Calculs de hautes performances sur le Earth Simulator : Un pas vers une meilleure prédictions des ouragans

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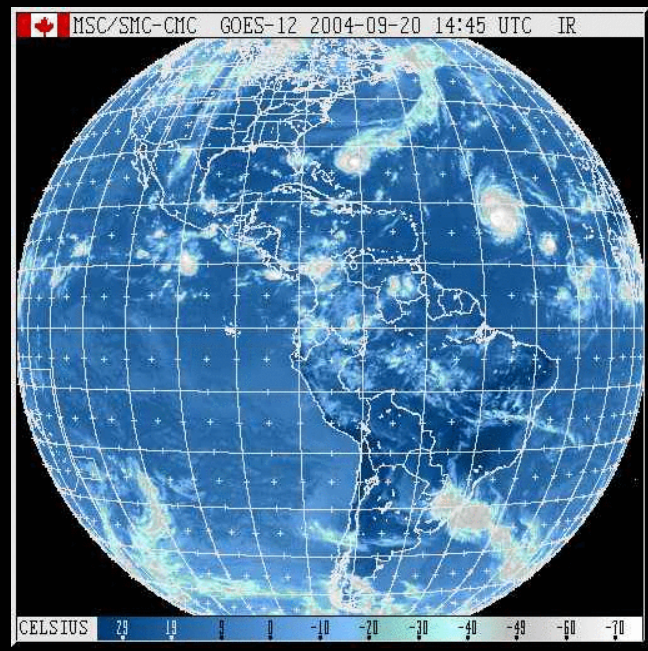
Recherche en Prévision Numérique (RPN)
Meteorological Service of Canada
Québec, Canada

Collaborators:

Earth Simulator Center: W. Ohfuchi
McGill University: Y. Martinez and P. Yau



19e Forum de l'ORAP, Paris (France), 30 Mars 2006

Acknowledgement to CFCAS

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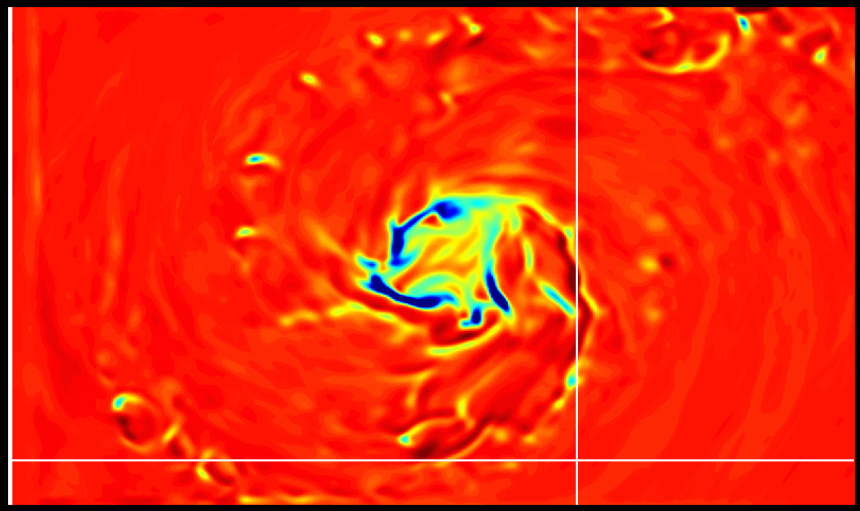
How much resolution do we need?



- **1) Introduction**
- **2) Wave activity diagnostics of a simulated hurricane**
- **3) A grand challenge on the Earth Simulator: A Canada - Japan collaboration on high impact weather**
- **4) Reality check**

Unified system of equations equations

generalized pressure

AIR

H2O

$$P = \frac{p'}{\rho_*}$$

$$P = RT_* q'$$

$$\frac{d\mathbf{v}}{dt} + \left[\nabla - \frac{N_*^2}{g}\mathbf{k}\right]P - B\mathbf{k} = R_V$$

$$\frac{dB}{dt} + N_*^2 w = R_B$$

$$\frac{d}{dt}\left(\frac{P}{c_*^2}\right) + \nabla\cdot\mathbf{v} - \frac{g}{c_*^2}w = R_P$$

buoyancy

$$b = -g\frac{\rho'}{\rho_*}$$

$$b = g\frac{T'}{T_*}$$

generalized buoyancy

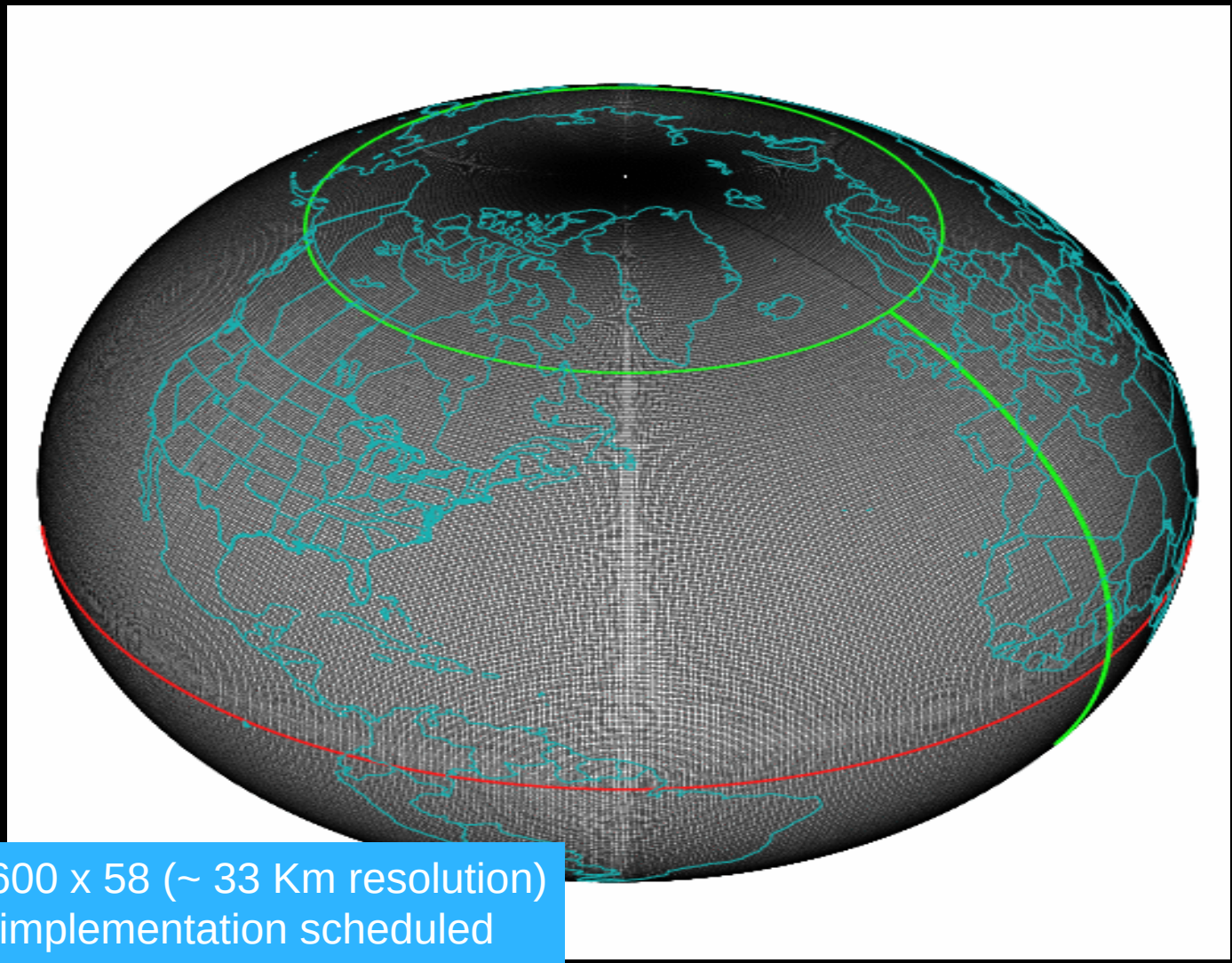
$$B = b - \gamma_W P$$

$$B = b - \gamma_A P$$

$$\gamma_A = g/(c_p T_*)$$

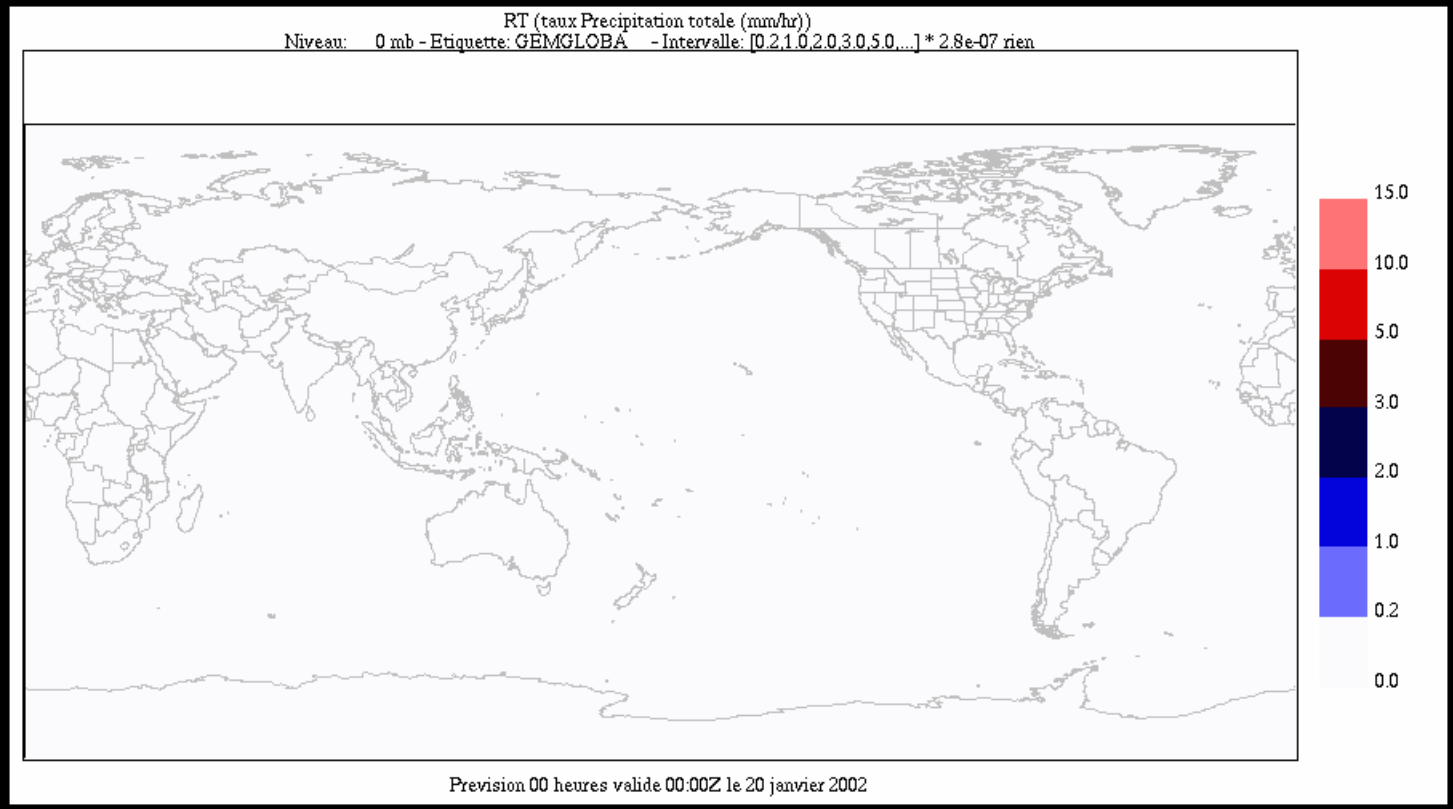
Ref: Girard et Al. 2005: MWR

A major technological transfer in 2005-06 at MSC: GLOBAL GEM GRID AT 35km with improved physics and cloud representation



Grid: 800 x 600 x 58 (~ 33 Km resolution)
Operational implementation scheduled for spring 2006 on ~ 300 PEs
Will average 10 min/day

Instantaneous precipitation rate (mm/hr) for the Operational GEM model
A 5 day animation (20/01/2002 to 25/01/2002) (HR=100km, TR=45 min.)



