The Use of a Self-Evolving Additive Inflation in the CNMCA Ensemble Data Assimilation System

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Outline

- Implementation of the LETKF at CNMCA-the Italian National Met Center
- Treatment of model error in the CNMCA-LETKF
  - The Self Evolving Additive Noise formulation
    - Forecast verification over 20-days test period
  - The SPPT (Stochastic physics perturbation tendencies) implementation
- Summary and future developments

Ensemble Kalman Filter (LETKF) at the Italian Nat Met Center

- At CNMCA the **LETKF** (Hunt et al. 2007) formulation was chosen, because algorithmically simple to code, intrinsically parallel, etc.
- **OPERATIONAL SINCE JUNE 2011**

Analysis Ensemble Mean

$$\bar{x}^a = \bar{x}^b + \mathbf{X}^b \bar{w}^a$$

Analysis Ensemble Perturb.

$$X^a = \mathbf{X}^b W^a$$

Analysis Ensemble

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

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

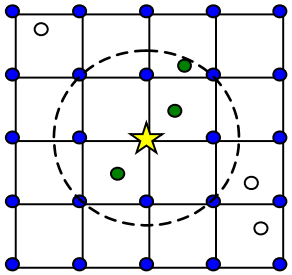
$$\tilde{P}^a = [(m-1)I + Y^{bT} R_l^{-1} Y^b]^{-1}$$

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

$$W^a = [(m-1)\tilde{P}^a] \qquad w^a = W^a + [\bar{w}^a, \ldots\ldots, \bar{w}^a]$$

- 40+1 member ensemble at 0.09° (~10Km) grid spacing 45 vertical lev
- 6-hourly assimilation cycle run and (T,u,v,pseudo-RH,ps) as a set of control variables

Observations: RAOB (also 4D), PILOT, SYNOP, SHIP, BUOY, Wind Profilers, AMDAR-ACAR-AIREP, MSG3-MET7 AMV, MetopA-B/Oceansat2 scatt. winds, NOAA/MetopA-B AMSUA/MHS radiances



Horizontal/vertical localization(obs weight smoothly decay with a pseudo-gaussian function of distance)

Adaptive selection radius based on a fixed number of effective obs

Treatment of model error

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

- Multiplicative Inflaction: Relaxation to Prior Spread according to Whitaker et al (2012)

an. pert. $$\mathbf{x}_{\mathrm{a}}^{'} = \mathbf{x}_{\mathrm{a}}^{'} \sqrt{\alpha \frac{\sigma_{\mathrm{b}}^2 - \sigma_{\mathrm{a}}^2}{\sigma_{\mathrm{a}}^2} + 1}$$ α = 0.95

σ2 = variance

- Additive Noise from EPS (climat. noise before june 2013)

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

$\mathbf{x}_i^n$ 36-12h/42-18h forecast differences valid at analysis tyme

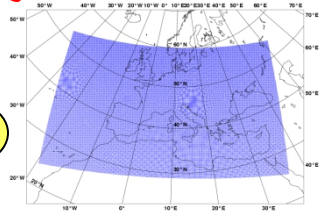
- Lateral Boundary Condition Perturbation of determ. IFS using EPS

- Climatological Perturbed SST

CNMCA LETKF DA SYSTEM

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

Observations (±6h)



00 06 12 18

Data Assimilation System

LETKF Analysis

00 06 12 18

12 Blended Mean

Additive Infl.

00 06 12 18

COSMO F.G.

FG00 FG06 FG12 FG18

40+1 members
0.09° grid spacing
45 vert. lev.

00 06 **BC Pert.** 00 SST Perturb. 12 18

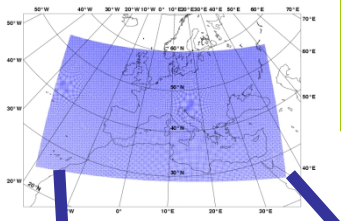
EPS 00 06 12 18

IFS B.C. **IFS Analysis**

CNMCA NWP SYSTEM since 1 June 11

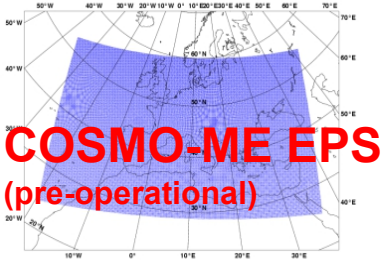
LETKF analysis ensemble (40+1 members) every 6h using RAOB (also 4D), PILOT, SYNOP, SHIP, BUOY, Wind Profilers, AMDAR-ACAR-AIREP, MSG3-MET7 AMV, MetopA-B/Oceansat2 scatt. winds, NOAA/MetopA-B AMSUA radiances
+ Land SAF snow mask,
IFS SST analysis once a day

Ensemble Data Assimilation:



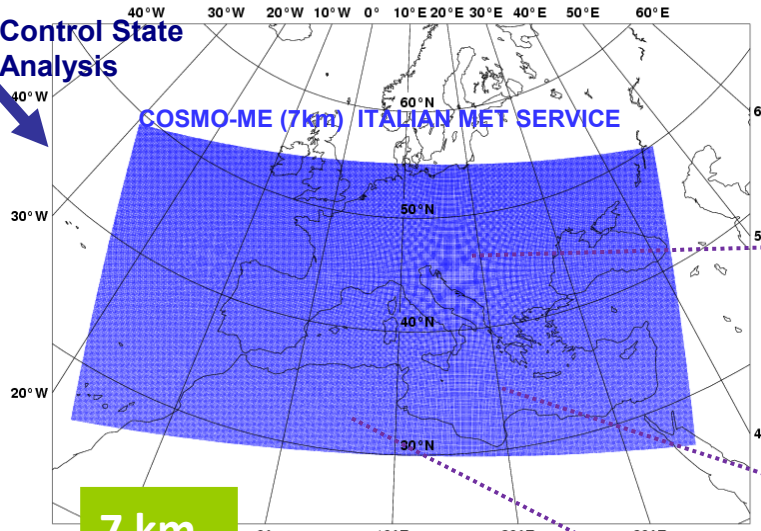
10 km
45 v.l.

LETKF Analysis



COSMO-ME EPS
(pre-operational)

Control State Analysis

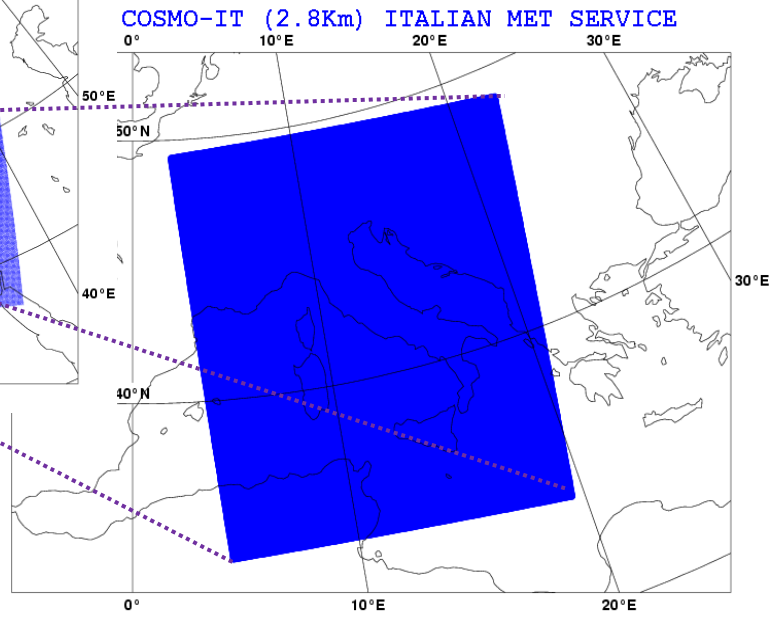


7 km
40 v.l.

- compressible equations
- parameterized convection

2.8 km
65 v.l.

- compressible equations
- explicit convection



Self-Evolving Additive Noise

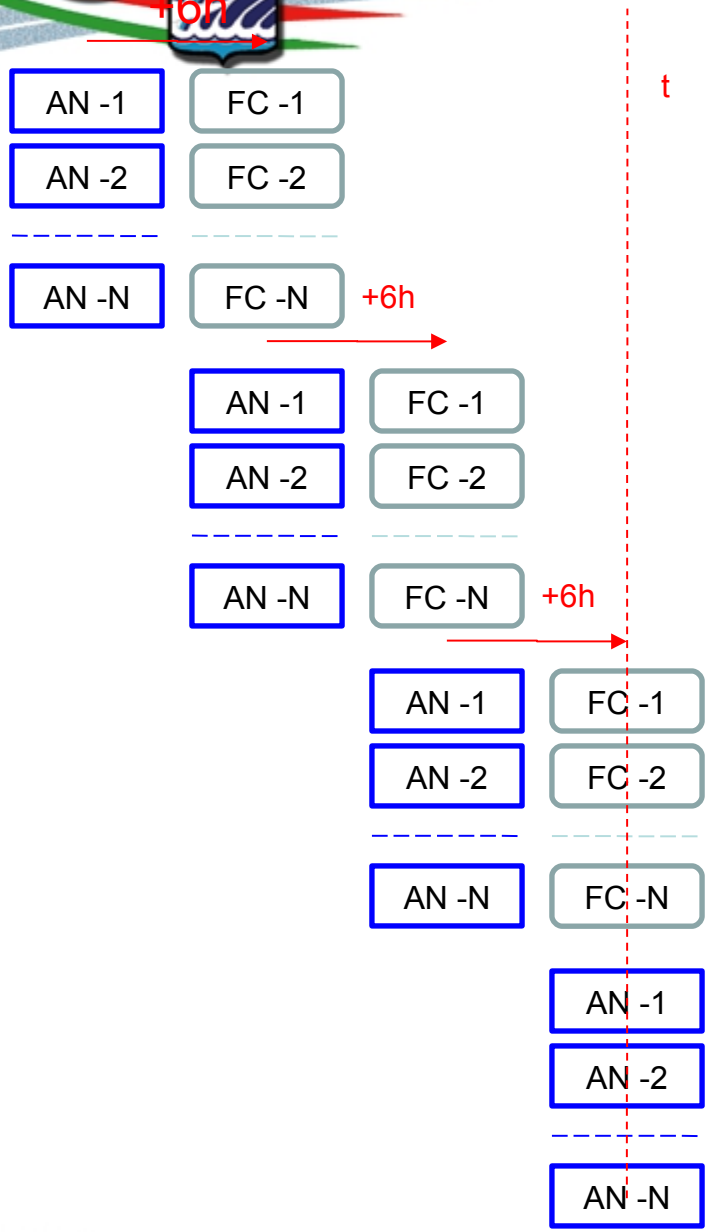
AIM: Find additive perturbations that are both consistent with model errors statistics and a flow-dependent noise

The self-evolving additive inflaction (idea of Mats Hamrud – ECMWF) is chosen. The idea is different from that of the evolved additive noise of Hamill and Whitaker (2010)

- Difference between ensemble forecasts valid at the analysis time is calculated. The mean difference is subtracted to yield a set of perturbations that are scaled and used as additive noise. The ensemble forecasts are obtained by the same ensemble DA system extending the end of the model integration.

