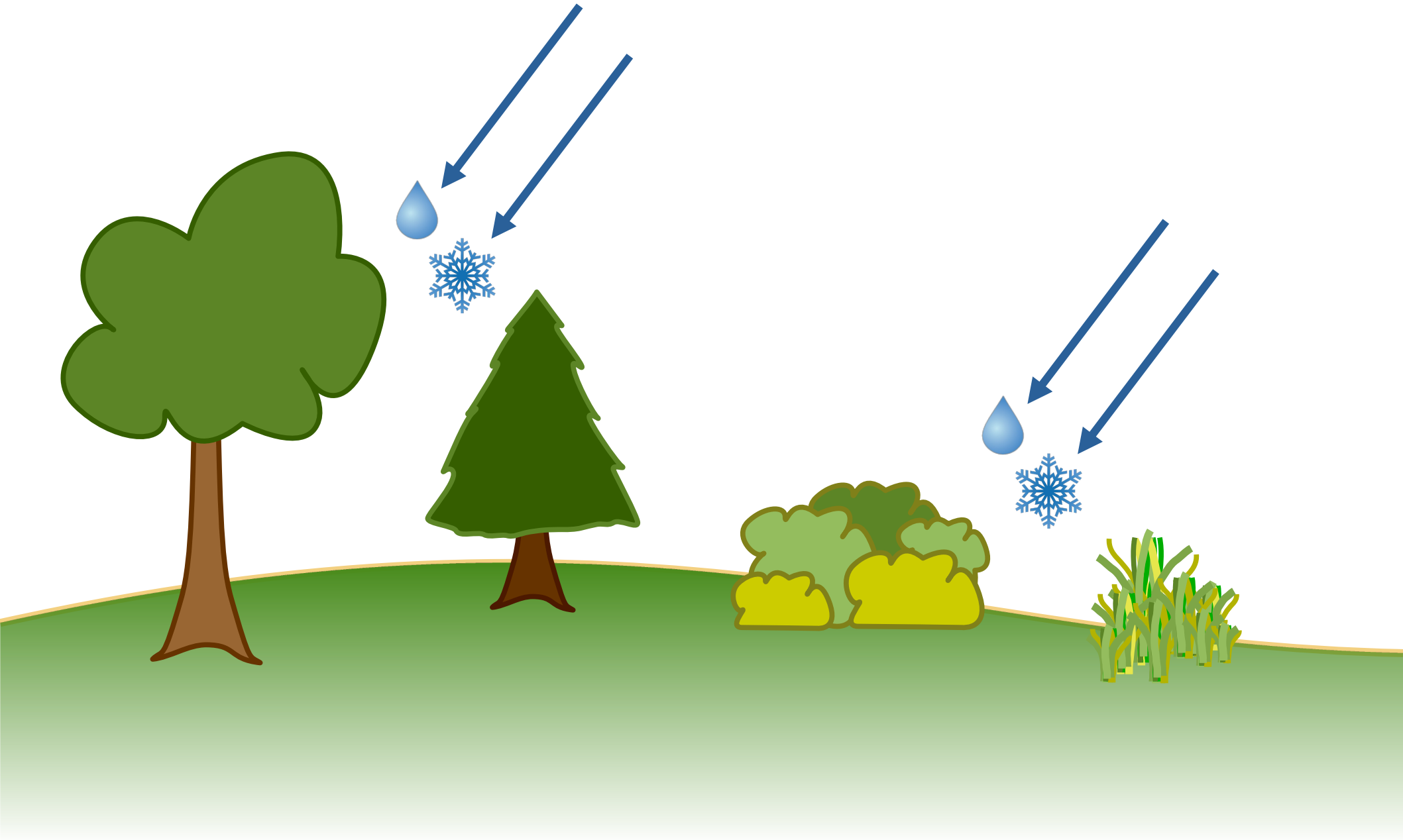
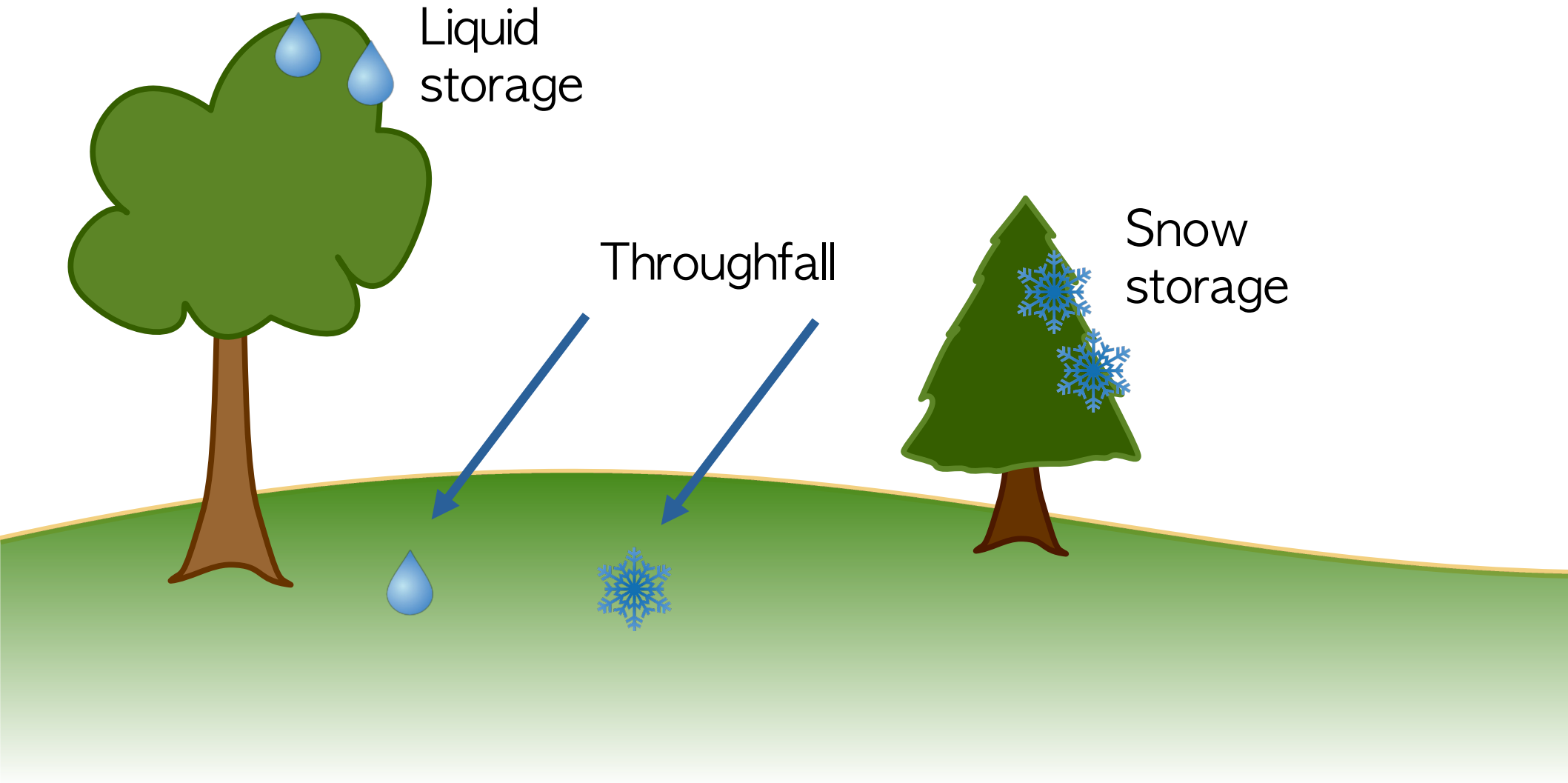
CTSM Hydrology

