Progress Report on Global Dynamical Cores

Celal S Konor, Ross P Heikes and David A Randall

Department of Atmospheric Science
Colorado State University

Objectives

- *A global cloud resolving/permitting model with 4 km (or less) horizontal grid distance*
- *Dynamical core of global climate models*
- *GCM dynamical core of Global Q3D MMFs*

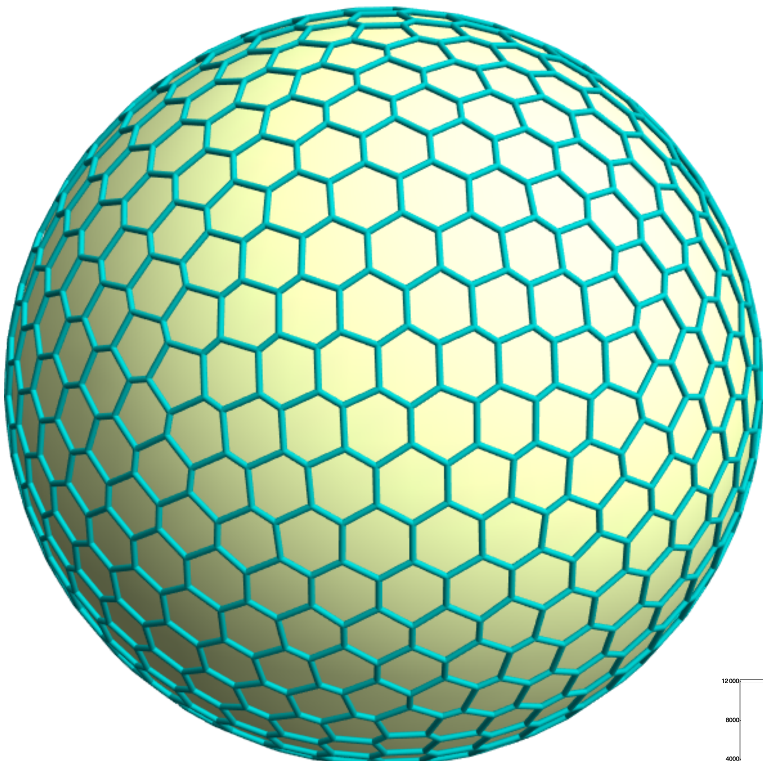
Fourteenth CMMAP Team Meeting, 22-24 January 2013, Boulder, CO
Dynamical Framework Working Group

Global Dynamical Cores

Unified
Z-grid
Icosahedral
Model

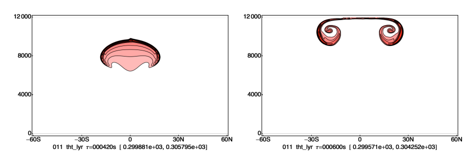
1-Current status of UZIM (Unified Z-grid Icosahedral Model)

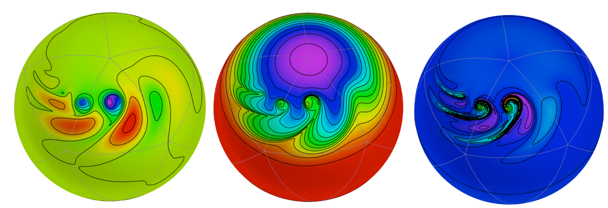
- Height vertical coordinate version of UZIM has been completed. (No mountains)
- Sigma vertical coordinate and CP-grid version of UZIM has produced the first results.(Permits mountains)



UZIM

- Nonhydrostatic Unified equations
- Z-grid: Vorticity and Divergence are predicted
  (all variables are predicted at the cell centers)
- Icosahedral hexagon and pentagon grid





