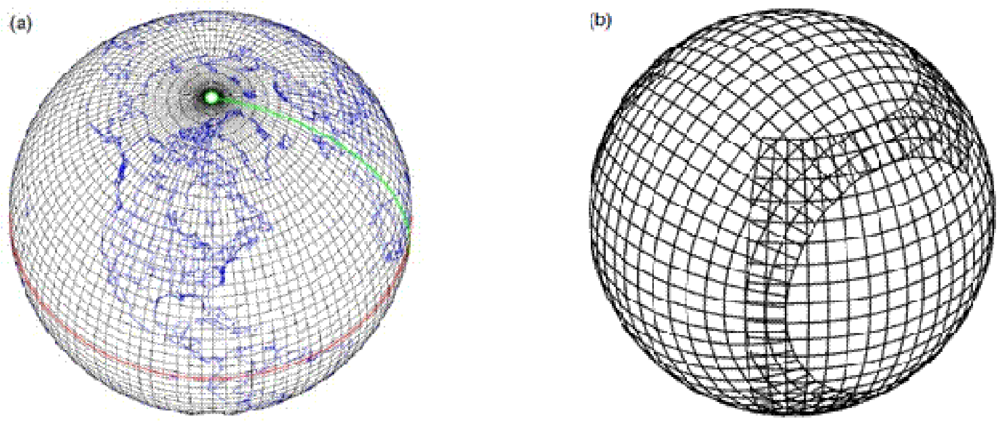
Participation à DCMIP 2012

GEM Lat-Lon *versus* GEM Yin-Yang



Abdessamad Qaddouri
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Claude Girard

Collaboration: Bernard Dugas, Ayrton Zadra et Paul Vaillancourt

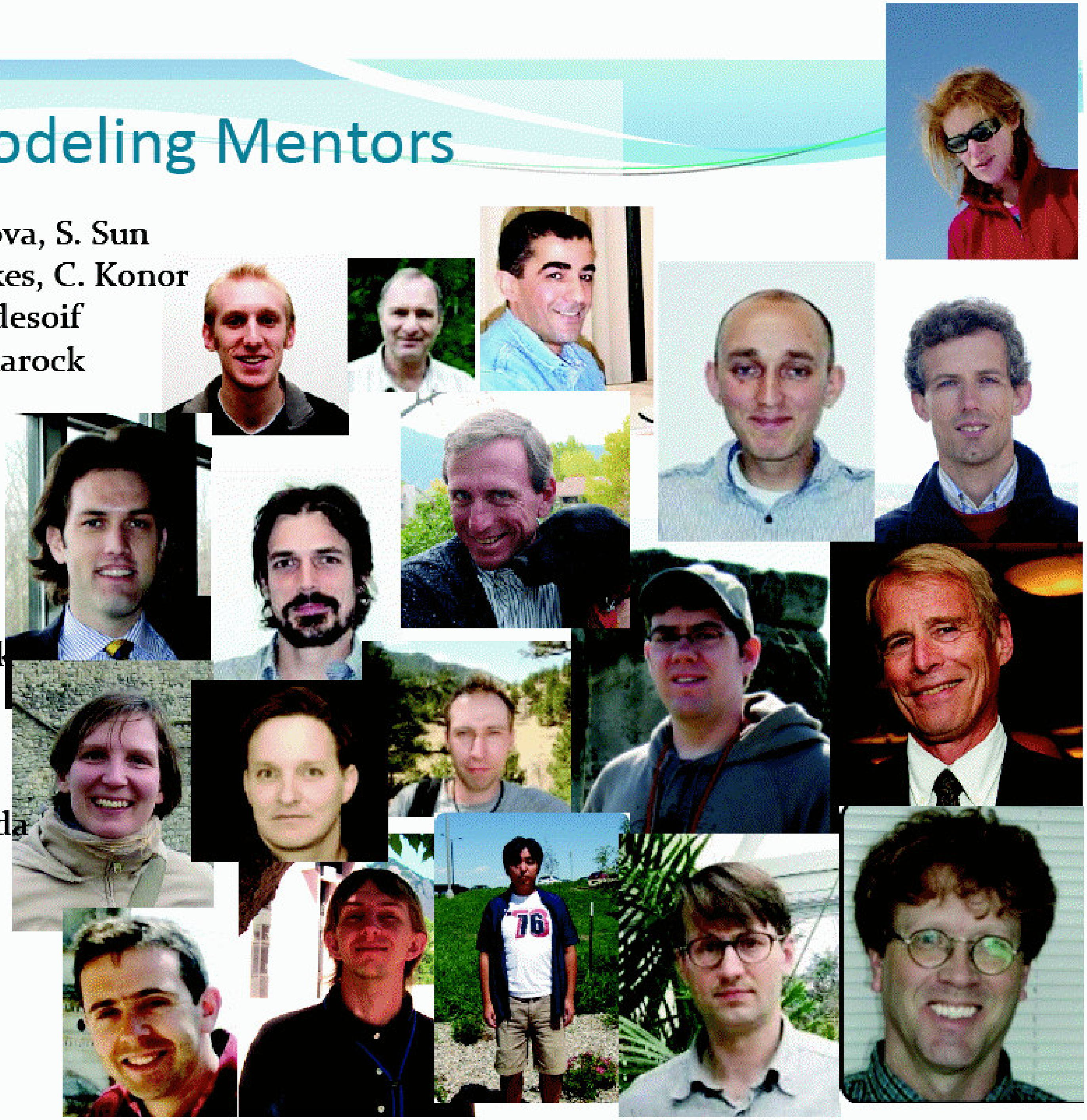
DCMIP = Dynamical Core Model Intercomparison Project

The Ideas behind DCMIP

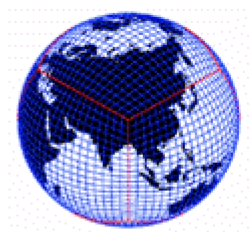
- The 2-week summer school and model intercomparison project DCMIP-2012 highlighted the newest modeling techniques for global climate and weather models
- Took place at NCAR from July/30-August/10/2012
- Brought together over 26 modeling mentors and organizers, 37 students, and 19 speakers
- DCMIP-2012 paid special attention to non-hydrostatic global models and their dynamical cores that now emerge in the GCM community
- Hosted 18 participating dynamical cores (3 participated remotely)

DCMIP Modeling Mentors

R. Bleck, T. Smirnova, S. Sun
D. Dazlich, R. Heikes, C. Konor
T. Dubos, Y. Meurdesoif
M. Duda, W. Skamarock
T. Frisius
A. Gassmann
M. Giorgetta
M. Gross
L. Harris
J. Kent
J. Klemp, S.-H. Park
J. Lee
S. Malardel
T. Melvin
H. Miura, R. Yoshida
A. Qaddouri
K. Reed
D. Reinert
L. Silvers
M. Taylor
R. Walko, M. Otte



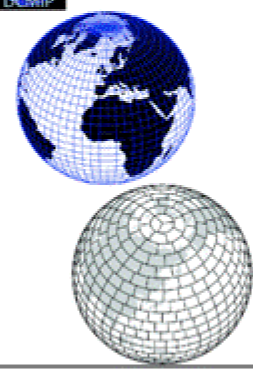
DCMIP Models: Cubed-Sphere Grids



Cubed-sphere grids

- CAM-SE (NCAR & Sandia Labs)
- FV3-GFDL (GFDL & NASA)
- MCORE (University of Michigan & University of California, Davis)

DCMIP Models: Latitude-Longitude



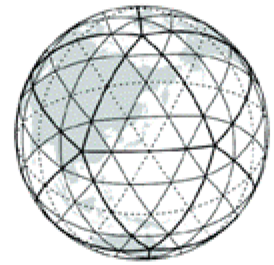
Latitude-longitude or Gaussian grids

- CAM-FV (NCAR)
- PUMA (University of Hamburg)
- GEM-latlon (Environment Canada)
- ENDGame (U.K. Met Office)

Reduced Gaussian grid

- IFS (ECMWF)

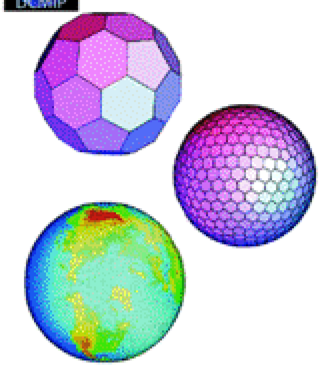
DCMIP Models: Triangular Grids



Spherical geodesic or icosahedral-based grids

- ICON-MPI-DWD (Max-Planck Institute, German Weather Service)
- DYNAMICO (IPSL, Paris)
- NIM (NOAA)
- NICAM (RIKEN, JAMSTEC)
- OLAM (University of Miami)

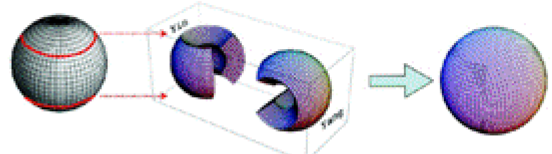
DCMIP Models: Hexagonal Grids



Hexagonal or spherical Voronoi grids

- FIM (NOAA)
- ICON-IAP (IAP Kühlungsborn)
- MPAS (NCAR)
- OLAM (University of Miami)
- UZIM (Colorado State University)

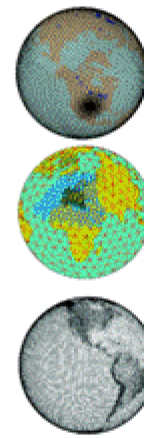
DCMIP Models: Yin-Yang Grid

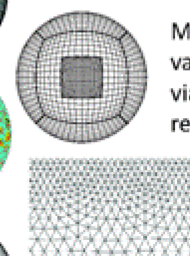


Yin-Yang grid

- GEM-yinyang (Environment Canada)

DCMIP Models: Nested Grids

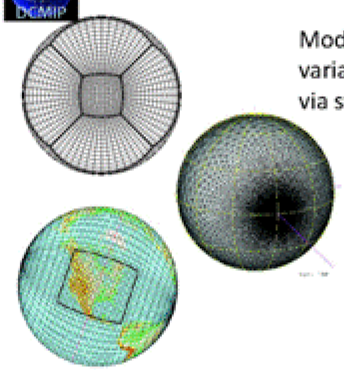




Models with optional variable-resolution-grid via embedded high-resolution regions

- CAM-SE
- FV3-GFDL
- ICON-MPI-DWD
- OLAM
- MPAS

DCMIP Models: Stretched Grids



Models with optional variable-resolution-grid via stretched grids

- FV3-GFDL
- NICAM
- GEM-latlon

The Architecture of the DCMIP Test Suite

The tests are hierarchical and increase in complexity

http://earthsystemcog.org/projects/dcmip-2012/test_cases

- **3D Advection**
  - Pure 3D advection without orography
  - Pure 3D advection in the presence of orography
- **Dry dynamical core without rotation**
  - Stability of a steady-state at rest in presence of a mountain
  - Mountain-induced gravity waves on small planets
  - Thermally induced gravity waves on small planets

- **Dry dynamical core with the Earth's rotation**
  - From large (hydrostatic) to small (nonhydrostatic) scales, nonlinear baroclinic waves on a shrinking planet with dynamic tracers PV and θ
- **Simple moisture feedbacks**
  - Moist baroclinic waves with large-scale condensation
  - Moist baroclinic waves with simplified physics (simple-physics)
  - Idealized tropical cyclones

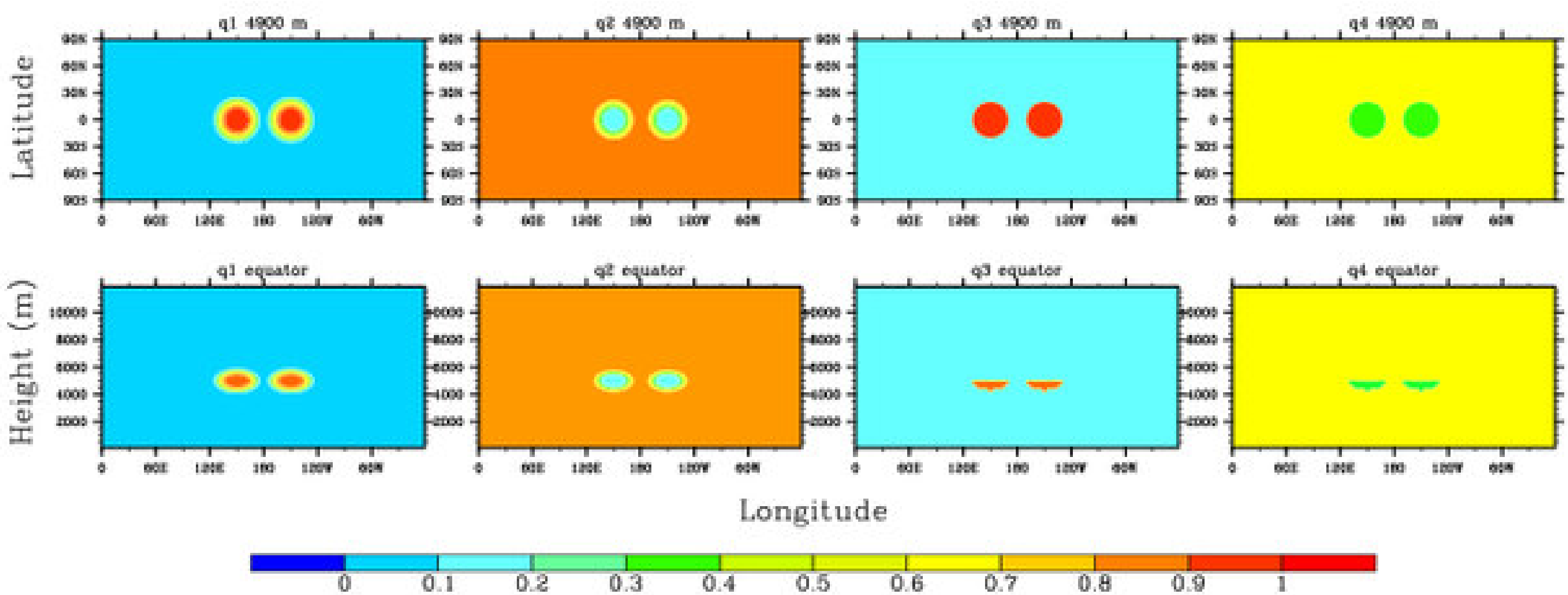
Test Case	Description
Pure advection	
1-1	3D deformational flow
1-2	3D Hadley-like meridional circulation
1-3	2D solid-body rotation of thin cloud-like tracer in the presence of orography
Impact of orography on a non-rotating steady-state at rest: Hydrostatic scales	
2-0-x	optional: Accuracy of the pressure-gradient calculation in presence of a mountain
Orographic and non-orographic gravity waves on a non-rotating small-planet: Non-hydrostatic scales	
2-1	Mountain waves over a Schär-type mountain on a small planet
2-2	Mountain waves over a Schär-type mountain on a small planet with wind shear
3-1	Non-orographic gravity waves on a small planet
Rotating planet: From hydrostatic to non-hydrostatic scales	
4-1-x	Dry baroclinic instability on a shrinking planet with dynamic tracers EPV and Θ reduction factors 1, 10, 100, 1000 to enable extreme grid spacings down to $\Delta x \approx 110$ m
Simple moist interactions	
4-2	Moist baroclinic instability with large-scale condensation
4-3	optional: Moist baroclinic instability with simplified physics forcings
5-1	Idealized tropical cyclone with simplified physics forcings
Complex moist interactions	
5-2	optional: Idealized tropical cyclone with full physics package

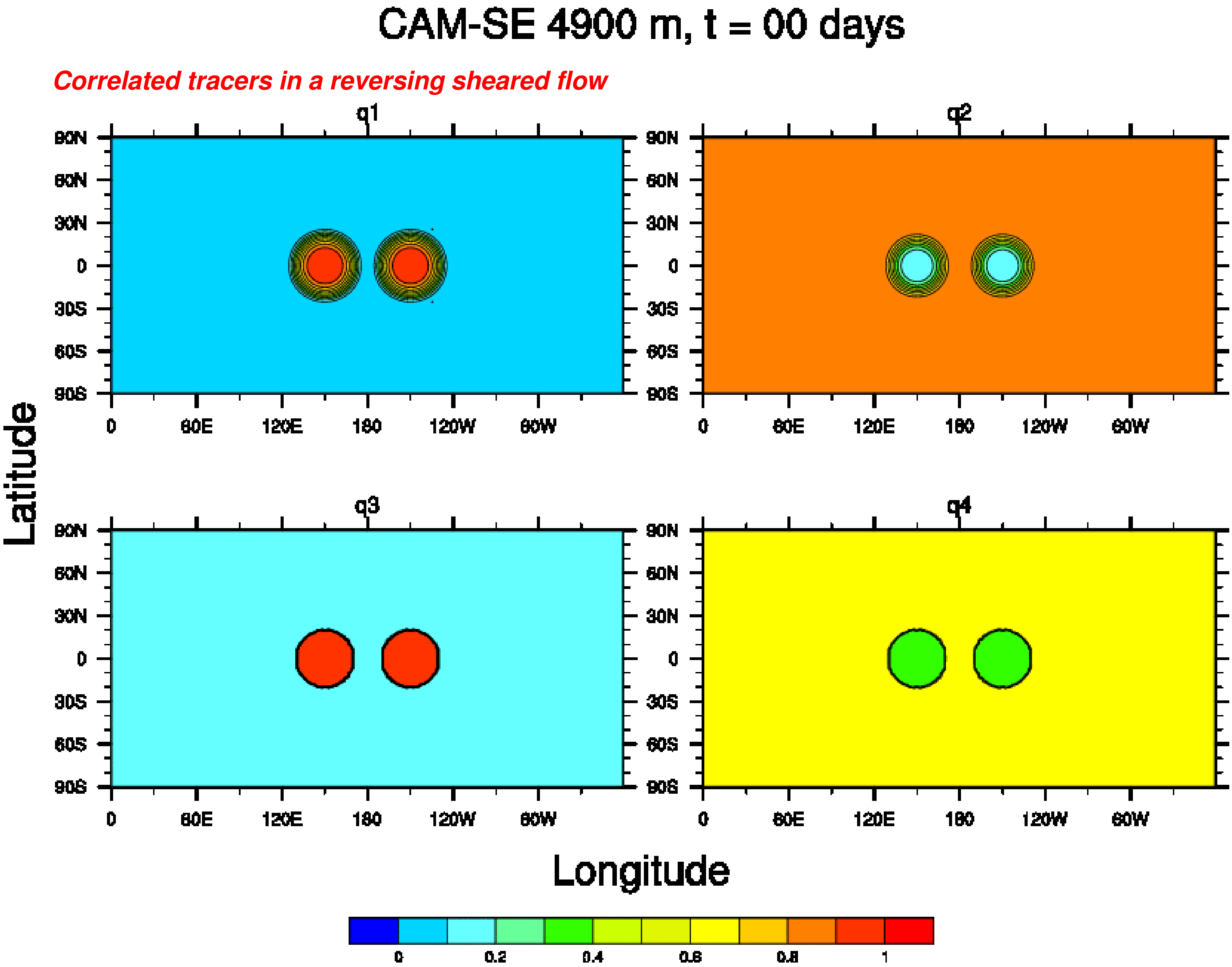
3D Advection: Test 11 (3D deformational flow)

We setup four tracers:

smooth $(q1)$ — correlated $(q2 = 0.9 - 0.8q1^2)$

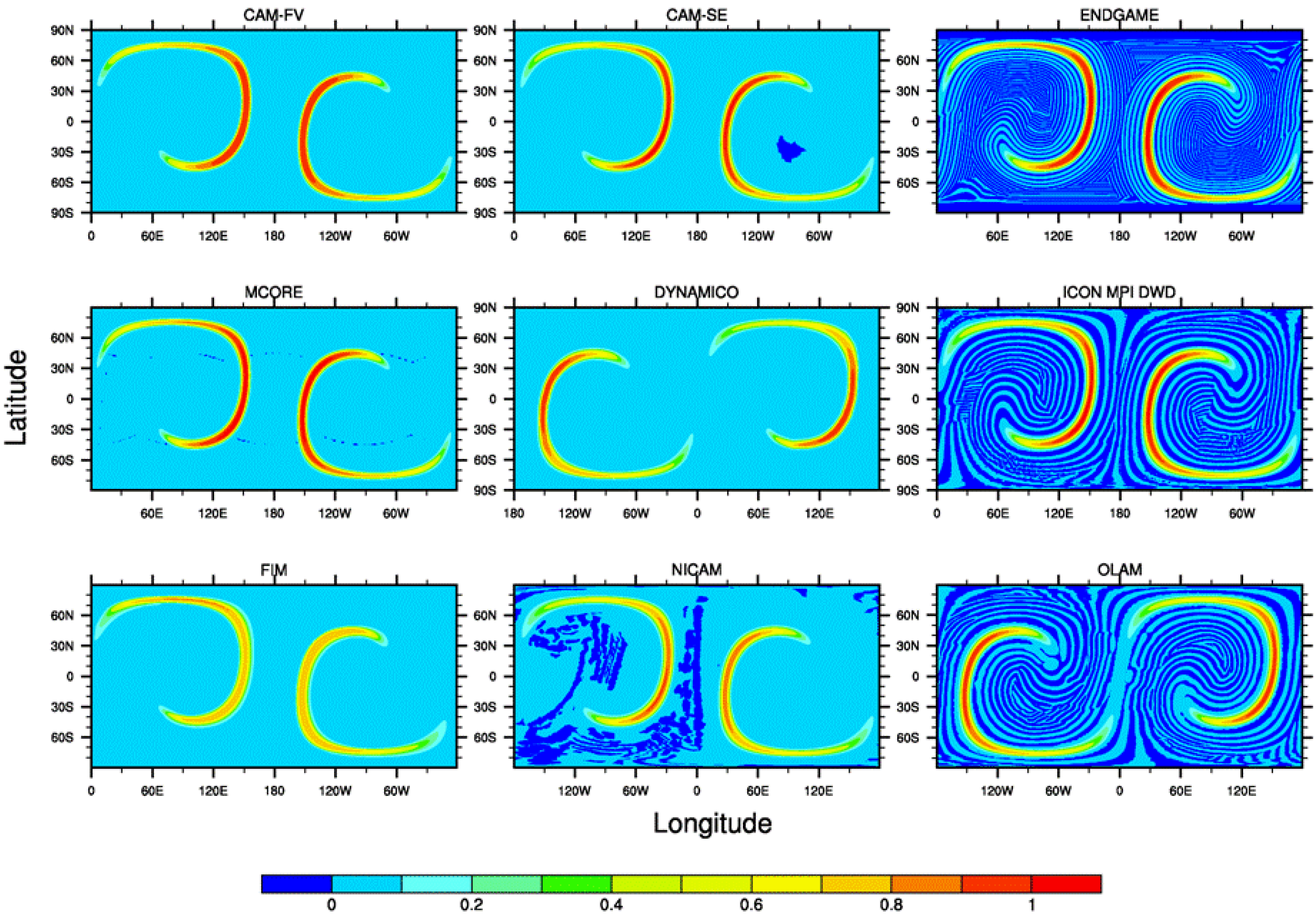
slotted ellipse $(q3)$ — multiple sum $(q4 = 1 - \frac{3}{10}[q1 + q2 + q3])$