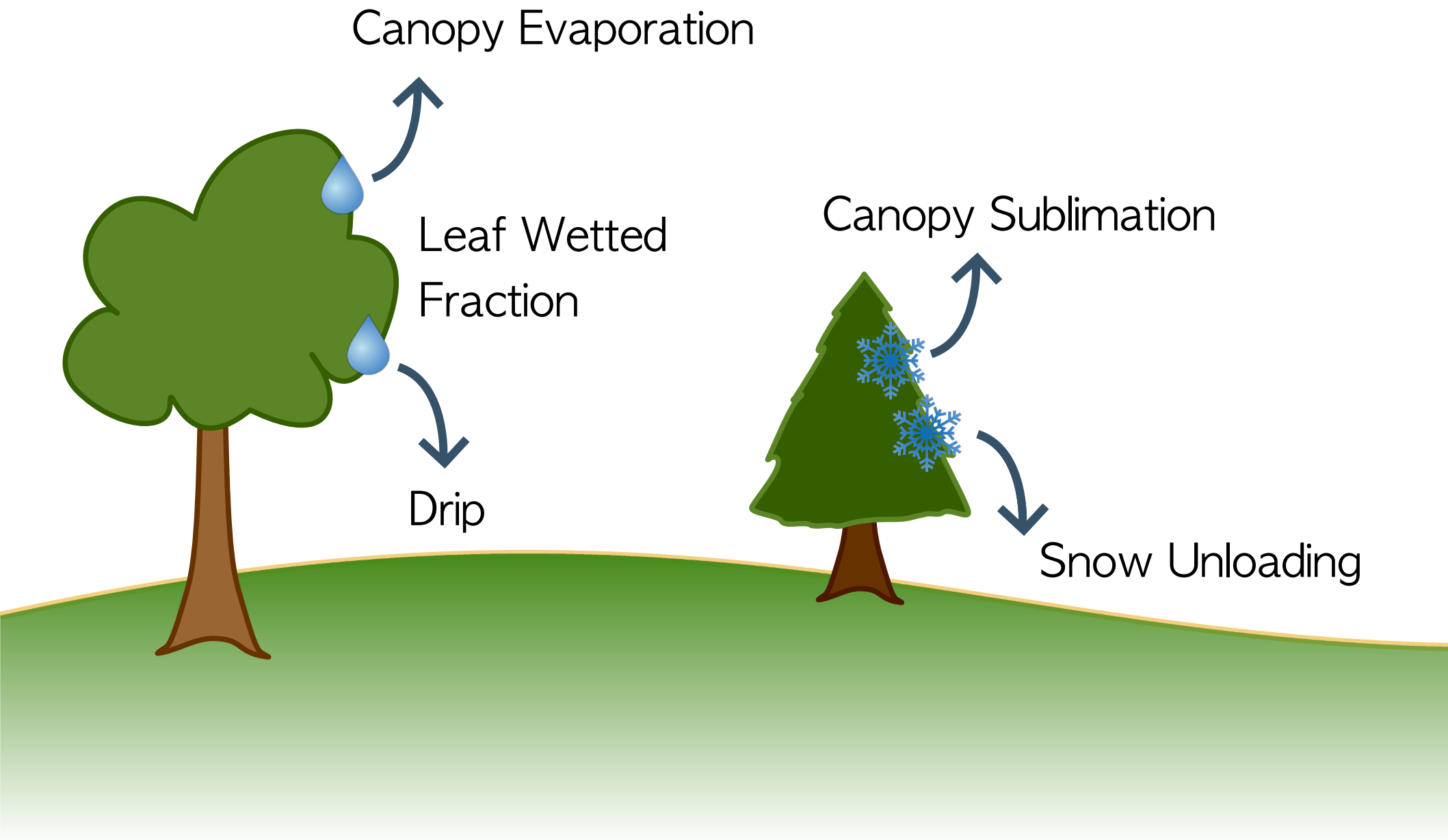
Canopy Hydrology



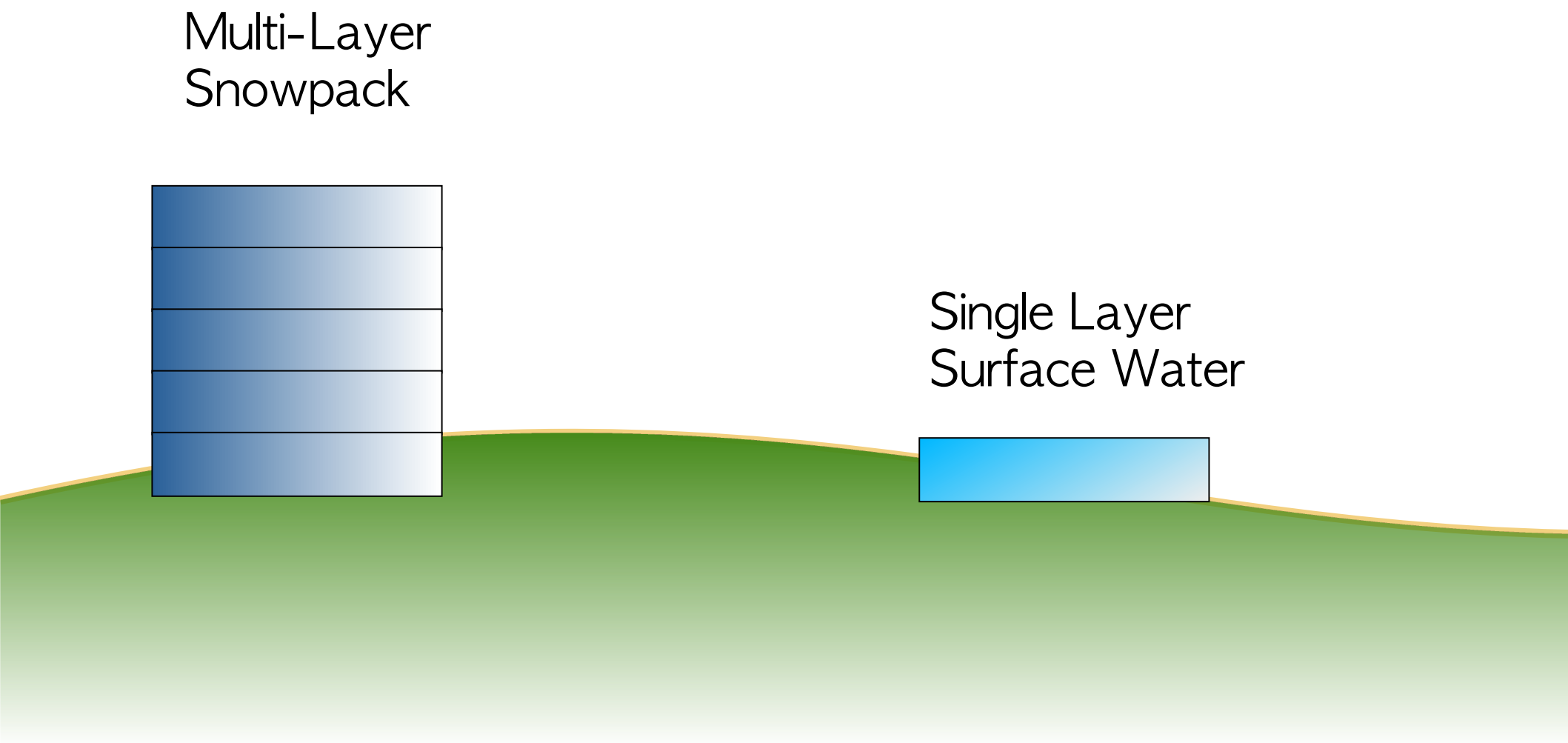
Canopy Hydrology



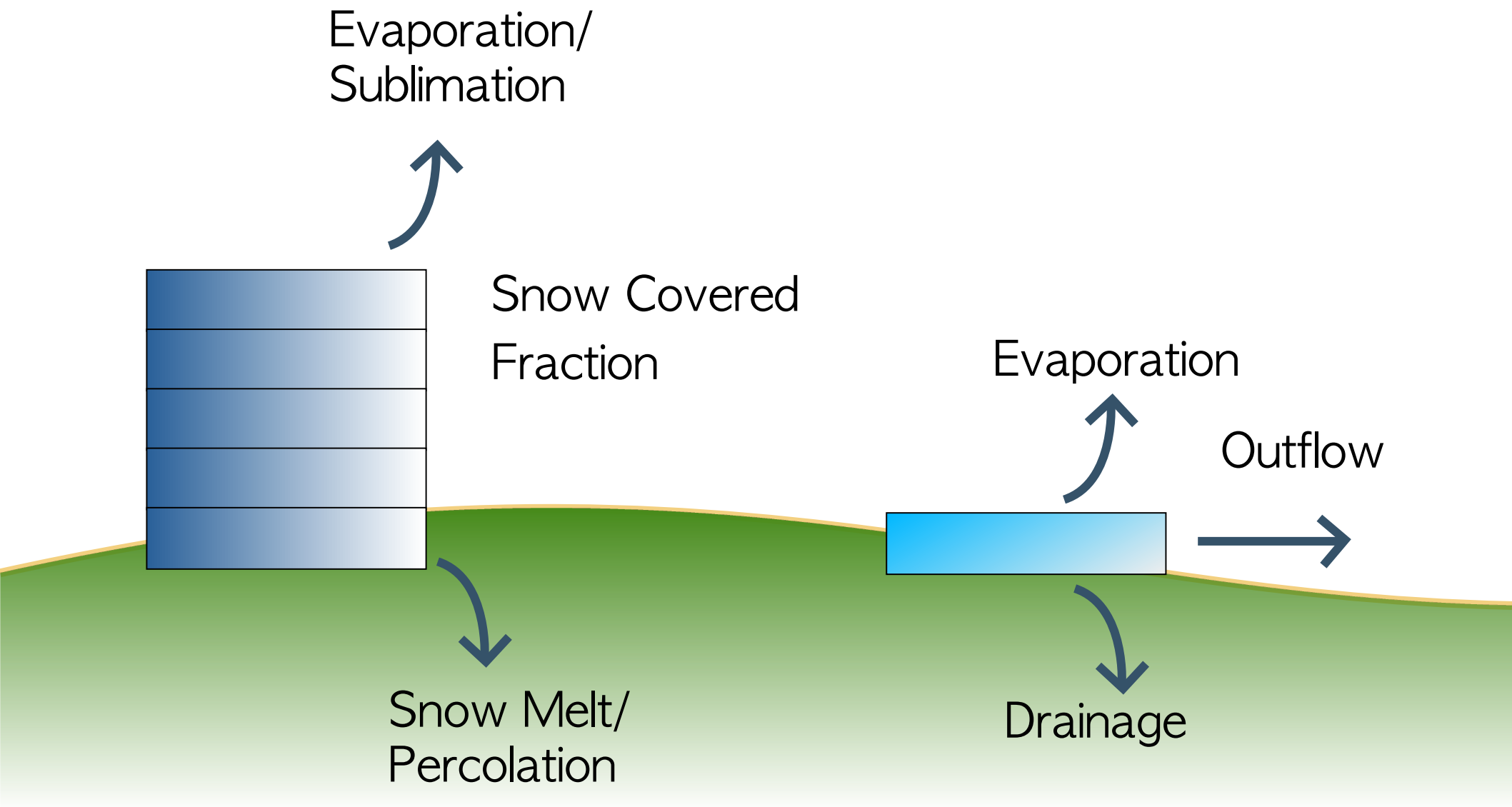
Canopy Hydrology



Snow and Surface Water



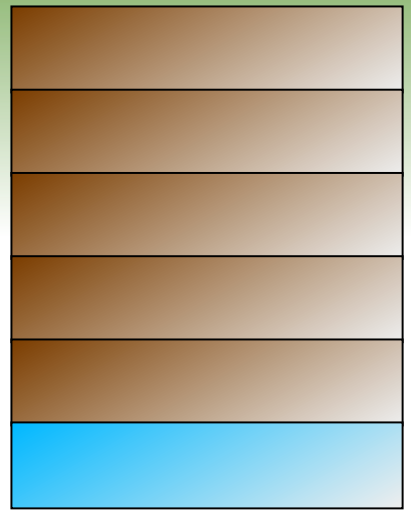
Snow and Surface Water

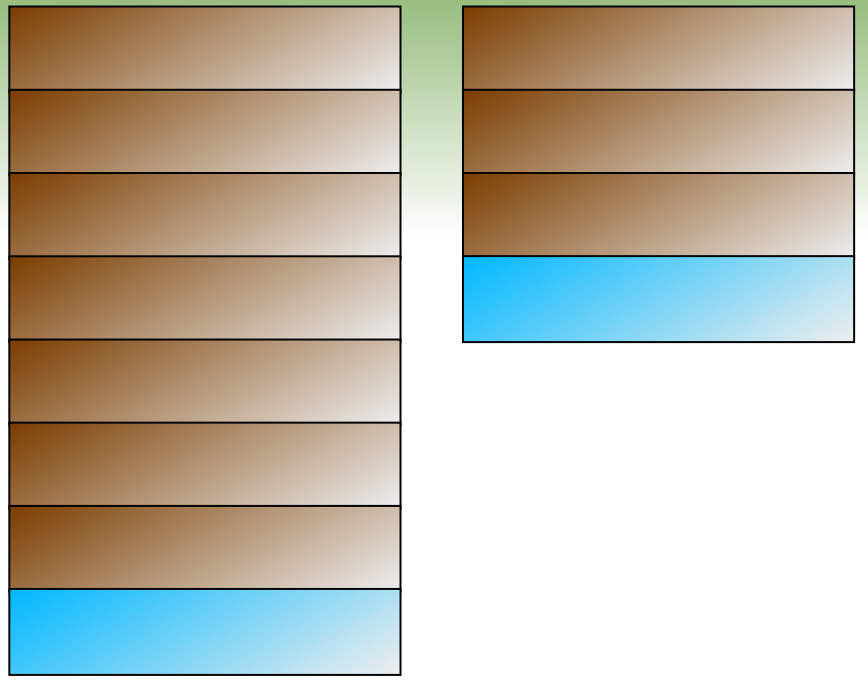


Soil Moisture

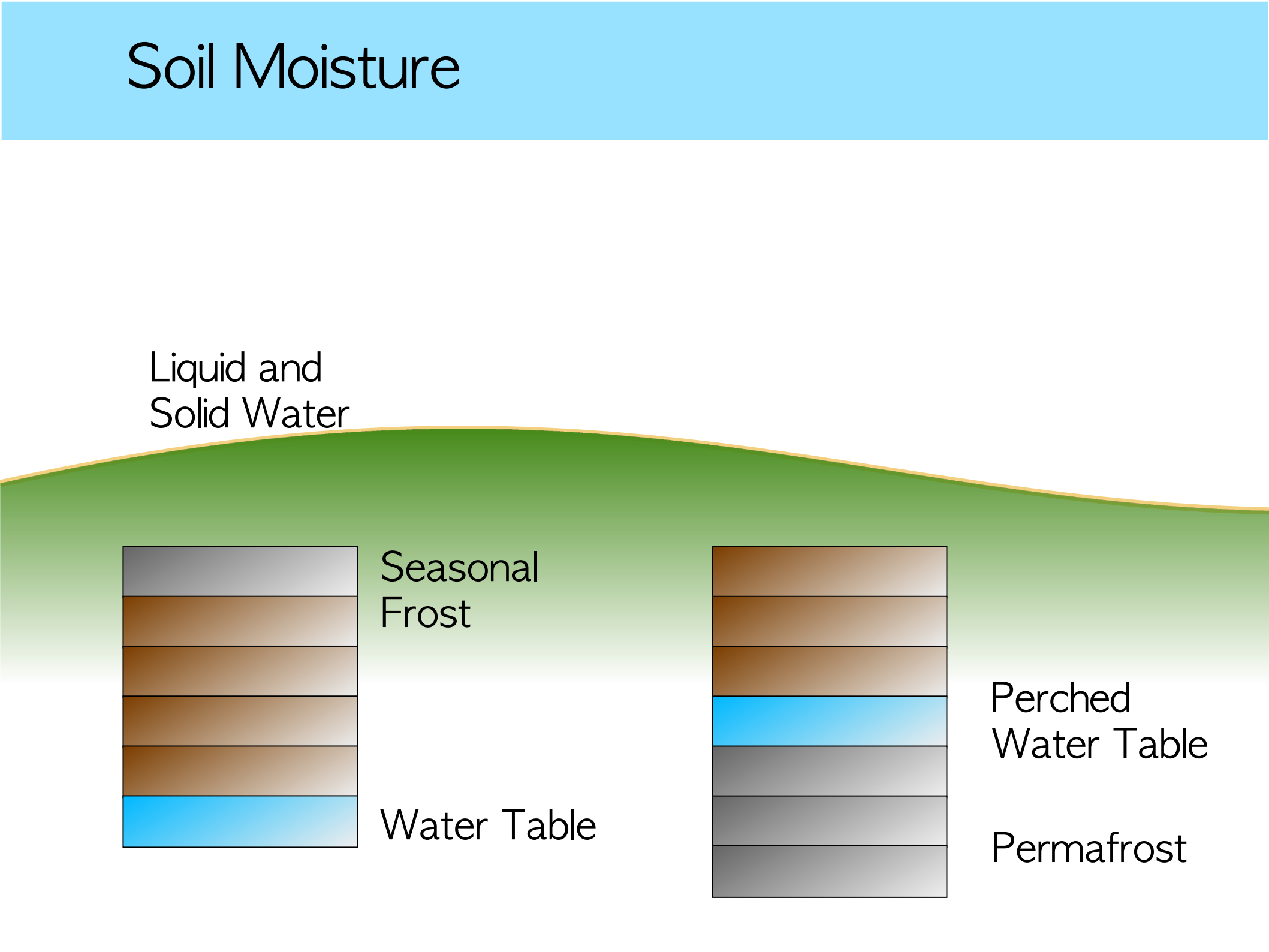
Multi-Layer
Soil Column

Spatially Variable
SoilThickness

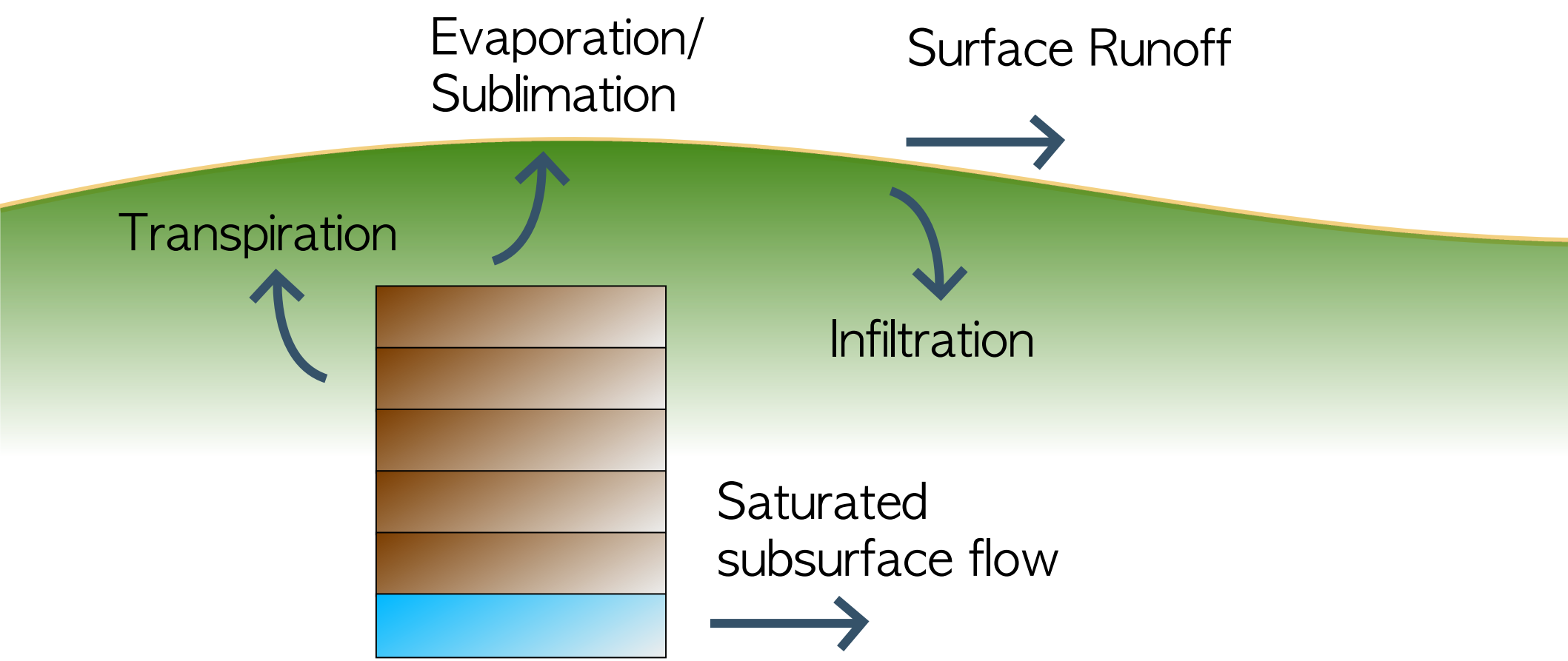




Soil Moisture



Soil Moisture



CTSM Hillslope Hydrology

Hillslope Hydrology

Motivation:

