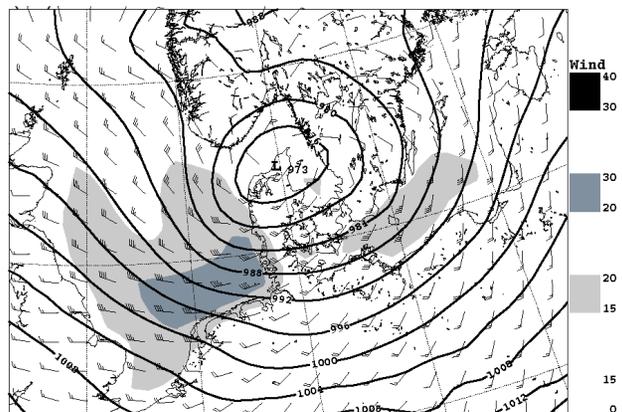


Some Algorithmic Challenges in Climate Modeling



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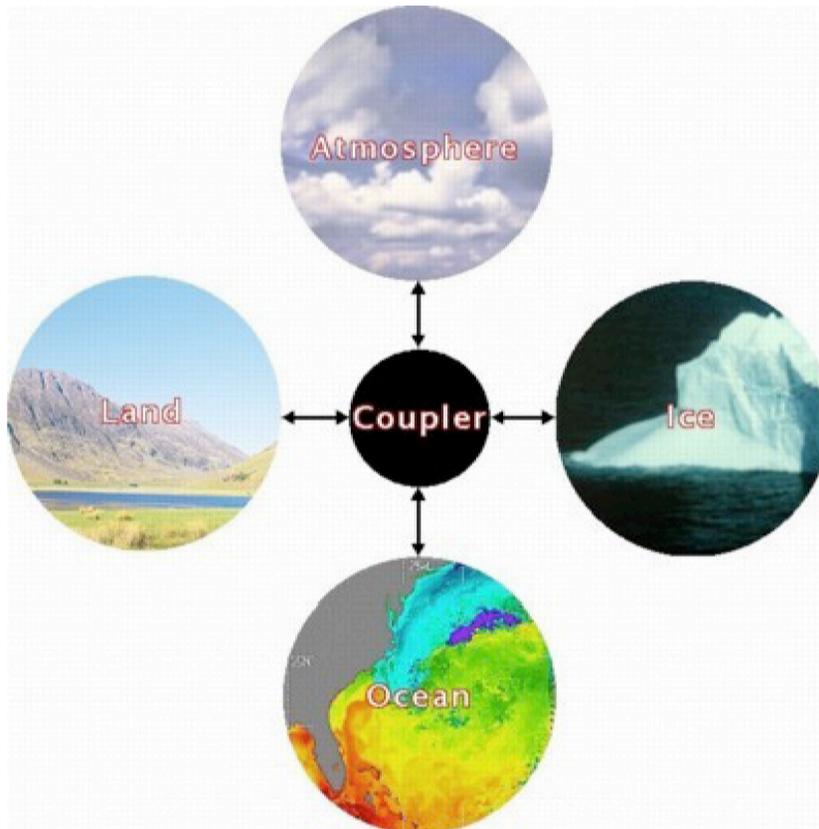
Outline

1. **Re-gridding** (coupling model components in coupled climate system models) - a challenge for next generation modeling systems that are likely to use non-traditional spherical grids and perhaps mesh-refinement technology
2. Some challenges when formulating **atmospheric solvers on non-traditional grids**



Coupled Climate System Model

-an example: NCAR's CCSM
(Community Climate System Model)

