Large
Atmospheric
Computation on the
Earth
Simulator

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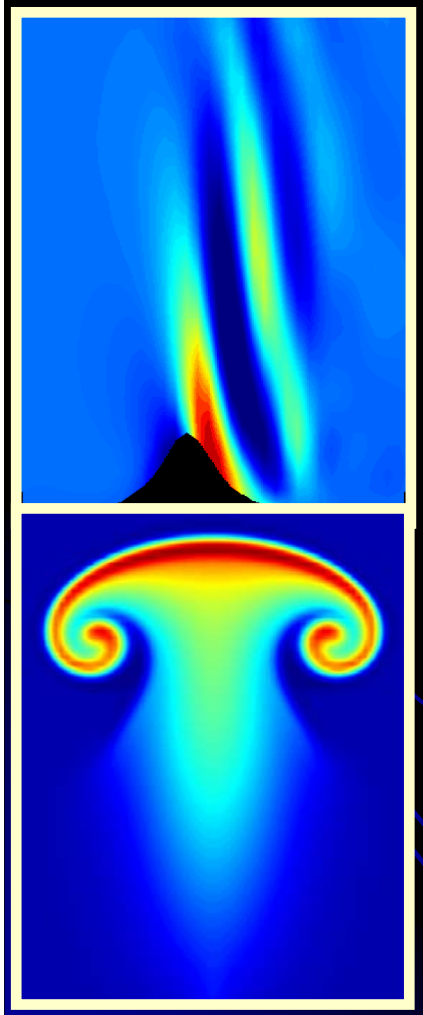
with
MC2

The Canadian MC2 Model v4.9.8

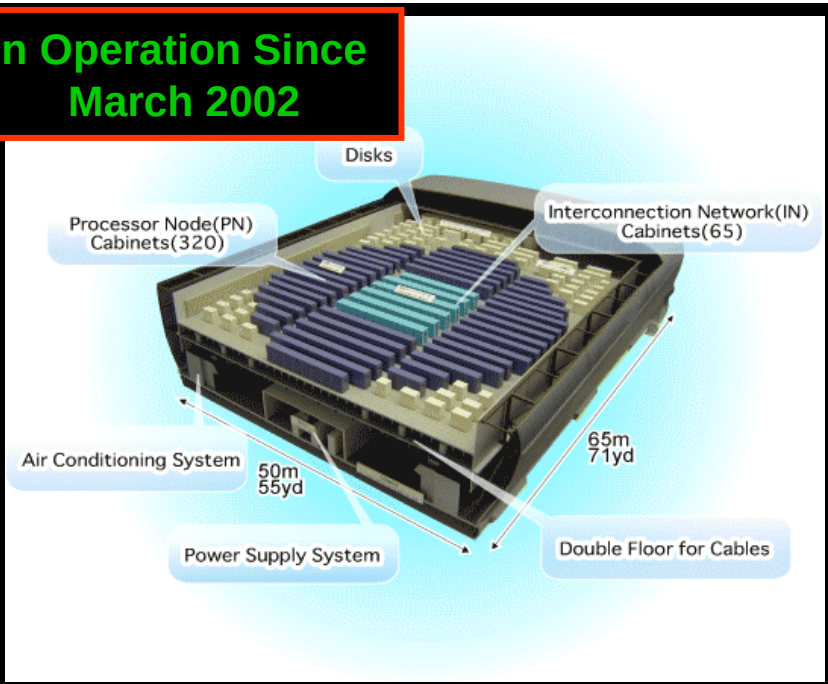
Mesoscale Compressible Community Model



- 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_12_05_04.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

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

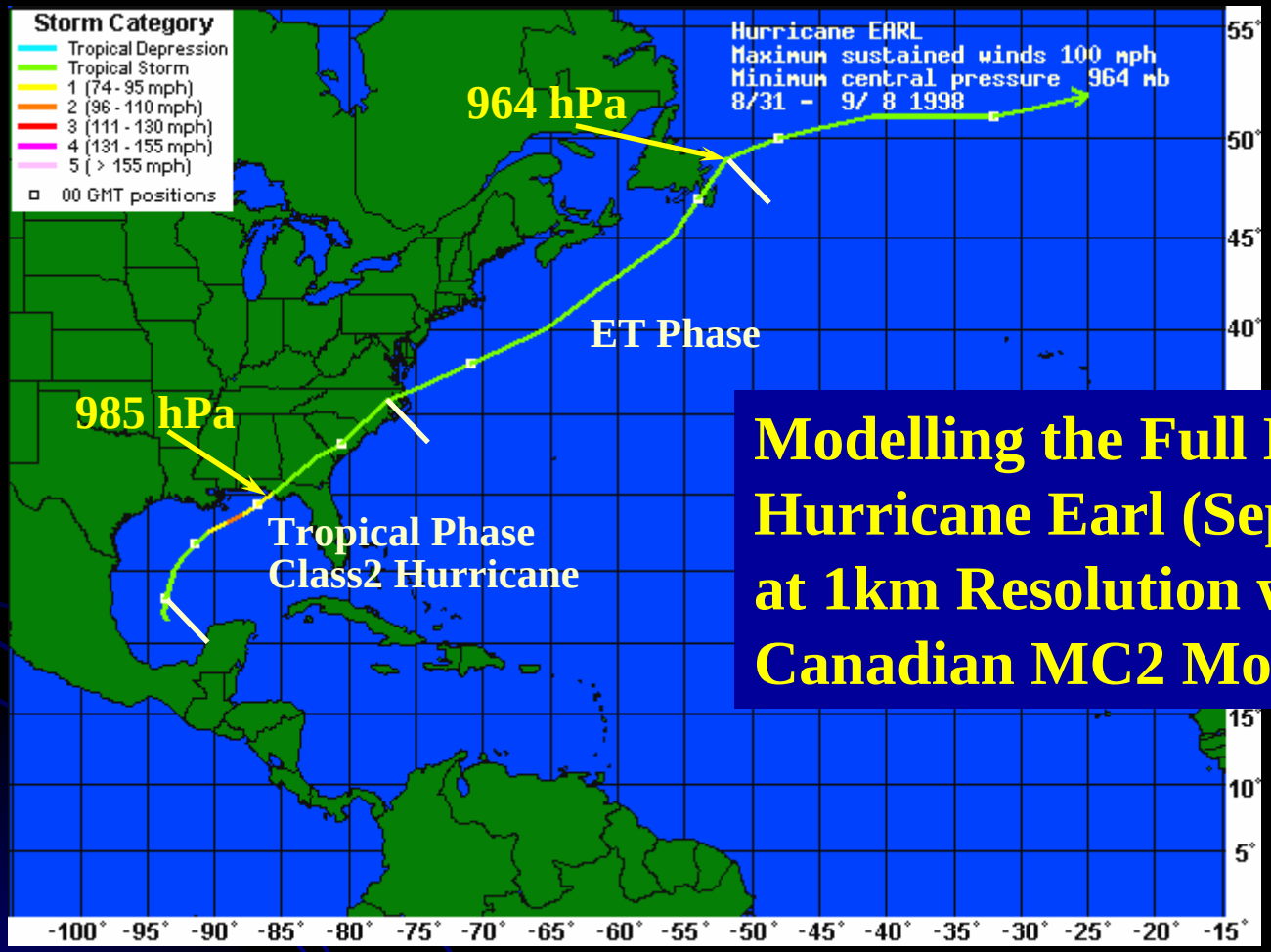
Amdahl's law Parallelization ratio

Sustained performances:

36 TF on some benchmarks (640 nodes)
27 TF with AFES (640 nodes)
(10 km global climate simulation)

13 TF with MC2 (495 nodes)
(1 km 11000 x 8640 x 51 grid)
(3.2 GF/Pe)

LACES: A Grand Challenge project on the Earth Simulator

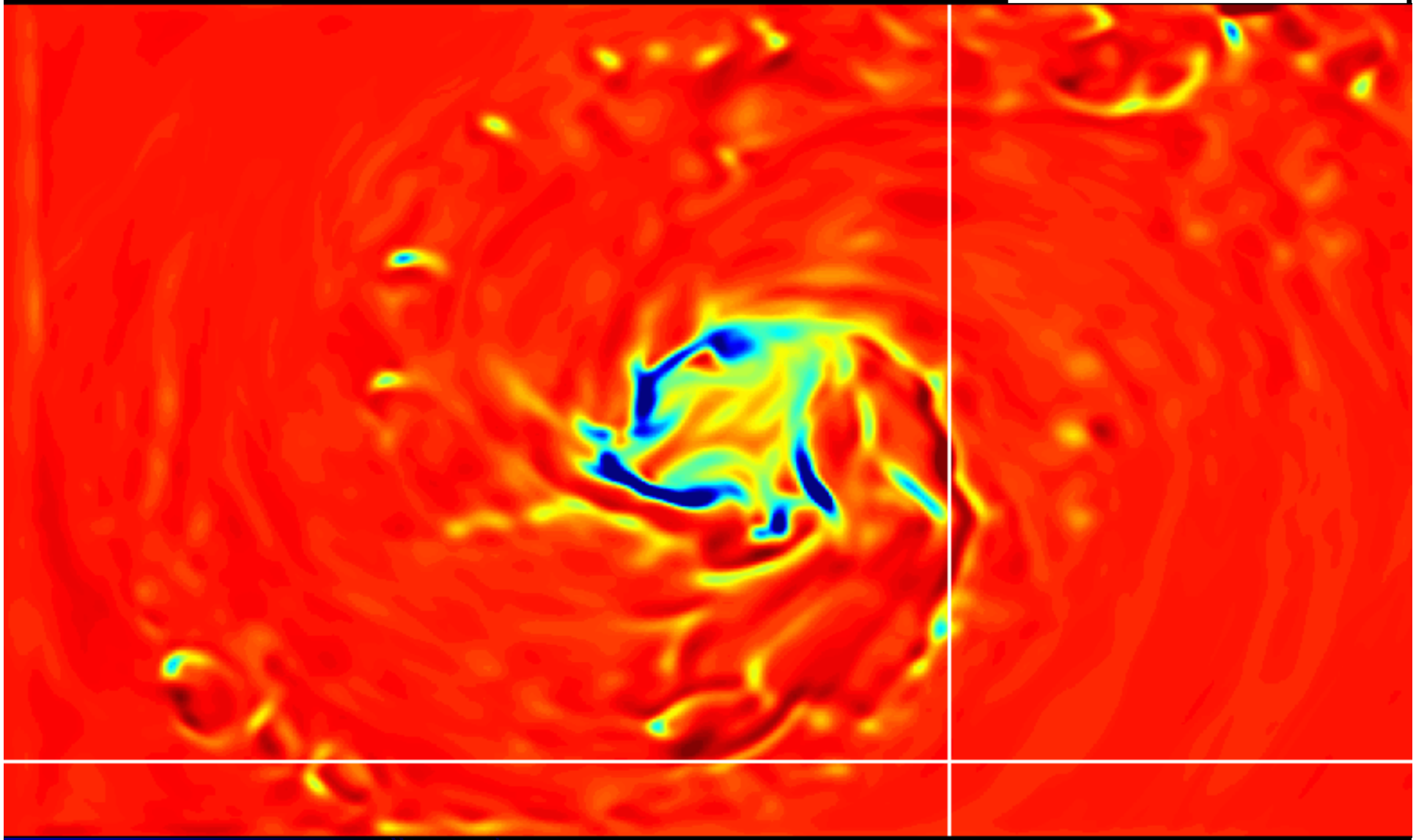


Modelling the Full Lifecycle of Hurricane Earl (Sept 1998) at 1km Resolution with the Canadian MC2 Model

September 1998: Classified as a very active TC period

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

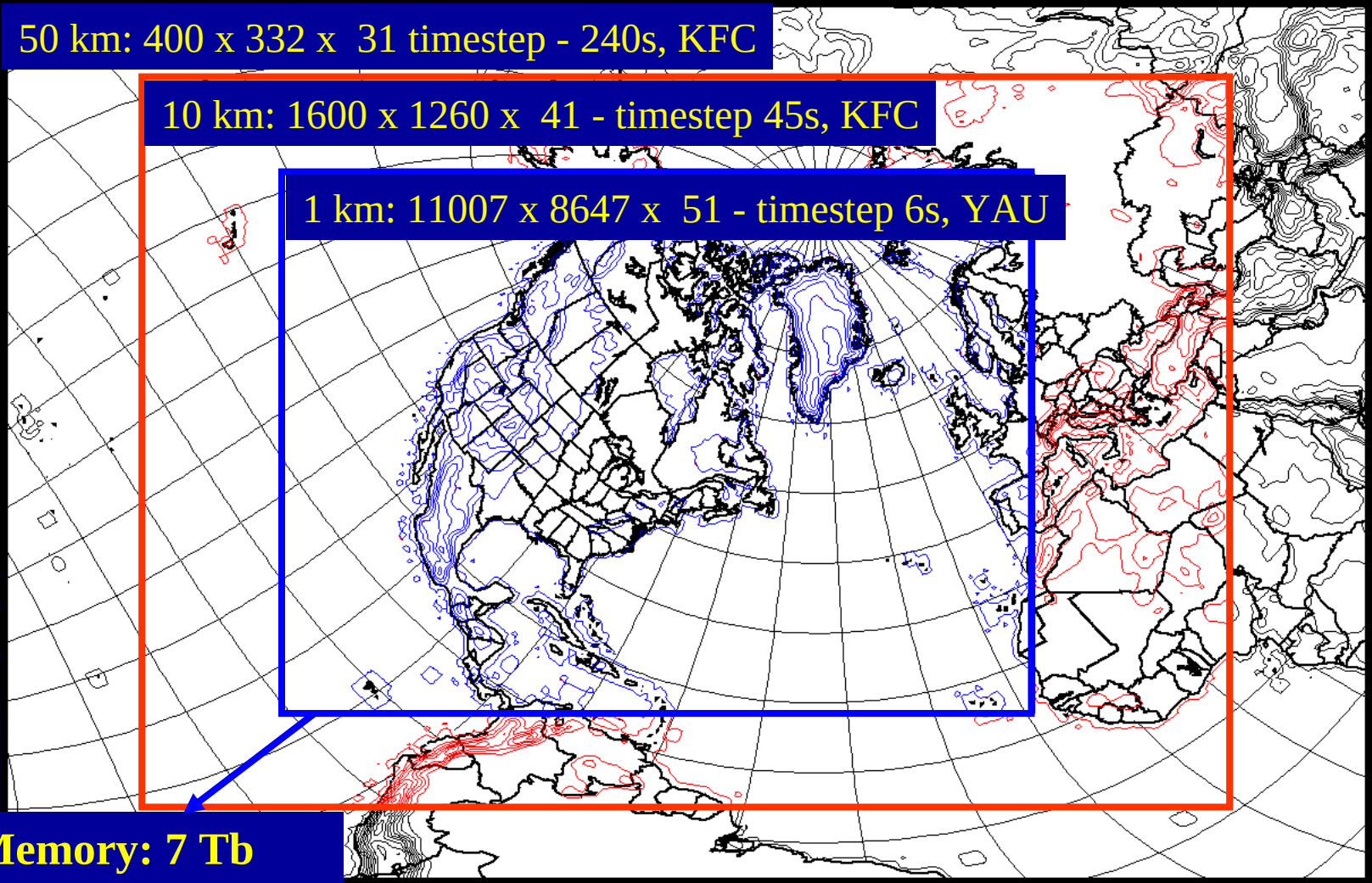
COMPARE III Workshop
Tokyo, Japan
December 13-15, 1999



