Status and results of HIRLAM 4D-Var

Nils Gustafsson

Who made the HIRLAM 4D-Var?

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Magnus Lindskog

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Ole Vignes

Tomas Wilhelmsson

Sigurdur Thorsteinsson

HIRLAM 4D-Var Developments.

1995-1997:	Tangent linear and adjoint of the Eulerian spectral adiabatic HIRLAM. Sensitivity experiments. ”Poor man´s 4D-Var”. J_c(DFI)
1997-1998:	Tangent linear and adjoints of the full HIRLAM physics.
2000:	First experiments with ”non-incremental” 4D-Var.
2001-2002:	Incremental 4D-Var. Simplified physics packages (Buizza vertical diffusion and Meteo France package).
2002:	4D-Var feasibility study.
2003:	Semi-Lagrangian scheme (SETTLS), outer loops (spectral or gridpoint HIRLAM) and multi-incremental minimization.
2005:	Reference system scripts. Extensive tests of 4D-Var
2006:	**BUG correction**! Continued extensive tests. Control of lateral boundary conditions

Semi-implicit semi-Lagrangian scheme for the HIRLAM 4D-Var (SETTLS, Hortal)

General equation

$$\frac{dX}{dt} + S = Z$$

S = linear terms

Z = non-linear terms

Semi-implicit semi-Lagrangian discretization

$$\frac{X_A^+ - X_D^0}{\Delta t} + \frac{(1+\epsilon_g)S_A^+ + (1-\epsilon_g)S_D^0}{2} =$$

$$\frac{((1-\epsilon_g)(2Z^0 - Z^-)_D + (1+\epsilon_g)Z_A^0)}{2}$$

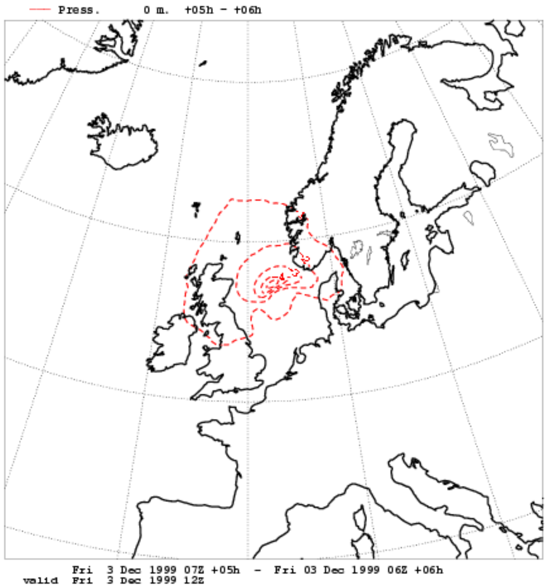
Status of HIRLAM 4D-Var
TL and AD physics

- TL and AD versions of the HIRLAM physics were originally derived. These turned out to be very expensive due to many mutual dependencies between processes.
- The “Buizza” simplified physics is available (vertical diffusion of momentum + surface friction).
- The simplified Meteo France physics package (Janiskova) is available. Vertical diffusion and large-scale condensation have been used in most HIRLAM 4D-Var tests. The large-scale condensation sometimes contributes to instabilities and minimization divergence at “high” horizontal resolution of increments (40 km).

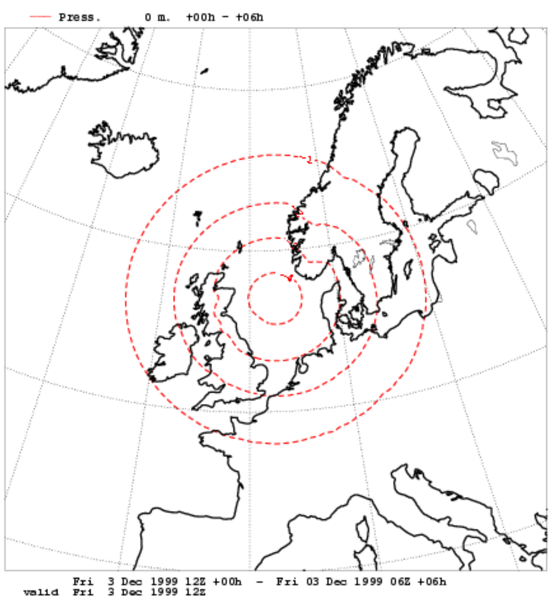
Scalar product tests and the BUG

- All TL and AD model subroutines were checked originally to obey <AD x, AD x> = <TL AD x, x>
- Checking a complete model run to obey < TL x, TL x > = <AD TL x, x > indicated an error (The TL and AD models could not be used to calculate singular vectors).
- The semi-Lagrangian TL and AD codes were re-structured to permit scalar product tests of every line of the code. The second type of test were introduced everywhere.
- A serious BUG was found in the right hand side of the AD semi-implicit semi-Langrangian equations (sign error for one part of the linearised Coriolis force)
- Now, a complete model run over 6 h obeys the scalar product test with 15 digits accuracy!

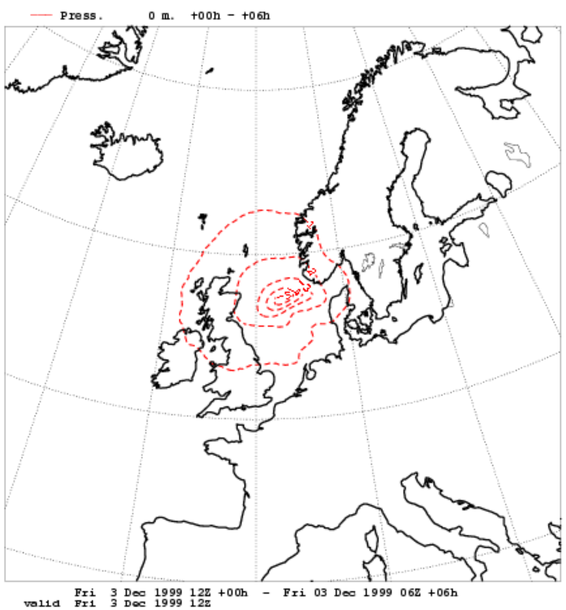
Surface pressure increments for the Danish storm



