# The 35th EWGLAM and the 20th SRNWP meeting, 30/09-3/10, 2013, Antalya, Turkey

## **The overview of HIRLAM-B DA&UO activities**

Jelena Bojarova & the HIRLAM Team
via Claude Fischer

ALADIN

*HARMONIE*

Hirlam
High Resolution Limited Area Model

# Structure of the talk

1. **Short-term framework for meso-scale DA in HIRLAM-B**
   - **new BUFR format**
   - **radar data, common QC tool, radar data exchange**
   - **GNSS**
   - **Mode-S**
   - **ATOVS, IASI**
   - **scatterometer winds and overall tuning of DA system**
   - **blacklisting & COPE**
   - **cloud mask initialisation**
2. **Long-term algorithmic investments**
   - 2DEnsVAR
   - Hybrid 4DVAR
   - HIRLAM 4DEnsVAR
   - phase-error correction via image registration
   - super-hybrid
   - hybrid FA+3DVAR for radar radial winds

Hirlam + ALADIN = *HARMONIE*

# Short term framework for meso-scale DA
## & Challenges

Dynamical "spin-up" problem

QC & Blacklisting

Low model top

3h RUC 3DVAR ( + 1h RUC 3DVAR in research) +
High-resolution high-frequency observations :

- conventional observations +
- Mode-S + AMDAR +
- ATOVS + IASI +
- radar, GNSS, ASCAT/QSCAT +
- screen-level observations for UA DA +
- assimilation of cloud information and low-peaking radiances

VarBC

Thinning/ super-obbing

Best estimate of model parameters

Correlated observation errors

Overall tuning of DA system

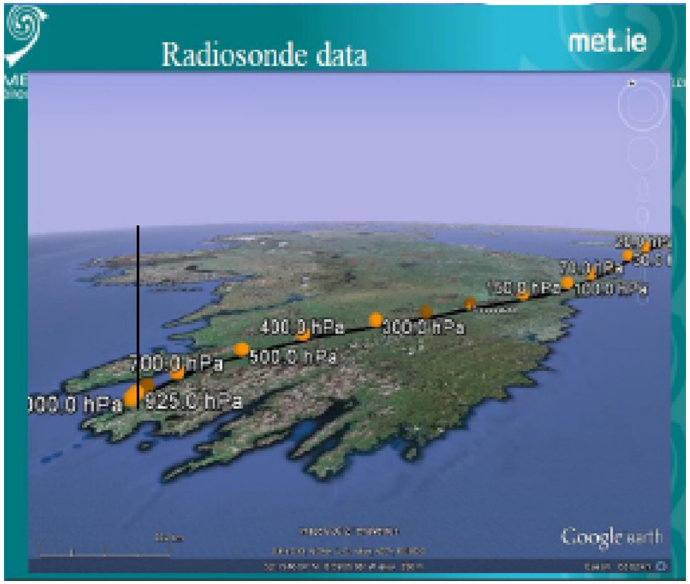
Preservation of structures.

# Improved use of existing observation network

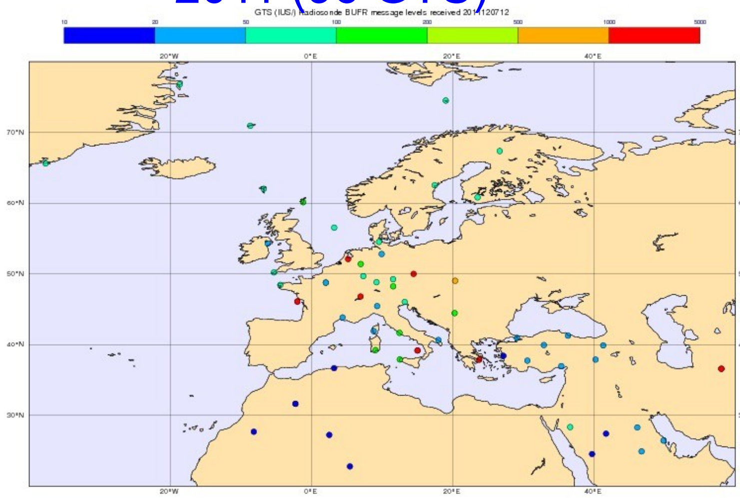
## Radiosonde observations

TAC data format -> TDCF data format

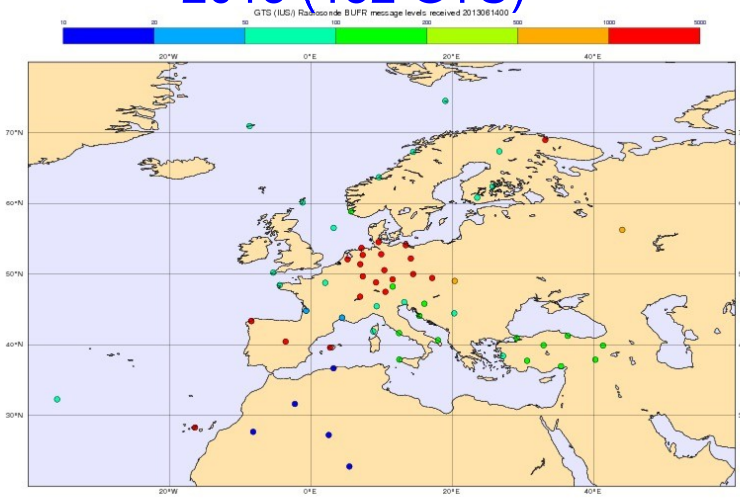
Higher resolution,
Better accuracy,
More Metadata




2011 (96 GTS)



2013 (152 GTS)



*By Eoin Whelan, METIE*

# Assimilation of radar data in HARMONIE

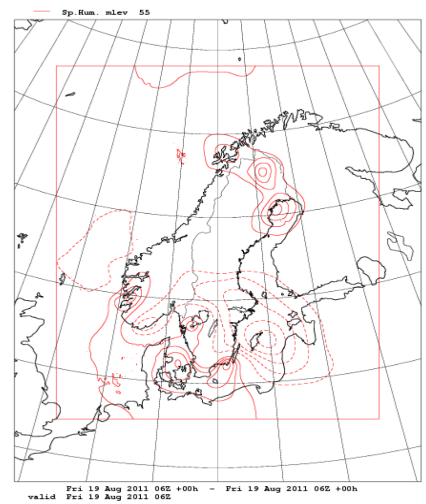
Case study ( in collaboration with MetCoOp)
(2.5 km AROME; 65 vertical levels;
DA: 3h RUC 3DVAR;
Forecast + 30h from 00, 06, 12, 18)

Two weeks August 2011

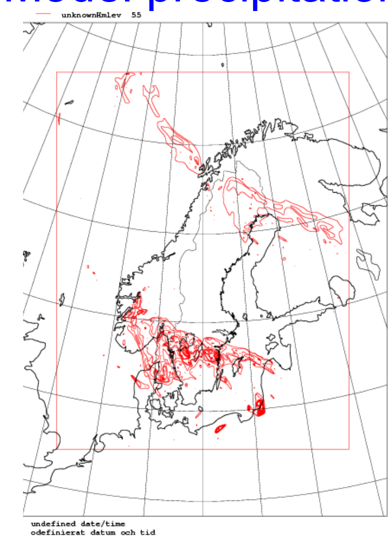
Conventional +
radar radial winds +
reflectivities (no lowest elevation)

Gives clear positive impact on specific humidity and temperature scores in the middle atmosphere (500 hPa)

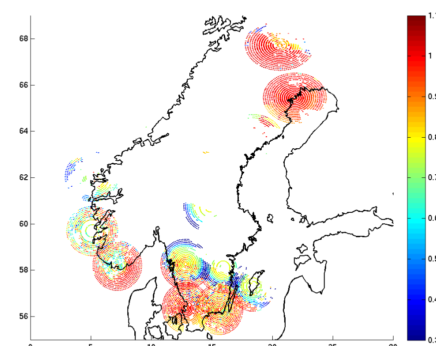
Analysis increment



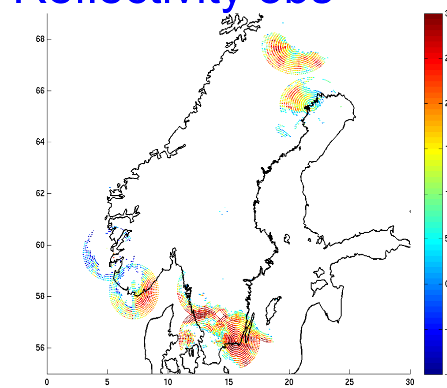
Model precipitation



Hum. pseudo-obs



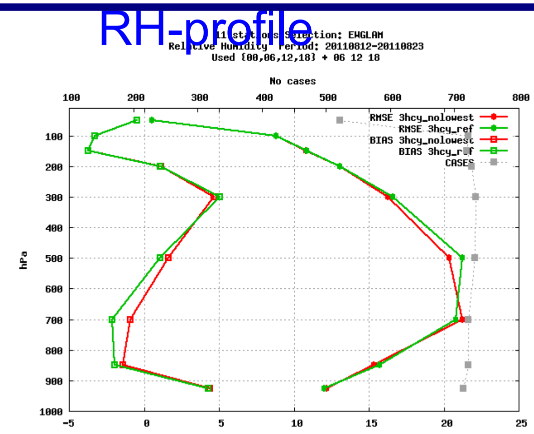
Reflectivity obs



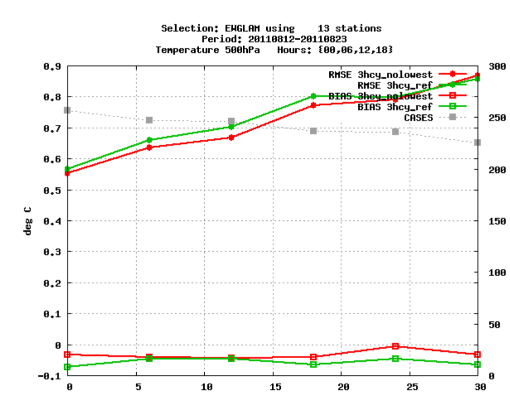
With radar data

No radar data

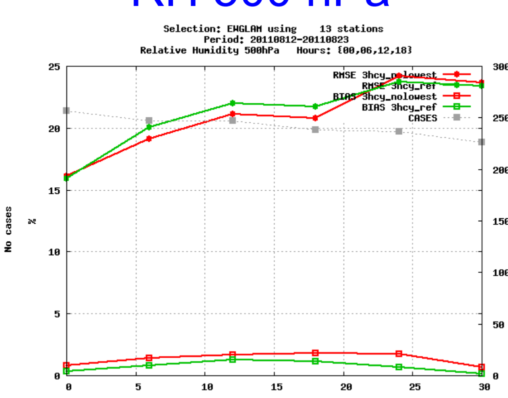
RH-profile




T 500 hPa




RH 500 hPa




*By Martin Ridal, SMHI*

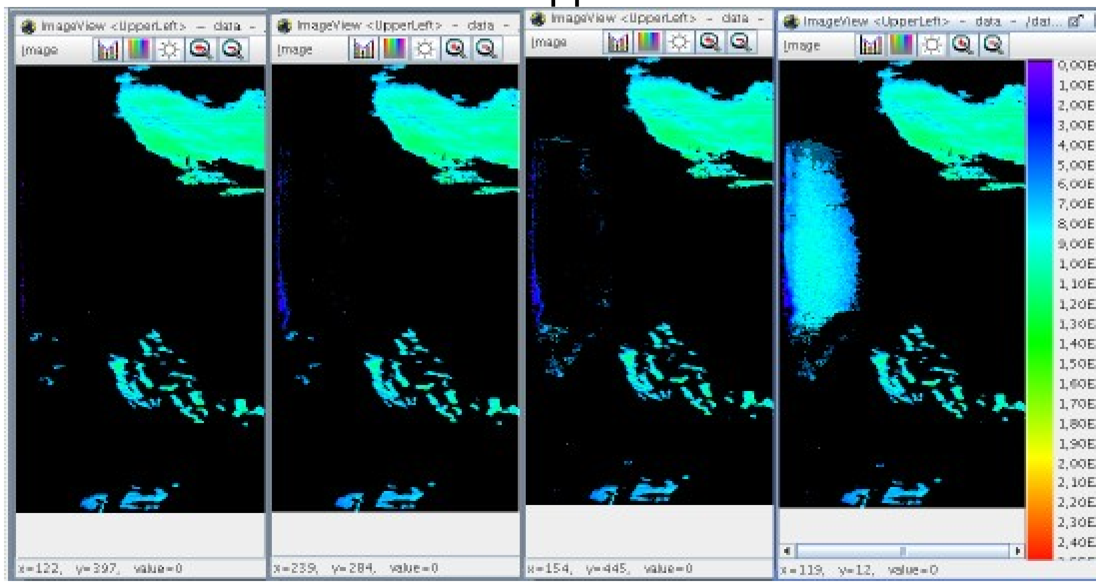
# Radar data pre-processing : common quality control

is a core issue for radar data assimilation. Joint efforts at several HIRLAM NMS's (KNMI, SMHI, METIE, AEMET, DMI ) are taken to understand cons and pros of the BALTRAD QC Toolbox intended as the common radar data QC tool in OPERA.

