Current limited area applications

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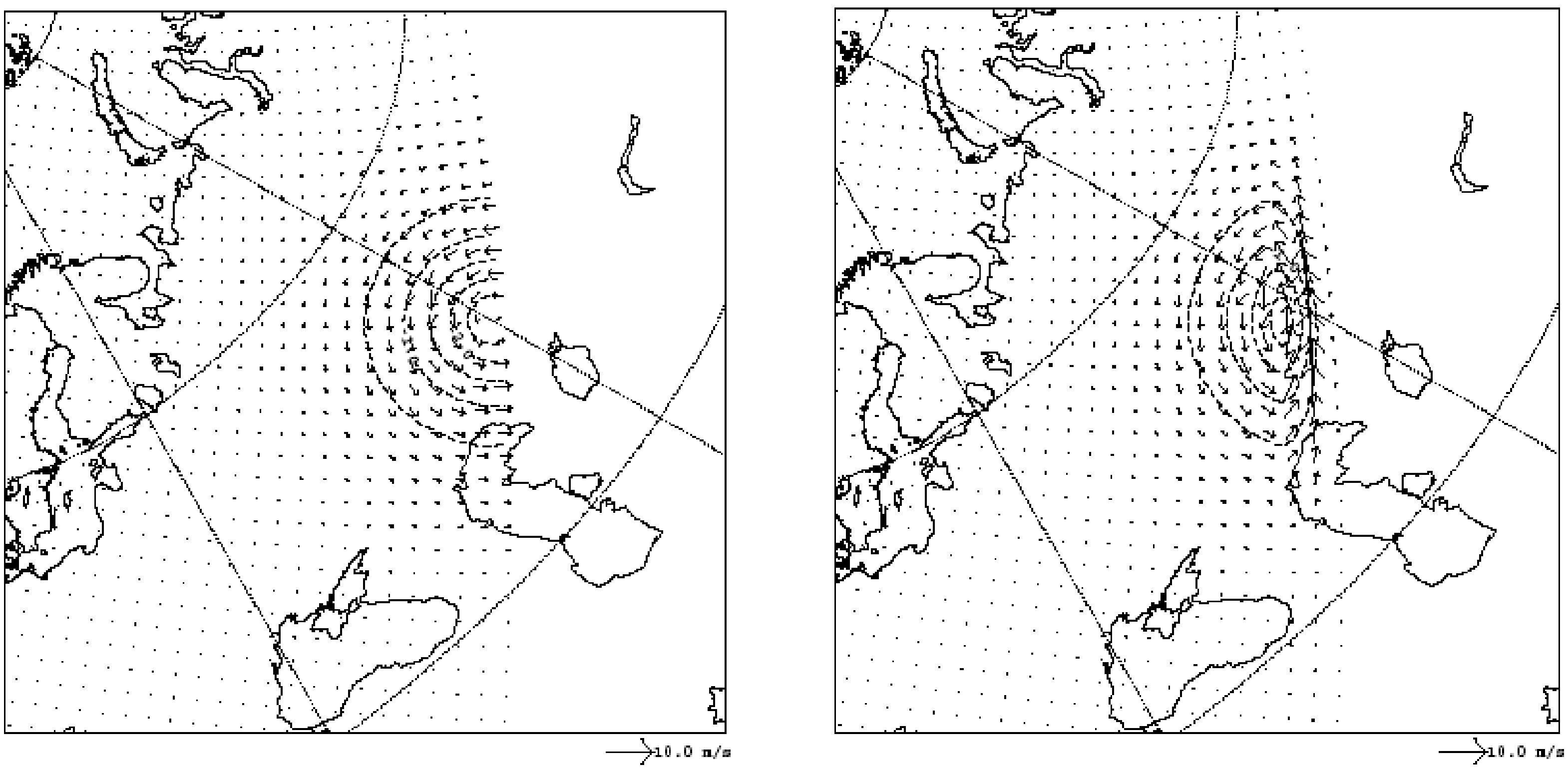
Outline of talk

(contributions from many HIRLAM staff members)

- Specific problems of Limited Area Model (LAM) data assimilation
- Overview of assimilation techniques for LAM
- HIRLAM 3D-Var
- Different strategies for operational implementation
- Further developments of HIRLAM 3D-Var
- HIRLAM 4D-Var – status and development
- Use of remote sensing data in HIRLAM 3D-Var
- Concluding remarks

Specific problems of LAM data assimilation

(1) Do we need to have zero increments on the lateral boundaries?



Single observation experiments with HIRLAM 3D-VAR without and with zero on the lateral boundaries

Specific problems of LAM data assimilation

1. Do we need to have zero increments on the lateral boundaries (Coupling to the larger scale model)
2. How do we handle larger scales – how do we use observations outside the lateral boundaries (Coupling to larger scale model)
3. Short observation cutoff – need for re-analysis cycles
4. The computational problem – can we afford 4D-VAR for nowcasting and short range forecasting
5. The adjustment problem – many mesoscale observing system provide moisture related variables (radar precipitation, satellite clouds, etc). How can we manage to assimilate these variables and keep the information in the forecast?
6. Quite limited staff resources for development and operational applications.

Overview of assimilation techniques for Limited Area Models

Model/group	**Model**	**Resolution**	**Assimilation**
HIRLAM	Hydrostatic	6-55 km 31-40 levels	3D-VAR (4D-VAR soon?)
COSMO	Non-hydrostatic	7-28 km 31-45 levels	Nudging towards observations
ALADIN	Hydrostatic and non-hydrostatic	7-14 km 31-37 levels	Dyn. Adaptation 3D-VAR
UK Met Office	Non-hydrostatic	12 km	3D-VAR + nudging of moisture variables
JMA	Non-hydrostatic	10 km	4D-VAR

The JMA Limited Area Model 4D-Var

- Applied to a 10 km mesoscale model with 20 km increments
- Use of one hour precipitation observations derived from radar as well as surface stations
- 4D-VAR includes moist physics in the adjoint model (large-scale condensation, evaporation of falling precipitation and moist adiabatic adjustment).
- Control of lateral boundary conditions during the assimilation, by adding another “background constraint” valid for the lateral boundary increments at +3 hours.
- 20 minimization iterations

HIRLAM 3D-VAR – background error formulation

Transform the model state increment vector in such a way that the corresponding transform of a model forecast error state vector could be assumed to have a covariance matrix equal to the identity matrix.

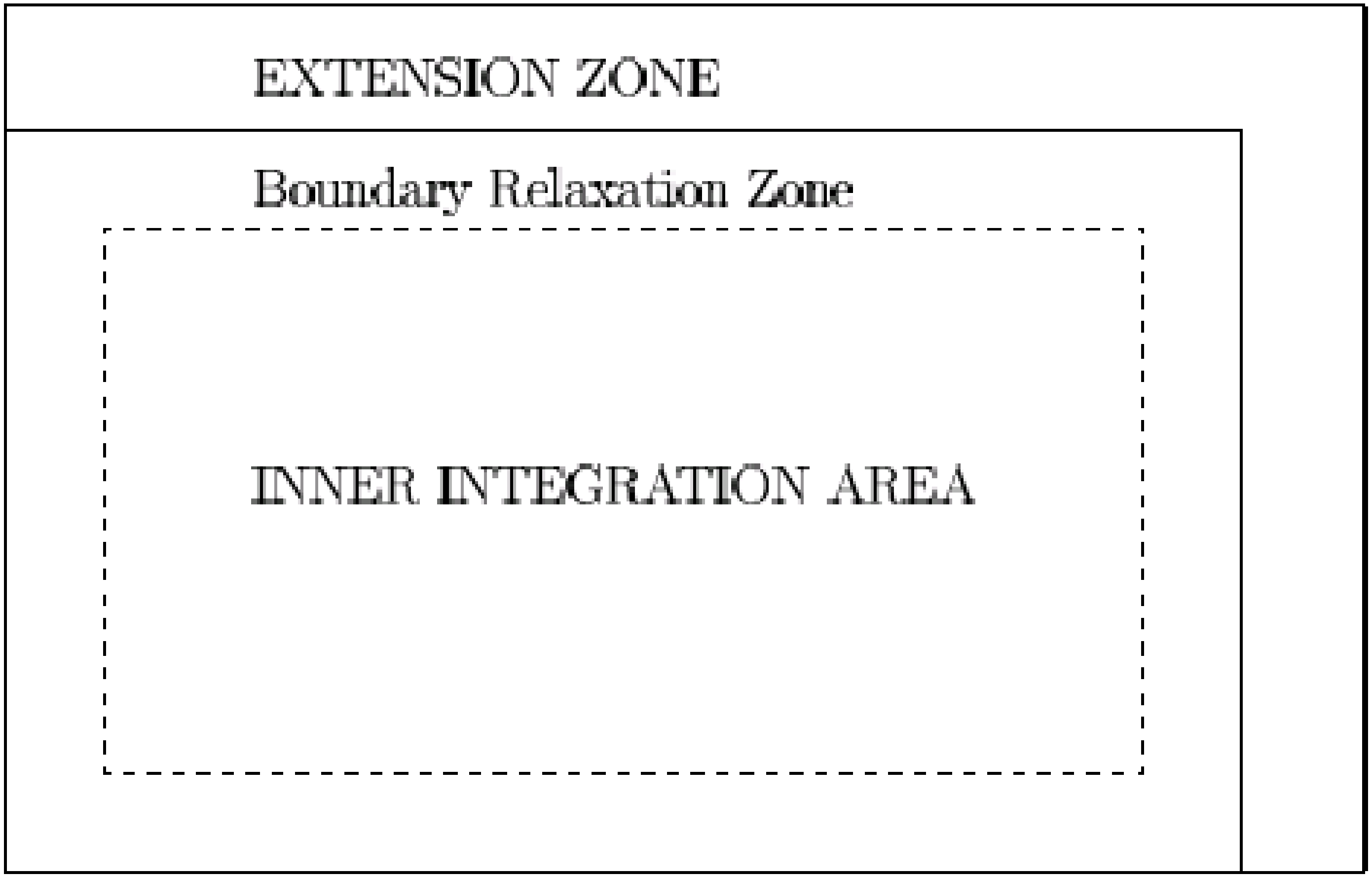
The following series of transforms are applied in the reference HIRLAM 3D-VAR:

1. Normalize with forecast error standard deviations
2. Horizontal spectral transforms (using an extension zone technique)
3. Reducing dependencies between the mass field and the wind field increments by subtracting geostrophic wind increments from the full wind increments
4. Project on eigen-vectors of vertical correlation matrices
5. Normalize with respect to horizontal spectral densities and vertical eigen-values