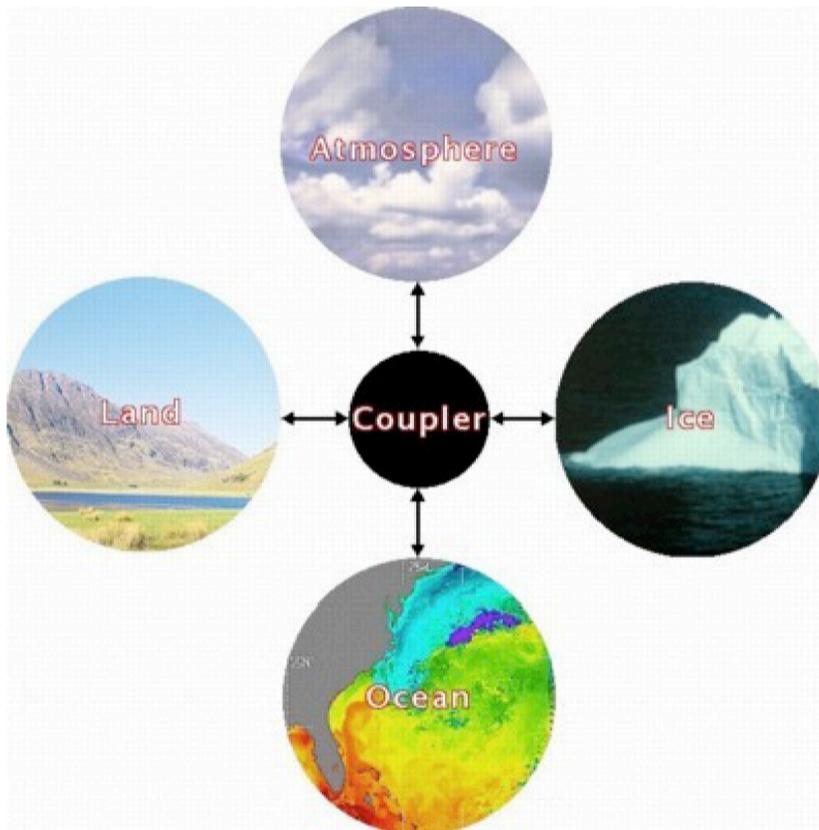


Land, ocean and atmosphere components of coupled climate system models are often implemented on different spherical grids, individually designed to enhance the accuracy or capture features unique to their respective settings.

Coupled Climate System Model

-an example: NCAR's CCSM
(Community Climate System Model)

Atmosphere uses regular latitude-longitude grid:

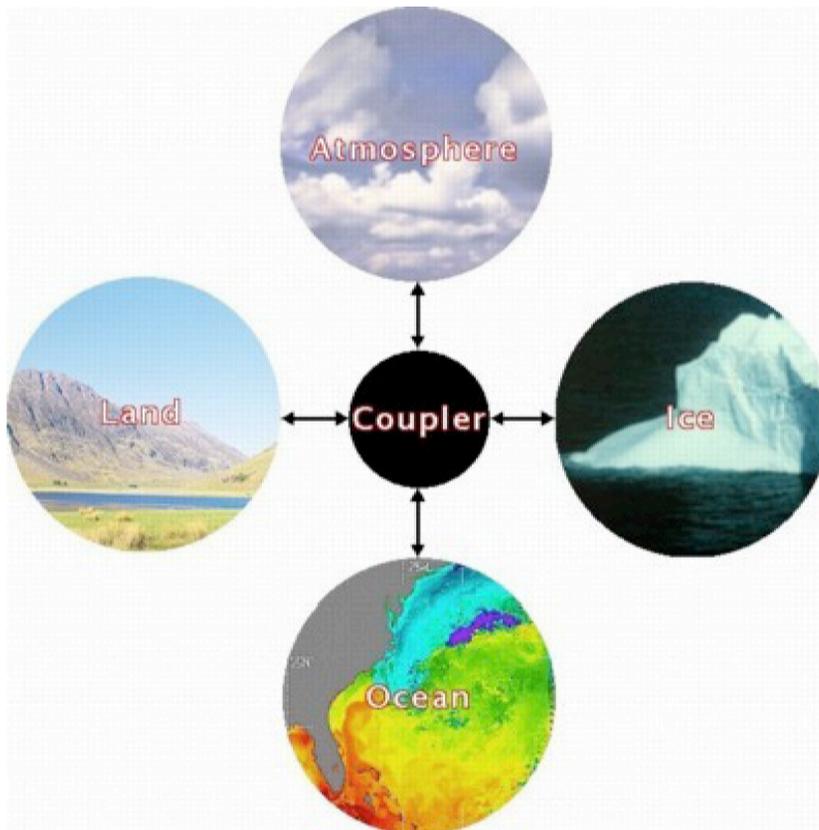


“Natural” grid for the sphere but it is not well suited for massively parallel processing (MPP)

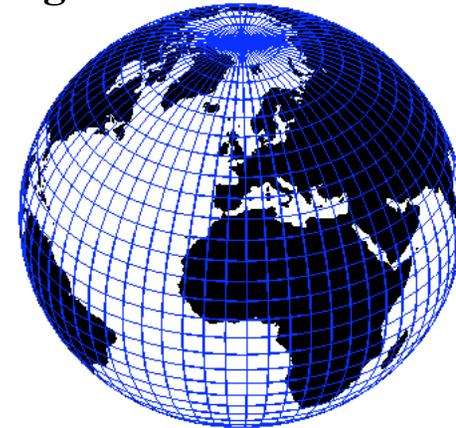
* polar filters are the bottleneck in the case of finite-volume/finite-difference discretizations) - more on this later!