- ➔dealias
- ➔bRopo
- ➔beamb
- ➔HAC
- ➔POO
- ➔RADVOL-QC
- ➔BALTRAD-HMC
- ...

bROPO

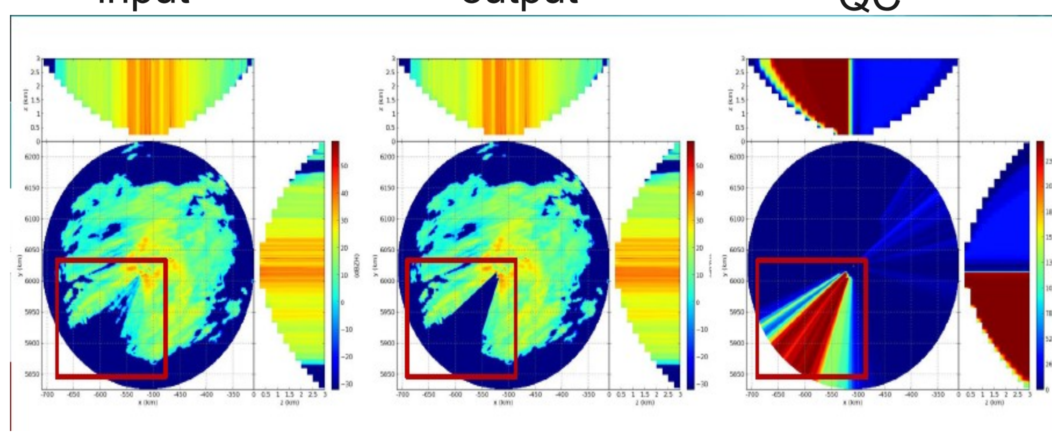
various filters applied | no filter



*by Lorenzo Rodriguez Magaz and Calos Geijo, AEMET*

beam blockage

input | output | QC



*by Eoin Whelan, METIE*

# Radar data assimilation : raw radar data exchange

- Small countries => efficient radar data exchange is required;

- Flagged volume data to be distributed by OPERA by end of 2014

- Meanwhile, a “demonstration infrastructure” project by SMHI testing the real-time dissemination of data from ODC via BALTRAD “life feed”.

- The implementation of “foreign” radar data is well progressing at several HIRLAM consortia NMS's.

The technical implementation at DMI of raw radar data from Denmark, Sweden, Finland, Norway and Poland lead to the conclusion that even small local differences in the format (ODIM HDF5) lead to annoying problems introducing data into the DA system. Flexible pre-processing tools and strict format rules are essential.

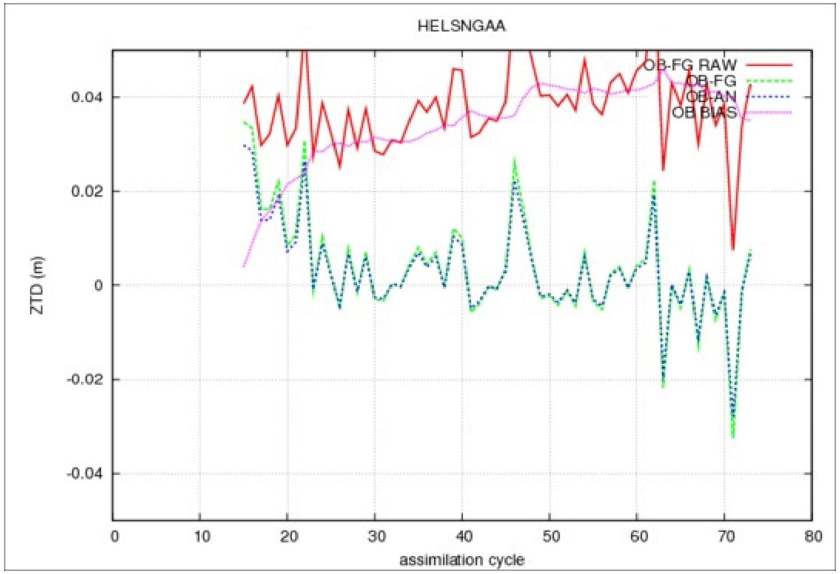
# ZTD GNSS data : status for implementation

x Station dependent bias correction with the synoptic weather regime time-scale is essential;

x VARBC algorithm for GNSS with the **off-set only** is under investigation by joint efforts of at AEMET, MET Norway, SMHI and DMI
(We deeply acknowledge support from Paul Poli (ECMWF) and Partick Moll (MF) );

x Accounting of low model top in the observation operator reduces severe positive bias

Bias diagnostics (active station)
VarBC , OB-FG without VARBC, OB-FG with VarBC, OB-AN

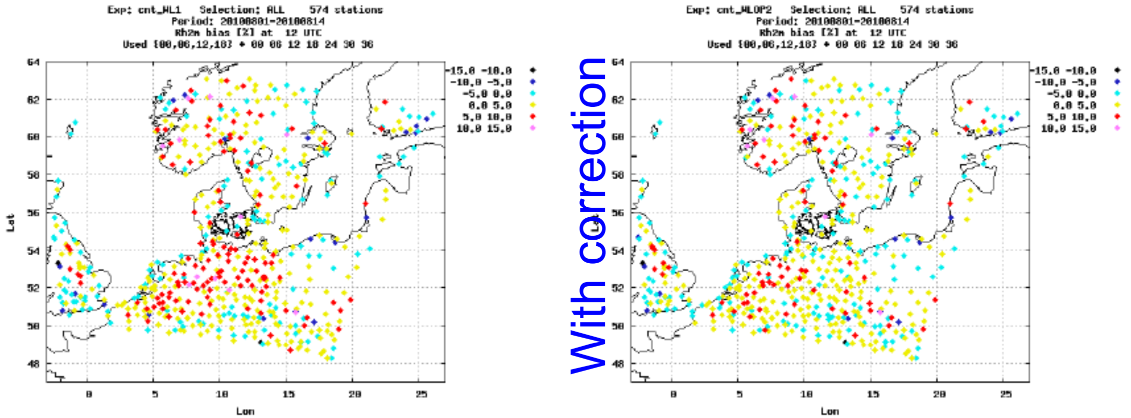



*By Magnus Lindskog, SMHI*

**OB – FG differences**

Without correction

With correction



*By Jana Sanchez Arriola, AEMET*

Correction of obs. op. due to low model top (Hernrik Vedel, DMI)

$$ZTD_{top} = 10^{-6} a * R_d * P_{top}/g$$

where a = 77.6 K/hPa
$R_d$ is the gas constant for dry air
g is the gravitational acceleration.
$p_{top}$ is the pressure at the top of the model.

# Mode-S observations and data production

Period 2012/08/09 10:00-10:15

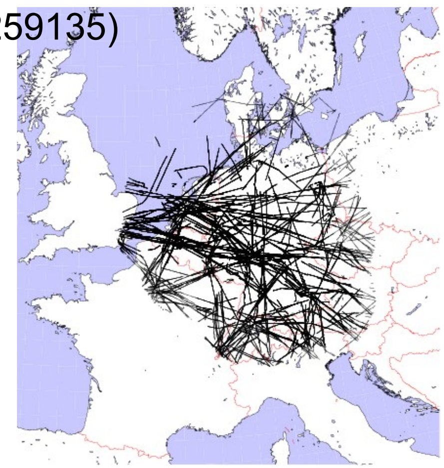
Information on the Mode-S EHS research and the data production status can be found on **http://mode-s.knmi.nl/**

Currently, Mode-S EHS derived meteorological information is available for NMHS, after signing a ***Non Disclosure Agreement.***

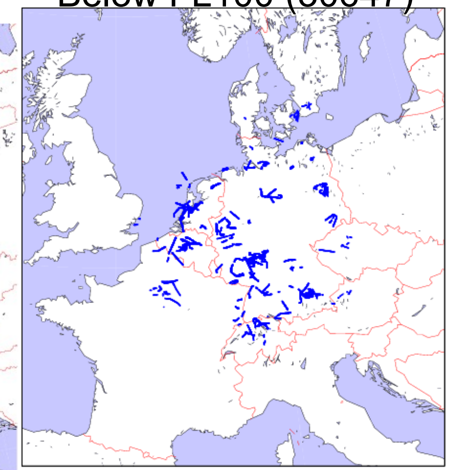
Data are available in NETCDF, ASCII and BUFR format each 15 minutes with a delay of 10 minutes

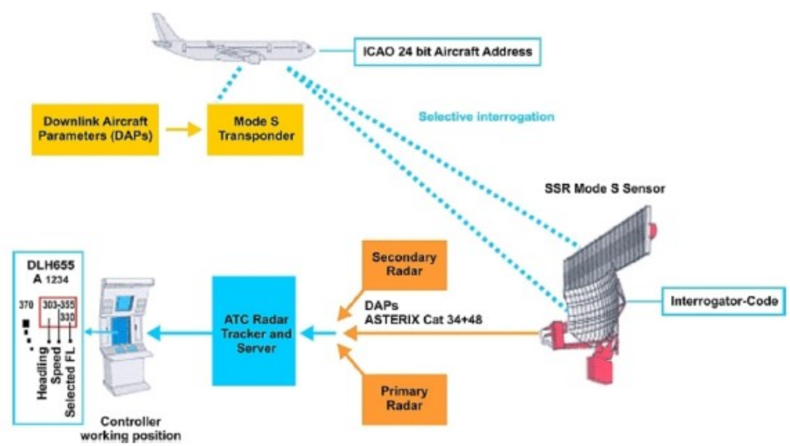
Data can be distributed using personal ftp-account. Contact ***mode-s@knmi.nl***

All observations (259135)



Below FL100 (30647)






