HARMONIE UPPER-AIR DATA ASSIMILATION

BACKGROUND ERROR STATSTICS AND METHODOLOGIES

LACE Data Assimilation Working Days
24-26 September, 2014, Zagreb, Croatia

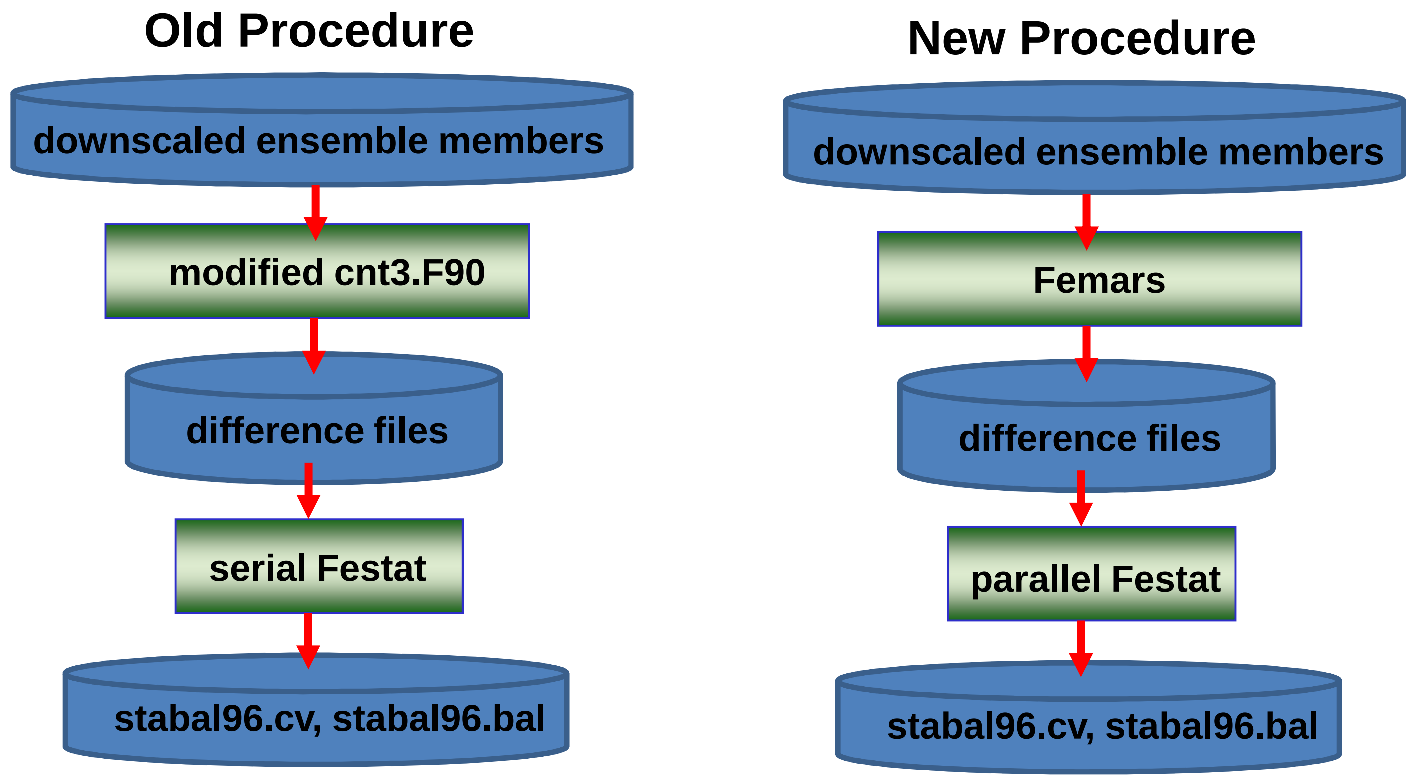
Magnus Lindskog, Roger, Jelena, Ulf, Malte, Jan, Sibbo,
Carlos, Nils, Tomas, Gert-Jan, Heiner and other HIRLAM colleagues

Structure

- Introduction
- Background error statistics
  - Integrated system for generation of statistics
  - Festat
  - Ensemble Data Assimilation
  - Spin-up
- Methodologies for data assimilation
  - 4D-Var
  - Method for Assimilation of cloud information
  - Handling of phase/alignment errors
  - Large scale information from host model
- Plans towards one unified framework
- Summary

Introduction

HARMONIE approach for generating background error statistics:
Background error statistics is calculated from differences of HARMONIE 6h forecasts, started from analyses belonging to the ECMWF ensemble data assimilation system. Lateral boundary conditions are taken from the corresponding ECMWF forecasts. Recently procedure streamlined and system technically improved, Work on analyzing spin-up issues and on introduction of HARMONIE EDA.



Data assimilation methodologies:
Several new methodologies have been developed with promising results. The challenge will be to efficiently combine them.

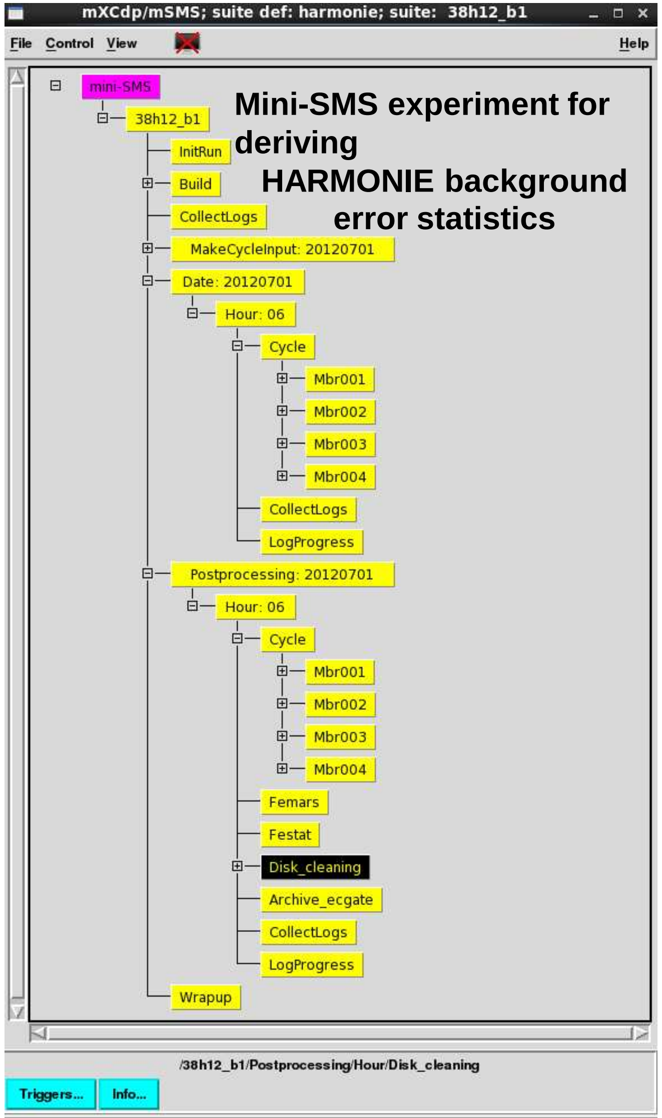
Integrated system for generation of statistics

SMHI

in cy38h1.2

https://hirlam.org/trac/wiki/HarmonieSystemDocumentation/Structurefunctions_ensys