4D-Var, spectral TL prop. of incr



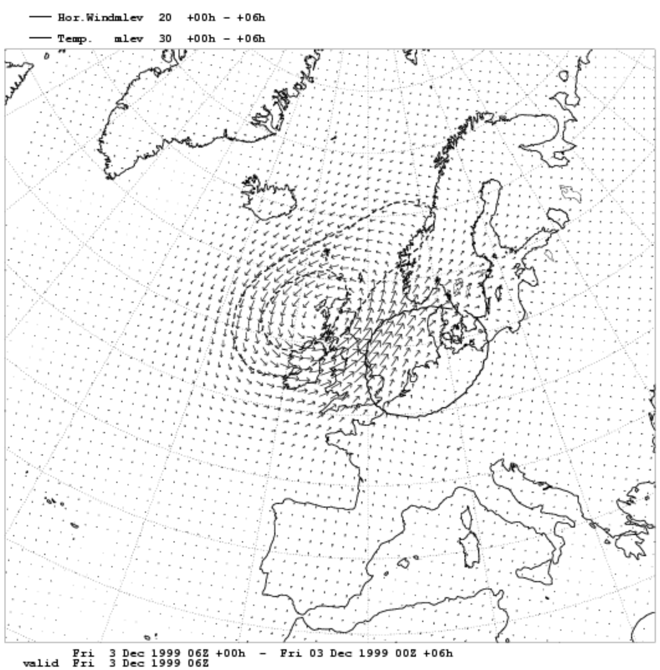
3D-Var



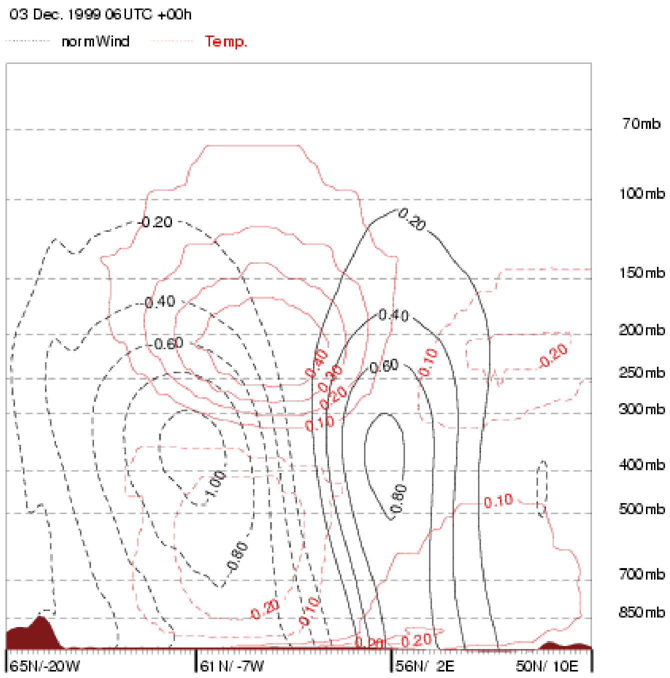
4D-Var; gp model prop. of incr.

Effects of a -5 hPa surface pressure observation increment at +5 h on the initial wind and temperature increments

Winds at model level 20 (500 hPa) and temperatures at level 30 (below)