- The error introduced during the first hours may have a component that will project onto the growing forecast structures having probably a benificial impact on spread growth and ensemble-mean error

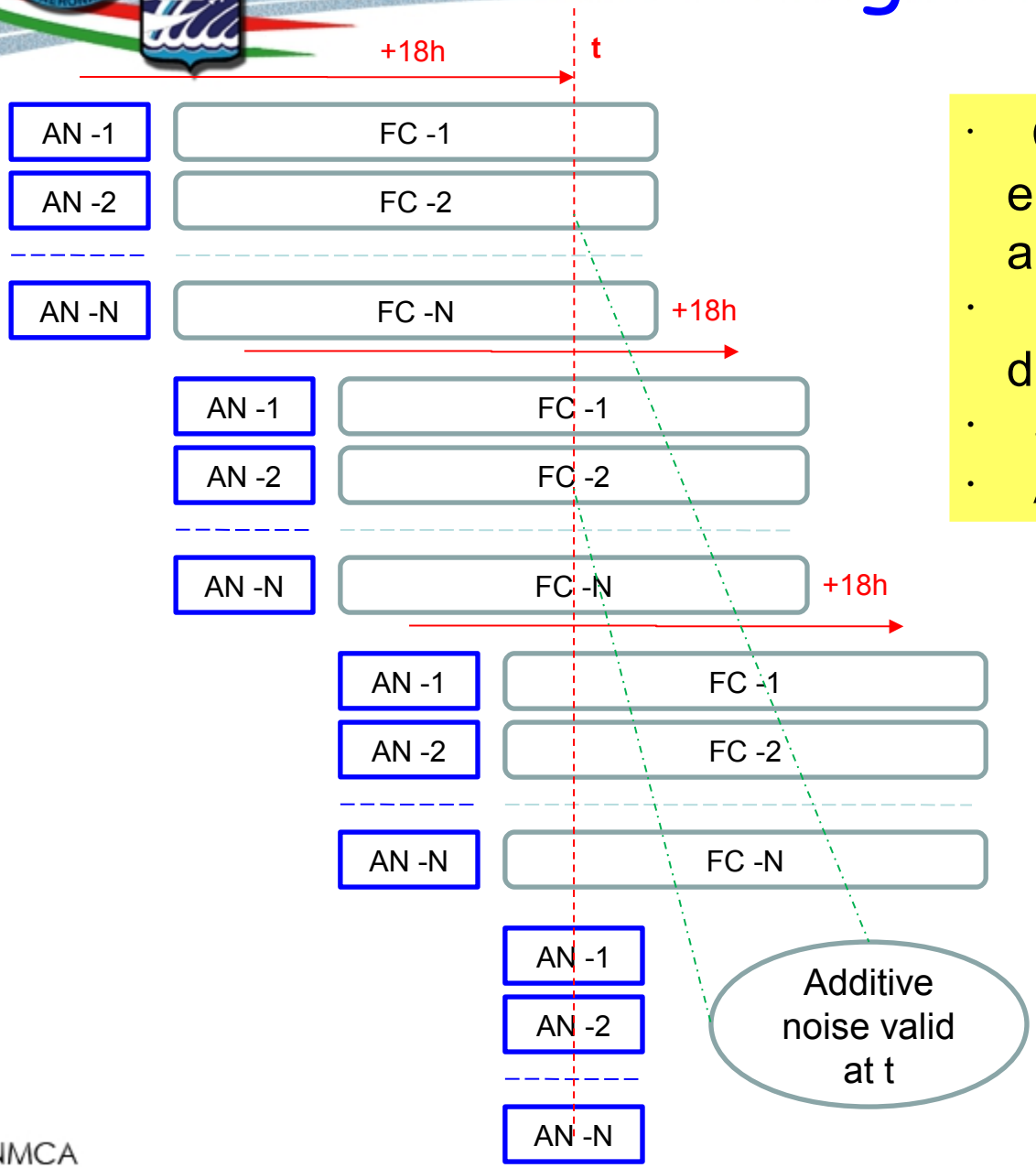
Self-Evolving Additive Noise



Additive noise valid at t

The end of model forecast Integration needs to be extend

Self-Evolving Additive Noise



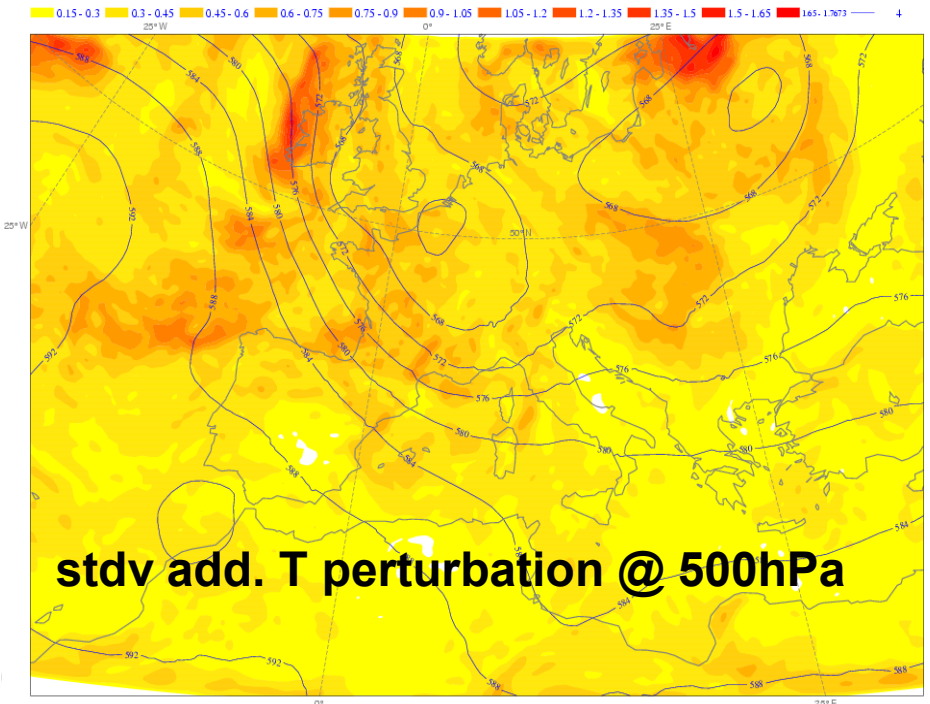
- Compute the difference of ensemble forecasts (i.e. 18h and 12h) valid at time t
- Remove the mean difference
- Scale the perturbations
- Add to the t analysis

Self-Evolving Additive Noise

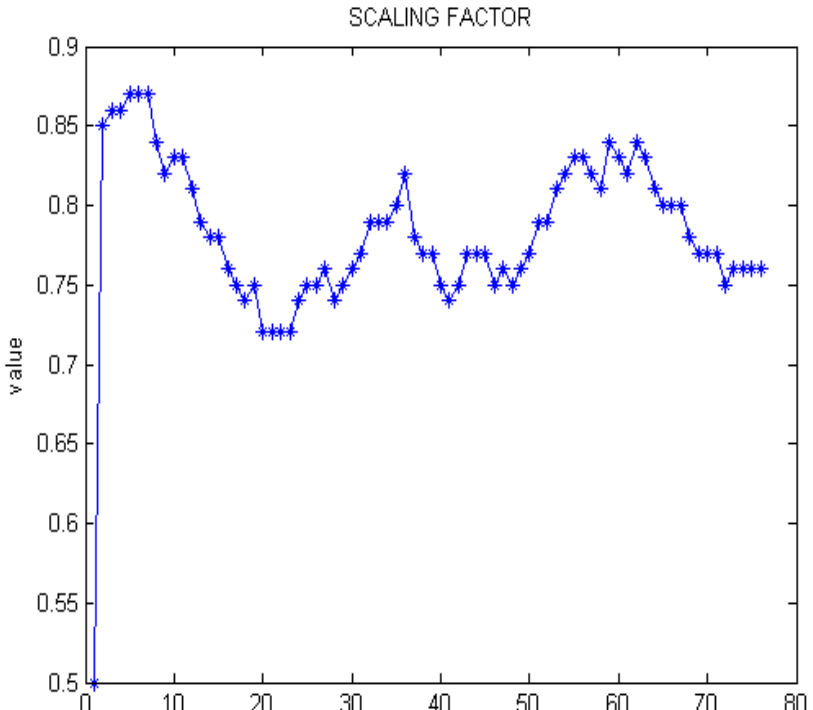
Features of the first version:

$$\mathbf{x}_i^a \leftarrow \mathbf{x}_i^a + \alpha \mathbf{x}_i^n ,$$

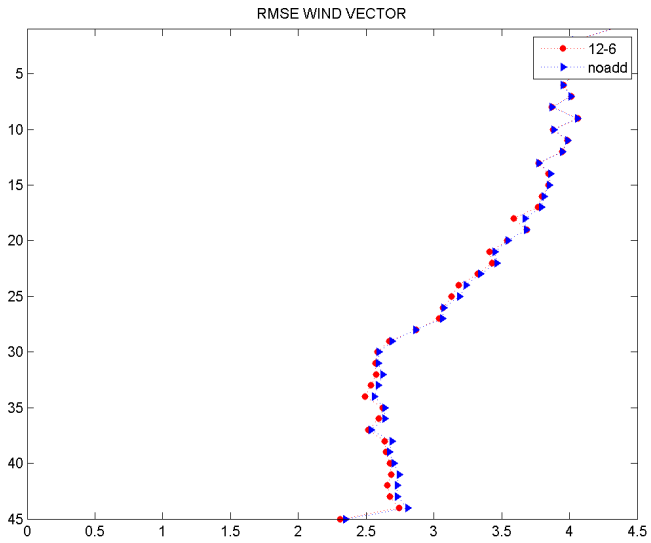
- 12h-6h forecast differences
- spatial filtering of ensemble difference using a low pass 10th order Raymond filter
- Adaptive scaling factor using the surface pressure obs inc statistics