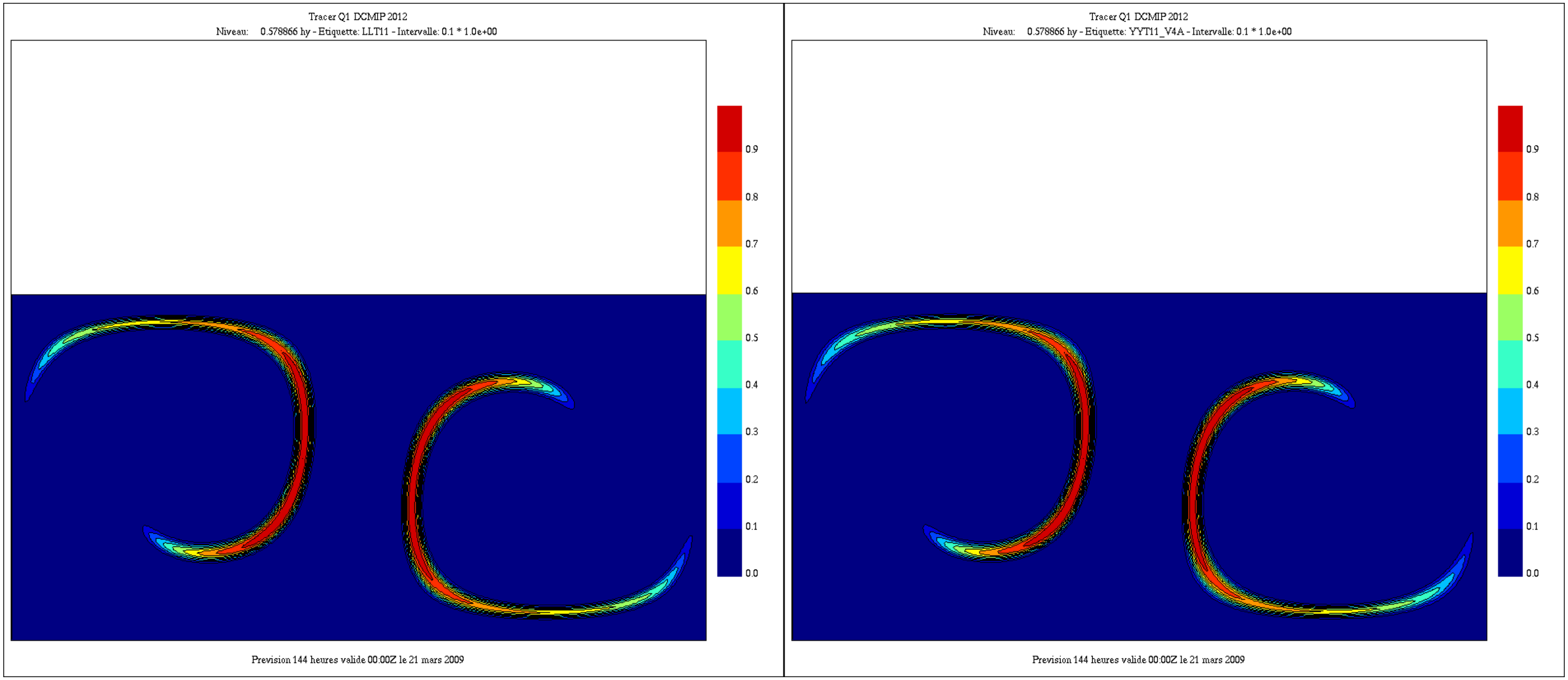


CAM-SE 4900 m, t = 00 days
Correlated tracers in a reversing sheared flow
q1
q2
q3
q4
90N
60N
30N
0
30S
60S
90S
0
60E
120E
180
120W
60W
Latitude
Longitude
0
0.2
0.4
0.6
0.8
1

Q1 Test 11 4900 m, t = 6 days



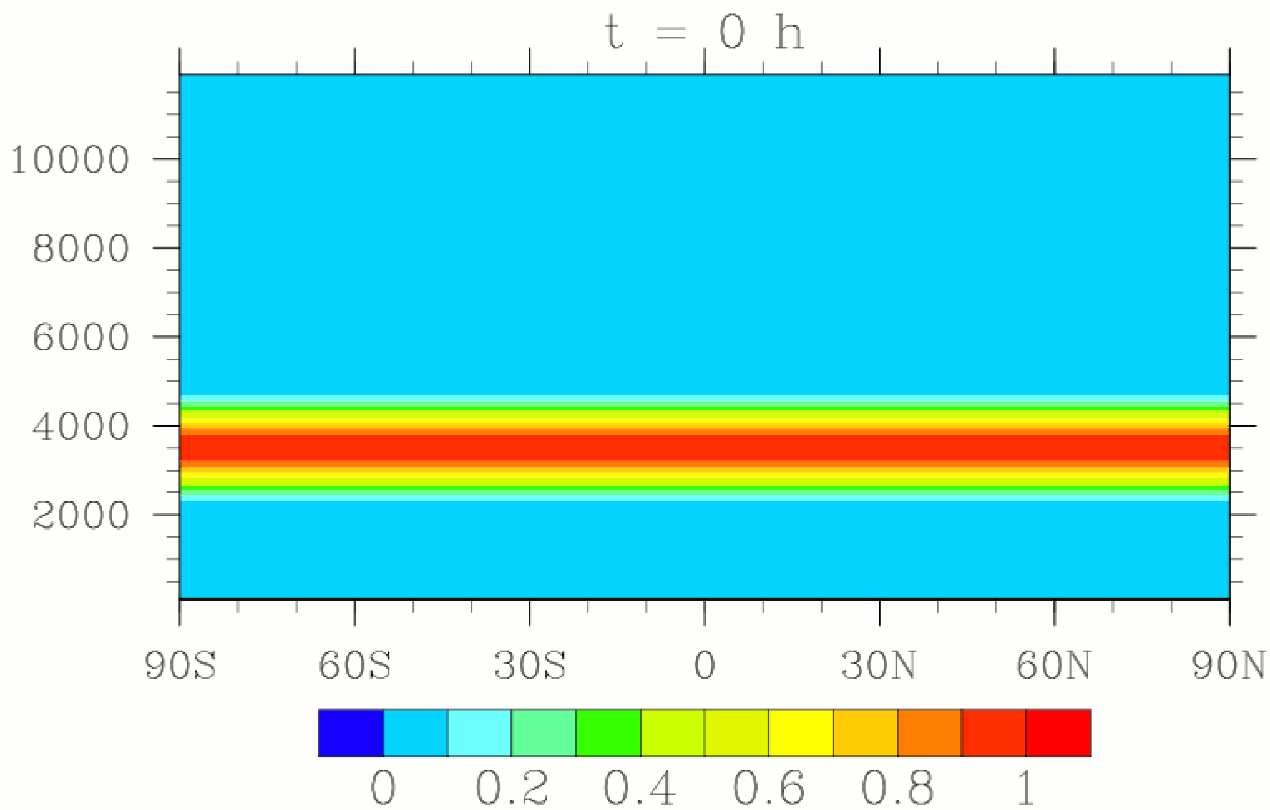
Q1 Test 11 Near 4900 m t= 6 days



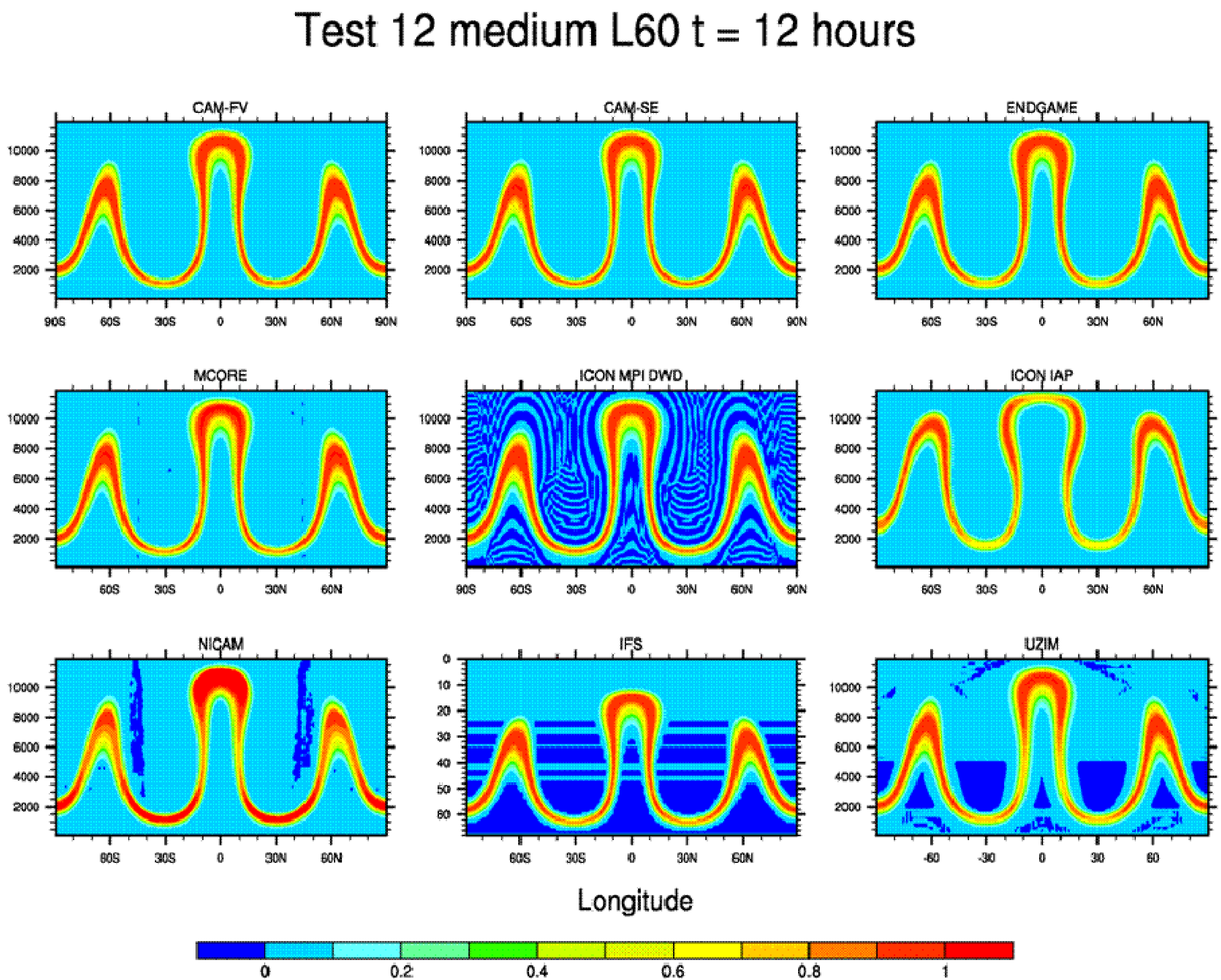
LL YY

3D Advection: Test 12 (Hadley-cell like circulation)

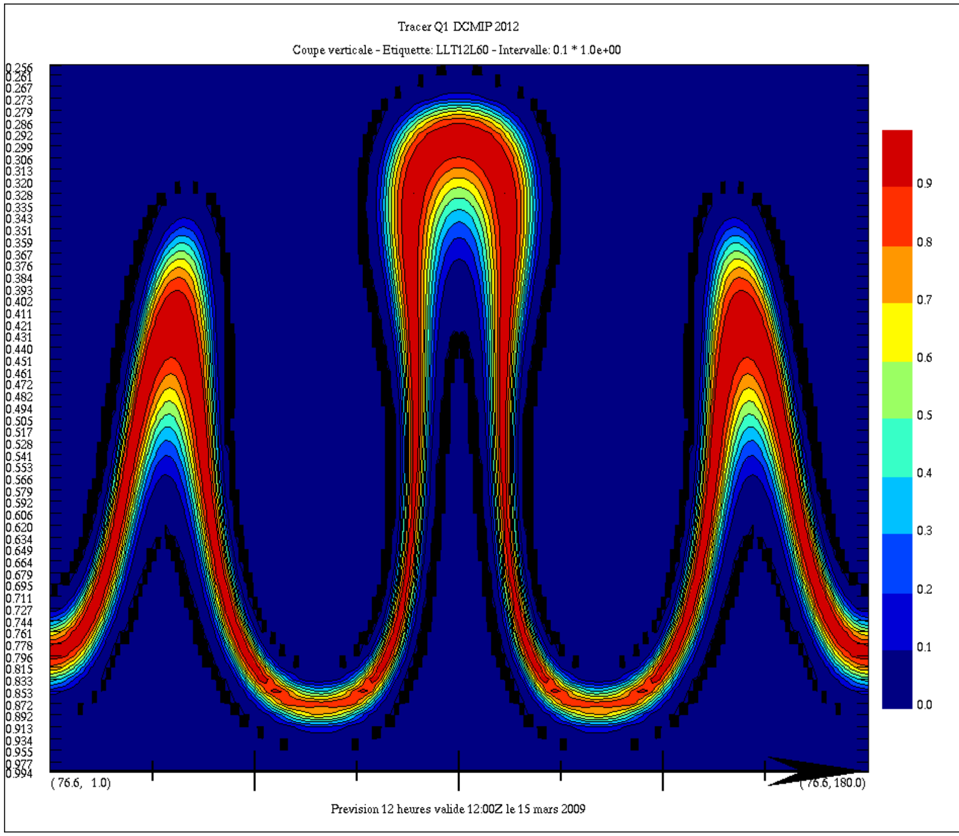
Tracer q is stretched thin after 12 h, but it is still resolved, comes back to its original position after 1 day



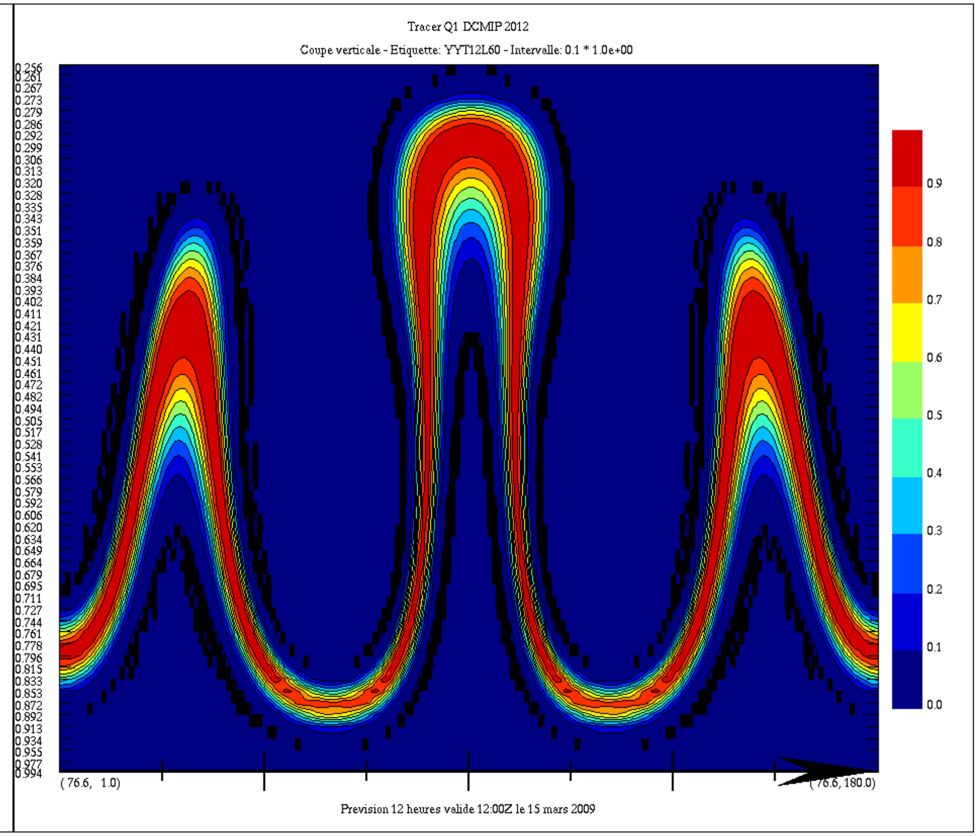
Animation CAM-FV


Test 12 medium L60 t = 12 hours
CAM-FV
CAM-SE
ENDGAME
MCORE
ICON MPI DWD
ICON IAP
NICAM
IFS
UZIM
10000
8000
6000
4000
2000
90S
60S
30S
0
30N
60N
90N
Longitude
0
0.2
0.4
0.6
0.8
1

Test 12 medium L60 t= 12 hours



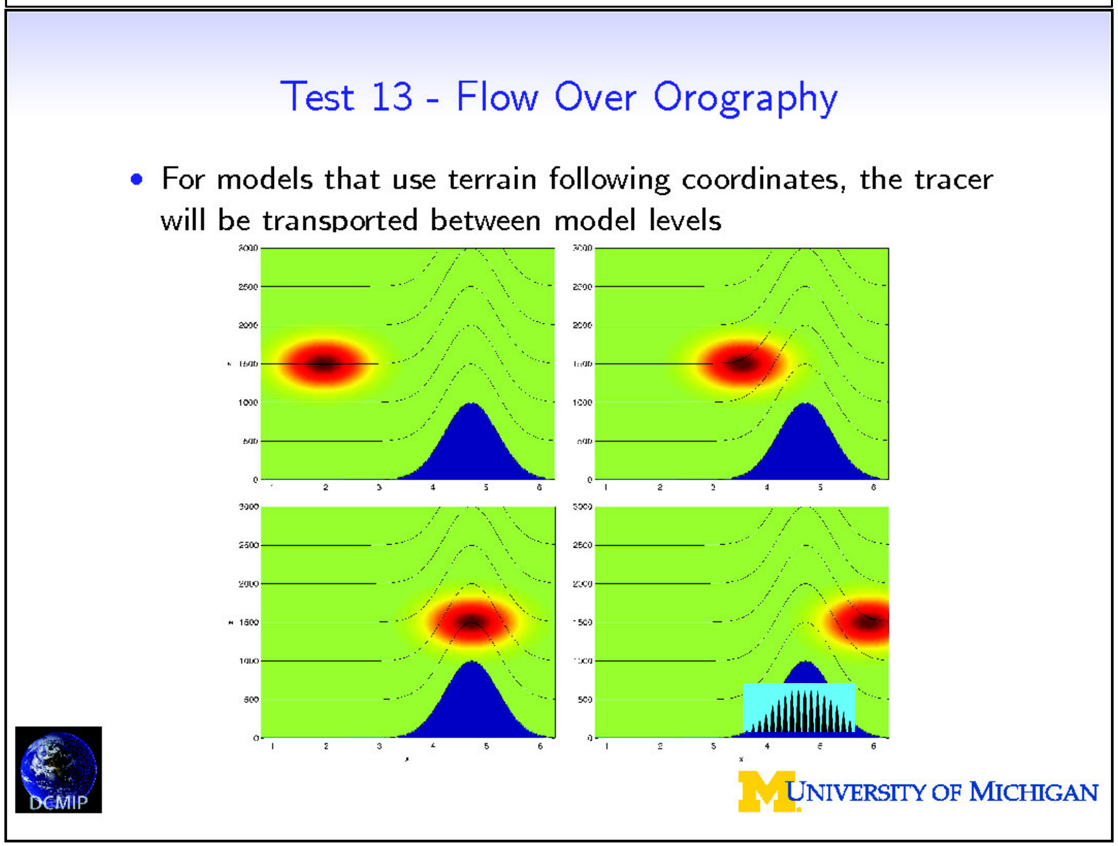
LL



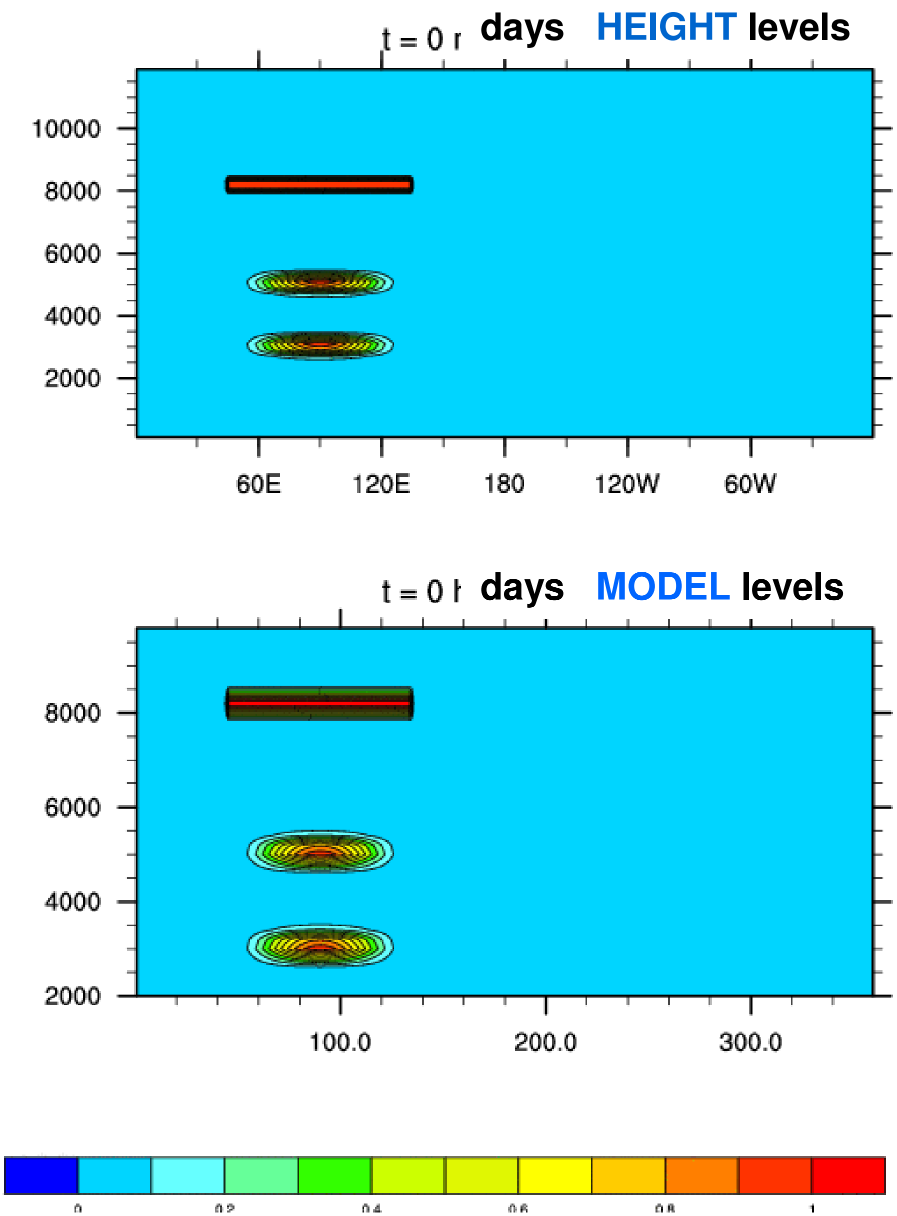
YY

3D Advection: Test 13 Solid body rotation of thin cloud tracer in presence of orography