frame every hour

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

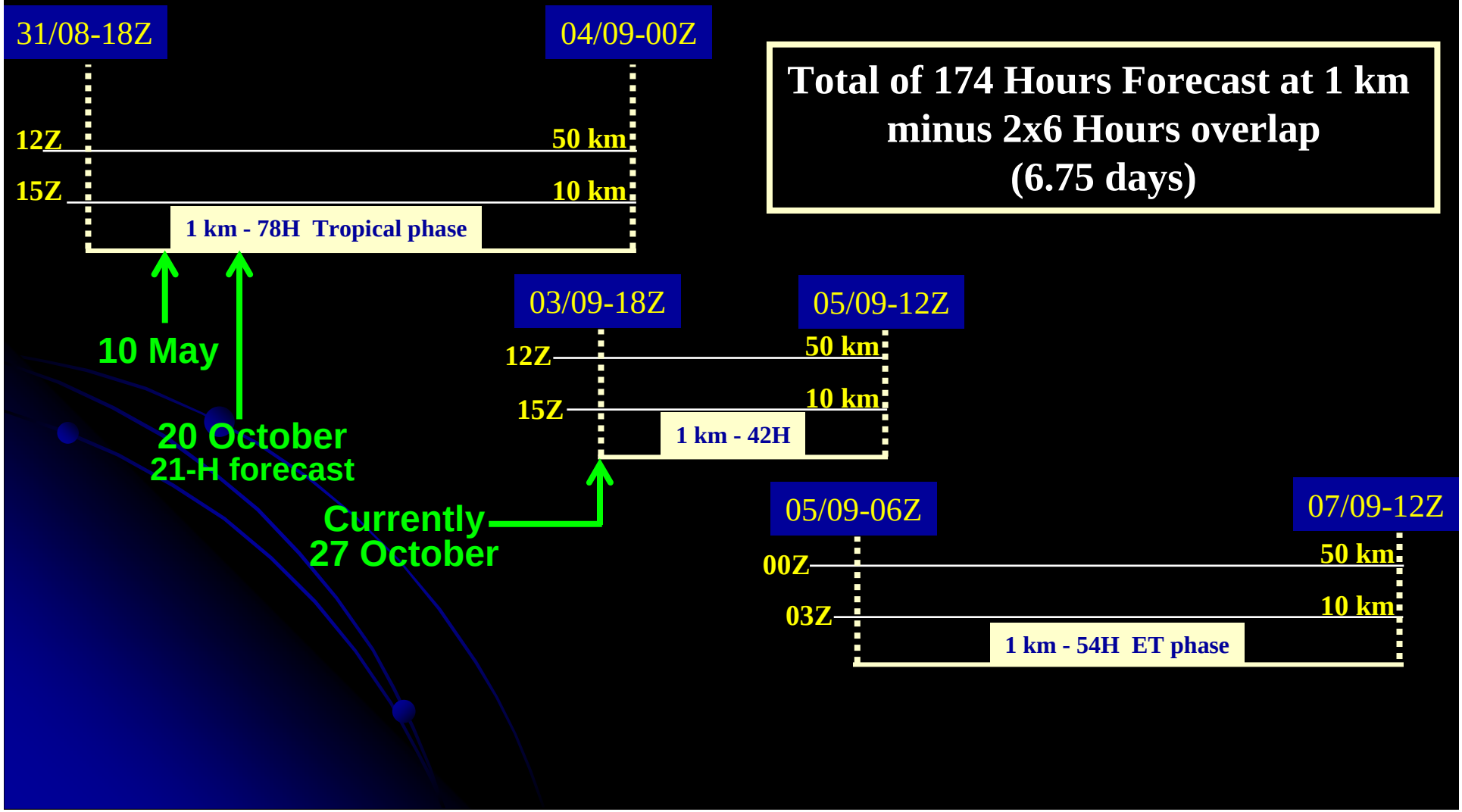
Grid Strategy for EARL on the ES: 3 Stages Rotated Mercator grids



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

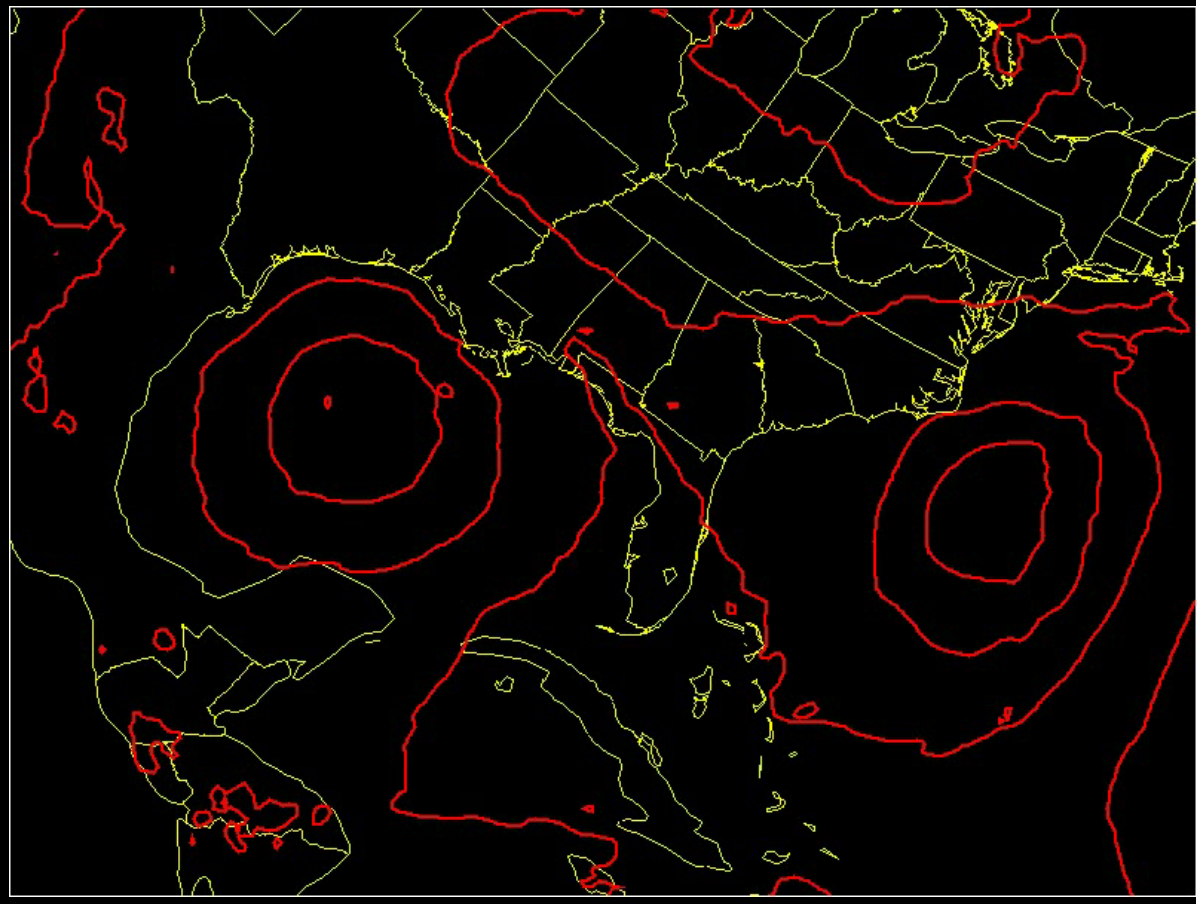
Time strategy for the Simulation of the Full Lifecycle of Hurricane EARL on the ES



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

- Elliptic iterative DM pressure solver (4.8 giga equations at once)
- Parallel I/O software
  - Model output
  - Restart files
- Startup of order 4000 MPI processes on a vector architecture
- Predictibility issues at 1 km reso. on a very large domain