Acknowledgement to M. Roch and S. Bélair

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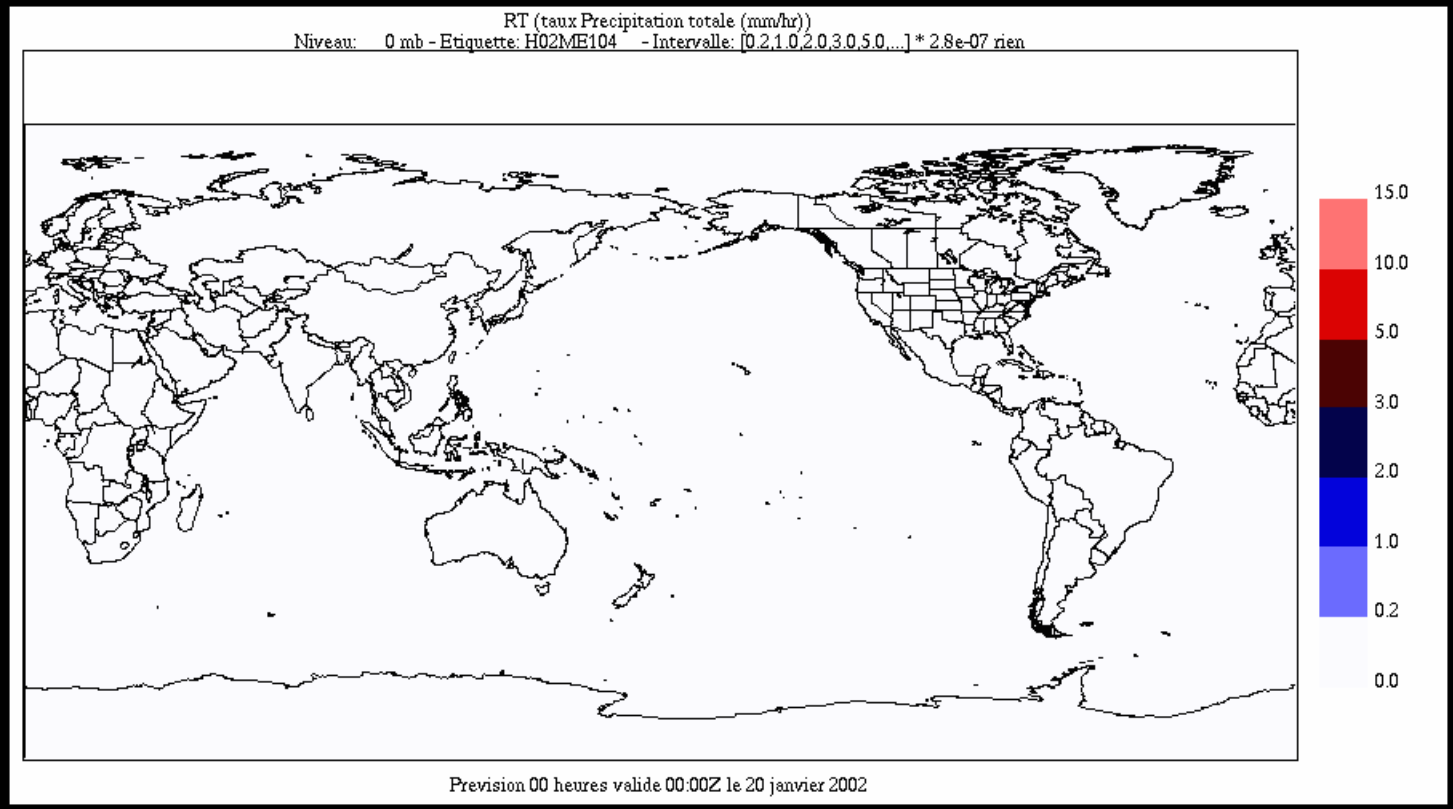
Instantaneous precipitation rate (mm/hr) for the Meso-Global GEM model
A 5 day animation (20/01/2002 to 25/01/2002) (HR=33km, TR= 15 min.)



Acknowledgement to M. Roch and S. Bélair

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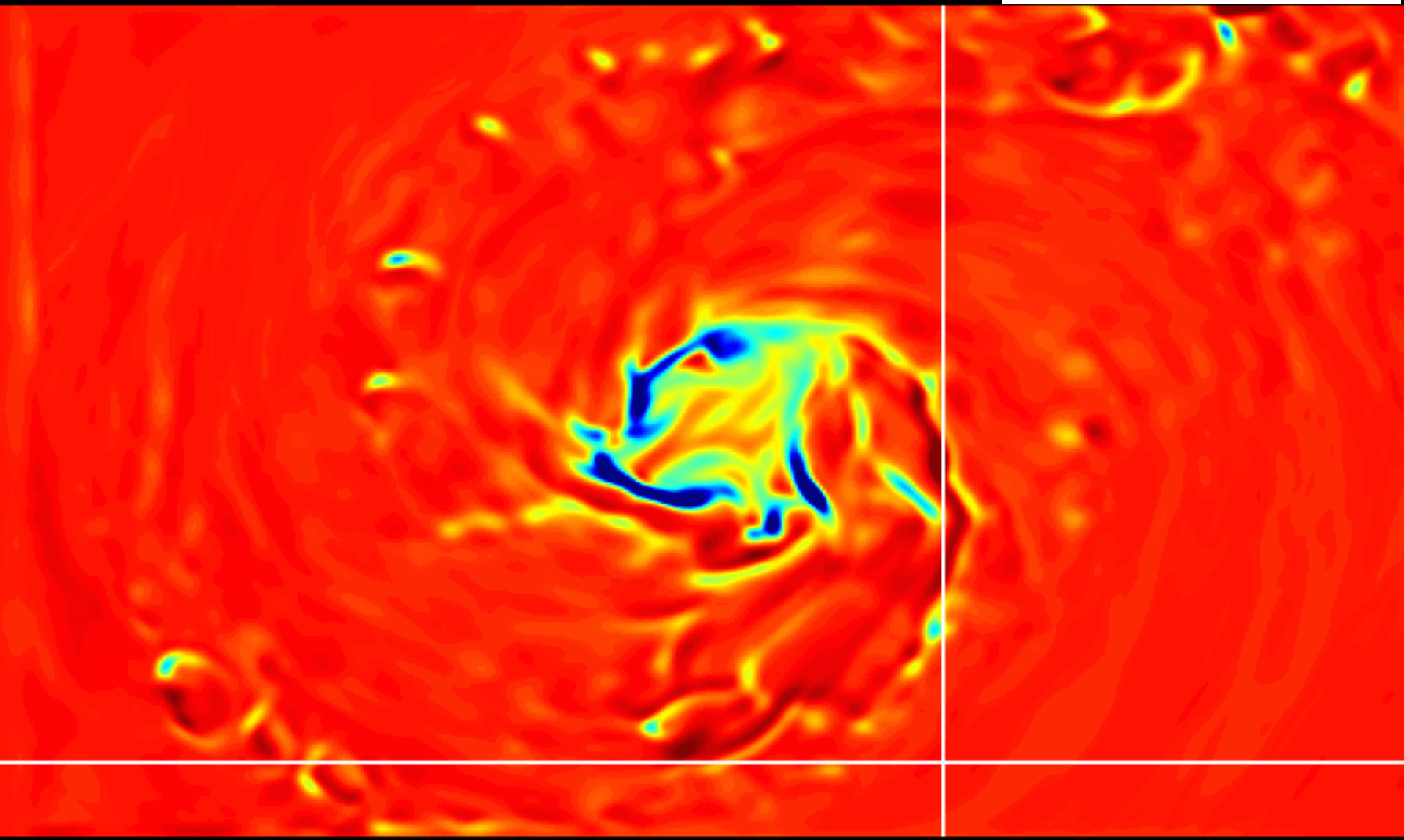
Typhoon FLO - Septembre 1990
2km 16-30 H Forecast of Relative Vorticity at 20m

COMPARE III Workshop
Tokyo, Japan
December 13-15, 1999



max= 700-800 e^{-5} sec^{-1}

frame every hour

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2) Wave activity diagnostics of a simulated hurricane

