Non-hydrostatic, semi-implicit, semi-Lagrangian adiabatic core for HIRLAM

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Introduction

- NH SISL development is completed in general lines, the model is in stage of preoperational testing
- The main goals were:

  To bring the semi-anelastic, pressure-coordinate, NH approach to a logical and definite finish in HIRLAM framework

  To upgrade the NH model computationally

  (to enhance the numerical efficiency)

Dynamics

- **Semi-anelastic pressure-coordinate equations of motion and thermodynamics in Lagrangian form**

- ***HS equations + additional equation for vertical acceleration*** (the vertical momentum equation), which includes (additional) ***NH geopotential***

- non-divergence of motion in pressure-coordinates

- prognostic (non-adjusted) surface pressure

Discrete model

- Hybrid (ECMWF) coordinates, C-grid staggering
- Semi-Lagrangian (SL) trajectory calculations

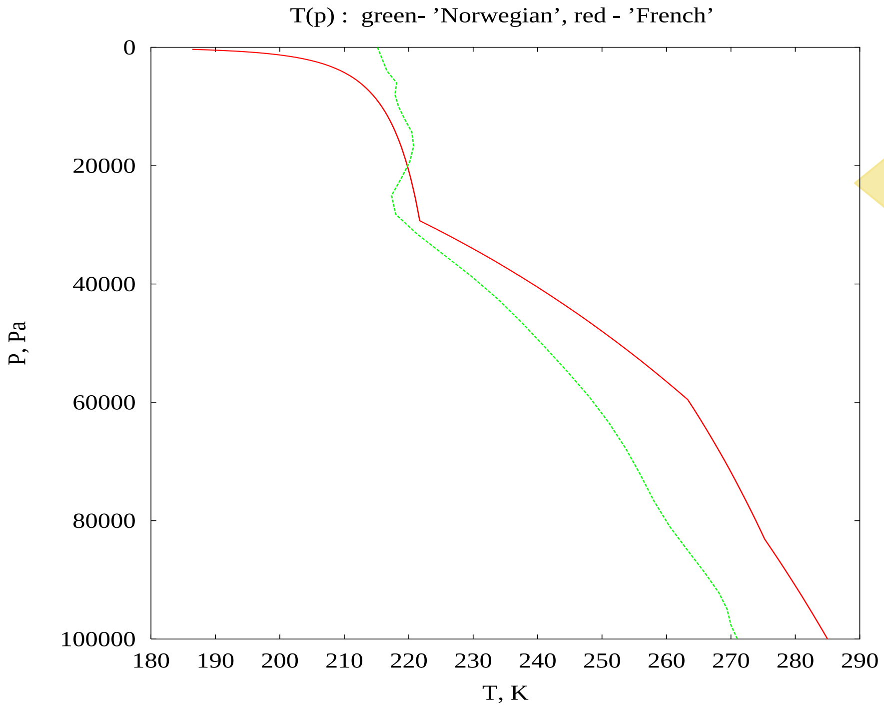
For trajectory calculations and interpolating the existing (McDonald & Haugen) routines from HS HIRLAM are employed

- Two level time stepping

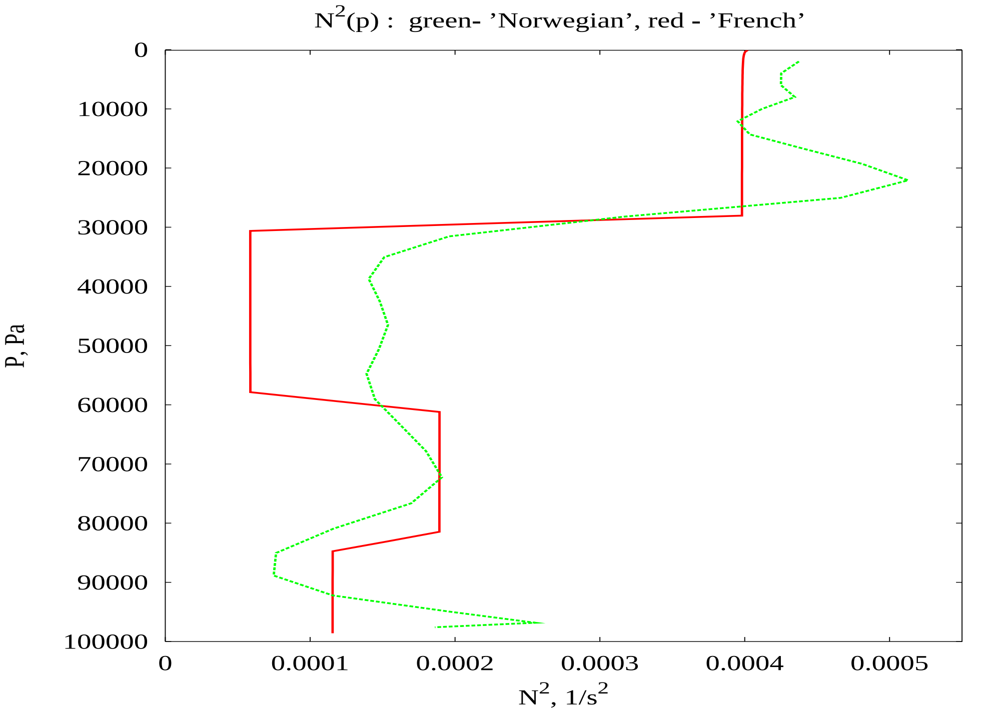
Specific features

- **Separation of forces** to the main state and perturbation (nonlinear) part makes use of **pressure(height)-dependent** reference temperature $T(p)$, Brunt-Väisälä frequency $N(p)$, and mean surface pressure $p^0_S(x,y)$ *[*concordant with the reference temperature $T(p)$*]*

- **Dynamic variables are presented by fluctuations** T', p'_S



Examples of reference temperature...

