HARMONIE DA progress and Hybrid VAR/Ensemble DA

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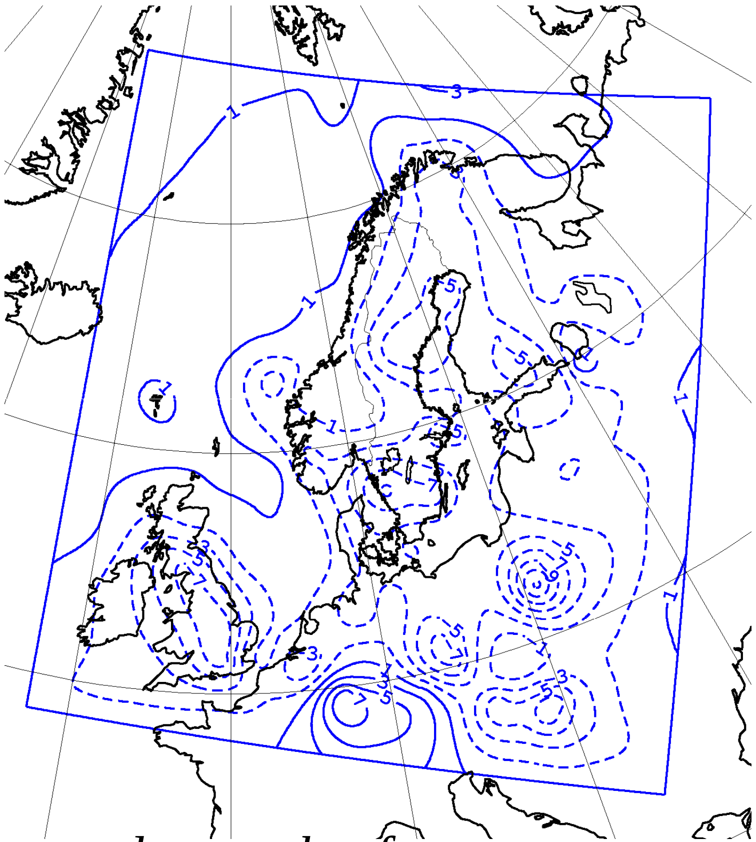
with great help from Jelena Bojarova and Magnus Lindskog

Status HARMONIE data assimilation, example from SMHI



Area and example of temperature analysis increment at model level 40 (tenths of K).

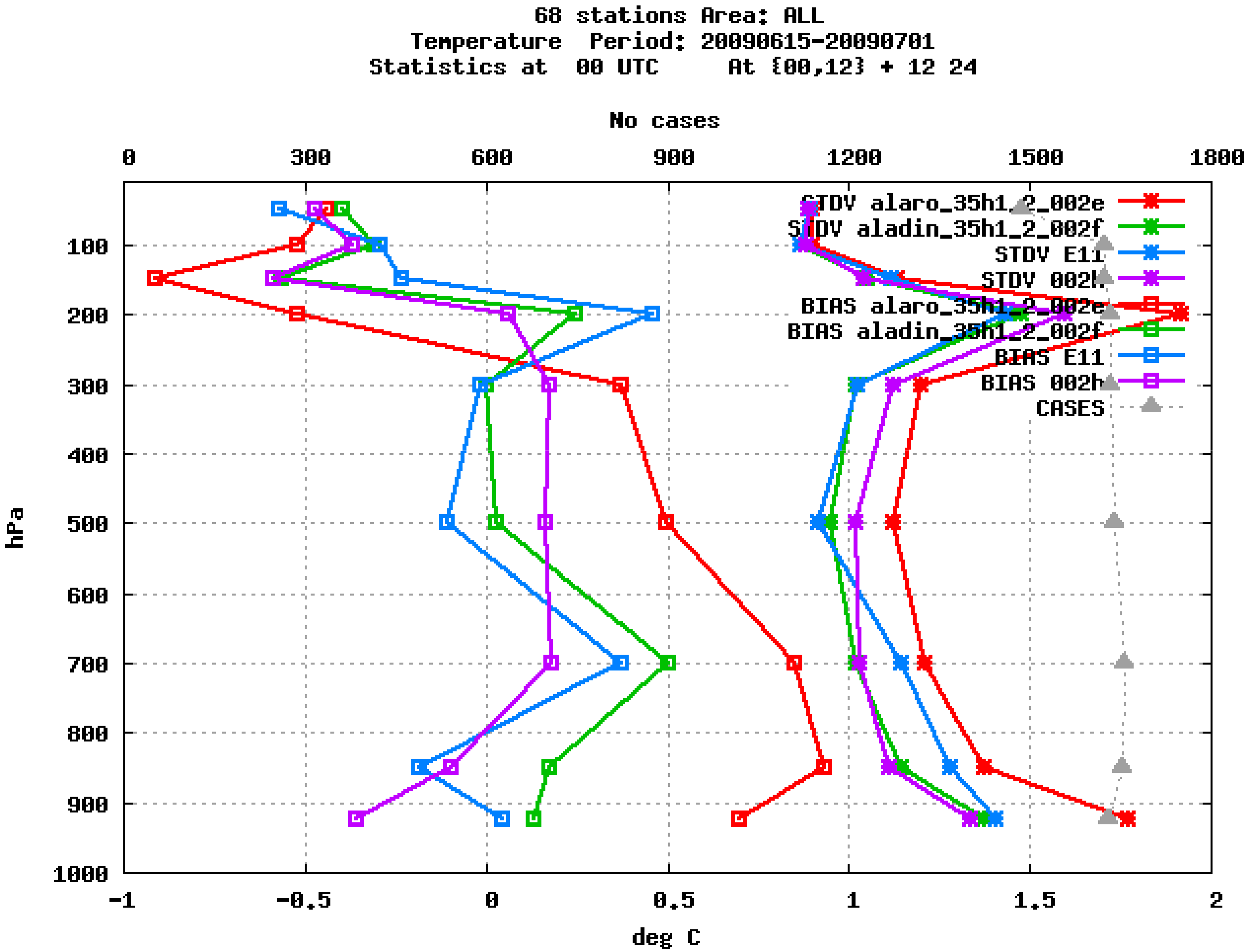
- SMHI HARMONIE ALARO area similar to HIRLAM E11 domain, but 5.5 km hor. res.
- 3D-VAR with 6 h data assimilation cycle (and CANARI surface data assimilation)
- Structure functions from down-scaled ECMWF forecasts of ensemble data assimilation exp.
- Conventional types of observations
- No observations close to lateral boundaries used (250 km)