Topography controls many land processes

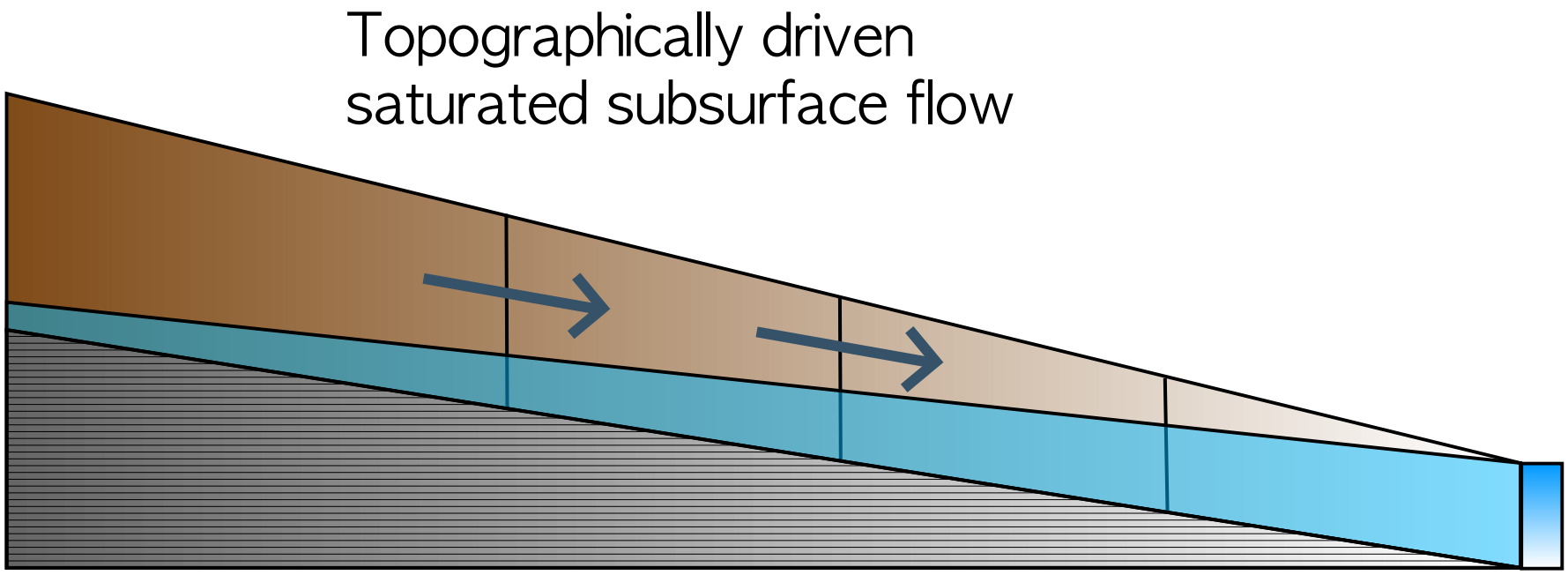
In the model, topography is only considered implicitly

(e.g. for runoff generation)

Or not at all (e.g. for insolation)

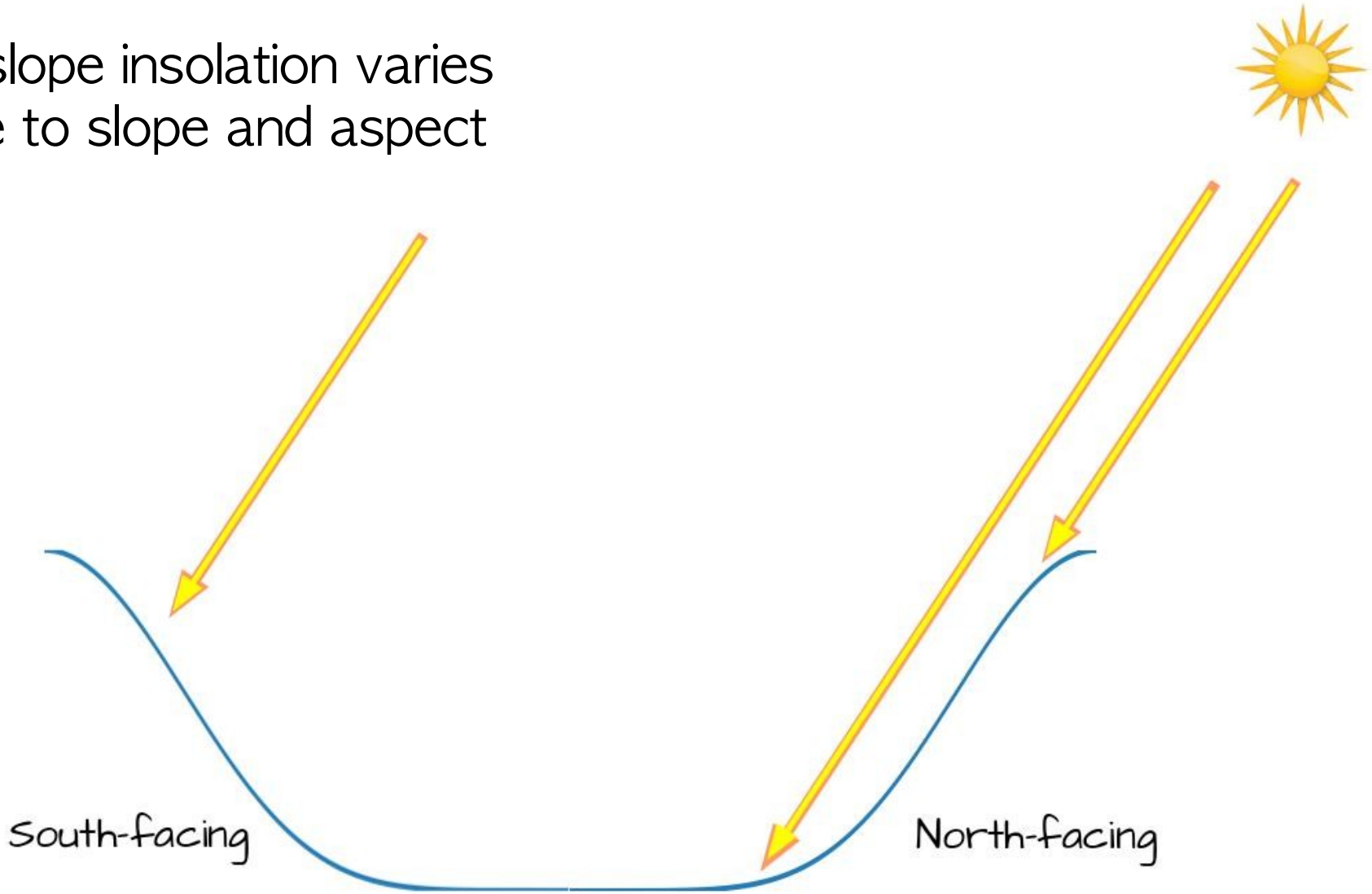
To explicitly represent topographic controls on some processes, CTSM can be operated in the “hillslope hydrology” configuration

