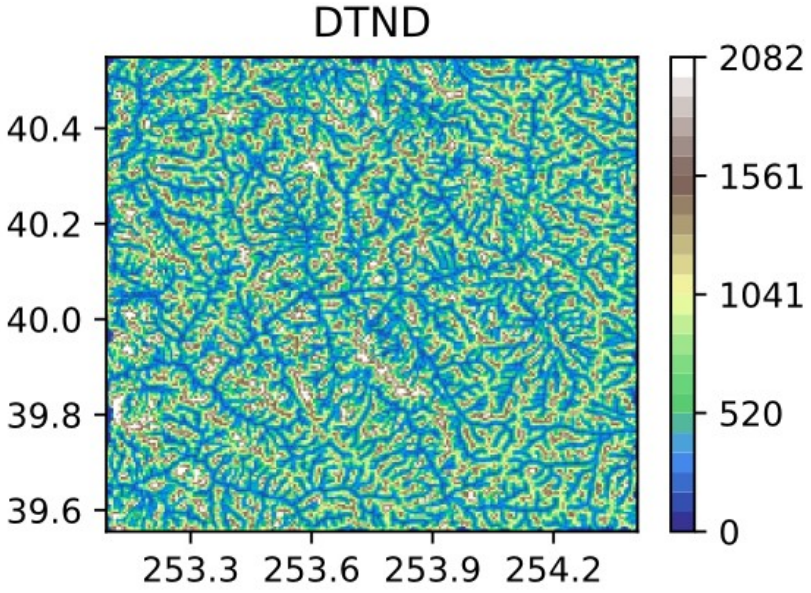
"Development of a global representative hillslope dataset for use in Earth system models", Journal of Advances in Modeling Earth Systems,17, https://doi.org/10.1029/2024MS004410

