Academic Case Studies of Explicit Convection

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LAM Testbeds

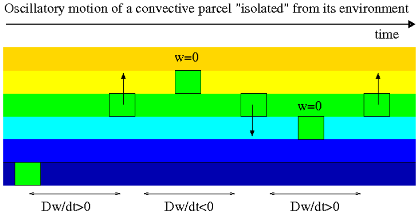
- Idealised 3D convective bubble experiments with Meso-NH and Arome in Cartesian geometry
- Similar results between Meso-NH and Arome for well resolved bubbles (by the 2.5 km resolution of Arome but also finer ones).
- Very different results for a "single column" bubble : 5 mm accumulated rainfall in Meso-NH against more than 300 mm in Arome in less than 2 hours.

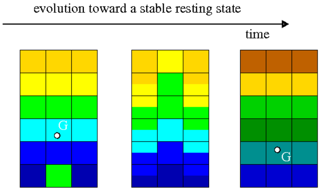
Small Planet Testbed

Similar idealised experiments may be done with the NH IFS-Arpege-Aladin-Arome dynamics and the setting of IFS for a small planet (Wedi and Smolarkiewicz, 2009).

- r=a/100 ($\simeq$ 63 km) , T159 $\Longrightarrow$ $\Delta x \simeq 1.3$ km
- $\Delta t = 10$ s
- NH and dynamics setup from IFS

Dry convection (1)

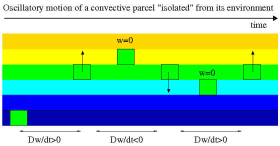


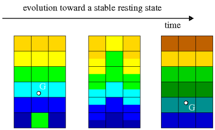


The bubble is adiabatically buoyant in a stable environment

- It accelerates upward until it reaches its level of neutrality
- it overshoots this level in a slowing down motion
- it goes down and oscillates around the equilibrium level

Dry convection (2)





- Thanks to mass conservation, a convergence zone is formed near the surface to compensate for the ascending motion. Environmental air will step by step fill the space left by the ascending bubble.
- In the 3D environment, horizontal pressure forces create gravity waves around the initial ascent which reorganize mass, energy and momemtum toward a new resting state (because the Rossby Radius of deformation is very big compared to the scale of the perturbation).

Dry convection (3)

- The only sources/sinks of water vapor in the dynamics are numerical.
- Vapor is lighter than dry air. At the same temperature, moist air is more buoyant than dry air.
- Near the ground, a perturbation of about $+3$ g/kg of vapor is equivalent to a perturbation of $+1$ K in term of buoyancy (θ_v).

Moist convection

- The bubble starts to go up as for dry convection.
- But before reaching the level where it starts going down, it reaches its level of condensation.
- The bubble is warmed up by latent heat release and then it becomes buoyant again.
- Thanks to further condensation, it is usually able to reach the tropopause, but is stops shortly above as it quickly reaches a level of neutrality in the strongly stratified stratospheric air.
- Water loading and evaporation+melting may strongly inflence the buoyancy of the air parcels.

Explicit Convection

- Dry convection is purely treated by the dynamics. The buoyancy may nevertheless be influenced by the moisture content (and water loading).
- Condensation is the "motor" of strong moist convective motions. The "fuel" (the moisture) alimentation is then an important control factor of convective motions (enormous quantity of energy, as seen for example with the DDH)
- Explicit moist convection is the result of very complicated and non linear interactions between the Dynamics and the Physics of the model.

Convective Bubbles : Reference experiments REF

- The reference for the radio-sounding profiles used for these experiments is
  Klemp J. B. and R. B. Wilhelmson, 1978 : The Simulation of Three-Dimensional Convective Storm Dynamics, J. Atmos. Sci., 35, 1070-1096.
- Numerical values were available for Meso-NH experiments. They were adapted for hybrid coordinates for tests with Arome and included in the academic test-bed for small planet experiments with IFS (vertical interpolation on ECMWF levels).
- For the REF bubble tests shown here, only the temperature and humidity profiles are used. The initial conditions are no-wind conditions.

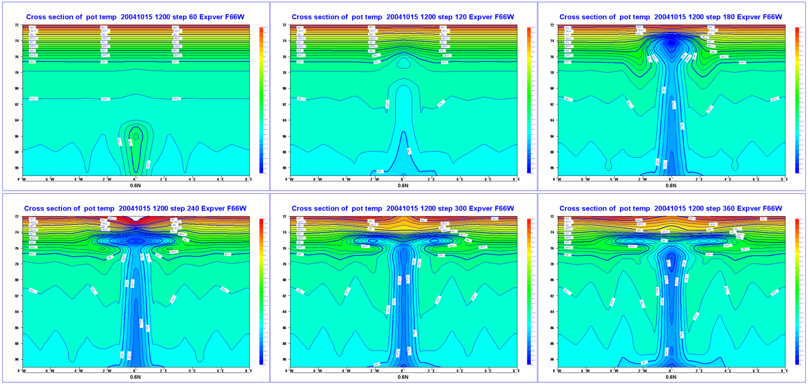
Warm and moist bubble settings

Uniform profil of T and q_v all around the planet + a warm anomaly (+2K) in the three lowest full levels and a moist anomaly (1.5 times the original value = +6g/kg) only at the lowest level above the surface

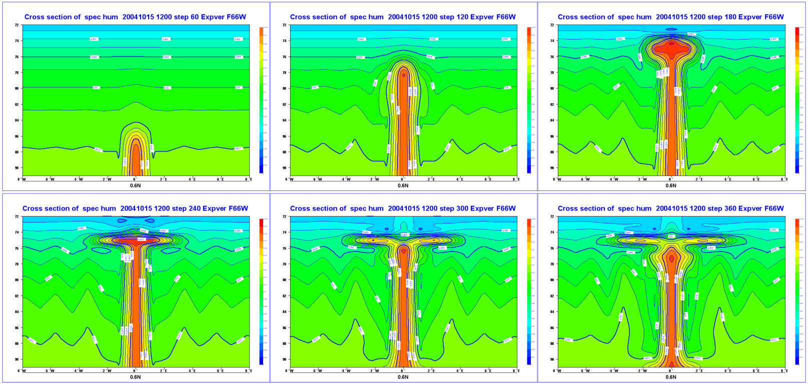
DIRAC the bubble is in the column situated at lon=0 deg, lat=0.5625 deg (nearest point from the equator along the Greenwich medirian)

SQUARE the bubble cover the 16 columns situated between lon=0/3.375 deg and lat=+/-1.6875 deg

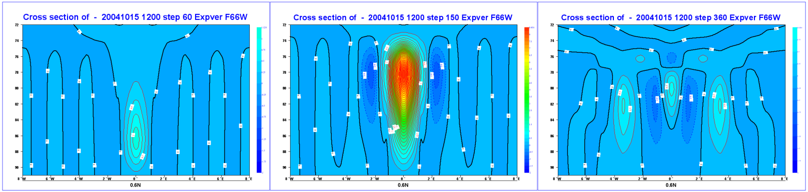
DIRAC : Vertical cross-sections of theta after 10, 20, 30, 40, 50 and 60 min



