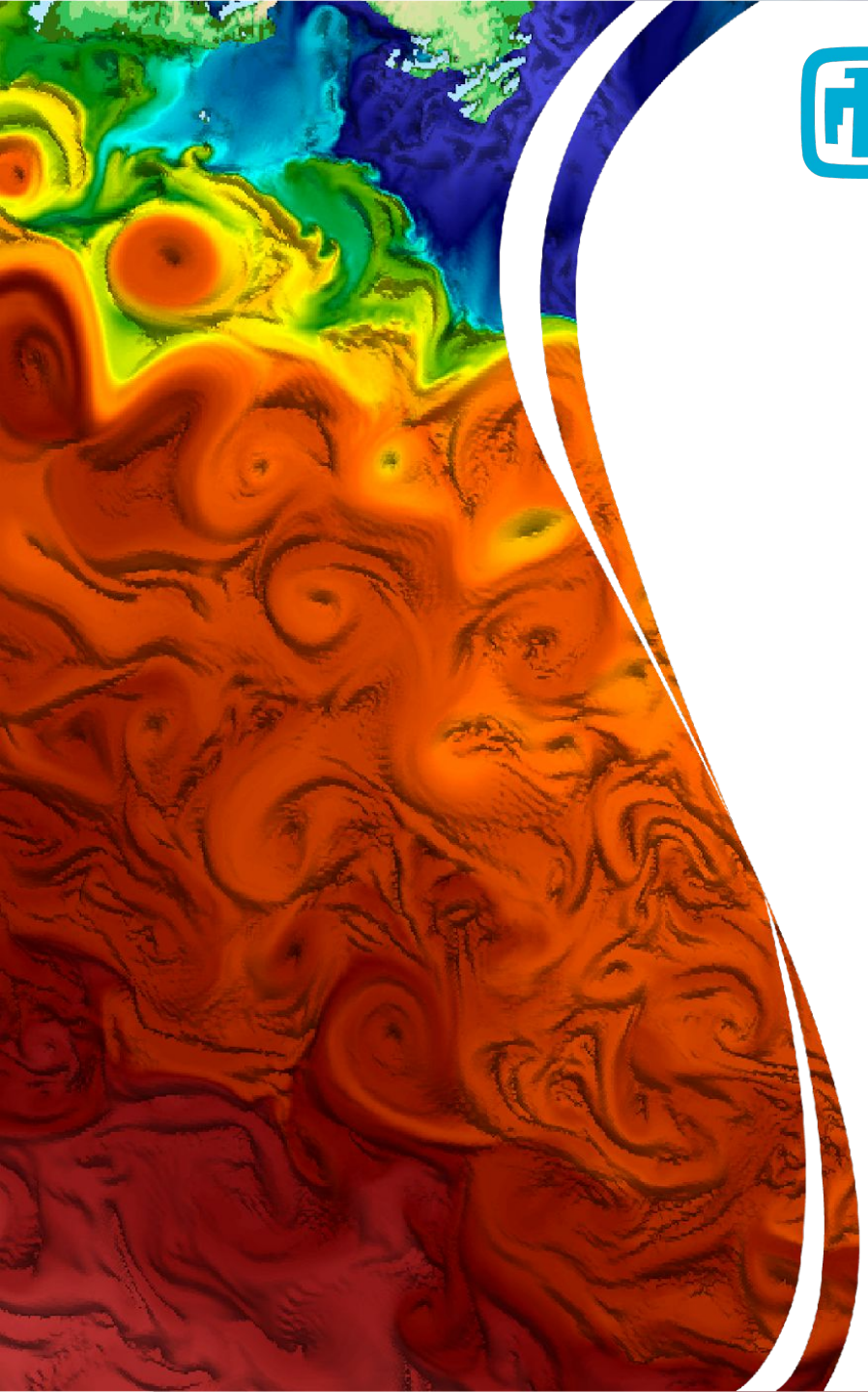

Sandia National Laboratories

E3SM Energy Exascale Earth System Model

Topography and SGH generation for