Medium-range forecasting at NOAA/ESRL with a hybrid-isentropic global circulation model

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FIM is a global atmospheric circulation model used at ESRL for experimental real-time and retrospective medium-range weather prediction. It solves the relevant prediction equations on a 3-D spatial grid uniquely combining two features: an **icosahedral** horizontal grid and an adaptive, nearly **isentropic** vertical grid.

Feature 1: the icosahedral horizontal grid. Created by iteratively dividing the 20 triangular faces of an icosahedron into smaller triangles. A final tesselation step converts triangles into hexagons and a few (12) pentagons.
Advantages: Severe spherical-grid singularity near poles is replaced by a much weaker singularity at 12 locations (the pentagons). Convex shape of grid cells is ideal for approximating differentials by line integrals along cell perimeters.
Caveats: Use of lookup tables, typical for unstructured grids, can impact efficiency. Grid resolution in zonal direction exhibits a wave # 5 periodicity in the extratropics, wave # 10 near the equator. This can affect the growth rate of certain planetary waves.

History of isentropic modeling: Attempts to extend isentropic analysis practices to NWP date back to the 1950s. First successful numerical simulation: 1965. First real-data forecasts: 1974. In operational use since 1994. Biggest problem in the early days: coordinate-ground intersections (Fig 1).

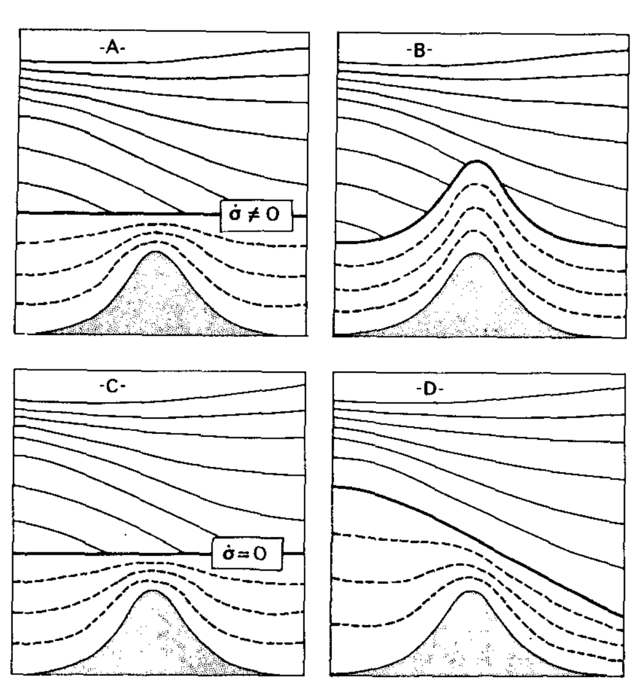


Fig 1. Four ways to avoid coordinate-ground intersections (from Bleck, 1978). Coordinate layers below the heavily drawn interface are to various degrees non-isentropic. The interface is fixed (i.e. permeable) in schemes A,B; material (i.e. flow-following) in schemes C,D.

