The CNMCA Operational LETKF Data Assimilation System: Recent Developments

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Outline

- The EnDA implementation of CNMCA: Local Ensemble Transform Kalman Filter (LETKF)
- Comparison HRM-COSMO LETKF
  - Observation Increment Statistics
  - Forecast verification
- COSMO-LETKF: Experiment with most recent EPS perturbation
- Future developments

Ensemble Kalman Filter (LETKF)

- 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. The obs error covariance R elements are modified by distance-dependent localization factors ρ [0-1] , so that far-away obs have large errors (R localization – $R_l = \rho^{-1} R$). This explicit localization reduces the problem dimensionality and the spurious correlations between distant locations due to limited ensemble size

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

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

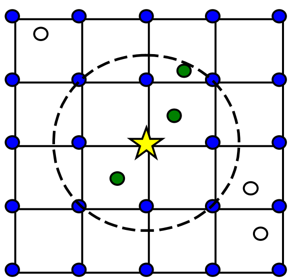
Analysis Ensemble $x^a = x^b + \mathbf{X}^b w^a$

[redacted] $^a = \tilde{P}^a Y^{bT} R_l^{-1}(y - H($[redacted]$^b))$

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

$Y^b = [(H(x_1^b) -$ [redacted]$), \ldots\ldots, (H(x_m^b) -$ [redacted]$)]$

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



– 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 LETKF Implementation

- 40+1 member ensemble at 0.09° (~10Km) grid spacing (HRM model), 40 hybrid p-sigma vertical levels (top at 10 hPa)
- 6-hourly assimilation cycle run and (T,u,v,qv,ps) as a set of control variables
- Observations: RAOB, SYNOP, SHIP, BUOY, AIREP, AMDAR, ACAR, AMV (MSG, MET7), WindPROF, SCAT(METOP), AMSU-A (METOP,NOAA) radiances (very soon)
- Horizontal localization with 800 Km circular local patches (obs weight smoothly decay with a pseudo-gaussian function of hor. distance)
- Vertical localization to layers whose depth increases from 0.2 scale heights at the lowest model levels to 2. scale heights at the model top (obs weight smoothly decay with a pseudo-gaussian function of scale height)
- Adaptive selection radius using a fixed number of effective observations (sum of obs weights)
- Daily large scale blending of the mean analysis with the IFS analysis to compensate the limited satellite data usage

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

α = 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

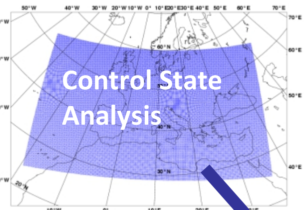
- Lateral Boundary Condition Perturbation using EPS

- Climatological Perturbed SST

CNMCA NWP SYSTEM since 1 June 11

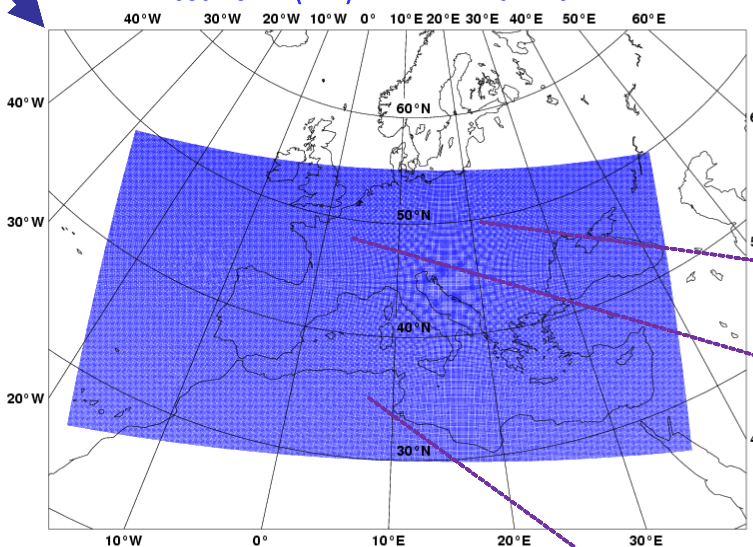
LETKF analysis ensemble (40+1 members) every 6h using TEMP, PILOT, SYNOP, SHIP, BUOY, Wind Profiler, AMDAR-ACAR-AIREP, MSG/MET7 AMV, METOP scatt. winds, NOAA/METOP AMSUA radiances (very soon)
+ Land SAF snow mask, IFS SST analysis once a day

Ensemble Data Assimilation:



10 km
40 v.l.

