NIM Model Design

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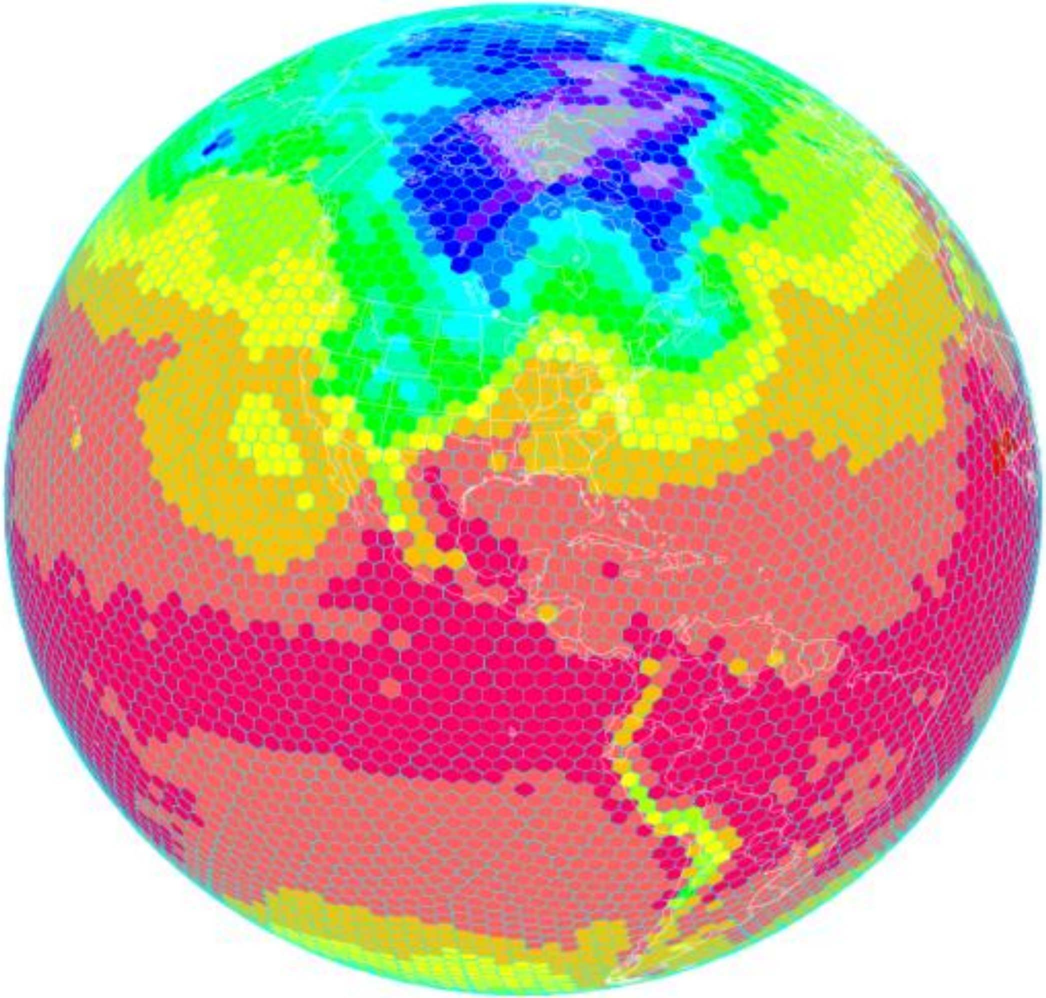
NIM Model Design

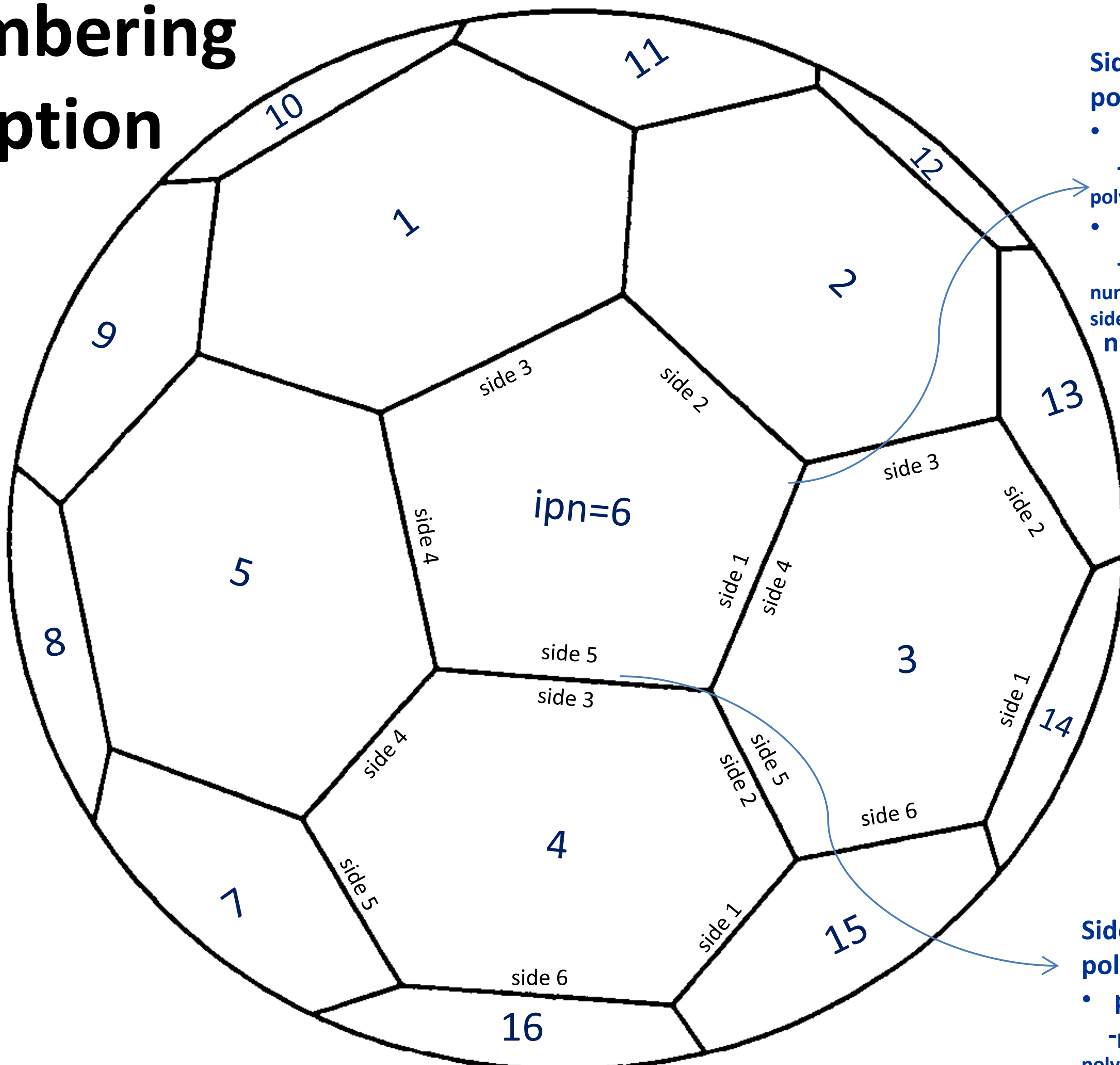
- NIM (and FIM) Description
- **Primary design driver: Cloud and precipitation prediction.**
- Design driver: Earth Analysis and short range prediction.
- Design driver: Extend prediction to sub-seasonal.

2001: We began design of a new generation of global models.



Initial Design: Alexander MacDonald and Jin Luen Lee.
Key decision: Icosahedral grid point model, finite volume (D Randall, SJ Lin)
Key Innovation: Method for coding on irregular grids – MacDonald et al

Grid Numbering Description



Side number 1 of polygon(ipn) 6:

- **prox(isn=1,ipn=6)=3**

  -polygon number 3 is on polygon number 6 side 1
- **proxs(1,6)=4**

  -polygon number 3 side number to polygon number 6 is side 4

nprox(ipn=6) = 5

Side number 5 of polygon(ipn) 6:

- **prox(isn=5,ipn=6)=4**

  -polygon number 4 is on polygon number 6 side 5
- **proxs(5,6)=3**

  -polygon number 4 side number to box polygon 6 is side 3

nprox(ipn=4) = 6

MacDonald, Middlecoff, Henderson, Lee; 2011. A general method for modeling on irregular grids. International Journal of High Performance Computing Applications. Vol 25, Issue 4.

