ATM 265, Spring 2019
Lecture 13
Global Atmospheric Models from Around the World
May 8, 2019

Paul A. Ullrich (HH 251)
paullrich@ucdavis.edu

Why Multiple Models?

Figure: Relative error metrics for 20th century CMIP3 annual cycle climatology (1980..1999). A value of -0.2 means that the model has an error 20% smaller than the typical model error for that quantity.
Source: NASA

In general, the model mean is a significantly more skillful approximation to the real climate than any individual model result.

Why do you think this is the case?
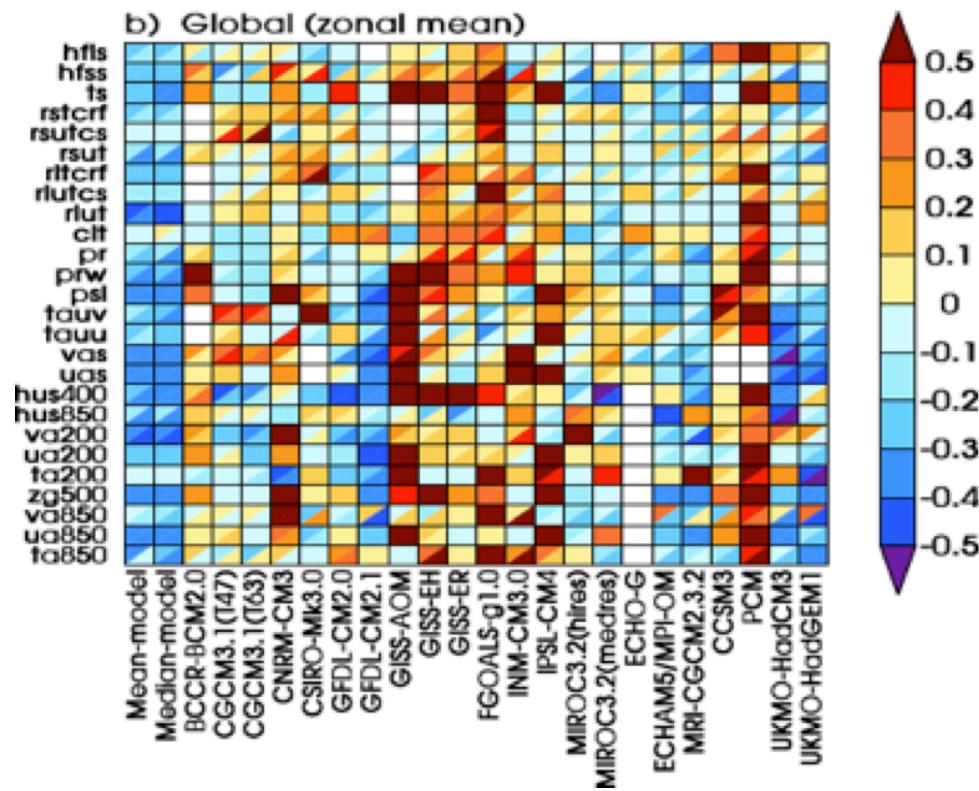
Operational Global Atm. Models

IPCC participating model

Global Atmospheric Models

Outline:

- Ocean-Land-Atmosphere Model (OLAM)

- Unified Z-Grid Icosahedral Model (CSU/UZIM)

- UK Met Office Unified Model / ENDGame

- Non-hydrostatic Icosahedral Cloud-resolving Atmosphere Model (NICAM)

- NCAR / CESM / Community Atmosphere Model (CAM)

- NCAR / Model for Prediction Across Scales (MPAS)

- DOE / E3SM

- ECMWF / Integrated Forecasting System (IFS)

- GFDL / Finite-Volume Cubed (FV3)

- Environment and Climate Canada / Global Environmental Multiscale Model (GEM)

Ocean-Land-Atmosphere Model (OLAM)

Authors:

Robert Walko (University of Miami, Miami, FL)