ultra-high resolution grids

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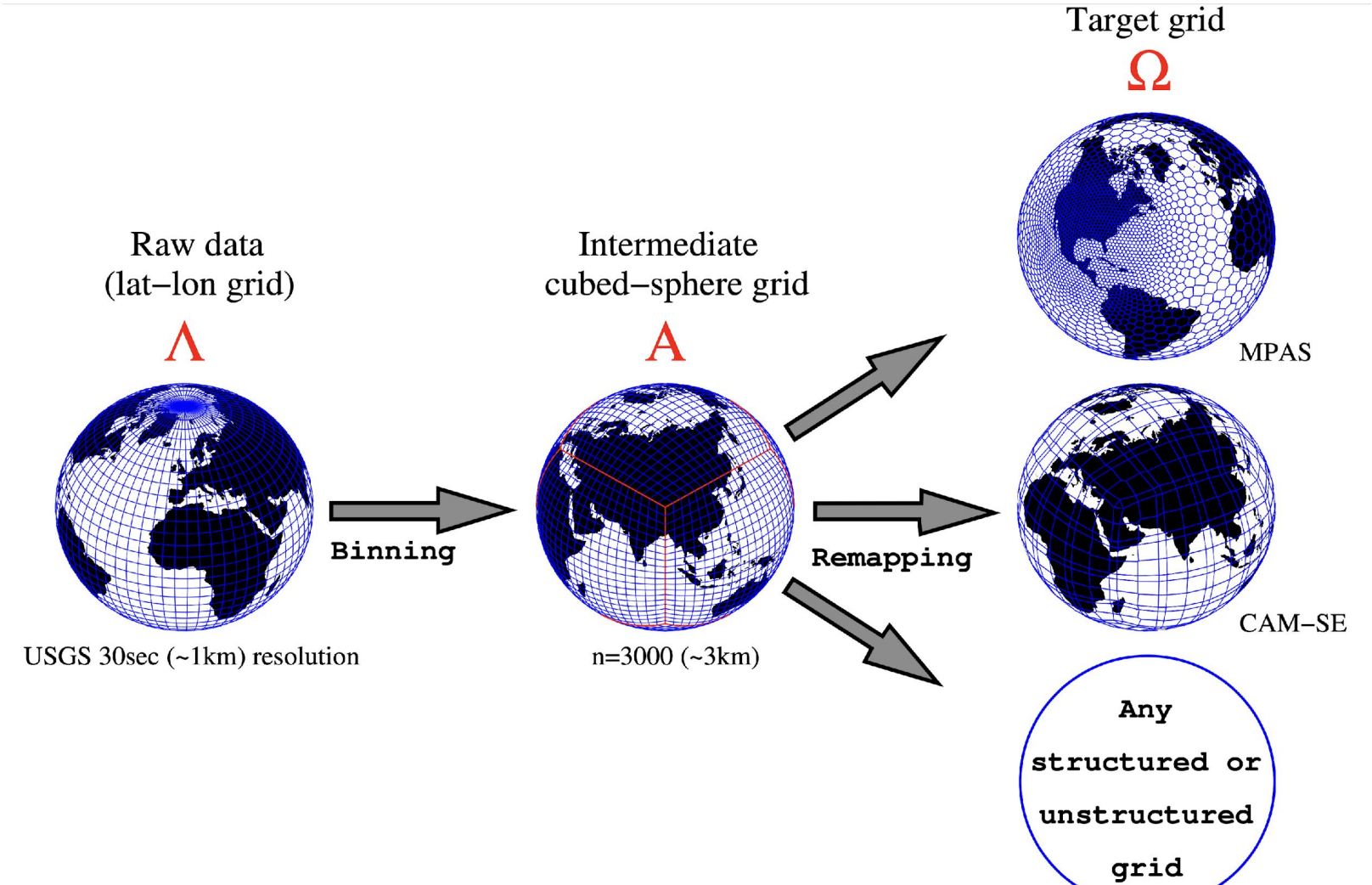
AMWG Meeting, February 4, 2026