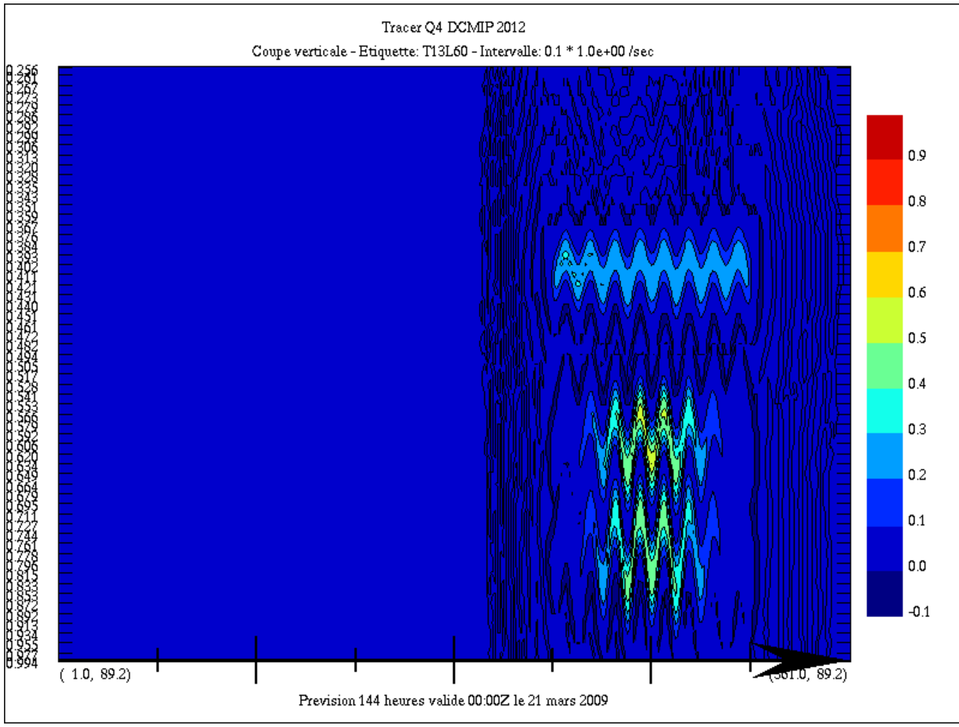
- Horizontal solid-body rotation over a mountain
- The mountain is a 3D variant of Schär mountain (Schär et al, Mon. Weather Rev, 130, 2002)
- The tracers are initialised as thin cloud like layers
- For models that use terrain following coordinates, the tracer will be transported between model levels



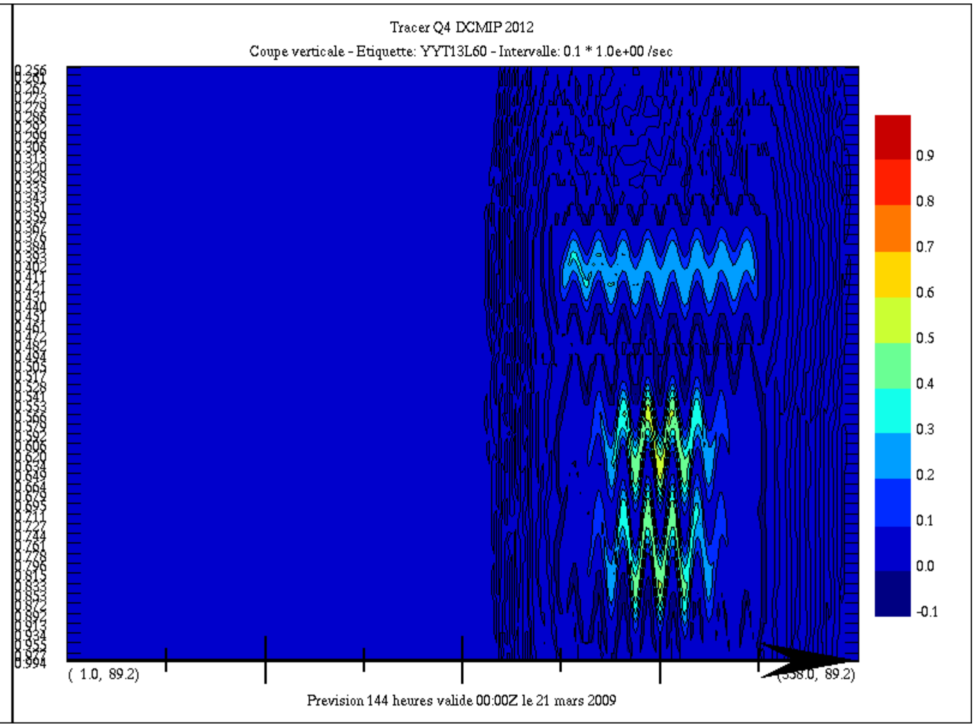
Animation GFDL FV3



Test 13 L60 (Model levels)   t=T/2



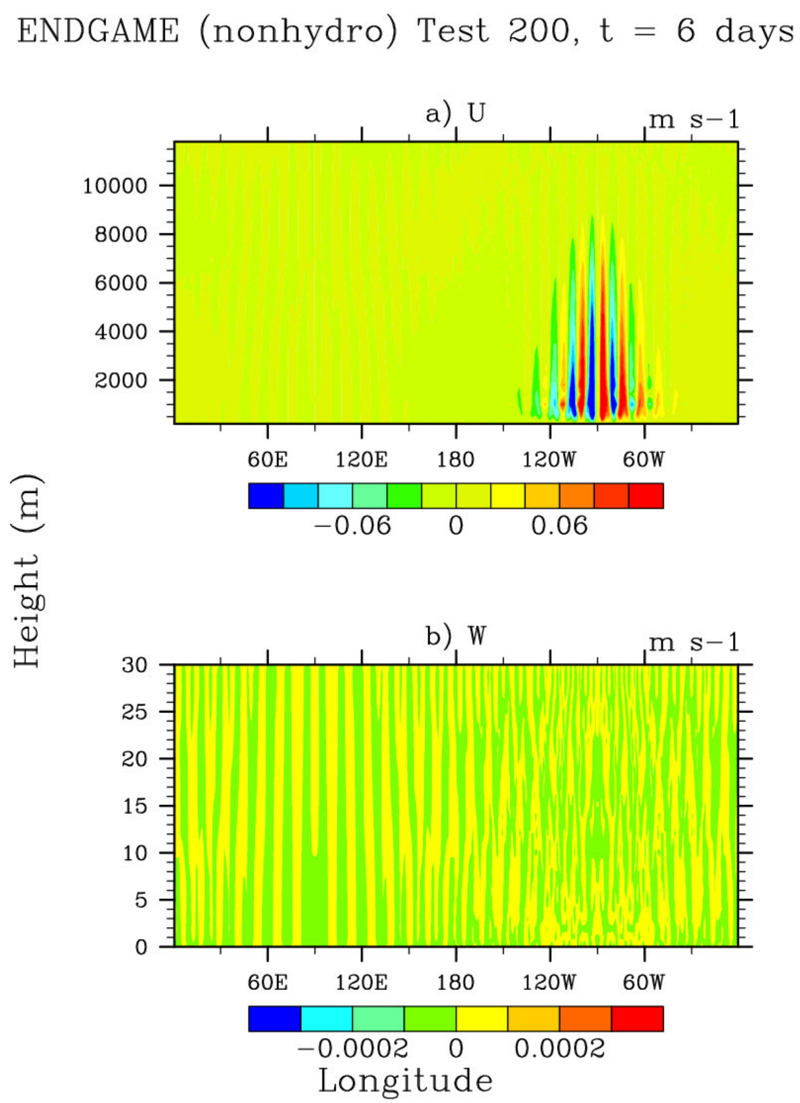
LL

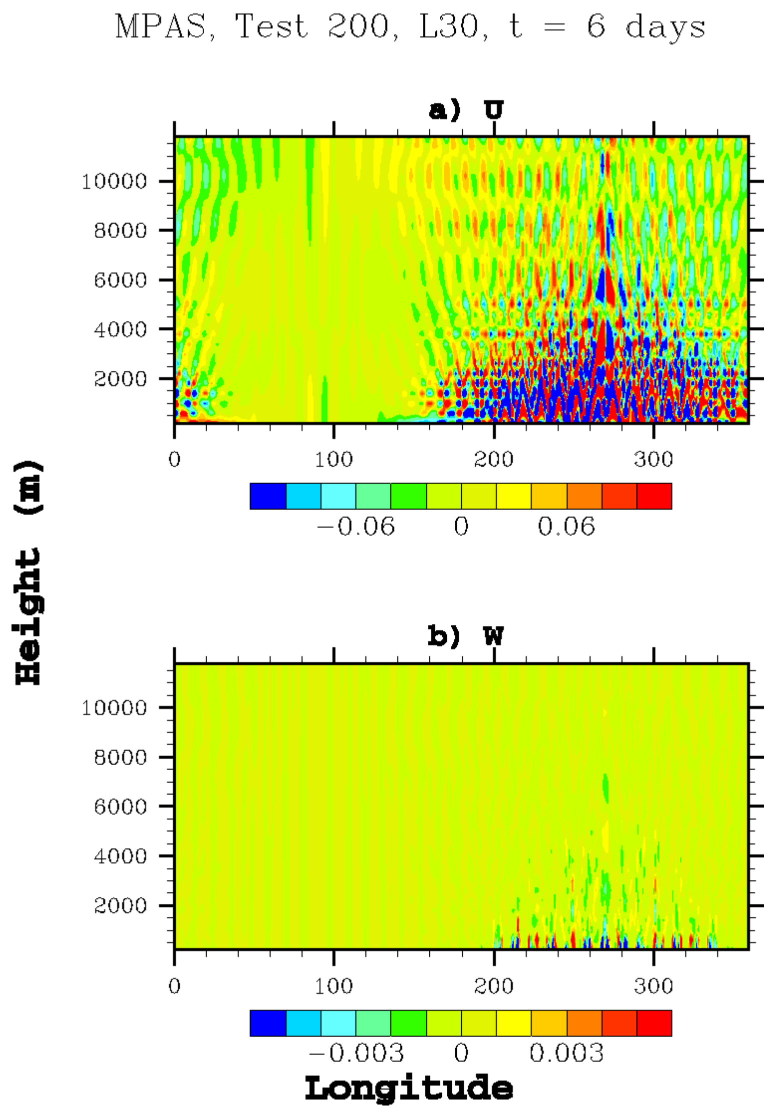


YY

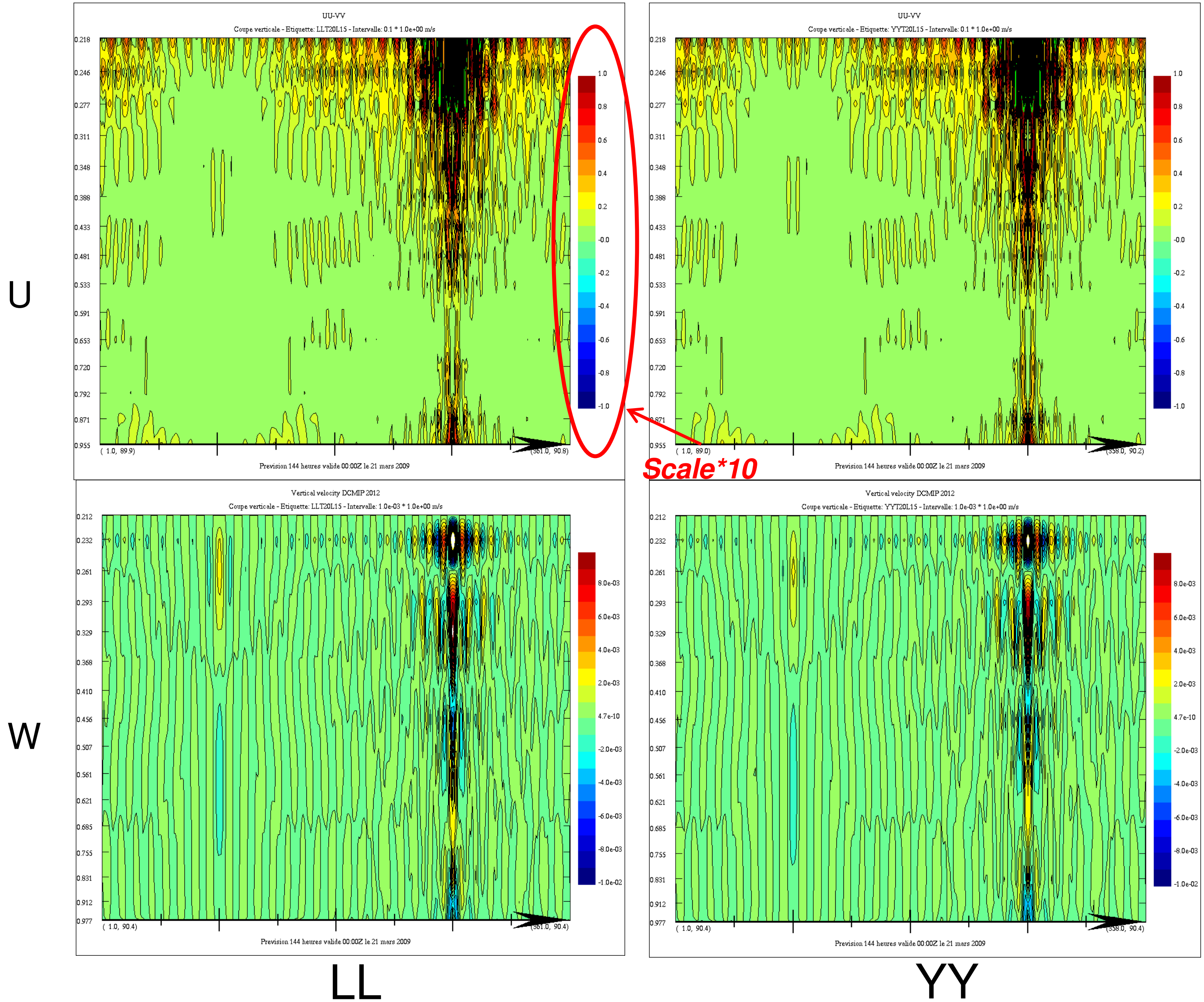
Test 20 (Steady-State Atmosphere at Rest in Presence of Orography)

Evaluate accuracy of the pressure-gradient calculation over a Schaer-type mountain





Test 20 L15 t= 6 days



Vertical advection: Eulerian Scheme

linear extrapolation near boundaries
is not only possible but in fact effective

$$\frac{\partial F}{\partial t} = -\dot{\sigma}\frac{\partial F}{\partial \sigma}$$

$$\left(\frac{\partial F}{\partial t}\right)_k = -\overline{\left(\dot{\sigma}\frac{\Delta F}{\Delta \sigma}\right)_k}^{\sigma} = -\frac{1}{2}\left[\dot{\sigma}_{k+\frac{1}{2}}\frac{F_{k+1}-F_k}{\Delta\sigma_{k+\frac{1}{2}}} + \dot{\sigma}_{k-\frac{1}{2}}\frac{F_k - F_{k-1}}{\Delta\sigma_{k-\frac{1}{2}}}\right]$$

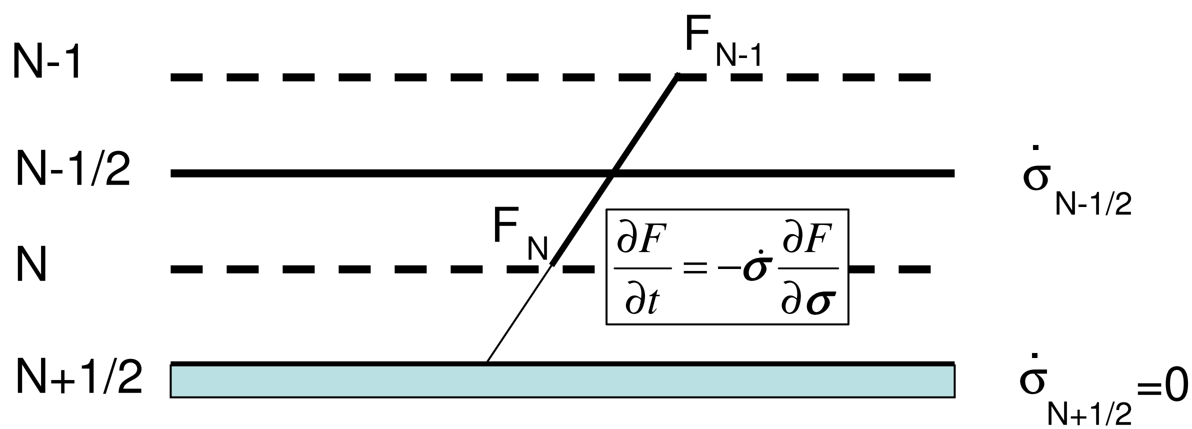
$$\left(\frac{\partial F}{\partial t}\right)_N = -\overline{\left(\dot{\sigma}\frac{\Delta F}{\Delta \sigma}\right)_N}^{\sigma} = -\frac{1}{2}\dot{\sigma}_{N-\frac{1}{2}}\frac{F_N - F_{N-1}}{\Delta\sigma_{N-\frac{1}{2}}}; \qquad \dot{\sigma}_{N+\frac{1}{2}} = 0$$

$$F_N^+ = F_N\left(1 - \frac{\Delta t\dot{\sigma}_{N-\frac{1}{2}}/2}{\Delta\sigma_{N-\frac{1}{2}}}\right) + \frac{\Delta t\dot{\sigma}_{N-\frac{1}{2}}/2}{\Delta\sigma_{N-\frac{1}{2}}}F_{N-1}$$

$$F_N^+ = F_N\left(1 - \frac{\delta\sigma}{\Delta\sigma_{N-\frac{1}{2}}}\right) + \frac{\delta\sigma}{\Delta\sigma_{N-\frac{1}{2}}}F_{N-1} \qquad \begin{cases} \delta\sigma = \Delta\sigma_{N-\frac{1}{2}} \Rightarrow F_N^+ = F_{N-1} \\ \delta\sigma = \Delta\sigma_{N-\frac{1}{2}}/2 \Rightarrow F_N^+ = (F_N + F_{N-1})/2 \\ \delta\sigma = -\Delta\sigma_{N-\frac{1}{2}}/2 \Rightarrow (3F_N - F_{N-1})/2 \end{cases}$$

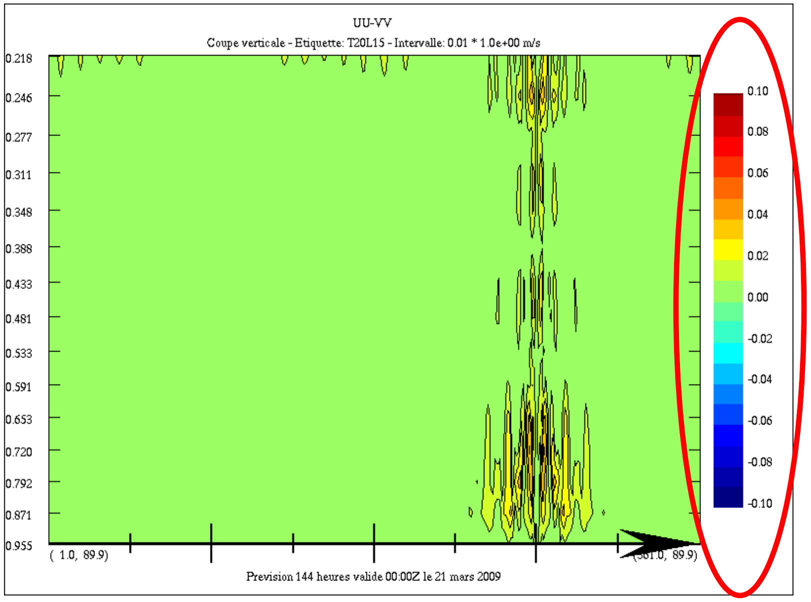
Semi-Lagrangian scheme:

a similar approach (linear extrapolation)
is not only possible but no doubt desirable
It is now being developed for GEM



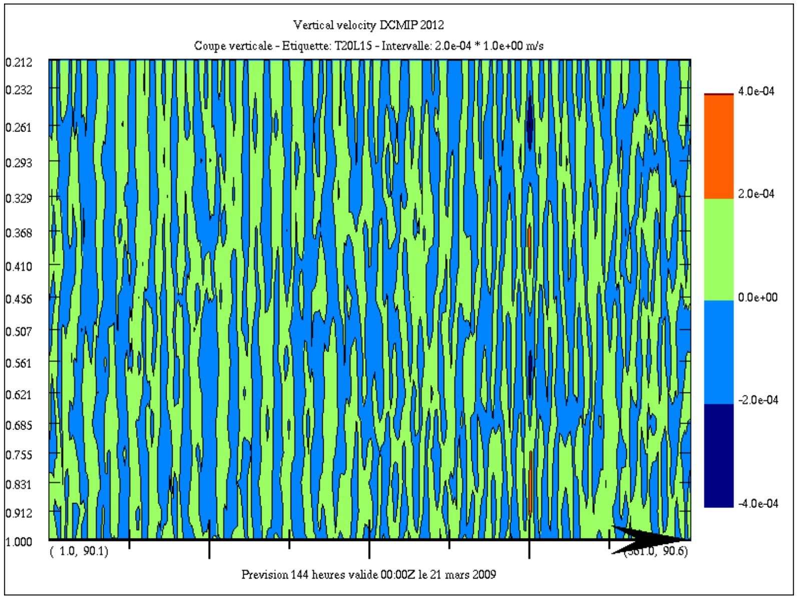
Test 20 L15 t= 6 days

U



Same Scale

W



- ***Corrections à No Top thermodynamic level (Claude et André)***
- ***Extrapolation linéaire***
- ***Rcoef (0,2)***

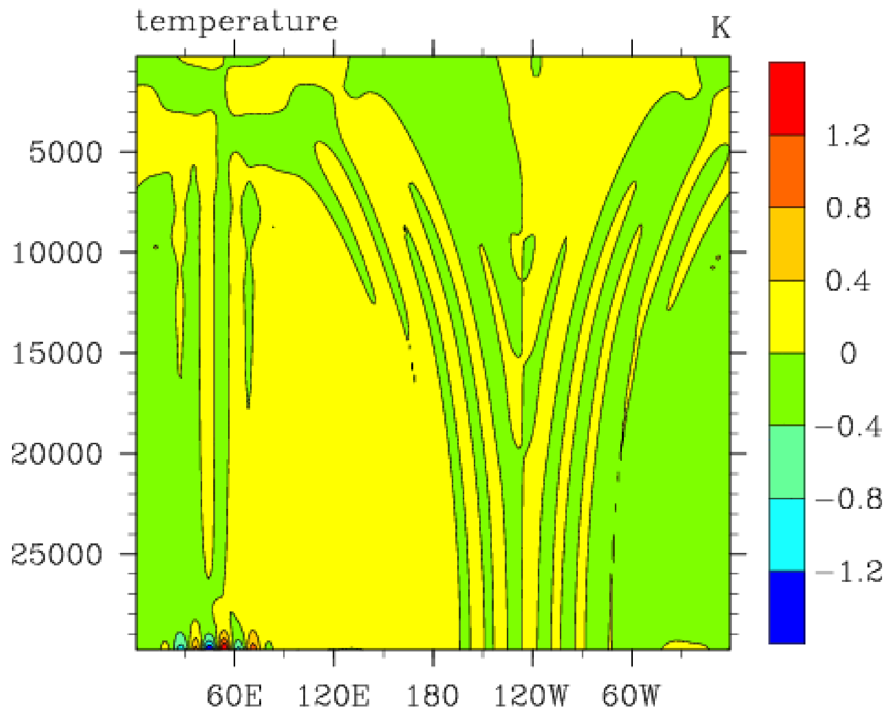
LL

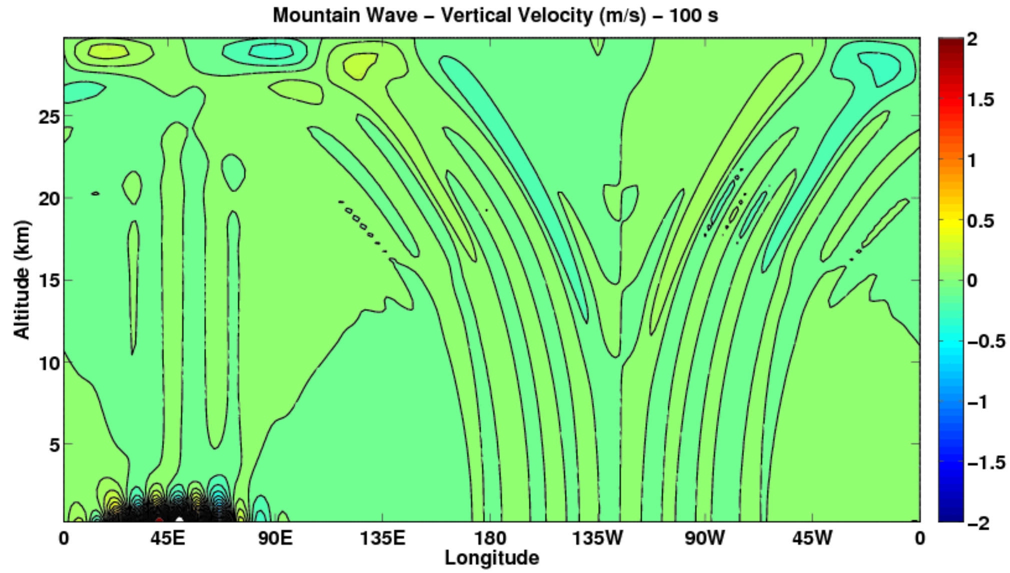
SMALL PLANET

Radius of the Earth is scaled so that the simulation is in the non-hydrostatic domain

$$
\begin{cases}
\text{Radius } a = \dfrac{a_{ref}}{X} \\
\text{Time Step } \Delta t = \dfrac{\Delta t_{ref}}{X} \\
\text{Angular Velocity } \Omega = X\,\Omega_{ref} \\
\text{Rayleigh friction (Sponge near the model top) } \mathrm{R} = X\,R_{ref} \\
X > 1
\end{cases}
$$

