Some performance evaluations of the 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*

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**

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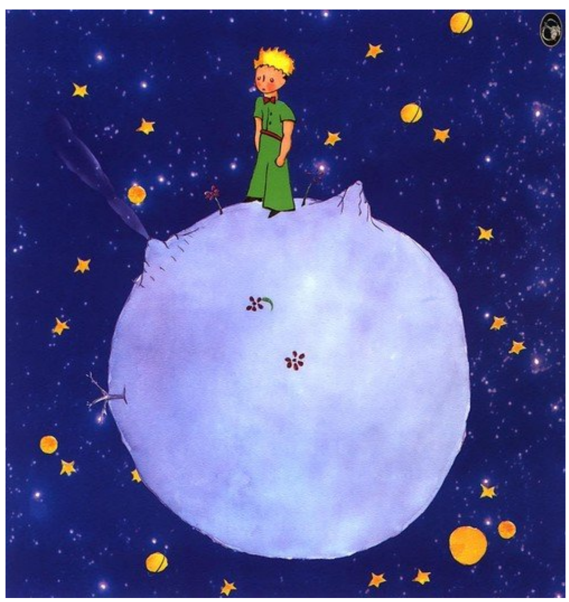
A testing strategy

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.**

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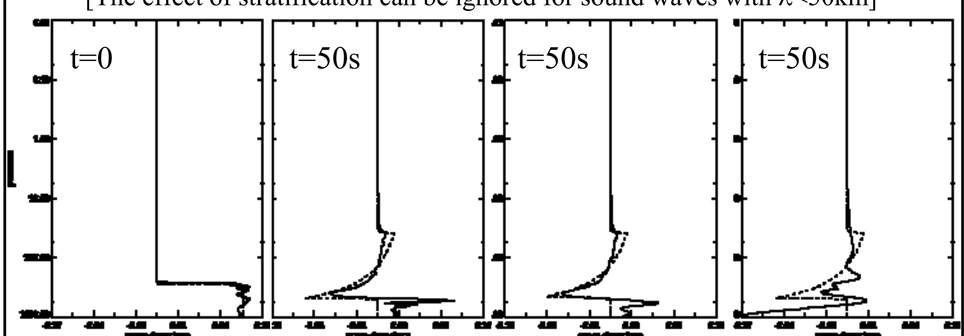
A spherical acoustic wave in a stratified (isothermal) atmosphere on a reduced-radius sphere

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)

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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

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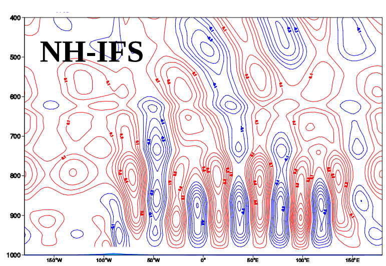
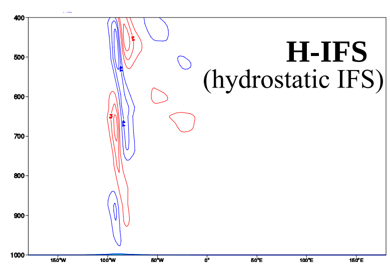
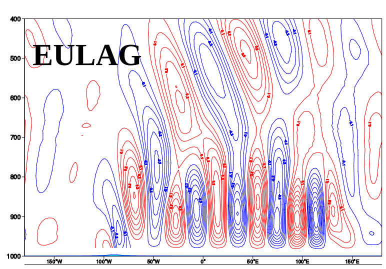
Quasi two-dimensional orographic flow with linear vertical shear







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.

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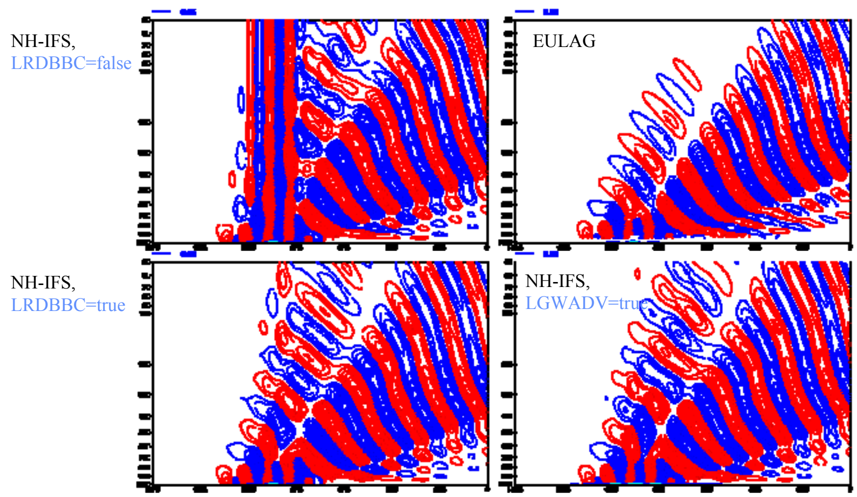
3D Schär - mountain on the sphere

(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).