U.S. DEPARTMENT OF ENERGY

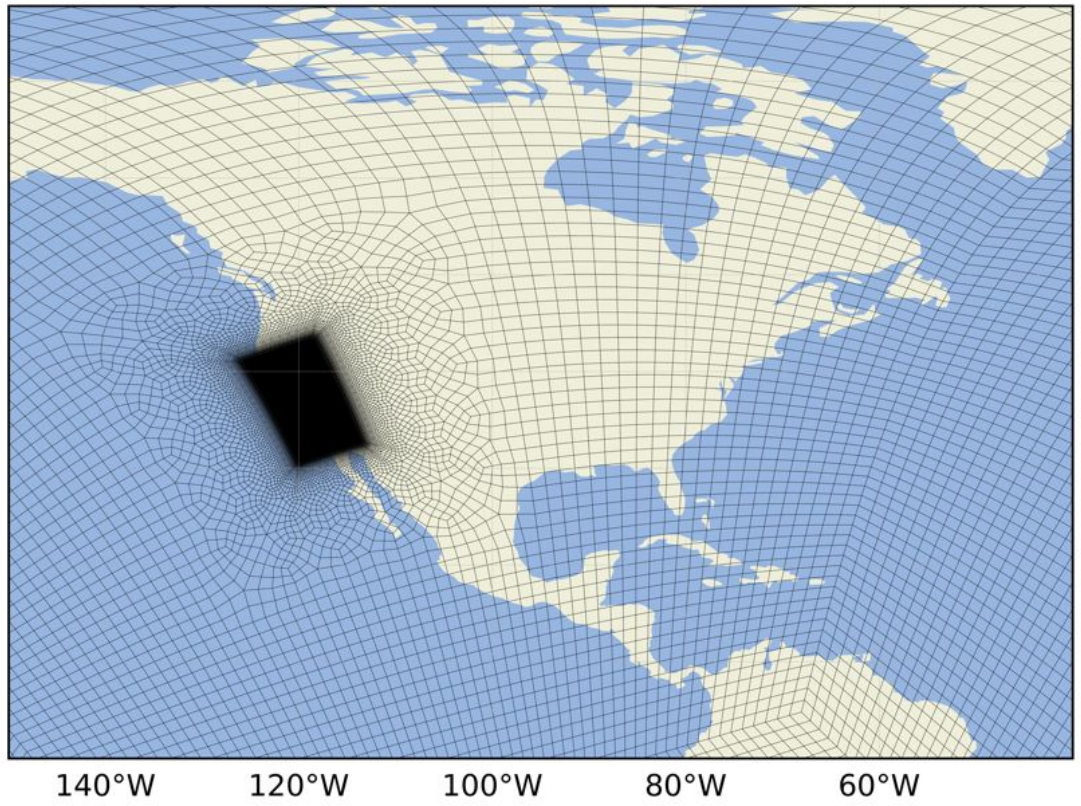
NCAR Topo

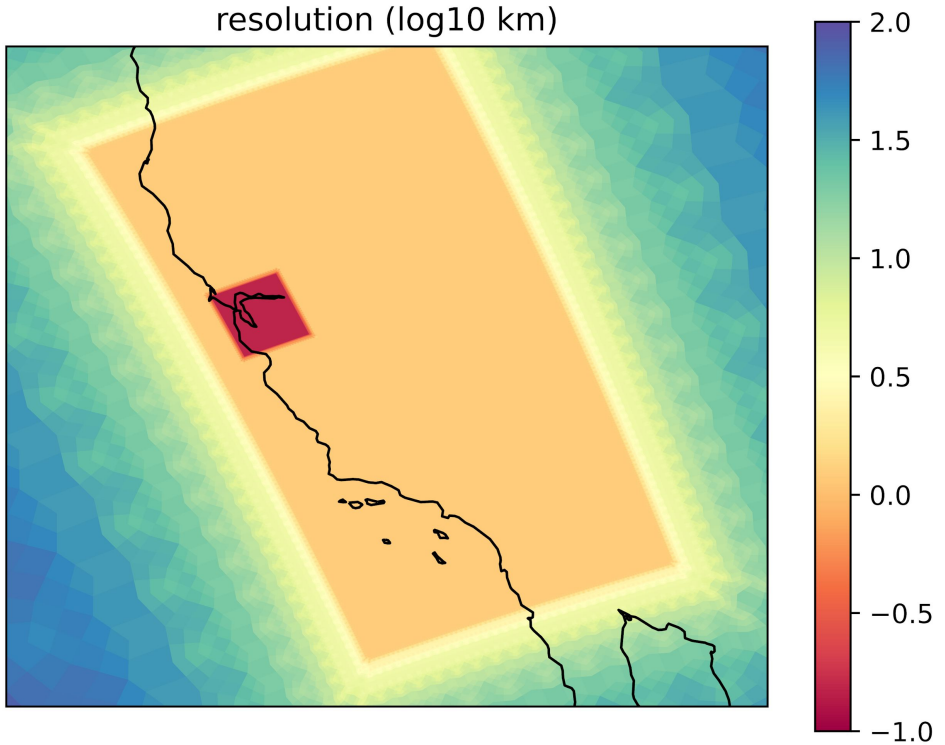
- P.H. Lauritzen, J.T. Bacmeister, P.F. Callaghan, M. Taylor, *NCAR Topo (v1.0): NCAR global model topography generation software for unstructured grids*, GMD 20115



