Efforts towards better representation of land surface heterogeneity in E3SM

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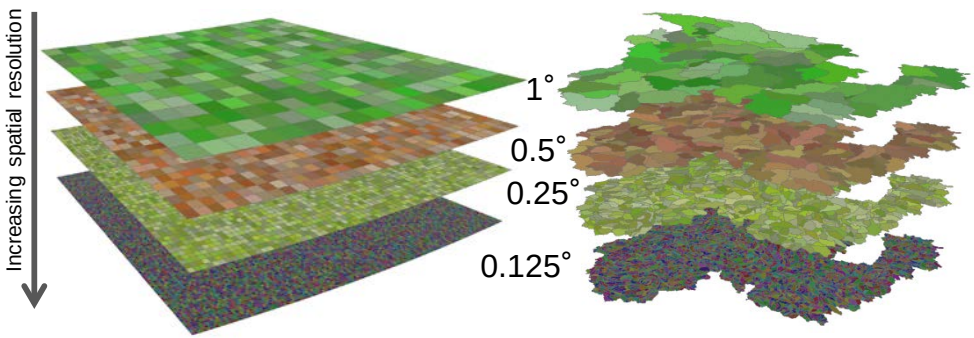
Outline

- Motivations
- Developments required
  - Development of topography-based subgrid structures
  - Development of surface data for the new subgrid structure
  - Development of downscaling methods
  - Implementation of the new subgrid structure and downscaling methods in E3SM
- Summary: Status and next steps

Motivations

- **Topography Matters:** a major control on land surface processes through its influence on atmospheric forcing, properties of soil and vegetation, network topology (connectivity) and drainage area.

- Land surface spatial structure that captures spatial heterogeneity influenced by topography is expected to improve representation of land surface processes in land surface models.



Tesfa et al., 2014, Journal of Geophysical Research

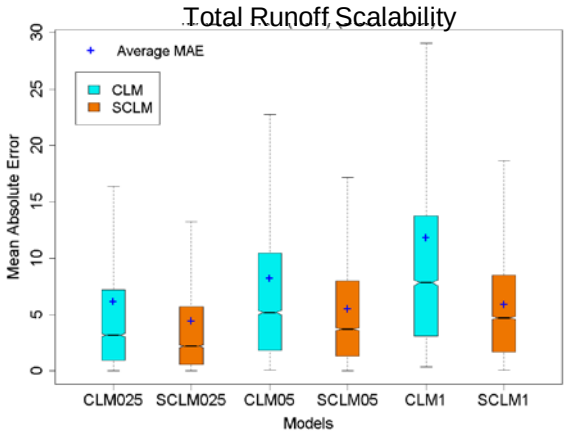


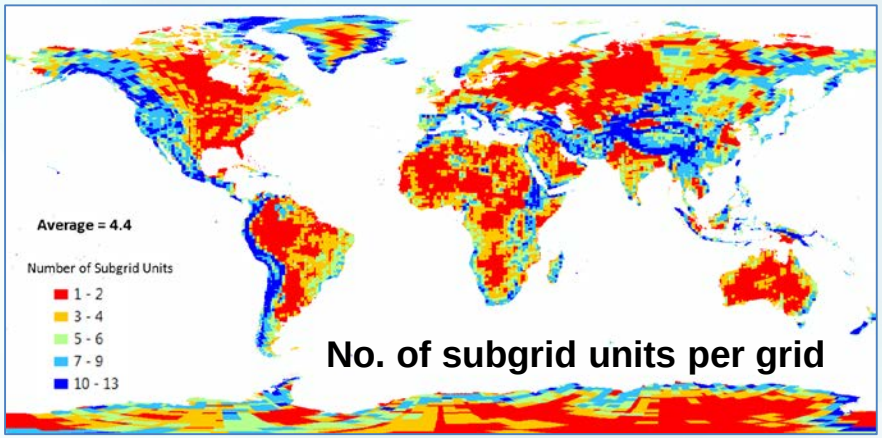
Fig 1: Improved runoff scalability for the Subbasin-based land surface modeling