NW-SE cross section with temperatures and normal winds

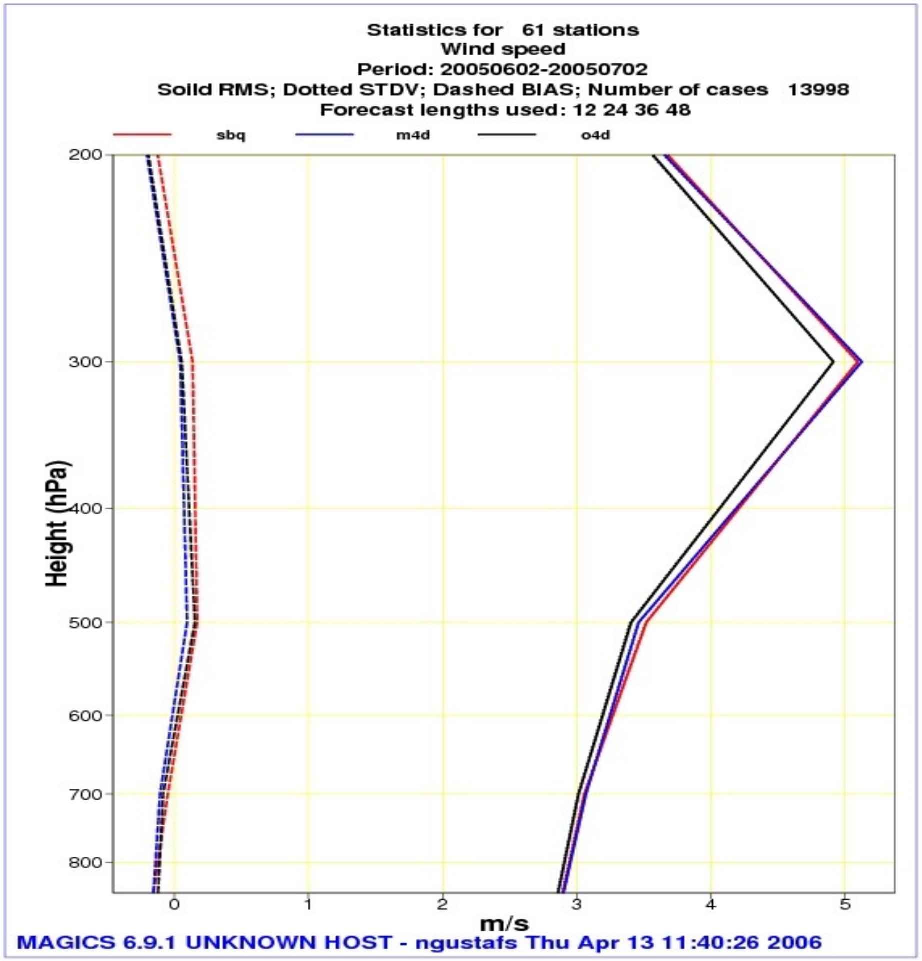


Recent (post-BUG) 4D-Var tests

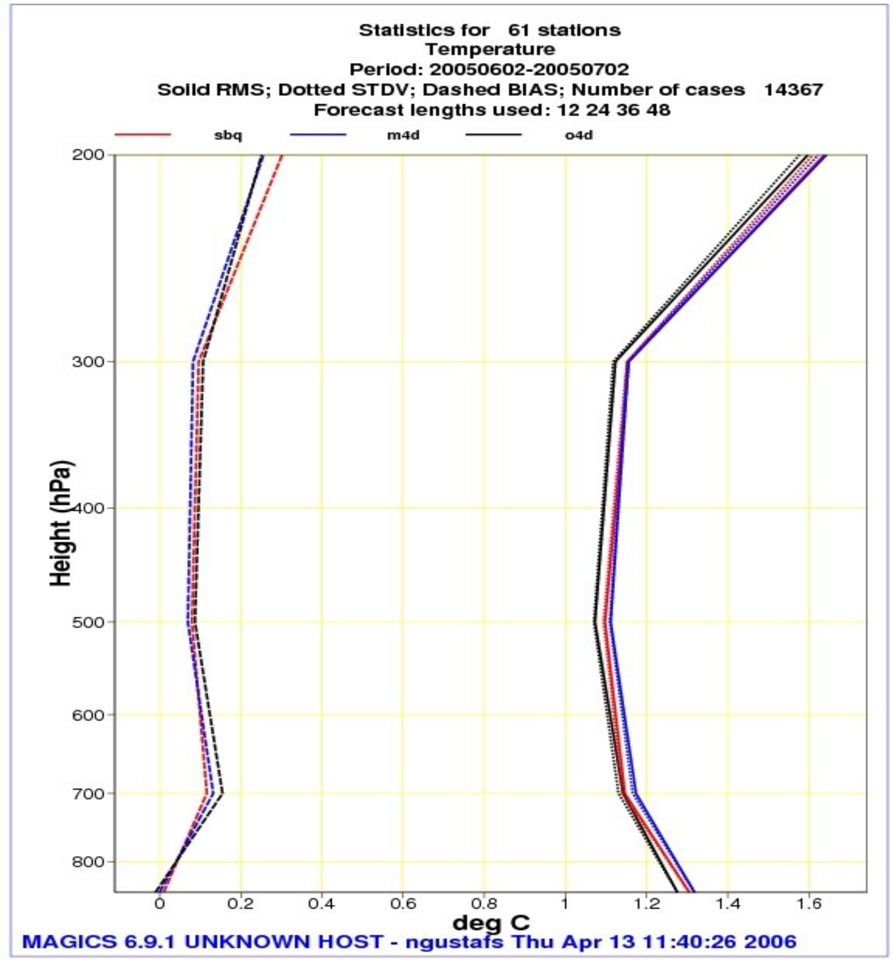
- The SMHI 22 km area (306x306x40 gridpoints)
- SMHI operational observations (including AMSU-A and ”extra” AMDAR observations)
- 6 h assimilation cycle; 3D-Var with FGAT; 6 h assimilation window in 4D-Var; 1 h observation windows
- 66 km assimilation increments in 4D-Var (linear grid); 44 km assimilation increments in 3D-Var (quadratic grid)
- Statistical balance structure functions (the NMC method)
- Meteo-France simplified physics (VDIFF+LSC)
- Non-linear propagation of assimilation increments
- 3 months of data (January 2005, June 2005, January 2006