Test 21 (Flow over Topography, Gravity waves Without Wind



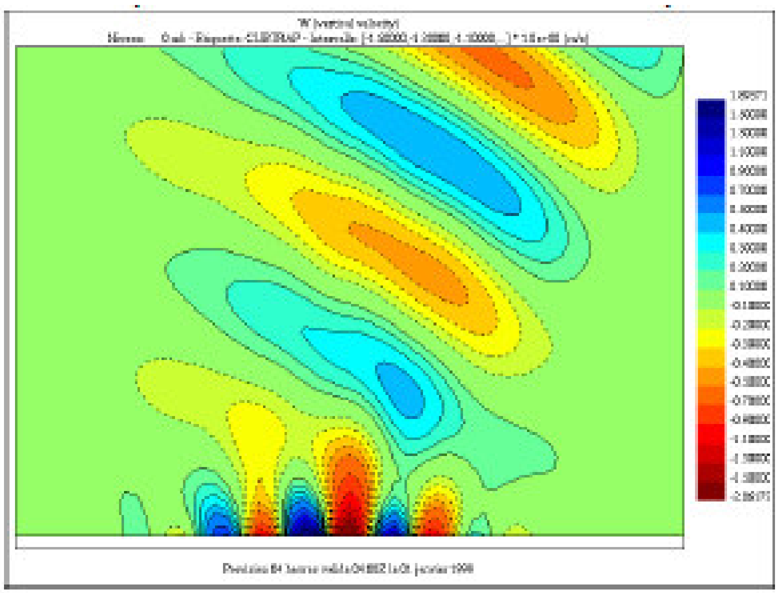


Animation MCORE

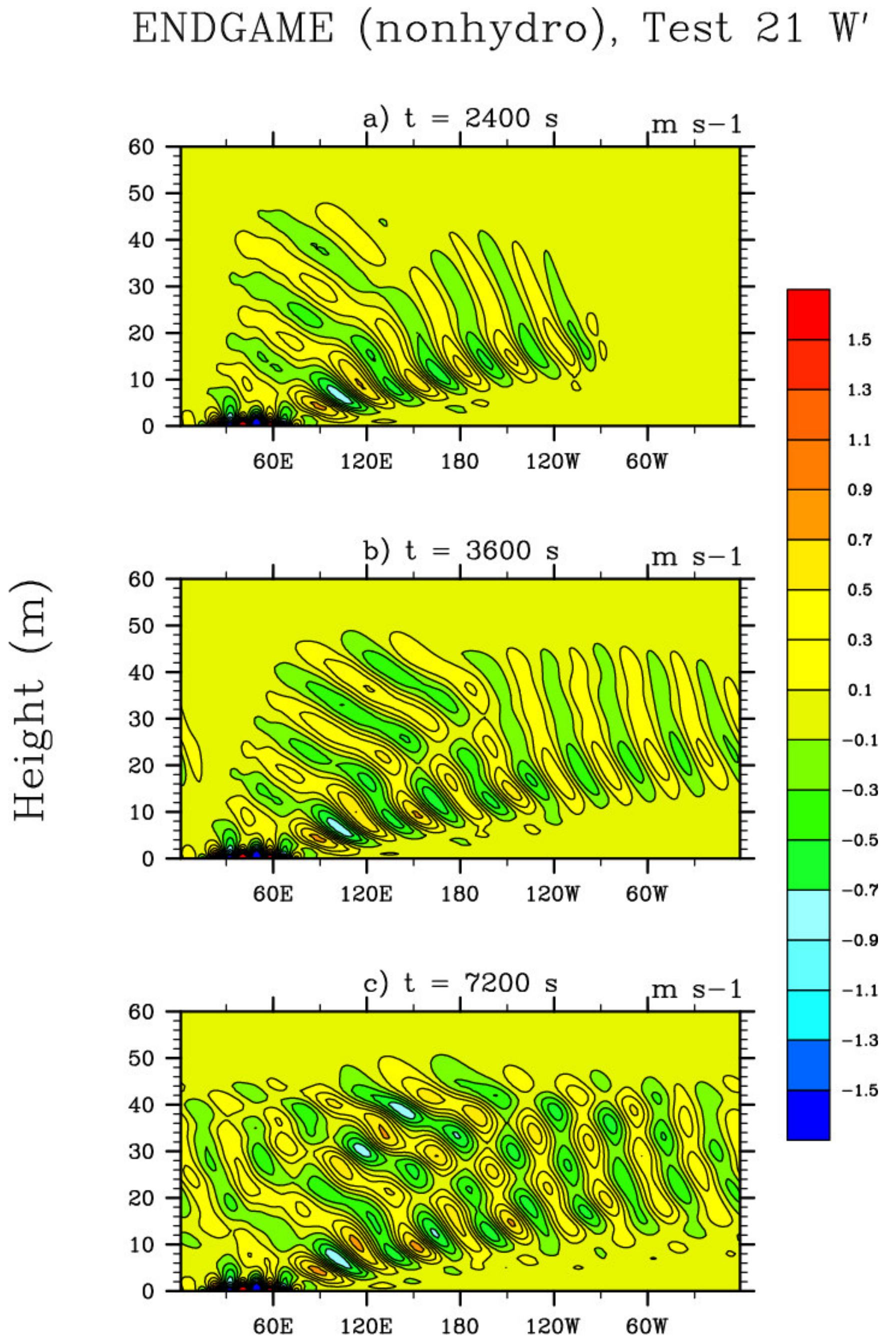
Reduced‐size Earth with a circumference at the equator of 80 km and No rotation

Δx ≈ 333.6 m Δz = 500 m

X=500

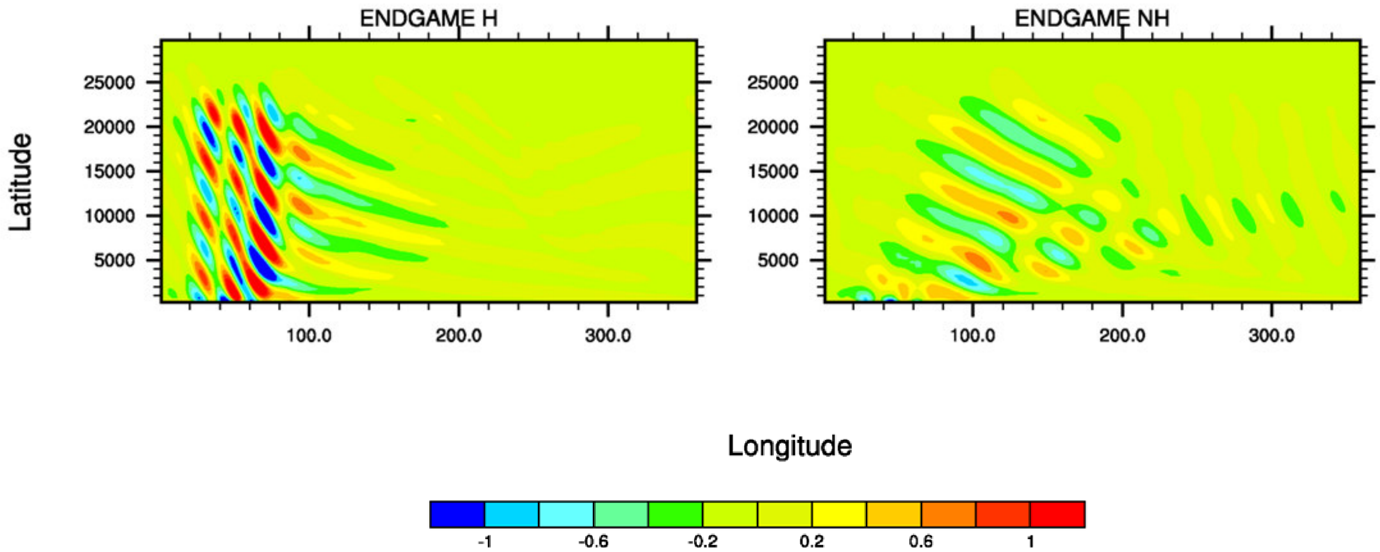


Schär's case of Claude (Slice GEM)



Test 21 T' t=3600 s

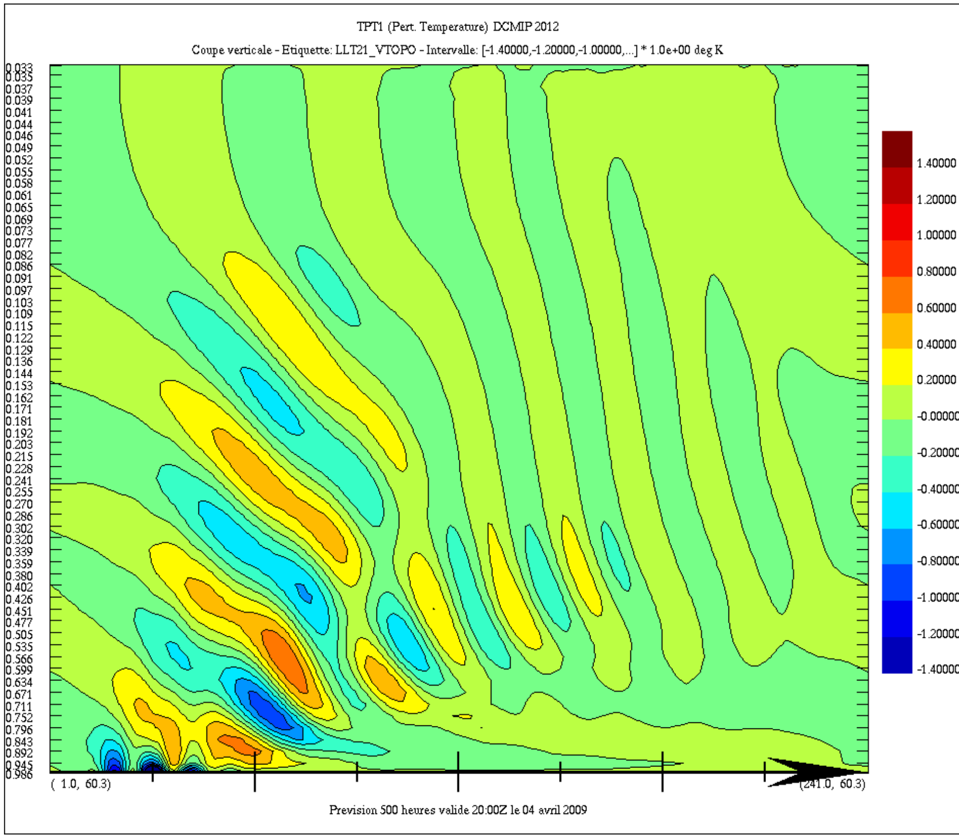
ENDGAME



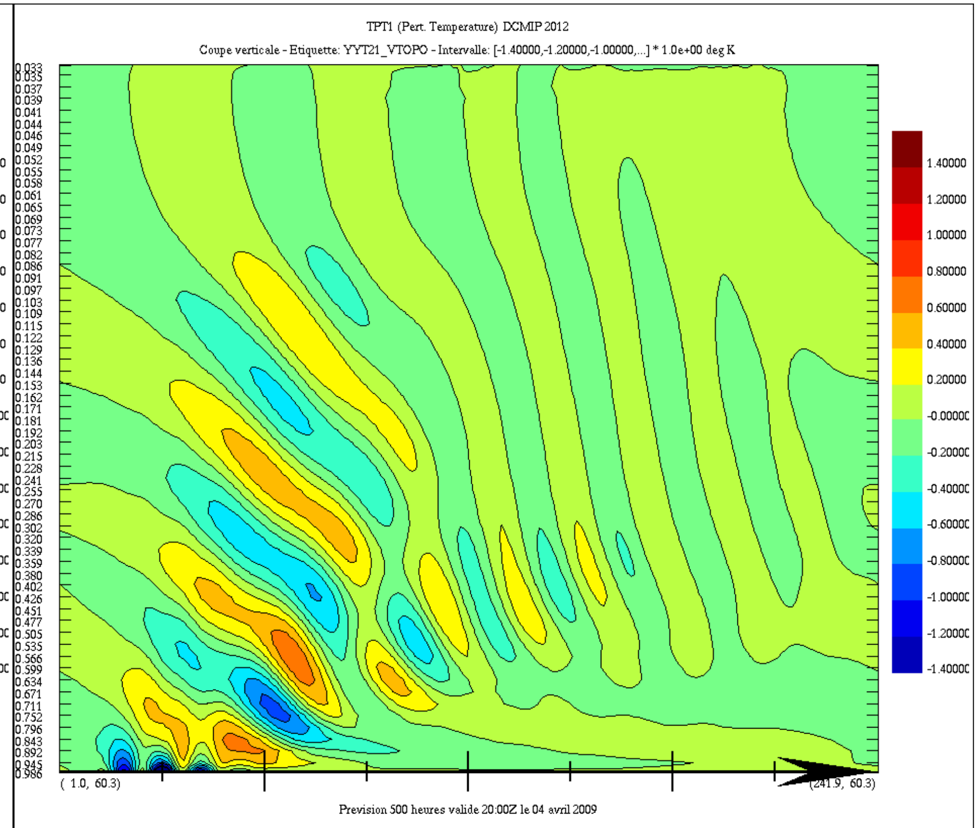
Distinguishes between <u>Hydrostatic</u> and <u>NonHydrostatic</u> responses

Test 21 T' t=3600 s

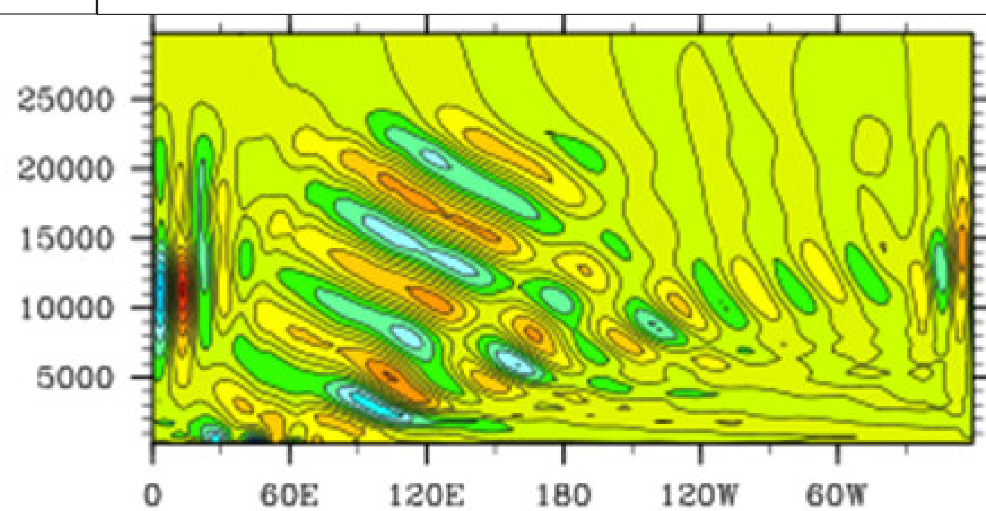
LL

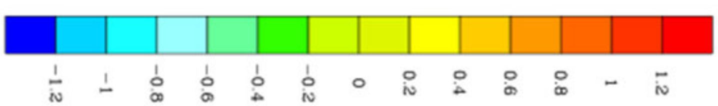


YY

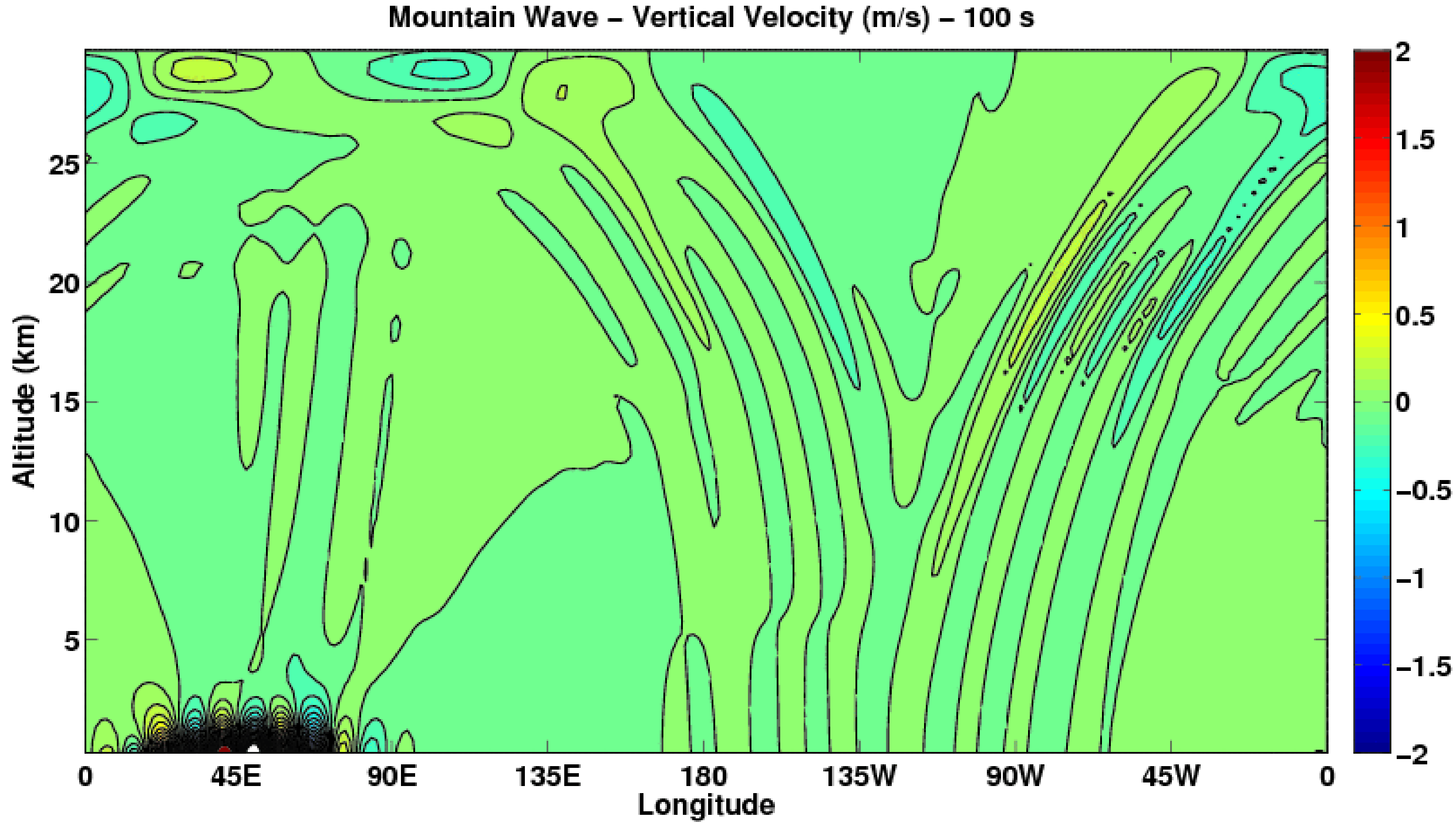


IFS





Test 22 (Flow over Topography, Gravity waves With Wind Shear)