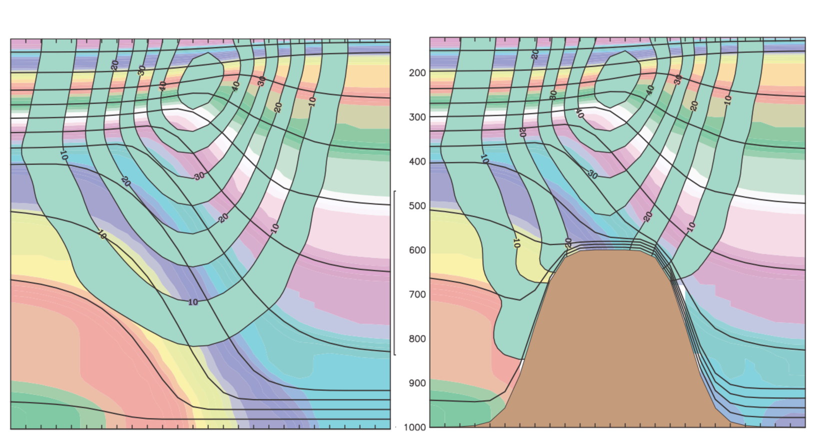
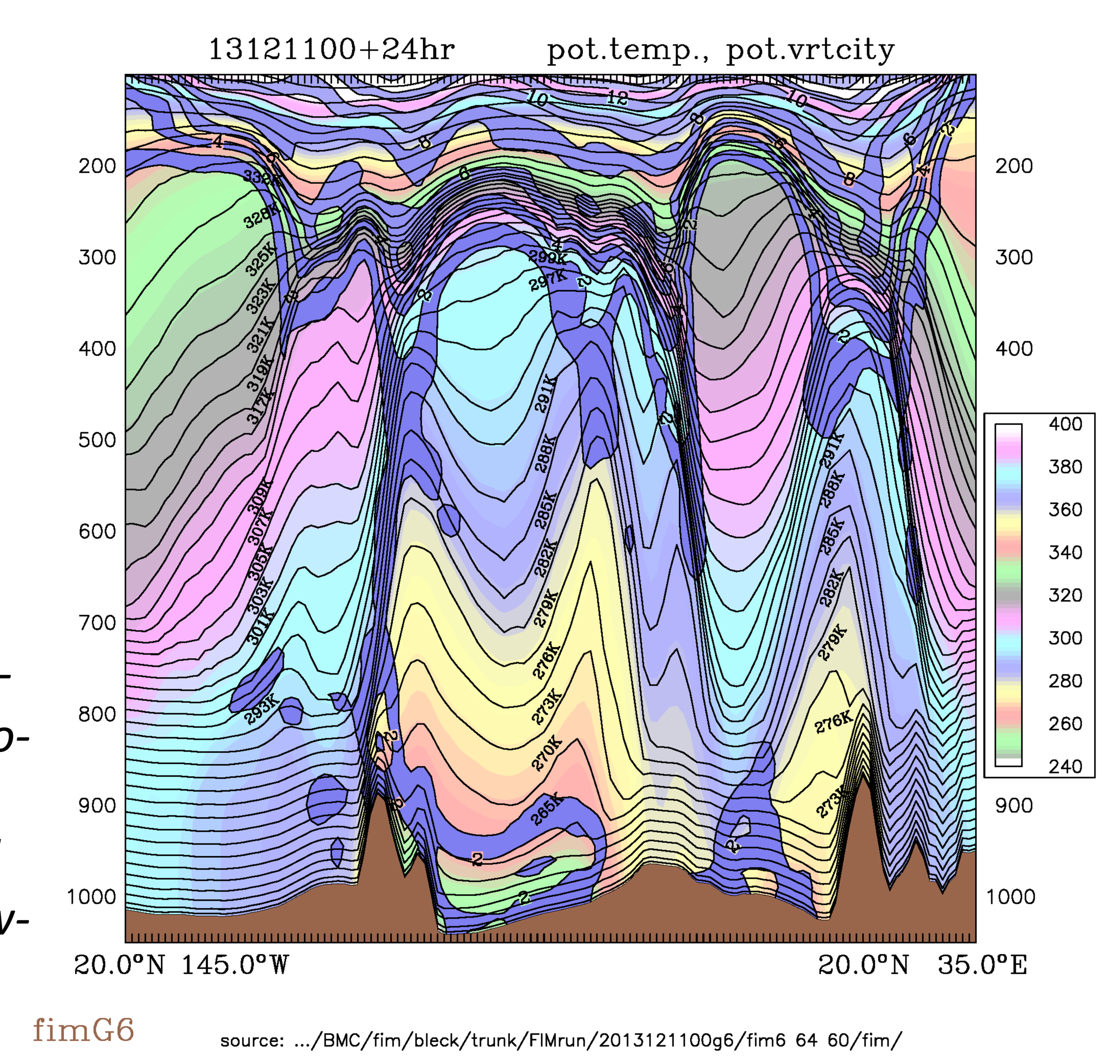


Fig 2. FIM grid layout over (a) flat terrain; (b) high mountains. Solid lines are either coordinate surfaces or isotachs; potential temperature shown in color.

Feature 2: the adaptive, nearly isentropic grid. Coordinate layers generally follow isentropes but must abide by minimum thickness constraints. If potential temperature in a layer veers from its assigned "target" value (e.g., by diabatic effects), layer interfaces will migrate vertically to reach the target -- hence the term "adaptive grid". The thickness constraint inhibits interface migration; hence, the grid is terrain-following near the ground before becoming isentropic higher up. Above the transition level, FIM behaves like a *stacked shallow-water model*.
Advantages (isentropic subdomain): Optimally resolves wind shear in frontal zones and details in the 3-D potential vorticity (PV) field. Vertical component of motion vanishes in adiabatic flow, which reduces vertical dispersion.
Caveats: Layer migration spawns vertical velocities (relative to the grid). To keep these small, it is prudent to cap migration rate. Due to variable layer thickness, transport equations must be solved in *flux* form for conservation. Spatio-temporal changes in vertical resolution can modulate truncation error (desirable in some situations, undesirable in others).