Extreme Regionally Refined Model (RRM)

- Variable resolution grid transitioning from 110 km global to 100m over San Francisco region
- Zhang, Bogenschutz, Taylor, Cameron-Smith, *Zooming in: SCREAM at 100 m using regional refinement over the San Francisco Bay Area*, GMD 2026





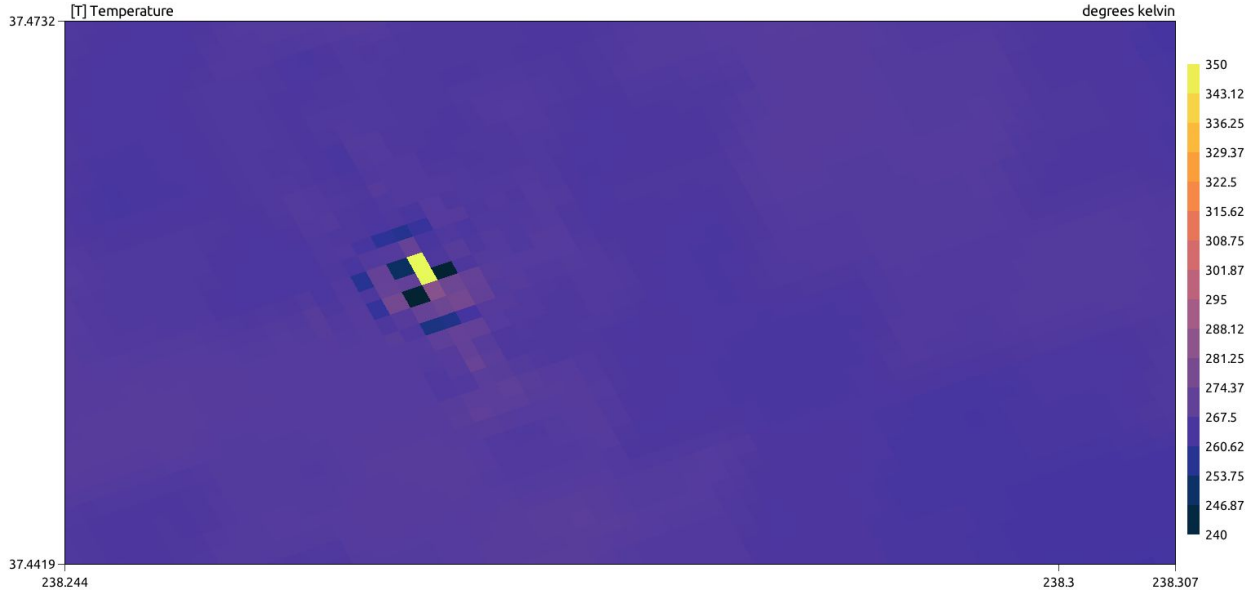
Challenges at High Resolution

- New 250m global USGS dataset (86400 x 172800) from Jishi Zheng et al. GMD 2026.
- `bin_to_cube:`
  - Needed to map USGS lat/lon data to a cubed-sphere grid
  - Uses a binning algorithm – much faster than incremental remap algorithms
  - Requires too much memory to process 250m grid (638GB)
  - 500m USGS data set mapped to 800m cubed-sphere: run time > 1 week. (Jishi Zheng)
  - Parallel mapping tools (ESMF and MBTR) based on mesh intersections, both failed with the 250m lat/lon source grid. (millions of tiny cells near pole)
- `cube_to_target:`
  - Incremental remap “aave” style algorithm maps cubed-sphere grid to model grid
  - Computing cell intersections is incredibly expensive
  - Long run times with 800m cubed-sphere grid. Would require weeks of run time with 250m cubed-sphere grid
  - Could replace cube_to_target with parallel mapping tools (ESMF and MBTR)
    - Should work – but would probably require long compute time on 100’s of nodes