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

ESMF

Hydrostatic

FIM

Flow-following 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

Non-Hydrostatic

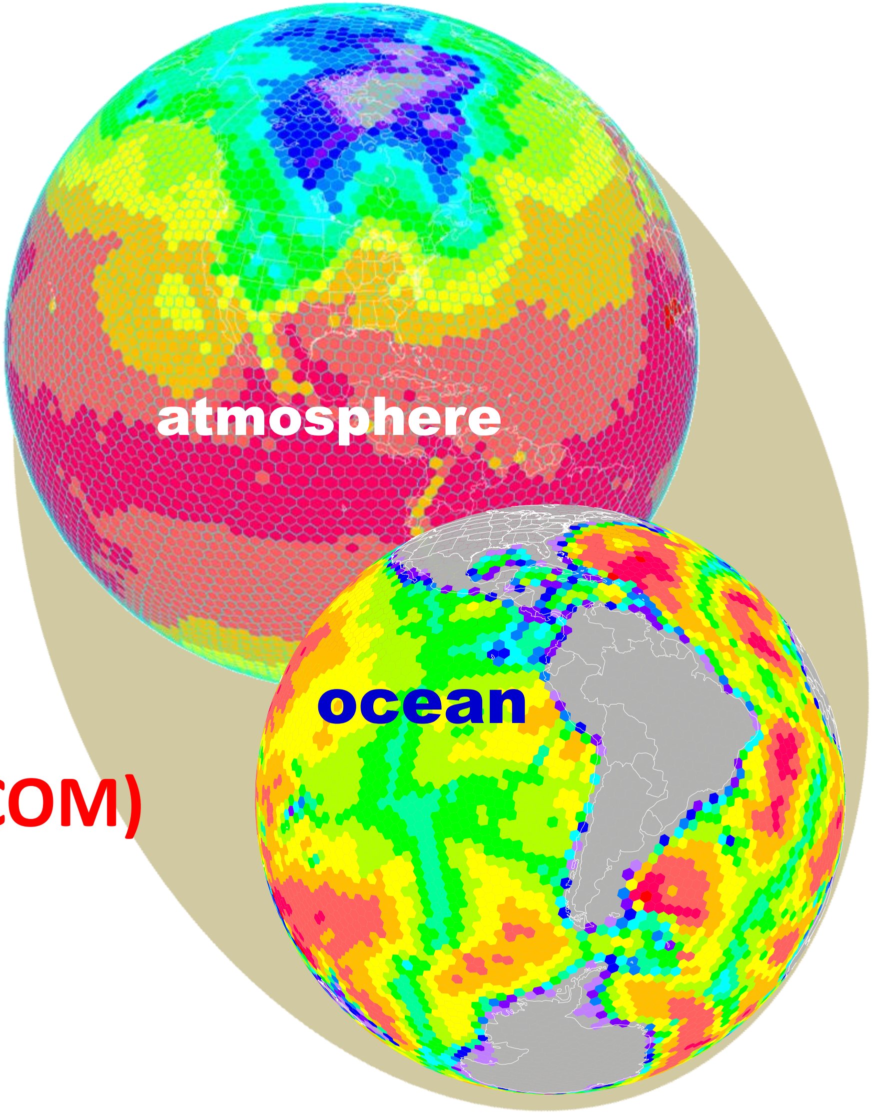
NIM

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.

Coupled Atmospheric-Ocean Modeling on an Icosahedral Grid at NOAA/ESRL

Flow-following* finite volume Icosahedral Model (FIM)



Icosahedral Ocean Model (iHYCOM)

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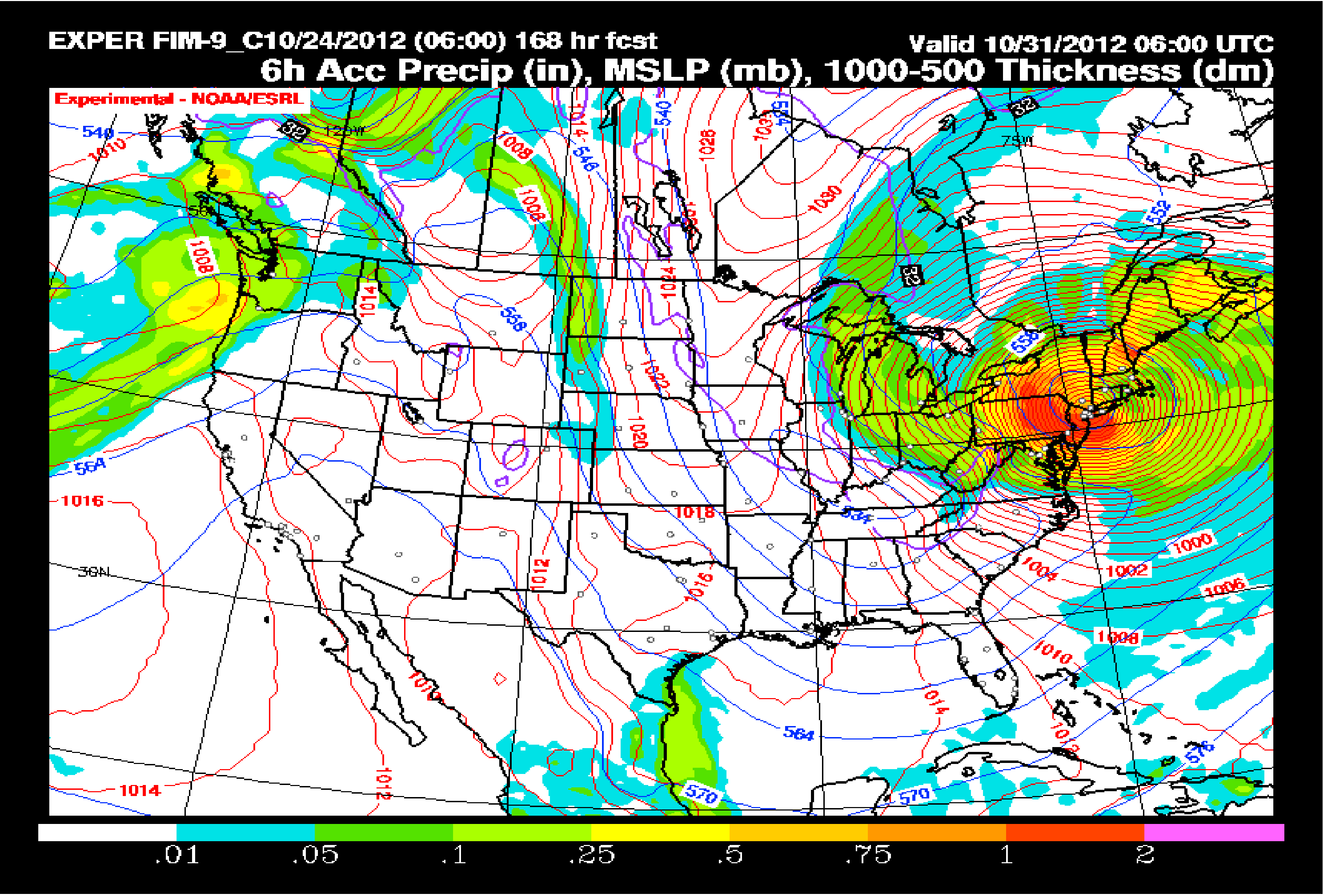
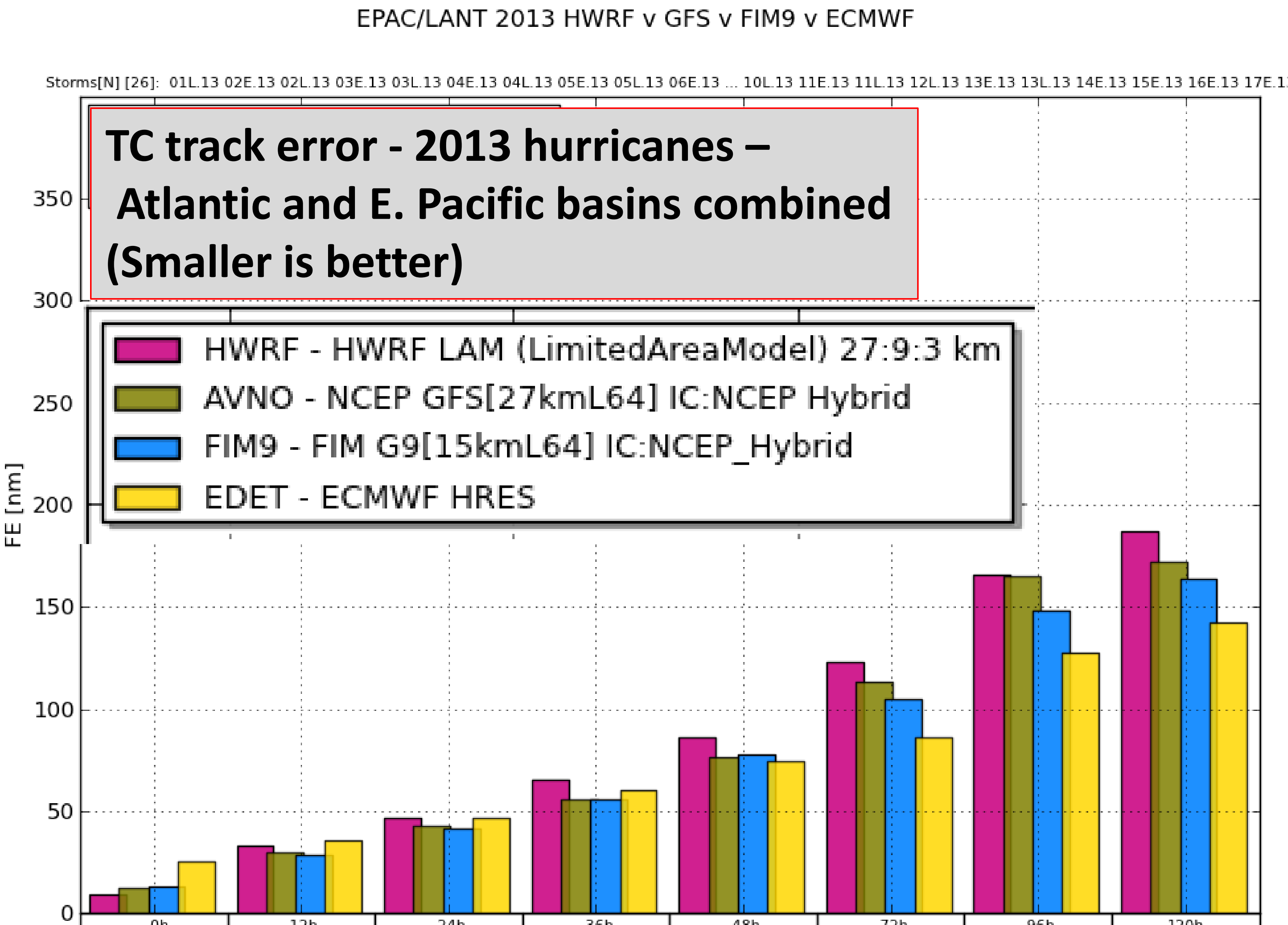
* flow-following = vertically quasi-Lagrangian



Wednesday, October 24: ESRL's FIM predicts 948 mb low into northern New Jersey.