- HRM hydrostatic model
- parameterized convection

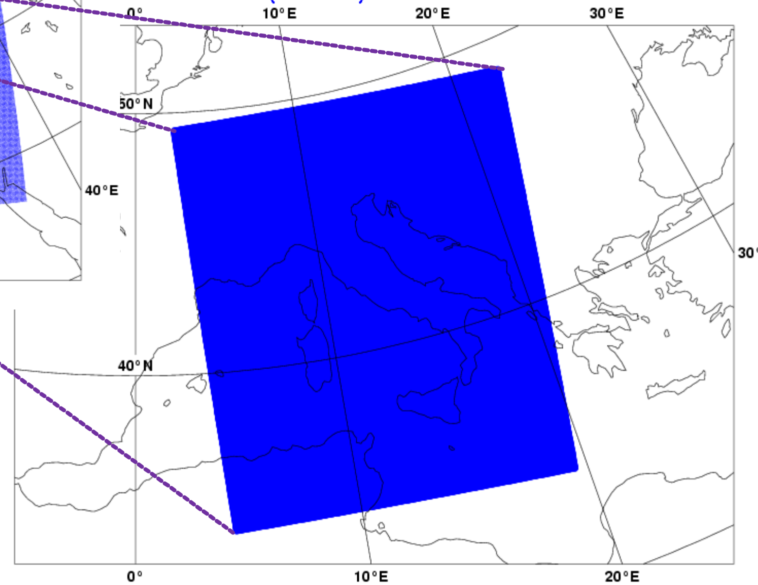


7 km
40 v.l.

- compressible equations
- parameterized convection

2.8 km
50 v.l.

