Errors representation in the operational CNMCA-LETKF system

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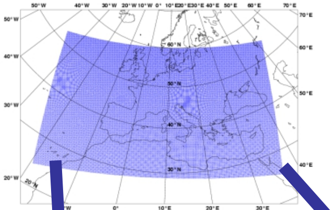
Outline

- ◆ Representation of background error in the CNMCA LETKF system
- ◆ SPPT implementation in COSMO model and experiments using CNMCA-LETKF DA and COSMO-ME EPS
- ◆ Self-evolving additive noise
- ◆ Conclusions

CNMCA NWP SYSTEM since 1 June 11

Ensemble Data Assimilation:

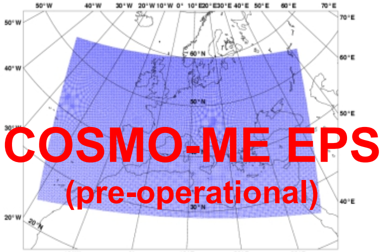
LETKF analysis ensemble (40+1 members) every 6h using RAOB (also 4D), PILOT, SYNOP, SHIP, BUOY, Wind Profilers, AMDAR-ACAR-AIREP, MSG3-MET7 AMV, MetopA-B/Oceansat2 scatt. winds, NOAA/MetopA-B AMSUA radiances
+ Land SAF snow mask,
IFS SST analysis once a day



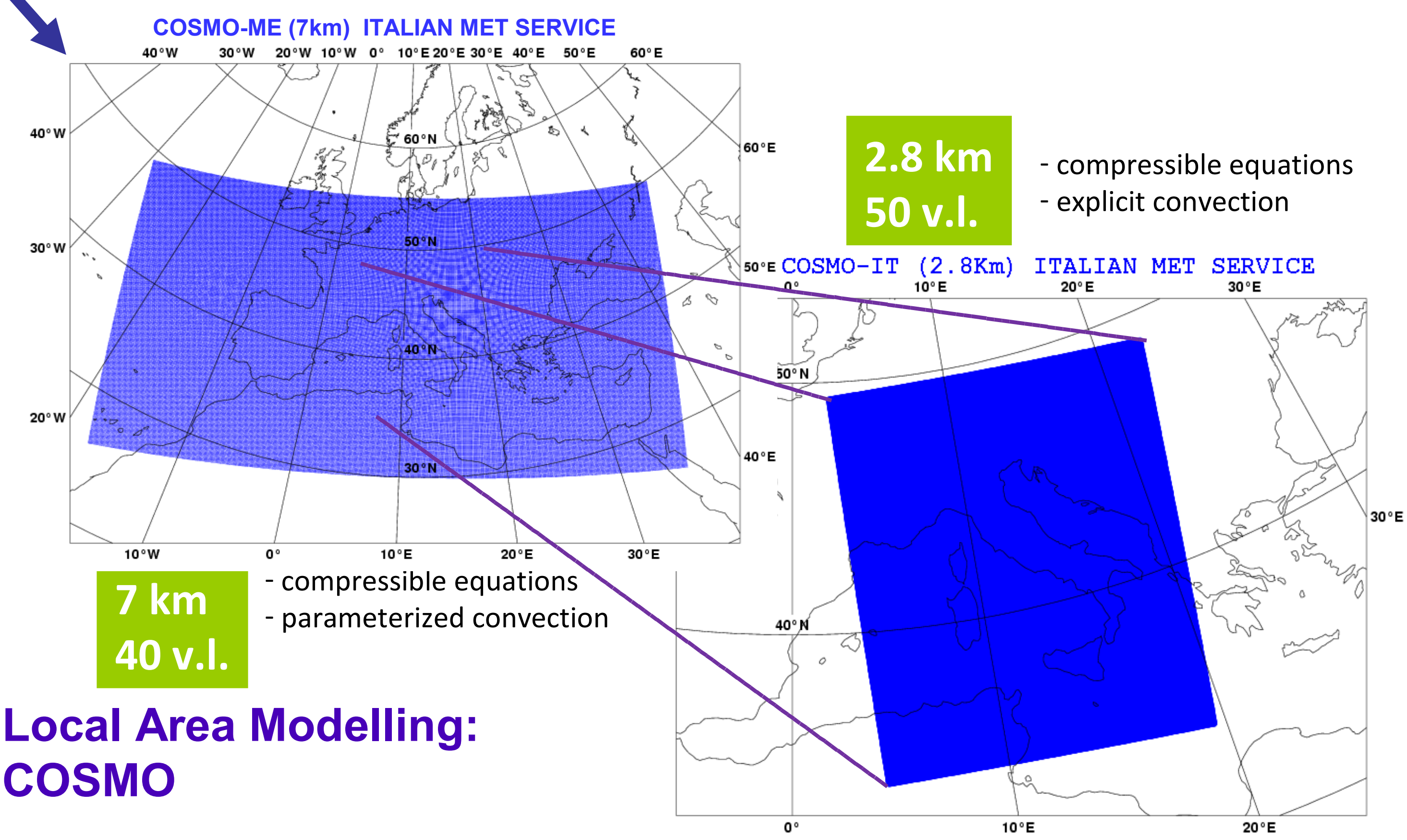
10 km
45 v.l.

Control State Analysis

LETKF Analysis



COSMO-ME EPS
(pre-operational)



2.8 km
50 v.l.

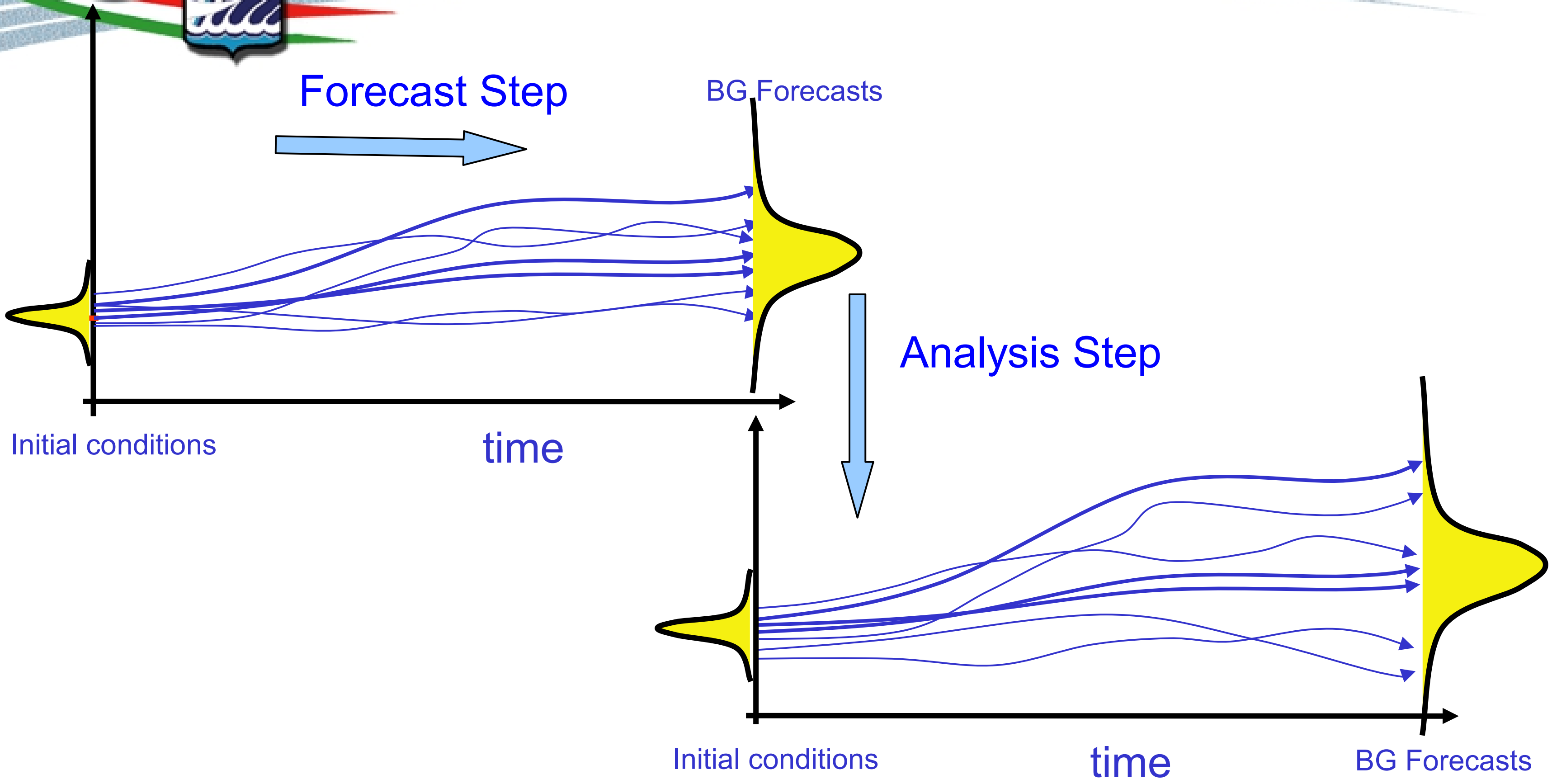
- compressible equations
- explicit convection

7 km
40 v.l.

- compressible equations
- parameterized convection

Local Area Modelling: COSMO

Ensemble DA



EnDA has an **update (analysis) step** where the state estimate x_b and an estimate of the forecast uncertainty P_b are adjusted to new observations y, and a **forecast step**, where the updated state and the uncertainty estimate are propagated forward to the time when the next set of observations become available. **Accurate estimates of forecast uncertainty** are required in order to optimally blend the prior forecast with new observations.

Sources of error

- For small ensemble sizes the sampling variability over the course of several update/forecast cycles can induce substantial error (called *sampling error*).
- Forecast errors derive also from mis-specification of observation errors, from errors in the forward observation operators, in boundary conditions (bottom and lateral) and due to the model deficiencies (called *model error*).
- The sources of model error can be due to lack of resolution, approximate parameterizations of physical processes, etc.

- Neglecting or under-estimating any of these sources of error in the ensemble forecast system will cause the assimilation to give too little weight to observations (filter divergence).
- There are two important methods to counter this behavior in practice: localization of ensemble covariance estimate and inflaction to increase the spread of the ensemble

Covariance Inflaction

Generally an *ad hoc* procedure (with at least one tunable parameter) is applied to avoid the filter divergence, that inflates either the background covariance or the analysis covariance during each data assimilation cycle.

- "Multiplicative inflation" instead multiplies the background covariance matrix (or equivalently, the perturbations of the background ensemble members from their mean) by a constant factor larger than one

- "Additive inflation" adds random perturbations with a certain covariance structure to the analysis covariance during each cycle

Covariance Inflaction

In the 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. $$\mathbf{x}_{\mathrm{a}}' = \mathbf{x}_{\mathrm{a}}' \sqrt{\alpha \frac{\sigma_{\mathrm{b}}^2 - \sigma_{\mathrm{a}}^2}{\sigma_{\mathrm{a}}^2} + 1}$$

$\alpha = 0.95$

σ^2 = 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 using EPS

- Climatological Perturbed SST

Stochastic Perturbed Physics Tendency

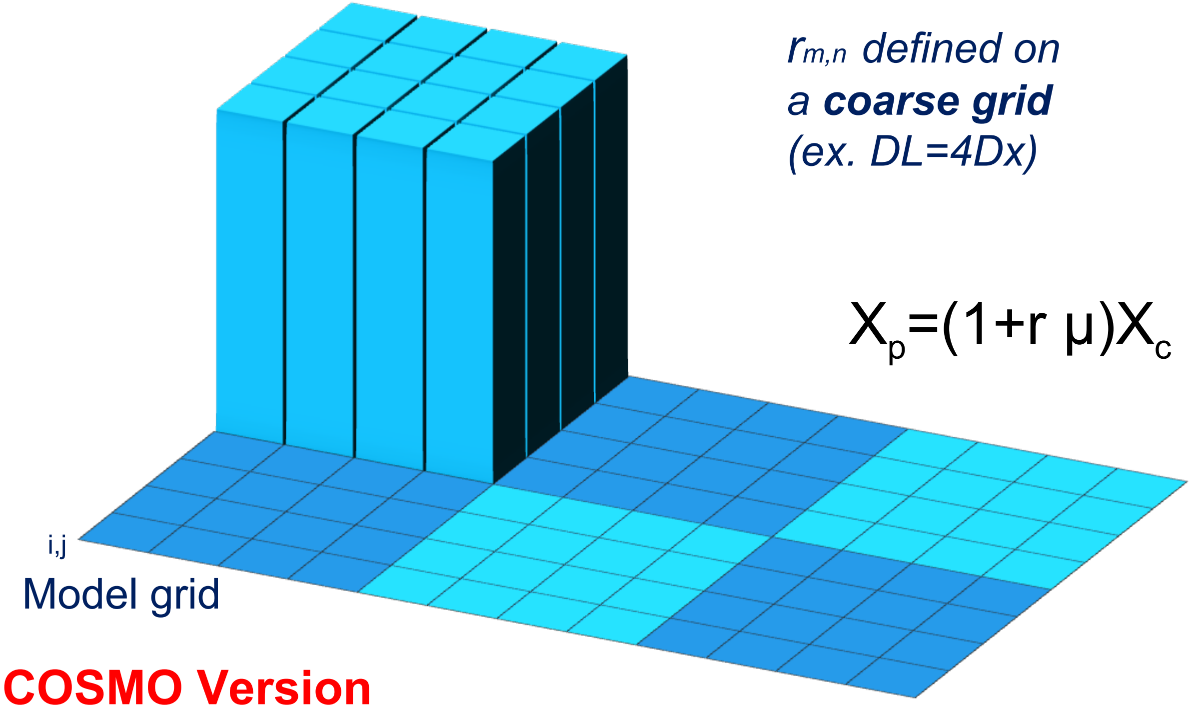
- Model uncertainty could be represented also with a stochastic physics scheme (Buizza et al, 1999; Palmer et al, 2009) implemented in the prognostic model
- This scheme perturbs model physics tendencies by adding perturbations, which are proportional in amplitude to the unperturbed tendencies X_c:

$$X_p=(1+r\mu)X_c$$

where r is a random pattern and μ is a tapering factor (μ=1 in Buizza et al, 1999) to reduce/remove perturbations in stratosphere (and optionally near surface)

Stochastic Perturbed Physics Tendency

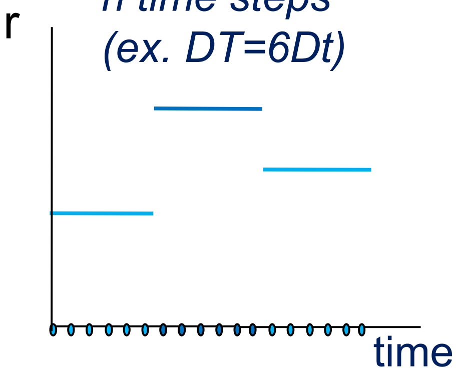
In Buizza et al. 1999: Spatial correlation is imposed using the same r in a whole column and drawing r for a coarse grid with spacing DL (boxes). Temporal correlation is achieved by drawing r every n time steps (DT)



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

$X_p=(1+r\ \mu)X_c$

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



COSMO Version

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.