Main Challenges



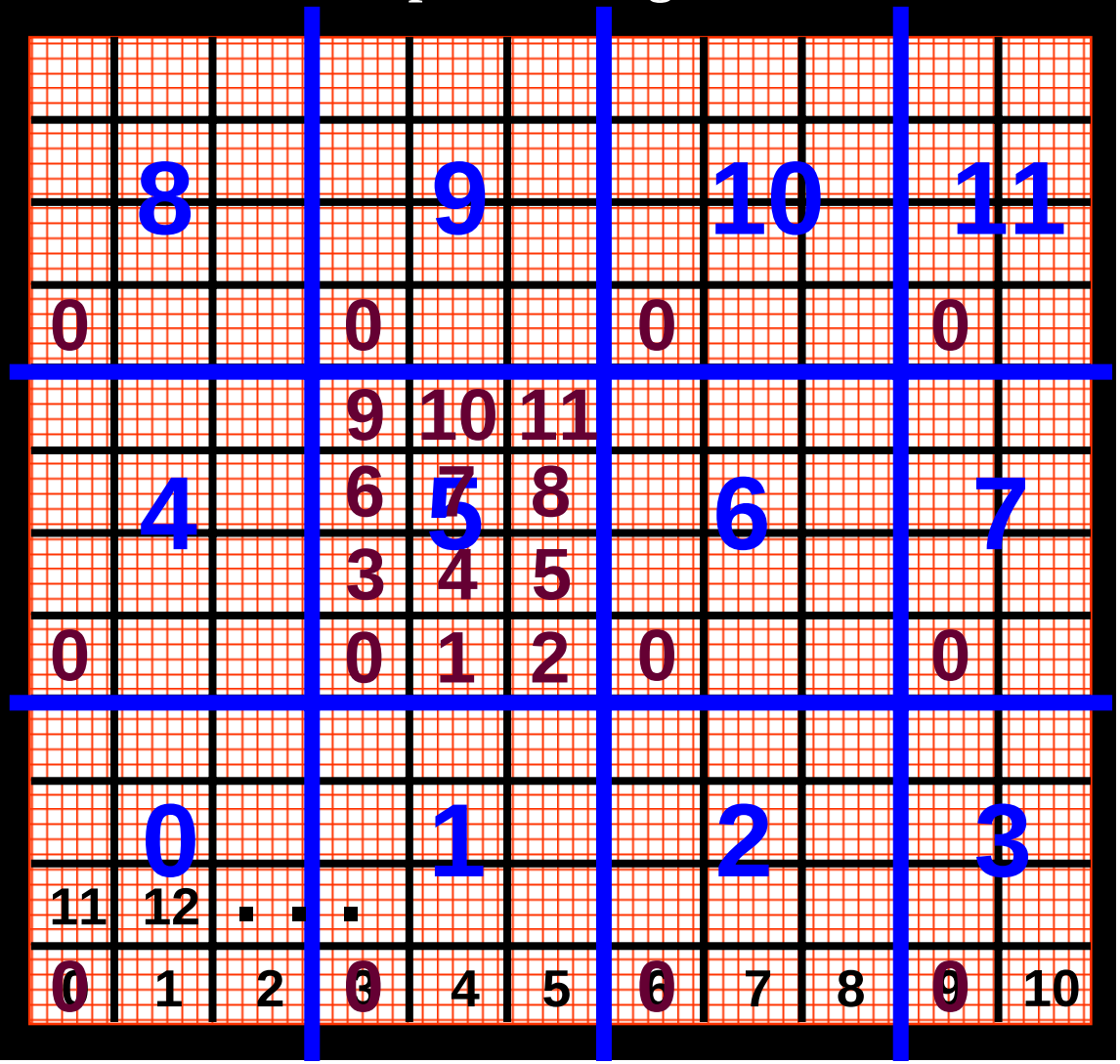
Mean Sea Level Pressure
from 10km run
12Z 01/09 to 00Z 04/01

Technical: I/O - an Important Issue

- Preprocessor MC2NTR gone
- All computation performed within the DM main program
- Global distribute/collect removed