*By Siebren de Haan, KNMI*

# “Coordinated radar data impact studies”

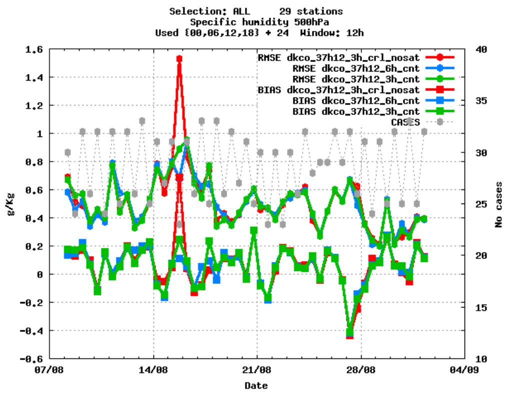
**Baseline experiment: Conventional + ATOVS**

Significant improvement in prediction of the specific humidity (+24h forecast) valid at the 15th of August 2010 18 UTC due to assimilation of the ATOVS observations .(plot a)

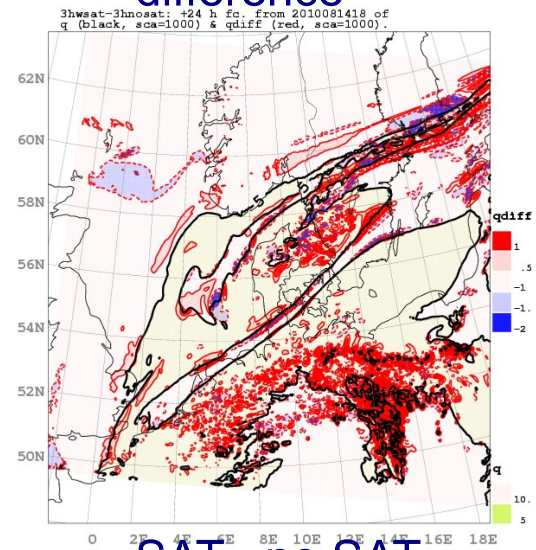
The improvement comes from the corrected position of the front in +24h forecast valid on the 15th August 2010 18 UTC(plot b)

The improvement in front position comes from the analysed field valid on the 14th August 2010 18UTC

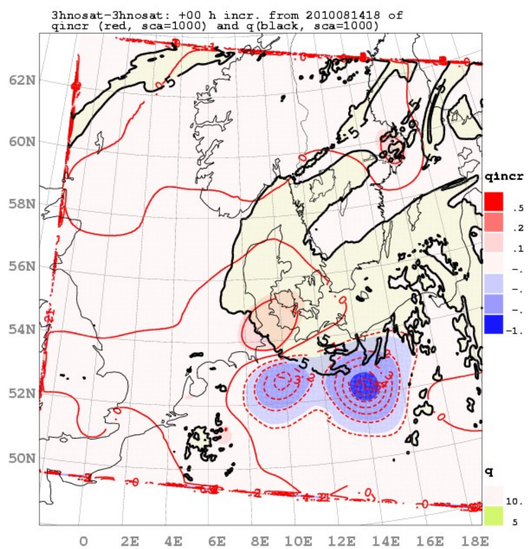
Specific humidity
At 500hPa



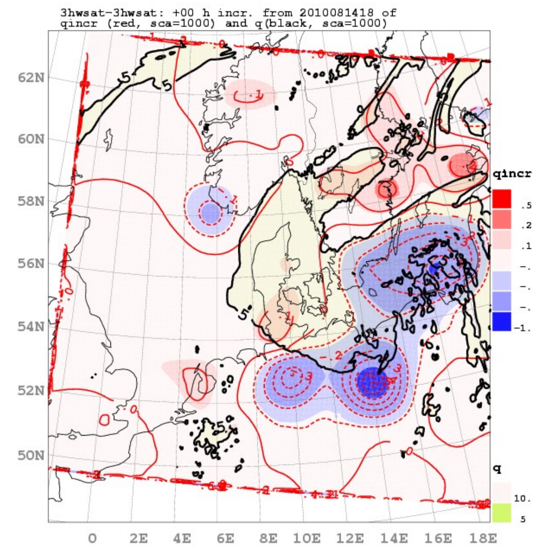

+ 24h forecast difference




SAT– no SAT




No SAT bg -
No SAT an




SAT bg -
SAT an

Analysis difference

*By Sigurdur Thorsteinsson, IMO*

# Optimal selection of the predictors: ATOVS

ATOVS observations improves prediction of large scale features such as fronts even for small size domain with relatively low model top (10hPa).

- manual domain specific blacklisting of “bad” paths
- assimilation of lower peaking channels
- optimal selection of bias predictors

(DO NOT OVERFIT!)

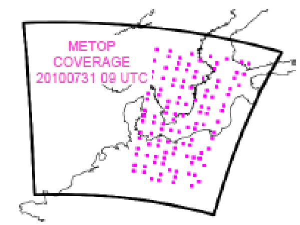
are important in order to obtain positive impact

**Data usage**

**AMSU-A from:** NOAA-15, NOAA-16, NOAA-18, NOAA-19, METOP
Used channels: ch 6-9 + ch 5 (over sea)
Except NOAA-19 ch 8, METOP-A ch 7

**AMSU-B/MHS from:** NOAA-18, METOP
Used channels: ch 5 + 3,4 (over sea)

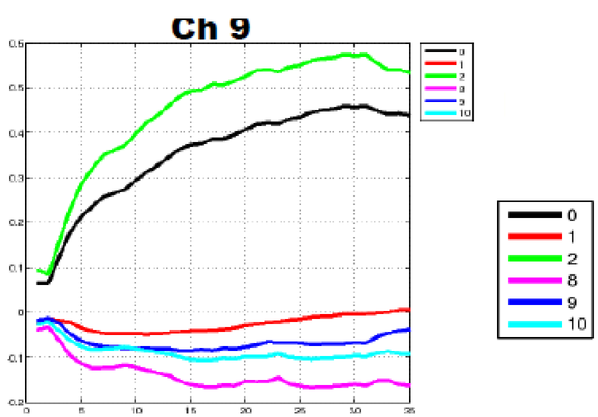
In addition LISTE_LOC_${HH} in BATOR to reject data from satellite passes that just touches the domain (manual procedure and domain specific)



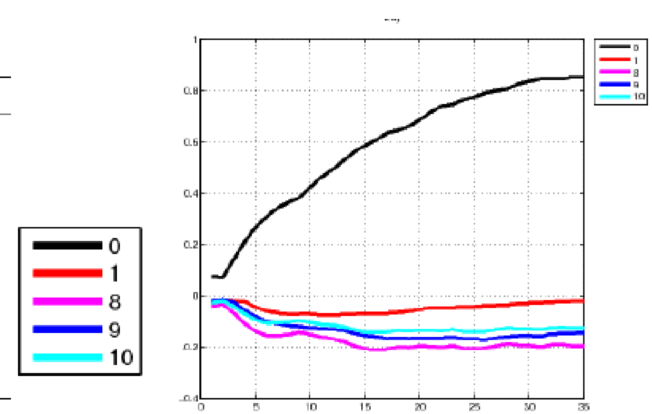

**Thinning**

Minimum and average thinning distances for different ATOVS instruments

| Instrument | RMIND_RADIC (km) | RFIND_RADIC (km) |
|---|---|---|
| AMSU-A | 60 | 80 |
| AMSU-B | 40 | 80 |
| MHS | 40 | 80 |




| Predictor no. | Predictor |
|---|---|
| 0 | constant |
| 1 | 1000-300hPa thickness |
| 2 | 200-50hPa thickness |
| 5 | 10-1hPa thickness |
| 6 | 50-5hPa thickness |
| 8 | nadir view angle |
| 9 | nadir view angle **2 |
| 10 | nadir view angle **3 |

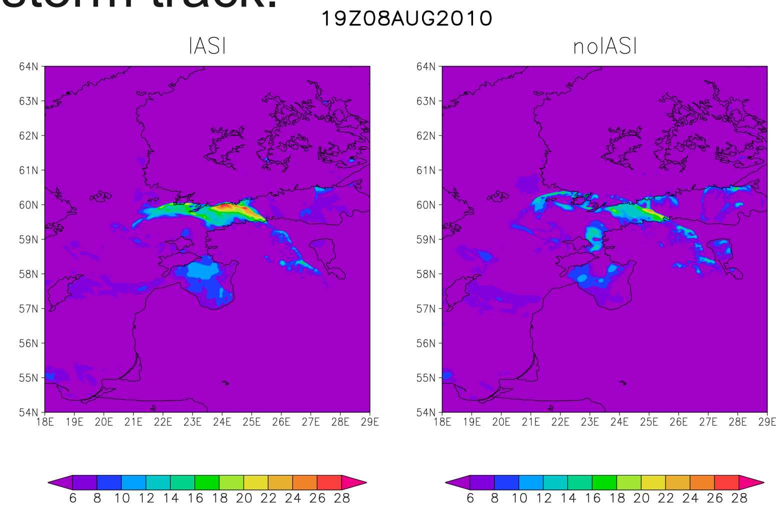


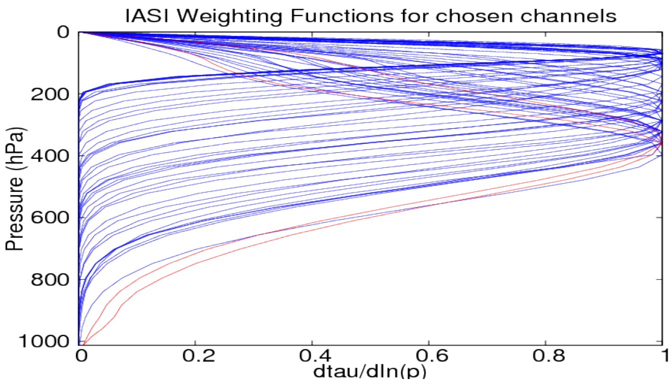

*By Magnus Lindskog et al, SMHI*

# Assimilation of IASI for LAM domain

Case study: severe storm on the 8th of August 2010. Heavy thunderstorms with intense downbursts and the wind gusts up 33 m/s were observed;

IASI impact on +36h forecasts : system is better structured; maximum wind speed is larger; wind field is wider. However, no significant impact on the storm track.




*Weighting functions for the selected channels in a standard atmosphere. Red channels were only assimilated over sea.*

**Highlighted Challenges :**

Assimilation of low-peaking channels and radiances in cloudy conditions; estimation of the "best fit" emissivity, dependent on the surface type . DA will be tried as a devise to estimate unknown parameters.