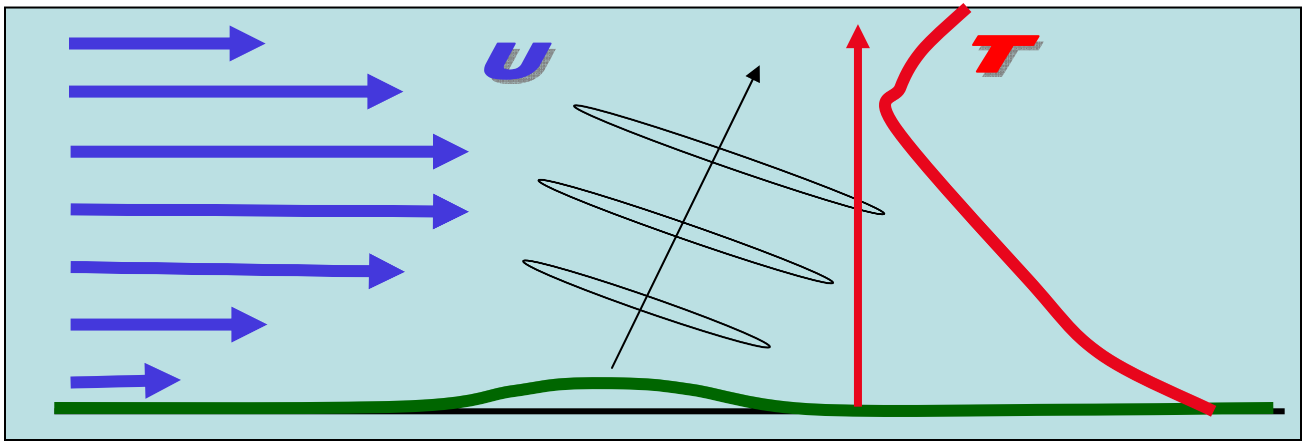


...and corresponding Brunt-Väisälä frequency

Norvegian: area-mean temperature over Norway 2001.03.22

French: a model distribution of T(p) and U(p) , proposed by F. Bouttier for tests and model comparison

Model experiments

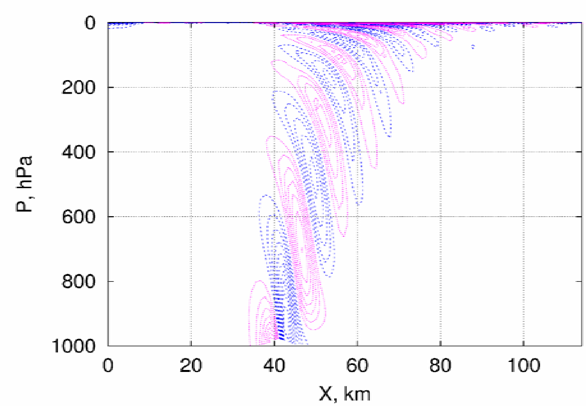


(1) Debugging

(2) Quality control

8 ARTIFICIAL TESTS

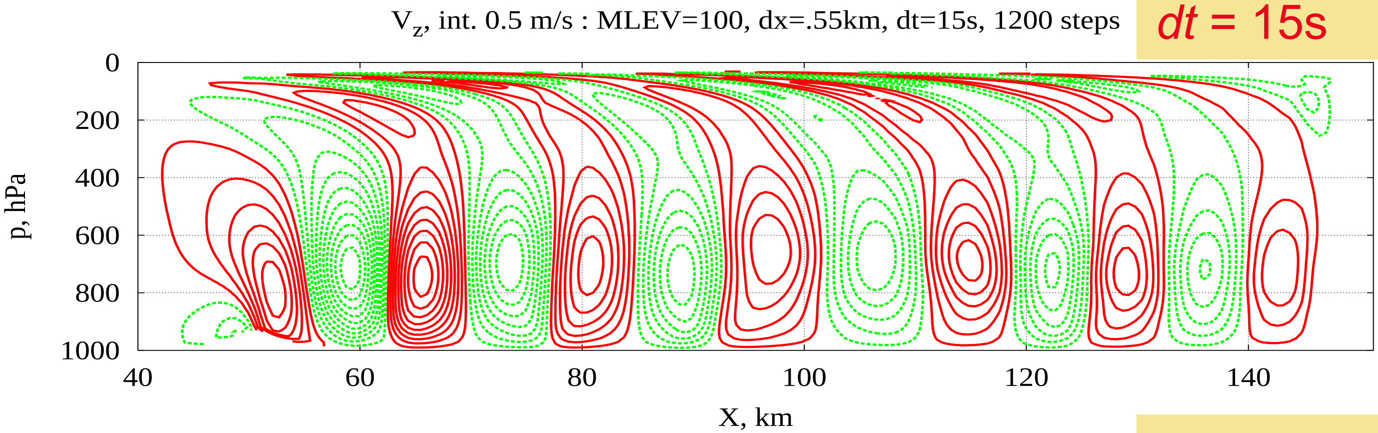
Stationary flow over circular hill. Vertical velocity distribution, contour interval 0.1 m/s.



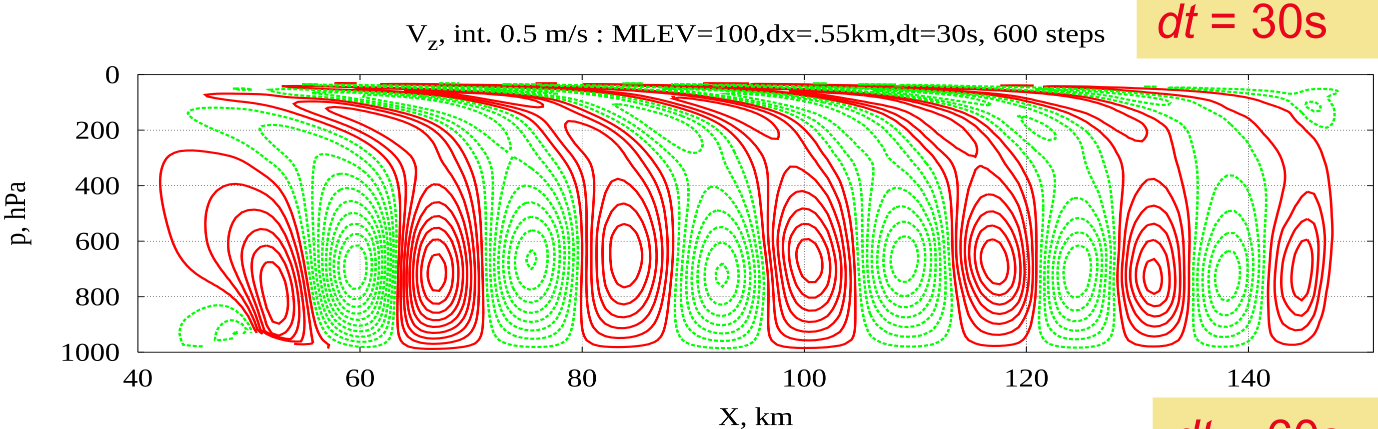
$\Delta x = \Delta y =$ **1km; Vertical resolution: 60 level ECMWF grid.** $a = 3$ *km*, $h = 200$ *m*, $N = 0.015$ *1/s*, $U =$ **20 m/s.**