Unified equations with the sigma coordinate

Quasi-hydrostatic module

$$\sigma \equiv \frac{p_{qs} - (p_{qs})_T}{(p_{qs})_S - (p_{qs})_T}$$

$$m \equiv (p_{qs})_S - (p_{qs})_T$$

$$\left(\frac{\partial}{\partial t}\right)_\sigma \theta + \mathbf{v} \cdot \nabla_\sigma \theta + \dot{\sigma}\frac{\partial \theta}{\partial \sigma} = \frac{Q}{c_p \pi}$$

$$\frac{\partial m}{\partial t} = \frac{\partial (p_{qs})_S}{\partial t} = \int_{\sigma_S}^{\sigma_T} \nabla_\sigma \cdot (m\mathbf{v}) d\sigma$$

$$\frac{\partial z}{\partial \sigma} = -\frac{m}{g}\frac{\kappa \pi_{qs}}{p_{qs}} c_p \theta$$

$$\frac{\partial (m\dot{\sigma})}{\partial \sigma} = -\nabla_\sigma \cdot (m\mathbf{v}) - \frac{\partial m}{\partial t}$$

$$(m\dot{\sigma})_S = (m\dot{\sigma})_T = 0$$

$$\frac{\partial \eta}{\partial t} + \cdots + \mathbf{k} \cdot \nabla_\sigma \times \left[\frac{g}{m}\left(\nabla_\sigma (mz) - \frac{\partial}{\partial \sigma}(z\nabla_\sigma p_{qs}) - \frac{\partial}{\partial \sigma}(z\nabla_\sigma \delta p)\right)\right] = 0$$

$$\frac{\partial D}{\partial t} + \cdots + \nabla_\sigma \cdot \left[\frac{g}{m}\left(\nabla_\sigma (mz) - \frac{\partial}{\partial \sigma}(z\nabla_\sigma p_{qs}) - \frac{\partial}{\partial \sigma}(z\nabla_\sigma \delta p)\right)\right] = 0$$

Nonhydrostatic module

$$w = w_c - \frac{1}{g\rho_{qs}} m\dot{\sigma}$$

$$w_c \equiv \left(\frac{\partial}{\partial t}\right)_\sigma z + \mathbf{v} \cdot \nabla_\sigma z$$

$$\left(\frac{\partial}{\partial t}\right)_\sigma z = -\int_{\sigma_S}^{\sigma} \left(\frac{\partial}{\partial t}\right)_\sigma \left(\frac{mR\pi_{qs}\theta}{gp_{qs}}\right) d\sigma$$

$$\nabla_\sigma \cdot \left(\frac{m}{\rho_{qs}}\nabla_\sigma \delta p\right) + \nabla_\sigma \cdot \left(g\nabla_\sigma z \frac{\partial}{\partial \sigma}\delta p\right) + \frac{\partial}{\partial \sigma}\left(\frac{g^2 \rho_{qs}}{m}\frac{\partial}{\partial \sigma}\delta p\right)$$
$$= -\nabla_\sigma \cdot \left(\frac{m}{\rho_{qs}}\nabla_\sigma p_{qs}\right) - \nabla_\sigma \cdot \left(g\nabla_\sigma z \frac{\partial p_{qs}}{\partial \sigma}\right) - \nabla_\sigma \cdot \left(m\mathbf{G}_H - \mathbf{v}\frac{\partial m}{\partial t}\right)$$
$$+ g\frac{\partial}{\partial \sigma}\left[-w\left(\frac{\partial}{\partial t}\right)_\sigma \rho_{qs} + \left(\frac{\partial}{\partial t}\right)_\sigma (\rho_{qs} w_c) + G_z\right] + \frac{\partial^2 m}{\partial t^2}$$

