Performance evaluation of non-hydrostatic IFS (NH-IFS)

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Nonhydrostatic IFS

- **Based on the limited-area model ALADIN-NH *(Bubnova et al 1995, Benard et al 2004a,b, Benard et al 2005)* and coded into the IFS by Météo-France and its ALADIN partners.**
- **The idea was to gradually extend the hydrostatic shallow atmosphere framework to the deep-atmosphere fully compressible equations within the existing spectral two-time-level semi-implicit semi-Lagrangian code framework.**
- **Mass-based vertical coordinate *(Laprise, 1992),* equivalent to hydrostatic pressure in a shallow, vertically unbounded planetary atmosphere.**

Hierarchy of test cases

- Acoustic waves
- Gravity waves
- Planetary waves
- Convective motion
- Idealized dry atmospheric variability and mean states
- Idealized moist atmospheric variability and mean states
- Seasonal climate, intraseasonal variability
- Medium-range forecast performance at hydrostatic scales
- High-resolution forecasts at nonhydrostatic scales

A testing strategy

Small planet:

The size of the computational domain is reduced without changing the depth or the vertical structure of the atmosphere (reduced radius of the planet $a < a_{Earth}$)

a_{Earth} = Earth's radius

A spherical acoustic wave in a stratified (isothermal) atmosphere on a reduced-radius sphere

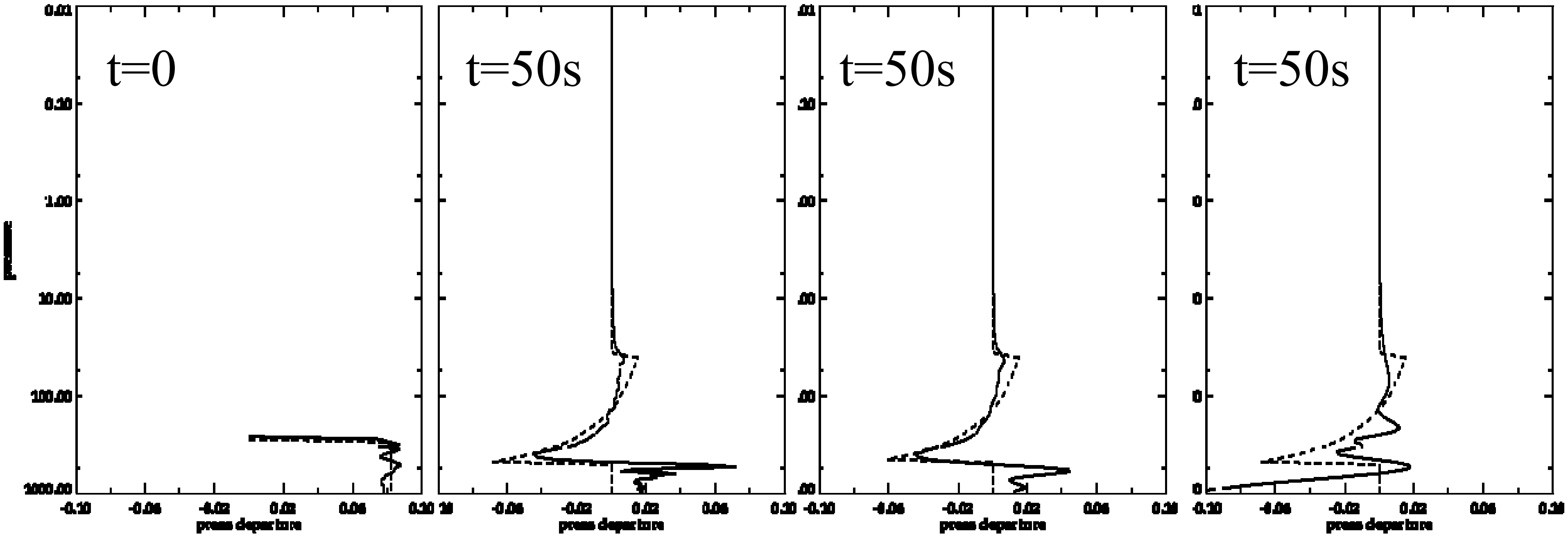
- **Analytic solution** *(Landau and Lifschitz, Fluid Mechanics, §70)*
- **Semi-implicit (SI) scheme for acoustic waves works as expected and enables the use of a considerably larger time-step compared to the explicit calculation (0.01s → > 10s). The vertical propagation of the acoustic wave is then of course heavily distorted.**
- **Useful test case for examining the effect of the 'stability parameters' SITR = reference temperature, SITRA = acoustic reference temperature, NSITER = number of iterations in the iterative-centred-implicit (ICI) scheme.**

A spherical acoustic wave in a stratified (isothermal) atmosphere on a reduced-radius sphere

SITR=350, SITRA=100

analytical solution (dashed line)

[The effect of stratification can be ignored for sound waves with λ<50km]

