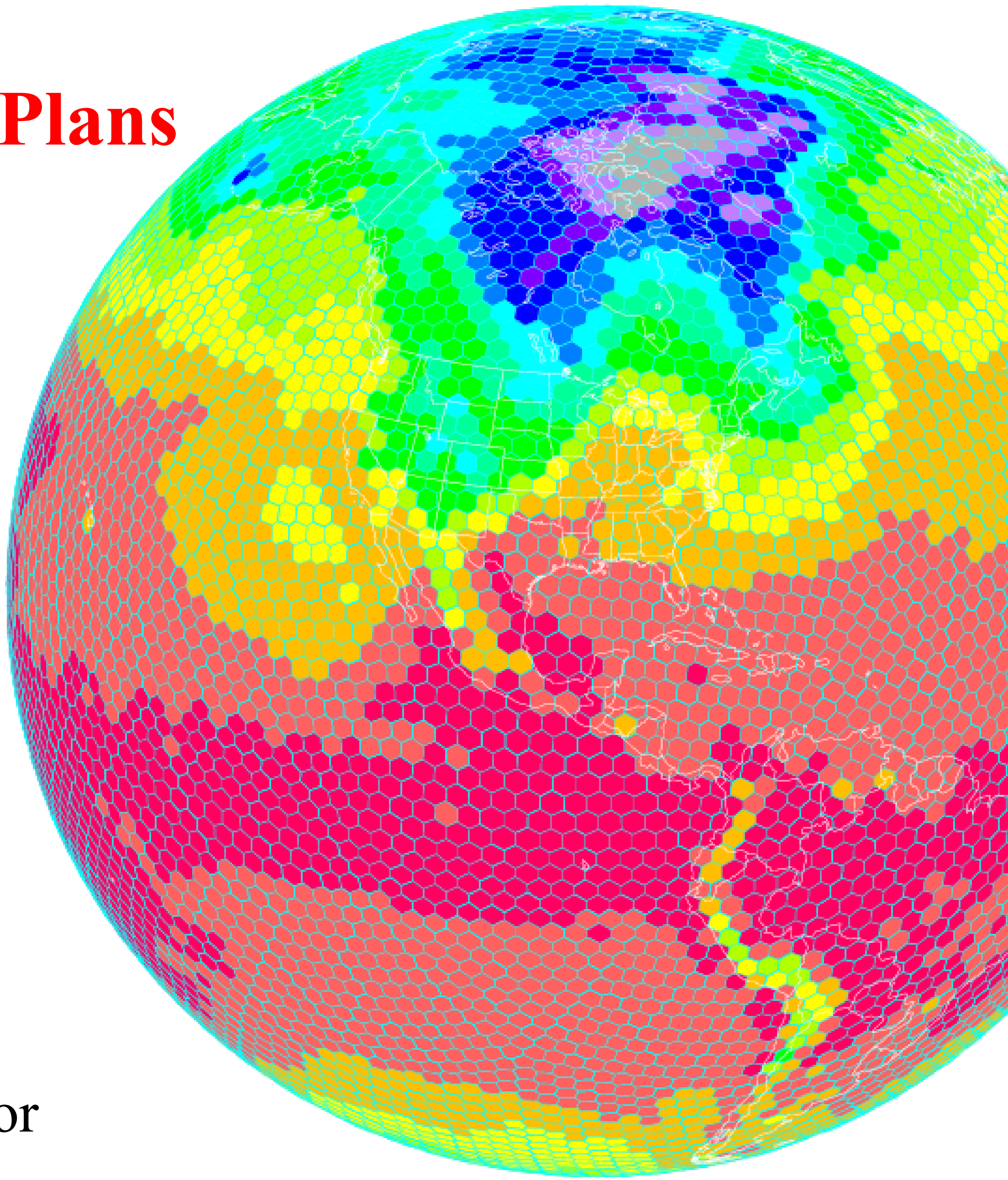
ESRL Global Model Plans

A presentation to:
ECMWF 15th Workshop
On HPC in Meteorology
October 2, 2012

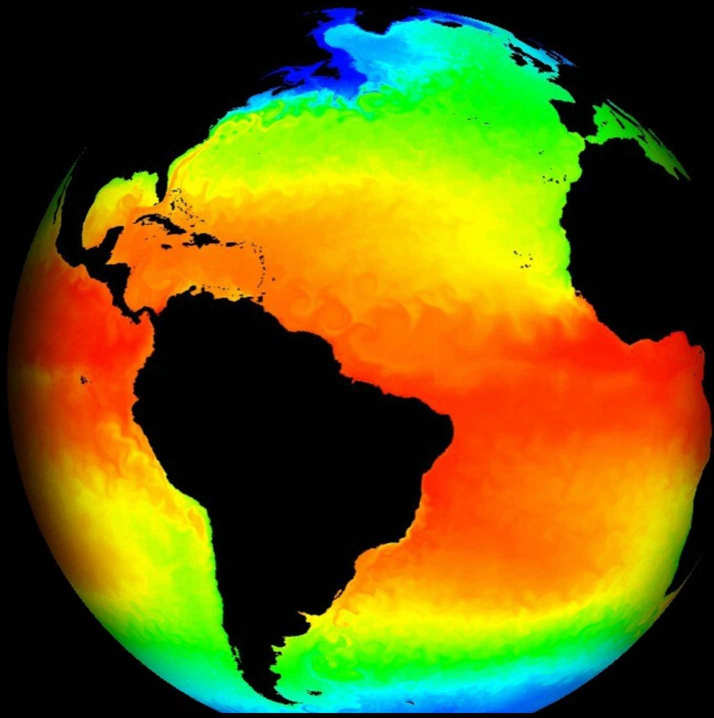


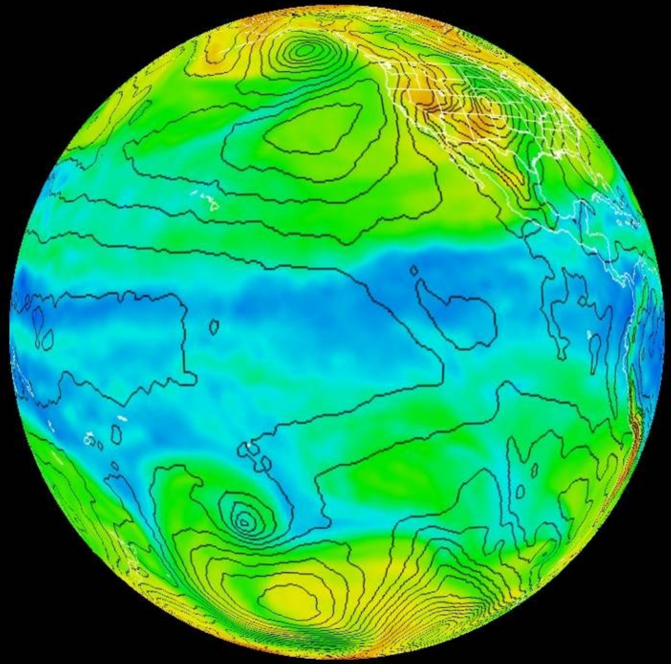
Alexander E. MacDonald
Director
Earth System Research Lab
Boulder, Colorado