Scaling up with a subdomain size of 500 x 50 on vector processor system

Block partitioning the PEs



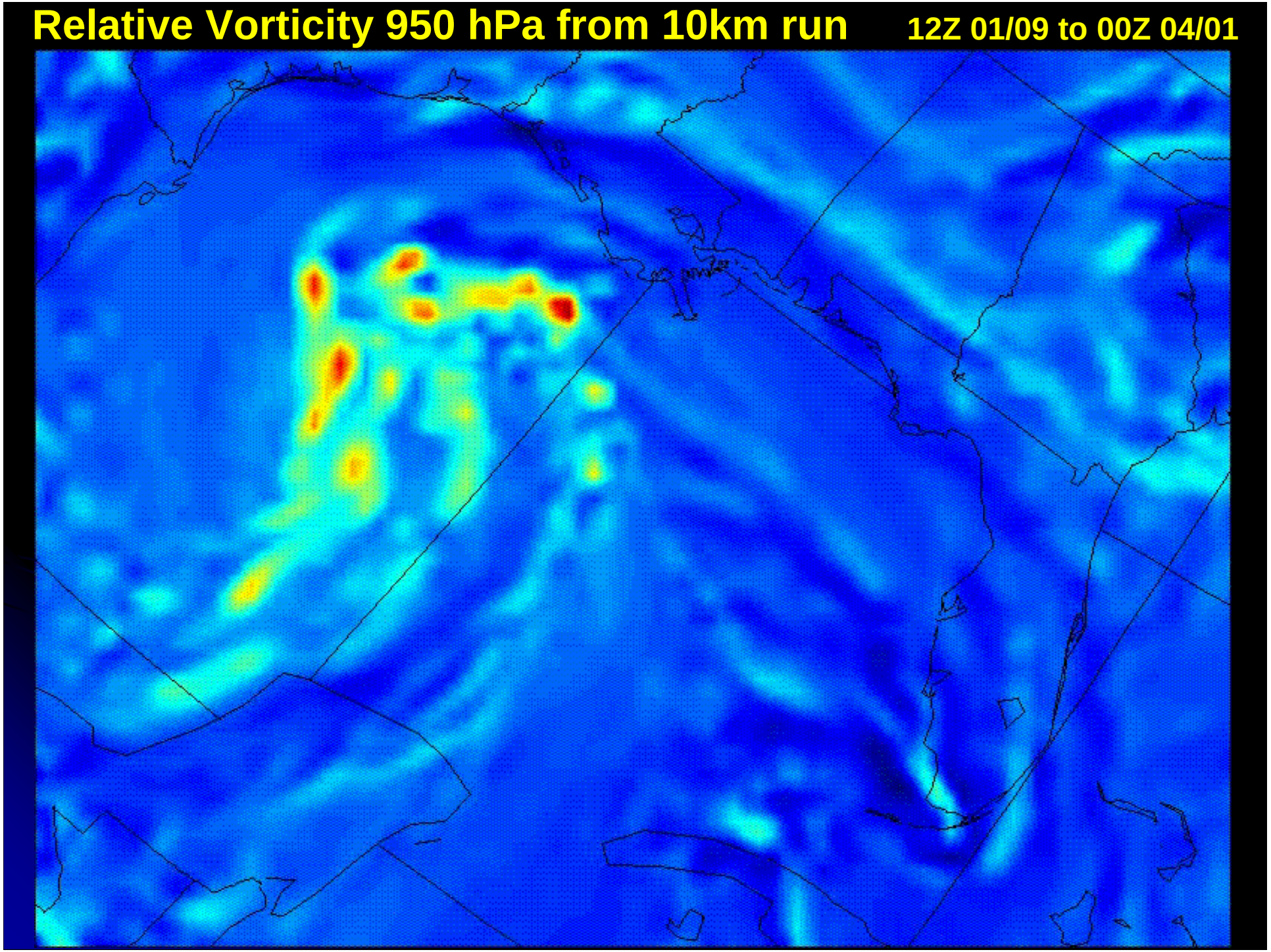
Data: Nearing Catastrophe

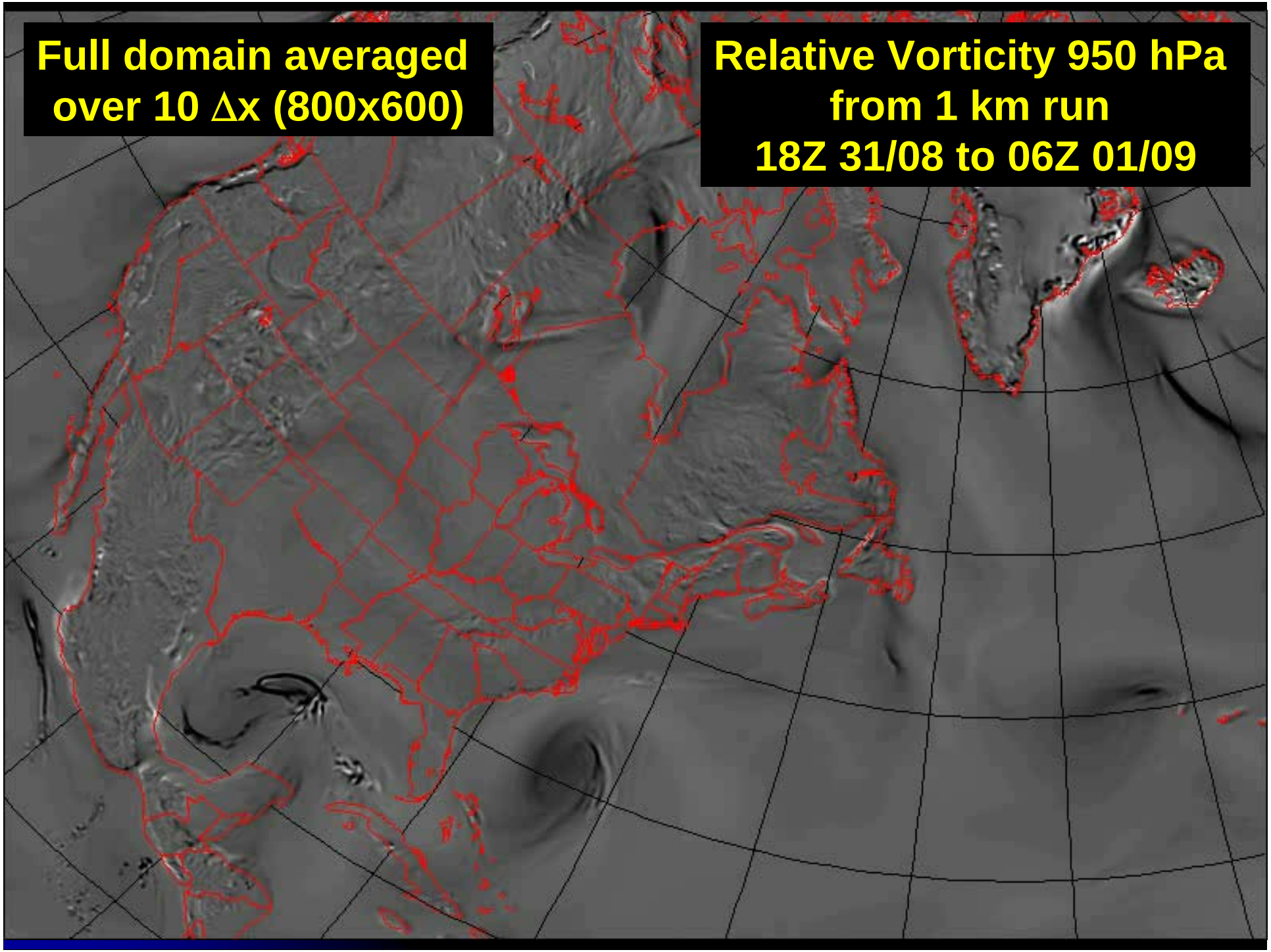
	Full domain 11000 x 8640	Reduced domain 3000 x 2000	Full Domain Averaged 4 DX	Full Domain Averaged 10 DX
10 min		3D: U,V,W,T,P,HU, QN,QP,QI,QG		3D: U,V,W,T,P,HU, QN,QP,QI,QG
15 min	2D: QR, PN, RT, PR, FC, FV			
30 min			3D: U,V,W,T,P,HU, QN,QP,QI,QG	
	8 x 64 files 49 GBytes	24 x 12 files 151 GBytes	4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

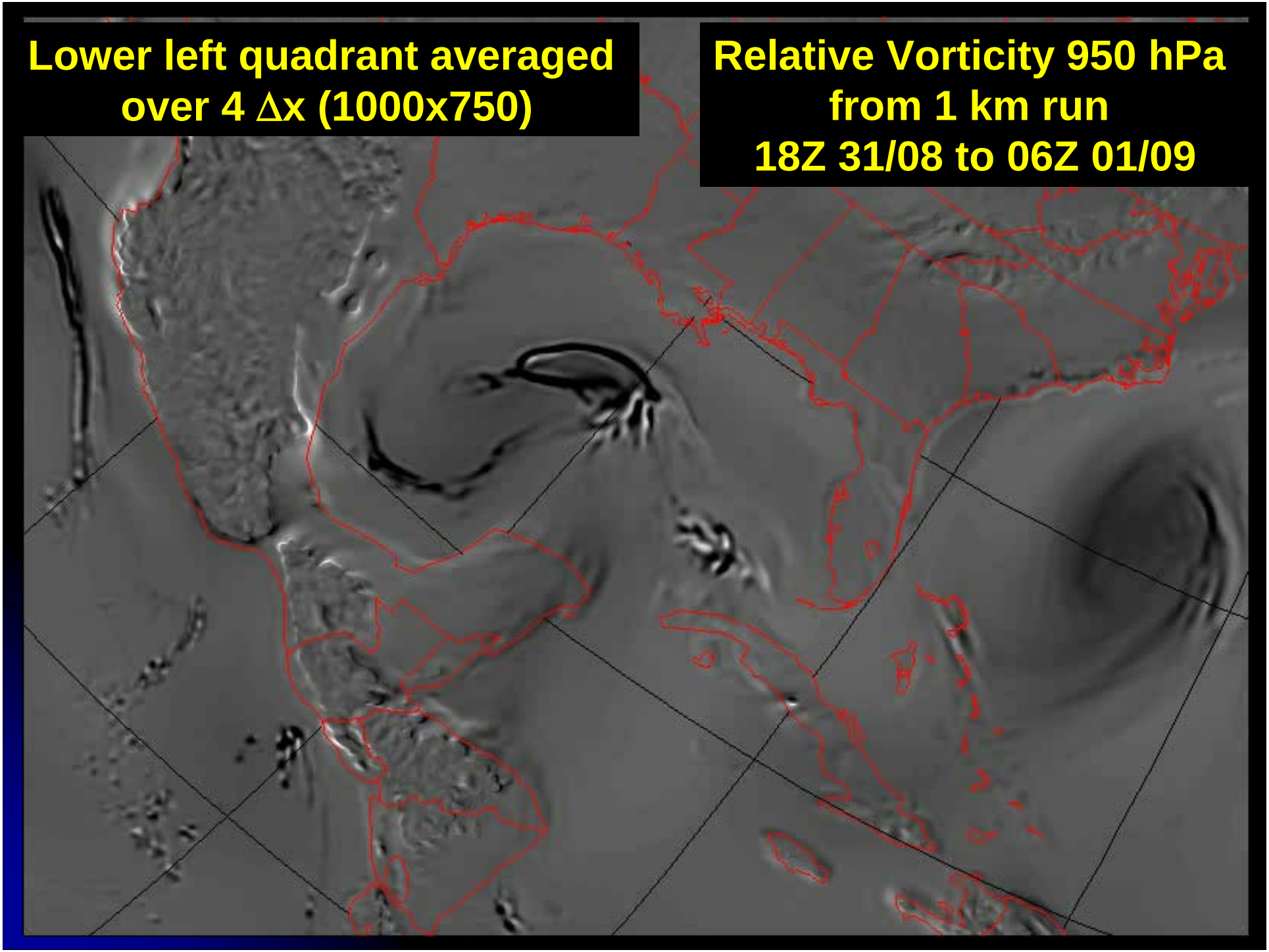
Grand total: 1300 files, 243 GBytes/4H ➔ **4.7 TB** for first 78H