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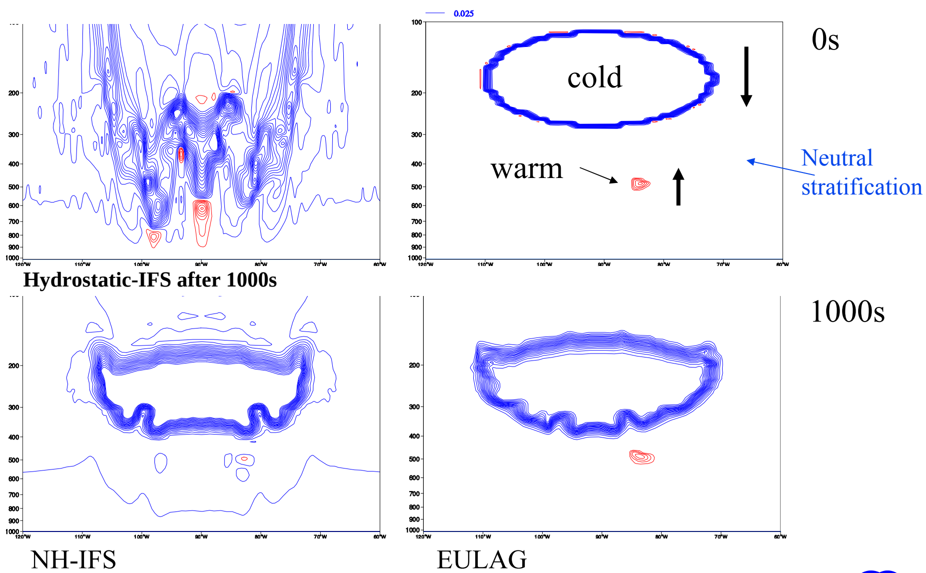
Convective motion (3D bubble test)



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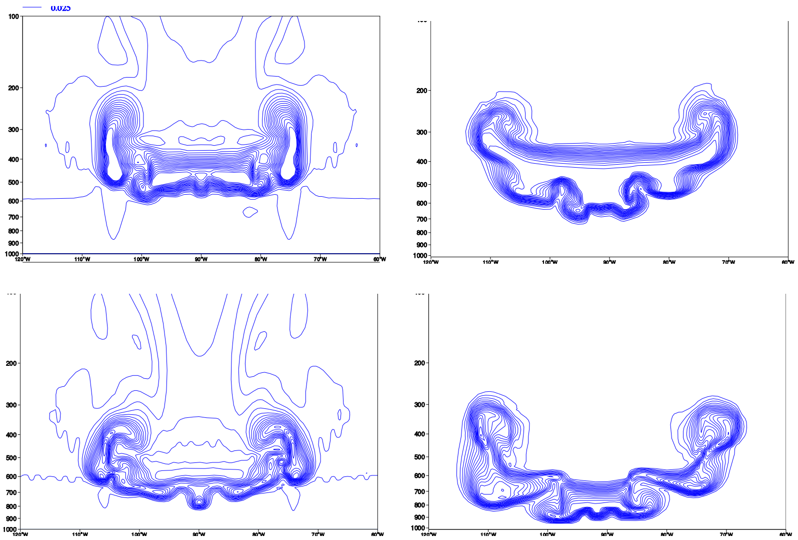
Convective motion (3D bubble test)



1800s

2400s

NH-IFS EULAG

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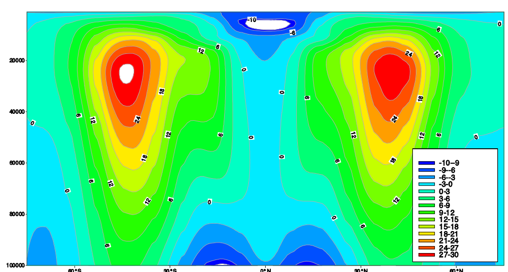
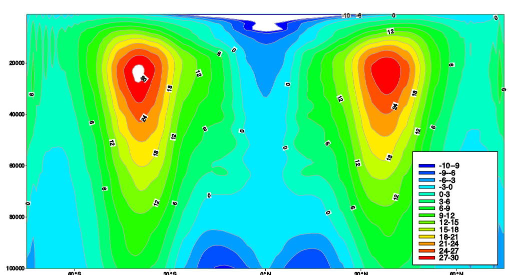


NH-IFS



EULAG

Held-Suarez climate on reduced-size planet

$a=0.1a_{Earth}$, $T_L159L91$
Equivalent to
$\Delta x = 12.5$ km

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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.**

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).**

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