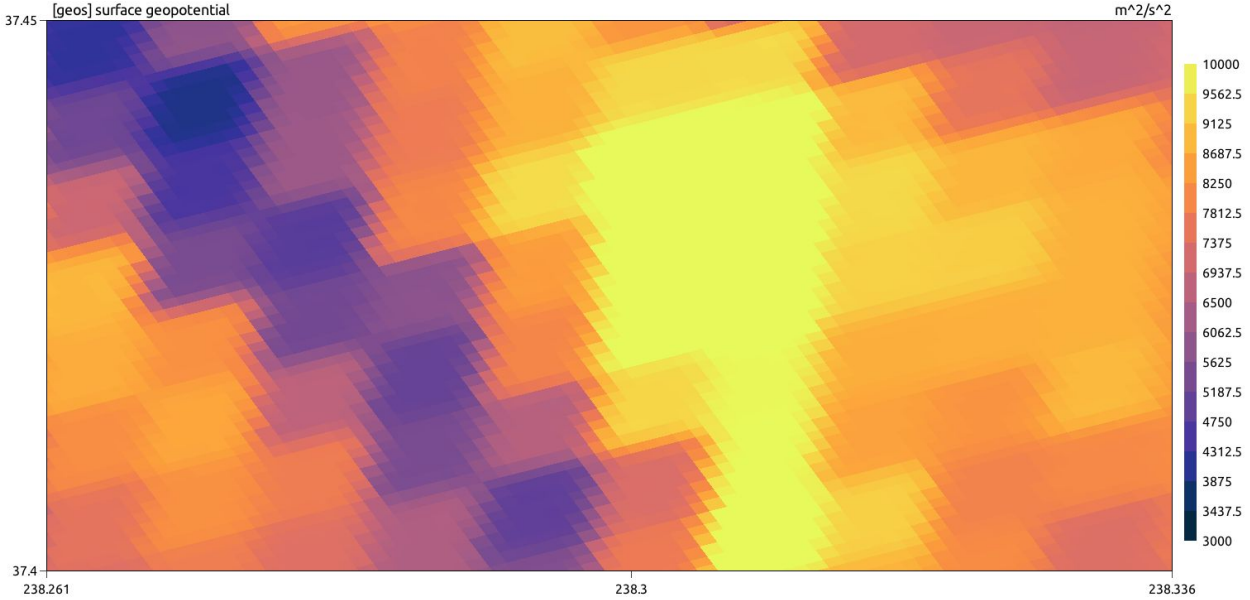
Extreme Regionally Refined Model (RRM)

- Pushing existing tool to its limits – topography is too coarse for 100m
- Blocky mountains create a CFL problem – require a 2.5x reduction in dycore timestep

With desired timestep, Temperature would blow up, always at the corner of one of the large rectangular mountains



Lower resolution topography mapped to 100m mesh with ‘aave’ cube_to_target algorithm creates large square mountains with sharp corners