- compressible equations
- explicit convection



Local Area Modelling: COSMO

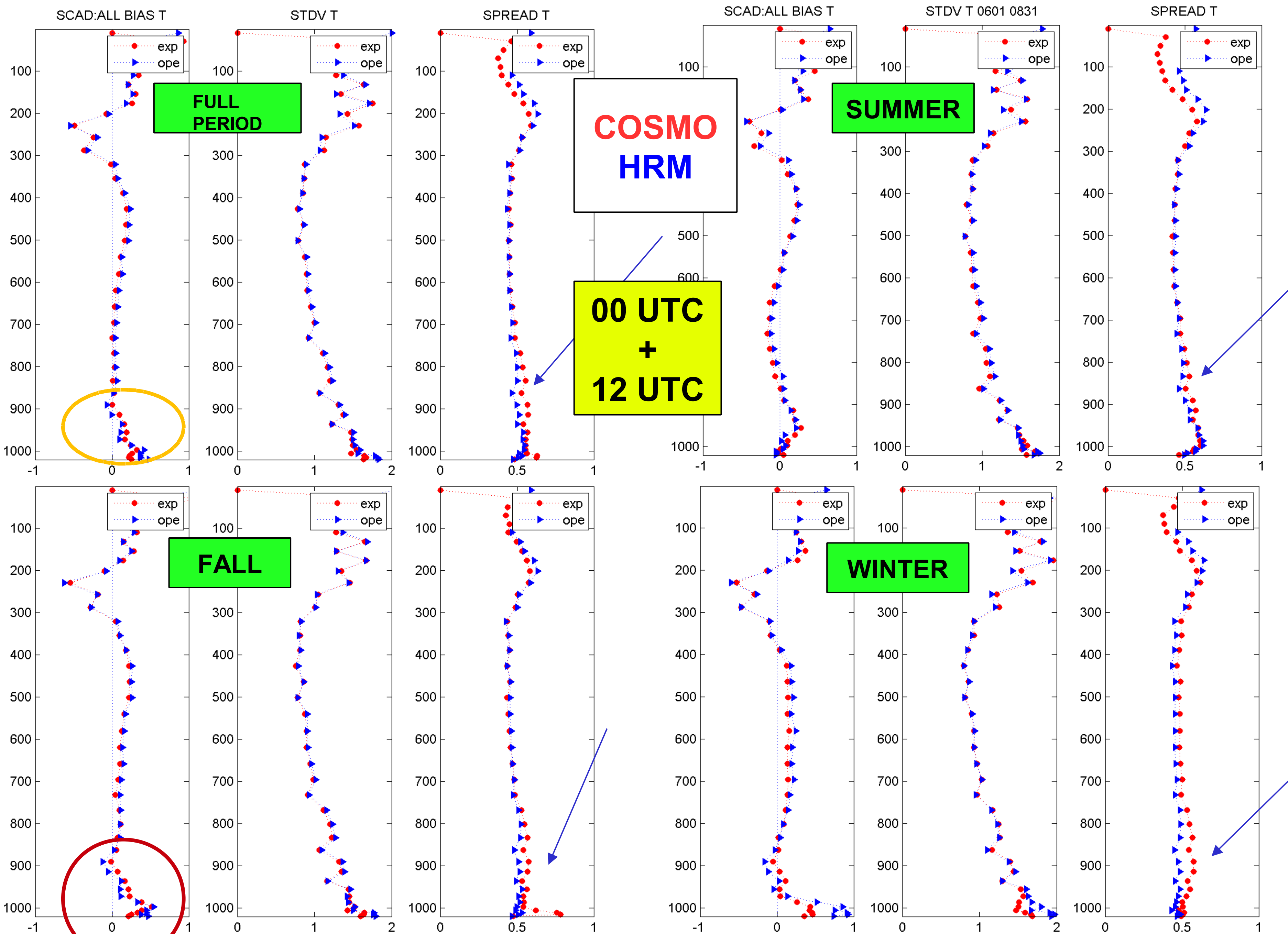
COSMO model in CNMCA-LETKF

- HRM hydrostatic model is subtituted by COSMO non-hydrostatic model in CNMCA LETKF system taking into account of that:
  - The model top is raised from $\frac{1}{28}$21.5km ($\frac{1}{28}$43hPa) to $\frac{1}{28}$26km ($\frac{1}{28}$18hPa) using 45 vertical levels to reduce the influence of the sponge layer (upper levels Rayleigh damping zone)
  - Initial pressure perturbation fields are derived using the hydrostatic balance equation
- The CNMCA-LETKF system using COSMO model is experimental running since February 2012 with basicly the same settings of the operational one
- Observation increment statistics (obs-BG) is continously monitored and deterministic forecasts from this system are objectively verified against conventional observations

