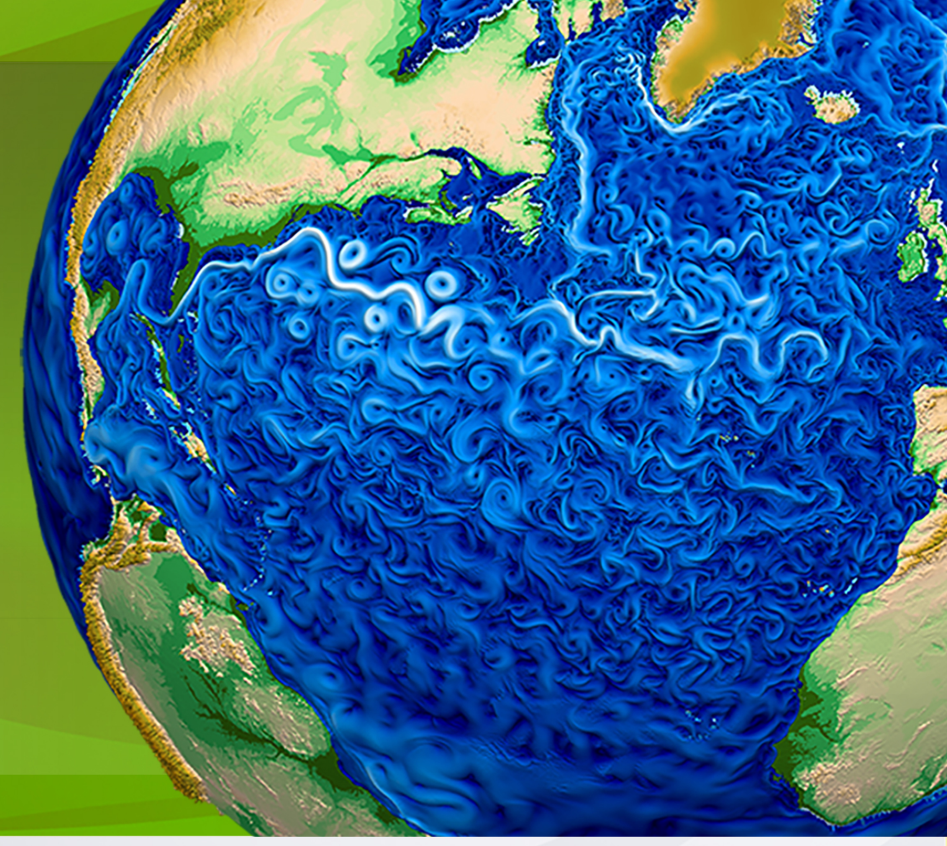

P: Land–Atmosphere Coupling in ACME with Subgrid Orography

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Subgrid orography in ACME

Introduction:

Until now, atmosphere and land models in coupled climate simulations usually have run on the same grid, with one elevation per grid cell. In ACME, however, the two models will run on different grids, using subgrid-scale topographic classes to simulate the influence of orography on precipitation, land surface hydrology, glacier surface mass balance, and other processes.

The atmosphere model will include up to 12 elevation classes per grid cell. Land grid cells will have irregular boundaries based on watersheds, with up to 4 topographic units per grid cell (Figure 1). In addition, glaciated regions will have up to ~10 elevation classes per grid cell, with dynamically changing areas. To permit more flexibility in choices of component grids and to allow the changing ice thickness to influence atmospheric processes, land–atmosphere coupling will be much more complex than a simple horizontal remapping between two grids.

We have developed a coupling approach that combines horizontal remapping with vertical interpolation between adjacent elevation classes to optimize accuracy, along with normalization to ensure exact conservation of energy. Here we outline the main ideas and challenges.

Coupling with static topography

Accurate, conservative remapping of fluxes:

For optimal accuracy, fluxes are remapped between models in three steps. Here we describe mapping from the atmosphere to the land; the reverse mapping is similar.

1. ***Vertical interpolation***. For each elevation class in a land grid cell, estimate the flux by interpolating between neighboring atmosphere elevation classes. Consider elevation class 1 (h = 600 m) in land cell L1 of Figure 2 below. The overlying atmosphere grid cell has fluxes F = 300 at 300 m and F = 200 at 800 m. By linear interpolation, F = 240 at h = 600 m.
2. ***Horizontal remapping***. A given land cell (e.g. L2) may overlap more than one atmosphere cell. Horizontal remapping is required to weight the fluxes from each atmosphere cell in proportion to the area of the overlap region. This is done by sparse matrix multiplication, with matrix coefficients computed once and stored. The resulting fluxes are shown in red.
3. ***Normalization***. Energy is conserved if the mean flux in a given atmosphere cell is equal to the mean flux in the land cells with which it overlaps. This is not true of the red fluxes. For each atmosphere cell we can compute an additive normalization factor and map this factor back to the land model, resulting in the maroon fluxes that conserve energy exactly.

A1	A2
h = 300 m, F = 300	h = 200 m, F = 400
h = 800 m, F = 200	h = 700 m, F = 300
h = 1300 m, F = 100	h = 1200 m, F = 200

L1	L2	L3
h = 600 m, F = 240 / 240	h = 500 m, F = 300 / 310	h = 400 m, F = 360 / 380
h = 1200 m, F = 120 / 120	h = 1100 m, F = 180 / 190	h = 1000 m, F = 240 / 260

Figure 2. Coupling between the land and atmosphere with elevation classes. In this simple example, two atmosphere grid cells (blue), each with three elevation classes, overlap three land grid cells (green), each with two elevation classes. Fluxes (in arbitrary units) computed on the atmosphere grid are vertically interpolated to land elevation classes, with horizontal remapping as needed where more than one atmosphere cell overlaps a land cell.

