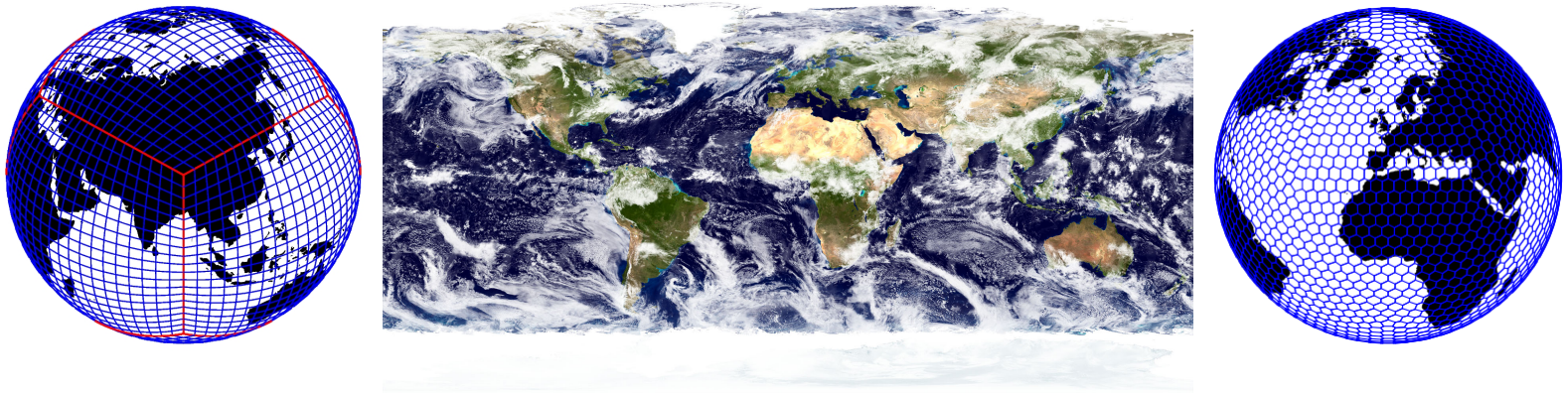
Physical Consistency & Scalable Algorithms



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Some requirements and constraints in global climate modeling

from a community model developers perspective

- NCAR Community Atmosphere Model (CAM) applications:

  - Paleo-climate: millennia long simulations, dx ~300km
  - Climate change: decade to century long simulations, dx ~100km
  - Ultra high resolution: seasonal simulations, dx ~25km and finer

- Model must be **robust** and **"accurate"** in a very wide resolution range

- Throughput to do science:

Climate change	> 5 years per day
Paleo	> 40 years per day (strong scaling needed!)

- Each development cycle of CAM requires literally 100s of decade and longer simulations to develop, tune and validate the model!

- **Conservation of mass and energy (locally)**

  Since frictional heating occurs on scales well below the truncation limit, conserving energy most likely imply that a “fixer” is needed.

  Currently global energy fixers are used
  (at high processor counts this can be a scalability bottleneck)

- **Consistent and shape-preserving multi-tracer transport**

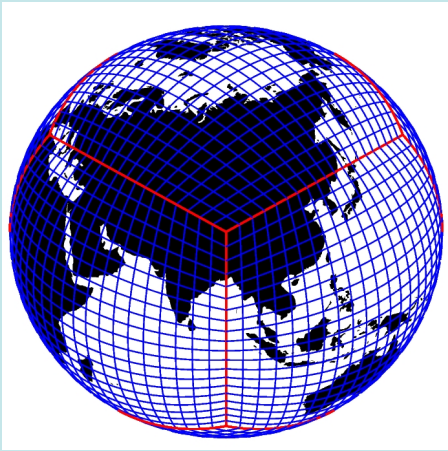
  Inclusion of prognostic aerosols, moments for microphysical parameterizations, chemistry, etc. requires the solution to many continuity equations.

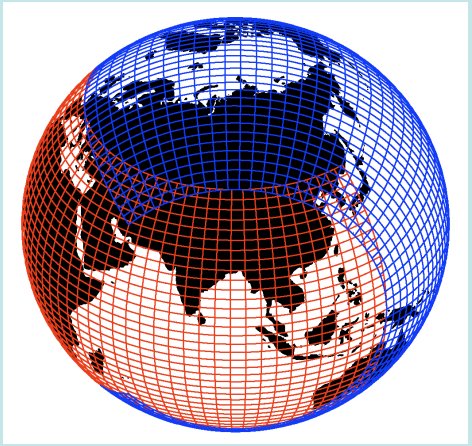
  Transport might dominate the computational cost of resolved scale fluid flow solver
  (CAM5: 26 prognostic continuity equations; CAM-chemistry: 126)