Status SMHI HARMONIE system

- **Experiments with SMHI HARMONIE system (including data assimilation) in spring/summer 2009 (one summer period, one winter period)**
- **System run daily (‘pre-operationally’) since Spring 2009**
- **Bad scores until this summer (lack of low clouds and low level biases)**
- **ALARO replaced by ALADIN to find problem with ALARO**
- **DFI problem in ALARO discovered and solved.**
- **New experiments with improved ALARO DFI carried out and are just finalized**

SMHI HARMONIE data assimilation

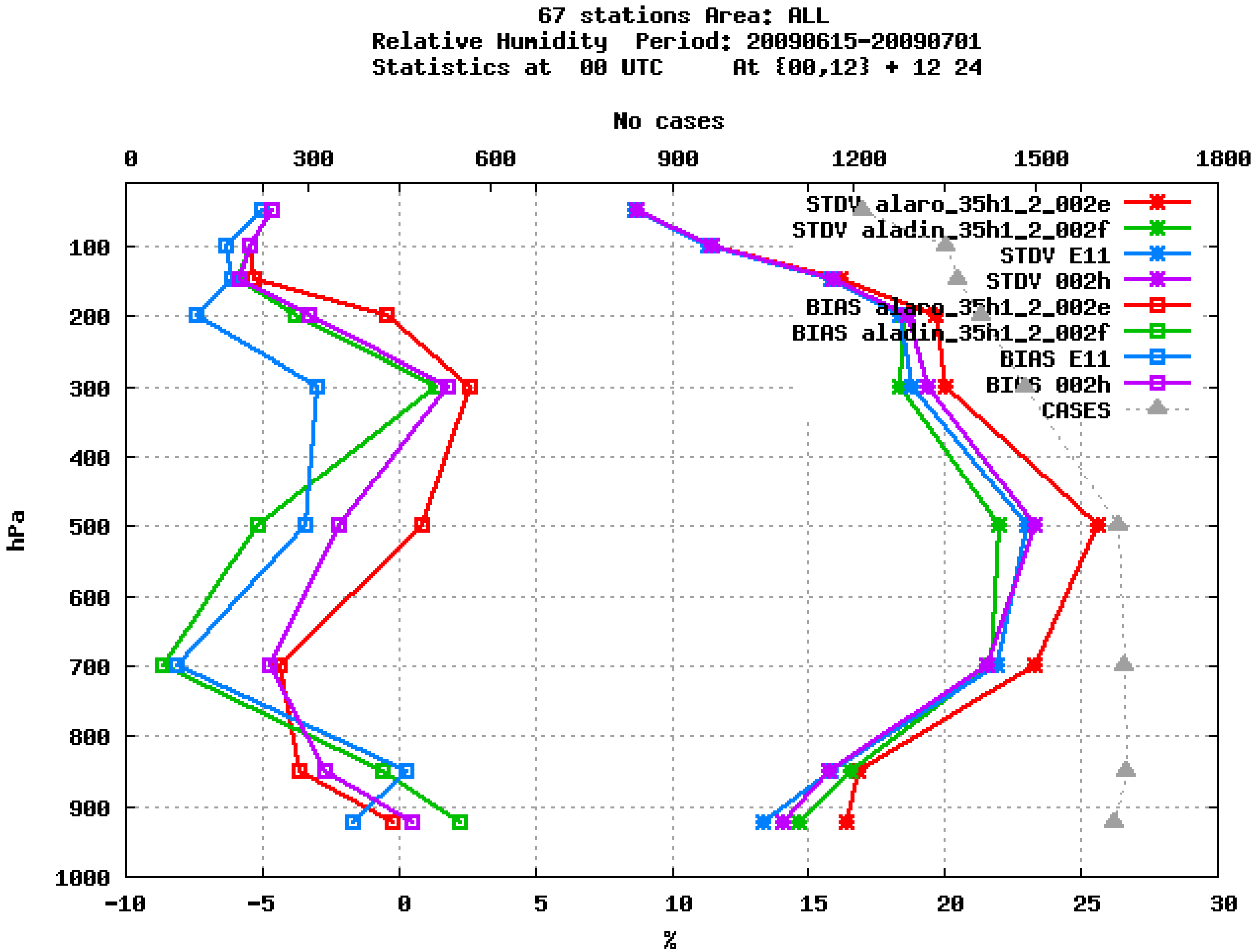
(summer period temperature verification scores)