TC track error - 2013 hurricanes – Atlantic and E. Pacific basins combined (Smaller is better)



	0h	12h	24h	36h	48h	72h	96h	120h
hwrf	9[196]	33[159]	47[137]	65[117]	86[96]	123[59]	166[42]	187[28]
avno	12[196]	30[159]	43[137]	56[117]	76[96]	113[59]	165[42]	172[28]
fim9	13[196]	28[159]	42[137]	56[117]	78[96]	105[59]	148[42]	164[28]
edet	25[196]	36[159]	47[137]	60[117]	74[96]	86[59]	127[42]	143[28]

NIM

NON-HYDROSTATIC ICOSAHEDRAL MODEL

NIM Solution Components

$$\frac{\partial U}{\partial t} + \frac{\partial (Uu)}{\partial x} + \frac{\partial (Vu)}{\partial y} + \frac{\partial (Wu)}{\partial z} + \gamma R \pi \frac{\partial \Theta'}{\partial x} - fV = S_u$$

$$\frac{\partial V}{\partial t} + \frac{\partial (Uv)}{\partial x} + \frac{\partial (Vv)}{\partial y} + \frac{\partial (Wv)}{\partial z} + \gamma R \pi \frac{\partial \Theta'}{\partial y} + fU = S_v$$

$$\frac{\partial W}{\partial t} + \frac{\partial (Uw)}{\partial x} + \frac{\partial (Vw)}{\partial y} + \frac{\partial (Ww)}{\partial z} + \gamma R \pi \frac{\partial \Theta'}{\partial y} - \frac{gR}{C_v \bar{\bar{\theta}}} \Theta' + \rho' g = S_w$$

$$\frac{\partial \Theta}{\partial t} + \frac{\partial (U\Theta)}{\partial x} + \frac{\partial (V\Theta)}{\partial y} + \frac{\partial (W\Theta)}{\partial z} = S_\Theta$$

$$\frac{\partial \rho}{\partial t} + \frac{\partial U}{\partial x} + \frac{\partial V}{\partial y} + \frac{\partial W}{\partial z} = S_\rho$$

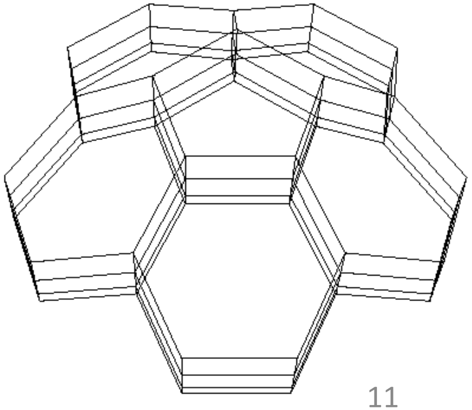
Time tendency | Flux terms | Forcing Terms | Source Terms

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

$\rho(x,z,t) = \bar{\rho}(z) + \rho'(x,z,t)$; $\nabla p = \gamma R \pi \nabla \Theta$ $\quad p = p_0 \left(\frac{R\Theta}{p_0}\right)^\gamma$ $\quad S_\Theta = \frac{\Theta \dot{H}}{C_p T}$

NIM Strategy

- Use of exact same (divergent) equation form for all variables participating in Reversible Isentropic Processes (Pressure, potential temperature, and water vapor).
- No diffusion for thermodynamic variables.
- Finite volume formulation with fixed control volumes.
- Full three dimensional advection (Gauss divergence theorem on the control volume).
- High resolution in the vertical (192 levels).



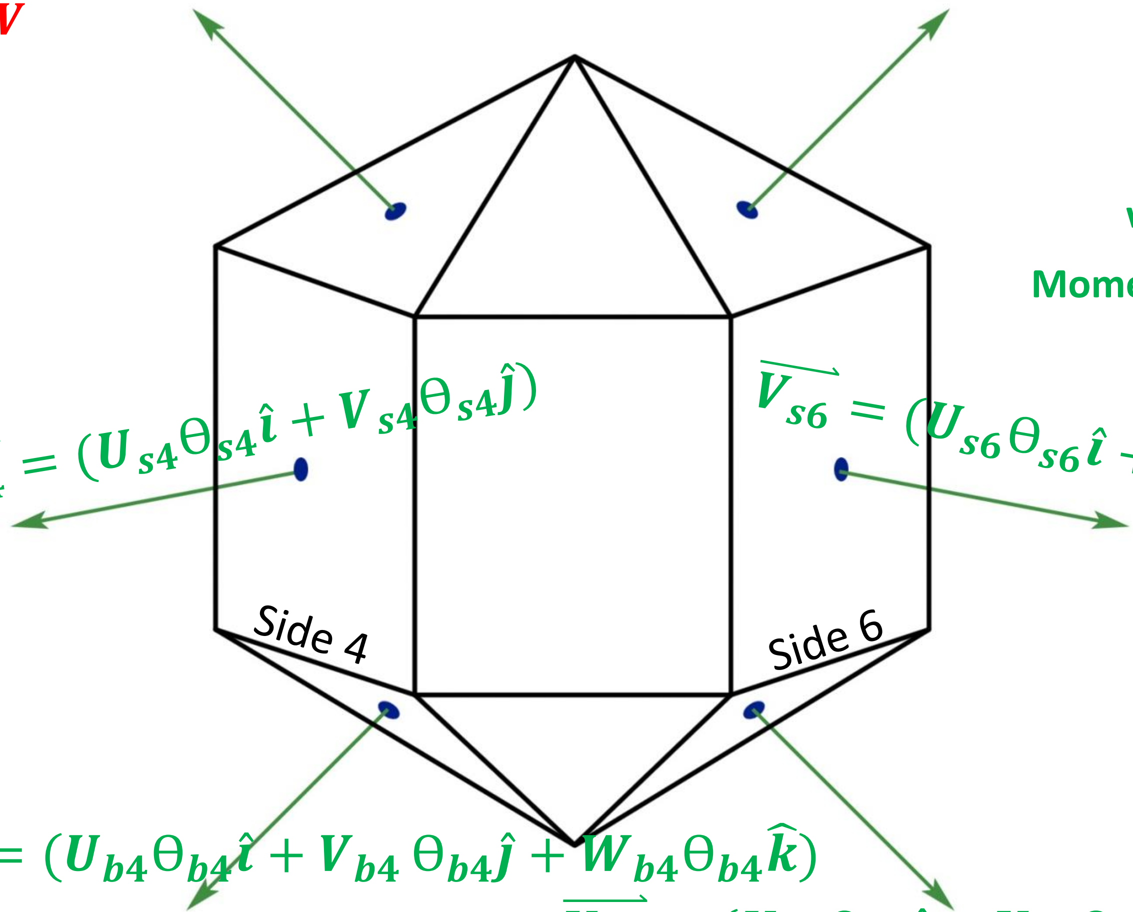
NIM: Flux Uses Gauss Divergence Theorem

$$\iiint_V (\nabla \cdot \overrightarrow{V_3}\theta)\, dV \;=\; \frac{\partial}{\partial x}(U\theta)+\frac{\partial}{\partial y}(V\theta)+\frac{\partial}{\partial z}(W\theta) \;=\; \iint_S (\overrightarrow{V_3}\theta \cdot \vec{n})\, ds$$

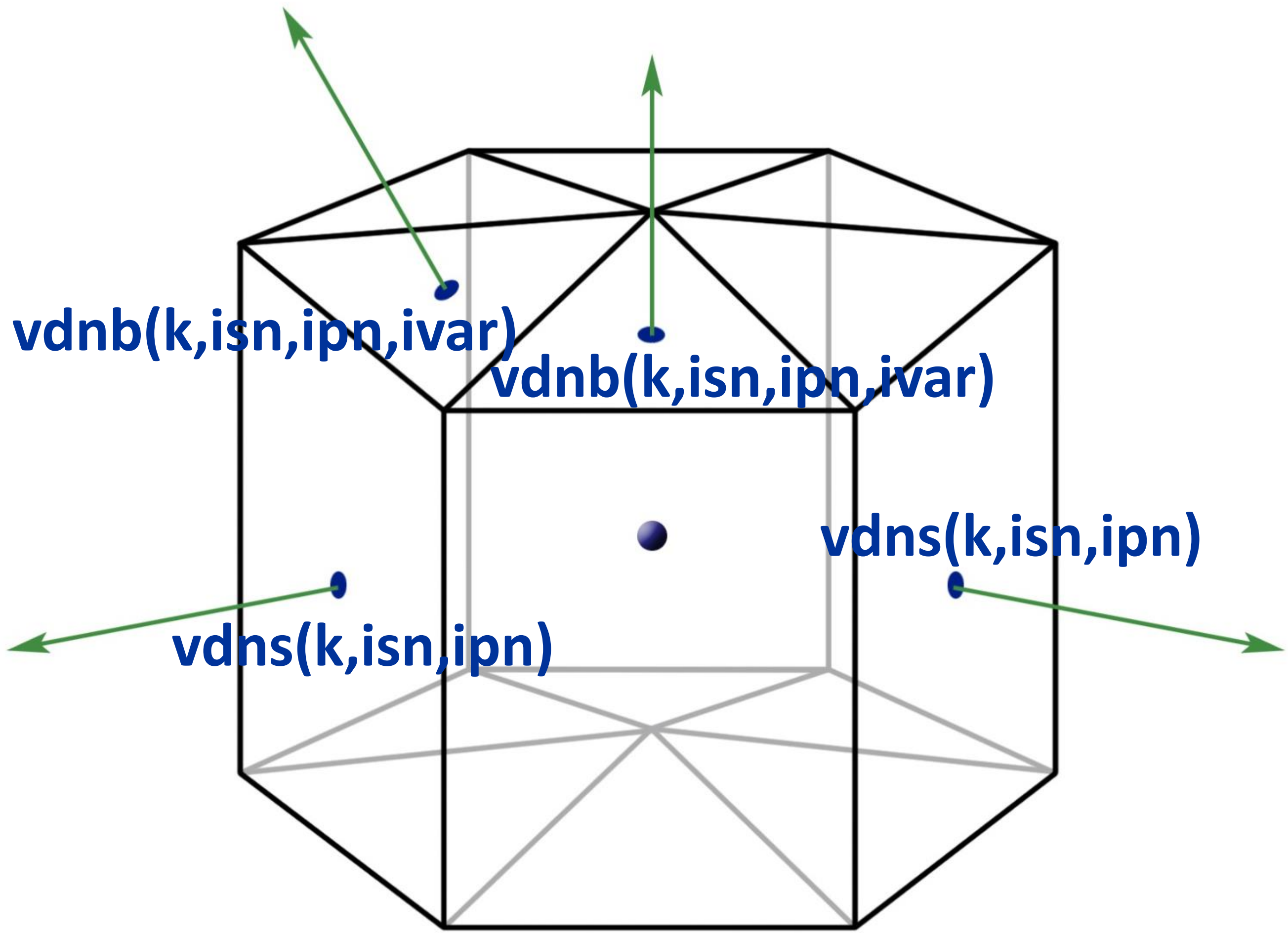
$(U, V, W) = (u\rho, v\rho, w\rho)$

where scalars are: u, v, w, θ

Momentum vector: $\overrightarrow{V_3} = U\hat{\imath} + V\hat{\jmath} + W\hat{k}$