DIRAC : Vertical cross-sections of q_v after 10, 20, 30, 40, 50 and 60 min



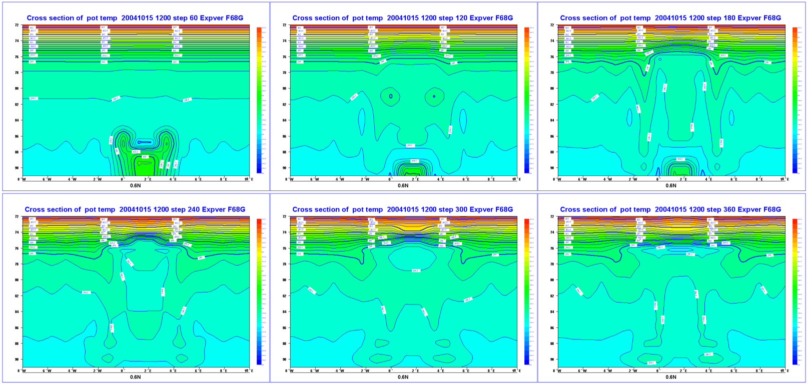
DIRAC : Vertical cross-sections of w after 10, 25 and 60 min



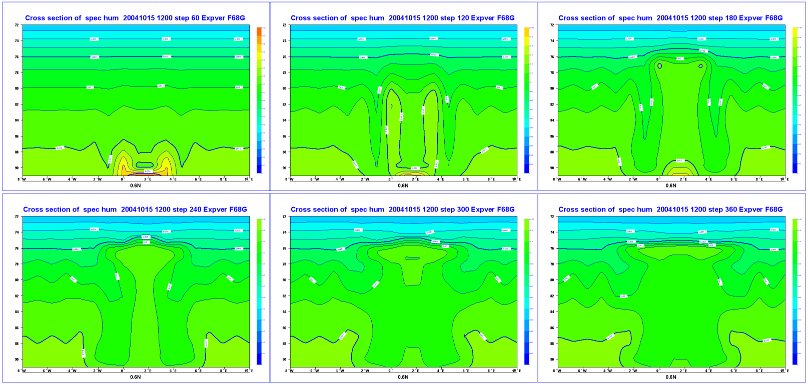
Comments

- The evolution (of a very badby resolved) ascent shows like an anomalous source of q_v and cold θ from the ground.

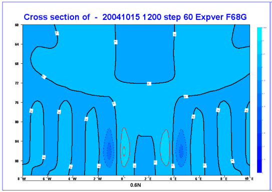
SQUARE : Vertical cross-sections of θ after 10, 20, 30, 40, 50 and 60 min

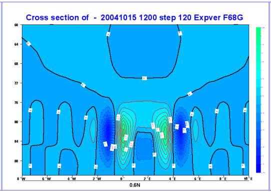


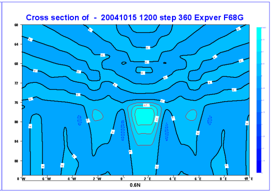
SQUARE : Vertical cross-sections of q_v after 10, 20, 30, 40, 50 and 60 min



SQUARE : Vertical cross-sections of w after 10, 25 and 60 min







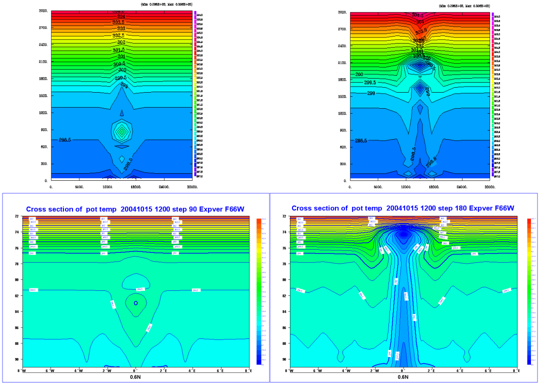
Comments

- The big bubble is not lifted as a whole. The side crown is lifted first, but the central part never ascent.

Comparison with Meso-NH simulations

Similar adiabatic experiments were ran with Meso-NH on a cyclic, cartesian geometry (2,5 km resolution). Meso-NH has a grid point Eulerian dynamics on a C-grid and an advection scheme in flux form (PPM type).
The intervals for Meso-NH and IFS graphics are the same, but unfortunatly not the color pallette! So, be carefull, it may be misleading.

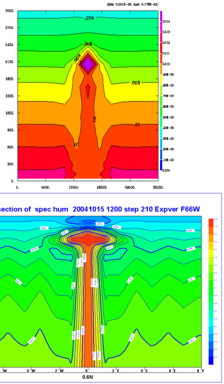
DIRAC (MNH top, IFS bottom) : Vertical cross-sections of θ after 15, 30 min



Comments

In both model, the initial warm bubble is lifted. In both model, values of θ colder than the initial coldest value are "emitted" from the ground. But, in IFS, the dynamics creates an isolated and long life column of potentially very cold air, much colder than the air in the environment. In Meso-NH, only a few pulses of potentially cold air are lifted, and then the stratification goes back to some rather uniform state.

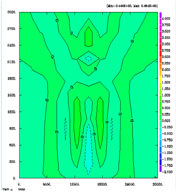
DIRAC (MNH top, IFS bottom) : Vertical cross-sections of q_v after 25 min

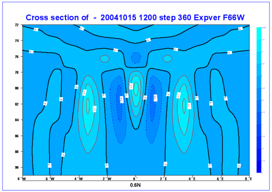


Comments

In both model, the initial moist lower part of the bubble is lifted. But in IFS, an isolated column of very moist air appears (more than 16g/kg) as if moist air was pumped from the ground. In Meso-NH, we also observe some kind of moister column but this moister air may rather come from the lifting of environmental air (mixing ratio in the column is only 10g/kg and the environmental value near the ground is 12g/kg).

DIRAC (MNH top, IFS bottom) : Vertical cross-sections of w after 60 min

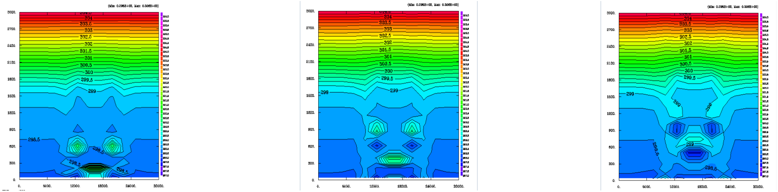


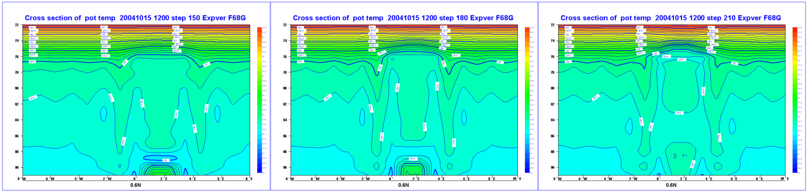


Comments

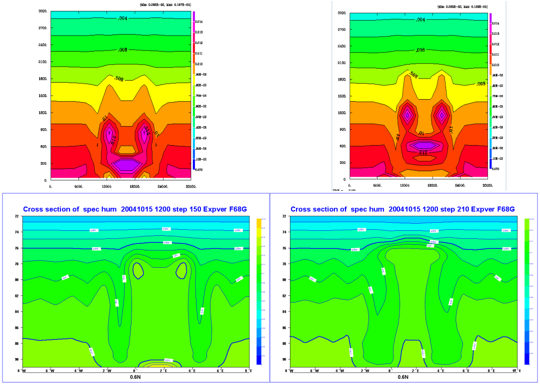
In Meso-NH, subsiding motion is associated with a return to a steady and stably stratified situation. In IFS, light ascent remains for a long time in the cold by moist column.