ALARO(OLD) ALADIN E11 ALARO (NEW)

SMHI HARMONIE data assimilation

(summer period relative humidity verification scores)



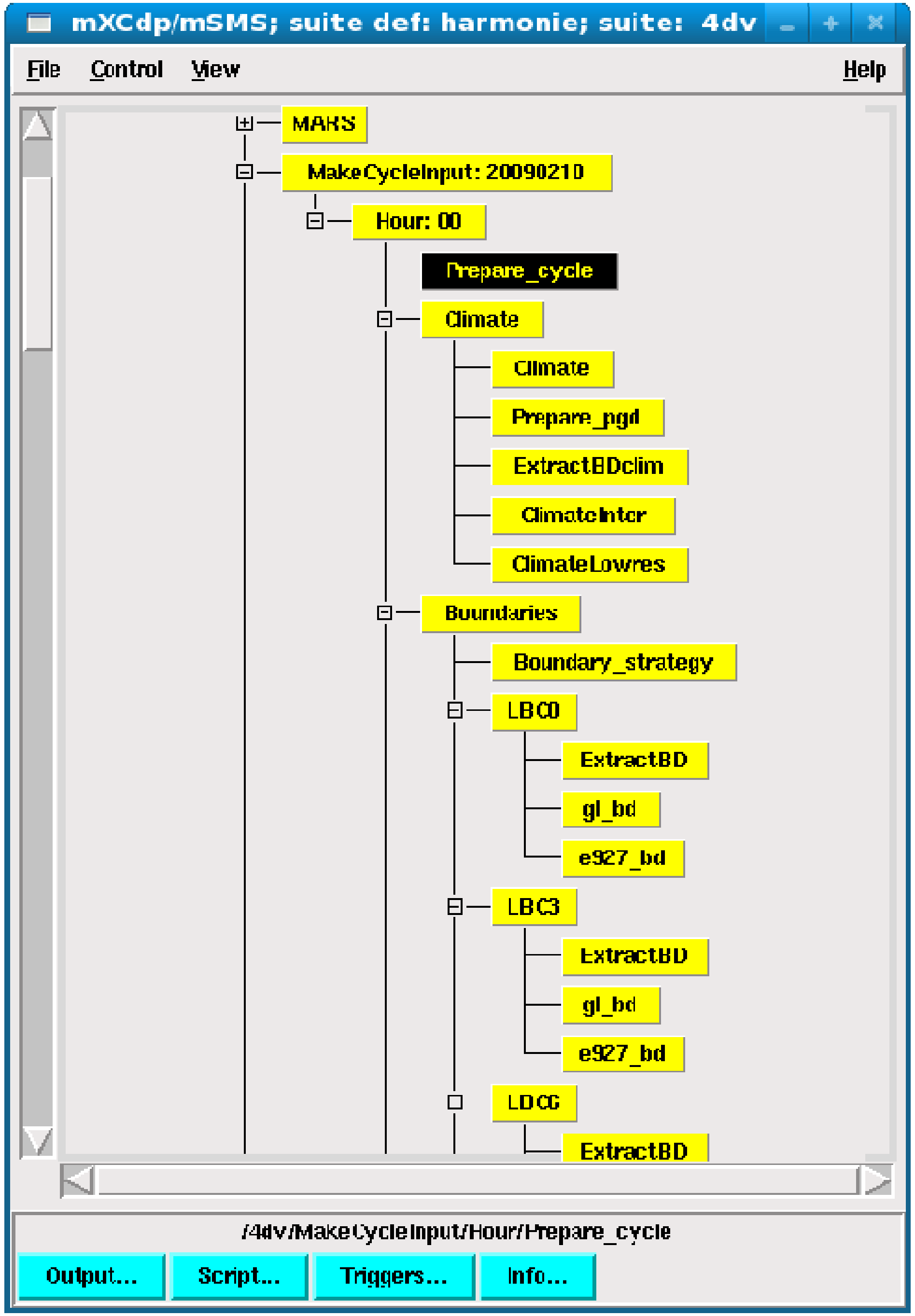
ALARO(OLD) ALADIN E11 ALARO (NEW)

Status HARMONIE data assimilation

- **The HARMONIE mini-sms system used by all HIRLAM researchers that work with ALADIN model.**
- **On-going work with implementing HARMONIE data assimilation locally at several institutes (SMHI, AEMET, DMI, met no and KNMI)**
- **HARMONIE data assimilation system prepared for assimilation of various satellite observations.**
- **Extension zone problem remains.**
- **More work on structure functions for high resolution DA (AROME, 2.5 km) needed.**
- **Surface/soil assimilation coupled to SURFEX needs to be implemented (AROME)**
- **HARMONIE 4D-Var under development and evaluation**