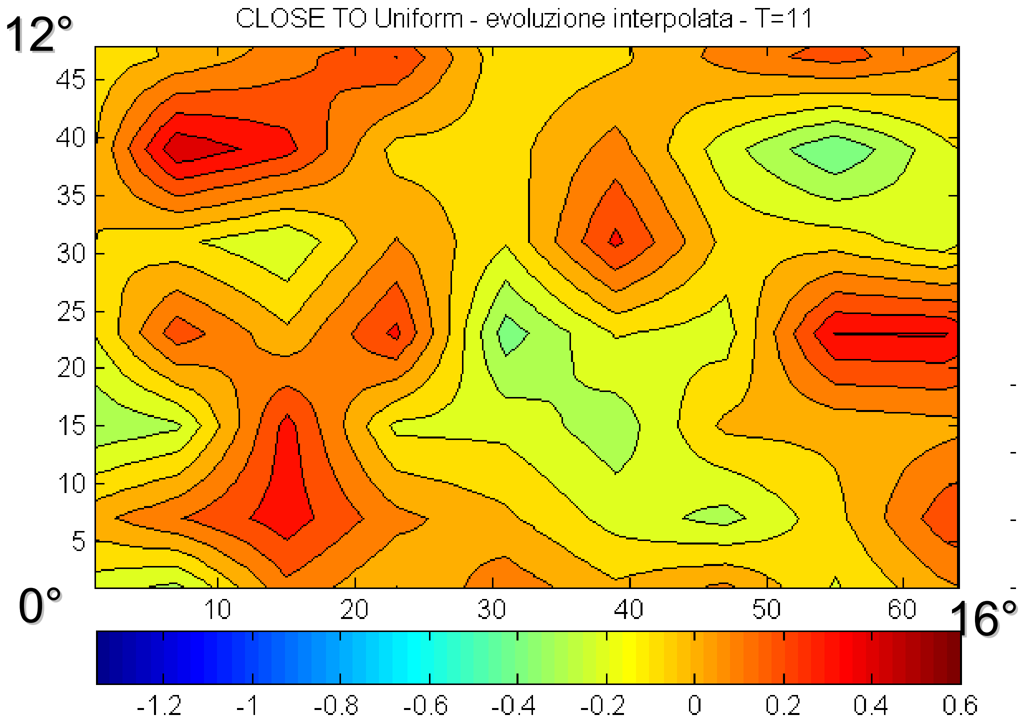
Stochastic Physics

smoothed random pattern

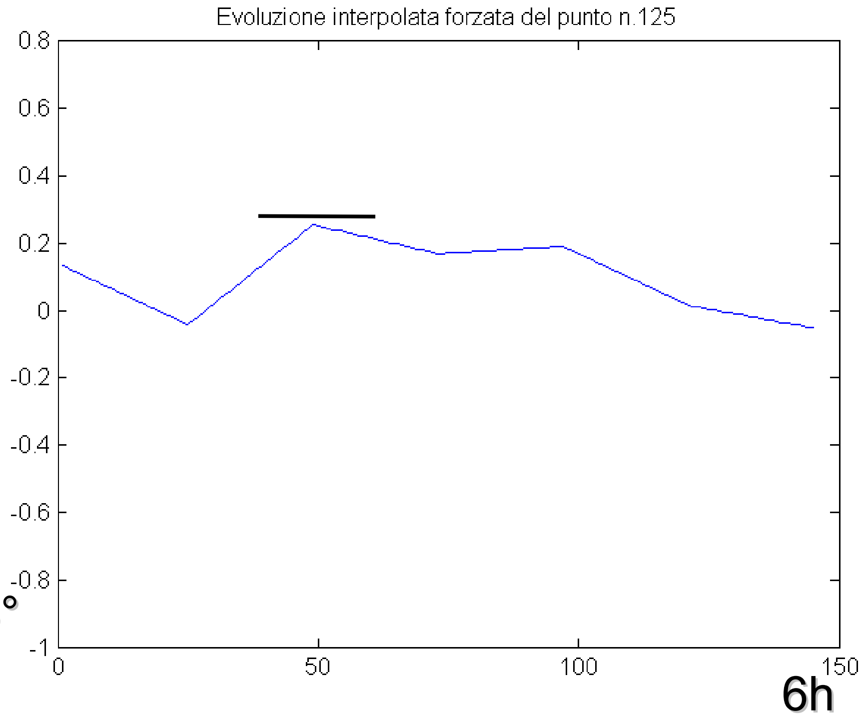
Toy model and plots by A. Cheloni

Model grid spacing: 0.25° (28 km)

Time step: 150 s



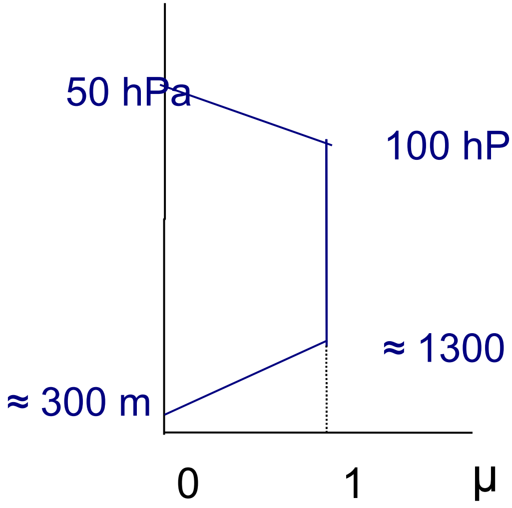
2.5° coarse grid with bilin. interp.



1h coarse time grid with lin. interp.

Stochastic Physics

- SW corner of perturbation (coarse) grid shifted randomly for each member (seed number)
- Perturbations are reduced/removed in stratosphere (and optionally near surface)



- Perturbations of T and qv tendencies are reduced/removed (optionally), if they lead to particular humidity values (exceeding the saturation value or negative values)
- Option for composition of indipendent random patterns having different resolution and stdv (to be tested)
- Run reproducibility using restart option

Stochastic Physics in COSMO

- Two new modules:
  - src_random_numbers.f90 to generate machine-independent pseudo-random numbers
  - src_stoch_physics.f90 to calculate the physics perturbations

The stochastic physics is called by organize_eps.f90, if lstoch_phys=.true. in namelist EPSCTL and leps=.true. in RUNCTL

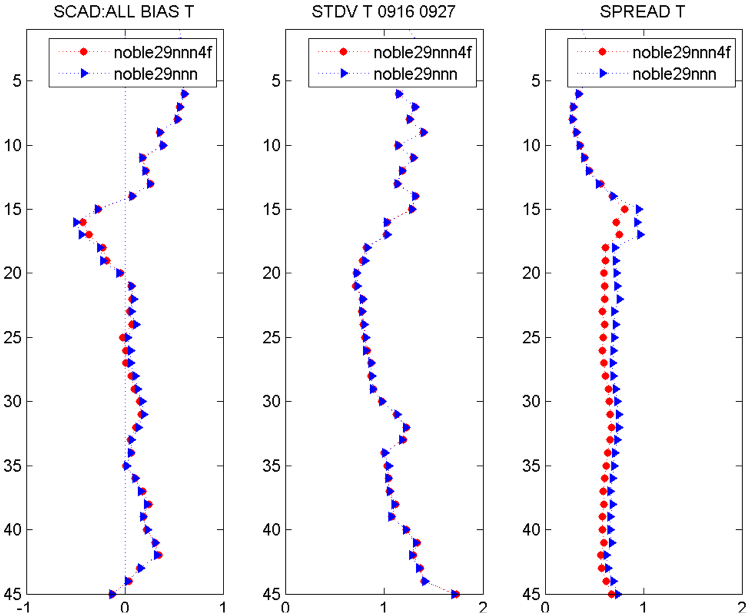
Perturbations grid is defined by:

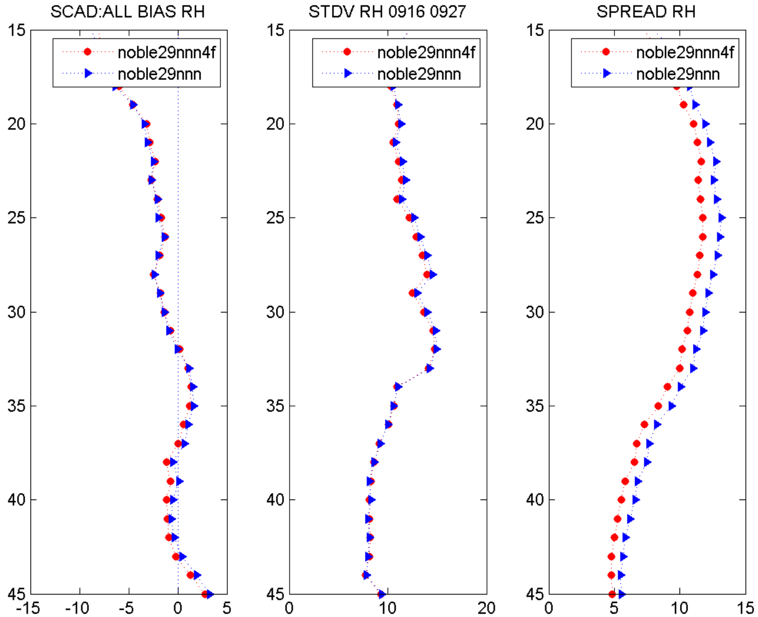
ie_rn, je_rn, dlat_rn, dlon_rn, ninc_rn, hinc_rn

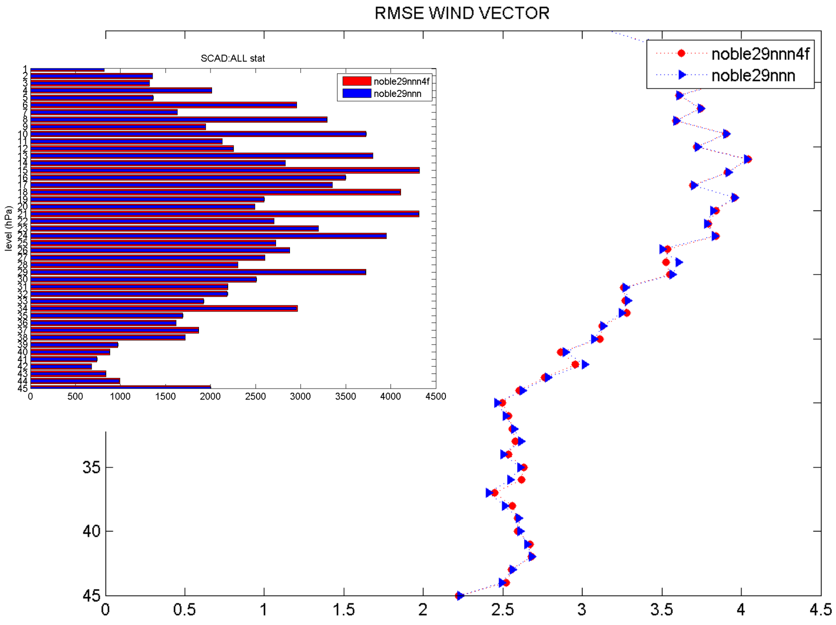
Other namelist parameters are:

- nseed_rn (external seed)
- npattern_rn (number of random pattern)
- lqv_pertlim, lvtaper_rn, vtaper_rn (perturbation limit)
- lhorint_rn, ltimeint_rn (horiz. and time interp,)
- range_rn (uniform and gaussian distribution)
- lgauss_rn, stdv_rn (gaussian distribution)

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

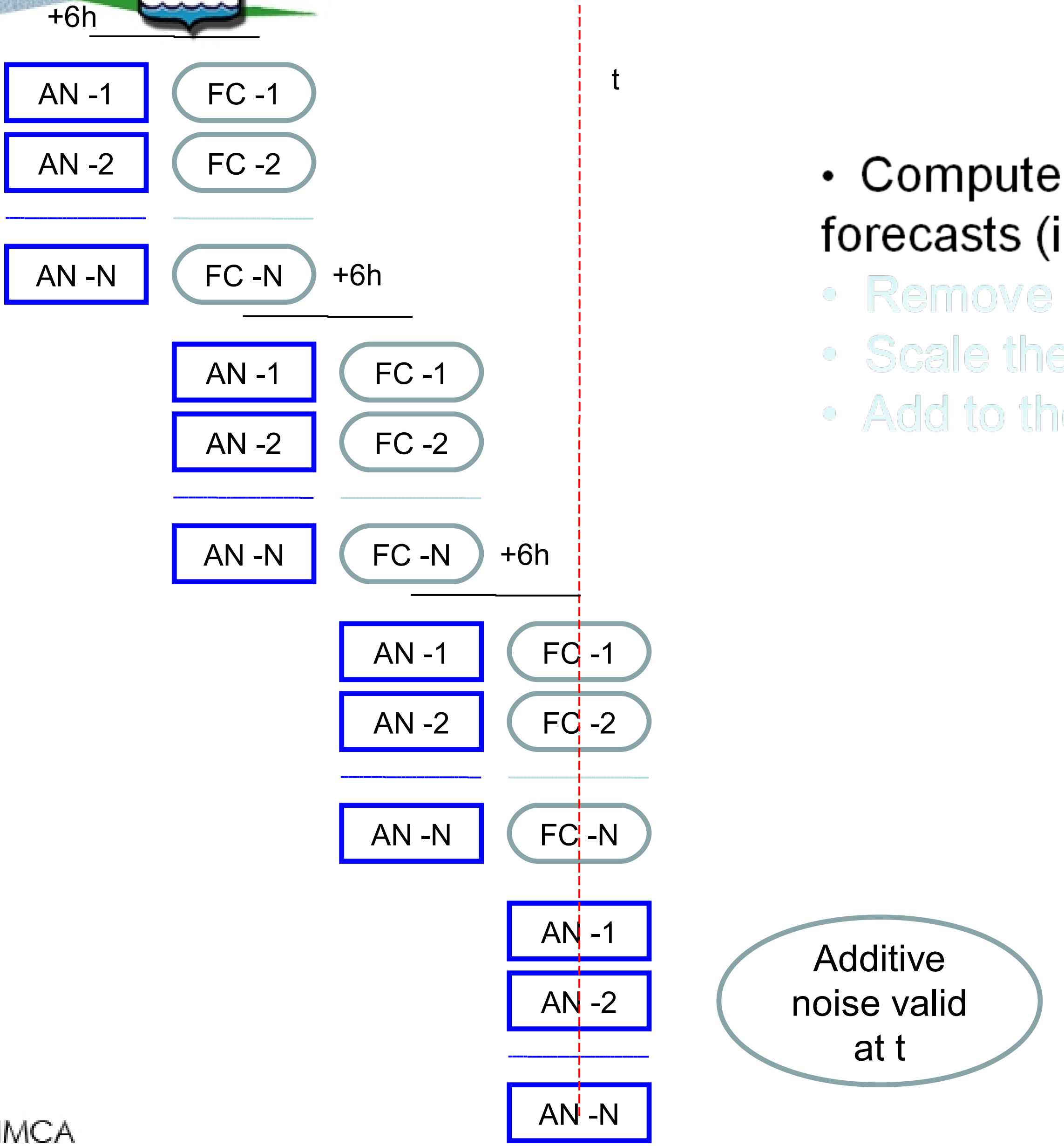
The impact on COSMO forecasts of SPPT seems to be smaller than those of additive noise (preliminar result)

Self-Evolving Additive Noise

- A new additive inflaction formulation is needed, because the additive noise from EPS is not consistent with COSMO model errors statistics.
- The self-evolving additive inflaction (idea of Mats Hamrud – ECMWF) was chosen. The idea is different from 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.