- Downscaled forecasts for Mbr001-Mbr004 (Jan, July 2012 and at 00, 12 UTC)
- Femars produces difference files of +6h forecasts, 4 per forecasting Date/time: Mbr001-Mbr002, Mbr002-Mbr003, Mbr003-Mbr004. These are callled ensdiff_YYYYMMDDHH_00$fclen_001, .., ensdiff_YYYYMMDDHH_00$fclen_004 and are stored in ec:/harmonie/$uid/$exp/femars
- Festat (parallel) is run for the last Date/time of the experiment (DTGEND). It reads in all difference files from the experiment (in ec:/harmonie/$uid/$exp/femars) and produces background error statistics files: c2a:$TEMP/hm_home/$exp/archive/extract/ stab_$exp_2012070106_$ncase.bal.gz, stab_$exp_2012070106_$ncase.cv.gz,)



Festat

SMHI

Old Serial Festat

stat hor. f-plane balance between geop. and vort.

$$\phi^z_{mn} = \beta_z(m,n)\,\zeta^z_{mn}, \qquad \beta_z(m,n) = \frac{\mathrm{cov}(\phi^z_{mn}, \zeta^z_{mn})}{\mathrm{var}(\zeta^z_{mn})} = \frac{\overline{\phi^z_{mn}\zeta^{z*}_{mn}}}{\overline{\zeta^z_{mn}\zeta^{z*}_{mn}}}.$$

New Parallel Festat

analytical hor. f-plane balance between geop and vort.

$$\Delta\phi(\mathbf{h}, z) = f_0\zeta(\mathbf{h}, z) \Leftrightarrow (\Delta\phi)^z_{mn} = f_0\zeta^z_{mn} \Leftrightarrow \phi^z_{mn} = \frac{f_0}{\Delta_{mn}}\zeta^z_{mn}, \qquad \Delta_{mn} = -\left(2\pi\frac{k^*}{N_s}\right)^2.$$

Results from Comparison

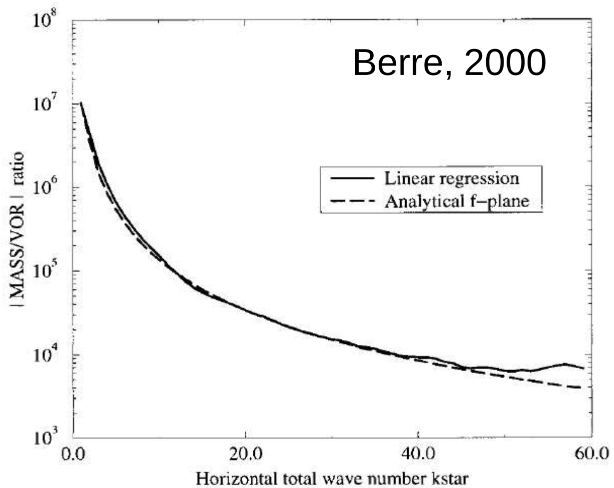
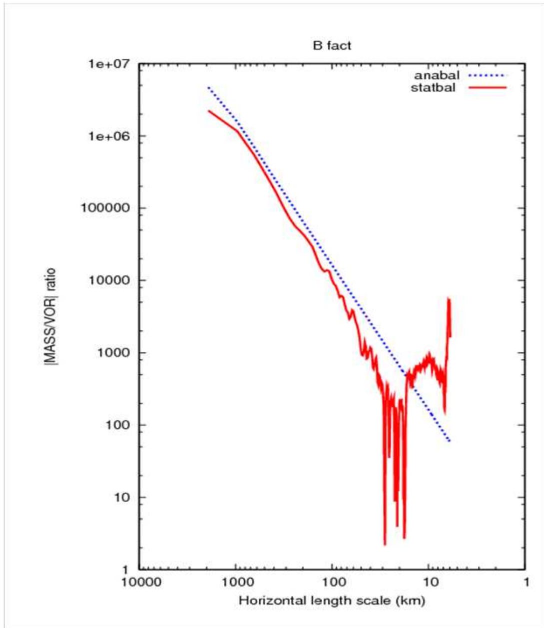
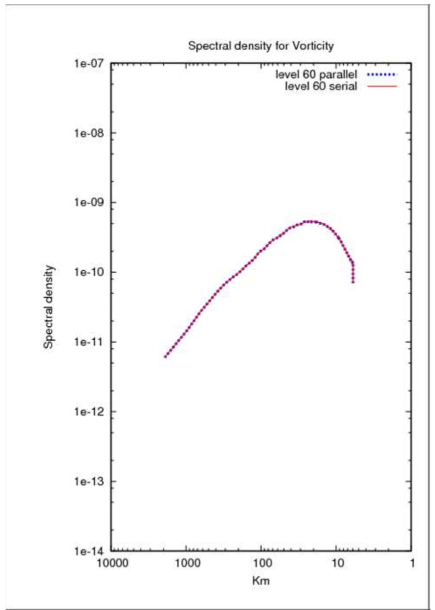


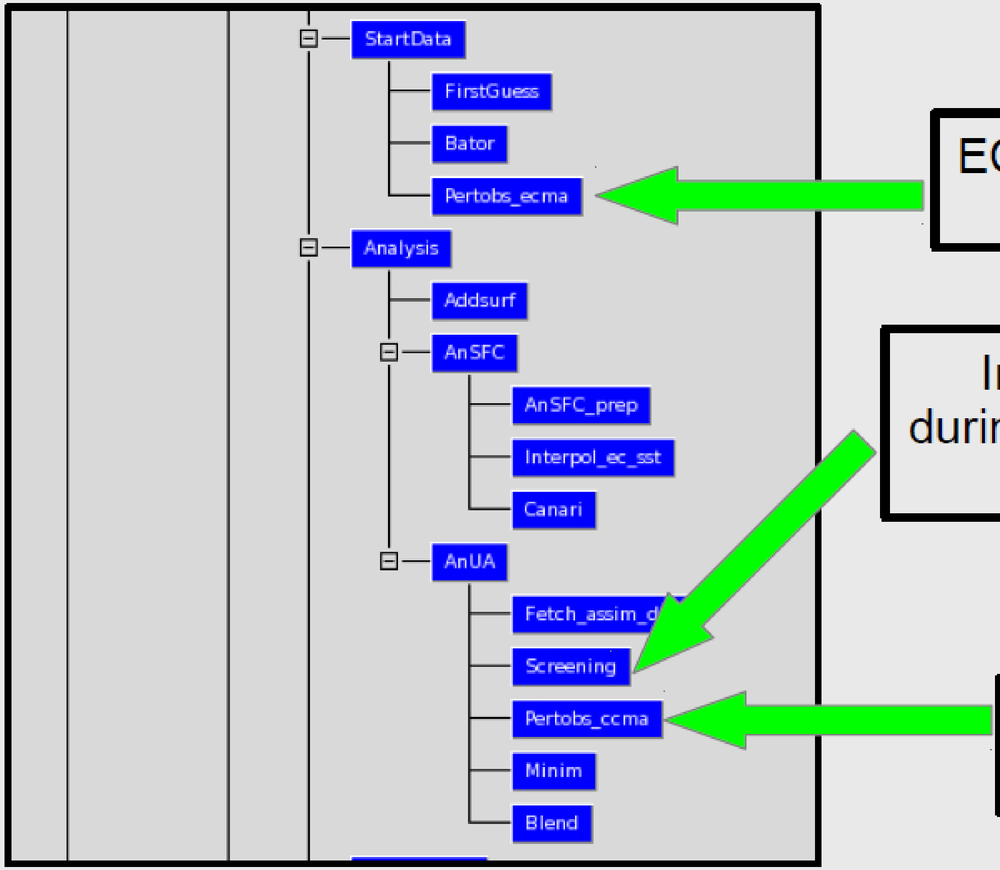
FIG. 6. Absolute value of the ratio between the spectral coefficients of geopotential and those of vorticity (units: J kg⁻¹ s), according to a linear regression (solid line, after a vertical and isotropic average) and to an analytical *f*-plane expression (dashed line), as a function of horizontal total wavenumber k^*; note that the scale corresponding to each value of k^* is equal to $2288.82/4k^*$.