Hillslope Hydrology



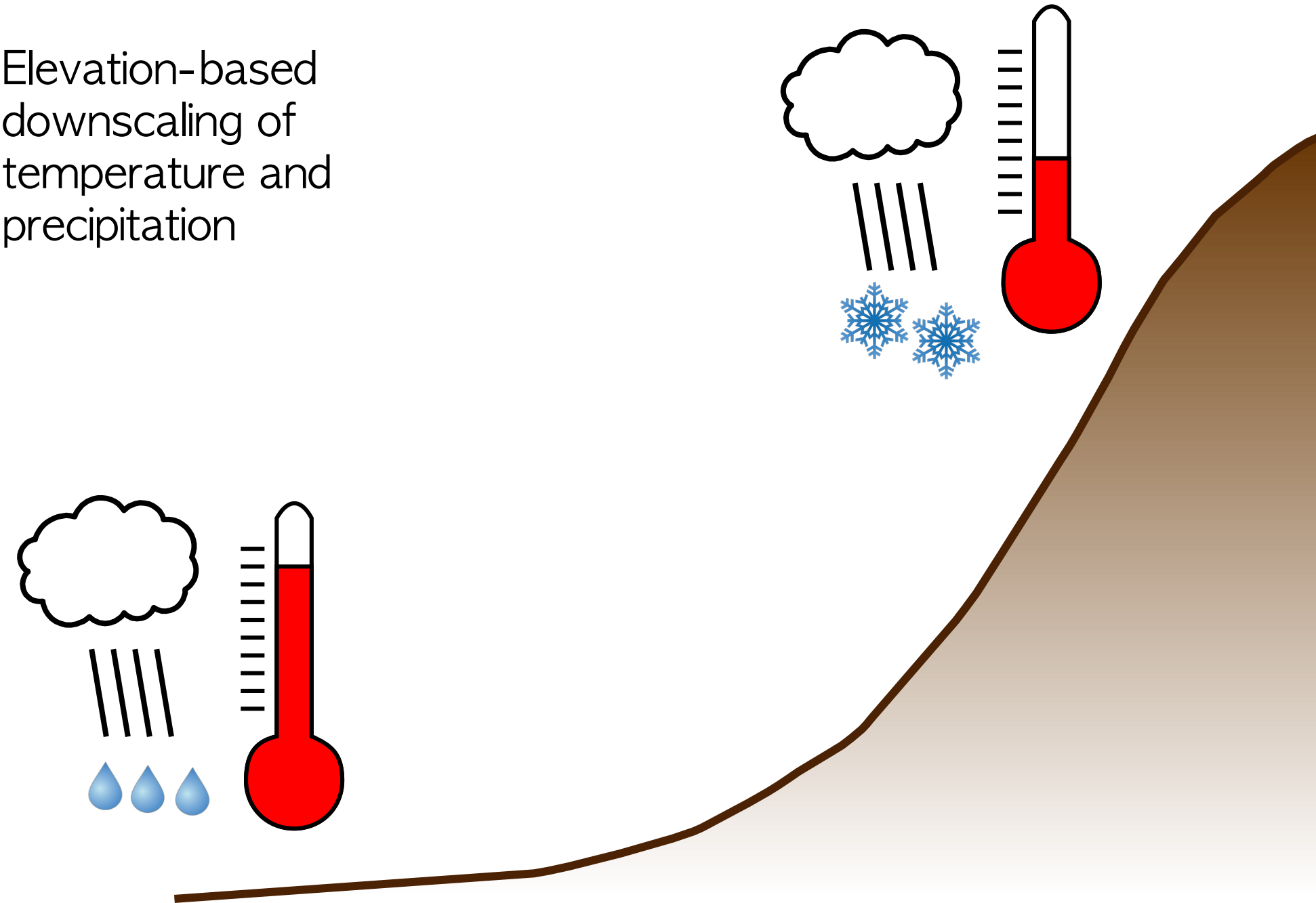
Hillslope Hydrology

Hillslope insolation varies due to slope and aspect



Hillslope Hydrology

Elevation-based downscaling of temperature and precipitation



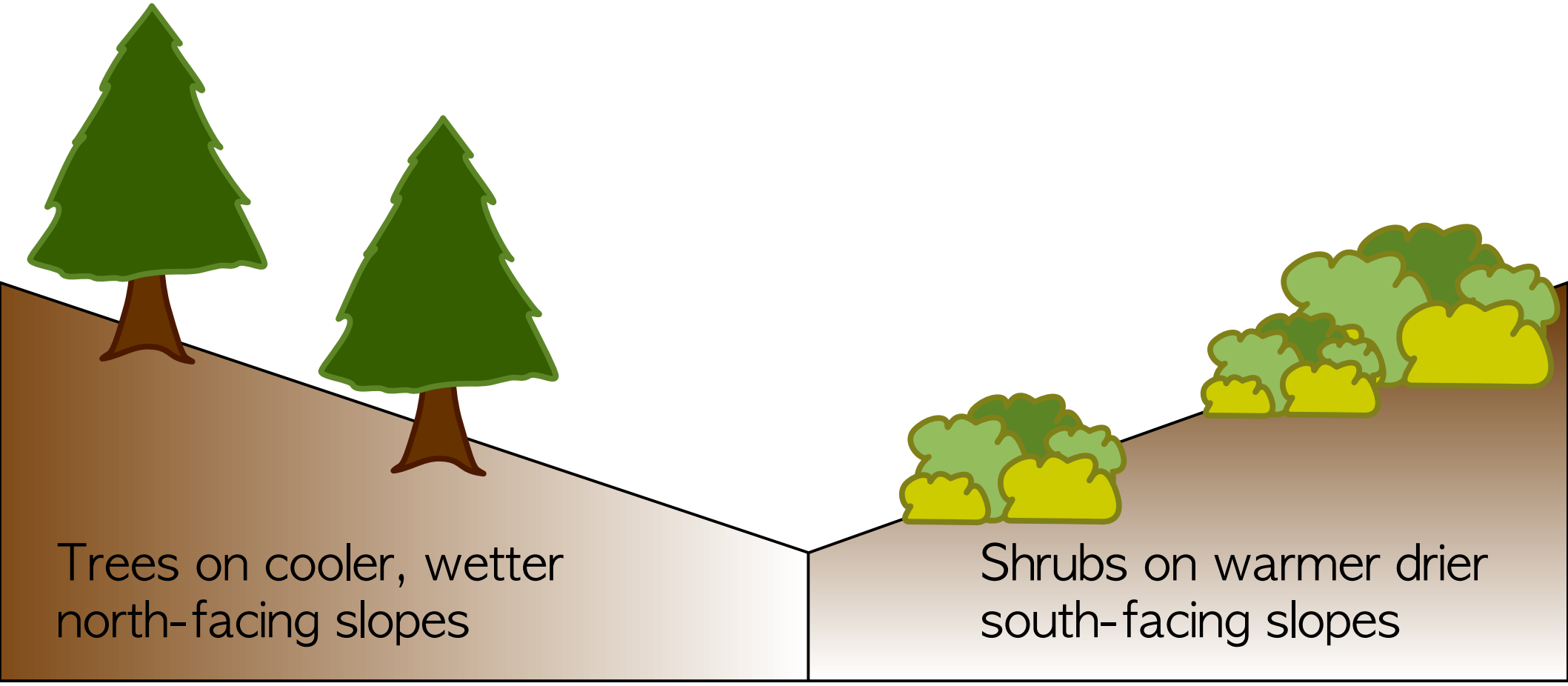
Hillslope Hydrology

Observed vegetation patterns imply variations in soil moisture



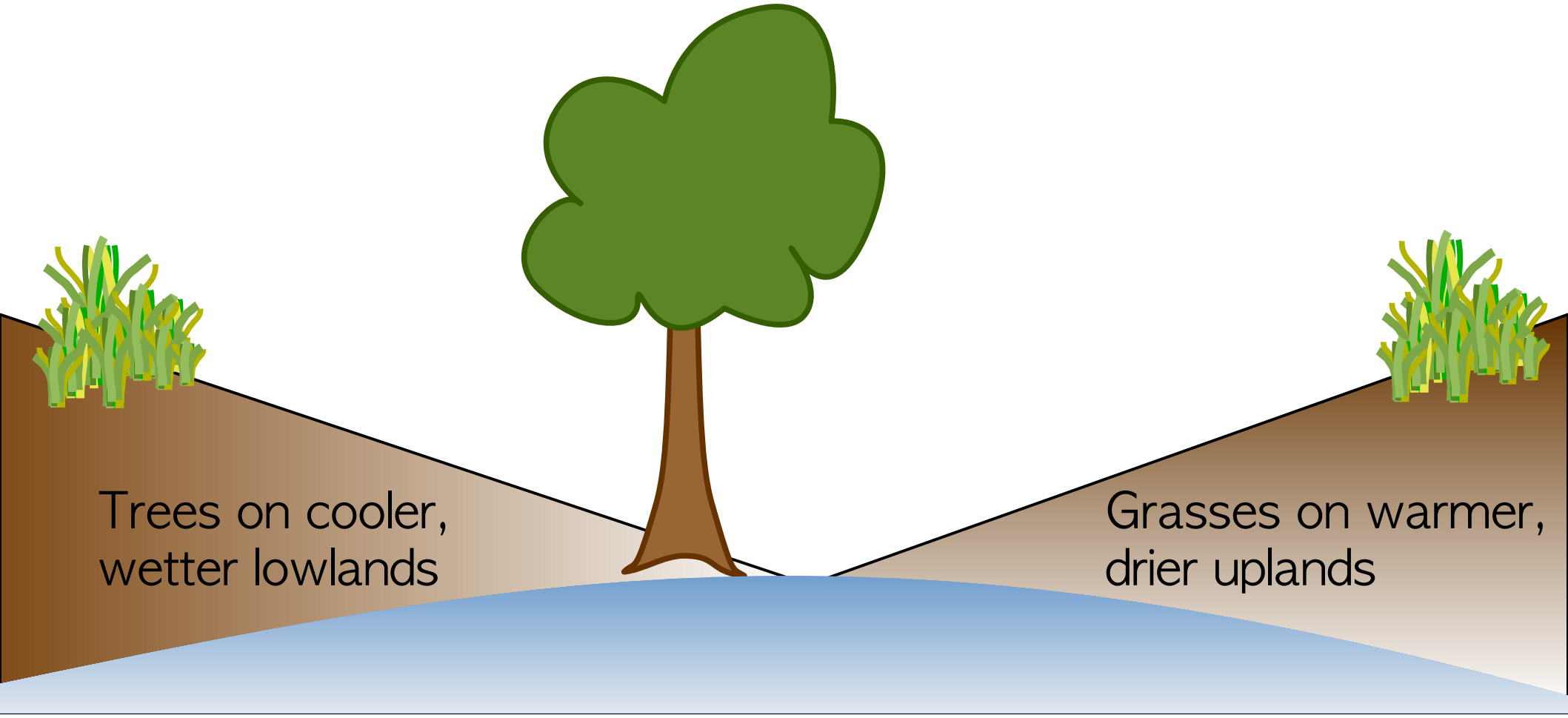
Hillslope Hydrology

Feedbacks between
microclimate, soil moisture,
and vegetation



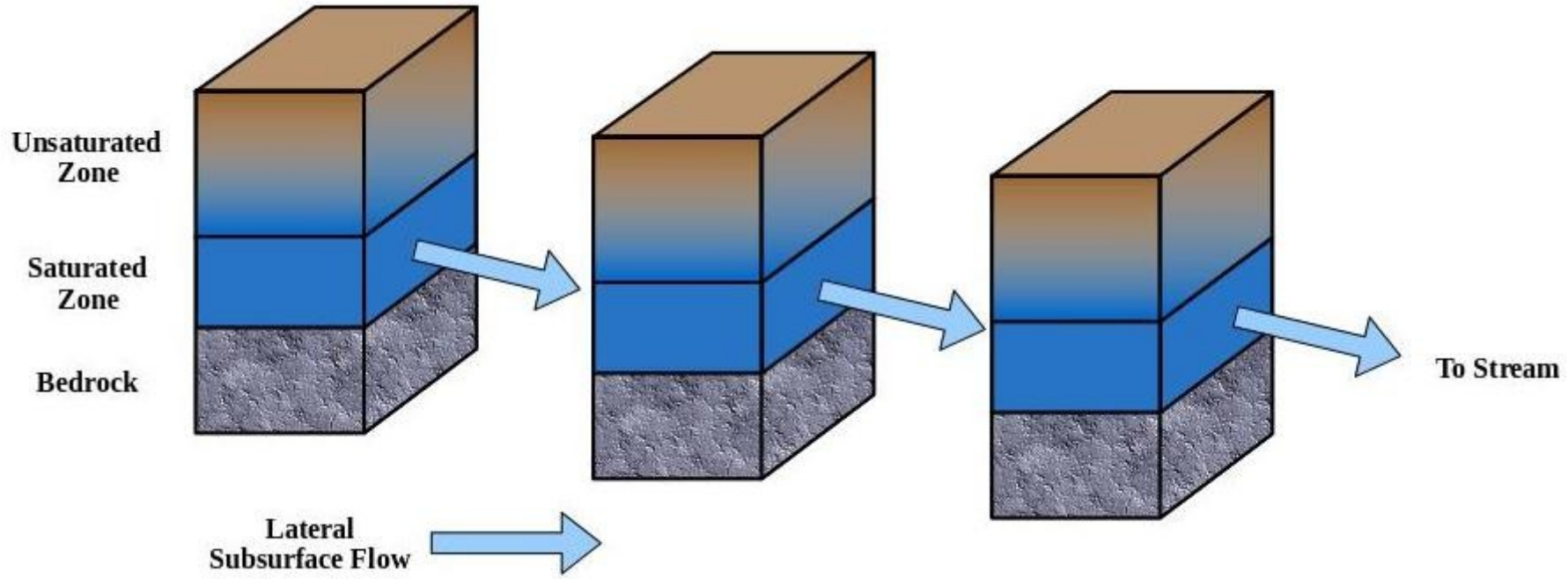
Hillslope Hydrology

Feedbacks between
microclimate, soil moisture,
and vegetation



Hillslope Hydrology

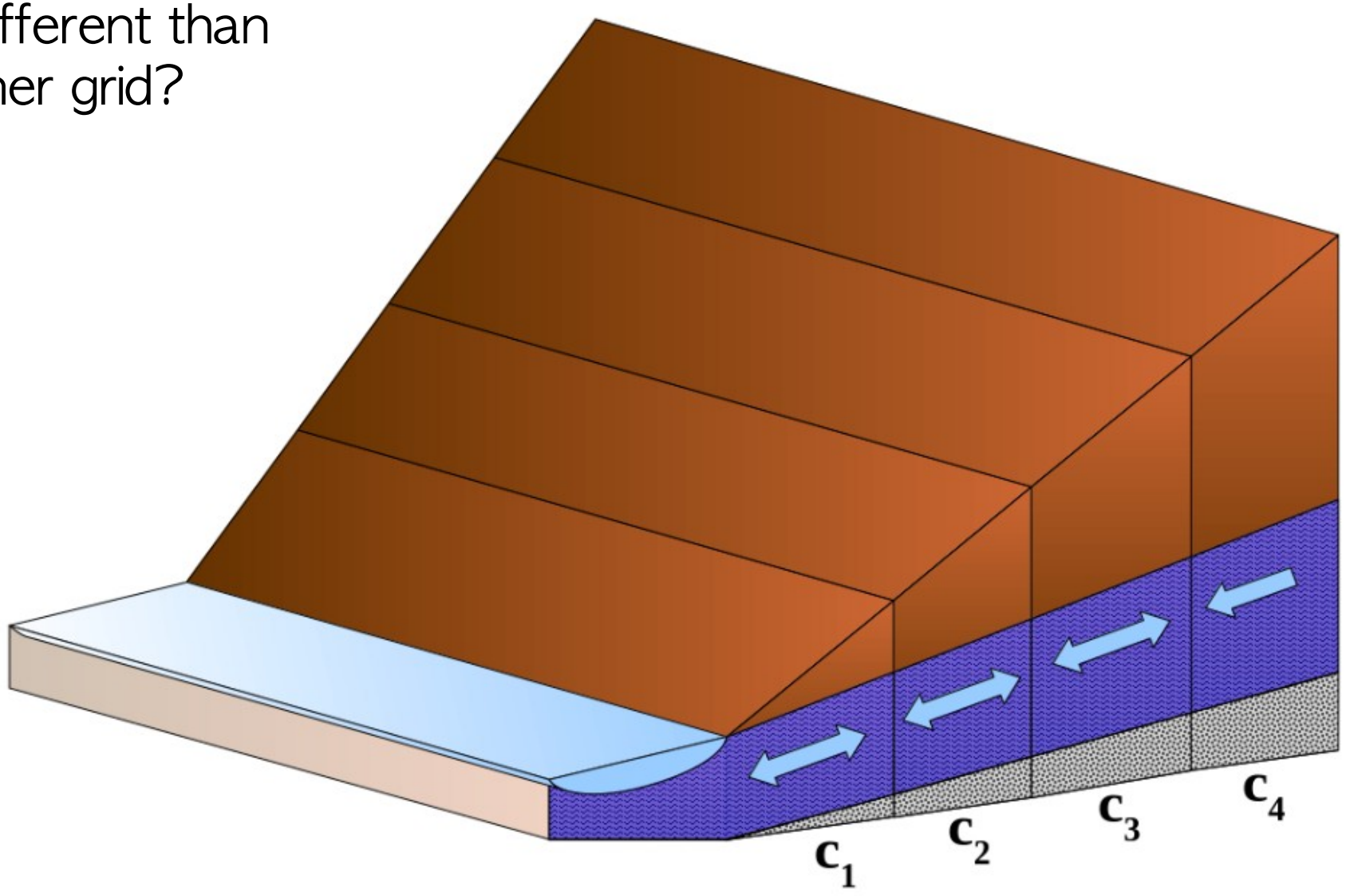
How is a hillslope represented in CTSM?



Multiple columns per gridcell/landunit

Hillslope Hydrology

How is a multi-column hillslope different than using a finer grid?



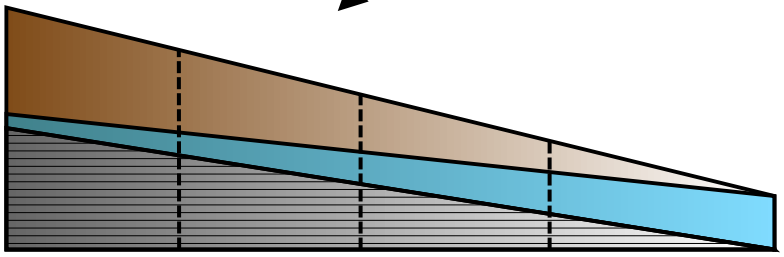
Hillslope Hydrology

How is a multi-column hillslope different than using a finer grid?



1° to 0.5°

1° to O(100m)





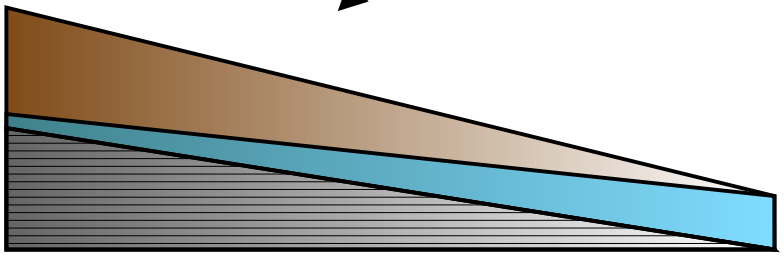
Hillslope Hydrology

How is a multi-column hillslope different than using a finer grid?



1° to 0.5°

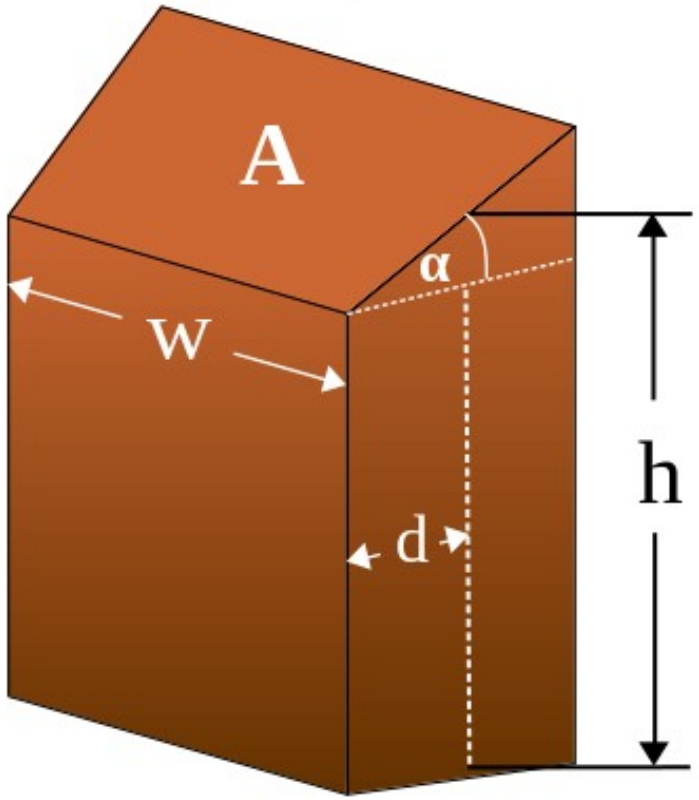
1° to O(100m)

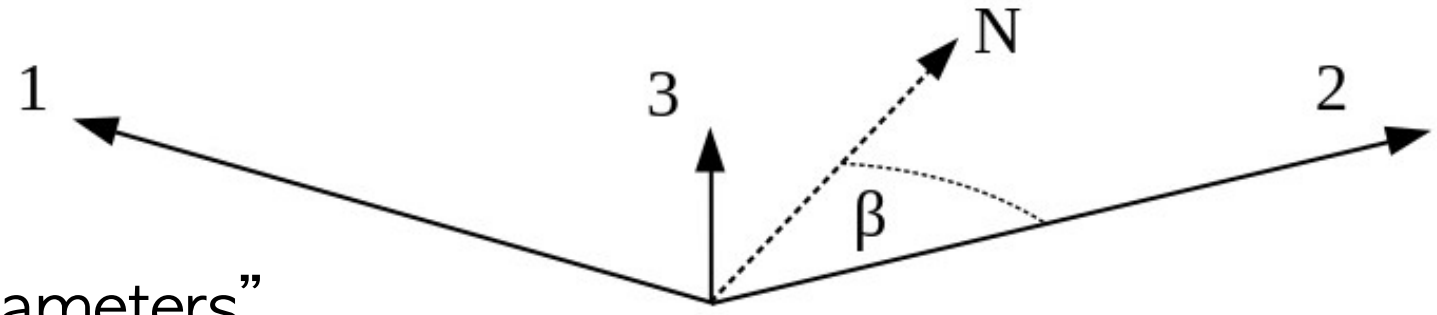




Hillslope Hydrology

How is a hillslope column represented in CTSM?