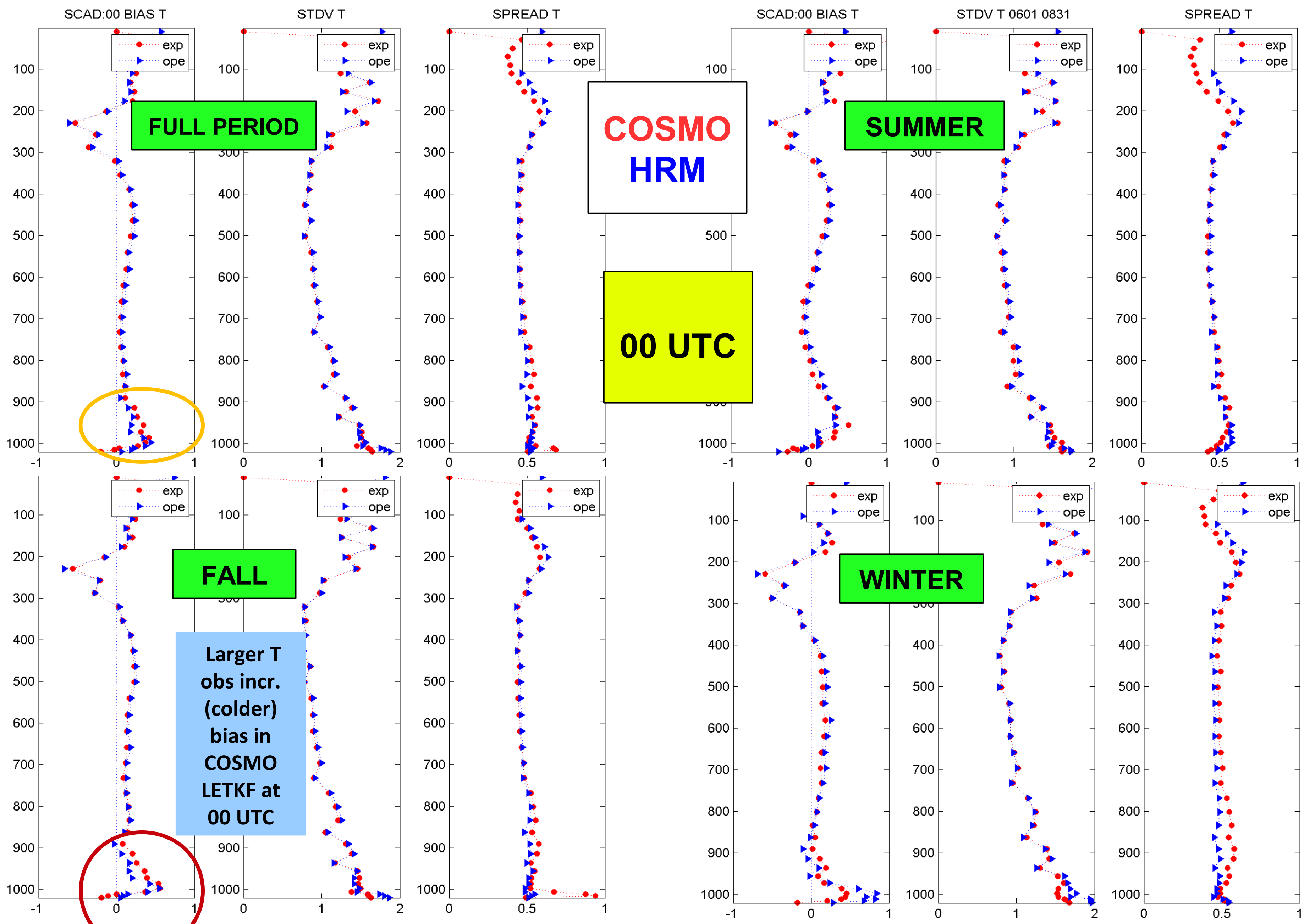
HRM vs COSMO LETKF

Radiosoundes obs increment statistics
(obs -BG ensemble mean)
on 40 pressure levels
from 1 jun 2012 to 11 feb 2013
(00 and 12 UTC)