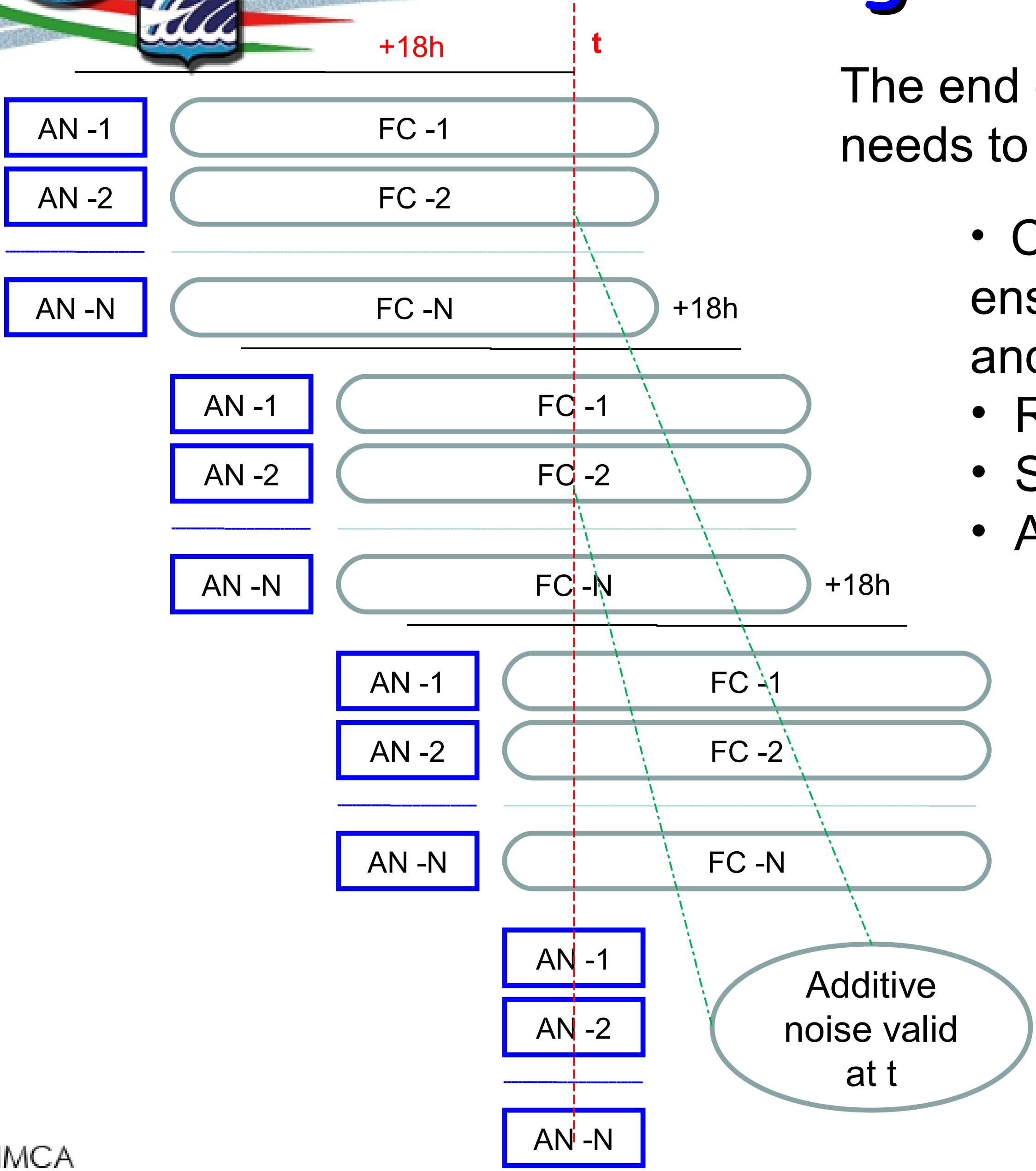
- The self-evolving additive perturbations are both consistent with model errors statistics and a flow-dependent noise
- The error introduced during the first hours may have a component that will project onto the growing forecast structures having probably a benificial impact on spread growth and ensemble-mean error

Self-Evolving Additive Noise



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

Self-Evolving Additive Noise



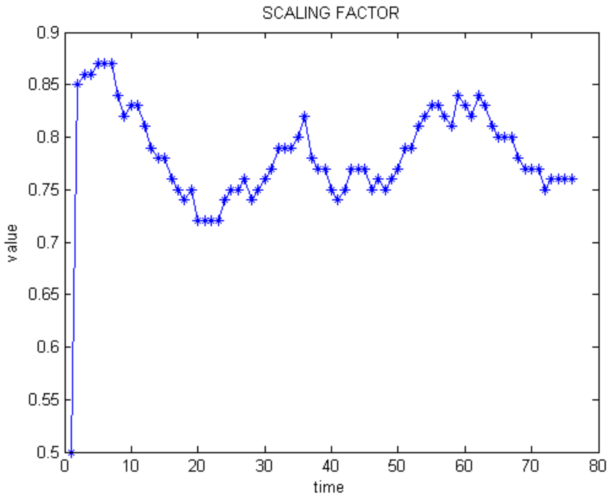
The end of model forecast integration needs to be extend

- 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

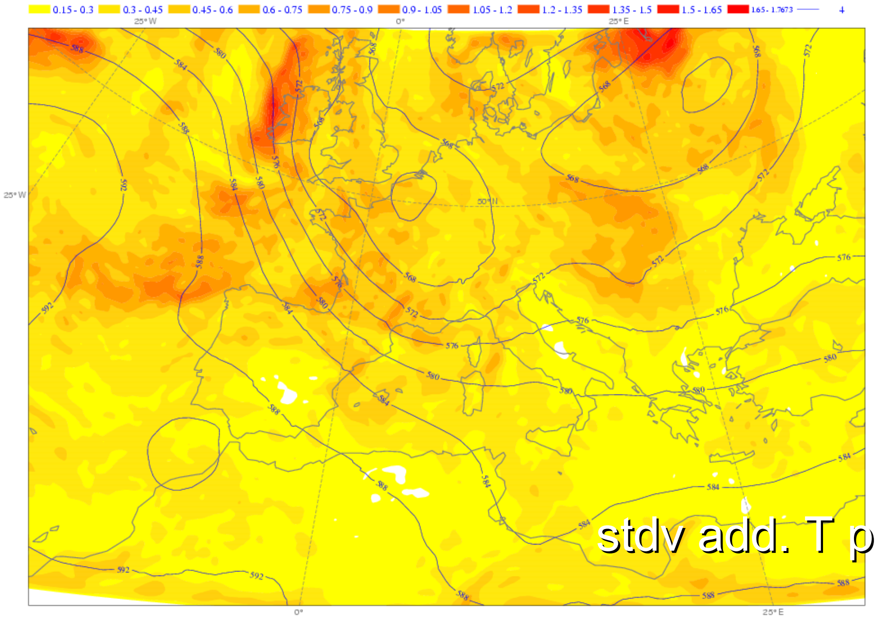
Self-Evolving Additive Noise

Other features in the current version:

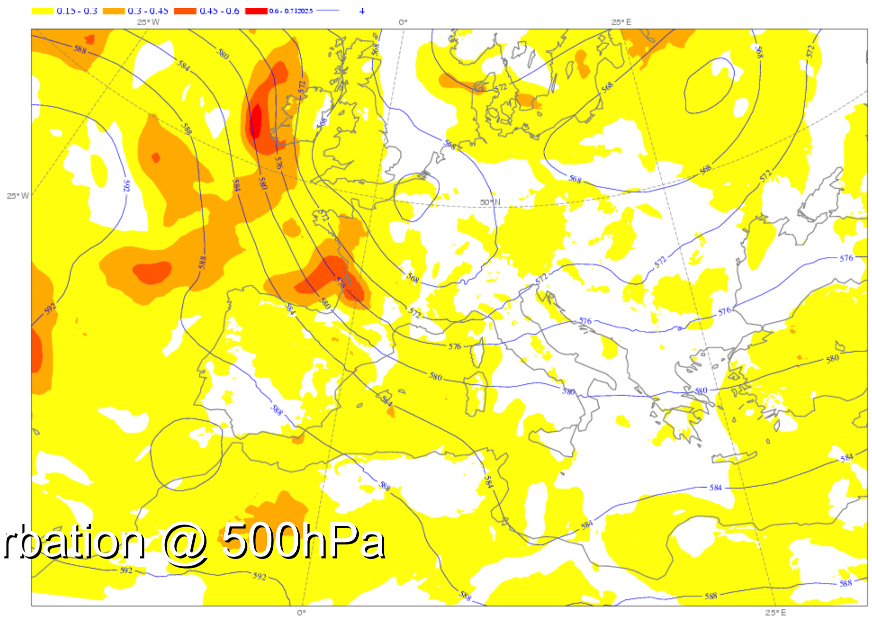
- 12h-6h forecast differences
- spatial filtering of ensemble difference using a low pass 10th order Raymond filter
- adaptive scaling factor using the surface pressure obs inc statistics



SELF EV. ADD

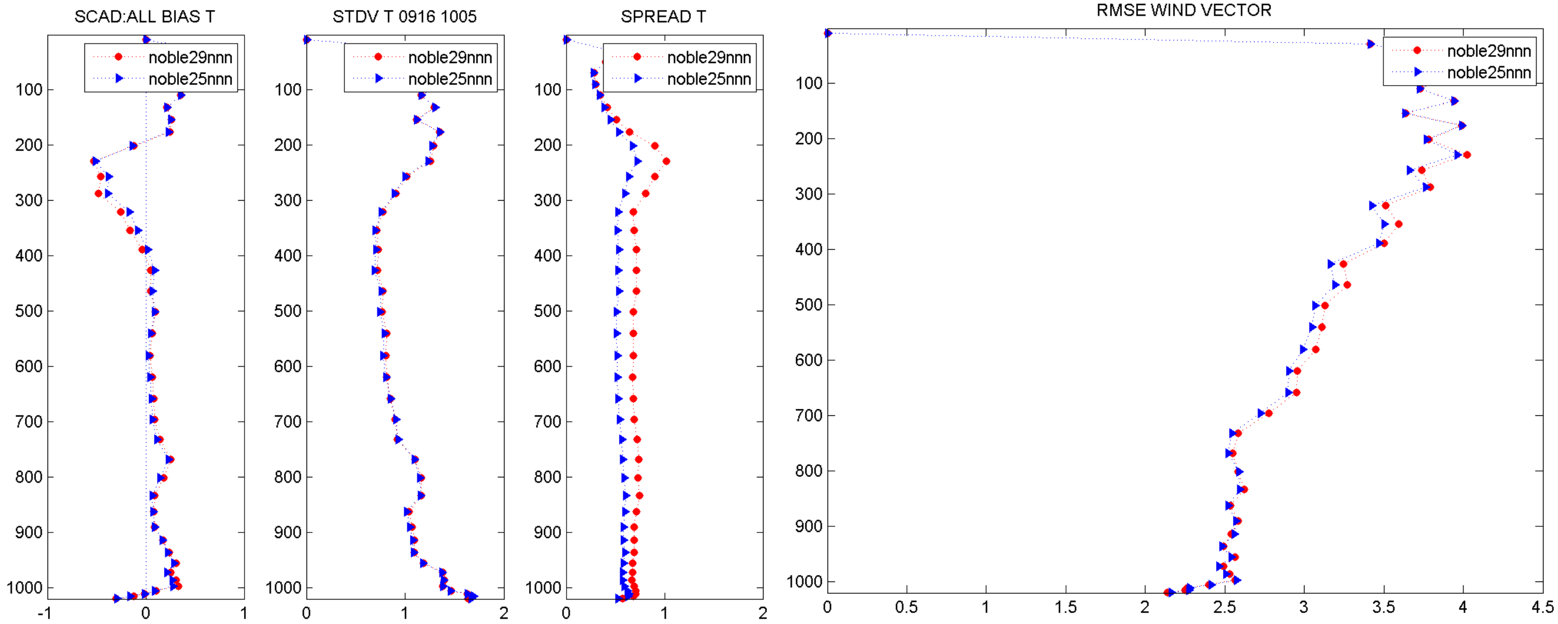


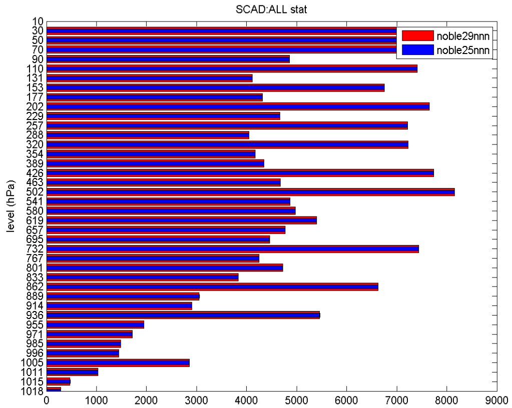
IFS ADD

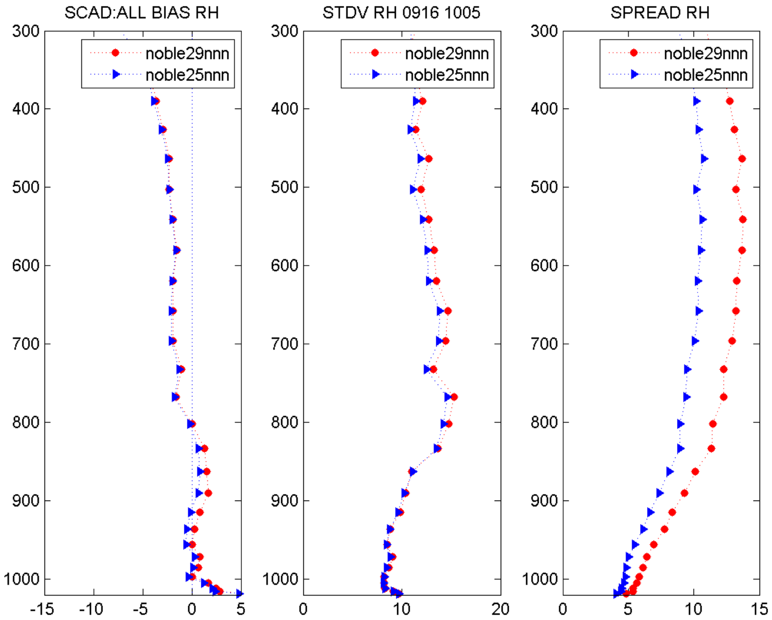


stdv add. T perturbation @ 500hPa

OBS INCREMENT STATISTICS (RAOB)
SELF-EVOLVING ADD. VS IFS ADDITIVE







The self-evolving additive noise increases the spread

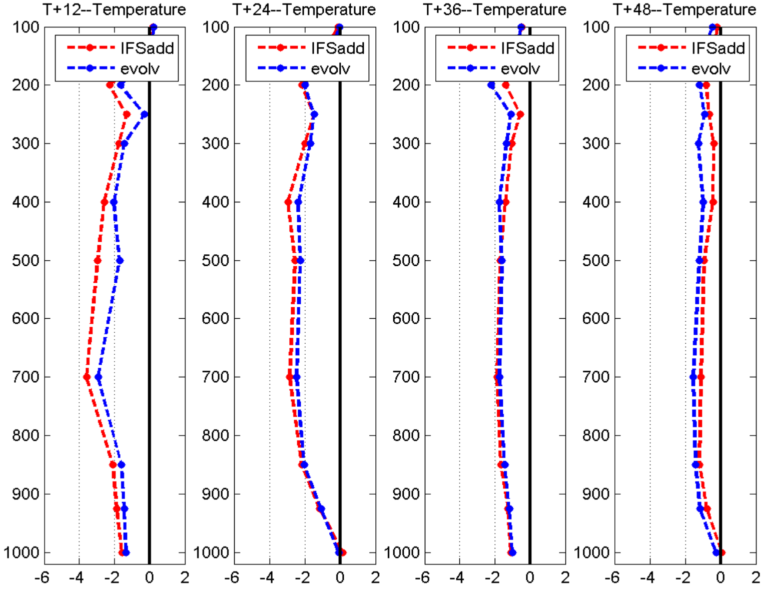
Self-Evolving Additive Noise

Relative difference (%) in RMSE, computed against IFS analysis, with respect to NO-ADDITIVE run for 00 UTC COSMO runs from 16-09-2012 to 05-10-2012