Roni Avissar (University of Miami, Miami, FL)
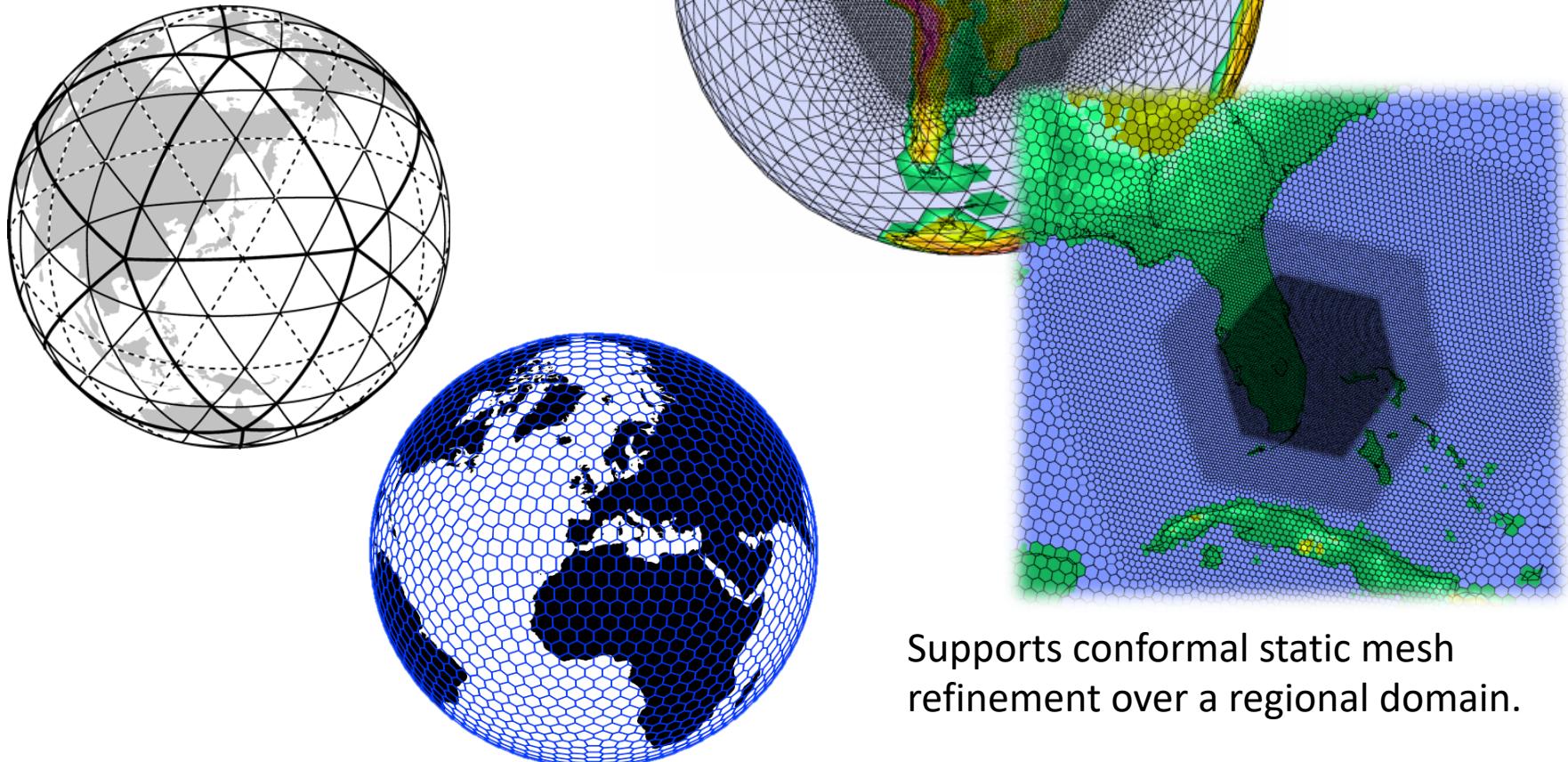
Martine Otte (US Environmental Protection Agency)

Operational Model, Non-Hydrostatic, Deep Atmosphere

Used by: US Environmental Protection Agency
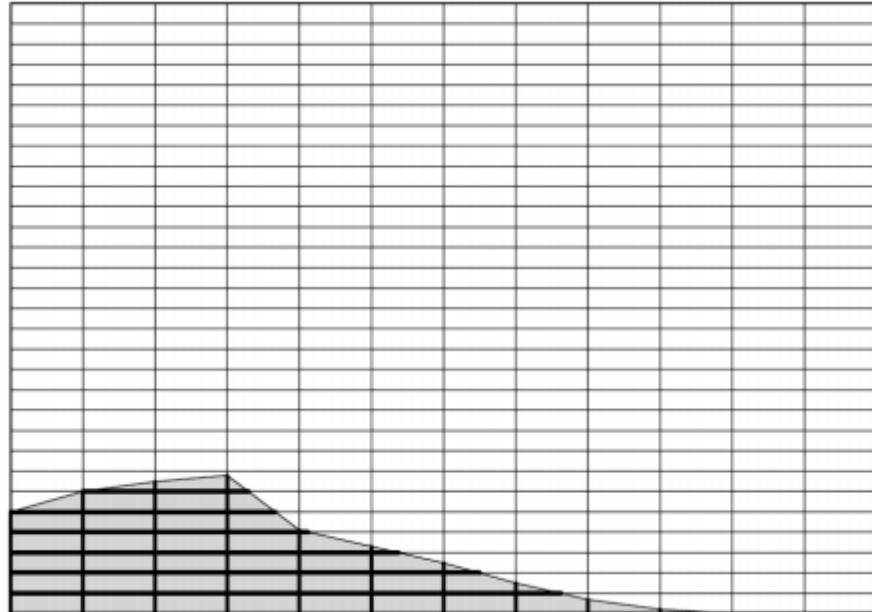
Based on: Limited-Area Model RAMS (1986)

OLAM

The model is based on an icosahedral triangular or hexagonal grid.

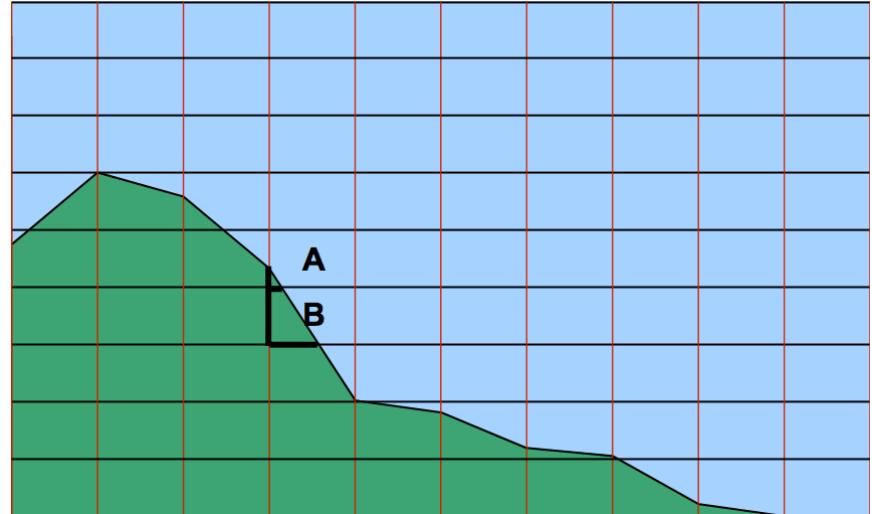Supports conformal static mesh refinement over a regional domain.