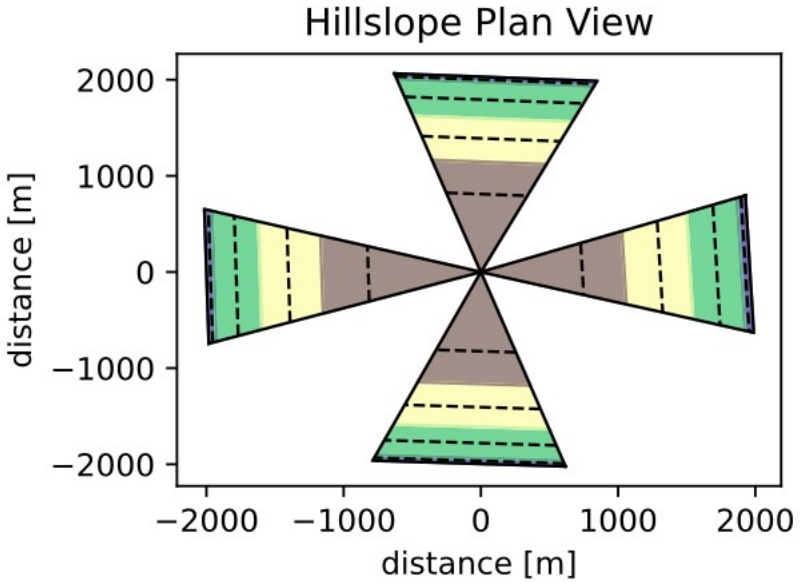
Hillslope geomorphic parameters

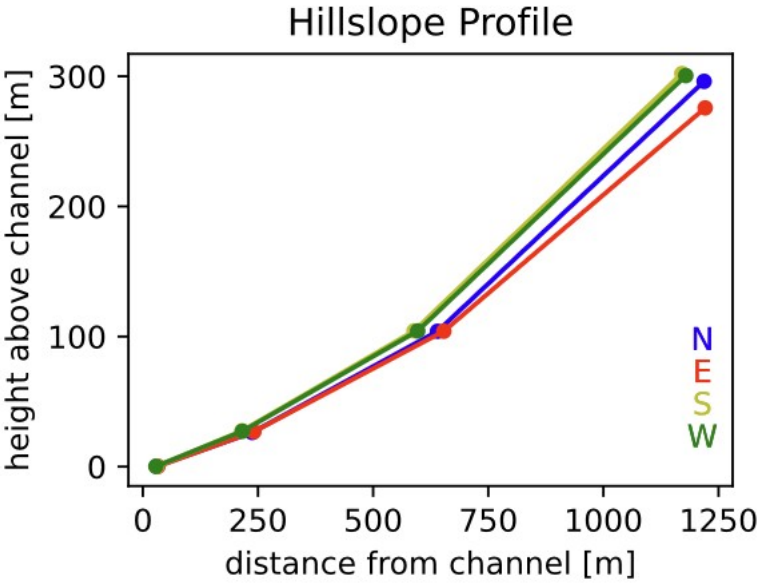


Hillslope geomorphic parameters

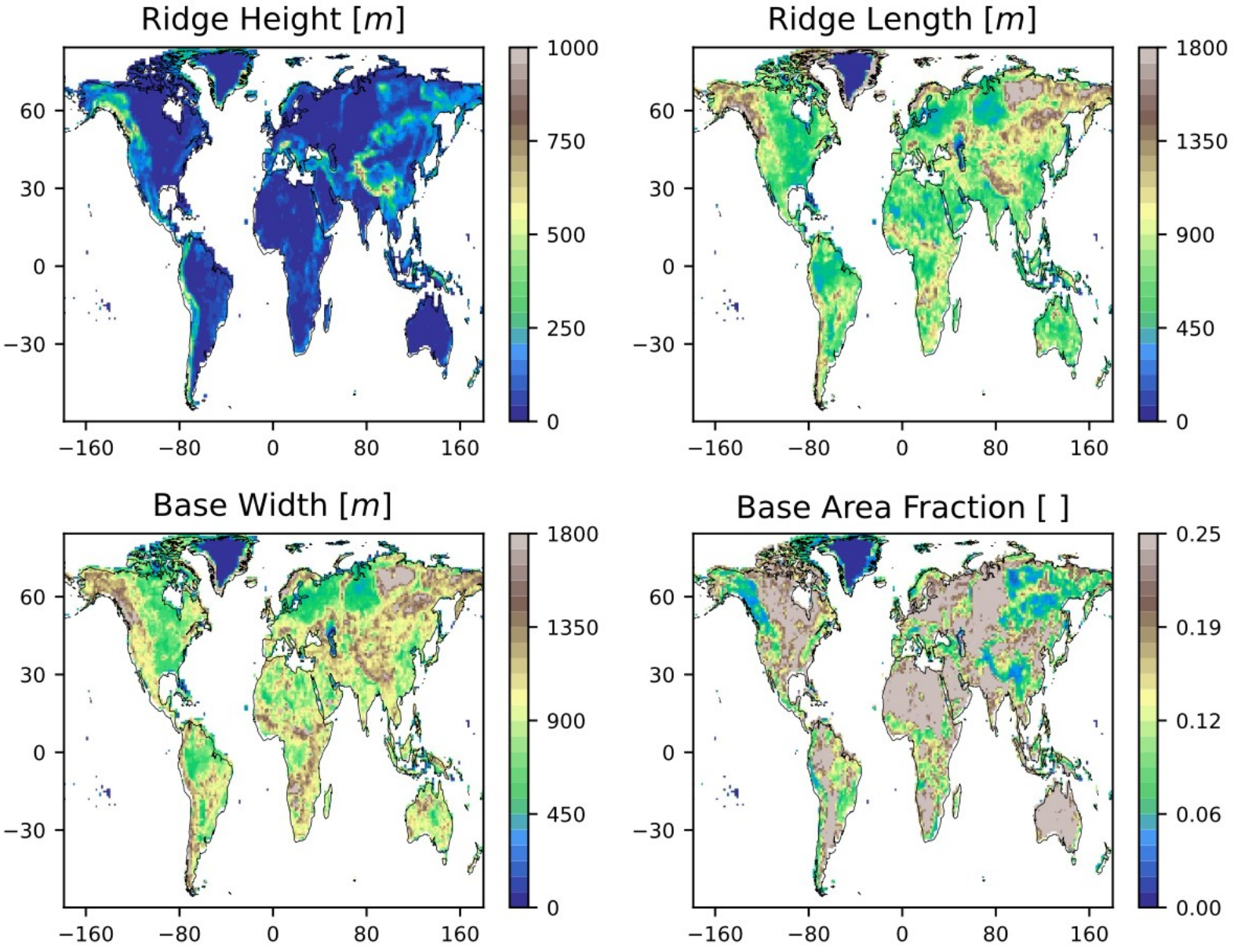








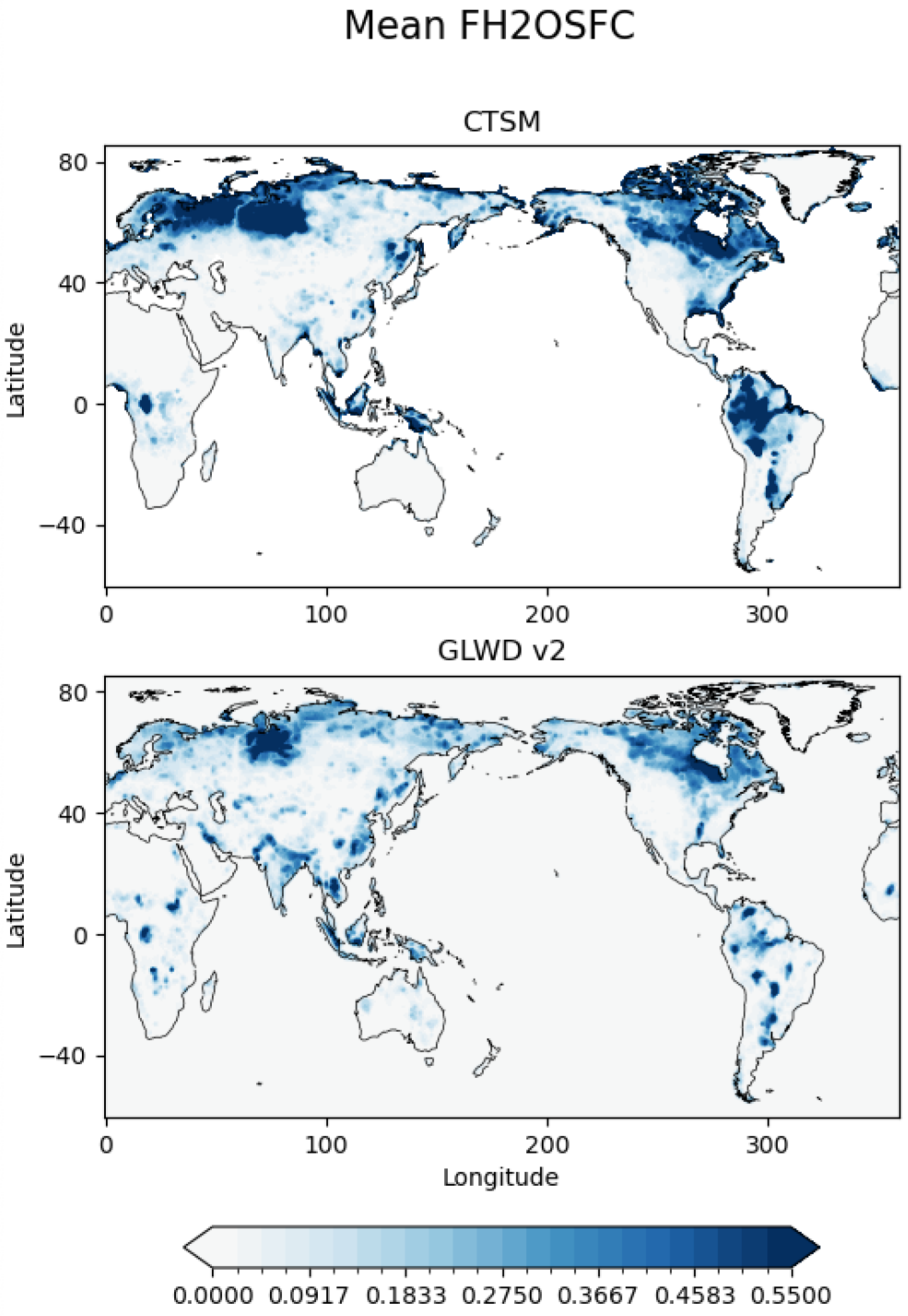
Hillslope geomorphic parameters