*By Tuuli Perttula, FMI*

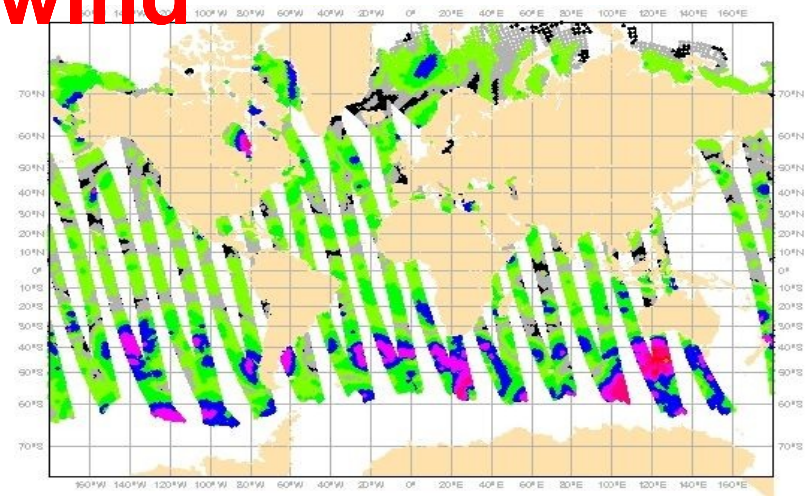
# Assimilation of scatterometer wind & overall tuning of DA set up

Assimilation of scaterometer observations is able to correct winds in the of 1-2 m/s

Positive impact can be seen on 850hPa scores (against AIREP observations)

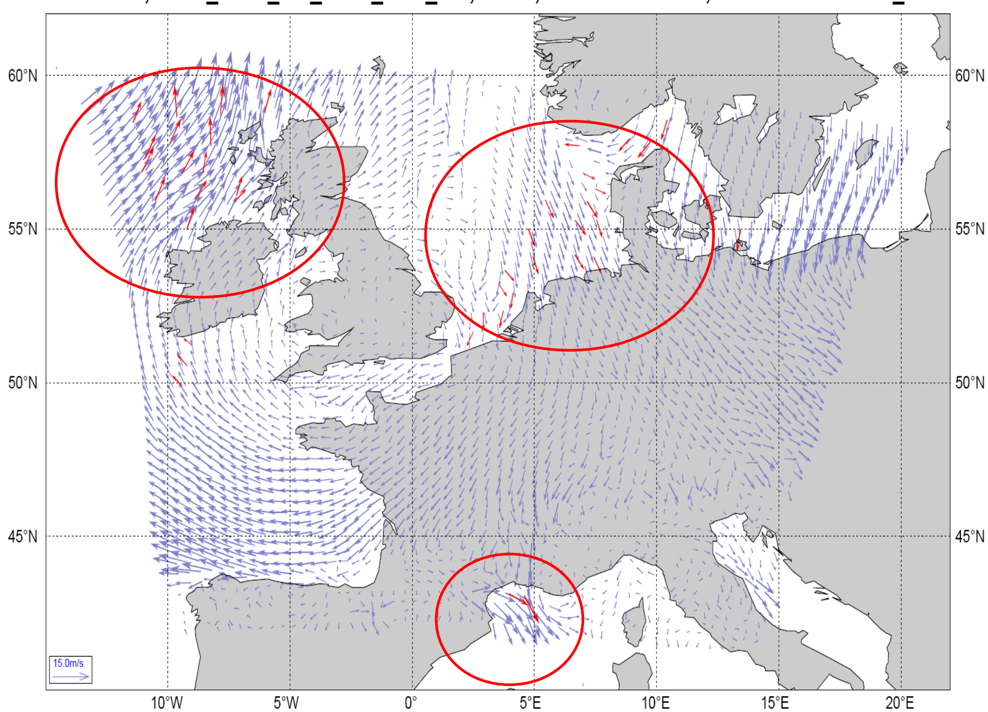
**Conclusion:**

- Too large weights are given to observations;
- more strict QC control is required
- overall tuning of the DA configuration is needed: thinning, QC, super-obbing, correlated obs.errors

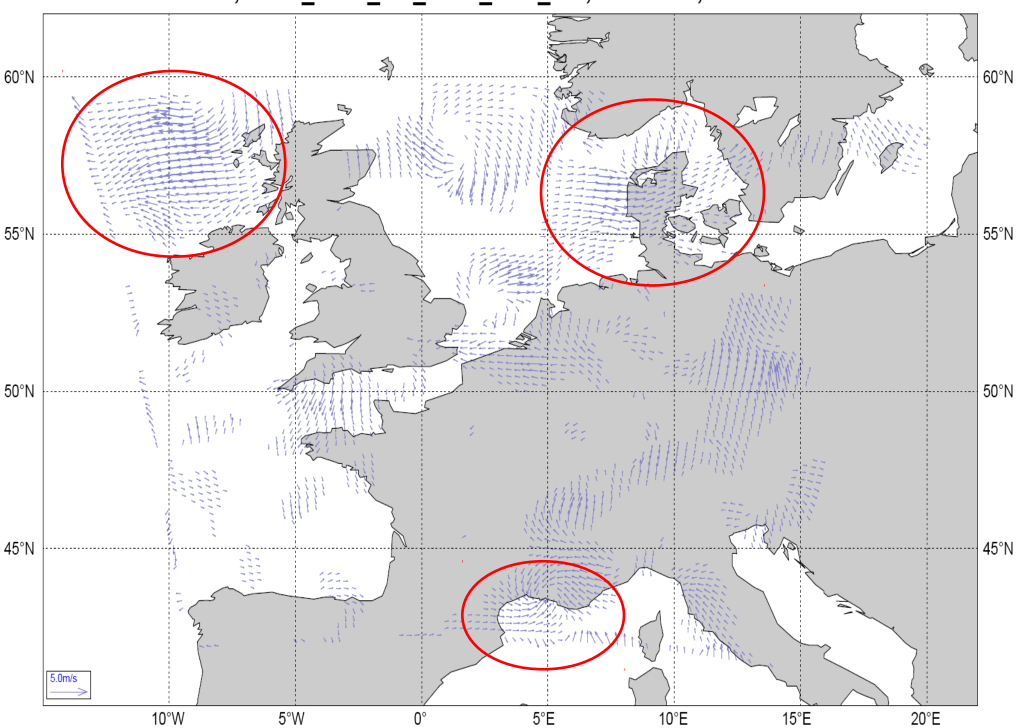


ASCAT (METOP-A)
QuickSCAT
Oceansat-2

Harmonie; D800_MW2_DA_conv_scat_def; FC+6; VT: 2007110412; assimilated ascat_coa




Harmonie; D800_MW2_DA_conv_scat_def; AN-FC+6; VT: 2007110412




*By Gert-Jan Marseille, KNMI*

# Blacklisting & COPE

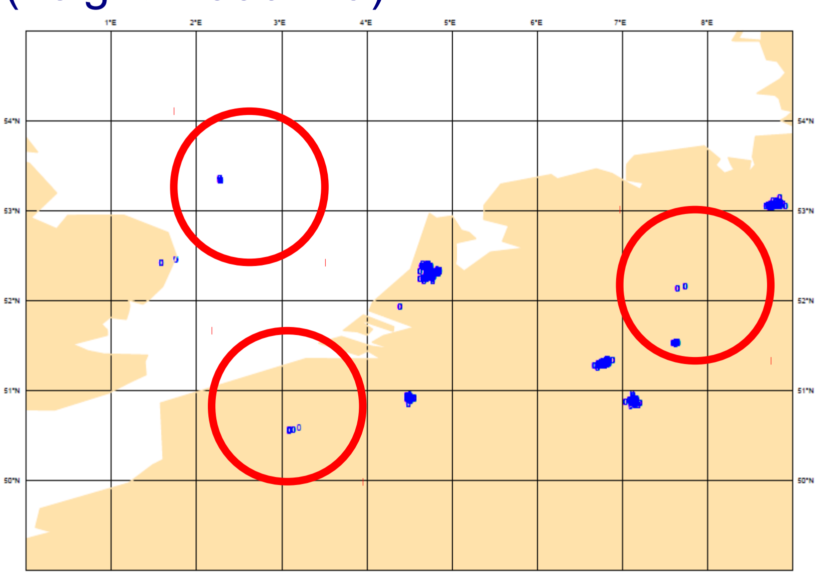
DA: 1hRUC 2,5km AROME 300x300

Dramatic impact of the wrong measurement (small domain, small DA window, high relative weight of observation)

Flexible and powerful blacklisting methodology + joint monitoring is essential for small size domain RUC systems =>
HIRLAM put heavy expectations on COPE collaboration

AMDAR position error problem is under control. Thank to Lars Isaksen (ECMWF)

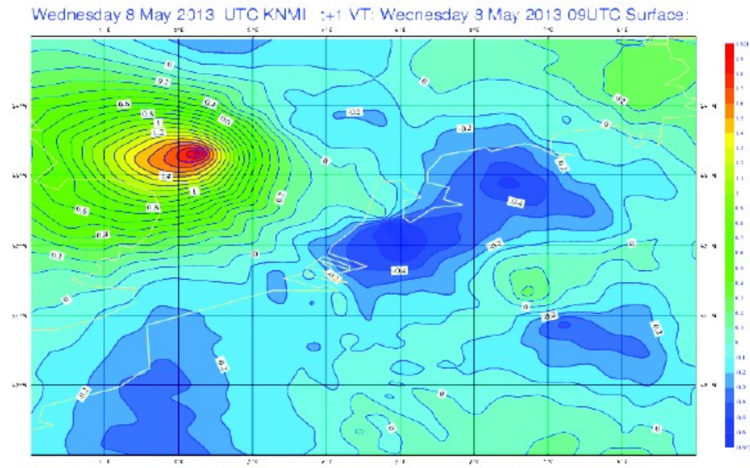
Erroneously reported position of the AMDAR measurement (height < 990hPa)