OLAM

Cut cell method used in the vertical (improves horizontal pressure gradient calculation)

Cut cells treated by scaling surface area of cells by "exposed" area.

Colorado State University Unified Z-grid Icosahedral Model (UZIM)

Authors:

Dave Randall (Colorado State University, Fort Collins, CO)

Don Dazlich (Colorado State University, Fort Collins, CO)

Ross Heikes (Colorado State University, Fort Collins, CO)

Non-Operational Model, Non-Hydrostatic, Shallow Atmosphere

**Based on:**

Unified model system (Arakawa and Konor 2009)

Vorticity-Divergence Z-grid (Randall 1994)

UZIM

The model is based a hexagonal grid which has been optimized via a post-processing step.

Z-Grid formulation:
Each hexagon stores the vorticity and divergence at that point (instead of the zonal and meridional velocities).

This has been shown to have better numerical properties, but requires a global solve at each time step to recover u, v.
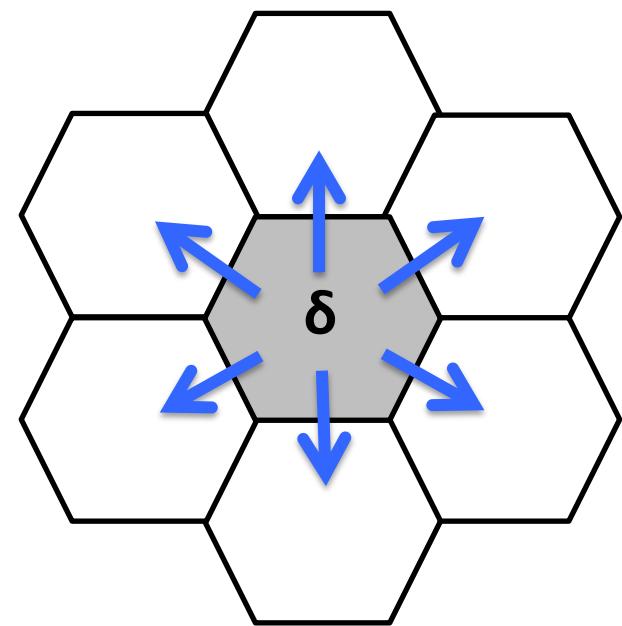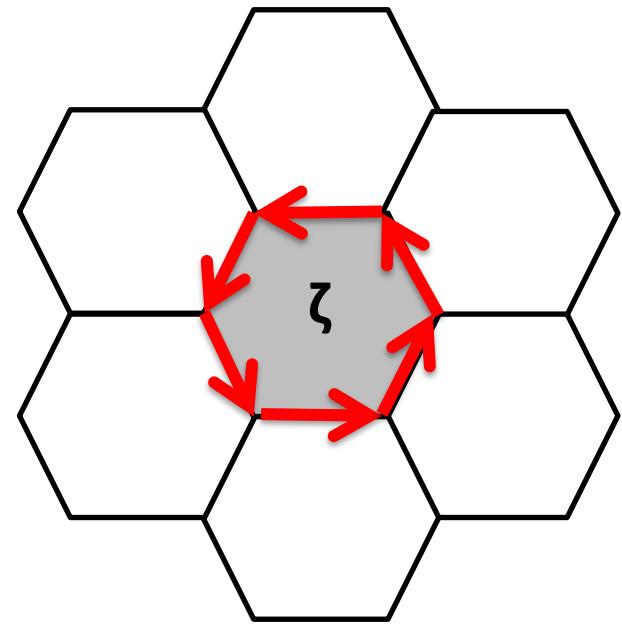
UZIM

- Third-order Multi-Step scheme (Adams Bashforth) for time stepping

- Positivity preserving Flux-Corrected Transport (FCT)

- "Unified" approach for treatment of vertically propagating sound waves

- Topography not yet implemented (plan is for cut cells)

ENDGame

UK Met Office Model

Authors:

John Thuburn (University of Exeter)

Thomas Melvin (UK Met Office)

Many Others…

**Operational Model, Non-Hydrostatic/Hydrostatic, Shallow/Deep Atmosphere**

Philosophy: "Unified" model used for both Numerical Weather Prediction applications and Climate applications. Must satisfy NWP benchmarks: Must forecast at 25km 7 days in < 3 hours.

ENDGame

- Includes modification to ellisoidal geopotential.

- C-Grid in the horizontal

- Charney-Phillips vertical staggering

- Fully implicit (iterative) scheme for non-advective terms

- Scheme not inherently conservative (a posteriori correction scheme needed)

The model is based a latitude-longitude grid. The small timestep restriction is overcome using a semi-Lagrangian methodology.
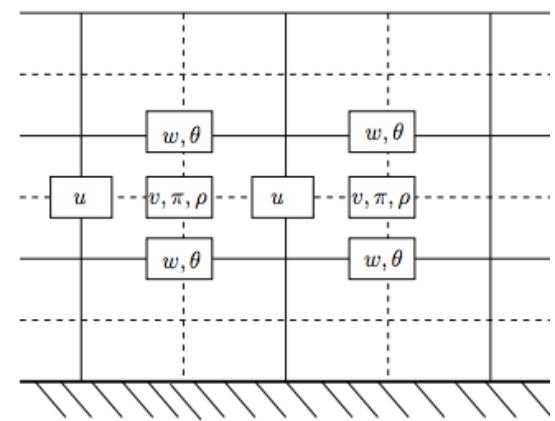
Nonhydrostatic Icosahedral Cloud-resolving Atmospheric Model (NICAM)