Quasi-hydrostatic: Red terms only

Nonhydrostatic unified: Red and blue terms together

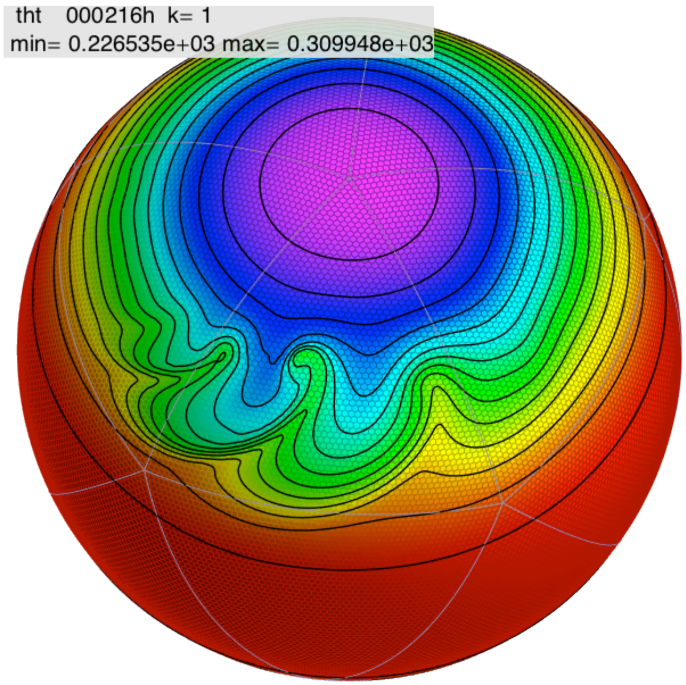
UZIM Results

“Baroclinic wave” test case (Jablonowski and Williamson 2006)

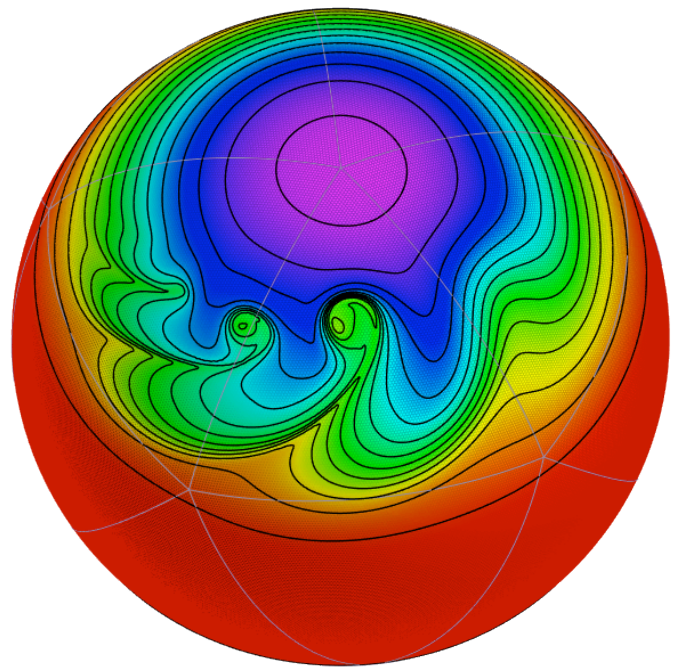
Day 9

Surface potential temperature

UZIM Sigma (quasi-hydrostatic)



UZIM Height



G6 (40K cells, horizontal resolution is approx. 120 km),
vertical resolution is approx. 30 mb.

G7 (163K cells, horizontal resolution is approx. 60 km),
vertical resolution is approx. 500 m.

2-Mountain problem with the Z-grid dynamics

- Sigma vertical coordinate permits inclusion of “smooth” mountains to the Z-grid dynamics without extra work. But, the sigma vertical coordinate will have problems with the steep mountains.
- We studied the possibility of the height vertical coordinate Z-grid dynamics with the “block” mountains. We found a method to find streamfunction from vorticity with islands. But, the computational scaleability of the method is poor.