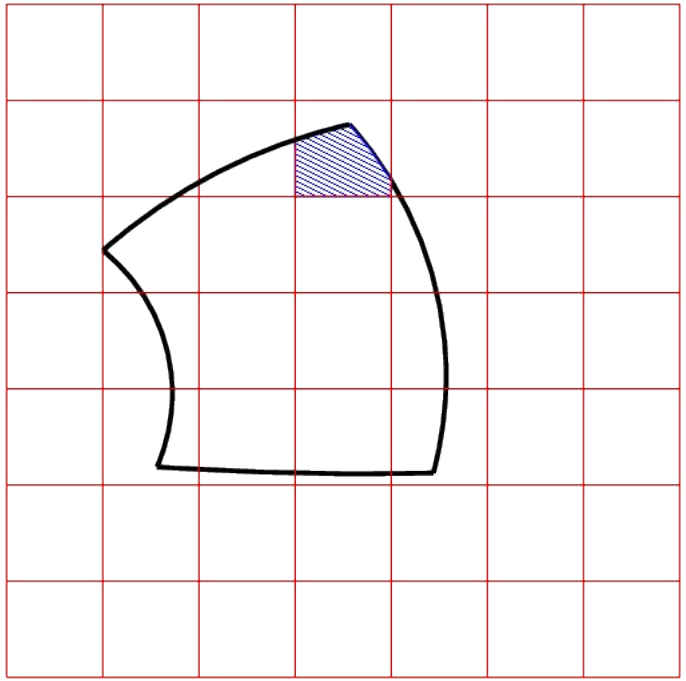


High-Res Topo Tool Chain

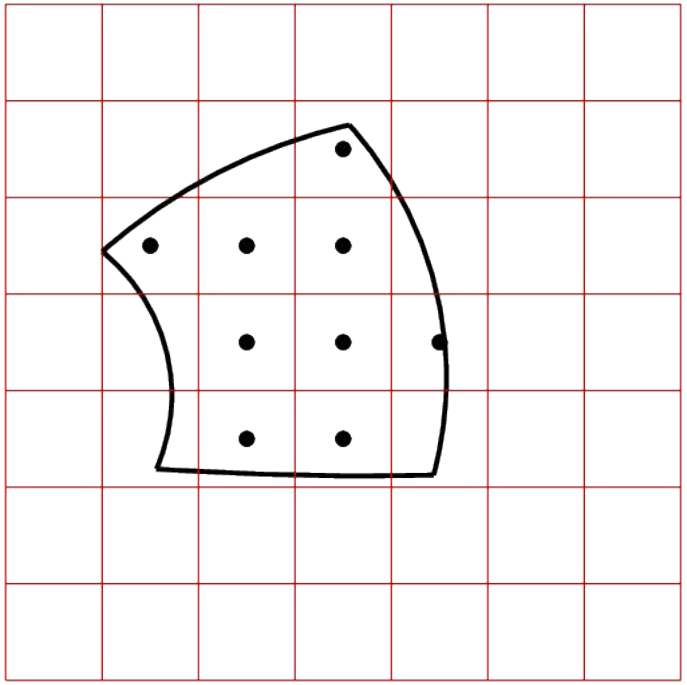
- Replace binning (used in bin_to_cube) and area averaging (used in cube_to_target) with disk averaging
- Implemented in MOAB grid tools package as “MBDA”
- Amazingly fast: Can map 250m global lat/lon data to any feasible target grid in a few minutes on one CPU node
- Surface roughness calculations:
  - Rewritten in terms of MBDA remap operation followed by NCO’s ncap2 for the algebra
- SGH: Variance between USGS source grid and 3km grid
  - Need to have this reduce to zero in regions where target grid has resolution finer than 3km
  - Take the minimum with variance between USGS source grid and target grid
- SGH30: Variance between 3km grid and target grid
  - Need to have this be zero in regions where target grid has resolution finder than 3km
  - Computes SGH30 only uses topo data low-pass filtered to 3km resolution

Disk Averaging Algorithm

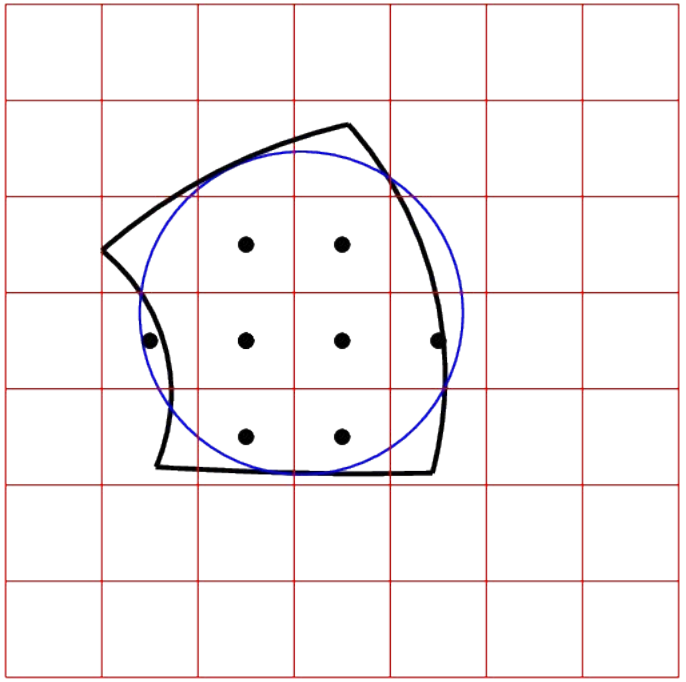
Example mapping algorithms between highres lat/lon grid (RED) and target cell (black). All algorithms are monotone and approximate a cell averaged value.