University of Tokyo Cloud Resolving Model

Authors:

Masaki Satoh (University of Tokyo)

Hirofumi Tomita (Japan Agency for Marine-Earth Science and Technology)

Hiroaki Miura (University of Tokyo)
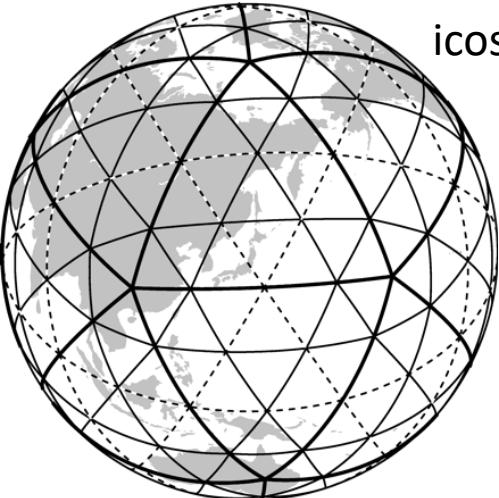
Ryuji Yoshida (AICS, Riken, Kobe)

Many Others…

Operational Model, Non-Hydrostatic, Shallow/Deep Atmosphere

Philosophy: Design a model for cloud resolving scales (3 km) global resolution.

(Note: Experimental runs have been produced at 800m)

NICAM

Global triangular icosahedral mesh.

Madden-Julien Oscillation Experiment
Left: Satellite, Right: NICAM.

- **Project goal:** Resolve horizontal scales well enough to not require a cumulus cloud parameterization.

- Model was among several designed to take advantage of the super-computing architecture of the Earth Simulator.

- **Highly local finite difference method:** Project aimed to use the simplest numerical method possible and maximize computational efficiency.

- A-grid finite-volume method with 2nd order central spatial discretizations plus terrain-following vertical coordinate. Split-explicit treatment of sound waves.

Integrated Forecast System (IFS)

European Center for Medium-Range Weather Forecasting (ECMWF)

Authors:

Nils Wedi (ECMWF)

Sylvie Malardel (ECMWF)

Many others…

Operational Model, Hydrostatic/Non-hydrostatic, Shallow/Deep Atmosphere

Philosophy: High-resolution high-throughput numerical weather prediction system using tried-and-tested numerical methods.

Integrated Forecast System (IFS)

Spectral transform method based on a latitude-longitude grid.

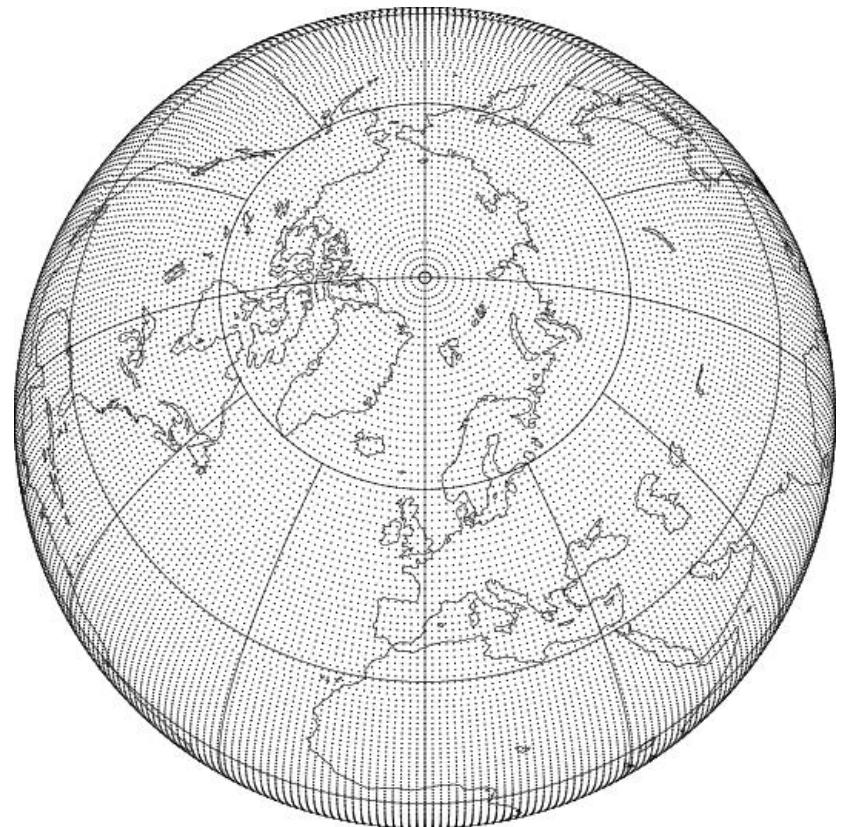| Year	Truncation	Resolution
1983	T63	~ 316 km
1987	T106	~ 188 km
1991	T213	~ 95 km
1998	T_L319	~ 63 km
2000	T_L511	~ 39 km
2006	T_L799	~ 25 km
2010	T_L1279	~ 16 km
2015	T_L2047	~ 9 km*
2020	.. T_L3999	1 − 9 km**