Deputy Assistant Administrator
NOAA Research

NOAA Earth System Research Laboratory

- Founded 2005
- Key Objective: Earth System Models



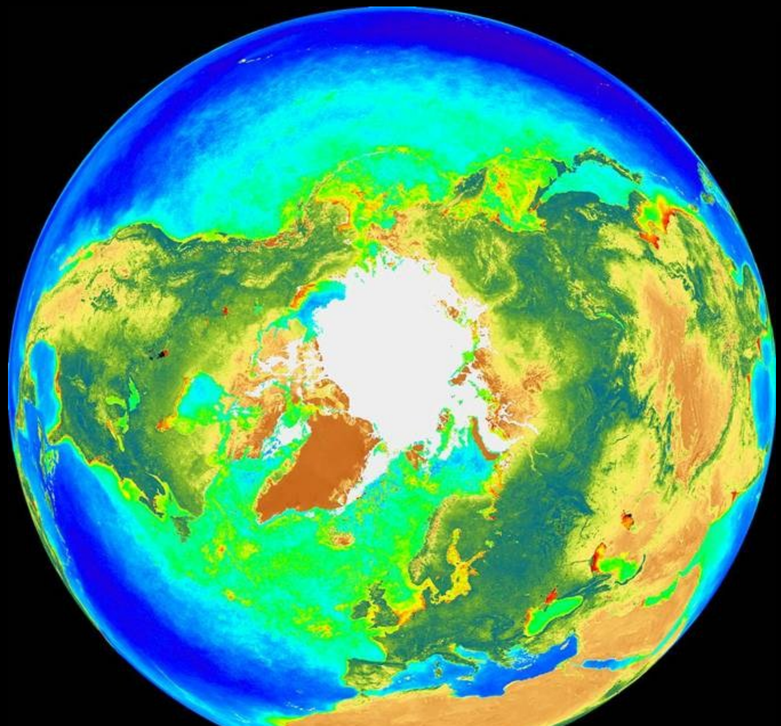


Earth System Models:

Physical,

Chemical,

Biological



Summary

1. **The key science**: Nonhydrostatic global atmospheric models with explicit convection, global ocean models, and advanced global assimilation.

2. **ESRL Models:** FIM, NIM and iHYCOM

3. **The key technology**: Massively Parallel Fine Grain Computers.

NOAA Global Model Research and Development
Initial Value Time Scales
(Resolution 2- 4 km Globally)

	Short Range	Medium Range	Long Range
Model Run Frequency	1 Hour	6 Hours	24 Hours
Prediction Period	24 Hours	Two Weeks	Three Months
Enabling Science	Heating Balanced Initial Field (Hot Start)	Hybrid EnKF Plus 4DVAR	Explicit Tropical Convection

0 — 1 Day — 10 Days — 100 Days

Key Enabling Technology: GPU Computers

A.E.MacDonald
July 25, 2012

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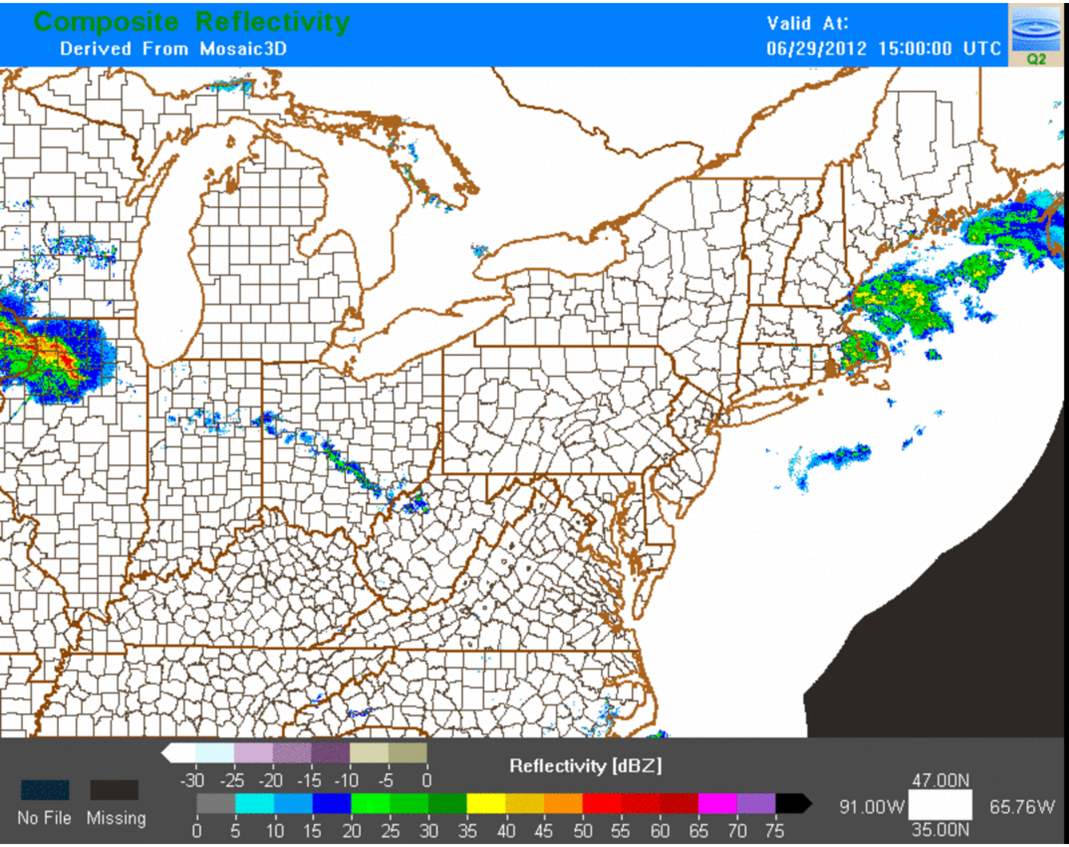
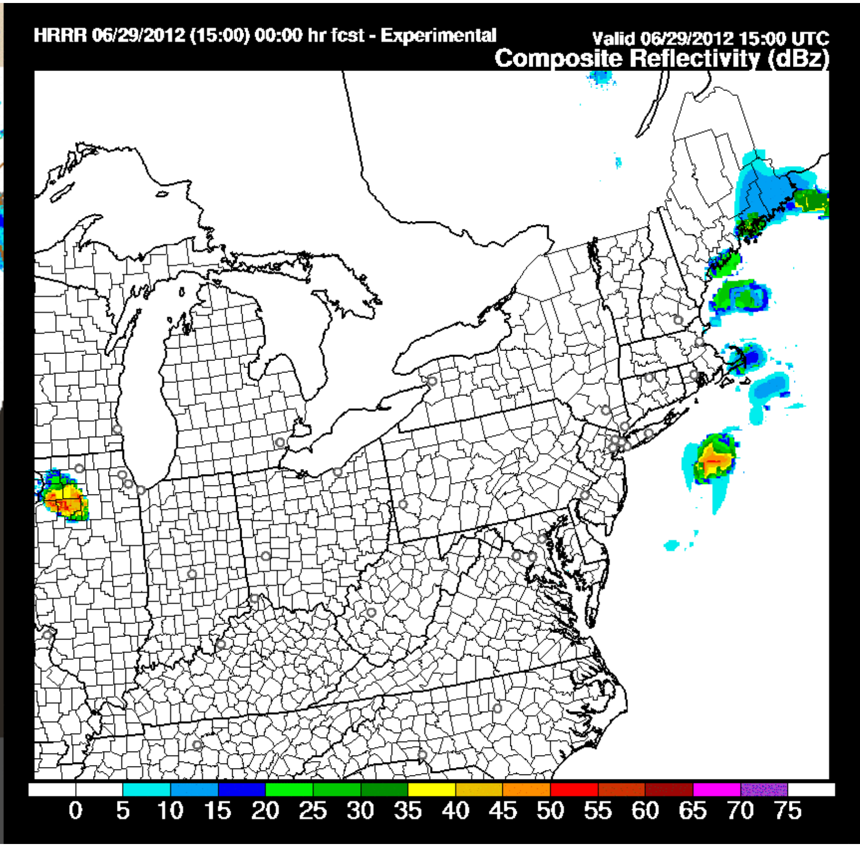
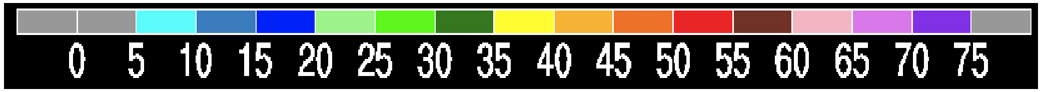
NOAA High Resolution Rapid Refresh forecast of mid-Atlantic derecho – 29 June 2012