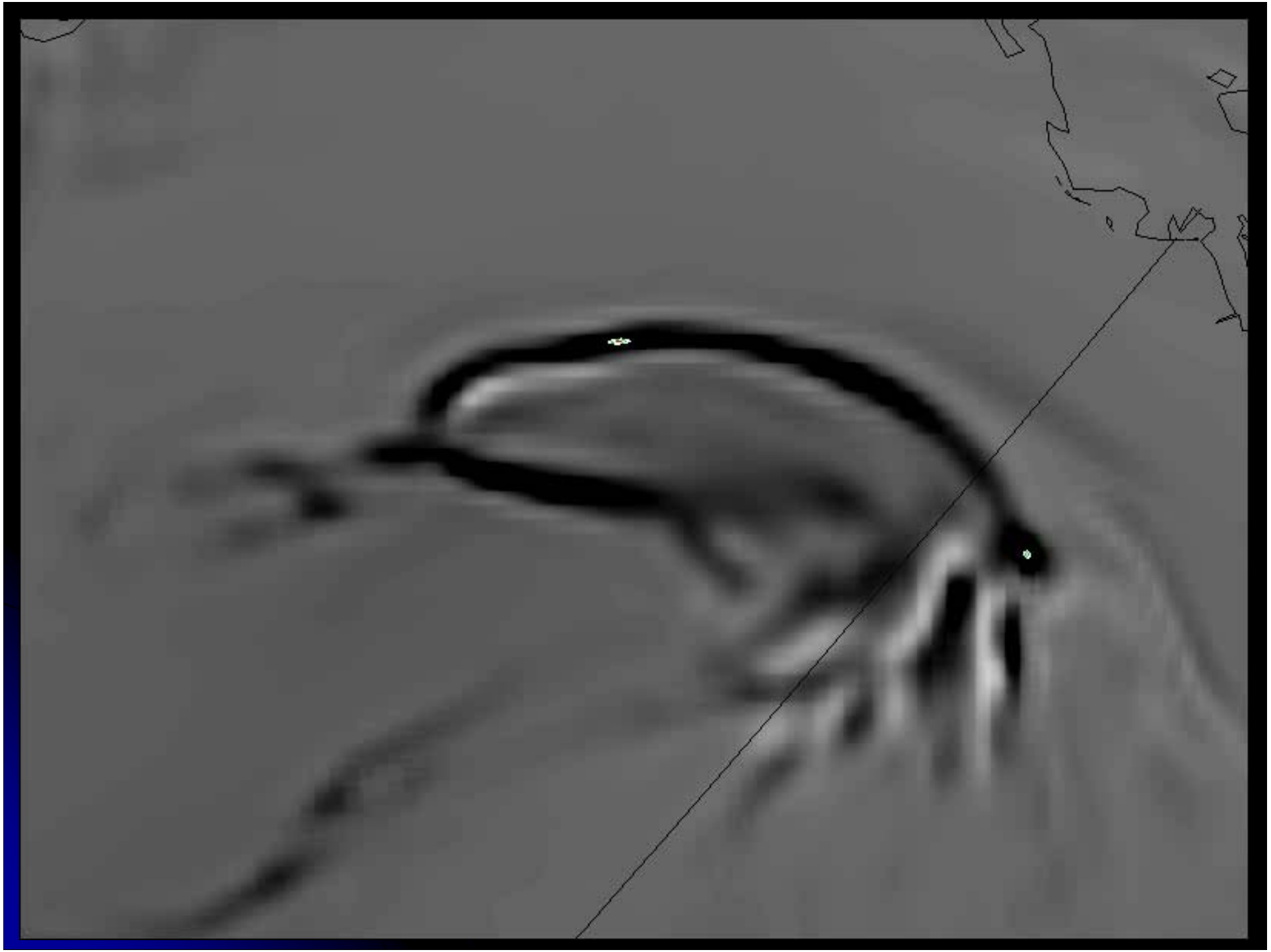
Database currently being assembled/maintained at RPN

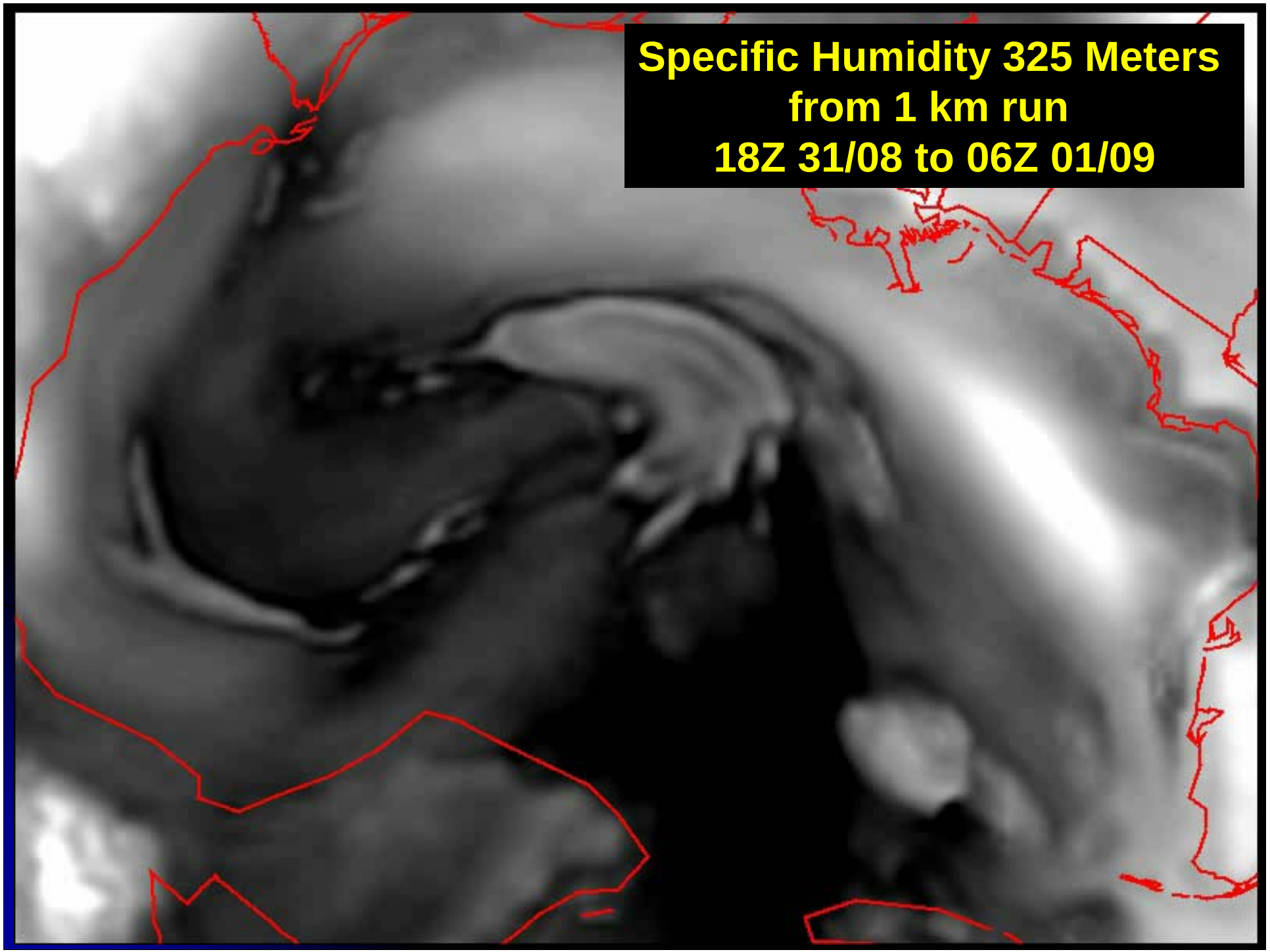
All data compressed to 16 bits


Relative Vorticity 950 hPa from 10km run
12Z 01/09 to 00Z 04/01


Full domain averaged
over 10 Δx (800x600)
Relative Vorticity 950 hPa
from 1 km run
18Z 31/08 to 06Z 01/09


Lower left quadrant averaged over 4 Δx (1000x750)
Relative Vorticity 950 hPa from 1 km run 18Z 31/08 to 06Z 01/09




Specific Humidity 325 Meters
from 1 km run
18Z 31/08 to 06Z 01/09

Future work:

- Complete database at RPN
- Diagnostic studies to start soon
- Lower/Higher resolution runs

Acknowledgment:

- Earth Simulator Center (ESC)
- Meteorological Service of Canada (MSC)
- Canadian Foundation for Climate and Atmospheric Science (CFCAS)