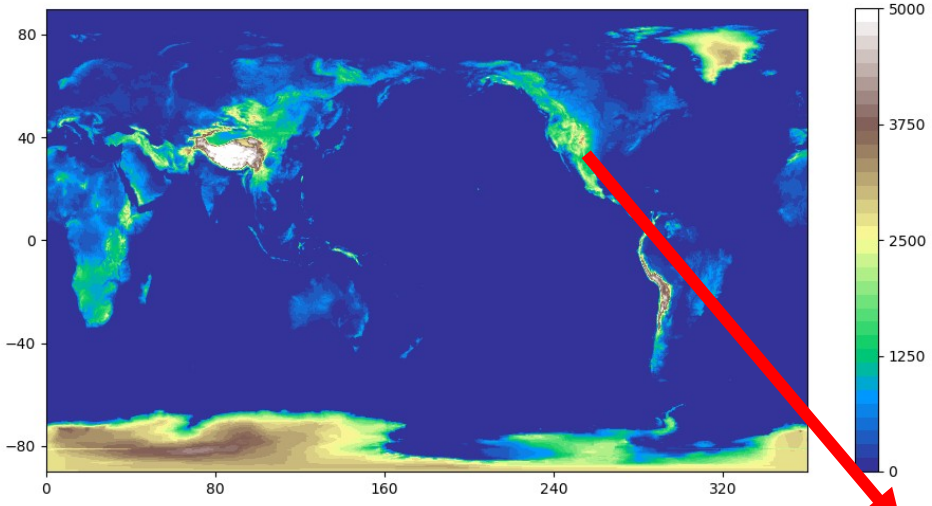


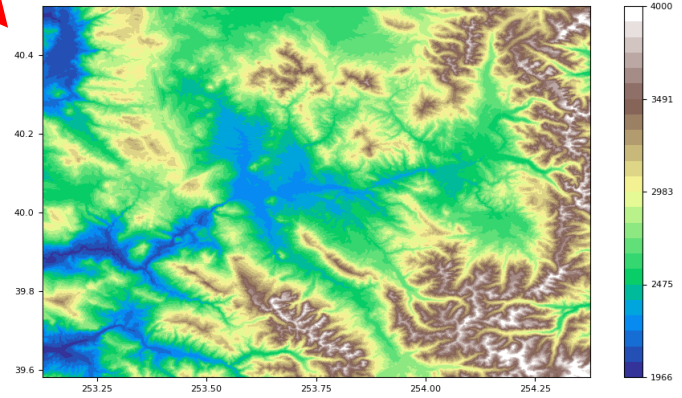


"Geomorphic parameters"

Geomorphic Parameters

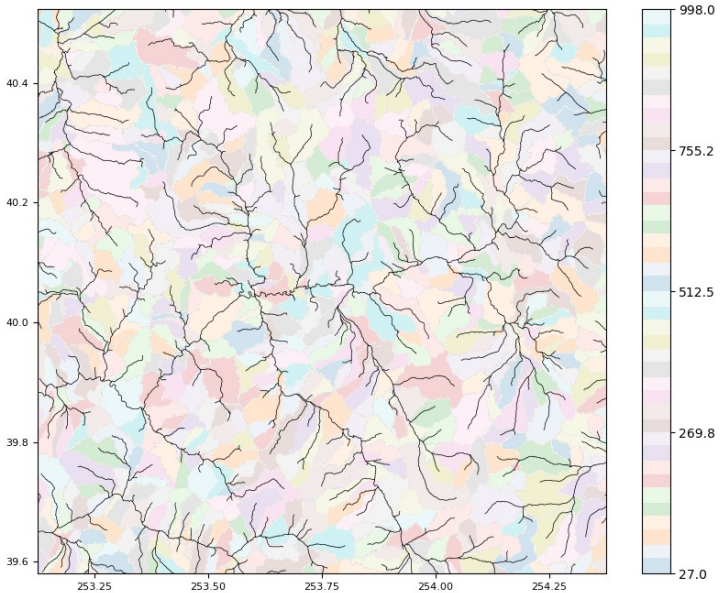
How are geomorphic parameters determined?

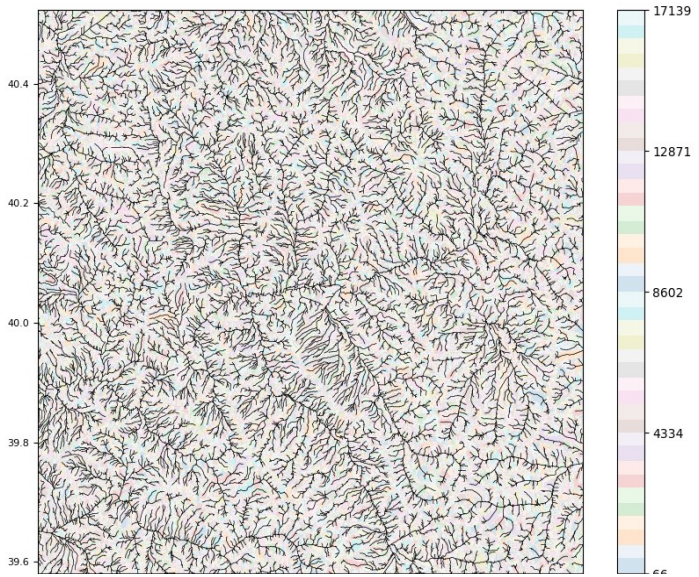


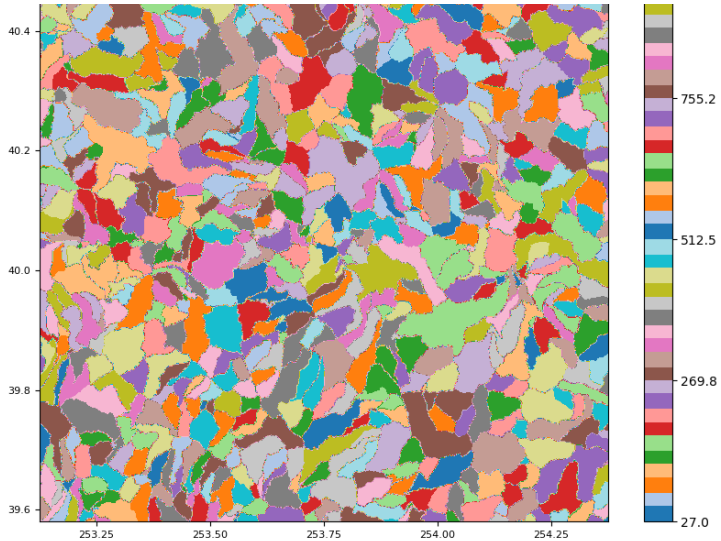


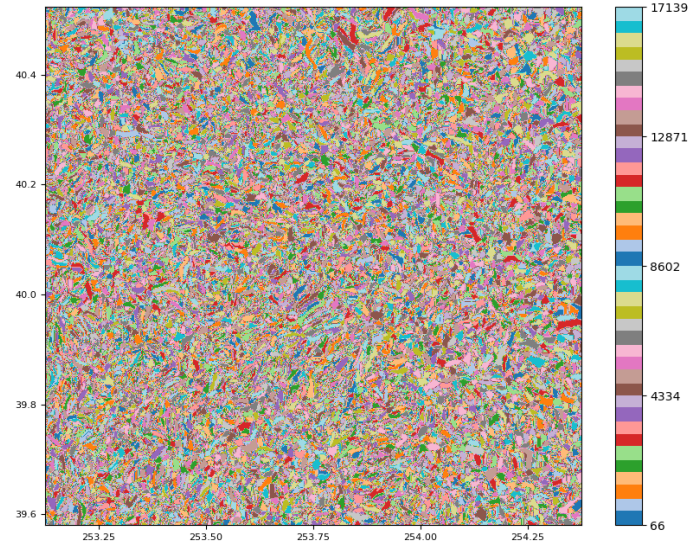
Only input data is a high resolution DEM

Stream Network and Catchment Identification



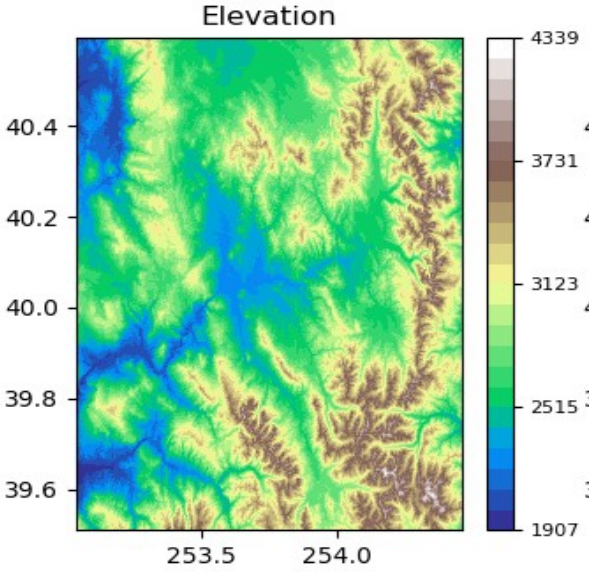




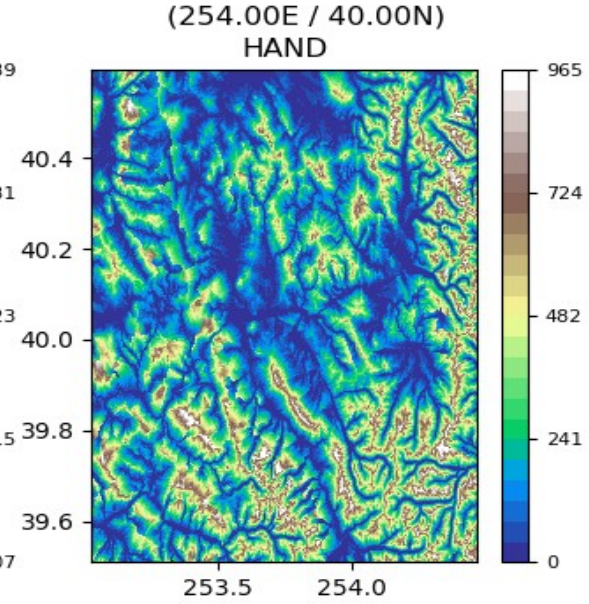


Representative Hillslopes

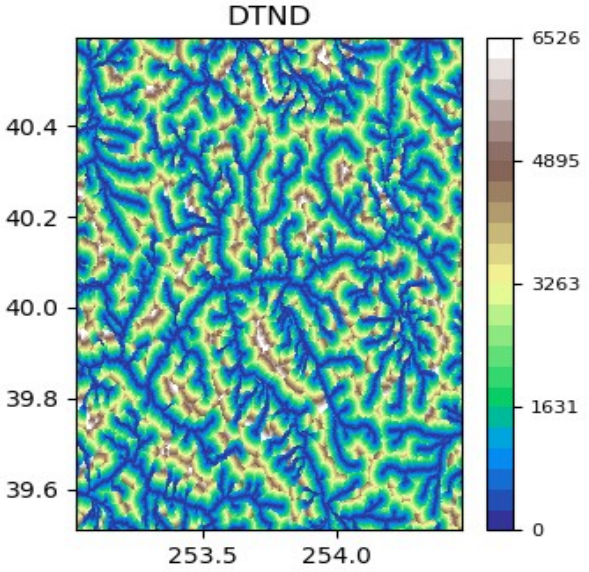
Original DEM



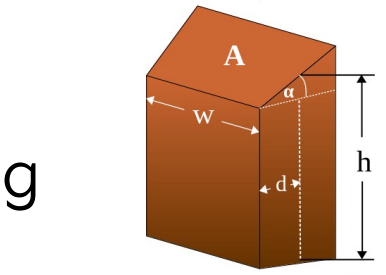
Height above channel

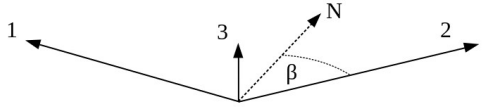


Distance from channel



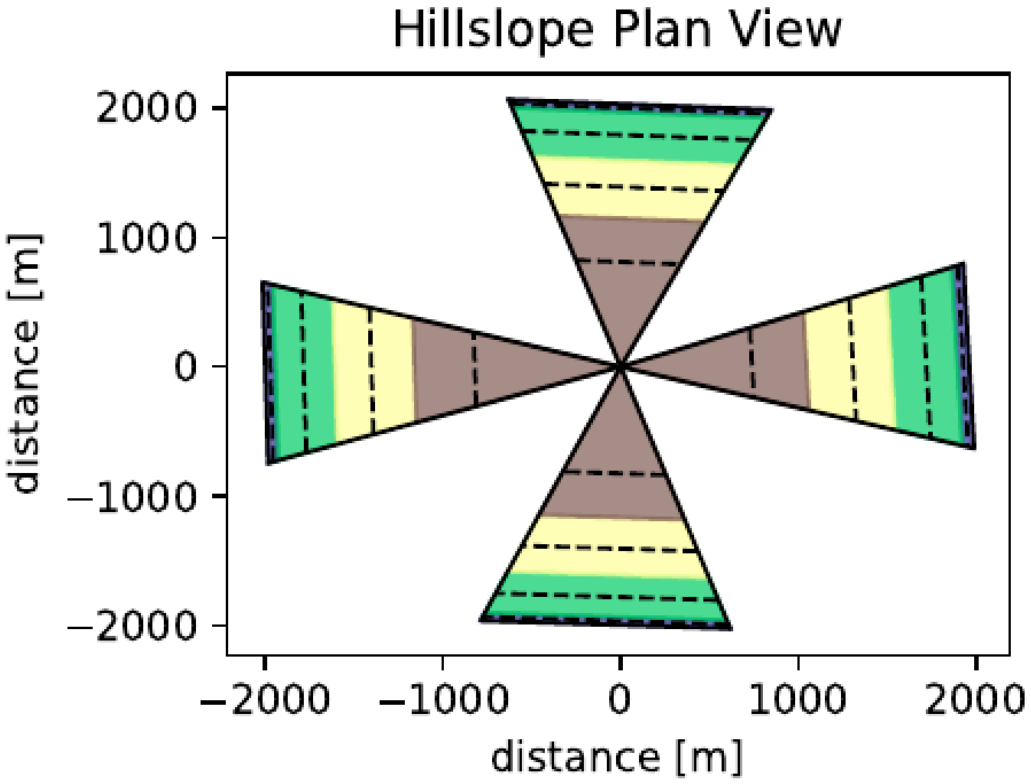
Representative hillslopes obtained by averaging over bins of elevation and aspect (azimuth)