SQUARE (MNH top, IFS bottom) : Vertical cross-sections of θ and qv after 25, 30 and 35 min





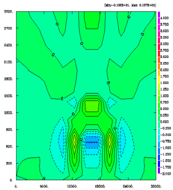
SQUARE (MNH top, IFS bottom) : Vertical cross-sections of θ and q_v after 25 and 35 min

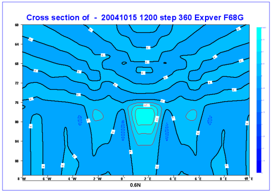


Comments

In both model, the external crown of the bubble (the points around the central 2*2 inner square) is lifted (more quickly in IFS than in Meso-NH, and quickly diluted in IFS). In IFS, the inner part is completly diluted before it goes up. In Meso-NH, the central part of the bubble is clearly lifted after 25/30 min.

SQUARE (MNH top, IFS bottom) : Vertical cross-sections of w after 60 min



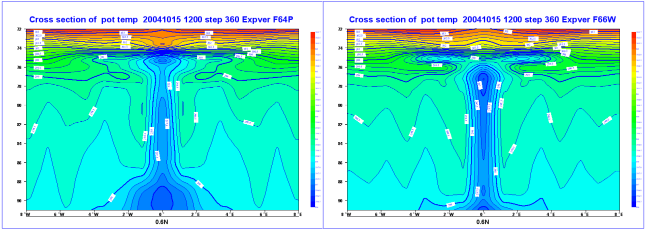


Comments

In this case again, the vertical velocity in the central part of the bubble remains slightly positive after one hour. In Meso-NH, downward vertical velocities are present before the system goes back to a stably stratified state.

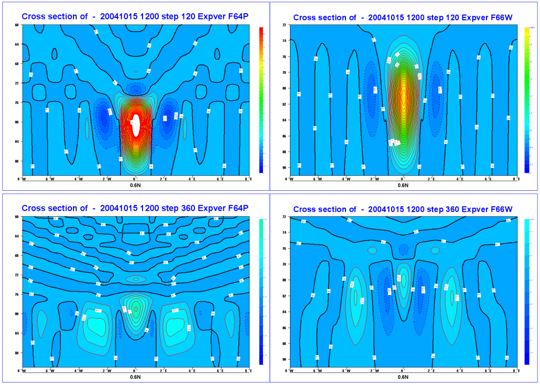
hydrostatic(left)/NH(right) for DIRAC

Cross-sections of θ after 60 min



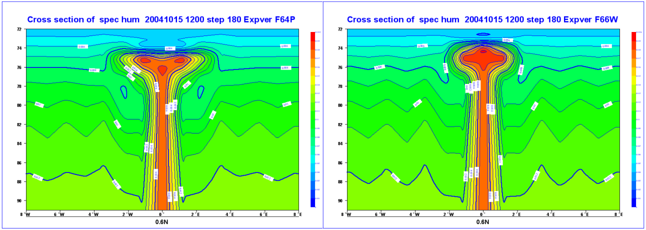
hydrostatic(left)/NH(right)

Cross-sections of w after 20 (top) and 60 (bottom) min



hydrostatic(left)/NH(right)

Cross-sections of q_v after 30 min



Comments

- As usually observed, the bubble lifting starts more quickly in hydro than in NH and the vertical velocities in the hydrostatic simulations are stronger (no "pressure brake" term, the hydrostatic adjustment is instantaneous and corresponds to strong values of diagnosed w). The hydrostatic simulations are more noisy that the NH ones.
- Hydrostatic simulations of the DIRAC bubble show anomalous sources at the boundary.

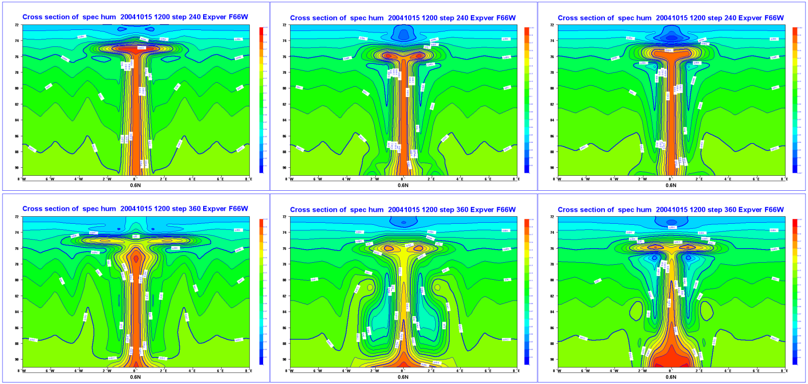
Sensitivity to the SL interpolations

The default interpolations for ARPEGE/IFS are : Hor. Quasi. Monotone for the hor. wind and T, 3D Quasi. Monotone for the total mass, standard interpolations for the NH variables. The only difference between the results on the left of the slides and the results in the middle is the value of the attribute LQM of the GFL of specific humidity.

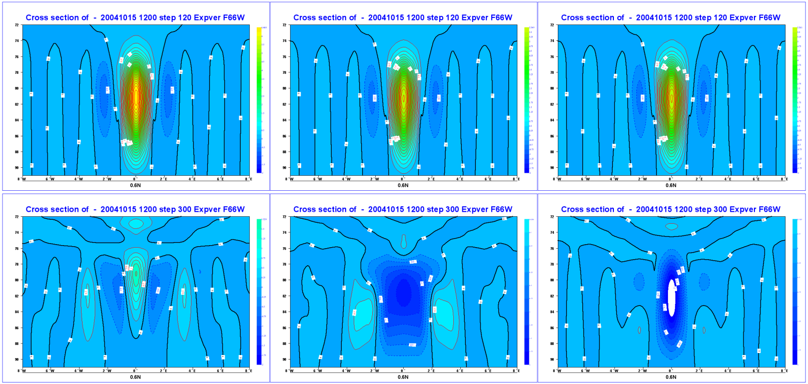
- LQM=T (default) on the left : the SL uses quasi-monotone interpolations for q_v
- LQM=F in the middle : the SL uses standard interpolations for q_v

For the experiment on the right side, all the quasi monotone operators are switch off in the dynamics (GFL+GMV).