Coordinate choices reminiscent of scheme D (Fig 1) are found in the models *of Zapotocny et al.* (1994)*; Konor & Arakawa* (1997); and in FIM (Figs 2,3). Today, non-isentropic, finite-thickness layers are no longer introduced to avoid coordinate-ground intersections. Rather, they are used to permit super-adiabatic lapse rates which in a purely isentropic coordinate model would lead to coordinate folding. This aspect, rather than numerical requirements, guides the choice of minimum layer thickness.

Fig 3. Sample meridional section across N. Pole, beginning/ending at 20⁰N. Shown are FIM coordinate surfaces, θ (pastel colors), and PV (dark blue). Cyclonic eddies are flanked by extrusions of high-PV stratospheric air into troposphere; anticyclonic eddies are associated with tall domes of low-PV air.



Sample Results

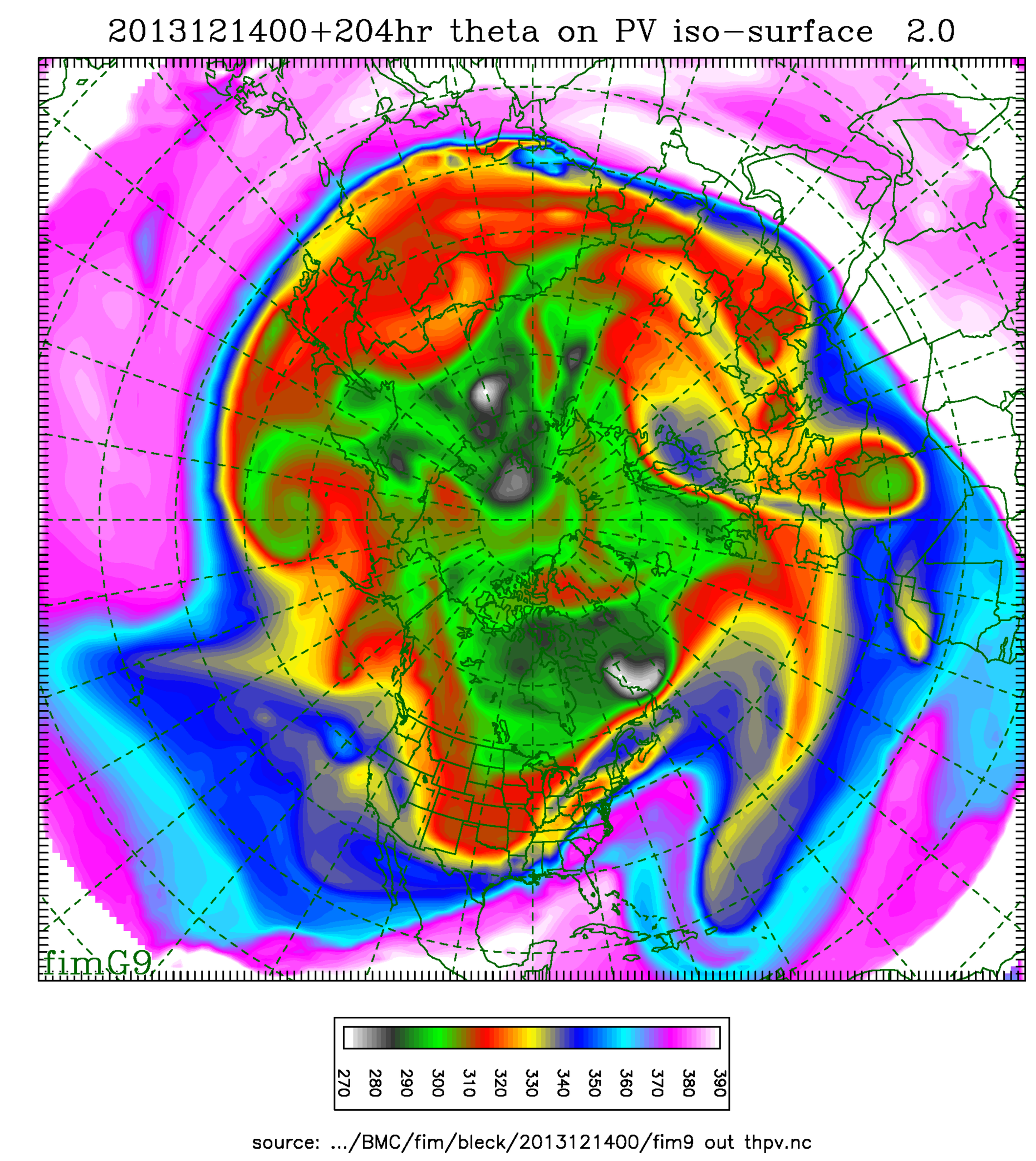


Fig 4. Isentropic grids excel in depicting the evolution of the PV (pot. vorticity) field. Shown here is θ (pot. temperature) on a tropopause-level PV surface. θ(PV) is a "dynamic" air mass tracer useful for illustrating Rossby wave breaking and associated vortex rollup – the essence of extra-tropical weather. Note distinct blocking pattern over Europe. Grid size in this FIM simulation: 15km.