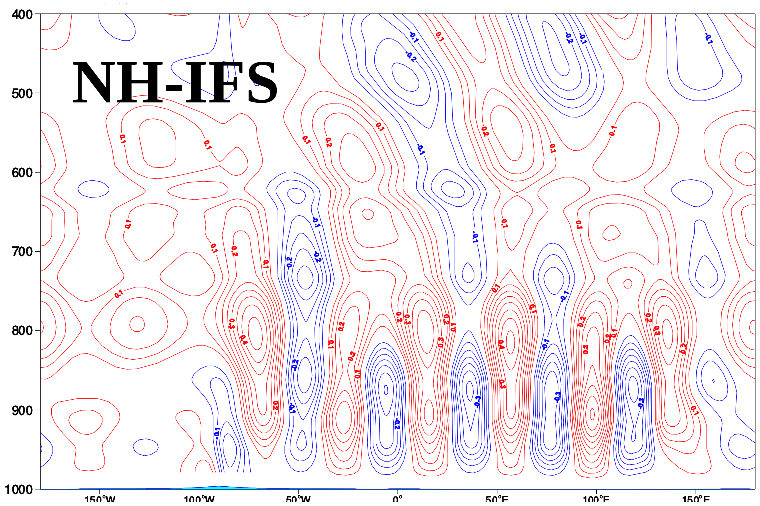


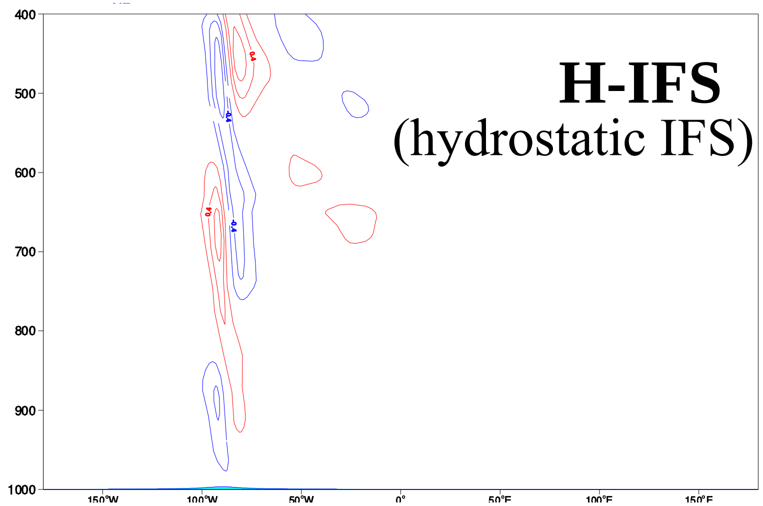
explicit, dt=0.01s — explicit, dt=0.01s — SI, dt=1s (NSITER=1) — SI, dt=10s (NSITER=5)

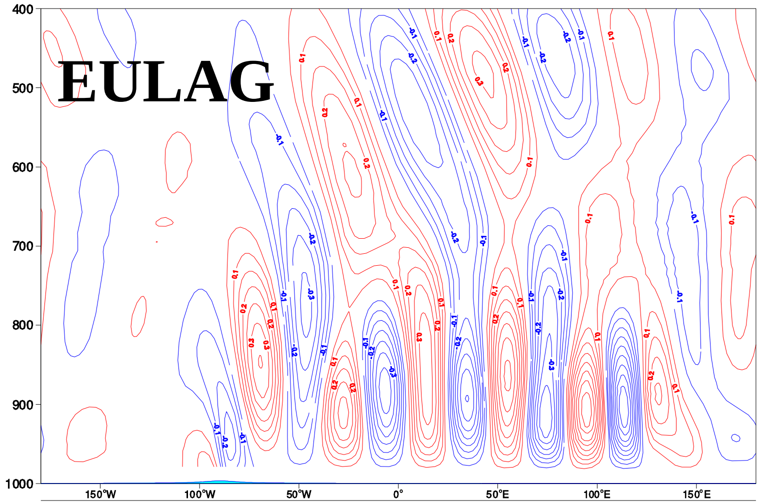
Gravity waves

- **Comparable results to a variety of LES benchmarks and analytic solutions.**
- **We show results from the following test cases:**
  - Quasi two-dimensional orographic flow with linear vertical shear
  - 3D Schär - mountain on the sphere
  - Effect of critical levels on the non-linear flow past a three-dimensional hill