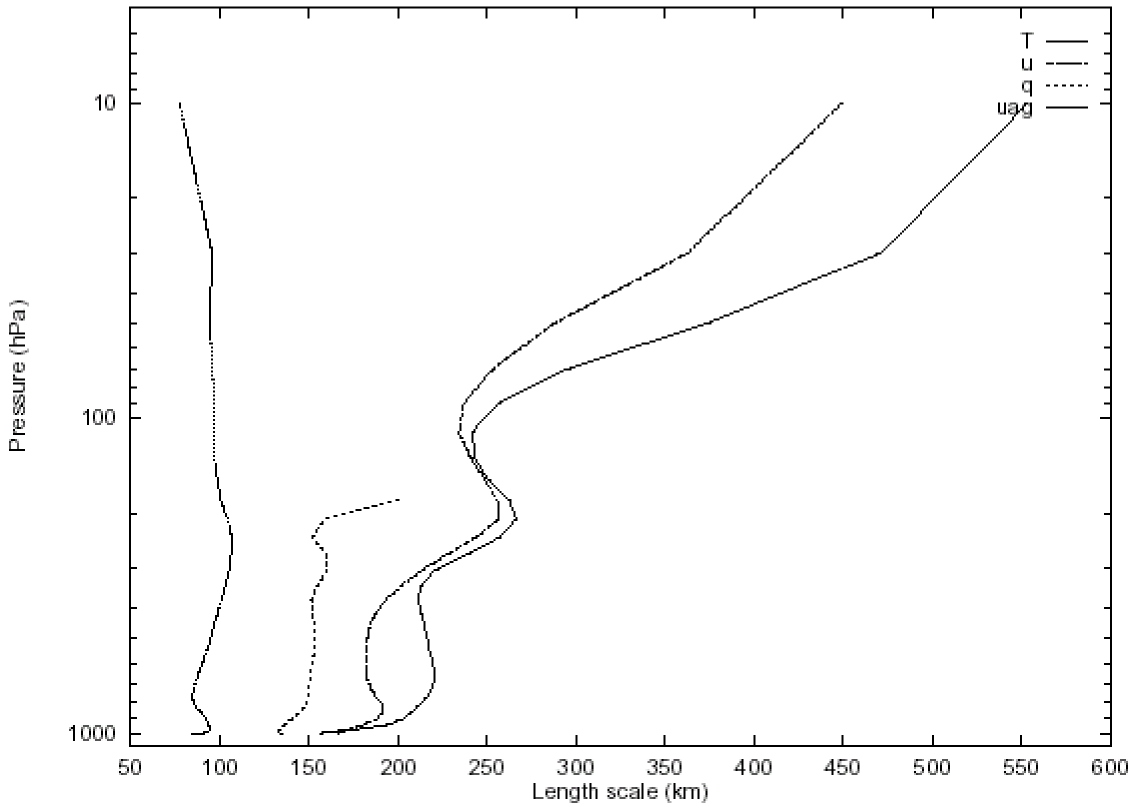
Structure function are non-separable; different horizontal scales at different levels and different vertical scales for different horizontal scales

Forecast error statistics are derived by the NMC-method from differences between 48 h and 24 h forecasts valid at the same time. Forecast error standard deviations are re-scaled.

HIRLAM 3D-Var area extension



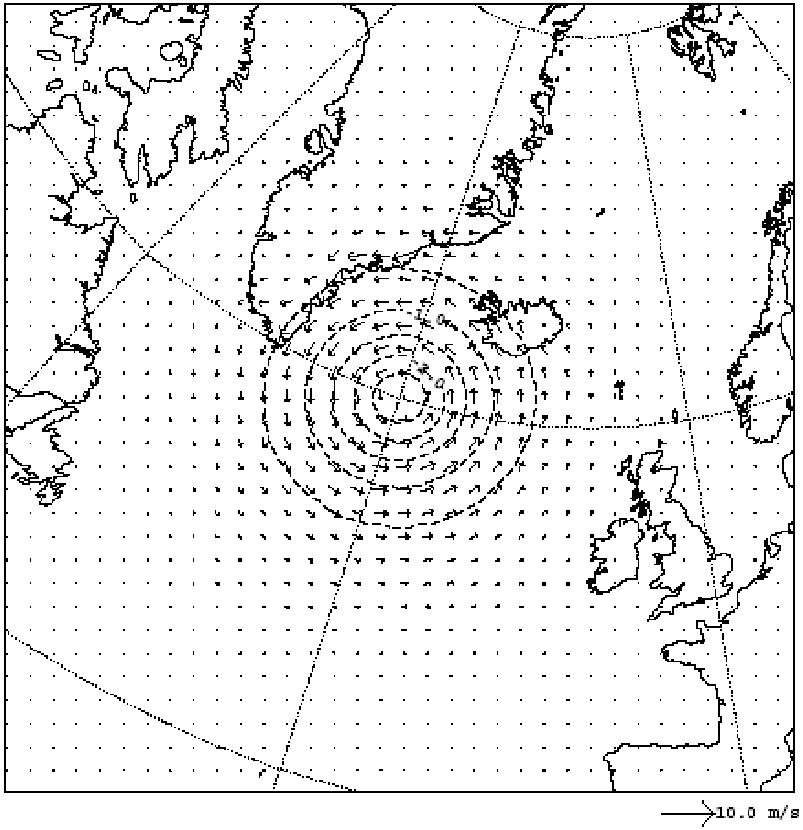
Horizontal scales at different levels in the HIRLAM 3D-VAR, derived by the NMC-method from differences between 48h and 24 h forecasts valid at the same time



HIRLAM 3D-VAR, handling of observations

- Development started from ECMWF OBSPROC software.
- Data screening including data thinning, background check, redundancy check etc.
- Horizontal and vertical interpolations, calculation of surface pressure etc.
- Observation operators for remote sensing data; ATOVS (RTOV X), radar radial winds, ground-based GPS data
- Variational quality control
- Diagnostics of innovation vectors

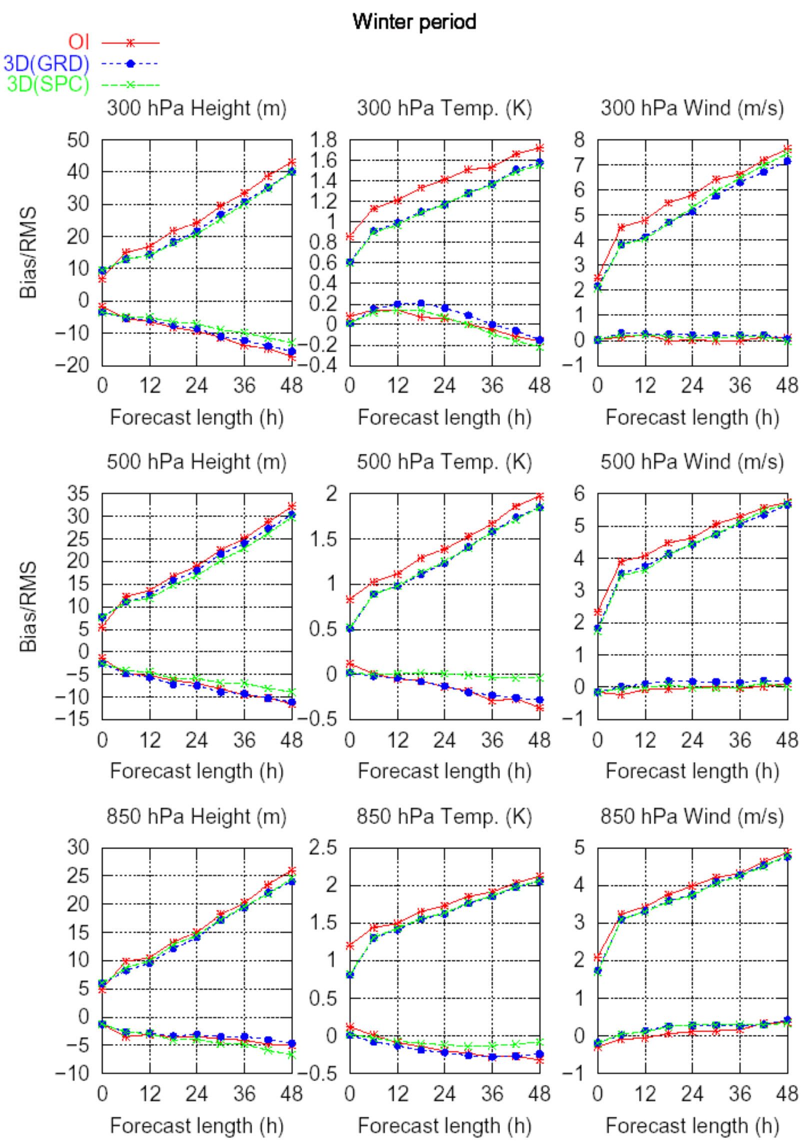
Single temperature observation impact exepriment



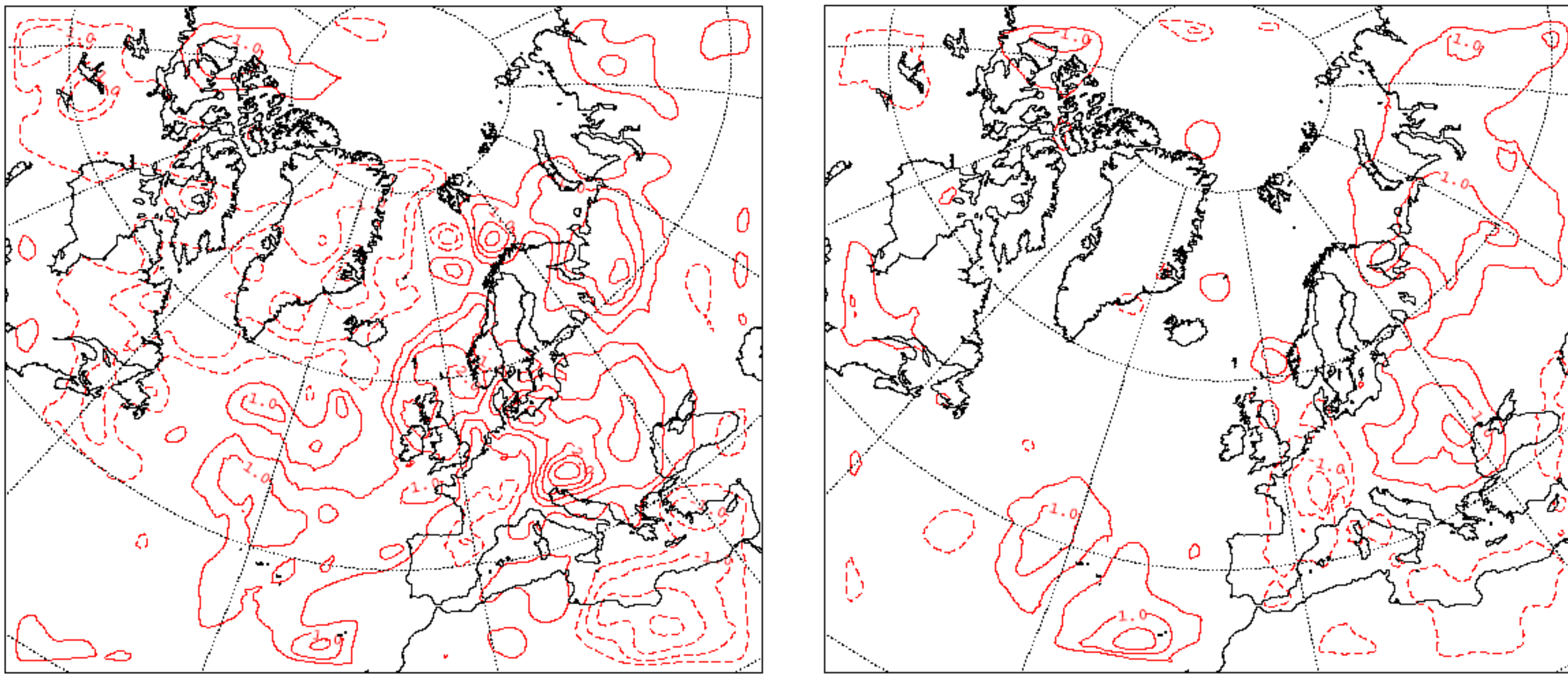
Pre-operational impact studies of 3D-VAR at DMI and SMHI – comparison with OI