Flow over Agnesi ridge, $a_x = 3$ km, $h = 600$ m

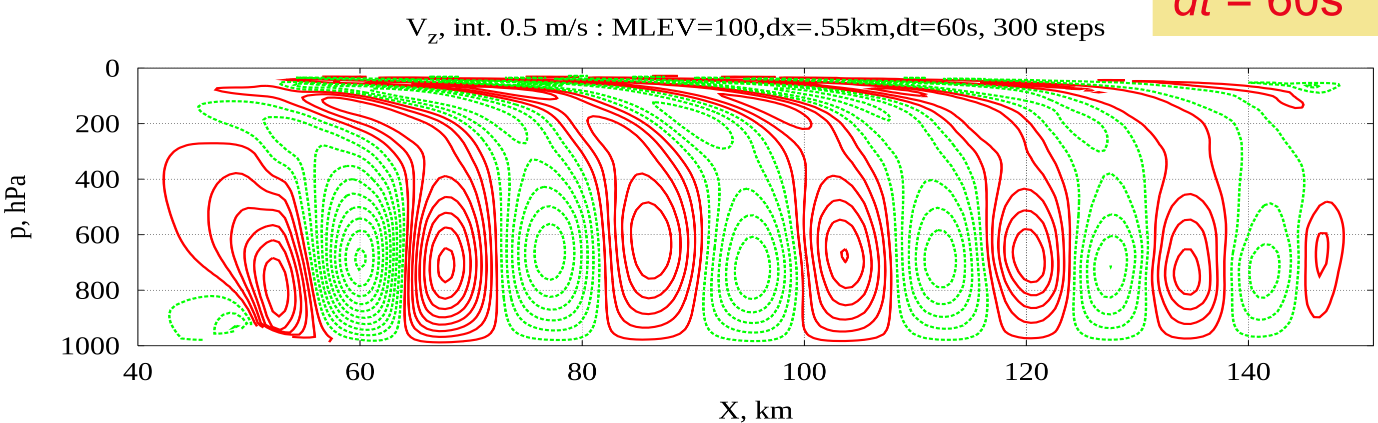
dt = 15s



dt = 30s



dt = 60s



Link to ref. State profiles

$$dt_{cr} = 13s$$

dx = .55 km,

276x100 grid,

100 levels

Integration period: 3 h

Reference state (*U(p)* and *T(p)*):

‘French’ profile

Time step estimates

There is no strict upper limit of max Δt for NH SISL.

In the table, estimations of maximum reliable Δt are presented

Max U, **[*m/s*]**	***T(p)***	***Δx,*** **[*km*]**	$\Delta t_{Cr} = \frac{\Delta x}{U}$ **[*min*]**	Δt **[*min*]**	$\Delta t/\Delta t_{Cr}$	parcel path (max), [*km*]
40	const	5.5	2.3	4.6	2.0	11
55	real	5.5	1.67	4.0	2.4	13.2
40	real	2.2	0.92	2.8	3.0	6.6
42	real	0.55	0.22	1.0	4.6	2.5

Real-condition experiments

I. Norwegian experiment (mountains)

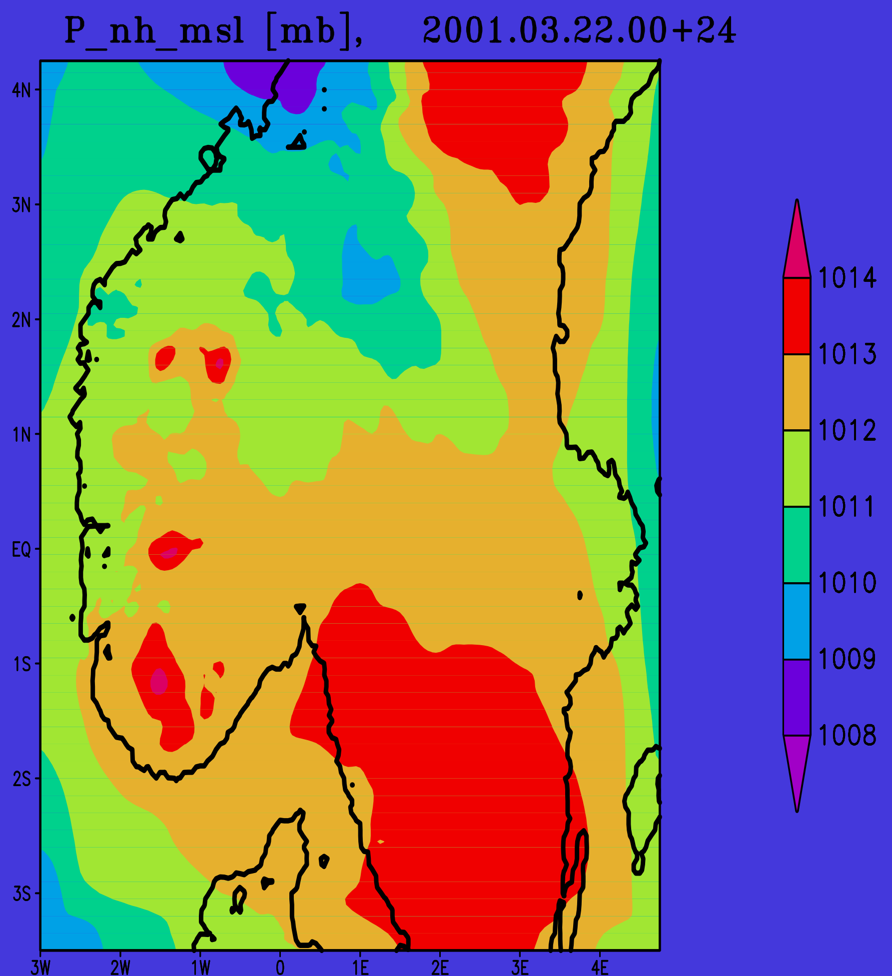
- Resolution 5.5 km
- Grid 156x156, 31 levels
- HIRLAM 5.0.0

  Physics included (v5.0.0)