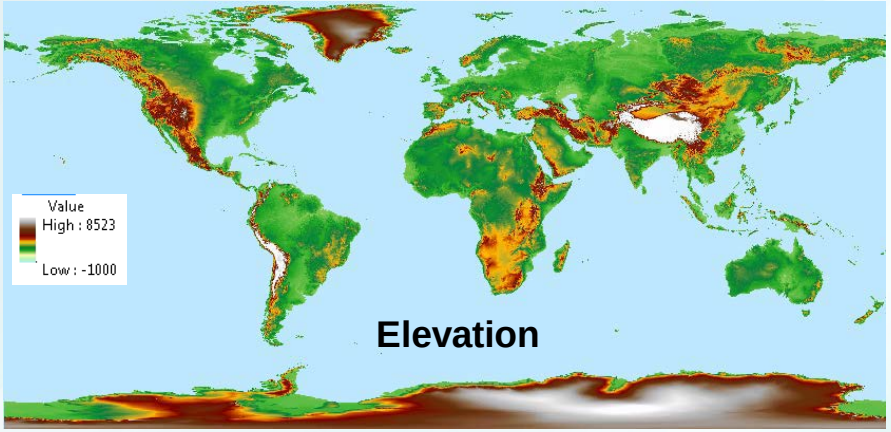
- Our past studies (Leung and Ghan, 1995&1998; Tesfa et. al 2014 a&b) emphasize the importance of improved representation of topographic heterogeneity in Earth System Models to improve simulations of land surface processes especially over topographically heterogeneous areas..

Developments required

✓ Development of topography-based subgrid structure

- Multiple types of subgrid structures have been developed and evaluated for their capability to capture impacts of topographic heterogeneity (Tesfa and Leung, 2017).



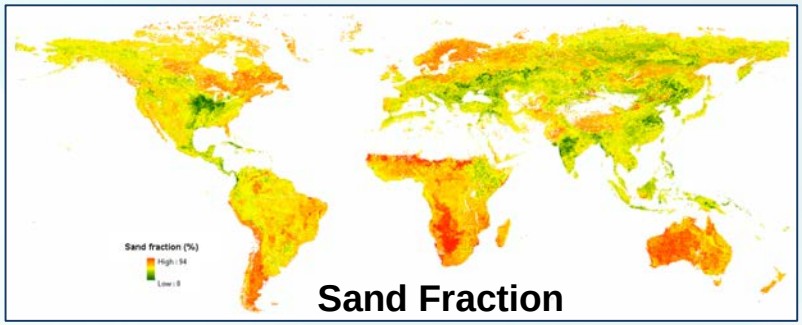


- Capturing effects of topography on land surface processes, vegetation and land cover, and land-atmosphere interactions
- Representing topographic heterogeneity in ELM using optimal number of subgrid units per grid
- Reduced computational demand compared to discretizing grid into fine resolution grids

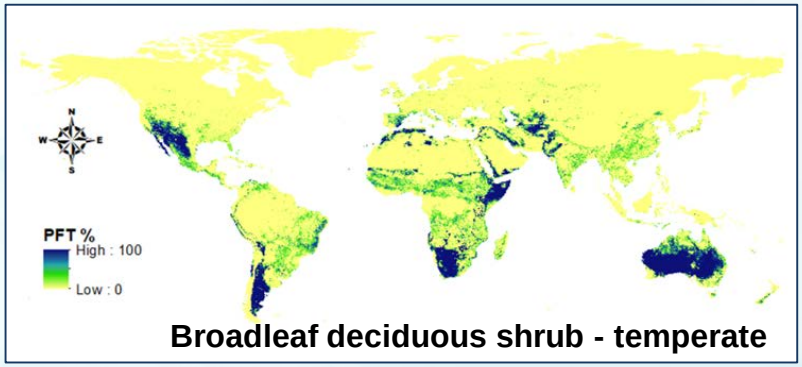
Developments required

✓ Development of surface data for the new subgrid structure

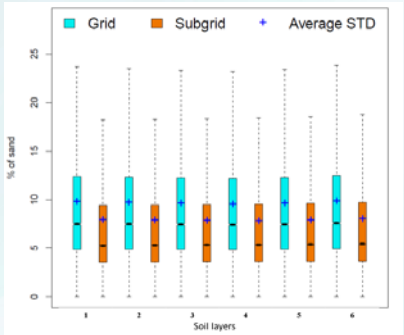
- Various datasets have been developed for the topography-based subgrid structure for NE30 grids: soil properties and PFTs.
- Analyses have been done on the PFTs and soil properties to evaluate whether the subgrid units are representing more homogenous areas.