Average upper air forecast verification scores – June 2005

sbq = 3D-Var m4d = bugged 4dvar o4d = corrected 4dvar



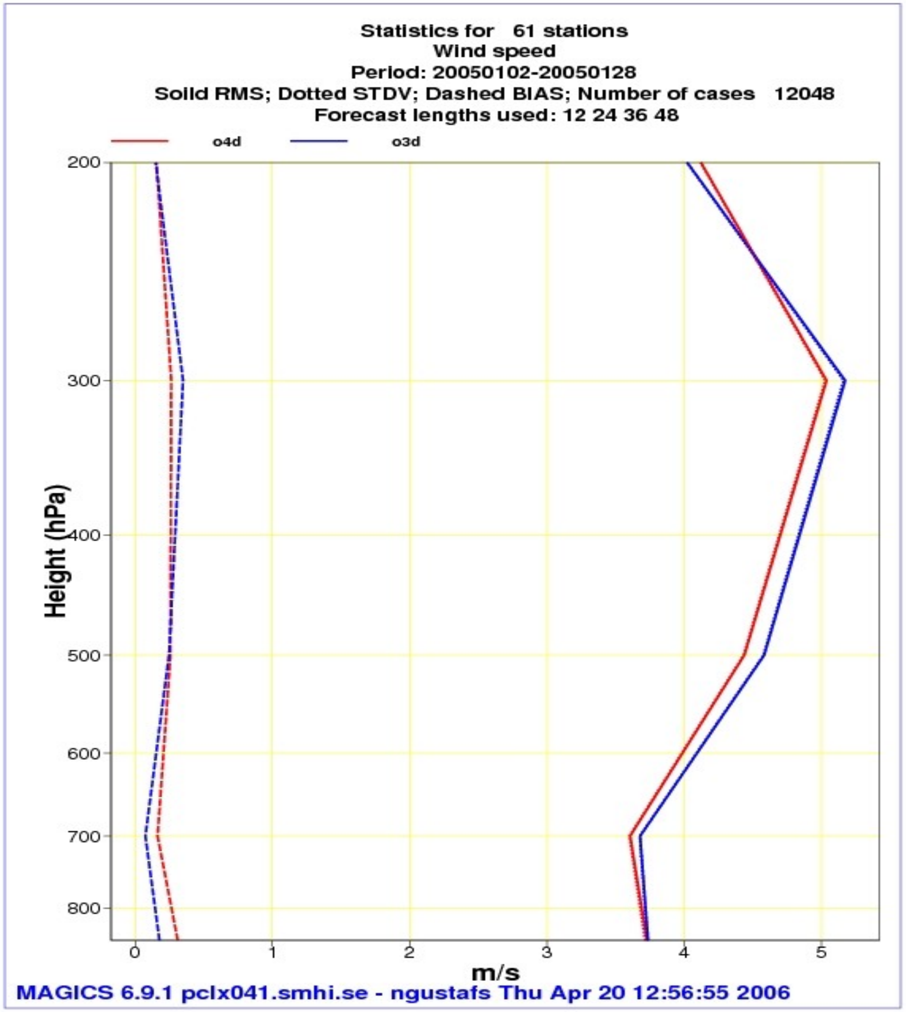
Wind speed



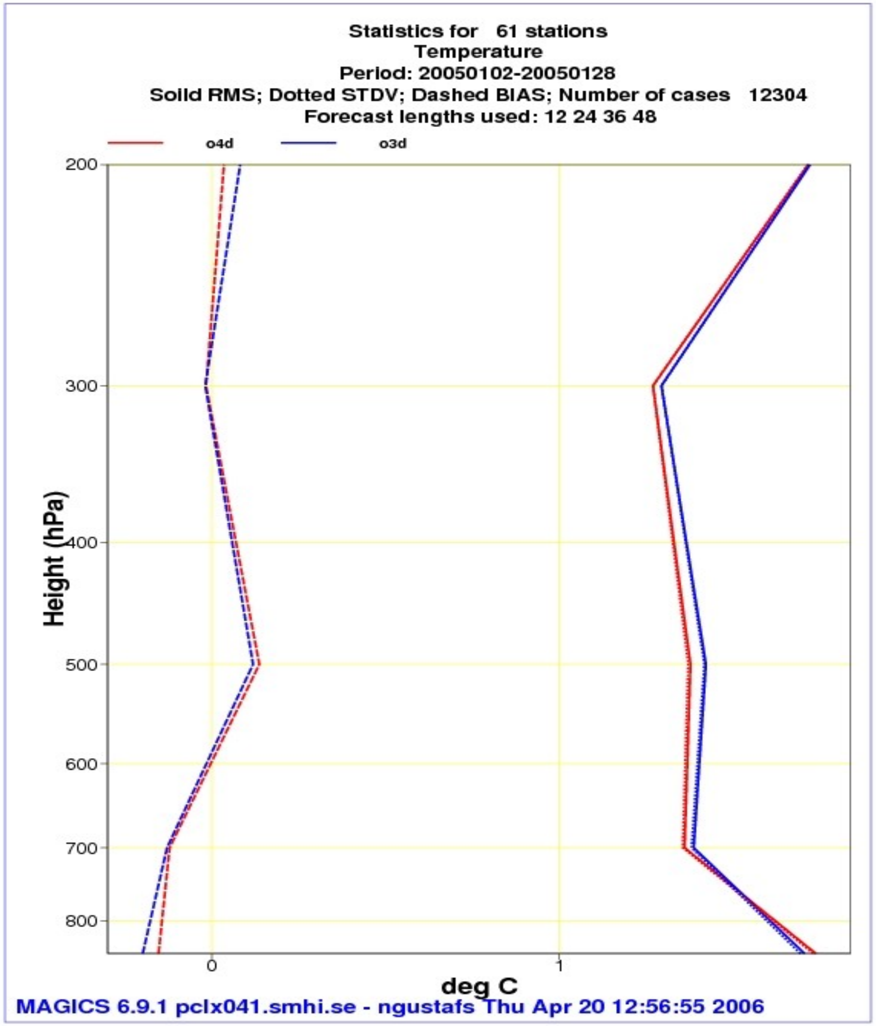
Temperature