Resulting statistics very similar (more or less identical).
Statistics produced much quicker with parallel festat.

Observation perturbation in ensemble data assimilation (EDA)



ECMA (odb_can) perturbation(1)
PERTSURF="yes"

In-line ECMA (odbvar) perturbation during the screening using IFS solution(2)
PERTATM=ECMAIN

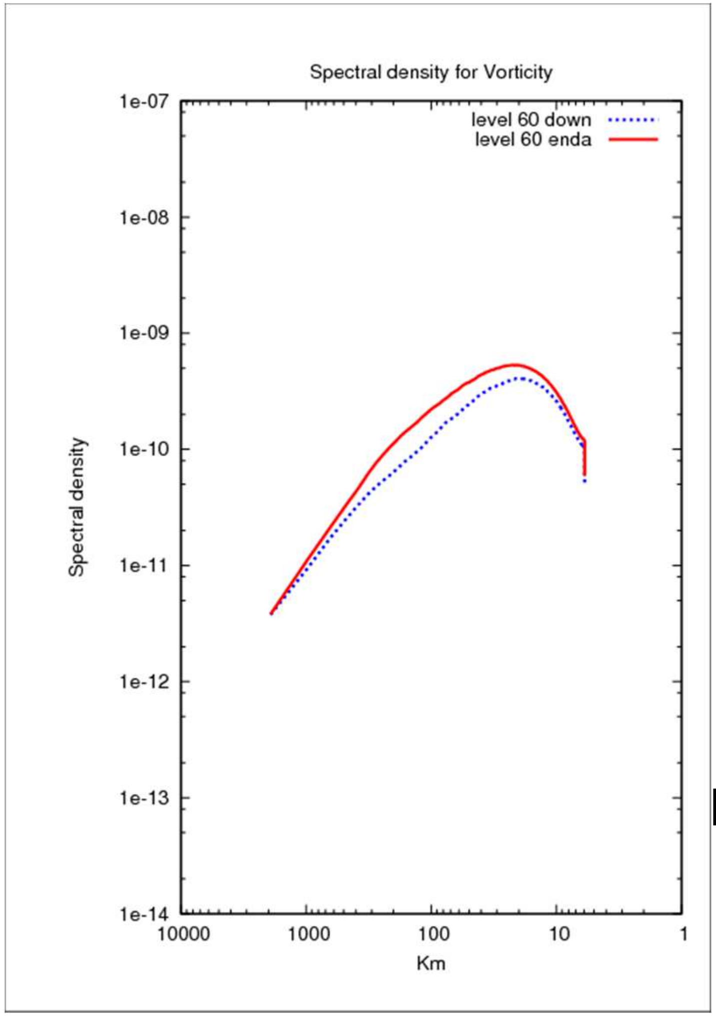
CCMA (odb_ccma) perturbation(1)
PERTATM=CCMA

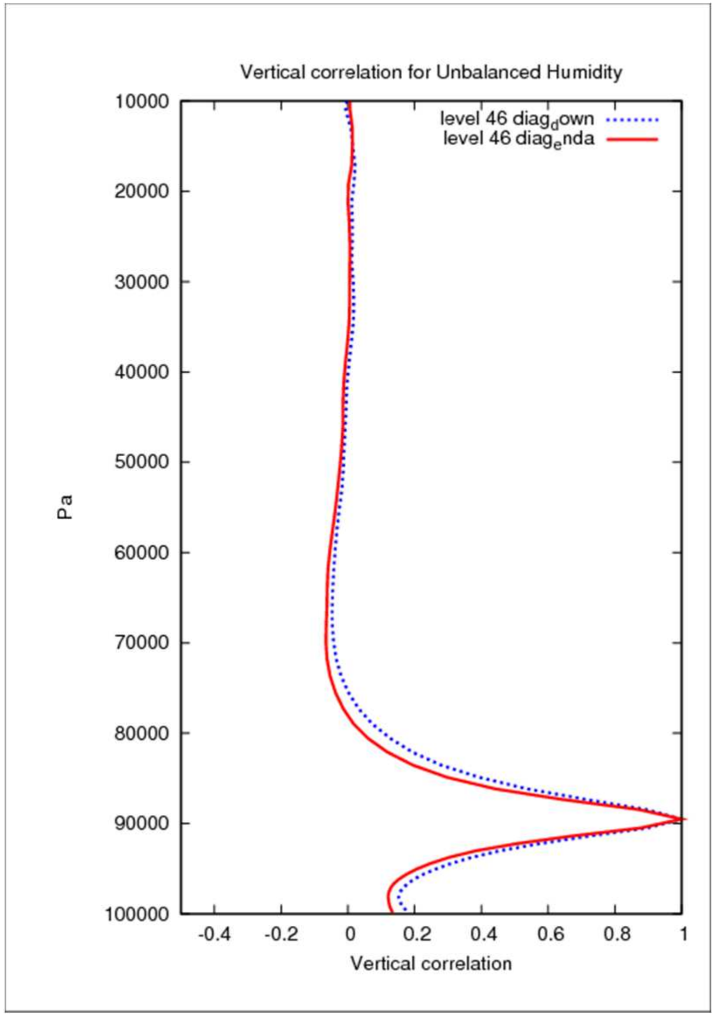
Observation perturbation: $y^p = y + \delta$; $\delta = \mathcal{N}(0,\sigma_o^2)$
δ – a random number using Gaussian distribution;
σ_o – the observation error.

<u>Note</u>: We use separate routines, but both (1) and (2) use the same module for random number generation:
(1) – Pertcma.F90,
(2) – pertobs.F90, and pertobs_uncorr.F90

Background error statistics based on 4 ensemble members run for Jan, July 2012 and at 00, 12 UTC