Quasi two-dimensional orographic flow with linear vertical shear



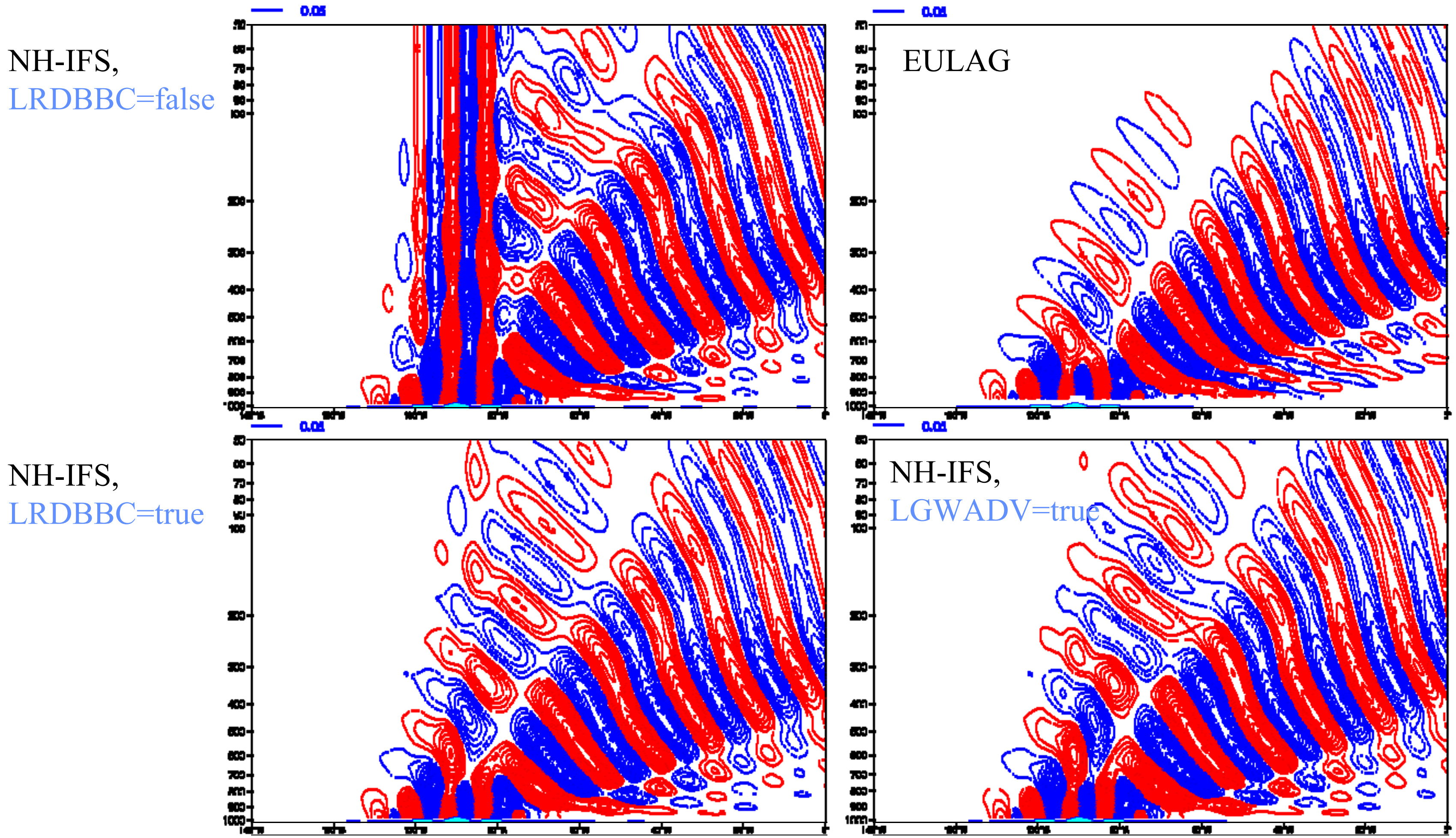




The figures illustrate the correct horizontal (NH-IFS, EULAG) and the (incorrect) vertical (H-IFS) propagation of gravity waves in this case *(Keller, 1994)*.
Shown is vertical velocity.