Coupled Climate System Model

-an example: NCAR's CCSM
(Community Climate System Model)



Land model uses regular latitude-longitude grid:

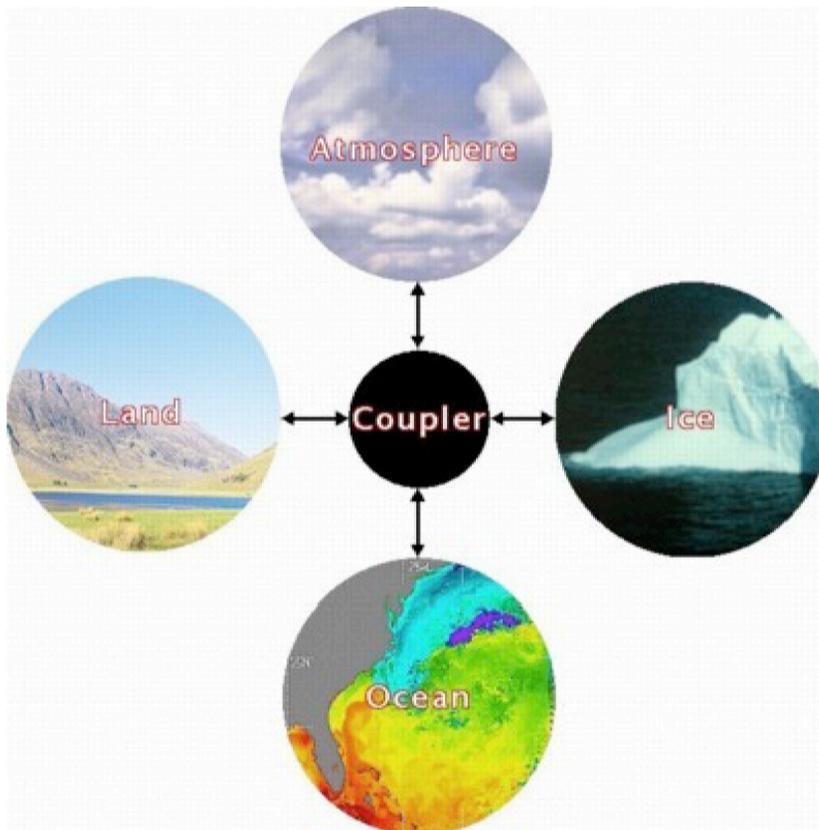


No MPP problems - most of the computation is in vertical columns rather than in the horizontal.

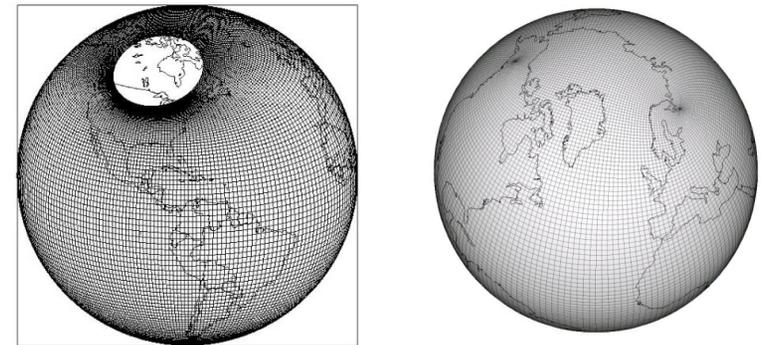


Coupled Climate System Model

-an example: NCAR's CCSM
(Community Climate System Model)



CCSM's Ocean and ice components use the dipole or tripole grid:



Singularities are over land! No inherent MPP problems.