* Hydrostatic, parameterized convection
** Non-hydrostatic, explicit convection

Integrated Forecast System (IFS)
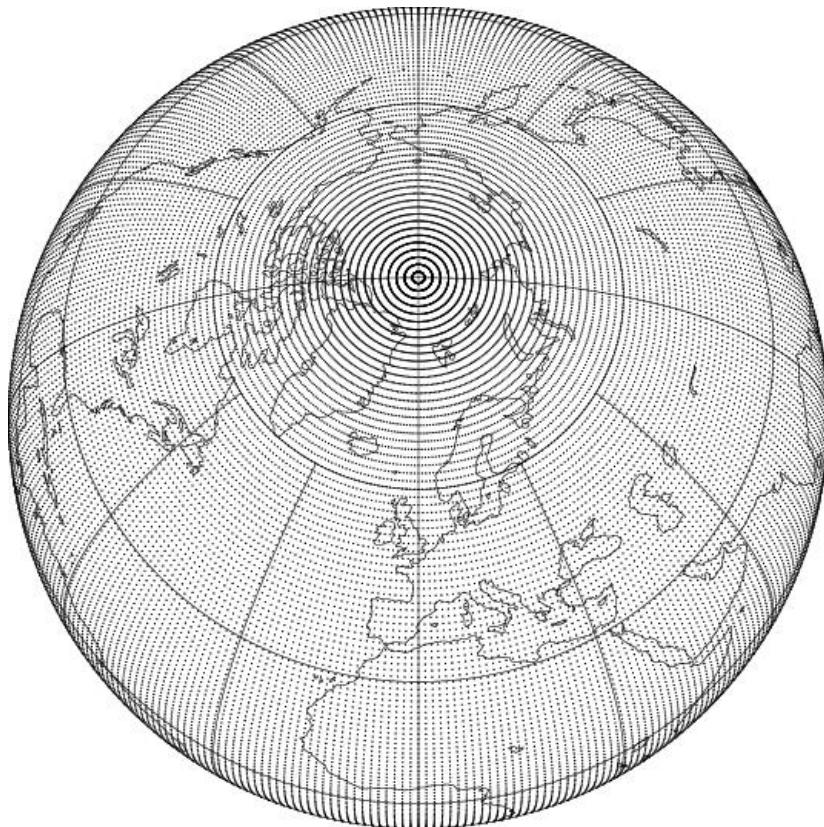
Northern hemisphere regular longitude-latitude grid.

Northern hemisphere reduced longitude-latitude grid (30% reduction in the number of grid points)

Community Earth System Model (CESM) Community Atmosphere Model (CAM)

National Center for Atmospheric Research (NCAR)

Authors:

David Williamson, Rich Loft, Rich Neale, Peter Lauritzen, etc. (NCAR)

Many others…

Operational Model, Hydrostatic, Shallow Atmosphere

Philosophy: A community resource for studying the atmosphere. Focus is on climate applications. Large-scale parallel scalability for the CAM-SE model.

Energy Exascale Earth System Model (E3SM) / E3SM Atmosphere Model (EAM)

Department of Energy (DOE)

Authors:

Dave Bader, Peter Caldwell, Mark Taylor, etc. (DOE)

Many others…

Operational Model, Hydrostatic, Shallow Atmosphere

Philosophy: A model branched from CESM targeted at extreme scale computing and answering questions related to DOE interests. Dynamical core extended to non-hydrostatic in 2019.

Community Atmosphere Model (CAM)

Support for four dynamical cores:

- *Spectral element (default)* – Default in CAM 5.2
- *Finite-Volume (previous default)* – Used in IPCC AR5 and AR6
- **Semi-Lagrangian (deprecated)**
- **Global Spectral Transform (Eulerian dynamics)** – Used in IPCC AR4

Spectral Element

Finite-Volume
Semi-Lagrangian
Eulerian

Community Atmosphere Model (CAM)

In the vertical:

- Hybrid sigma-pressure coordinate

- Floating Lagrangian layers

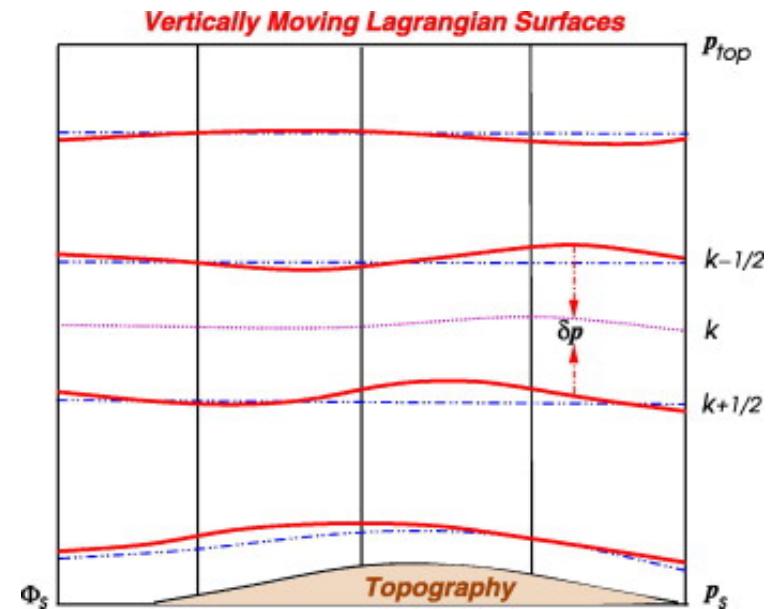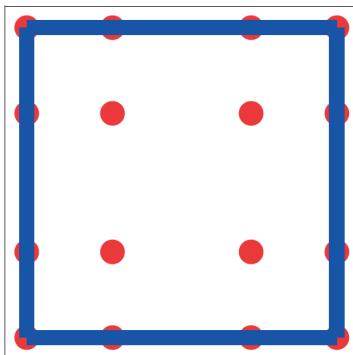- All physical parameterizations must work within a column (only column physics)