`cube_to_target:`
Target cell value is the area weighted average of the (partial) blue cells contained inside the target cell

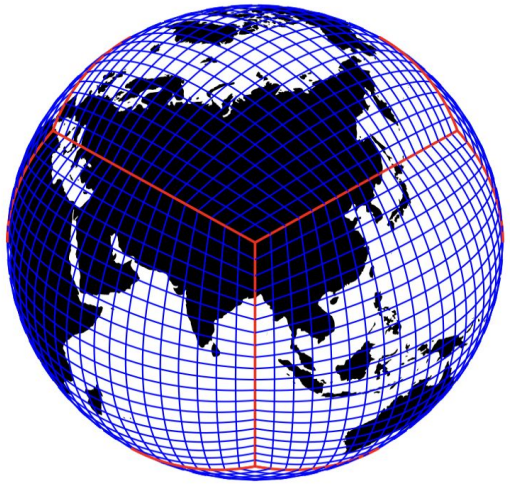


`bin_to_cube:`
Target cell value is the unweighted average of all lat/lon cell values (black donts) contained in target cell



`MBDA:`
Target cell value is the unweighted average of all lat/lon cell values (black dots) in a disk with area = area of target cell

High-Res Topo Tool chain



n=3000 (~3km)

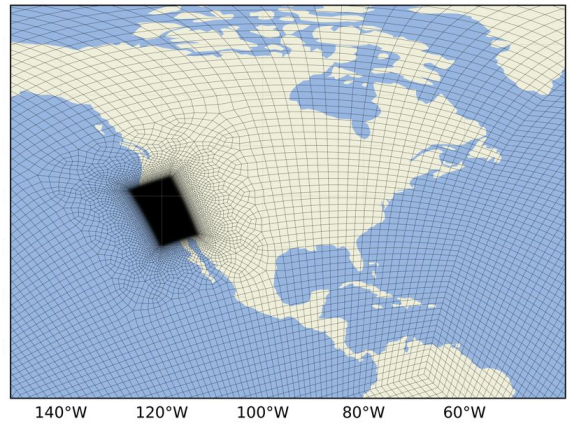
SGH30: Variance between USGS and 3km. Computed with MBDA and ncap2