Coupled Climate System Model

-an example: NCAR's CCSM
(Community Climate System Model)

An intricate problem introduced by defining the model components on different spherical grids:

- the exchange of information between the grids is non-trivial
- re-gridding algorithm must:
 - * conserve 1st order quantities such as mass/fluxes
 - * not introduce unphysical negative/large values (mixing ratios, ...)
 - * be capable of interpolating vector quantities
 - * deal with land/ocean fractions

**Existing software packages lack functionality and high-order accuracy
Optimization for specific grid pairs seems viable for climate modeling
(see, e.g., Lauritzen and Nair (2008); Ullrich and Lauritzen (2008))**

Coupled Climate System Model

-an example: NCAR's CCSM
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An intricate problem introduced by defining the model components on different spherical grids:

- the exchange of information between the different components
- re-gridding algorithm must
 - * conserve order quantities such as mass/fluxes
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Major Challenges

Preparing our coupled climate system models for massively parallel distributed memory computers as well as meeting the “needs”/expectations of the user community

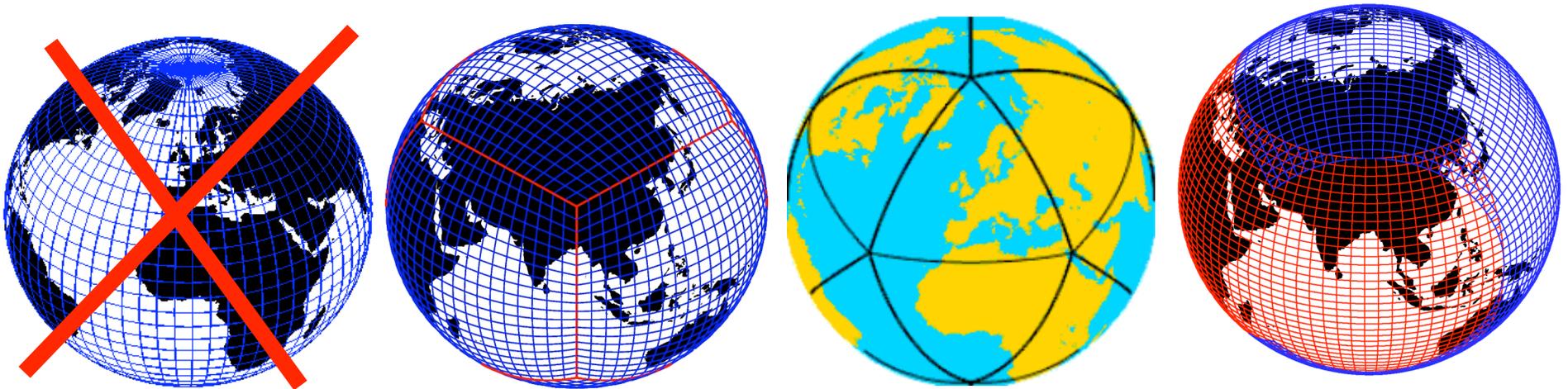
User group is very broad:

- “Regional climate modelers” (short term climate runs): “Consistent” regional climate modeling using varying global grid resolution
- “Global climate-change modelers”: Century long simulations
- “Paleo climate modelers”: Run at low resolution but for 1000s of years (this group needs “strong scaling”)

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Scalability: One solution - use a more isotropic grid (avoid pole problem, can use full 2D domain decomposition in horizontal directions, if equations are solved explicitly there is only nearest neighbor communication):





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NCAR ASP Summer Colloquium on Dynamical Cores

June 2-13, 2008; Organizers: Lauritzen, Jablonowski, Taylor, Nair

“Idea”: Gather global dynamical core community, have them port their models to NCAR supercomputers and have them oversee the students run idealized test cases defined by the colloquium organizers.

- 11 models: **NCAR** (CAM spectral+finite-volume), **NASA** (GISS, GEOS FV, GEOS FV cubed-sphere), **CSU**, **NCAR/Sandia** (HOMME), **Duke University** (OLAM), **NCEP** (GEF), **MIT** (MITgcm)
- ~ 40 graduate students; collectively produced 1.4 TB of data
- 12 keynote lecturers (see upcoming Springer Lecture Notes in Computational Science and Engineering)