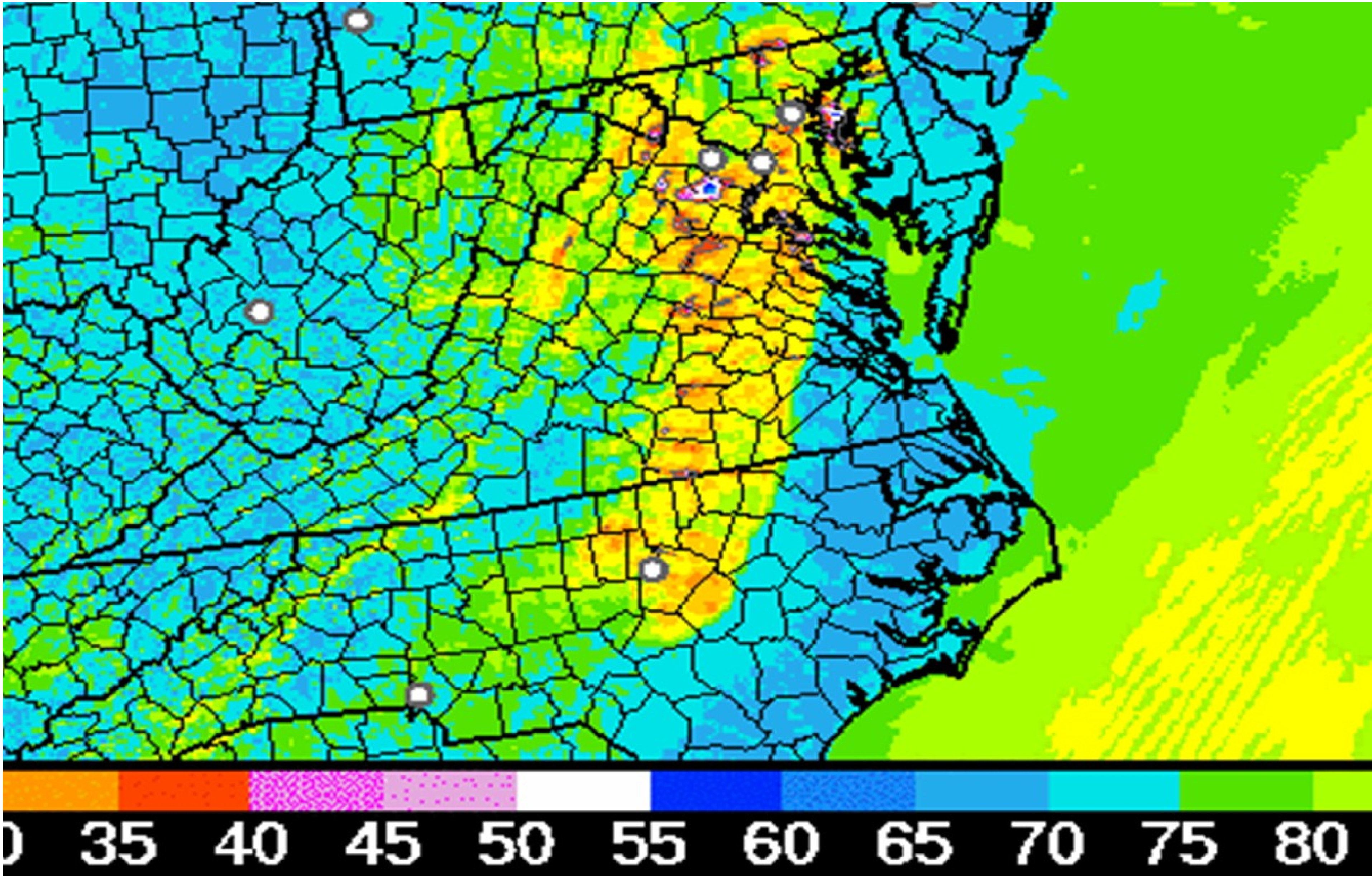




Composite Reflectivity (dBZ)



ESRL/GSD's HRRR model predicted a 65 knot gust in the DC area 12 hours in advance.



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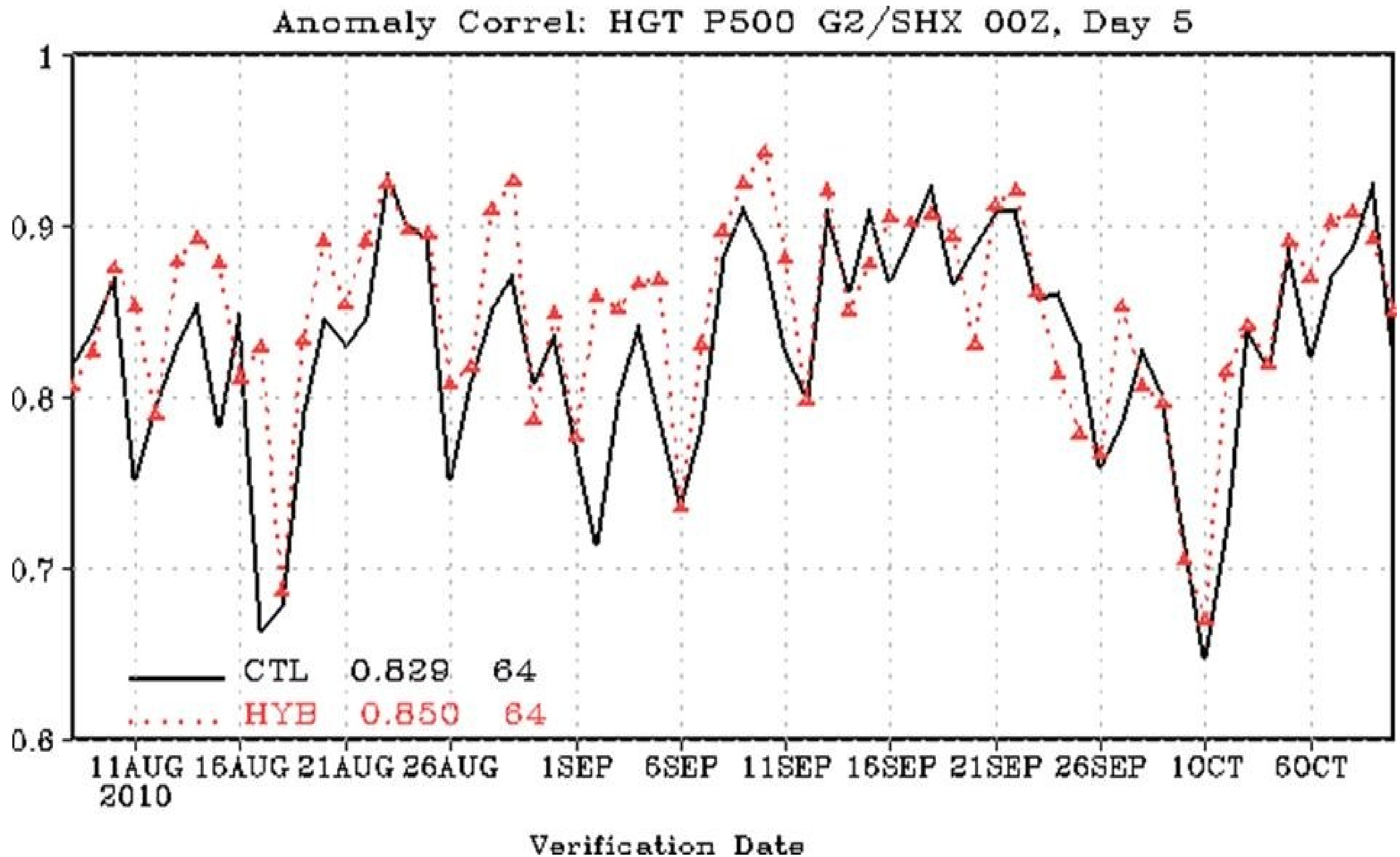