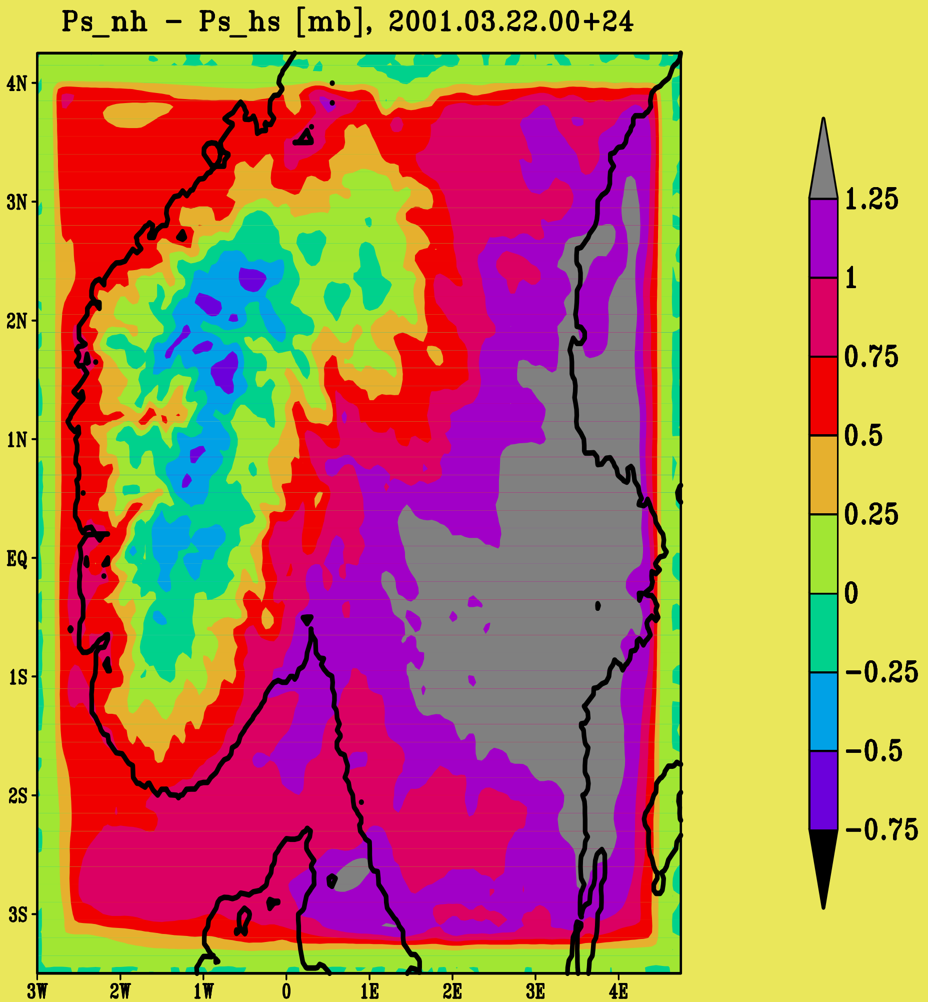
MSL pressure 24 h forecast. *Resolution 5.5 km, time-step 4 min*

NH model gives ~1 mb larger MSL pressure on plane, ~1 mb lesser at mountain tops

NH SISL



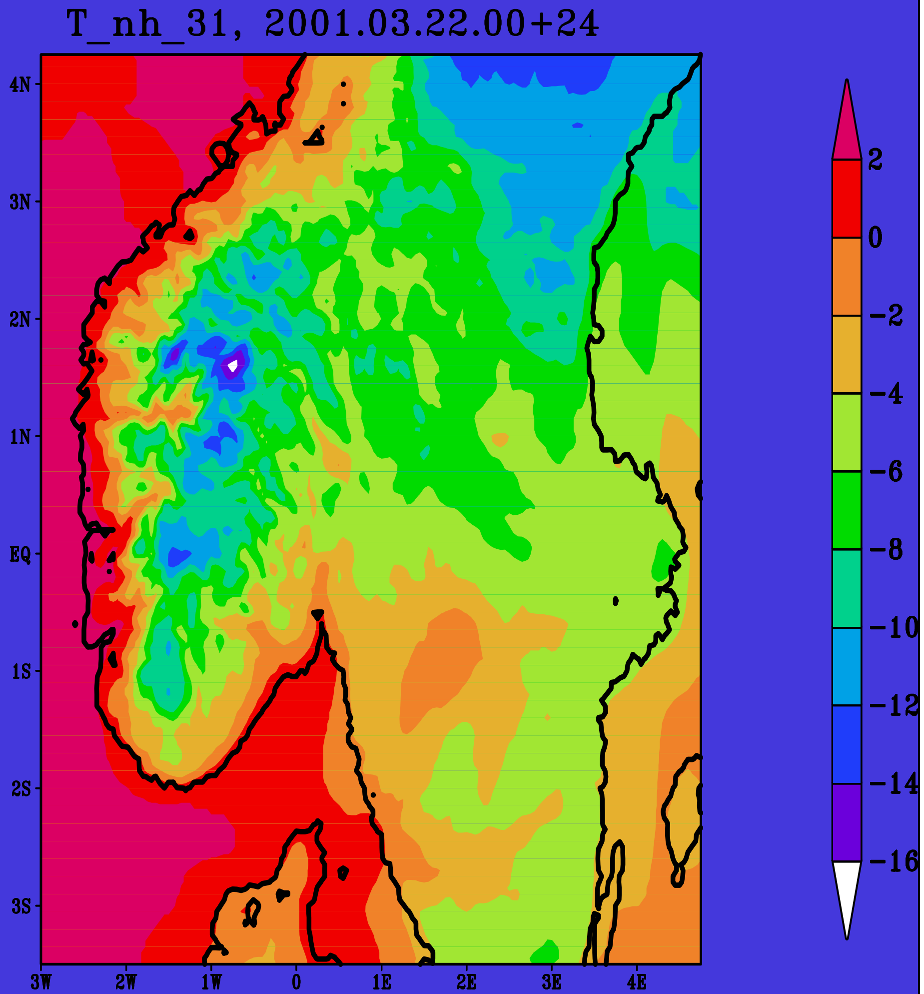
NH – HS SISL



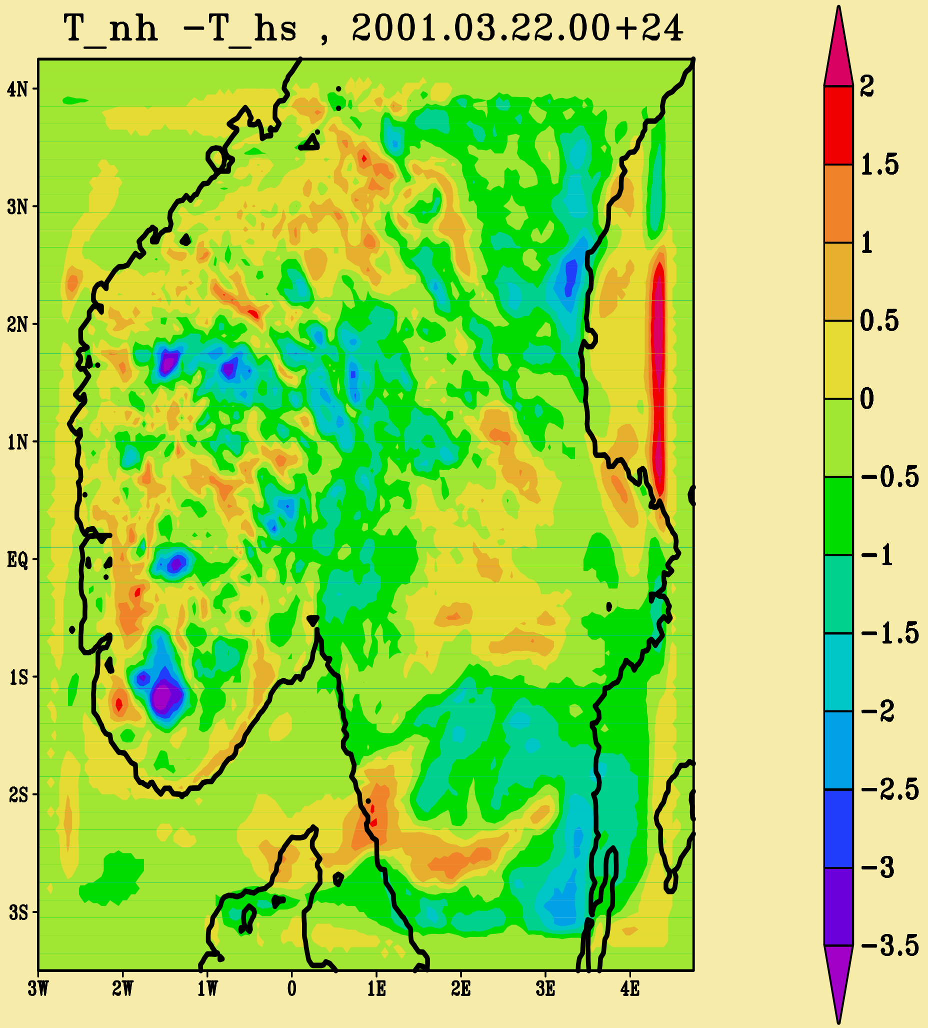
10 m temperature, 24 h forecast. ***Resolution 5.5 km, time-step 4 min***

