Watershed Concepts in CLM

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Hydrology Concepts: What we know

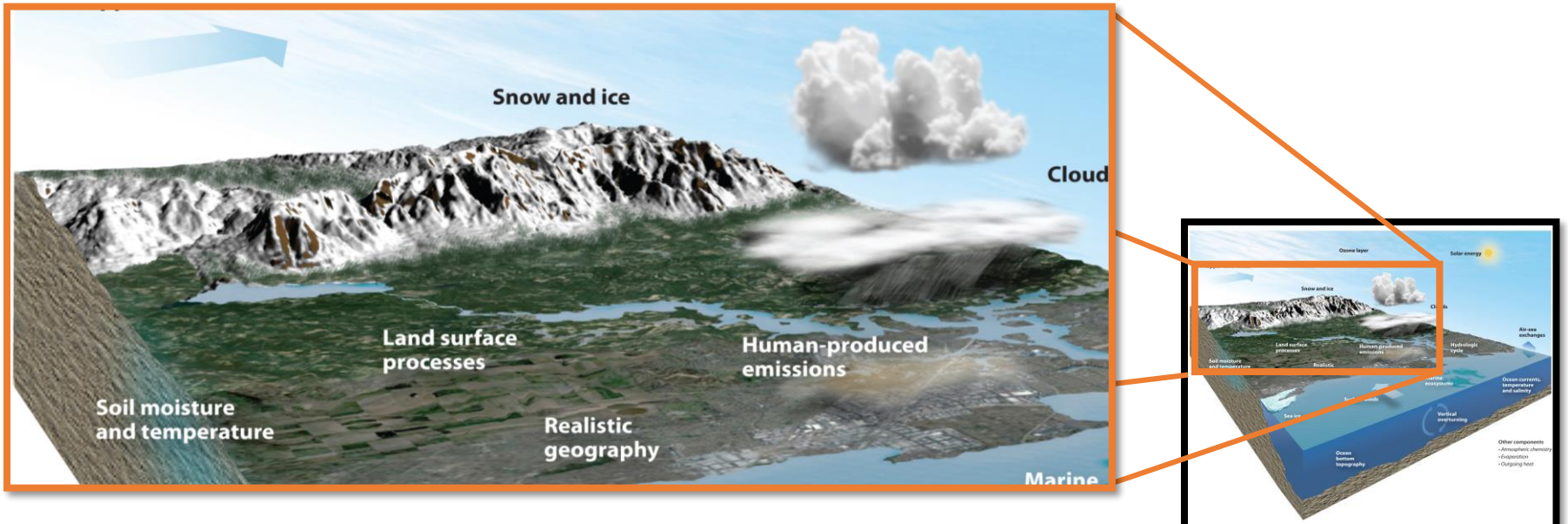
1) Down-slope convergence creates valleys which can support vegetation and ET in rain-less periods

2) Terrain factors change systematically along a topographic gradient, e.g. from ridge to valley, *in general*:
   a) Soil and regolith become thicker
   b) Slope becomes gentler

3) Uplands and lowlands are primarily linked through lateral flow below the water table

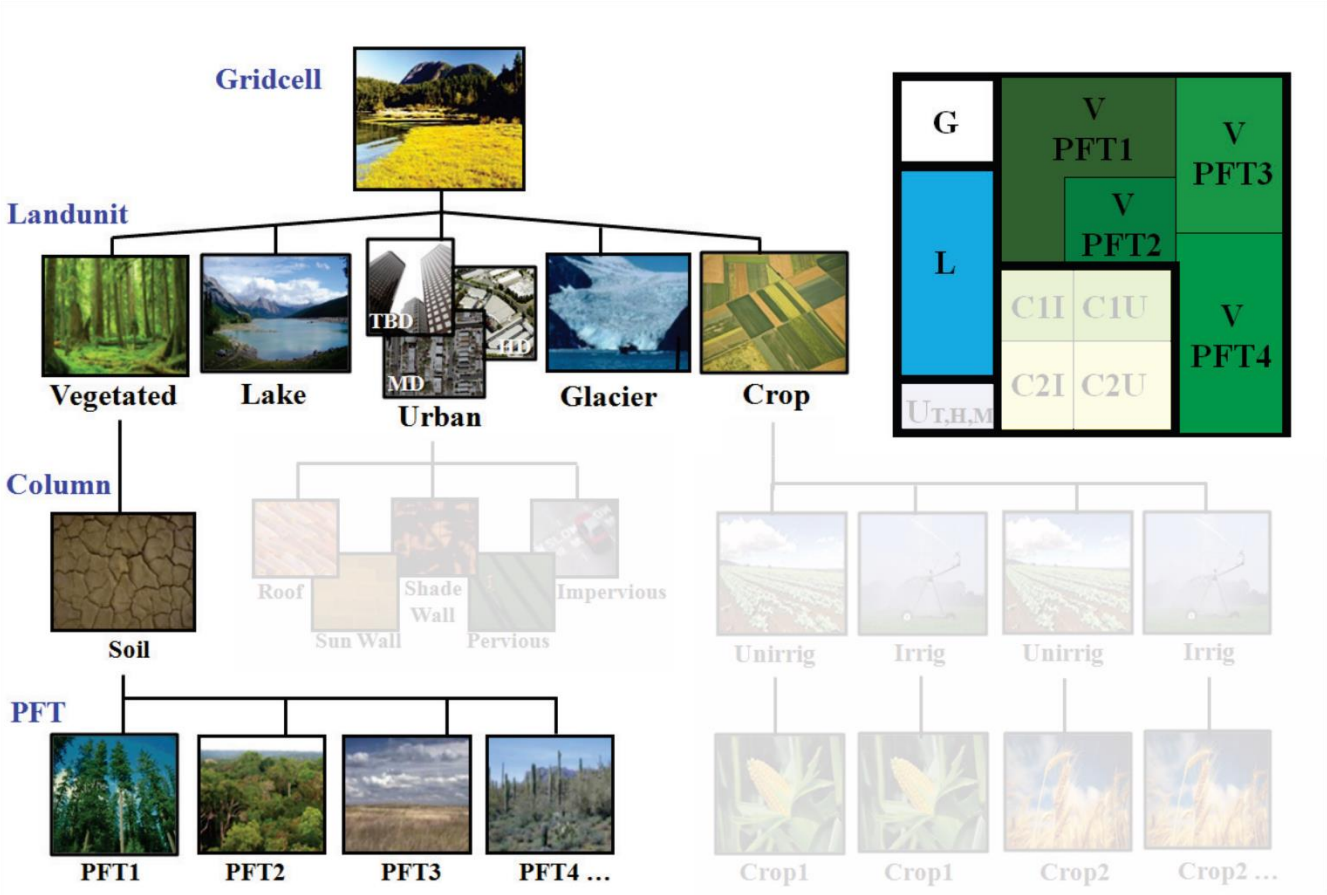
Project Motivation

- Land water strongly influence surface energy & BGC fluxes, and exchanges with atmosphere/ocean
- Climate influences freshwater availability/quality
- Lateral subsurface flow critical to represent terrestrial water, but missing from most Land Surface / Earth System Models
- Need efficient representation of hillslope hydrology dynamics *within gridcells* for global water cycle interactions with climate



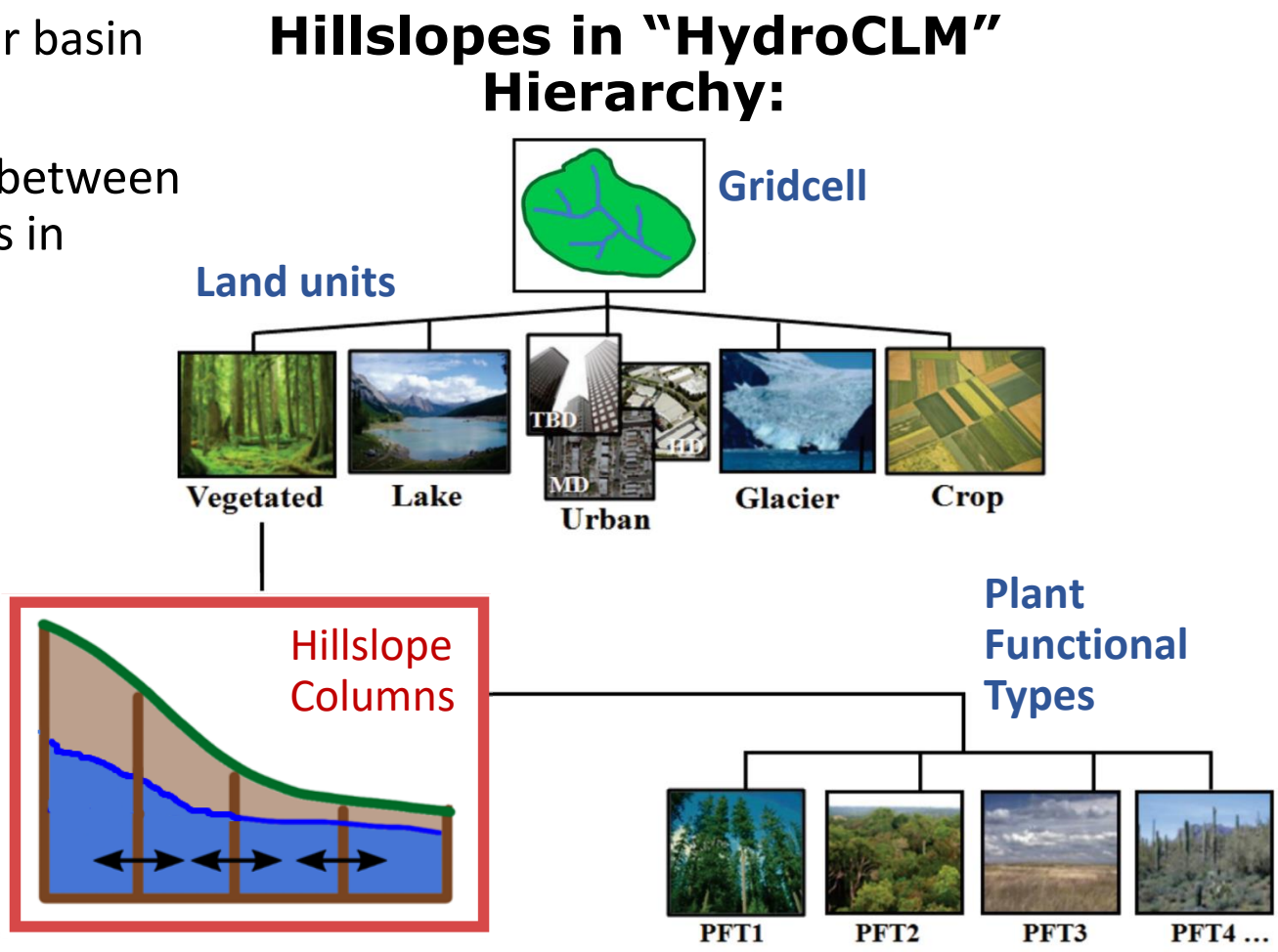
Implementing Hillslope Flow

Current Default CLM Hierarchy :