- One winter month and one summer month
- 3 experiments: OI with grid-point model, 3D-VAR with grid-point model and 3D-VAR with spectral model
- 44 km grid; 31 levels

Bias and RMS verification scores by comparision with European radiosonde observation



Non-linear normal mode surface pressure initialization increments with OI initial data (left) and 3D-Var initial data (right)

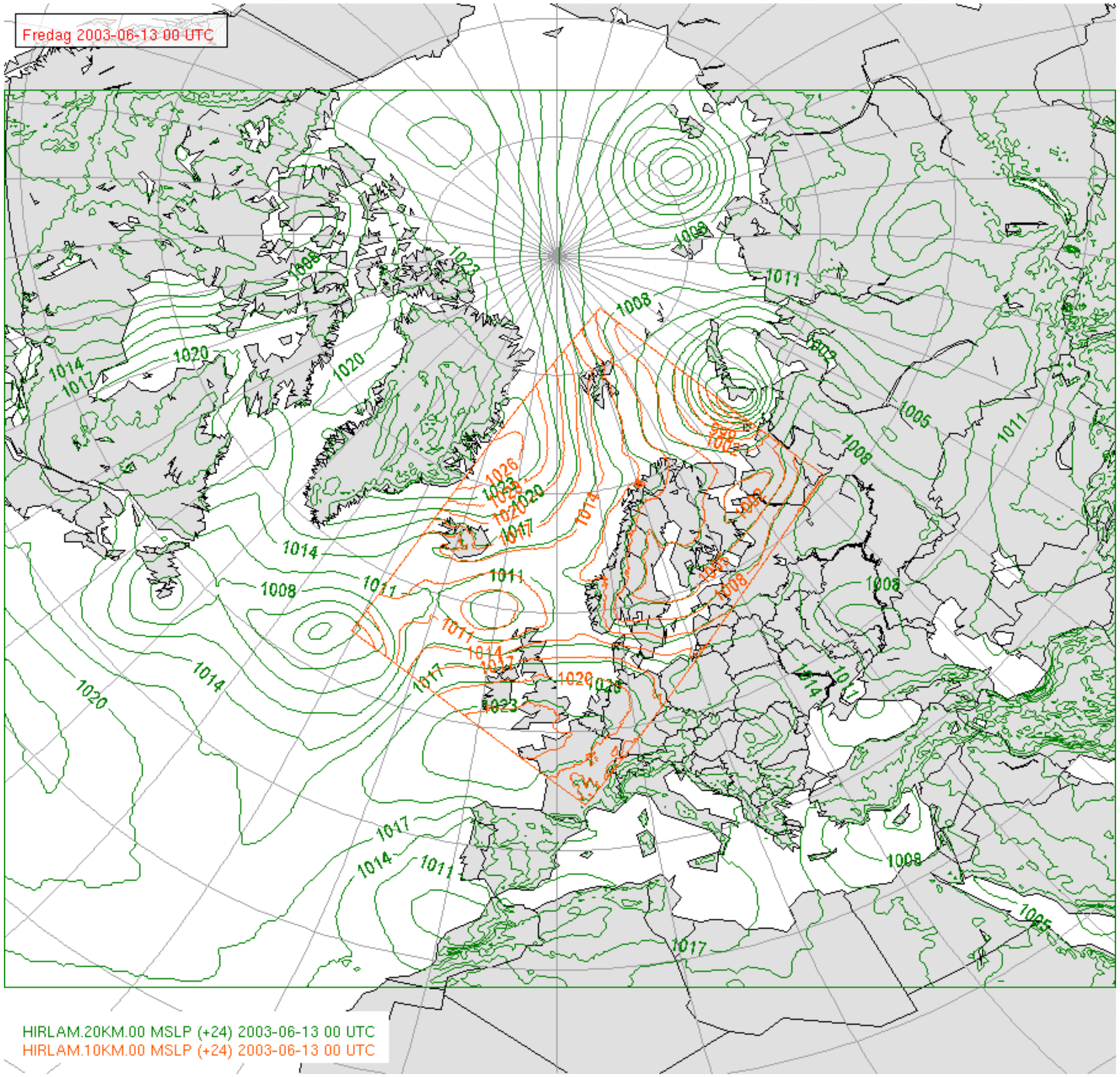


Different strategies for running HIRLAM with 3D-VAR operationally

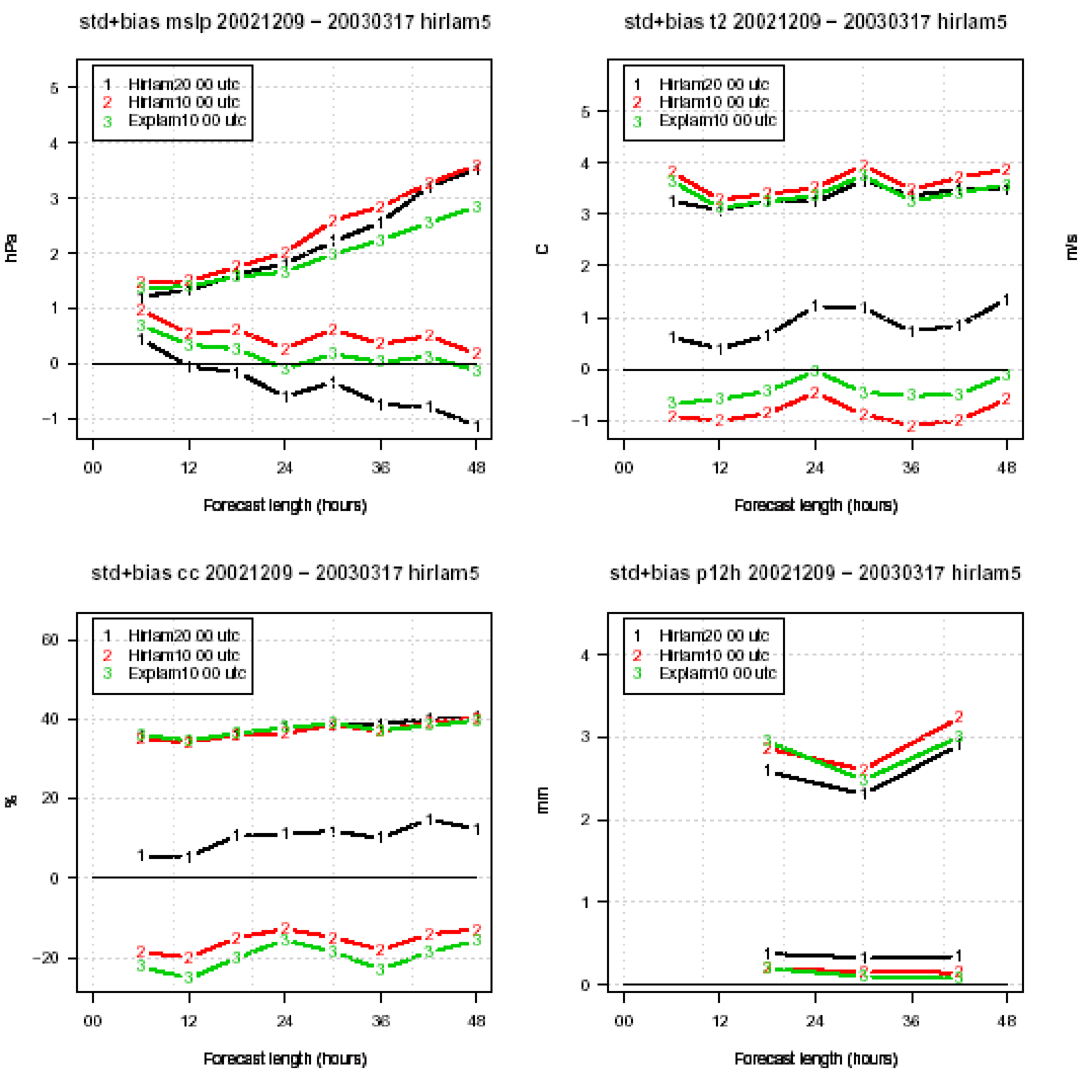
Availability of ECMWF forecasts 4/day in lateral boundary frames has changed the conditions for LAM forecasting!

- **SMHI**: A 44 km HIRLAM on a large area uses ECMWF boundaries and provides boundaries for a 22 km HIRLAM
- **DMI**: A 45 km HIRLAM on a large area uses ECMWF boundaries and is restarted 1/day from ECMWF data. Double nesting down to a 15 km and a 6 km HIRLAM
- **DNMI**: Two model runs, 20 km on a large area and 10 km on a small area, both using ECMWF boundary data. Assimilation only for the 20 km model.

DNMI 20 km and 10 km HIRLAM areas



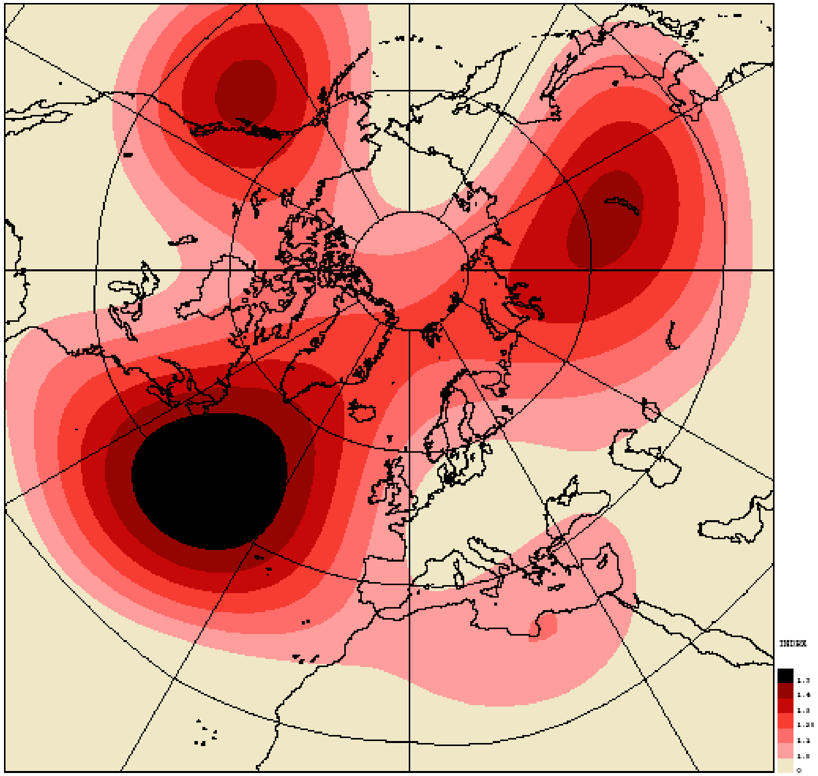
DNMI HIRLAM verification scores: (1) 20 km with ECMWF boundaries, (2) 10 km with 20 km HIRLAM boundaries and (3) 10 km with ECMWF boundaries



Developments of HIRLAM 3D-VAR

- Seasonal variations of forecast error standard deviation - done
- FGAT, first guess at appropriate time - done
- Statistical balance background constraint including moisture balance (Loik Berre) – developed but not yet utilized operationally
- 2D index field to represent horizontal variations of average forecast error standard deviations – ongoing work, based on innovation vector statistics
- Ensemble assimilations to replace the NMC method for estimation of background error statistics – ongoing work

2D index field to represent horizontal variations of forecast error standard deviations



HIRLAM 4D-Var developments

1995-97: Tangent linear and adjoint of the Eulerian spectral adiabatic HIRLAM. Sensitivity experiments. ”Poor man´s 4D-Var”.