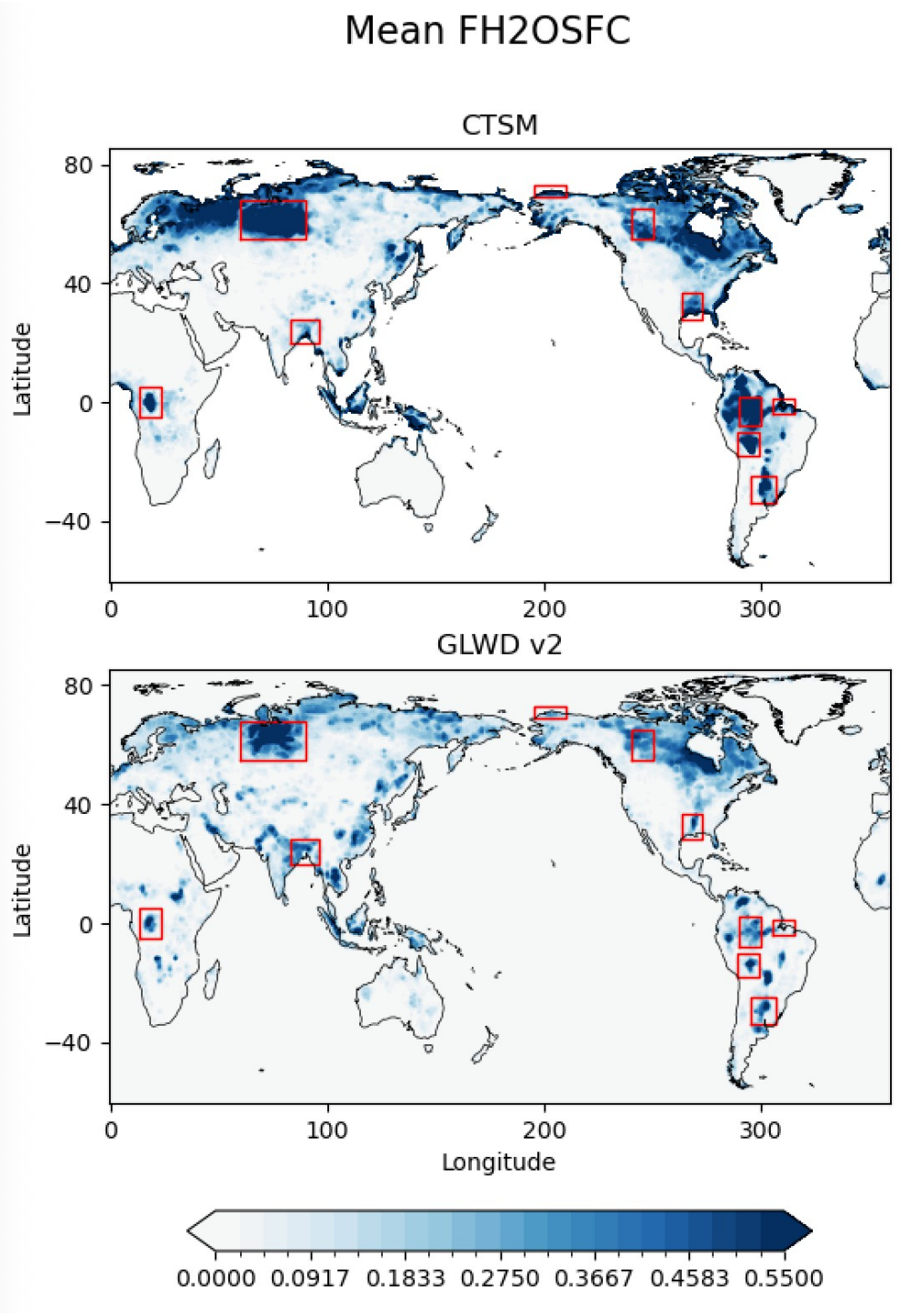
Prognostic Wetlands

- Standard CTSM unable to realistically simulate inundation spatial extent
- Observation-based inversion method used to diagnose inundation
- Hillslope model enables use of prognostic inundation
- Facilitates terrestrial methane modeling