Implementing Hillslope Flow

- ~1x1° Gridcell level assumes role of drainage basin
- Few representative multi-column hillslopes per basin (if not singular)
- Lateral connections between neighboring columns in hillslope

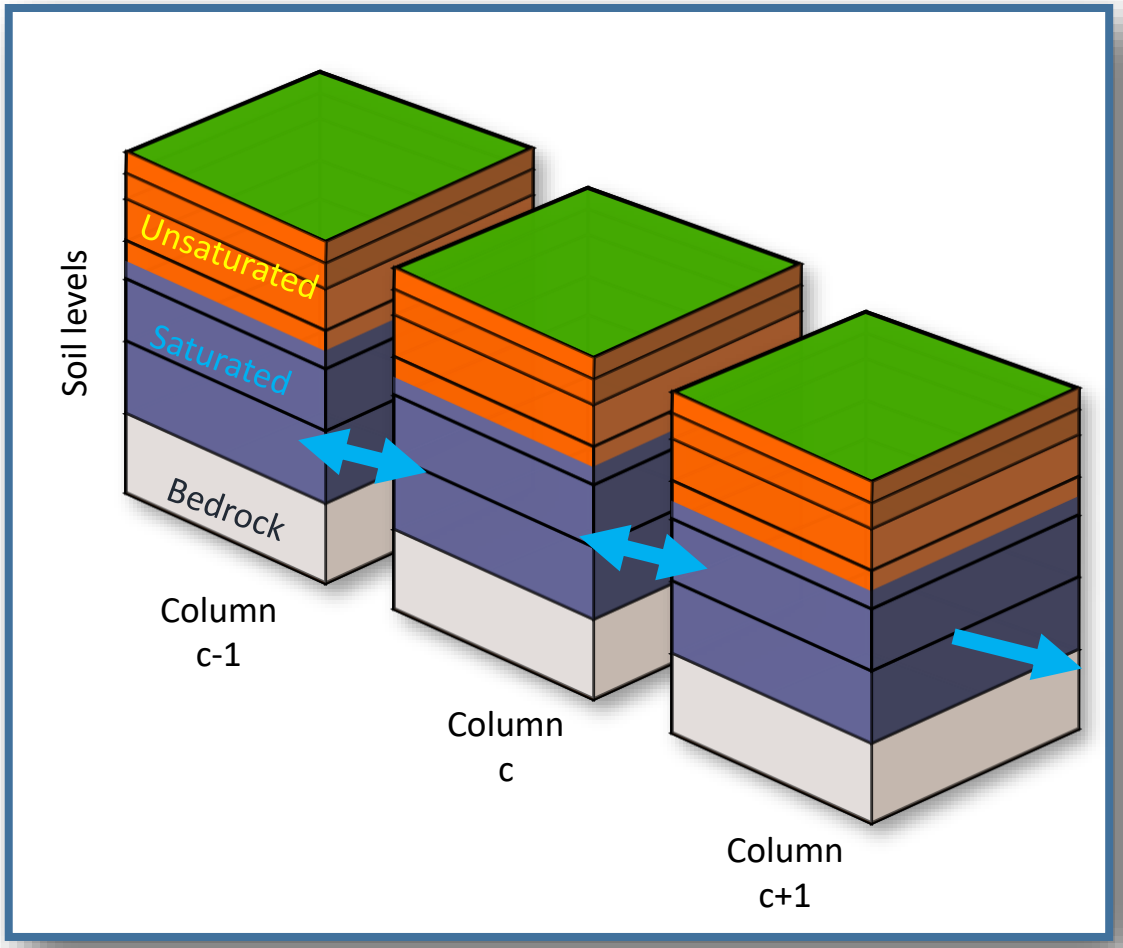


New Structure →

Implementing Hillslope Flow

- Columns have distinct:
  - Elevations
  - Slopes
  - Surface areas
  - Bedrock depths
  - Vegetation
- Lateral saturated flow between columns based on water table gradient

Hillslope Column Lateral Connectivity In a Gridcell:



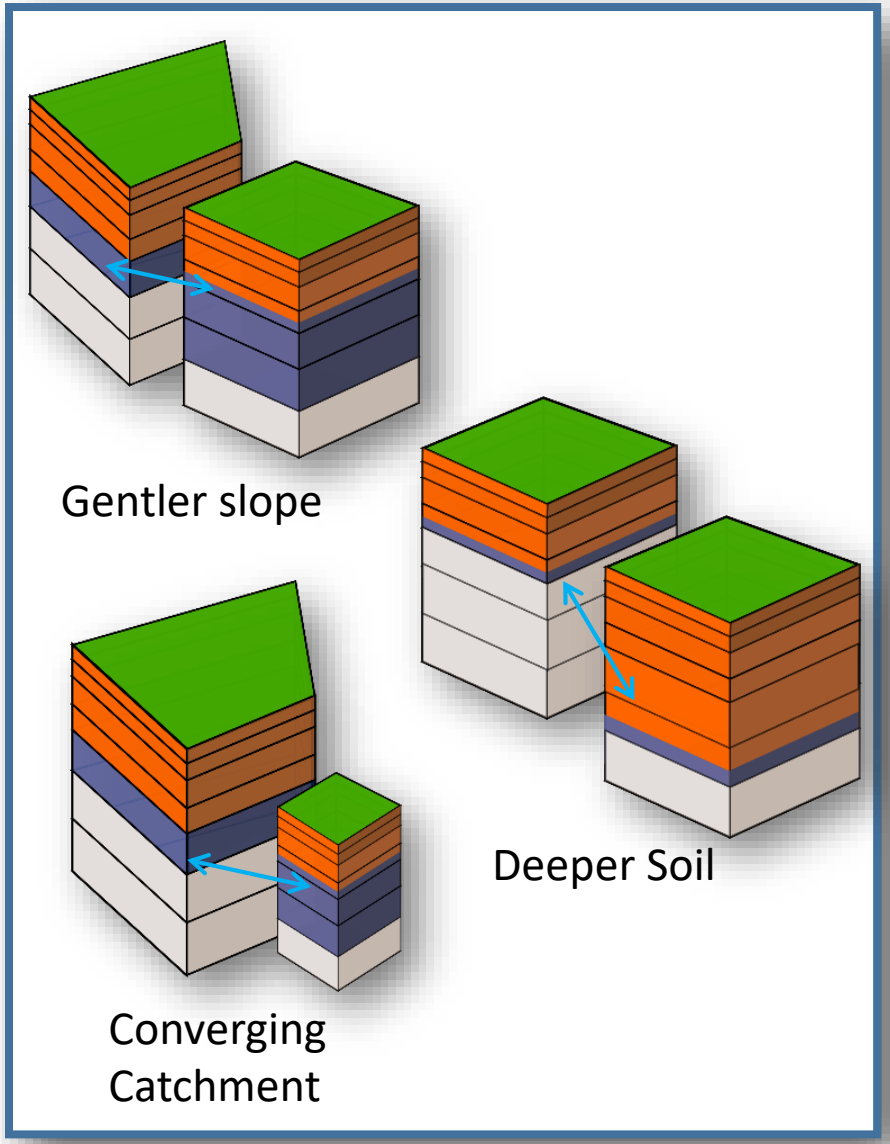
Applying the Hydrology Community Knowledge Base

What we know in general:

1. Down-slope convergence creates wetter valleys which can support vegetation and ET in rain-less

2. Terrain factors change systematically along a topographic gradient, e.g. from ridge to valley, in general:
   - Soil and regolith become thicker
   - Slope becomes gentler

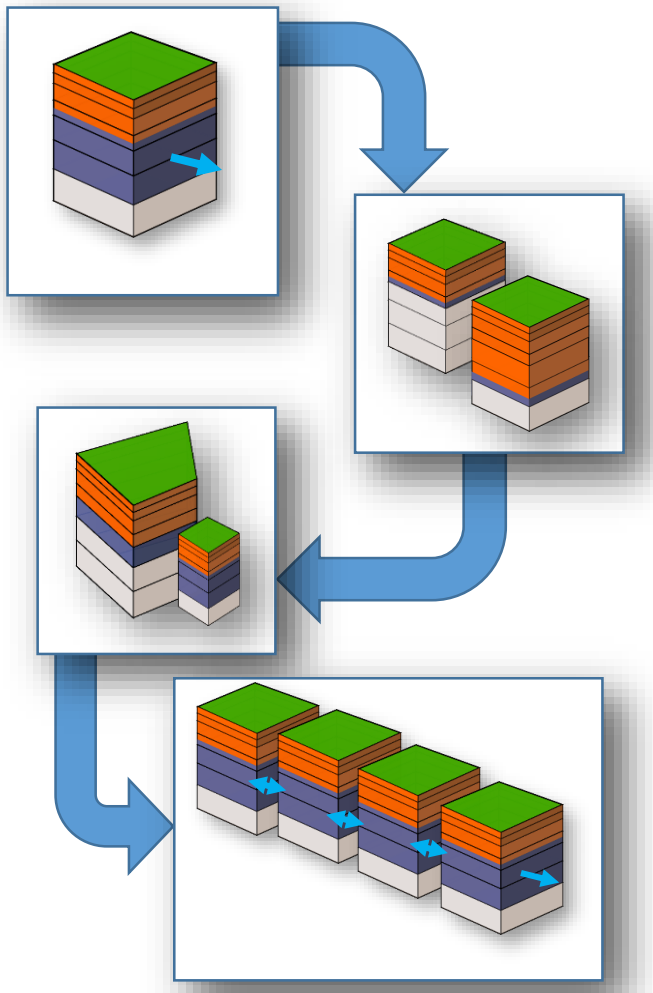
Going from Ridge to Valley:



Terrain Controls

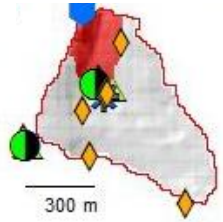
After individual evaluation of each parameter's sensitivity:

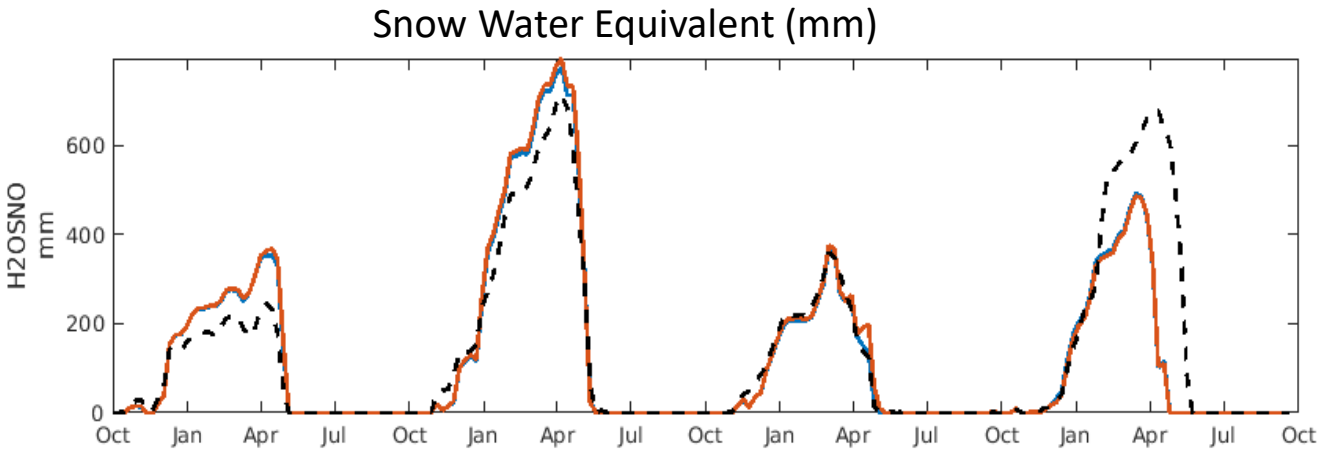
Trial	Description
A	Single Column
B	4 Columns, Connected, Deepening Soil
C	B + Converging Basin
D	Full suite, C + Slowing Slope



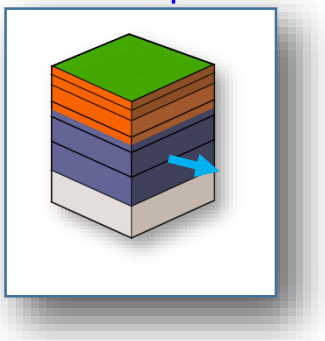
Effects of Applying Basin Topography

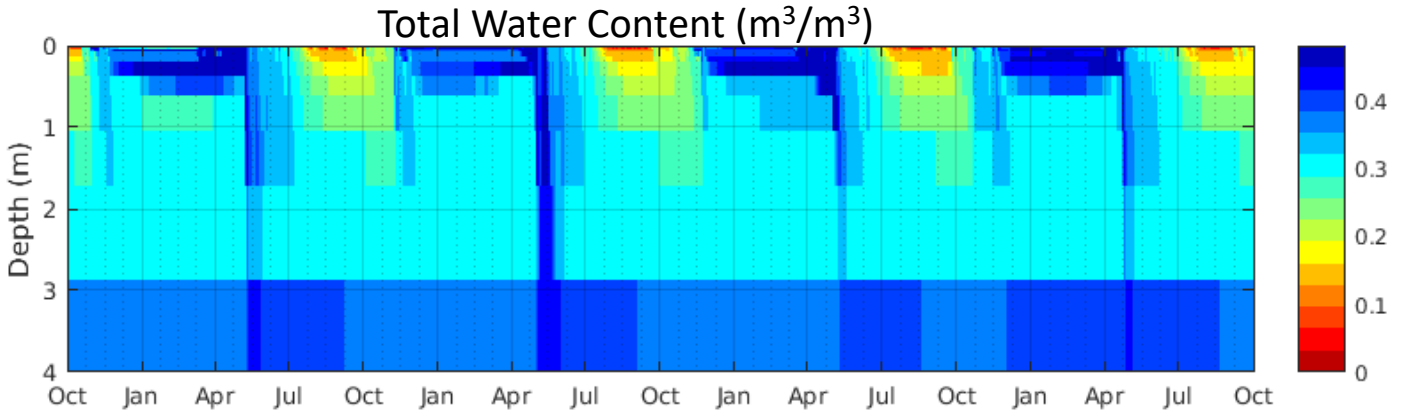
Forcing/Obs. from Reynolds Creek Mountain East





A) Single Column Hillslope

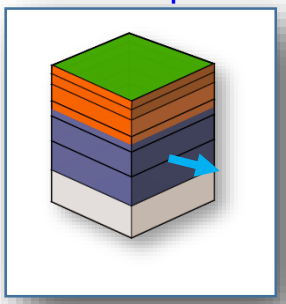


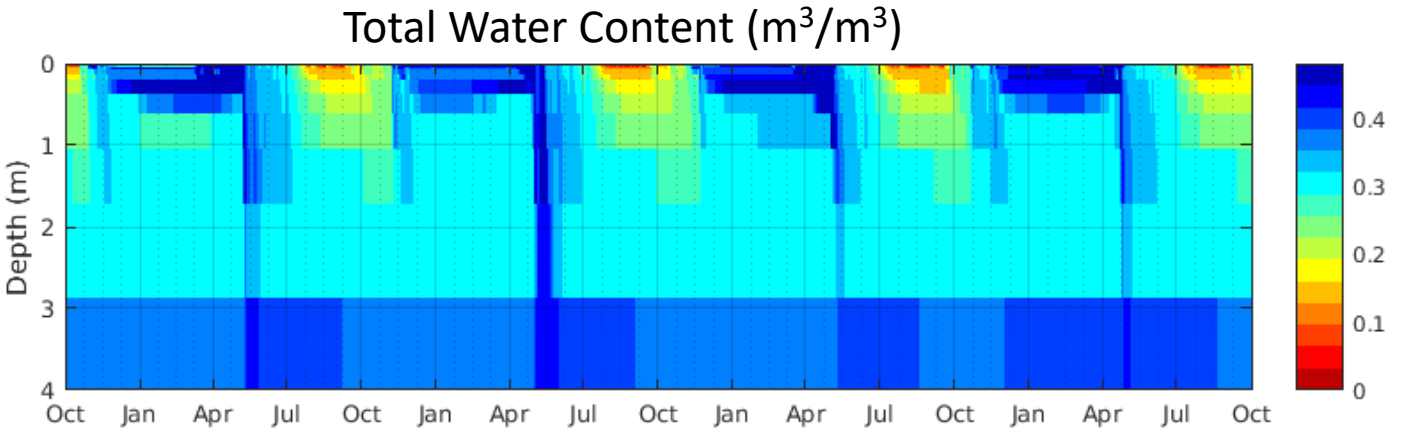


- "Default" single column can't retain moisture from spring melt events

Effects of Applying Basin Topography

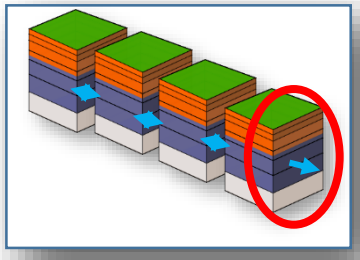
A) Single Column Hillslope

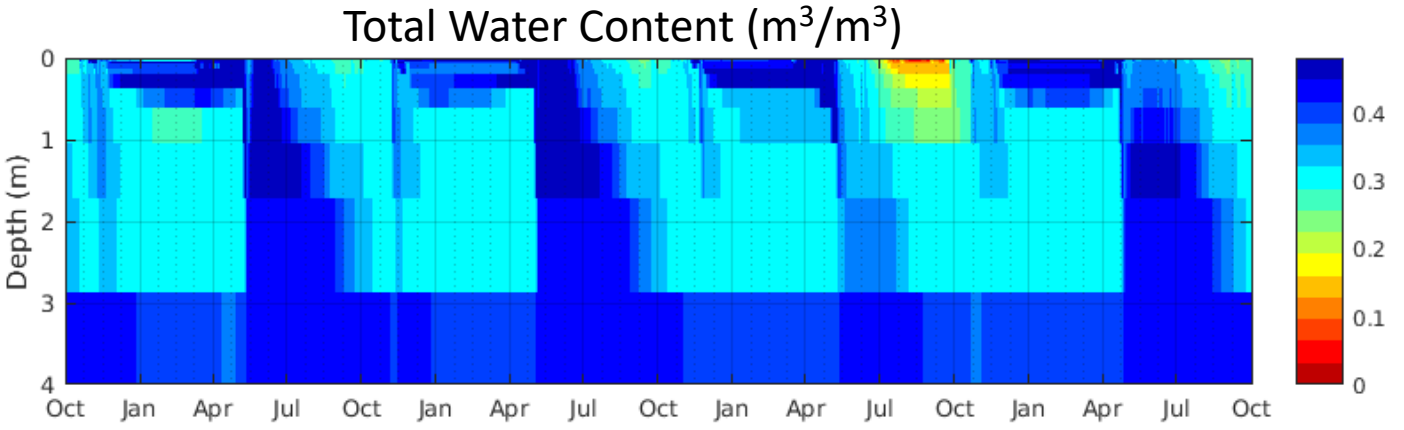




- Basin representation with a combination of terrain factors can significantly reduce dry periods in lowland …