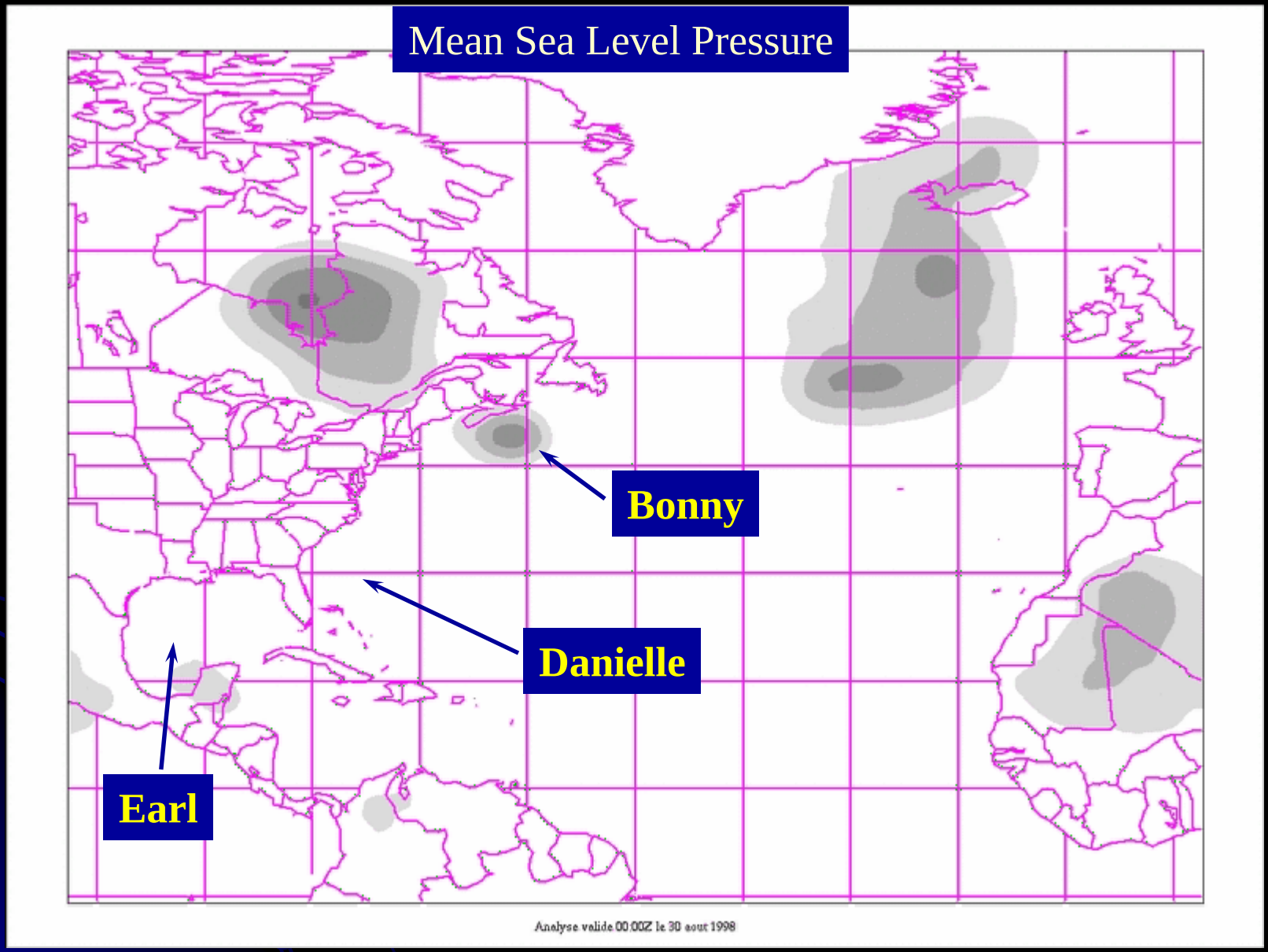
THE END

Thank You !