Cross-sections of q_v after 40 (top) and 60 (bottom) min



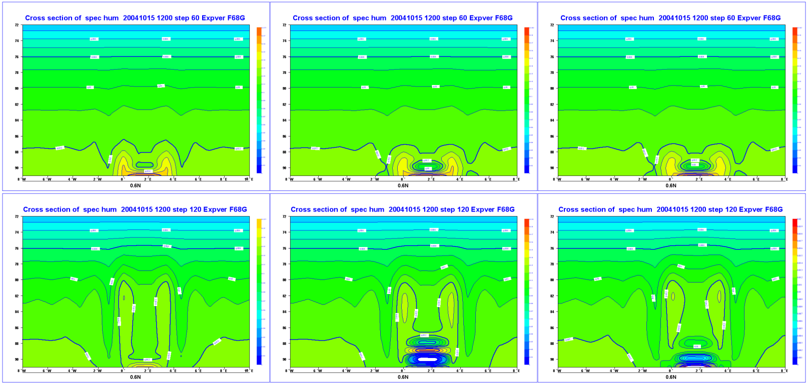
Cross-sections of w after 20 (top) and 50 (bottom) min



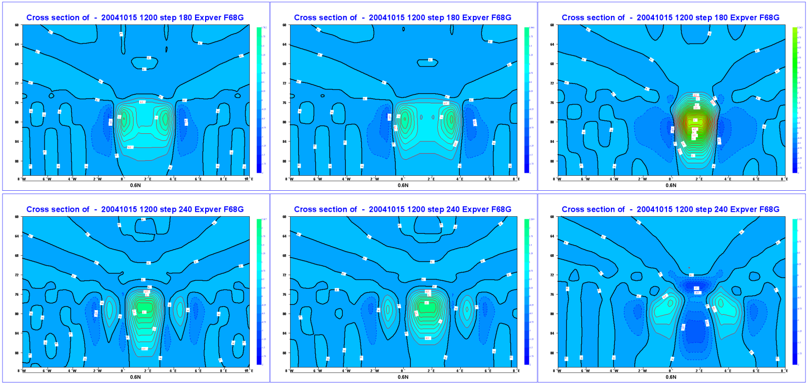
Comments

- q_v is not a passive scalar in the dynamics (and that's very nice!). The concentration of q_v has an impact on the buoyancy (through Tv) which impact the vertical velocity.
- With LQM=F for q_v only, the column of q_v is not so marked, but quite dry values of high q_v appears from somewhere (above? nowhere?) on each side of the ascent. A strong subsidence not present with LQM=T replaces the ascent after about 35 min. I guess it is linked with the dryer air in the middle of the layer shown in the figures.
- With no LQM, the conservation of q_V, especially near the ground is even worst than in the two other experiments.
- In all cases, high values of q_v remain "glued" on the first level above the surface.

SQUARE : Cross-sections of q_v after 10 (top) and 20 (bottom) min



Cross-sections of w after 30 (top) and 40 (bottom) min



Comments

- Strange q_v oscillations above the surface if LQM=F for q_v
- Clear feed back on w

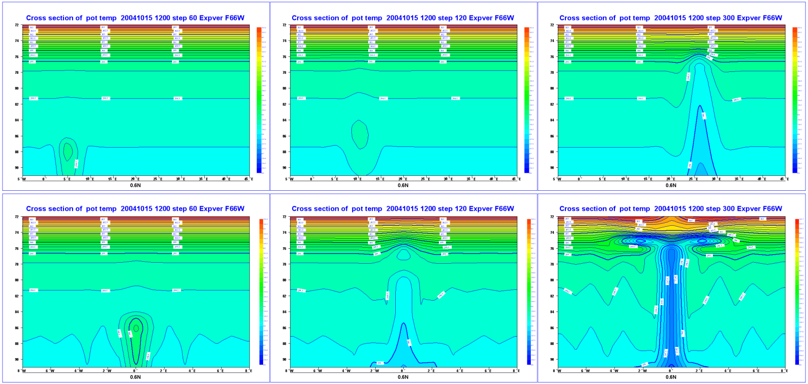
Uniform zonal advection

The following experiments are designed to test the behaviour of the semi-Lagrangian scheme in a less symetric context than the one of the no initial wind reference bubbles.

- ADV10 : Initial uniform zonal wind, U=10 m/s
- Results are also compared with some Meso-NH simulations.

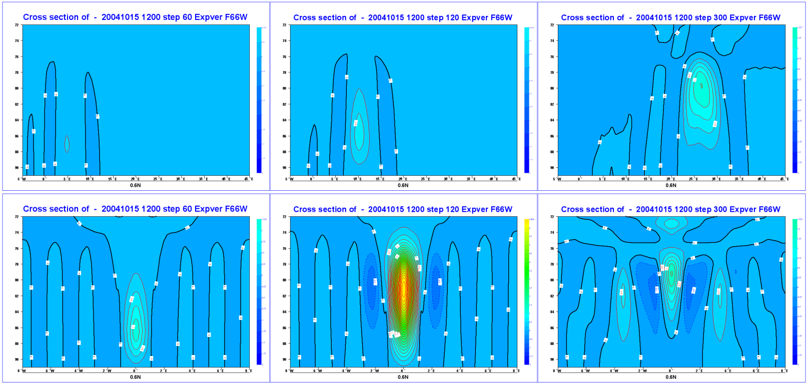
DIRAC : Vertical cross-sections of θ after 10, 20 and 50

top : ADV10, bottom : REF



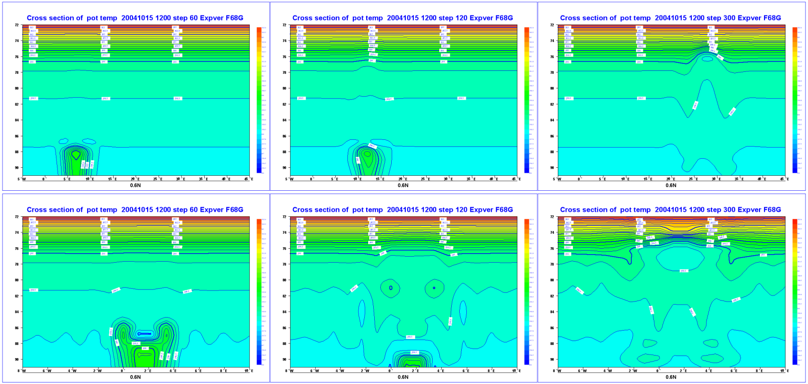
DIRAC : Vertical cross-sections of w after 10, 20 and 50

top : ADV10, bottom : REF



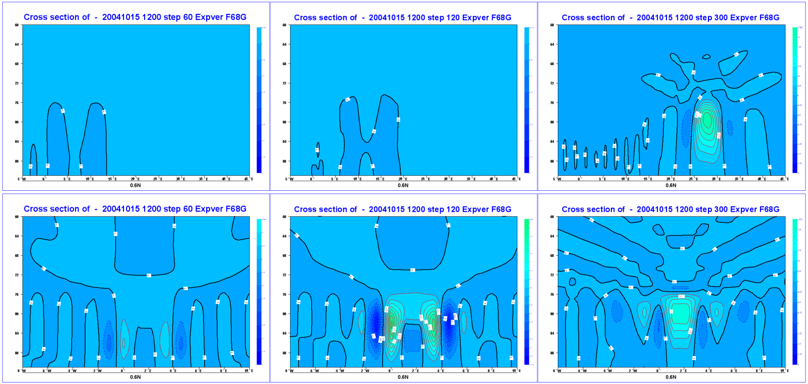
SQUARE : Vertical cross-sections of θ after 10, 20 and 50

top : ADV10, bottom : REF



SQUARE : Vertical cross-sections of w after 10, 20 and 50

top : ADV10, bottom : REF

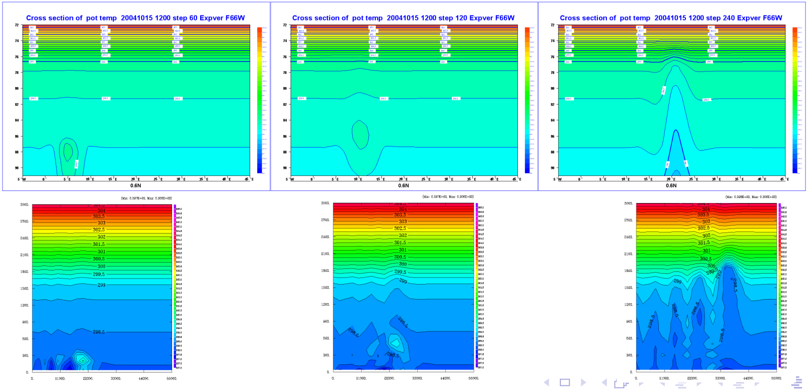


Comparison between IFS/ADV10 and MNH/ADV10

Comparison both for DIRAC and SQUARE bubbles.
IFS results (top) and Meso-NH results (bottom)