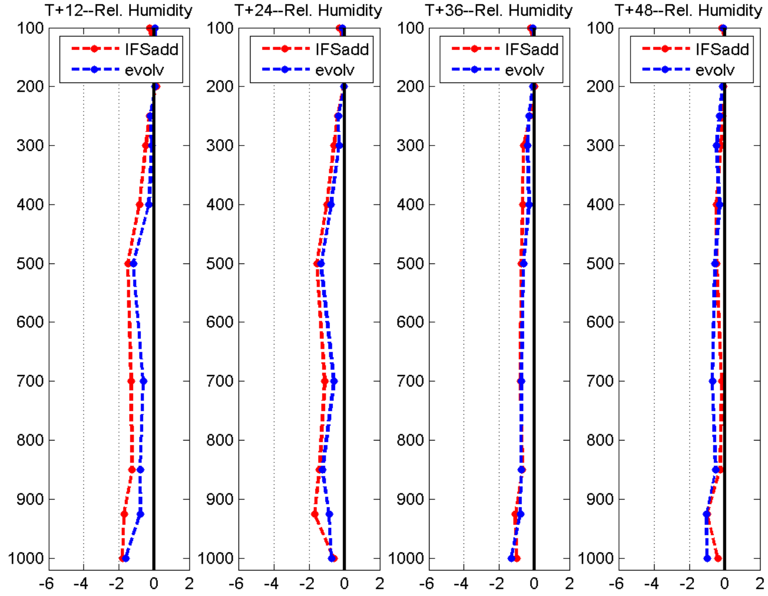
negative value = positive impact

IFS ADD

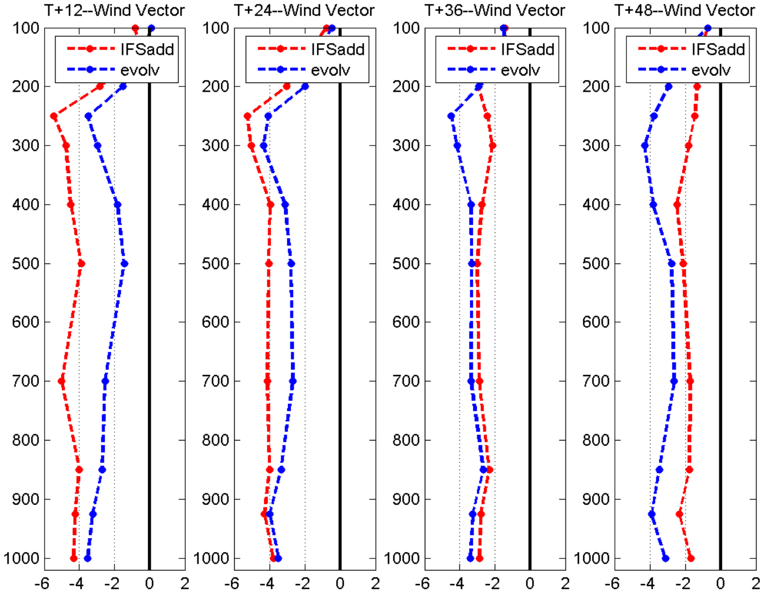
SELF EV. ADD



+12h **+24h** **+36h** **+48h**

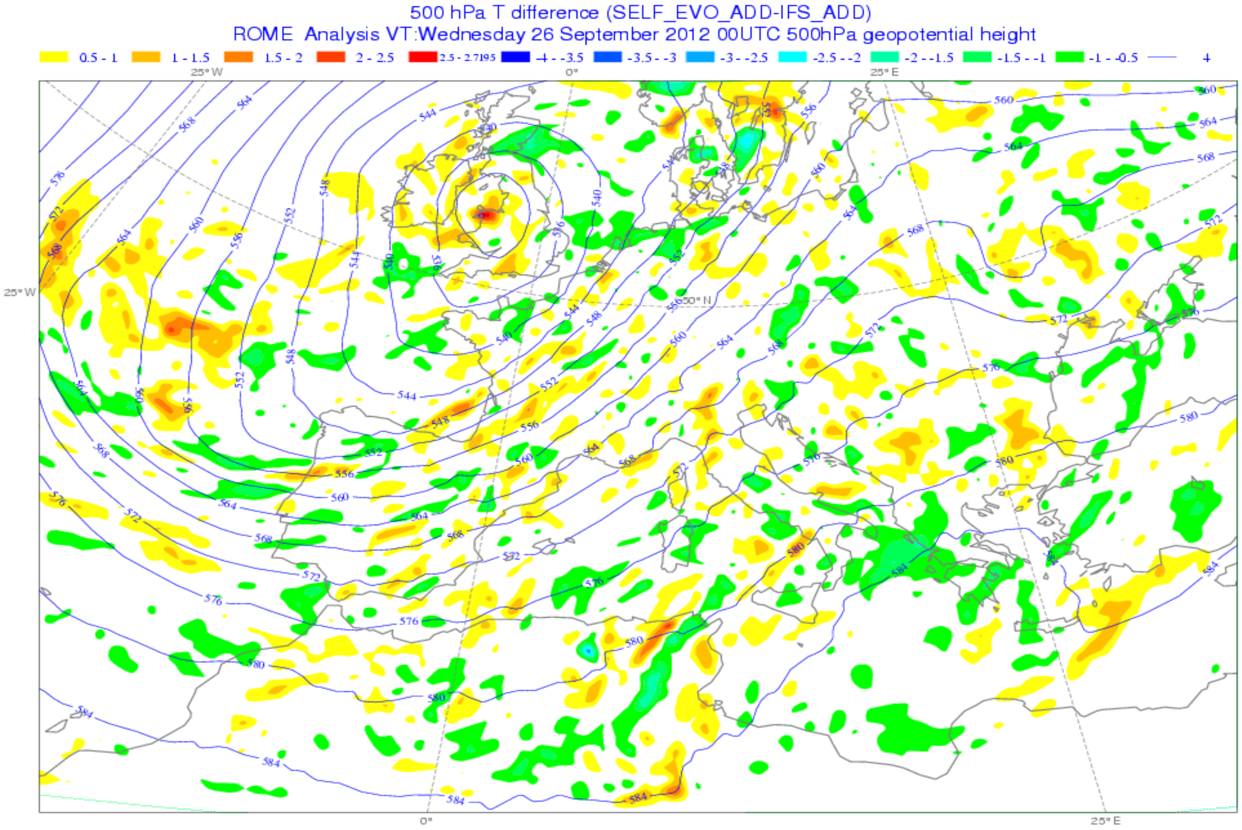


+12h **+24h** **+36h** **+48h**



Self-Evolving Additive Noise

ANALYSIS@500hPa: SELF EVOLVING ADDITIVE – IFS ADDITIVE



The impact of the self-evolving additive on COSMO day 2 forecast is larger than those of additive from IFS.
More work is needed to understand the slight worsening in day 1 forecast.

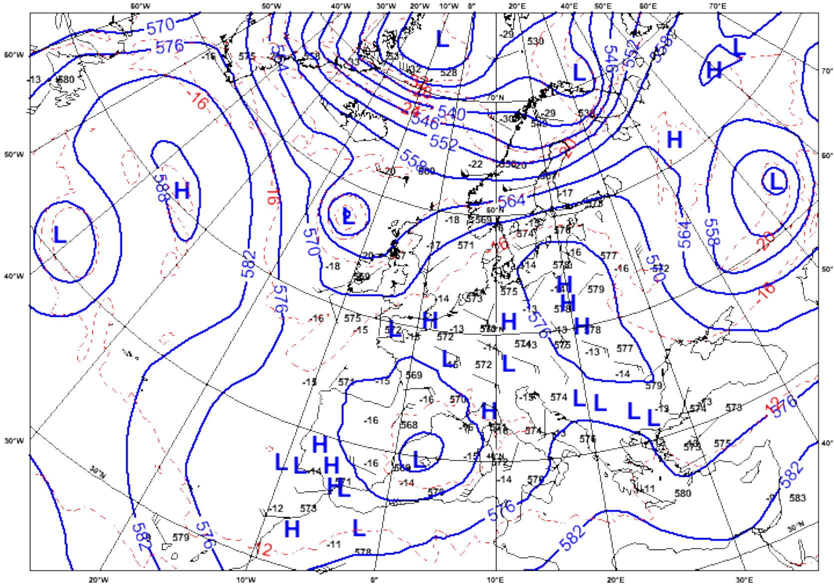
Future experiments:
- tuning of scaling factor and smoothing
- use of 18h – 12h ensemble forecast difference

Experiment to test SPPT

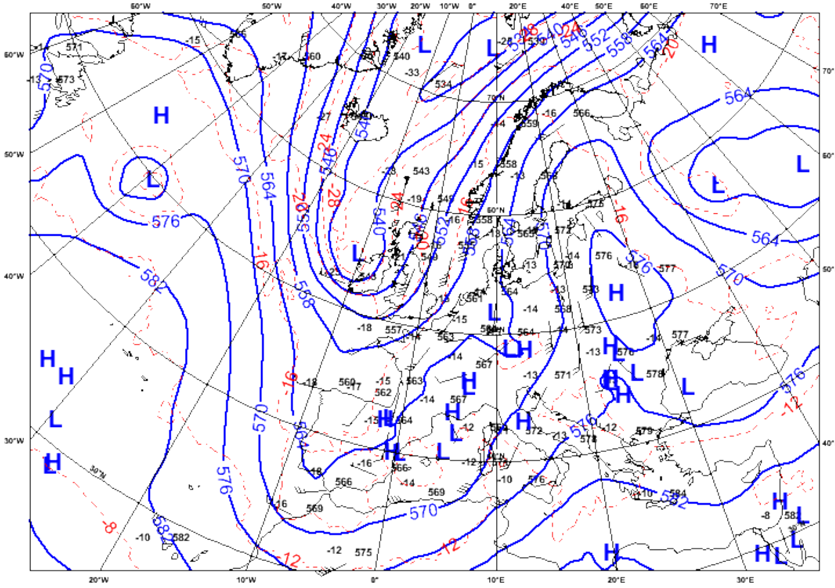
05 June 2011 case

Situation over Italy: southwesterly flow from North Africa

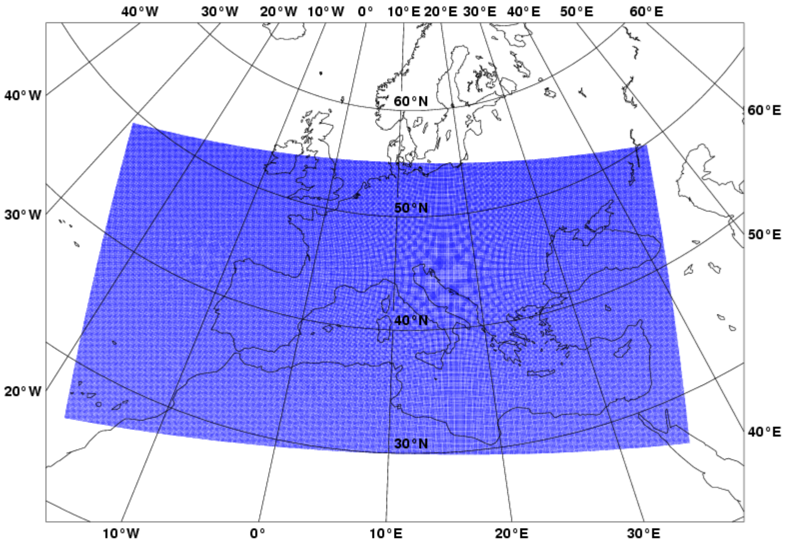
ROME Analysis VT:Domenica 5 Giugno 2011 00UTC
Geopotenziale 500 hPa + Temperatura 500 hPa n.a.



ROME Analysis VT:Martedi 7 Giugno 2011 00UTC
Geopotenziale 500 hPa + Temperatura 500 hPa n.a.



Experiment to test SPPT



COSMO-ME (7km)

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

10 members

Options used: SPPT settings

leps = T

lstoch_phys = T

lqv_pertlim = T - no qv-T perturbation, if qv<0 or qv>qvs

lvtaper_rn = T - stratosph. / boundary layer tapering of random numbers r (define μ)

lhorint_rn = T - random numbers horizontal interpolation

dlat_rn = 5°

dlon_rn = 5° - same random number for a spatial box 5° x 5°

ltimeint_rn = T - random numbers time interpolation

hinc_rn = 6h - new random numbers every 6h

lgauss_rn = T - random numbers from gaussian distribution

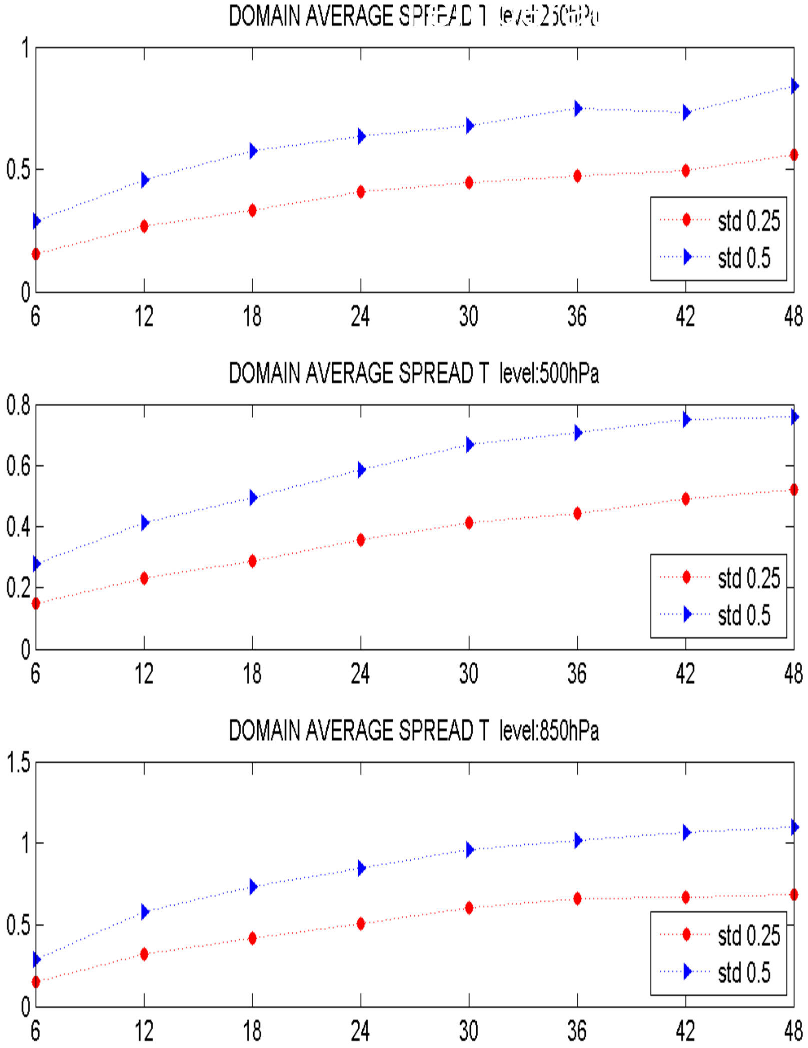
stdv_rn = 0.25,0.5 - standard deviation of random numbers from gauss. distr.

range_rn = 0.75,1. - cutoff value of random numbers from gauss. distr.