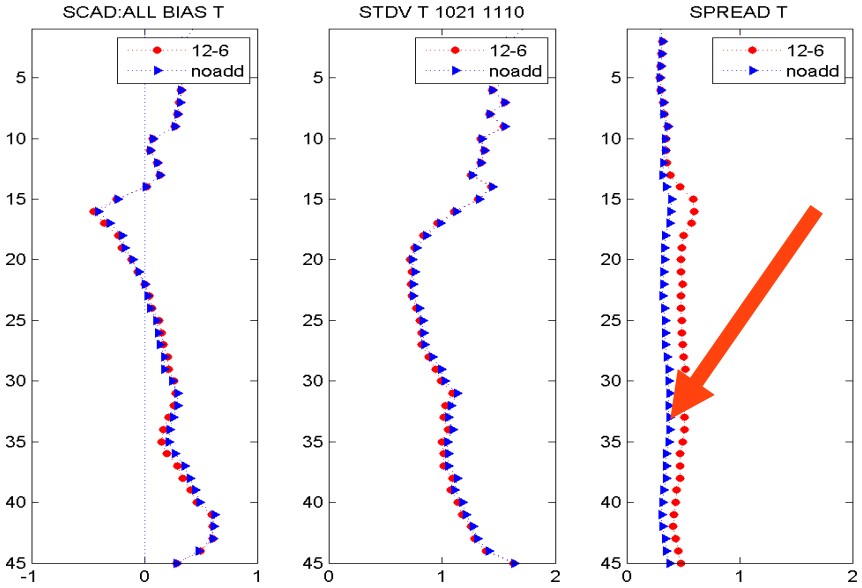


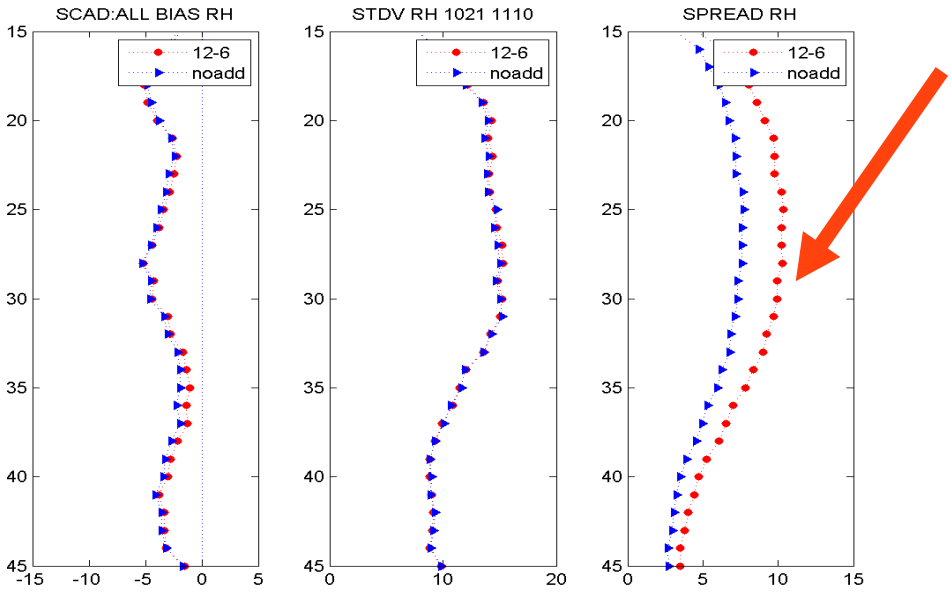
stdv add. T perturbation @ 500hPa



Obs Increment Statistics







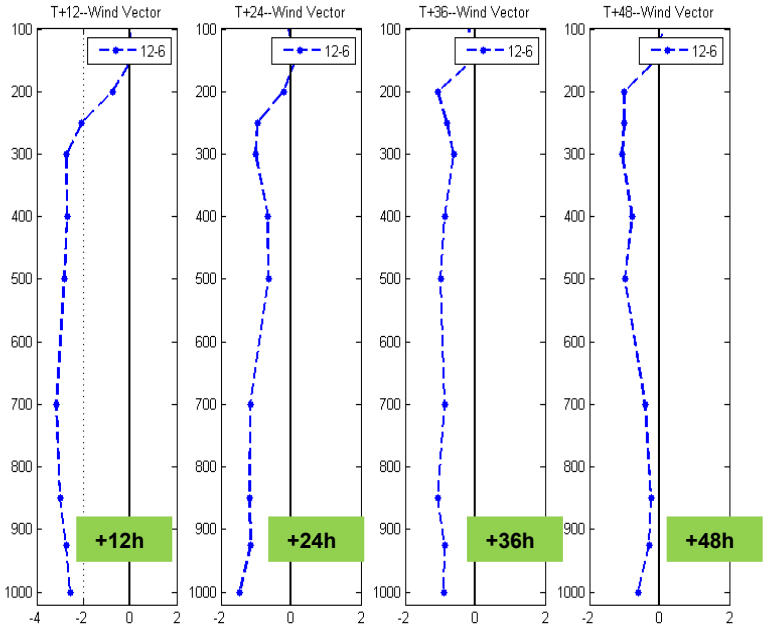
OBS INCREMENT ON **MODEL** LEVELS (TEMP + RAOB obs)

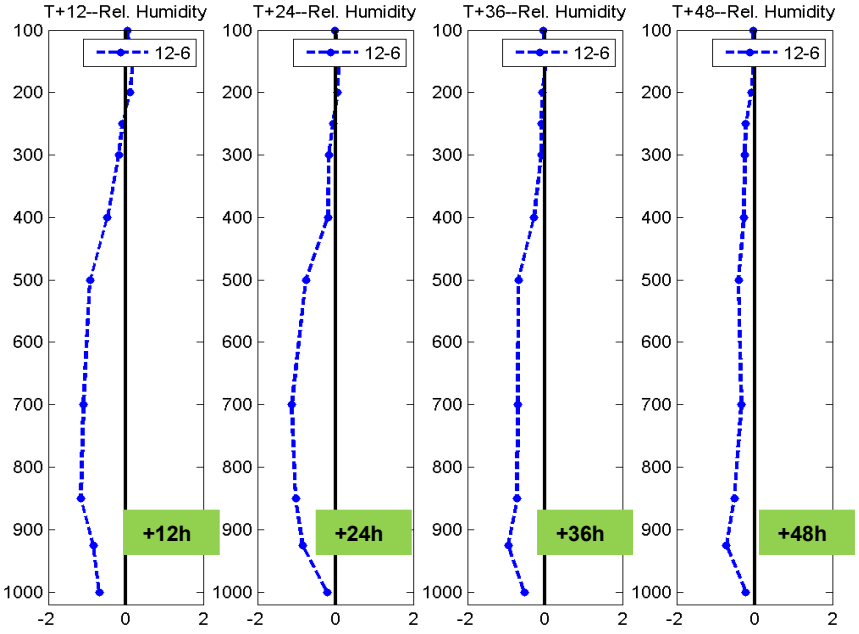
NO ADDITIVE VS **EVOLVED ADD**

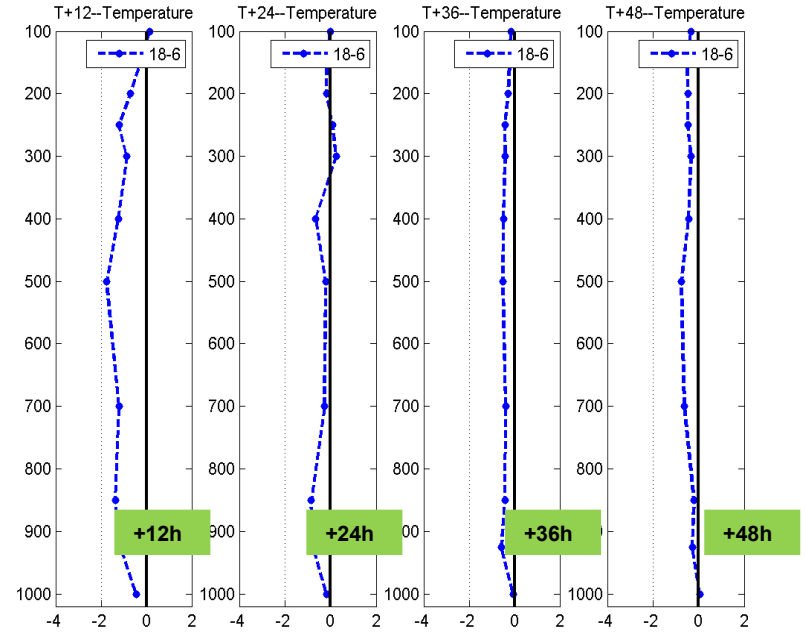
21 oct 2013 – 10 nov 2013

Forecast Verification

Relative difference (%) in RMSE,
computed against IFS analysis, with respect
to NO-ADDITIVE run
for 00 UTC COSMO runs from
21-oct 2013 to 10 nov 2013
negative value = positive impact