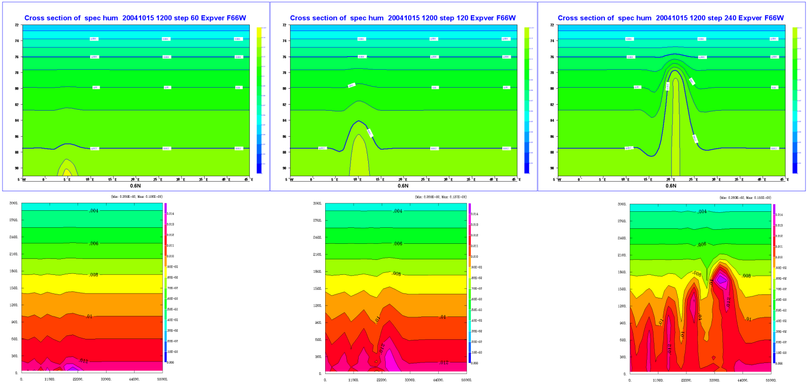
DIRAC : Vertical cross-sections of θ after 10, 20 and 40 min

top : IFS/ADV10, bottom : MNH/ADV10



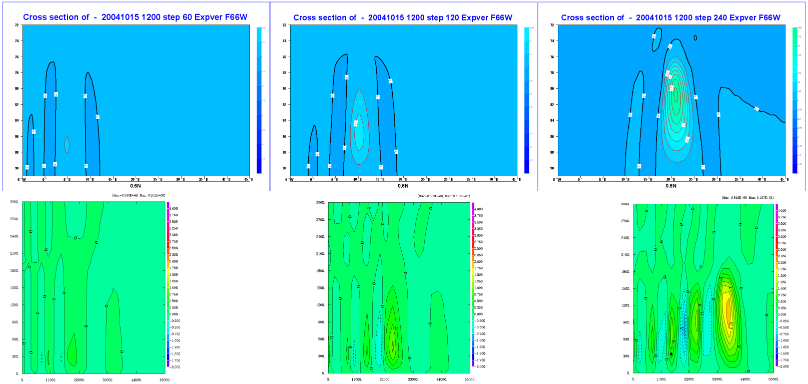
DIRAC : Vertical cross-sections of q_v after 10, 20 and 40

top : IFS/ADV10, bottom : MNH/ADV10



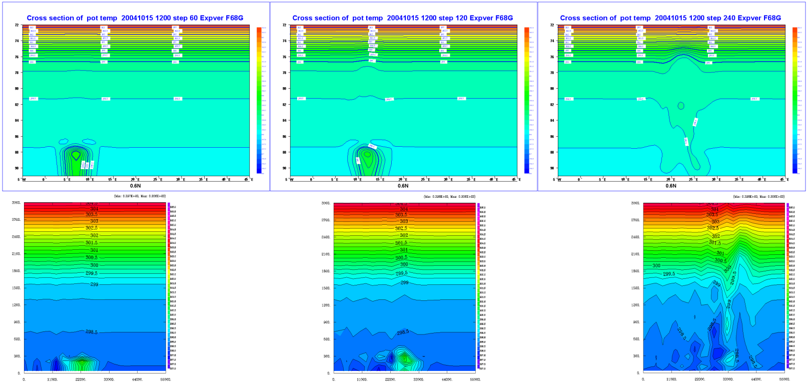
DIRAC : Vertical cross-sections of w after 10, 20 and 40

top : IFS/ADV10, bottom : MNH/ADV10



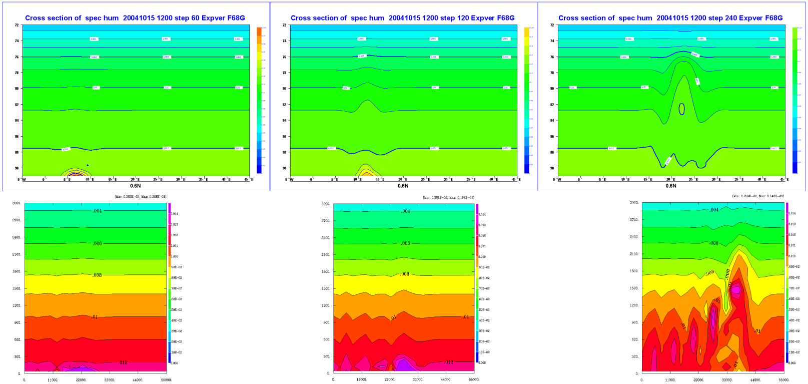
SQUARE : Vertical cross-sections of θ after 10, 20 and 40

top : IFS/ADV10, bottom : MNH/ADV10



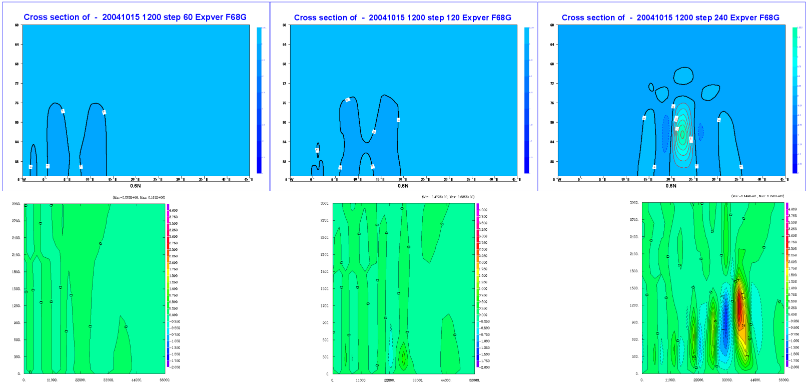
SQUARE : Vertical cross-sections of q_v after 10, 20 and 40

top : IFS/ADV10, bottom : MNH/ADV10



SQUARE : Vertical cross-sections of w after 10, 20 and 40

top : IFS/ADV10, bottom : MNH/ADV10



Quick analysis (1)

- The advection is “diluting” (diffusing?) the bubbles, both the DIRAC and SQUARE bubbles, and both in Meso-NH and IFS. It is absolutly normal as the DIRAC bubble is badly resolved and the SQUARE bubble has strong gradient around. Nevertheless, the dilution process is much stonger in IFS than in Meso-NH.
- The production of potentialy cold air and moist air from the surface is still observed in the advection case, but much smoother (probably because the convective motion is much smoother).
- The advection filters some small scale features which were well seen in the no-wind case (but were they correct?) : no cat face and rabbit ears any more!, both in IFS and MNH.