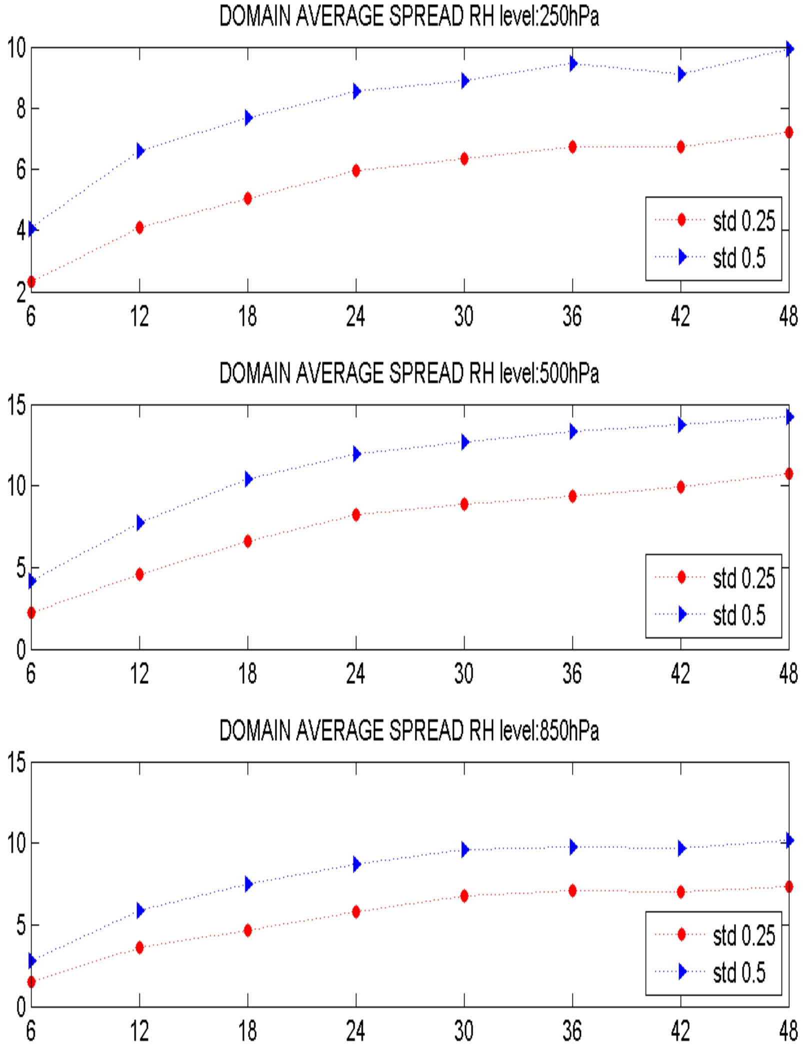
Experiment: 05 June 2011 case

Domain Averaged Spread for 10 members

Temperature



Relative Humidity

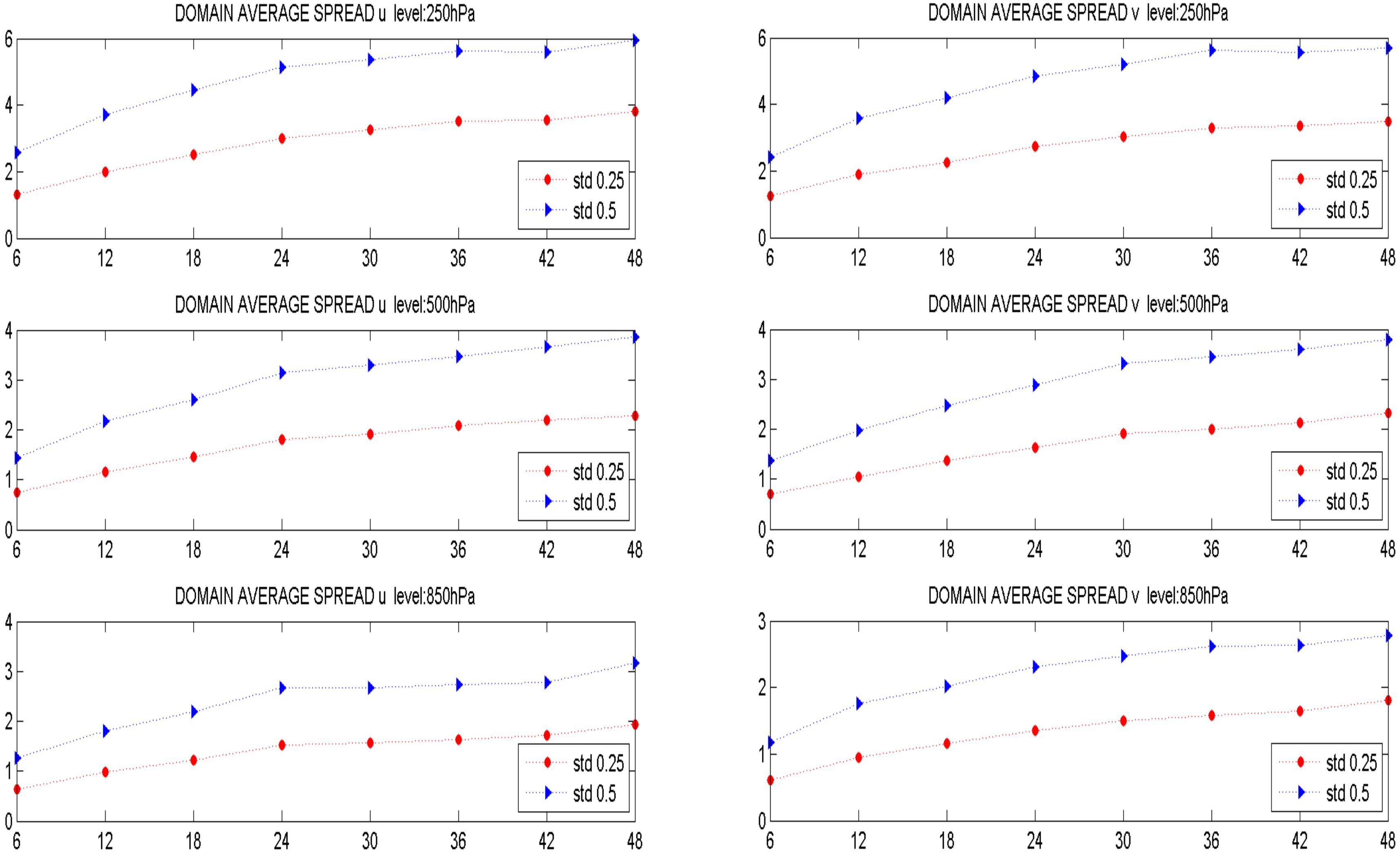


Experiment: 05 June 2011 case

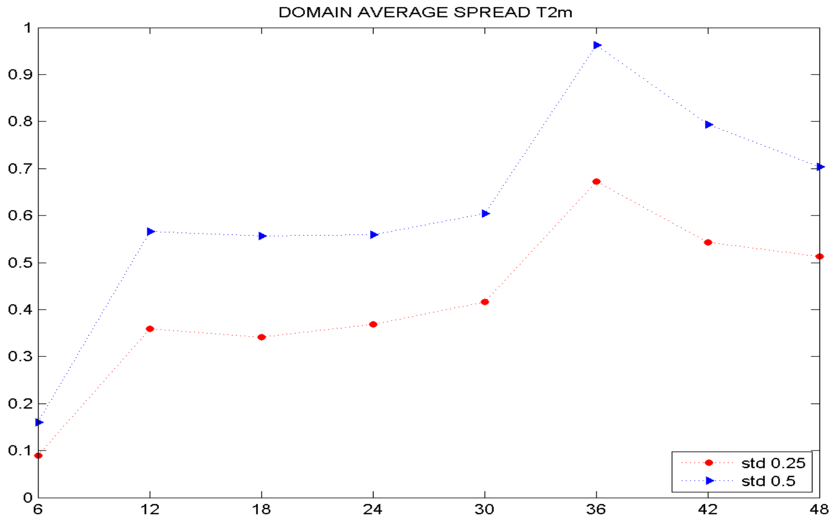
Domain Averaged Spread for 10 members

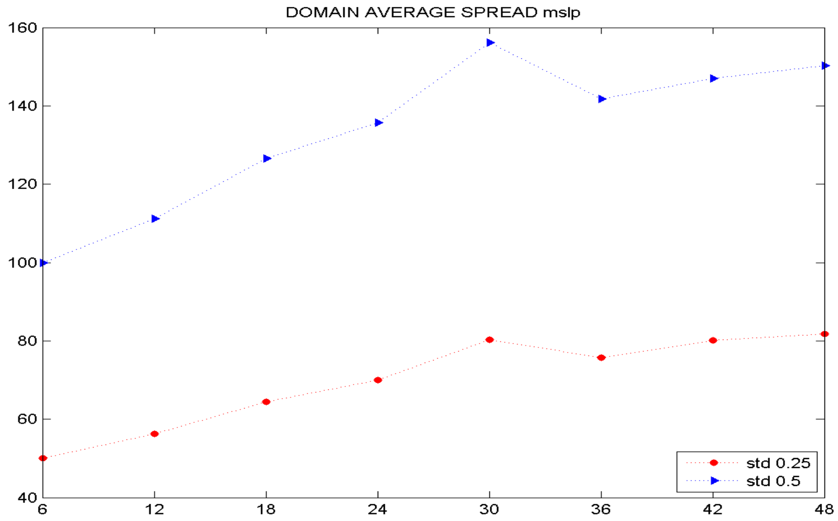
Zonal wind

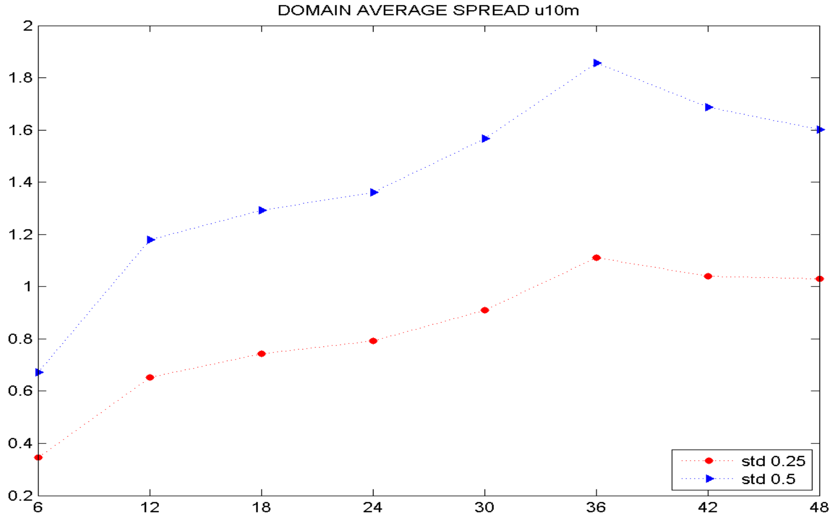
Meridional Wind

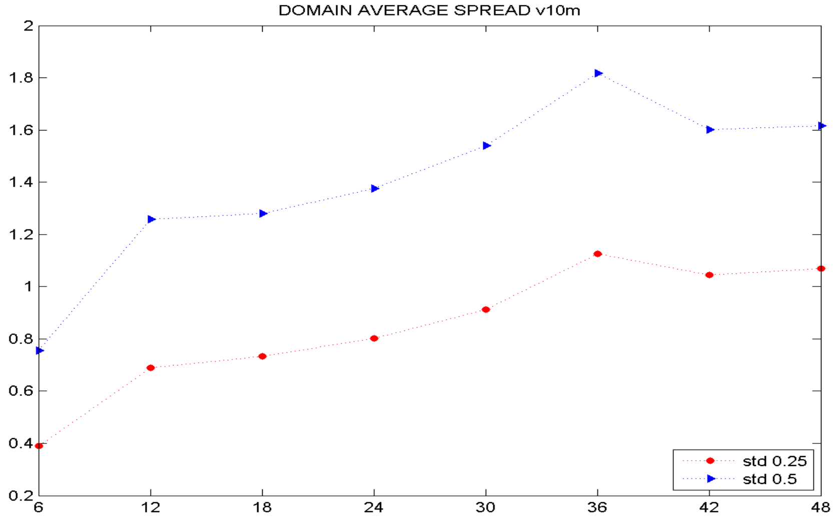


Experiment: 05 June 2011 case


Temperature


MSL Pressure


10m Zonal Wind

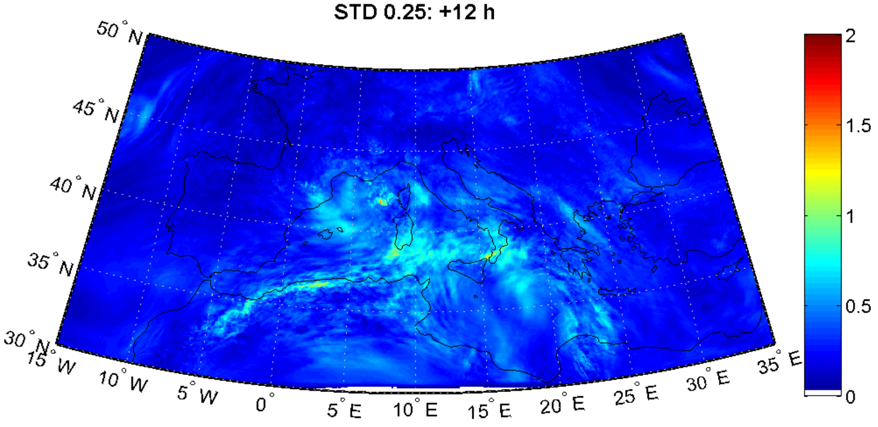

10m Meridional Wind

Experiment: 05 June 2011 case

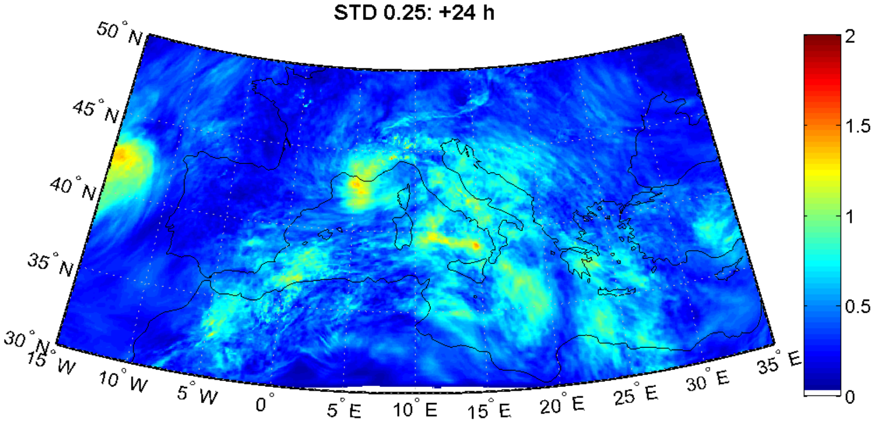
500 hPa Temperature Spread for 10 members