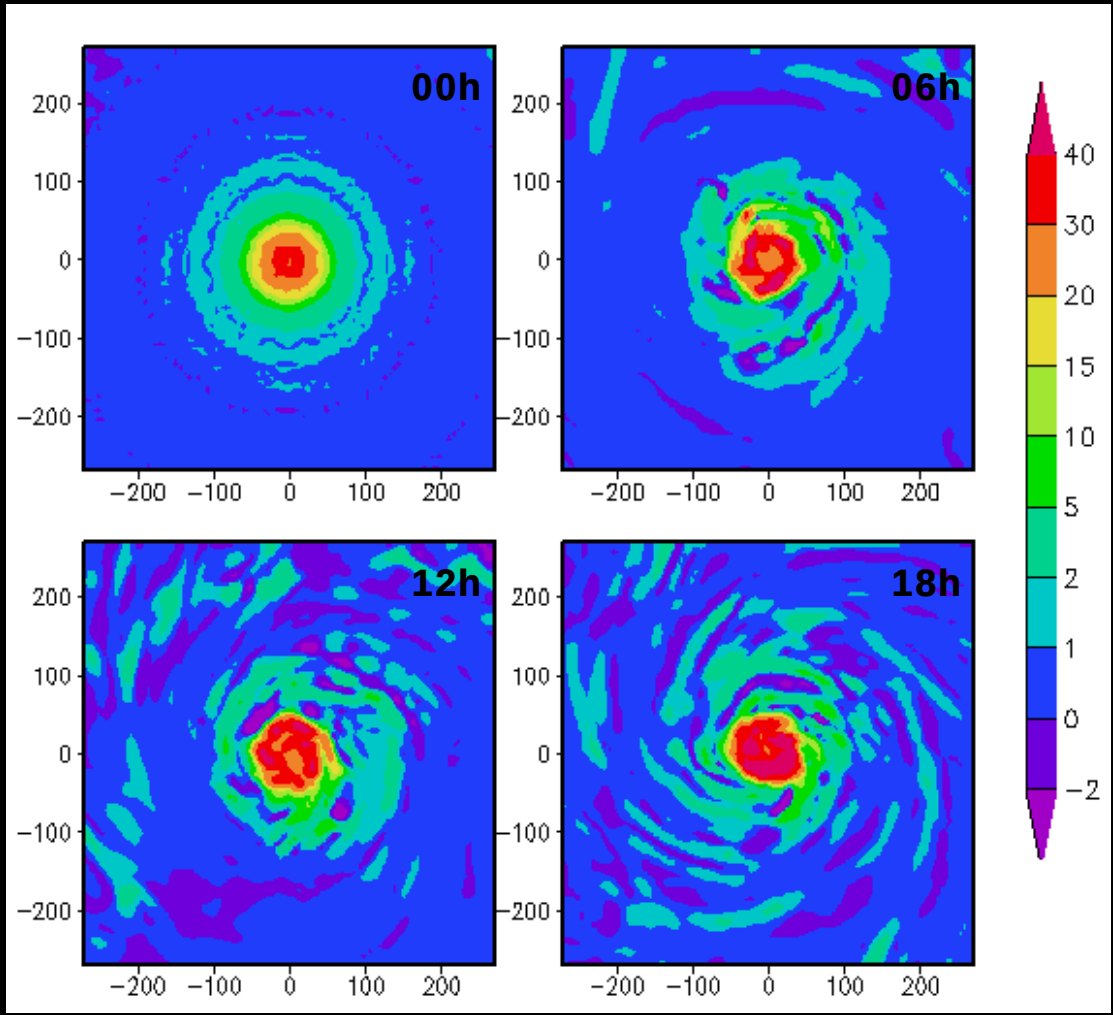
Background and Motivation

- Can-we characterize and quantify the dynamics and significance of the spiral bands?
- Recent studies have shown that inner spiral bands have characteristics of vortex Rossby waves
- Vortex Rossby waves (VRW) and gravity waves are mixed (Rossby number [U/Lf] is not small)

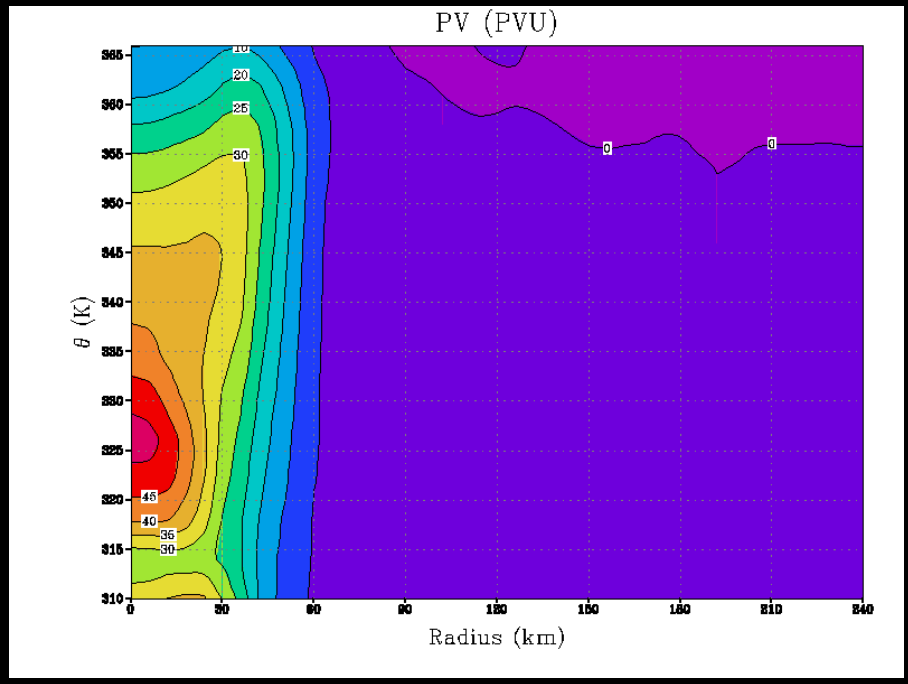
- Apply Empirical Normal Mode (ENM) method to separate the waves to isolate the effect of VRW on a simulated hurricane -Chen and Yau 2001 (6 km grid size, 24 h simulation sampled every 2 minutes)

Chen, Brunet and Yau 2003: Spiral Bands in a Simulated Hurricane. Part II: Wave Activity Diagnostics. Journal of Atmospheric Sciences: Vol. 60, No. 10, pp. 1239–1256.

PV at 6 km


00h
06h
12h
18h
200
100
0
−100
−200
−200 −100 0 100 200
40
30
20
15
10
5
2
1
0
−2

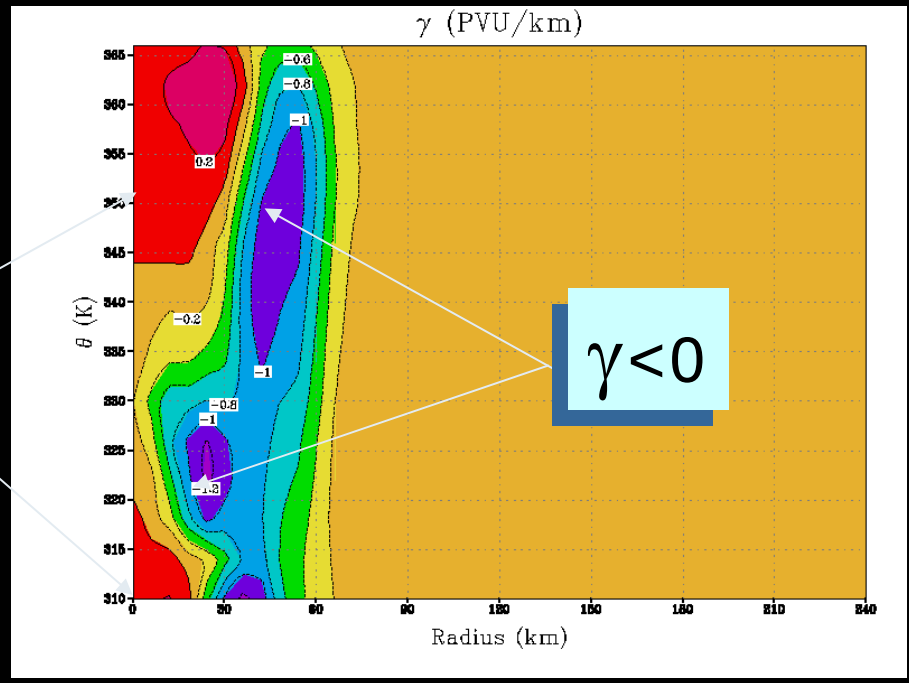
Basic State (24 hour mean)



Potential Vorticity

$\gamma > 0$

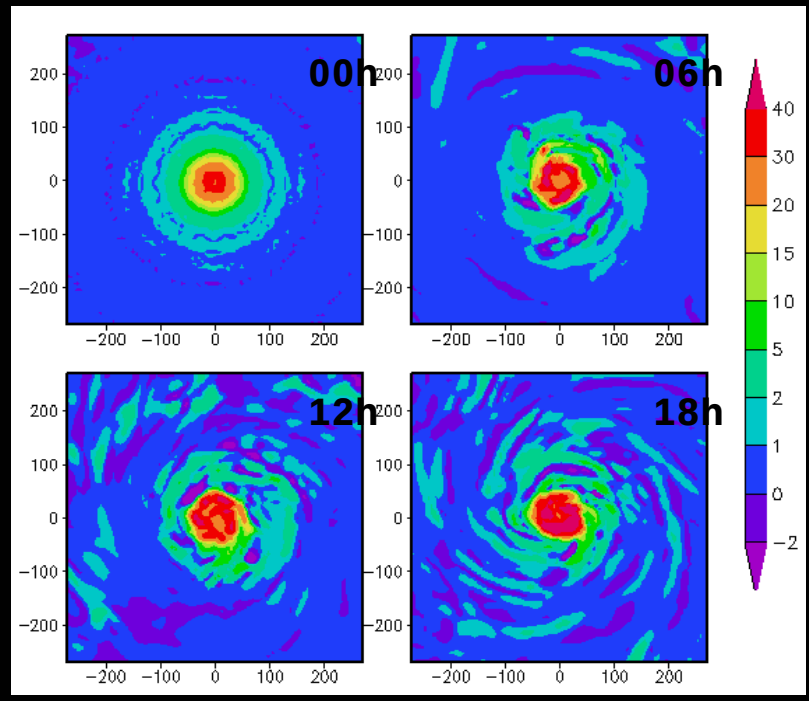
Potential Vorticity
Radial Gradient



$\gamma < 0$

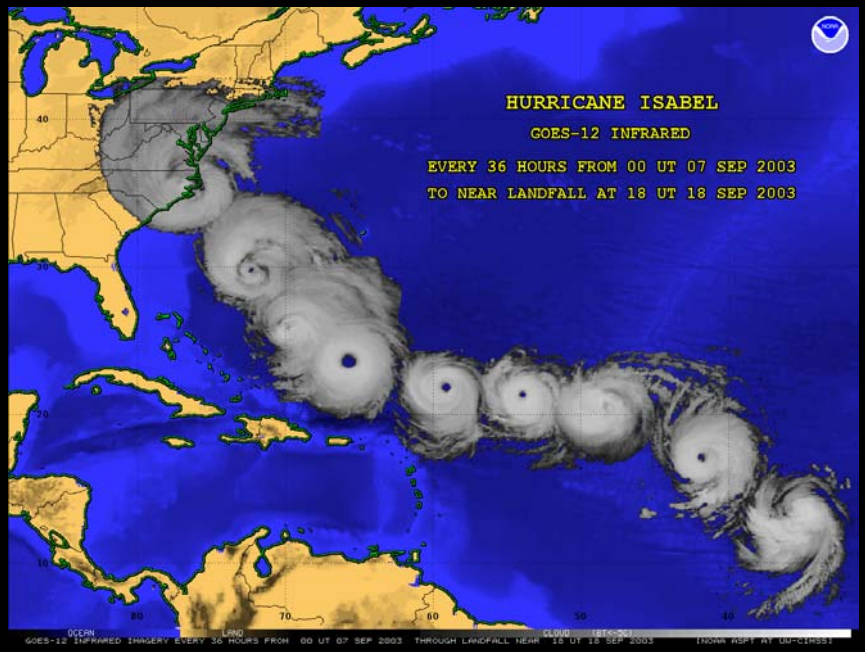
Period and variance (%) of most important ENMs that contribute to 47% of the total variance

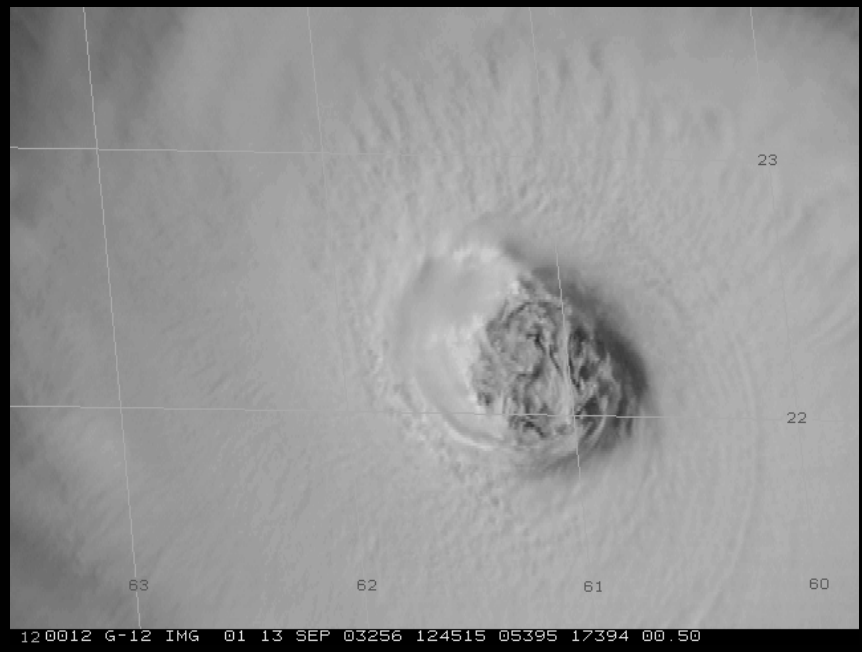
Wave number	ENM number	Period (hour)	Variance (%)
1	1	2.4	11
1	2	2.4	8
1	720	1.6	3
1	721	1.6	4
2	1	1.0	8
2	2	1.0	7
2	720	1.1	3
2	721	1.1	3



- NWP models with timestep less than one hour should start to resolve properly Vortex Rossby waves

Hurricane Isabel north of Puerto Rico
(on the 2003/09/12, 12:45 – 14:45 animation)
GOES 12 visible image - Pixel size:1km





VRW angular momentum transfer leads to 1-2 m/s per hour acceleration of the mean flow

Acknowledgement to Y. Chartier

Conclusions from Chen et al.