Quick analysis (2)

- In Meso-NH a stong (gravity?) wave develop behind the first bubble. It also exists in IFS but very smooth. Is this gravity wave correct? (wave propagating backward with respect to the flow???).
- In Meso-NH the θ and q_v values in the first layers above the ground are changing with time in agreement with the local horizontal and especially vertical circulation. It does not seem to be the same in IFS.

Experiment description

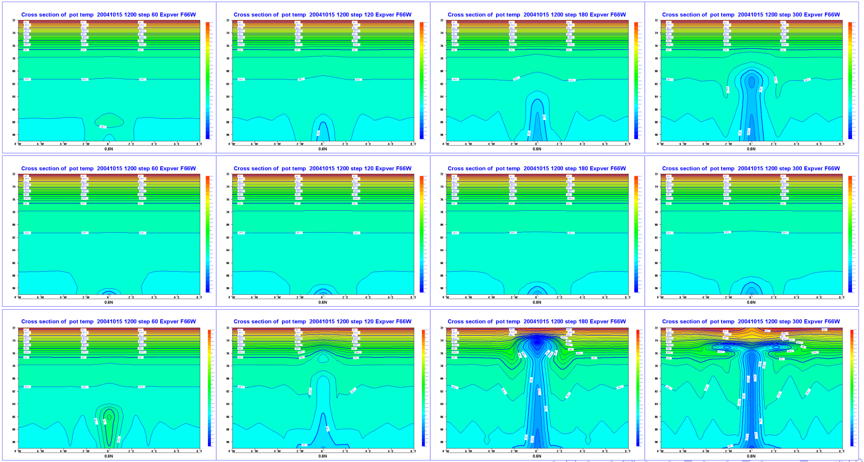
REF experiment (Quasi) no diffusion

DIFF HDIRxx=100.

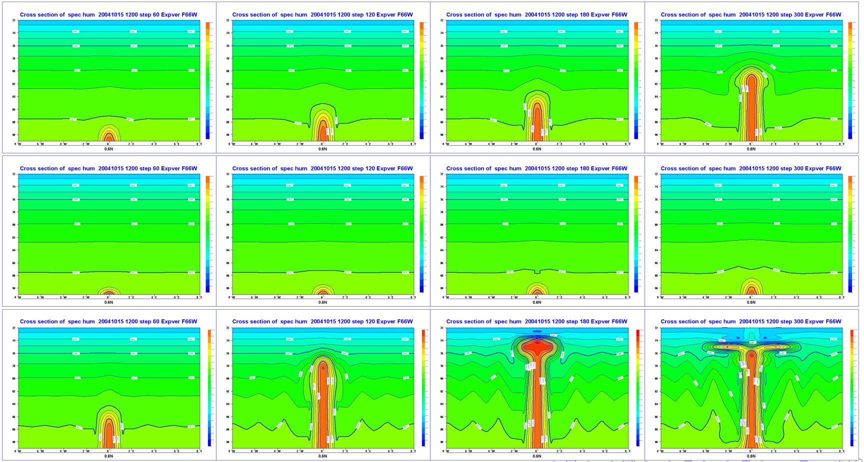
OPERDIFF HDIRxx=15.

In the OPERDIFF test, the ratio between the time step and the charateristic damping time of the diffusion is the same that what is used in operation for a real planet. The DIFF test corresponds to a medium diffusion coefficient previously used by Nils Wedi for bubble cases on the small planet.

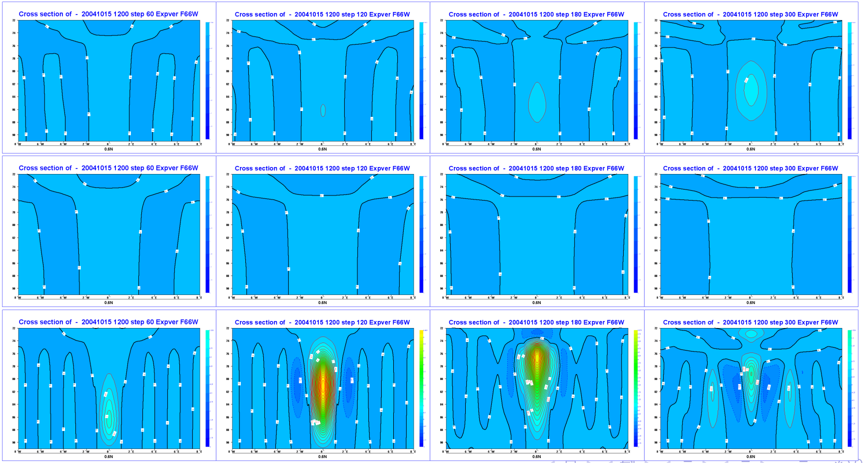
DIRAC : θ after 10, 20, 30 and 50 min — No initial wind — DIFF / OPERDIFF / REF



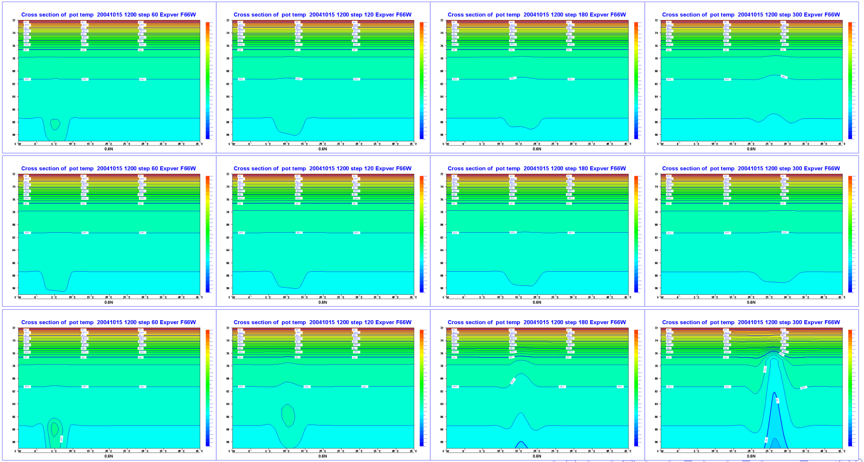
DIRAC : q_v after 10, 20, 30 and 50 min — No initial wind — DIFF / OPERDIFF / REF



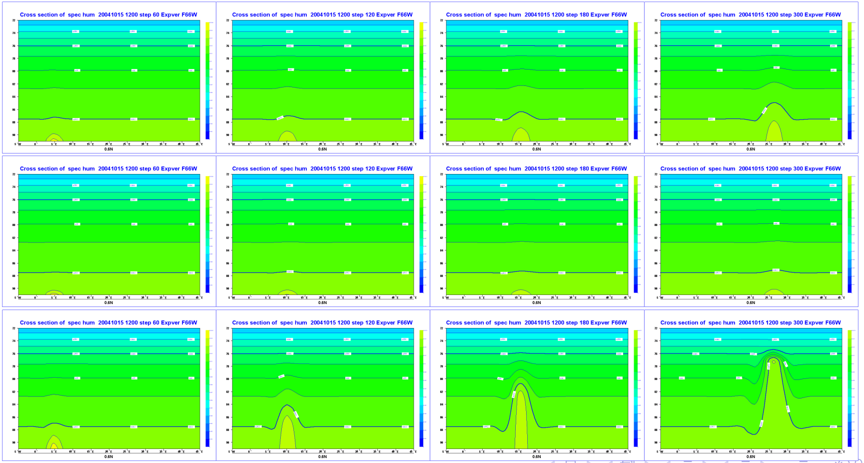
DIRAC : w after 10, 20, 30 and 50 min — No initial wind — DIFF / OPERDIFF / REF