stdv=0.25 range=0.75

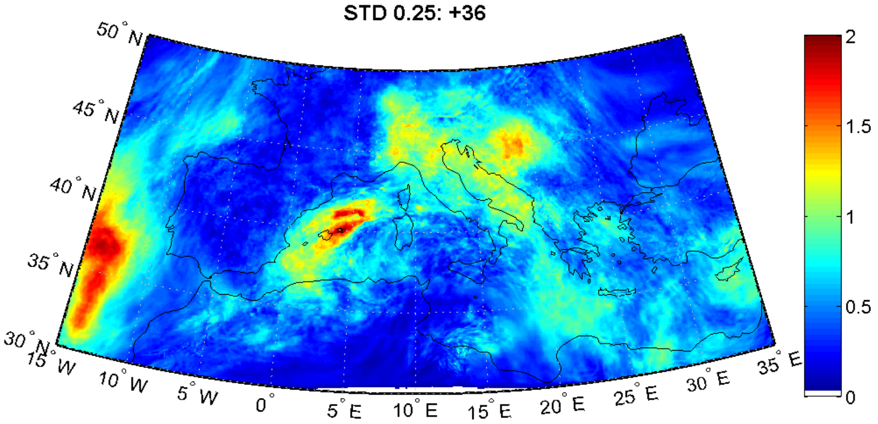
T+12h



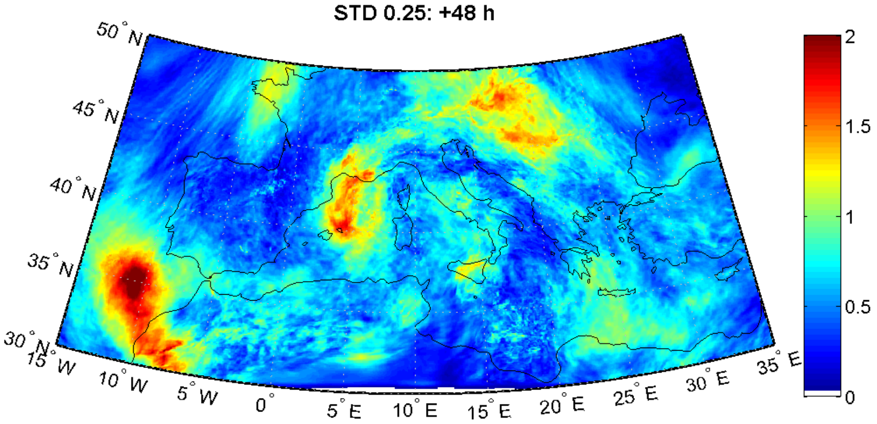
T+24h



T+36h



T+48h

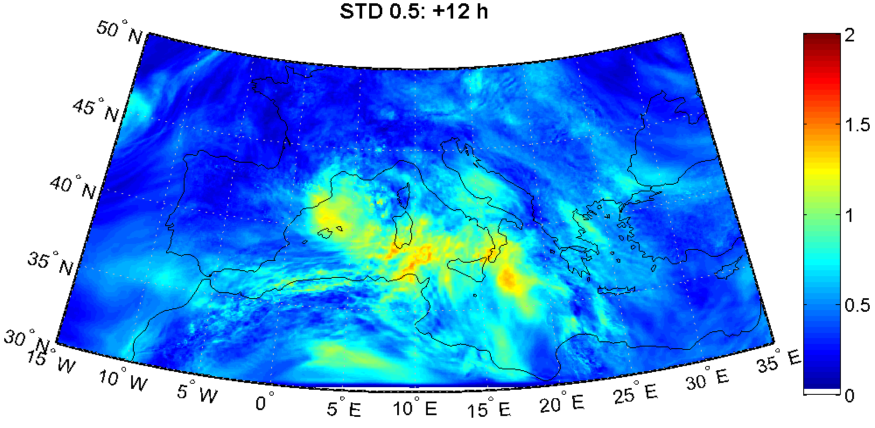


Experiment: 05 June 2011 case

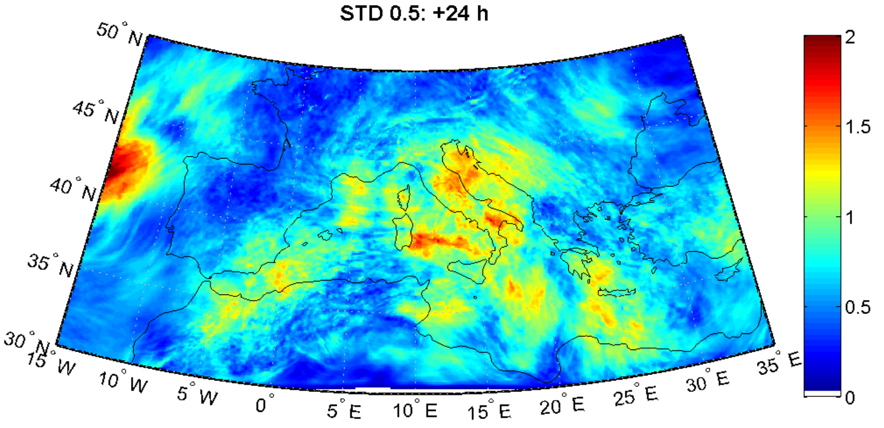
500 hPa Temperature Spread for 10 members

stdv=0.5 range=1.

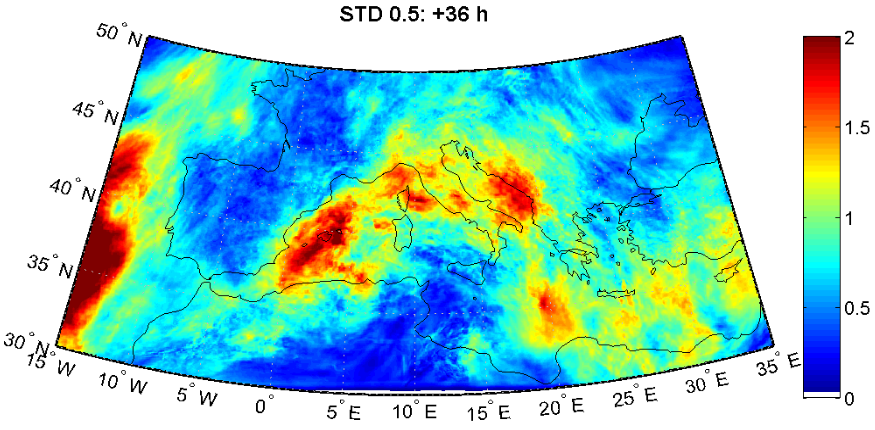
T+12h



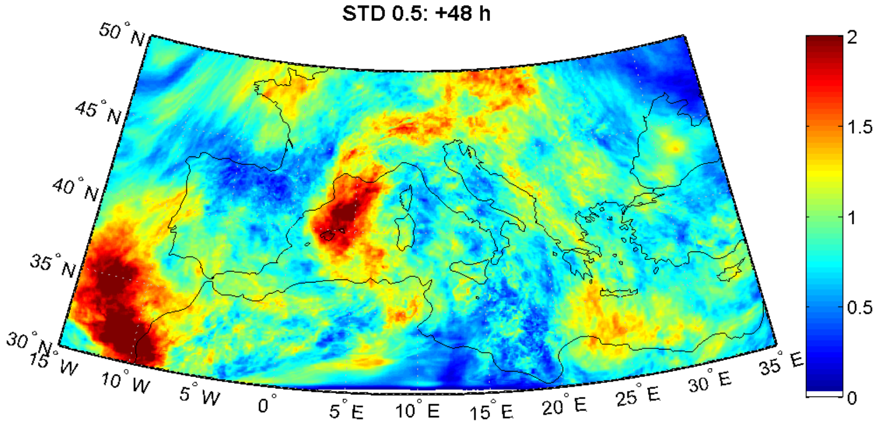
T+24h

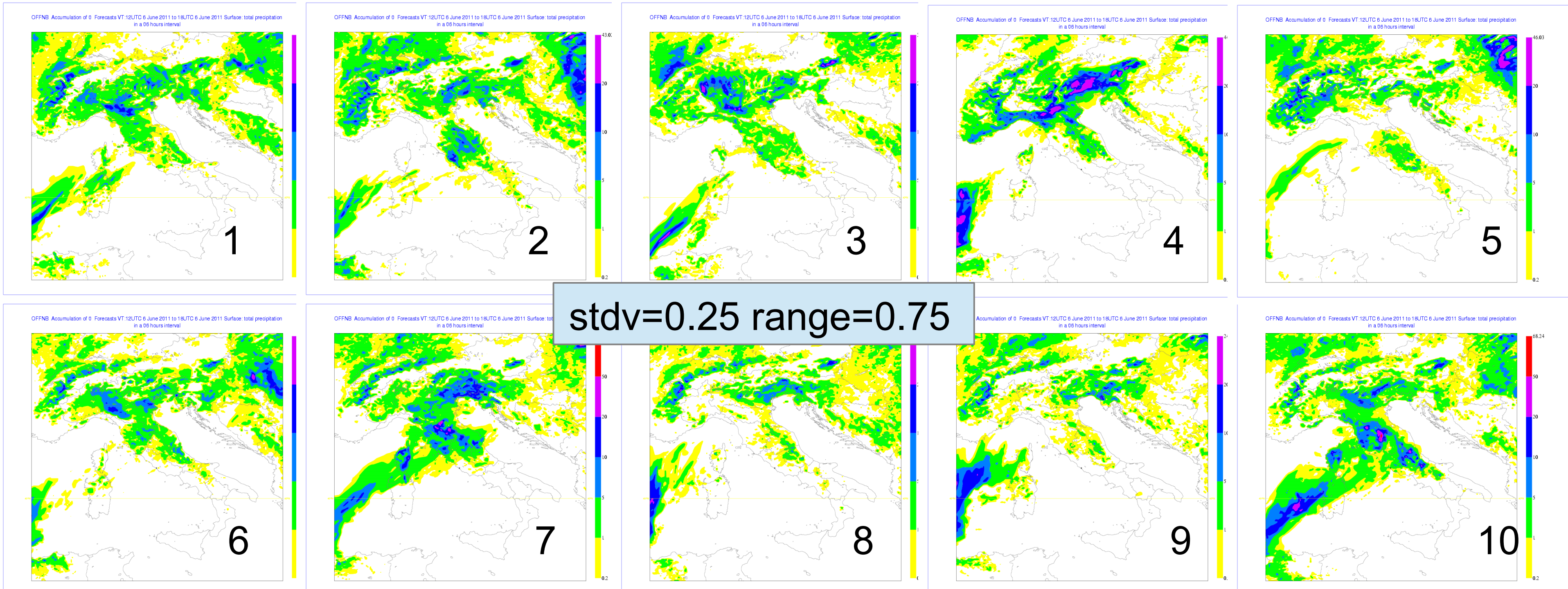


T+36h

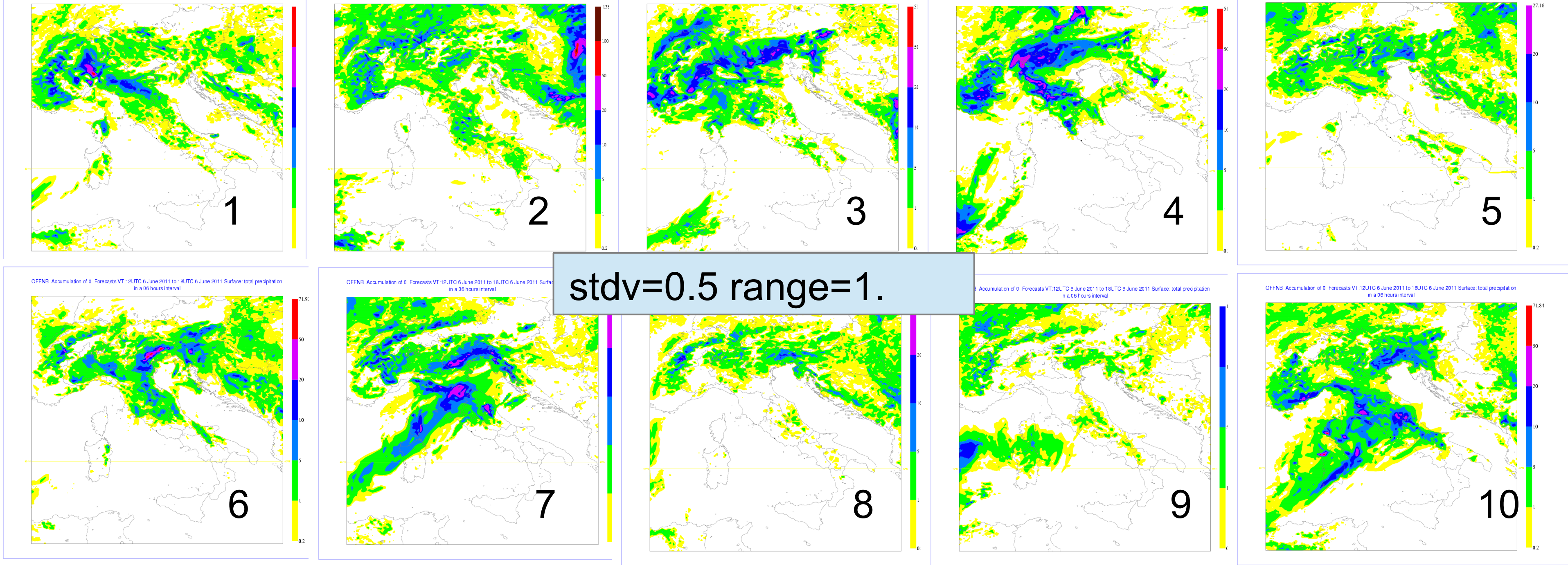


T+48h





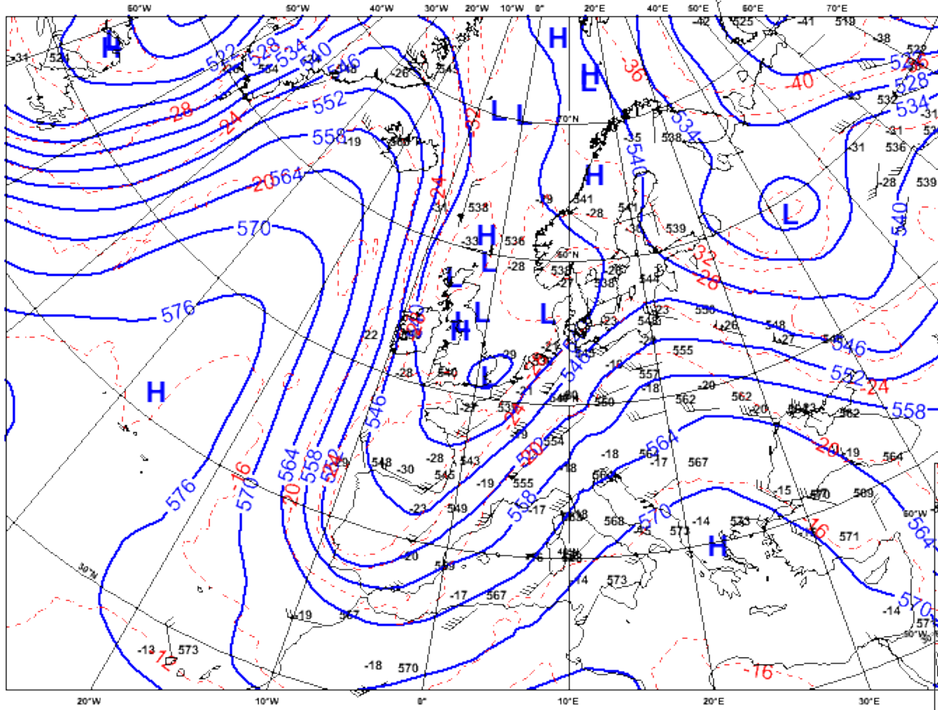
stdv=0.25 range=0.75



stdv=0.5 range=1.

