The CNMCA Operational LETKF Implementation: Description and Results

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and contributions of

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Outline

- The CNMCA Ensemble Data Assimilation System:
  - Local Ensemble Transform Kalman Filter (LETKF)
  - Background Covariance Inflaction
- Control State LETKF
- Comparison with CNMCA 3DVar and IFS 4DVar analysis
- Tests with AMSU-A radiances and Outer Loop
- Future developments

Data Assimilation at CNMCA

The first data assimilation cycle CNMCA was based on an OI scheme, then a 3DVar algorithm was implemented. In 2006 the following questions were raised at CNMCA:

1. Can we improve on our currently operational 3DVar without the complications of 4DVar?

2. Can we develop a system to consistently evaluate initial and forecast uncertainties?

Ensemble data assimilation (EnDA) has proved to be a viable and competitive alternative to variational methods (*Houtekamer*, 2005; *Fertig et al.*, 2007; *Miyoshi*, 2007)

Ensemble data assimilation provides "optimal" analysis errors estimates for ensemble forecasting and it overcomes the need for ad hoc inverse methods

Ensemble Kalman Filter DA

• At CNMCA the **LETKF** (Hunt et al. 2007) formulation was chosen, because algorithmically simple to code, intrinsically parallel, etc.

• The analysis is done in the space of the ensemble perturbations and computed separately at each grid point selecting only the obs in a vicinity. This explicit localization reduces the problem dimensionality and the spurious correlations between distant locations due to limited ensemble size

Analysis Ensemble Mean $\quad \overline{\mathbf{x}}^a = \overline{\mathbf{x}}^b + \mathbf{X}^b \overline{\mathbf{w}}^a$

Analysis Ensemble Perturb. $\quad \mathbf{X}^a = \mathbf{X}^b \mathbf{W}^a$

Analysis Ensemble $\quad \mathbf{x}^a = \mathbf{x}^b + \mathbf{X}^b \mathbf{w}^a$

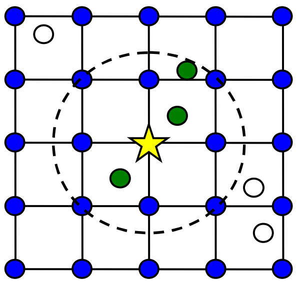
$$\overline{w}^a = \tilde{P}^a Y^{bT} R^{-1}(y - H(\overline{x}^b))$$

$$\tilde{P}^a = [(m-1)I + Y^{bT} R^{-1} Y^b]^{-1}$$

$$Y^b = [(H(x_1^b) - \overline{H(x^b)}), \ldots\ldots, (H(x_m^b) - \overline{H(x^b)})]$$

$$W^a = [(m-1)\tilde{P}^a]$$

$$w^a = W^a + [\overline{w}^a, \ldots\ldots, \overline{w}^a]$$

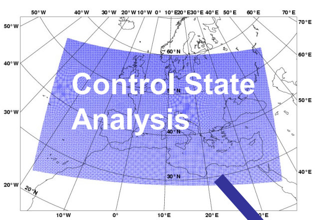


– ensemble mean analysis is the linear combination of forecast ensemble states which best fits the observational dataset

– analysis ensemble members are locally linear combinations of background ensemble members

CNMCA NWP SYSTEM since 1 June 11

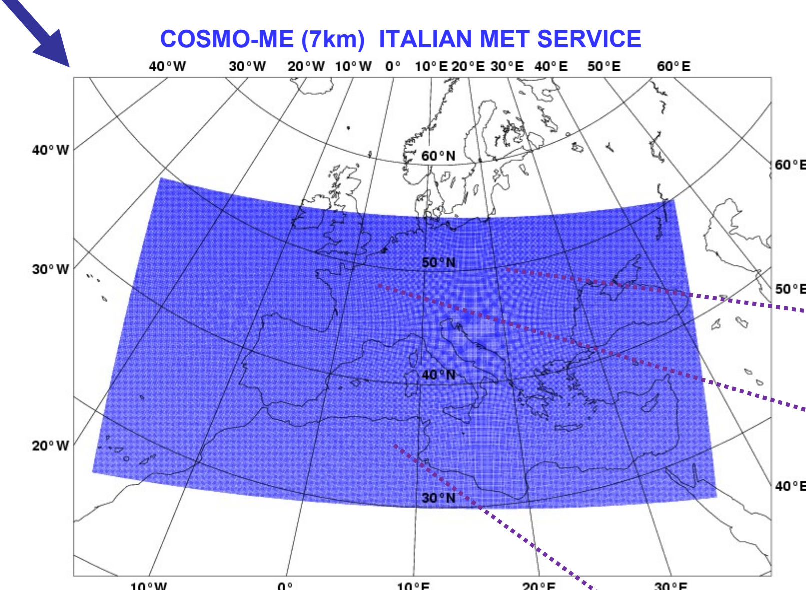
Ensemble Data Assimilation:



10 km
40 v.l.

- HRM hydrostatic model
- parameterized convection

LETKF analysis ensemble (40 members) every 6h using TEMP, PILOT, SYNOP, SHIP, BUOY, Wind Profiler, AMDAR-ACAR-AIREP, MSG AMV, METOP/ERS2 scatt. winds, NOAA/METOP AMSUA radiances (very soon)
+ Land SAF snow mask,
IFS SST analysis once a day

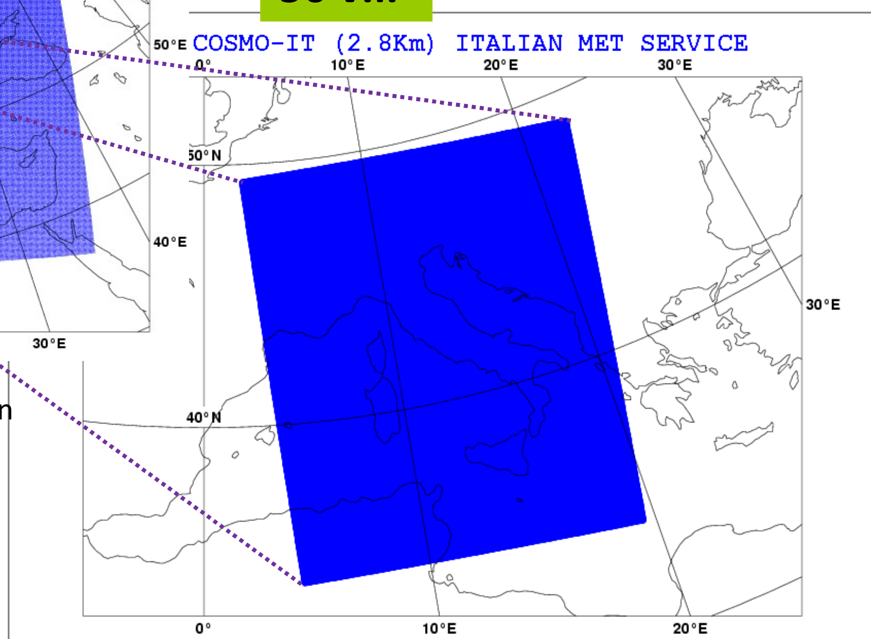


7 km
40 v.l.

- compressible equations
- parameterized convection

2.8 km
50 v.l.

- compressible equations
- explicit convection



Local Area Modelling: COSMO

Covariance Inflaction

In the CNMCA LETKF implementation, model errors and sampling errors are taken into account using:

- State Dependent Multiplicative Inflaction according to Whitaker et al (2010)

an. pert. $$\mathbf{x}_a' = \mathbf{x}_a' \sqrt{\alpha \frac{\sigma_b^2 - \sigma_a^2}{\sigma_a^2} + 1}$$

$\alpha = 0.95$
σ^2 = variance

- Climatological Additive Noise

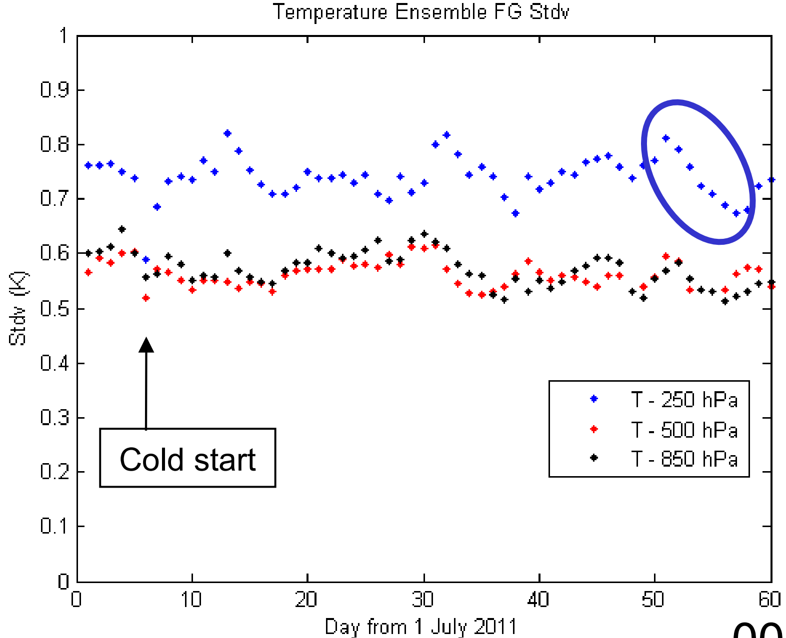
an. memb. $$\mathbf{X}_i^a \leftarrow \mathbf{X}_i^a + \alpha \mathbf{X}_i^n, \quad \alpha \mathbf{X}_i^n \sim N(0, \mathbf{Q})$$

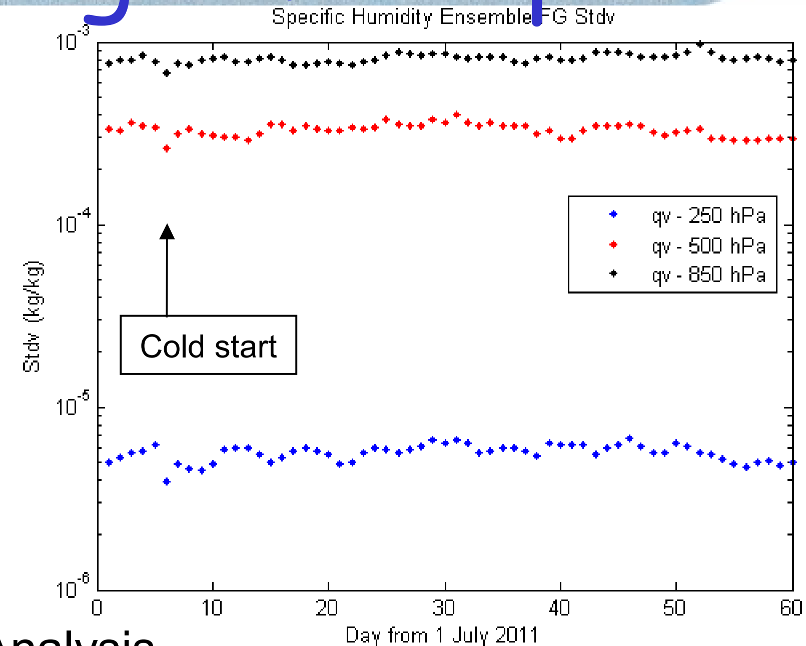
α Scale factor

$\mathbf{X}_i^n$ randomly selected, 48-24h forecast differences

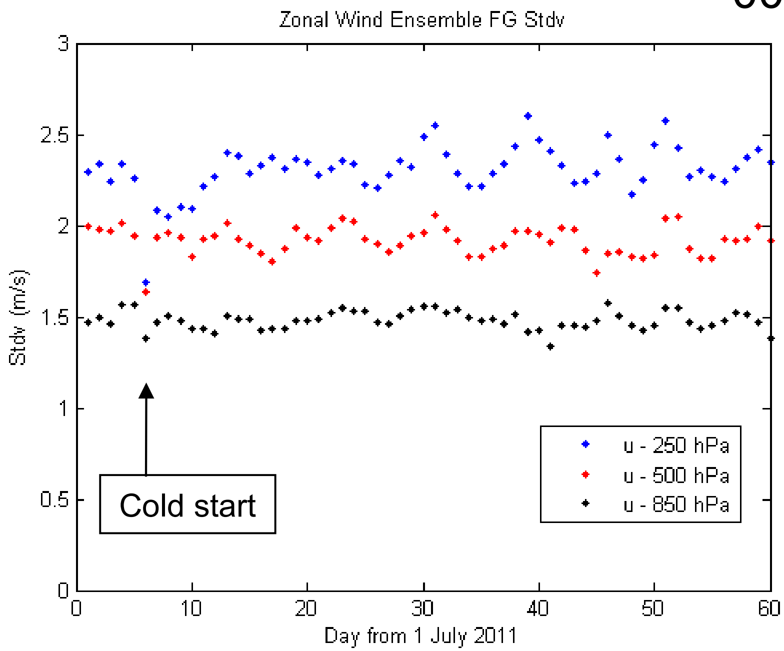
- Lateral Boundary Condition Perturbation using EPS
- Climatological Perturbed SST