Temperature differences are mostly < 0.5 C, except on mountain tops, where ***ΔT***~ -3 C

NH SISL



NH - HS SISL

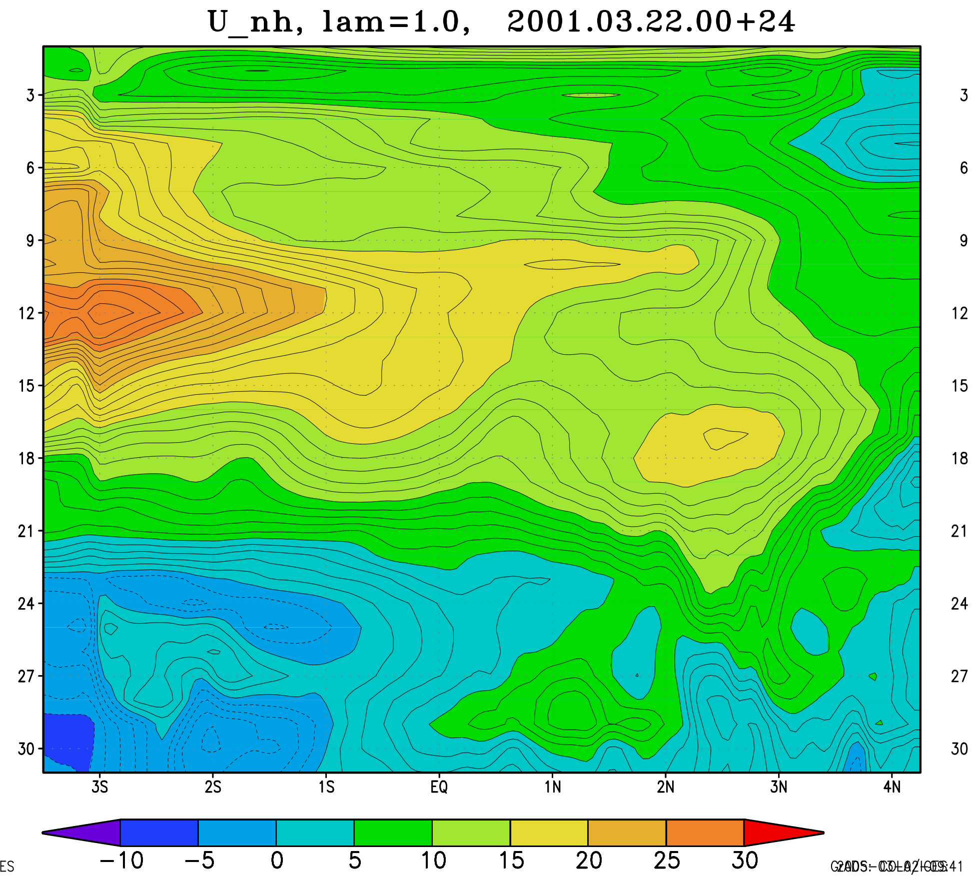


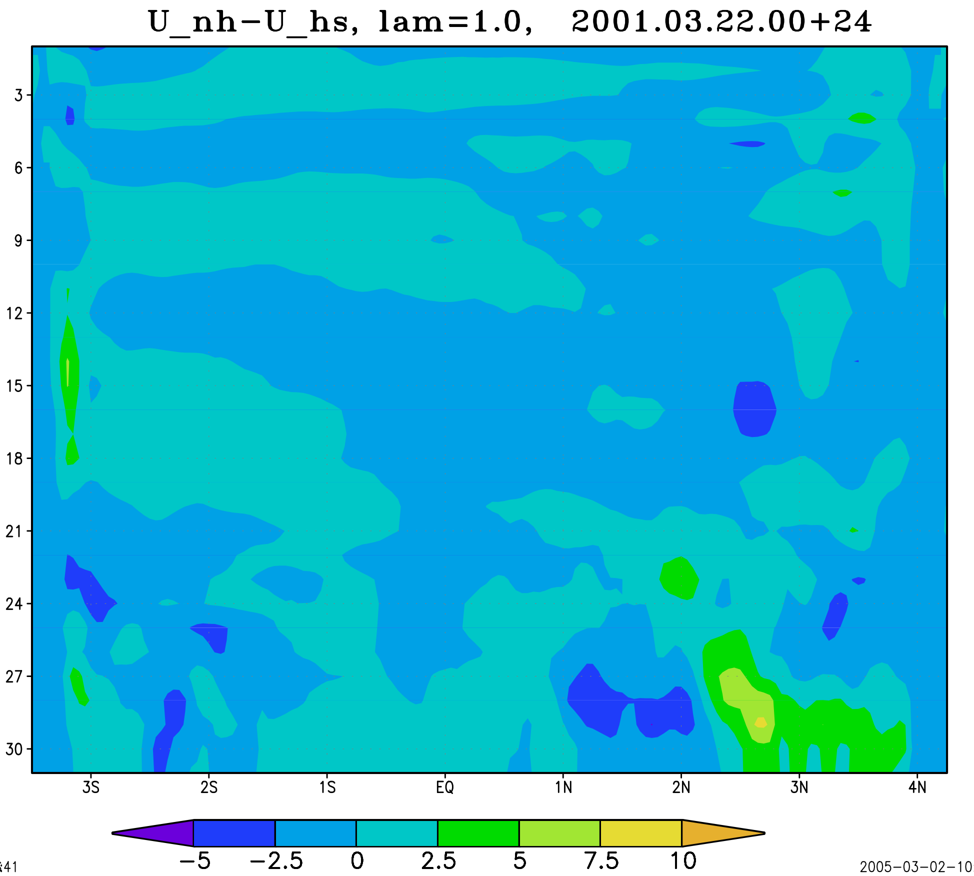
U vertical cross section, 24 h forecast.