Average upper air forecast verification scores – January 2005

o3d = 3D-Var　　o4d = 4D-Var



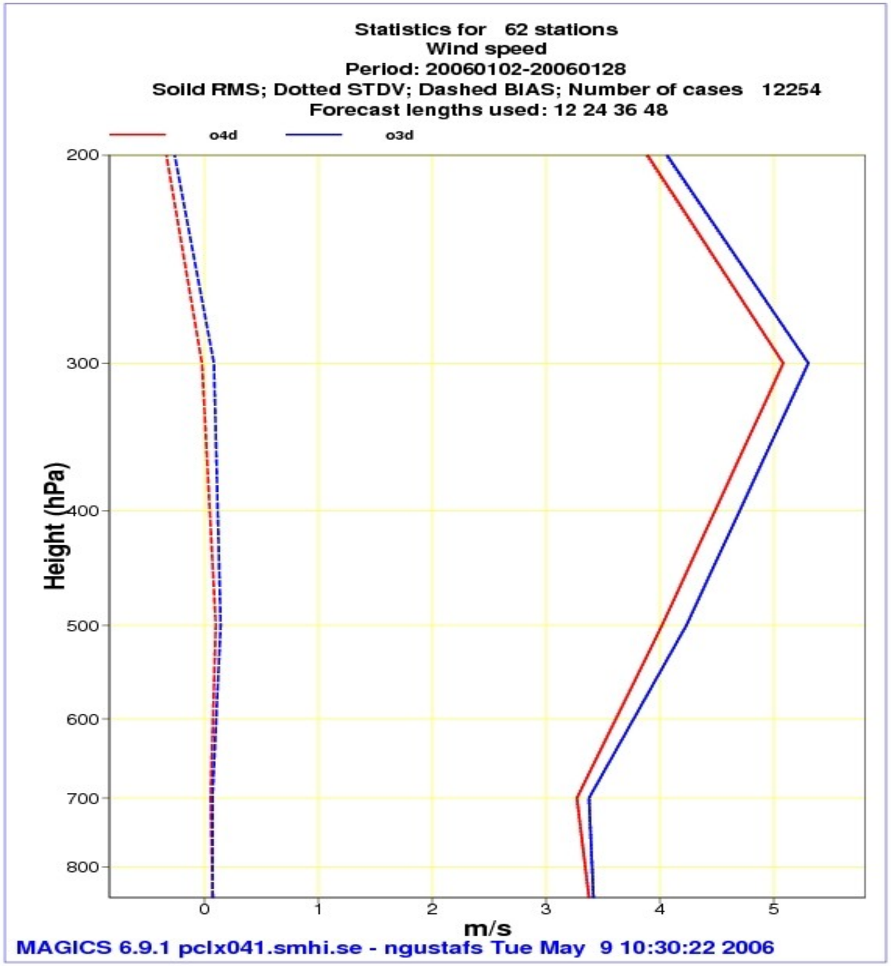
Wind speed



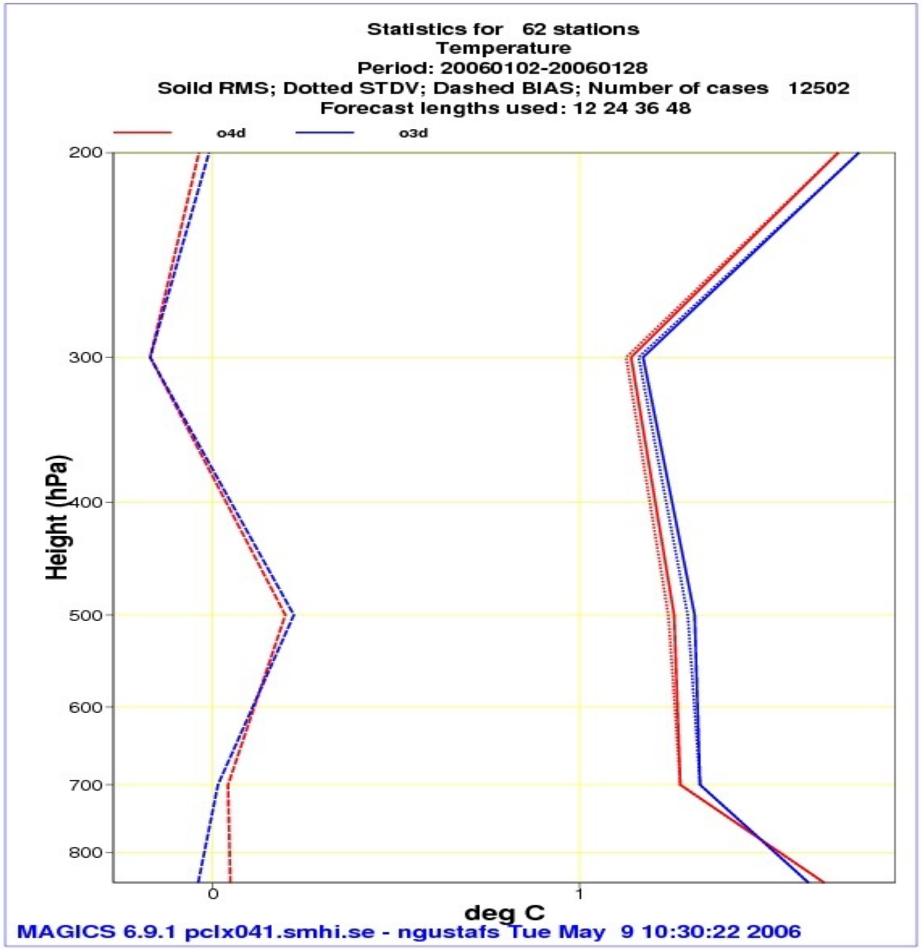
Temperature

Average upper air forecast verification scores – January 2006