Status HARMONIE 4D-Var

- **First ALADIN 4D-Var version (within OLIVE framework) developed by Bernard Chapnik with help from Filip Vana and MF ARPEGE 4D-Var experts (end 2008).**
- **ALADIN 4D-Var implemented in HARMONIE mini-sms and is technically working (September, 2009) .**
- **4D-Var included in HARMONIE 35h1branch (September 2009).**
- **4D-Var working week for a wider HIRLAM, ALADIN and LACE community in Norrköping in December 2009**.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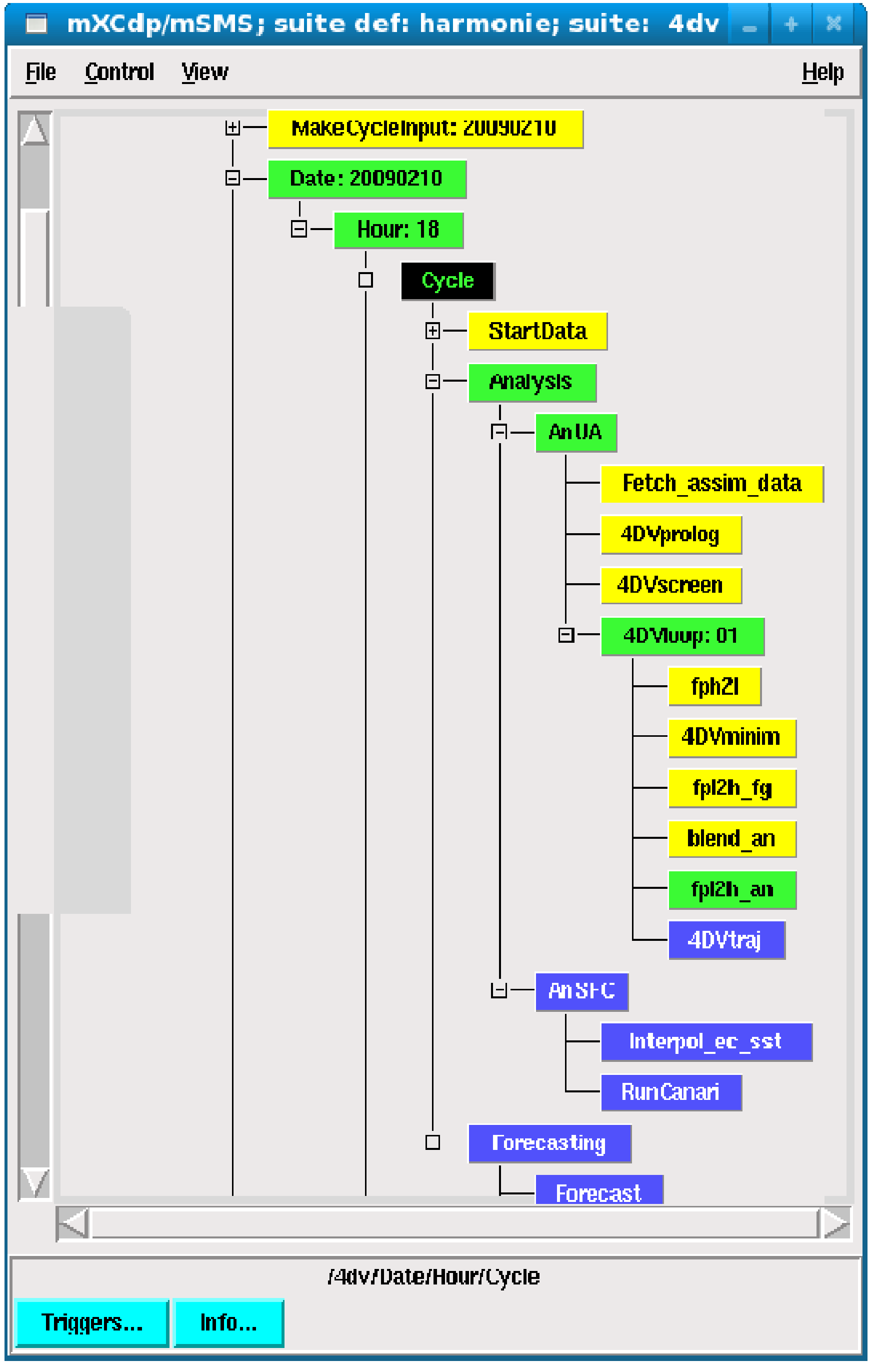
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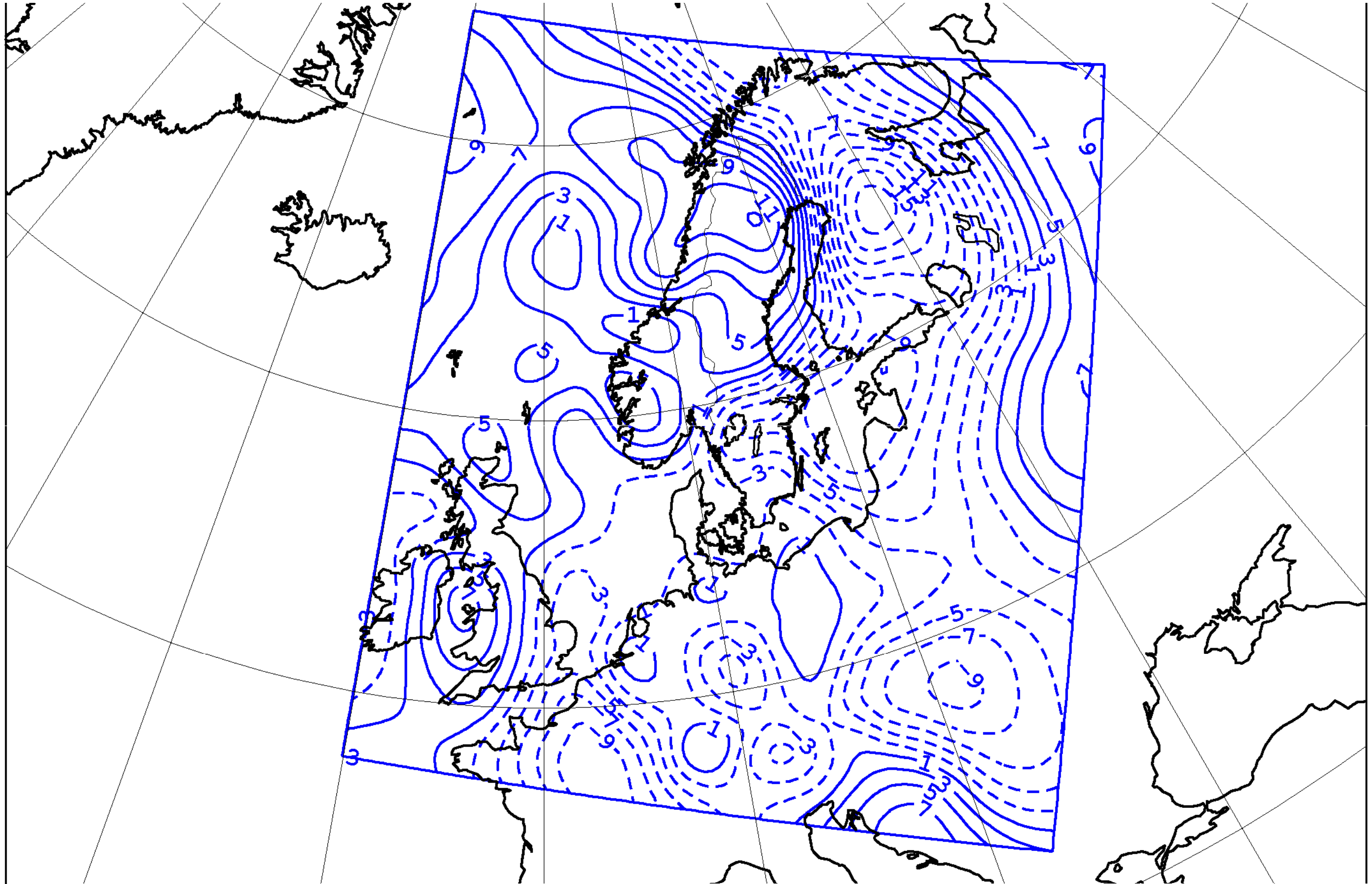
Status HARMONIE 4D-Var
(first HARMONIE 4D-Var assimilation increments)