  Enforcing shape-preservations might be computationally intensive

  In general: the higher the order of the numerical method the harder it is to limit & filters/limiters that do not degrade methods to 2^{nd}-order normally need wide haloes
  ⇔ locality (scalability) versus accuracy

Most modeling groups are migration to more isotropic grids and local numerical algorithms to improve throughput by increased parallelism





Cubed-sphere **Voronoi, Icosahedral, Geodesic** **Yin-Yang**

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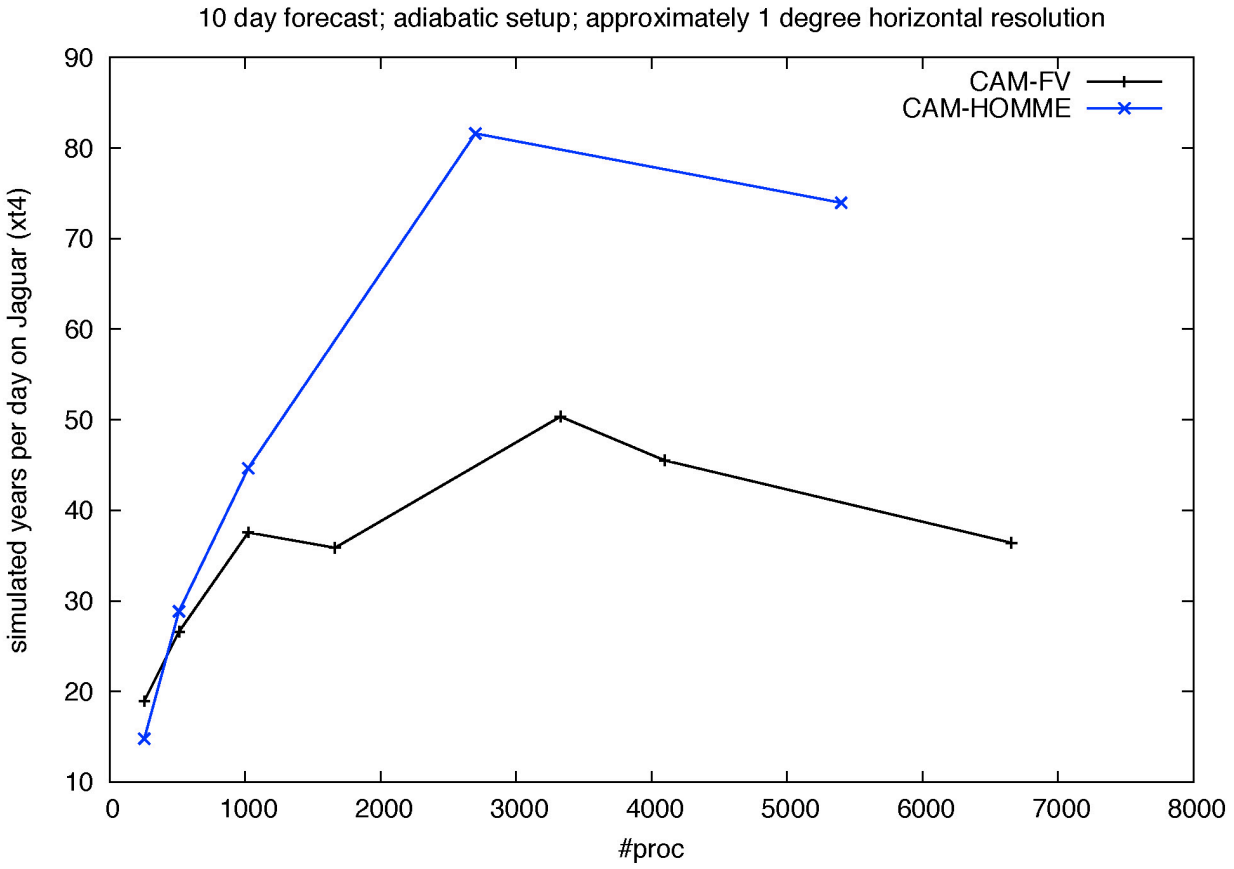
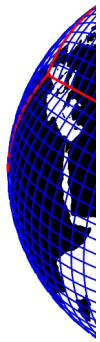
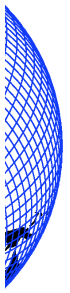