D) Last Column of Full Suite

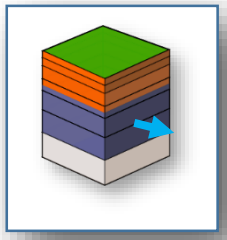




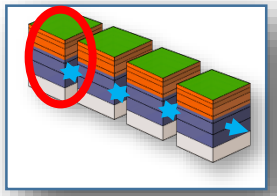
Effects of Applying Basin Topography

- … While keeping dry periods in upland

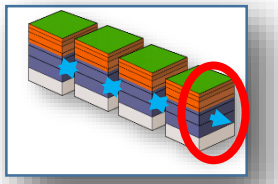
Single Column Hillslope

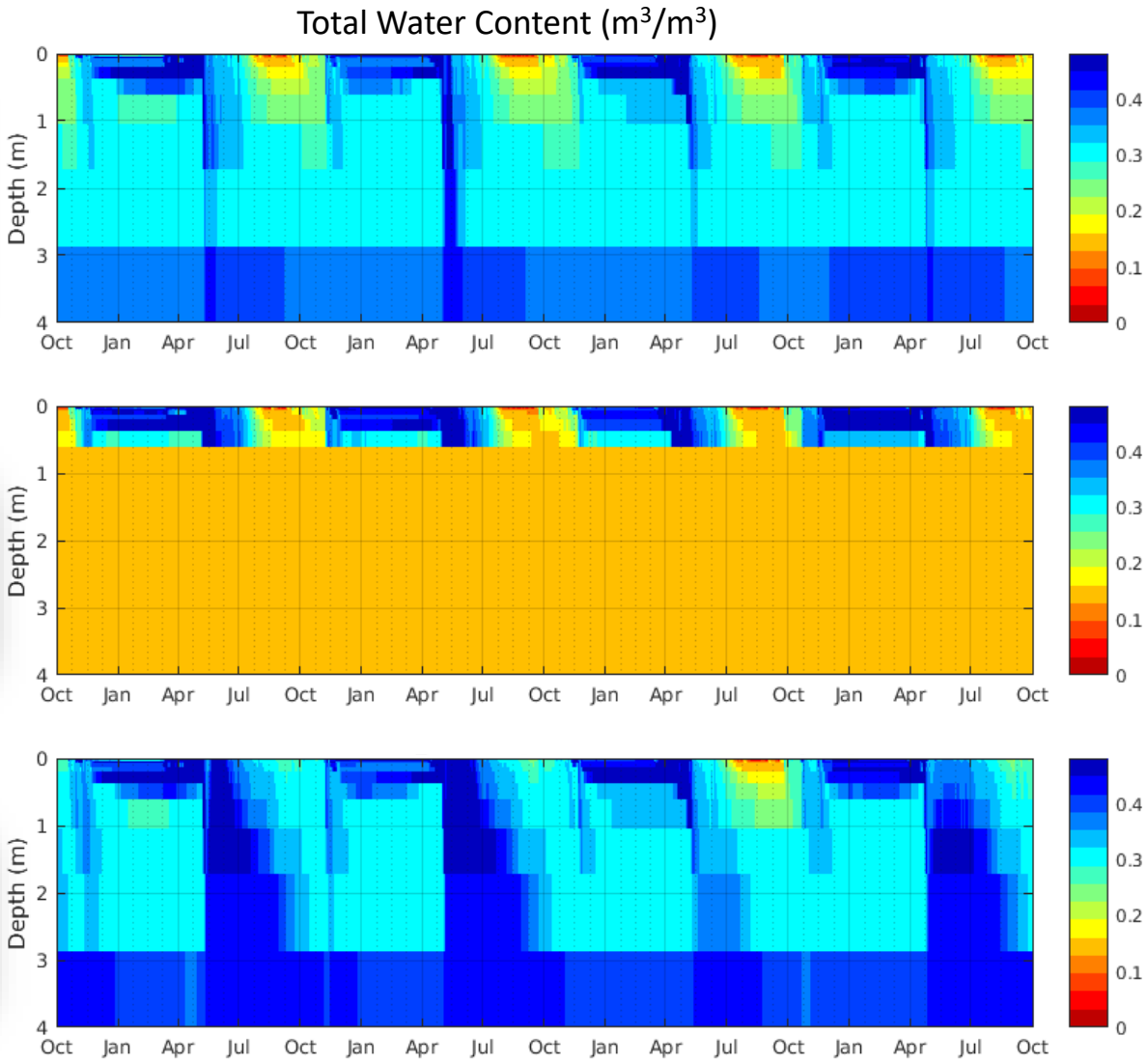


First Column of Full Suite



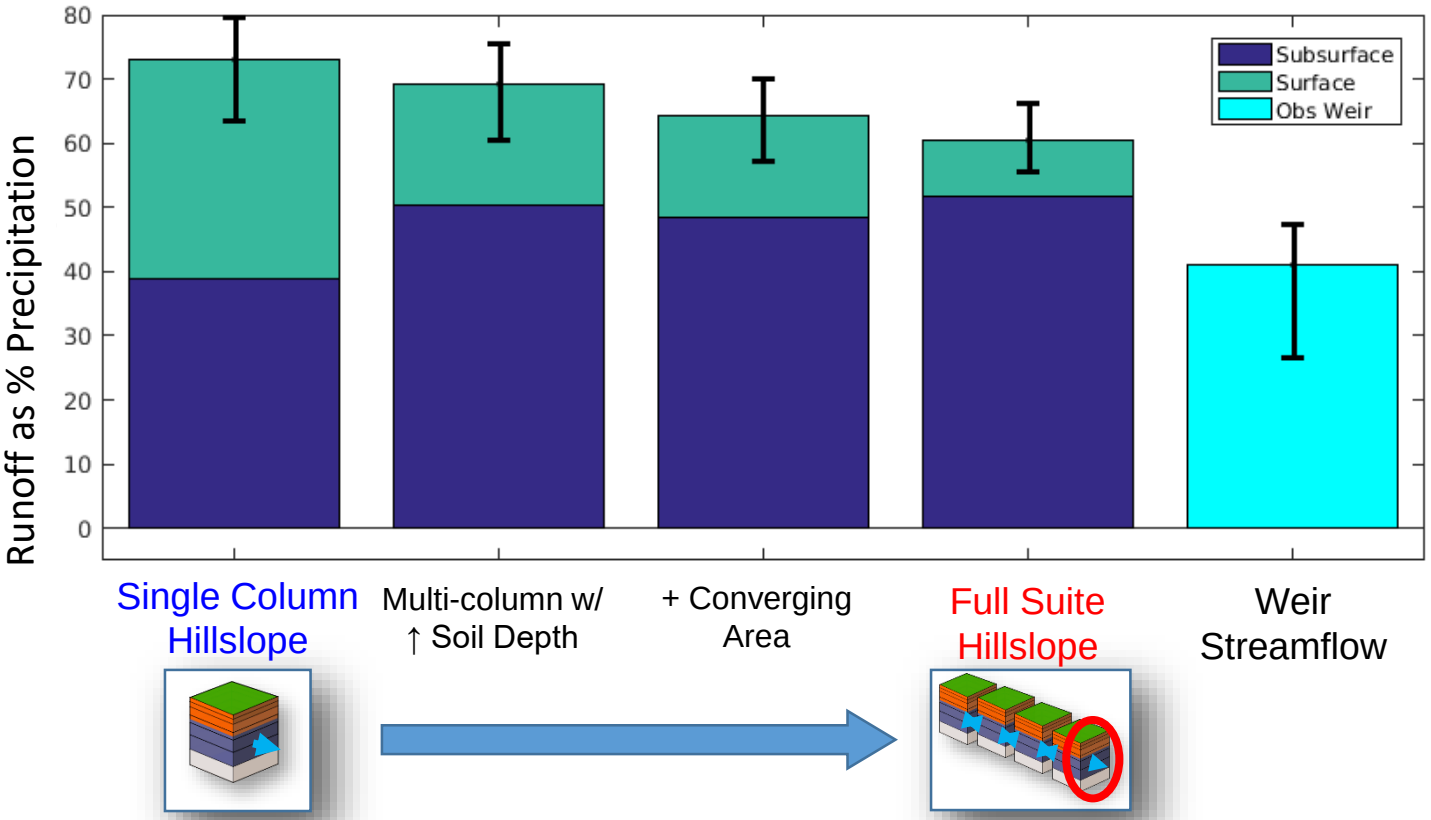
Last Column of Full Suite





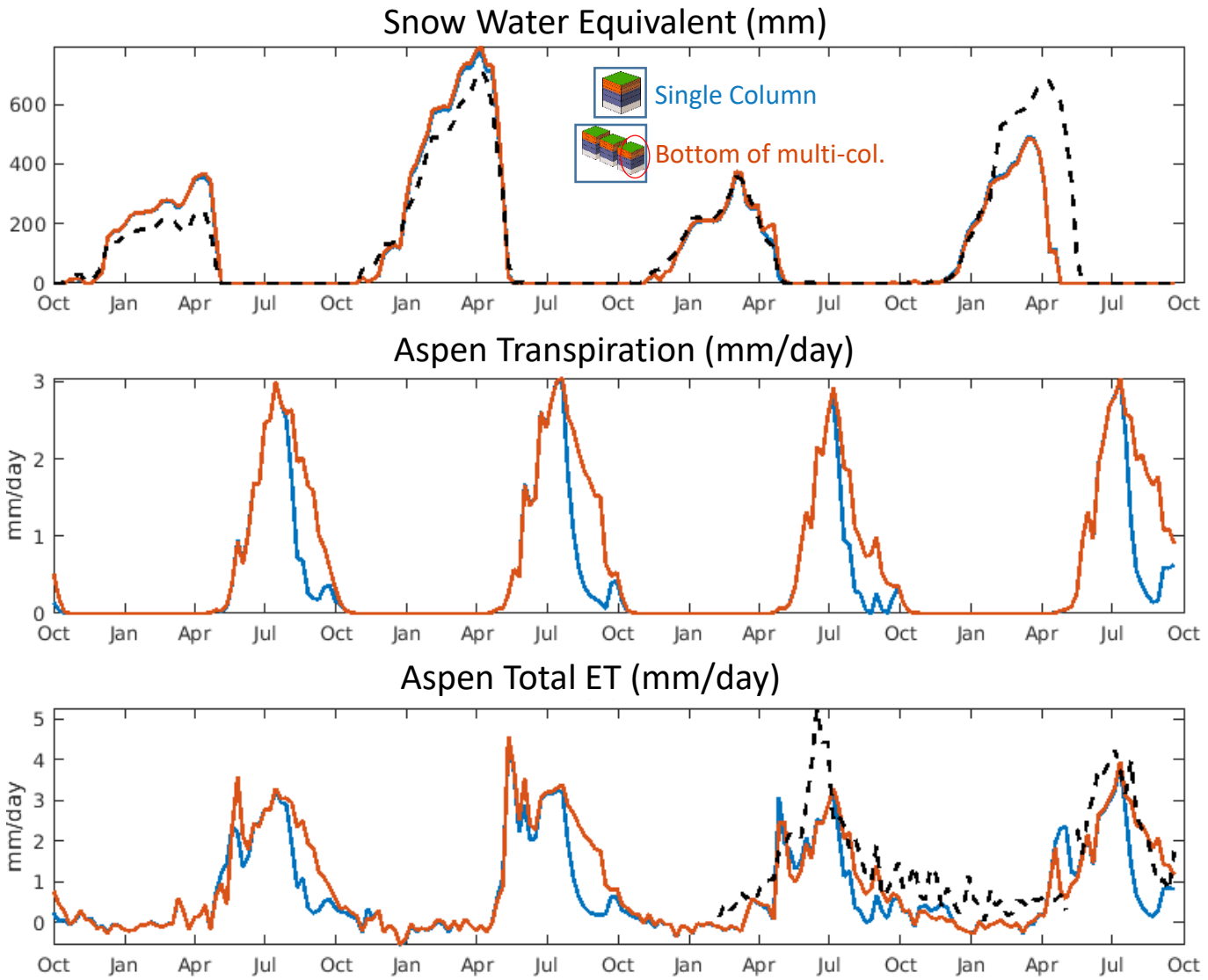
Hillslope Runoff Compared with Obs.