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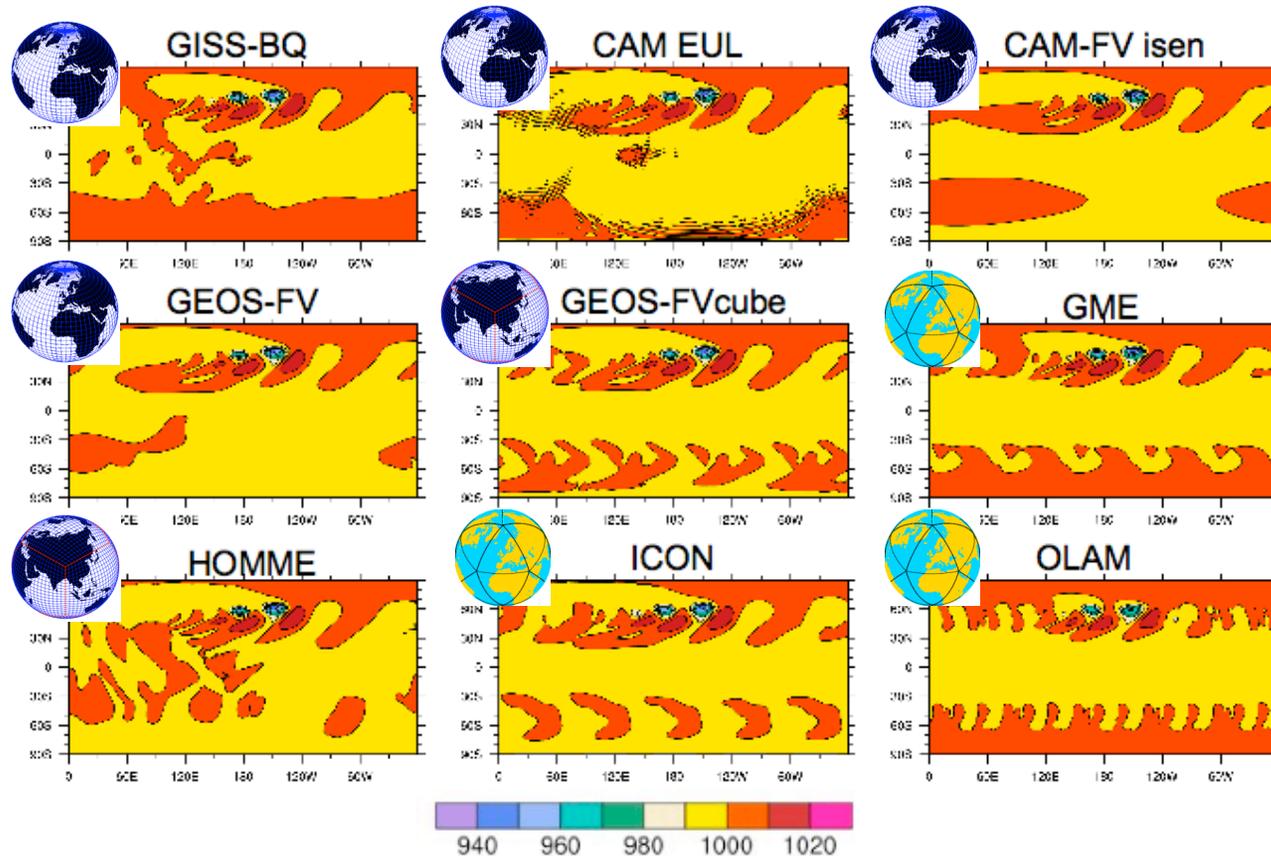


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Test 2: Baroclinic instability. Surface pressure at day 9. The tests starts with balanced initial conditions that are overlaid by a Gaussian hill perturbation. The perturbation grows into a baroclinic wave. Some models show cubed-sphere or icosahedral grid imprinting in the Southern Hemisphere. High order methods show spectral ringing in the 1000mb contour.

Major Challenges

Preparing our coupled climate system models for massively parallel distributed memory computers as well as meeting the “needs”/expectations of the user community

Some of the climate modelers requirements to the numerics:

- Computational grid should not be “visible”
- Numerics should also work well at low resolutions (large scale balances should be maintained well by the numerics)
- Efficiency:
 - * long runs
 - * tracer advection (next generation climate models will have 100s prognostic tracers)
- Conservation (mass, total energy, ...)

References:

Paul A. Ullrich and **Peter H. Lauritzen**, 2008: Geometrically Exact Conservative Remapping (GECORE): Regular latitude-longitude and cubed-sphere grids. *Mon. Wea. Rev.*: submitted.

Peter H. Lauritzen and Ramachandran D. Nair, 2008: Monotone and conservative Cascade Remapping between Spherical grids (CaRS): Regular latitude-longitude and cubed-sphere grids. *Mon. Wea. Rev.*: Vol. 136, No. 4, pp. 1416–1432.

Christiane Jablonowski, **Peter H. Lauritzen**, Mark Taylor and Ramachandran D. Nair. 2008: Idealized test cases for the dynamical cores of Atmospheric General Circulation Models: A proposal for the NCAR ASP 2008 summer colloquium

See <http://www.cgd.ucar.edu/cms/pel/publications.html>



Questions