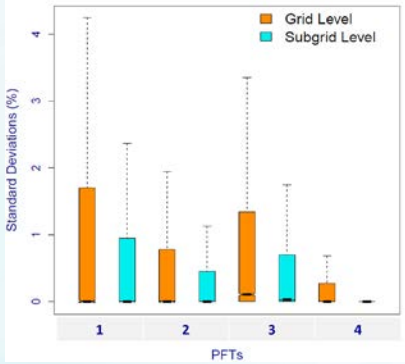


Sand Fraction



Broadleaf deciduous shrub - temperate





- Box plots are used to compare the standard deviation values at grid and subgrid levels.
- Generally, standard deviation values are lower at subgrid level than at grid level.

1 = Needle leaf evergreen trees (temperate)
2 = Needle leaf evergreen trees (boreal)
3 = Needle leaf deciduous trees (boreal)
4 = Broad leaf evergreen trees (tropical)

Developments required

✓ **Development of downscaling methods**

Precipitation downscaling methods explored

- **Requirements for methods:**
  - Physically-based methods
  - Simple methods:
    - Required input parameters are easy to obtain at global scale
    - Methods can be implemented in E3SM without introducing additional computational burden
- **General Formulation:** Precipitation spatial variability is affected by macro-geographical factors and local topography, which is mainly elevation; and generally spatial variability of precipitation over mountainous areas can be represented as a function of topographic elevation as:

$$P_s = P_g + \Delta P_e$$

P_s represents the precipitation value at each subgrid unit
P_g is grid level precipitation calculated by the atmosphere model
ΔP_e refers to the deviation of the subgrid precipitation from the grid level precipitation.

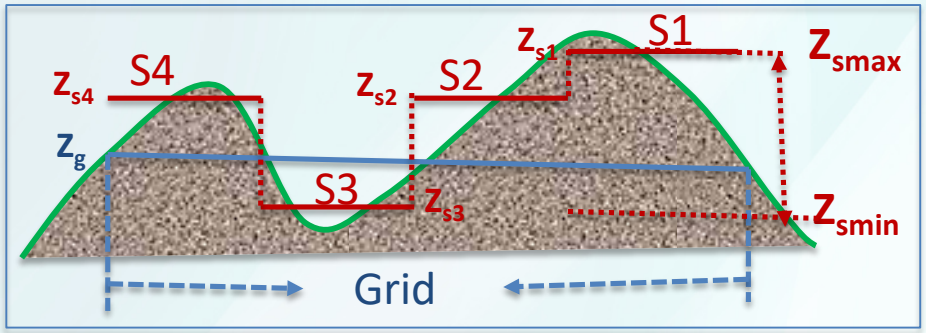
Developments required

✓ Development of downscaling methods

Precipitation downscaling methods explored

- ΔP_e can calculated based on various methods to scale the grid mean precipitation by subgrid topography. In this study we explored four methods:
- **Elevation Ratio Weighted Method (ERWM)**:

$$\Delta P_e = P_g * \frac{(Z_s - Z_g)}{Z_g} = P_g * \frac{Z_s}{Z_g} - P_g$$



- **Elevation Range Method (ERM):**

$$\Delta P_e = P_g * \frac{(Z_s - Z_g)}{Z_r}$$

$$Z_r = Z_{smax} - Z_{smin}$$

- **Elevation Range with Maximum elevation Method (ERMM):**

$$\Delta P_e = P_g * \frac{(Z_s - Z_g)}{Z_{smax}}$$

- **Froude Number Method (FRM):**

$$\Delta P_e = P_g * \frac{h}{Z_{smax}}$$

$$h = \min(Z_s - Z_g, FN)$$

$$FN = \frac{U}{N}$$

where,
P_s → precipitation value at each subgrid unit
P_g → grid level precipitation
ΔP_e → deviation of the subgrid precipitation from the grid level precipitation.