- Analysis shows wavenumber 1 and 2 leading ENMs are vortex Rossby wave modes

- The divergence (1~2 m/s per hour) of EP fluxes indicates that vortex Rossby waves play an important role in the intensification of the simulated hurricane

- Wave breaking signature:

  i) The simulation is too dissipative (6km)

  ii) How generic and realistic this is?

A full life cycle simulation that resolves convective scale and VRW is needed (1 km).

Large
Atmospheric
Computation on the
Earth
Simulator

RPN: Michel Desgagné,
Gilbert Brunet,
Michel Valin

ESC: Wataru Ohfuchi

McGill U.: Peter Yau, John Gyakum,
Yosvany Martinez

U. of Tokyo: Hiroshi Niino,
Yuki Fukurawa

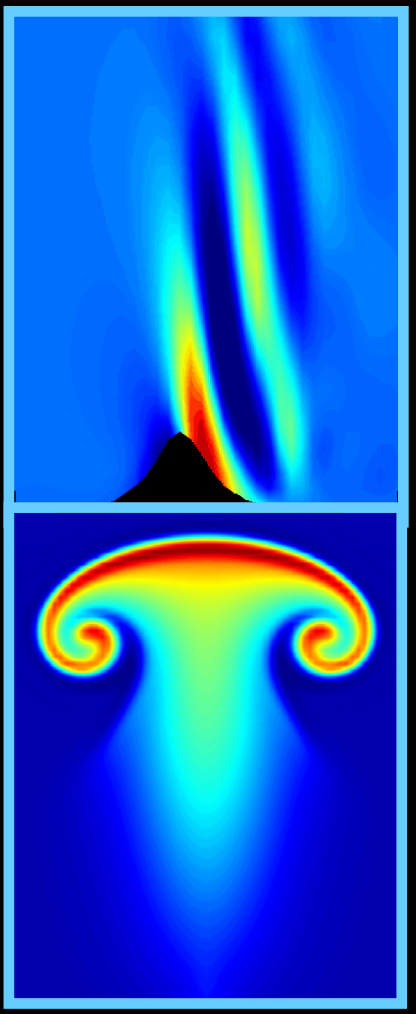
U. of Albany: Ron McTaggart-Cowan

Others:
Claude Girard, Pierre Pellerin
Robert Benoit, Mike Montgomrey

with
MC2

The Canadian MC2 Model v4.9.8

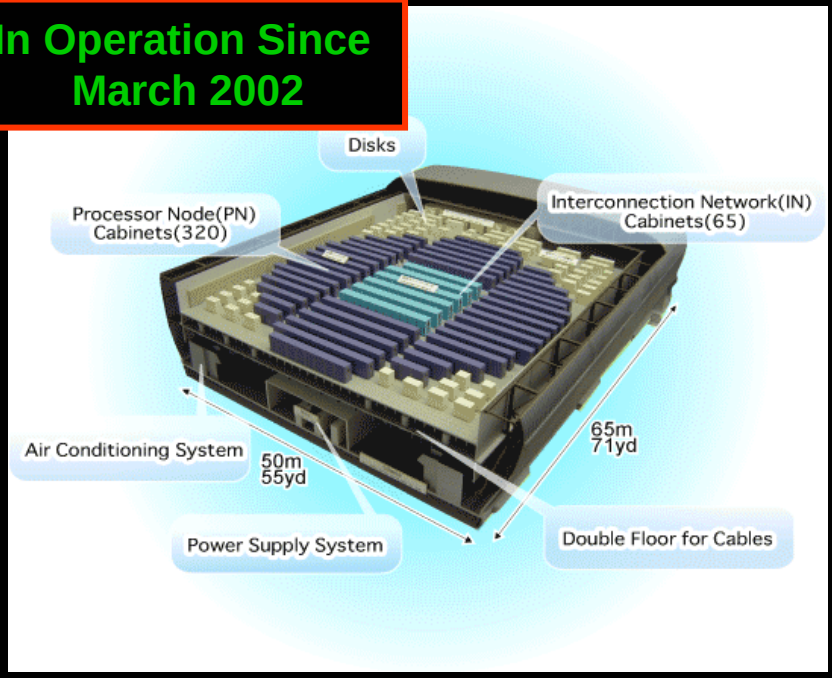
Mesoscale Compressible Community Model



- Nonhydrostatic compressible LAM
- Semi-implicit formulation with stationary isothermal hydrostatic basic state
- Fully 3D semi-Lagrangian advection (leapfrog)
- Terrain following heights vert. coordinate
- Staggering: Arakawa C - Tokioka B
- Minimal residual Krylov GCR/GMRES solver / 1D Jacobi/3D ADI line relaxation precond.
- Davies type lateral gravity-wave absorbers
- Full CMC/RPN physics v4.1 including:
  - many combinations of convective and large-scale condensation schemes (3 microphysics schemes)
  - TKE PBL + Force-restore/ISBA/CLASS surface schemes
  - Solar and infrared radiation scheme

http://www.cmc.ec.gc.ca/rpn/publications/pdf/Finetopo_22_11_2004.pdf

In Operation Since March 2002



Some Specs of the Earth Simulator:

- 640 nodes of 8 vector processors
- Processor peaks at 8 GF/sec.
- Shared memory/node = **16 GB**

Whole system:

- 5120 processors
- Peak = **40 TF/sec**
- Memory = **10 TB**
- Interconnect = 12.3 GB/sec x 2

Must demonstrate high Vectorization ratio (99%) and very good Scalability:

$$M \leq \frac{2-\alpha}{1-\alpha}$$

10 ➔ 140 ➔ 1600 NODES

$$E_n = \frac{S_n}{n} \geq 0.5$$

Parallelization Efficiency > 0.5 on a fixe problem size

$$S_n = \frac{T_1}{T_n}$$

Parallelization Scalability

$$\alpha = \frac{1-\frac{1}{S_n}}{1-\frac{1}{n}}$$

Amdahl's law Parallelization ratio

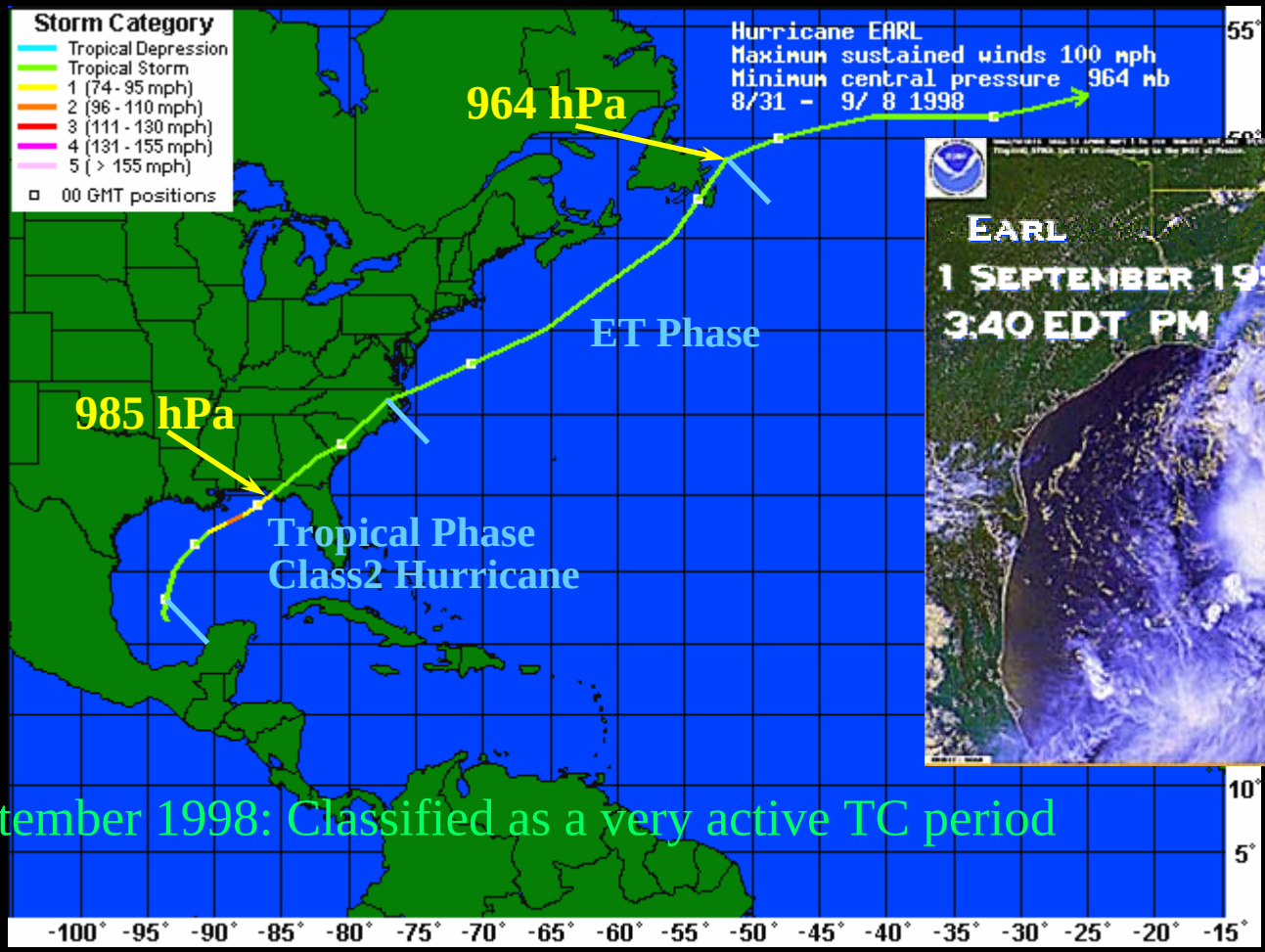
Sustained performances:

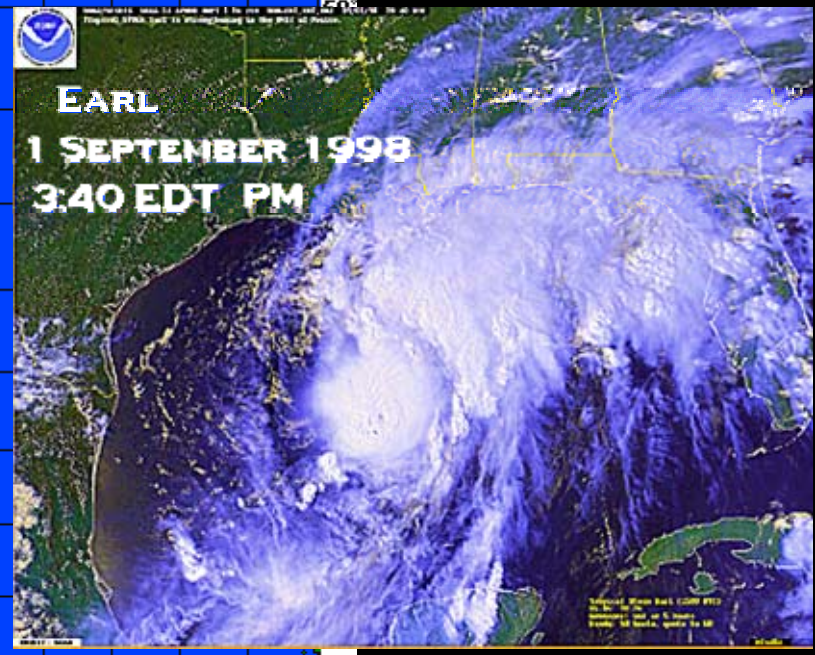
36 TF on some benchmarks (640 nodes)
27 TF with AFES (640 nodes – 67% of peak)
(10 km global climate simulation)

13 TF with MC2 (495 nodes)
(1 km - 11000 x 8640 x 51 grid)
22 x 180 processor topology
(3.2 GF/Pe – 40% of peak)

A Grand Challenge project on the Earth Simulator

Modelling the Full Lifecycle of Hurricane Earl at 1km Resolution with the Canadian MC2 Model





September 1998: Classified as a very active TC period

Desgagne, Ohfuchi, Brunet, Yau, McTaggart-Cowan and M. Valin, 2004: Large Atmospheric Computation on the Earth Simulator: A report on the LACES project. Annual Report of the Earth Simulator Center (April 2003–March 2004), 225-227. The Earth Simulator Center, Yokohama, Japan.

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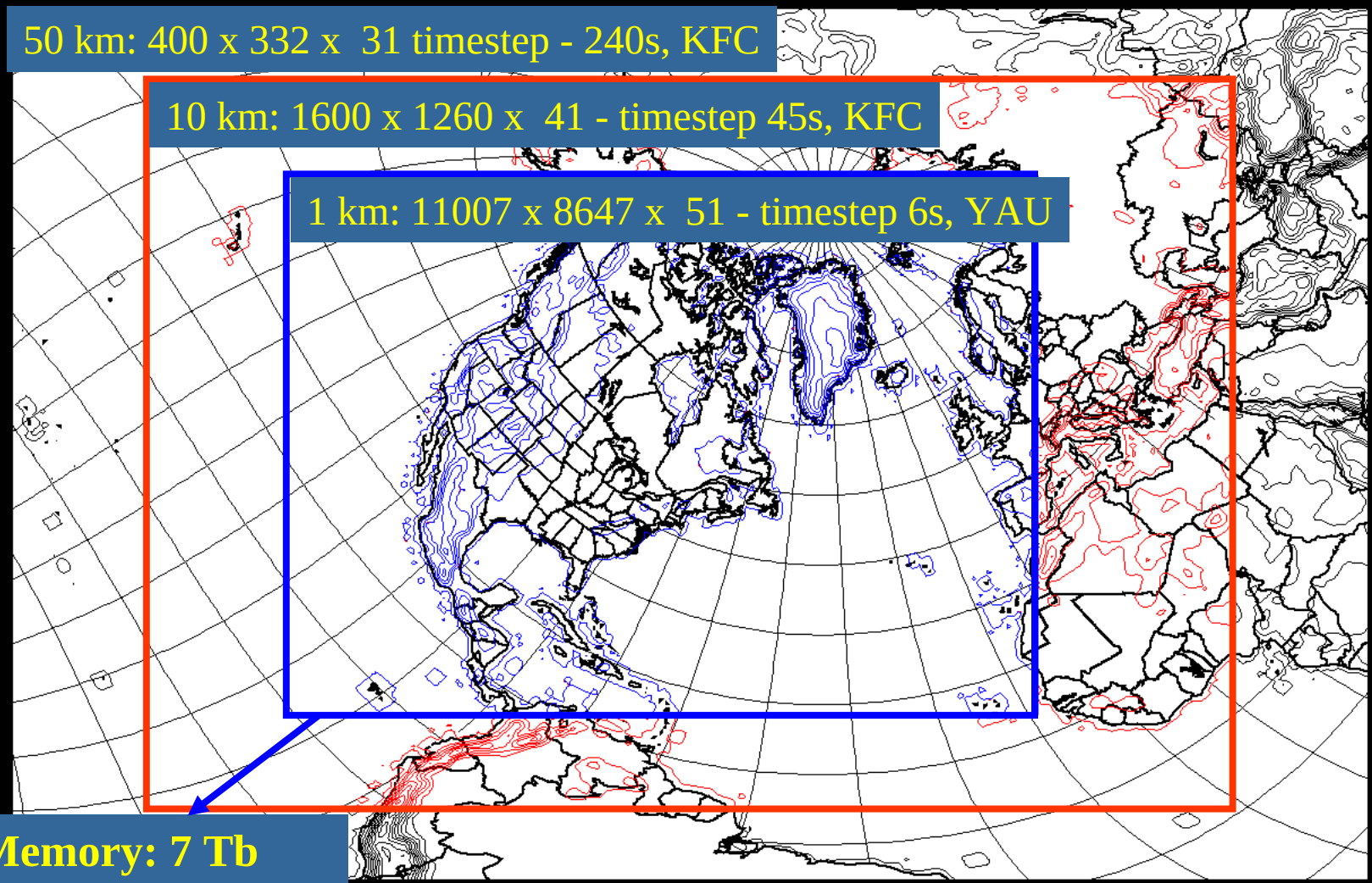
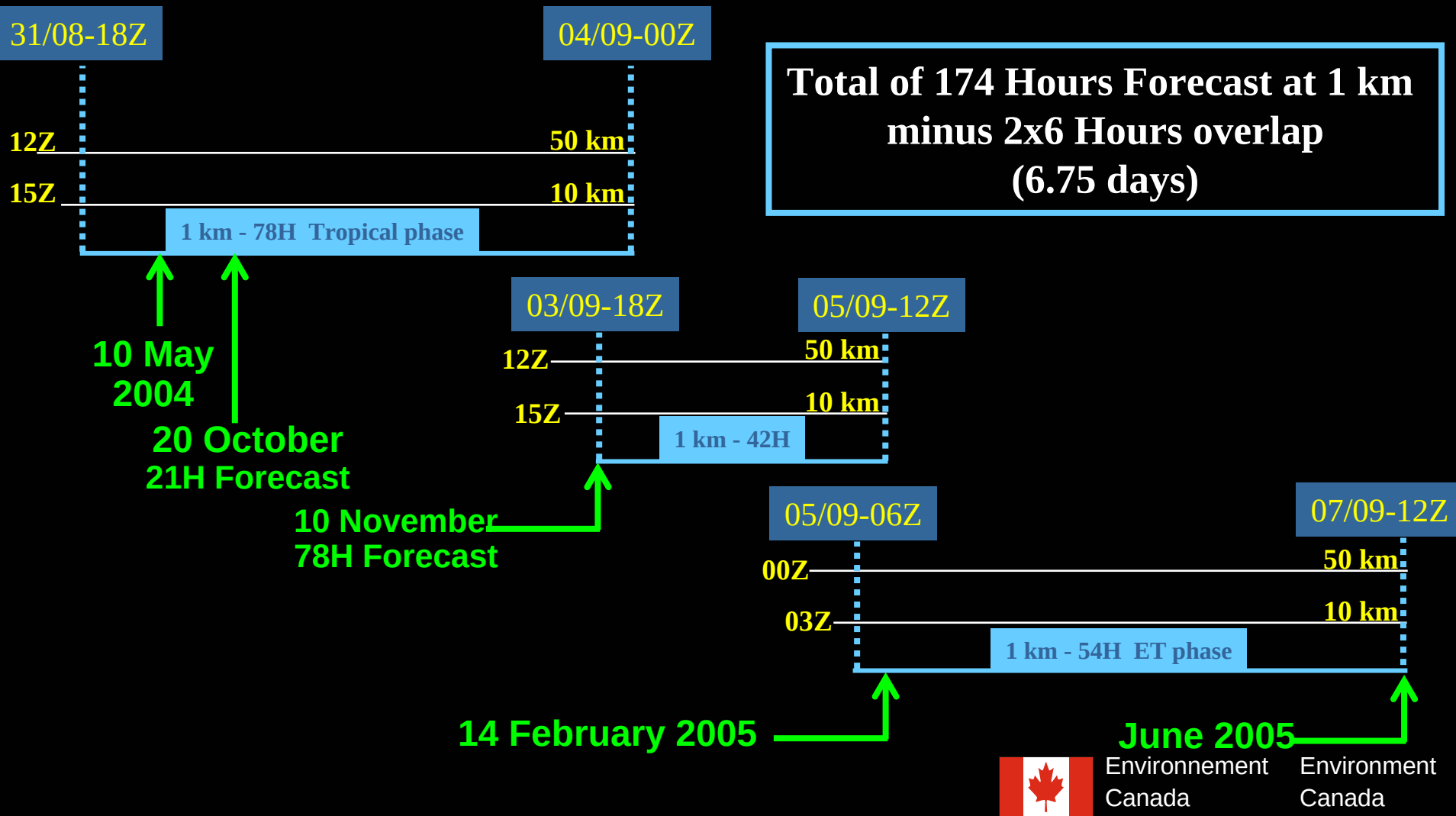
Grid Strategy for EARL on the ES: 3 Stages Rotated Mercator grids



Memory: 7 Tb
CPUs: 22 x 180 (3960)
Steps: 104400 X 6 sec.
Wall clock: 7-8 days

Outer 50 km grid: Initial and BCs from CMC analysis

Time strategy for the Simulation of the Full Lifecycle of Hurricane EARL on the ES



Total of 174 Hours Forecast at 1 km minus 2x6 Hours overlap (6.75 days)

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Data: Nearing Catastrophe

	Full domain 11000 x 8640	Reduced domain 3000 x 2000	Full Domain Averaged 4 DX	Full Domain Averaged 10 DX
10 min		3D: U,V,W,T,P,HU, QN,QP,QI,QG		3D: U,V,W,T,P,HU, QN,QP,QI,QG
15 min	2D: QR, PN, RT, PR, FC, FV			
30 min			3D: U,V,W,T,P,HU, QN,QP,QI,QG	
	8 x 64 files 49 GBytes	24 x 12 files 151 GBytes	4 x 64 files 29 GBytes	4 x 64 files 14 GBytes