Ensemble Kalmen Filter, developed by Whitaker and Hamill in ESRL, added 2 points of skill to NWS predictions this spring.

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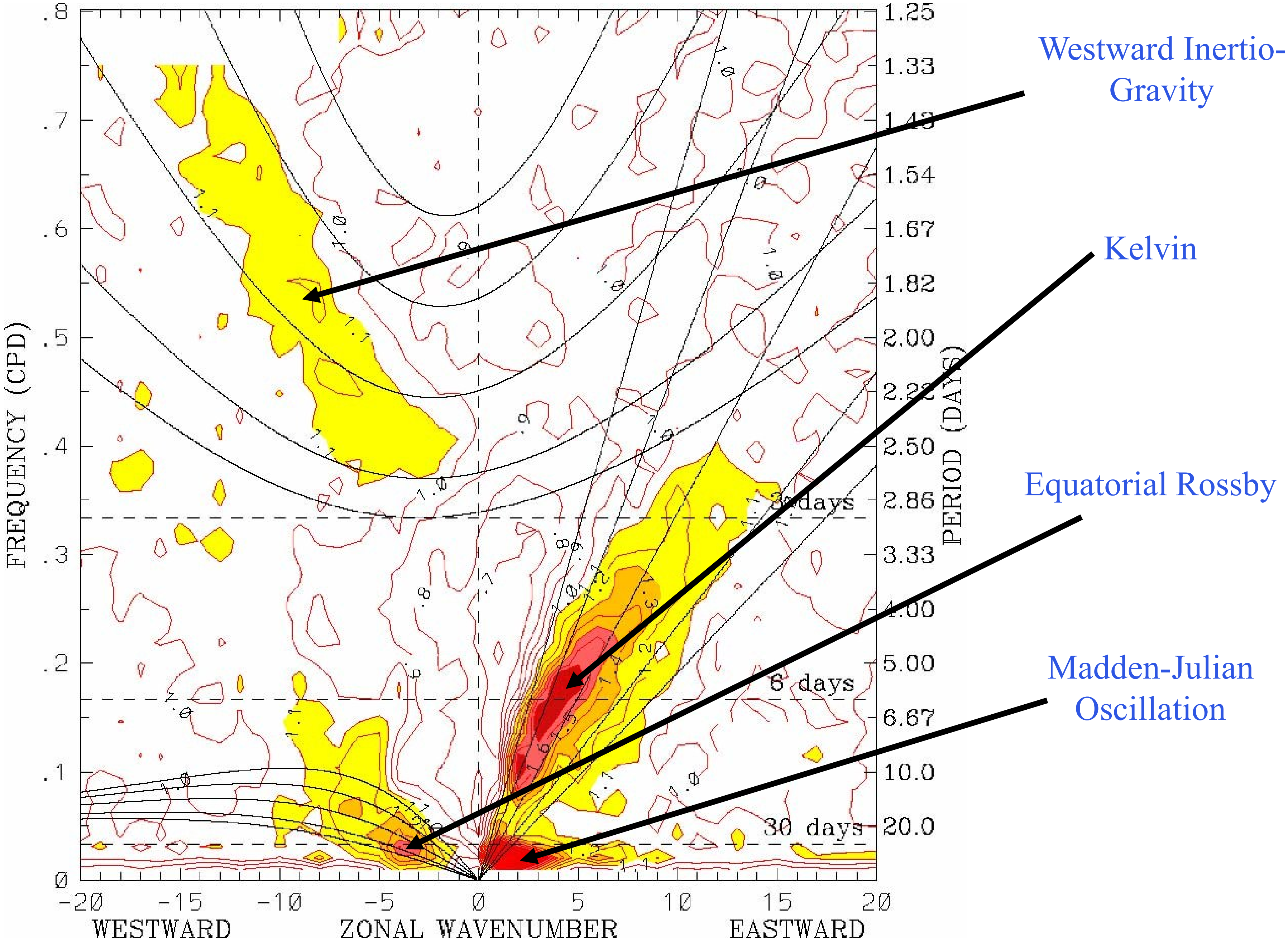
Key Enabling Technology: GPU Computers

A.E.MacDonald
July 25, 2012

From S. J. Lin,
W. Putnam



Westward Inertio-Gravity
Kelvin
Equatorial Rossby
Madden-Julian Oscillation
FREQUENCY (CPD)
PERIOD (DAYS)
ZONAL WAVENUMBER
WESTWARD
EASTWARD
3 days
6 days
30 days
.8
.7
.6
.5
.4
.3
.2
.1
0
1.25
1.33
1.43
1.54
1.67
1.82
2.00
2.22
2.50
2.86
3.33
4.00
5.00
6.67
10.0
20.0
-20
-15
-10
-5
0
5
10
15
20

ESRL finite-volume Icos- models (FIM/NIM)

ESMF

Hydrostatic | *Non-Hydrostatic*

FIM

flow-following finite-volume Icosahedral model

- Target resolution ≥ 10 km
- A hydrostatic model consists of 2-D finite-volume SWM coupled with hybrid σ-θ vertical solver.
- Produce accurate medium-range weather forecasts