1997-98: Tangent linear and adjoints of the full HIRLAM physics.

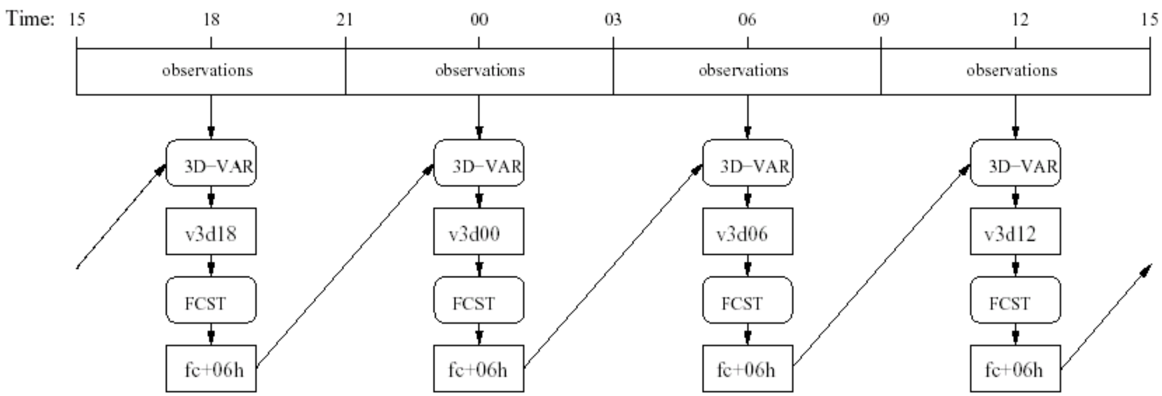
2000: First experiments with ”non-incremental” 4D-Var.

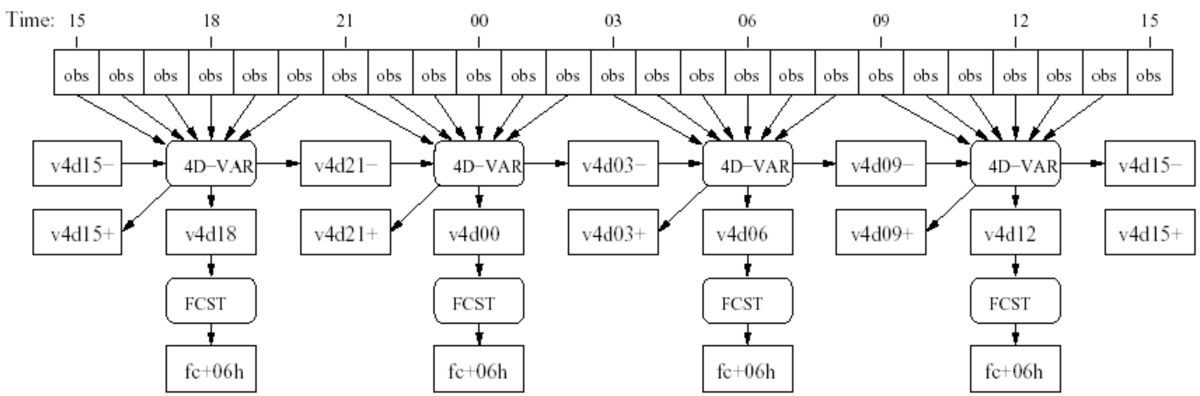
2001-2002: Incremental 4D-Var. Simplified physics packages (Buizza vertical diffusion and Meteo France package).

2002: 4D-Var feasibility study.

2003: Semi-Lagrangian scheme (SETLS), outer loops (spectral or gridpoint HIRLAM) and multi-incremenal minimization.

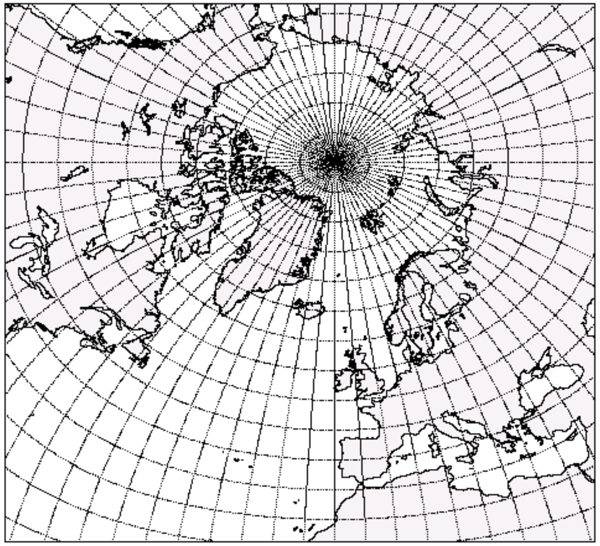
HIRLAM 3D-Var and 4D-Var data flow





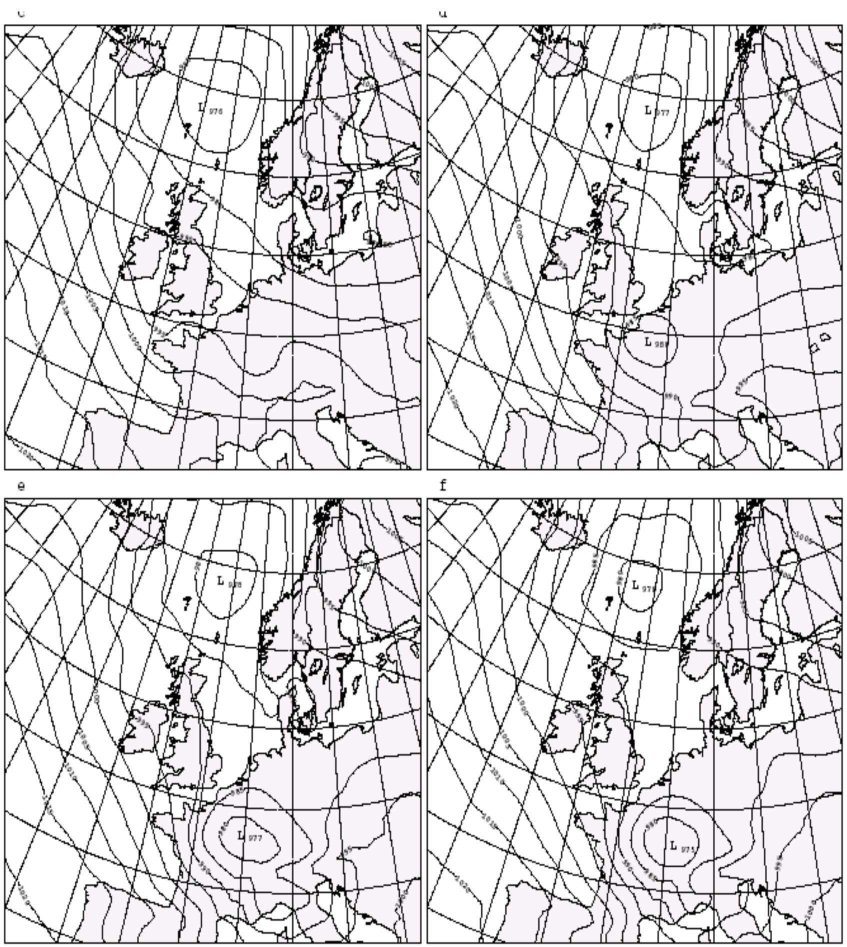
4D-Var feasibility and impact study at DMI

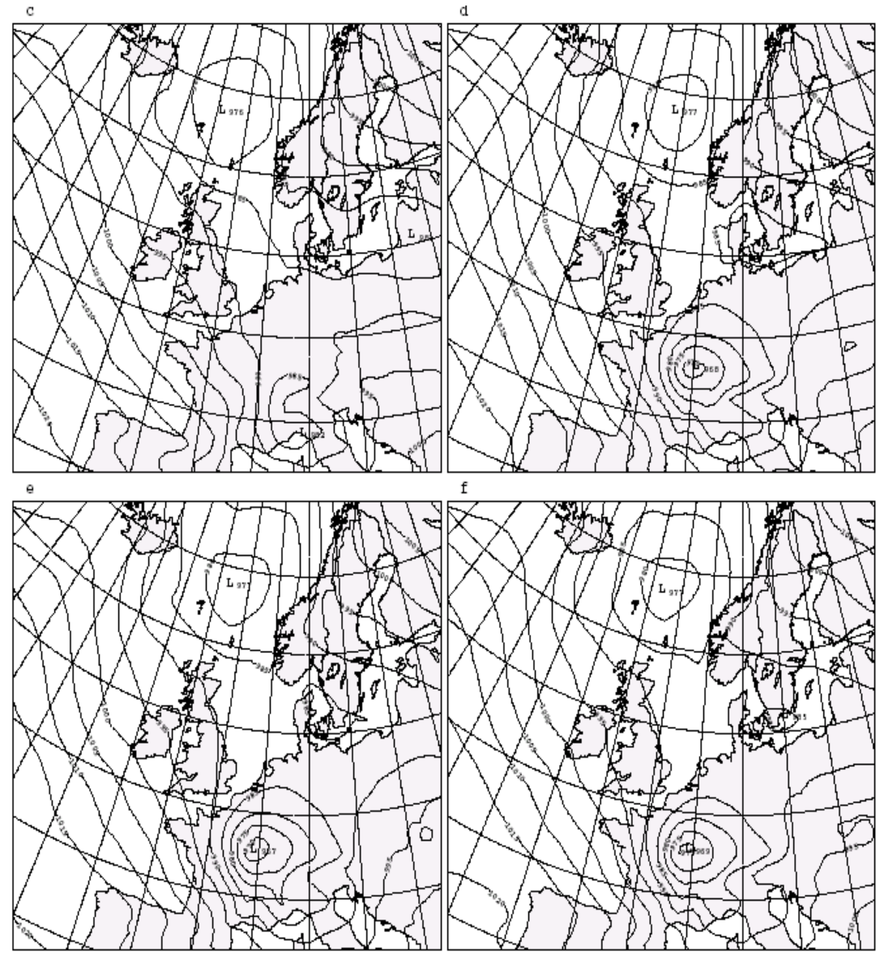
- DMI G area, 202 x 190 x 31 gridpoints, 50 km grid
- 4D-Var minimization with 150 km increments
- Buizza vertical diffusion
- One single outer loop
- Eulerian dynamics
- 6 h assimilation window, 1 h observation windows
- Several test runs: 1-10 Dec 1999, 20-30 Dec 1999, Feb 2002
- Conventional observations + AMSU A for Feb 2002
- On the average neutral impact in comparison with 3D-Var (positive for 06 and 18 UTC, negative for 00 and 12 UTC)