- Water Year 2004-2008, comparing with weir outflow
- Little change in soil storage
- More spring melt infiltration = more later ET



Effects of Applying Basin Topography

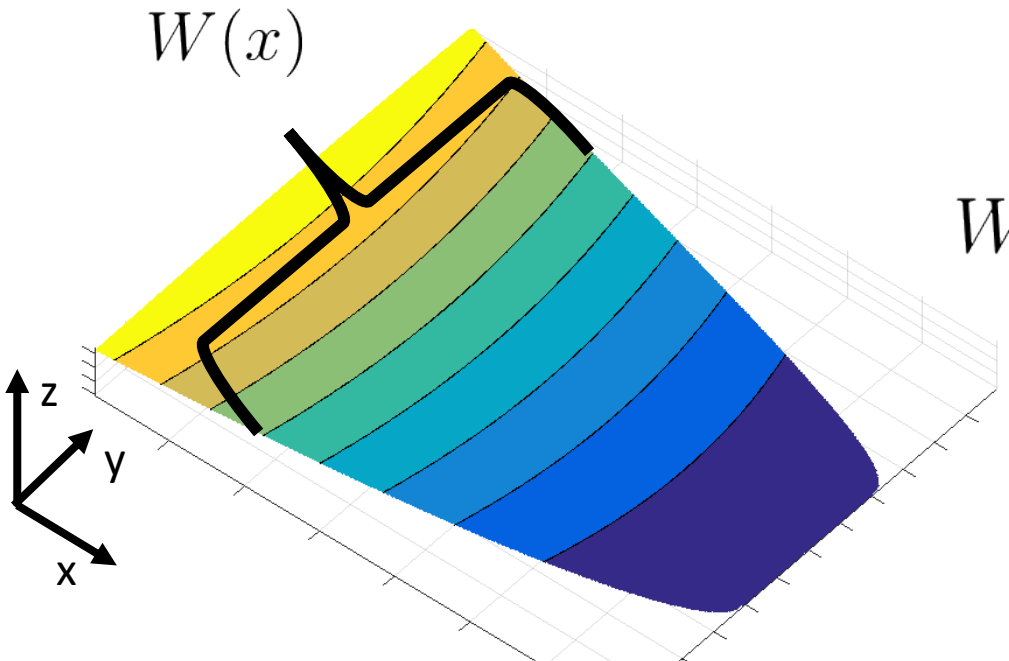
- Unstressed lowlands while retaining moisture stress upland
- Influence of vegetation heterogeneity, LAI
- Two-way street: how will hydrology affect carbon cycle? – long-term climate feedbacks



Hillslope topographic function

- Systematic approach: Confine hillslope to few parameters
- Column Widths and areas from topographic function

$$z(x,y) = H(1 - \tfrac{x}{L})^n + \omega y^2$$



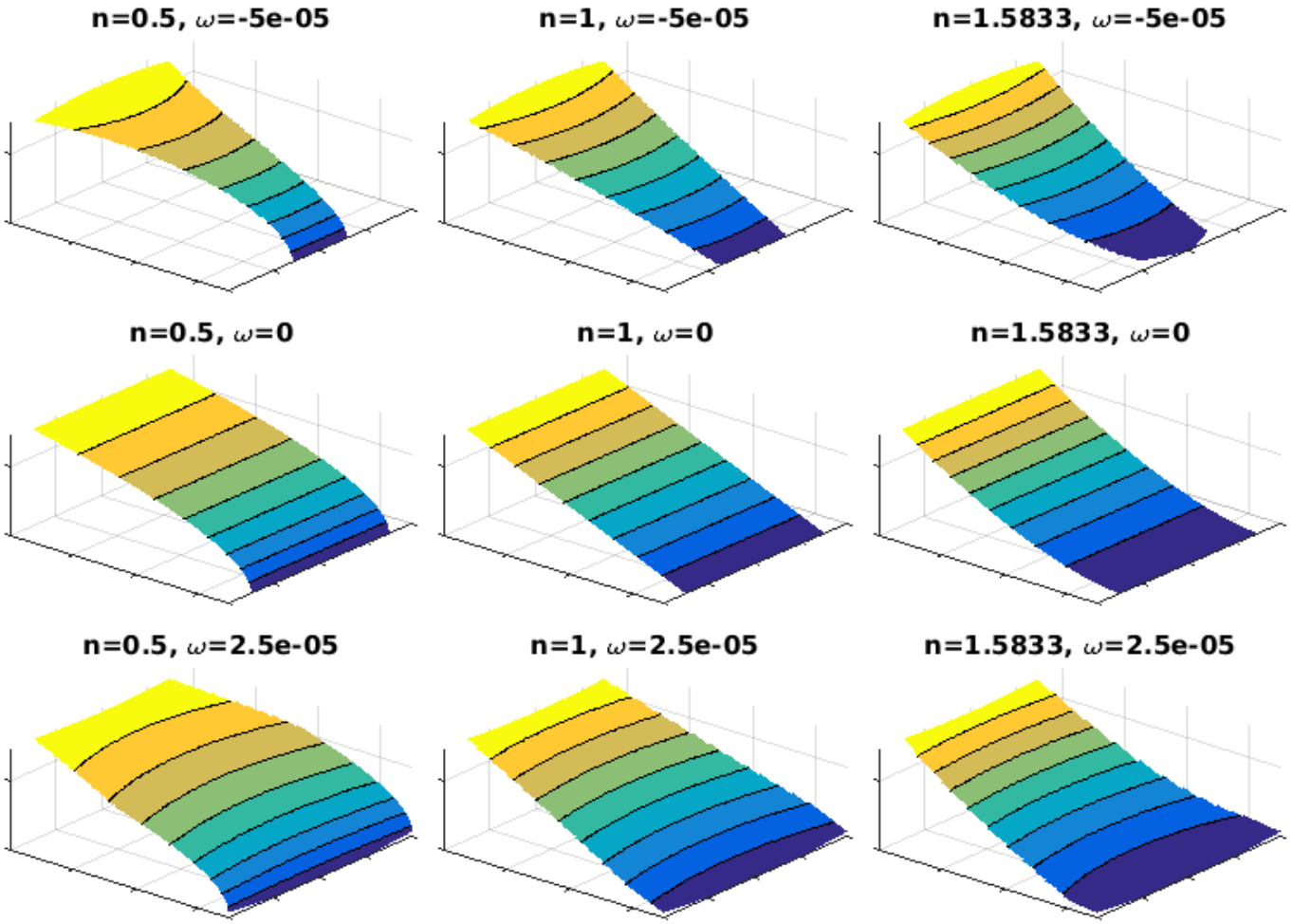
$$W(x) = W_0 e^{c_1([1-\frac{x}{L}]^{2-n}-1)}$$

$$c_1 = \frac{-2\omega L^2}{H(2-n)n}$$

Hillslope topographic function

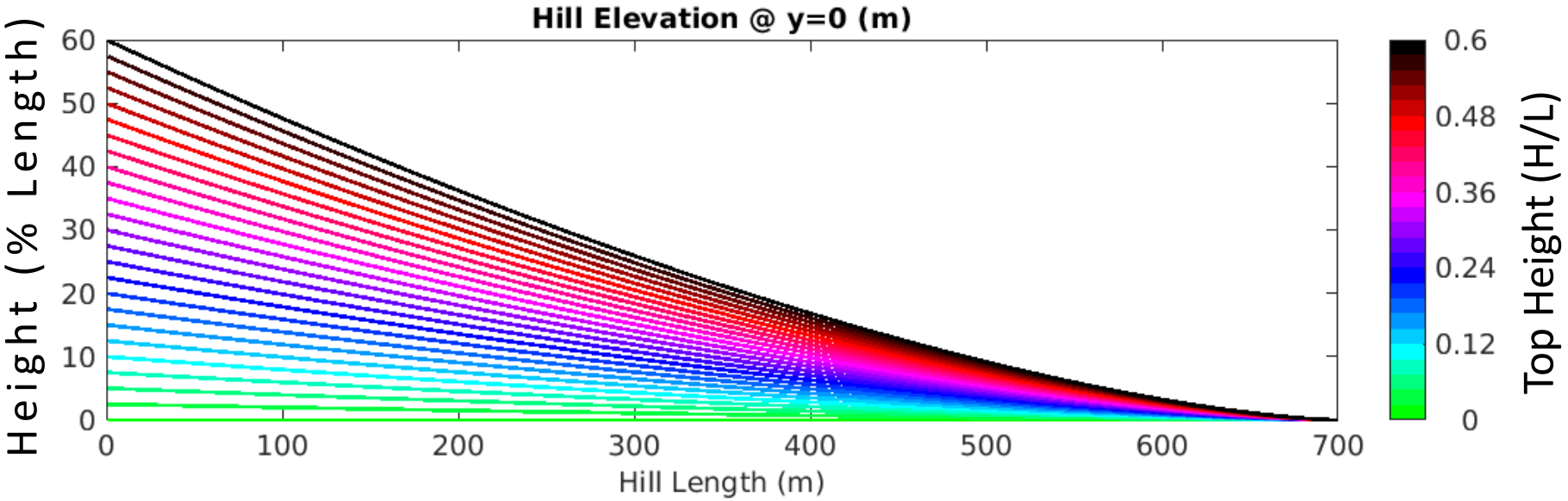
$$z(x,y) = H(1 - \frac{x}{L})^n + \omega y^2 \qquad W(x) = W_0 e^{c_1([1-\frac{x}{L}]^{2-n}-1)}$$