Data courtesy of Art Mirin



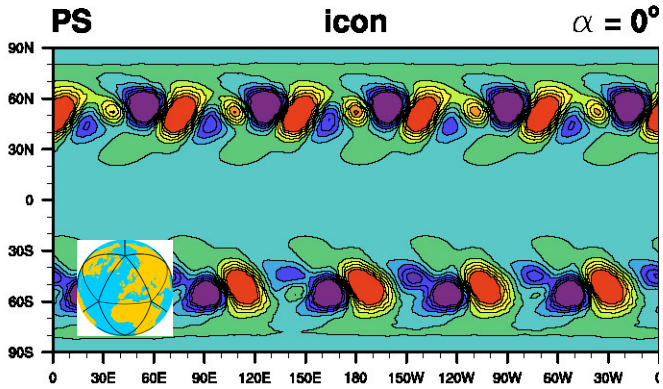


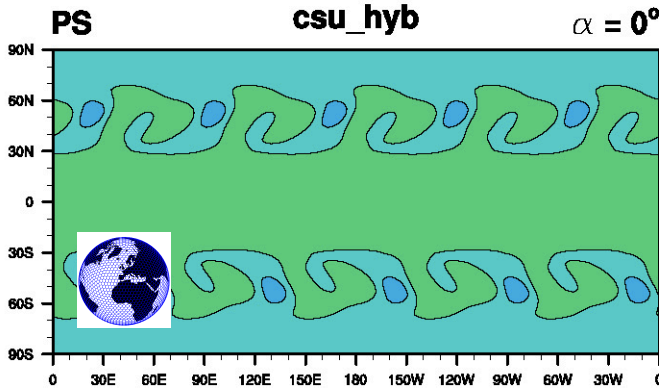
Cubed-sphere **Voronoi, Icosahedral, Geodesic** **Yin-Yang**

How is accuracy impacted by switching to unstructured grids?

At higher resolution our standard diagnostics do not indicate problems. However, our diagnostics were not designed to emphasize such problems (zonal averages, …).

It seems likely that there is a lower resolution limit (depending on grid and numerical method)





Figures:
Surface pressure for different models at ~2 degree resolution

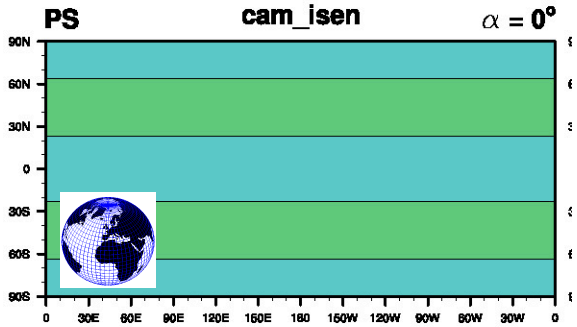
<u>Initial condition:</u>

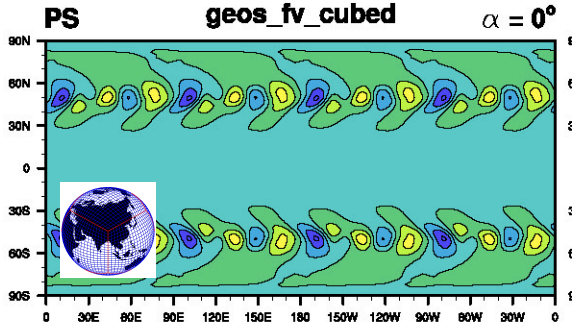
balanced steady-state solution to equations of motion;