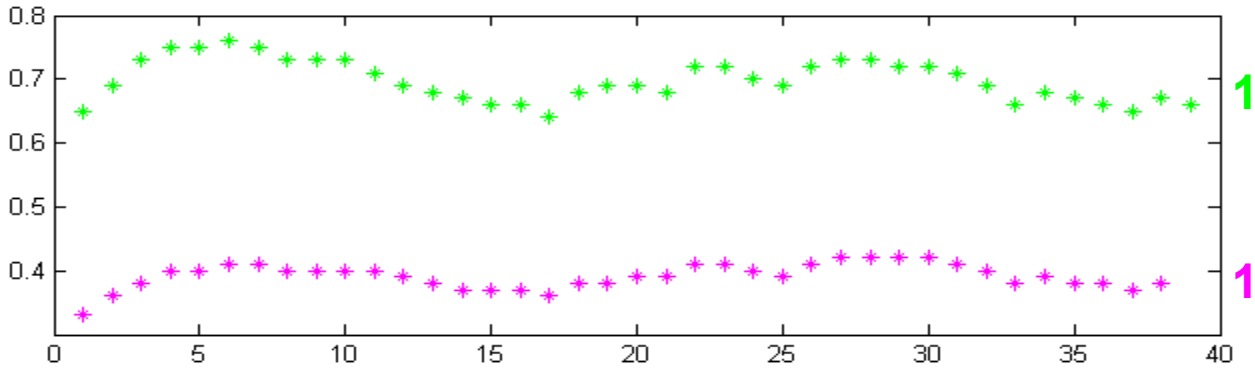


Self-Evolving Additive Noise

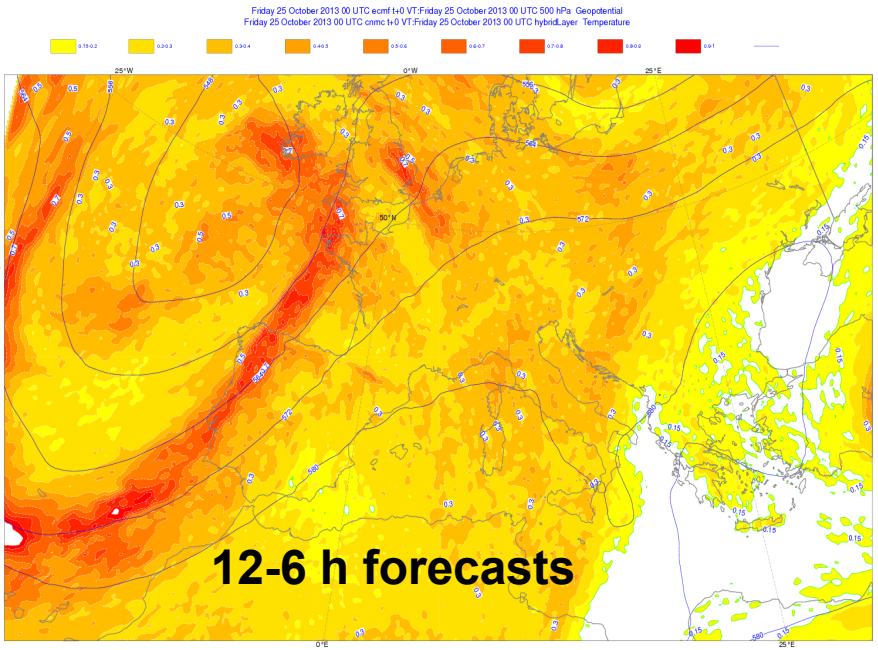
Can we get some benefit increasing the time difference between forecasts ?

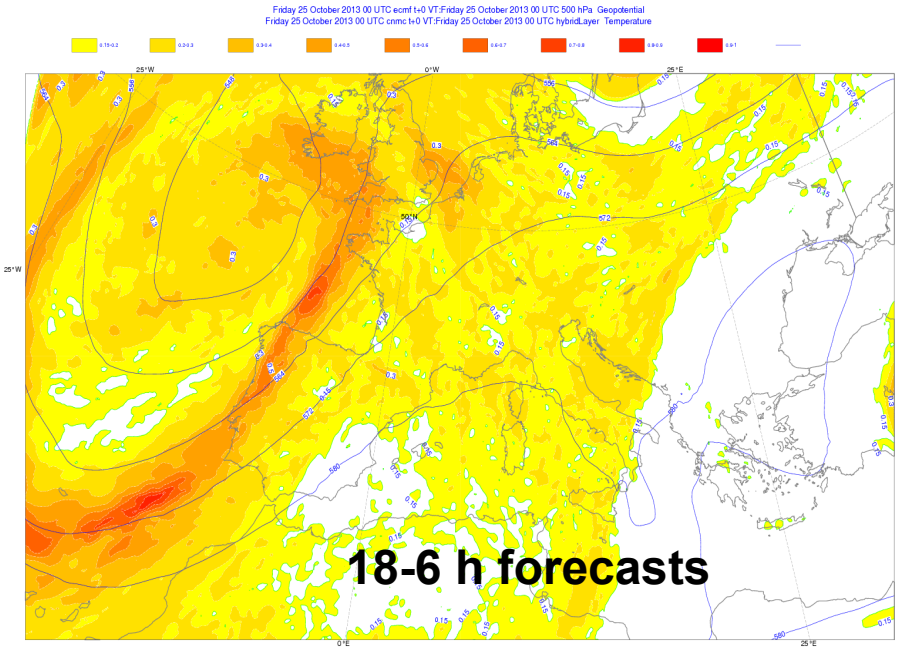
18-6 h vs *12-6 h*

Self-Evolving Additive Noise

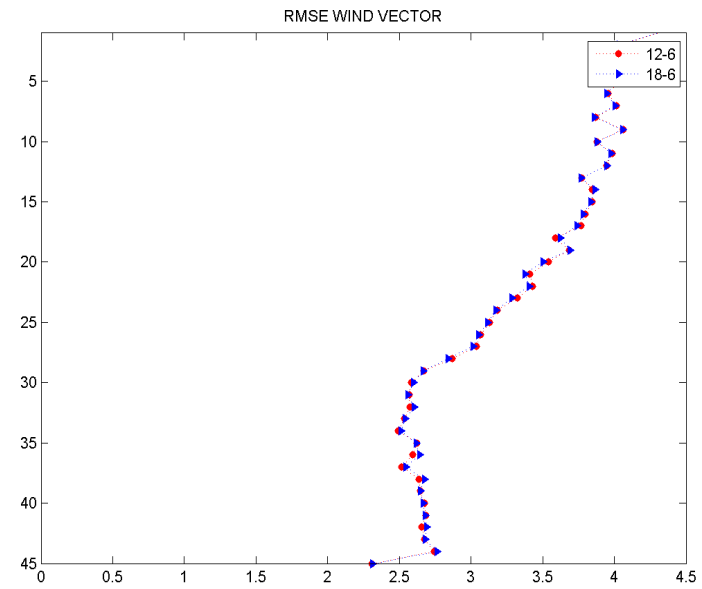


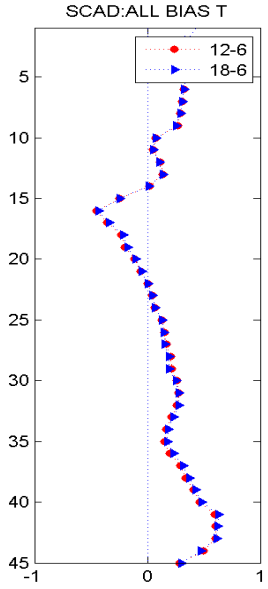
stdv add. T perturbation @ 500hPa

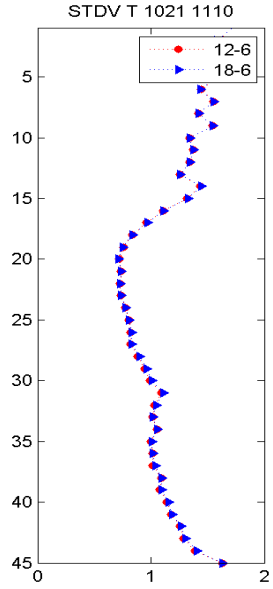


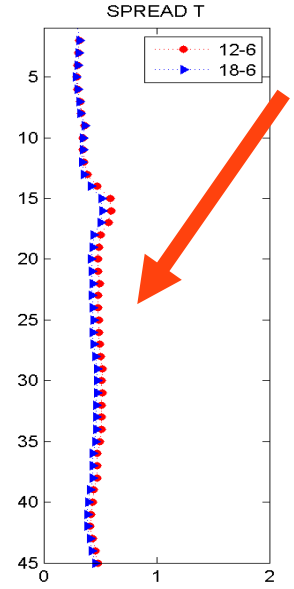


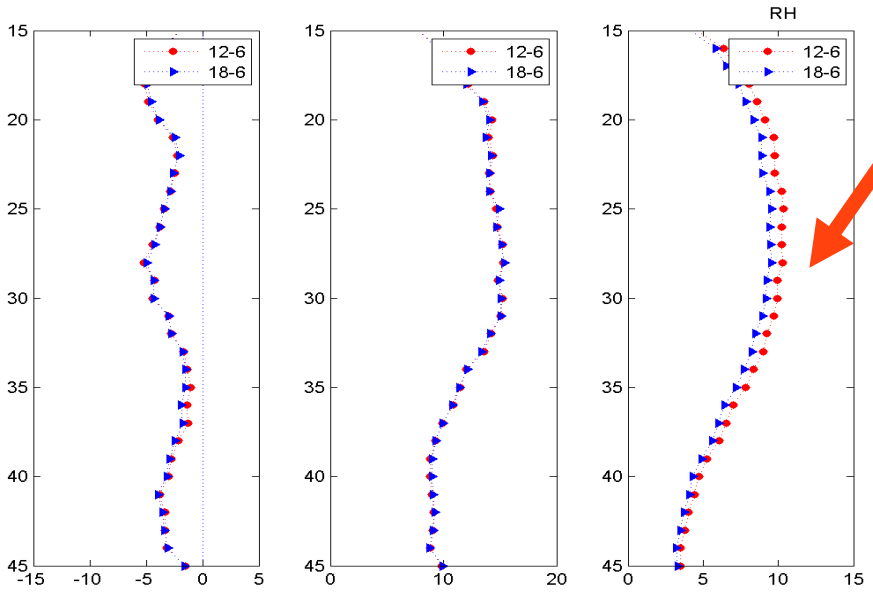
Obs Increment Statistics











OBS INCREMENT ON **MODEL** LEVELS (TEMP + RAOB obs)