Grand total: 1300 files, 243 GBytes/4H ➔ **4.7 TB** for first 78H

Database currently being assembled/maintained at RPN

All data compressed to 16 bits

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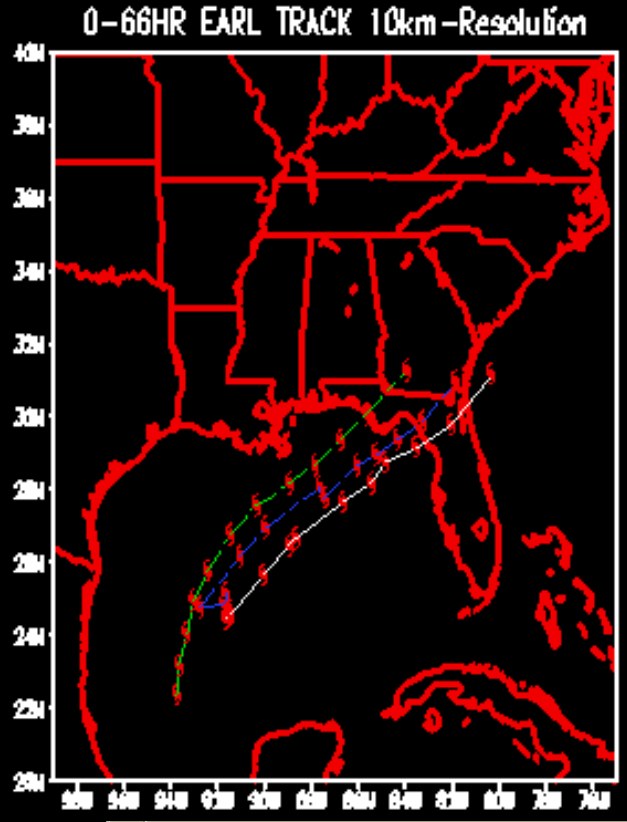