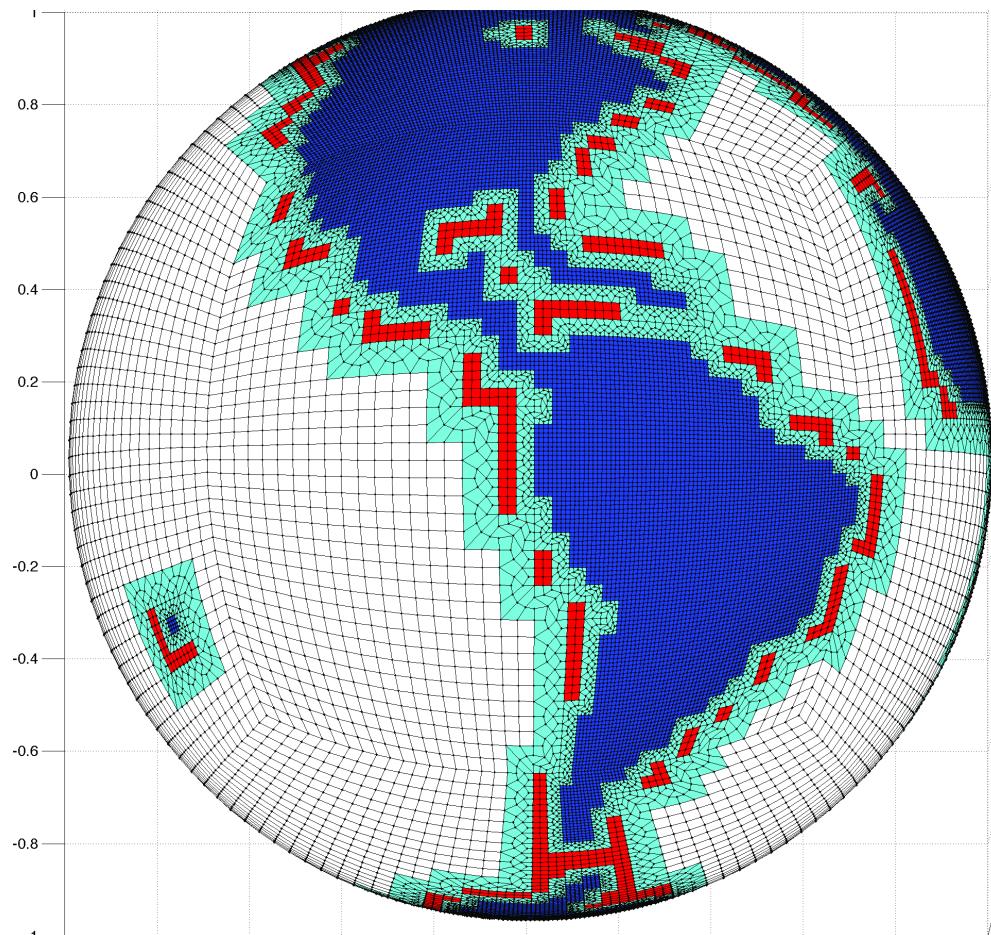**Vertically Moving Lagrangian Surfaces**

Figure: Nair et al. (2009)

Community Atmosphere Model (CAM)

CAM-SE is built as a completely unstructured model on a conformal grid.

Using mesh refinement, essentially any grid shape is supported.

Arbitrarily shaped quadrilateral elements supported by spectral element method.

Model for Prediction Across Scales (MPAS)

National Center for Atmospheric Research (NCAR)

Authors:

Bill Skamarock (NCAR)

Joe Klemp (NCAR)

Todd Ringler (Los Alamos National Laboratory)

Many others…

Non-Operational Model, Non-Hydrostatic, Shallow/Deep Atmosphere

Philosophy: Large-scale parallel scalability (next-generation atmospheric dynamics code) and support for variable resolution meshes.
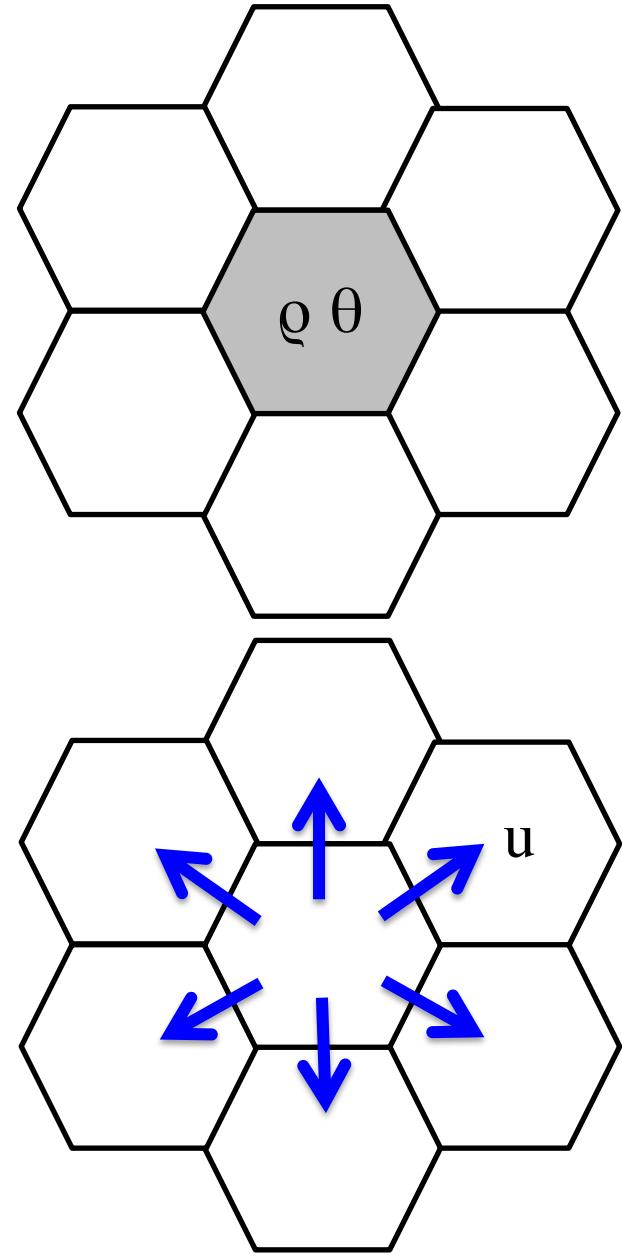
MPAS