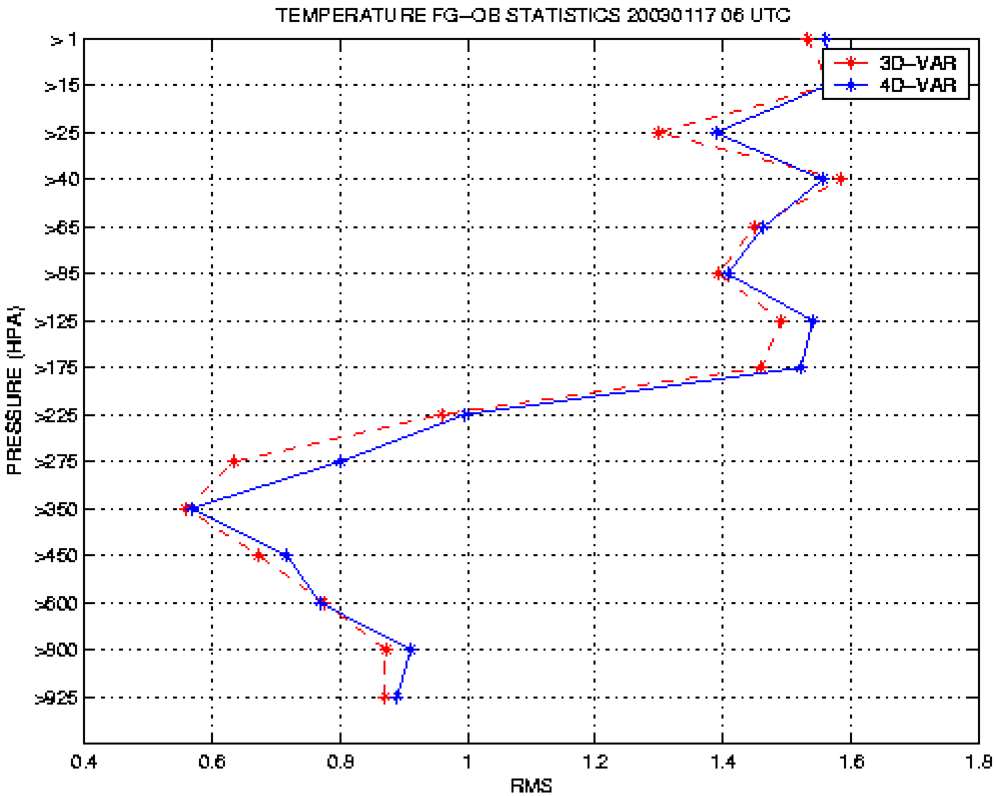
DMI operational G area

HIRLAM forecasts for the French Christmas storm, valid 28 Dec 1999 00UTC. 3D-Var (left), 4D-Var (right). c. 24h, d. 12h, e. 6h, f. analysis





Radiosonde reporting times



ID	UTC	ID	UTC
11240	03	11010	04
06060	04	14015	05
10304	05	10771	05
06476	05	OVYA2	05
16080	05	16044	05
16320	05	16560	05
16429	05	10393	05
10238	05	10618	05
LDWR	06	03502	06
03953	06	02935	06
47122	06	47158	06
11520	06		

Operational HIRLAM 4D-Var (on a PC-cluster at SMHI)?

Computer timings, 438 x 310 x 40 grid-points, 22 km horizontal resolution:

Model/assimilation run	Number of PEs	Wall clock time (s) SGI 3000
Non-linear forecast, +3h, 1.5 min timestep	31	425
4D-Var minimization, 40 km increment, Buizza physics, 20 iterations	20	7474

Computer timing estimates, same geometry, SL scheme, 64 PEs SGI 3000:

Non-linear forecast, +48h, 5 min timestep	20 min
4D-Var minimization, 3 x 20 iterations, 40 km increment	50 min

HIRLAM work on remote sensing data

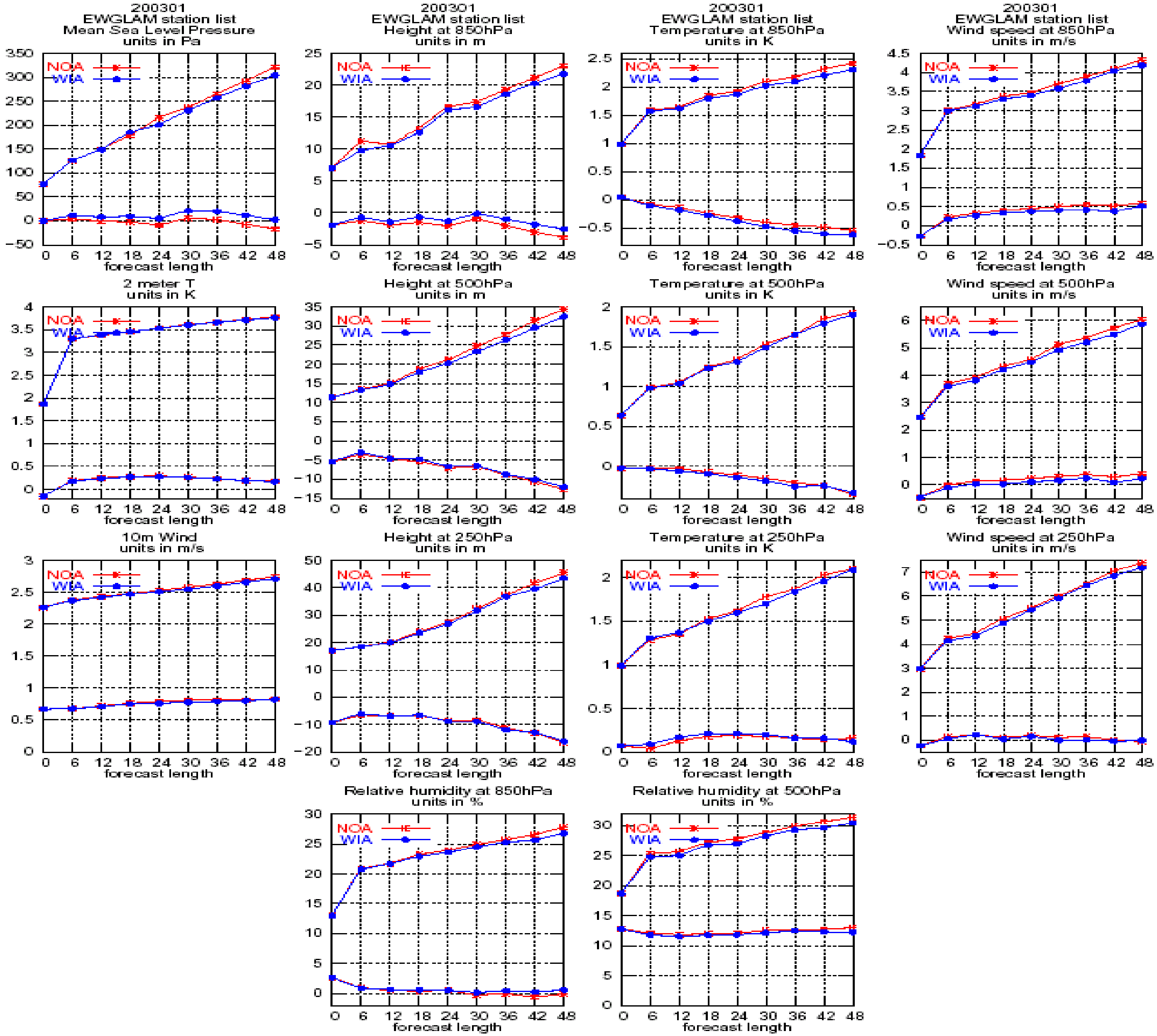
ATOVS data: AMSU-A radiances over sea (data thinning and bias-correction). Operational at DMI and DNMI. EUMETSAT re-transmission of ATOVS data from the Atlantic and Arctic areas. Work with AMSU-A over land and ice, HIRS and AMSU-B.

Radar radial wind vectors and radar VAD profiles: De-aliasing (wind speed ambiguity). Formation of super-observations. Spatial and temporal filters. Development of observation operators taking radar beam bending and spread into account. Impact studies.

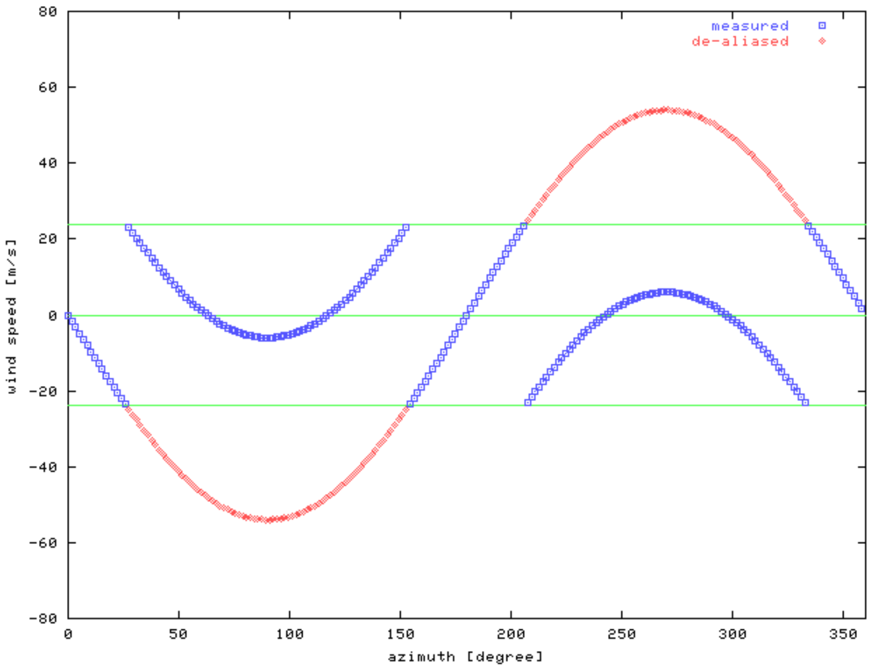
Ground-based GPS data: Assimilation of Zenith Total Delay. Bias correction (individual for each station) and possibly a horizontally correlated error. Impact studies. Use of slant delays.

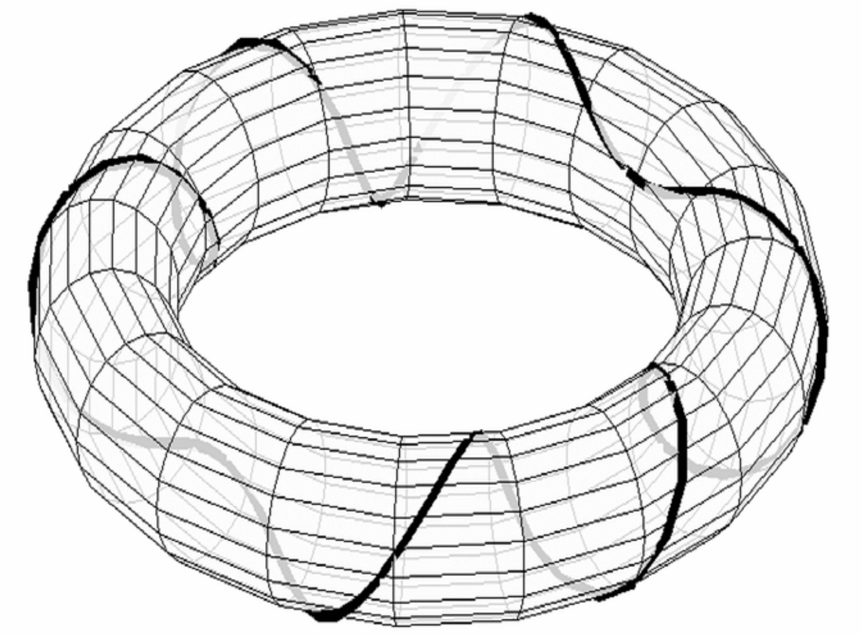
Other data: Scatterometer winds, MODIS/MERIS IWV and WV above clouds, wind profilers.