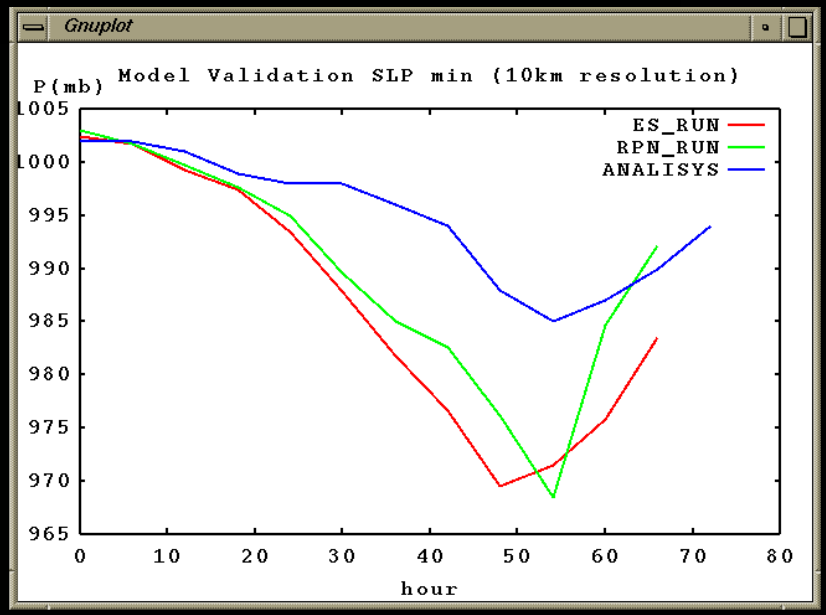

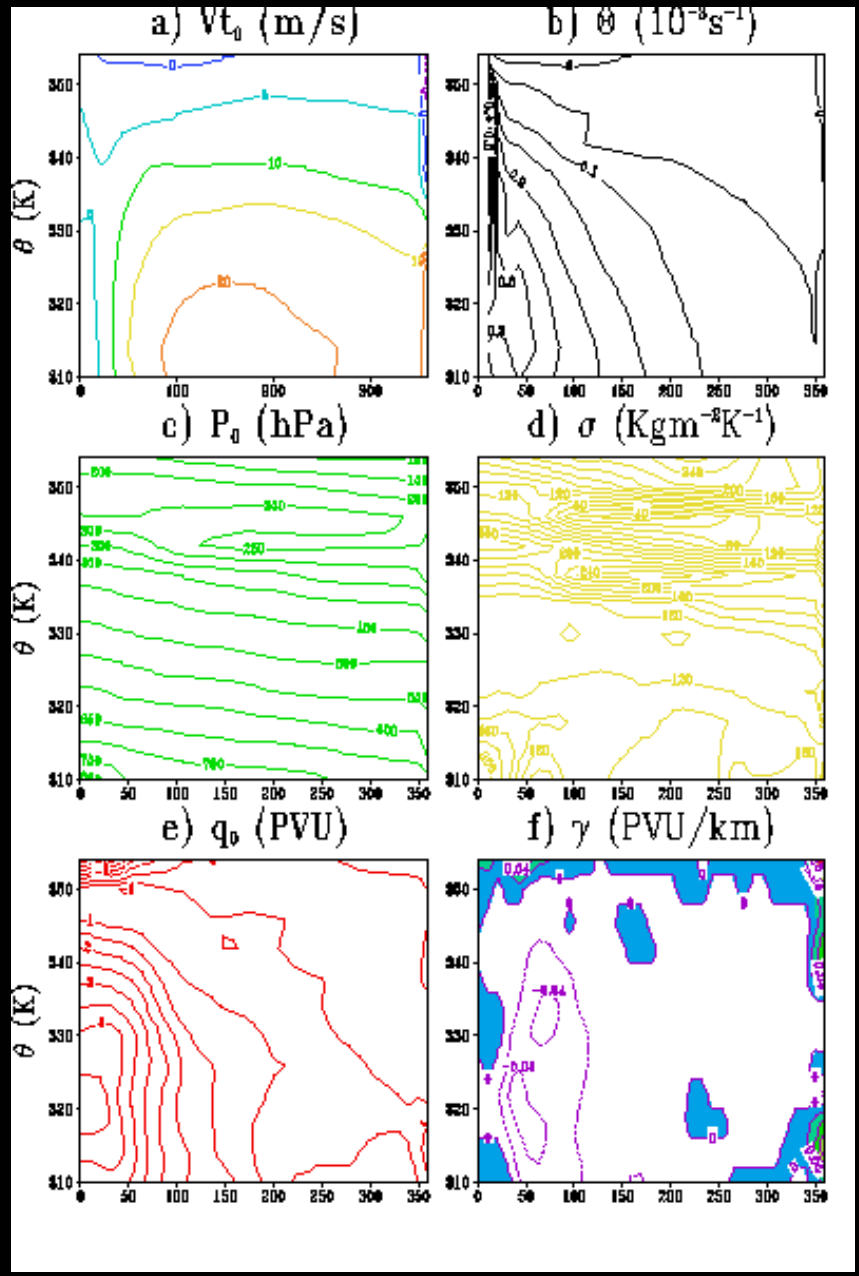

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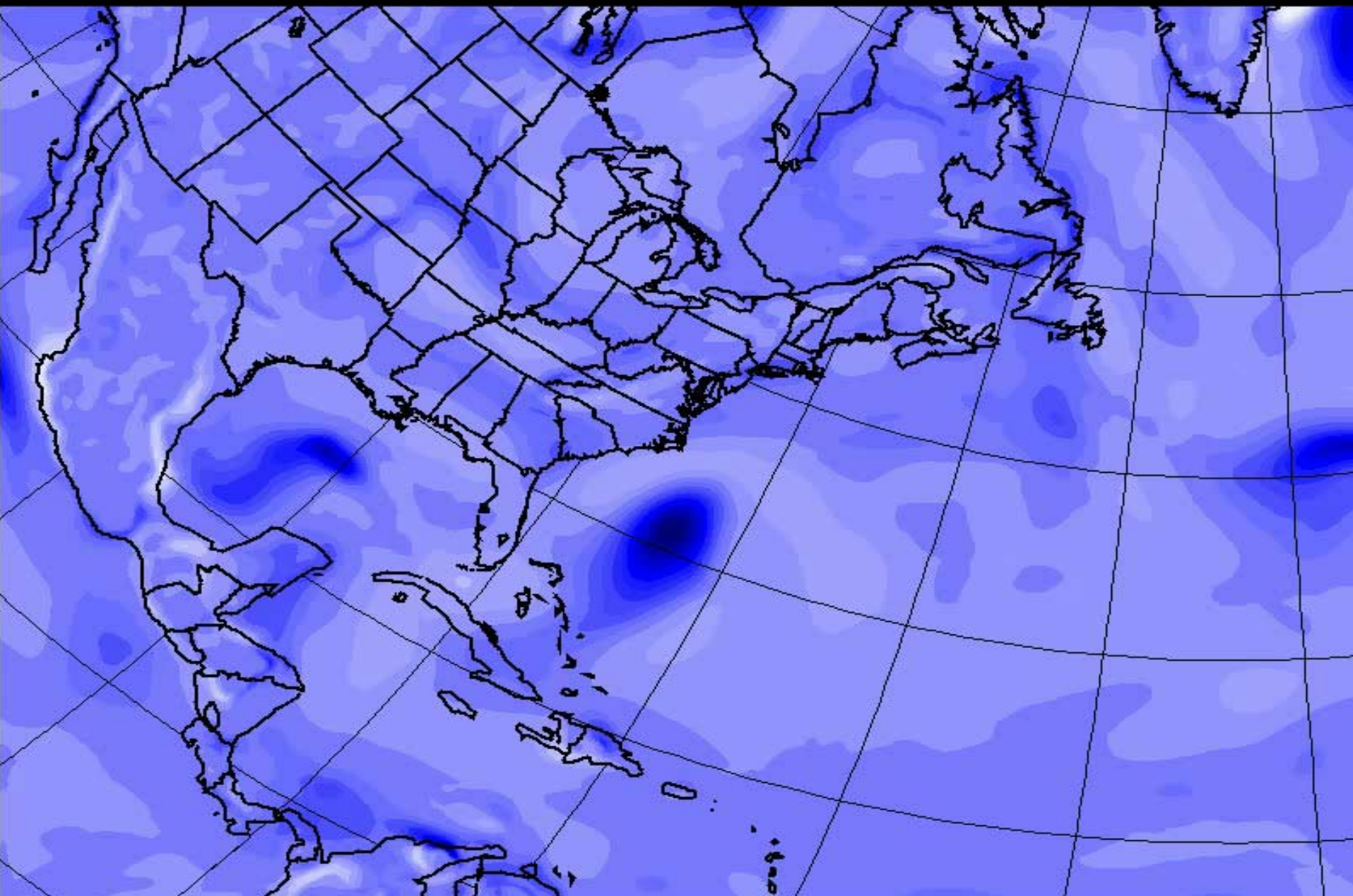
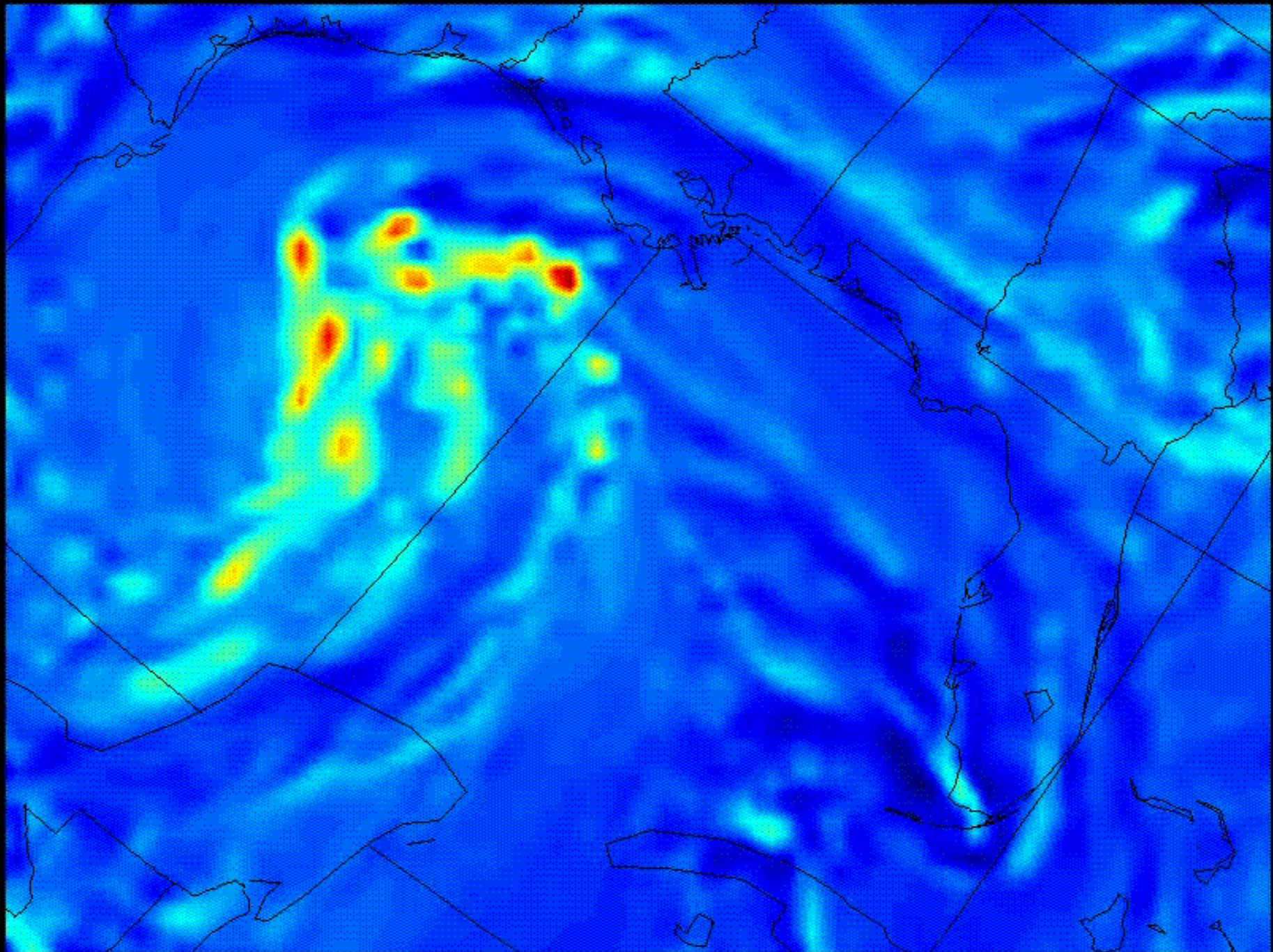
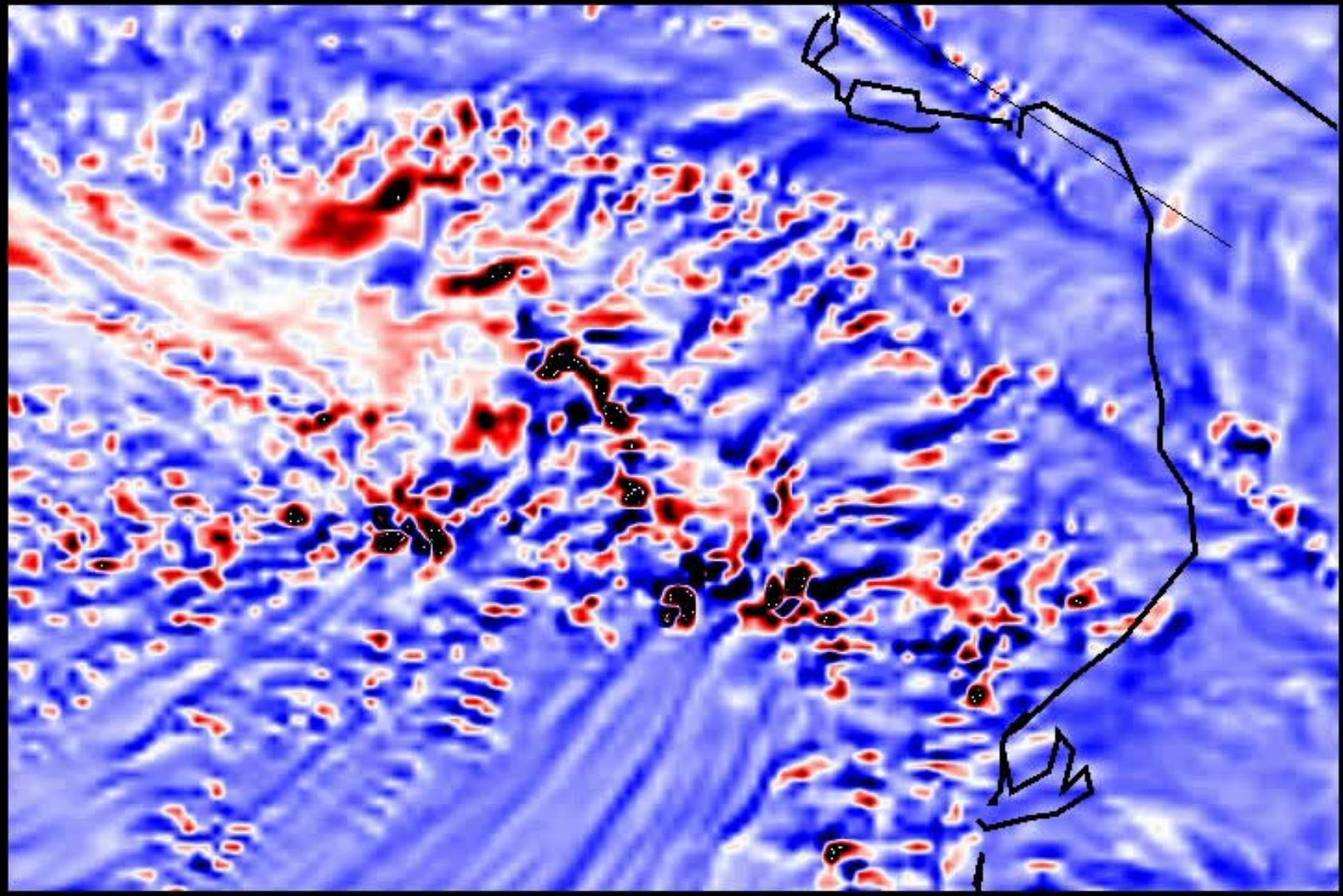
Relative Vorticity at 950 hPa (10km)



Relative Vorticity 950 hPa from 10km run

12Z 01/09 to 00Z 04/01





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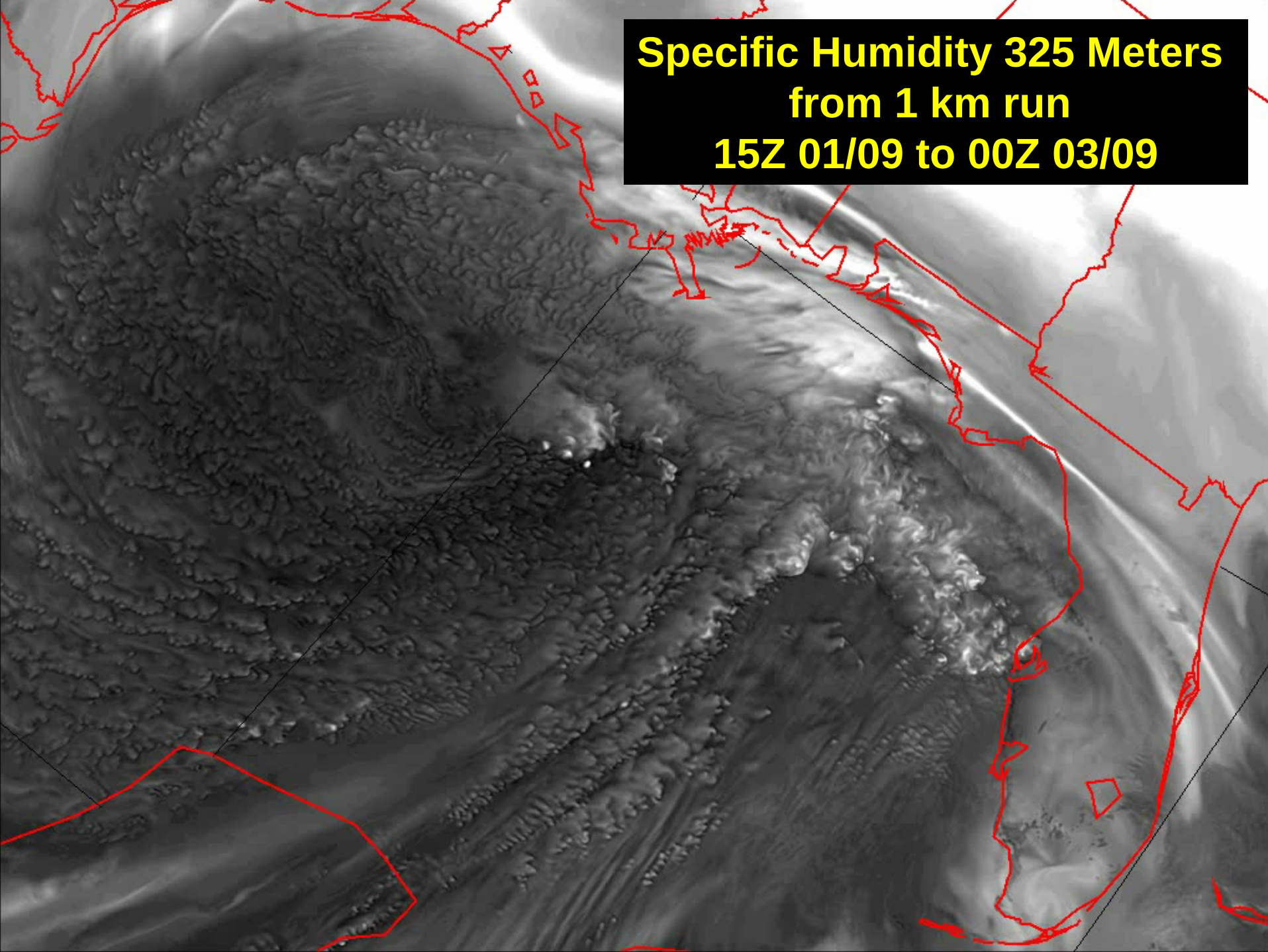