- Downscaled
- EDA



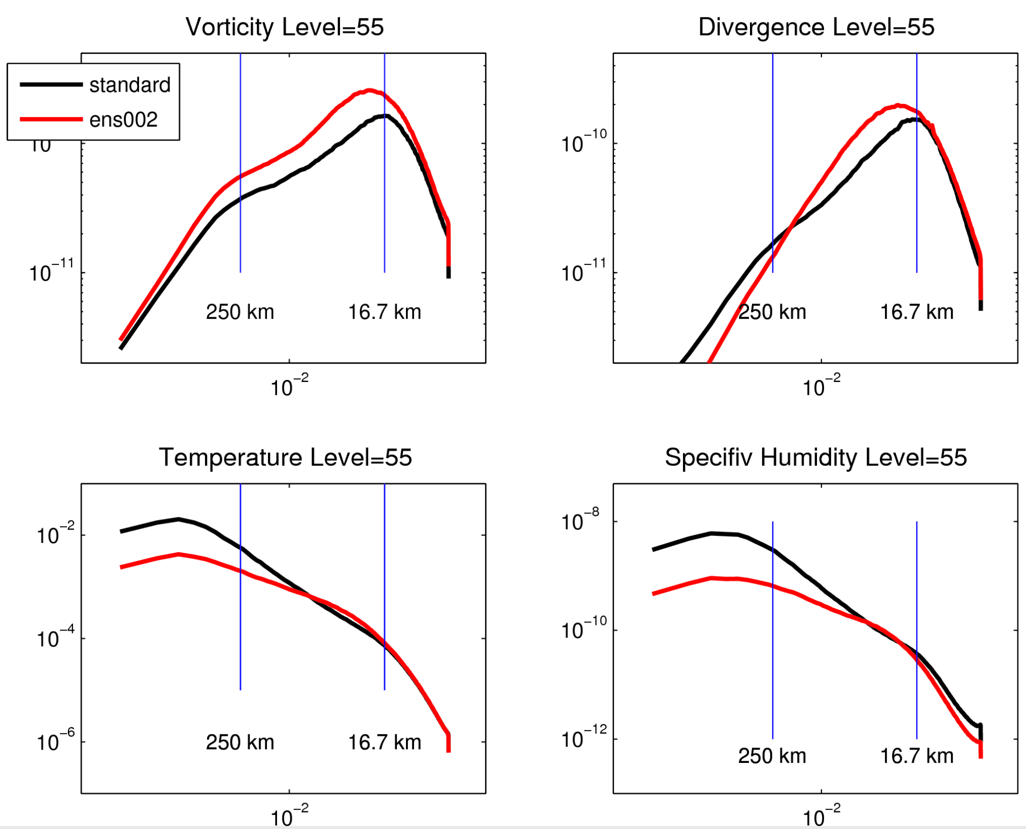


Data assimilation experiments remains to be carried out

More Ensemble Data Assimilation

Background error statistics based on 6h forecast differences

- **standard B-Matrix** : downscaled ECMWF ensemble at the boundaries and intial condition (REDNMC=0.6)
- **new B-Matrix**: same ECMWF boundaries for all members. Ensemble Members differ in the data which has been assimilated and other crude assumptions (REDNMC=0.9)



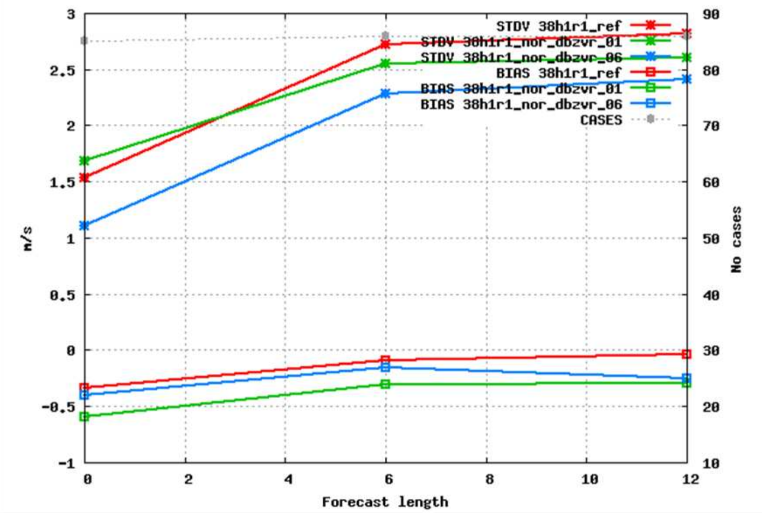
Forecast evaluation

Root mean square error (RMSE) Radiosonde wind at 925hPa (~750m)
Summer experiment

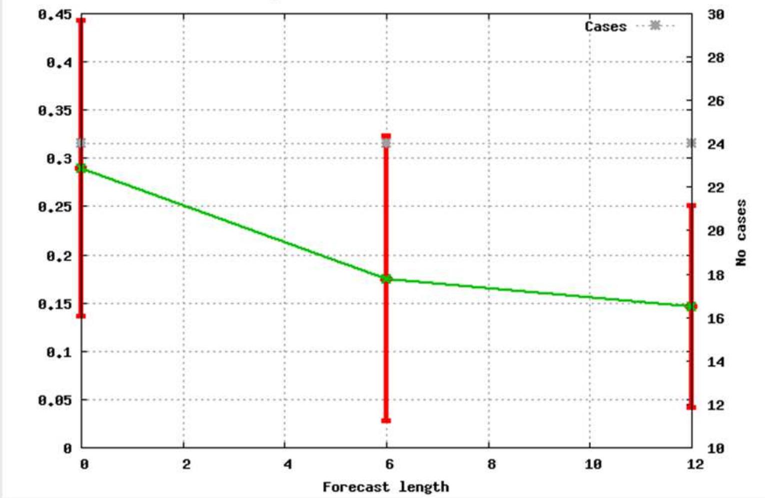
Summer period

(Winter period no significant changes)

RMSE and BIAS



Difference (95% confidence)



Default model
Default model + radar
New model statistics + radar

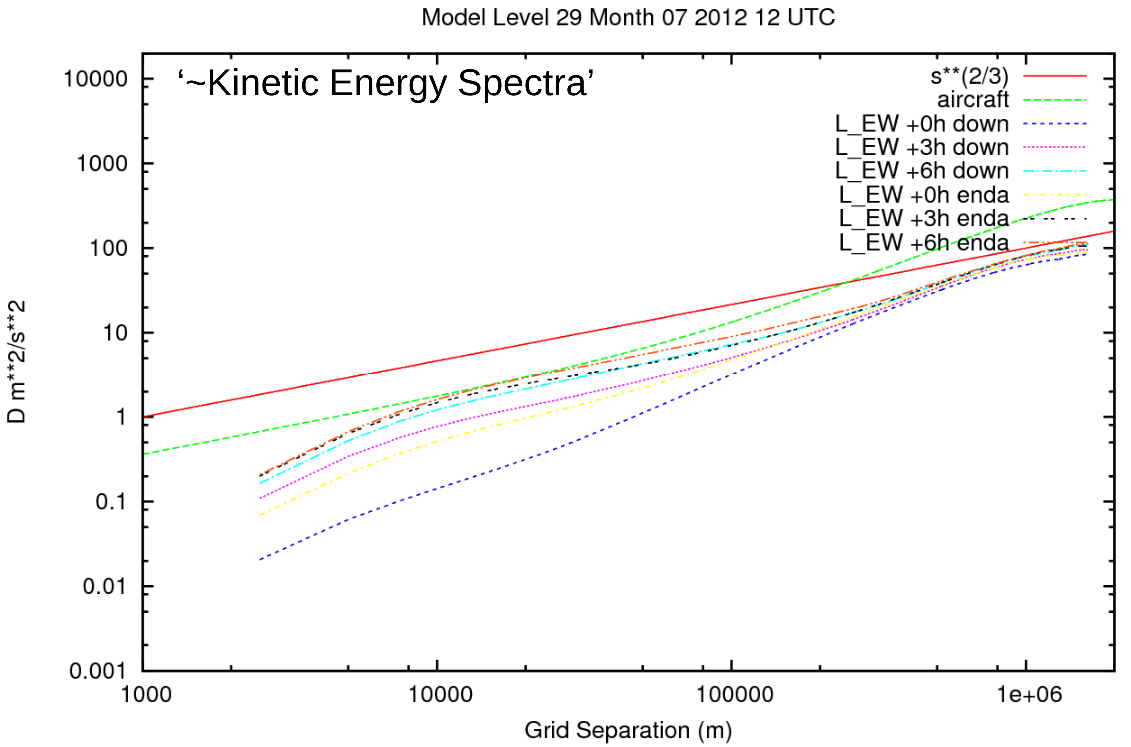
Improved wind forecast with radar data and new model error statistics