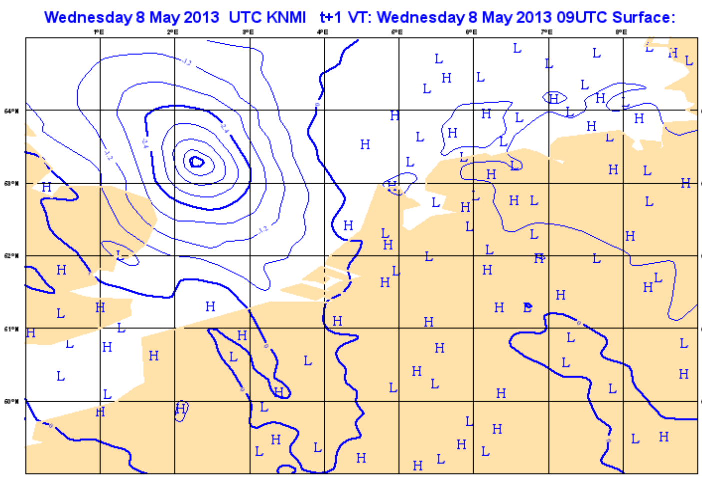
*By Jan Barkmeijer, KNMI*

Anomalous increments

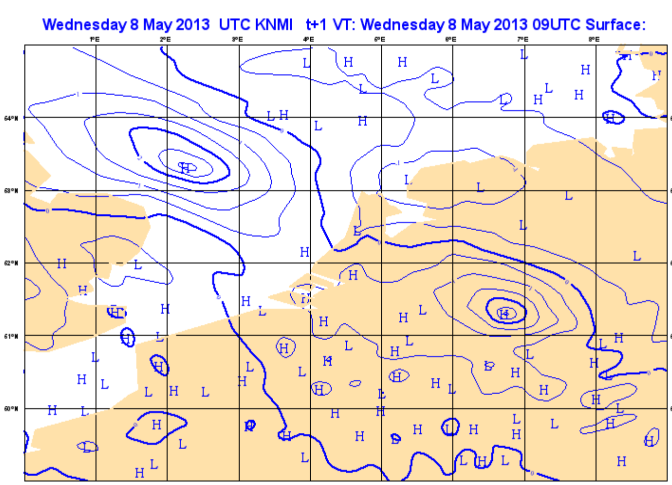
T 850hPa




U 850hPa




V 850 hPa



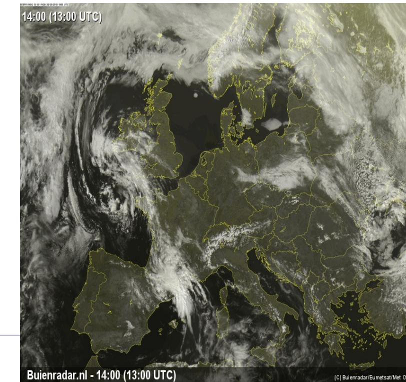
# Cloud mask initialisation

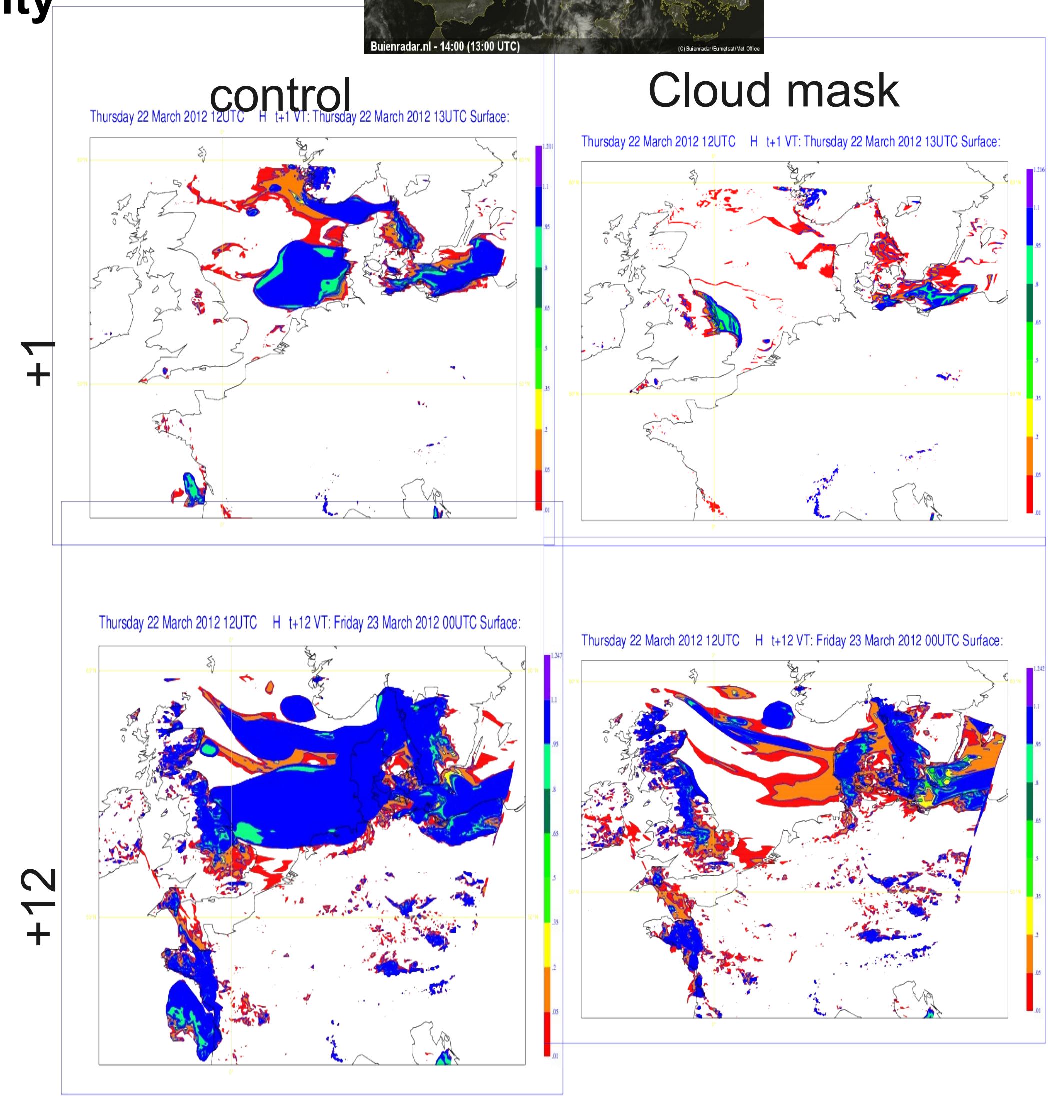
## Keep virtual temperature constant :

**preserve buyoancy when changing humidity**

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

( temperature and humidity profiles are modified using cloud mask nowcasrting SAF, MSG cloud top temperature and SYNOP cloud base heigh). Correction is applied after Var DA.




x Removes artificial fog up to +24 h forecast;

x Improves short range forecast for precipitation, surface pressure, cloud cover and the upper air temperature

x Longer lasting impact on larger domain

**The scheme must be integrated into the variational data assimilation system**

*By Sibbo van der Veen, KNMI*

# Structure of the talk

1. **Short-term framework for meso-scale DA in HIRLAM-B**
   - new BUFR format
   - radar data, common QC tool, radar data exchange
   - GNSS
   - Mode-S
   - ATOVS, IASI
   - scatterometer winds and overall tuning of DA system
   - blacklisting & COPE
   - cloud mask initialisation
2. **Long-term algorithmic investments**
   - **2DEnsVAR**
   - **Hybrid 4DVAR**
   - **HIRLAM 4DEnsVAR**
   - **phase-error correction via image registration**
   - **super-hybrid**
   - **hybrid FA+3DVAR for radar radial winds**

Hirlam + ALADIN = HARMONIE

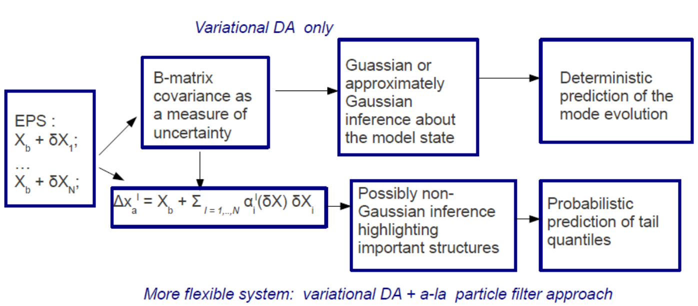
# Longer term algorithmic developments in the HIRLAM community

* Ability to reflect the flow-dependency is crucial for efficient DA for maso-scale phenomena

* “4DEnsVAR framework” is decided as the long term perspective “algorithmic investment”

* Long term core data assimilation developments should fit consistently in the OOPS/IFS code restructuring and should rely on the OOPS paradigm as the framework for the novel developments

* The HIRLAM community foresees a consistent and mutually enriching DA-EPS development which will result in a reliable probabilistic forecasting system on convection-permitting scales



# Large-scale error constraint

**HIRLAM approach**

$$J = J_b + J_k + J_o$$

With preconditioning;
function of host model vorticity only

$$J_k(\hat{\zeta}) = \frac{1}{2}(\hat{\zeta} - \hat{\zeta}_{ls})^T B_{ls}^{-1}(\hat{\zeta} - \hat{\zeta}_{ls})$$

$$J_k(\hat{\chi}) = \frac{1}{2}(L_{ls}\hat{d}_k + L_{ls}L_b^{-1}\hat{\chi})^T(L_{ls}\hat{d}_k + L_{ls}L_b^{-1}\hat{\chi})$$

Where

$$\hat{d}_k = \hat{\zeta}_b - \hat{\zeta}_{ls}$$

$L_b$ is the transform operator based on B

$L_{ls}$ is the transform operator based on $B_{ls}$

**HARMONIE approach**

$$J = J_b + J_o + J_k$$

Without preconditioning;
function of the host model state

$$J_k = (x - x_{ls})^T V^{-1}(x - x_{ls})$$

V is the diagonal matrix
(no spatial structures in $x_{ls}$ )

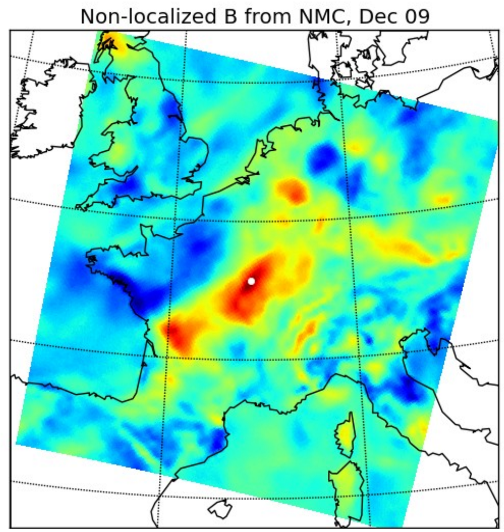
Performance of the Jk constraint as a way to account for large scale error in the HIRLAM implementation is superior to the performance of Jk in the HARMONIE implementation =>
**The comparison of two methodologies in the clean scientific environment is needed**

*By Per Dahlgren, SMHI*

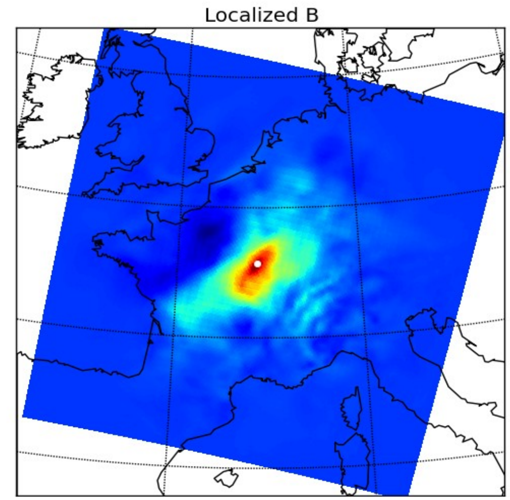
# 2DEnsVAR : Advanced spatialisation tool

Long time series climatological ensemble is able to represent non-homogeneity and anisotropy induced by orography and land-sea mask

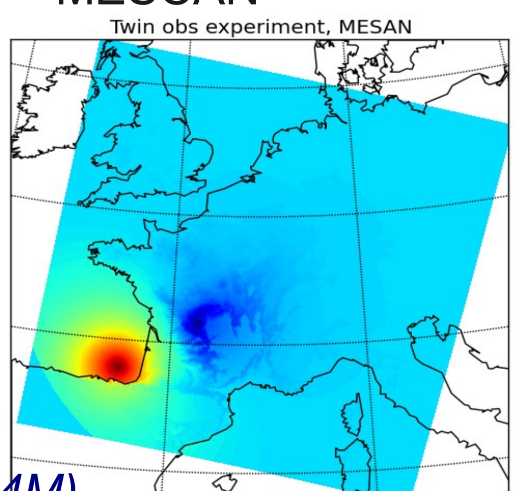
Non-localized B from NMC



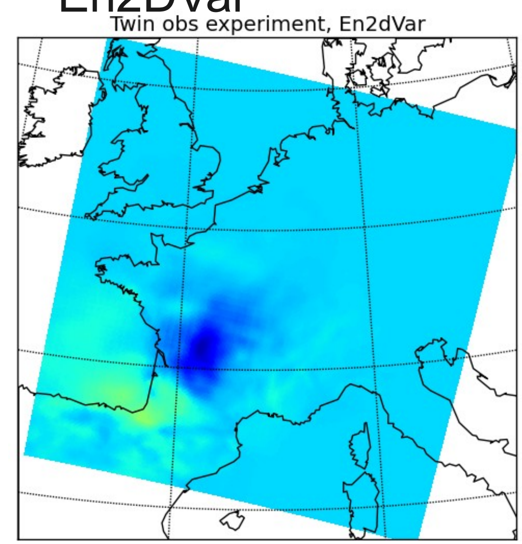

Localized B from NMC (Schur product)