The model is based a hexagonal grid which has been optimized via a post-processing step.
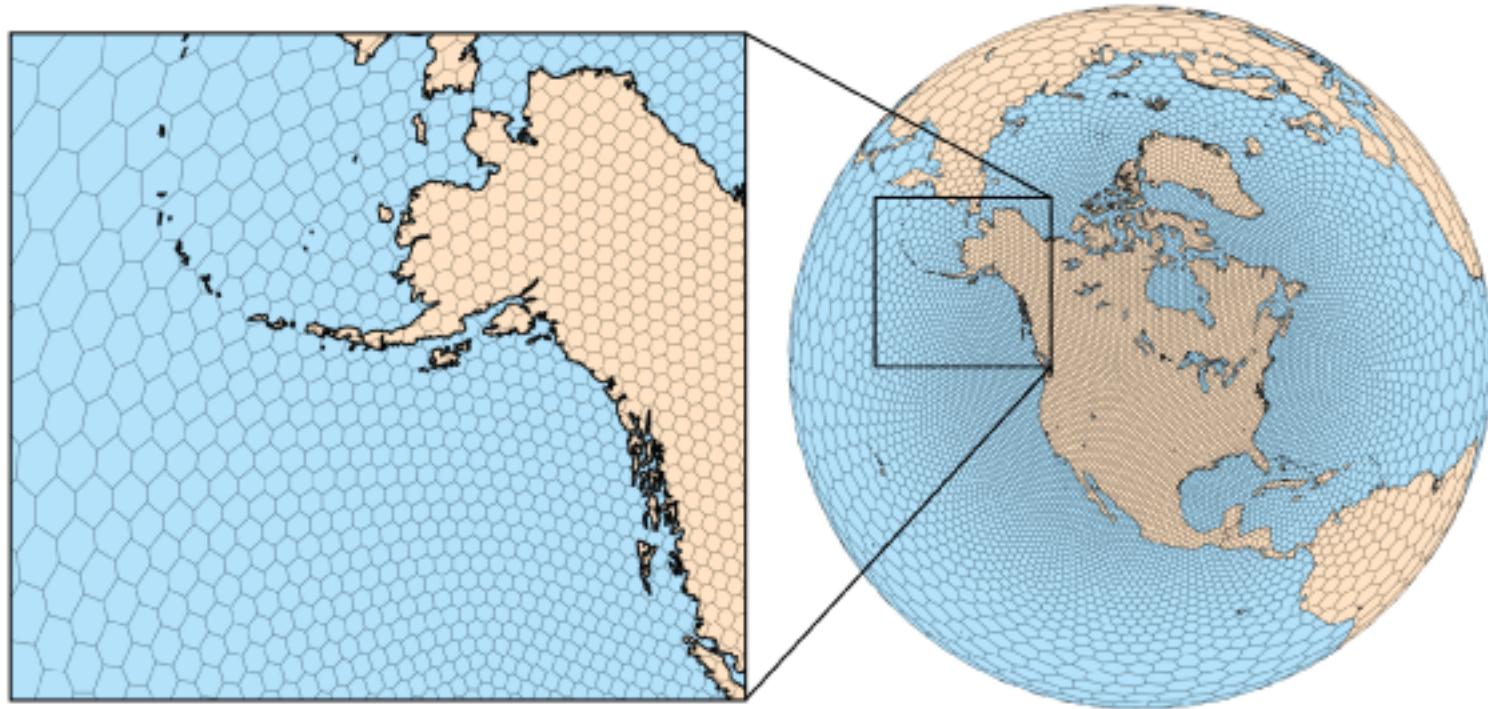
C-Grid formulation:
Each hexagon stores the density and potential temperature at that point.

Velocities are stored as perpendicular components at each edge.

Issues: Number of velocity components is greater than number of density components.

MPAS

Figure: An example of a variable-resolution centroidal Voronoi mesh used in MPAS.

Finite-Volume Cubed (FV3)

Geophysical Fluid Dynamics Laboratory (GFDL)

Authors:

Shian-Jiann (SJ) Lin (GFDL)

Richard Rood (University of Michigan)

Lucas Harris (GFDL)

Many others…

Operational Model, Hydrostatic, Shallow Atmosphere
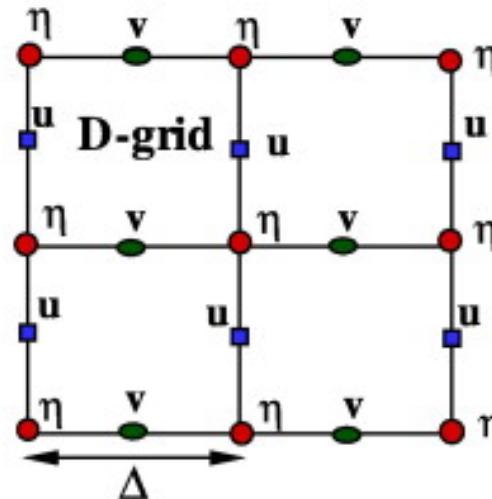
Experimental Non-hydrostatic mode