Meteorologisk institutt

Spin-up

Spin-up in Downscaled and EDA forecasts

Example



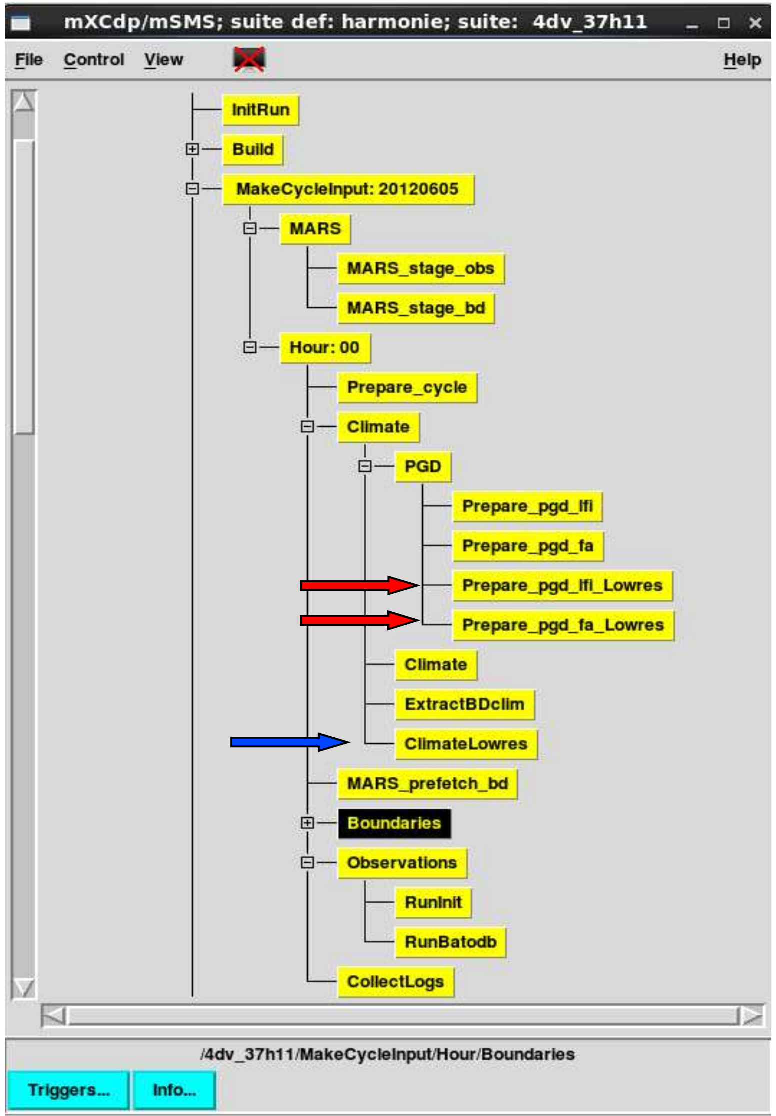
Spin-up during at least first 6h in downscaled HARMONIE, but reduced with HARMONIE EDA.

