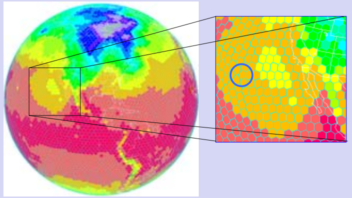

Potential temperature at FIM lowest atmospheric level - 240km resolution – N.Hem. winter case

New ways of discretizing the atmosphere/ocean for earth system prediction

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NOAA Research Goal:

Improve models to better analyze and predict the atmosphere, ocean and land-surface processes

http/fim.noaa.gov

NOAA ESRL contribution

The Flow-following Finite-volume Icosahedral Model – FIM

A unique combination of 3 numerical design advantages
- Icosahedral horizontal grid ("I" in FIM)
- Isentropic-sigma hybrid vertical coordinate ("F" for "flow following" in FIM)
- Finite-volume horizontal transport (also under "F")

History

2004-06
– Initial design of shallow water model for FIM

2007-current
– Continued FIM development – vertical coordinate, testing with GFS and WRF physics

2008-current
– Real-time and retrospective real-data testing

2008-current
– Evaluation for tropical cyclone forecasting as part of NOAA Hurricane Forecast Improvement Project (HFIP)

Started late 2009
– Incorporation of HYCOM equation set into icosahedral global model using FIM numerics and MPI decomposition.

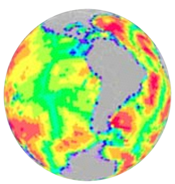
- Severe 2-pole problem in the traditional lat-lon grid there-by "diluted" into 12 rather benign grid anomalies.
- Because of near-circular shape of grid cells, the icosa-hedral grid is ideally suited for **finite volume** approach [8] where differential operators (divergence, vorticity, gradient) are expressed as line integrals along the perimeter of a grid cell.
- Caveat: Traditional 2-D discretizations cannot be used (Related work: [9,10,11,13])

The Icosahedral or "Soccer Ball" Grid

1) Black and white patches on a soccer ball created by cutting the tips off of each of the 20 triangles in an icosahedron, thereby creating 20 hexagons (white).
2) Severed triangle fragments combine into 12 pentagons (black).
3) Repeatedly subdivide triangles, con-vert final set of triangles back into hex-agons and pentagons.
(FIM supports arbitrary number and order of bisections and trisections ➔ *high granularity*)

Result: Honeycomb-like grids
- Number of pentagons remains constant during the refinement process
- Number of hexagons can be arbi-trarily large
- FIM tested and evaluated at up to 10km resolution (~10^7 polygons)

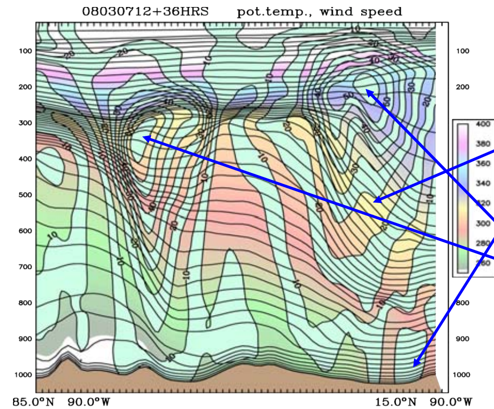
(Picture credit: G.Grell, Ning Wang, NOAA-ESRL)



Ocean depth on a 240 Km icosahedral grid

FIM - The Vertical Grid –

- A material coordinate eliminates non-physical vertical dispersion by eliminating cross-coordinate transport. [1,2,4]
- Lateral dispersion errors can be minimized by aligning coordinate surfaces with surfaces along which stirring preferentially occurs. These surfaces typically coincide with surfaces of constant entropy, suggesting that transport calculations be carried out in an isentropic coordinate system.
- FIM uses such a coordinate system, modified ("hybridized") to avoid intersections of coordinate surfaces with the ground. (HYCOM uses the analogous icopycnal system in the ocean.)
- Advantages:
  - ➢ Reduces false cross-isentropic **lateral dispersion** typically associated with horizontal transport.
  - ➢ Reduces false **vertical dispersion** associated with gravity-wave induced vertical motion.
  - ➢ Coordinate surfaces can be smoothed to suppress variability related to fine-grain convective heating patterns => future extension to non-hydrostatic scales.



Meridional vertical section through the model atmosphere, showing coordinate surfaces (solid lines), wind speed (m/s, shaded contours), and potential temperature (^{0}K, color). Ordinate: pressure (hPa)

Aspects of FIM's hybrid θ-σ vertical coordinate.

- In the free atmosphere, color follows coordinate layers, indicating that layers are isentropic (constant θ).
- Near the ground, layers follow the terrain (constant σ).
  - Due to the north-south temperature contrast, the σ domain extends up higher at equator than at poles.
  - Advantageous -- provides "guaranteed" resolution for the simulation of convective processes which are more prevalent at low latitudes.
- Two jet streams shown: polar jet, subtropical jet
  - Packing of isentropes beneath jets indicates presence of upper-tropospheric fronts, each representing an extrusion of stratospheric air into the troposphere.
  - Simulation of fronts is one of the strengths of the θ coordinate system.

FIM Vertical Grid – Continuity Equation –

Vertical migration of grid points and interlayer mass transfer are simultaneously inferred from the **mass conservation equation** written in the form

$$\left(\begin{array}{c}\text{vertical}\\\text{motion}\\\textit{of}\\\text{coordinate}\\\text{surface}\end{array}\right)+\left(\begin{array}{c}\text{vertical}\\\text{motion}\\\textit{through}\\\text{coordinate}\\\text{surface}\end{array}\right)=\left(\begin{array}{c}\text{vertically}\\\text{integrated}\\\text{horizontal}\\\text{mass flux}\\\text{divergence}\end{array}\right)$$

where only the right side is known initially.

- The Arbitrary Lagrangian-Eulerian (ALE, [5] algorithm provides the extra condition needed to determine the two terms on the left [2].
- Traditional hydrostatic models set the first term on the left to zero.

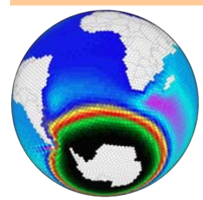
(related non-ALE isentropic coordinate work: [6, 7, 12, 14].)

Summary and Future of FIM:

- Advantageous numerical design for earth system modeling
- Collaboration with NCEP; will contribute at least to NCEP global ensemble. Uses NCEP ESMF/NEMS.
- Linked to WRF physics (and WRF community development)
- Presently being expanded into a research tool by coupling with inline chemistry (Grell poster) and ocean component (planned applications across ESRL)
- Discussions with other laboratories on collaboration
- Shared development with NIM (Lee poster)

Coupling to an Ocean Model –

- Work now underway to couple FIM to a global ocean circulation model, using ocean model HYCOM [3] which, like FIM, is a hybrid-isentropic stacked shallow water model
- Shares FIM's mix of prognostic and diagnostic variables. Rewritten for an icosahedral mesh, HYCOM can be coupled to FIM without spatial interpolation and can utilize the MPI parallelization techniques for unstructured grids developed for FIM.
- At 15-km FIM resolution, ocean eddies are resolved (crudely, at least). This removes one of the historic reasons for using a finer mesh in the ocean than in the atmosphere. Using identical meshes greatly simplifies the coupling.



Sea surface height in a 50-day baro-tropic, constant-depth simulation forced by zonally averaged FIM surface winds. Lowest/highest elevations are shown in black/purple, respectively.

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