Scandinavian area and example of temperature analysis increment at model level 40 (tenths of K) at the start of assimilation time window. Half resolution increments

Outlook for the HARMONIE data assimilation - 2010

- **Refine the present implementation for 5-10 km resolution (wider extension zone, structure functions, satellite data)**
- **First setup for 2.5 km resolution – AROME ("simple" structure functions, soil assimilation with SURFEX)**
- **Refined structure function for 2.5 km resolution (ensemble assimilation with perturbed observations?)**
- **Emphasis of high resolution observations (radar wind and reflectivity, cloudy satellite IR radiances, GPS)**
- **Improvements of 4D-Var (high resolution trajectories, multi-incremental minimization etc.)**

Mesoscale data assimilation and the use of ensembles

- **Will assumptions on weak non-linearities at 10 km resolution break down at the km scale ? Most likely yes !**
- **Can ensembles provide information on uncertainties and balances at the mesoscale ? Yes !**
- **Is it too risky to put all our efforts on 4D-Var, that works on the 10 km scale but may fail at the km scale ? Yes !**
- **Should we drop our investments in variational data assimilation and re-start with ensemble or even particle filters ? No, EnsKF and particle filters still have basic weaknesses !**
- **Can we develop hybrid data assimilation schemes that combine the best of the two worlds ? We believe so !**

Different approaches for using ensembles in variational data assimilation

- Covariance modeling with parameters of the covariance model determined from an ensemble. Use for example a wavelet-based covariance model (Loik Berre et al. Meteo-France)
- Use the ensemble-based covariances in a hybrid variational ensemble data assimilation (Barker et al. WRF, UK Met.Office, HIRLAM)
- Ensembles can also be used to determine static background error statistics

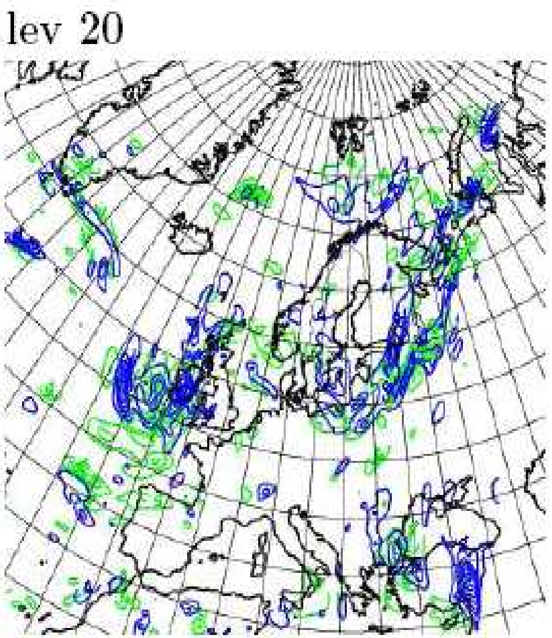
HIRLAM first approach to use ensembles in 3D-Var and 4D-Var