4D-Var

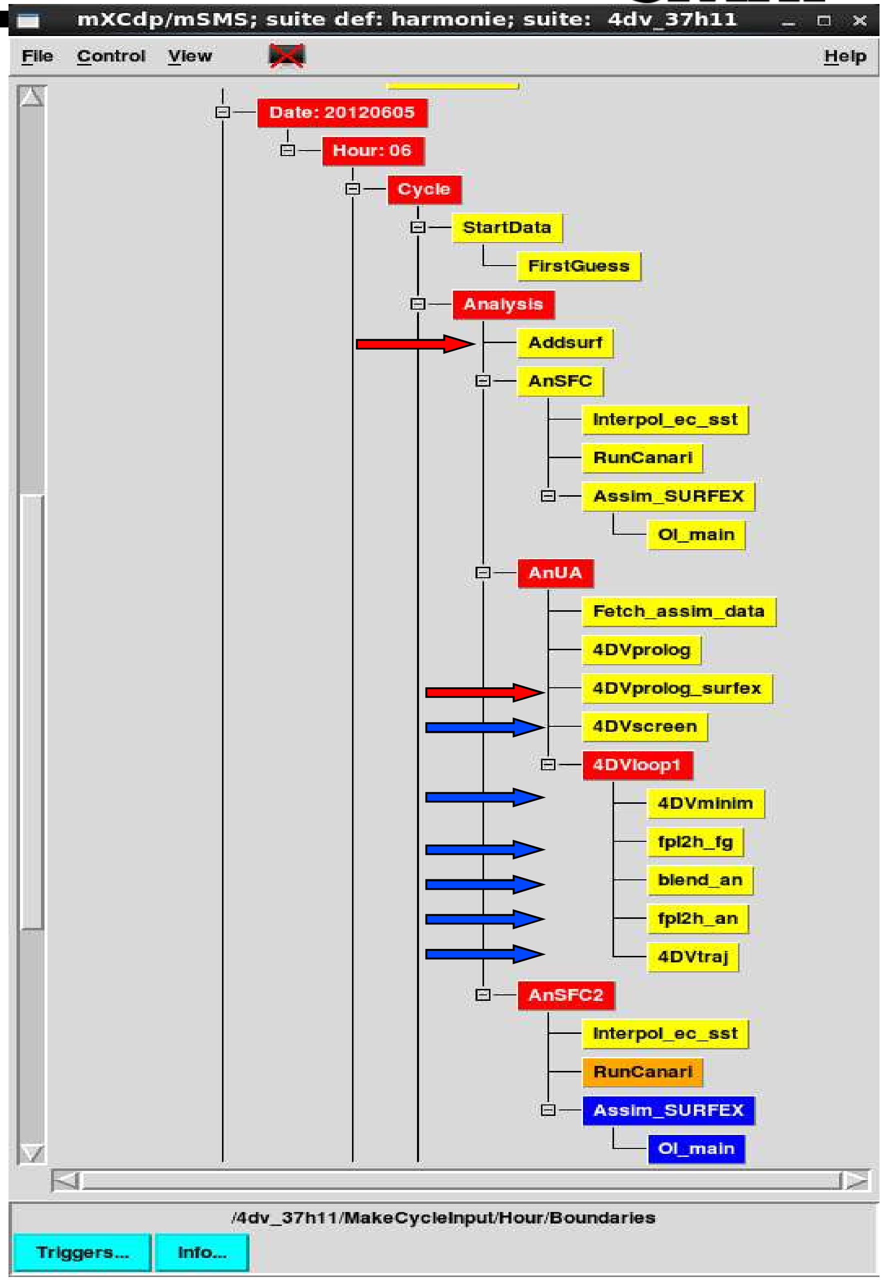
SMHI

Overview of changes needed for AROME and surfex

Modified (script and/or src)   New

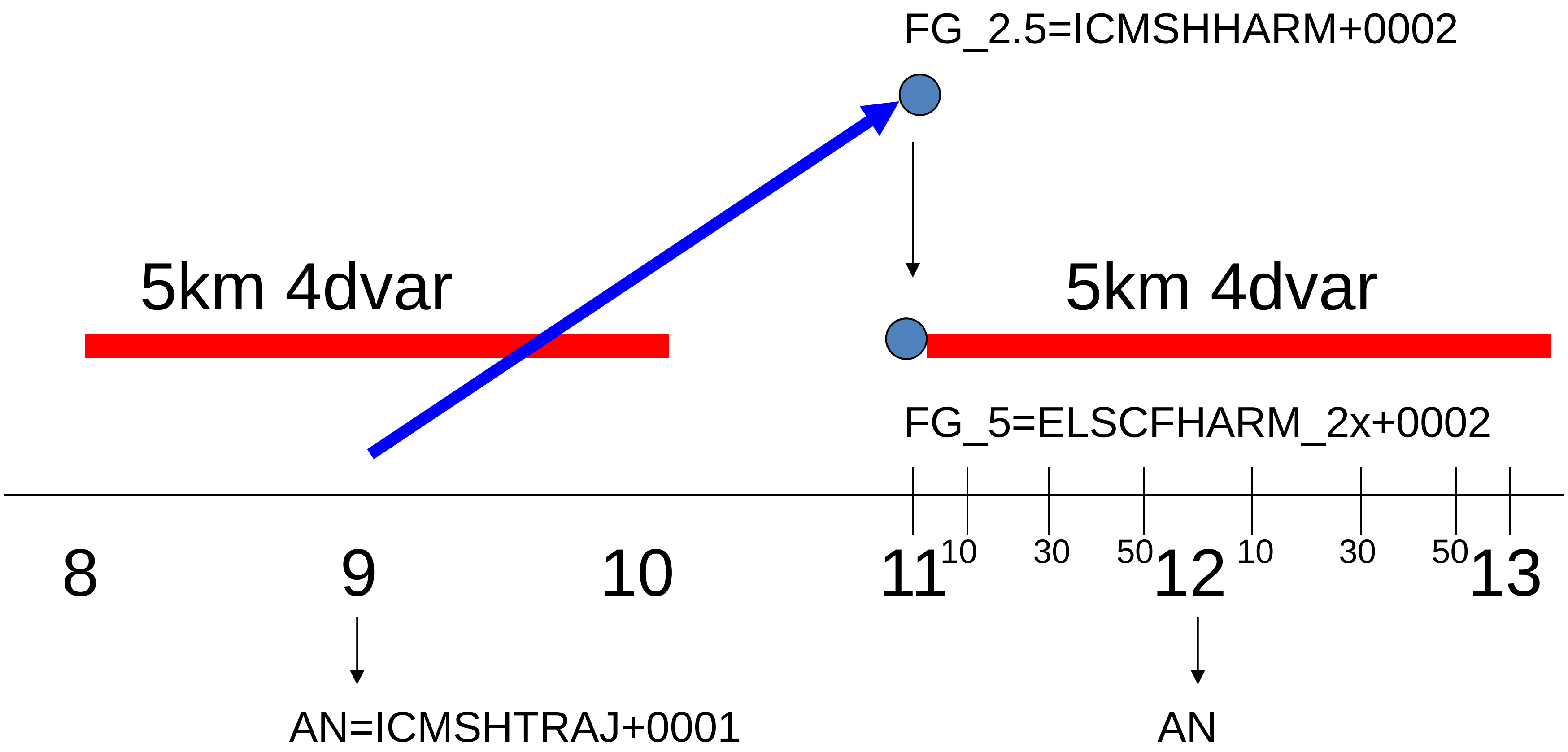


cy37



4D-Var

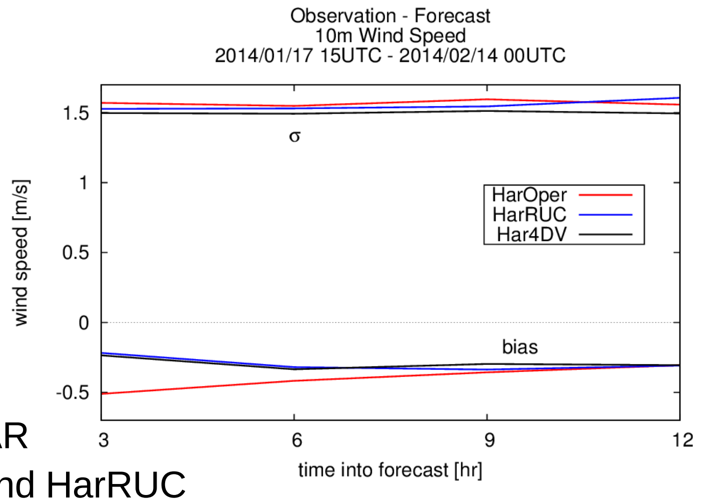
Design for AROME with 3h DA cycle

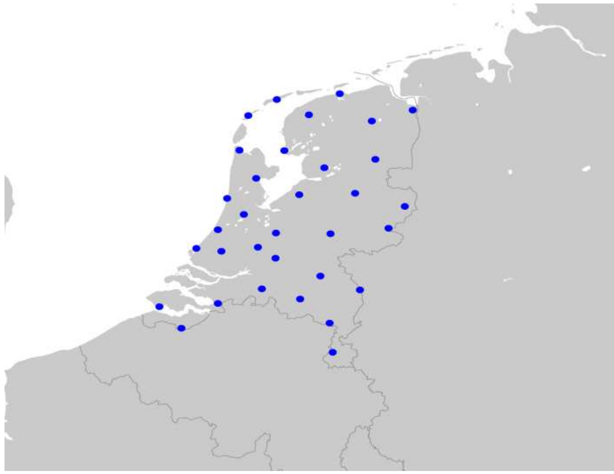


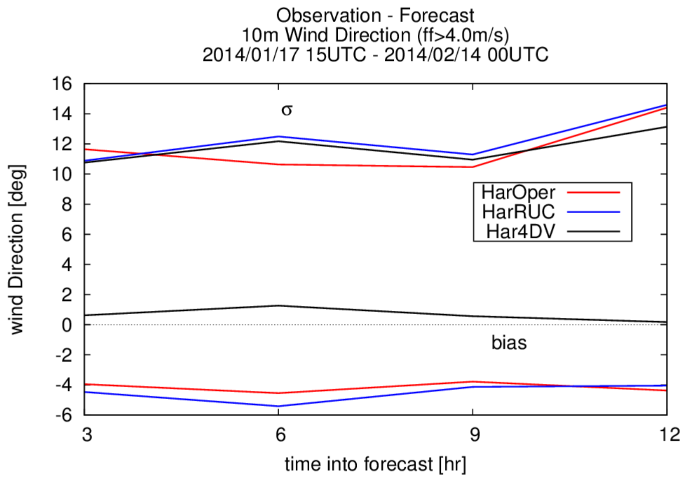
4D-Var

10m wind forecast verification

- NOT fair comparison!!
- Period: 17 Jan – 14 February 2014
- Only Dutch surface wind observations
- Collocation of all three runs
- Wind direction
  - bias is reduced for Har4DVAR
- Wind speed
  - standard deviation is slightly smaller for Har4DVAR
  - Bias is reduced in the first hours for Har4DVAR and HarRUC