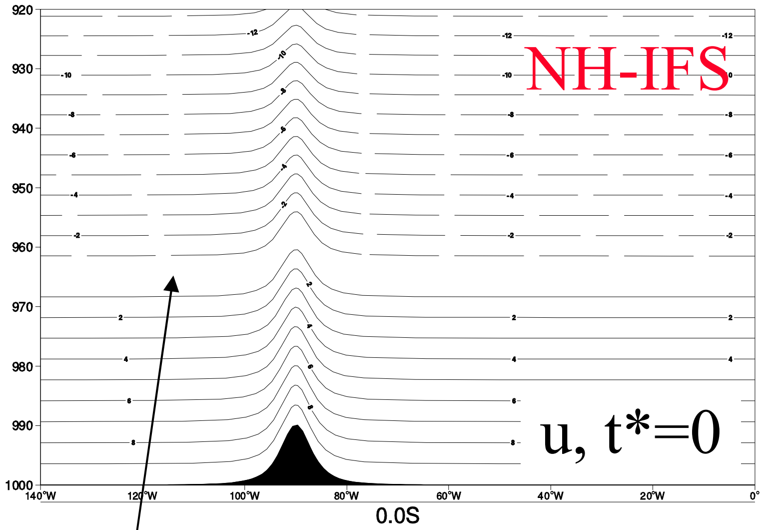
3D Schär - mountain on the sphere

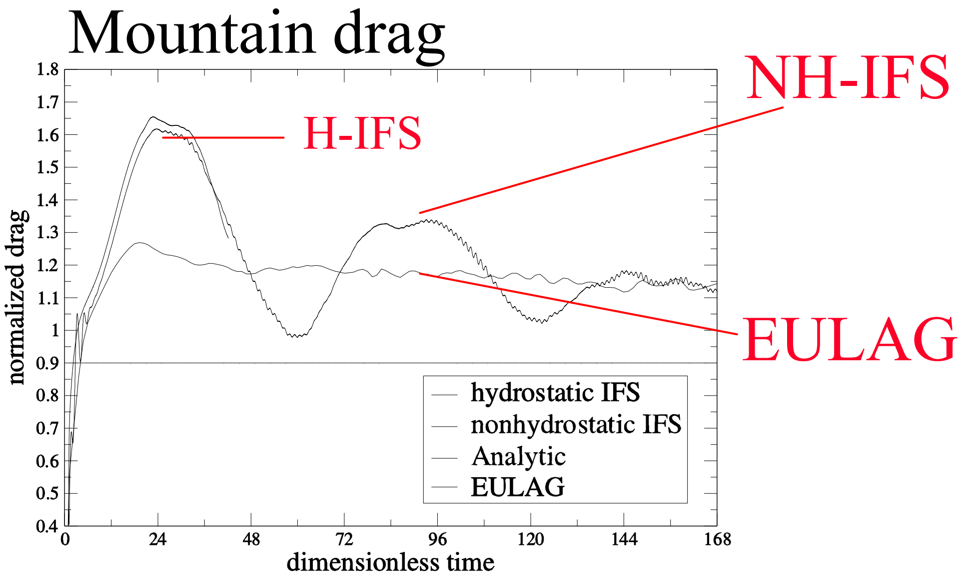
(Schär et al 2002, Klemp et al., 2003)

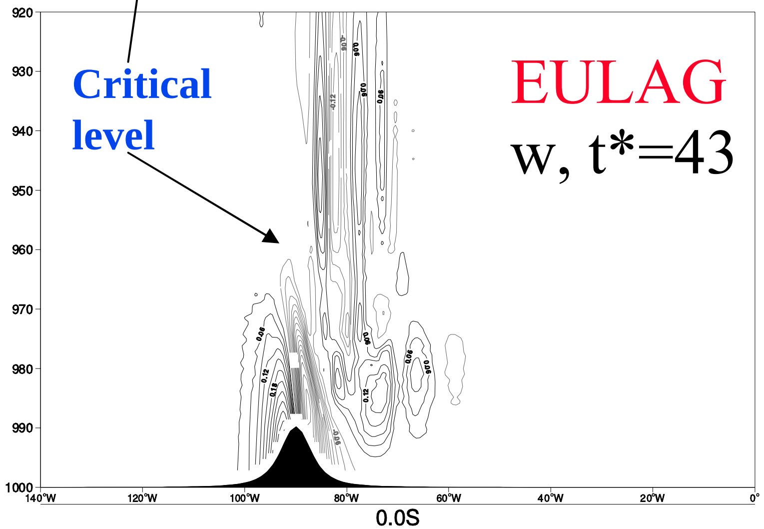


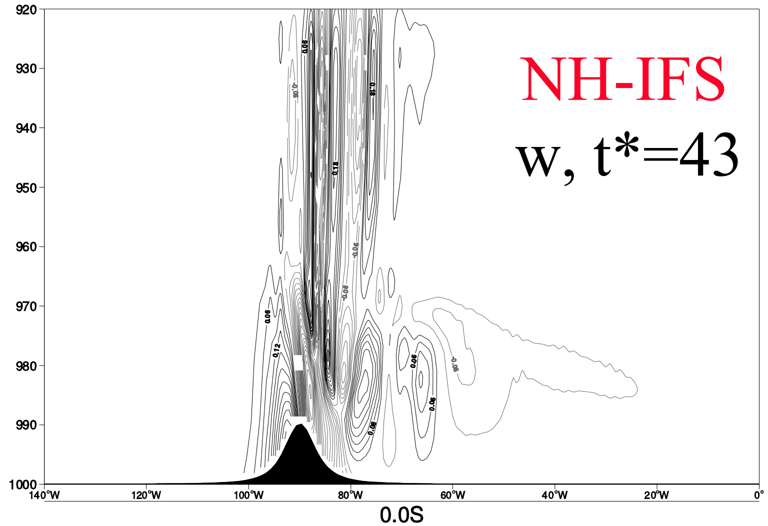
‘chimneys’ in the solution with marginally resolved orographic features solved with either LGWADV=T or LRDBBC=T (LGWADV=F).