$$c_1 = \frac{-2\omega L^2}{H(2-n)n}$$

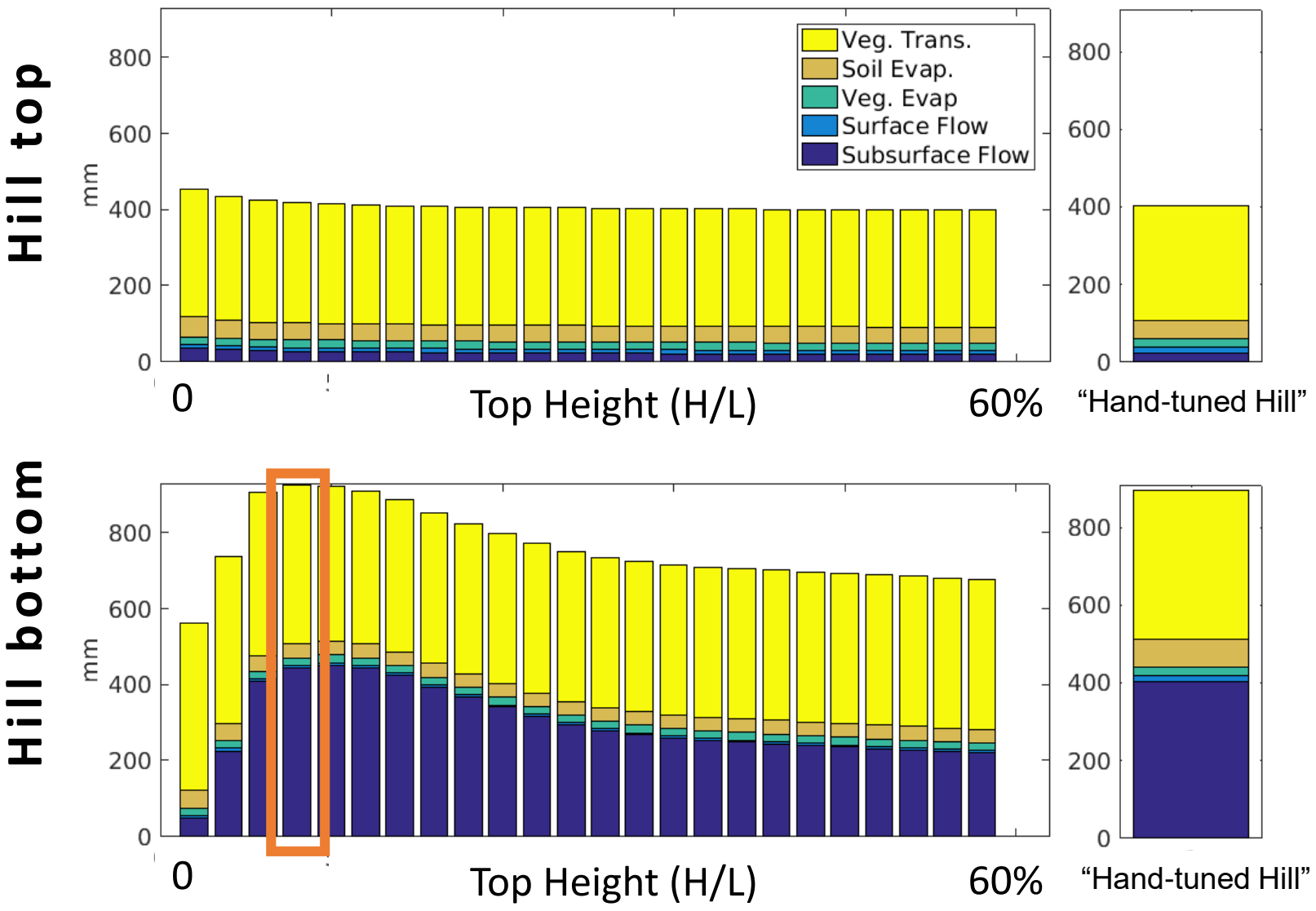


Column output – Height Variation

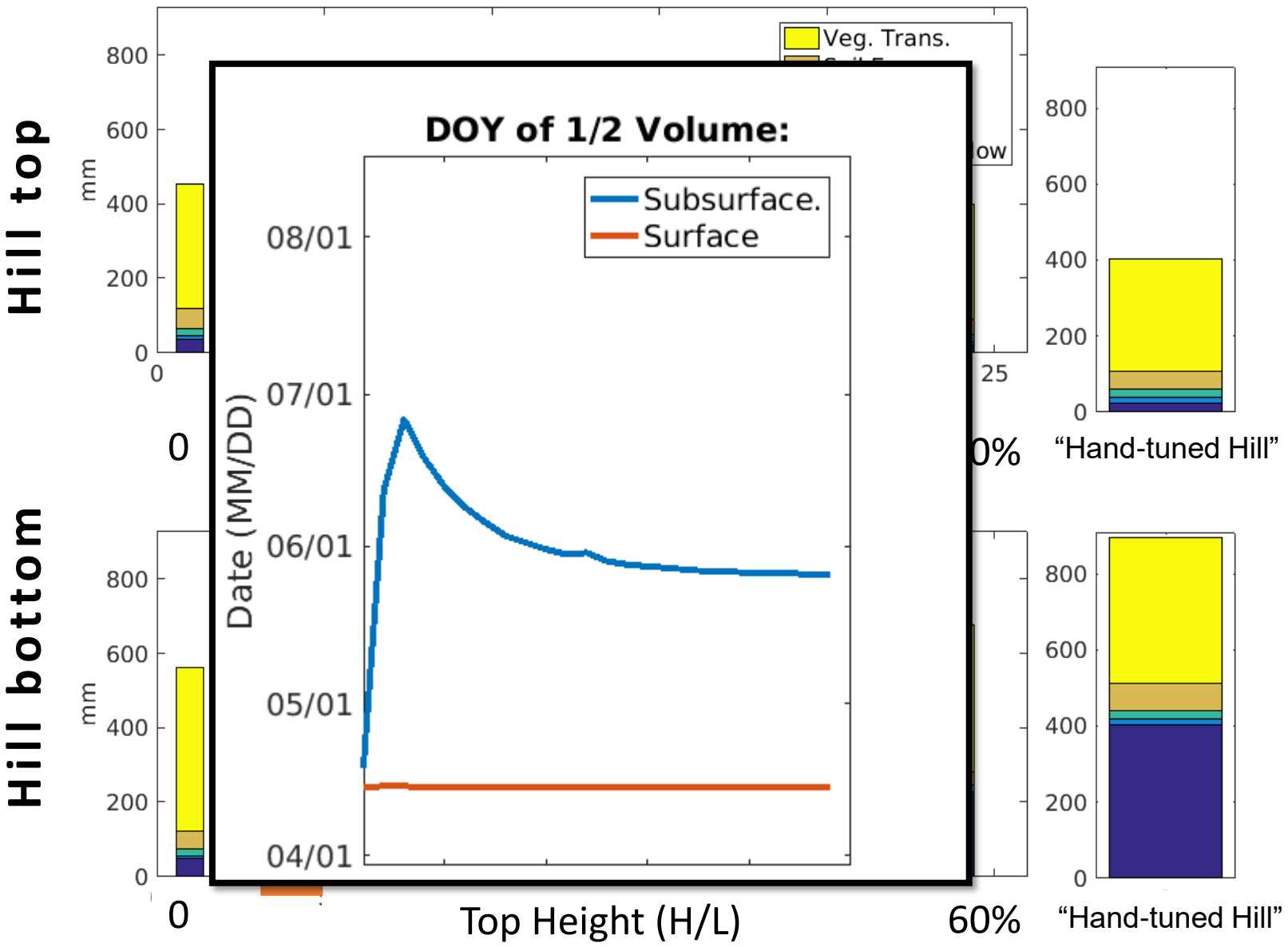
$$z(x,y) = H(1 - \frac{x}{L})^n + \omega y^2$$



Column output – Height Variation



Column output – Height Variation

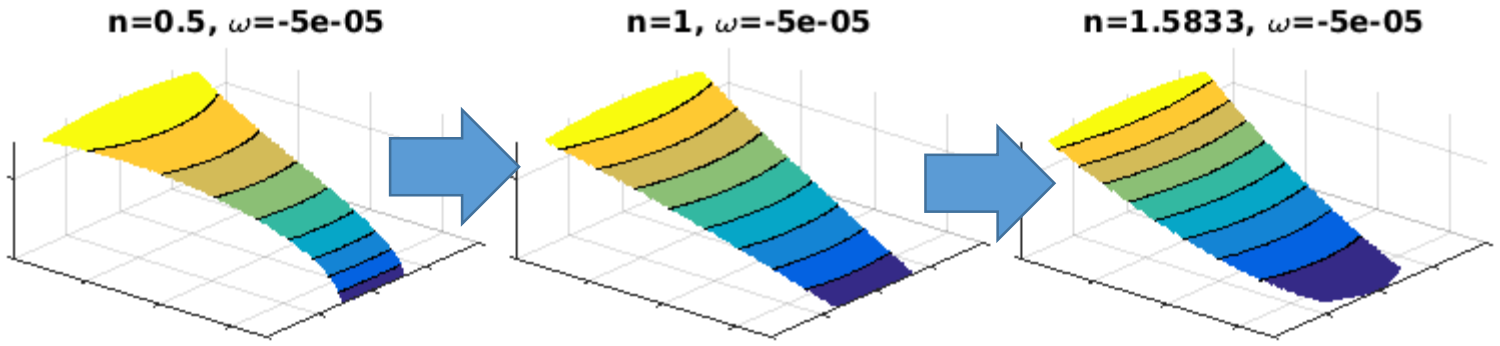


Column output – Profile Curve Variation

$$z(x,y) = H(1 - \frac{x}{L})^{n} + \omega y^2$$

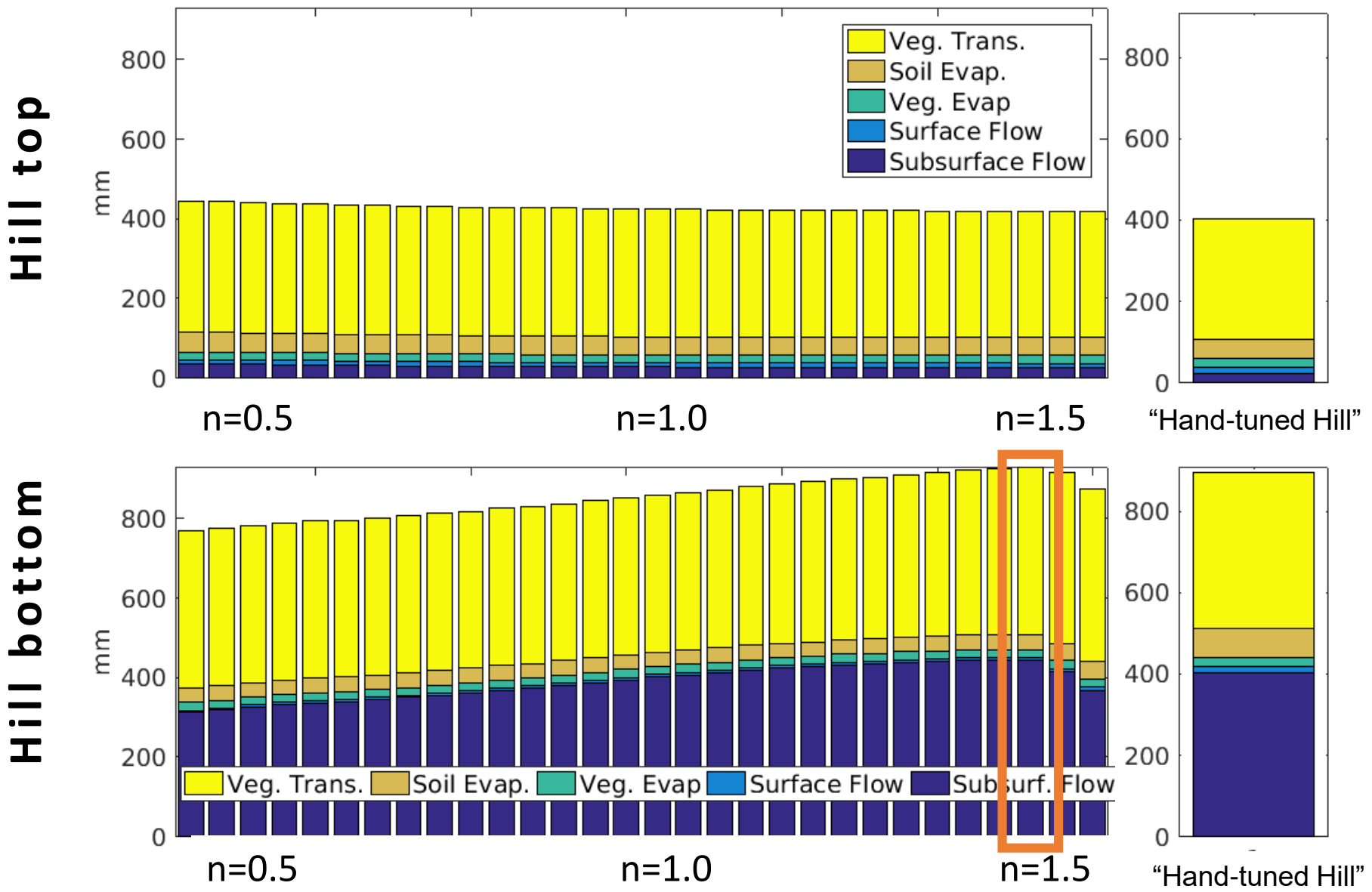
$$W(x) = W_0 e^{c_1([1-\frac{x}{L}]^{2-n}-1)}$$