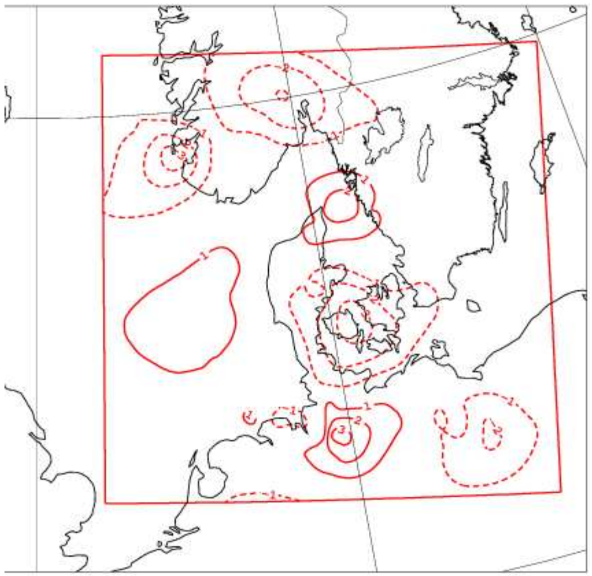


Current work

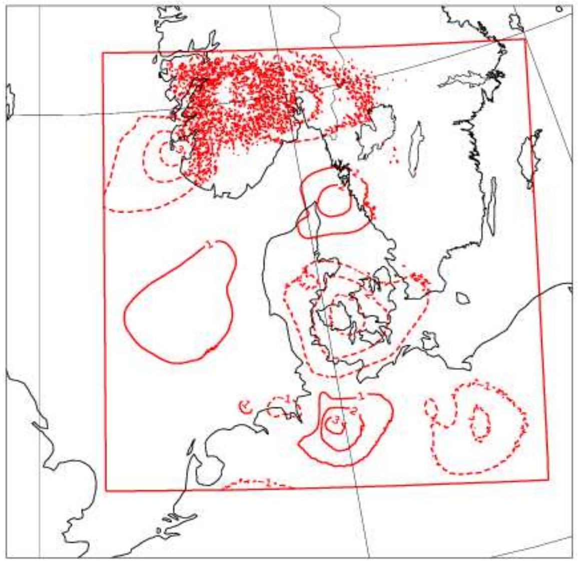
- Assimilation of of radar specific humidity pseudo observations
- Noise in conversion from low to high resolution in mountain areas

AROME 4D-Var temperature data assimilation increment after conversion to full resolution.

Low res



High res



Changing initial clouds in HARMONIE

Use:

- CM nowcasting SAF
- MSG CTP
- Cloud base heights

Relation between cloud

$$q = q_{sat}.((1-C).\sqrt{N} + C)$$

$$q \quad = \min(q \quad , C.q_{sat})$$

$$C = rh_{\max} - (rh_{\max} - rh_{\min}).\sin(\pi \frac{p}{p_s})$$

N: 3-D cloud cover

Preserve buoyancy when changing humidity (keep virtual temperature T_v constant)

$$T_v = T(1 + 0.61q - q_l - q_i - q_r - q_s - q_g)$$

(applied in a separate step after 3D-Var)

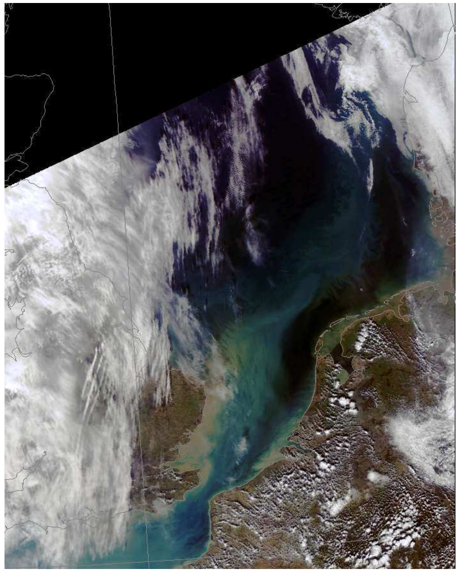
Method for Assimilation of cloud information

Results for cloud initialisation and 4D-Var

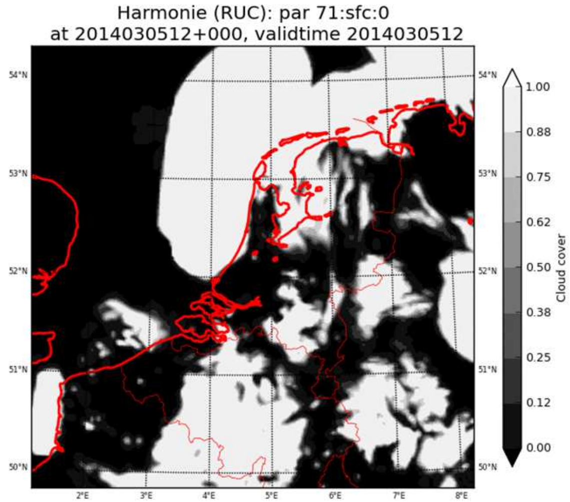
RUNS 5 mar 2014 12UTC +12h

Example of fog caused by initialisation?

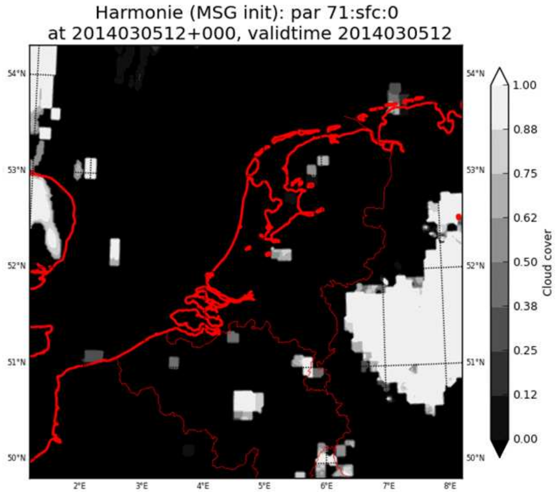
Satellite image



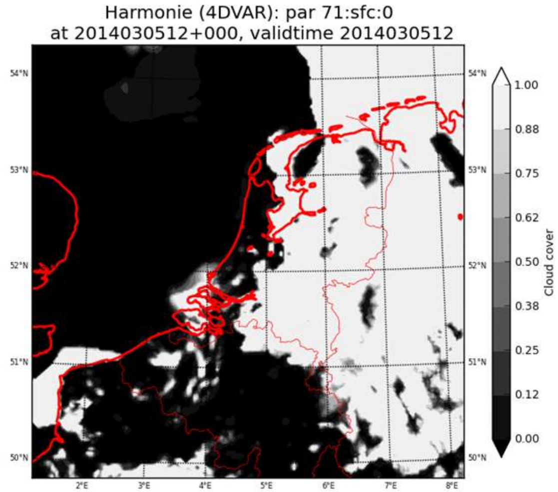
RUC



Cloud initialisation



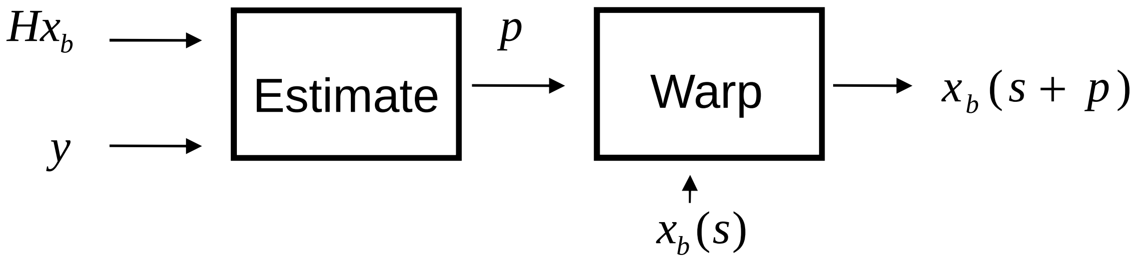
4DVAR



Handling of phase/alignment errors

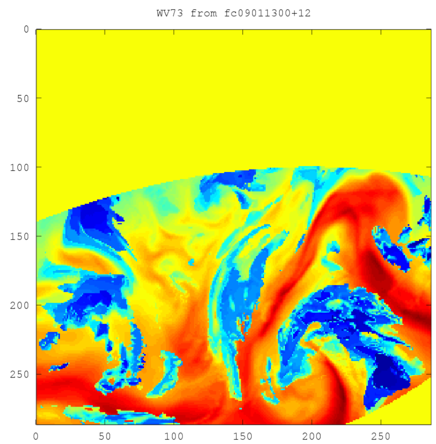
Method

- Use remote sensing image data to estimate the phase error (displacement field) and compensate for it by warping the background state.