MESCAN




En2DVar




*By Tomas Landelius, SMHI*
*(cooperation with MF within EURO4M)*

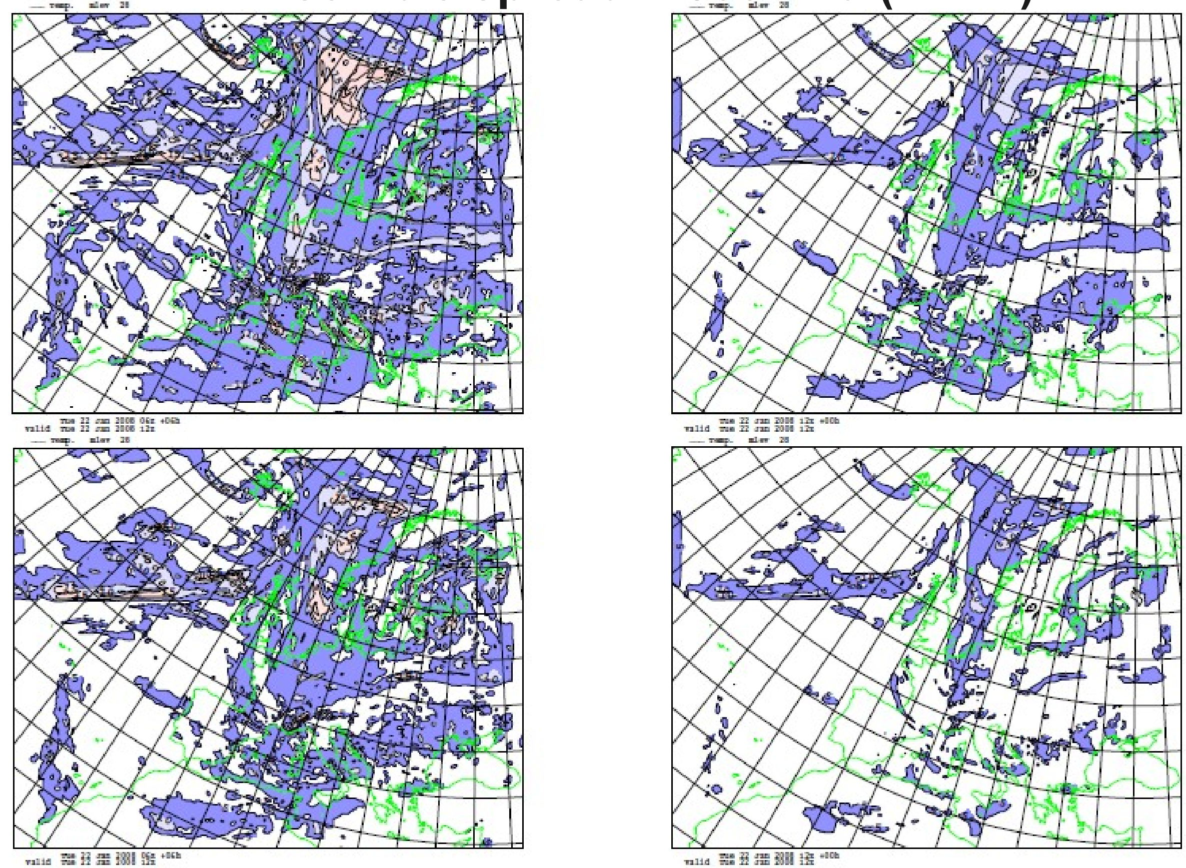
# HYBRID Ensemble 3-4 Variational DA

describes well flow-dependent structures and outperforms 3DVAR significantly and 4DVAR slightly using standard verification scores

## Ensemble spread T 800 hPa (ETKF)

3DVAR hybrid

4DVAR hybrid



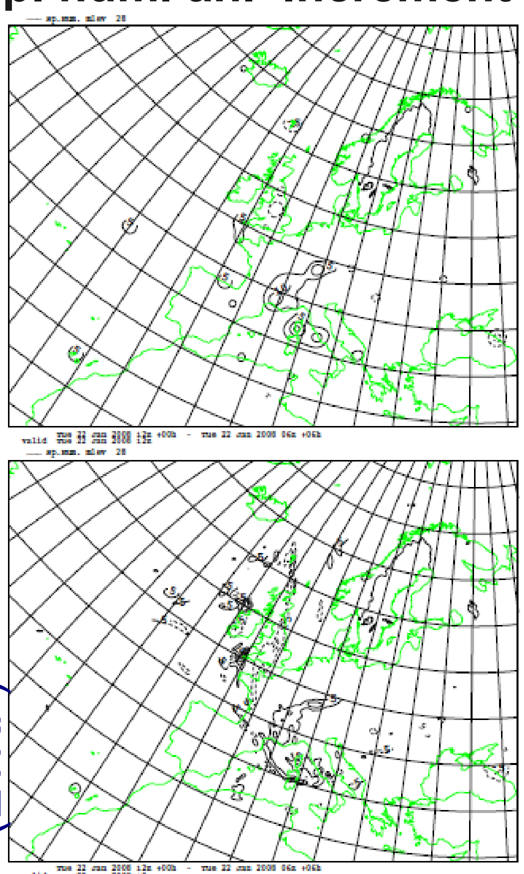
Forecast pert

Analysis pert

## sp. hum. an. Increment

3DVAR

3DVAR hybrid (ETKF)



$$J(\delta \mathbf{x}_{var}, \alpha) = \beta_{var} J_{var}(\delta \mathbf{x}_{var}) + \beta_{ens} J_{ens}(\alpha) + J_o$$

$$\delta \mathbf{x} = \delta \mathbf{x}_{var} + \sum^{K} (\alpha_k \circ \delta \mathbf{x}_k^{ens})$$

$$\delta \mathbf{x}_k^{ens} = \mathbf{x}_k^{ens} - \overline{\mathbf{x}^{ens}}$$

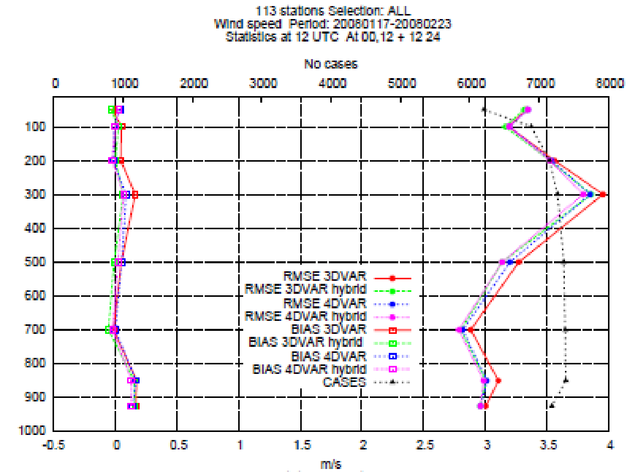
Ensemble: ETKF based rescaling scheme and EnsDA (HIRLAM forecasting system)

*By Jelena Bojarova, MET Norway, & Nils Gustafsson, SMHI*

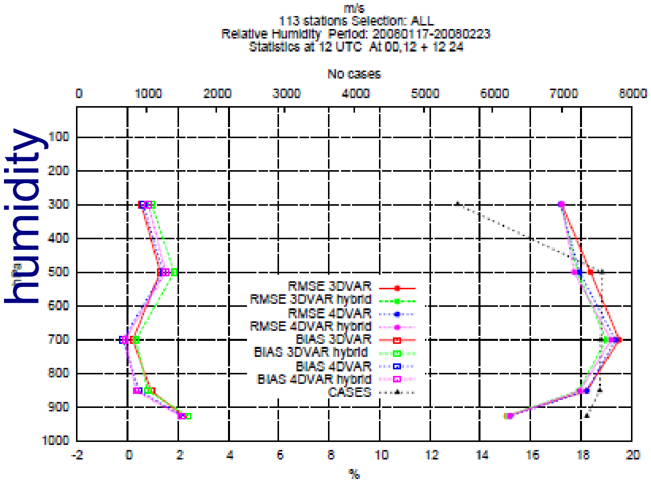
# HYBRID Ensemble 3-4 Variational DA

Verification scores+12, +24 forecasts against radiosondes : 3DVAR, 3DVAR hybrid, 4DVAR, 4DVAR hybrid

Wind speed

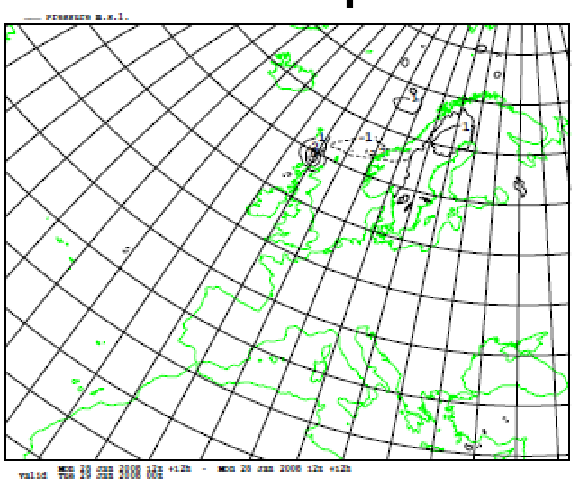



Relative humidity

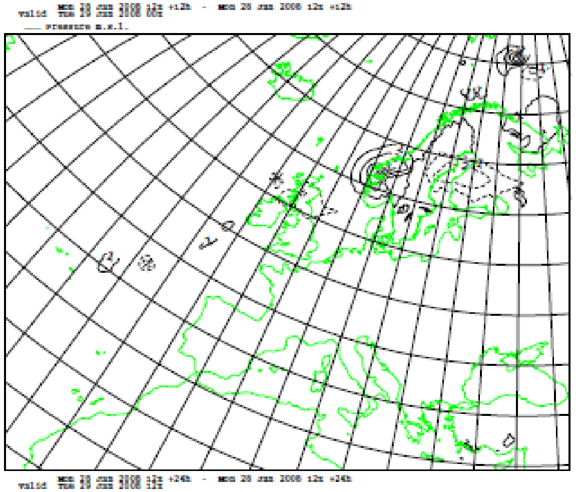



**Mean sea level pressure**

+00h



+12h



Difference between mean sea level pressure from 4DVAR_hybrid1 and 4DVAR_hybrid2. 4DVAR hybrid2 uses additional lagged ensemble with deliberately wrong validity time (+2h) and is able to capture phase error.

*By Jelena Bojarova, Met Norway, & Nils Gustafsson, SMHI*

# HIRLAM 4DEnsVAR

**Single obs . Wind incr 500 hPa, the 5th obs. window**

4D-Var :

$\delta x_t = \mathrm{M}(t_0, t)\delta x^B_{t_0}$

M Tangent-linear model

4D-Var Hybrid:

$\delta x_t = \mathrm{M}(t_0, t)\left(\delta x^B_{t_0} + \sum_{k=1}^{K} \alpha_k \circ \delta x_k^{EPS}(t_0)\right)$

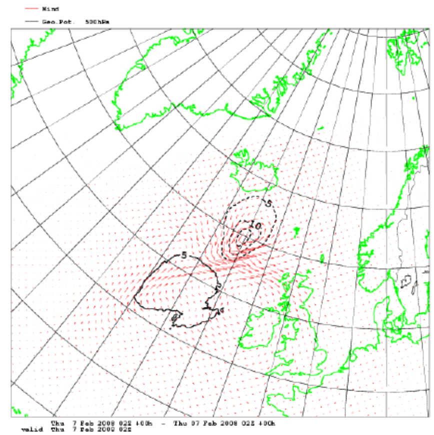
4DEnsVar (strong constraint):

$\delta x_t = \sum_{k=1}^{K} \alpha_k \circ \delta x_k^{EPS}(t)$

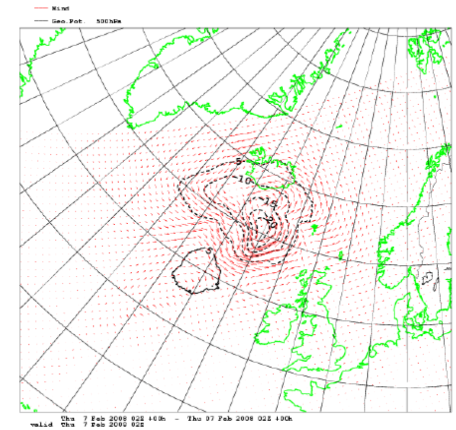
$+\delta x^B_{t_*}$ (optional term)

With time-variable localization $\alpha_k$ we will have

Weak constraint 4DEnsVar!