Definition of: vdns and vdnb



vdnb(0:nz,npp,np,nvar): v dot n at center of bottom
vdns(nz,npp,np): v dot n at center of each side
Example: vdns = nvecs * uv8s

k = vertical index : nz = # of z levels
isn = index number of side : npp = # of proximity points
ipn = index point number : np = # of horizontal points

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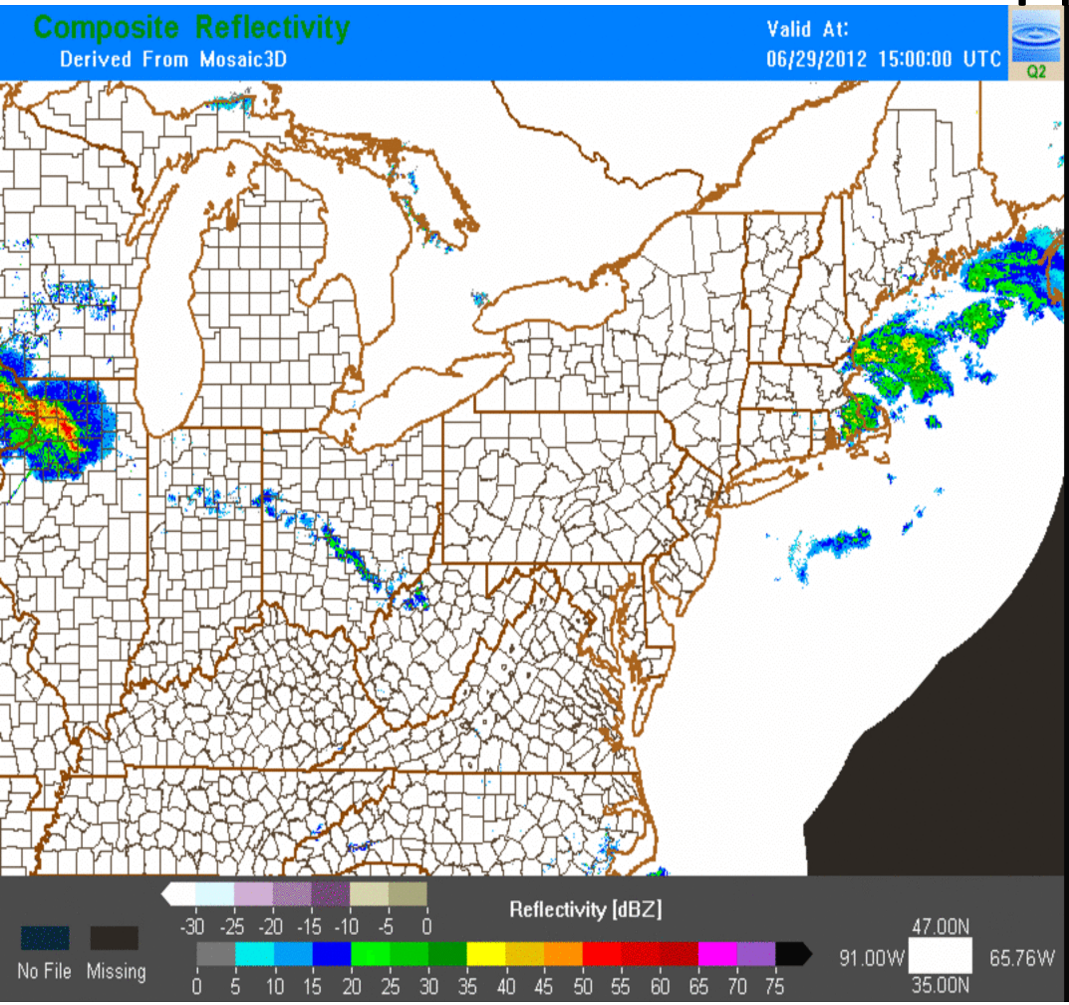
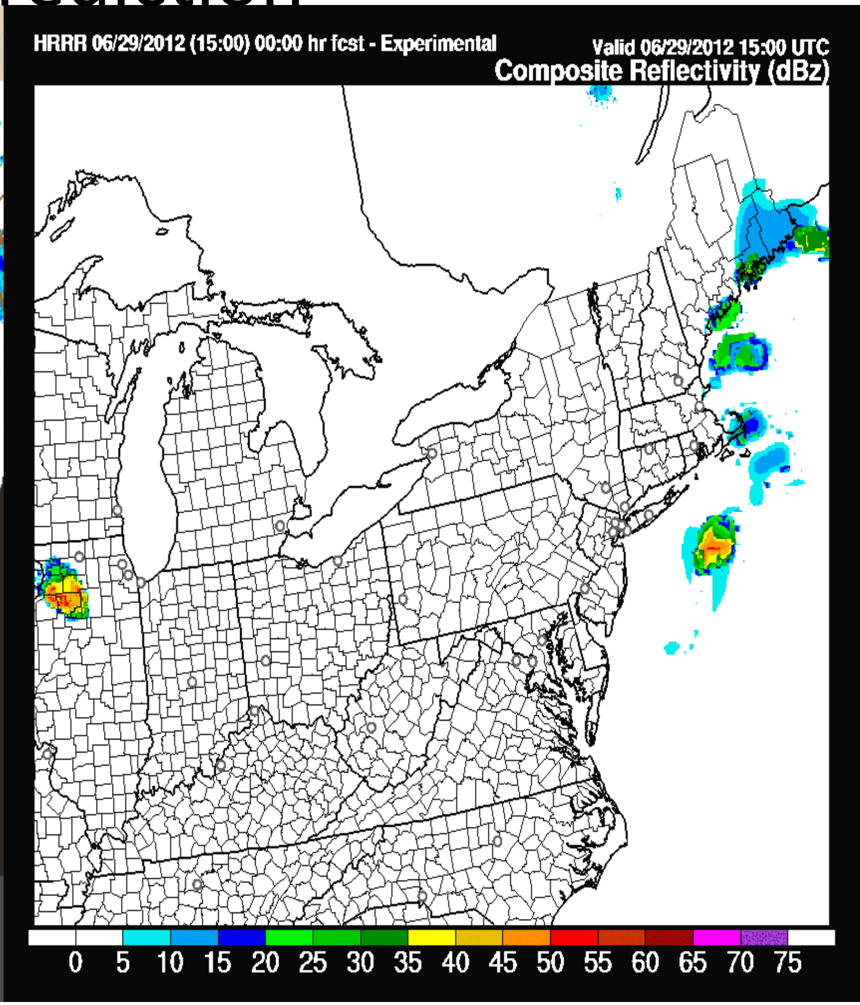
Observed Radar

Model Prediction



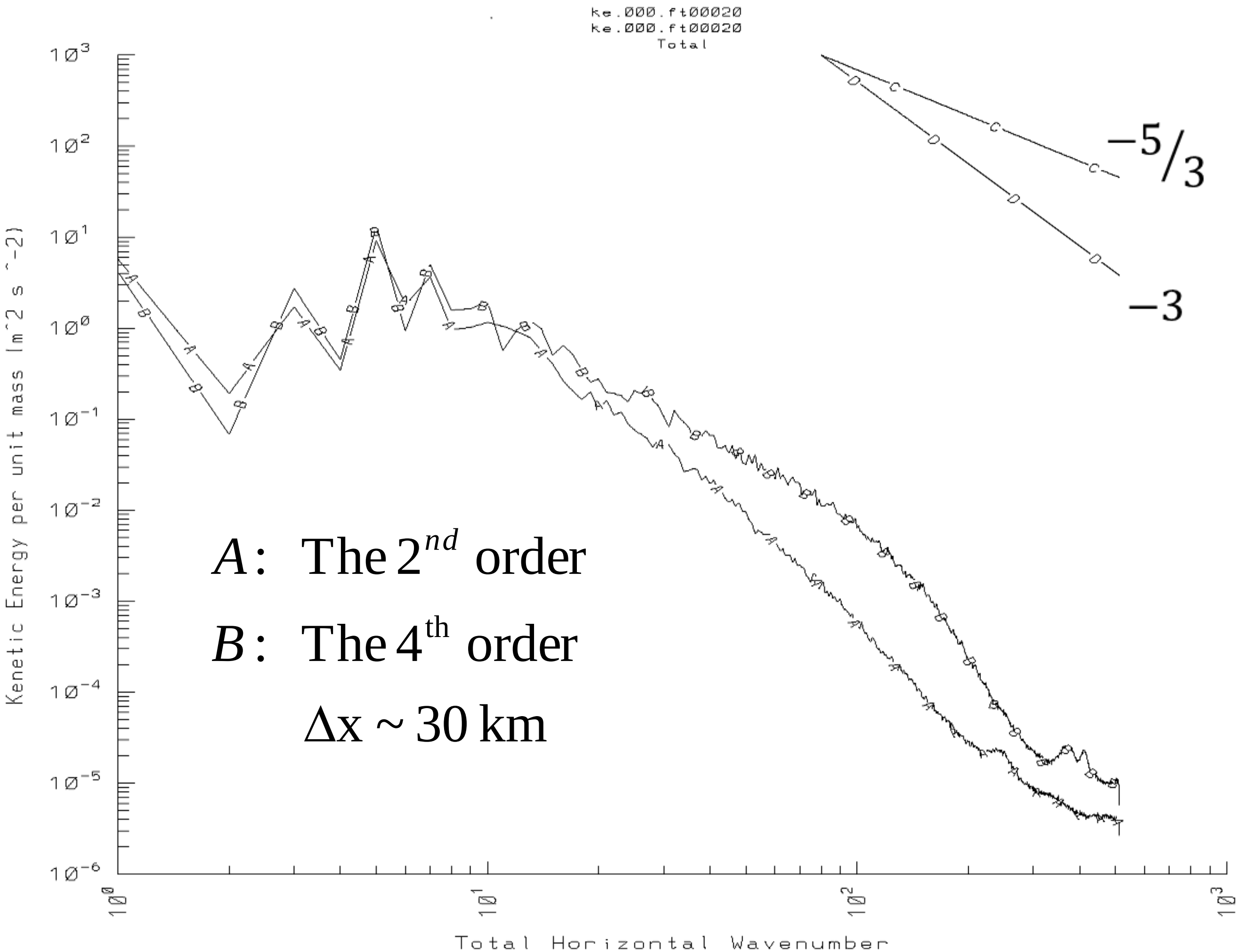


High Resolution Rapid Refresh Model run at ESRL .