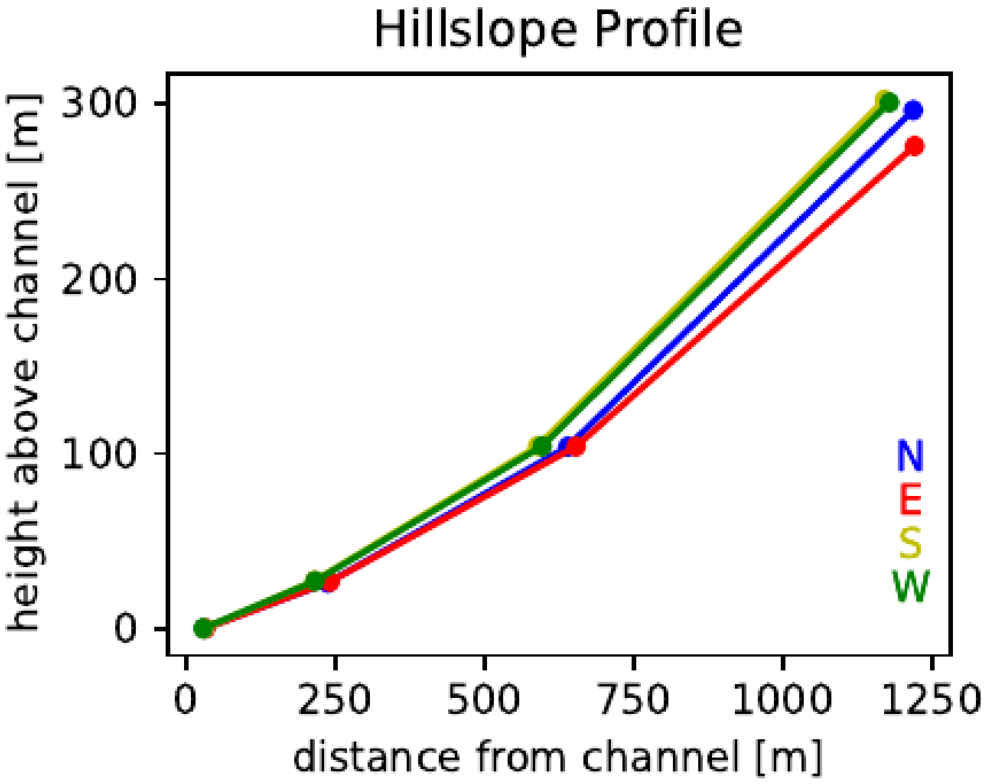




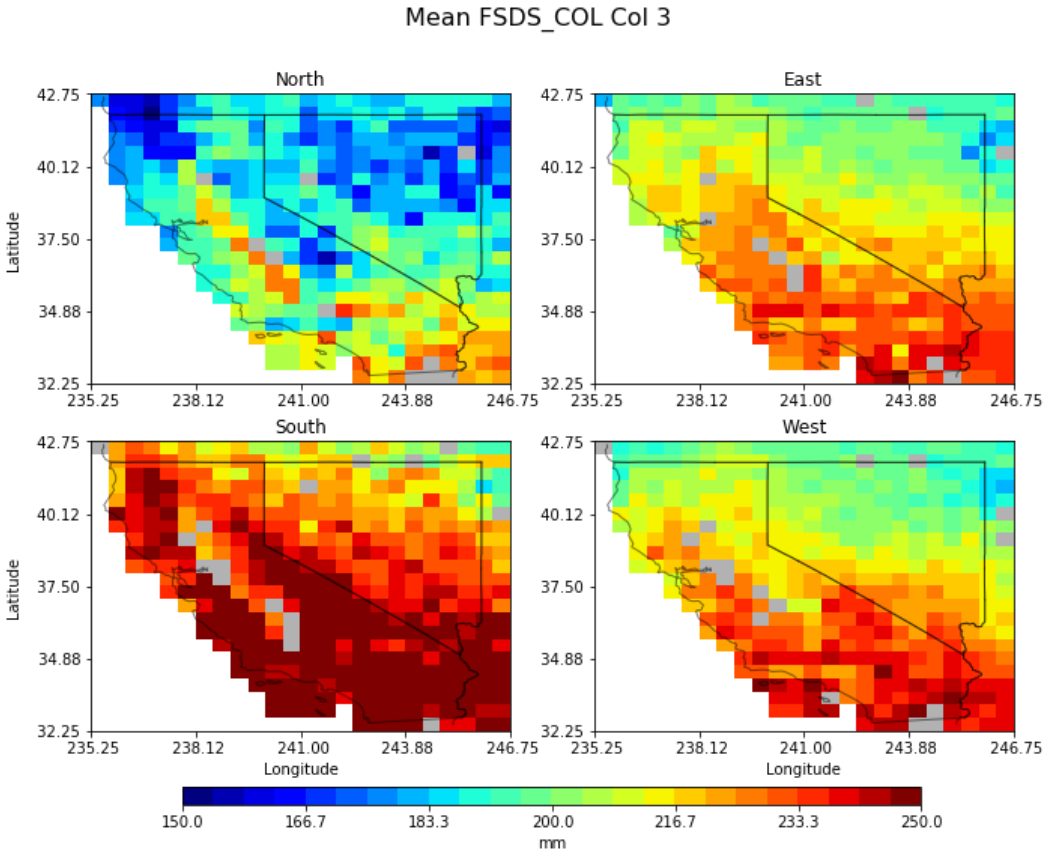
Hillslope Axes

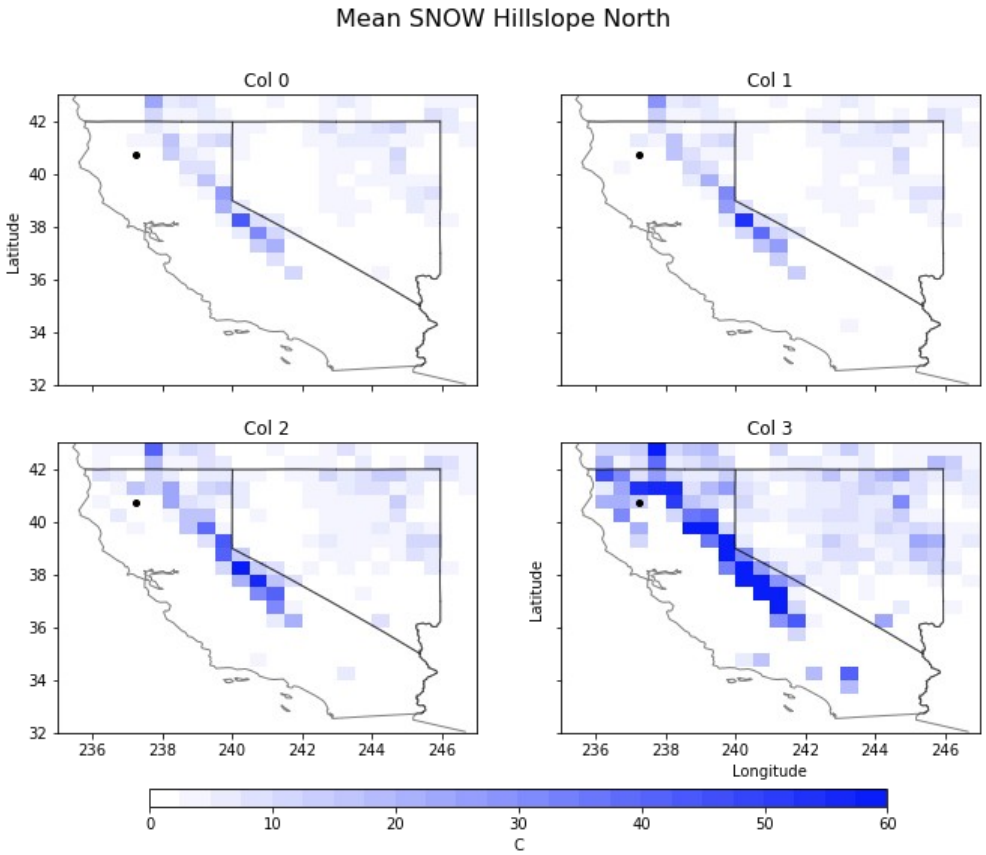
Hillslopes are defined by two axes:
1) aspect (azimuthal orientation)
2) elevation