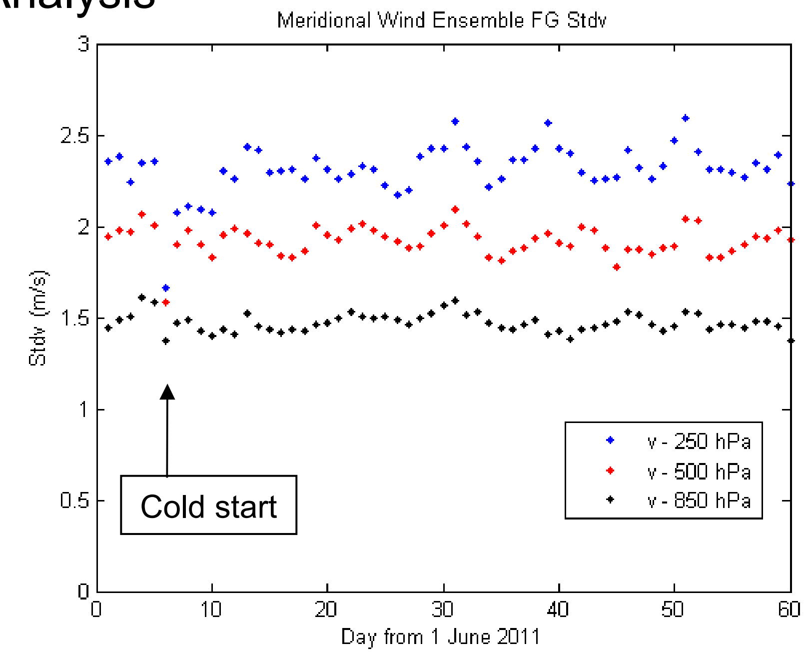
Ensemble Background Spread



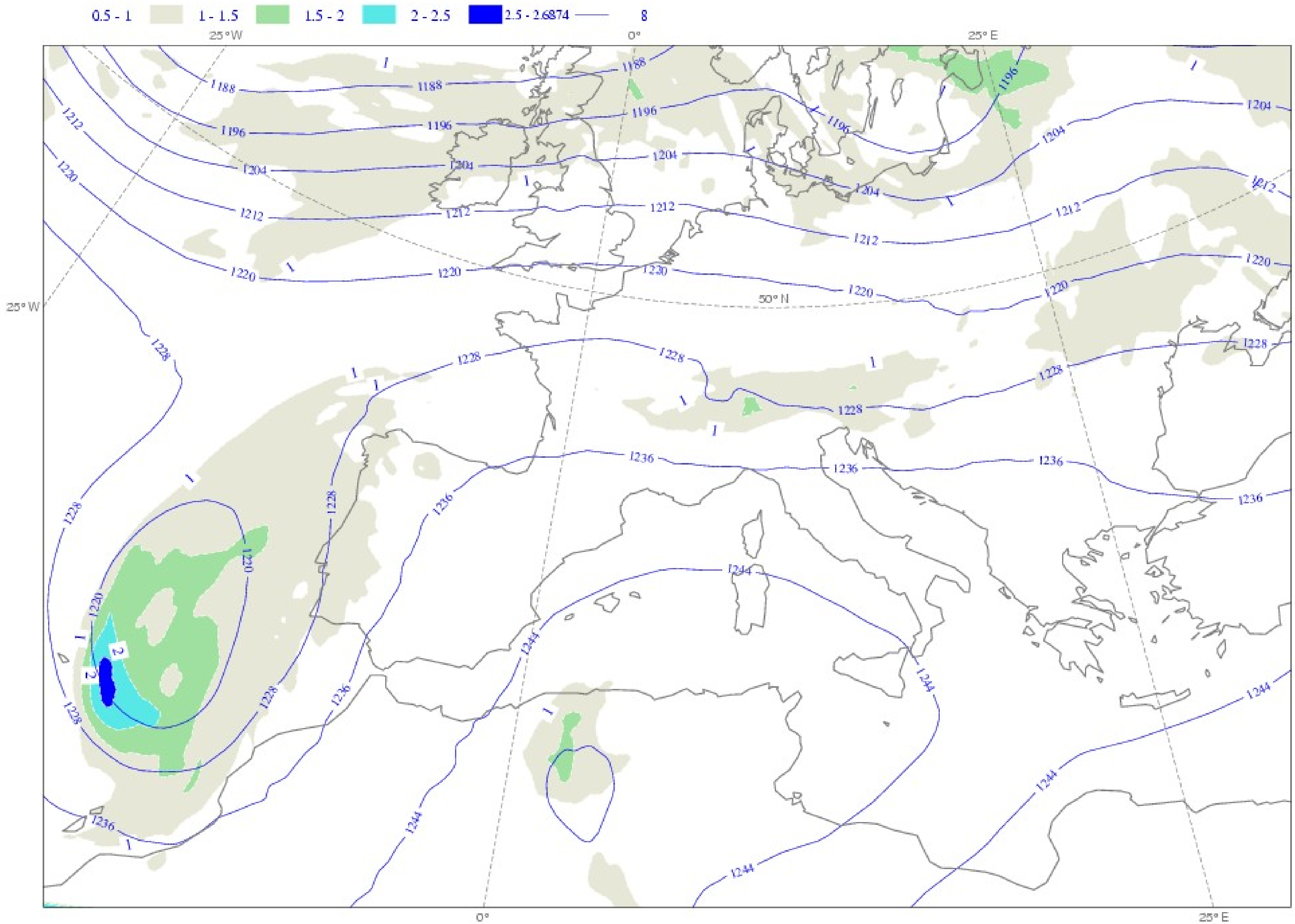


00 UTC Analysis



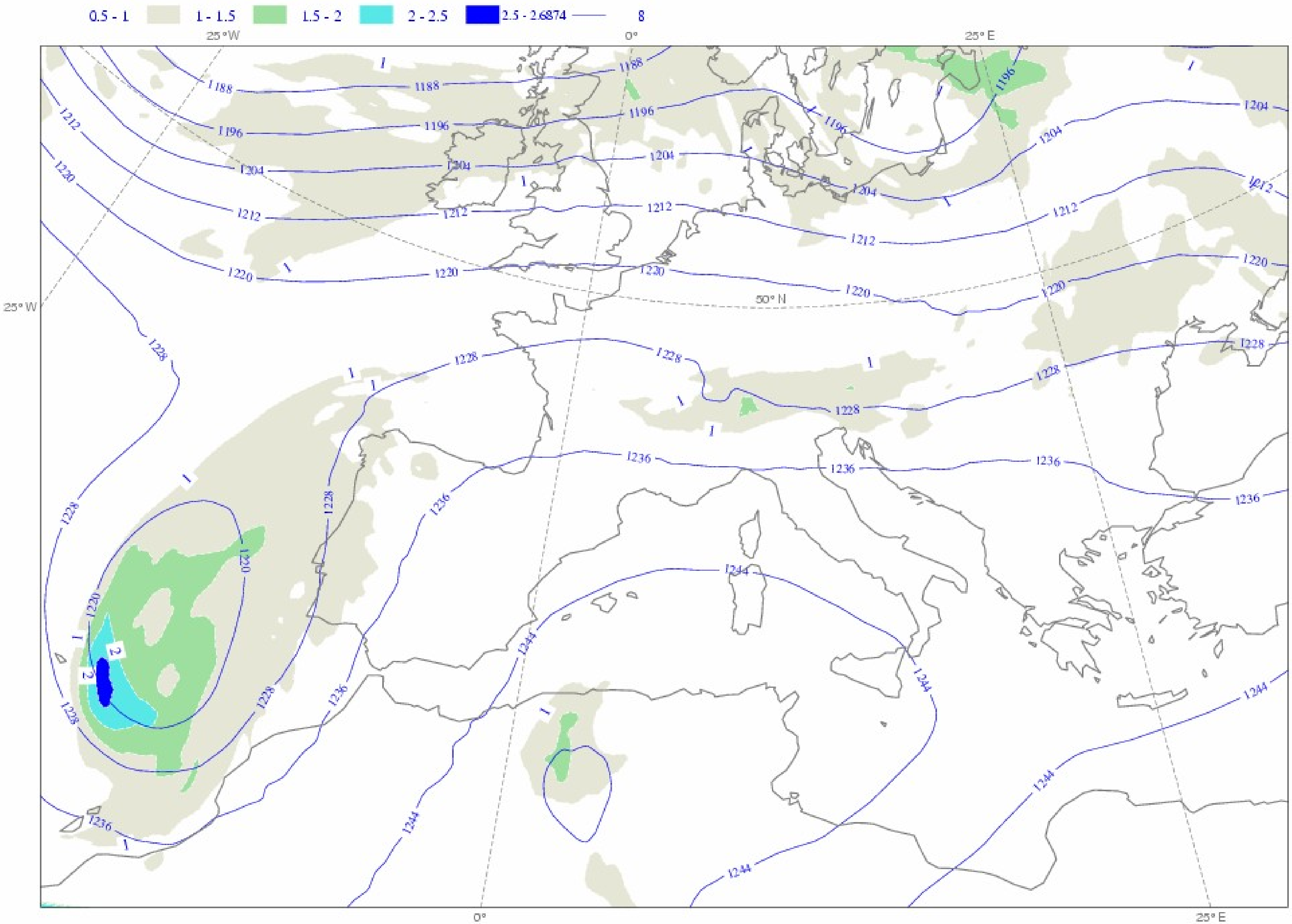


Ensemble Background Spread



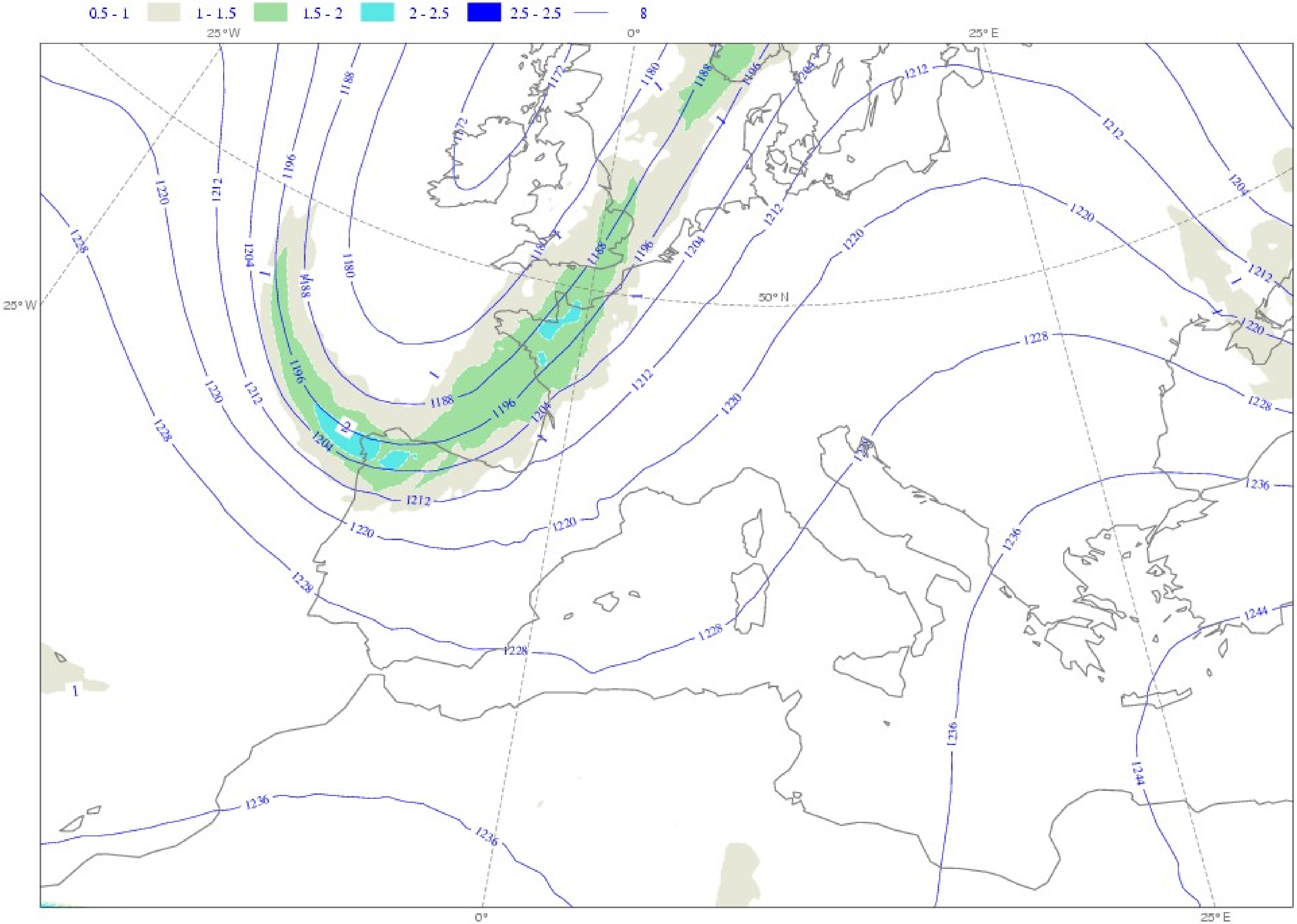
20 August 2011 00UTC: 200 hPa Temperature Spread

Ensemble Background Spread



20 - 26 August 2011 00UTC: 200 hPa Temperature Spread

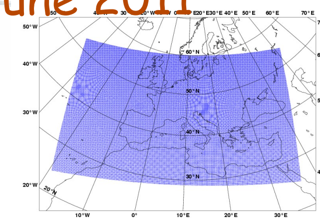
Ensemble Background Spread



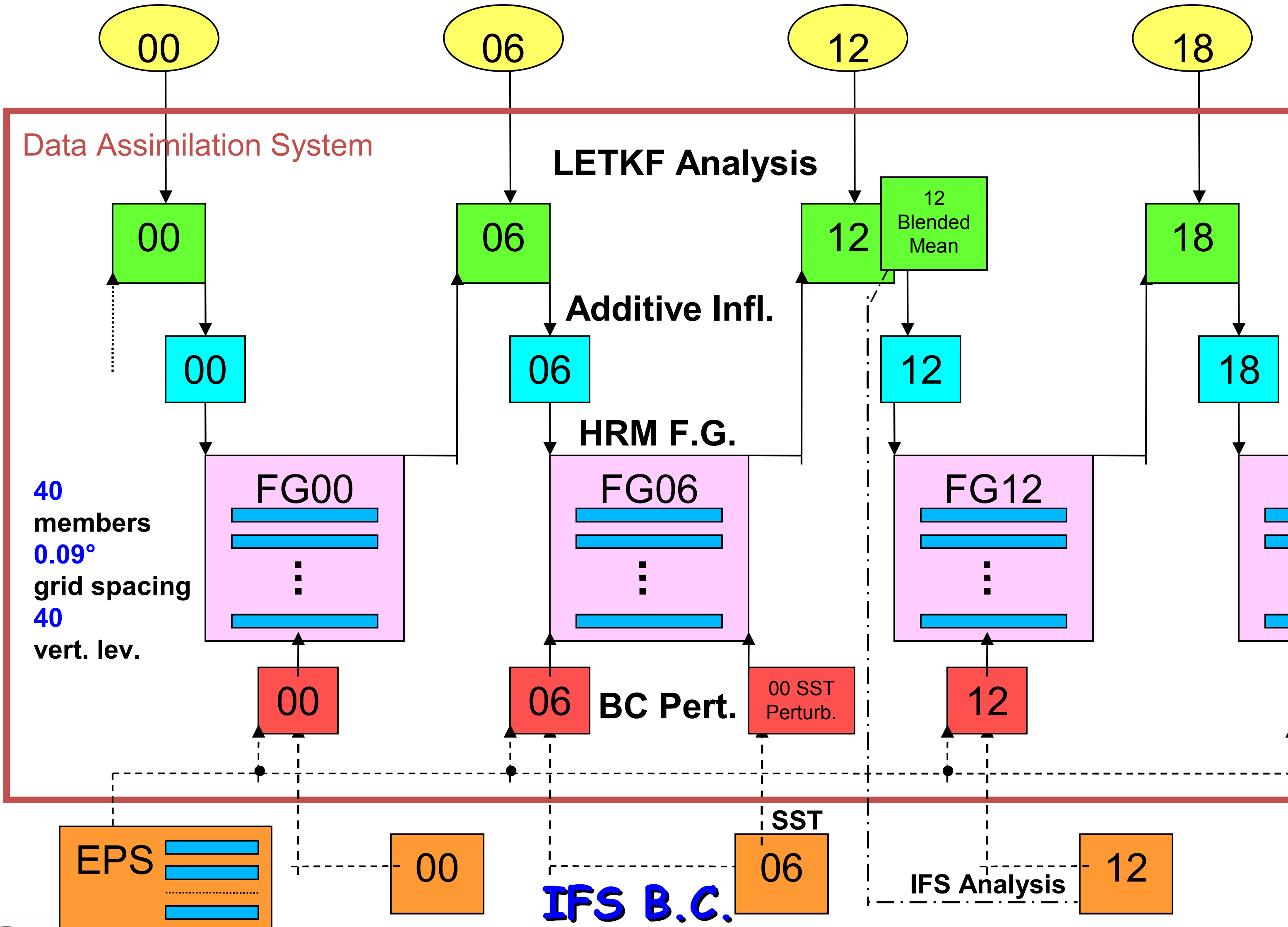
26 August 2011 00UTC: 200 hPa Temperature Spread