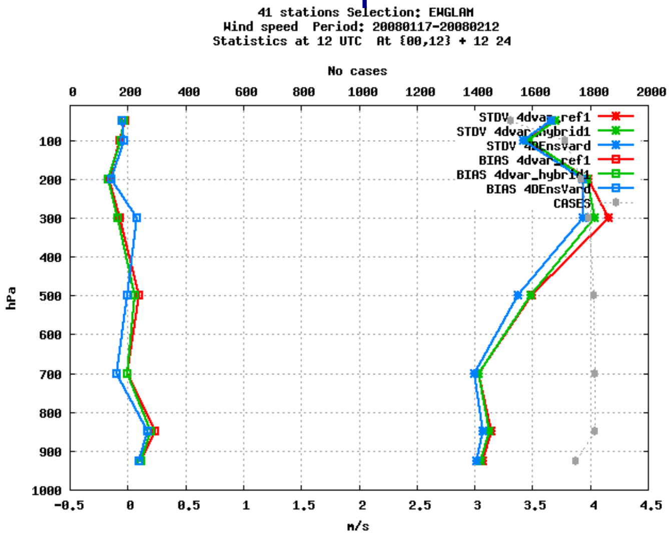



4DVAR



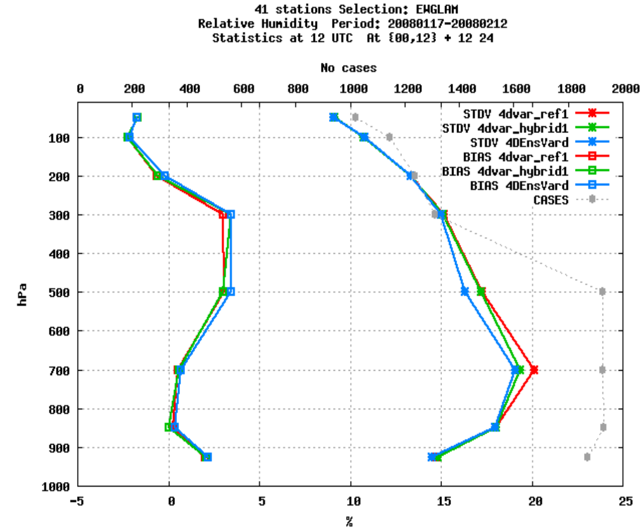

4DEnsVAR

wind speed




HIRLAM 4DEnsVAR outperforms 4DVAR and 4DVAR hybrid in wind speed and relative humidity standard verification scores !

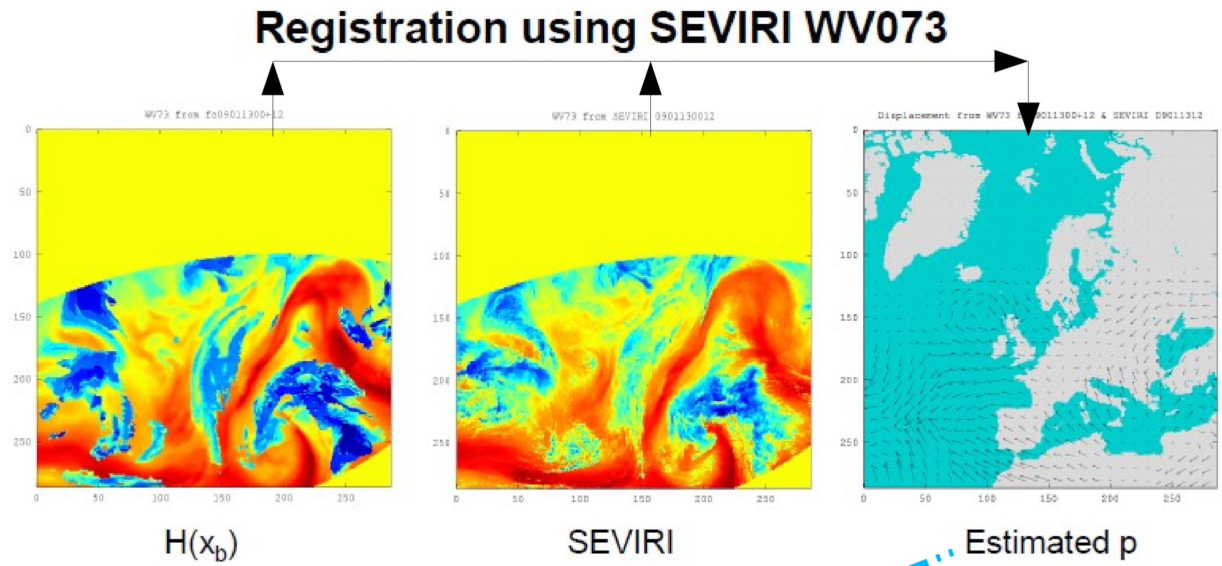
relative humidity



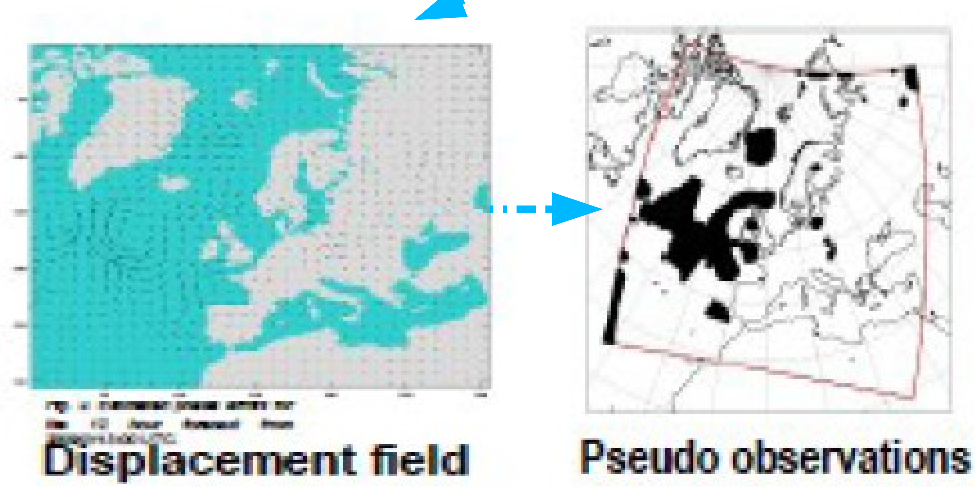

*Bra jobbat, Nils Gustafsson et al !*

# Phase-error correction using image registration

The warped field based on the water vapour images derived from from the SEVIRI observations are introduced **in the form of pseudo-observations.** They are used to modify the background field relying on the variational data assimilation and **its balance constraint.**

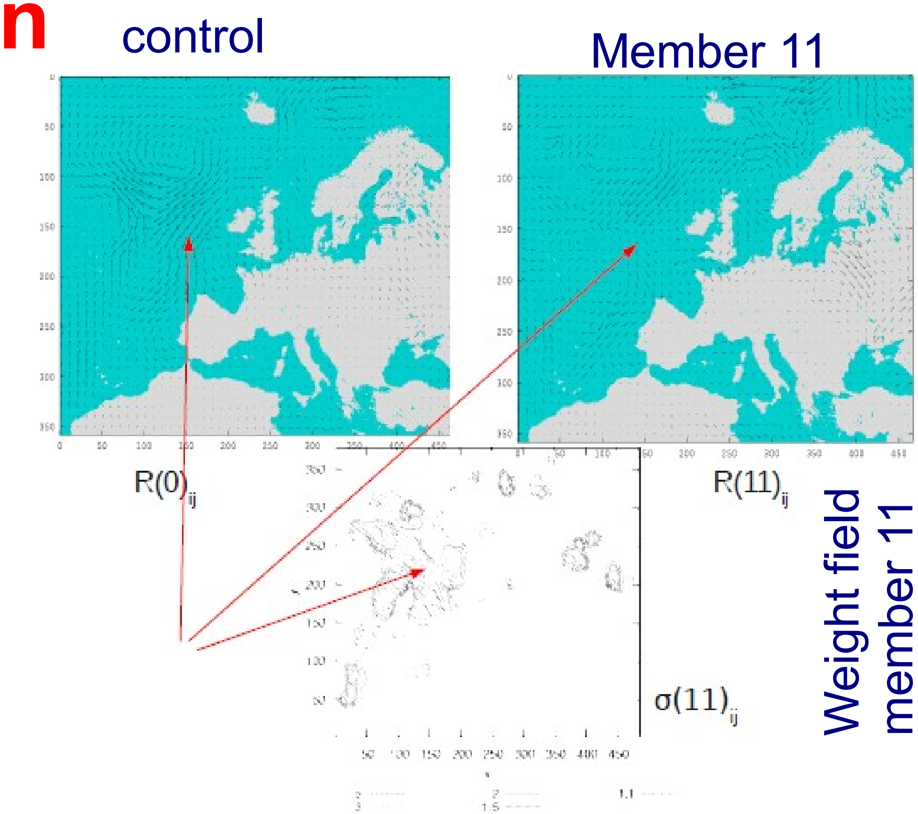



The resulting "phase-error " corrected field is used as the background field for standard 3DVAR assimilating other conventional + ATOVS observations.



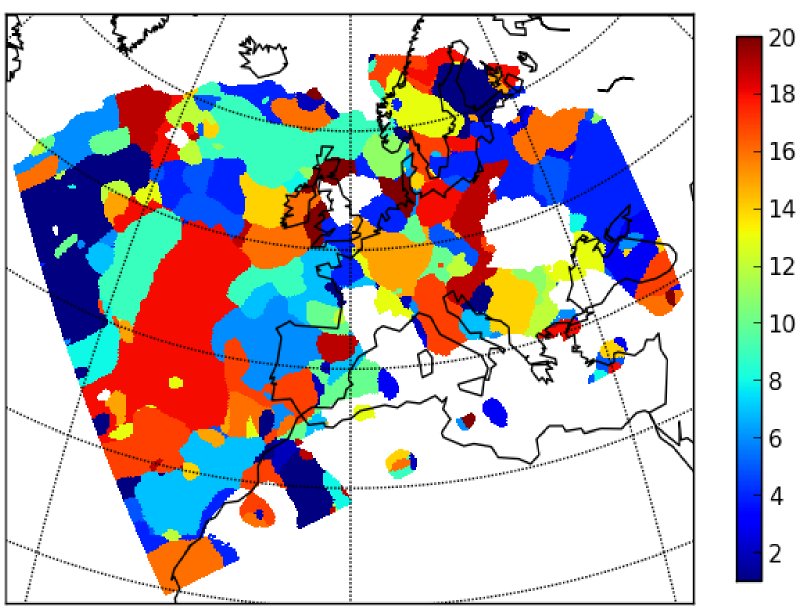

*By Tomas Landelius, et al, SMHI*

# The best member selection




- Use integrated water vapour ensemble forecasts and compare these to the SEVIRI image (or other "truth")
- Calculate horizontal displacement $R(m)_{ij}$ for each ensemble member $m$ including control ($m=0$) in each grid-point ($i,j$)
- For each grid-point with a "large" displacement error ( $|R(0)_{i,j}| > \delta$) in the control forecast assign an ad-hoc ensemble member weight $\sigma(m)_{ij} = max\,\{min([R(0)_{ij}/R(m)_{ij}],8),1\}/nmembers$

**Distribution of the "best" members**




*By Nils Gustafsson et al, SMHI*

Aim: to merge hybrid ensemble variational technique and phase-error correction.