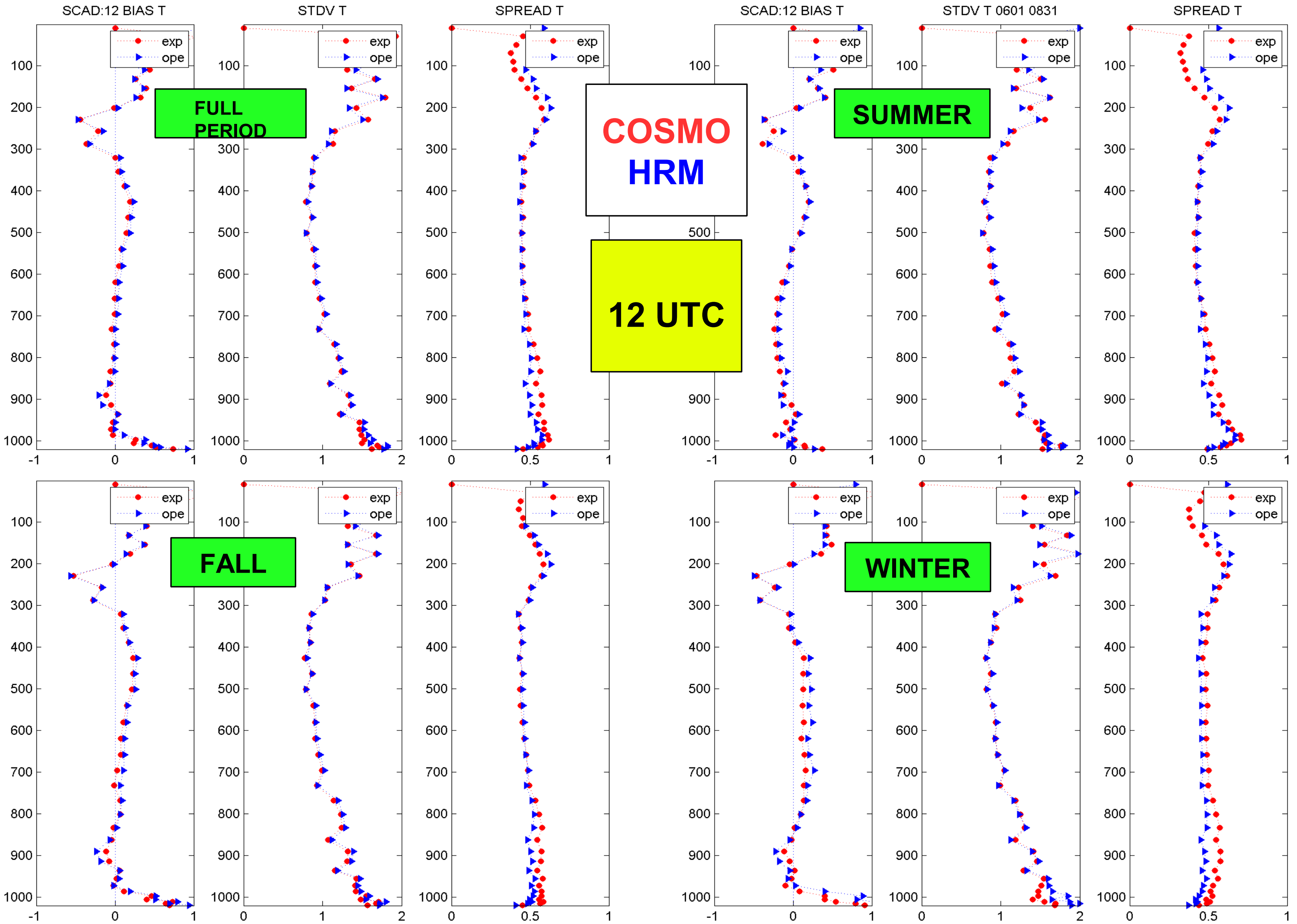
TEMPERATURE OBS INCR STATISTICS



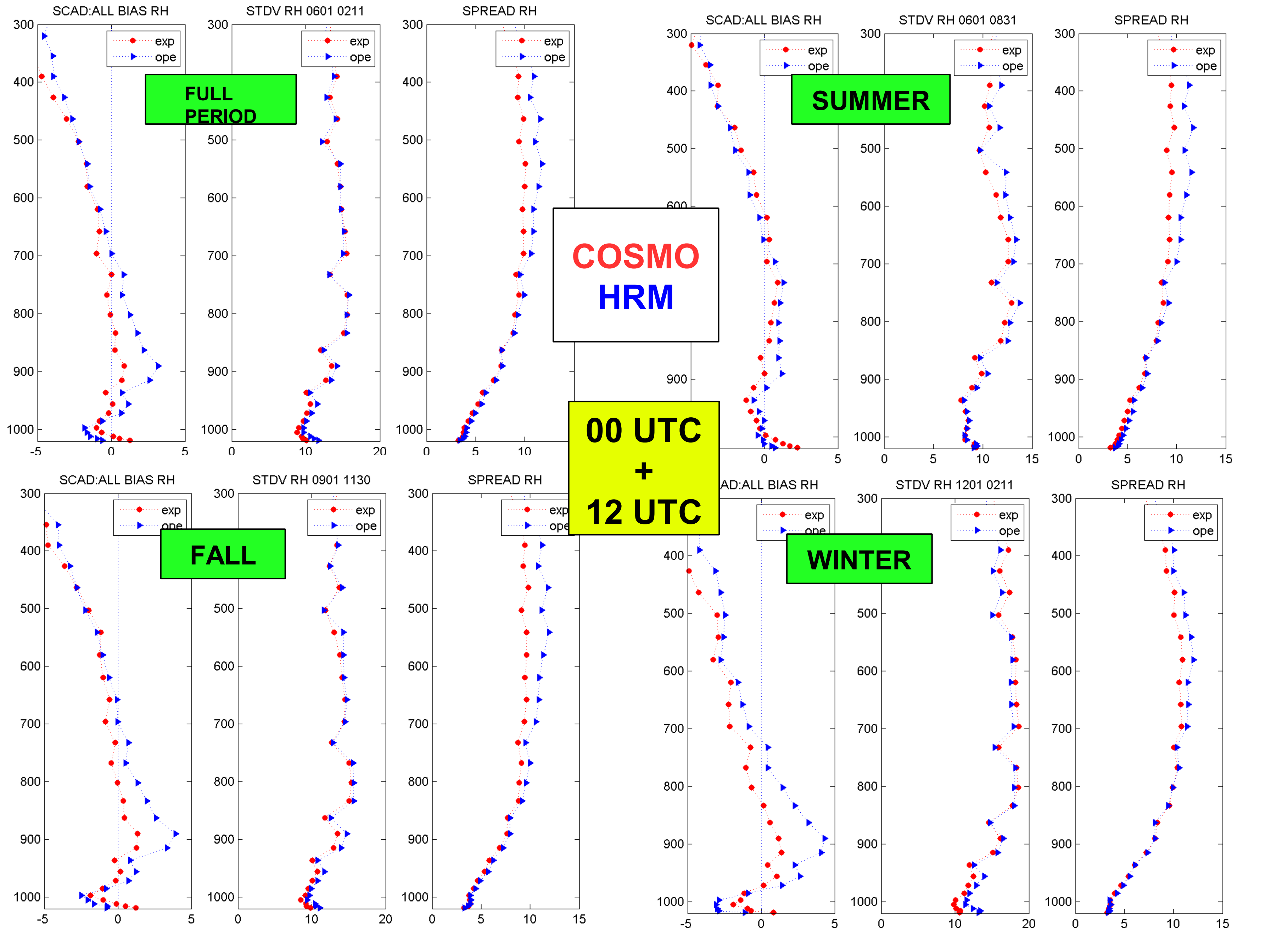