Specific Humidity 325 Meters
from 1 km run
15Z 01/09 to 00Z 03/09

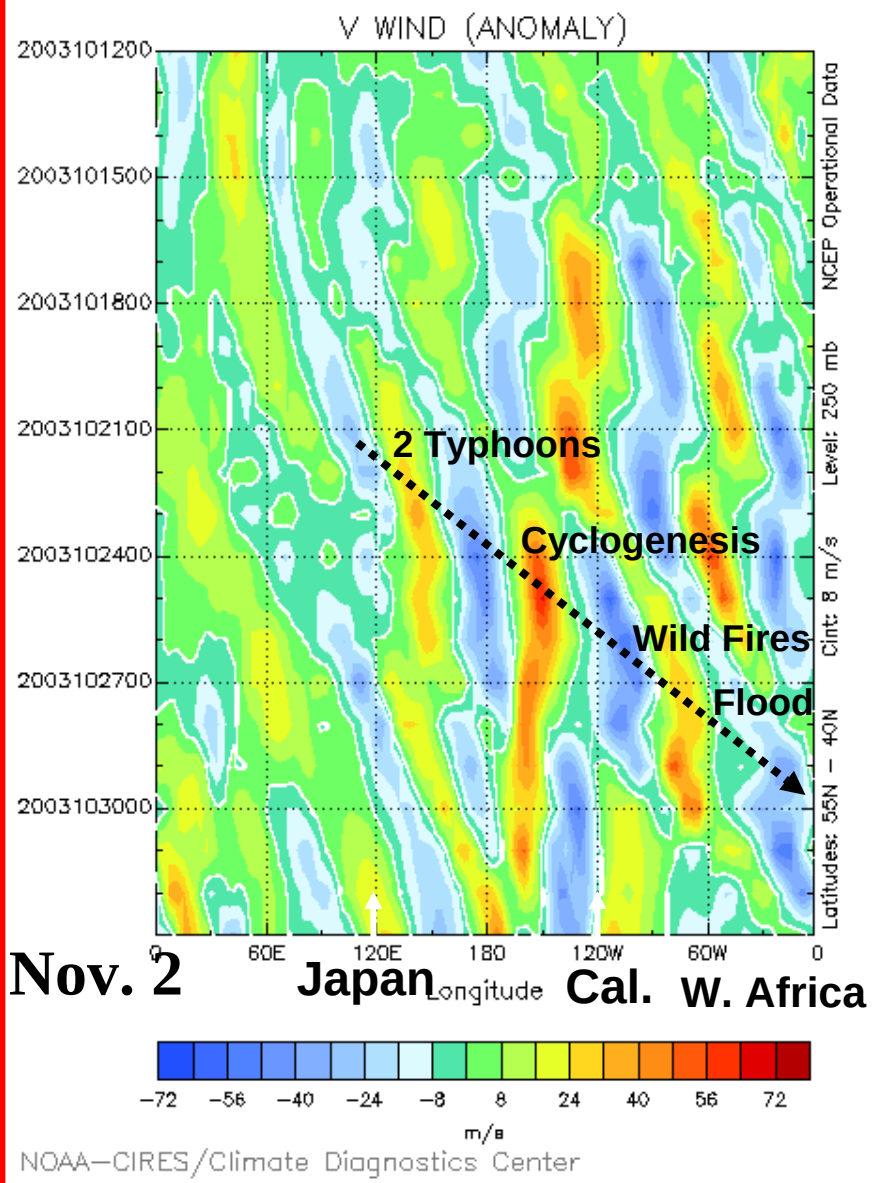
Time/Longitude: 250-mb Meridional Wind (m s^{-1}); 55-40N.

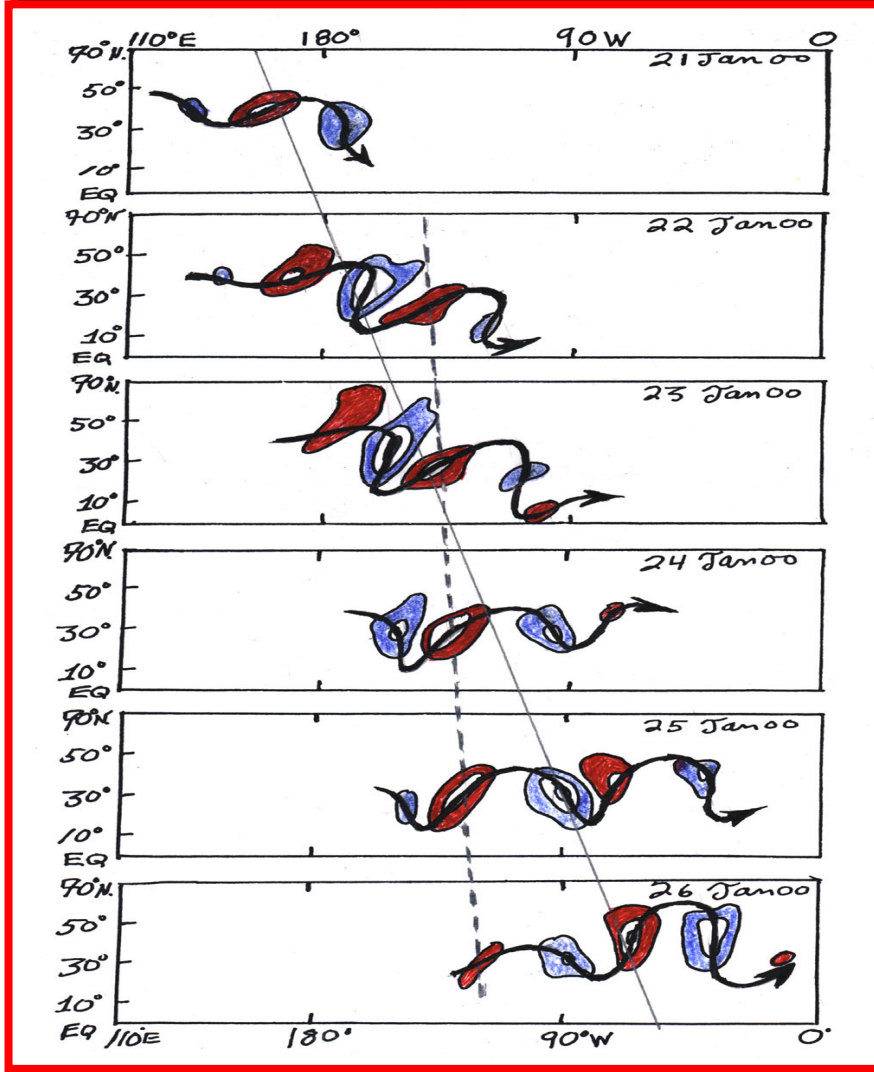
Oct. 12

Oct. 18

Oct. 24

Oct. 30





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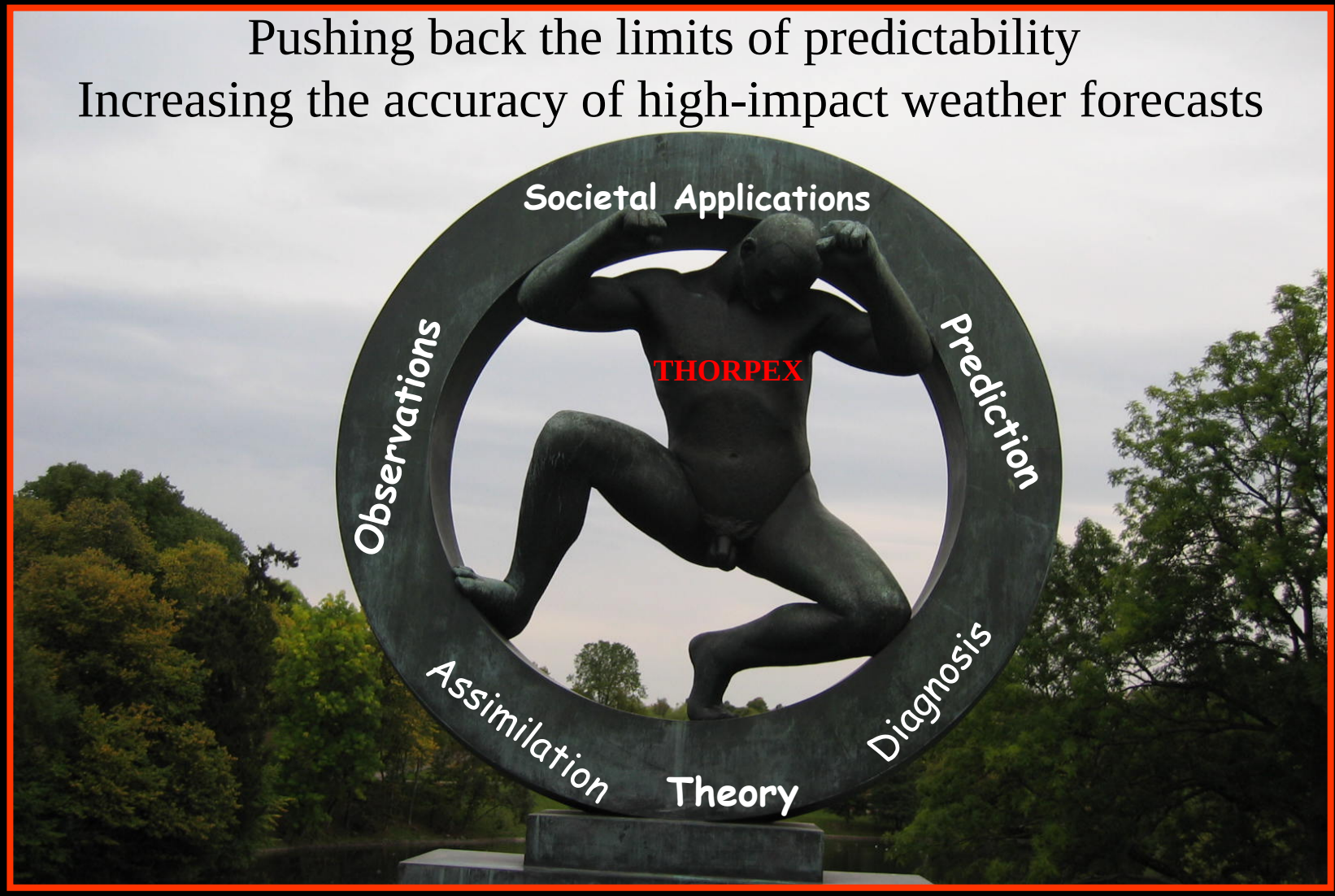
Reality check

- A full lifecycle reference simulation of hurricane Earl on the Earth Simulator for process studies. Order 1 wall clock hour of computation / 1 hour of simulation on 4000 vector processors.

- ES like computing power not available soon in Operational centers

- NWP hurricane strategy at the Meteorological Service of Canada:
  - better hurricane track predictions with **global-meso GEM** and 4D-VAR
  - **2-way nested vortex following LAM configuration** to obtain proper precipitation and intensity that depends on angular momentum transport, hence high resolution

Pushing back the limits of predictability
Increasing the accuracy of high-impact weather forecasts



THE END

Thank You !

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