CNMCA LETKF DA SYSTEM

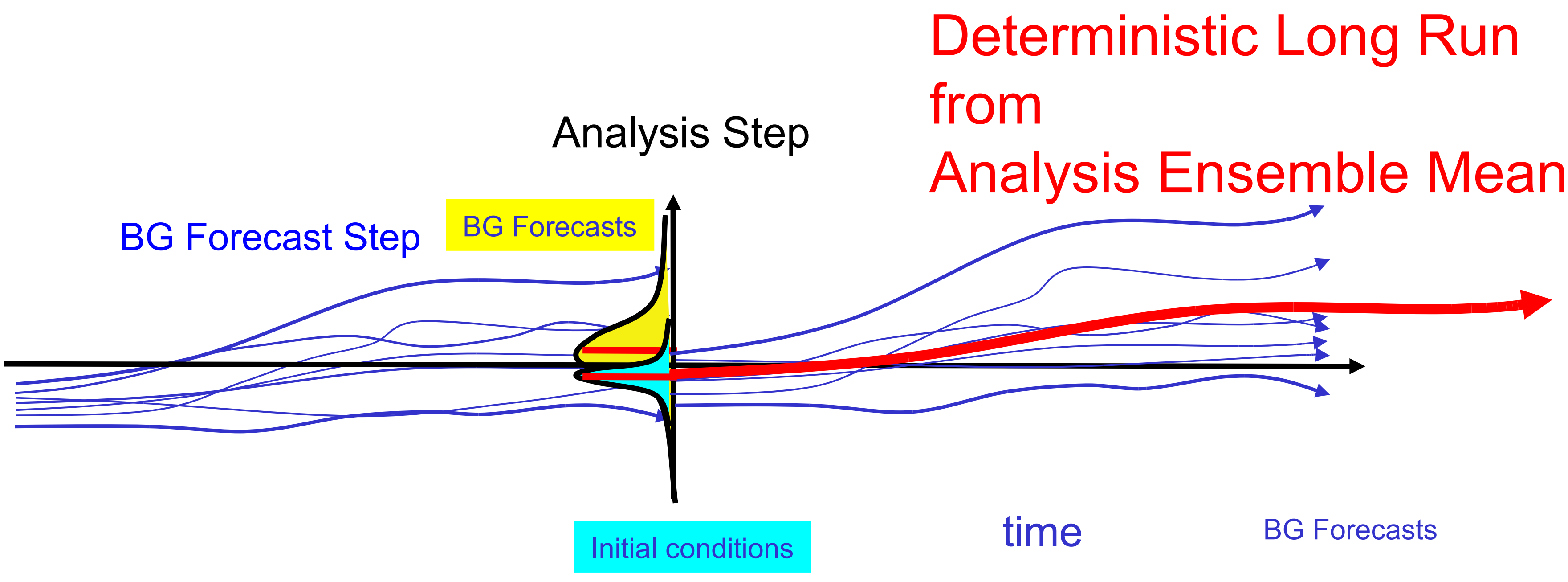
Pre-operational from Dec 2010. Operational from 1 June 2011



Observations (±6h)



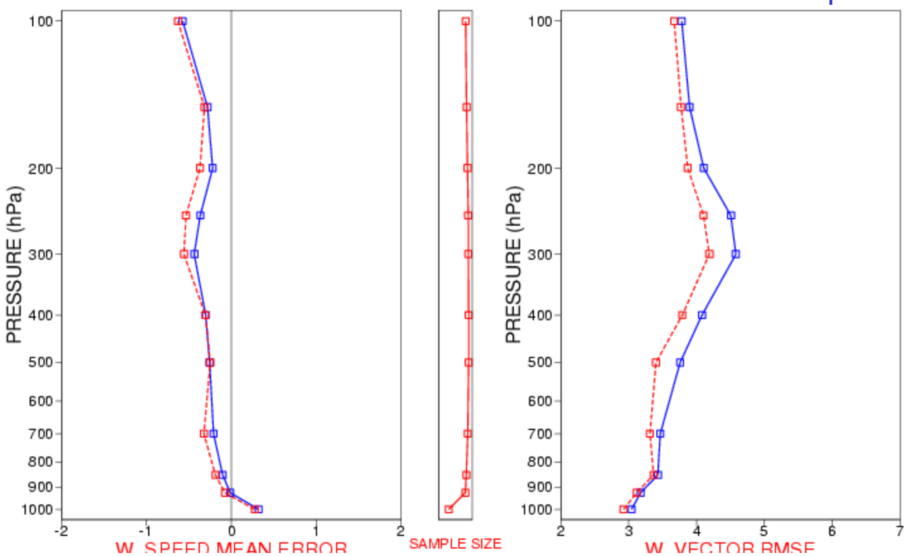
Deterministic Run from LETKF



3DVar/LETKF comparison

European stations
April and May 2011

WIND (m/s) 00 UTC FC + 12 h
Verification from 04/04/11 to 03/05/11
COSMO-ME_3DV: Blue COSMO-ME_LETKF: Red



WIND (m/s) 00 UTC FC + 24 h
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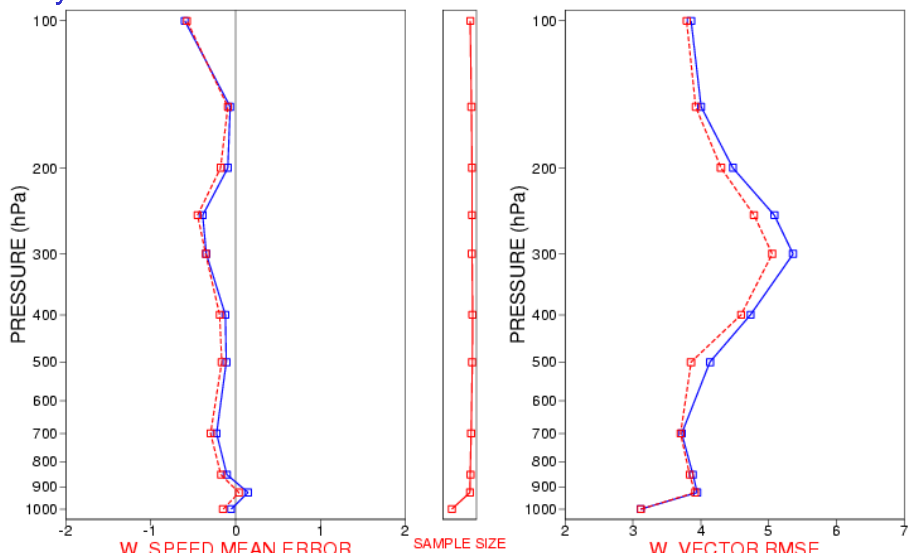

WIND (m/s) 00 UTC FC + 36 h
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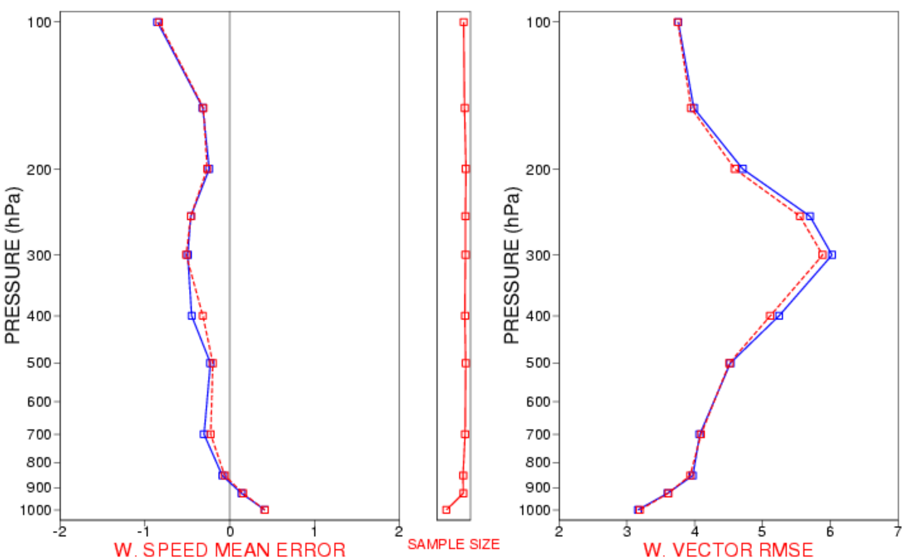

WIND (m/s) 00 UTC FC + 48 h
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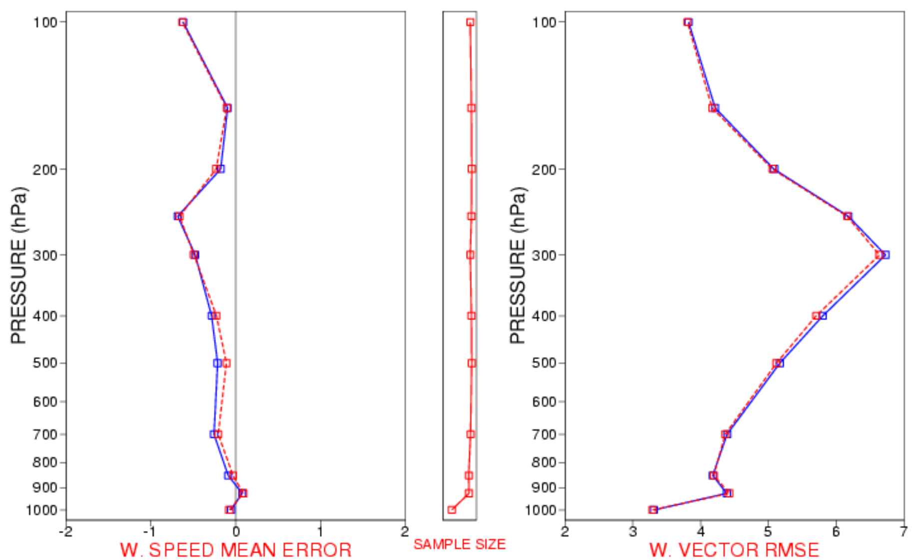