o3d = 3D-Var **o4d = 4D-Var**



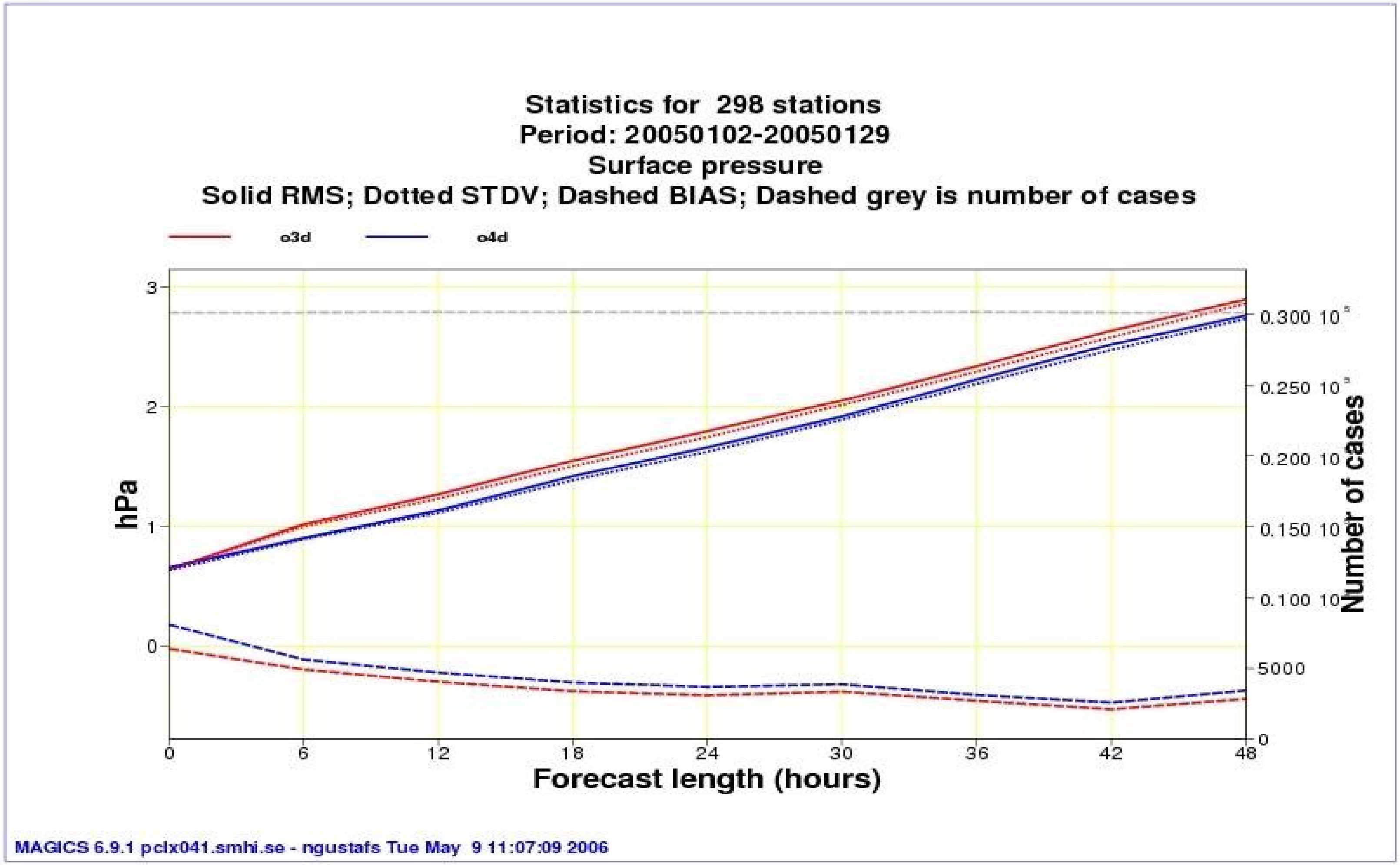
Wind speed



Temperature

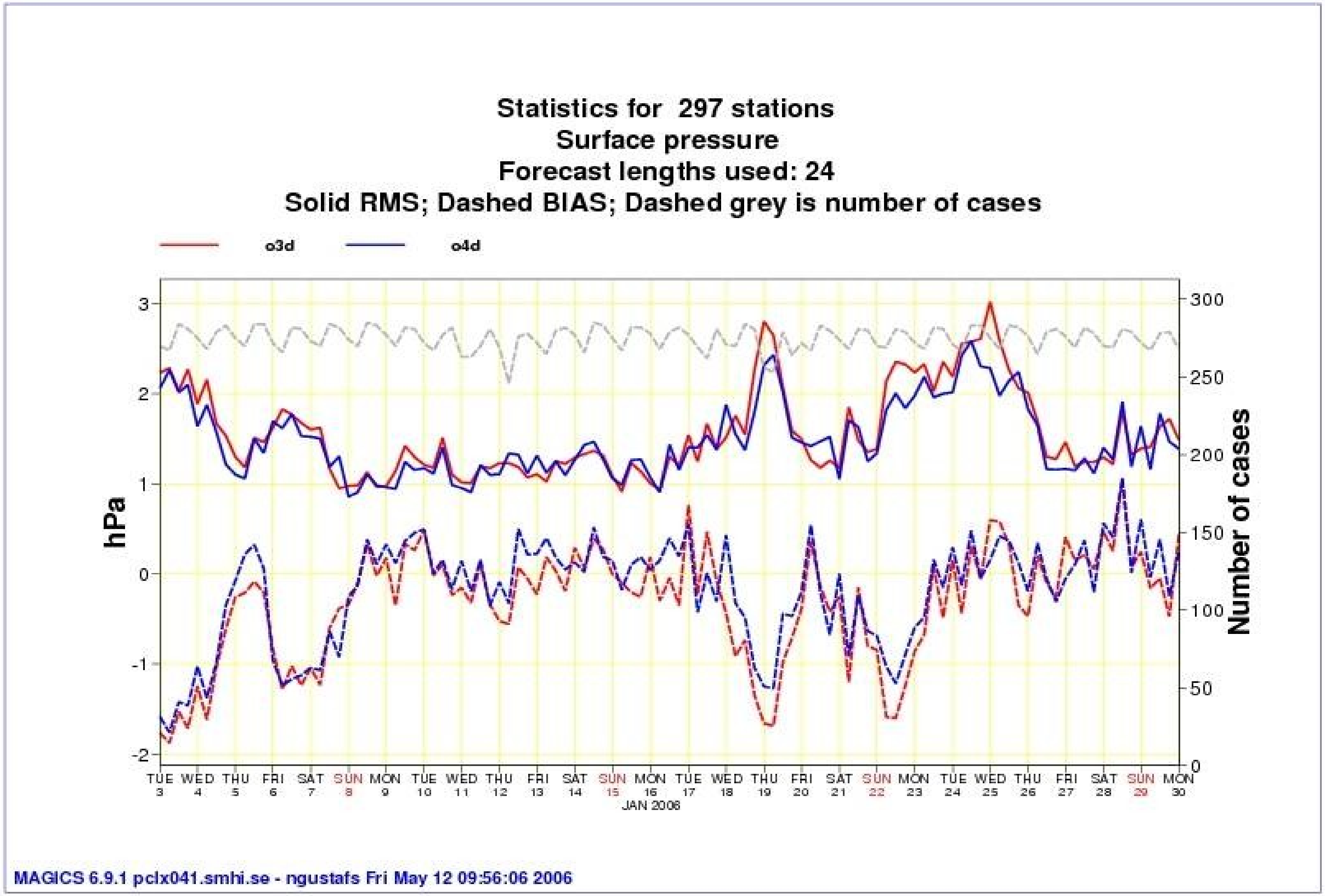
Mean sea level pressure forecast verification scores – January 2005