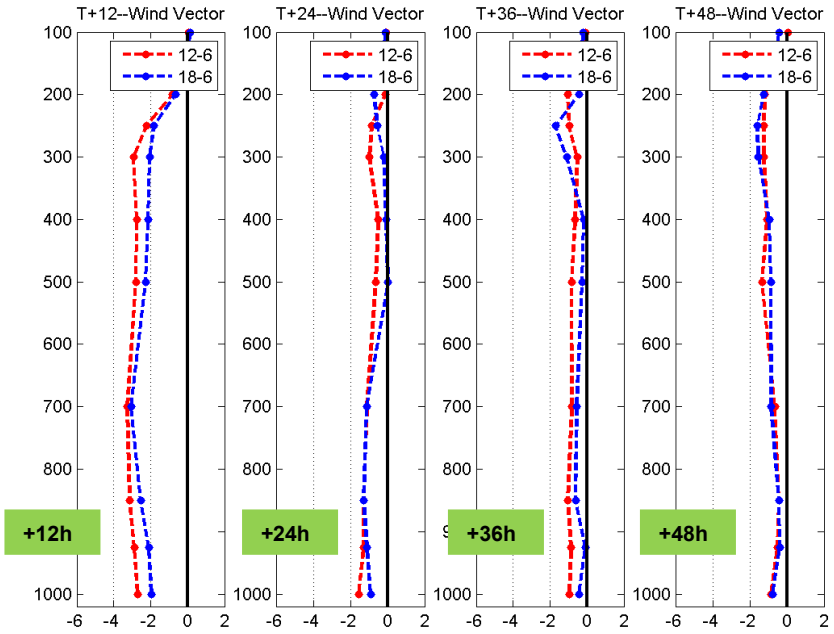
18-6h VS **12-6h**

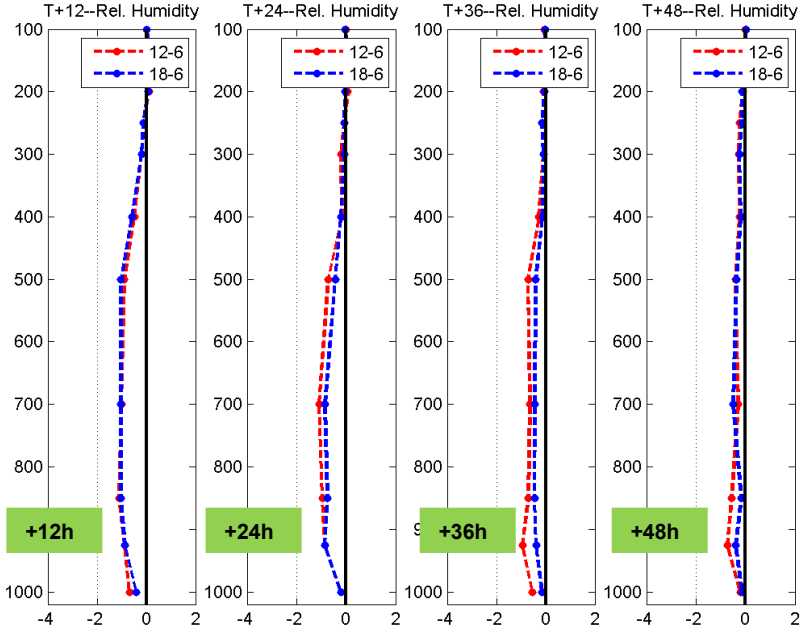
21 oct 2013 – 10 nov 2013

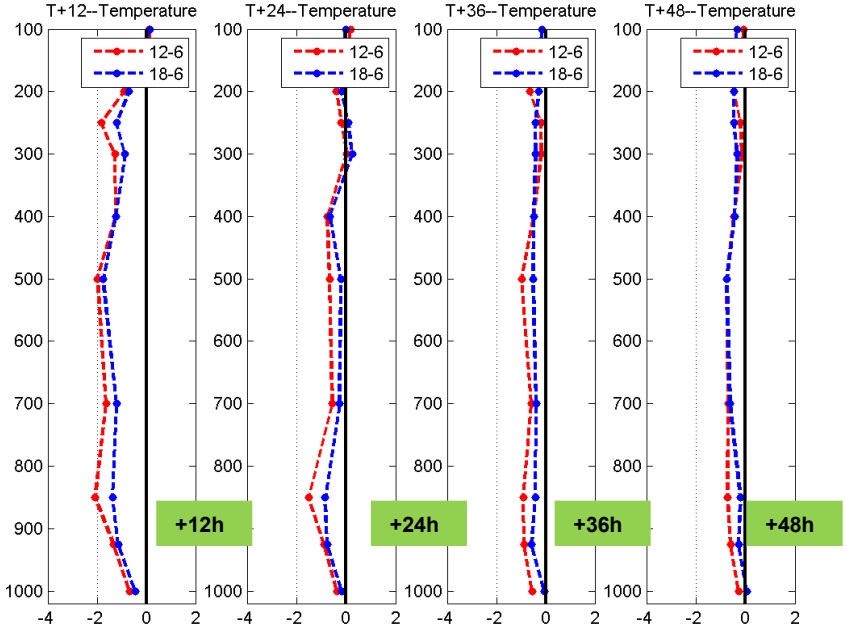
Forecast verification

Relative difference (%) in RMSE, computed against IFS analysis, with respect to NO-ADDITIVE run for 00 UTC COSMO runs from 21-oct 2013 to 10 nov 2013

negative value = positive impact







Operational Additive Noise

On june 2013 (HRM → COSMO) a new additive inflaction formulation was needed for the operational COSMO-LETKF since:

- The previous version of CNMCA-LETKF used a climatological additive noise based on HRM model.
- A climatological forecast database for COSMO at 0.09° and 45 v.l. is not available on the current integration domain
- Climatological additive inflaction has the technical disadvantage to require an “enough” long period of 36/48h forecasts (need to re-run the model or to interpolate old runs to the new resolution)

Moreover:

- A deficiency of climatological additive perturbations is that they are not dynamically conditioned to project onto the growing forecast structures (no relevance of flow of the day). It may take a while to project strongly.

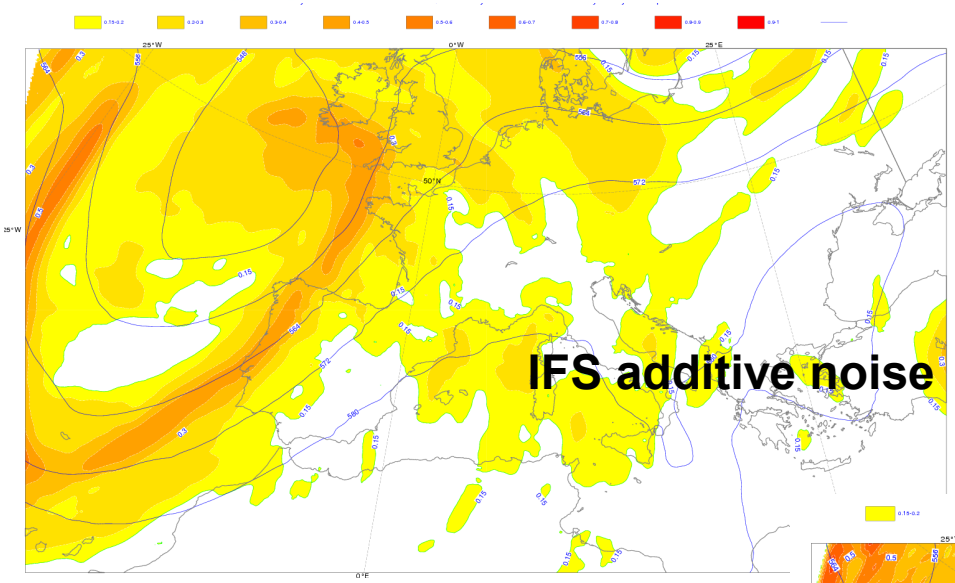
Additive Noise from IFS

First (!not last) solution:

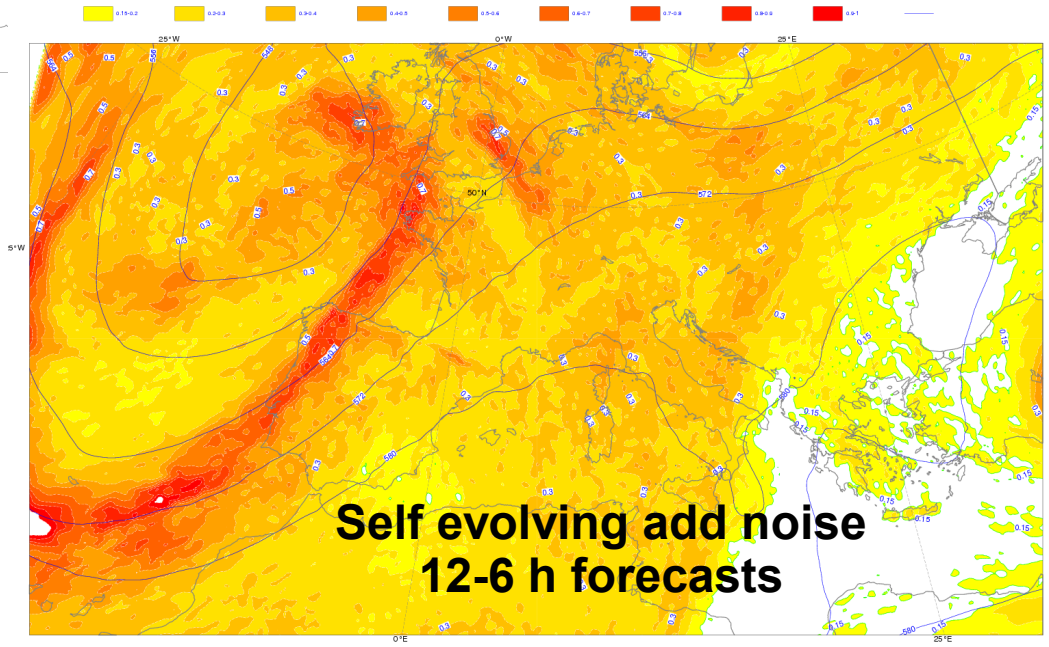
- The difference between EPS ensemble forecasts valid at the analysis time is computed and interpolated on the COSMO grid (36h and 12h at 00/12UTC run and 42h and 18h at 06/18UTC run)
- EPS forecasts on pressure levels are currently used.
- The mean difference is removed to yield a set of perturbations that are globally scaled and used as additive noise.