No divergence damping, high effective resolution.

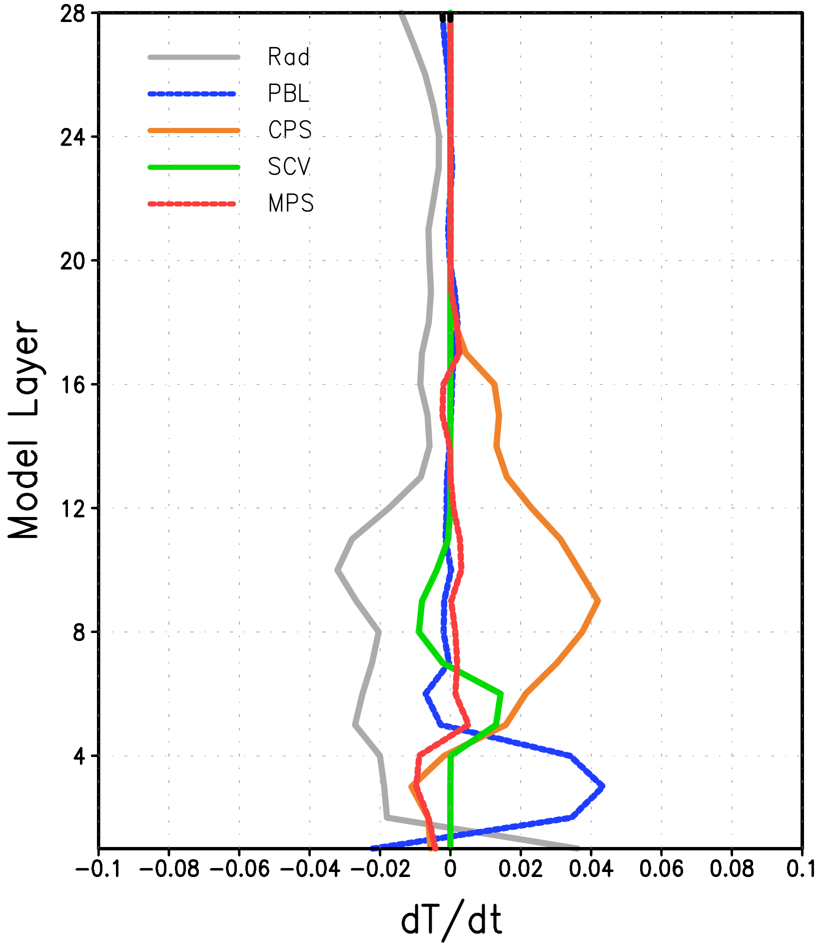
$$2^{nd}: \Delta_{\psi}^{2} = \nabla \bullet k_h \nabla \psi, \quad 4^{th}: \Delta_{\psi}^{4} = \nabla \bullet k_h \nabla \left(\Delta_{\psi}^{2}\right)$$

$$k_h = C_s^2 l^2 \left[\left(u_x - v_y\right)^2 + \left(u_y + v_x\right)^2\right]^{1/2} \quad \text{(Smagorinsky, 1963)}$$

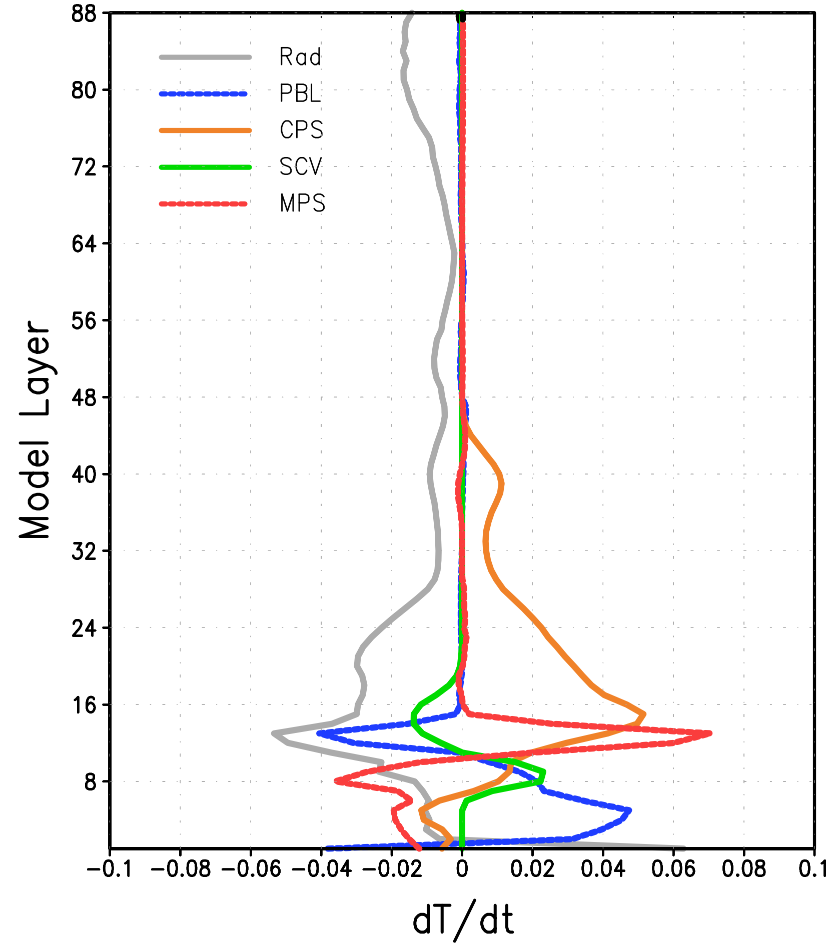


T Tendency from physics (K/6hr)

32 Levels



96 Levels



NIM will have 192 layers to resolve thin cloud layers, like western ocean stratus.

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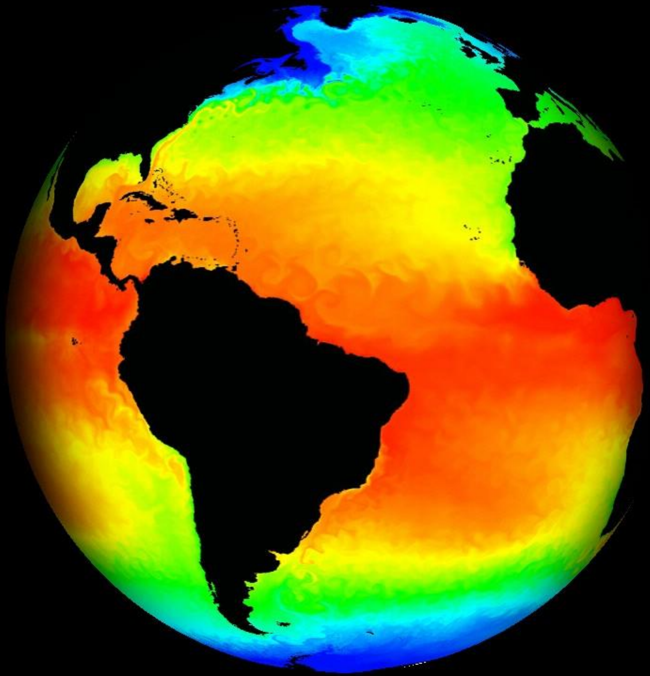
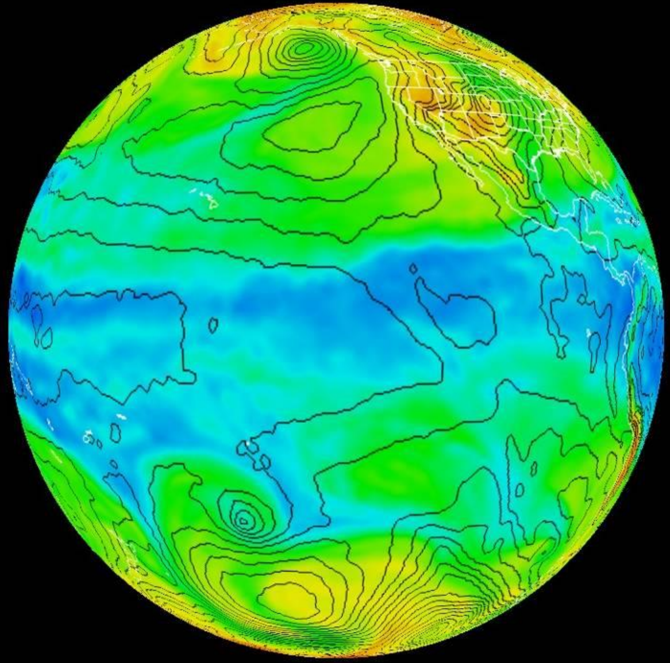
Constituent Volumes:



OCEAN

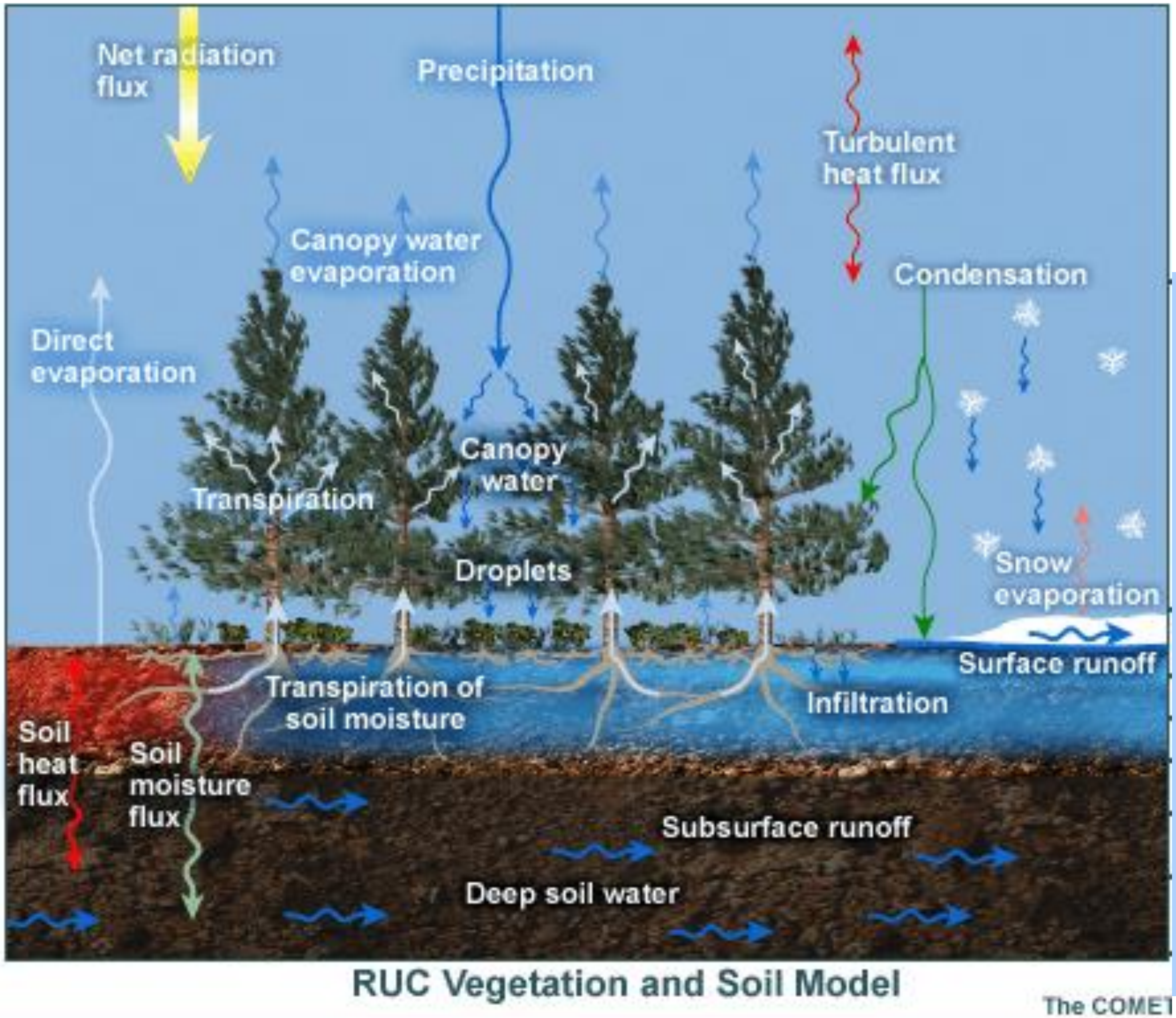


ATMOSPHERE

ESRL Land Surface 2013 Model Update

RUC Land Surface Model (LSM) increased from 6 to 9 levels
Changed PBL scheme from MYJ (Mellor-Yamada-Janjic) to MYNN (Mellor-Yamada-Nakanishi-Niino)
Increased surface roughness lengths

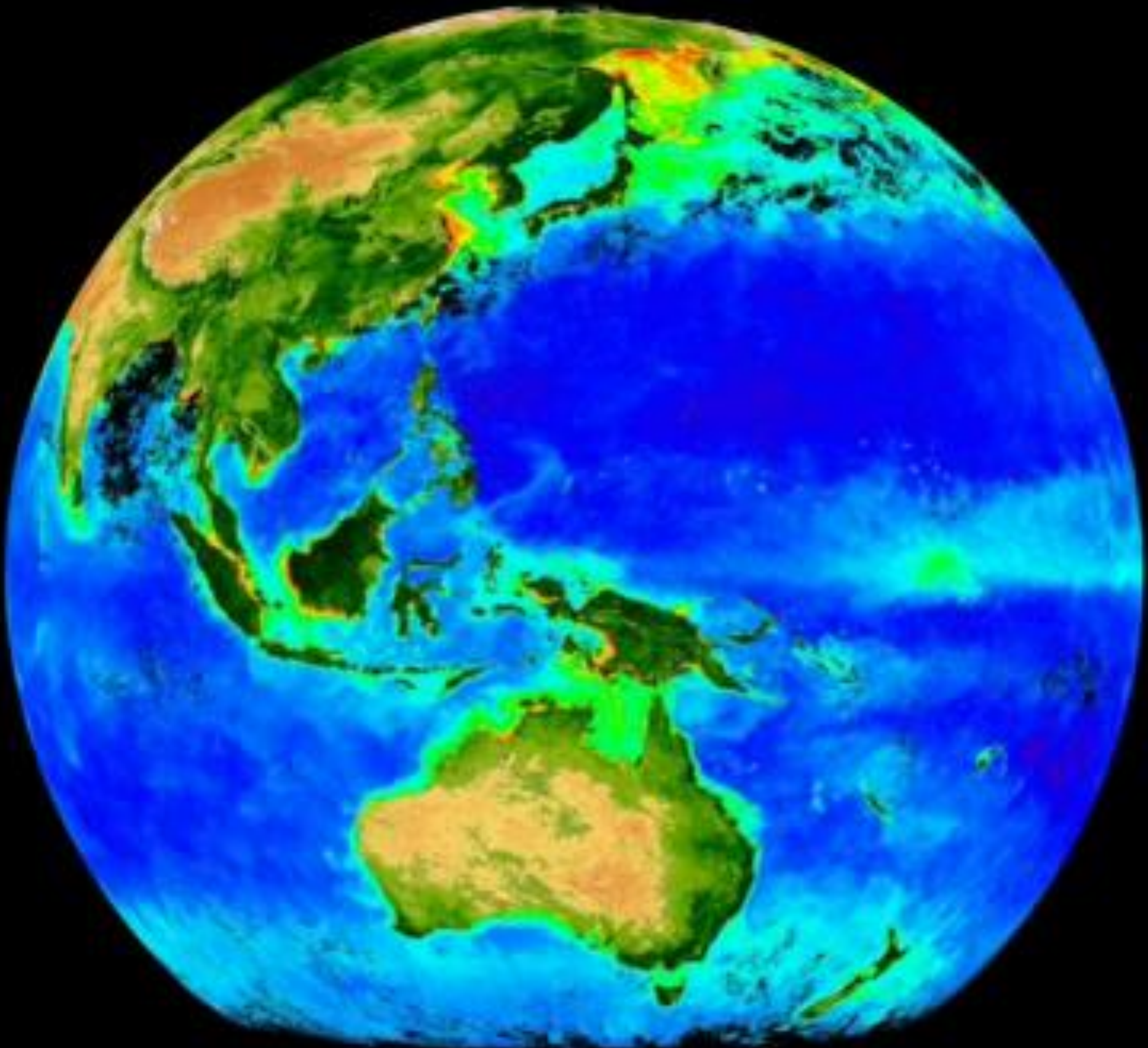
Tanya Smirnova - GSD



OLD	NEW
~ 8 m	~ 8 m
0 (cm)	0 (cm)
	1
	4
5	
	10
20	
	30
40	
	60
	100
160	160
300	300

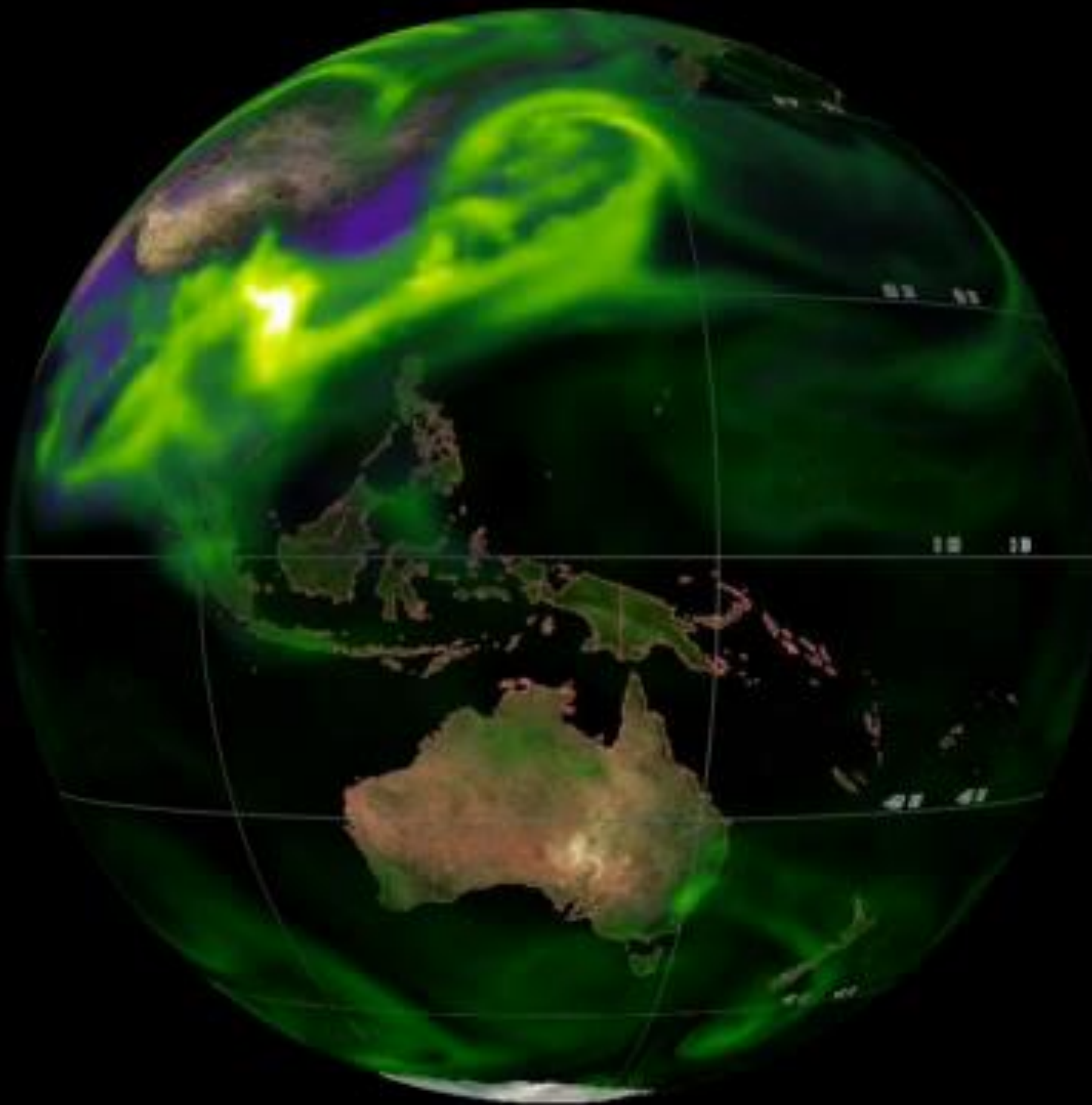
Biology:

The most complex part of the Earth System.



Chemistry:

There are about a hundred atmospheric constituents that need to be tracked.



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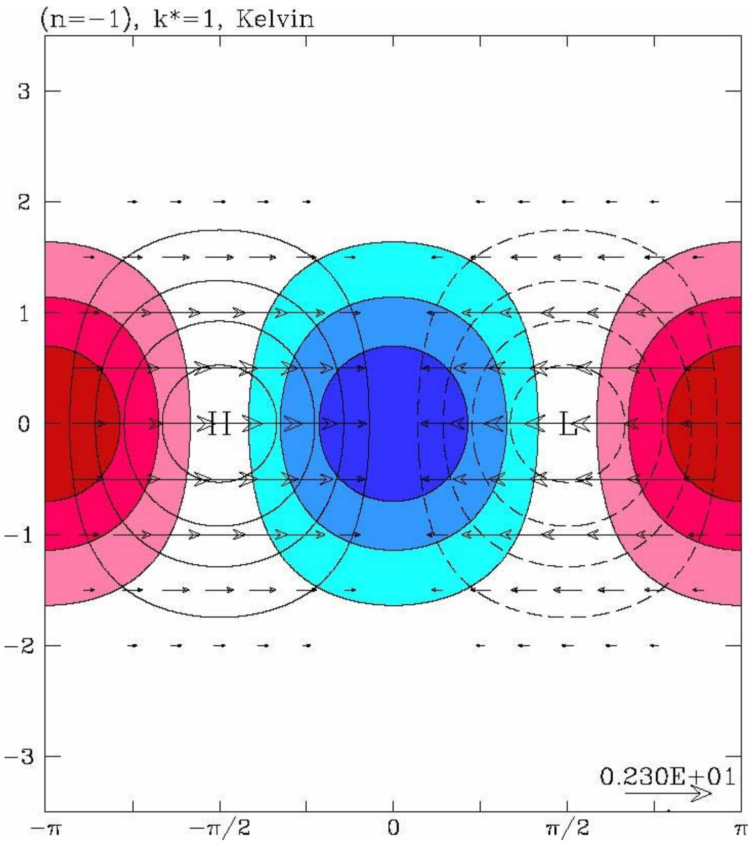
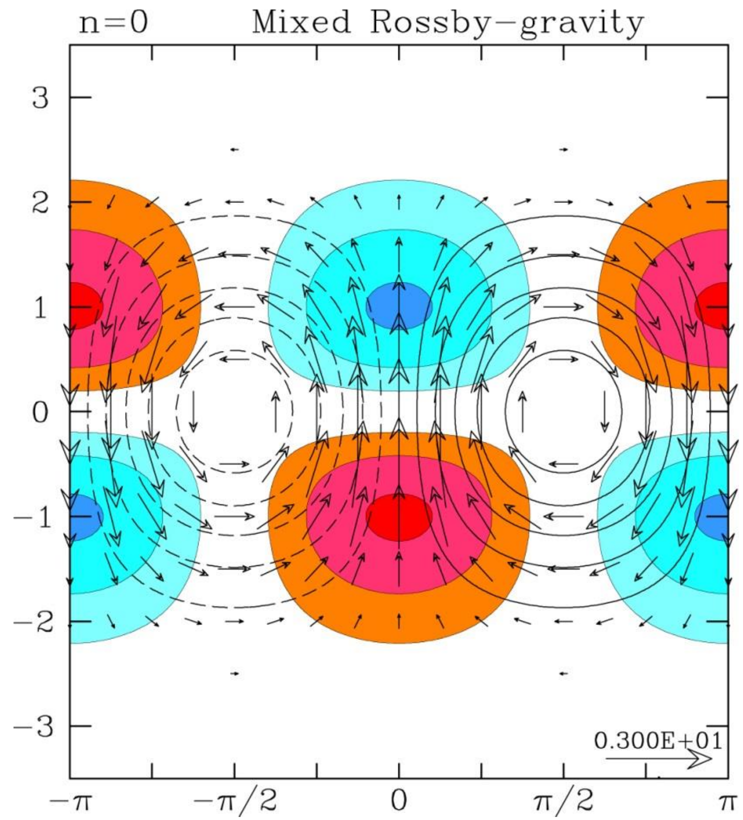
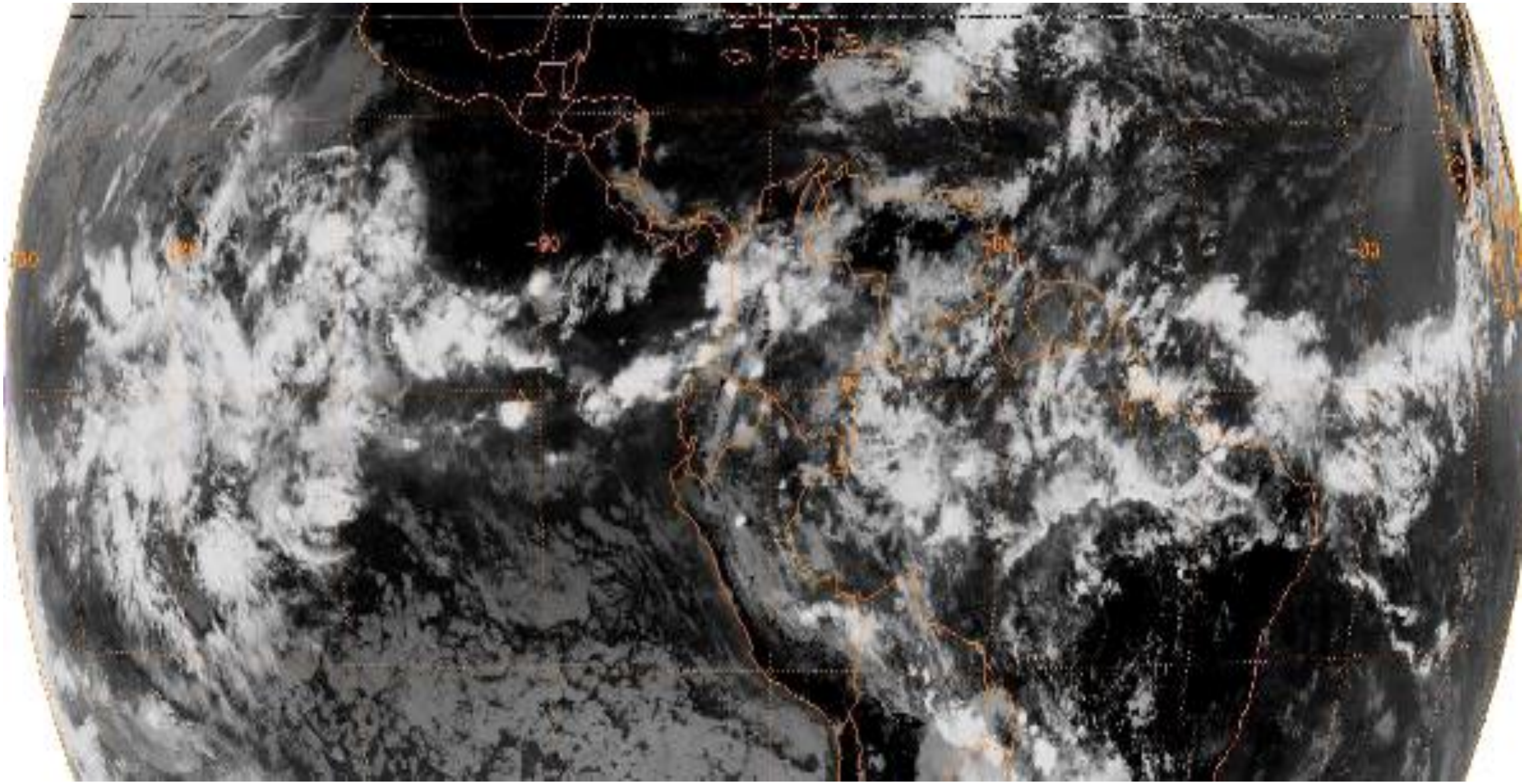
Equatorial Waves
Wavenumber-Frequency Spectral Analysis