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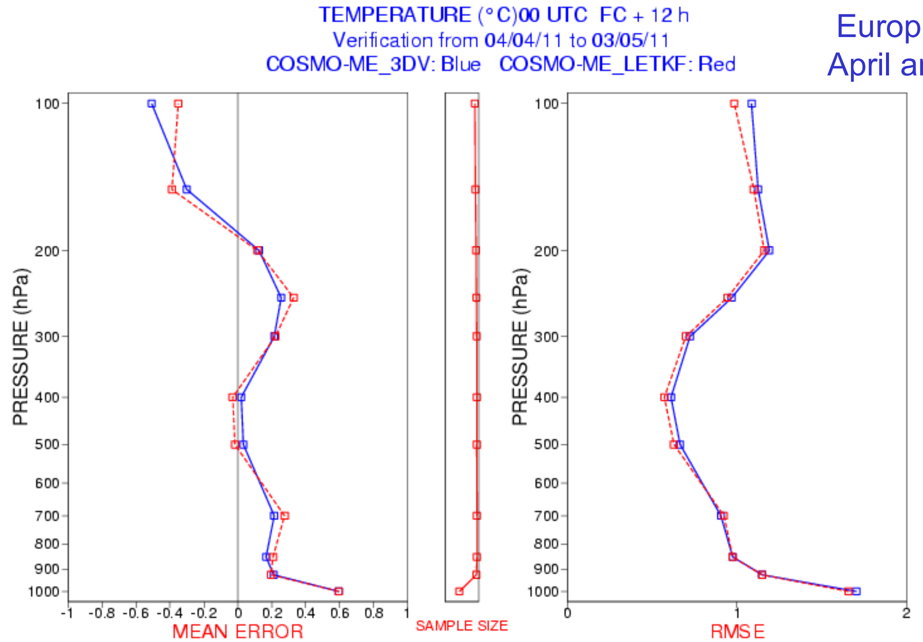
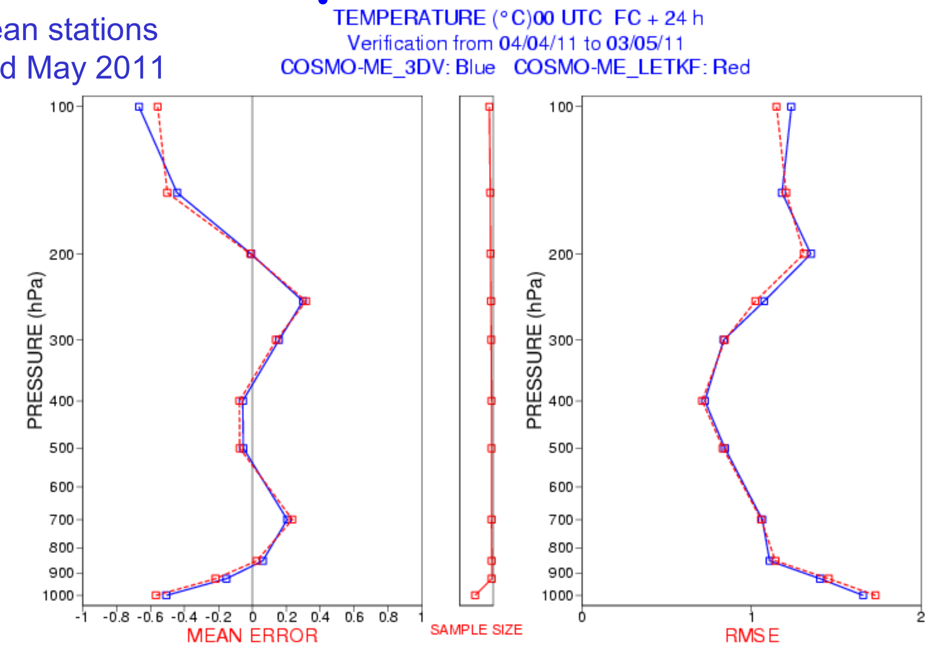
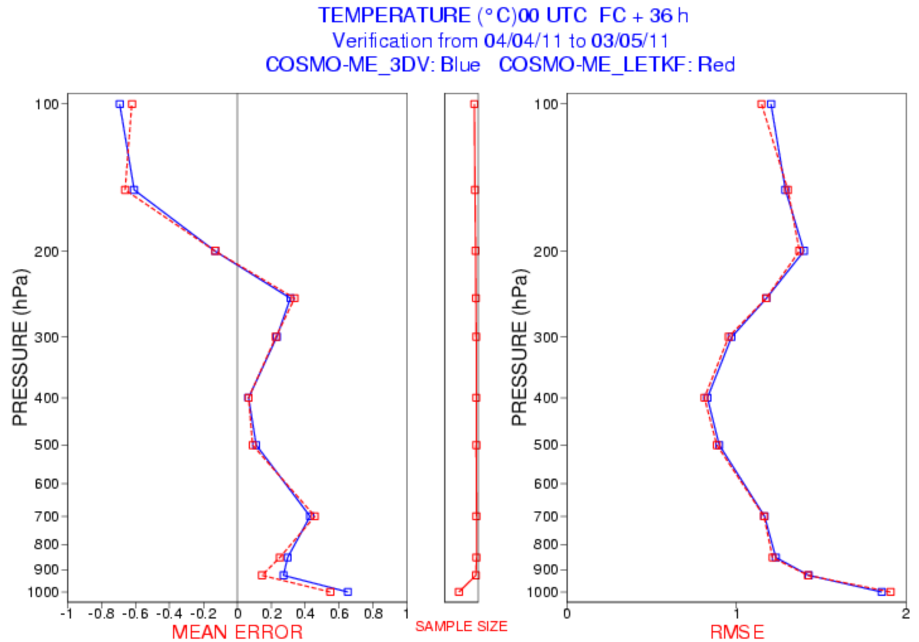
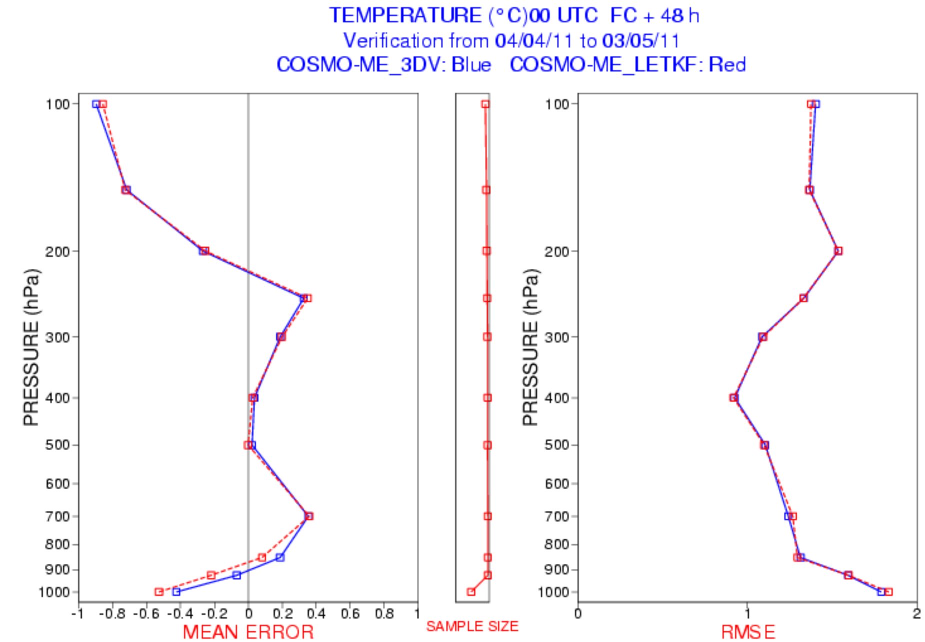
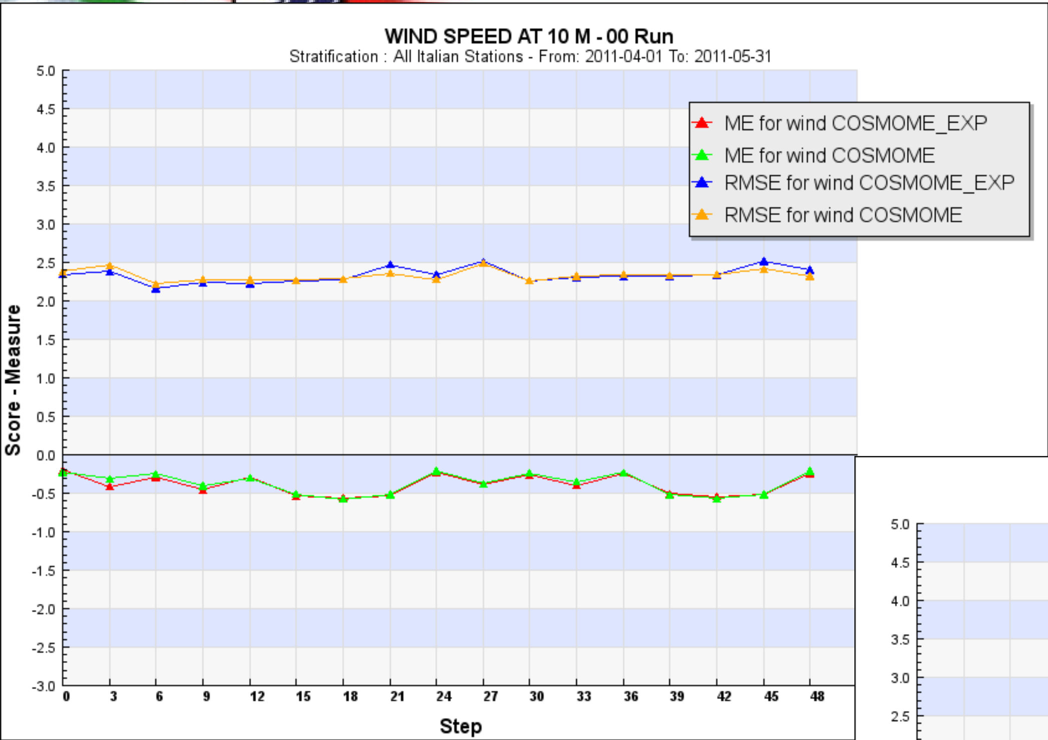






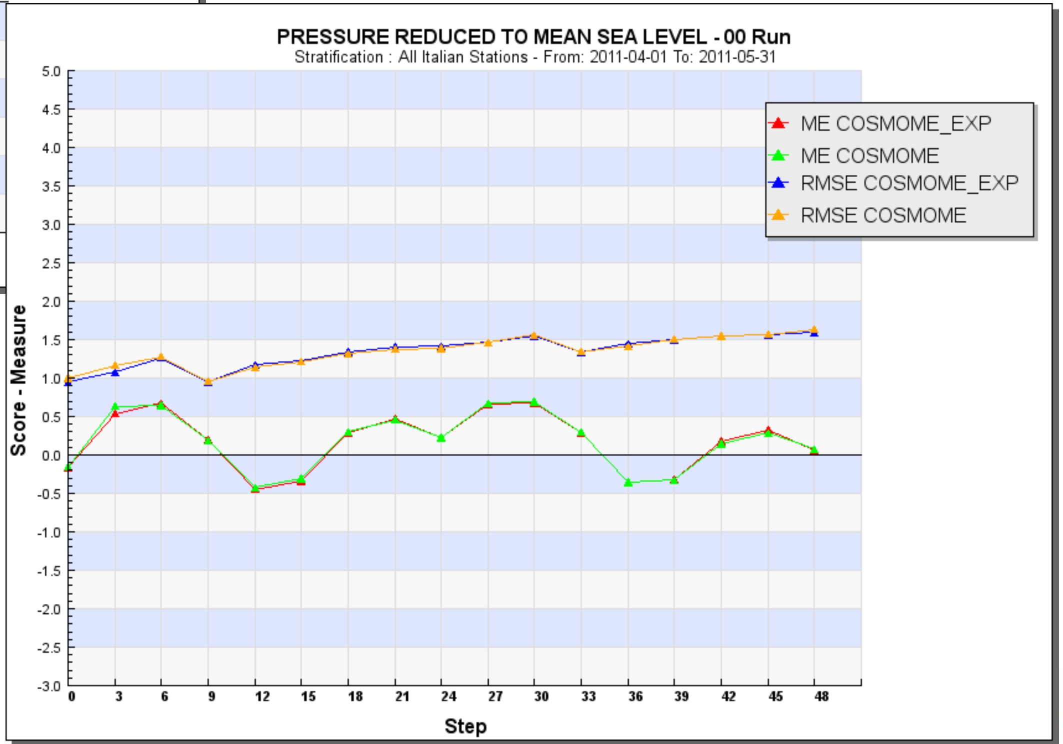


3DVar/LETKF comparison



Italian stations
April and May 2011

COSMOME EXP = with LETKF



3DVar/LETKF comparison

Italian stations
April and May 2011

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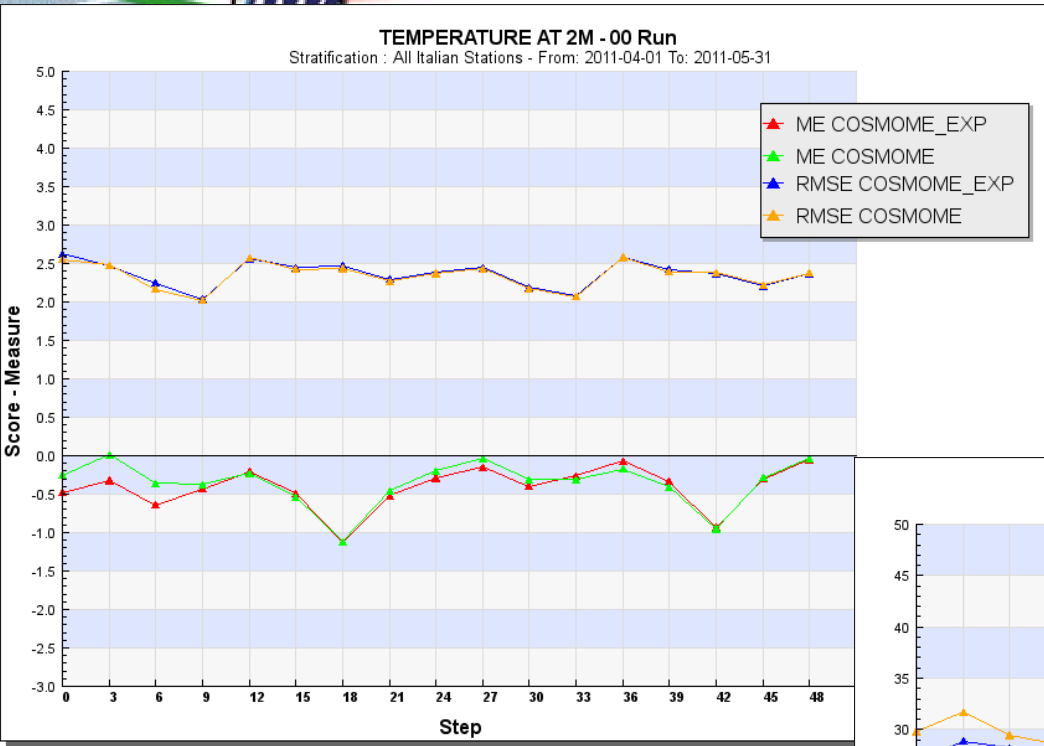