Effect of critical levels on the non-linear flow past a three-dimensional hill *(Grubisic and Smolarkiewicz, 1997)*





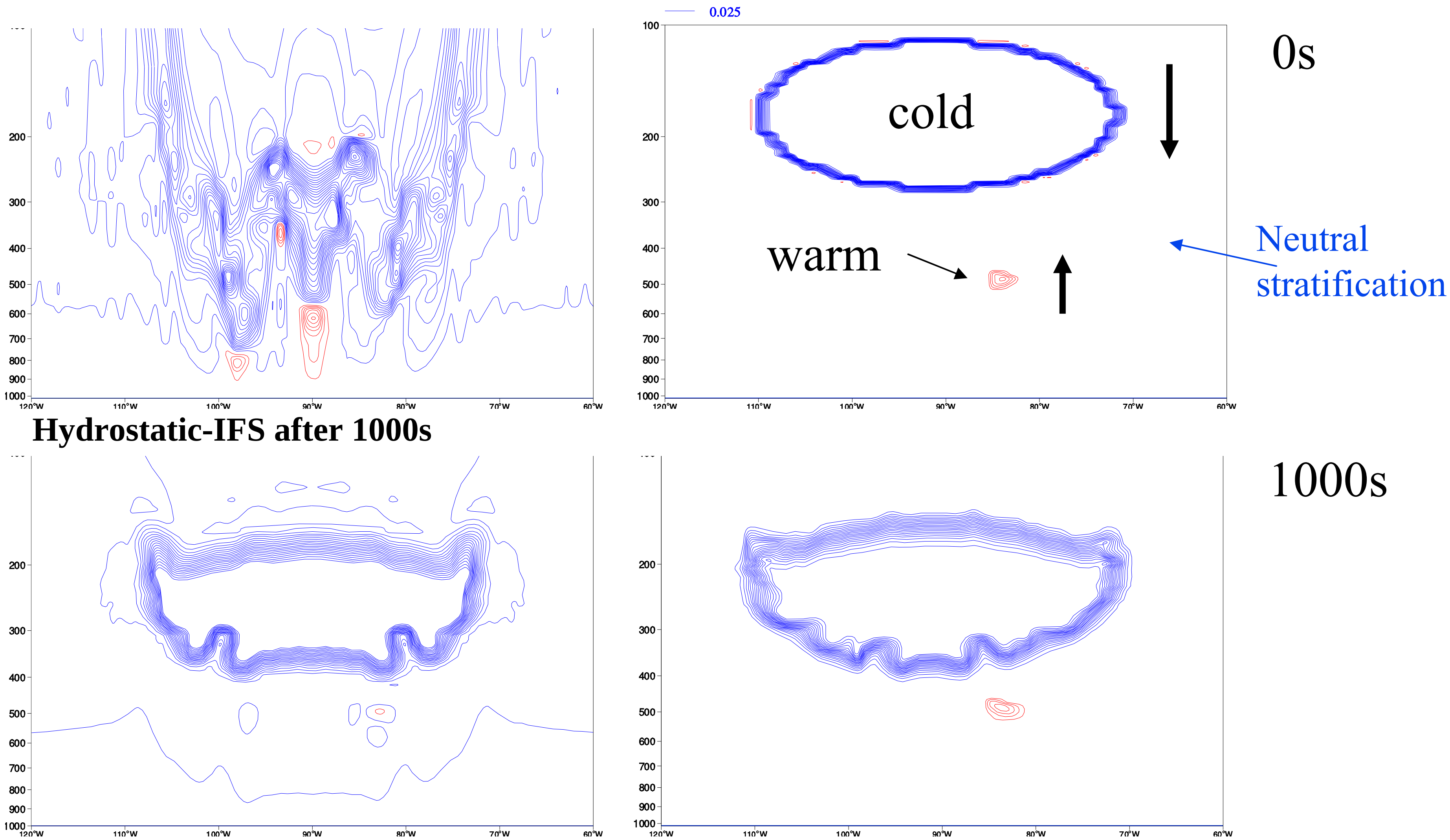




Planetary waves

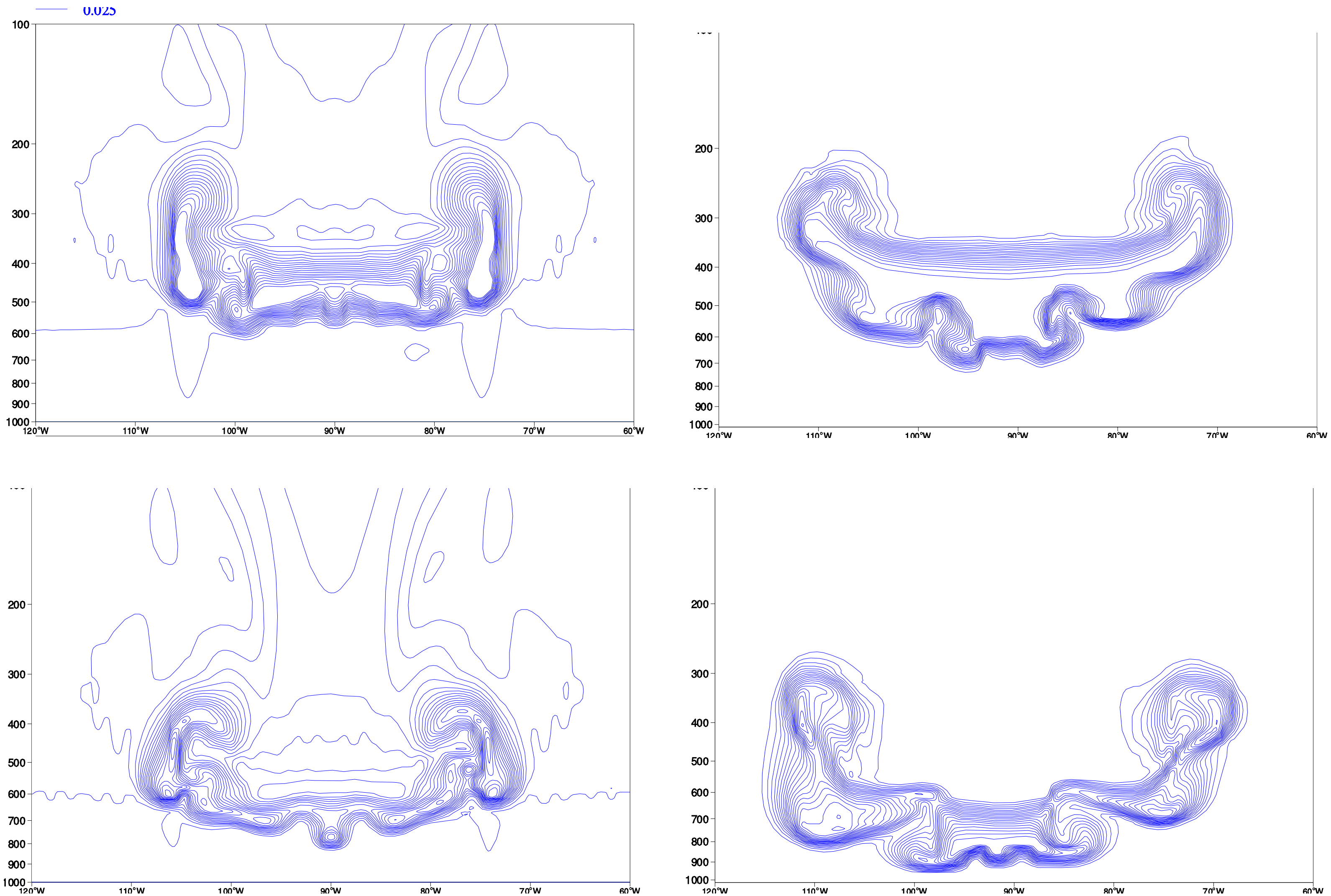
- **Matsuno-Gill pattern (to be done)**
- **Note: planetary waves in the nonhydrostatic IFS are represented as good as in the hydrostatic IFS, in real case comparisons.**

Convective motion (3D bubble test)



NH-IFS EULAG

Convective motion (3D bubble test)