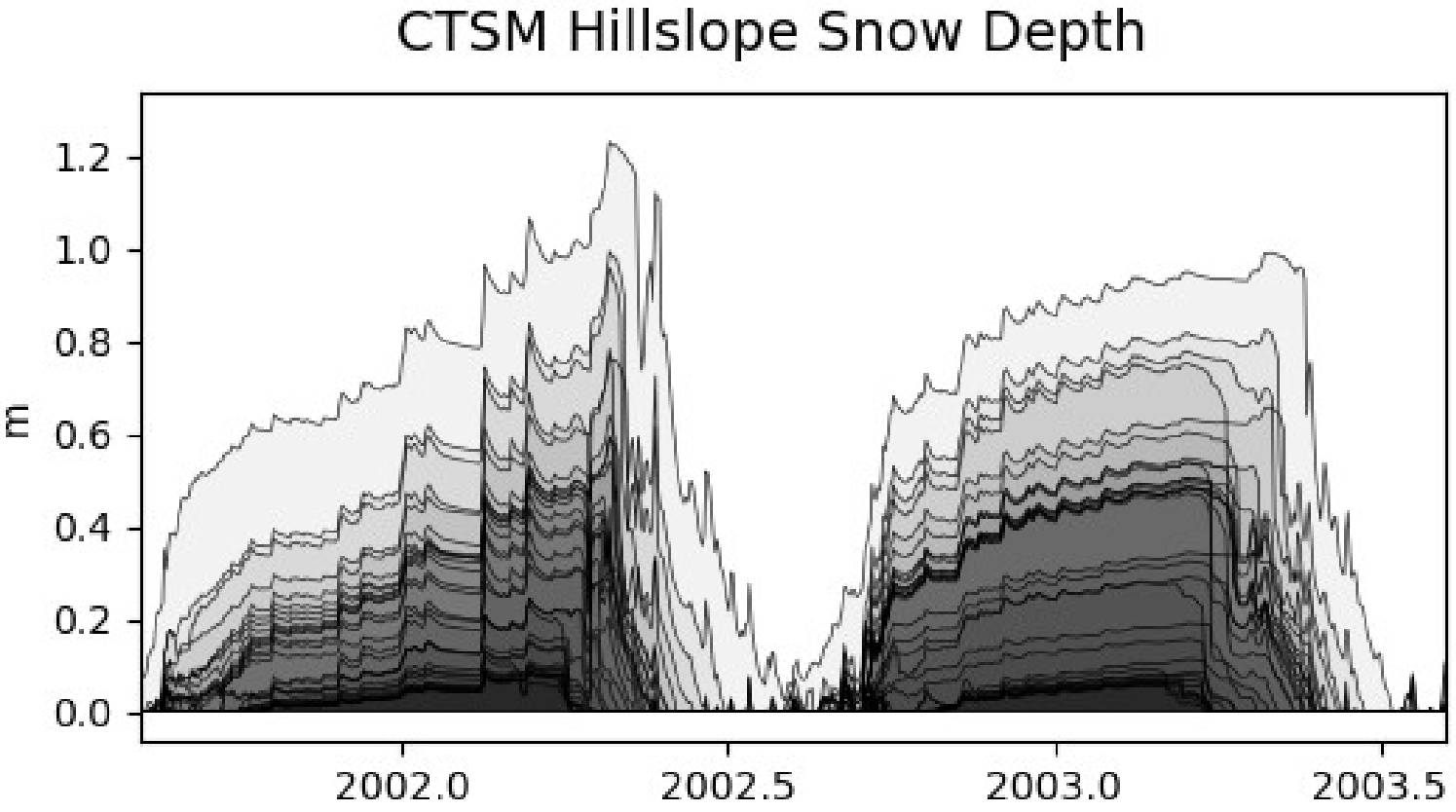
Hillslope Meteorological Downscaling





Each gridcell simulates an ensemble of microclimates

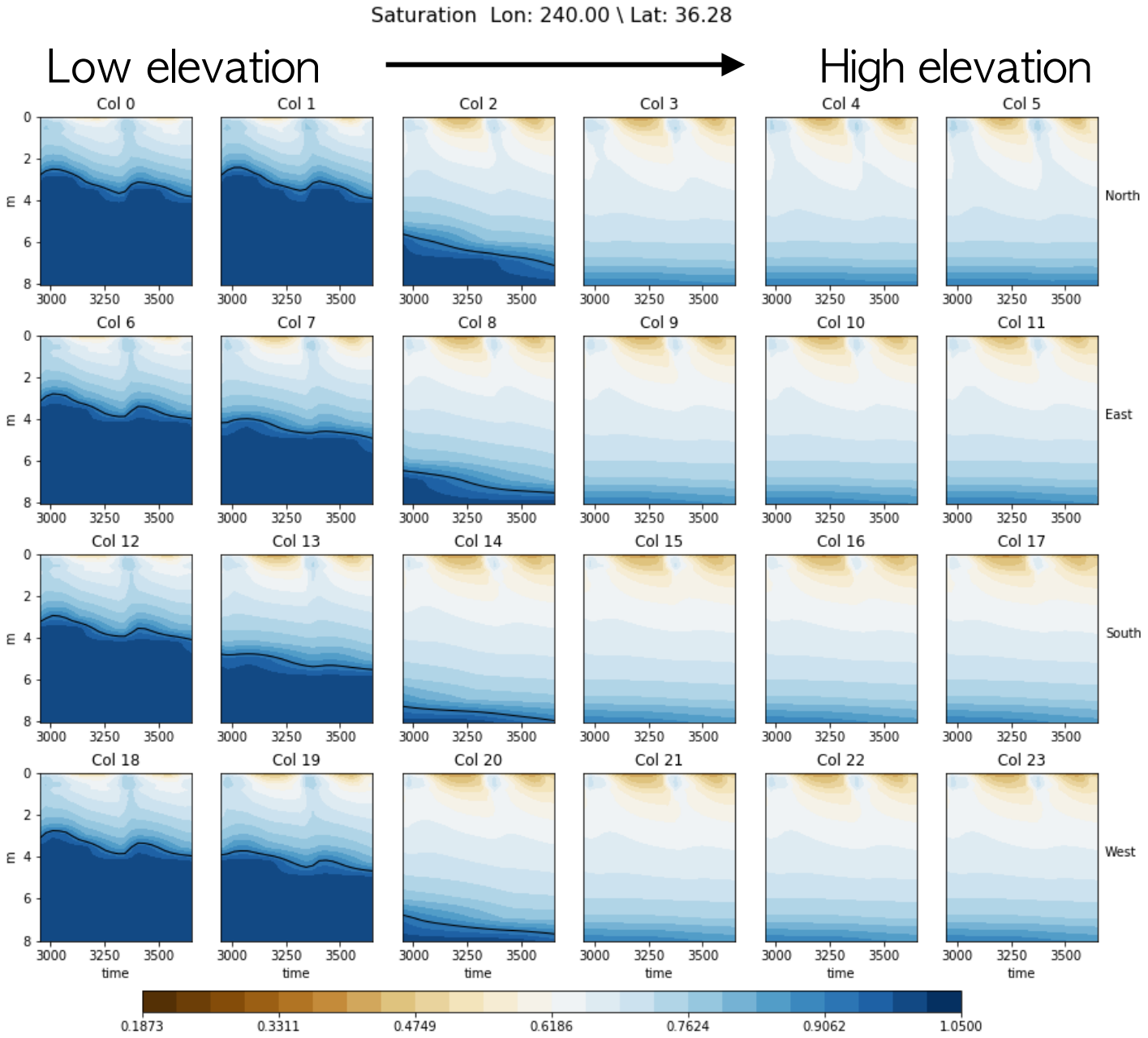
Hillslope Hydrology



Snowpack shows a wide range of amounts and duration

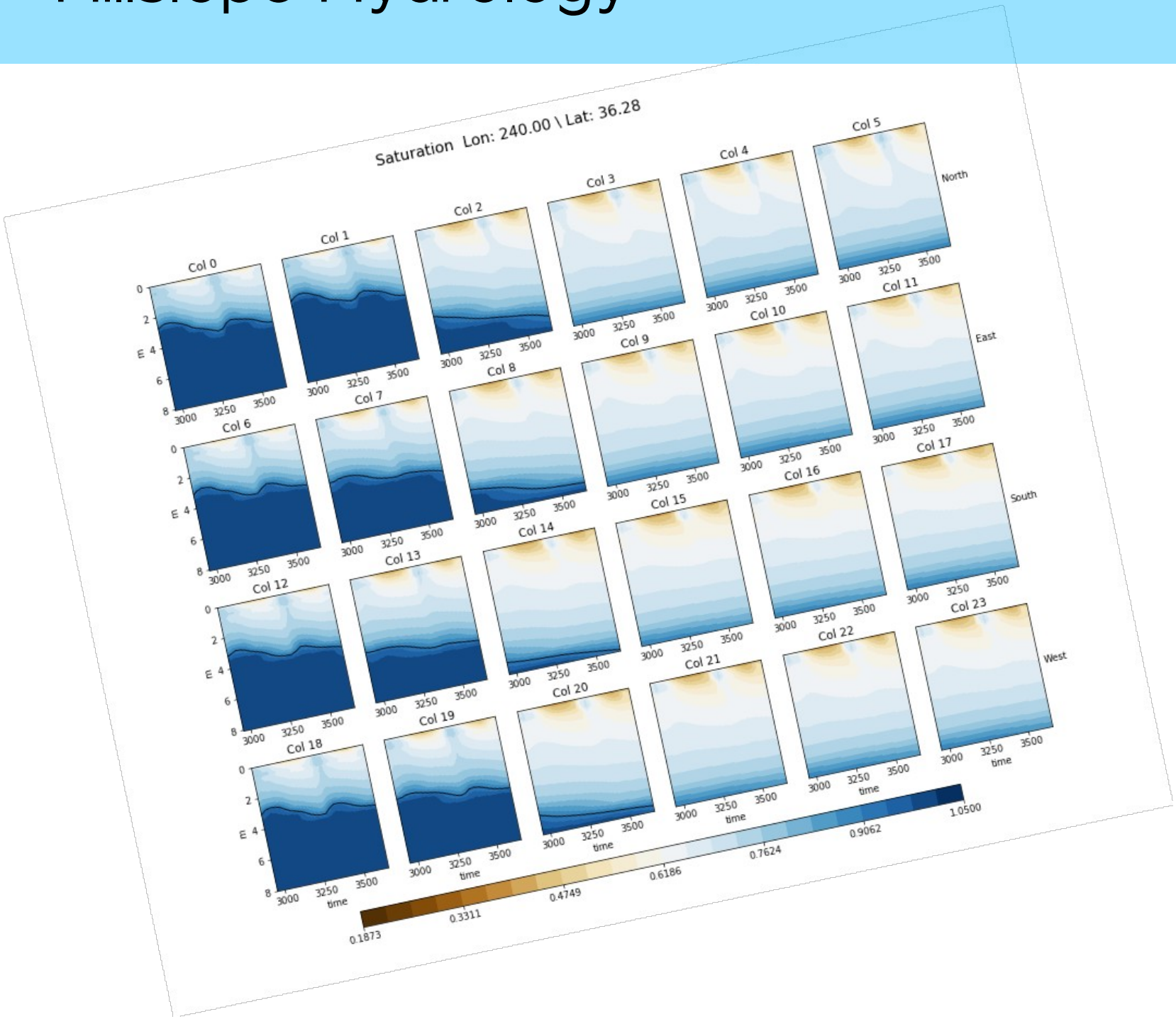
Ensemble of land states in each gridcell

Hillslope Hydrology

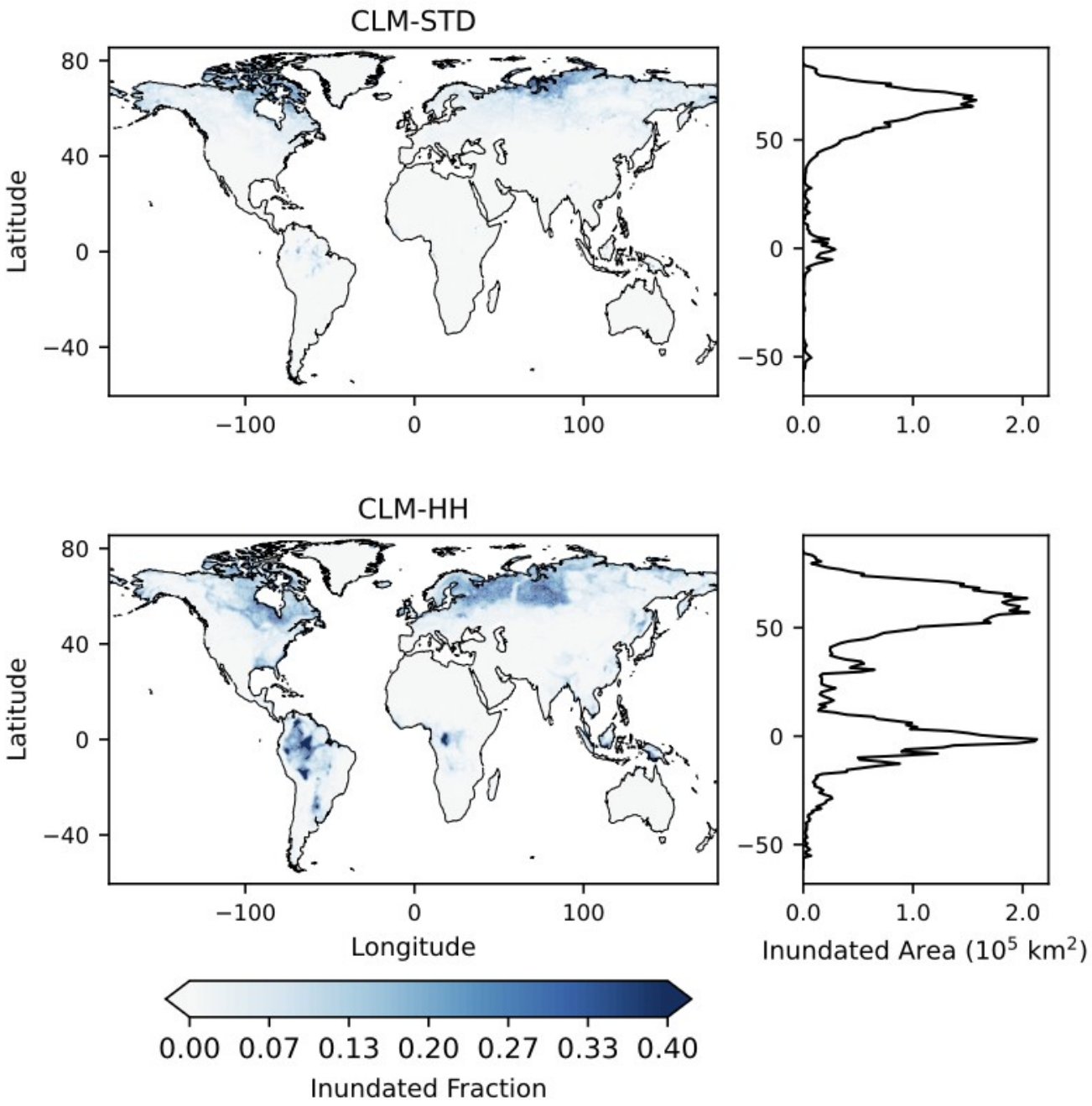


Soil moisture convergence leads to wetter lowlands and drier uplands

Hillslope Hydrology



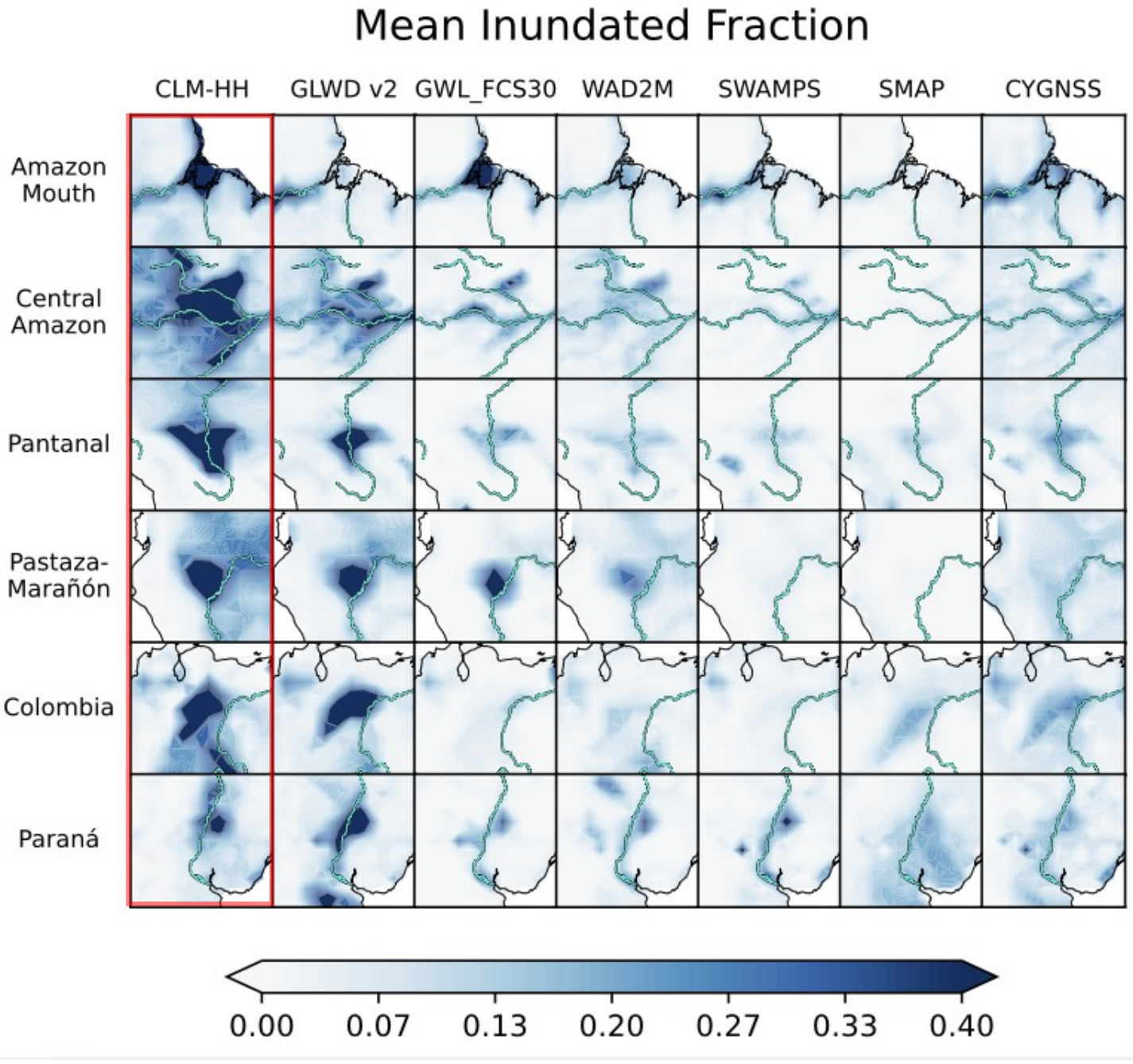
Inundation (Wetlands)