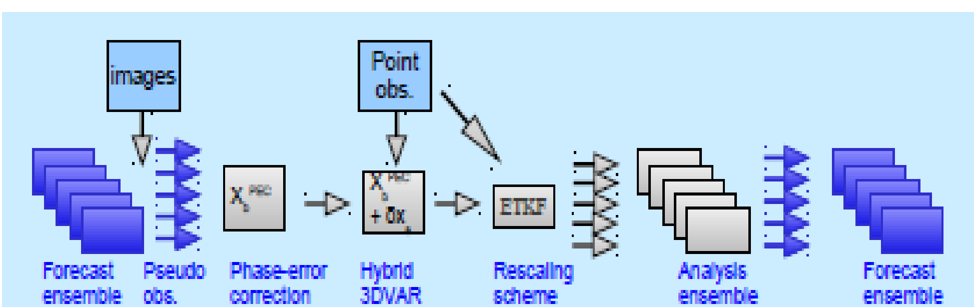
The HIRLAM ETKF rescaling perturbation scheme is able to capture variability .very well and describe spatially consistent structures (20 members)

# “super-hybrid” (assimilation of structures)

***Step 0:*** Select locally “best” ensemble member $m^*$ - ensemble member with the largest $\sigma(m)_{ij}$ <=> the largest displacement in control $R(0)_{ij}$ and the smallest displacement error in this member $R(m^*)_{ij}$

***Step 1:*** Generate pseudo-observations from the locally best ensemble members and assimilate these pseudo-observation using the hybrid ensemble variational technique in order to obtain phase-error corrected background utilizing flow-dependent balances.

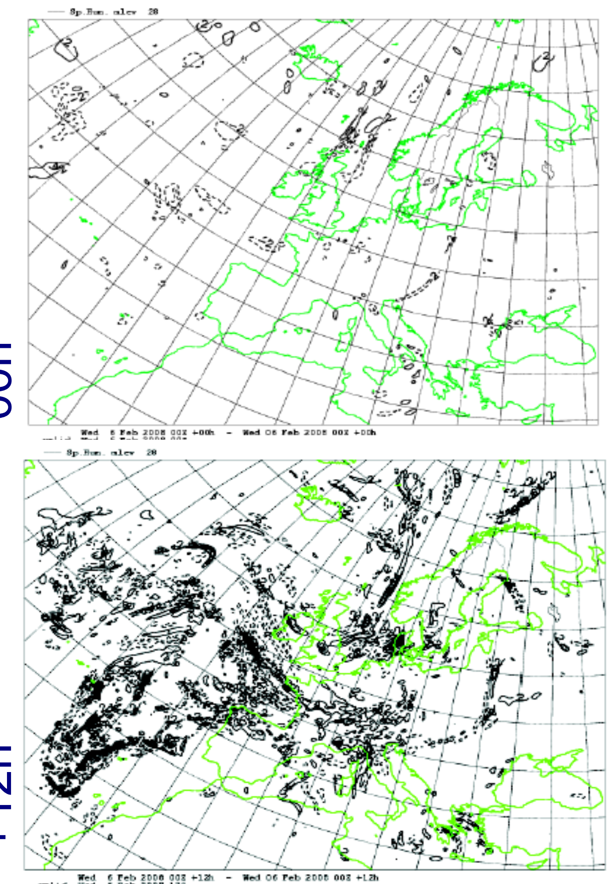
***Step 2:*** Perform the hybrid ensemble variational data assimilation using the phase-error corrected background and the “usual” observations preserving introduced structures.




**Specific humidity**

Inserted structures 00h

Evolved structures +12h



2 step “super-hybrid” - 3DVAR hybrid

Inserted structures evolves coherently in time

*Nils Gustafsson et al, SMHI. Thanks to the Swedish National Space Board*

# Phase-error correction via field alignment

## Assimilation of Doppler Wind Radar Data in HARMONIE

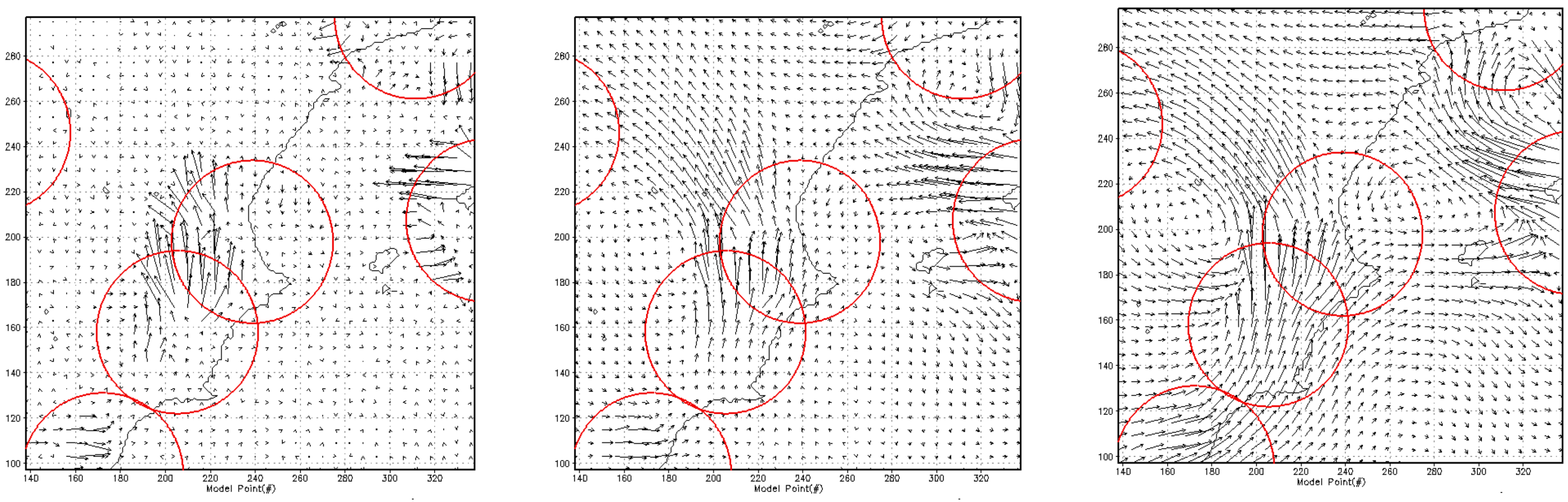
**Encouraging results with the following three-step “hybrid FA+ 3DVar” scheme**

**a) Correction of position errors using Field Alignment**

**b) *Upscale and filter the FA corrections using the model error covariances***

**c) 3DVar assimilation of radar data**

**(a) (b) (c)**

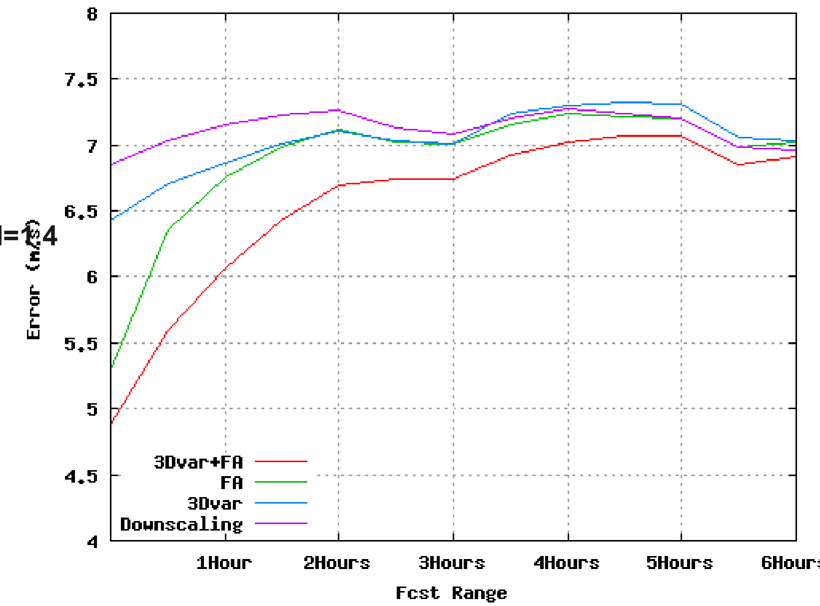



*By Carlos Geijo, AEMET*

# Verification of "hybrid FA+3DVAR" against own radar data

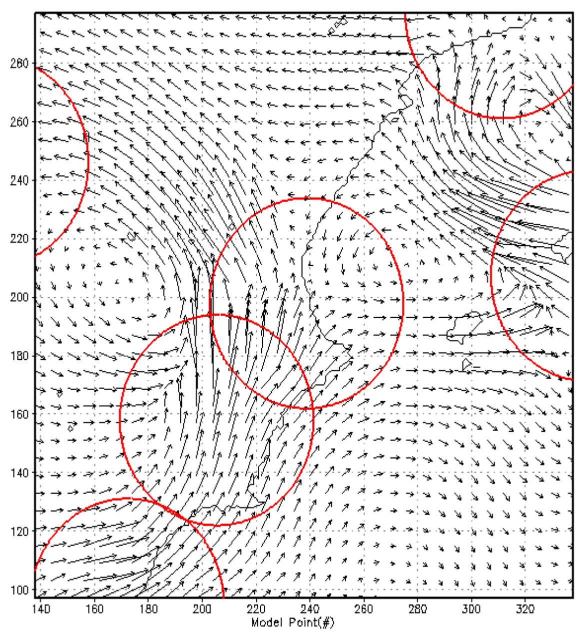
**Error ≡**

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

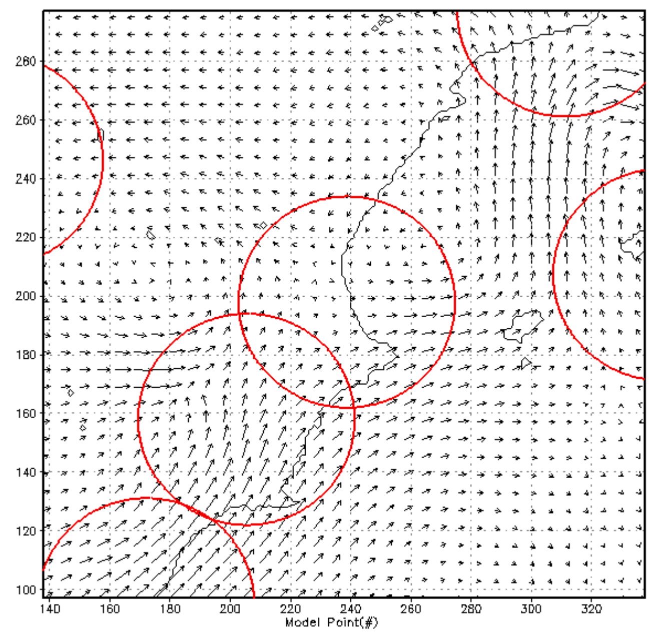



The hybrid FA+3DVAR scheme provides flow-dependent DA and retains more small scales information than the standard 3DVAR scheme. More potential for meso-scale NWP!

"hybrid FA+3DVAR"




3DVAR




Downscaling
3DVAR
FA
FA+3DVAR

*By Carlos Geijo, AEMET*

And Finally …

Thank You for attention

And Thanks to Claude !..

Hirlam + ALADIN = HARMONIE