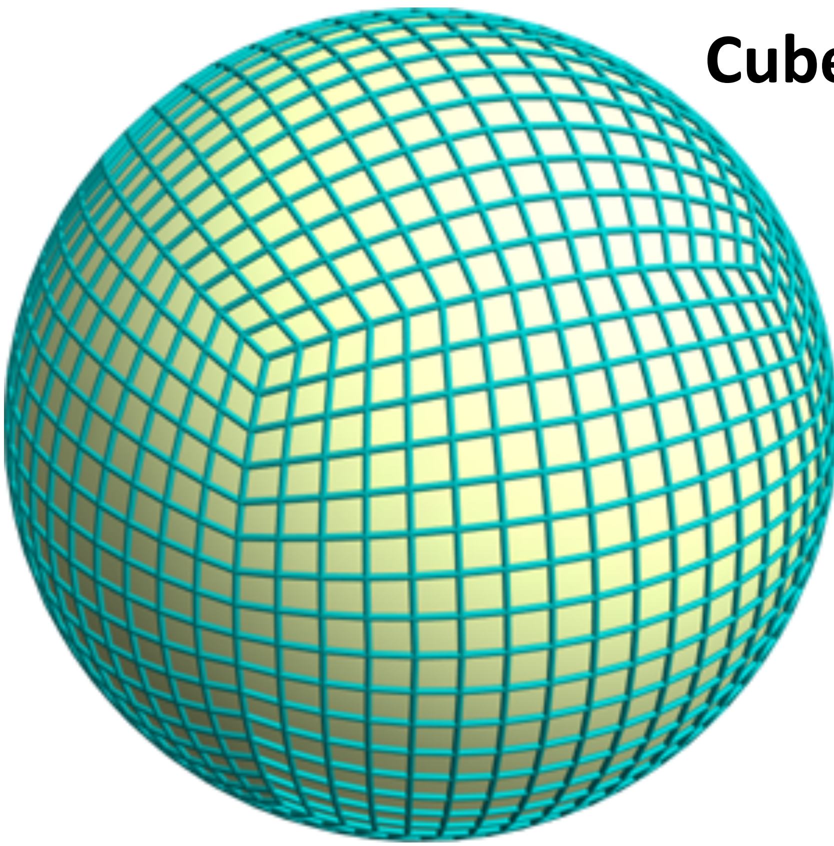
3-Mountain problem with the Vector-Vorticity dynamics

- Height vertical coordinate VV dynamical core permits inclusion of "steep" mountains on a square (or rectangular) grid.
- We constructed an icosahedral hexagon-pentagon grid model based on the VV dynamics. The model suffered from a serious computational mode problem on the hexagonal grid.

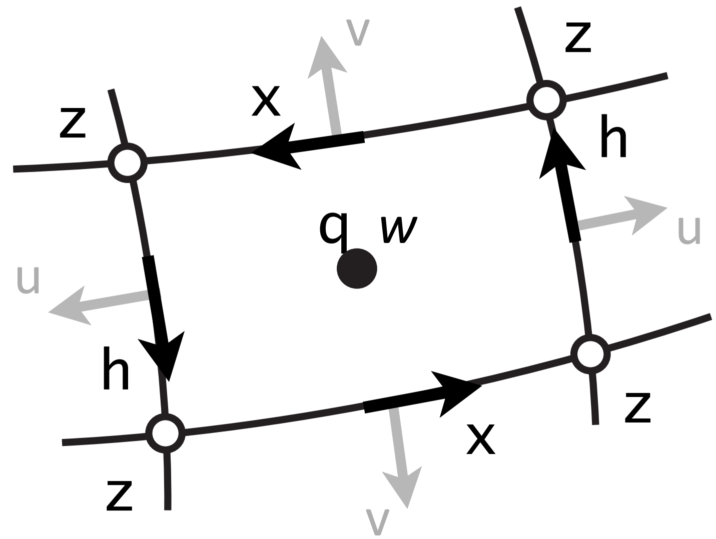
3-Mountain problem with the Vector-Vorticity dynamics (Cont.)

- One can expect that the VV dynamics can perform better on a quadrilateral grid, because there is no room for a computational mode caused by an extra degree of freedom on a quadrilateral grid.