- **Use the ETKF algorithm for re-scaling of a 6h forecast ensemble to an analysis ensemble (estimation of the analysis error covariance). Status: A first version seems to provide reasonable results. Will also be tried for next GLAMEPS version.**
- **Use ensemble of 6h forecasts to estimate the background error covariance and blend it with the static background error covariance. Status: Coded and is being tested.**

The HIRLAM ETKF re-scaling scheme

- **Follows Bishop et al. (2001)**
- **Uses observation positions and observation errors in HIRLAM 3-4D-Var (no re-coding of obs. operators)**
- **No localization of covariances (maybe too brave?)**
- **Simple multiplicative variance inflation based on observation innovations**
- **Ad hoc down-scaling of non-leading eigen-vectors of the ensemble space analysis error covariance matrix**
- **Additive variance inflation using perturbations with the structure of the static background error covariance**
- **Mixing with global TEPS perturbations along lateral boundaries and in the stratosphere**

ETKF-based HIRLAM ensemble vaiances (8 members only)



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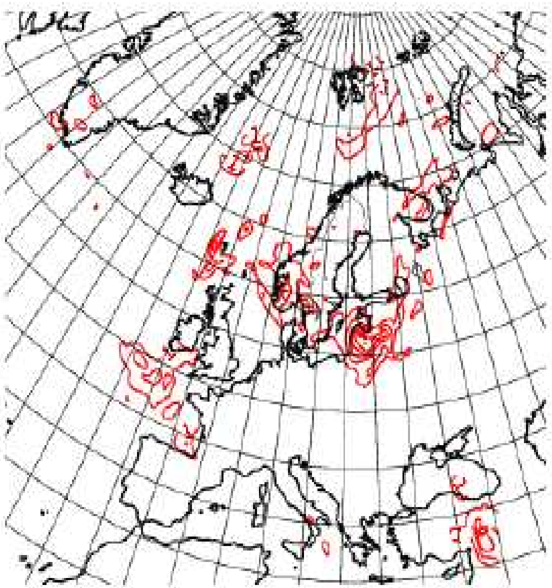

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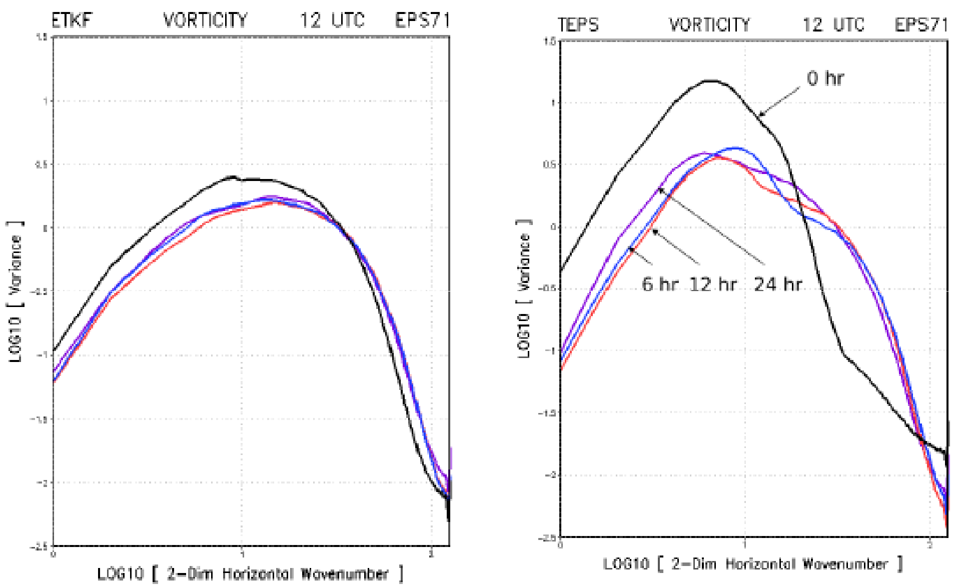
Control

Bojarova et al.