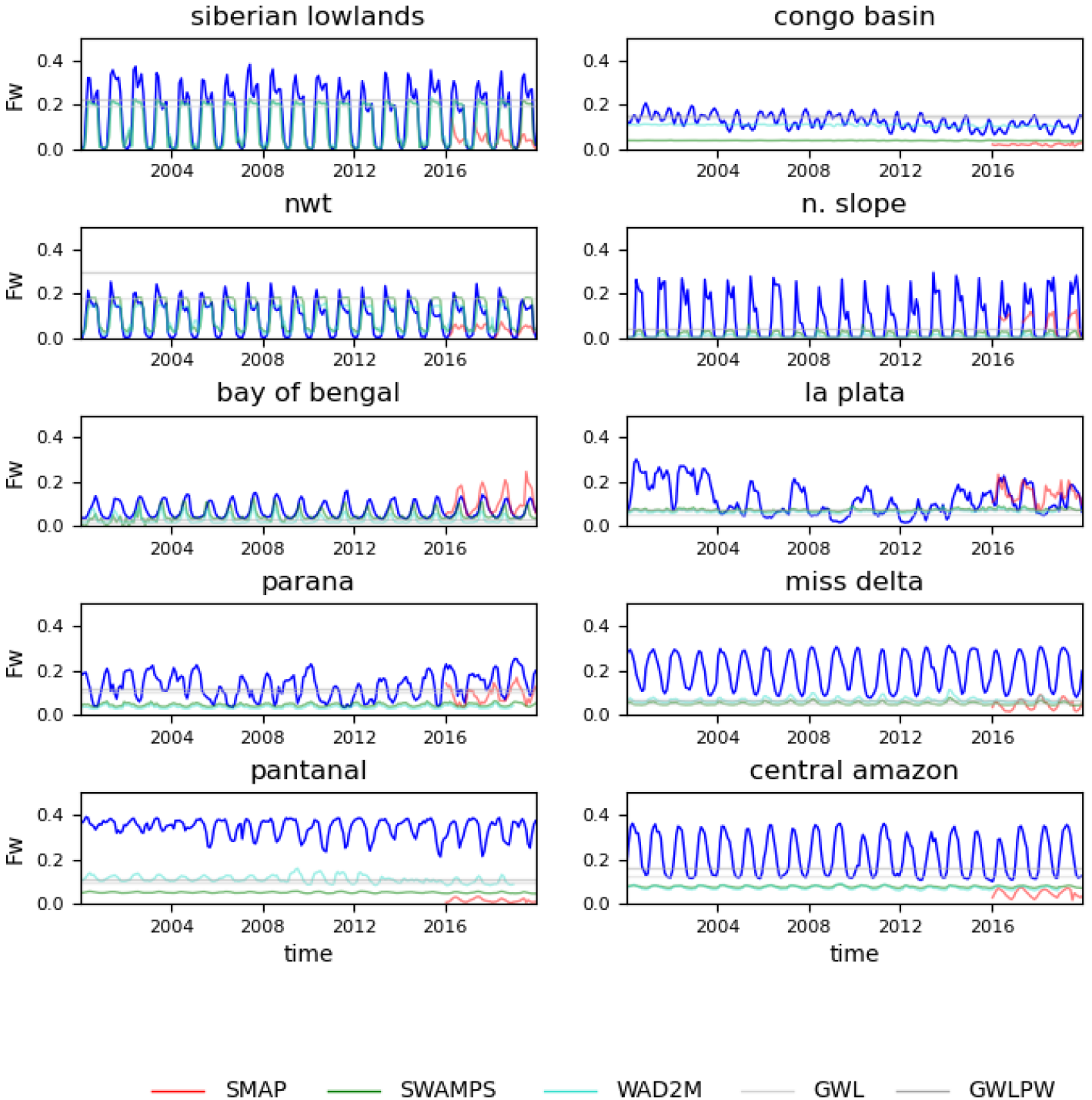
Prognostic Wetlands



Major wetland complexes



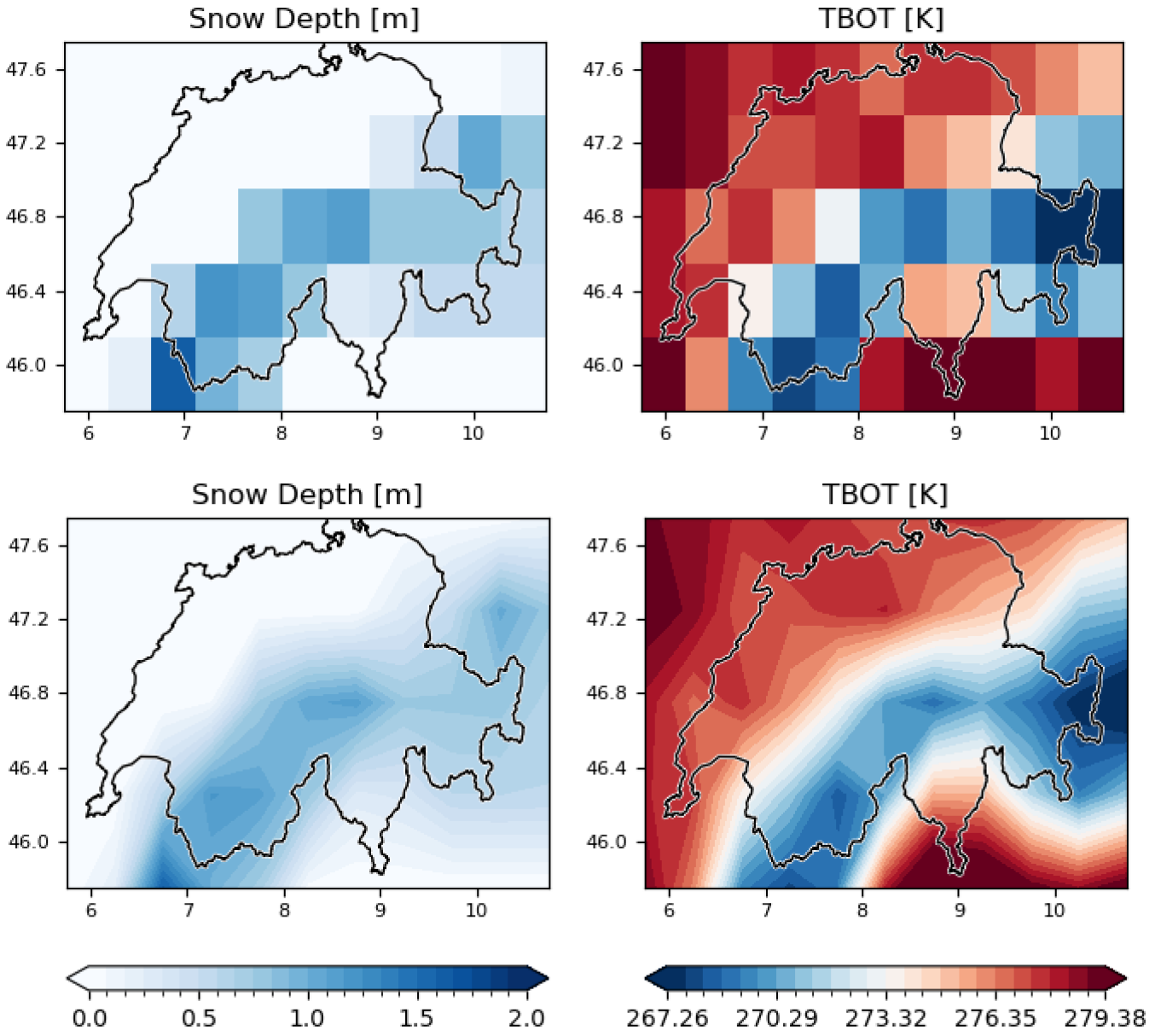
Major wetland complexes



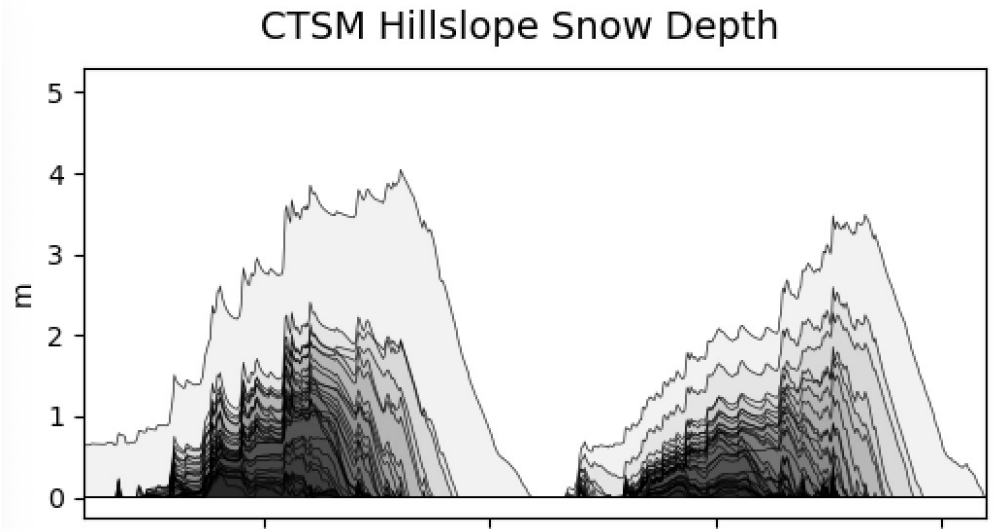
Hyper-resolution snow mapping using machine learning