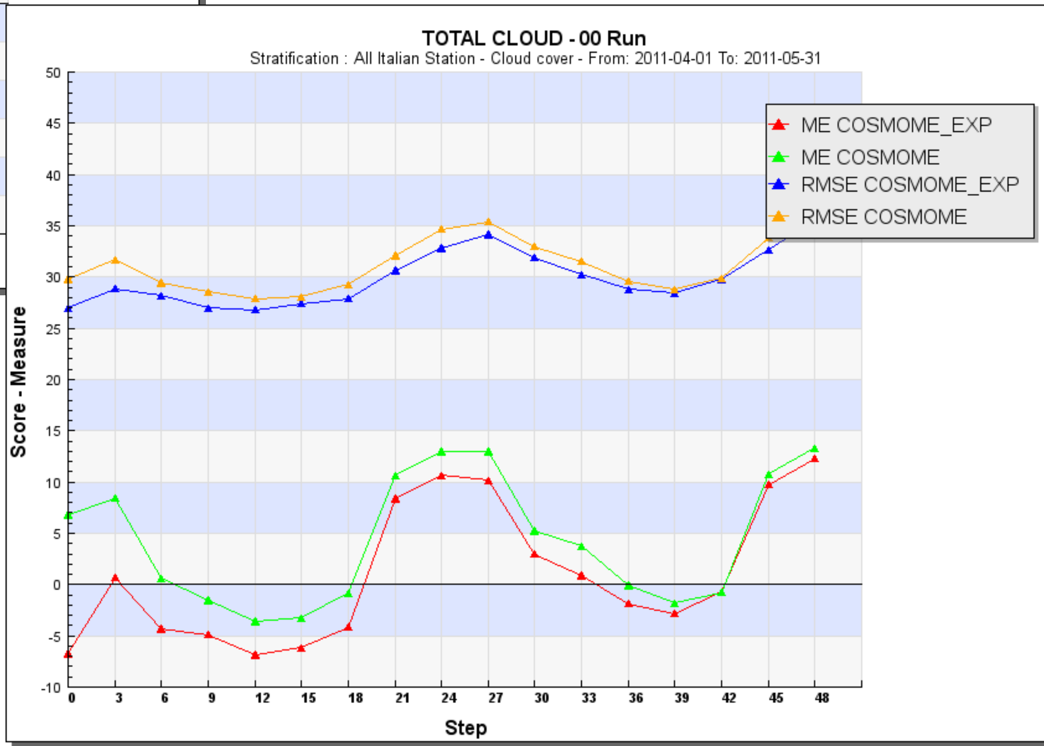

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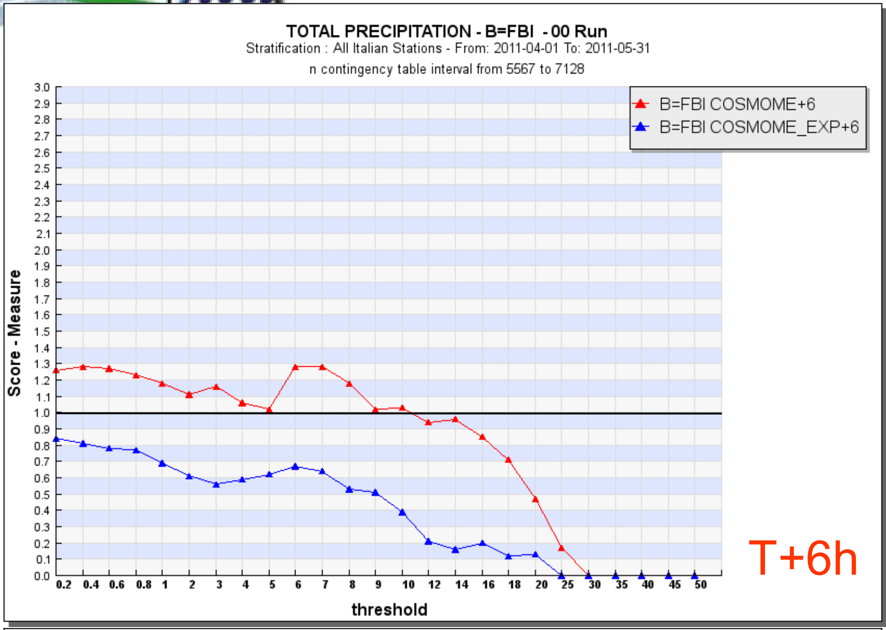
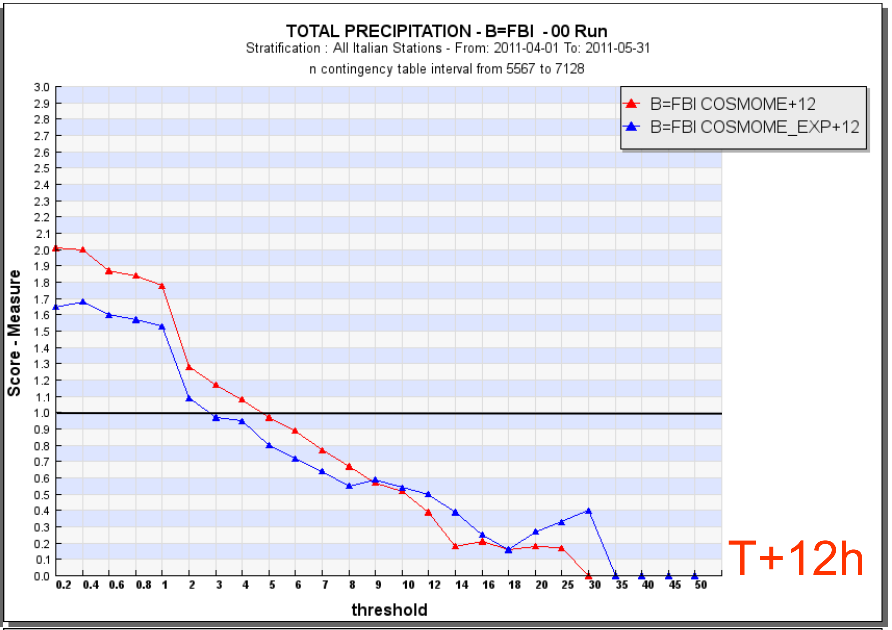
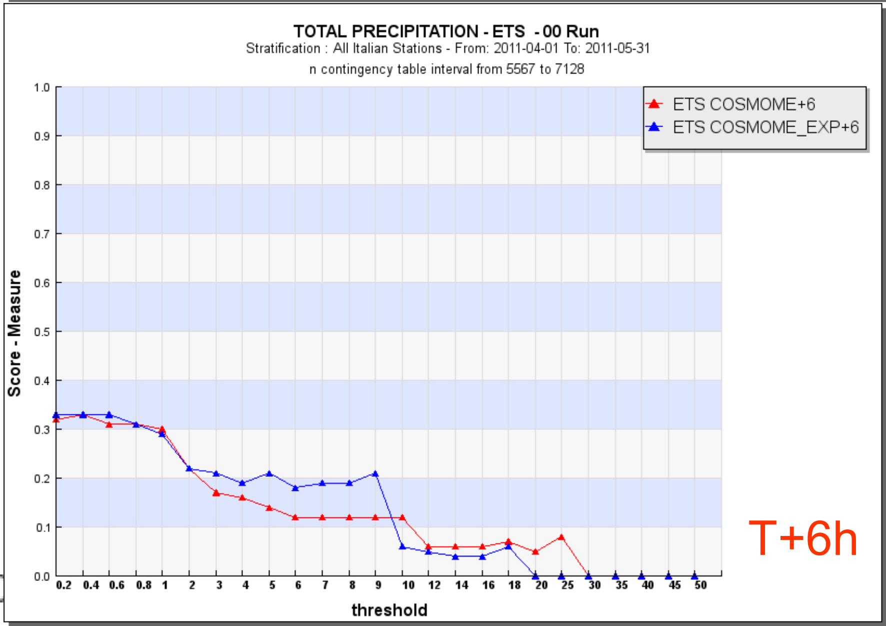
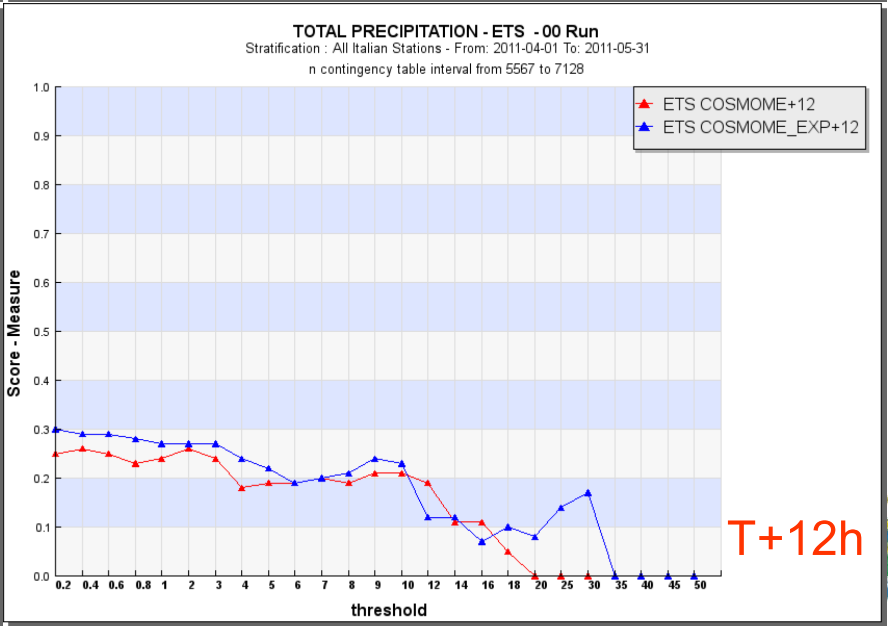
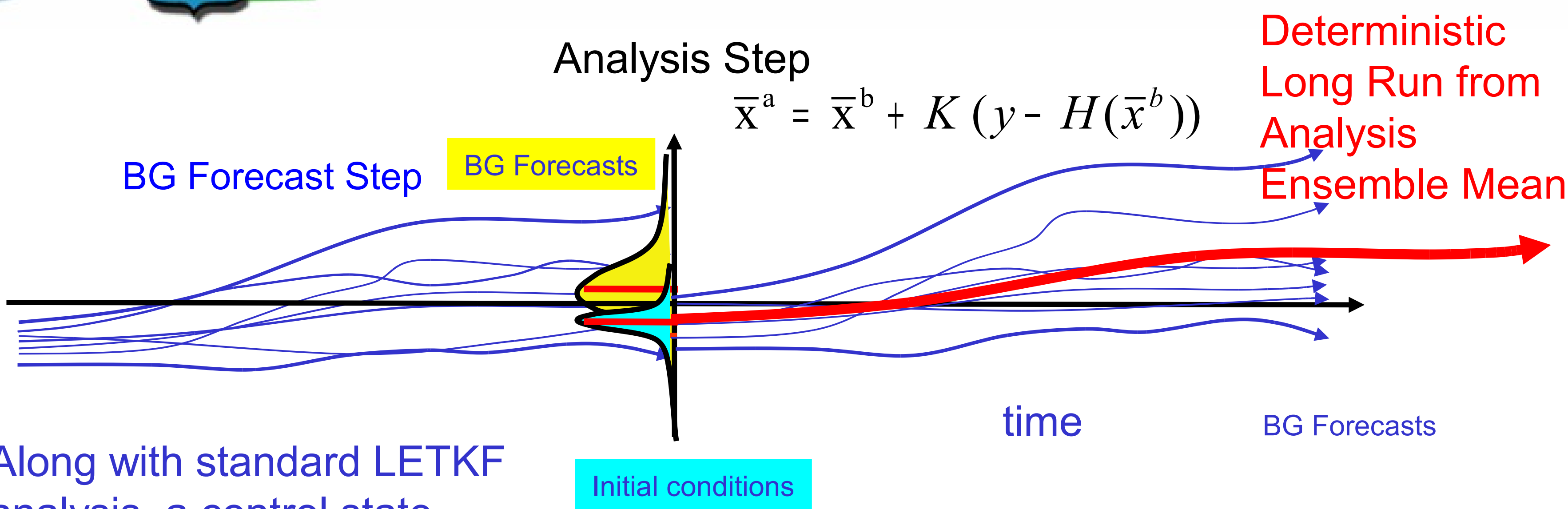