Resolution 5.5 km, time-step 4 min

Wind differences ~ 3 m/s (in some places up to 10 m/s

NH SISL | **NH - HS SISL**



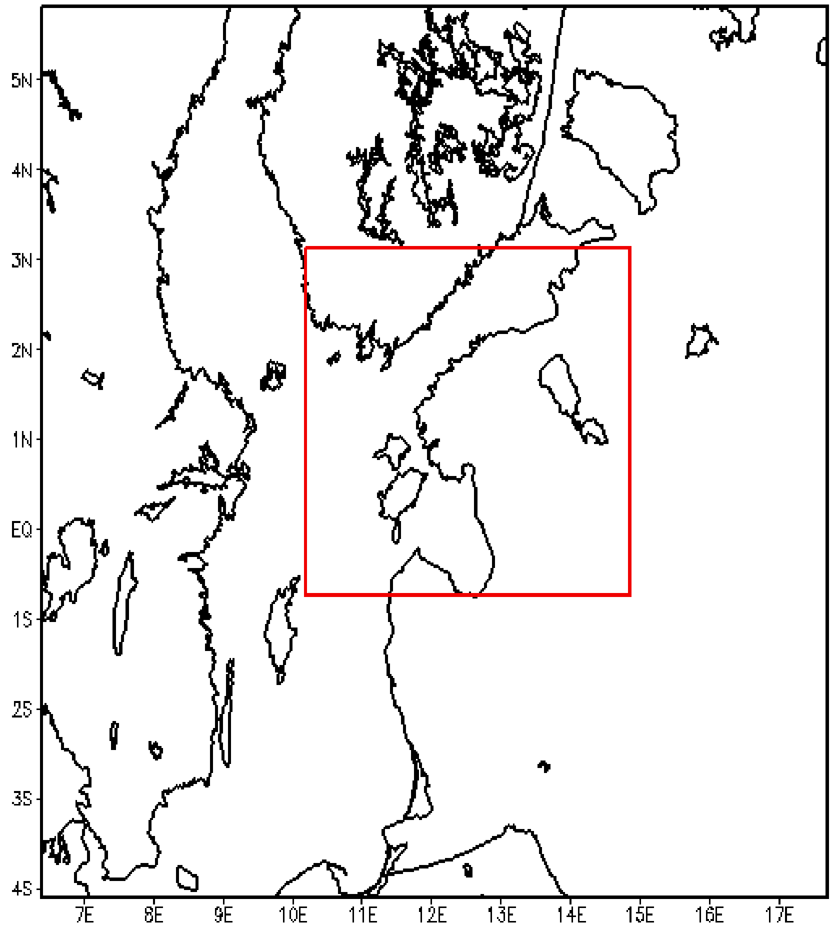


Real-condition experiments

II. ETB (Estonian B-area)

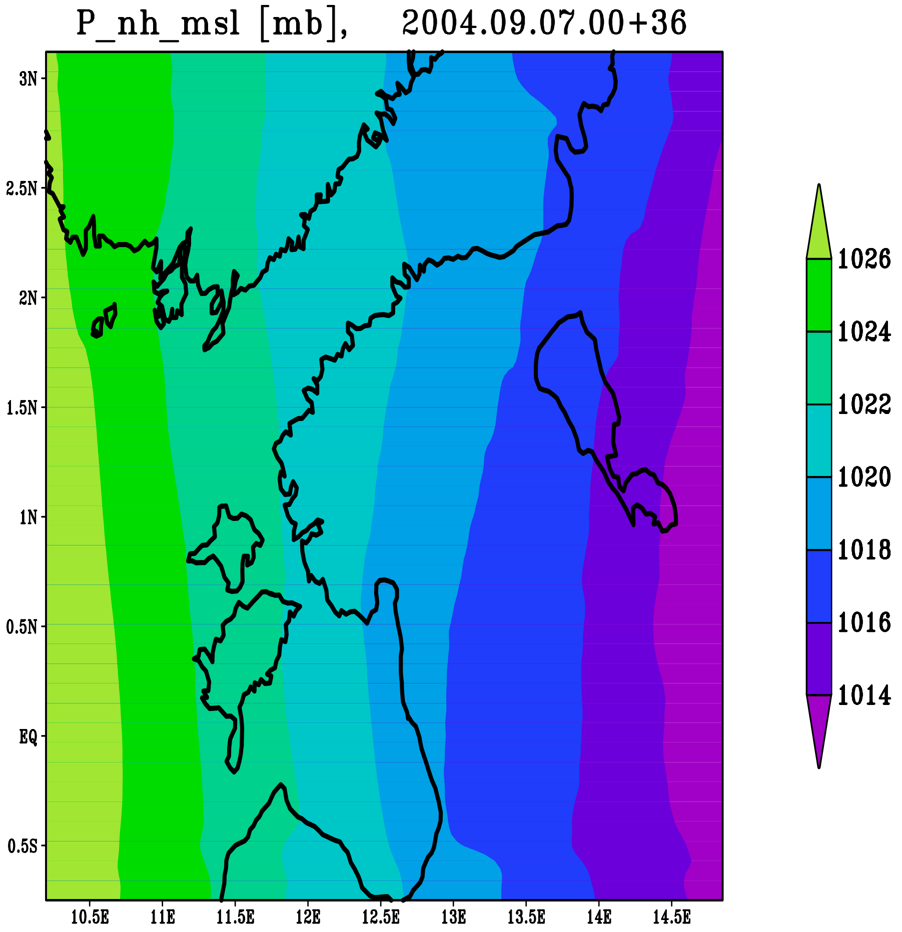
- resolution 3.3 km,
- Grid 186×170×40 (former 104x100x40, area increase 3.3x)
- Δt=150s
- Reference HIRLAM 6.1.0