NIM

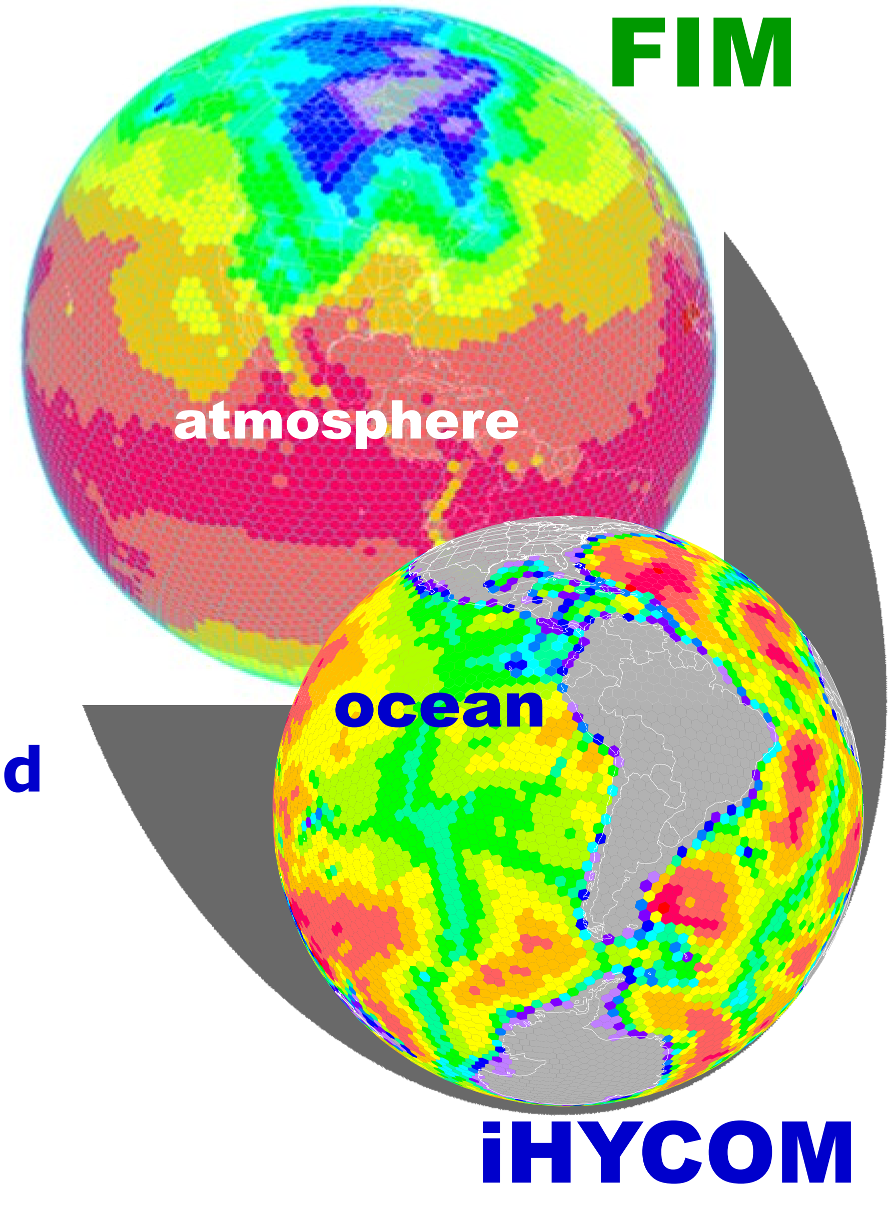
Nonhydrostatic Icosahedral model

- Target resolution : O (1 km) and beyond
- Extension of 2-D finite-volume integration into 3-D integration on control volume defined on the height coordinate.
- Use the latest GPU technology to speed up high-resolution model calculations.

NOAA Next-Generation Model Development

FIM – Flow-following finite volume Icosahedral Model

- "soccer-ball" grid design for uniform grid spacing
- "Isentropic" adaptive (flow-following) vertical coordinate
- New 14-day forecast twice daily
- Real-time experimental at ESRL



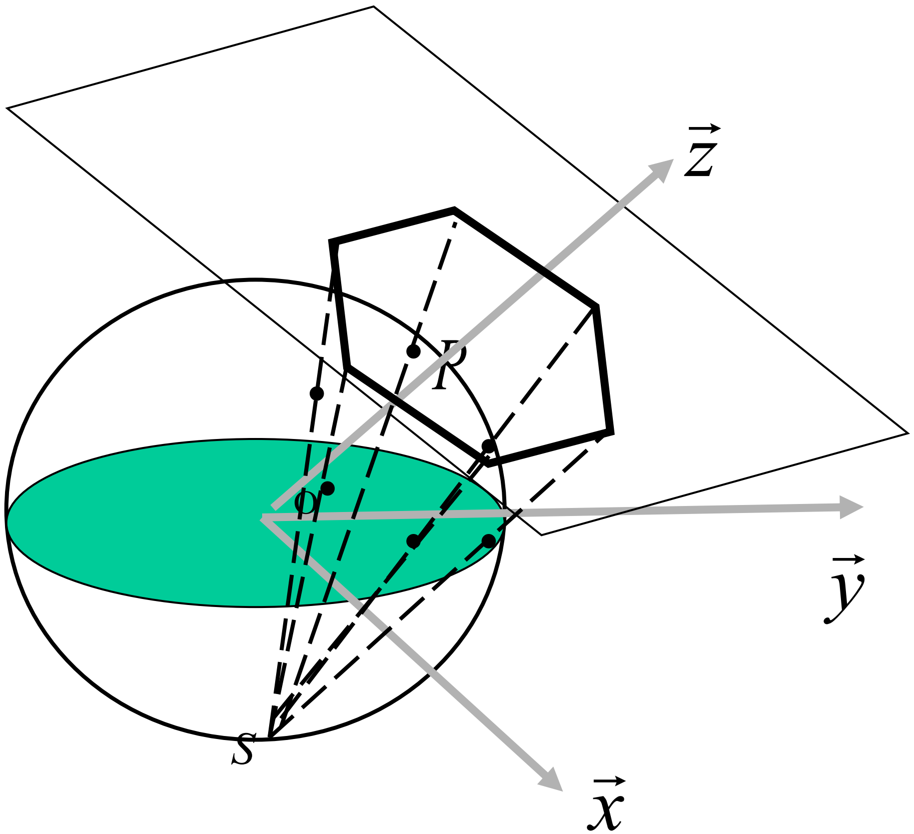
iHYCOM – Icosahedral Hybrid Coordinate Ocean Model

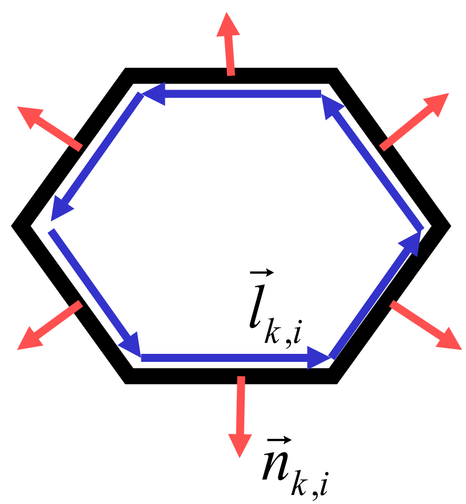
- Matched grid design to FIM for coupled ocean-atmosphere prediction system

Dynamical Core

- **Finite-volume Integrations on *Local Coordinate***

Lee and MacDonald (*MWR, 2009*): A Finite-Volume Icosahedral Shallow Water Model on Local Coordinate.





2-D f.-v. operator carried out on straight lines, rather than along the 3-D curved lines on the sphere

Novel features of NIIM

- **Finite-volume Integrations on *Local Coordinate***
- **Efficient Indirect Addressing Scheme on Irregular Grid**

- MacDonald, Middlecoff, Henderson, and Lee (2010, IJHPC) : A General Method for Modeling on Irregular Grids.

Novel features of FIM/NIM:

- **Finite-volume Integrations on *Local Coordinate***
- **Efficient Indirect Addressing Scheme on Irregular Grid**
- **FIM: Hybrid σ-θ Coordinate w/ GFS Physics**

- Bleck, Benjamin, Lee and MacDonald (2010, MWR): On the Use of an Arbitrary Lagrangian-Eulerian Vertical Coordinate in Global Atmospheric Modeling.

Novel features of FIM/NIM:

- Finite-volume Integrations on *Local Coordinate*
- Efficient Indirect Addressing Scheme on Irregular Grid
- FIM: Hybrid σ-θ Coordinate w/ GFS Physics
- Conservative and Monotonic Adams-Bashforth 3rd-order FCT Scheme

  - Lee, Bleck, and MacDonald (2010, JCP): A Multistep Flux-Corrected Transport Scheme.

.

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- **Conservative and Monotonic Adams-Bashforth 3rd-order FCT Scheme**
- **Grid Optimization for Efficiency and Accuracy**

 - Wang and Lee (2011, SIAM): Geometric Properties of Icosahedral-Hexagonal Grid on Sphere.