$$c_1 = \frac{-2\omega L^2}{H(2-n)n}$$

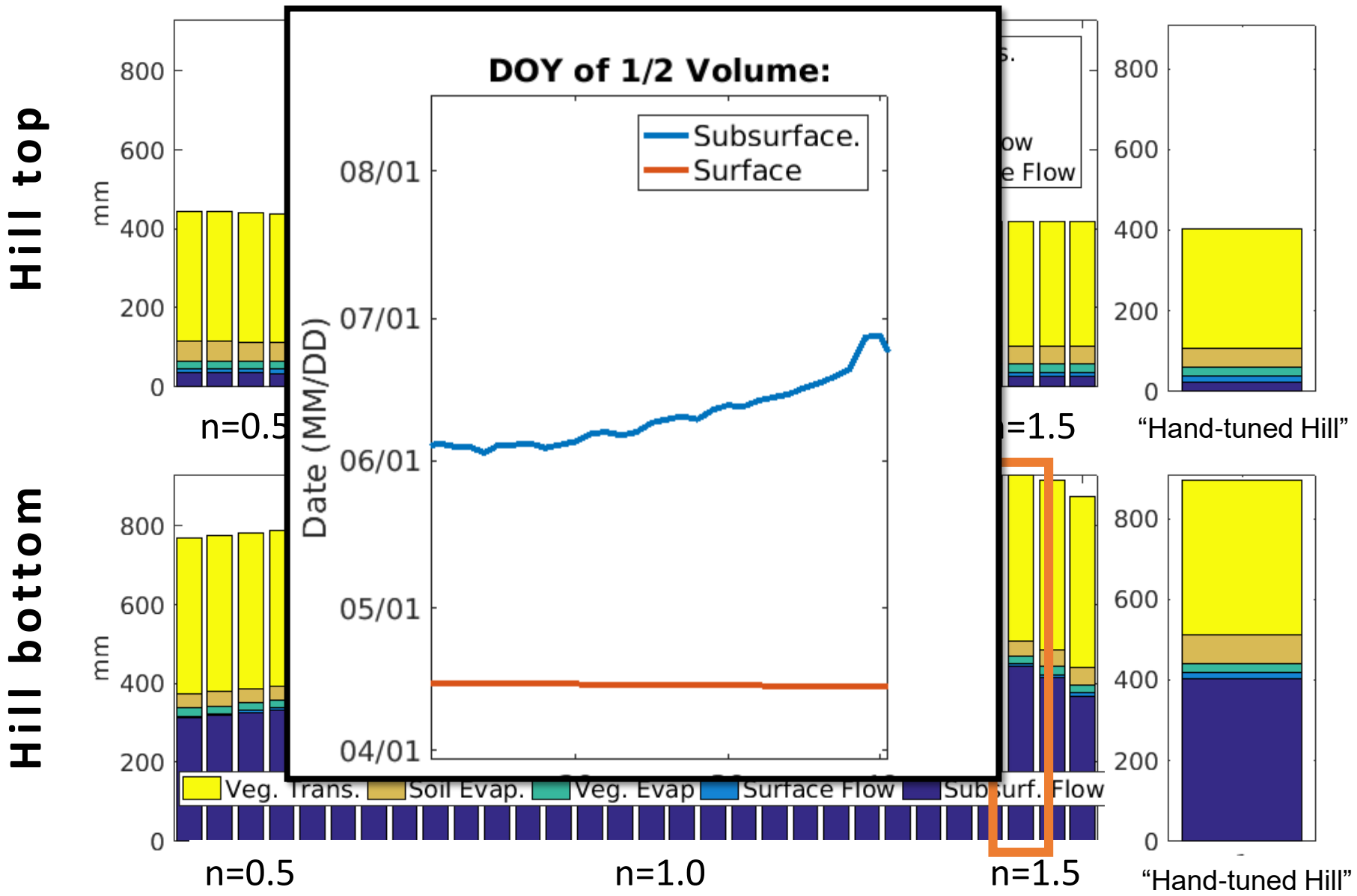


n = 0.5 n 1 n = ~1.6

Column output – Profile Curve Variation



Column output – Profile Curve Variation

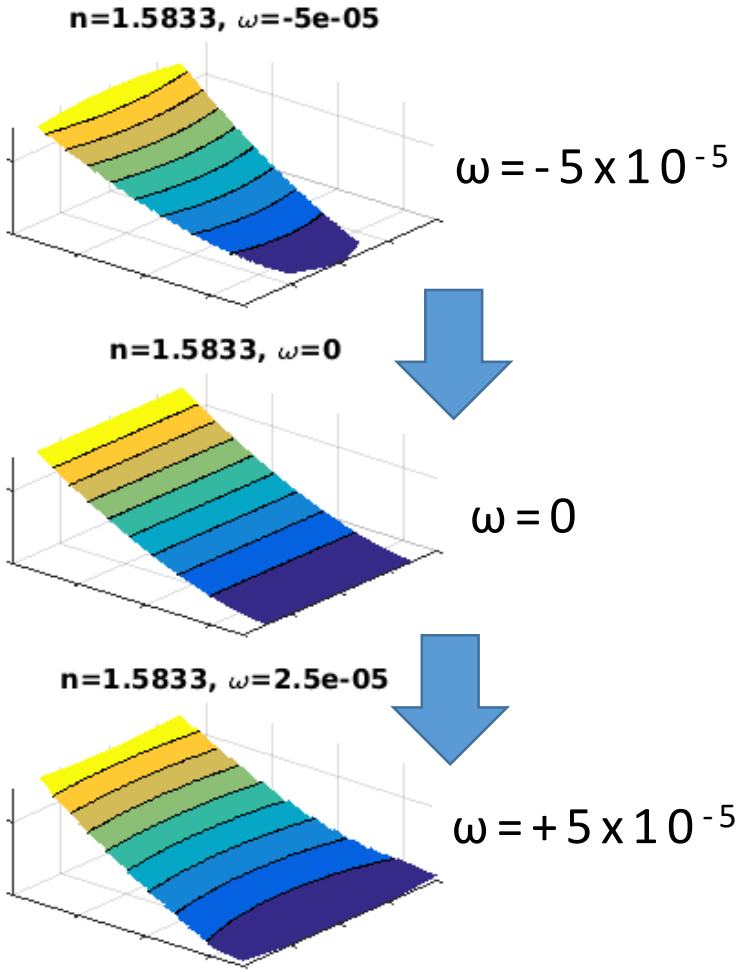


Column output – Plane Curve Variation

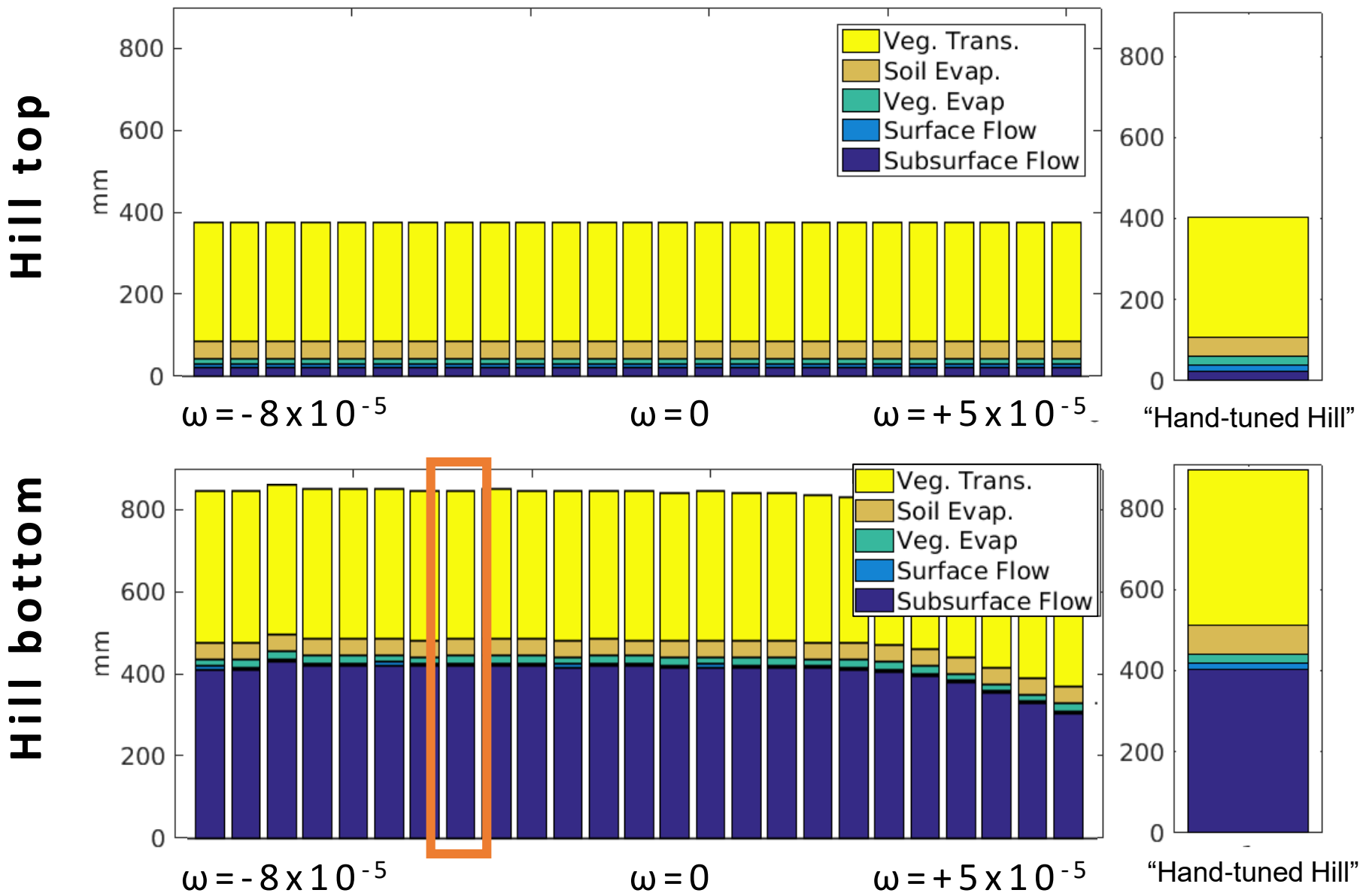
$$z(x,y) = H(1 - \frac{x}{L})^n + \omega y^2$$