This additive noise, derived from IFS model, is not consistent with COSMO model errors statistics, but it may temporarily substitute the climatological one (avoiding a decrease of the spread in the CNMCA COSMO-LETKF).

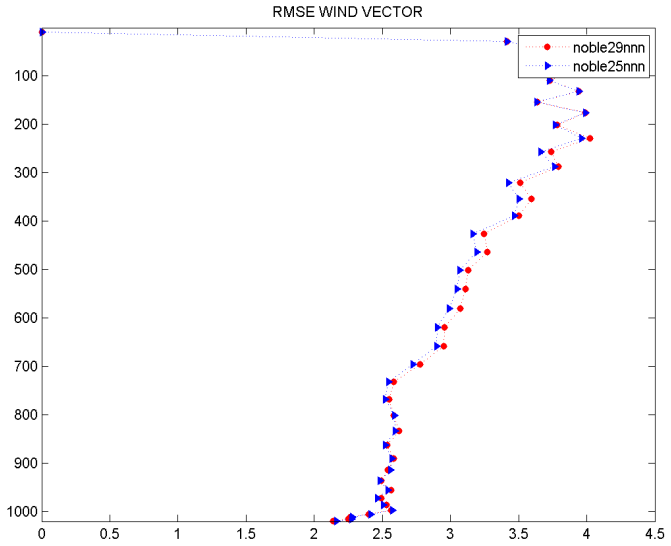
Operational vs Self Evolv Additive Noise

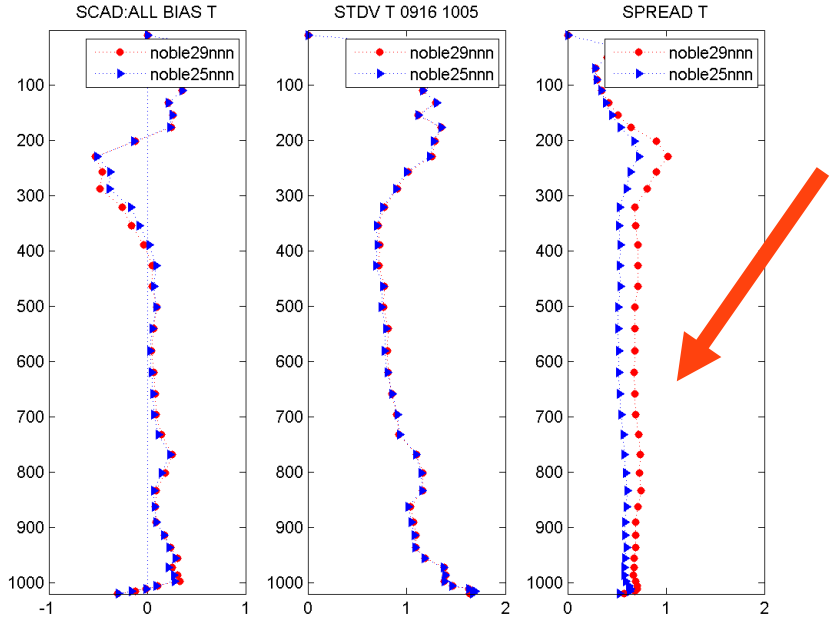


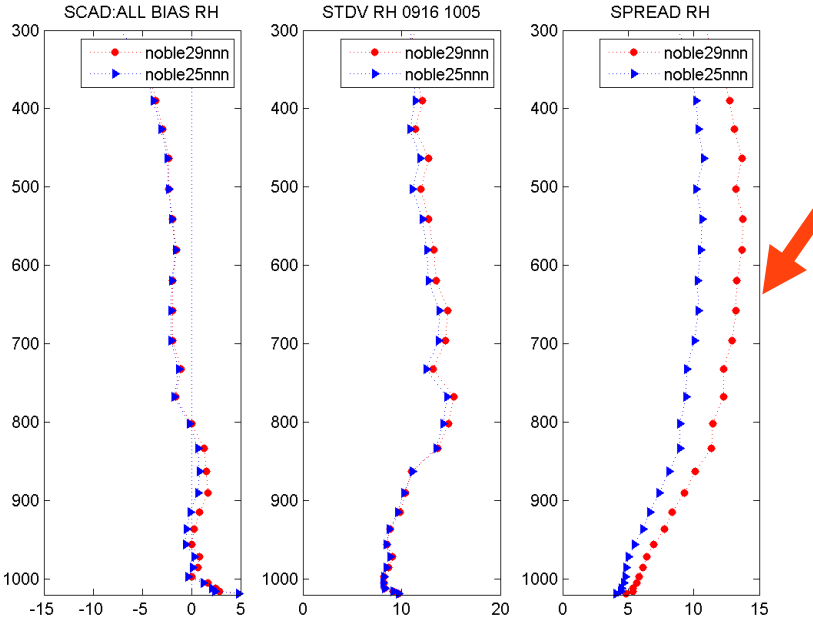
stdv add. T perturbation @ 500hPa



Obs Increment Statistics







OBS INCREMENT ON **MODEL** LEVELS (TEMP + RAOB obs)

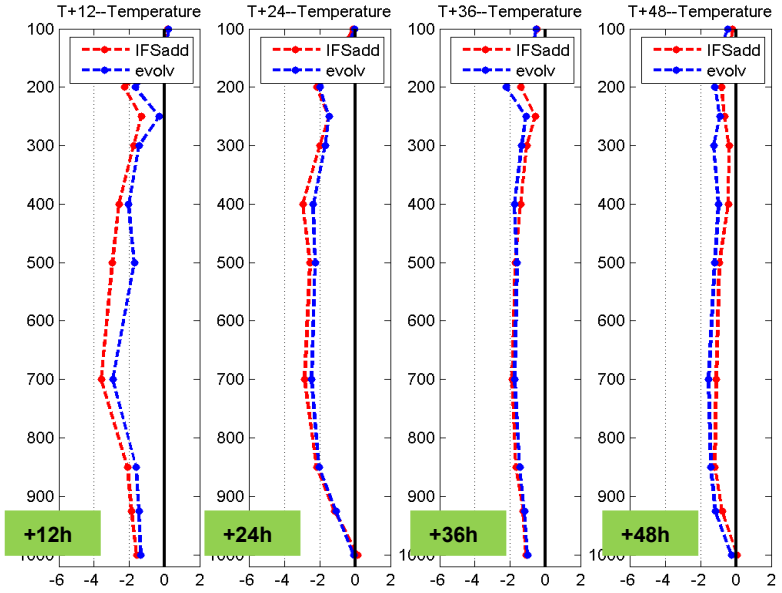
IFS ADD VS **EVOLVED 12-6h**

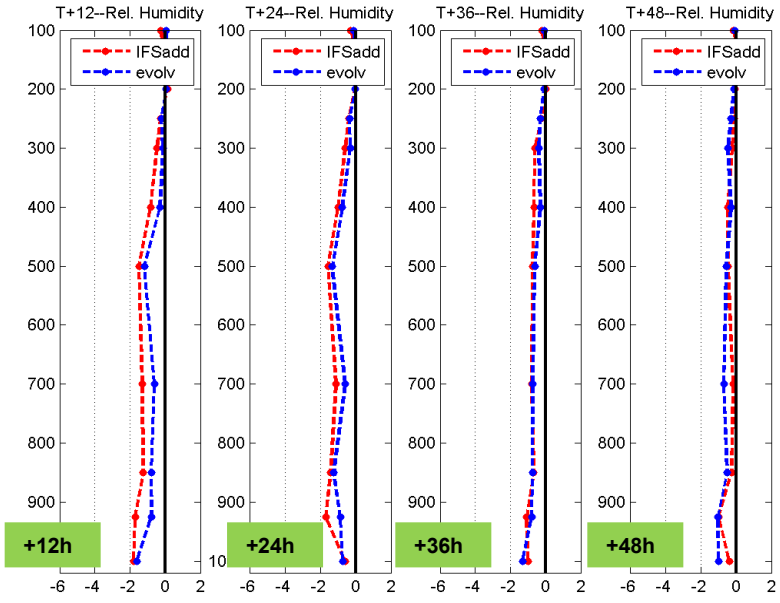
16 sept 2012 – 5 oct 2012

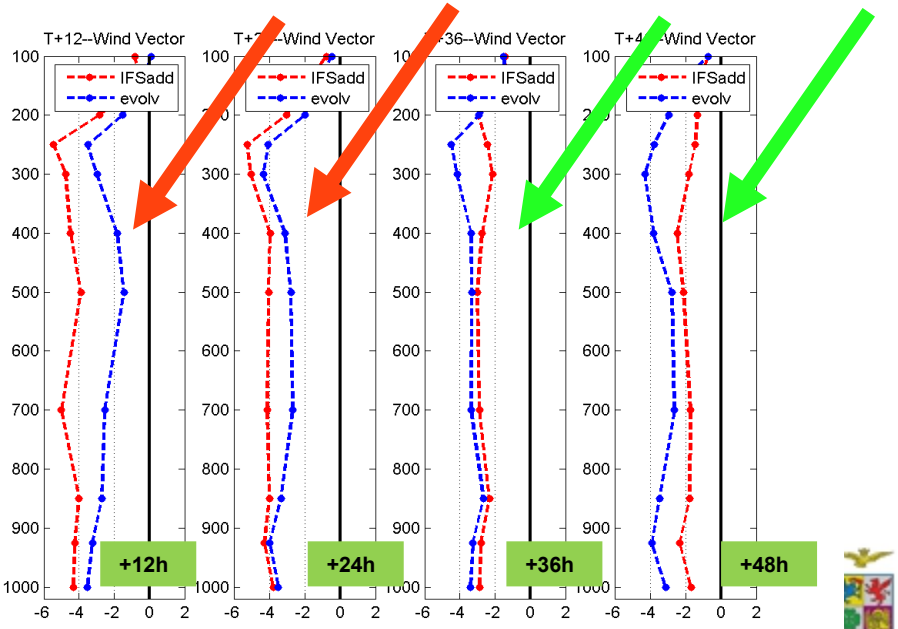
Forecast Verification

Relative difference (%) in RMSE, computed against IFS analysis, with respect to NO-ADDITIVE run for 00 UTC COSMO runs from 16 sept 2012 – 5 oct 2012