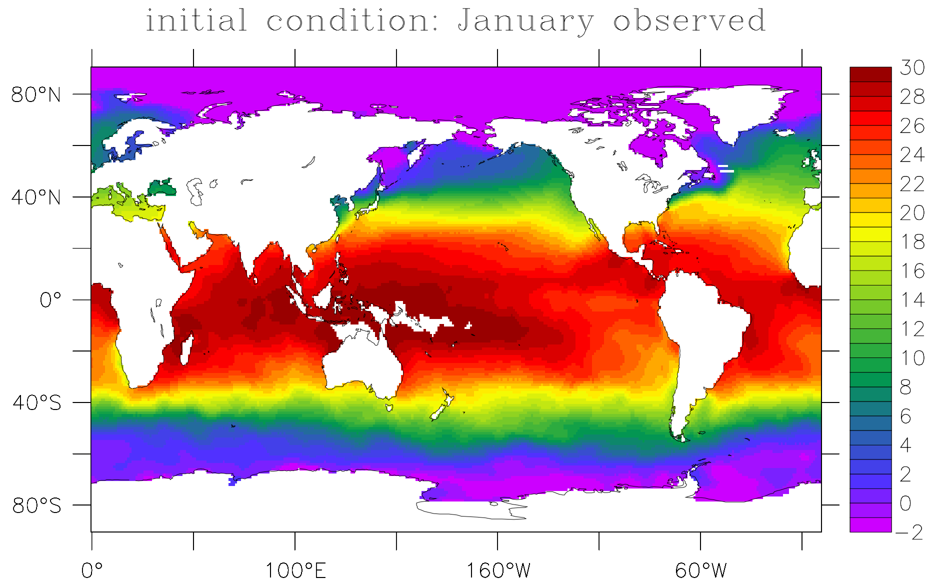

Hurricane Isaac track 7-day forecast by FIM9 (15km) from Friday 24 Aug 18z run
Position of Isaac – 18z 24 Aug
Observed track for Isaac
Isaac
OBS
-80°
Kansas
Missouri
Kentucky
West Virginia
Virginia
Oklahoma
Tennessee
North Carolina
Mississippi
South Carolina
Alabama
Georgia
Texas
Florida
Gulf of Mexico
Mexico
Cuba
Dominican Republic
Puerto Rico
Caribbean Sea
Guatemala
Honduras
Nicaragua
Costa Rica
Indiana
Vermont
New Hampshire
Massachusetts
Rhode Island
Connecticut
New Jersey
Delaware
Maryland
District of Columbia

iHYCOM: ESRL's New Ocean Model

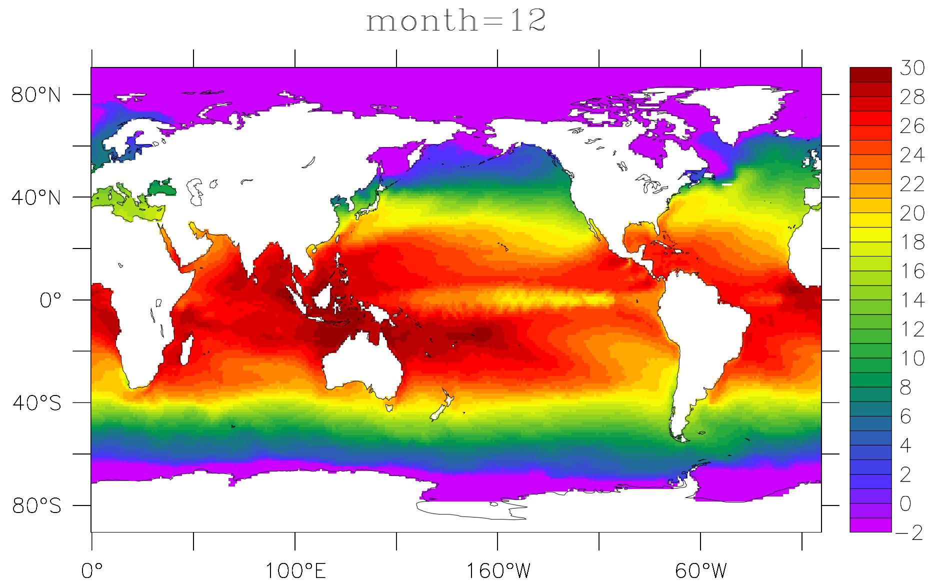
- Developers: Rainer Bleck and Shan Sun
- Uses ESRL advanced parallel desgin
- icosahedral horizontal mesh (same as in FIM)
- Arakawa A grid (same as FIM)
- leapfrog time stepping (different from FIM)
- 20 vertical hybrid layers as in HYCOM
  - constant z layers near the surface
  - isopycnic layers in the interior
- full complement of surface forcing
  - wind, heat, freshwater