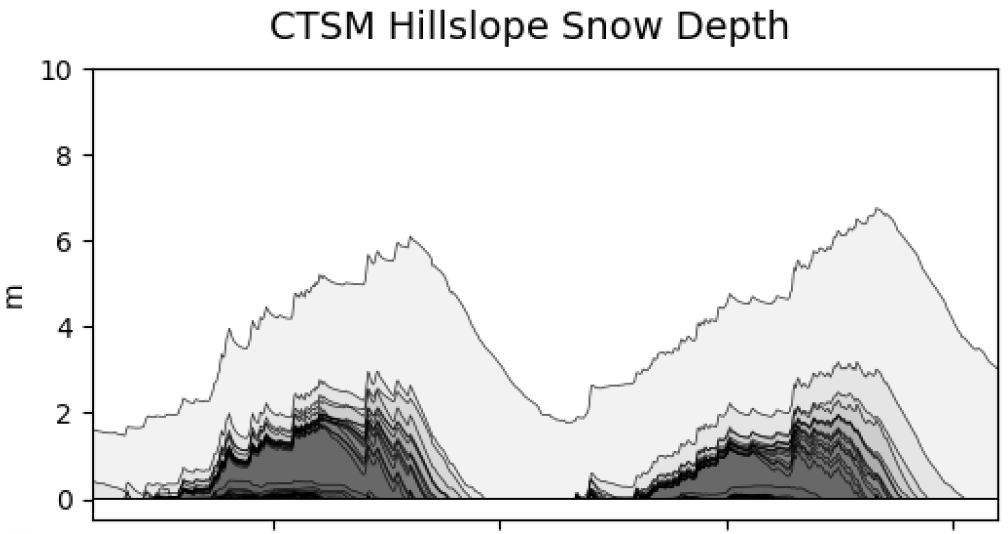
- Hillslope model provides an ensemble of snowpacks within a gridcell
- An ensemble can be used to train a ML emulator
- Predictors include hillslope geomorphic parameters and landcover information
- Predictions can be made at very high (hyper!) spatial resolutions, e.g. 30m

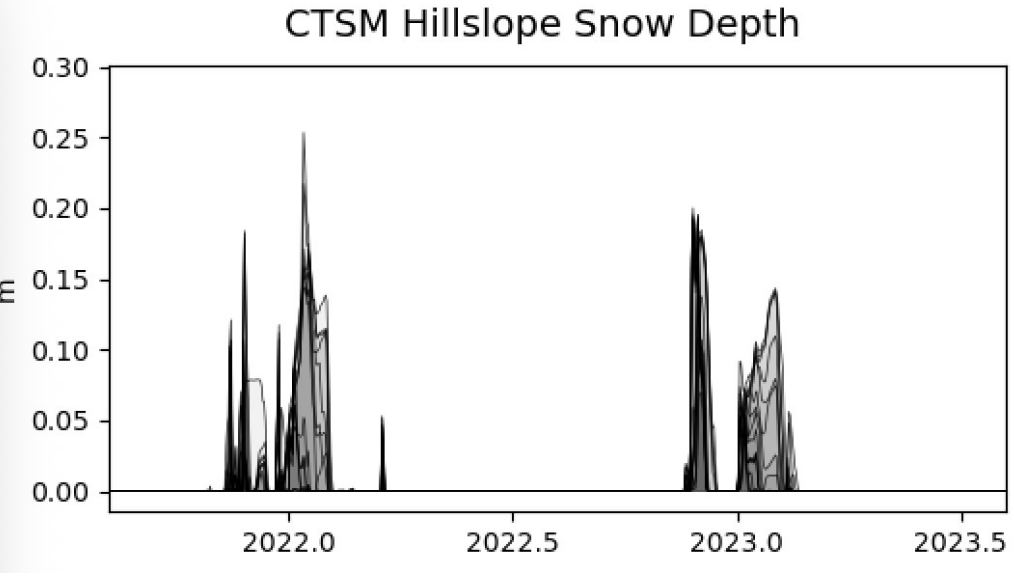
Gridcell Mean Maps (0.5 x 0.5 degree)

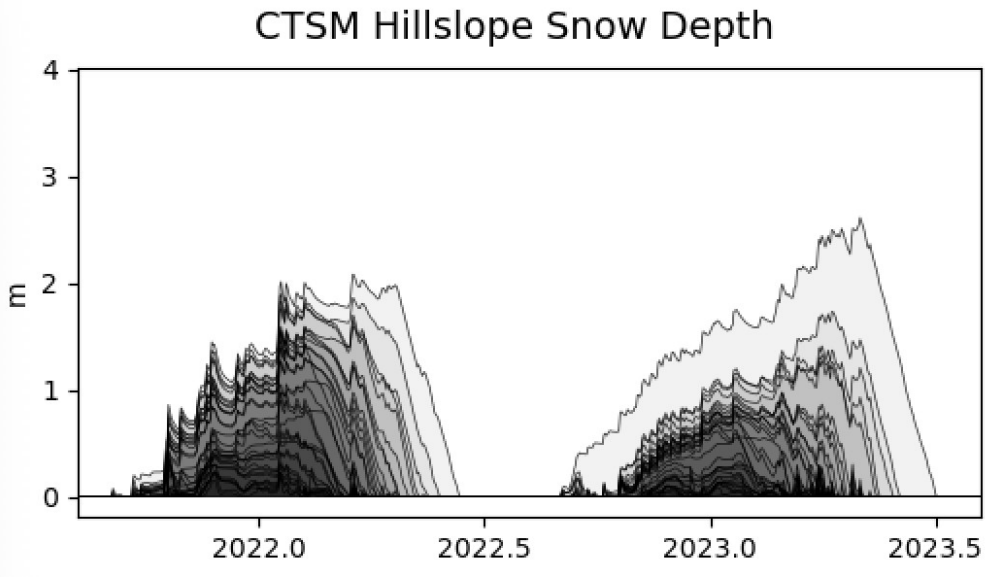


Hyper-resolution snow mapping using machine learning









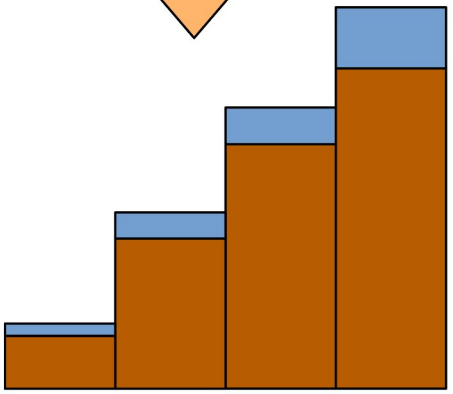
CTSM Hillslope Hydrology Simulation

Explicit representation of topographic effects

Downscaled shortwave radiation and meteorology

Subsurface lateral water flow

Predicts mass balance of discrete hillslope columns



Each gridcell contains hillslope columns whose geomorphic properties (e.g. elevation, slope, aspect) vary, providing a distribution of mass and energy balance predictions.