RPN

Environment Canada

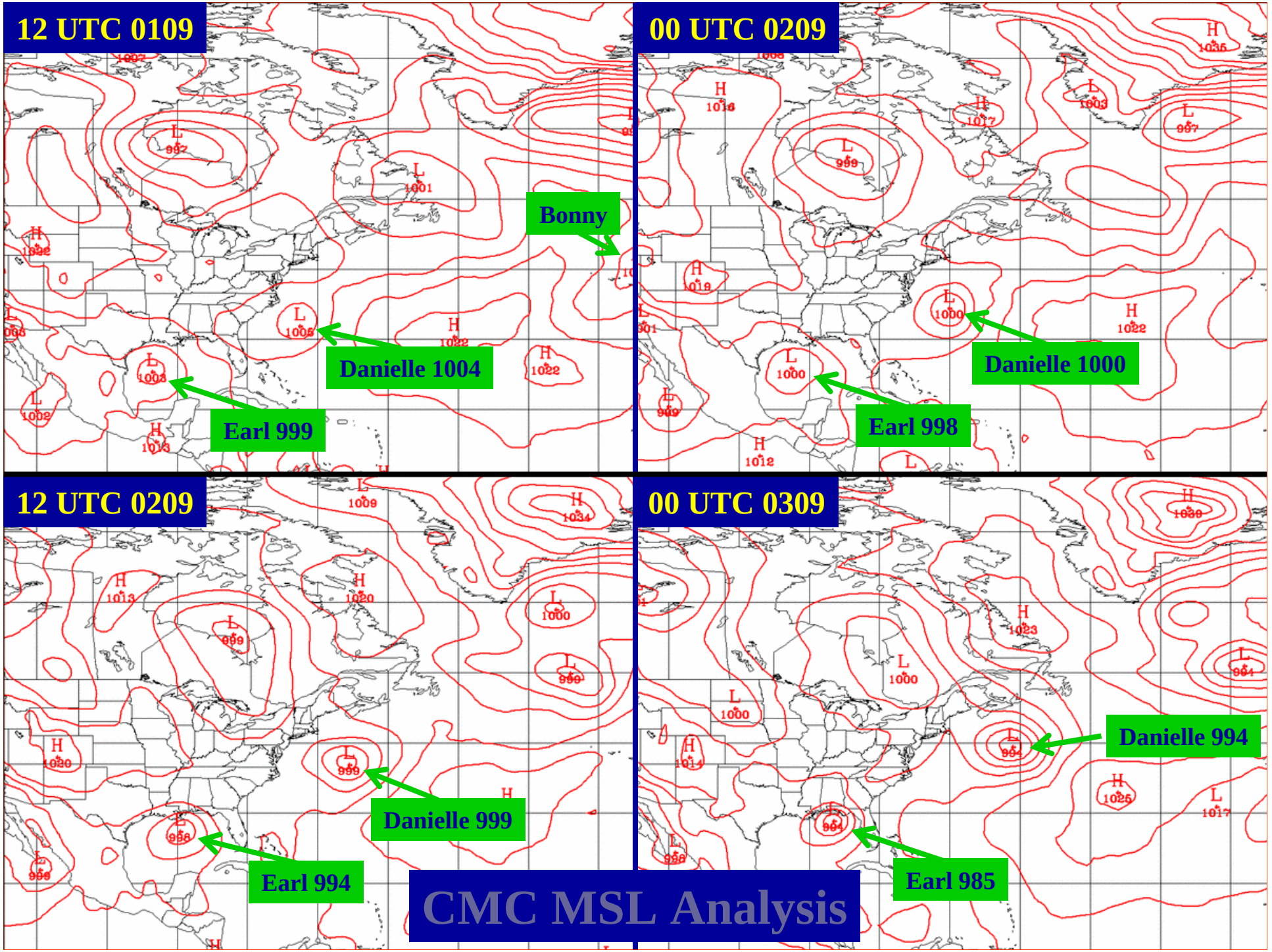
30 August to 9 September 1998

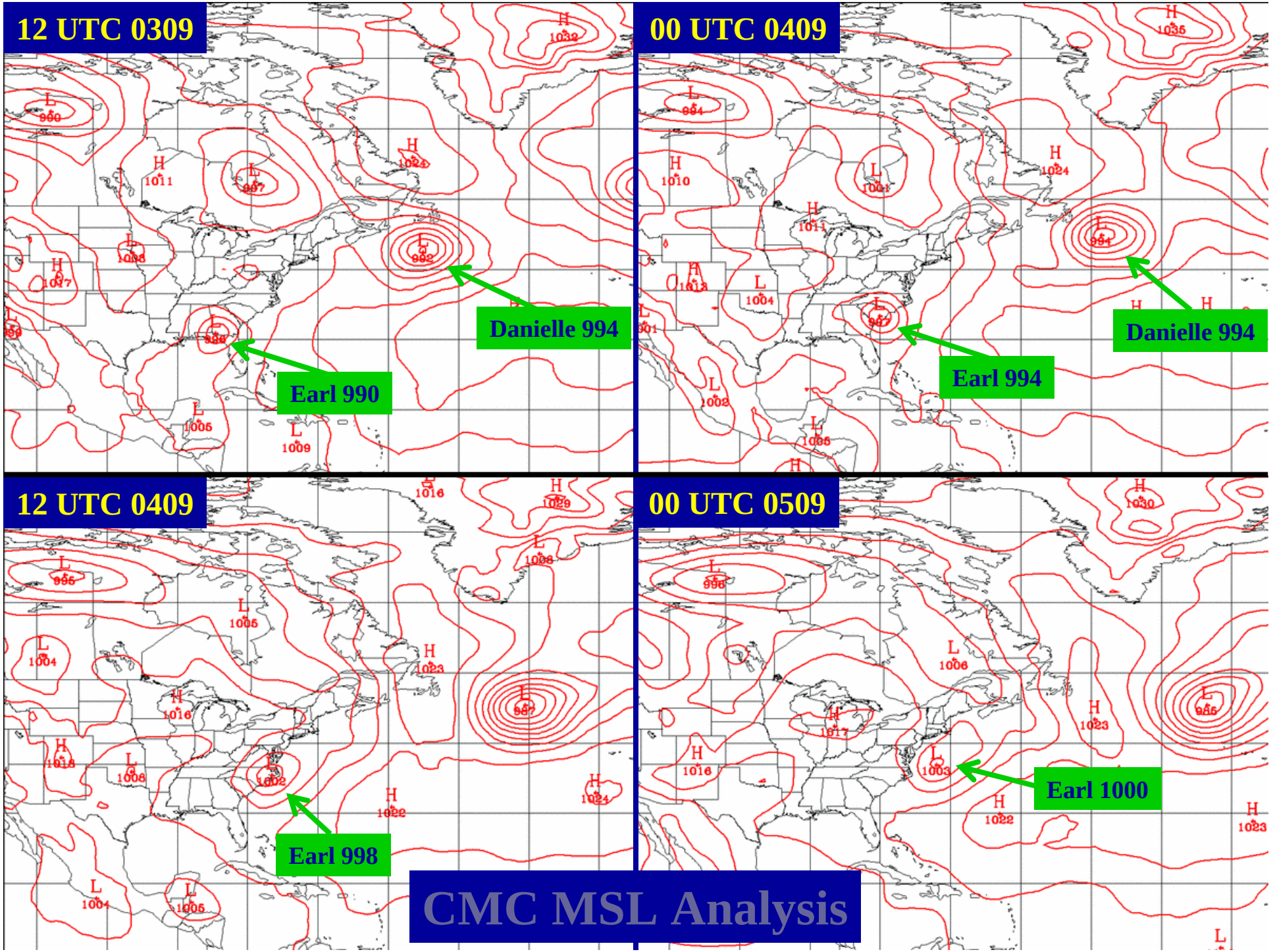


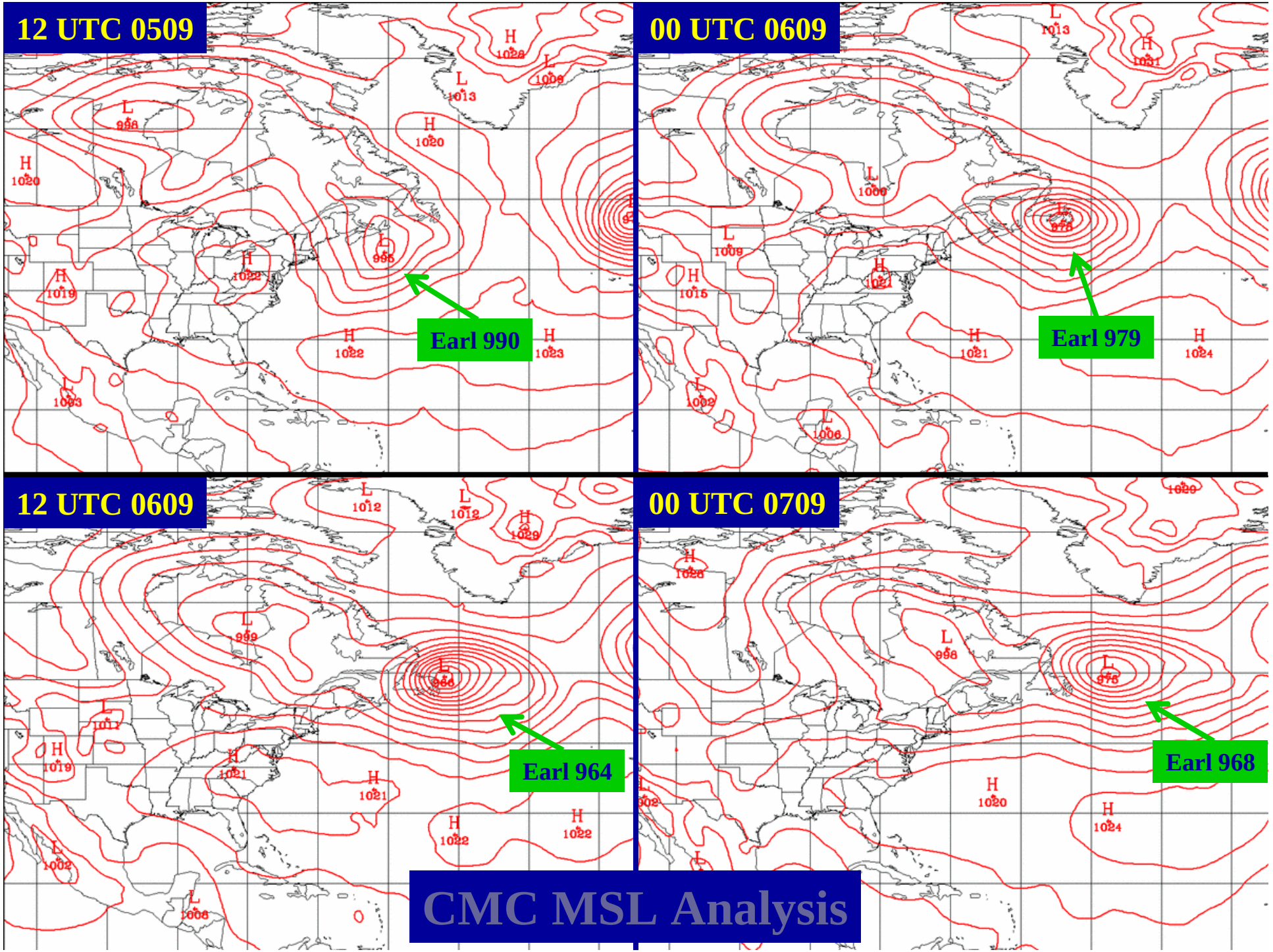
50km and 10 km output

	50 Km 393 x 325 x 31	10 Km 1593 x 1253 x 41
10 min		2D: QR, PN, RT, PR
15 min	2D: QR, PN, RT, PR	
60 min	2D: physics ➔10 km 3D: U,V,W,T,P,HU,QN	2D: physics ➔1 km 3D: U,V,W,T,P,HU,QN
	Total: 12 GBytes For 192 H forecast	Total: 218 GBytes For 183 H forecast

All data compressed to 16 bits


12 UTC 0109
Bonny
Danielle 1004
Earl 999
00 UTC 0209
Danielle 1000
Earl 998
12 UTC 0209
Danielle 999
Earl 994
00 UTC 0309
Danielle 994
Earl 985
CMC MSL Analysis


12 UTC 0309
Danielle 994
Earl 990
00 UTC 0409
Danielle 994
Earl 994
12 UTC 0409
Earl 998
00 UTC 0509
Earl 1000
CMC MSL Analysis


12 UTC 0509
Earl 990
00 UTC 0609
Earl 979
12 UTC 0609
Earl 964
00 UTC 0709
Earl 968
CMC MSL Analysis