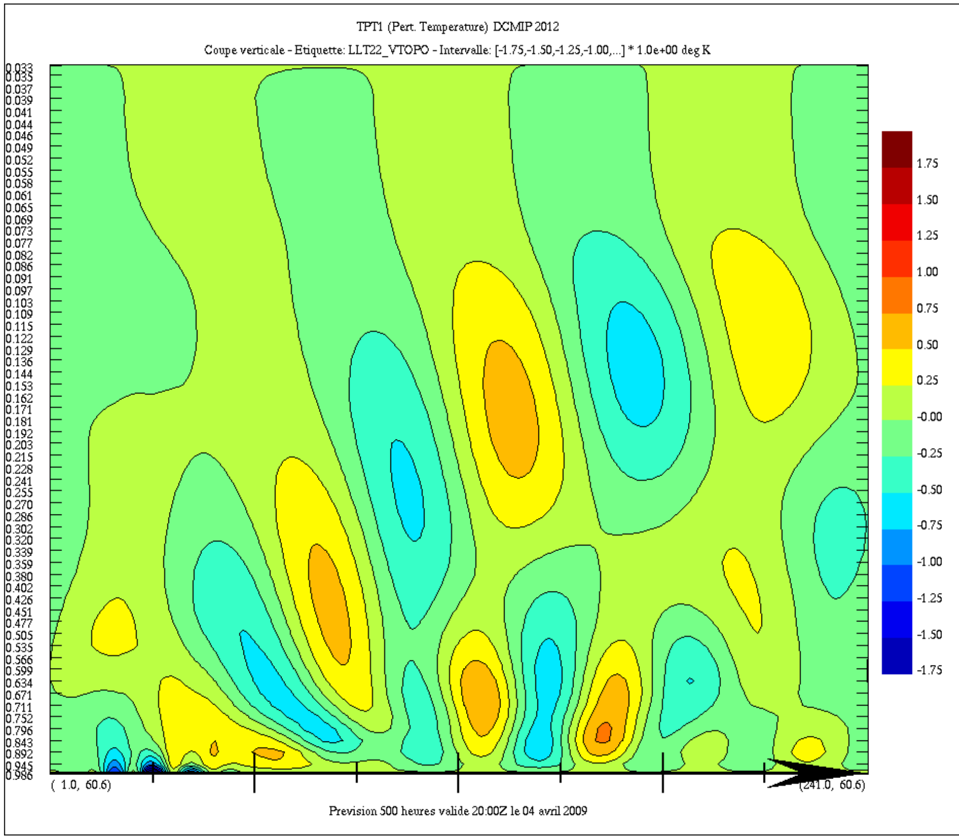
Animation MCORE

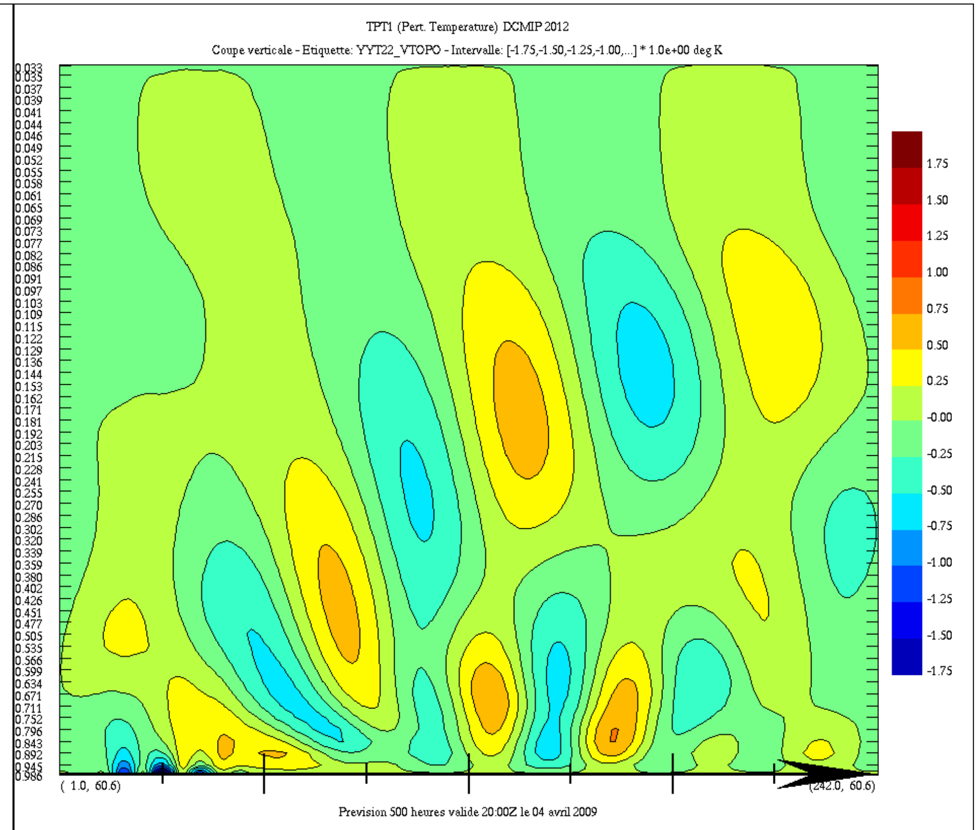
Reduced - size Earth with a circumference at the equator of 80 km and No rotation

Δx ≈ 333.6 m Δz = 500 m

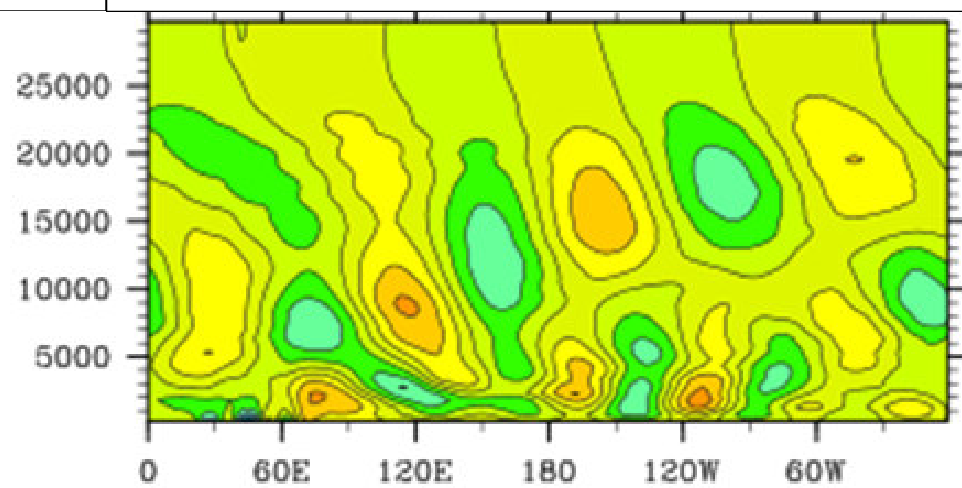
X=500

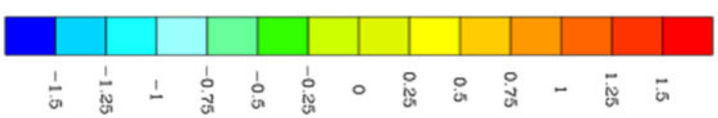
LL **Test 22 T' t=3600 s** YY





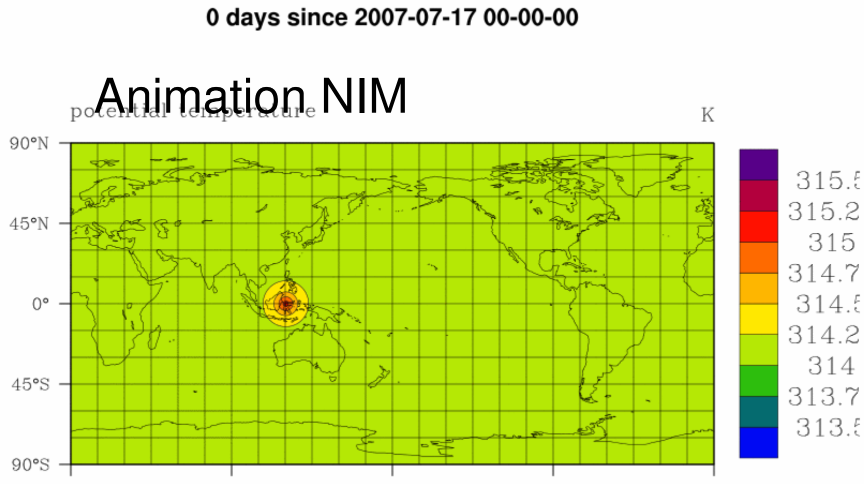
IFS

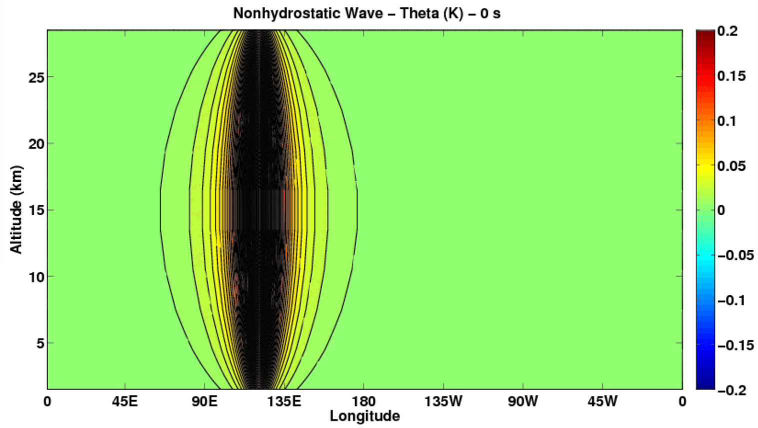




Test 30 (Warm Bubble Triggered Gravity Waves)

Animation NIM





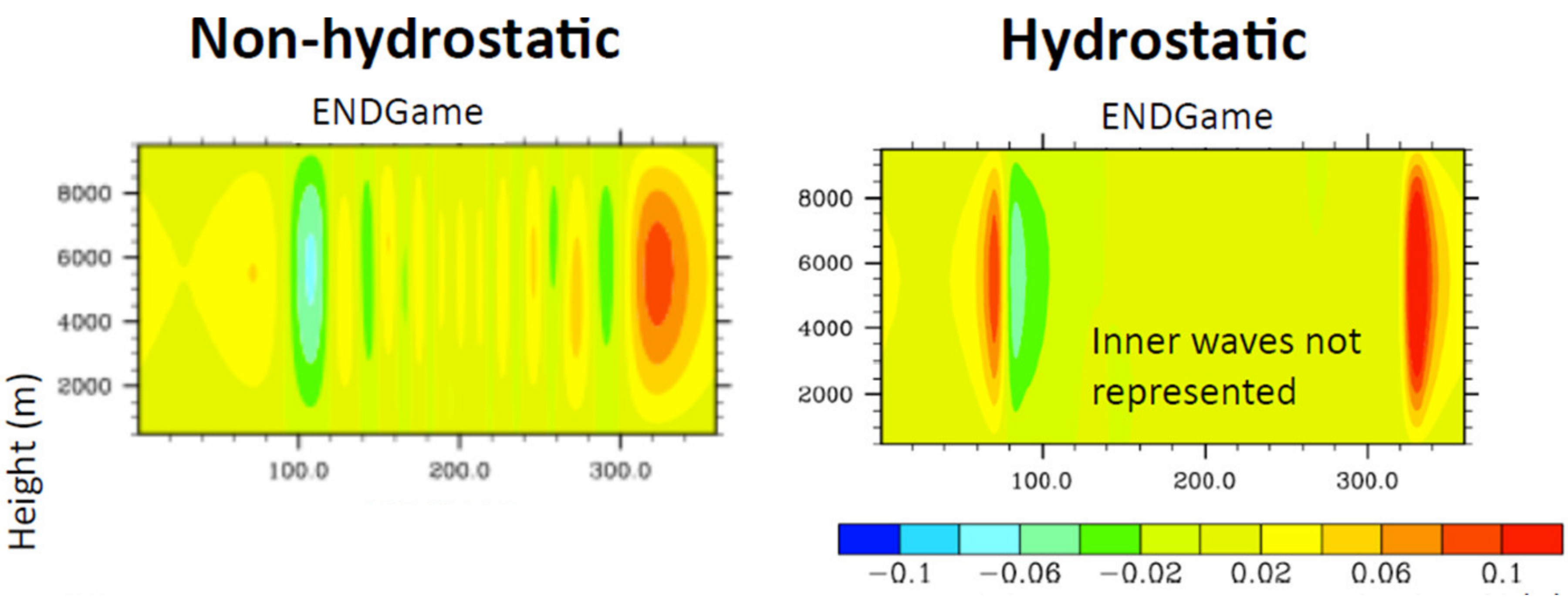
Animation MCORE

Example of NonHydrostatic response in potential temperature θ'

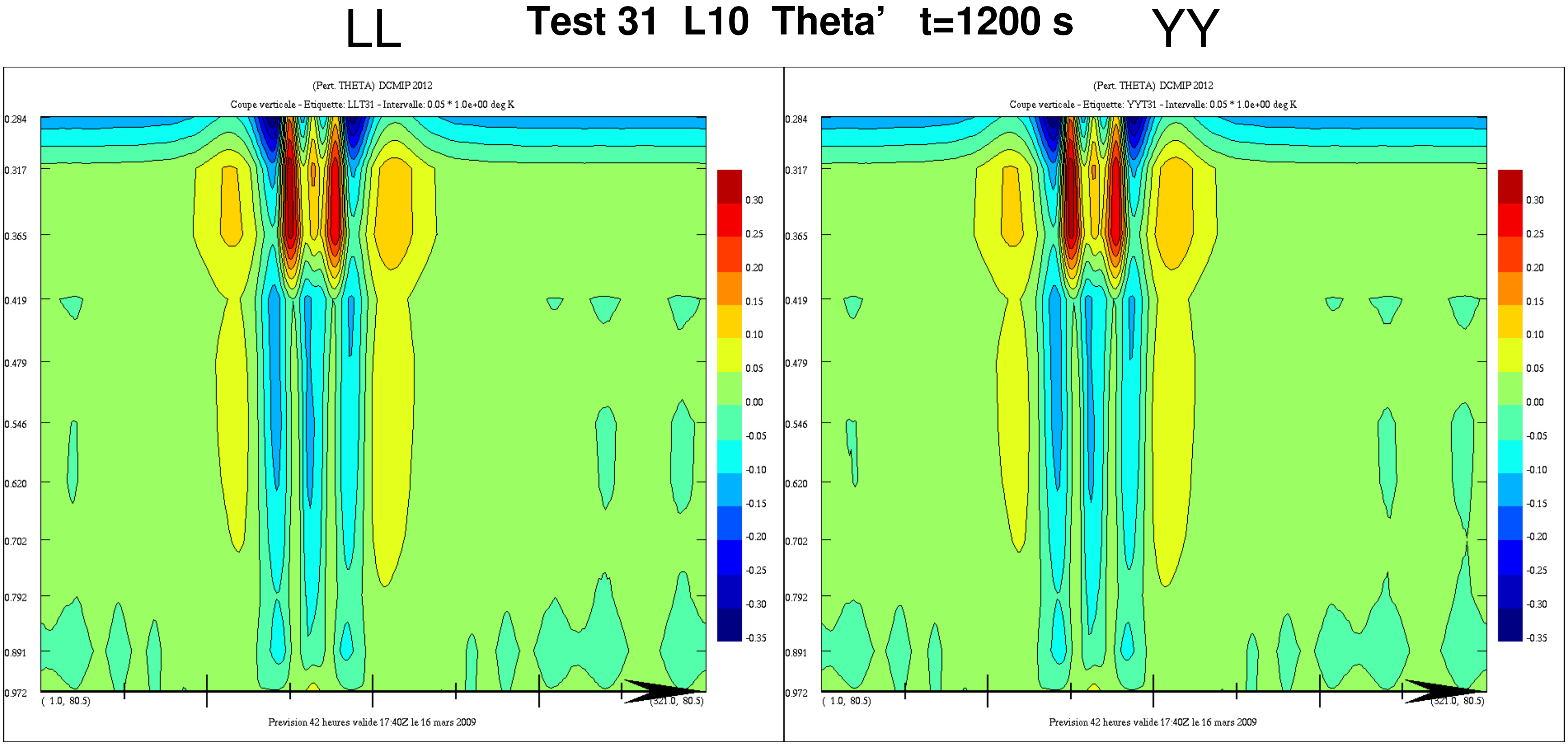
Non-orographic Gravity waves
Reduced‐size Earth with a circumference at the equator of 320 km and No rotation
$\Delta x \approx 1$ km $\Delta z = 1$ km

X=125

Test 31 L10 Theta' t=3600 s



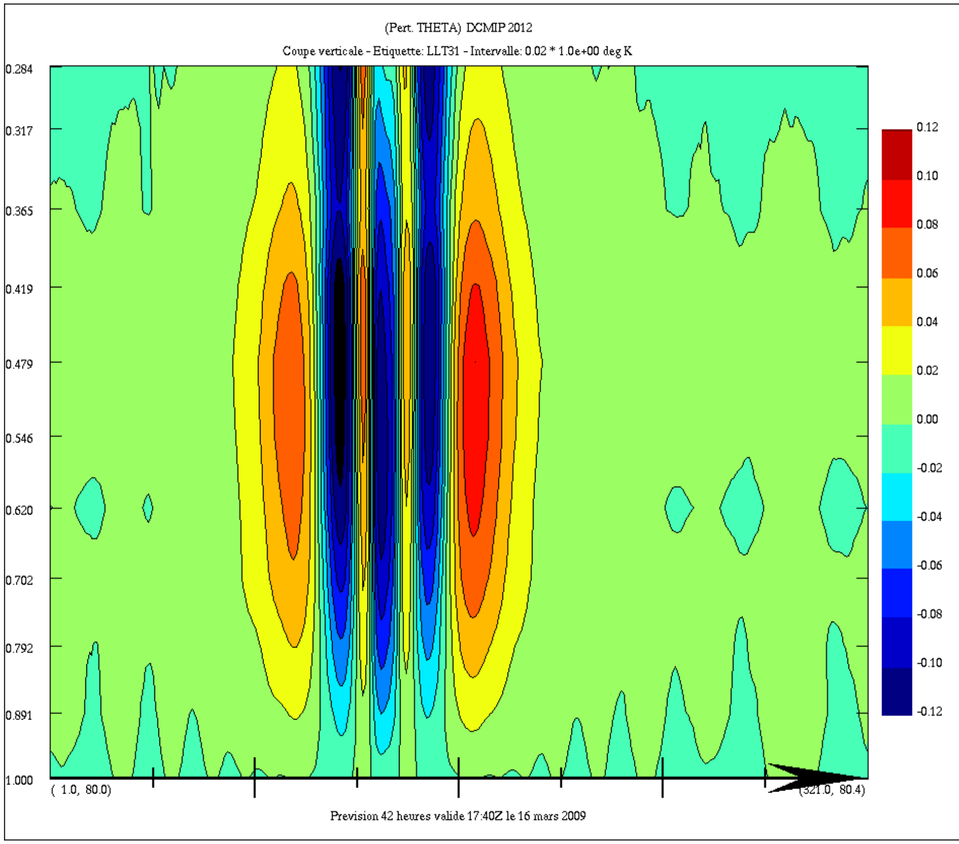
Test 31 L10 Theta' t=1200 s

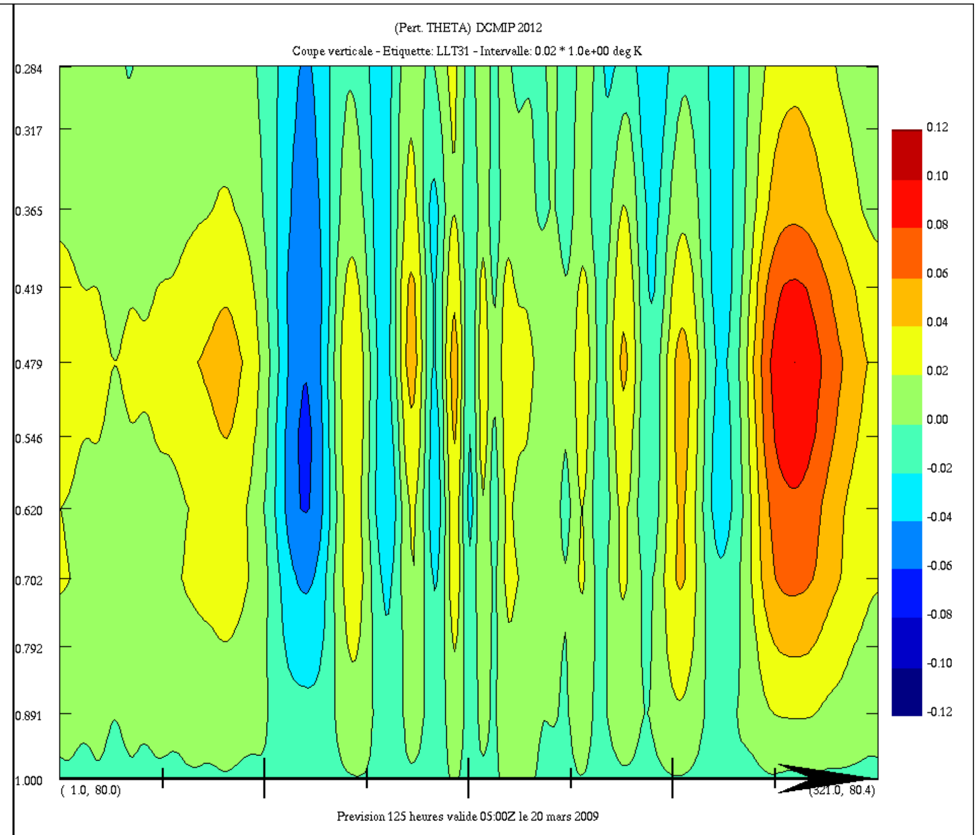


Test 31 Theta' t=1200 s

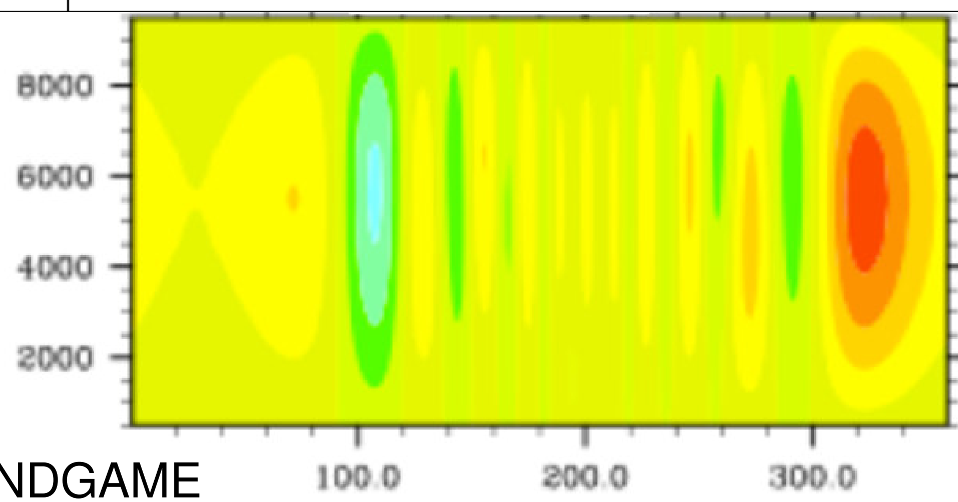
LL

Test 31 Theta' t=3600 s





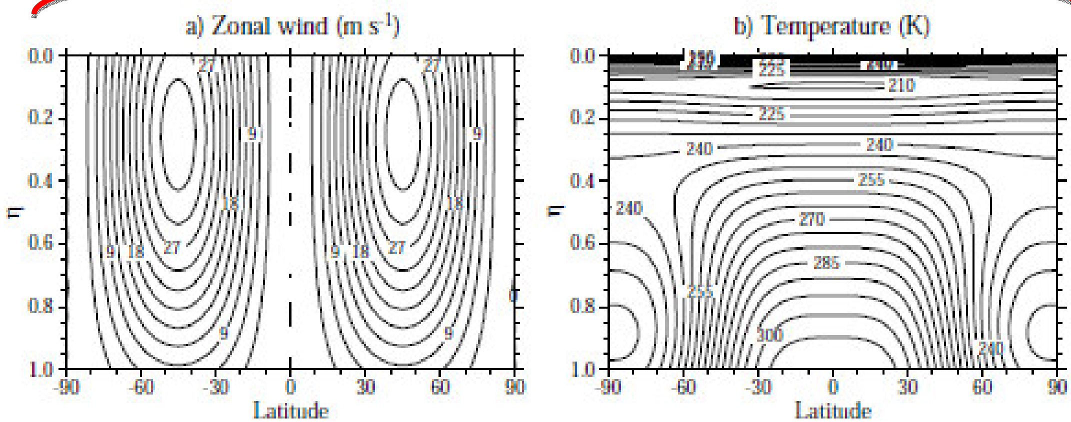
- ***Corrections à No Top thermodynamic level (Claude et André)***
- ***Extrapolation linéaire***



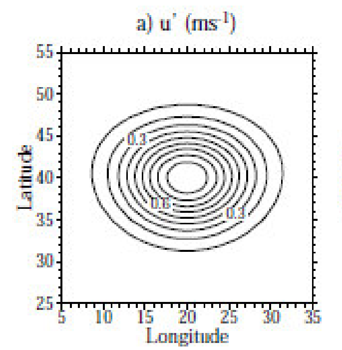
ENDGAME

Test 41X (Dry Baroclinic Instability)