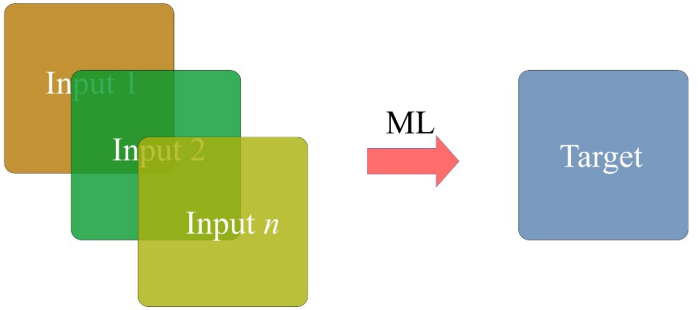
Machine Learning Emulator

Trained with discrete hillslope simulation output

Targets are snow depth and mass balance

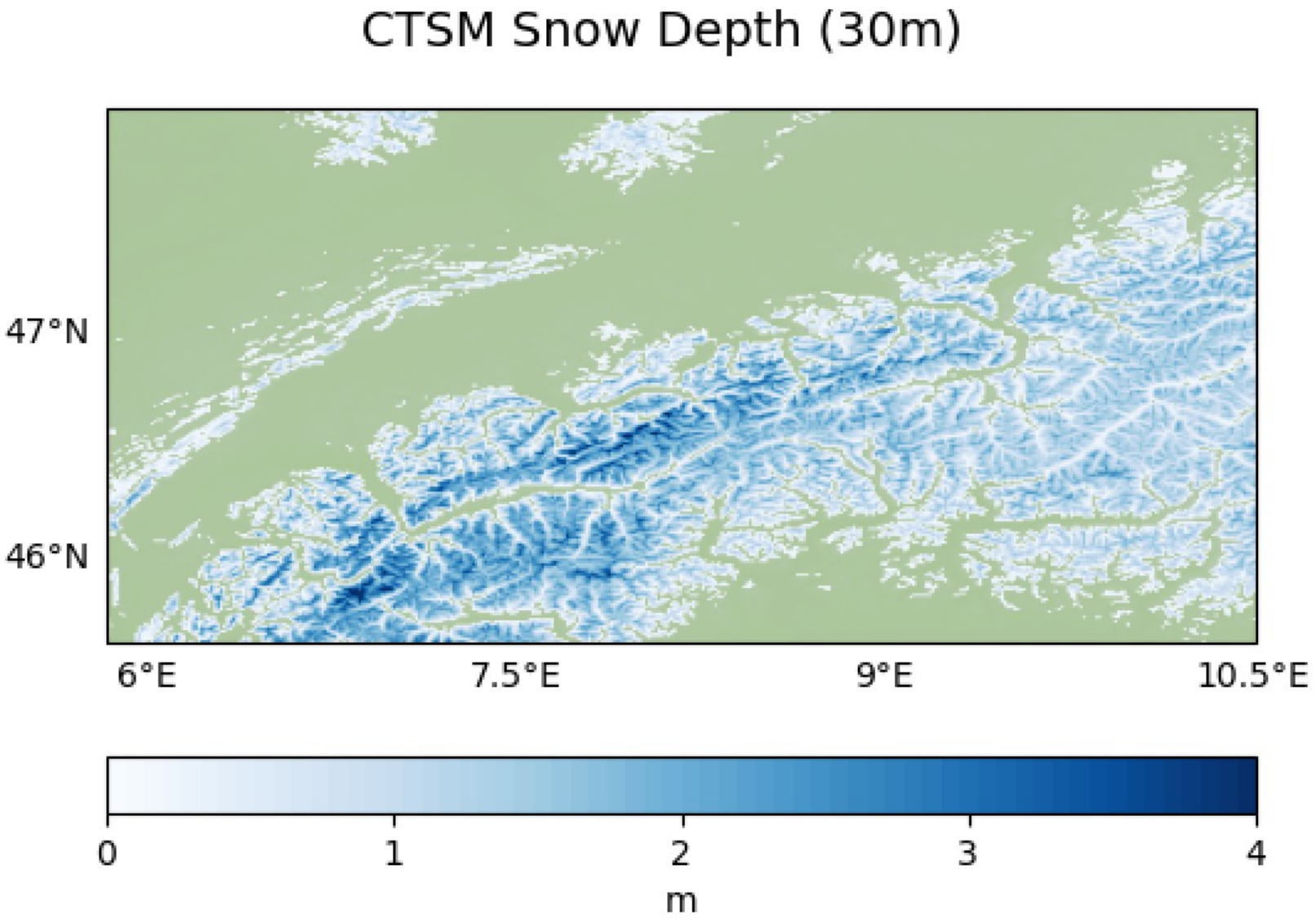
Predictors are hillslope terrain parameters