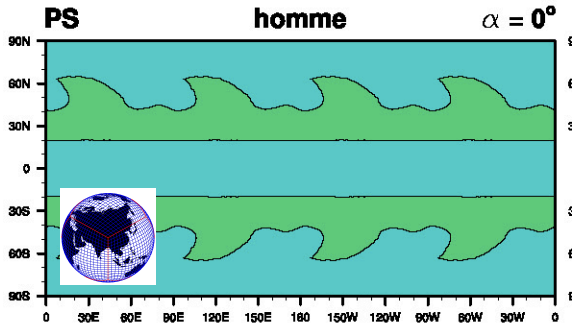
PS=constant

Spurious waves start growing

Lauritzen et al., 2010,
Journal of Advances in Modeling Earth Systems



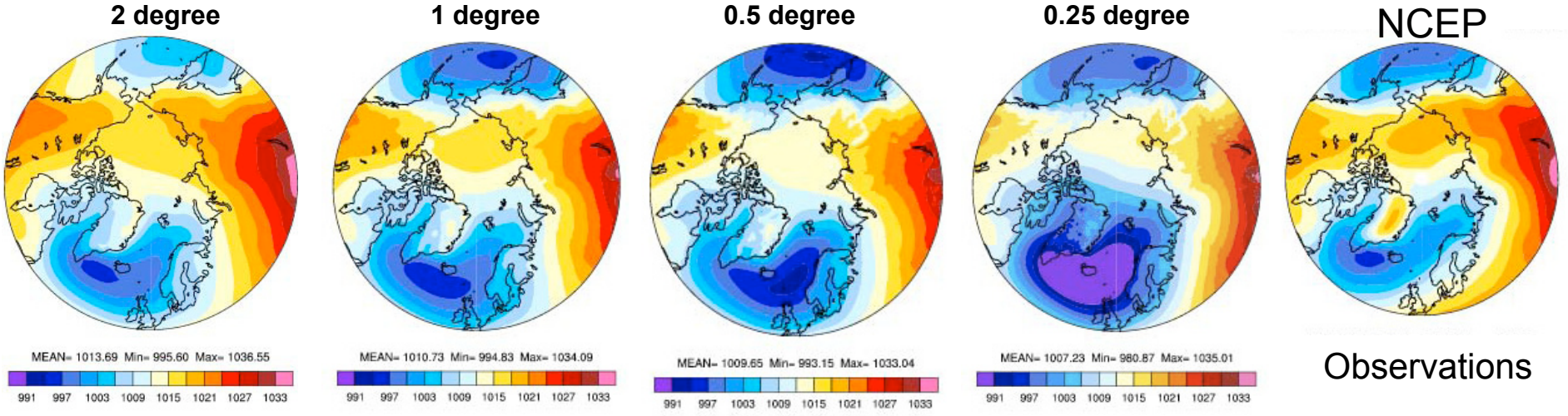




Climate models do NOT converge “out of the box”!

Just brute forcing horizontal resolution might not get you anywhere other than “burning” CPU cycles, producing nice movies and enormous amounts of data

Example: Mean-Sea-Level-Surface-Pressure in CAM-FV (10 year averages)



Increasing resolution must be accompanied by careful tuning and perhaps fundamental reformulation of physical parameterizations and increased complexity.

Aside: Few talk about vertical resolution as well as physics-dynamics coupling!

This will get even more challenging with **static** and (even “worse”) **adaptive mesh-refinement**

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Example of mesh-refinement on Voronoi grid

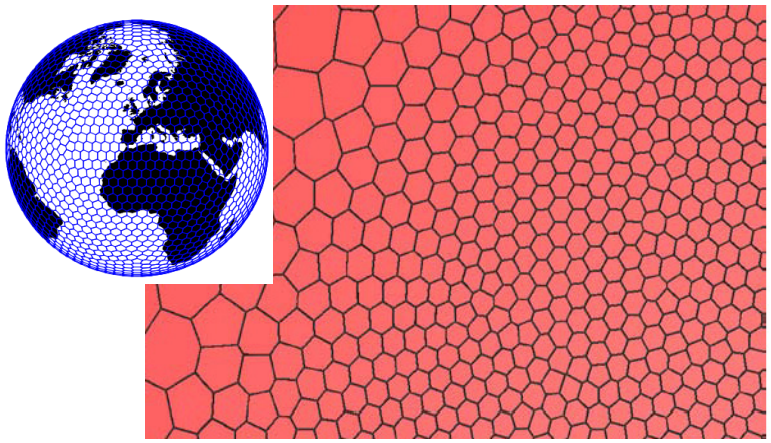

Figure courtesy of Bill Skamarock (NCAR)

Example of mesh-refinement on cubed-sphere

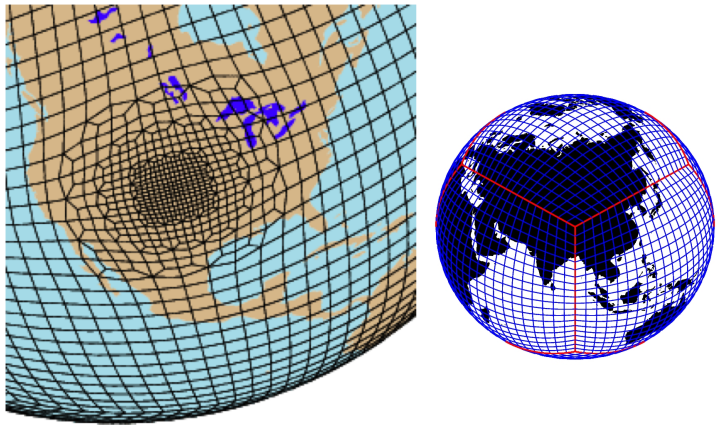

Figure courtesy of Mark Taylor (Sandia)

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