o3d = 3D-Var   o4d = 4D-Var

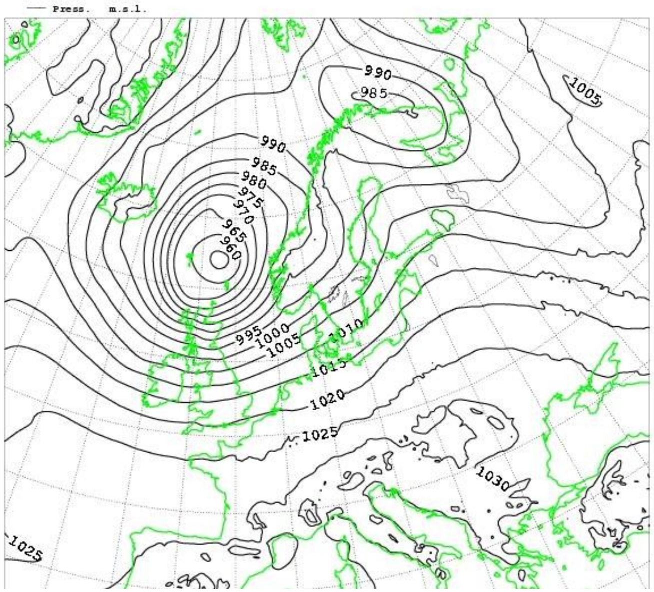


Time series of mean sea level pressure verification scores – January 2006

o3d = 3dvar   o4d = 4D-Var

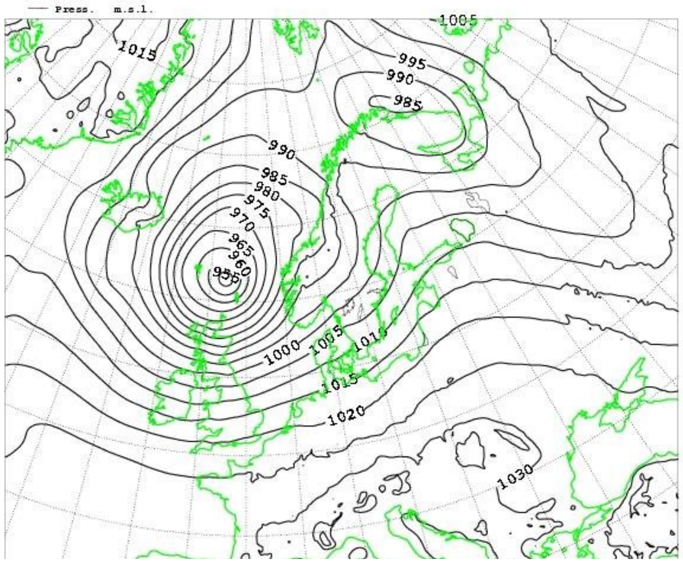


12 January 2005 case



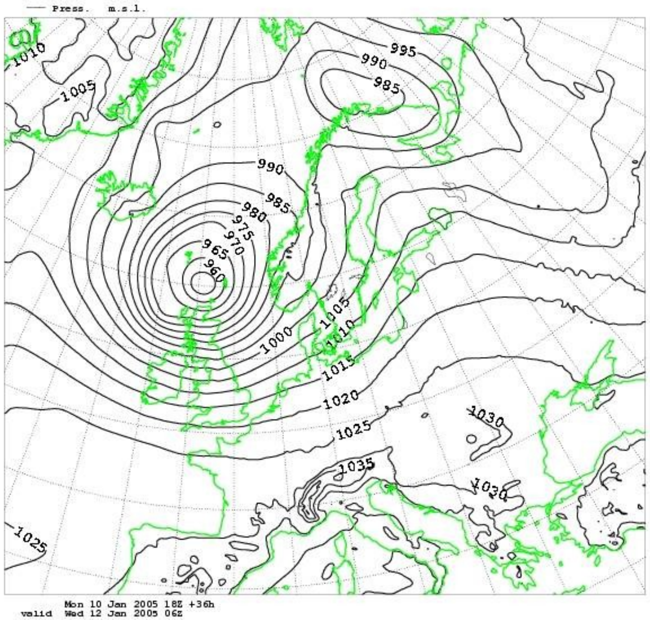
3D-Var

+0 h



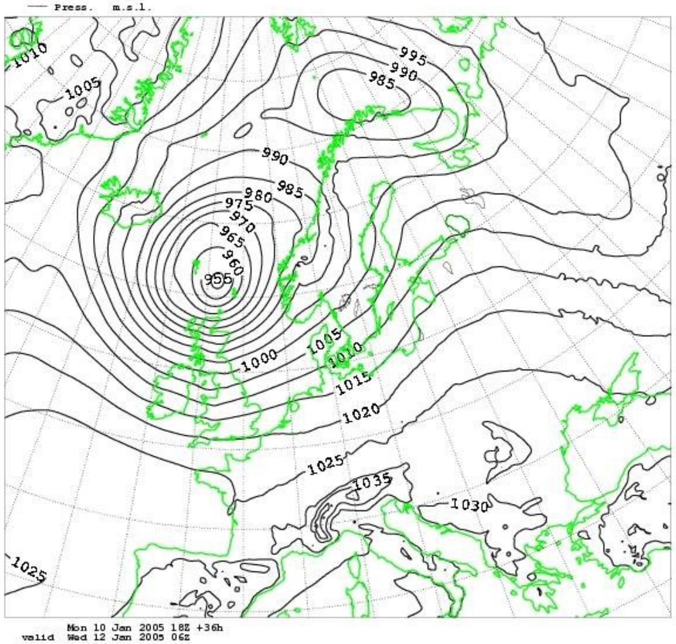
4D-Var

+0 h



3D-Var

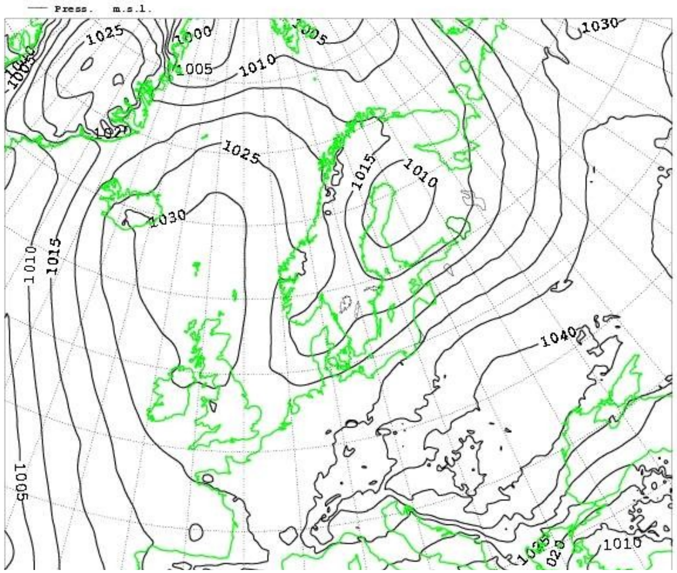
+36 h



4D-Var

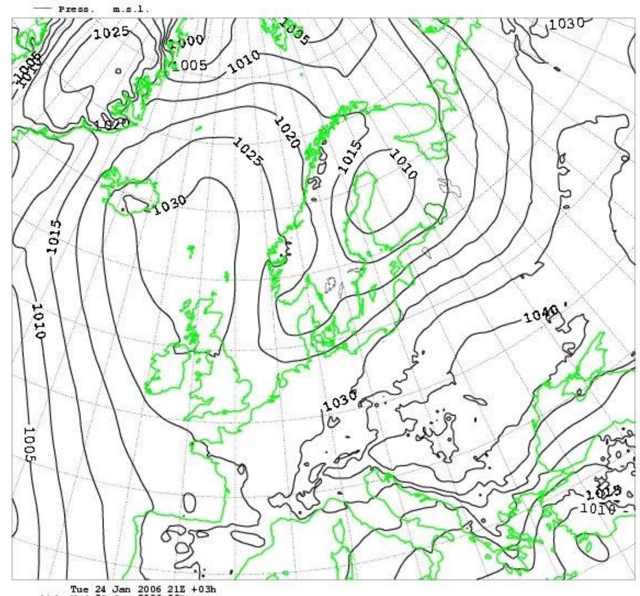
+36 h

25 January 2006 case



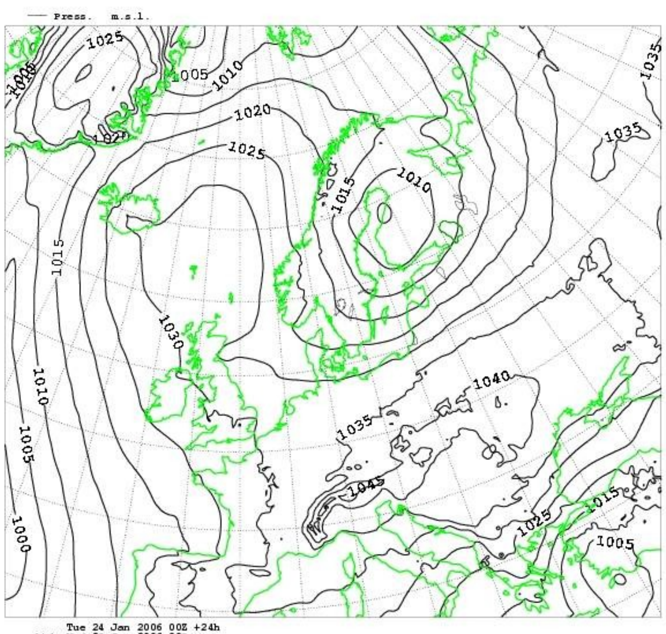
3D-Var

+0 h



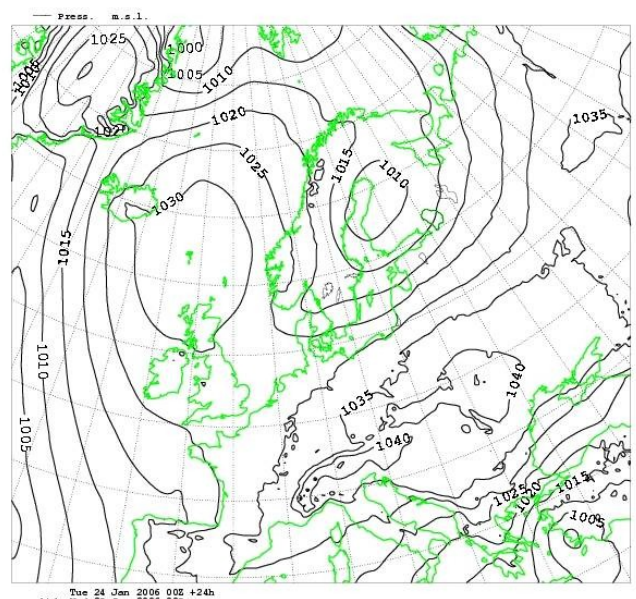
4D-Var

+0 h



3D-Var

+24 h



4D-Var

+24 h

Computer timings

SMHI LINUX-cluster DUNDER – Dual Intel Xeon 3,4 GHz, 2Gb mem/node, Infiniband interconnect