Provides mass balance for any set of inputs

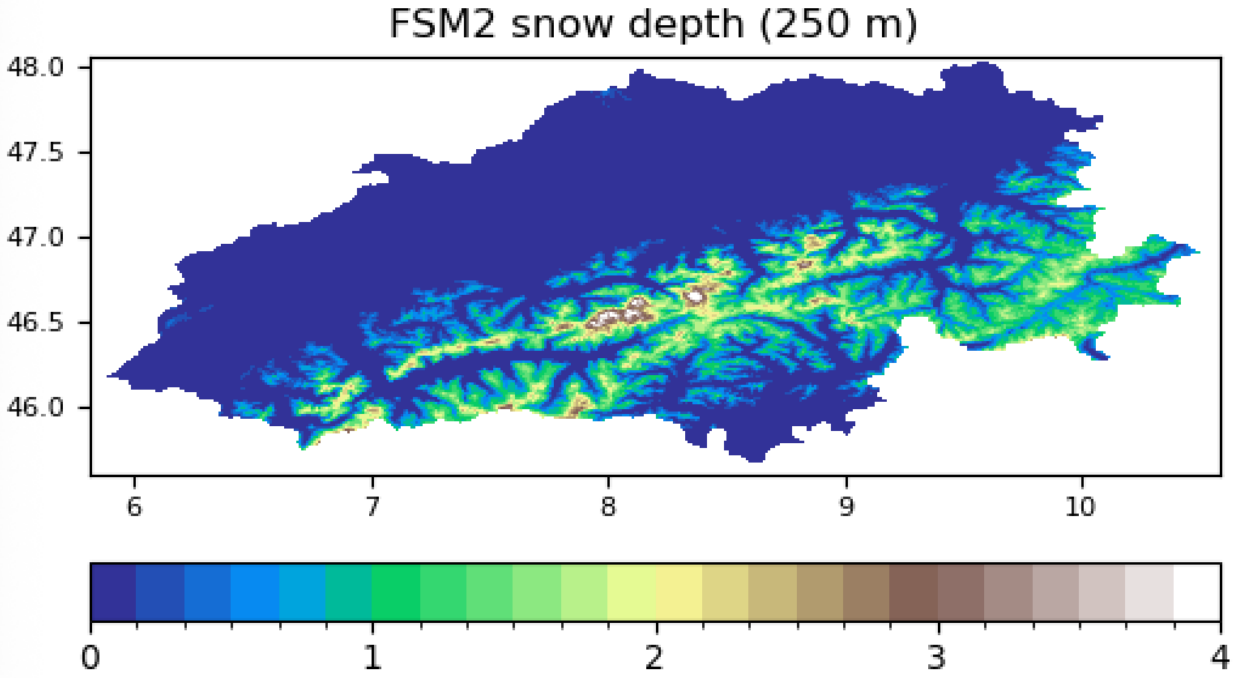


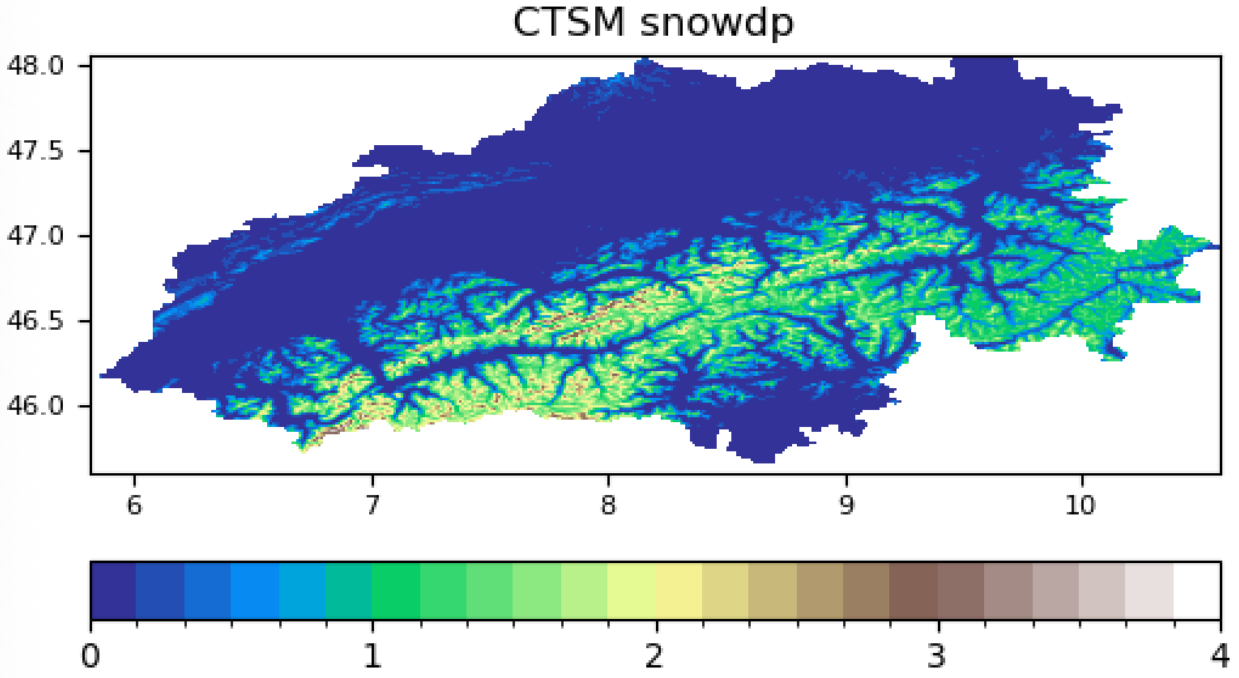
The ML emulator ingests high resolution (e.g. 30m) maps of geomorphic properties and outputs maps of target variables for use in calibration, validation, and CISM boundary conditions.

Snow mapping using machine learning: Swiss Alps



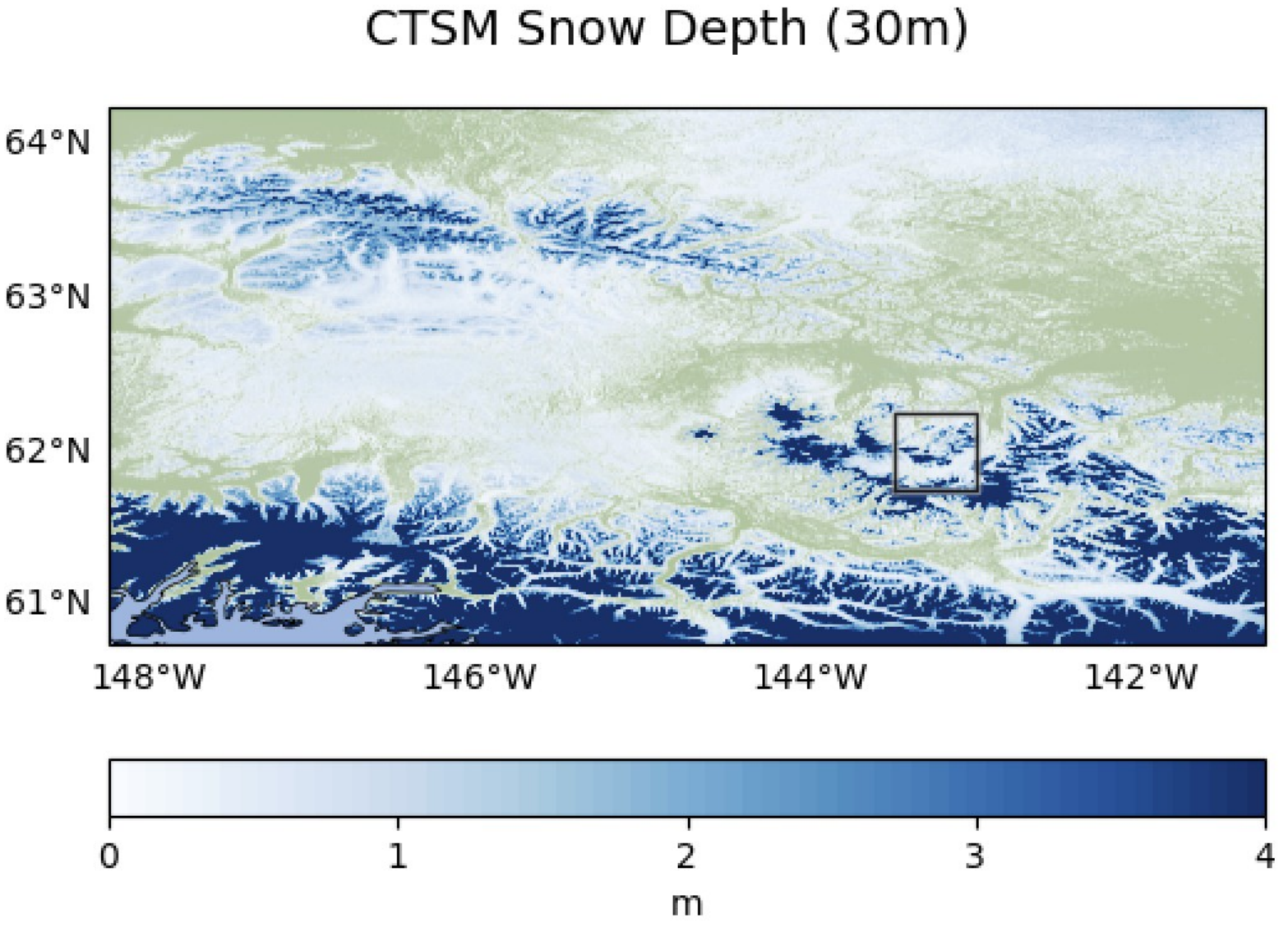
Comparison to a 250m dedicated snow model (FSM)