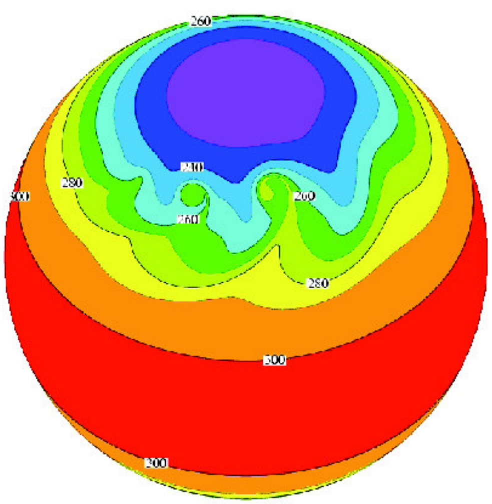
Steady-State



Zonal Wind perturbation



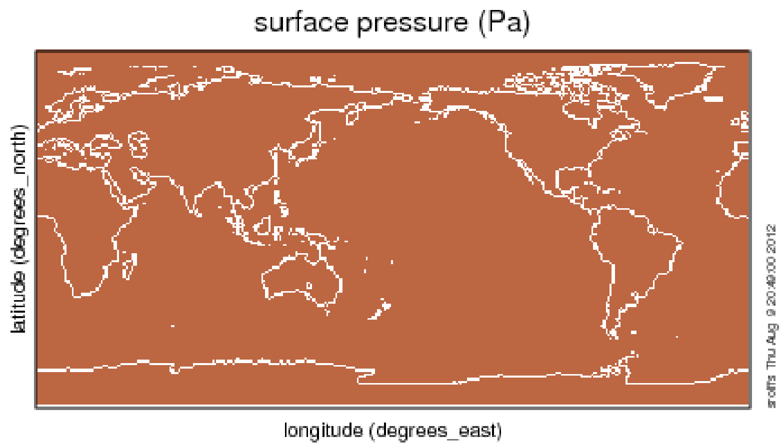
(20E,40N)



- 850 hPa temperature field (in K) of an idealized baroclinic wave at model day 9
- Initially smooth temperature field develops strong gradients
- Explosive cyclogenesis after day 7
- Baroclinic wave breaks after day 9
- Models start converging at 1°

Jablonowski and Williamson, QJ (2006)

X=1,10,100,1000



Range of surface pressure: 89103.7 to 103768 Pa
Range of longitude: 0 to 358.875 degrees_east
Range of latitude: -89.1415 to 89.1415 degrees_north
Current time: 0 hours since 2000-01-01 00:00:00
Frame 1 in File ifs.42.medium.L30.red_gauss.nonhydro.nc

Animation IFS

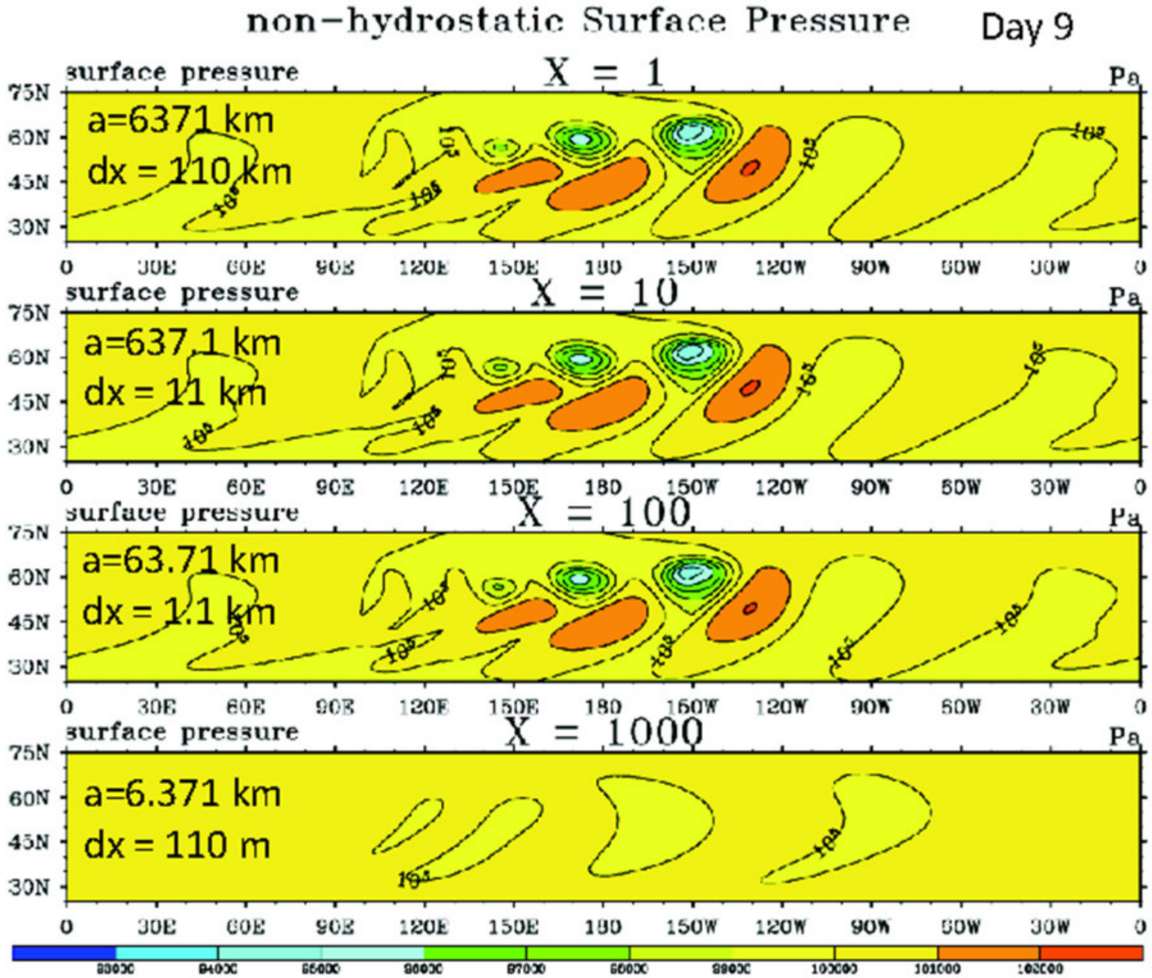
Full time series 1 deg L30 NonHydrostatic over 15 days

Test 41X:

Baroclinic wave on a shrinking Earth with radius *a*, X is the shrinking factor, 1°x1°L30

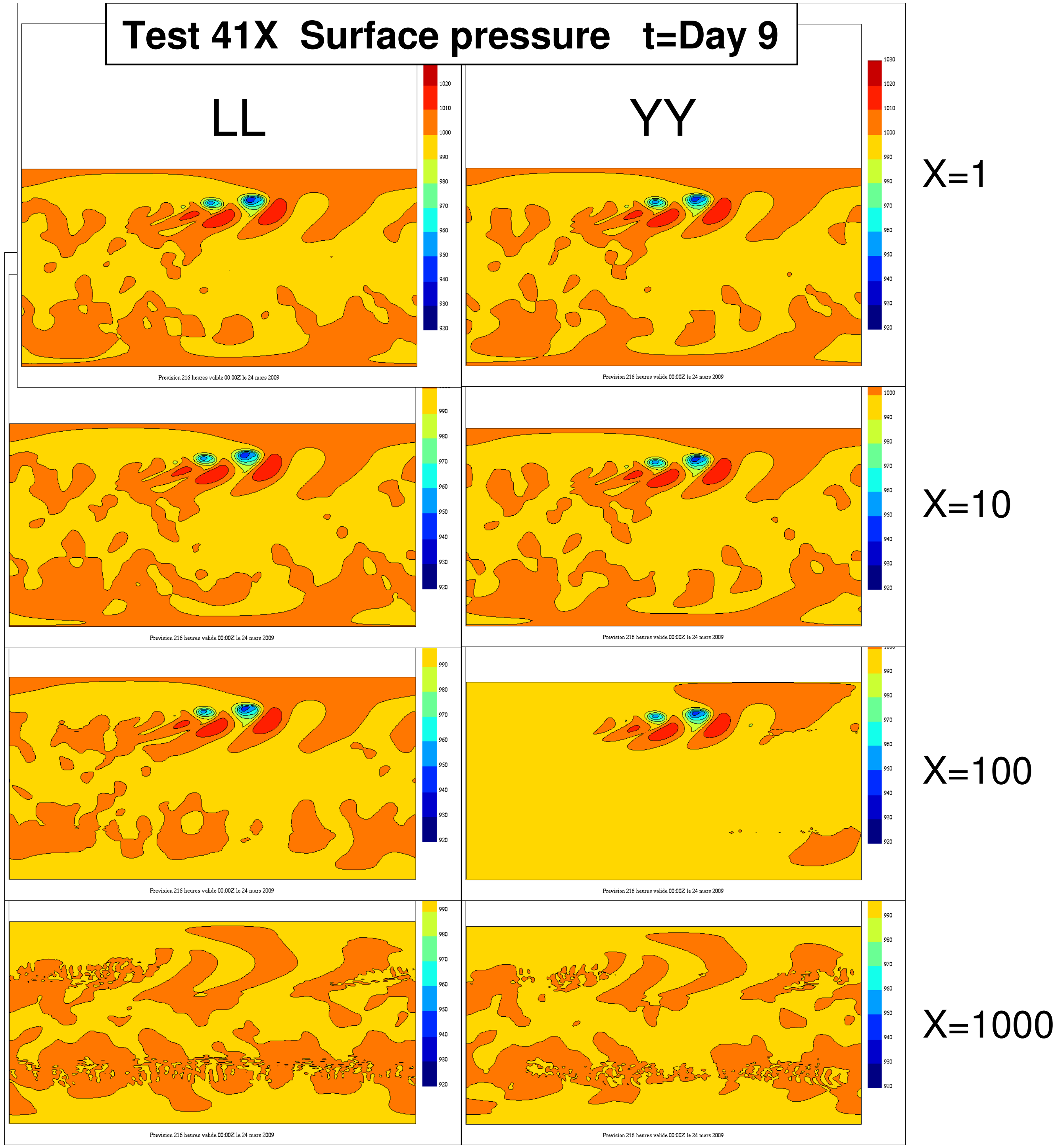
Baroclinic wave behaves very differently in non-hydrostatic models with X=1000

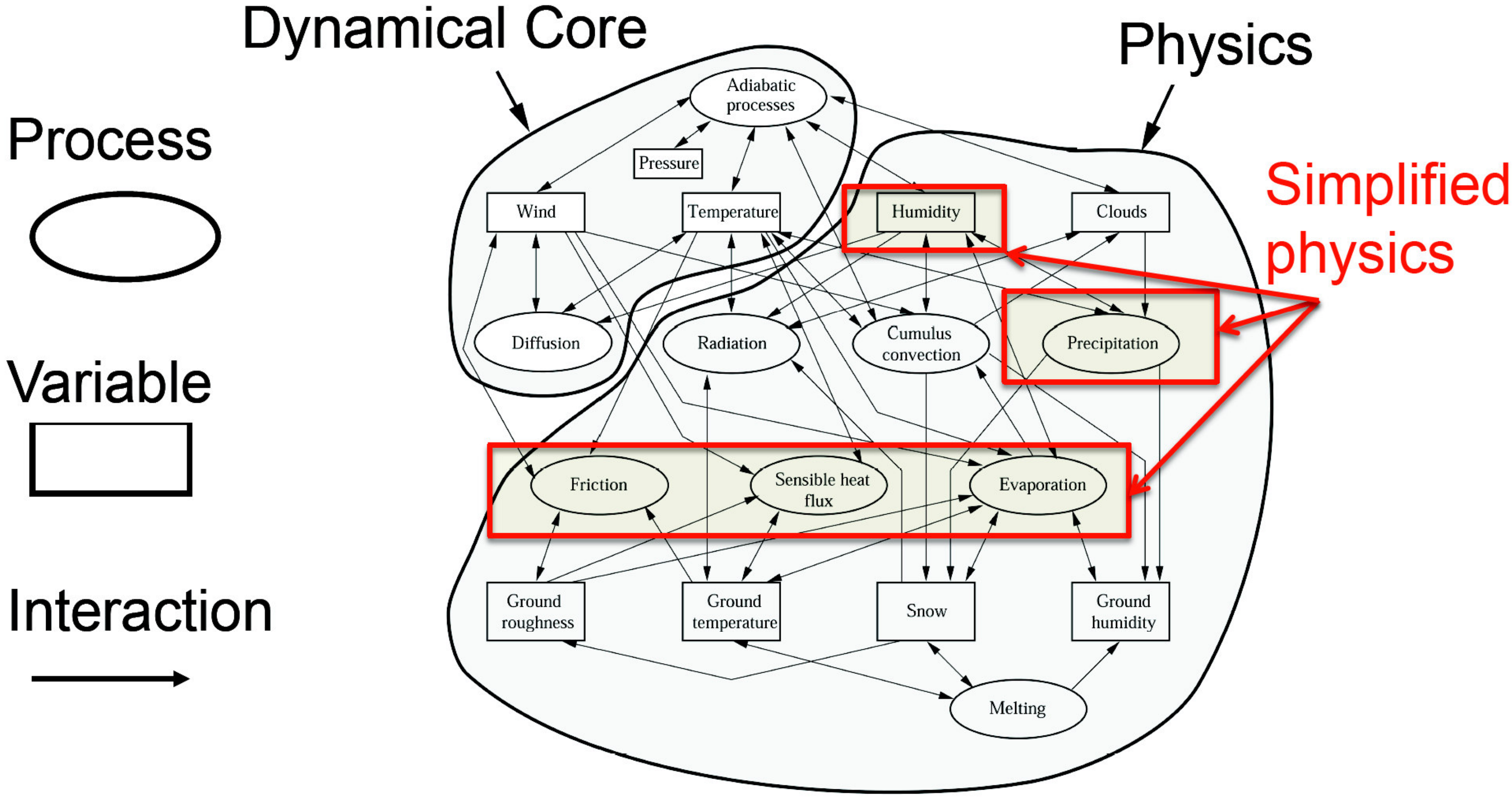
from Pilar Ripodas' poster



ICON-MPI-DWD

Test 41X Surface pressure t=Day 9

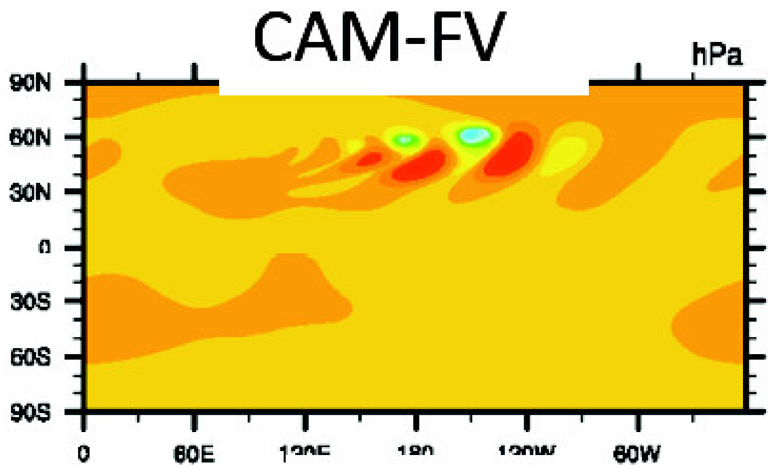




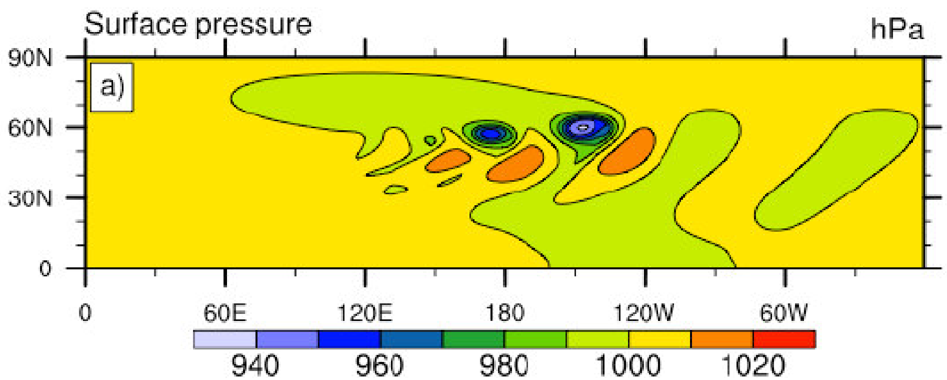
Replace the physics package: use only simple surface fluxes, large-scale condensation and vertical diffusion in BL

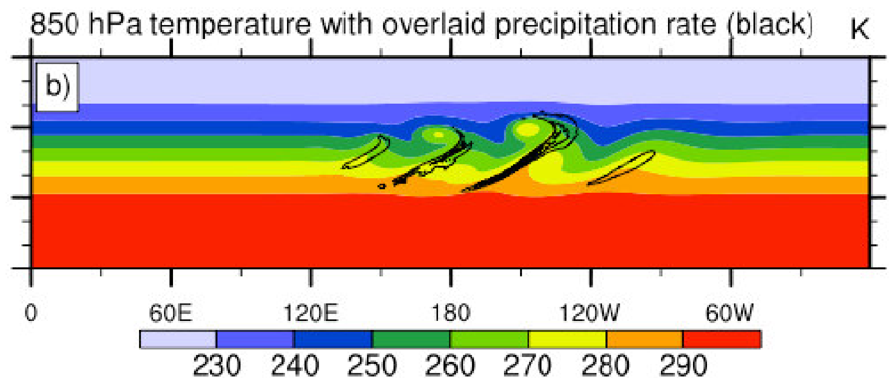
+ Aqua-Planet (Terre couverte d'eau à 29ºC SST)

Test 42 (Moist Baroclinic Instability)



Large-scale condensation in a moist baroclinic wave leads to an intensification in CAM-FV (1 deg L30), here at Day 9



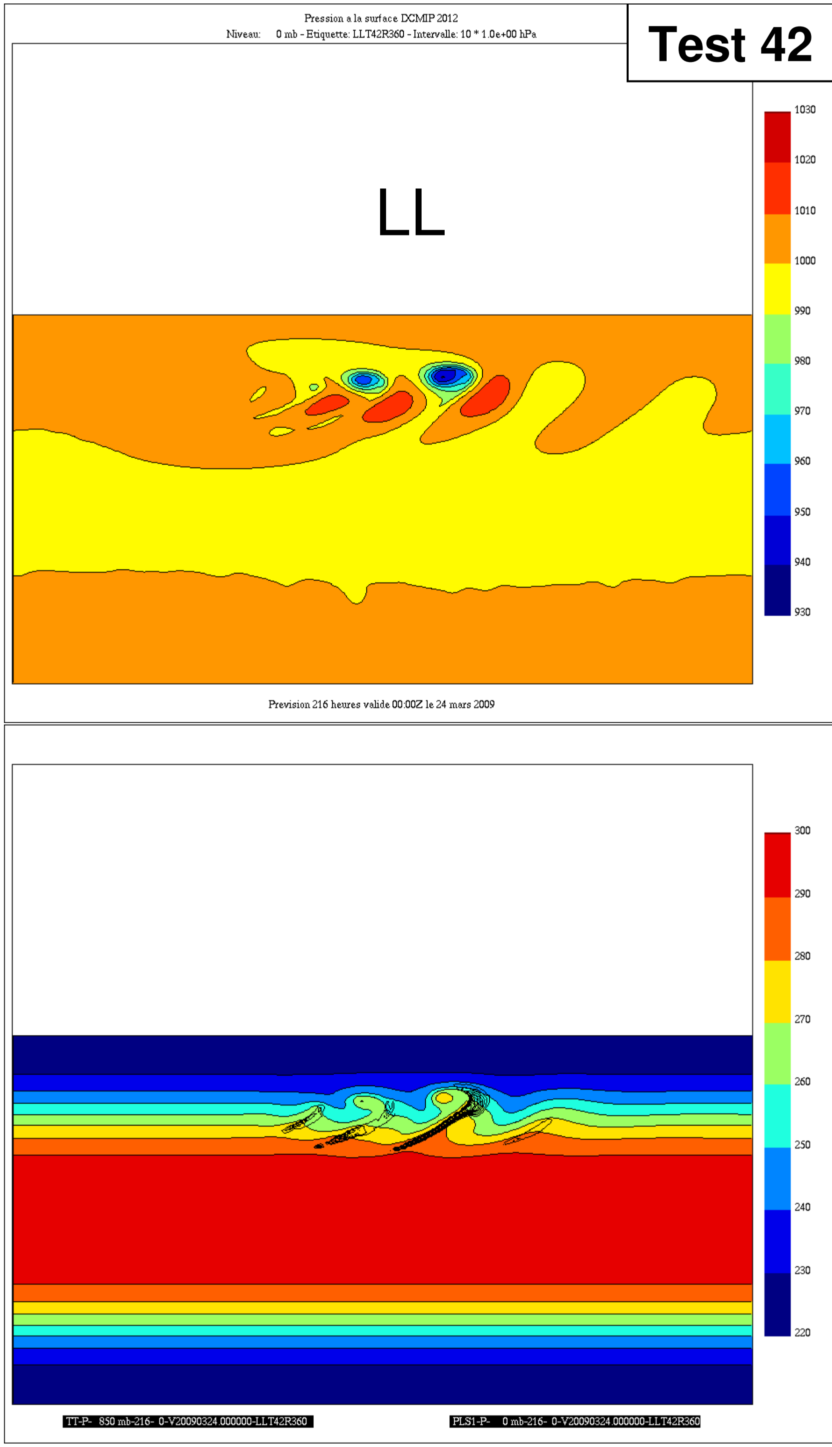


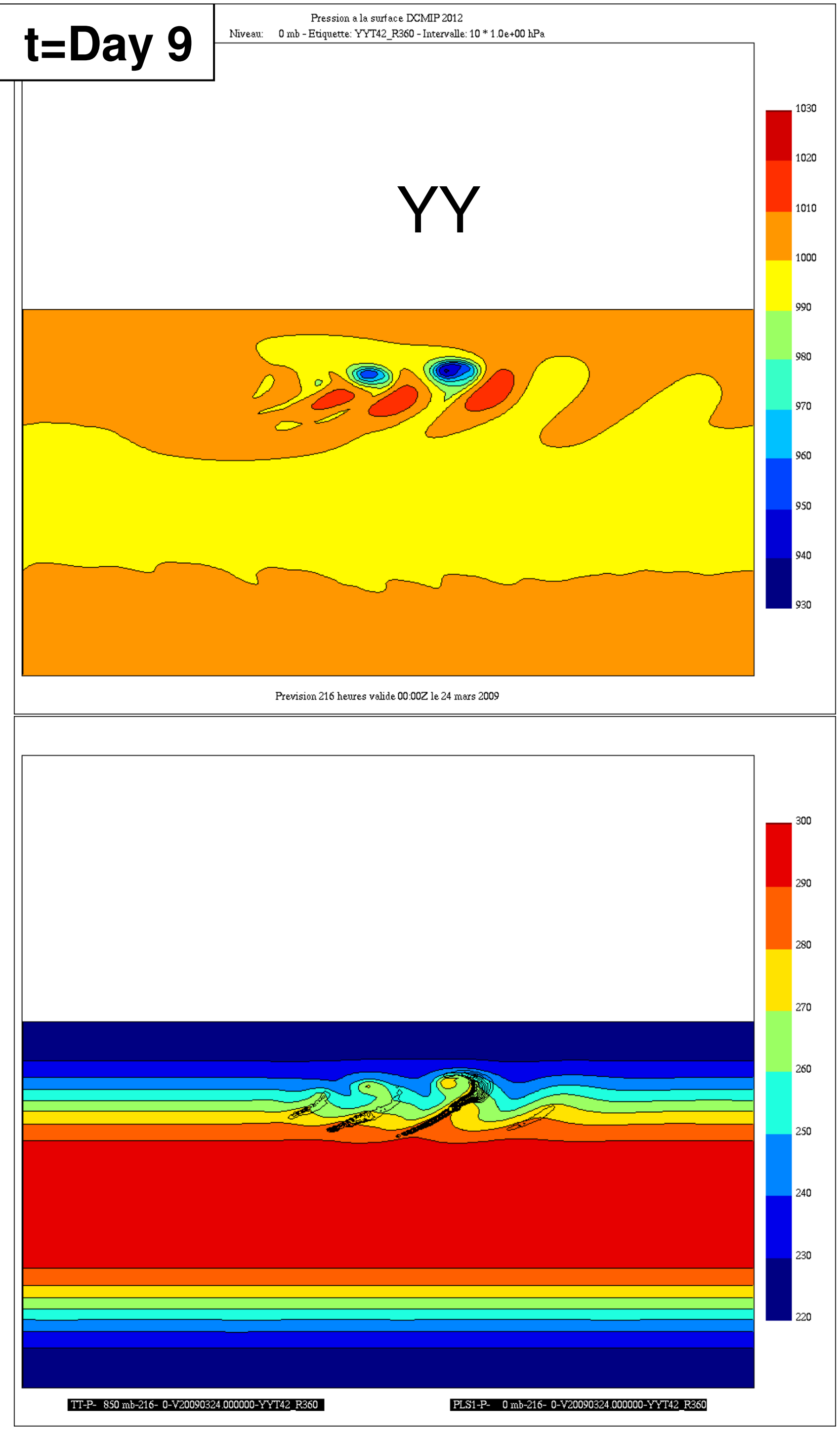
Provides a first glimpse at the non-linear physics-dynamics interactions in the presence of moisture