- Decompose into Symmetric and Antisymmetric Fields about the Equator





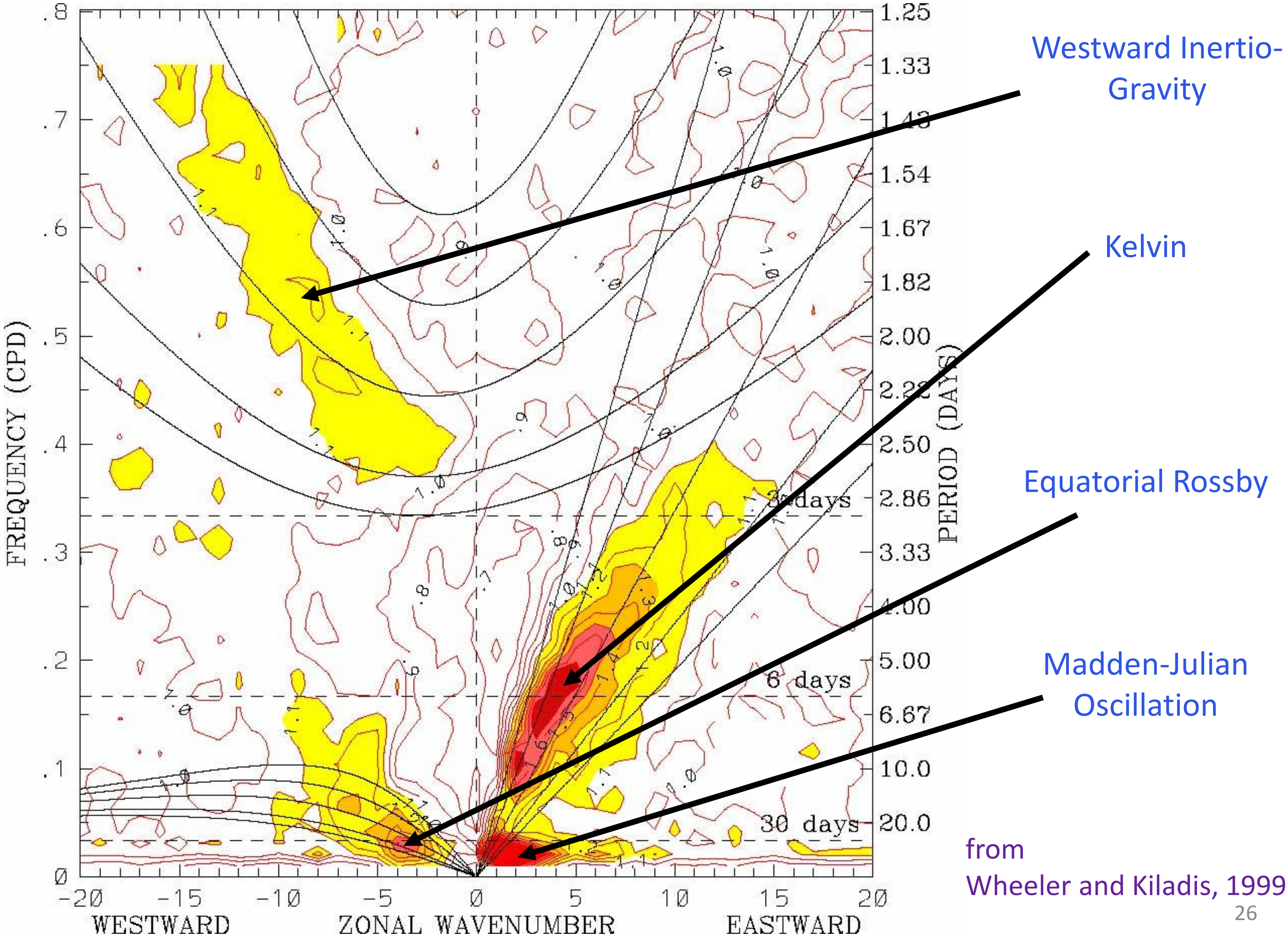
Matsuno, 1967. Could we make the FIM/NIM **Matsuno Compliant?**



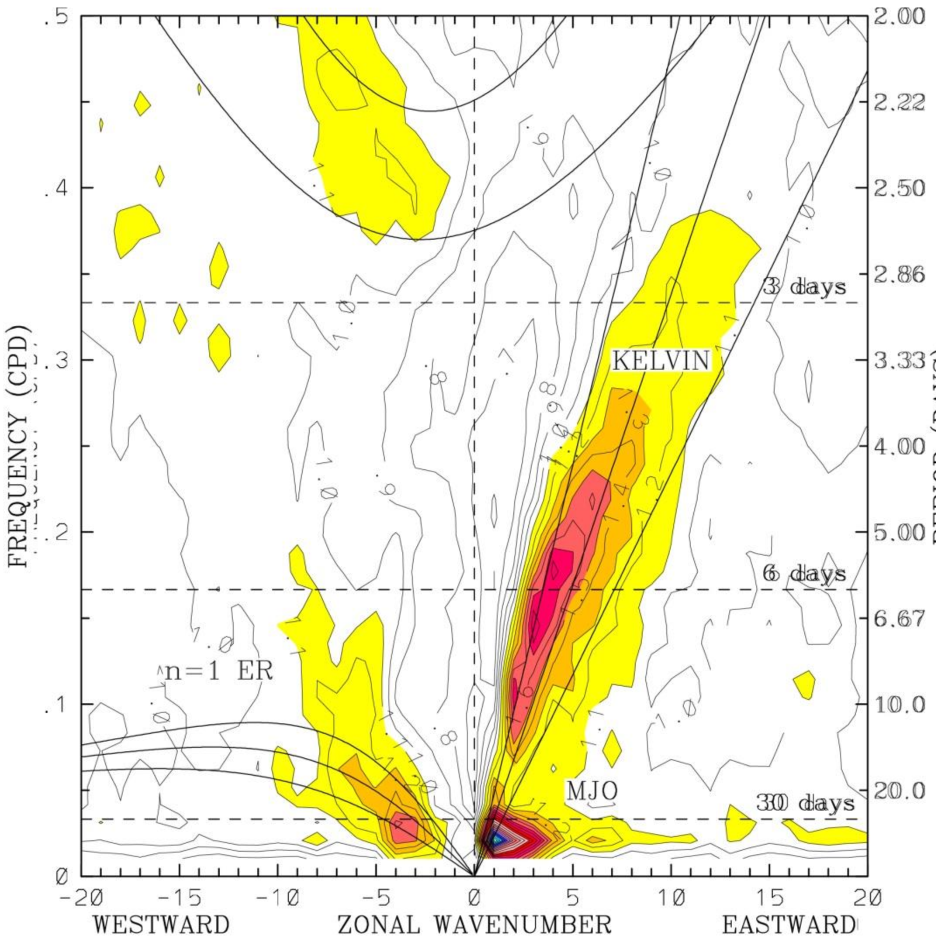
Atmospheric Kelvin Wave/MJO propagates across the American Tropics (blue line).

Our thanks to George Kiladis of ESRL for this analysis.

OLR total/background power spectrum, 15ºS-15ºN, 1983–2005 (Symmetric)

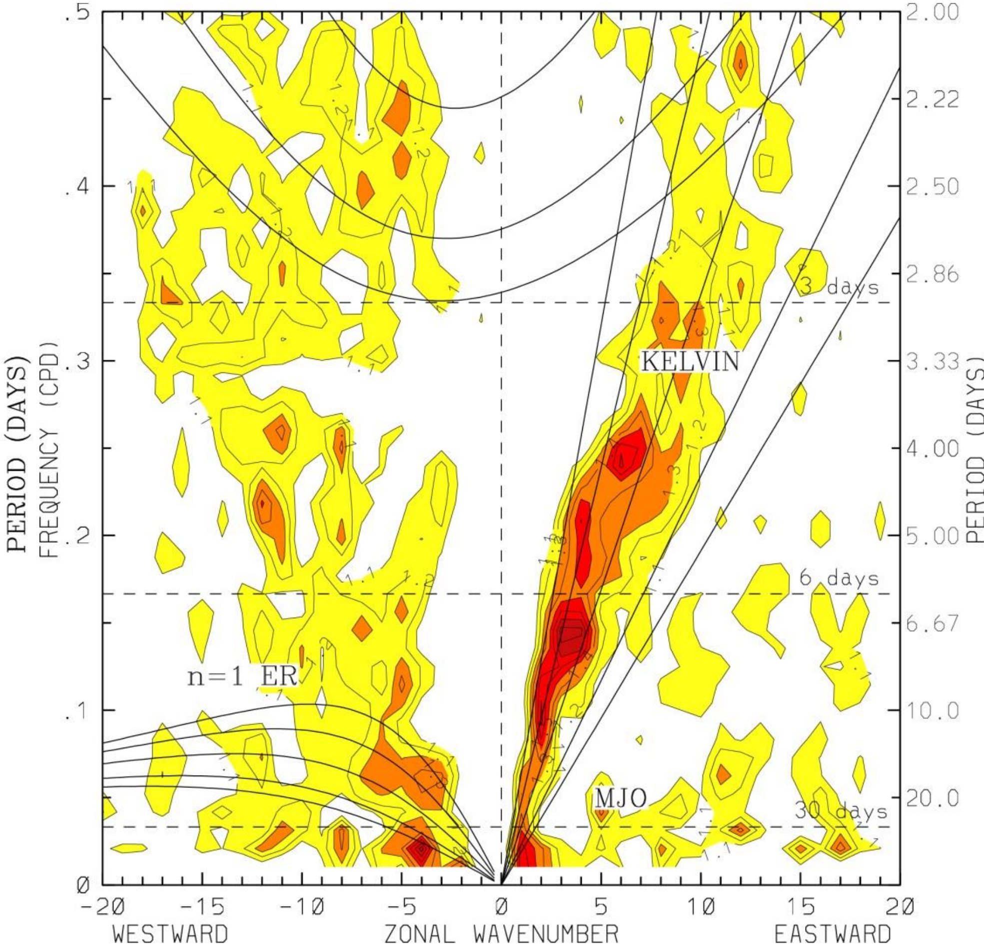


from
Wheeler and Kiladis, 1999



Observed

Outgoing Longwave Radiation



FIM – Grell Physics

Outgoing Longwave Radiation

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