1800s

2400s

NH-IFS

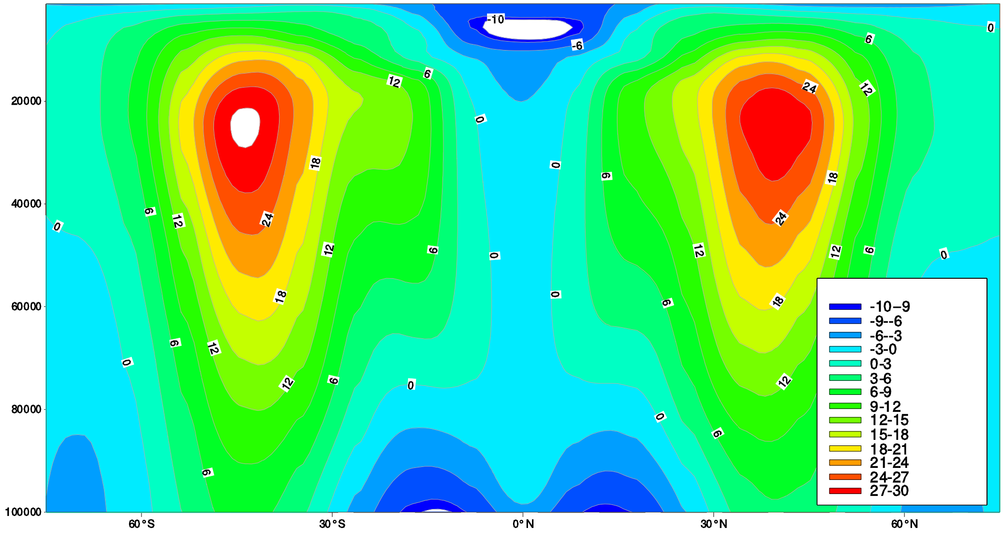
EULAG

ECMWF

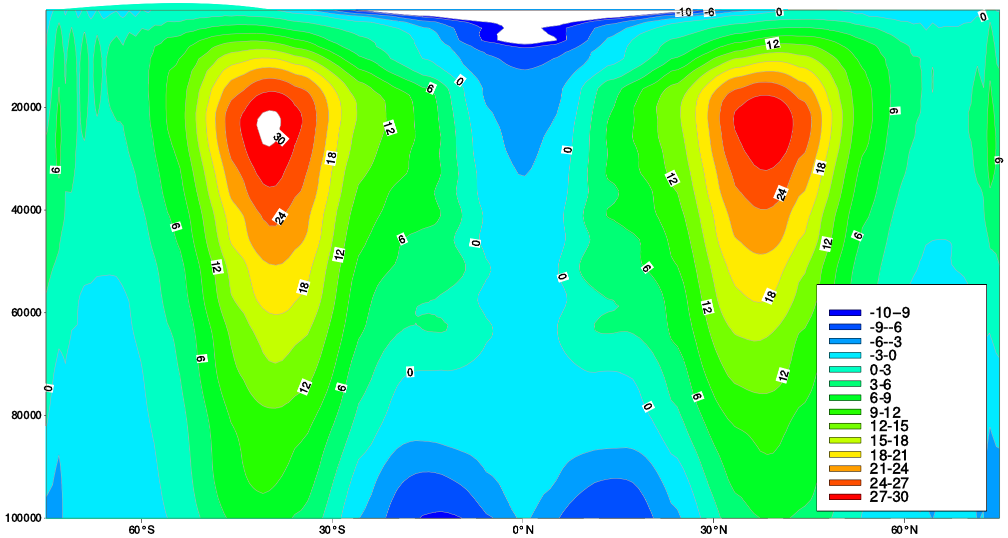
Convective motion (3D bubble test)

- The test case is useful as it discriminates hydrostatic and nonhydrostatic solutions.
- There is no analytic solution and the test case is known to be sensitive to diffusion (e.g. the asymmetry is lost in the IFS simulation due to the quick loss of amplitude of the warm bubble)
- Qualitatively similar solution, but the EULAG solution looks smoother.