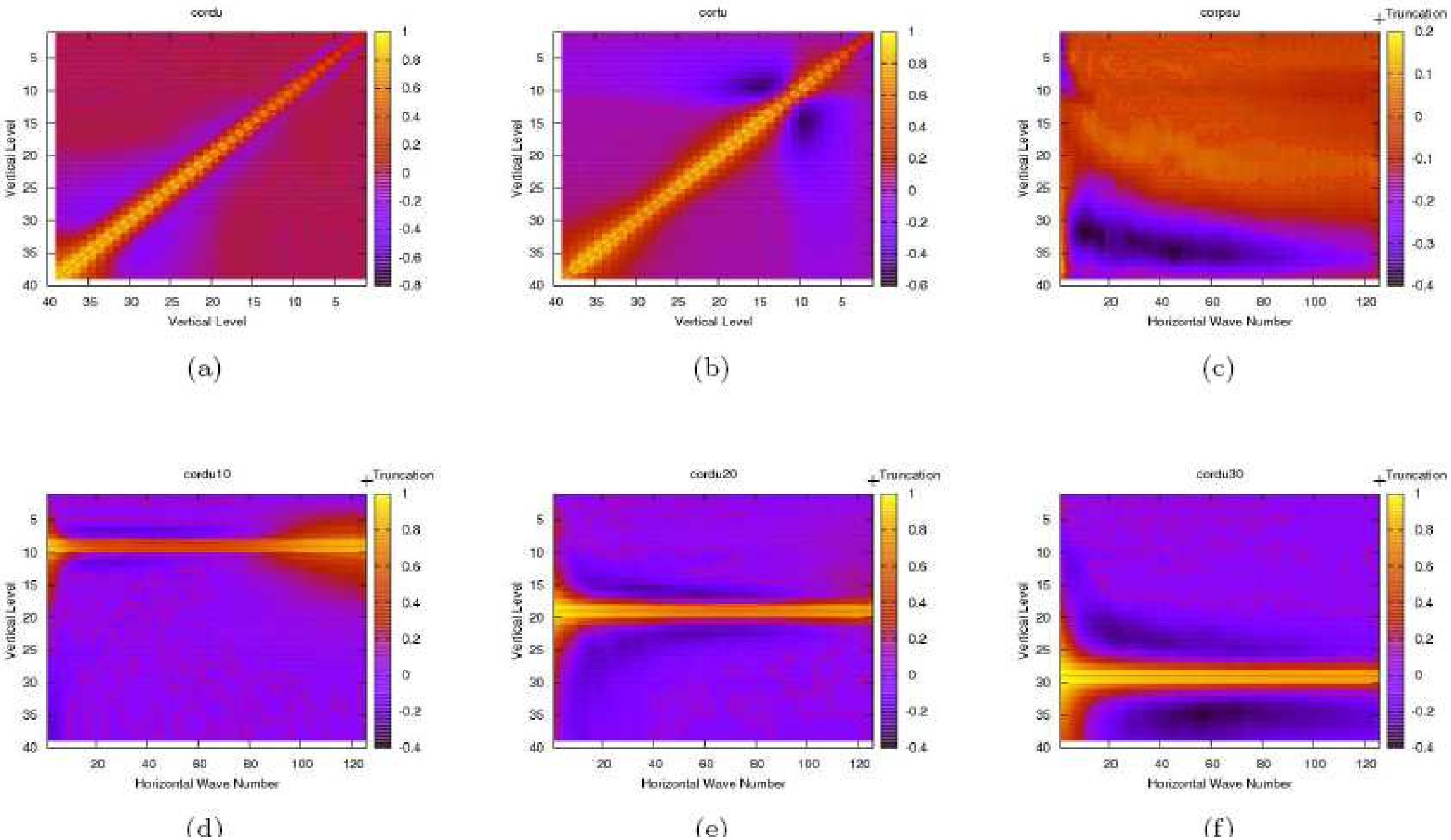
Diagnosis of ETKF perturbations-horizontal spectra



(a) (b)

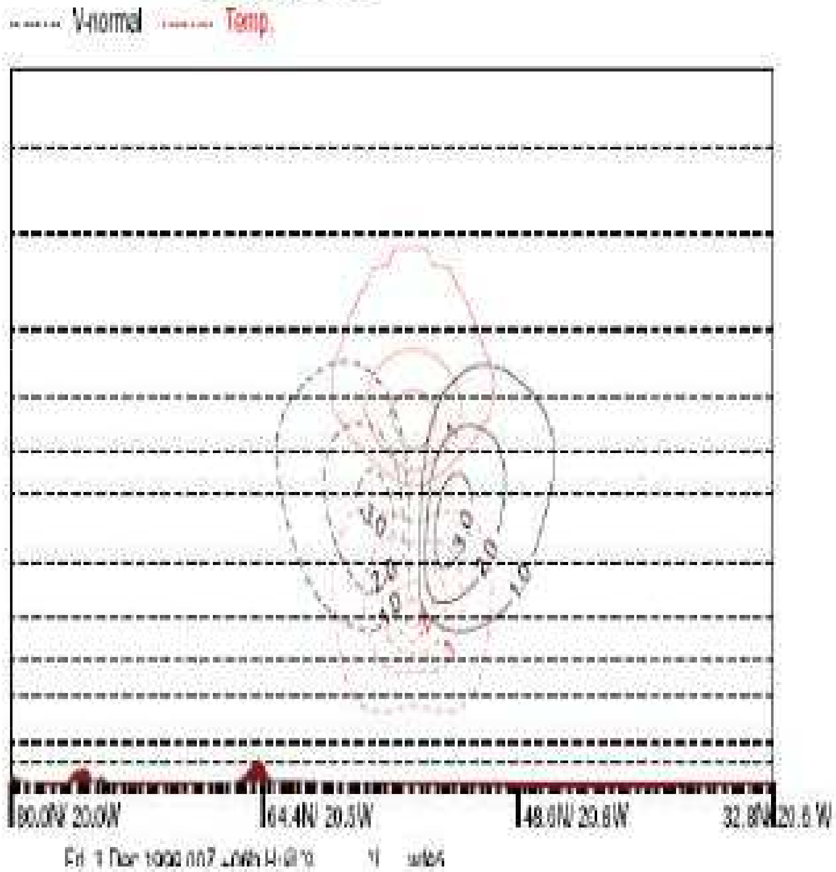
Figure 10: The horizontal spectral density of the variance for the forecast error of vorticity at 00h (black), 06h (blue), 12h (red) and 24h (magenta), estimated from the ETKF perturbations (a) and from the TEPS perturbations (b)

Diagnosis of ETKF perturbations -
+12 h vertical correlations and balance relations