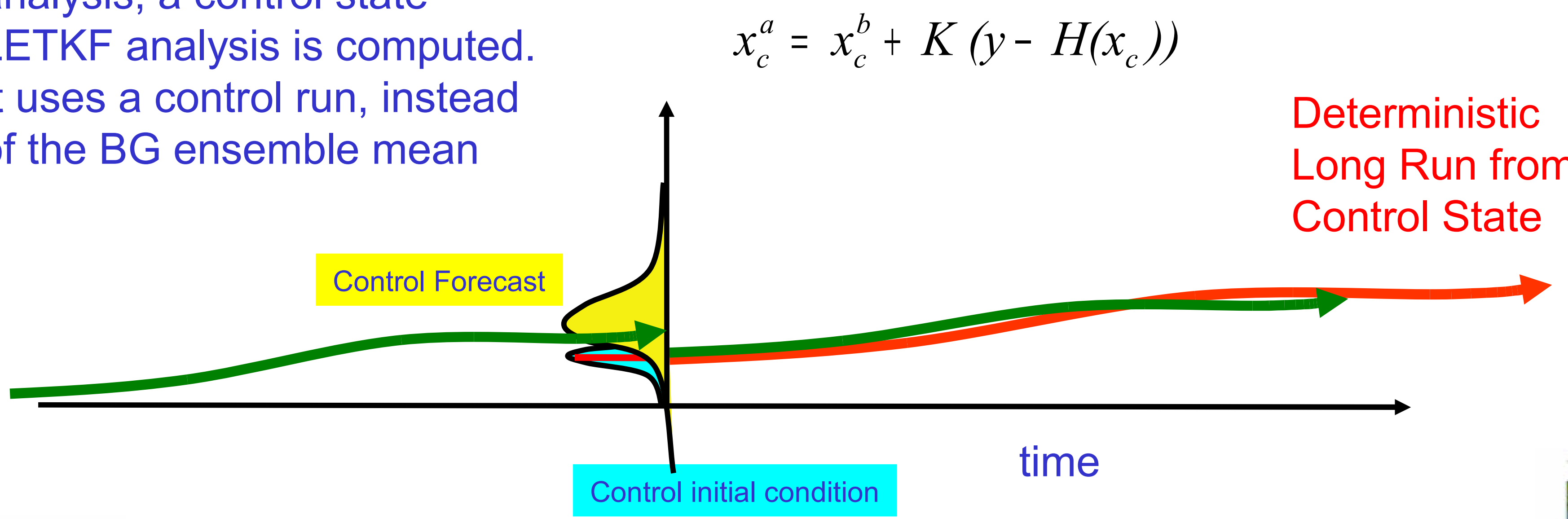




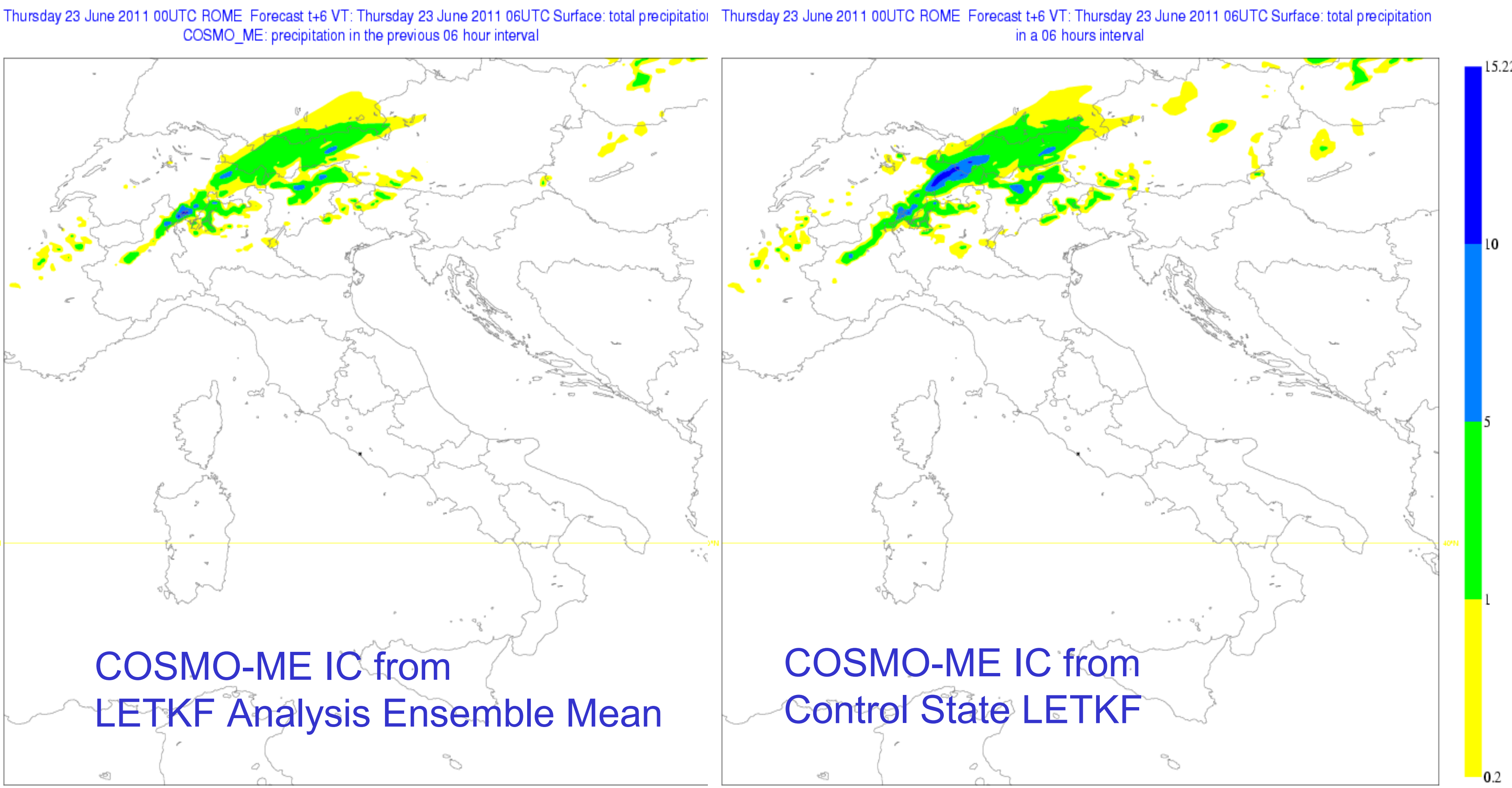
Deterministic Run from LETKF



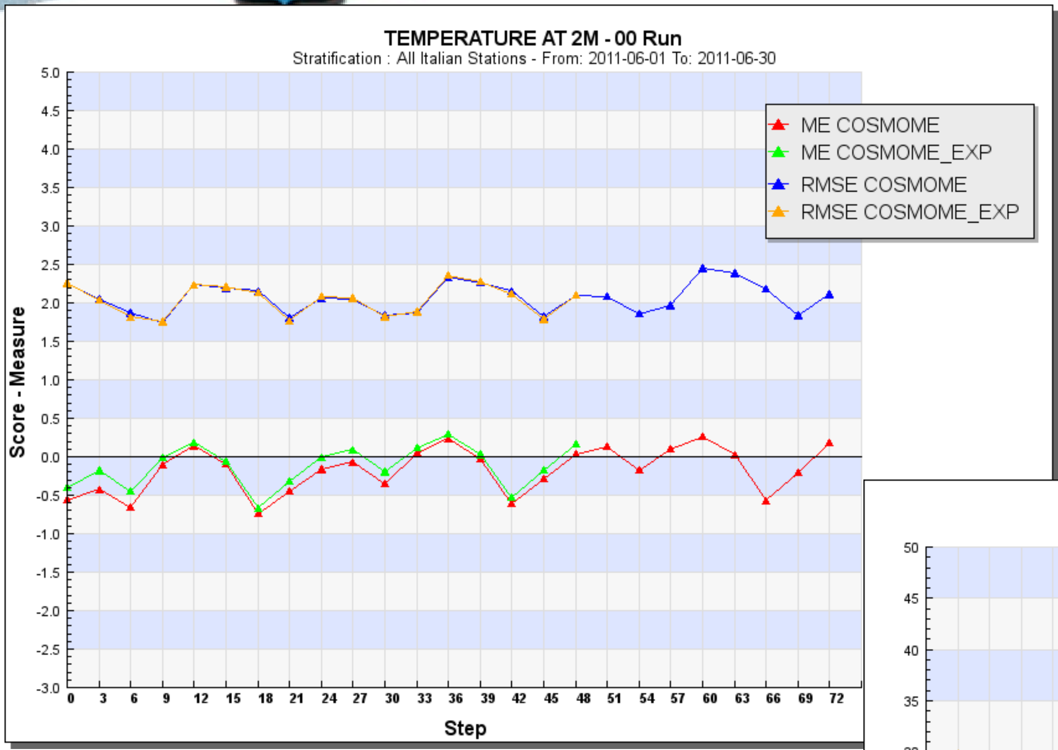
Along with standard LETKF analysis, a control state LETKF analysis is computed. It uses a control run, instead of the BG ensemble mean