$$W(x) = W_0 e^{c_1([1-\frac{x}{L}]^{2-n}-1)}$$

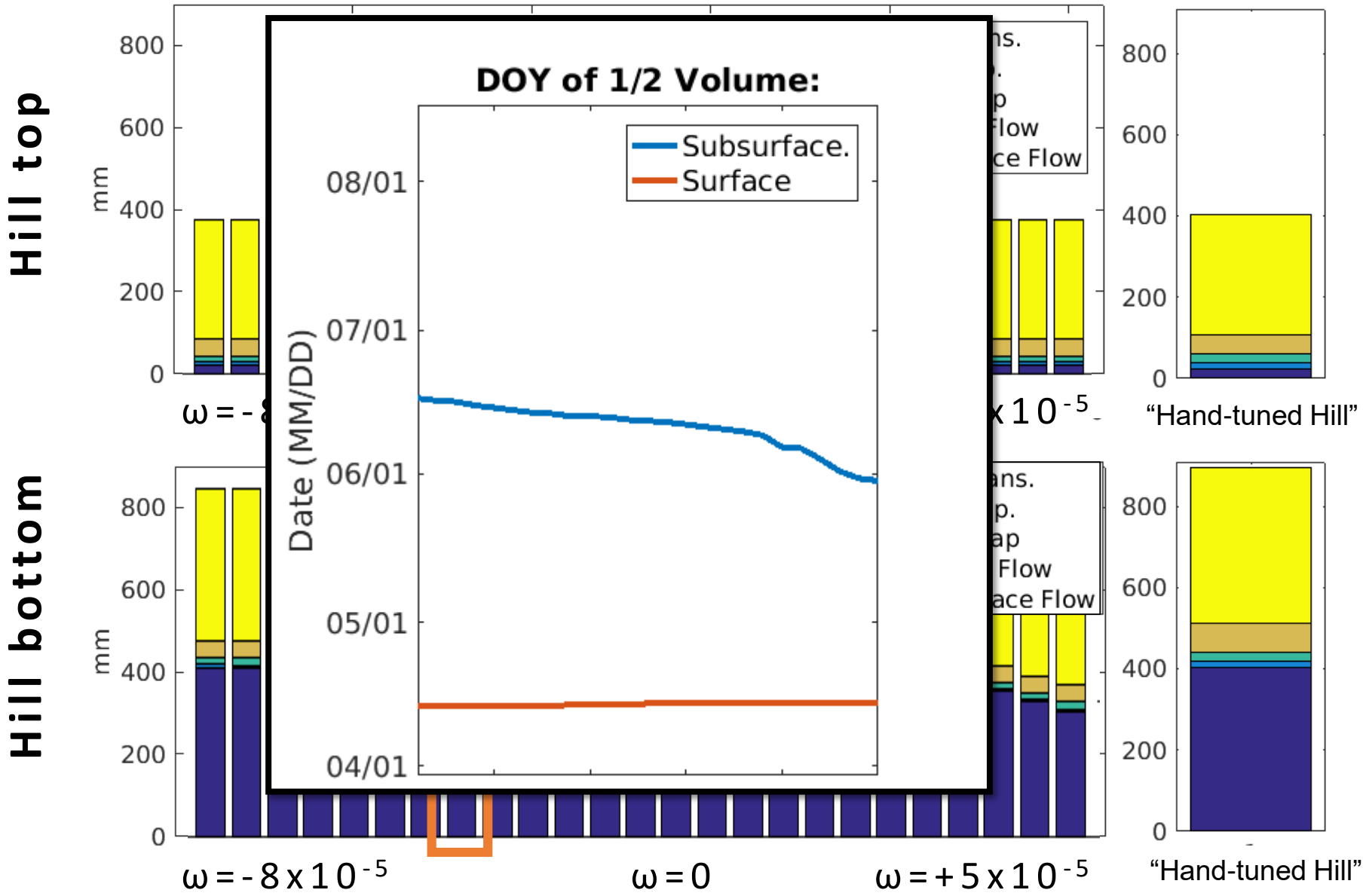
$$c_1 = \frac{-2\omega L^2}{H(2-n)n}$$



Column output – Plane Curvature Variation



Column output – Plane Curvature Variation



What have we learned?

- Simple hydrology concepts applied to ESM makes a difference!
  - Need terrain influences on Darcy's law (depth, slope, convergence) together to capture basin behavior
  - Hillslope columns (redistributing water, buffering stress) generate subgrid mosaic of dry and wet

- Topographic heterogeneity
  → groundwater heterogeneity
  → vegetation water/energy

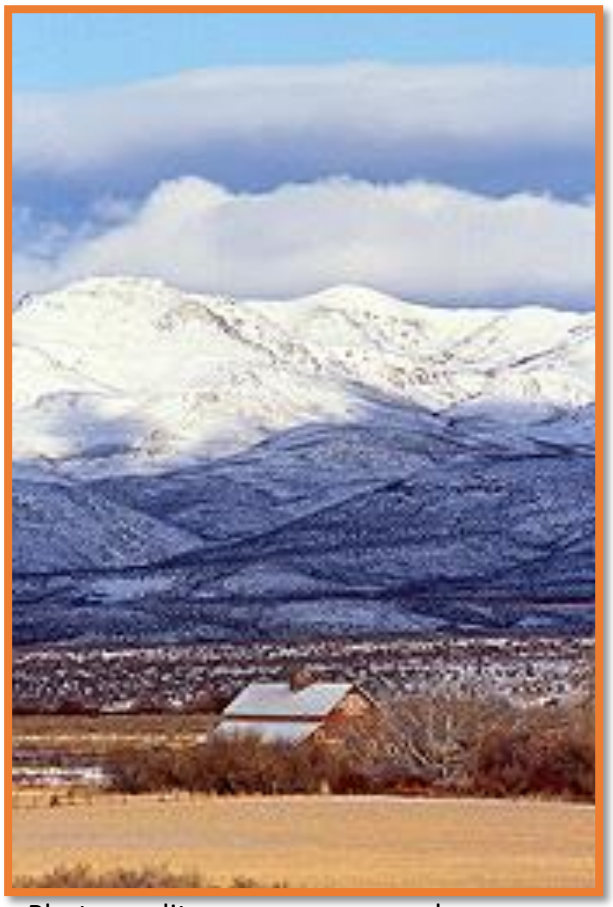
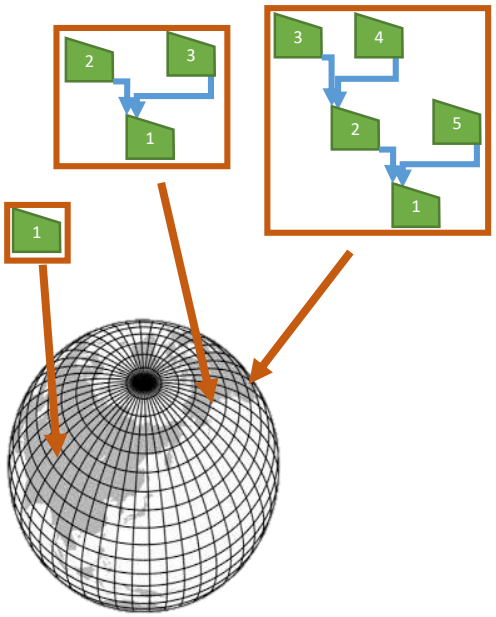
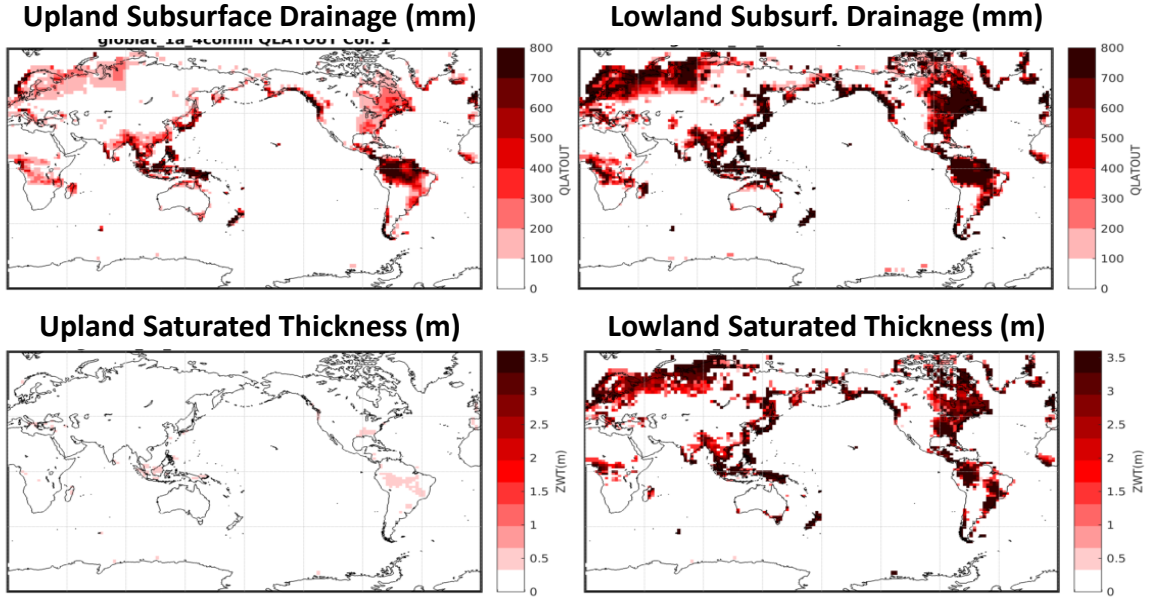


Photo credit: www.wcc.nrcs.usda.gov

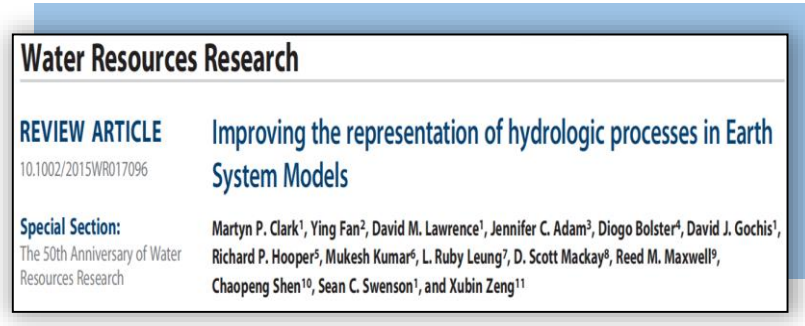
Questions to Answer with Global Implementations

1. How, and where, is water stress affected?
2. How is redistribution of groundwater affected by natural and anthropogenic climate forcings?
3. What is the role of water availability in ecosystem carbon uptake?
4. Are hillslope regions and their BGC processes different in their sensitivity to climate changes?





Acknowledgements



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