Z_s → elevation value at each subgrid unit
Z_g → grid elevation
Z_{smin} → minimum subgrid unit elevation
Z_{smax} → maximum subgrid unit elevation

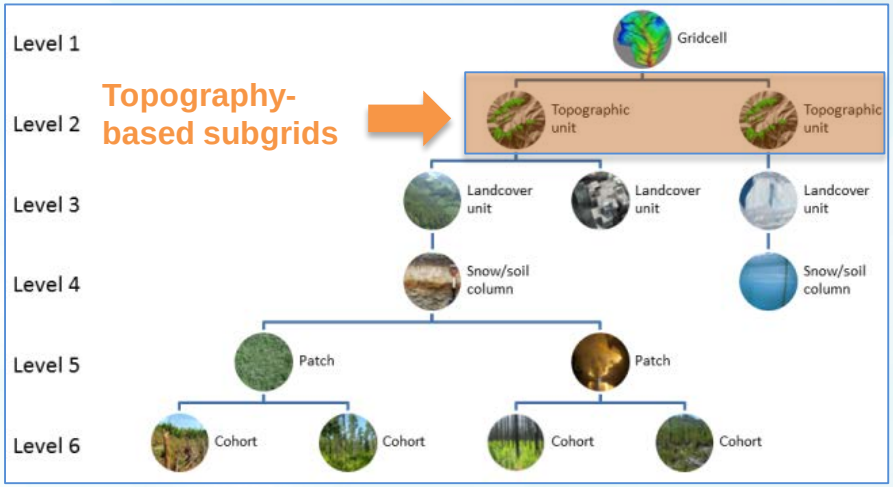
h → Actual height rise limited by the height of mountain barrier
FN → grid elevation

U → Wind speed
N → Brunt Vaisala Frequency parameter

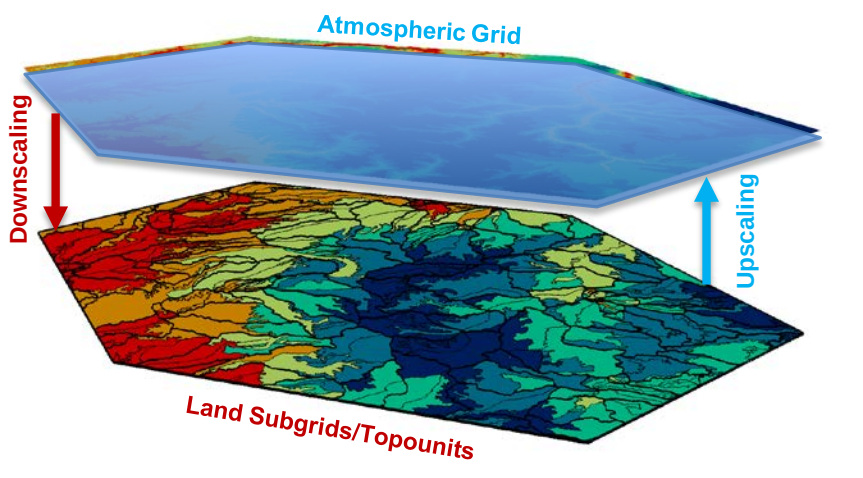
Developments required

✓ Implementation of the new subgrid structure and downscaling methods in E3SM

- The new subgrid structure has been implemented in the land surface model of E3SM between the grid and land unit levels as shown in the hierarchical subgrid structure diagram below:
- The FNM and ERMM precipitation downscaling methods have been implemented in E3SM code.
- The downscaling methods of other parameters developed at the University of Arizona have been implemented in E3SM code.



Hierarchical subgrid structure in ELM



Summary: status and next steps

- Topography-based subgrid structures have been developed and implemented in E3SM.
- Land surface data for the topography-based subgrid structures have been developed.
- Precipitation downscaling methods have been developed and implemented in E3SM.
- Downscaling methods of other climate parameters have been developed and implemented in E3SM (University of Arizona).
- E3SM branch with the implementation of the topography-based subgrid structure and the downscaling methods have been tested using the land developer test set.
- Running the code for longer period simulations to generate results required for a design document is in progress.
- Next steps include code review, simulations to evaluate the impacts of the new subgrid structure and the downscaling methods on land surface processes, and writing manuscripts documenting results.

Thank You!