1°x1° L30

dx = 110 km

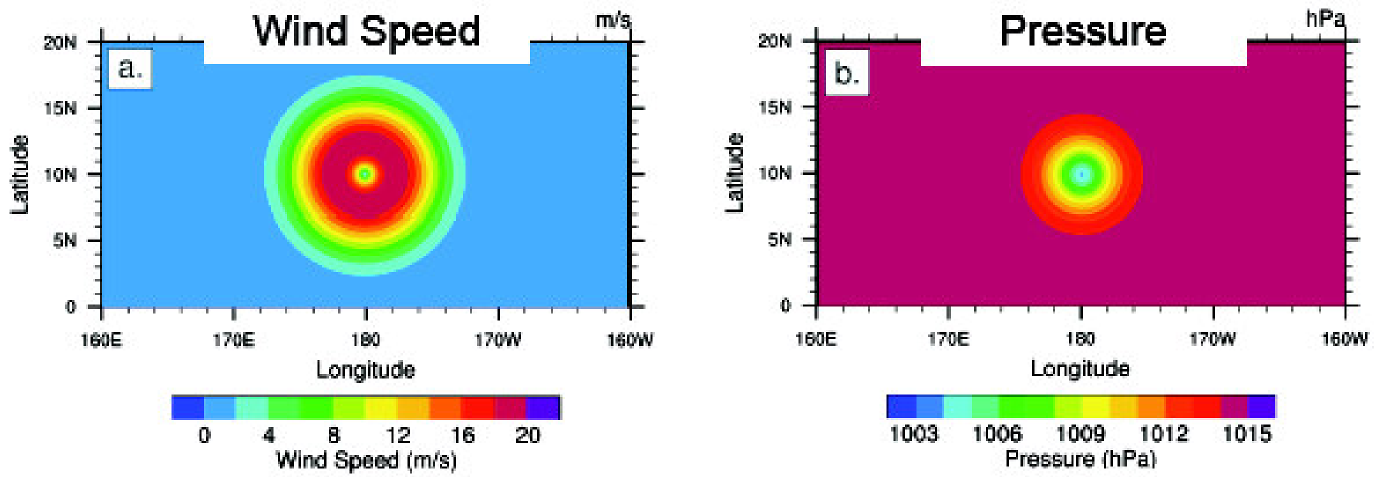
Test 42   1 deg L30   t=Day 9

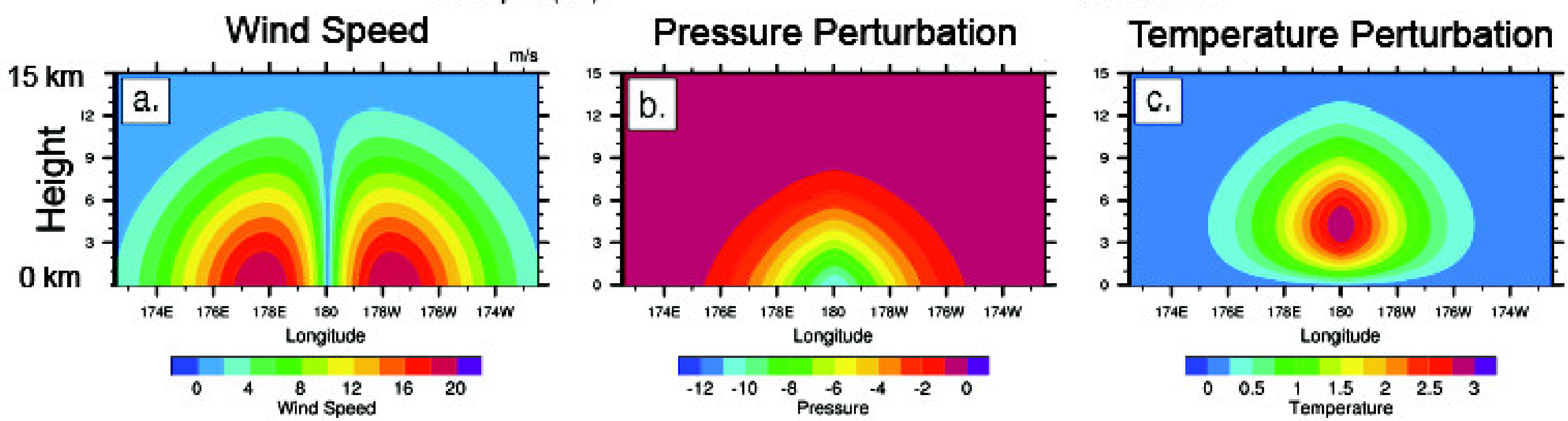




Test 51 (Tropical Cyclone with Simplified Physics)

100 m



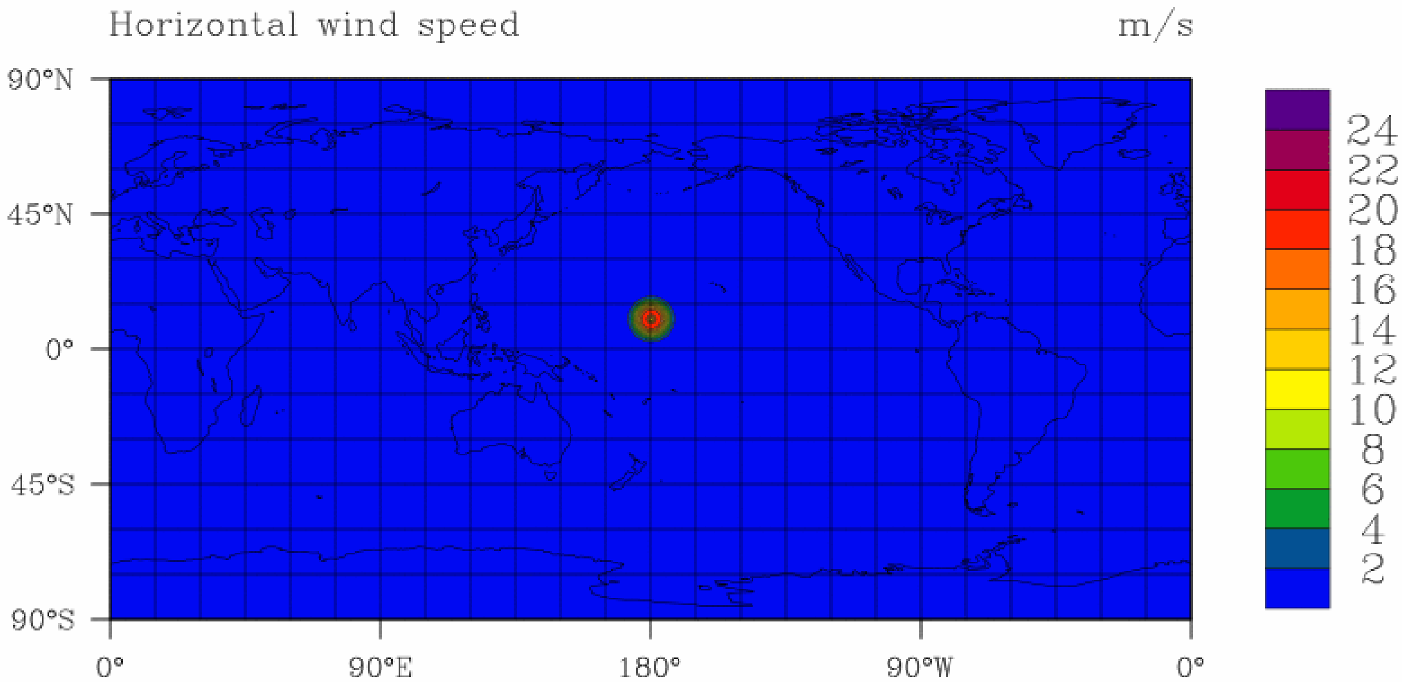


The vortex is centered at 10^o N and 180^o E.

Reed and Jablonowski, MWR (2011a)

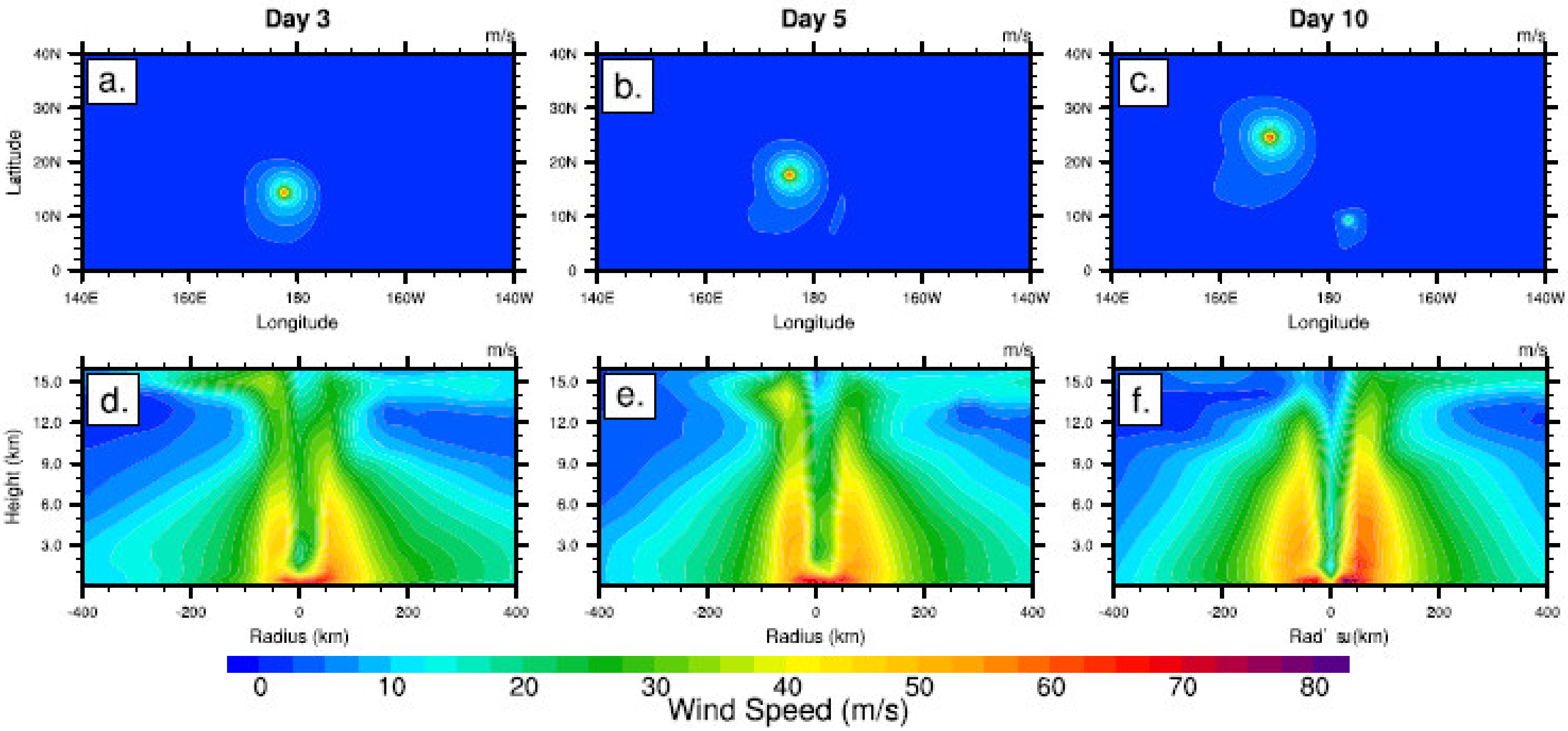
Idealized Tropical Cyclone on Aqua-Planet: Simulations with Simplified Physics

0 days since 2007-07-17 00-00-00



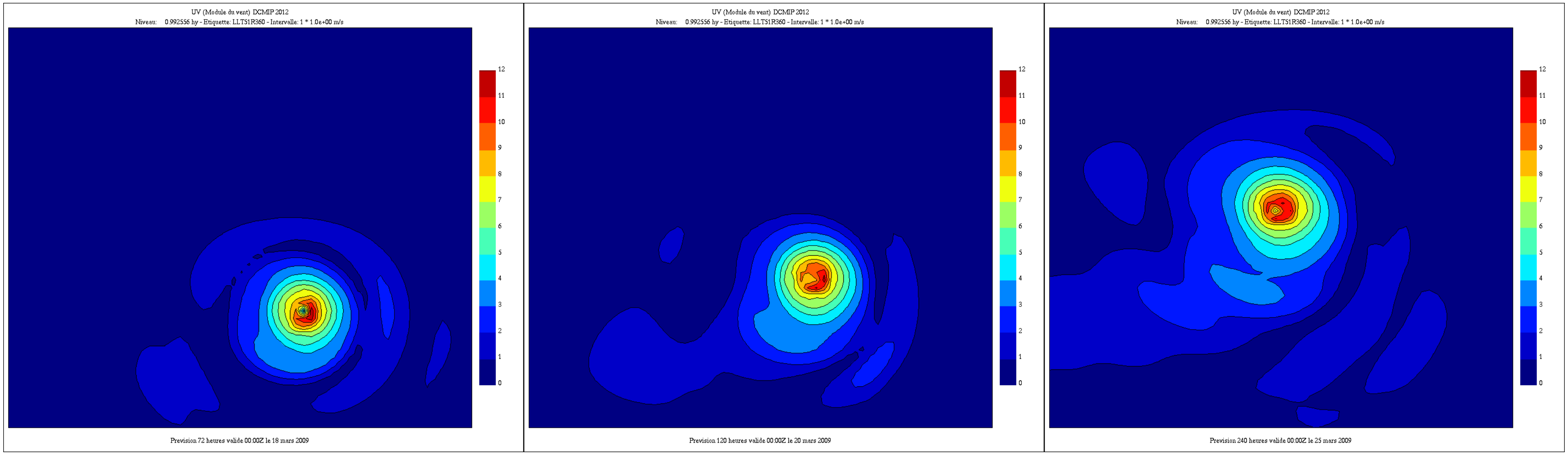
Animation NIM

Evolution of the tropical cyclone for 10 days (L30)
Wind speed at the 2nd model level (~150 m)