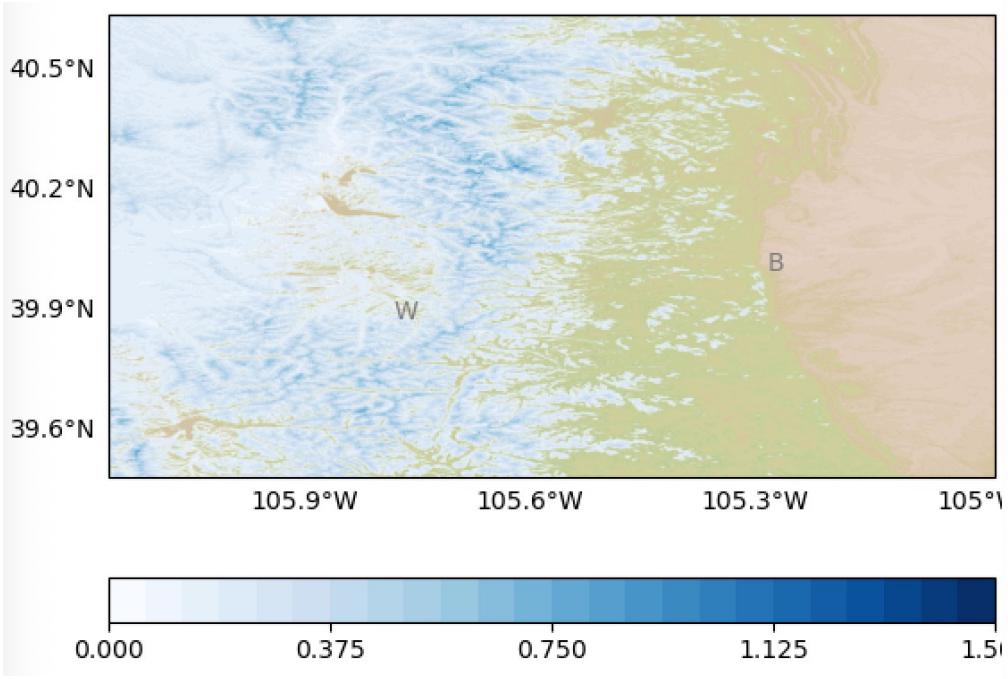
FSM data provided by J. Malle.

Snow mapping using machine learning: Alaskan glaciers

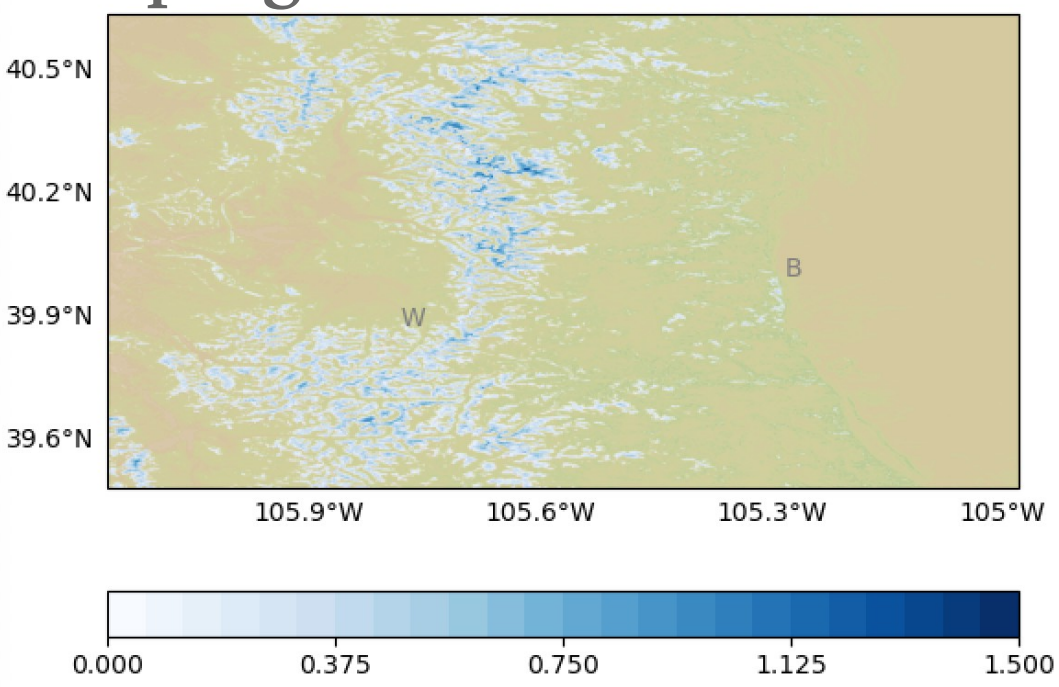


Snow mapping using machine learning: Colorado Front Range

Winter



Spring



Summary

Global hillslope dataset is available and methodology has been published

Hillslope simulations provide capability for prognostic wetland / inundation simulations, which enables terrestrial methane simulations

Machine learning (ML) methods can be used to interpolate in geomorphic parameter space to create hyper-resolution estimates of e.g. snow

Ongoing & Future Work

Calibrating wetland and methane code

Improving ML emulation methods for high resolution interpolation

Applying parameter space interpolation to other quantities

Creating hyper-resolution mountain glacier surface mass balance datasets