Physics (v6.1.0) included

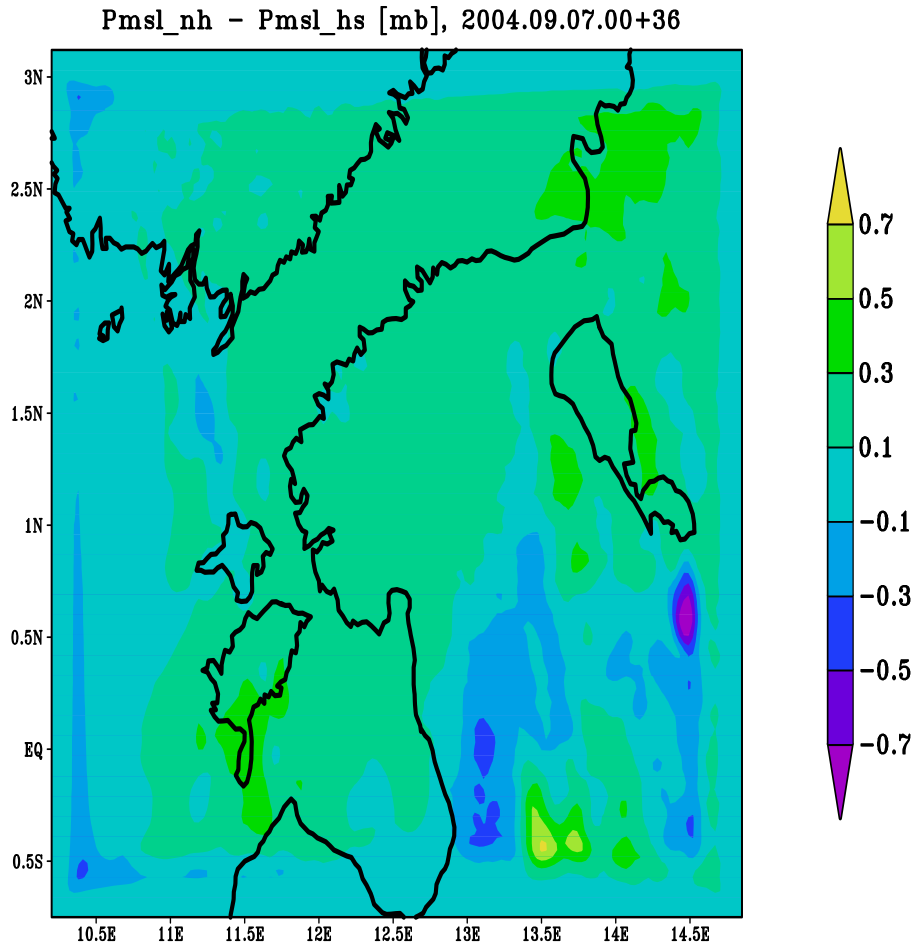


Mean sea level pressure 36 h forecast within ETB.
Resolution 3.3 km, time-step 1.5 min