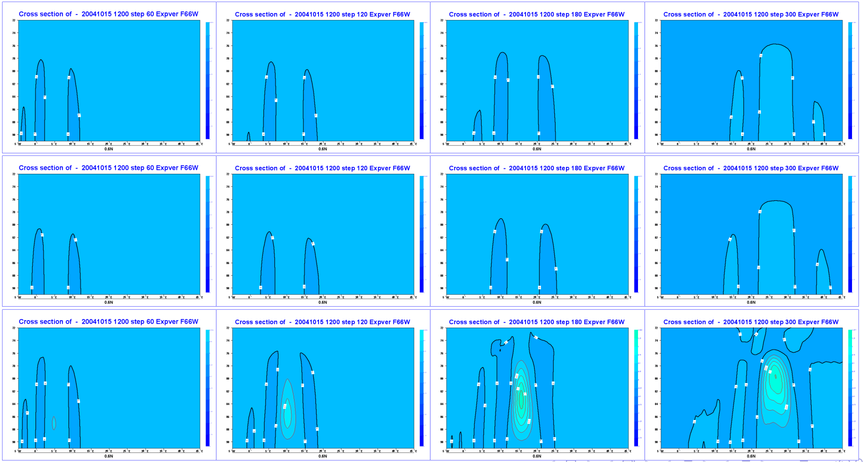
DIRAC : θ after 10, 20, 30 and 50 min — 10m/s initial wind — DIFF / OPERDIFF / REF



DIRAC : q_v after 10, 20, 30 and 50 min — 10m/s initial wind — DIFF / OPERDIFF / REF



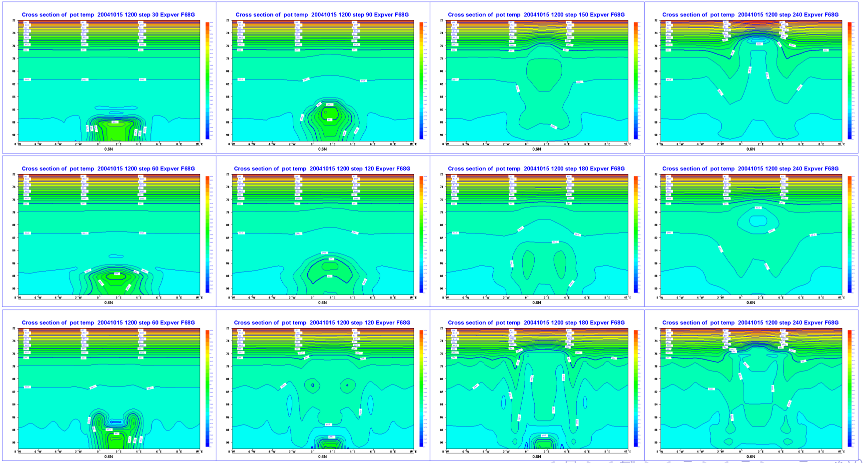
DIRAC : w after 10, 20, 30 and 50 min — 10m/s initial wind — DIFF / OPERDIFF / REF



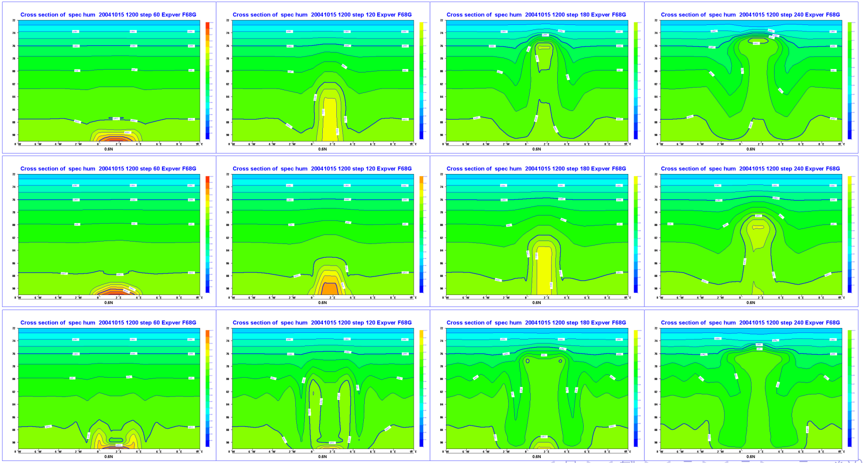
Analysis for DIRAC

- With medium diffusion and no wind, the development of the 1δx bubble is smoothed and delayed but the bubble still goes up.
- With strong diffusion or with a 10m/s zonal advection, the 1δx warm bubble is completly neutralized (in the OPERDIFF case, the bubble even becomes a cold non-buoyant bubble). The moist (smoothed) signature of the bubble remains near the ground (no lifting at all) and is advected eastward. Nearly no vertical velocity.

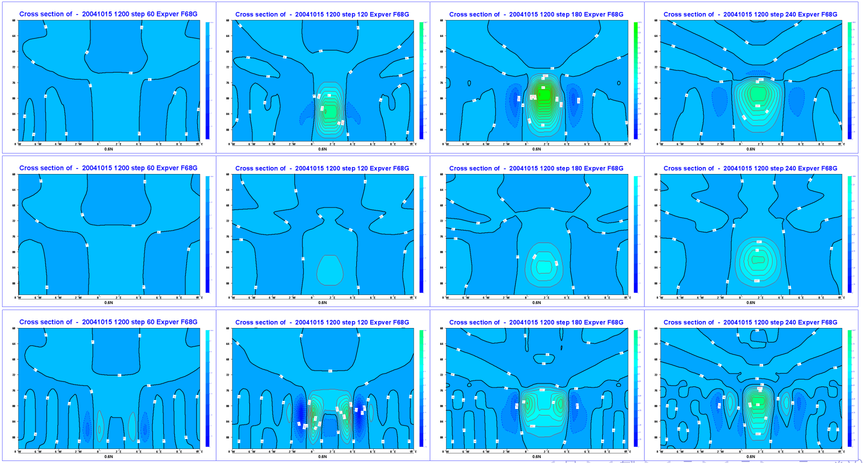
SQUARE : θ after 10, 20, 30 and 40 min — No initial wind — DIFF / OPERDIFF / REF



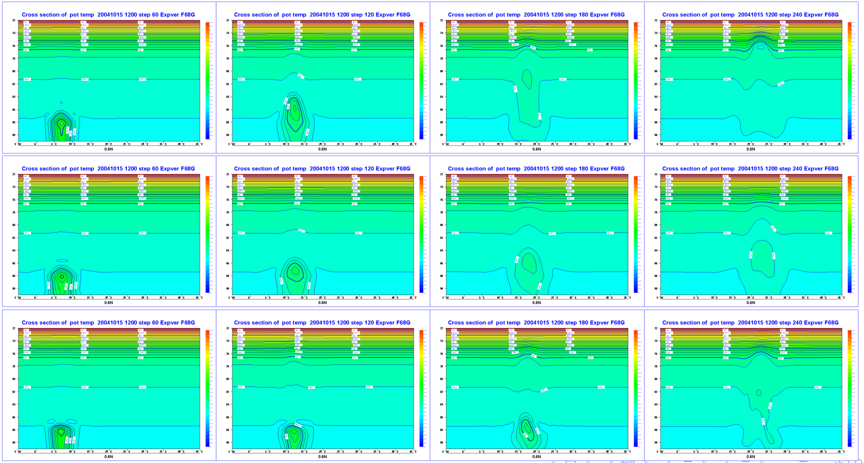
SQUARE : q_v after 10, 20, 30 and 40 min — No initial wind — DIFF / OPERDIFF / REF