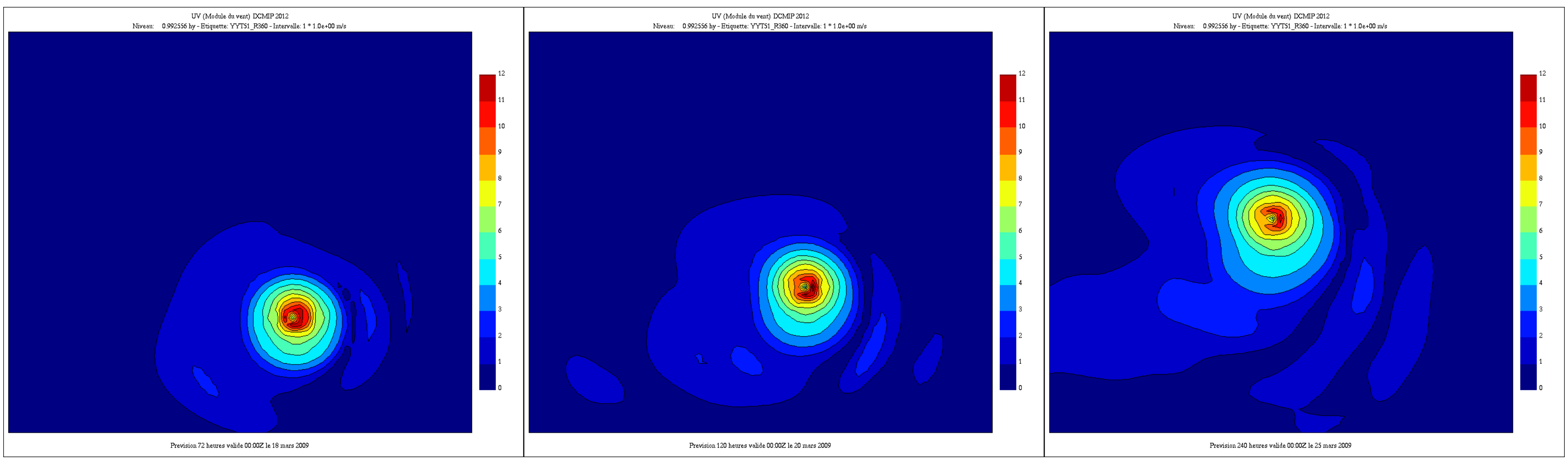


CAM5-FV .25 deg L30

LL



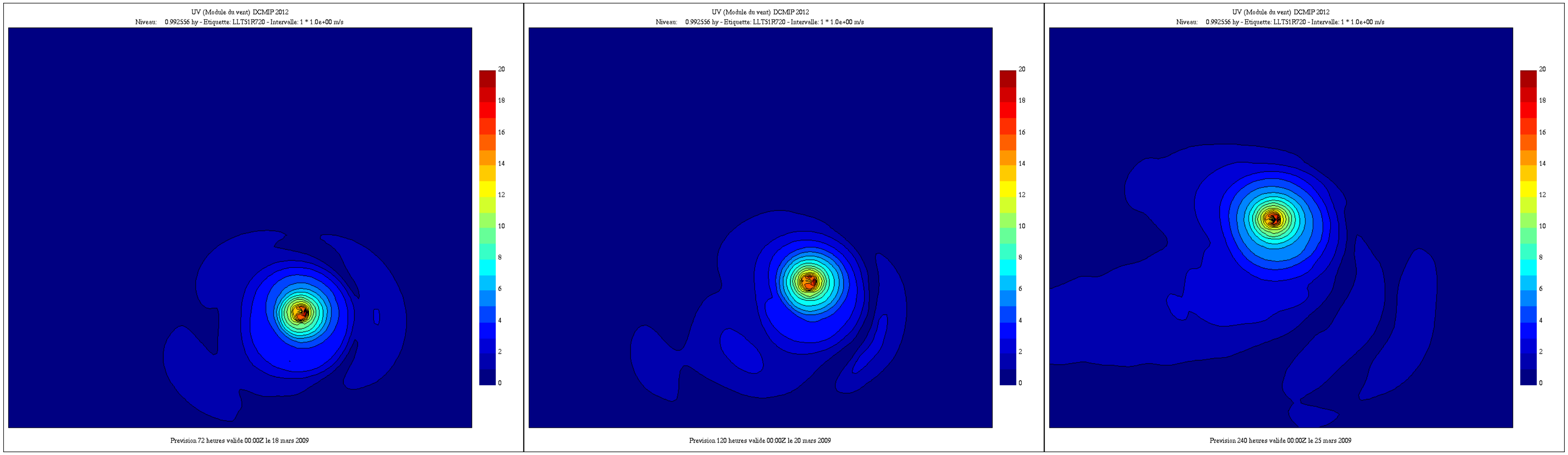
Day 3 Day 5 Day 10



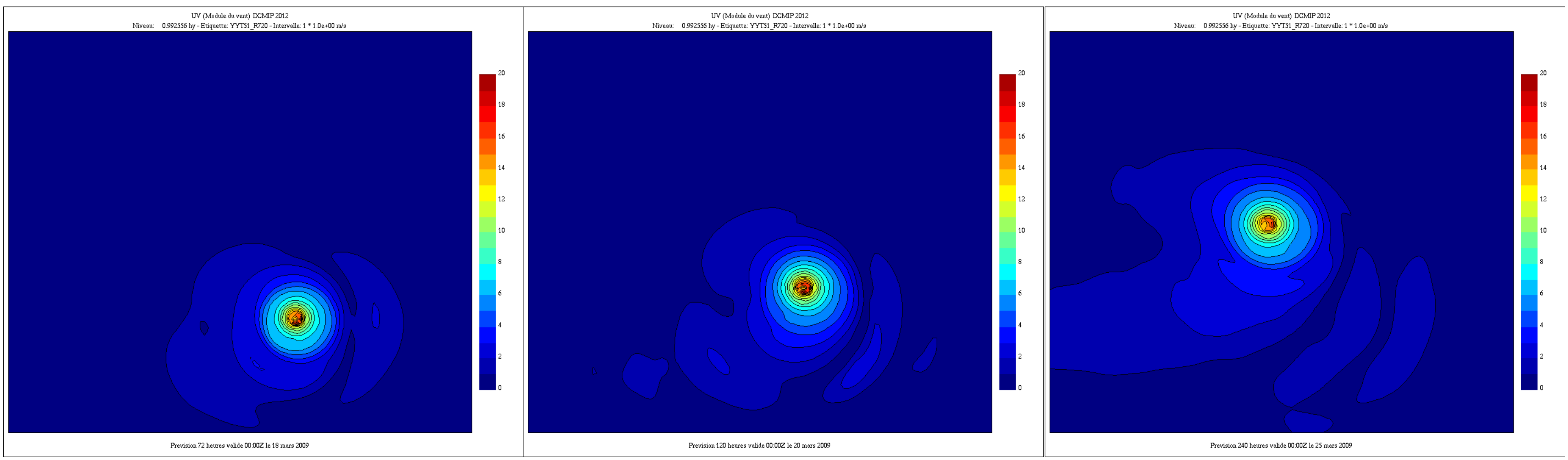
YY

1. deg L30

LL



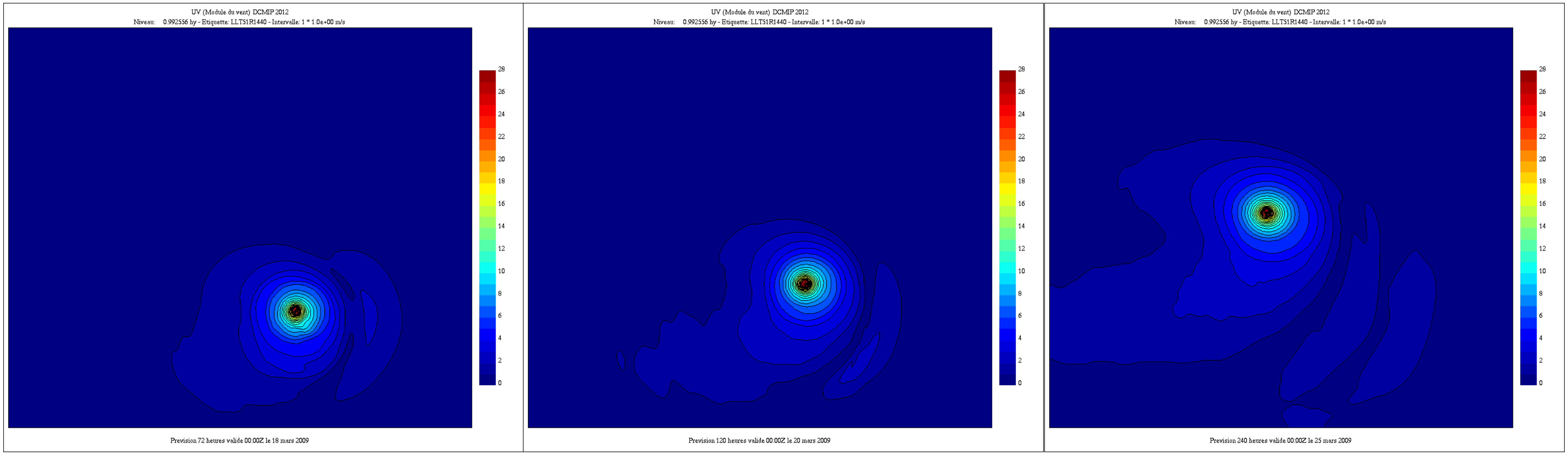
Day 3 Day 5 Day 10



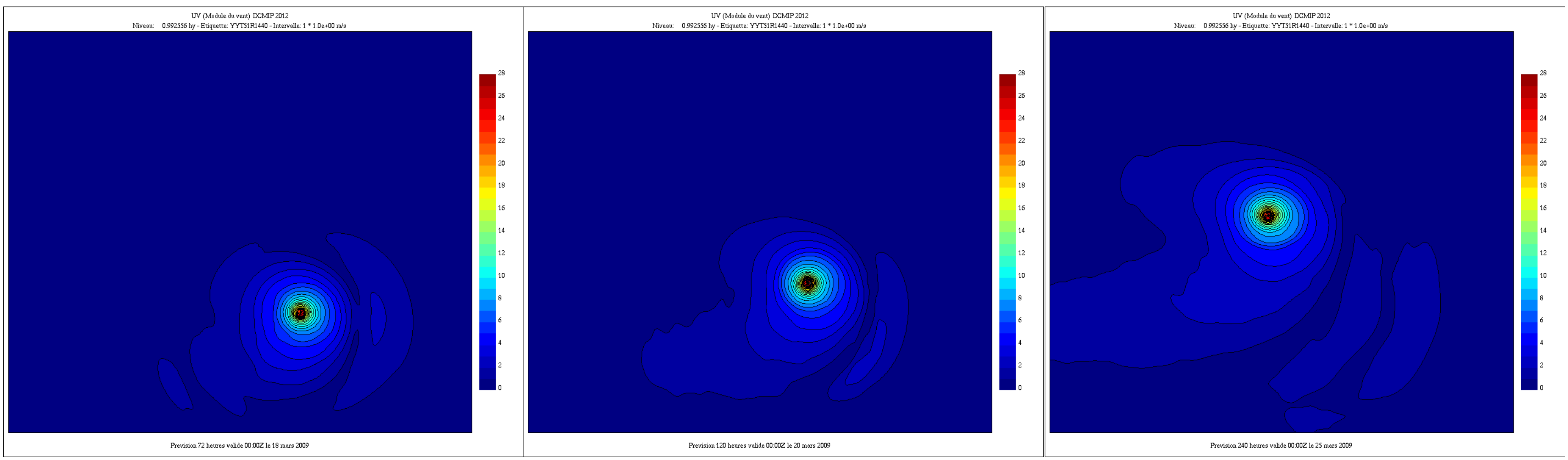
YY

.5 deg L30

LL



Day 3 | Day 5 | Day 10

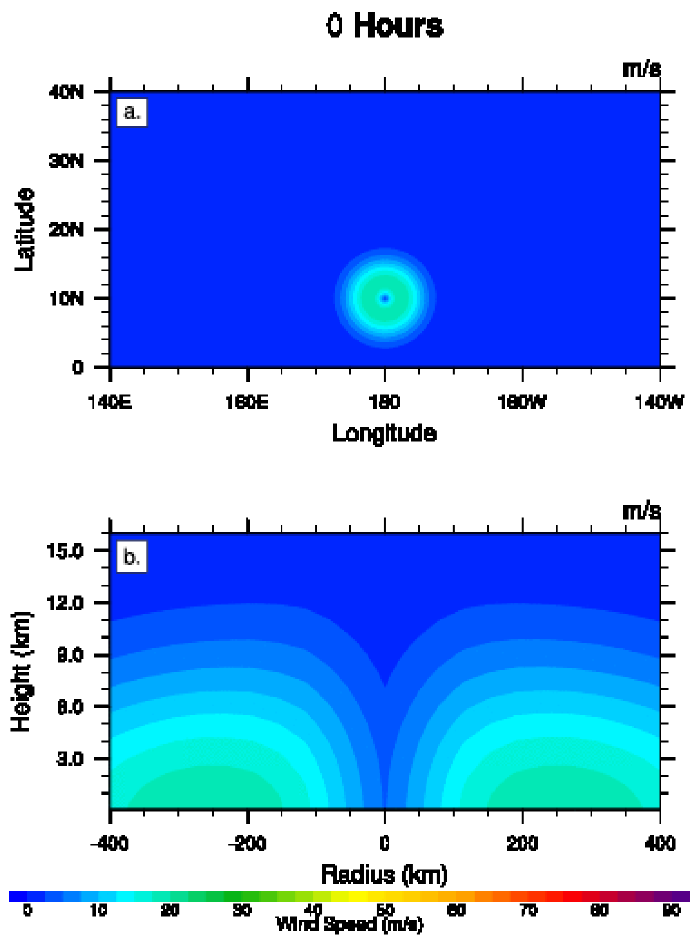


YY

.25 deg L30

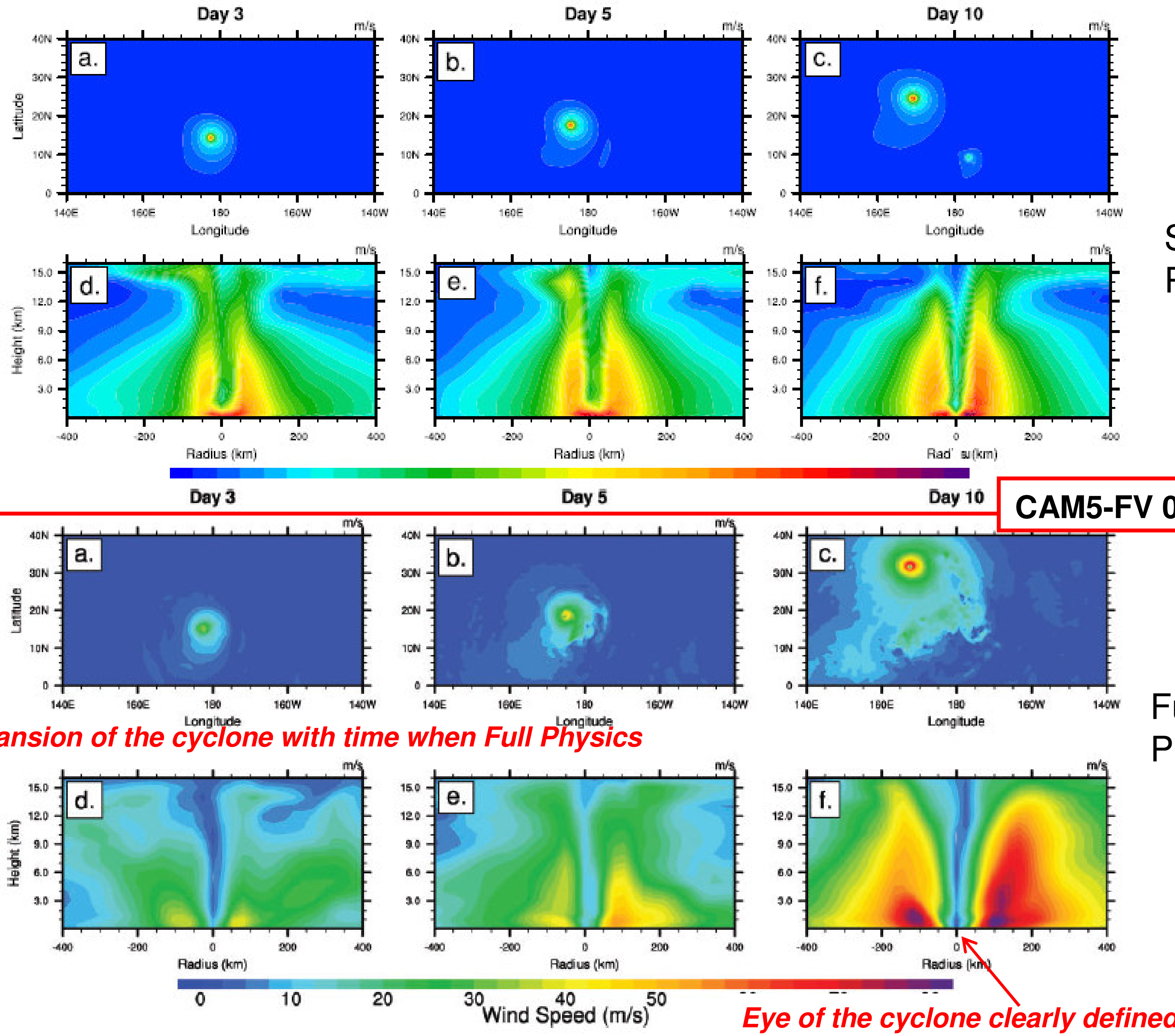
The intensity increases with the resolution
The cyclone is more concentrated in space with the resolution

Test 52 (Tropical Cyclone with Full Physics) OPTIONAL



Animation CAM-SE

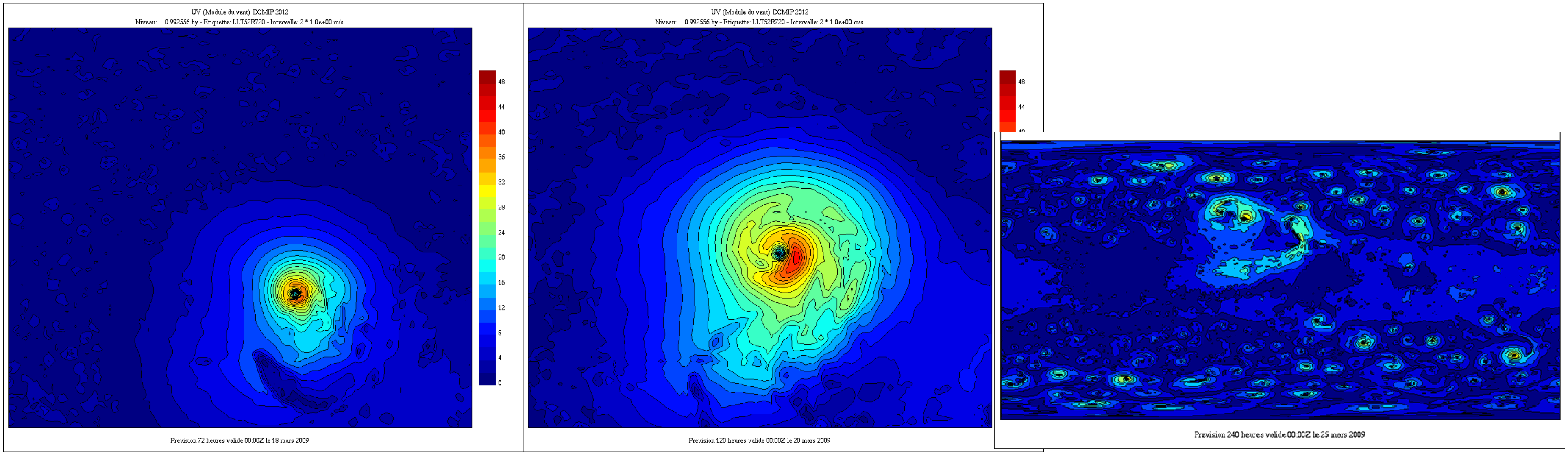
Idealized Tropical Cyclone on Aqua-Planet: Simulations with Full Physics .5 deg L30



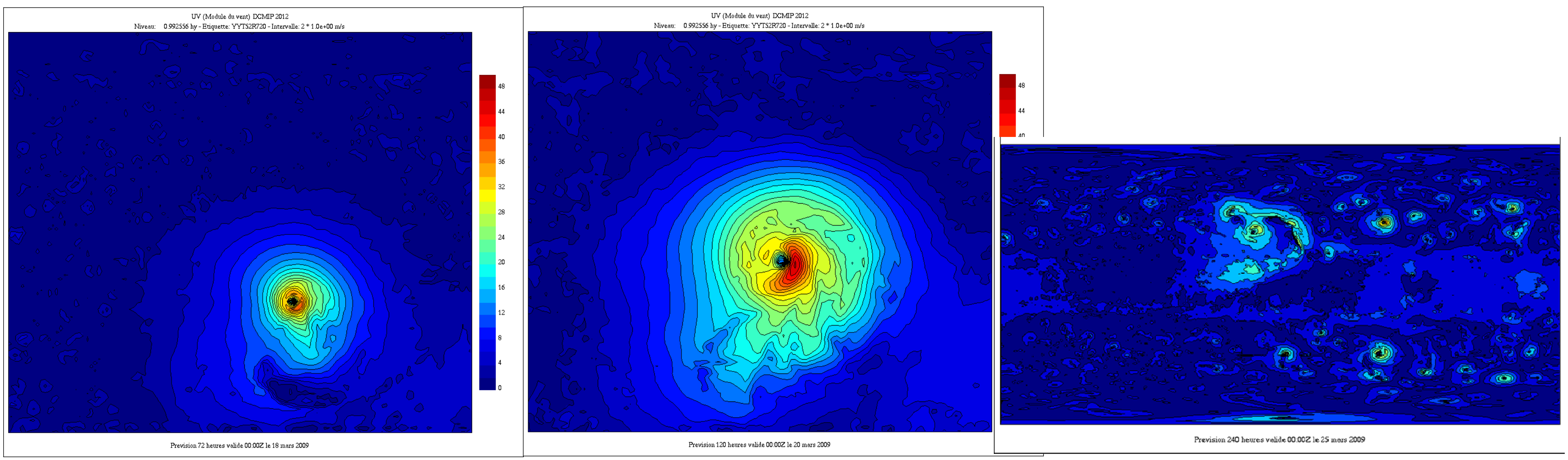
Simple Physics

Full Physics

LL



Day 3 | Day 5 | Day 10



YY

.5 deg L30

Several small cyclones at Day 10 …

SOMMAIRE

- GEM Yin-Yang et GEM Lat-Lon ont participé au projet DCMIP 2012.

- Les testcases comprennent des advections pures, des ondes de gravité orographique et non-orographique sur une planète sans rotation, des simulations Petite Planète pour obtenir un signal NonHydrostatique à faible coût de calcul, des ondes baroclines sèches et humides et des cyclones tropicaux avec physique simplifiée.

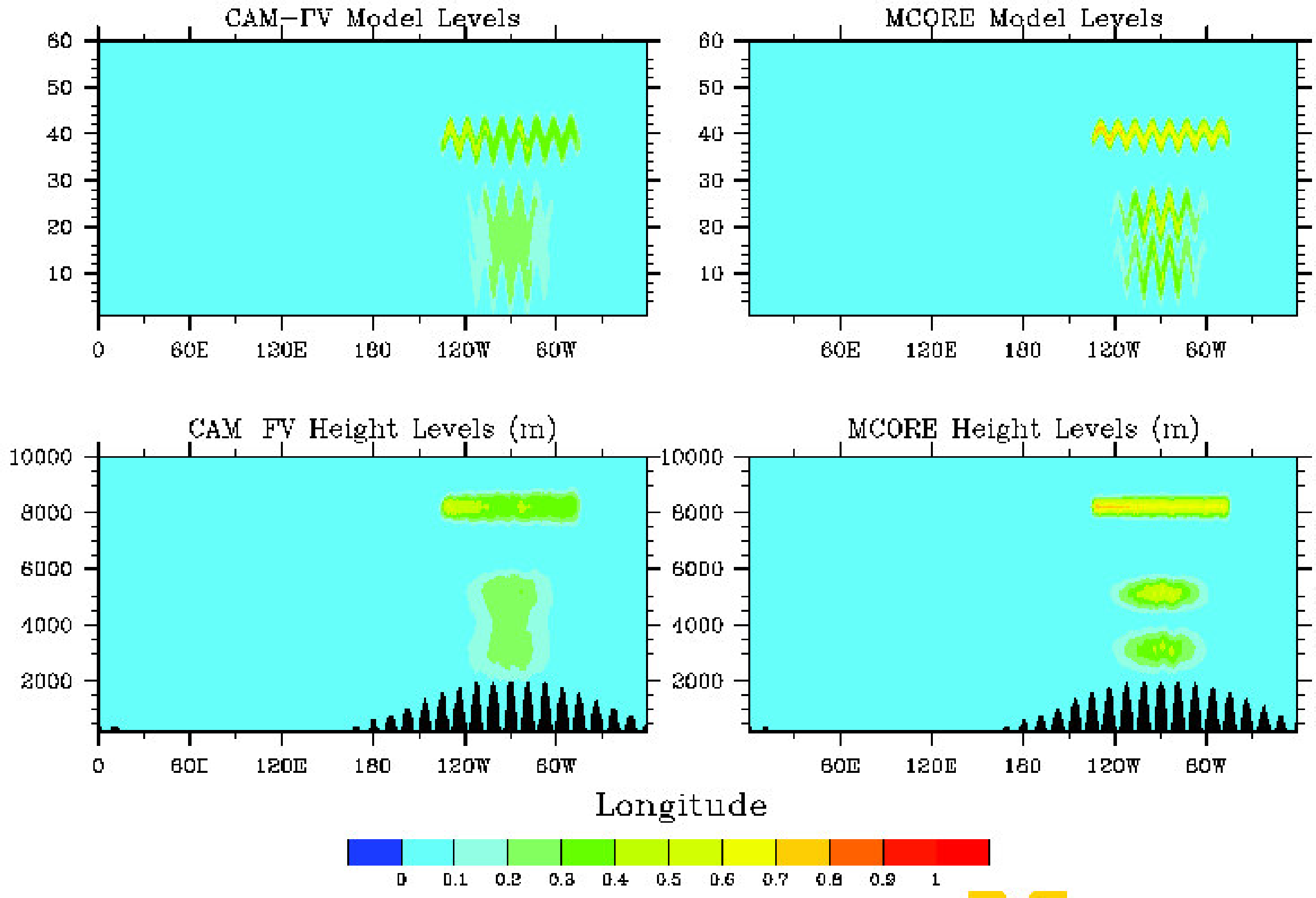
- GEM Yin-Yang et GEM Lat-Lon donnent des réponses très semblables.

- Les Test20 et Test31 ont été utiles pour comprendre et corriger une faiblesse dans l'advection semi-Lagrangienne près du toit et du sol.

- Pour le Test 52 (Pleine Physique, OPTIONNEL), GEM ne peut maintenir un cyclone unique jusqu'au Jour 10. Un ajustement incomplet d'Aqua-Planète en lien avec la radiation est probablement en cause.

Test 13 - Flow Over Orography

At time $t = T/2$, comparing CAM-FV and MCore on both model levels and interpolated to constant height levels



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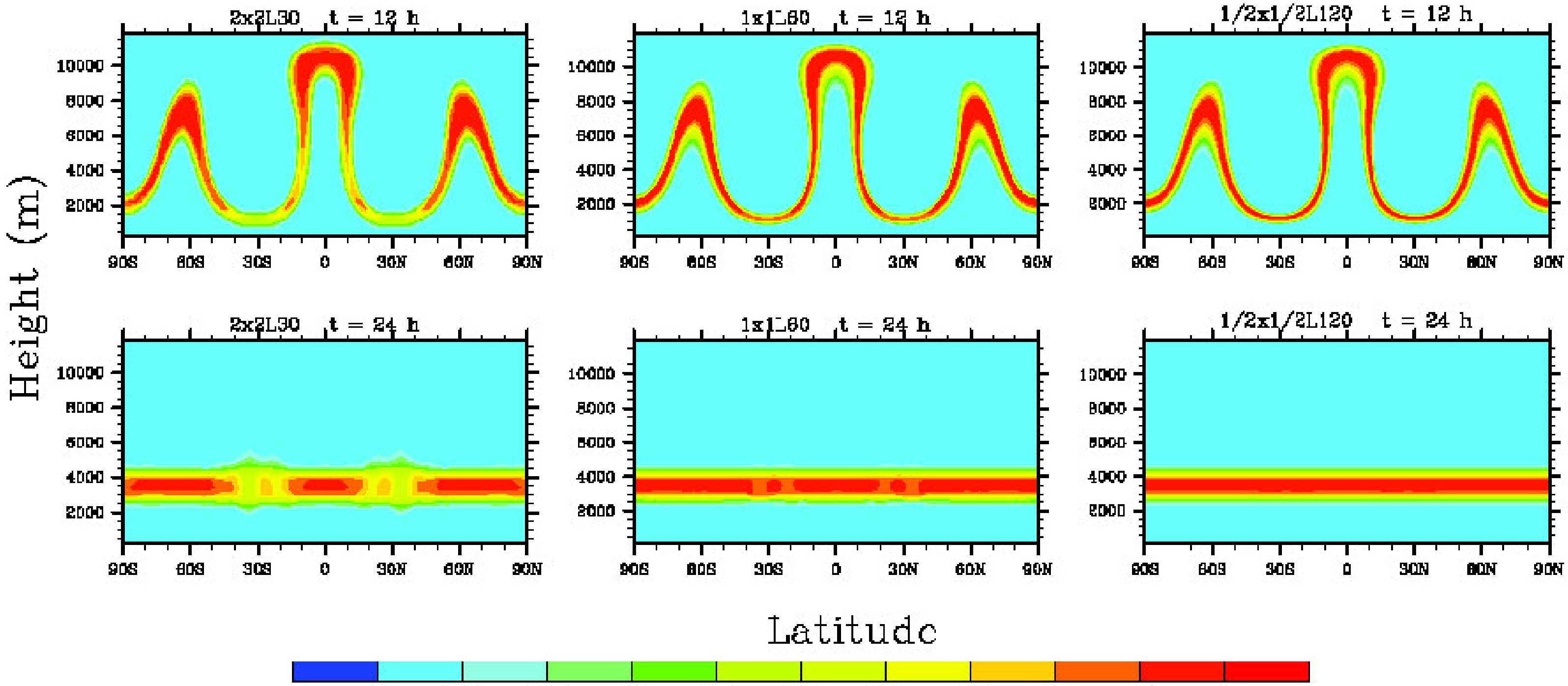
Test 12 - Hadley-Like Meridional Circulation

Comparison of results using CAM-FV at different resolutions.
Standard error norms can be computed at time $t = T$



- Baroclinic wave test, day 9 (Jablonowski and Williamson, 2006)