negative value = positive impact



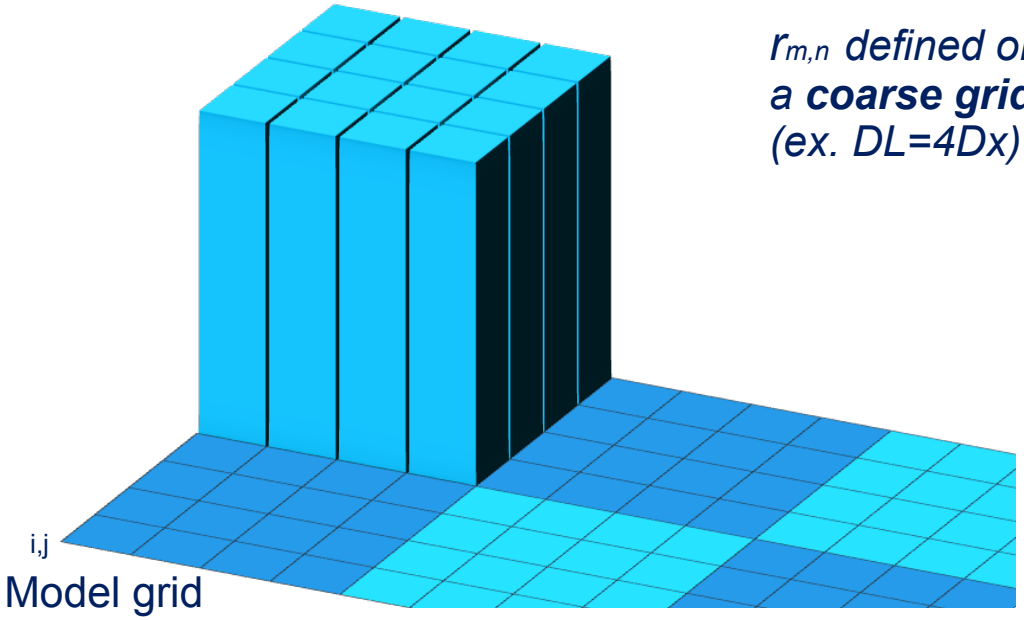




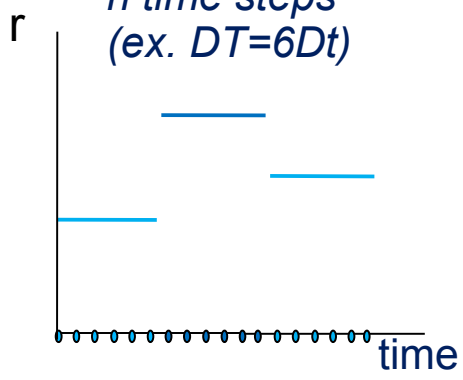
Stochastic Perturbed Physics Tendency

- Model uncertainty could be represented also with a stochastic physics scheme (Buizza et al, 1999; Palmer et al, 2009) implemented in the prognostic model
- This scheme perturbs model physics tendencies by adding perturbations, which are proportional in amplitude to the unperturbed tendencies **Xc**:

$$Xp=(1+r\,\mu)Xc$$



$r_{m,n}$ *defined on a* ***coarse grid*** *(ex. DL=4Dx)*



$r_{m,n}$ *changed every n time steps (ex. DT=6Dt)*

COSMO Version (by Lucio Torrisi)

Random numbers are drawn on a horizontal coarse grid from a Gaussian distribution with a stdv (0.1-0.5) bounded to a certain value (range= ± 2-3 stdv) and interpolated to the model grid to have a smoother pattern in time and horizontally in space. Same random pattern in the whole column and for u,v,t,qv variables.

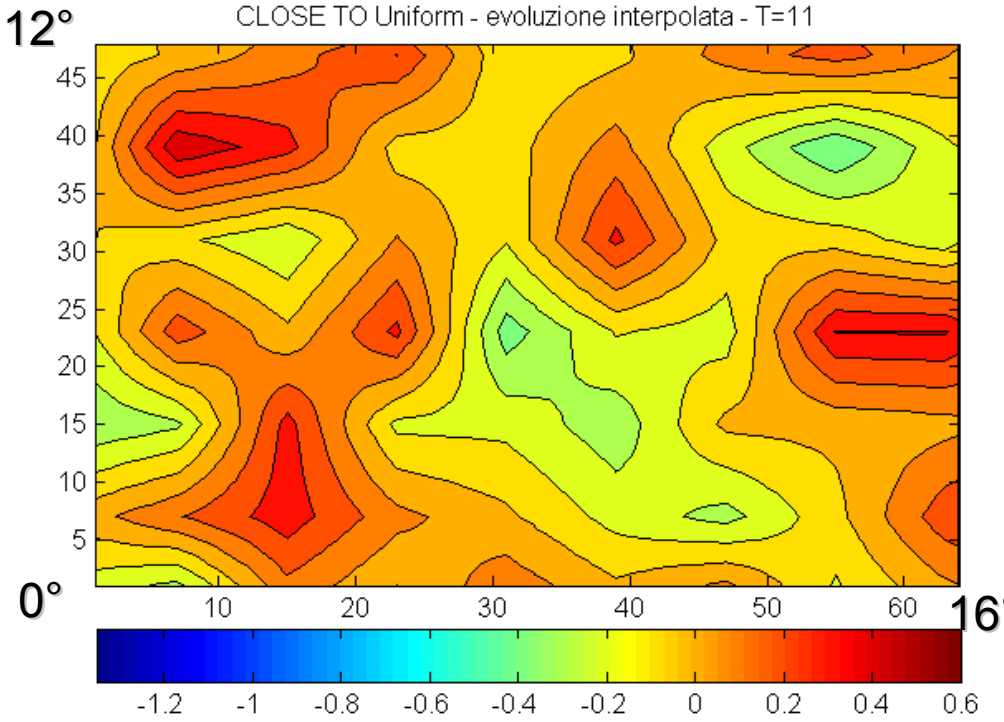
Stochastic Physics

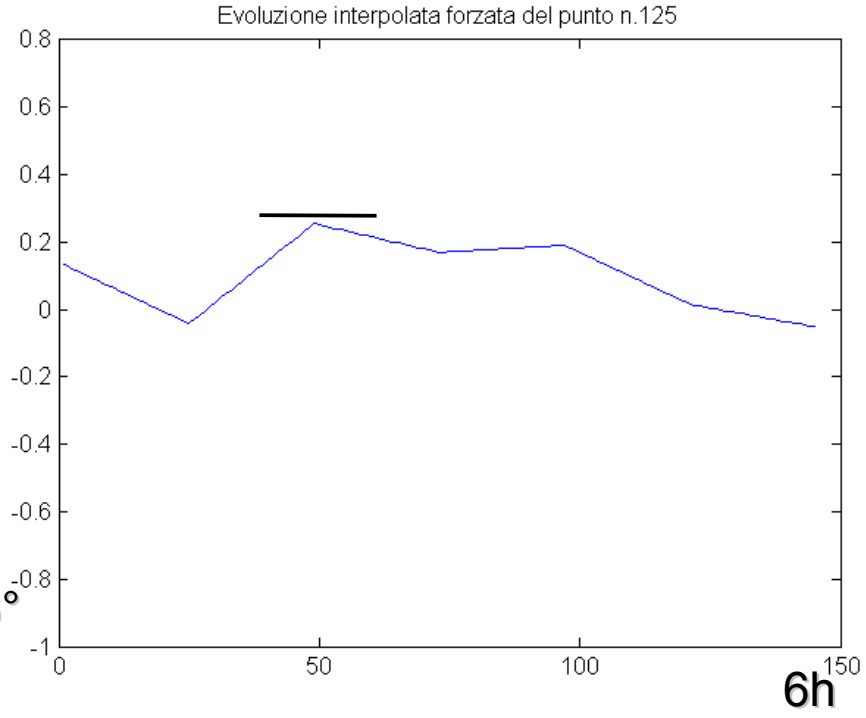
smoothed random pattern

Toy model and plots by A. Cheloni

Model grid spacing: 0.25° (28 km)