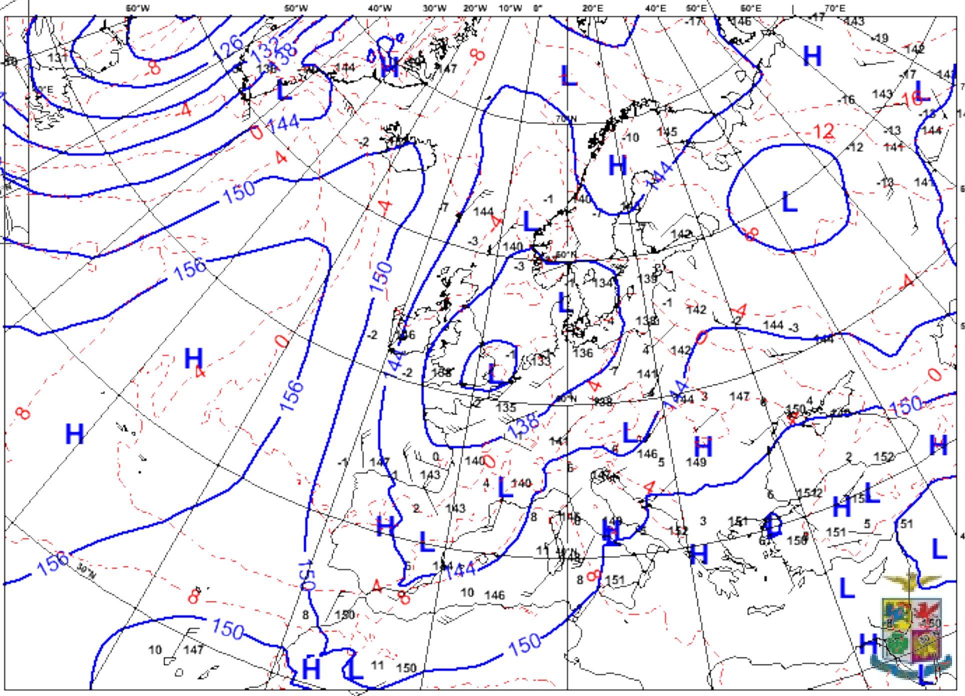
COSMO-ME EPS

ROME Analysis VT:Martedi 27 Novembre 2012 00UTC
Geopotenziale 500 hPa + Temperatura 500 hPa n.a.



40 members with 0.09° grid spacing, ~26km (~18hPa) model top, 45 vertical levels, IC from CNMCA LETKF, BC from deterministic IFS perturbed by ECMWF EPS

ROME Analysis VT:Martedi 27 Novembre 2012 00UTC
Geopotenziale 850 hPa + Temperatura 850 hPa n.a.

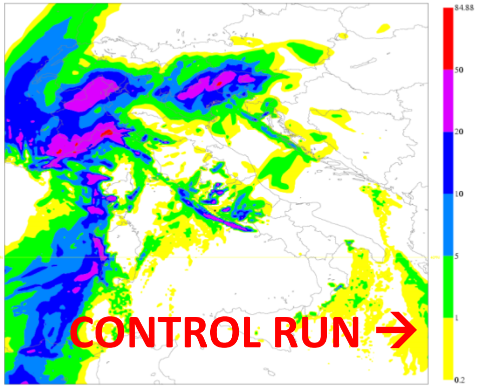


27 nov 2012 00 UTC

27 nov 2012

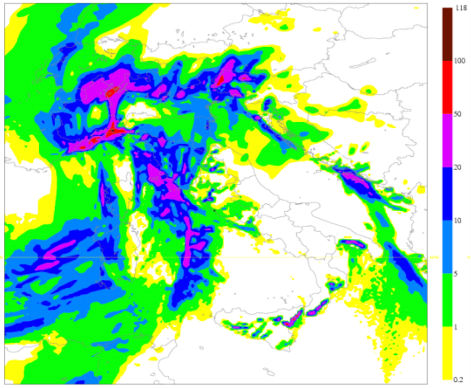
+18-24 **+24-30** **+30-36** **+36-42**

ROME Accumulation of 0 Forecasts VT:18UTC 27 November 2012 to 00UTC 28 November 2012 Surface: total precipitation
COSMO_ME: precipitation in the previous 06 hour interval

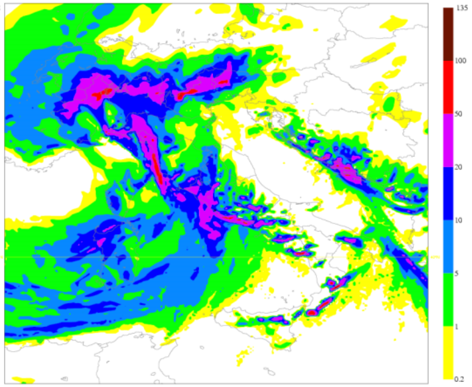


CONTROL RUN →

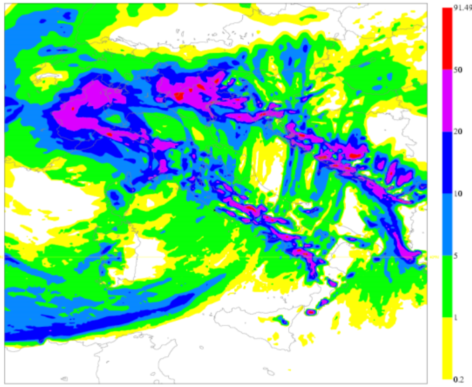
ROME Accumulation of 0 Forecasts VT:00UTC 28 November 2012 to 06UTC 28 November 2012 Surface: total precipitation
COSMO_ME: precipitation in the previous 06 hour interval



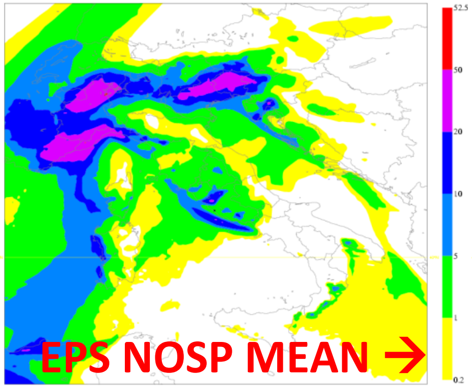
ROME Accumulation of 0 Forecasts VT:06UTC 28 November 2012 to 12UTC 28 November 2012 Surface: total precipitation
COSMO_ME: precipitation in the previous 06 hour interval



ROME Accumulation of 0 Forecasts VT:12UTC 28 November 2012 to 18UTC 28 November 2012 Surface: total precipitation
COSMO_ME: precipitation in the previous 06 hour interval

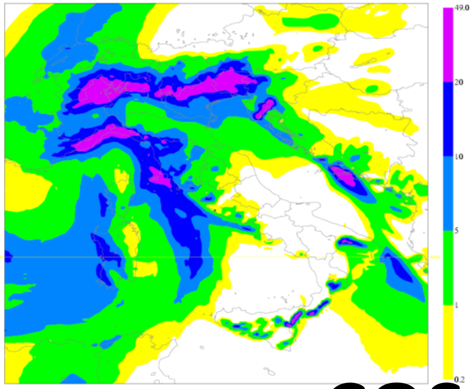


OFFNB Accumulation of 0 Forecasts VT:00UTC 27 November 2012 to 00UTC 28 November 2012 Surface: total precipitation
in a 06 hours interval



EPS NOSP MEAN →

OFFNB Accumulation of 0 Forecasts VT:00UTC 27 November 2012 to 06UTC 28 November 2012 Surface: total precipitation
in a 06 hours interval



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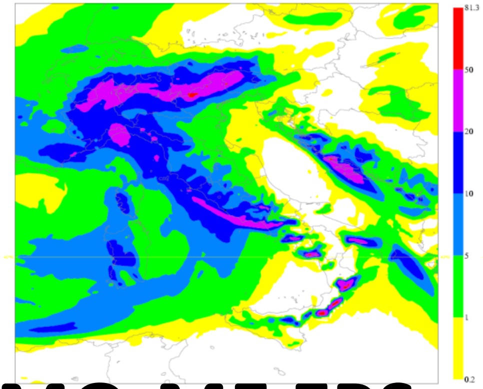
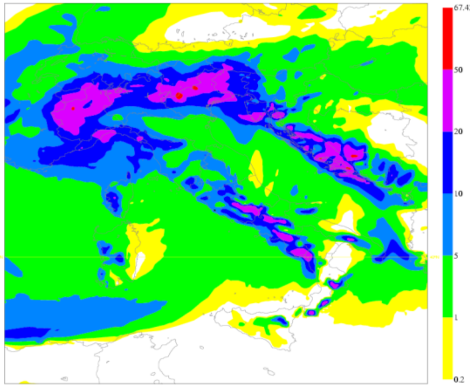
in a 06 hours interval

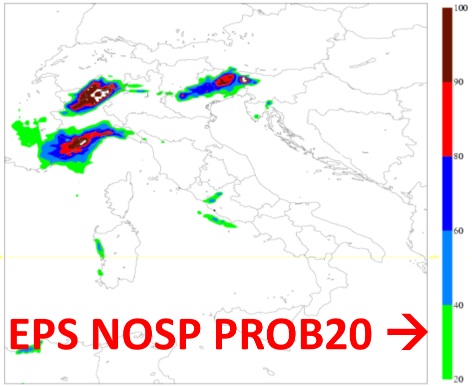


OFFNB Accumulation of 0 Forecasts VT:00UTC 27 November 2012 to 18UTC 28 November 2012 Surface: total precipitation
in a 06 hours interval



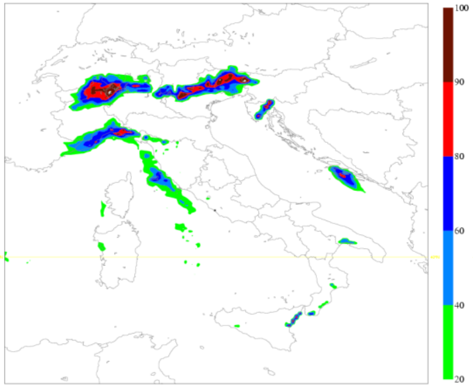
COSMO-ME EPS

OFFNB Accumulation of 0 Forecasts VT:00UTC 27 November 2012 to 00UTC 28 November 2012 Surface: total precipitation
in a 06 hours interval

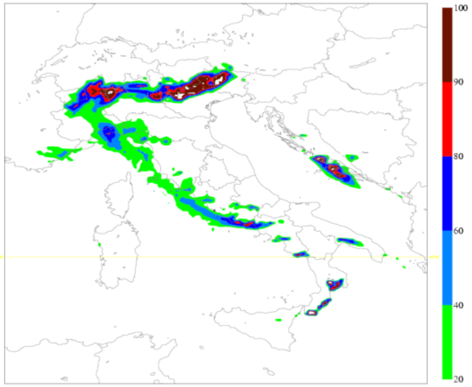


EPS NOSP PROB20 →

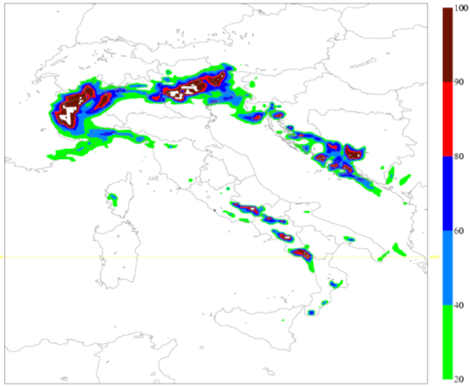
OFFNB Accumulation of 0 Forecasts VT:00UTC 27 November 2012 to 06UTC 28 November 2012 Surface: total precipitation
in a 06 hours interval



OFFNB Accumulation of 0 Forecasts VT:00UTC 27 November 2012 to 12UTC 28 November 2012 Surface: total precipitation
in a 06 hours interval



OFFNB Accumulation of 0 Forecasts VT:00UTC 27 November 2012 to 18UTC 28 November 2012 Surface: total precipitation
in a 06 hours interval