Forecast verification scores from implementation of AMSU-A radiances at DMI. Impact study for January 2003. NOA without AMSU A; WIA with AMSU A.

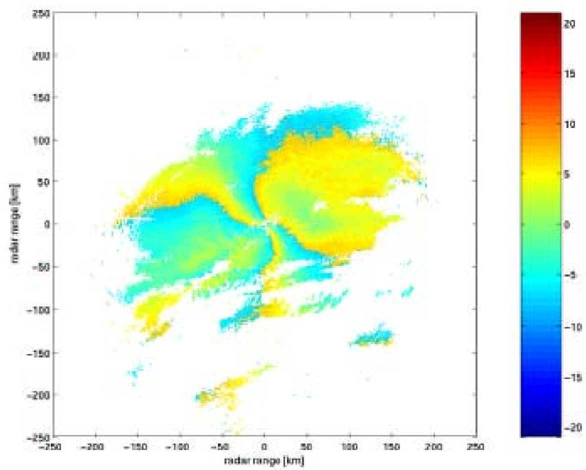


De-aliasing of radar radial winds

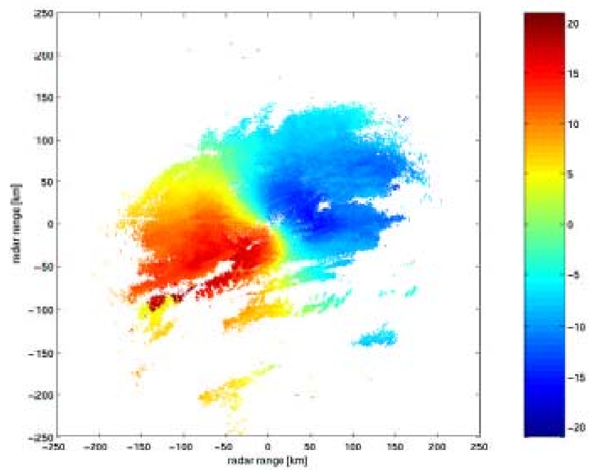




Radar wind dealiasing



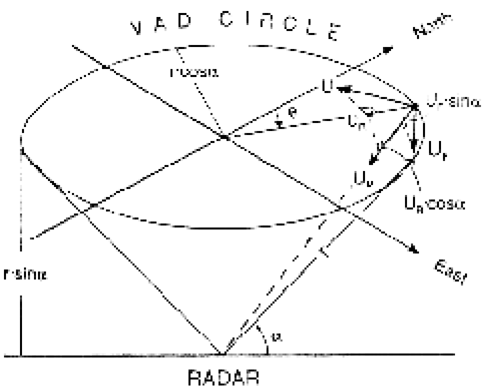
Aliased

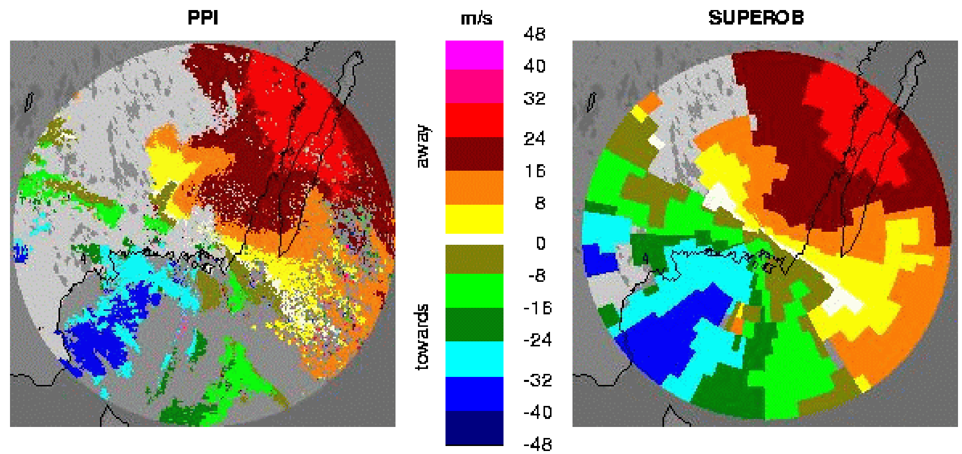


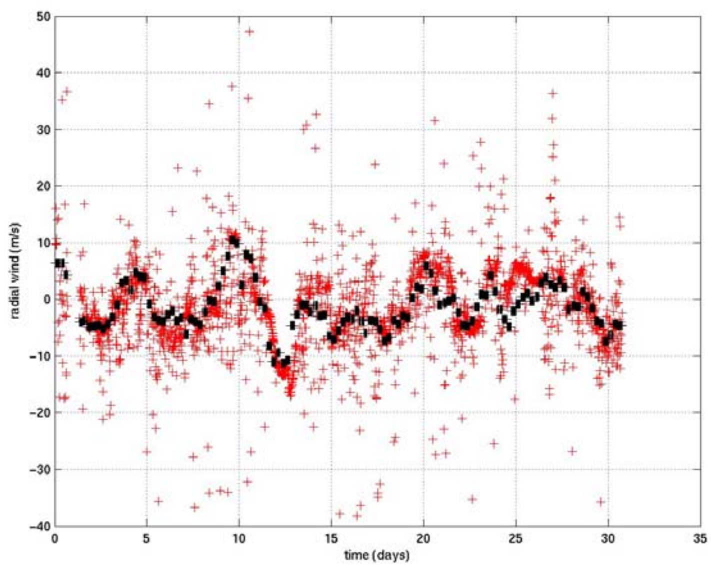
De-aliased

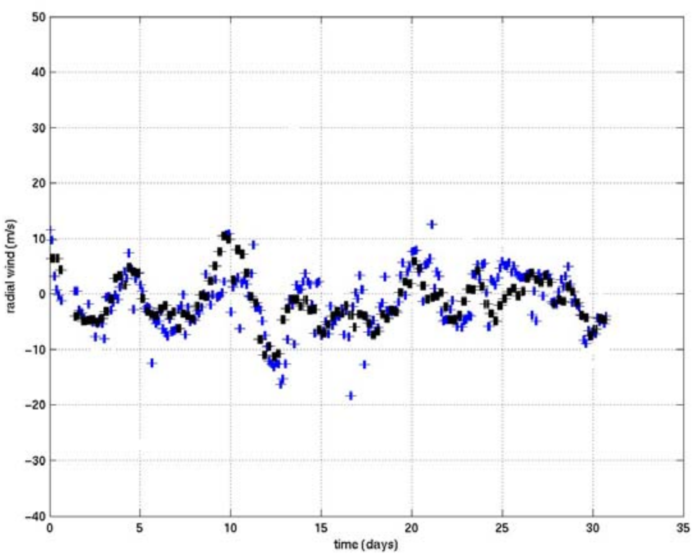
	SMHI (03)	Sigmet (91)
# obs	388147	
max v	35.63 m/s	
alias v	7.55 m/s	
# false	100	17205
Time	218 s	32 s

Filtering

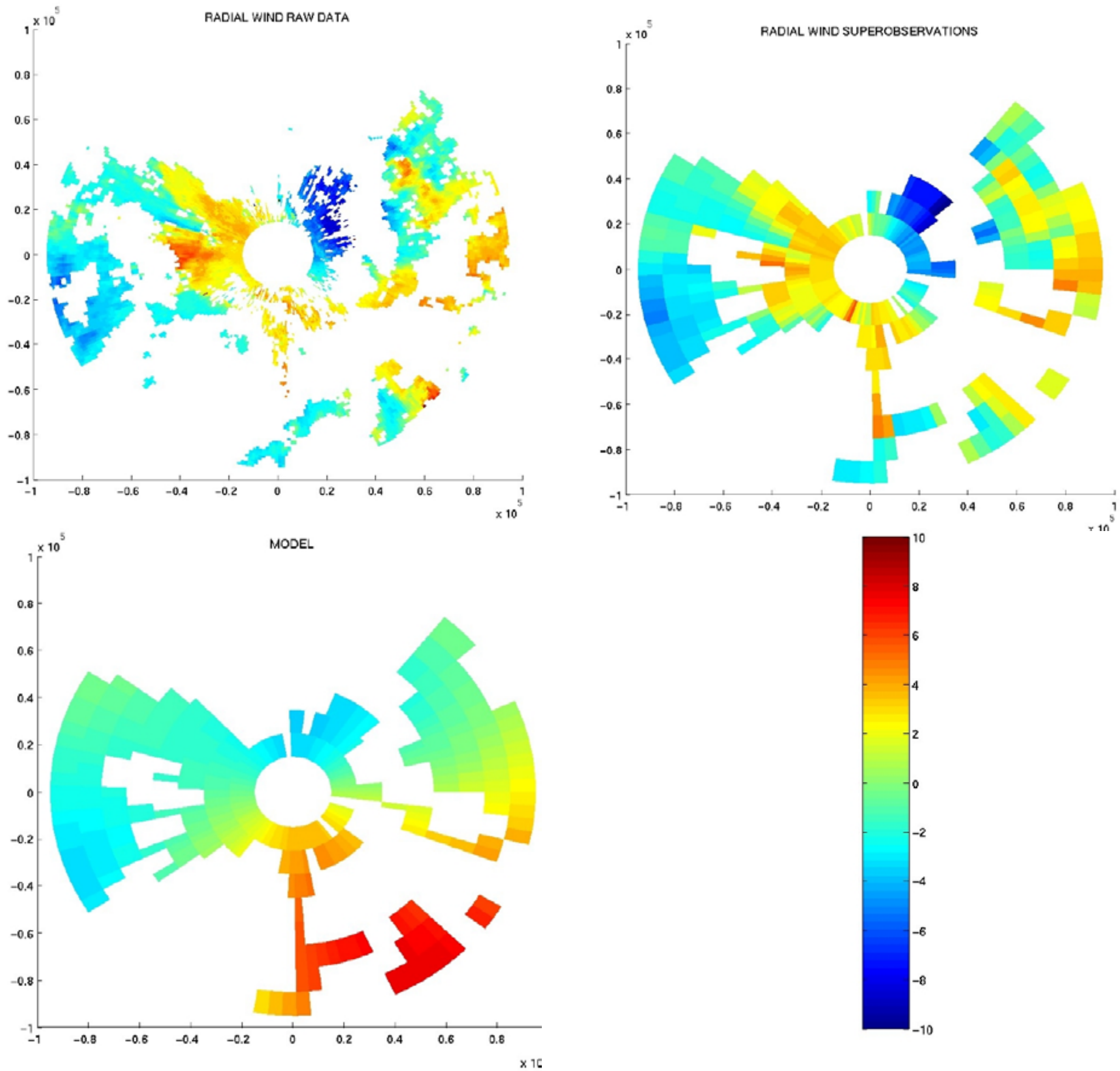

V A D C I R C L E
North
East
RADAR


PPI
m/s
SUPEROB
away
towards
48
40
32
24
16
8
0
-8
-16
-24
-32
-40
-48

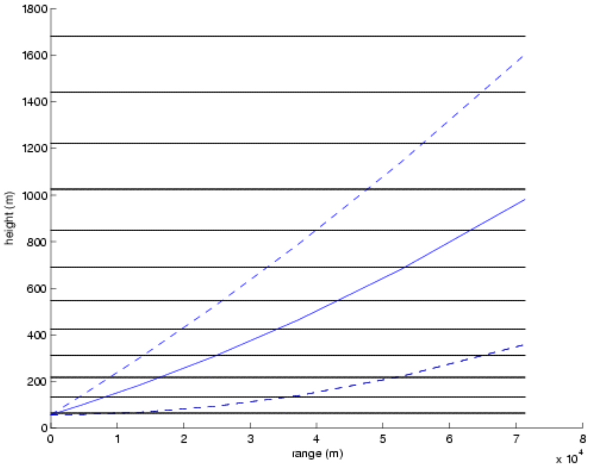

radial wind (m/s)
time (days)


radial wind (m/s)
time (days)