"Flat" model: inundated areas mainly at high latitudes during snowmelt

Hillslope model: inundated areas in tropics

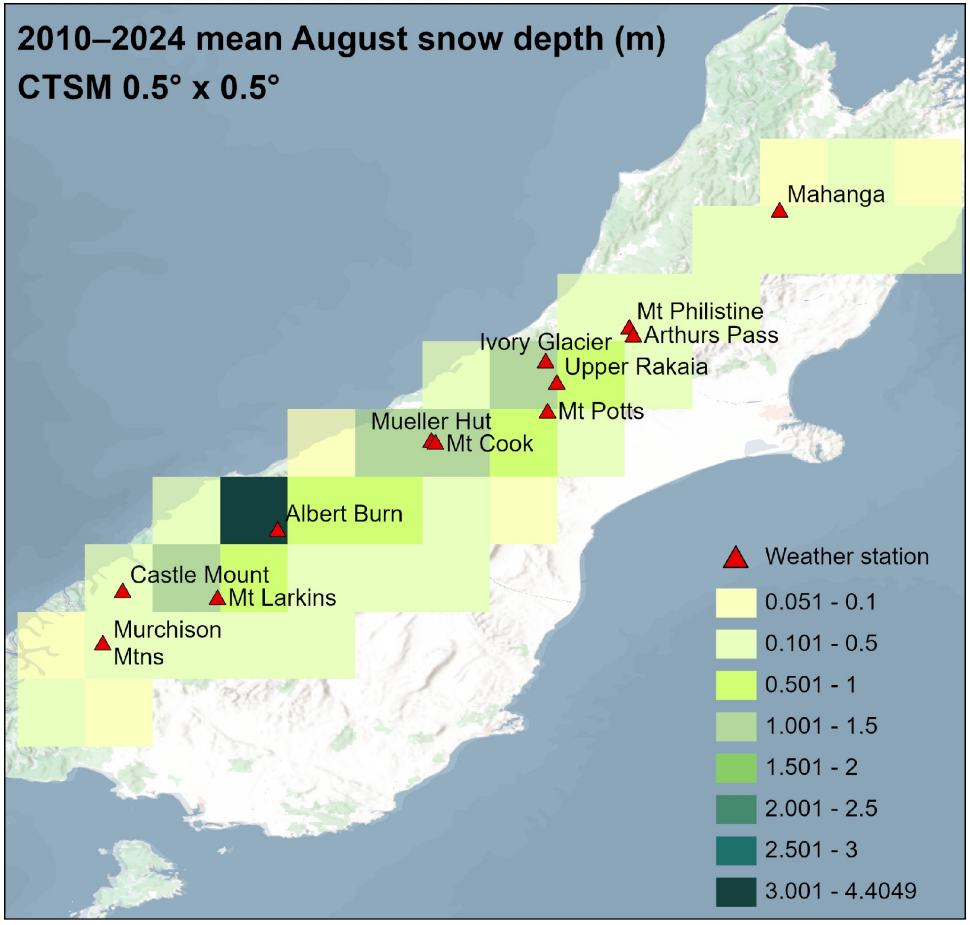
Hillslope Hydrology



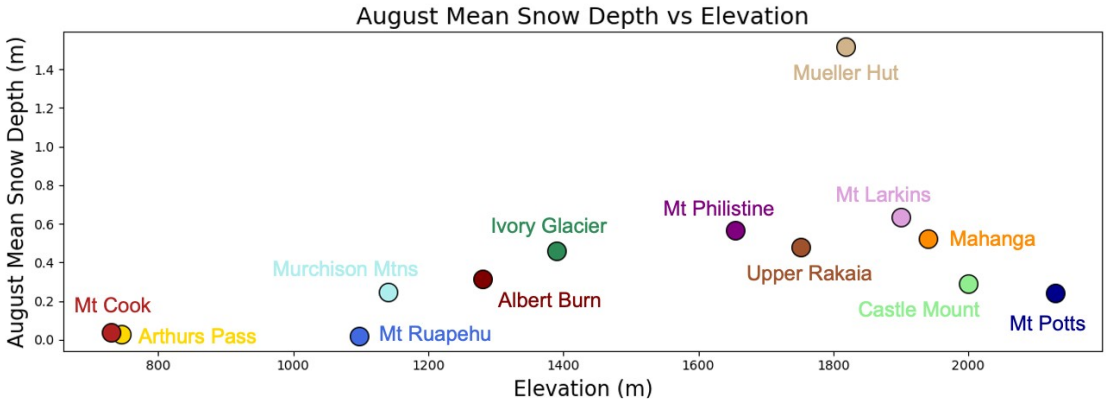
Good agreement with spatial pattern seen in observations

Hillslope Hydrology

Samar's New Zealand work



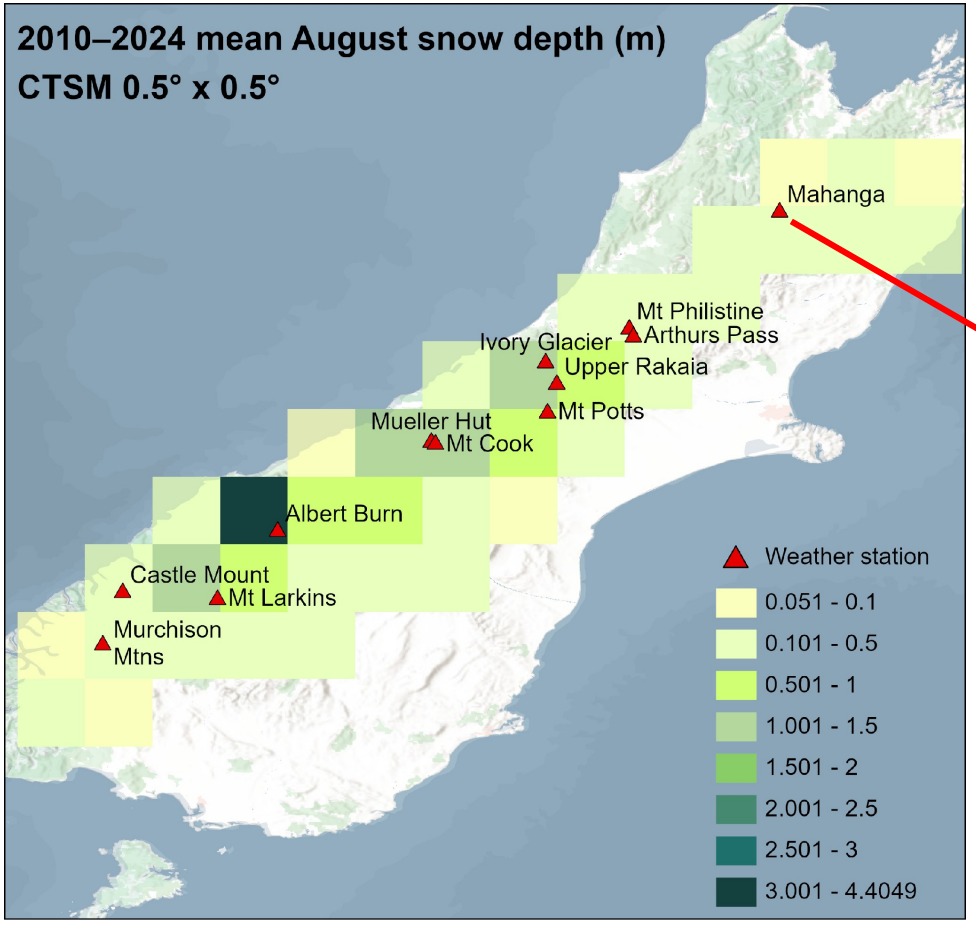
Observations from the New Zealand Snow and Ice Network (SIN)



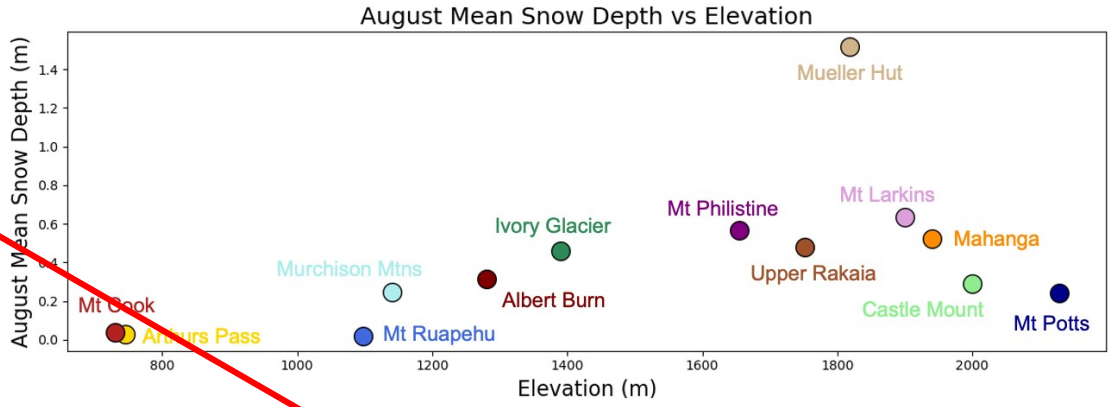


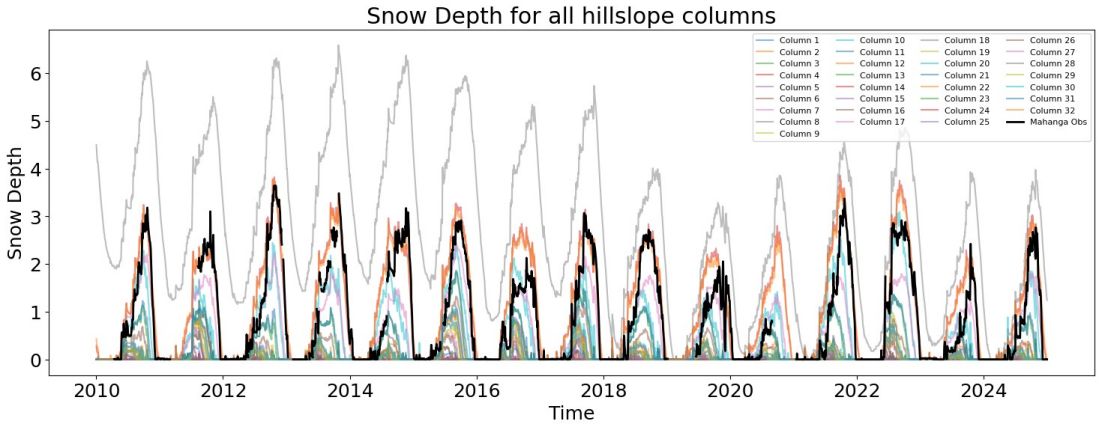
Special thanks to **Jono Conway** from **Earth Sciences New Zealand** for sharing the SIN data

Hillslope Hydrology



Observations from the New Zealand Snow and Ice Network (SIN)

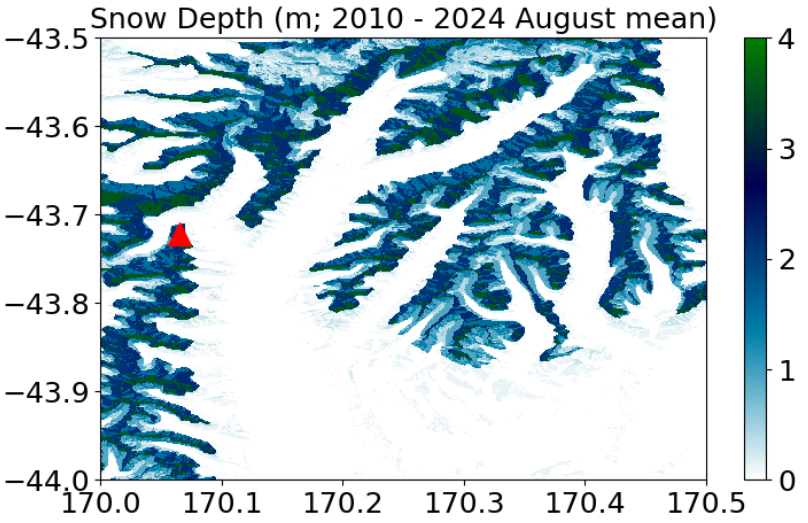


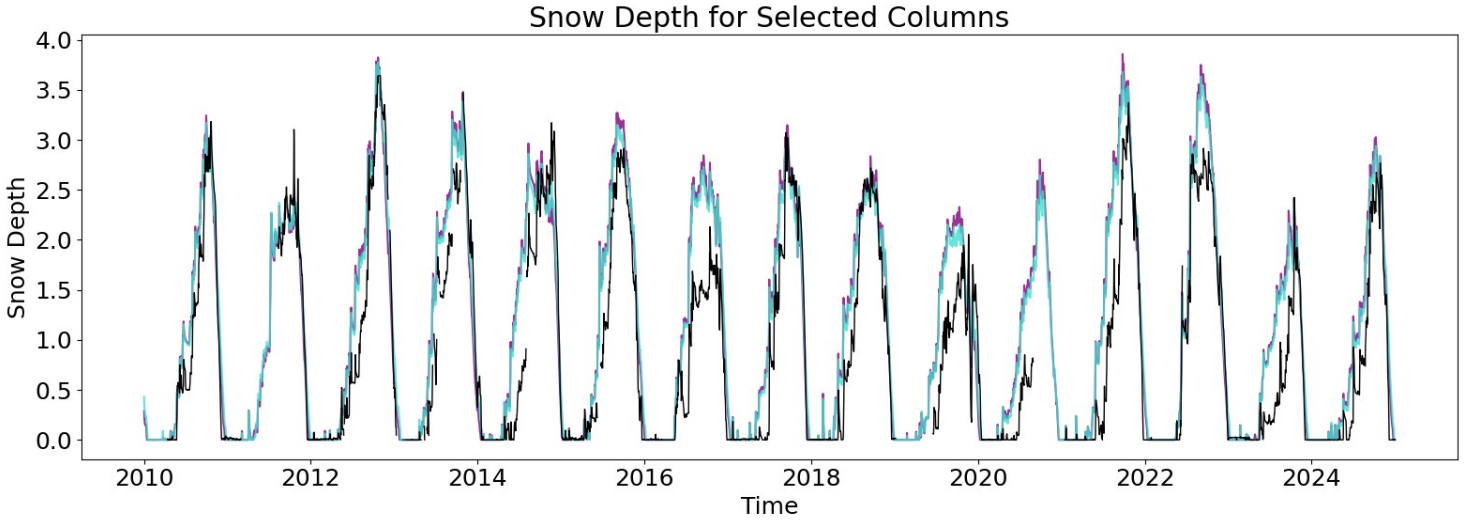


Hillslope Hydrology

Snowpack variability: Mueller Hut







When columns closest in elevation and aspect are selected, agreement with observations is quite good!

Hillslope Hydrology

Input Data

Currently, a 0.9x1.25 global input data file is provided

The scripts (python) to generate hillslope data are publicly available

The scripts can be applied to regional domains, and any DEM can be used

Hillslope Hydrology

Computational Cost

For a given spatial resolution (i.e. grid resolution), the hillslope model is more expensive due to the presence of more columns

Using 16 columns (4x4) is therefore similar to moving from 1° to 0.25° in terms of cost

This can be reduced by using smaller numbers of pfts per gridcell, i.e. 1 or 2 per gridcell.

Hillslope Hydrology

Summary

The hillslope configuration uses the standard model hydrology with two key additions:

Meteorological downscaling produces an ensemble of microclimates in each gridcell

Lateral subsurface flow redistributes soil moisture along topographic gradients

Hillslope Hydrology

Global representative hillslope dataset:
https://zenodo.org/records/15501249

Paper describing methodology:
https://doi.org/10.1029/2024MS004410

Scripts for creating geomorphic parameters:
https://github.com/swensosc/Representative_Hillslopes

Scripts for creating CTSM-specific input file:
https://github.com/ESCOMP/CTSM/pull/2425

Hillslope Hydrology

Future Directions

The hillslope model can be run with FATES, with each column having a separate FATES instance

Coupling to atmospheric models: how can the full hillslope information be passed and utilized by the atmosphere?