Sea Surface Temperature from FIMc8

Jan. observed



12 months

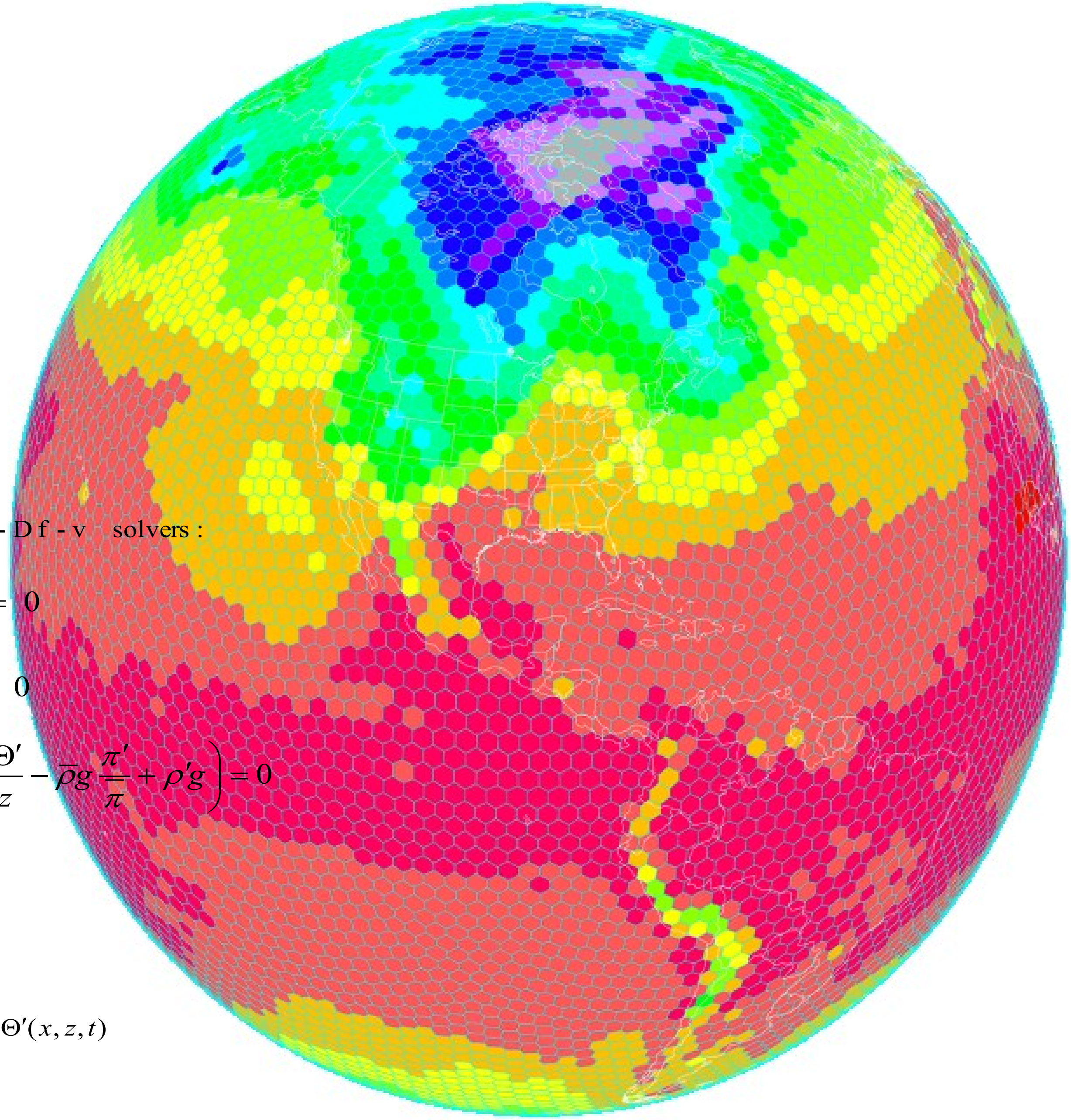


Nonhydrostatic Icosahedral Model

Jin-Luen Lee

Alexander E. MacDonald

And others.



Nonhydrostatic GEs in flux form on Z - coord with 3 - D f - v solvers :

$$
\begin{cases}
\dfrac{\partial U}{\partial t} + \dfrac{\partial (uU)}{\partial x} + \dfrac{\partial (vU)}{\partial y} + \dfrac{\partial (wU)}{\partial z} + \gamma R \pi \dfrac{\partial \Theta'}{\partial x} = 0 \\
\dfrac{\partial V}{\partial t} + \dfrac{\partial (uV)}{\partial x} + \dfrac{\partial (vV)}{\partial y} + \dfrac{\partial (wV)}{\partial z} + \gamma R \pi \dfrac{\partial \Theta'}{\partial y} = 0 \\
\dfrac{\partial W}{\partial t} + \dfrac{\partial (uW)}{\partial x} + \dfrac{\partial (vW)}{\partial y} + \dfrac{\partial (wW)}{\partial z} + \left(\gamma R \pi \dfrac{\partial \Theta'}{\partial z} - \overline{\rho} g \dfrac{\pi'}{\pi} + \rho' g \right) = 0 \\
\dfrac{\partial \Theta'}{\partial t} + \dfrac{\partial (u\Theta)}{\partial x} + \dfrac{\partial (v\Theta)}{\partial y} + \dfrac{\partial (w\Theta)}{\partial z} = \dfrac{\Theta \dot{H}}{C_p T} \\
\dfrac{\partial \rho}{\partial t} + \dfrac{\partial (u\rho)}{\partial x} + \dfrac{\partial (v\rho)}{\partial y} + \dfrac{\partial (w\rho)}{\partial z} = 0.
\end{cases}
$$

$$(U, W, \Theta, \rho) = (\rho u, \rho w, \rho \theta, \rho); \quad \Theta(x,z,t) = \overline{\Theta}(z) + \Theta'(x,z,t)$$

$$\rho(x,z,t) = \overline{\rho}(z) + \rho'(x,z,t); \qquad \nabla p = \gamma R \pi \nabla \Theta$$

$$p = p_0 \left(\frac{R\Theta}{p_0} \right)^{\gamma}; \quad \pi = \left(\frac{p}{p_0} \right)^{\kappa}$$

Nonhydrostatic Icosahedral Model

::: **Modeling Goal**

* Development of a non-hydrostatic icosahedral global model for **weather** and **climate** predictions

::: **Scientific Goals**

* Global cloud resolving model with realistic convection
* Equatorial waves analysis and super-parameterization
* Real-time weather prediction at resolutions below 10 km

::: **Computational Goal**

* CPU/GPU for efficient model integration

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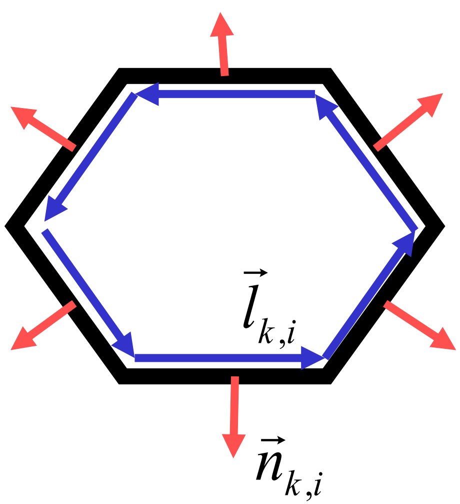
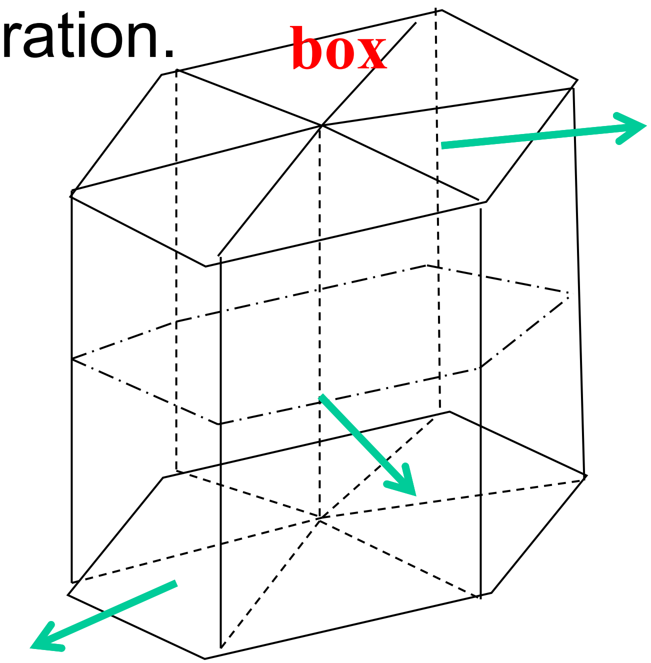
- **Novel Features of NIM:**

-Three-dimensional finite-volume integration.



3-D control volume box



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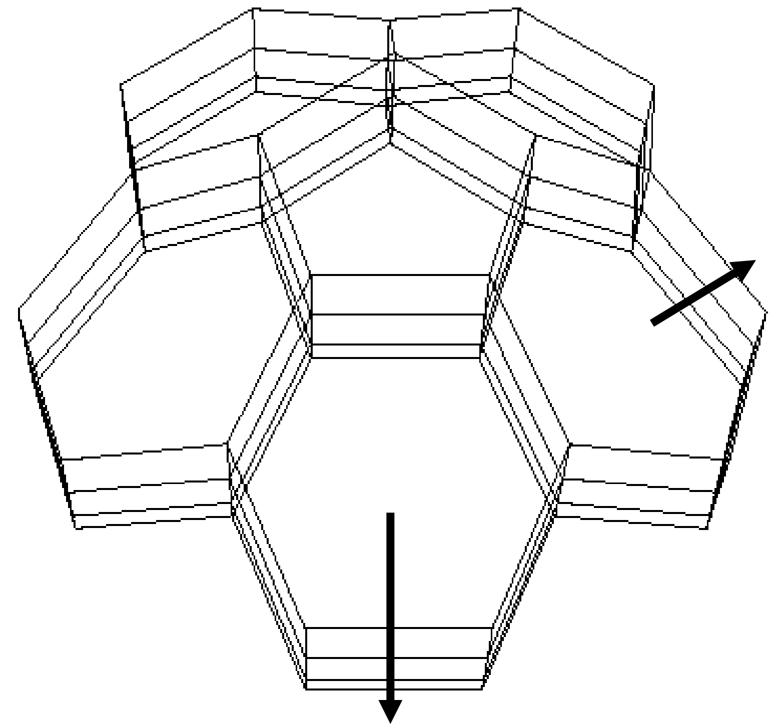
pressure gradient force (PGF)



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- Runge-Kutta (RK)-4^{th} solvers for vertically propagating acoustic waves, and conservative and positive-definite transport scheme.