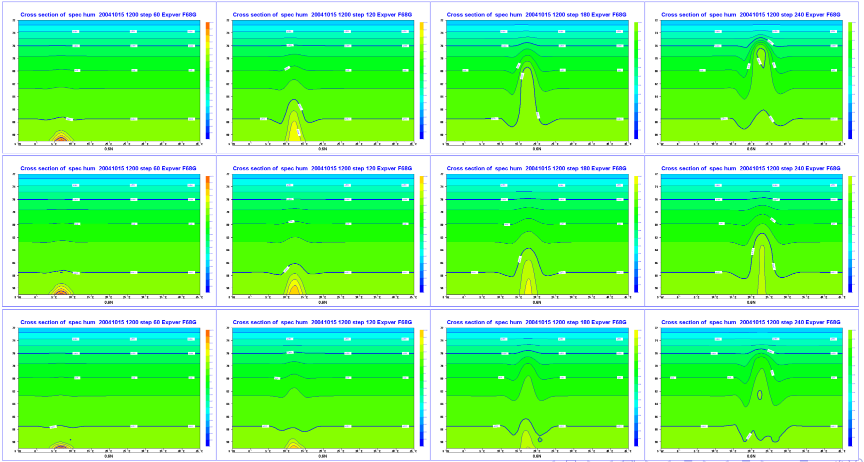
SQUARE : w after 10, 20, 30 and 40 min — No initial wind — DIFF / OPERDIFF / REF



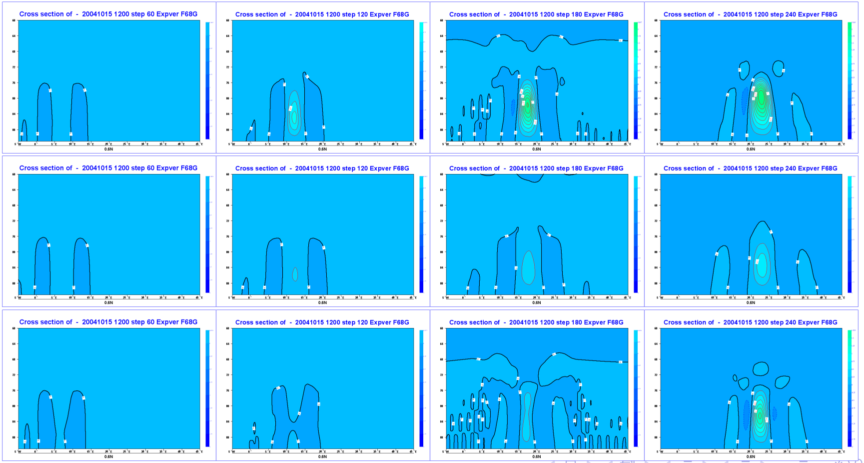
SQUARE : θ after 10, 20, 30 and 40 min — 10m/s initial wind — DIFF / OPERDIFF / REF



SQUARE : q_v after 10, 20, 30 and 40 min — 10m/s initial wind — DIFF / OPERDIFF / REF



SQUARE : w after 10, 20, 30 and 40 min — 10m/s initial wind — DIFF / OPERDIFF / REF



Analysis for SQUARE

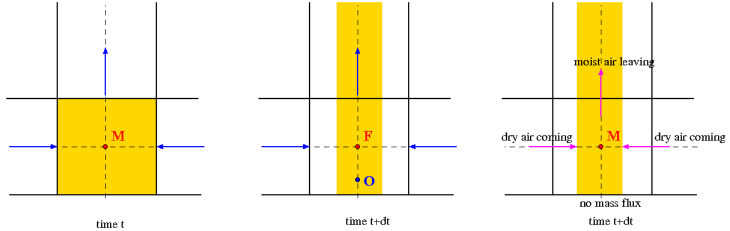
- The diffusion assure a better cohesion of the big bubble and the bubble is clearly lifted as a whole. The "production" of q_v at the boundary is now observed in this case.
- Increasing the diffusion smoothes and delays the development
- Increasing the diffusion increases the characteritic size of the convective system.

Conservation

Non-conservation properties of the ARPEGE/IFS SL Scheme were already reported in different contexts

- Larger scale experiments : GEMS
- Dust studies with Arome (AMMA Campain, Kocha, Tulet and Lafore, internal communications)

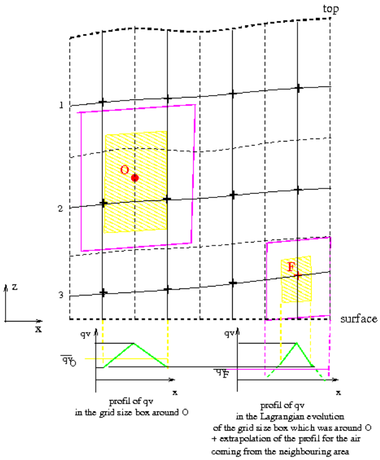
A Boundary Condition Problem?



Semi-Lagrangian No horizontal trajectory + Origin point under the last full level : $q_v^+(F) = q_v^-(O) = q_v^-(M)$

Eulerian flux form $q_v^+(M) = q_v^-(M) - \frac{dt}{\rho}\vec{\nabla}.(\rho q_v \vec{u})$

A more Systematic Local non conservation Problem?



q_v is conserved following a material volume element : $< q_v >^O = < q_v >^F$
With the semi-Lagrangian, we want to compute $< q_v >^F = \overline{q_v}^F$
With the trajectory computation+interpolations, we compute $\overline{q_v}^O$ (mean value inside the grid-size yellow box around O) rather than $< q_v >^O$ (mean value inside the magenta box around O).
And $< q_v >^O \neq \overline{q_v}^O$ if the Lagrangian volumes are changing during the Lagrangian evolution (divergent/convergent motion).

The politically correct ones...

- Continue to analyse and understand the limitations of the current dynamics and the consequences on the interactions with the different physics packages. Study the implications for the simulations of resolved convection.
- Work on possible solutions to improve the conservation properties (including boundary conditions but maybe not only)
- Work on possible solutions to improve the treatment of the badly resolved structures ("Intelligent" numerical diffusion scheme?)

The less politically correct ones...

- If not enough, accept the limitations and adapt the model to those limitations
  - Filter the signal from the physics not to force the dynamics with badly resolved structure?
  - Work on "convection" scheme specialized in the transition from parametrized to resolved convection, taking into account that the separation between the two is usually not physical but rather numerical (this may imply to pose the problem a bit differently, thinking in a full Dyn/Phys way and not Dyn on one side, (Phys/Dyn interface in the middle) and Phys in the other side).
  - Part of the Physics may then have to be Dynamics dependent, resolution dependent?