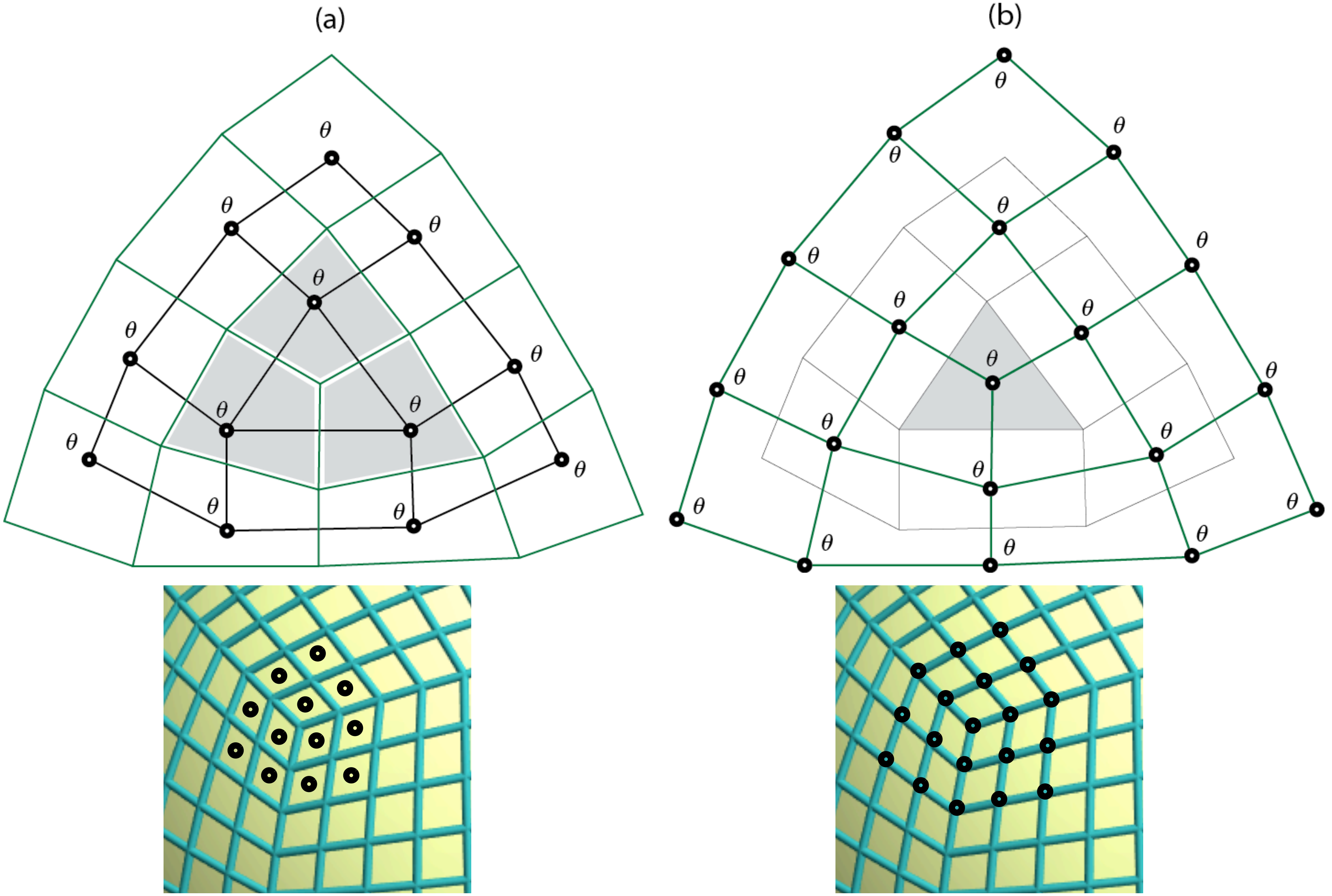
UVCM
Unified
Vector-vorticity
Cubed-sphere
Model



Cubed-sphere grid



Two possible grids on the cubed-sphere



4-Impact of mountain problem on computational efficiency

- It seems that we have to pay more money if we want to resolve the mountains well.
- We may have to change the way we do things. A recent chatter: The immersed boundary method (Peskin, 1972).

5-GCM of the global Q3D MMF

- We should also consider the cubed-sphere grid.