Two physics packages

NIM

GFS physics

- Same as that of FIM
- References :
- To compare the performance with FIM as operation

GRIMs physics

- **G**lobal/**R**egional **I**ntegrated **M**odeling **s**ystem (YSU, Korea)
- Reference : Hong et al. (APJAS 2012, in review)
- Climate research
- high-resolution run

* In Namelist, Physics= ‘grims’ or ‘gfs’

Two physics packages – GRIMs (cafeteria plan)

Radiation	**SW : 1-Albedo** **LW : GFDL**	**SW : 4-Albedo (GSFC)** Chou and Suarez 1999; Chou and Lee 2005; Ham et al. 2009			**SW : GSFC. LW: RRTMG ---WRF**
SFC	**M-O similarity** Hong and Pan (1996)		**+z0t, Vsfc** : Seol and Hong (2006) **+ OML** : Kim and Hong (2010)		**+ Revised Ch,Cm** Kim and Hong (2010)
LSM	**OSU1** Mahrt and Pan (1985)	**OSU2** Kang and Hong (2008)	**NOAH** + Seol (2010) Chen and Dudhia (2001)		
PBL	**MRF** Hong and Pan (1996)		**YSU** (Noh et al. 2003, Hong et al. 2006, Hong 2010)		
GWDO	**Alpert et al. (1989)**		**Kim and Arakawa (1995), Hong et al. (2008)**		
GWDC	-		**Chun and Baik (1998), Jeon et al. (2010)**		
Deep Convection	**SAS** Hong and Pan (1998) Park and Hong (2007)	**RAS** Moorthi and Suarez (1992)	**SAS + CMT** Han and Pan (2006) Byun and Hong (2007)	**SAS** **+ Han and Pan (2010)**	
Shallow convection	**Tiedke (1988)**			**Han and Pan (2010)**	
Micro Physics	**WSM1** Hong et al. 1998			**WSM2** Zhao and Carr (1995)	**WSM3. WSM5, WSM6** Hong et al. (2004)
Cloudiness	**Implicit** (Hong et al. 1998)			**Explicit** (Hong et al. 2010)	
Chemistry	**Diagnostic**			**Prognostic ozone**	

Development History of NIM

Design → **Dynamics** → **Physics** → **Aqua-planet**

2007
- by Jin and MacDonald

2009
- Dynamical core

2011
- physics packages implement
- SMS and GPU

2012
- Aqua-planet simulation with full physics
- Land-sea mask

Development Plan of NIM

Topography → **Physics** → **Realtime Runns** | **Operational Tests**

2012
- Dynamical core dry test

2013
- GFS & GRIMs physics implement
- SMS and GPU

2014
- Global 4 km rapid refresh
- Satellite hot start

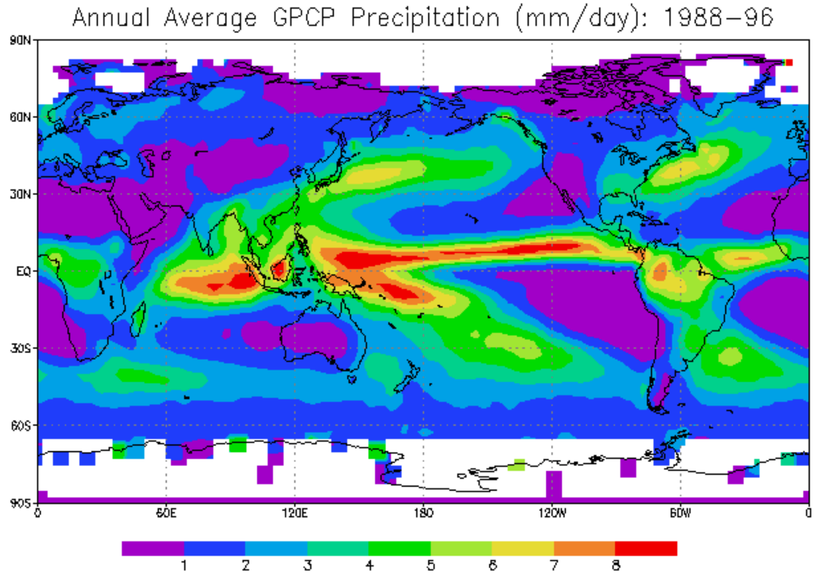
2015
-

Preliminary Results

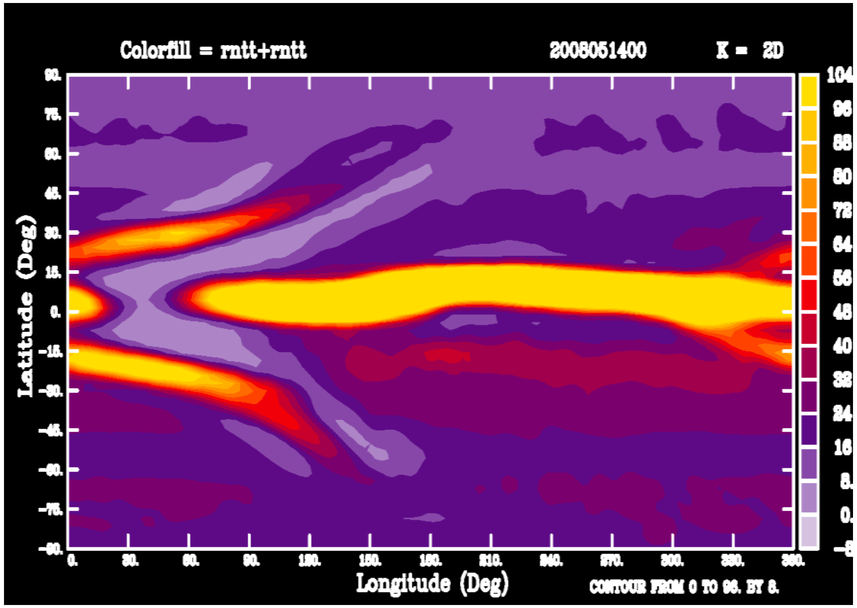
Aqua-planet simulations …

Precipitation

global precipitation (OBS)



NIM precipitation



Peta Flop Computing in 2012

DOE

Jaguar System

- 2.3 PetaFlops
- 250,000 CPUs
- 284 cabinets
- 7000 KW power
- **Cost: ~ $100 million**
- **Building: $75 million**
- **Reliability in hours**

Equivalent GPU System

- 2.3 PetaFlop
- 600 Kepler GPUs
- 10 cabinets
- 200 KW power
- **Cost: ~ $5 million**
- **Reliability in weeks**

- **Large CPU systems (>100 thousand CPUs) are unrealistic for operational weather forecasting**

	GPU cost	CPU cost
– Power & Cooling:	$8.4 M / year	$0.2M / year
– System Cost:	$100M	$5 M
– Facilities	$75M	$0.8M

- GPU-based systems will dominate super-computing within 3 years
  - 75 percent of HPC customers are expected to use GPUs in 2014 (HPC study, 2012)


Questions . . . .
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