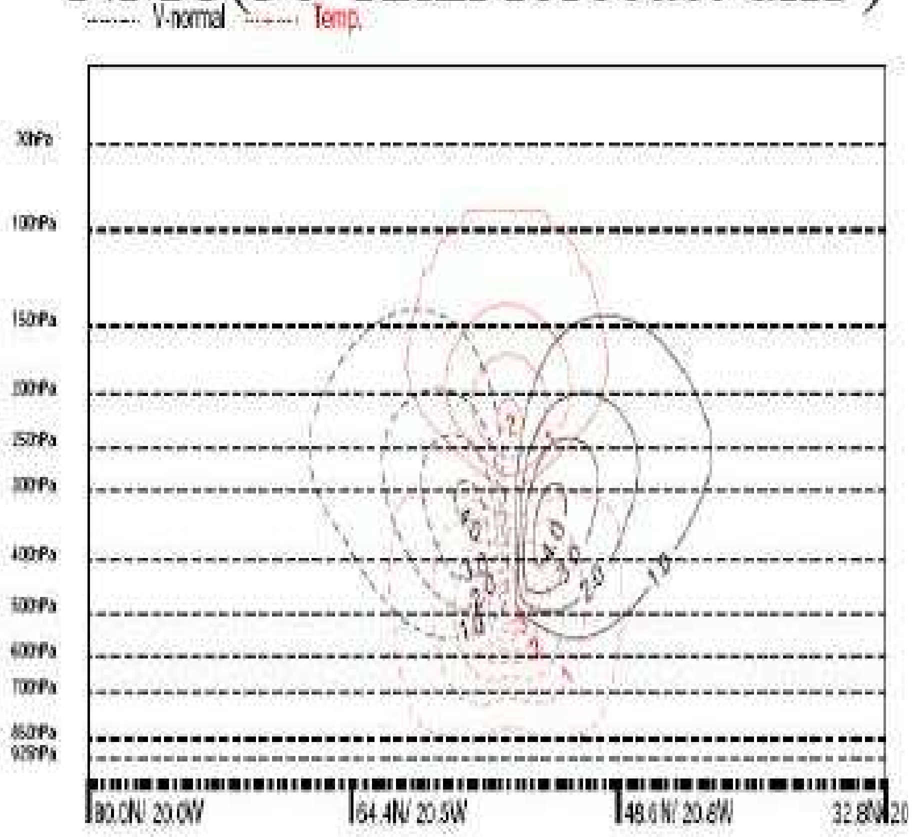


Single Observation Experiment

ETKF



NMC(36-12hh forecast diff)



Static background error statistics derived from an ETKF-based ensemble

Two "equivalent" formulations of hydrid variational-ensemble data assimilation:

Hamill and Snyder (2000), form linear combination of covariance matrix:

$$B = \beta_{3D} B_{3D} + \beta_{ens} B_{ens} \tag{1}$$

$$\frac{1}{\beta_{3D}} + \frac{1}{\beta_{ens}} = 1 \tag{2}$$

to preserve total variance

localization of B_{ens} is needed for small ensemble sizes (Schur product $B_{ens} = S \circ B_{raw-ens}$)

Lorenc (2003) augmentation of the control vector:

$$\delta x = \delta x_{3d} + \sum_{k=1}^{K} (a_k \circ \delta x_k^{ens}) \quad (3)$$

$$J(\delta x_{3D}, \mathrm{a}) = \beta_{3D} J_{3D}(\delta x_{3D}) + \beta_{ens} J_{ens}(\mathrm{a}) + J_o \quad (4)$$

$$\frac{1}{\beta_{3D}} + \frac{1}{\beta_{ens}} = 1 \quad (5)$$

$$J_{ens} = \frac{1}{2} \mathrm{a}^T \mathbf{A}^{-1} \mathrm{a} \quad (6)$$

$a_k \circ \delta x_k^{ens}$ means element-by-element multiplication ("localization" similar to Schur product)

The localization and ensemble weights **a** can be assumed to have a certain length scale.

First version of the HIRLAM implementation: **- a** has horizontal variations only and is controlled in spectral space with the assumption of isotropy - this is equivalent to the localization with a Schur product based on a distance-dependent correlation function. **Note:** This does not mean that the ensemble part of B is assumed isotropic, it is only the localization that is assumed to be isotropic !

- The localization is applied for vorticity, divergence, temperature, specific humidity and ln(ps) - for better balance by avoiding "elliptic" wind component correlations.

- As argued by Wang, Snyder and Hamill (2007) the implementation of the Lorenc (2003) formulation was quite simple in an existing variational assimilation system (5 days of coding in HIRVDA, but not yet fully debugged).

Possible extensions:

- Vertical localization (difficult with regard to satellite radiance information or other vertically integrated quantities) - now introduced in the WRF Hybrid.

- Different weights for different ensemble members in different sub-areas based on independent information not used in the assimilation (satellite or radar images, for example)

Outlook for 2010 - the ETKF and the hybrid VAR/Ens data assimilation

- Test ETKF for perturbation rescaling in GLAMEPS
- Evaluate the impact of the hydrid data assimilation in comparison with 3-4-Var in HIRLAM (the hypothesis is that the hybrid should beat 4D-Var as well as EnsKF)
- Possibly consider the hybrid also for HARMONIE data assimilation
- Investigate whether ideas of particle filters can be applied within the hybrid framework