The resulting fluxes, shown in red, do not conserve energy. Normalization then gives the energy-conserving maroon fluxes.The mean global flux is 250 in each model.

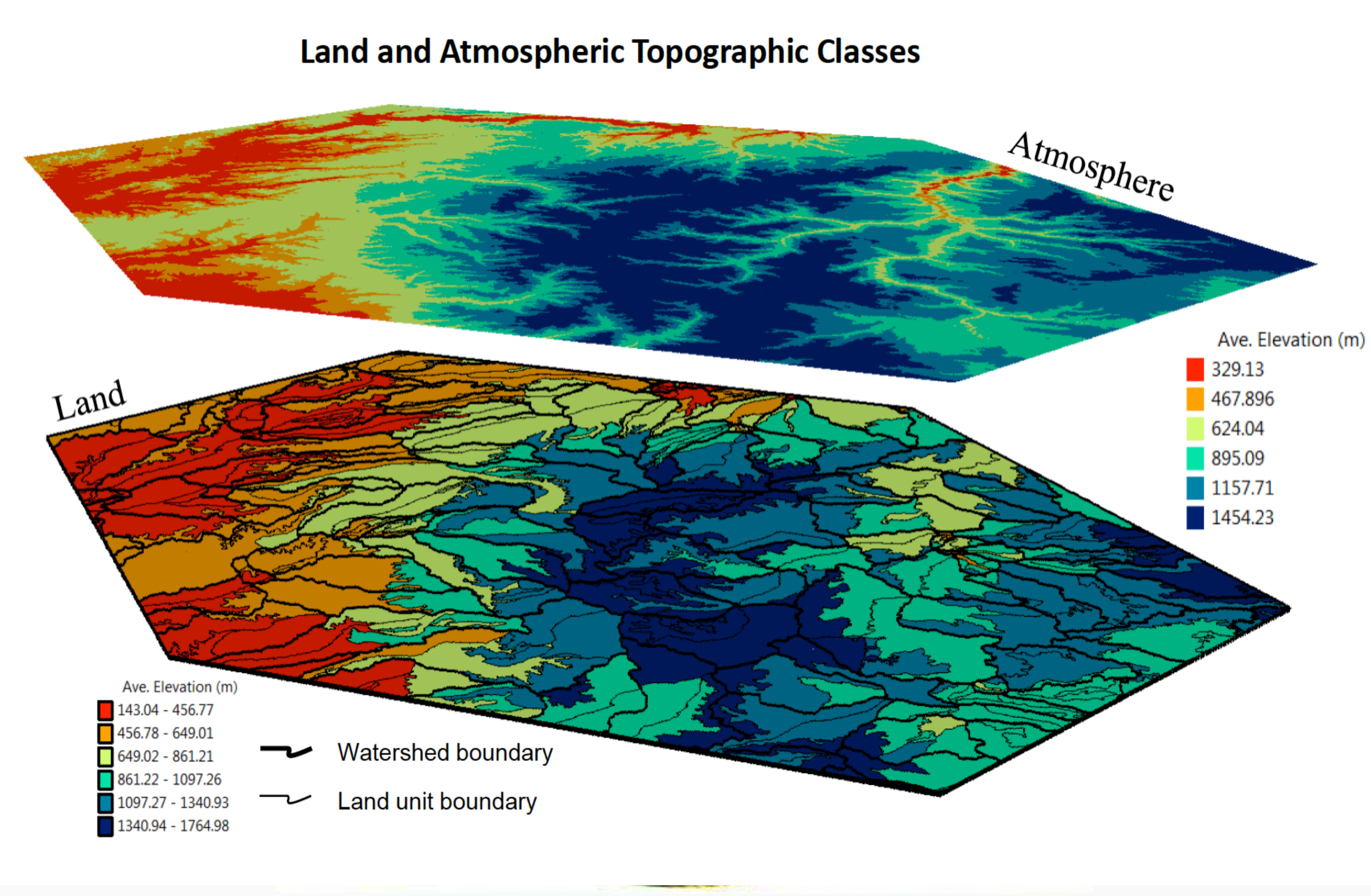

Figure 1. Representation of subgrid orography in ACME. The atmosphere model will have up to 12 elevation classes per grid cell. The land model will have irregular grid cells based on watersheds, with up to 4 topographic units per grid cell. Ice sheets will have dynamic topography, with up to 10 glacier columns per grid cell.

Coupling with dynamic ice-sheet topography

Incorporating glacier columns:

Ice sheets in ACME will be coupled interactively to other climate components. The glaciated area in each elevation class will change in time. This will require some changes relative to the scheme outlined for static topography:

- Elevation classes in the land model will be generalized to include dynamic glacier columns as well as static topographic units.
- At regular intervals (e.g., once per model year), the land model will send the coupler the new area and elevation in each elevation class for each grid cell. The coupler will remap these quantities onto the atmosphere grid. The atmosphere model will then adjust the area and elevation of its own elevation classes, so that its surface topography stays consistent with the land model. *Note*: The atmosphere model does not need to adjust the *number* of elevation classes during runtime.

Technical challenges:

- Vertical interpolation (combined with horizontal regridding, given that the land and atmosphere run on different grids) and normalization have not previously been supported in CESM or ACME. Significant new coupler functionality is needed, even for the case of static topography. It is unclear who will do this work, and when.
- Handling dynamic ice sheet topography will require new code in the land and atmosphere models, but is less challenging than the coupler issues.

ACME Accelerated Climate Modeling for Energy

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