Horizontal filtering



Radial wind observation operator (broadening)

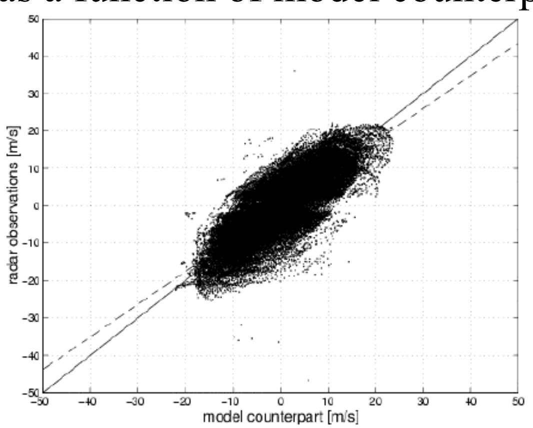


Broadening of radar pulse taken into account in observation operator through Gaussian weight function:

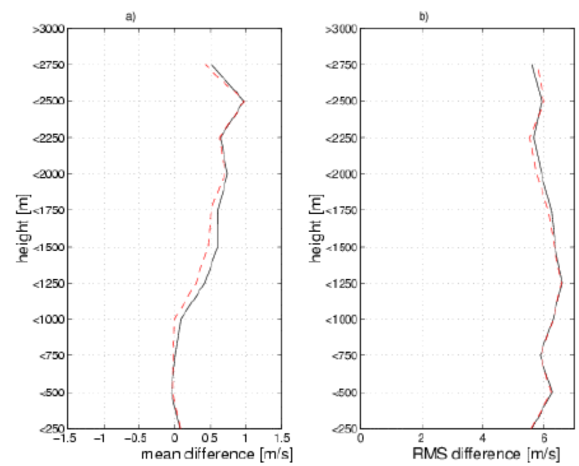
$$w = \frac{1}{2\pi} \exp(-(\frac{z - z_0}{\kappa})^2),$$

κ - range dependent response function

Scatter diagram of radial wind superobservations as a function of model counterpart.



Observation fit statistics



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Bending of radar pulse

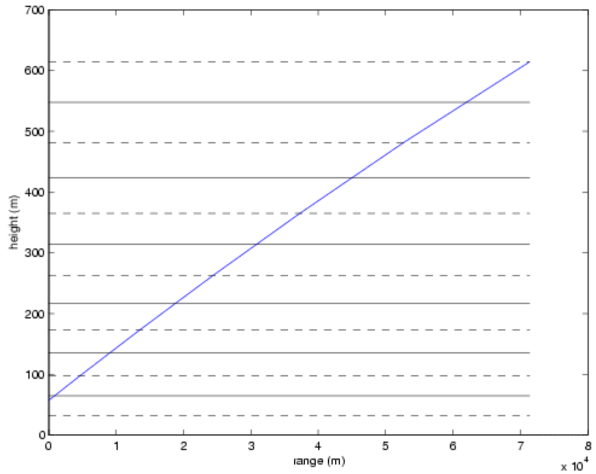
Snell's law:

$$n_i \sin\alpha_i = n_r \sin\alpha_r$$

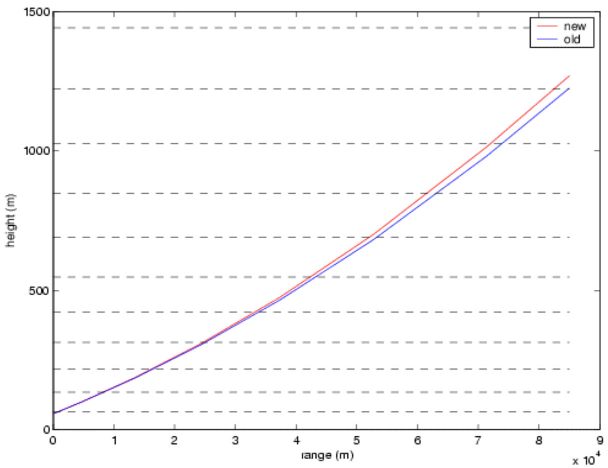
With α_i (incidence angle) known and n (refractive index) calculated from model state:

$$n = (\frac{77.6}{T}(p + 4810\frac{e}{T})) \times 10^{-6} + 1,$$

$$e = \frac{qp}{0.622}$$



Comparison of pulse propagation path for a particular case: Old 4/3 earth radius path approx. vs new path based on Snell's law



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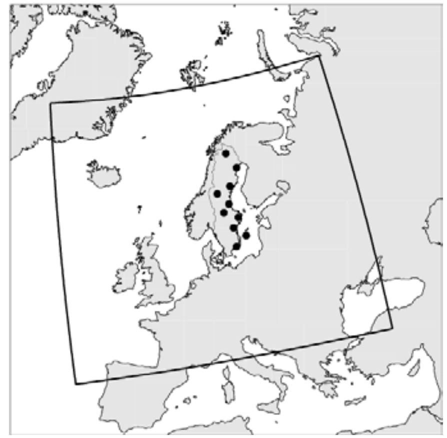
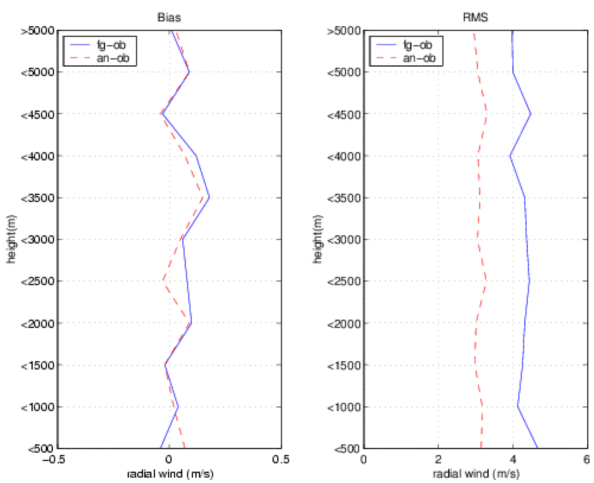
Ten-day assimilation experiment: 1-10 December, 1999

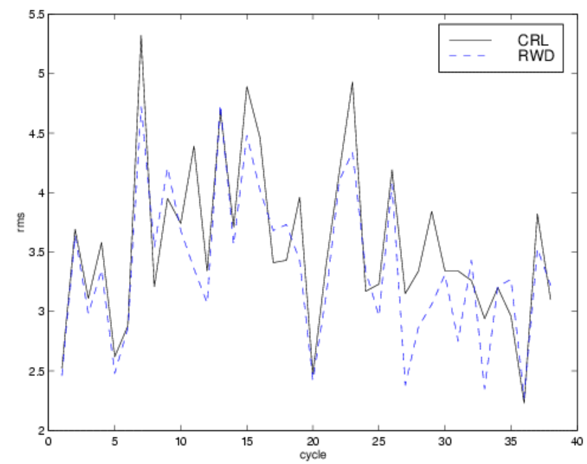
Integration area
and radar sites



Observation fit statistics



Verification of time-series
of +24 h wind forecasts
(against observations)



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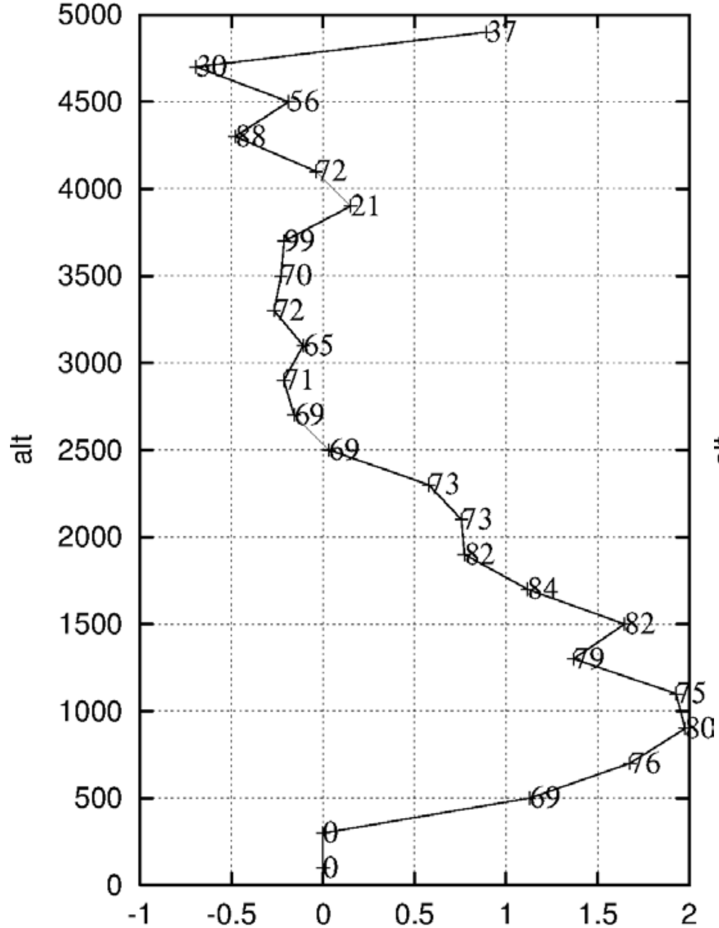
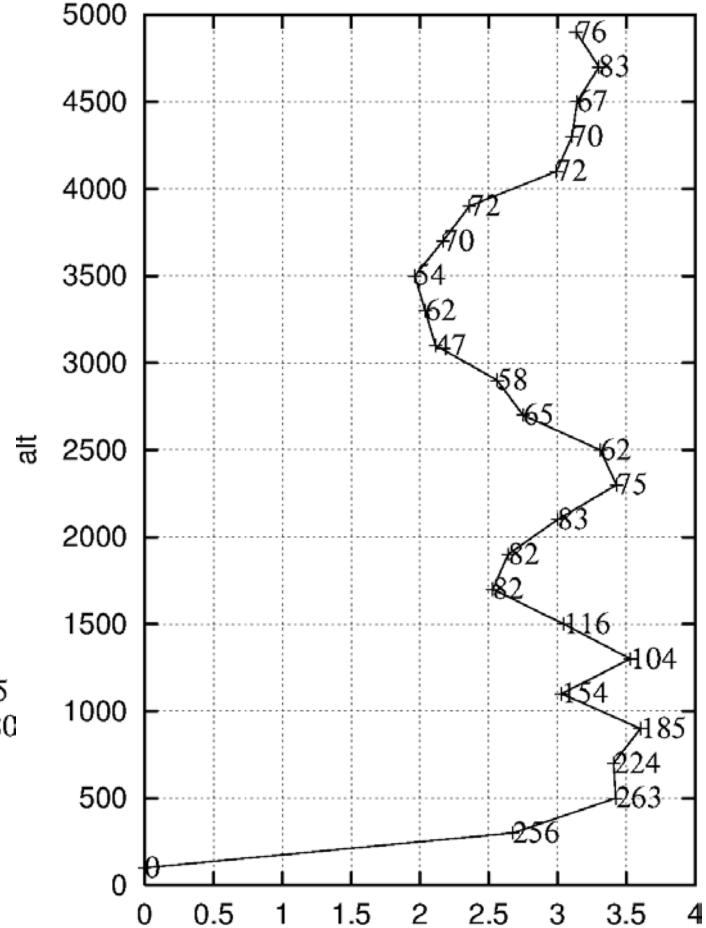
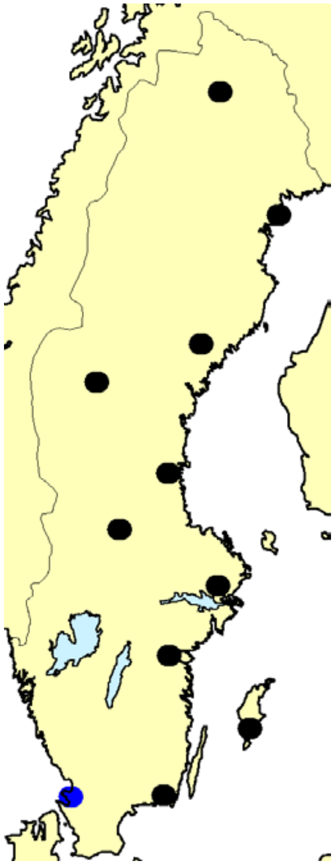
Results from pre-operational monitoring of VAD-profiles