Other GFDL models:
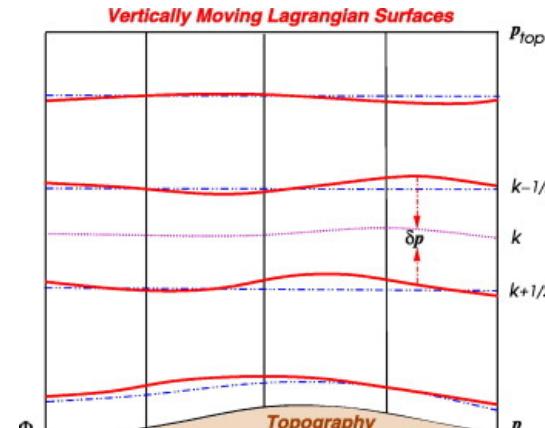AM3/CM3, HiRAM, CM2.5/2.6, LASG, Academia Sinica, GISS ModelE

FV3

Arakawa D-grid staggering for velocities.

Third-order finite-volume method on the cubed-sphere grid. Accuracy drops to second-order due to dimension splitting.

Floating Lagrangian layers

Global Environmental Multiscale Model (GEM)

Environment Canada / Canadian Meteorological Center (CMC)

Authors:

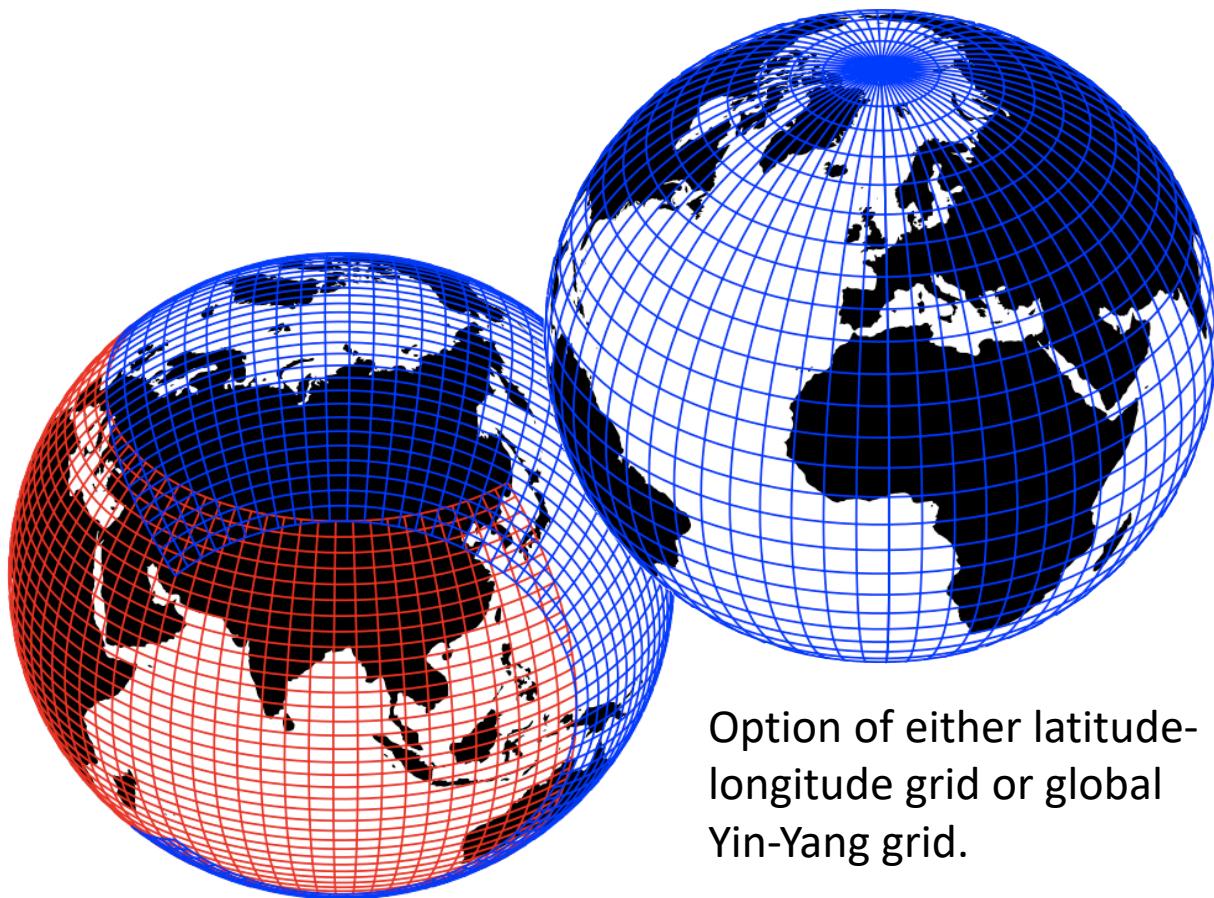Abdessamad Qaddouri (Environment Canada)

Jean Côté (Environment Canada)

Sylvie Graval (Environment Canada)

Paul Vaillancourt (Environment Canada)

Many others…

Operational Model, Hydrostatic/Non-hydrostatic, Shallow Atmosphere

GEM

Option of either latitude-longitude grid or global Yin-Yang grid.

Modified Charney-Phillips ("CP") grid