SGH: Variance between 3km and model grid. Computed with MBDA and ncap2

New 250m USGS lat/lon dataset

MBDA direct remap to target grid for topography

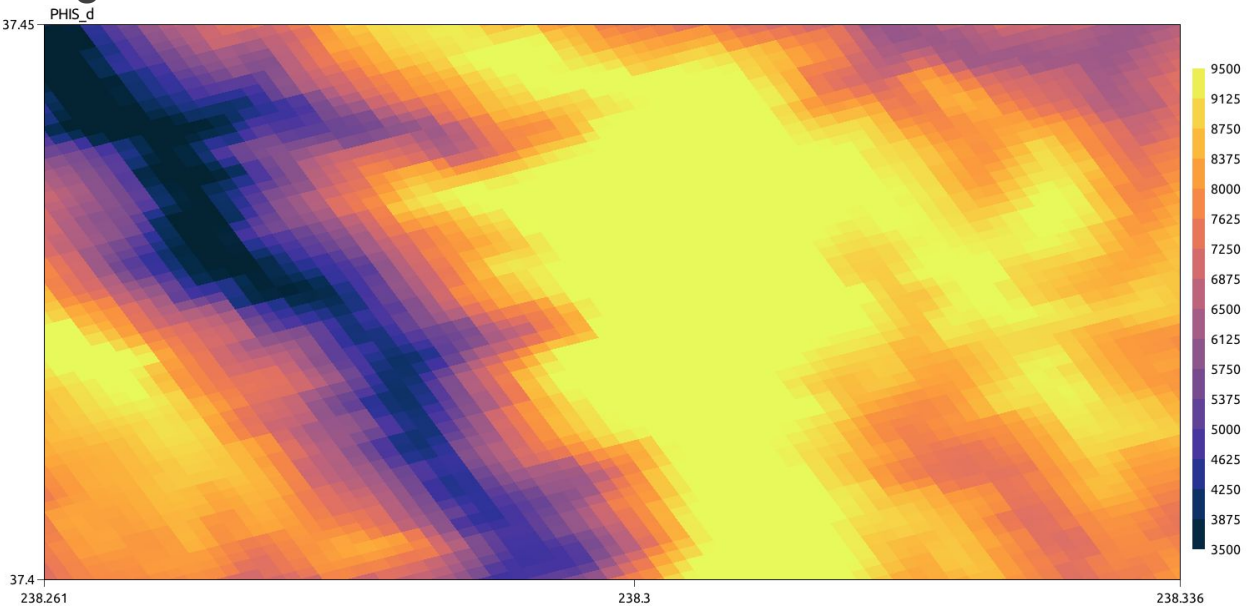
Any structured or unstructured grid



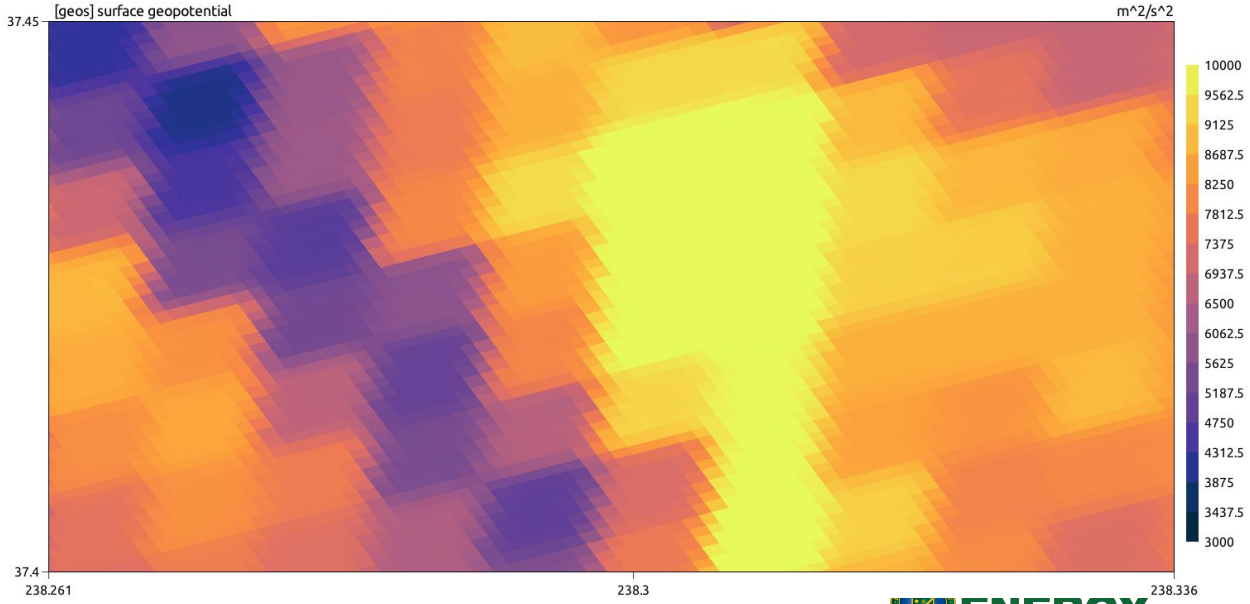
Extreme Regionally Refined Model (RRM)

- New toolchain using global 250m dataset can nearly match 100m RRM grid resolution
- Entire process: topography, dycore smoothing, SGH, SGH30: 30min on 1 CPU node.
- TBD: will this fix the blocky mountain CFL issue?

MBDA tool, mapping from 250m USGS grid direct to cube_to_target with 800m cubed-sphere source grid



cube_to_target with 800m cubed-sphere source grid.



Thanks!