Assimilation of ground-based GPS data

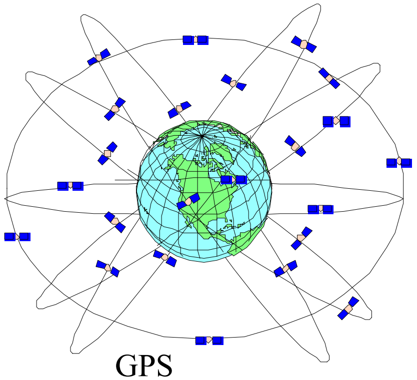
"One person's noise is another person's signal"

Advantages:

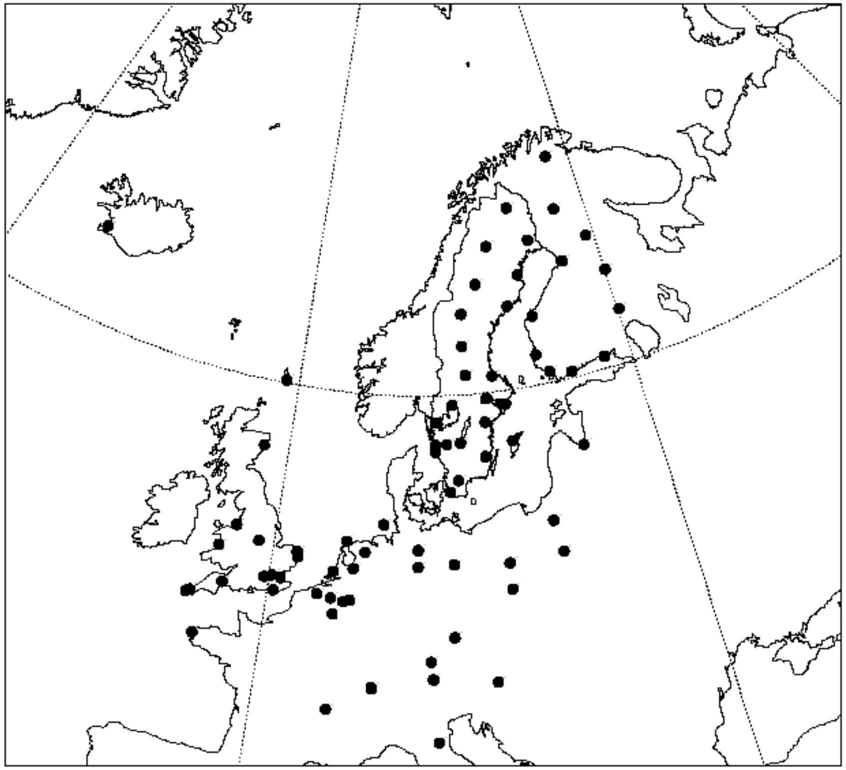
- High resolution
- 55 to 60 stations (in Sweden) every 15 minutes
- All weather, all the time
- Very cheap

Disadvantages:

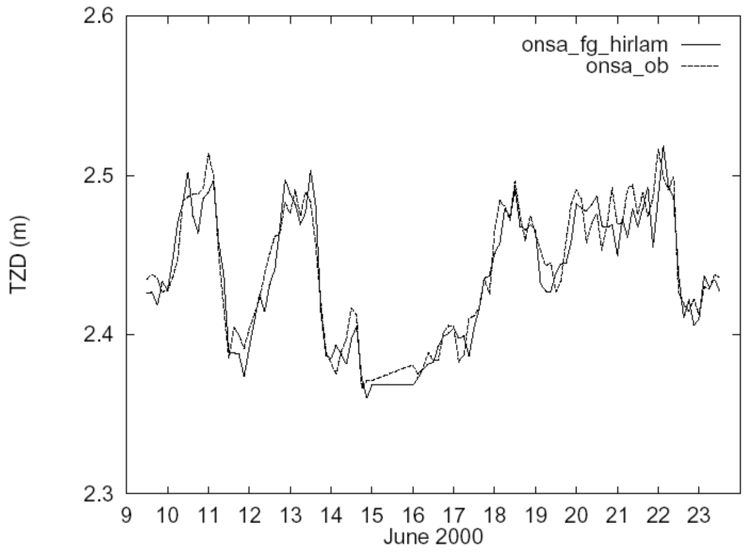
- Essentially only Integrated Water Vapour
- Possible biases and spatially correlated errors



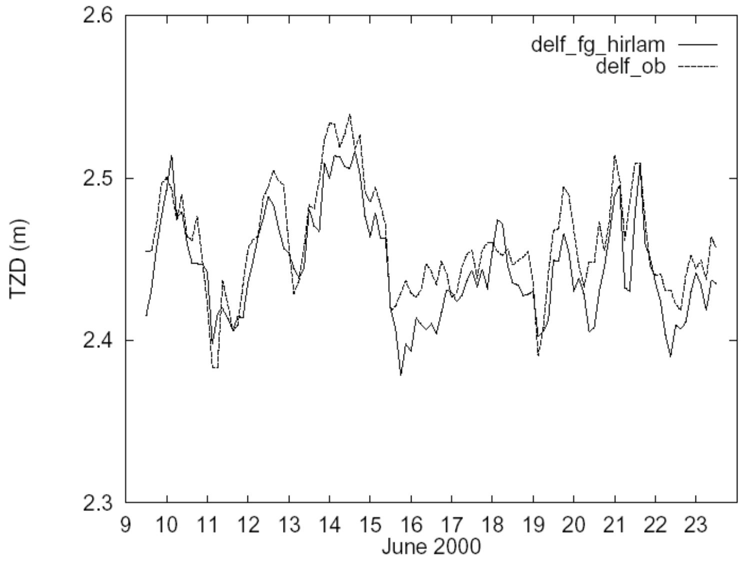
Example of an early (June 2000) GPS station network – processed by Onsala Space observatory



HIRLAM background GPS Zenith Total Delay (ZTD) compared with observations from Onsala and Delft

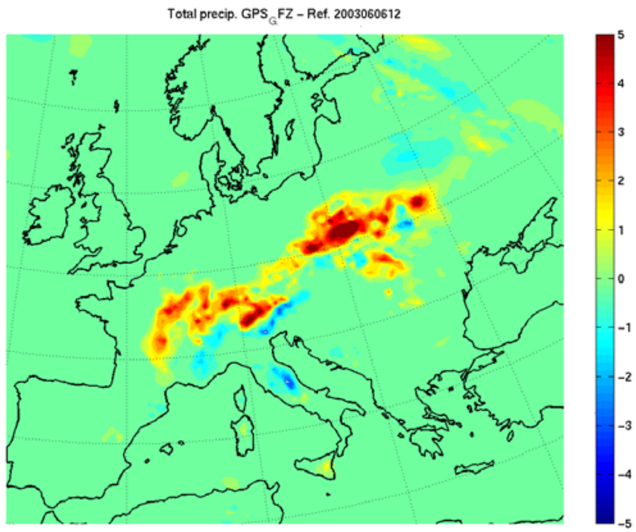


Onsala – no obvious bias problem

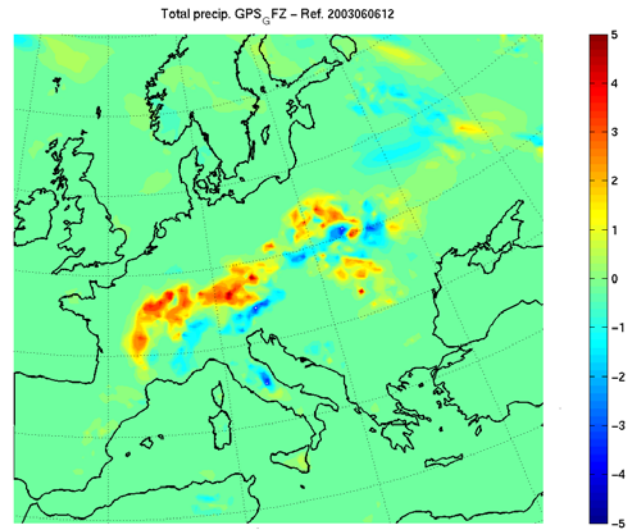


Delft – bias problem !!

Precipitation forecasts 0 - 6h with and without application of bias reduction scheme for GPS ZTD observations



Without bias reduction



With bias reduction

Concluding remarks

- HIRLAM 3D-Var is operational in several HIRLAM countries. This is an important step forward for operational NWP and, for example, for the use of remote sensing data.
- HIRLAM 4D-Var is (almost) prepared for pre-operational tests. Can we afford it operationally?
- The optimal scenario for application of LAM in Europe has to be studied more carefully (Can we use ECMWF boundaries all the way down to mesoscale models with a few km resolution?)

Challenges for the (remote?) future

- Operational 4D-Var on a computer that a small weather service can afford
- Use of mesoscale moisture related observations, for example, radar reflectivities
- 4D-Var for nowcasting and very short range forecasting with a NWP model at the km-scale