Control/Mean LETKF comparison

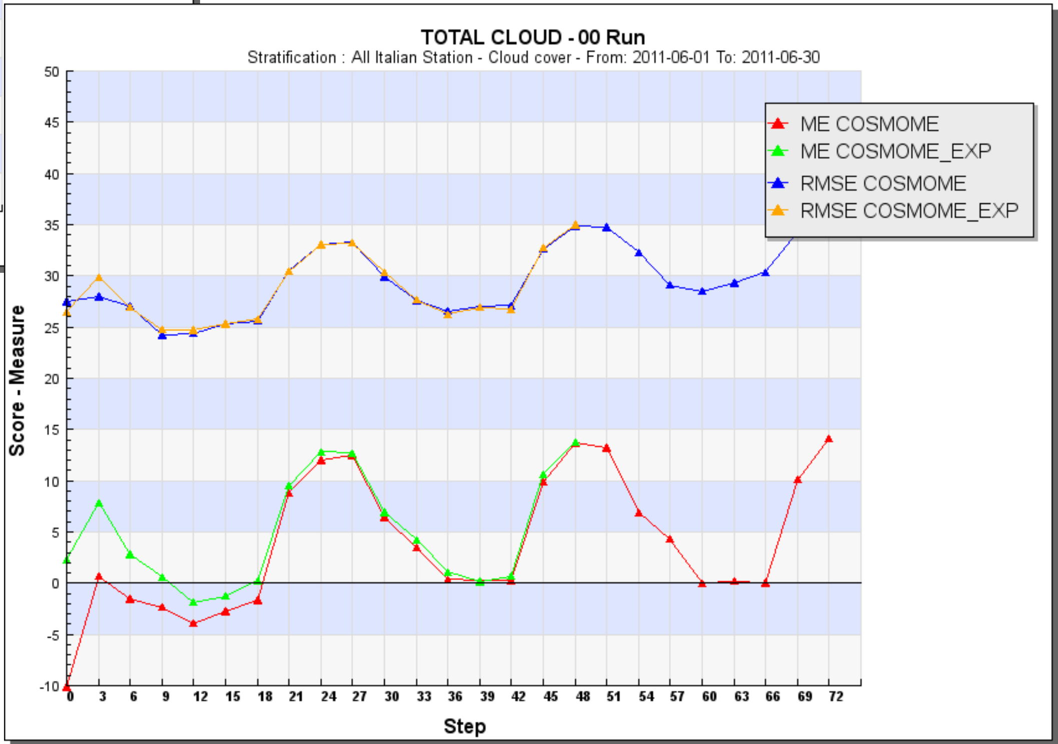


Control/Mean LETKF comparison



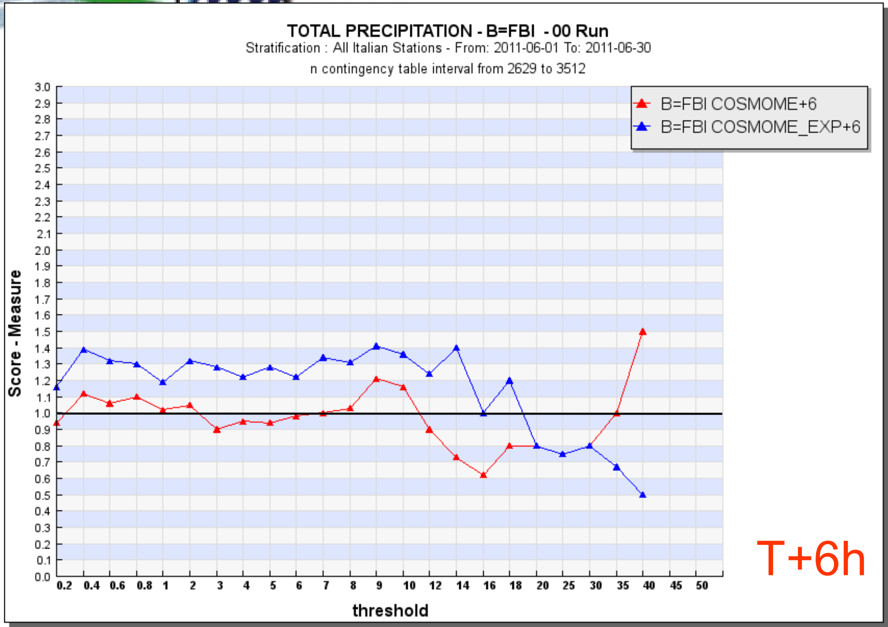
Italian stations
June 2011

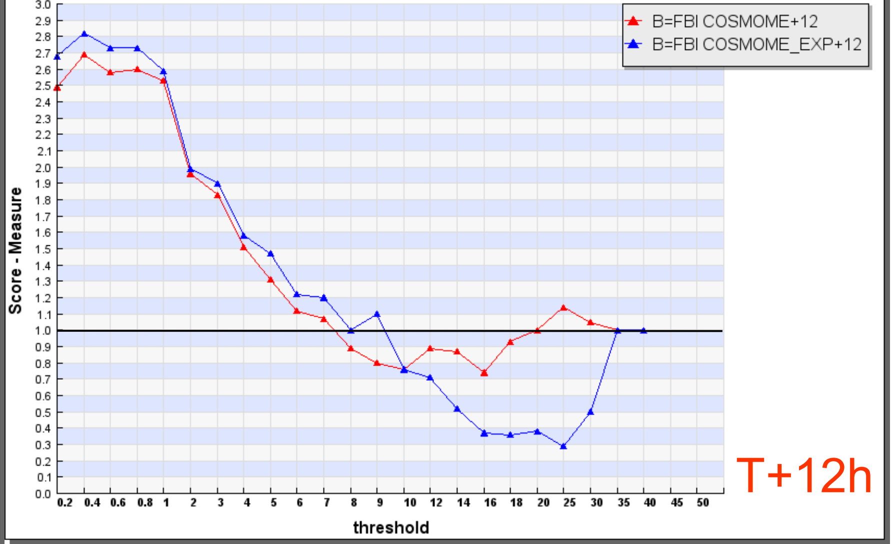
COSMOME EXP = with Control LETKF

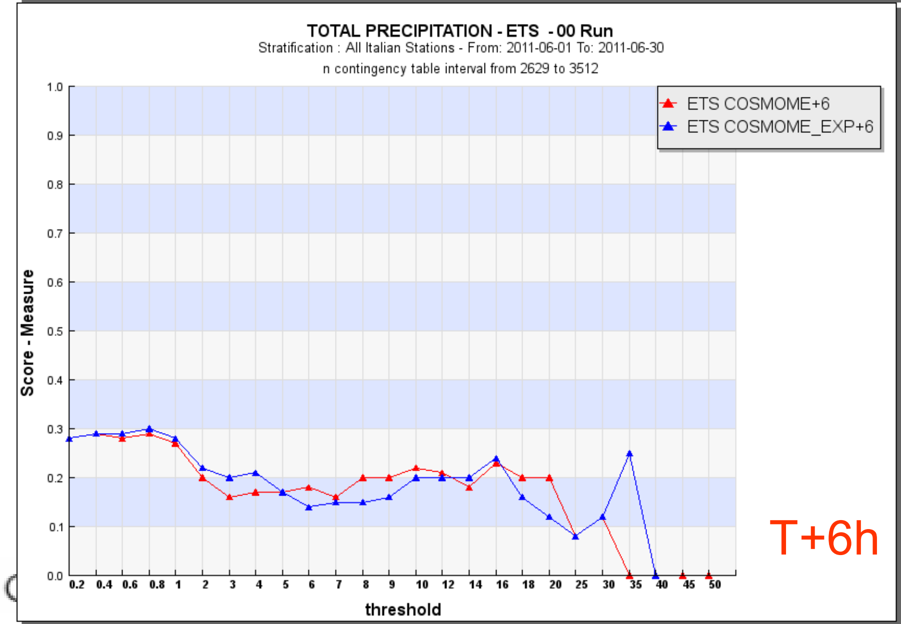


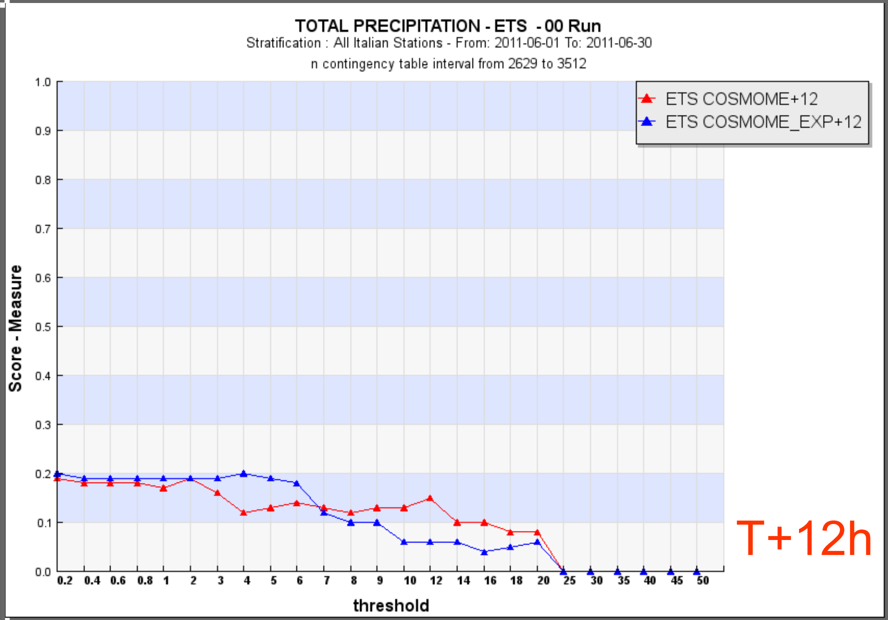
Control/Mean LETKF comparison

Italian stations
June 2011



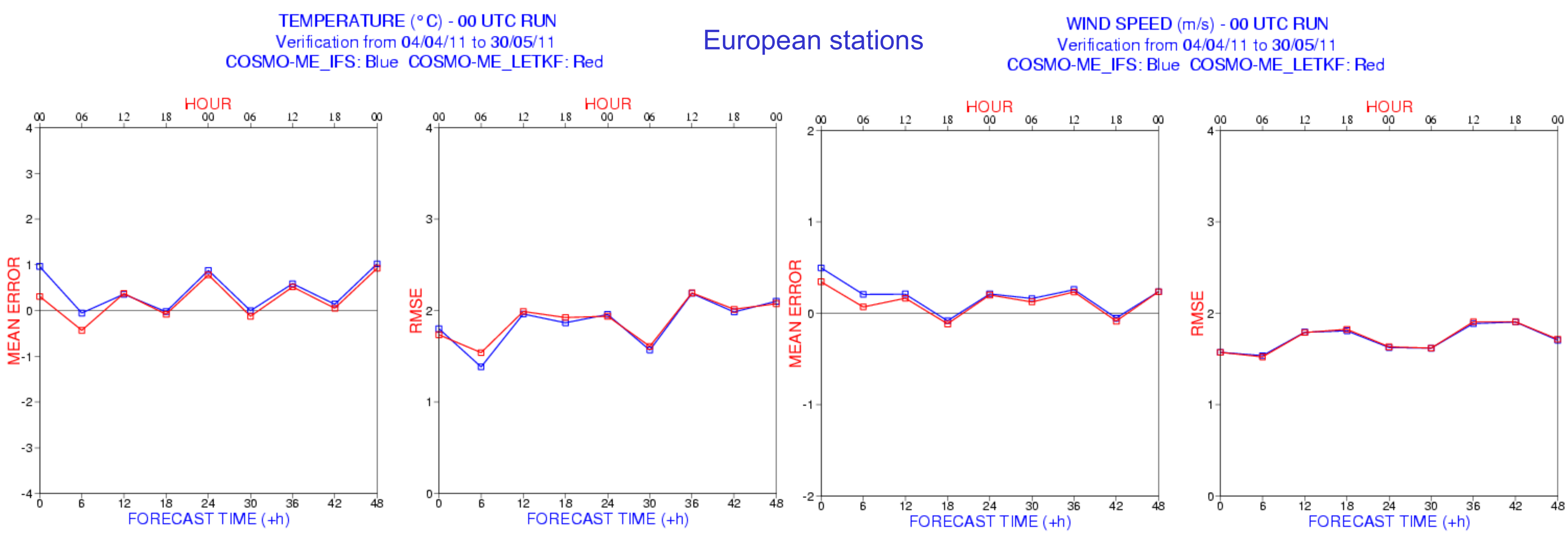






Comparison of LETKF/IFS analysis

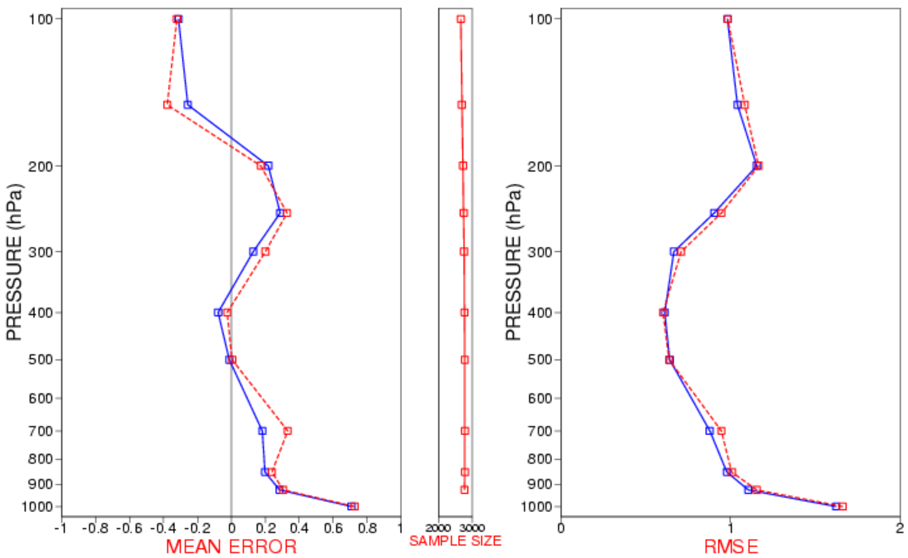
- The deterministic COSMO-ME runs, initialized by the 00 UTC LETKF analysis ensemble mean and by the global IFS 4DVAR system and driven by IFS boundary conditions, are objectively verified against the European observation network. In this evaluation you have to take into account the reduced number of observation types (no radiances in this experiment) used in the CNMCA LETKF system.



IFS/LETKF analysis comparison

European stations

TEMPERATURE (°C) 00 UTC FC + 12 h
Verification from 04/04/11 to 31/05/11
COSMO-ME_IFS Blue COSMO-ME_LETKF: Red



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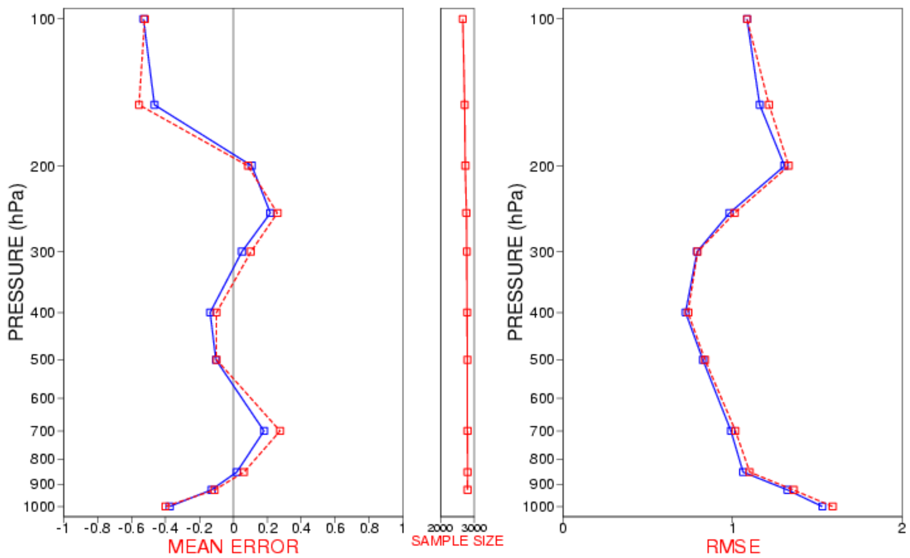

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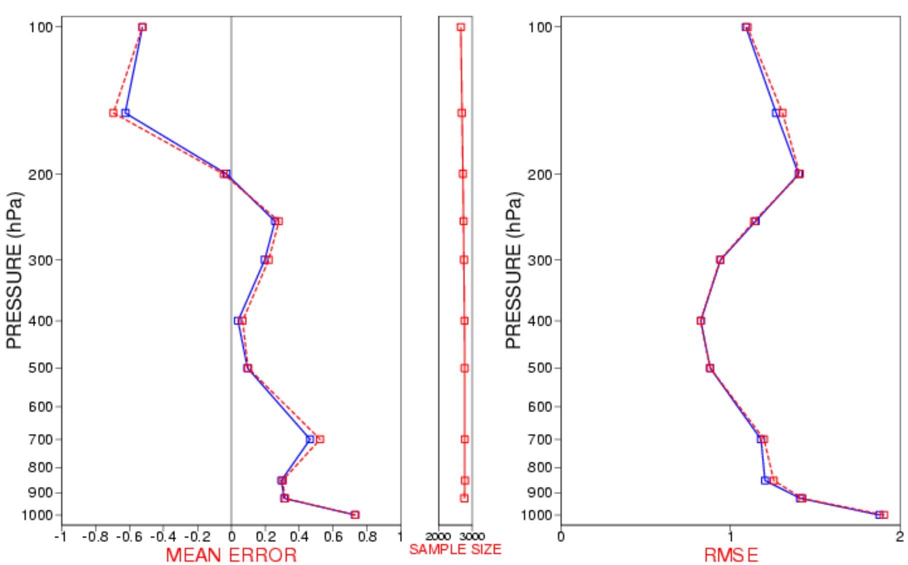

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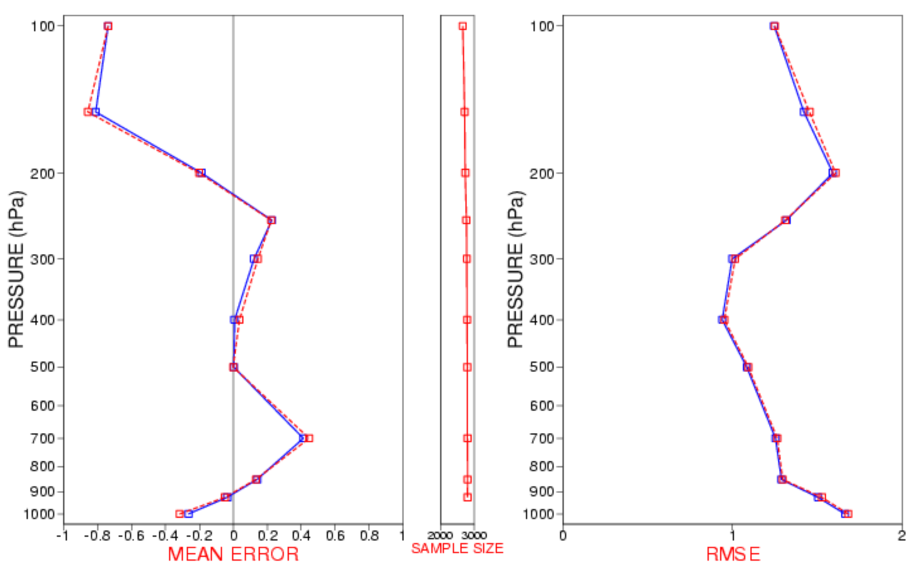