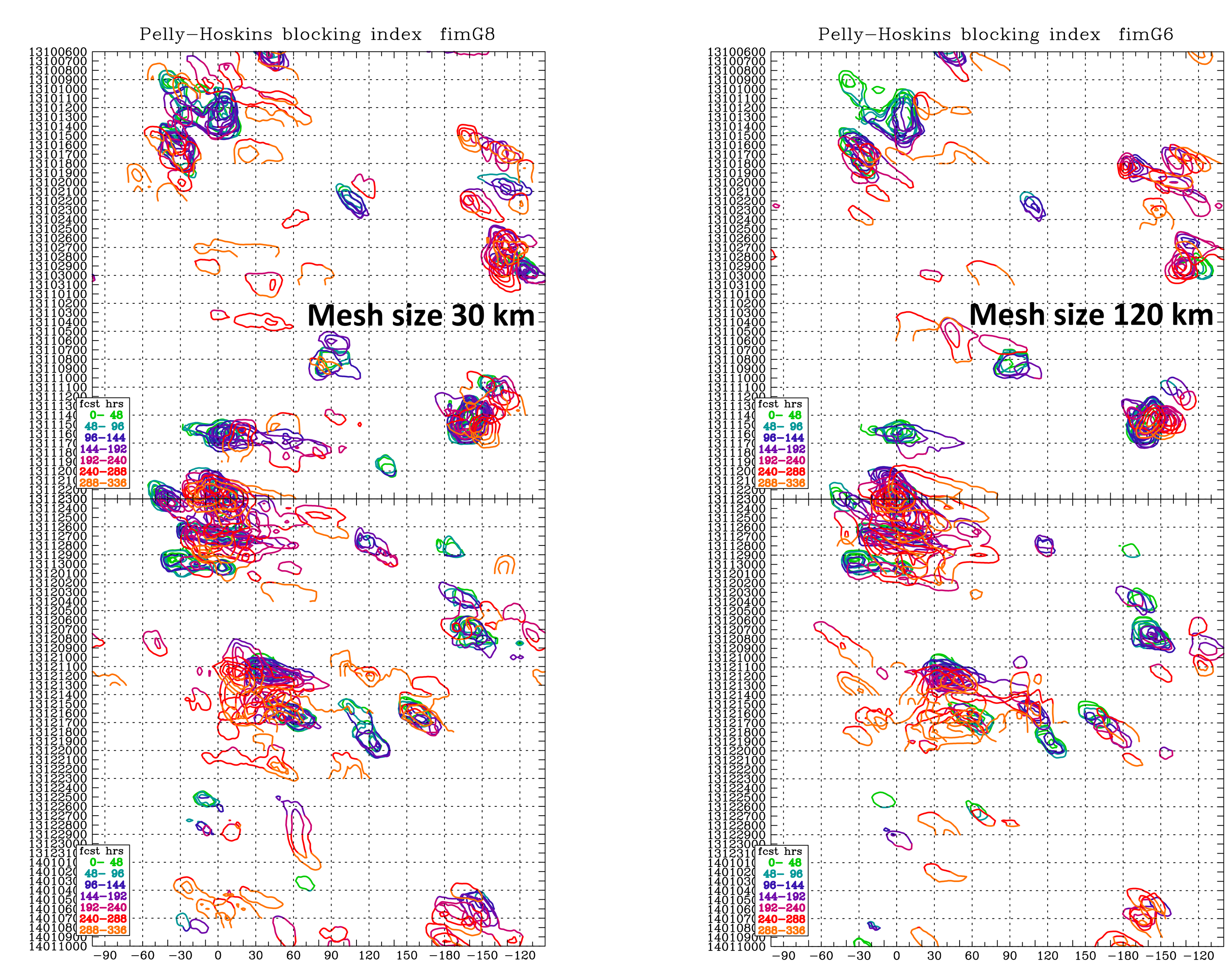


Fig 5. Hovmoeller diagram of the Pelly-Hoskins (2003) blocking index, from daily 2-week FIM simulations verifying between 06-Oct 2013 and 10-Jan 2014. Mesh size 30km (left) and 120km (right). Abscissa: longitude; ordinate: verification time. Forecast lead time indicated by color. Red/orange patches overlaying green patches indicate successful long-range predictions of blocks, shown here to be only weakly dependent on grid resolution. The Pelly-Hoskins blocking index singles out anomalous reversals of the meridional θ gradient on a tropopause-level PV surface, the field shown in Fig 4.

References:

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