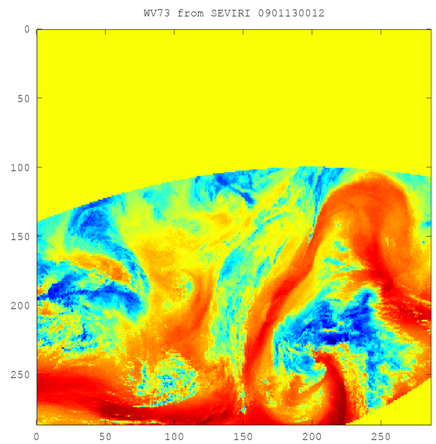


- Minimize the remaining additive error using a standard VAR-method.

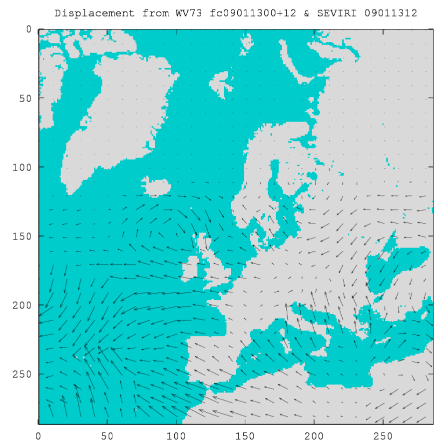
Example



$H(x_b)$



SEVIRI



Estimated p

SMHI

Method

AEMet

DEVELOPMENT OF AN FA ASSIMILATION ALGORITHM FOR RADAR DATA

The method developed at AEMET is based on the “Field Alignment” algorithm proposed by Ravela et al. from MIT in 2007

The method can give the most when used to improved on sequential algorithms like 3D-VAR, which clearly have (insurmountable) problems to handle position errors

The idea may seem simple, but the implementation of it is not. Some of the issues to face and solve are

- Efficient solver for the alignment equation
- Treatment of the forcing term: smoothing, scaling, data void areas
- Radar geometry
- Treatment of orography
- Robustness and convergence of the method (limited to alike situations)
- Excessive perturbation of the model state, initialization

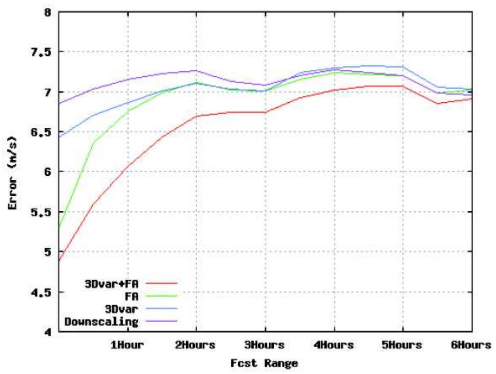
Example Results

Assimilation of Doppler Wind Radar Data in HARMON AEMet

- **Verification of forecasted radial wind using the own radar data:**

$$\text{Error} \equiv \langle (\text{Fcst} - \text{Radar})^2 \rangle^{1/2}_{PPI=0.5} + \langle (\text{Fcst} - \text{Radar})^2 \rangle^{1/2}_{PPI=1.4}$$

- **Results averaged over more than 150 cases:**



Large scale information from host model

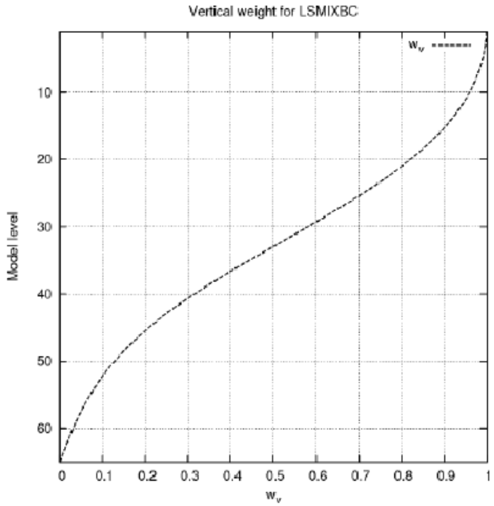
Large Scale Mixing (LSM)

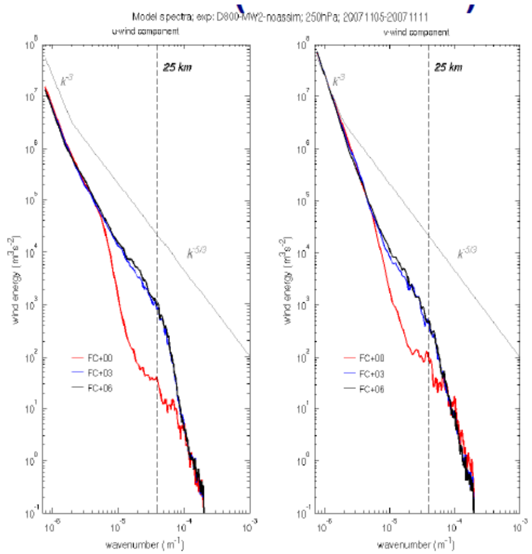
$$\hat{x}_b^{mixed}(m,n,lev) = w_{BC}\,\hat{x}_{ls}(m,n,lev) + (1-w_{BC})\,\hat{x}_b(m,n,lev)$$

$$w_{BC} = w_h w_v$$

$$w_h = \begin{cases} 1, & k^* \le 0.9\,k_C^* \\ \frac{1.1k_C^* - k^*}{0.2k_C^*}, & 0.9k_C^* < k^* \le 1.1k_C^* \\ 0, & k^* > 1.1k_C^* \end{cases}$$

$$k_C^* = \sqrt{M_{max}N_{max}\frac{R_{own}}{R_{ls}}}$$





only trust HOST (ECMWF) scales larges than ~100km

LSM positive impact on forecast verification scores

An alternative to LSM is a J_k-term like $J=J_b+J_k+J_o$

Unifying HARMONIE DA algorithmic developments

✔ Large scale error constraint:

➔ J_k as additional regularization term
$J = J_b + J_k + J_o$ (with preconditioning).

✔ Clouds mask initialisation $T_v = T(1 + 0.61 q_m - q_l - q_i - q_r - q_s - q_g)$

➔ constant virtual temperature constraint for adjusted temperature/humidity profiles **as a weak constraint** via Lagrangian multiplier

✔ Phase-error correction via image registration:

➔ extended control vector space (initially as 2D field) + regularization constraint + **warping transform operator, warping TL, warping AD**

and flow dependent background error statistics, etc., etc., long term work planned within OOPS (J_k more urguent)

Summary

SMHI

- The procedure for generation of HARMONIE background error statistics have been made more user-friendly.
- There is ongoing work towards introduction of HARMONIE EDA for generating background error statistics.
- HARMONIE 4D-Var work progresses but there are more issues to be solved and investigations to be carried out.
- Several different methodologies for improving various aspects of the initial state have been developed and results are encouraging.
- A unified framework is needed to benefit from these individual methodology developments.