Held-Suarez climate on reduced-size planet



NH-IFS



EULAG

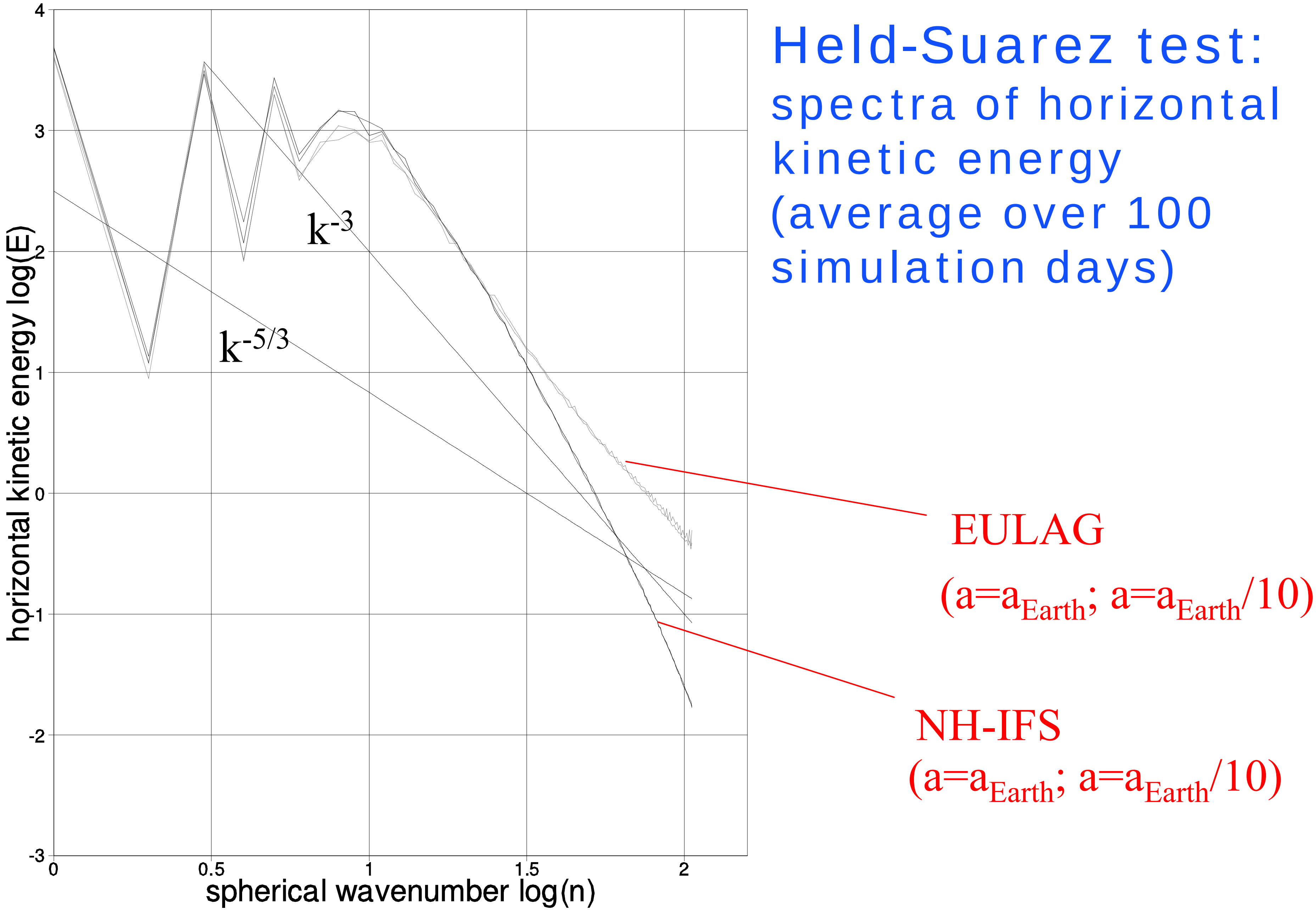
$a=0.1a_{Earth}$, $T_L159L91$

Equivalent to

$\Delta x = 12.5$ km

ECMWF

Held-Suarez test:
spectra of horizontal kinetic energy (average over 100 simulation days)



ECMWF

Idealized moist atmospheric variability and mean states

- **Aquaplanet intercomparison (APE): hydrostatic / non-hydrostatic very similar.**
- **Future: Evaluate NH-IFS on a small aquaplanet in comparison to EULAG at nonhydrostatic resolution**

Seasonal climate

- **Hydrostatic and nonhydrostatic seasonal climate simulations are the same for T159L91 ensembles except in the stratosphere (due to the difference in vertical discretisation: finite differences in NH-IFS and vertical finite elements in H-IFS).**

Medium-range forecast performance at hydrostatic scales

- **Tropospheric scores with NH-IFS are the same as with H-IFS at all resolutions tested (e.g. T159L91, T799L91, T1279L91).**
- **Stratospheric scores are less good due to different vertical discretizations (finite elements (VFE) in H-IFS, finite differences (VFD) in NH-IFS)**
- **For stability at least NSITER=1 is required at all resolutions when run with the relatively large time-steps used with the hydrostatic IFS.**
- **Cost: depending on the resolution (T_L159 – T_L1279 tested) the cost is 25-70 % higher**
  - ➔ 15% could be saved without recalculating the trajectory and without the associated interpolations at each iteration (LPC_CHEAP=T); however, creates noise in the stratosphere.

Vertical finite-element discretization (VFE)

- The basic version of NH-IFS, which has been evaluated at ECMWF, has a vertical finite-difference (VFD) discretization.
- Using the VFE integral operator to evaluate some of the vertical integrals in the non-linear part of NH-IFS, but with a VFD linear model in the semi-implicit part, gives similar scores, also in the stratosphere, to H-IFS (with VFE).
- Work on a full VFE scheme for NH-IFS in conjunction with alternative sets of prognostic variables (better suited to VFE discretization with no staggering) is in progress. (More on this in the presentation by J. Simarro.)

Future Work

- **Experiments with idealized moist dynamics/thermodynamics**
- **Investigate high resolution runs at non-hydrostatic scales**
- **Explore alternative options for physics-dynamics coupling in the ICI scheme (currently the physics is called in the final iteration only)**
- **Damping of resolved gravity waves at the model top** *(suggestion in Klemp et al., MWR 2008 in press, could be difficult to do)*
- **Evaluate deep atmosphere formulation** *(Staniforth, Wood QJRMS Vol. 129, 1289-1300, 2003)*
- **Work on VFE for NH-IFS in conjunction with alternative sets of prognostic variables**
- **Investigate approximated sound-proof equation sets**

Summary

- In selected local-scale test cases NH-IFS compares reasonably well with analytic solutions and LES benchmarks.
- The global NH-IFS model can be run stably with the same time-step as the hydrostatic model at hydrostatic resolutions (with NSITER=1); depending on the resolution (T_L159 – T_L1279 tested) the cost is 25-70 % higher.
- The NH-IFS model has a nearly identical model climate with the hydrostatic IFS (at T_L159L91) in the troposphere.
- NH-IFS and H-IFS produce very similar scores in the troposphere; in the stratosphere the performance is less good due to the difference in vertical discretization (VFE in H-IFS and VFD in NH-IFS).