NH SISL

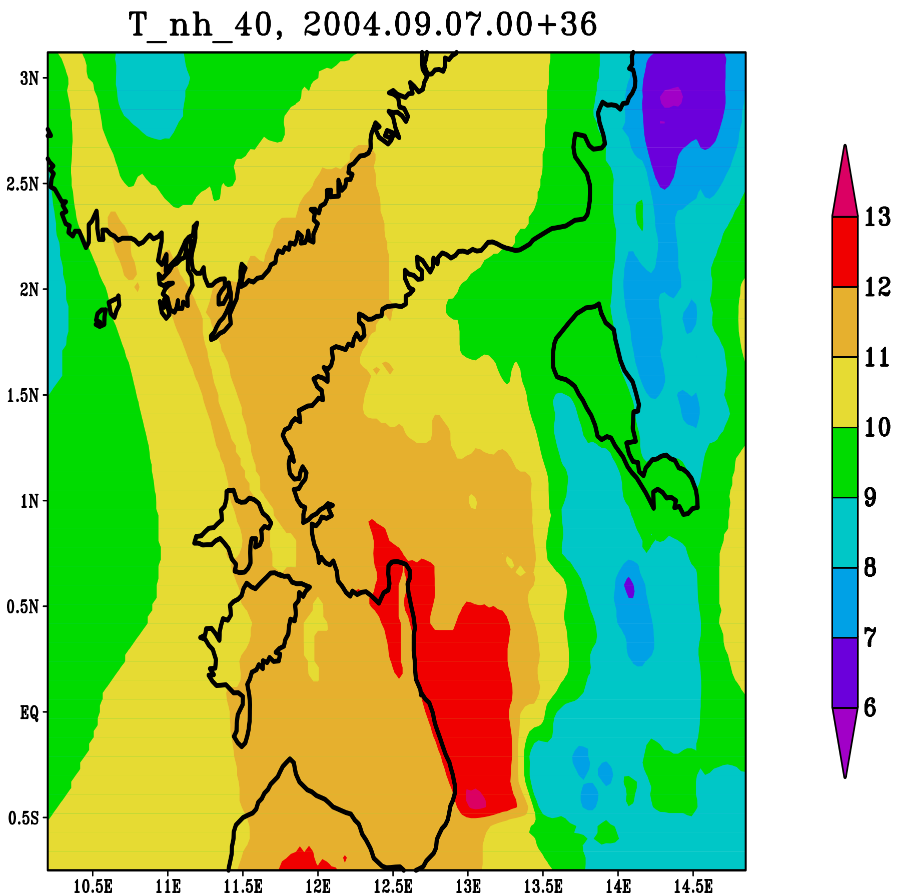


NH – HS SISL

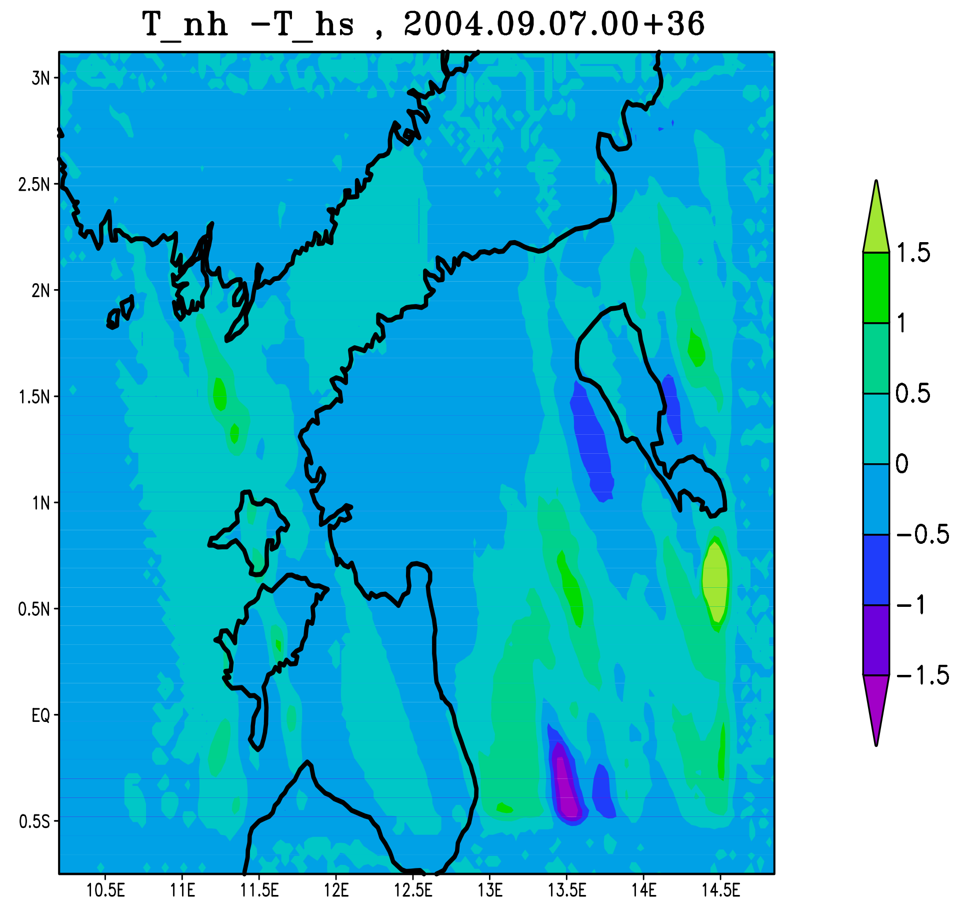


T_40 36 h forecast within ETB. *Resolution 3.3 km, time-step 1.5 min*

NH SISL



NH – HS SISL

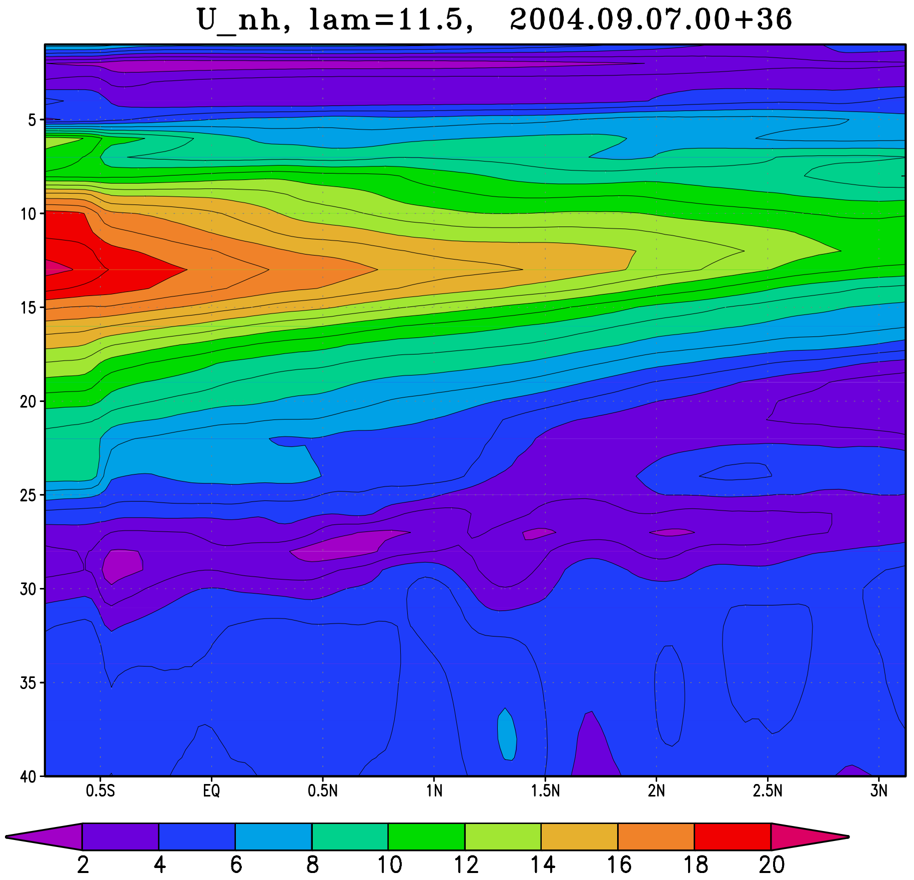


36 h forecast within ETB

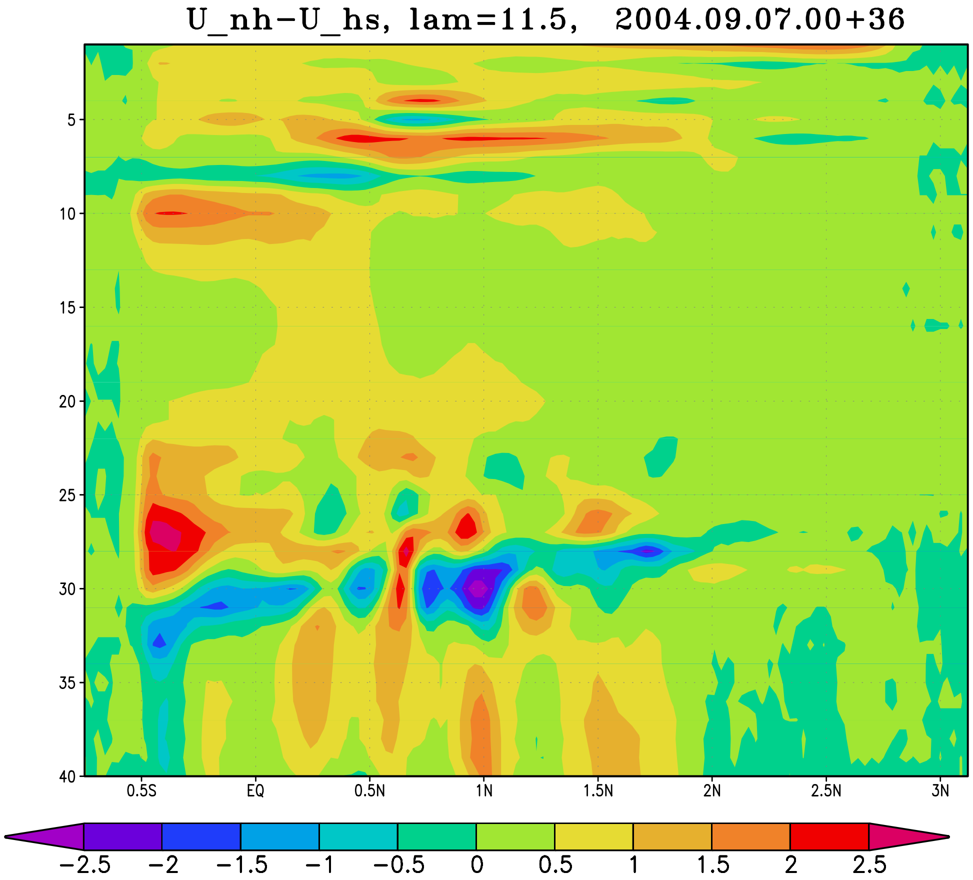
U-wind vertical cross section

Resolution 3.3 km, time-step 1.5 min

NH SISL



NH – HS SISL



Conclusions

NH SISL is completed:

- The stability and the time step are reasonable
- Comparison with theoretical results (mountain flows), as well as with other models (NH Euler, HS SISL) shows that NH SISL is reliable and ready for applications

Currently, the **NH SISL is implemented as the adiabatic core in ETB** (3.3 km resolution, grid 186x170, 40 levels, physics of HIRLAM 6.1.0) and the testing is activated

- The computational efficiency increase is substantial
- The NH-specific effect is moderate

NH SISL will be a suitable tool for model development (*complex terrain, boundary layer, moist convection*) at very high spatial resolutions (0.5 - 1km, 100 levels)