IFS/LETKF analysis comparison

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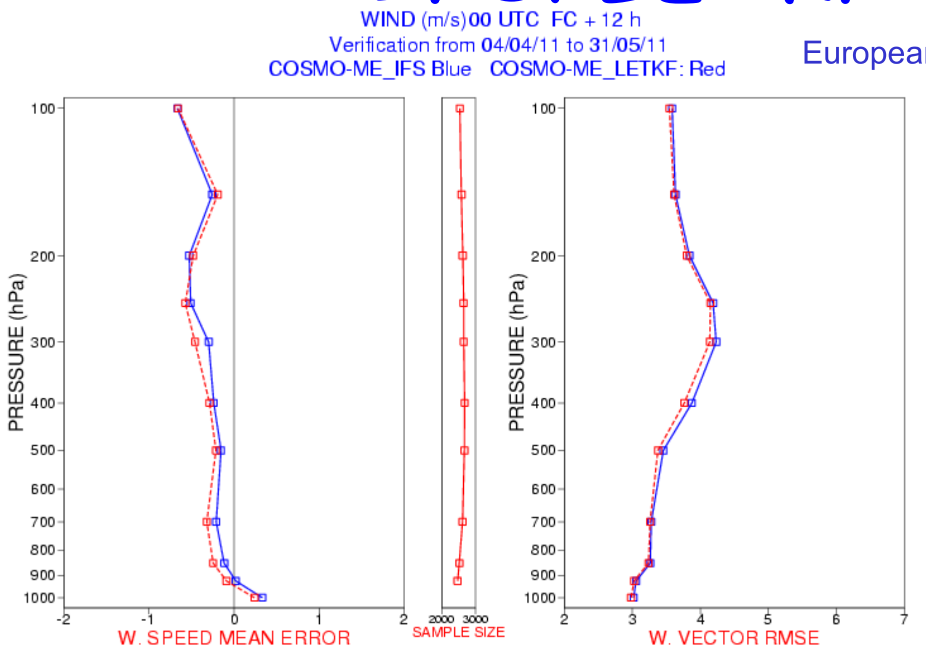
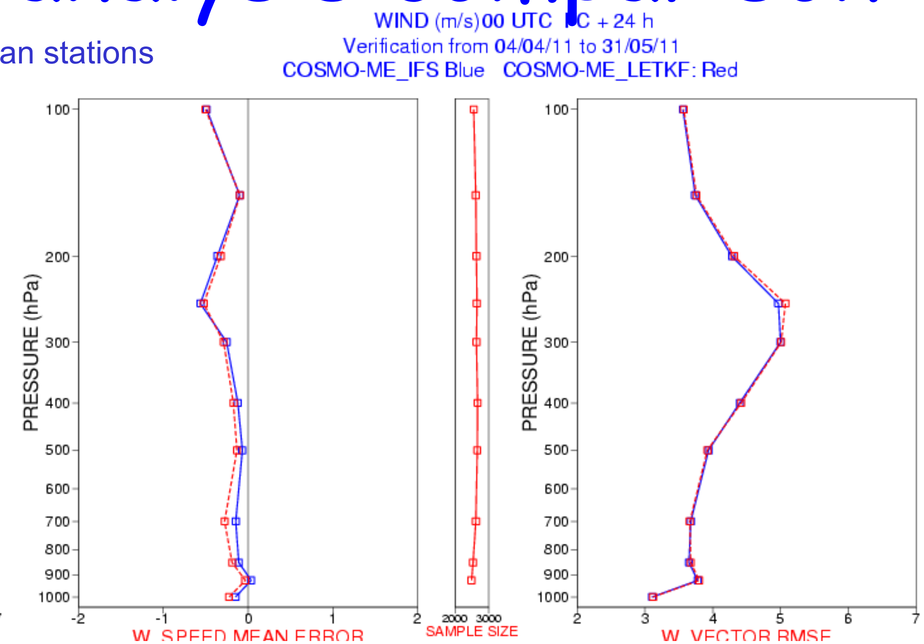
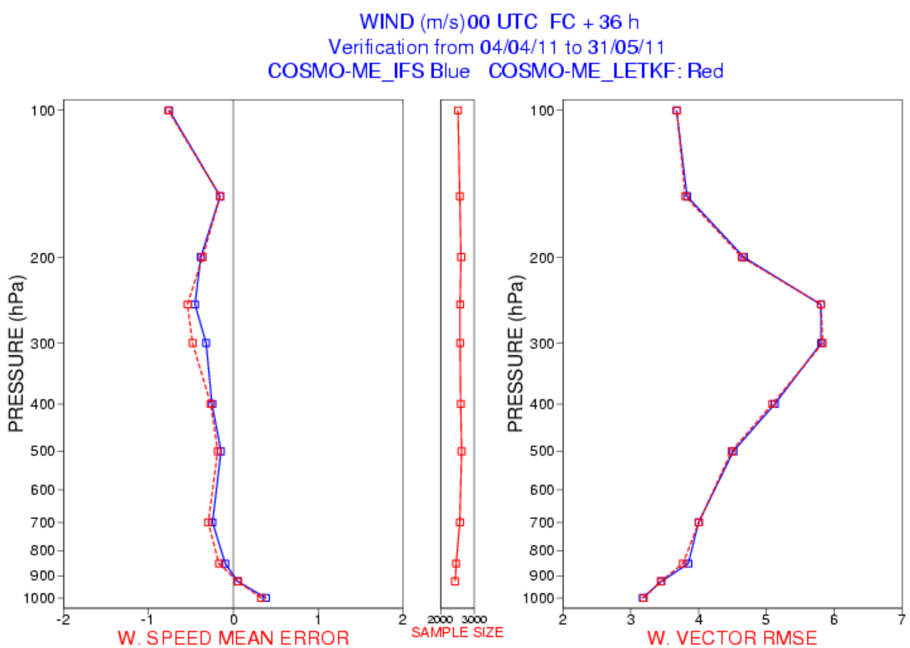
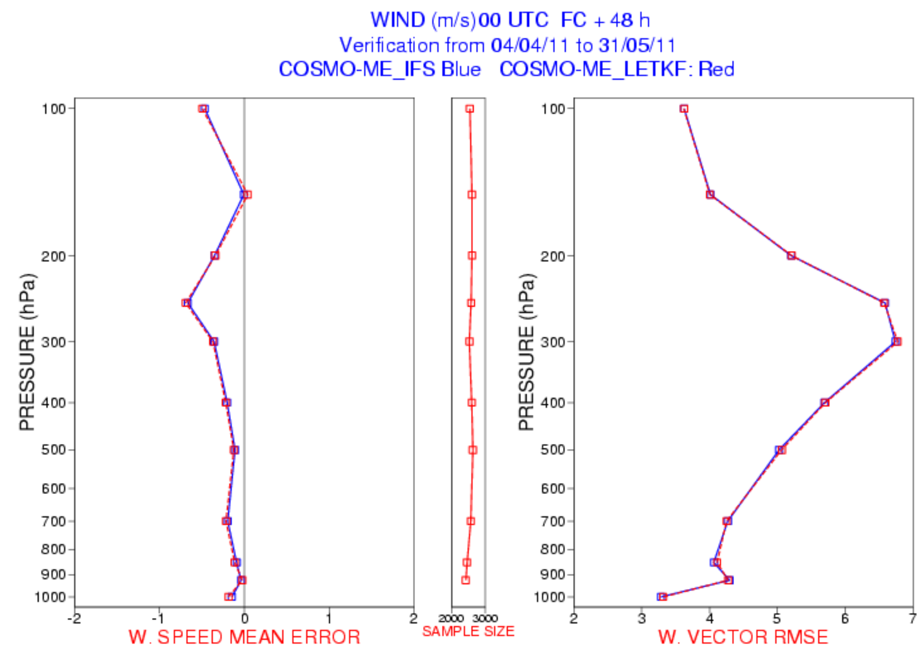






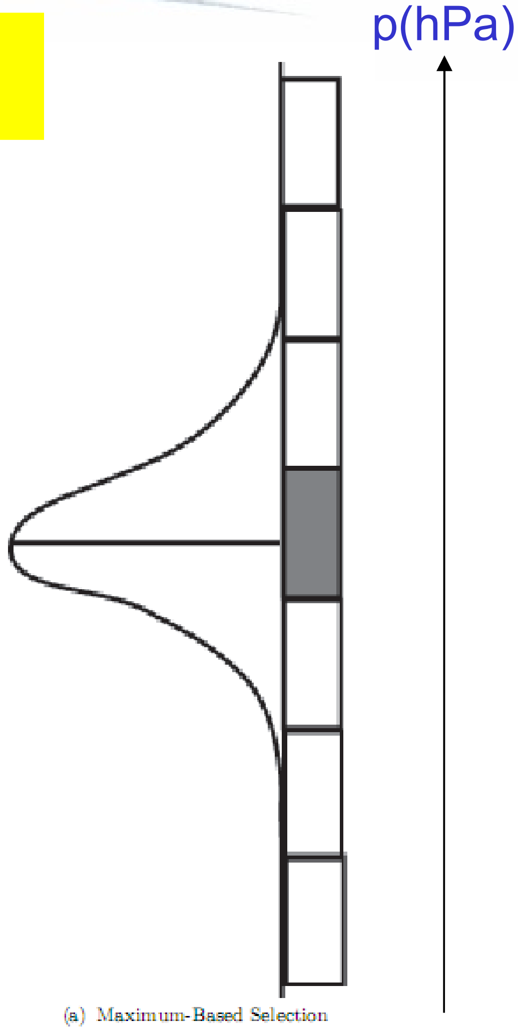


Radiances Treatment

AMSU-A Assimilation

Selecting which satellite radiances to assimilate is complicated by the fact that they not have a single well-defined vertical location
The weighting function at a particular model point indicates the sensitivity of that observation to the state at that model grid point
→"**MAXIMUM-BASED SELECTION**" **METHOD** (Fertig et al. 2007)

- **AMSU-A are treated as "single-level" observations**
- **Assign radiance observations to the model level for which the magnitude of the weighting function (wf) is largest.**
- ***Use also the wf shape as vertical covariance localization function***



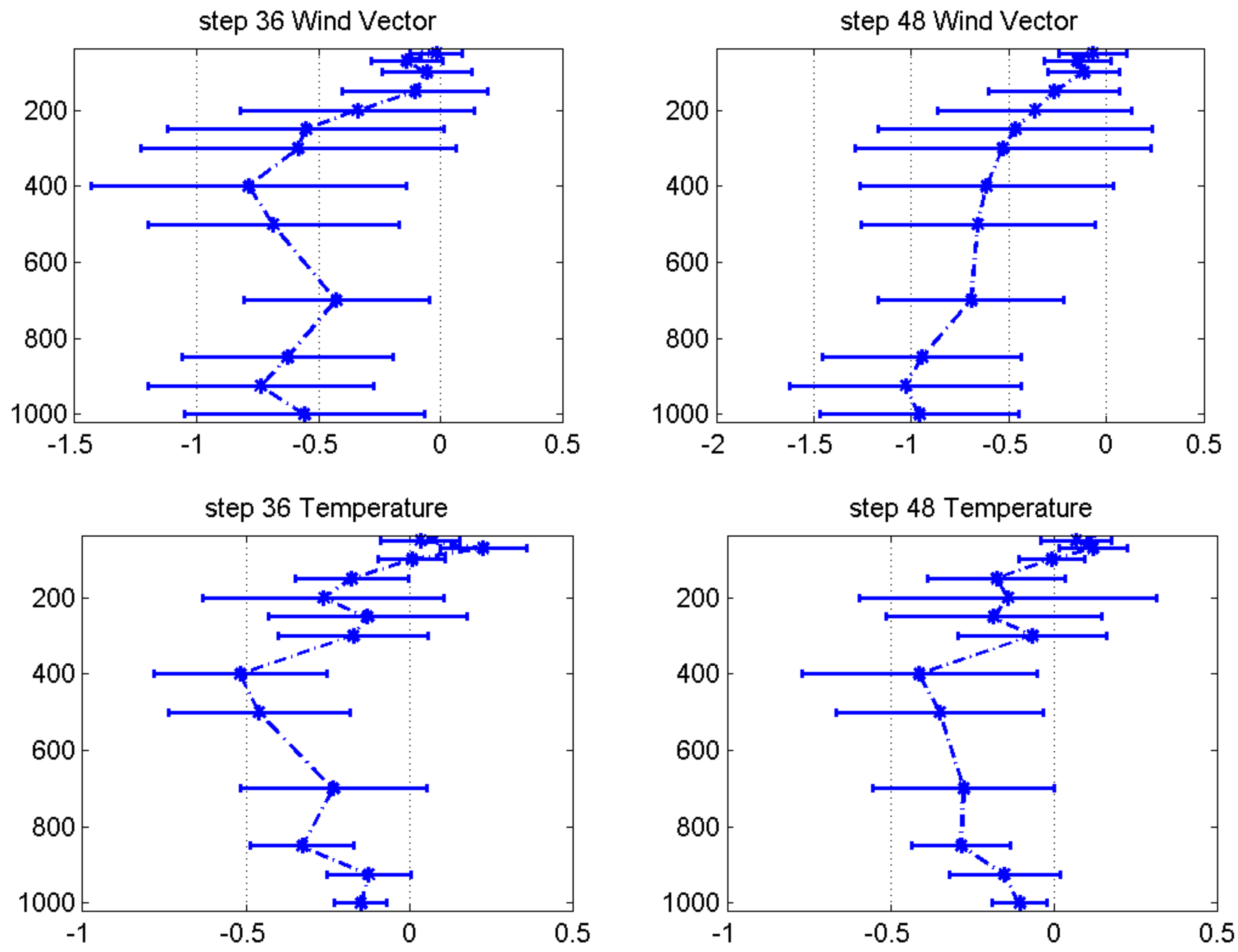
Weighting function (transmittance vert. derivative)

$$w_k = (\tau_{v,k-1} - \tau_{v,k}) / (\ln(p_k) - \ln(p_{k-1}))$$

Impact of AMSUA rad.

Relative difference (%) in RMSE computed against IFS analysis for 00 UTC EuroHRM runs (28km) from 11-10-2009 to 10-11-2009

RTTOV 9.3



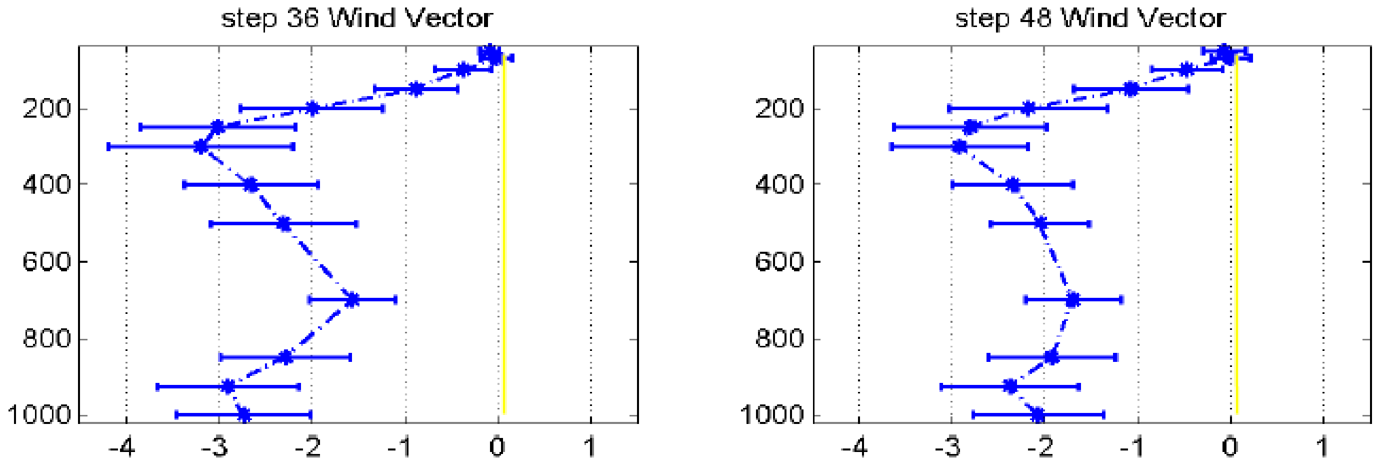
Handling Non-Linearities

Results

- No-cost LETKF smoother works:

LETKF an. $\overline{x}_n^a = \overline{x}_n^b + X_n^b \overline{w}_n^a$ Smoothed an. $\overline{x}_{n-1}^a = \overline{x}_{n-1}^a + X_{n-1}^a \overline{w}_n^a$

Relative difference (%) in RMSE computed against IFS analysis



- We tested Quasi Outer Loop and Running in Place algorithms (Yang and Kalnay, 2010) without any success
- We have not be able to have improvements from other variants of Outer Loop

Conclusions and Future Developments

- As far as we know, CNMCA is the first meteorological centre which uses operationally a pure ensemble data assimilation (LETKF) to initialize a deterministic NWP model (COSMO-ME).
- The long run is integrated from a control state LETKF derived using a control forecast instead of the FG ensemble mean
- The use of AMSU-A has improved the LETKF analysis.

- Assimilation of AMSU-B/MHS and IASI retrievals will be investigated soon.
- Balancing and non-linearities are issues to address
- Tests with COSMO model and shorter assimilation window
- Further tuning of model error representation (tuning of cov. localization, evolved additive noise, bias correction, etc.)
- Implement a Short-Range EPS based on LETKF

Thanks for your attention!