Time step: 150 s

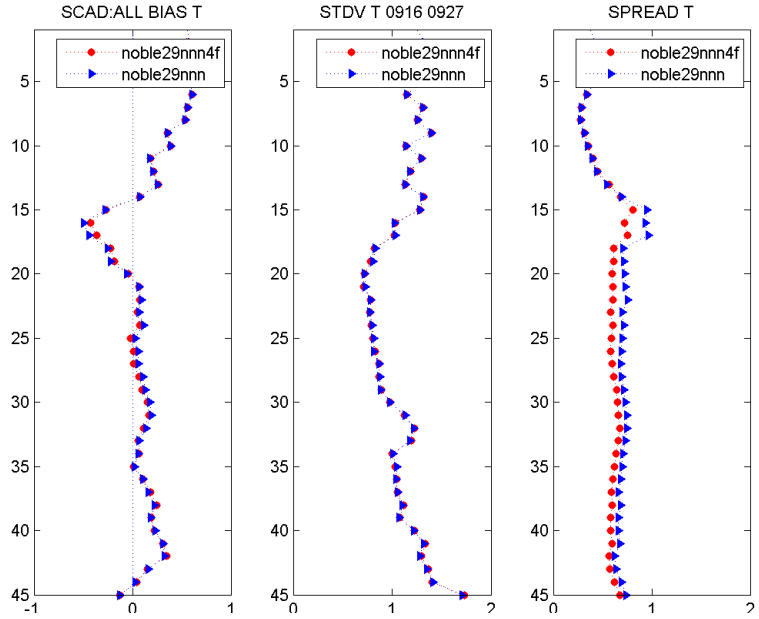


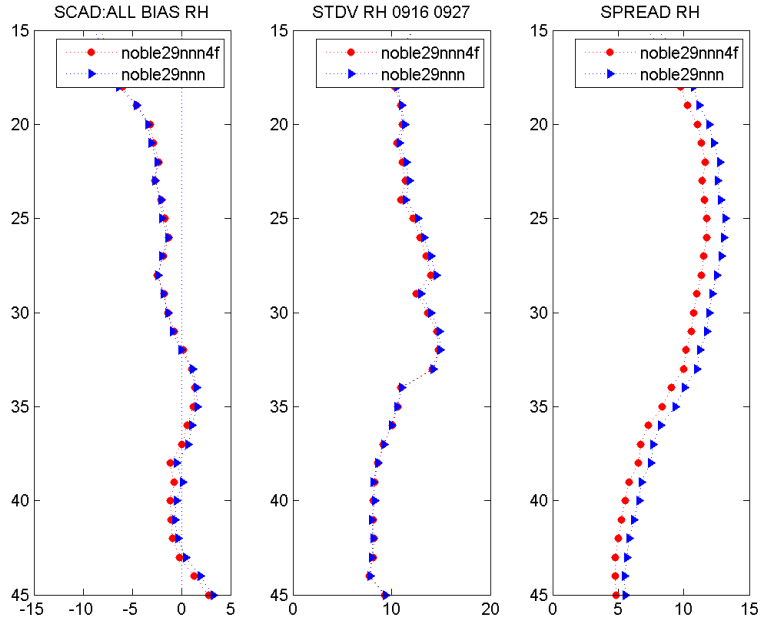


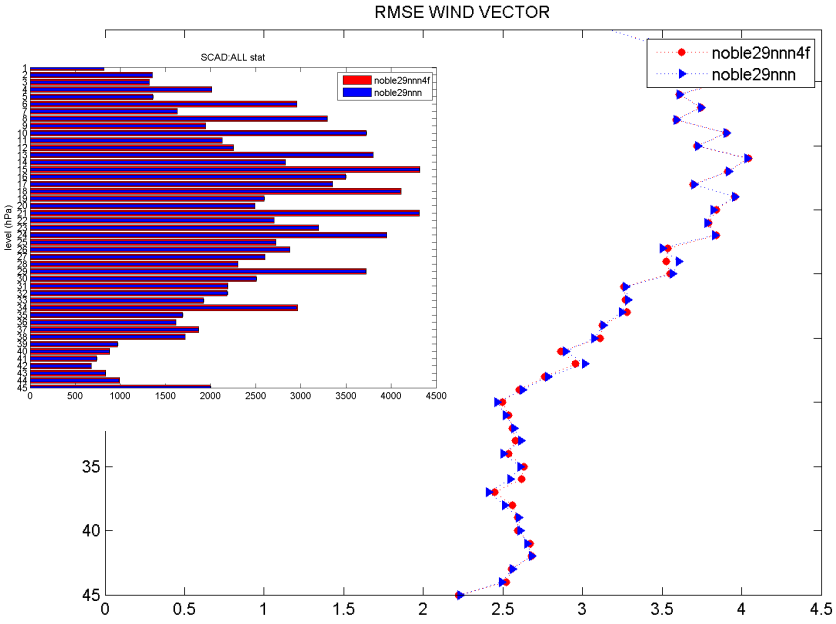
2.5° coarse grid with bilin. interp.

1h coarse time grid with lin. interp.

OBS INCREMENT STATISTICS (RAOB)
STOCHASTIC PHYSICS VS SELF-EVOLVING ADDITIVE







STOCHASTIC PHYSICS SETTINGS:
stdv=0.25, range=0.5
box 2.5° x 2.5°, 3 hour interp. in space and time
no humidity check

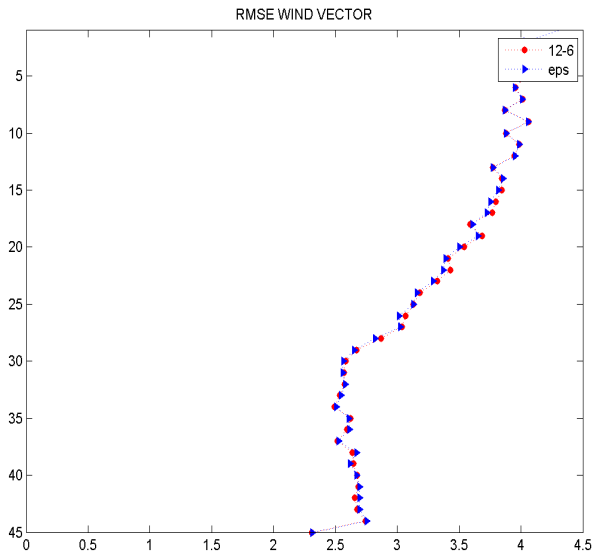
The impact on COSMO forecasts of SPPT seems to be smaller than those of additive noise (preliminar result)

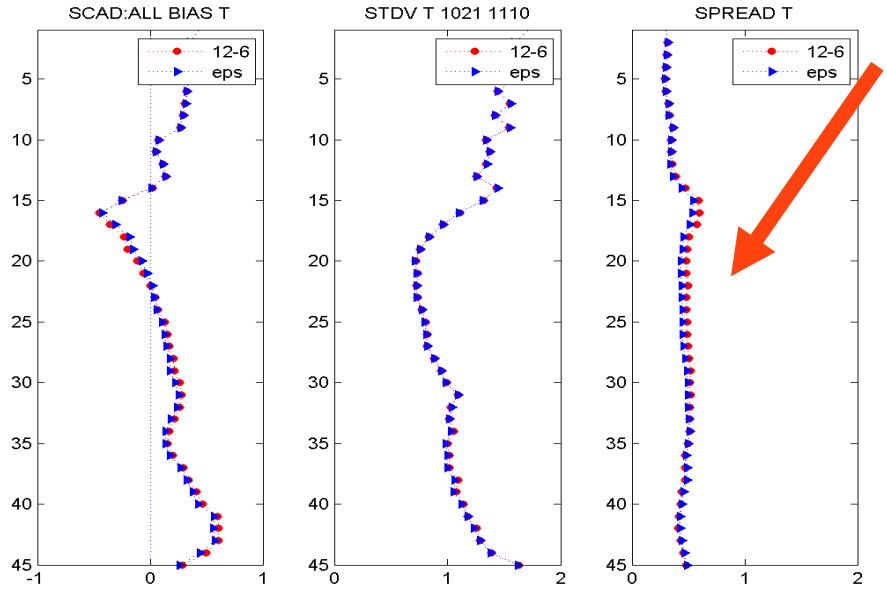
Summary and future steps

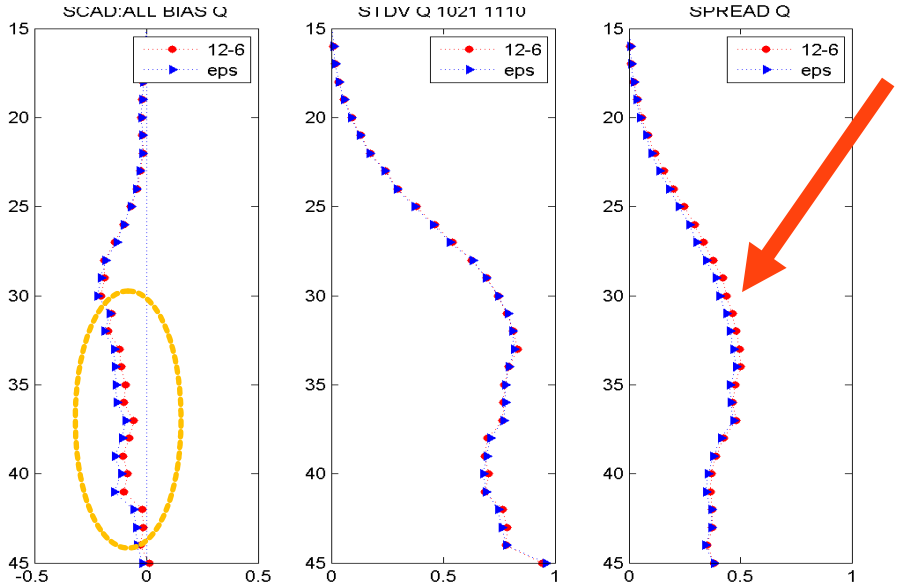
-"Self evolving additive noise" perturbations are both consistent with model errors statistics and a flow-dependent noise
- Additive noise computed using differences of forecasts with larger time distance (i.e. 18-6h) is computationally expensive and does not improve the scores as expected
- A better tuning of the 12-6 h forecast (filter and scaling factor) is planned
- A combination of self evolving additive noise and SPPT will be tested

Thanks for your attention!

Obs Increment Statistics







OBS INCREMENT ON **MODEL** LEVELS (TEMP + RAOB obs)
IFS ADD VS **EVOLVED 12-6h**

21 oct 2013 – 10 nov 2013

Forecast Verification

Relative difference (%) in RMSE, computed against IFS analysis, with respect to NO-ADDITIVE run for 00 UTC COSMO runs from 21 oct 2013 to 10 nov 2013

negative value = positive impact