13 nodes (26 proc) were used

Average example (3 Jan 2006 12UTC)

48 h forecast (22 km): 1005 seconds

66 km resolution 4D-Var : 1053 seconds

- 82 iterations (88 simulations)
- 30 min timestep

44 km resolution 4D-Var : 3971 seconds

- 90 iterations (97 simulations)
- 15 min timestep

Control of Lateral Boundary Conditions

(1) Introduce the LBCs at the end of the data assimilation window as assimilation control variables (full model state = double size control vector)

(2) Introduce the adjoints of the Davies LBC relaxation scheme and the time interpolation of the LBCs

(3) Introduce a "smoothing and balancing" constraint for the LBCs into the cost function to be minimized

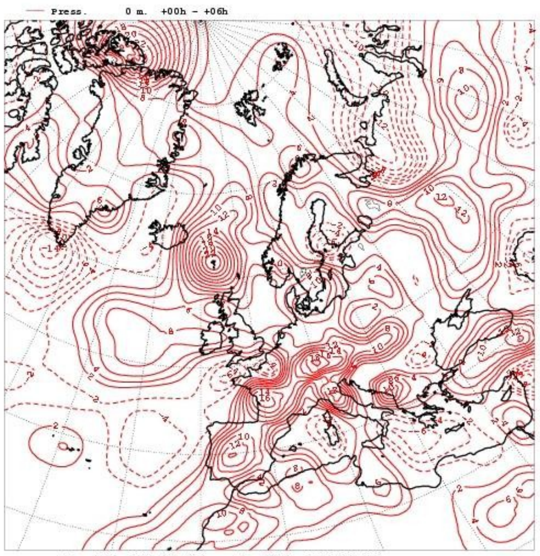
$$J = J_b + J_o + J_c + J_{lbc}$$

where

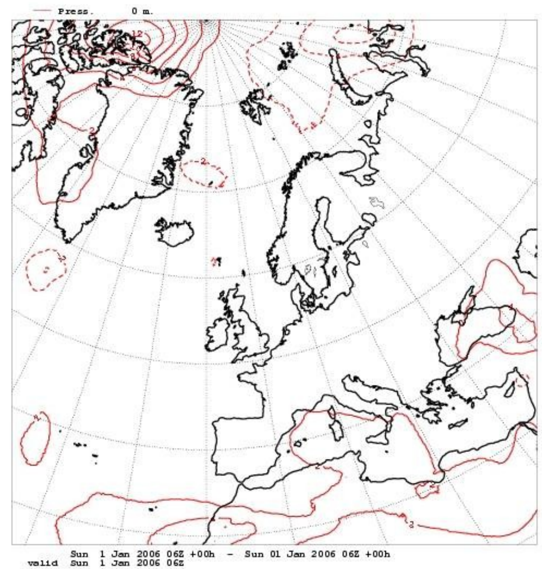
$$J_{lbc} = (X_{lbc} - (X_{lbc})^b)^T \; B^{-1} \; (X_{lbc} - (X_{lbc})^b)$$

and B is identical to B for the background constraint

Control of lateral boundary conditions, example

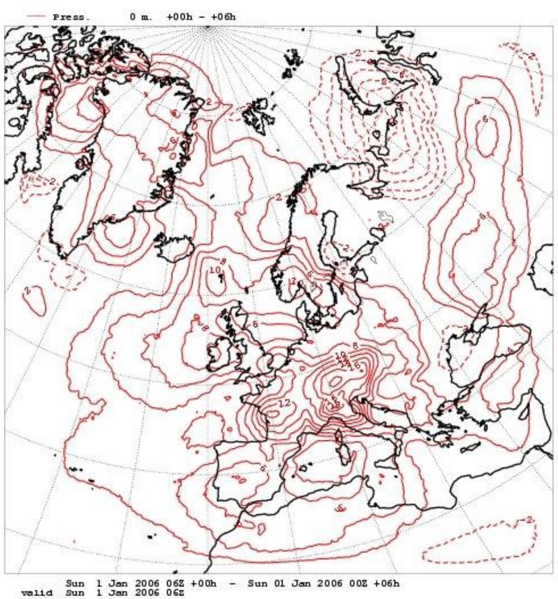


3D-Var incr.



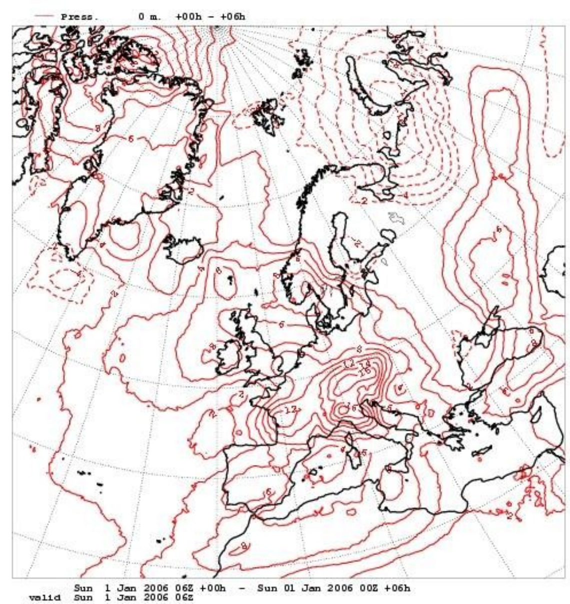
4D-Var diff

CntLBC-NoCNTLBC



4D-Var incr.

No CntLBC



4D-Var incr.

CntLBC

High priority development tasks

1. JC(DFI) (Bjarne JR, Xiaohua)
2. Control LBC (Nils, Sigurdur)
3. Evaluate moist processes (Magnus, Martin S., Per D.)
4. Tuning sigmab/sigmao (NN)
5. Investigate trajectory time resolution (NN)
6. Moisture control variable (Sigurdur)

Concluding remarks

- **HIRLAM 4D-Var is prepared for near real time tests. Can we afford it operationally? Yes!**
- **4D-Var provide significantly improved forecast scores compared to 3D-Var for synoptic scales and “dynamical” forecast variables.**
- **Some minimization convergence problems need to be solved.**
- **We need to look further into the handling of “gravity wave noise” and moist processes.**