27 nov 2012

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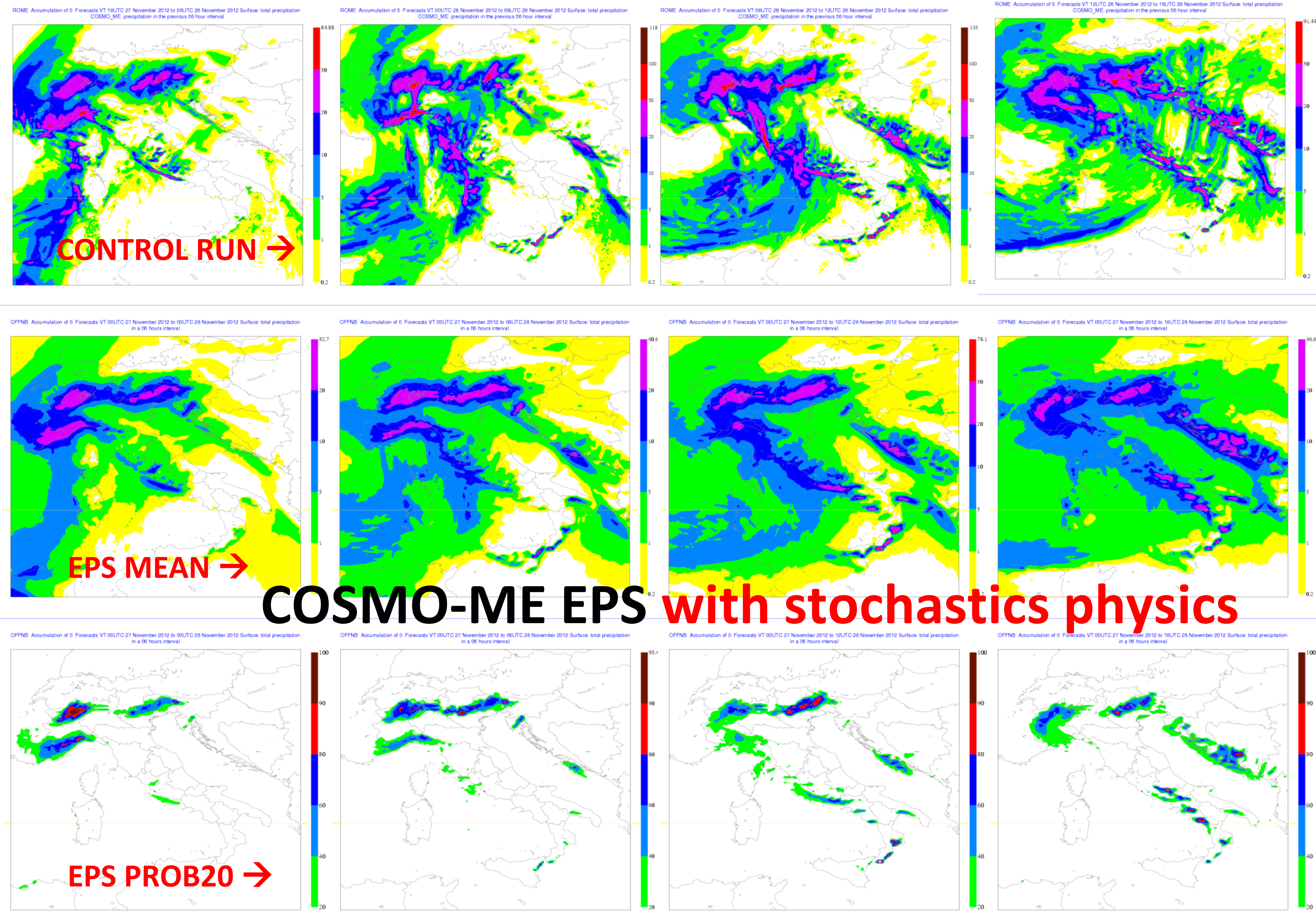
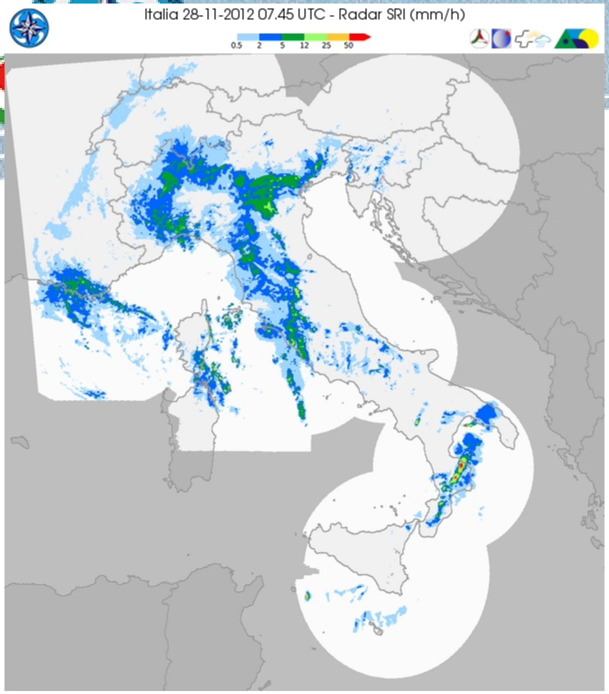
COSMO-ME EPS with stochastics physics

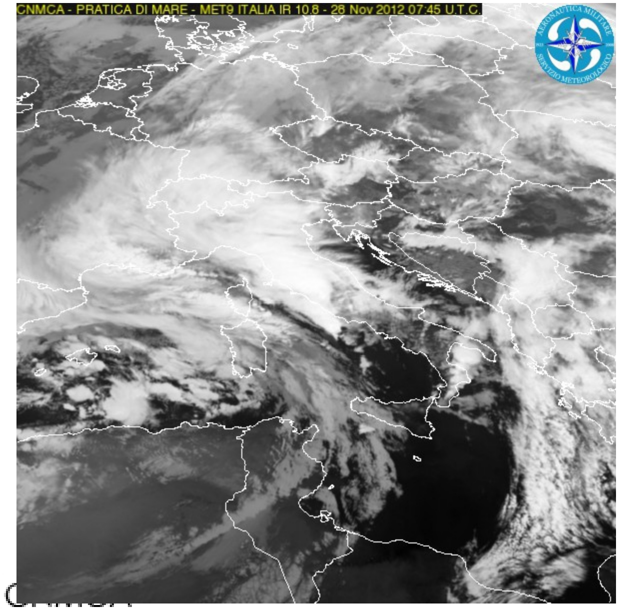


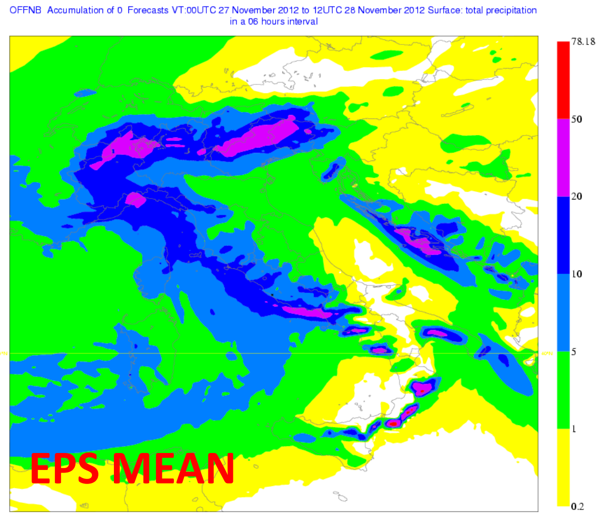
COSMO-ME EPS with and without stochastics physics

FORECAST 30-36h

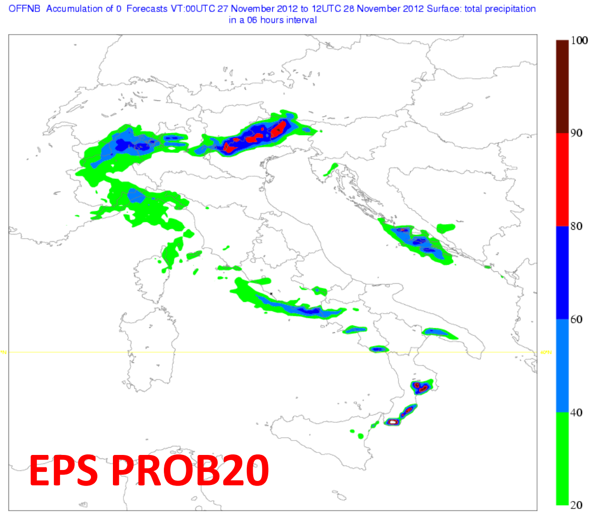


28 nov 2012 07:45 UTC

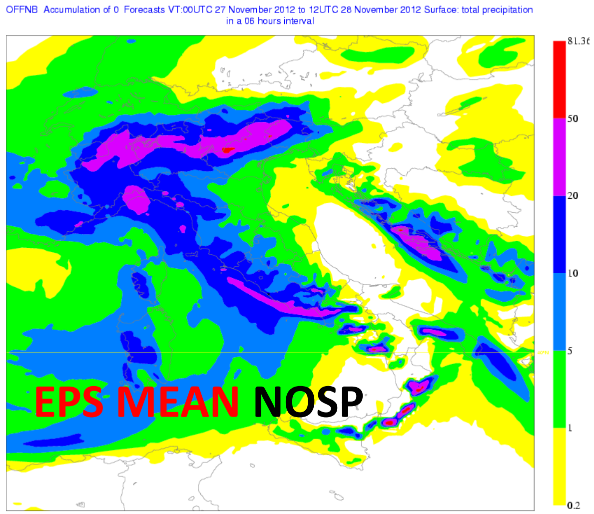




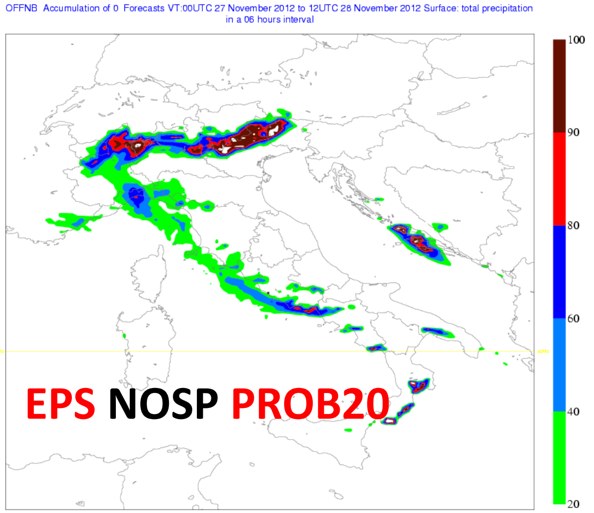
EPS MEAN



EPS PROB20



EPS MEAN NOSP



EPS NOSP PROB20

Conclusions

Based on CNMCA experience using LETKF

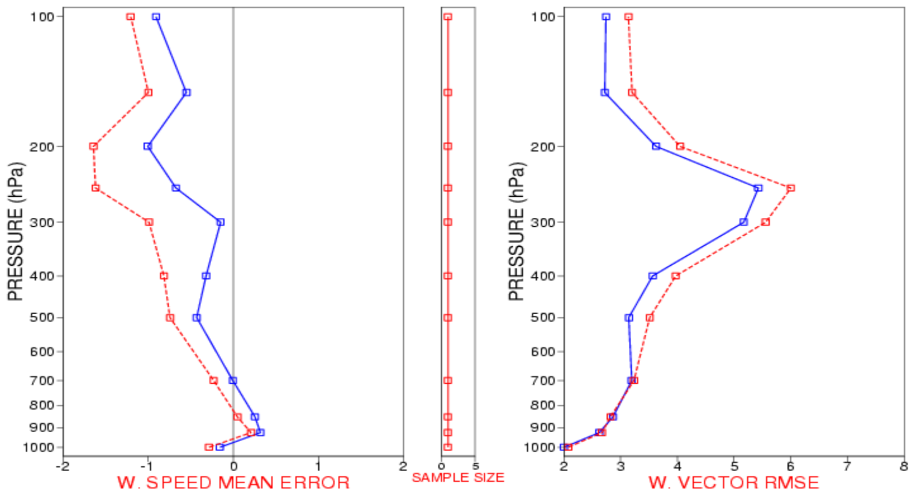
- DA:
  - Multiplicative inflaction accounts mainly for observation network related errors
  - Additive inflaction seems to more effective in representing model error in the DA cycle.
  - SPPT seems to be not so effective as additive noise
- EPS:
  - SPPT tested in COSMO-ME EPS ensemble contributing to the spread increase as a function of forecast time (with a drying effect)
  - More experiments are needed to evaluate the “best tuning” of SPPT in COSMO-ME EPS

Thanks for the attention!
Any questions?

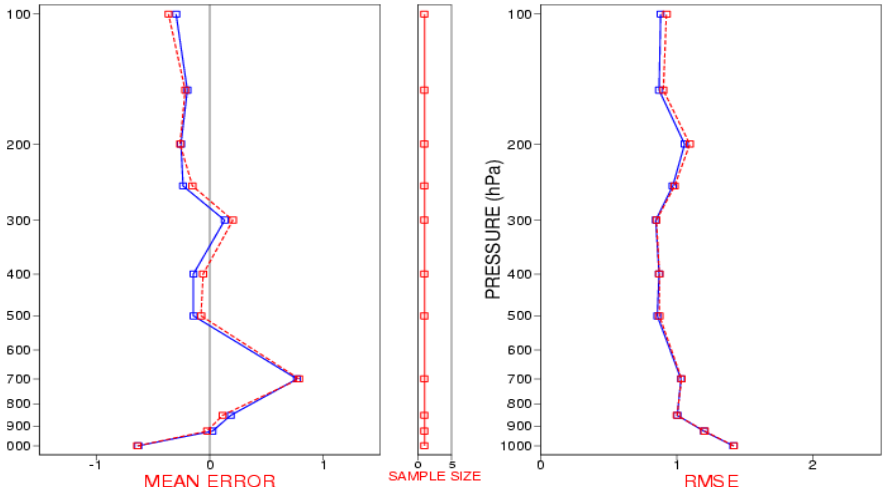
Experiment: 05 June 2011 case

Ensemble Mean Forecast against IFS Analysis

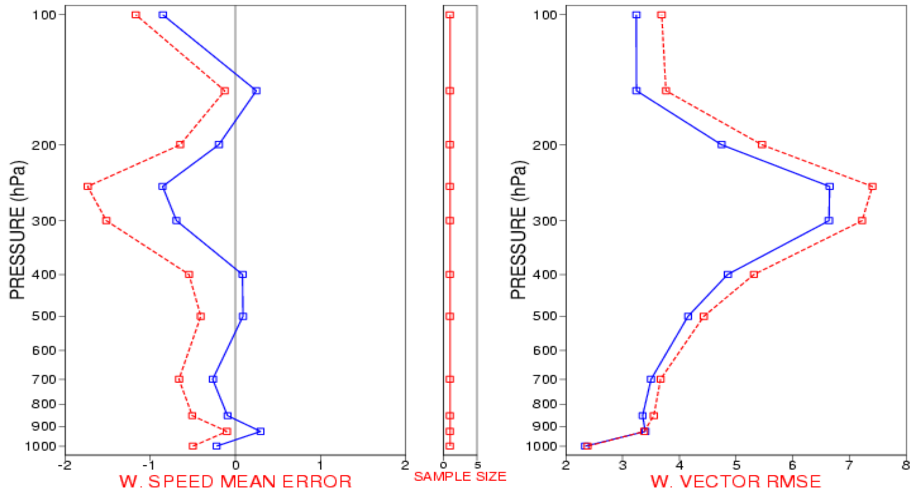
WIND (m/s)00 UTC FC + 24 h
Verification 05/06/11
COSMO-ME_0.25: Blue COSMO-ME_0.5: Red



TEMPERATURE (°C)00 UTC FC + 24 h
Verification 05/06/11
COSMO-ME_0.25: Blue COSMO-ME_0.5: Red



WIND (m/s)00 UTC FC + 48 h
Verification 05/06/11
COSMO-ME_0.25: Blue COSMO-ME_0.5: Red



TEMPERATURE (°C)00 UTC FC + 48 h
Verification 05/06/11
COSMO-ME_0.25: Blue COSMO-ME_0.5: Red