TEMPERATURE OBS INCR STATISTICS



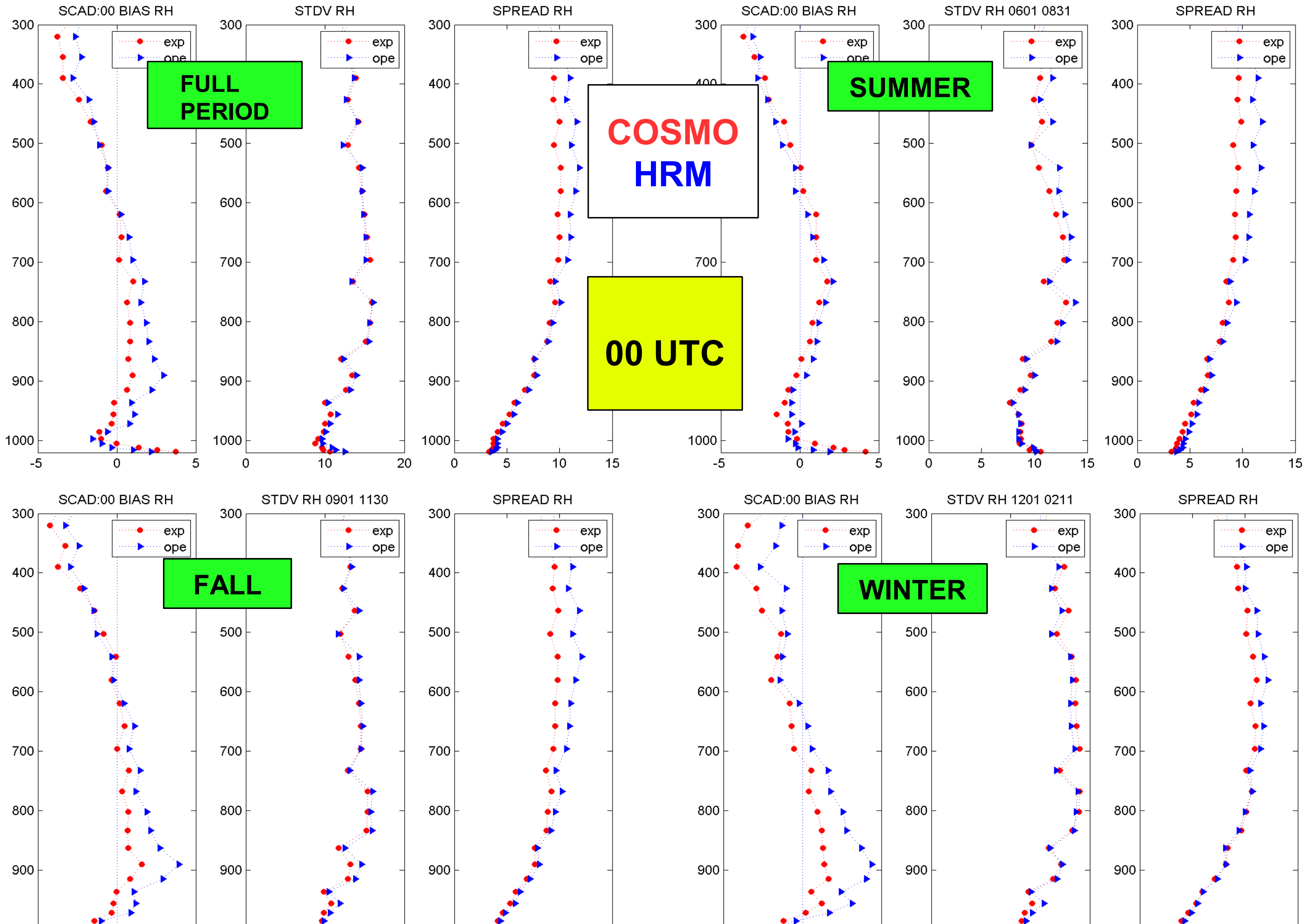
TEMPERATURE OBS INCR STATISTICS



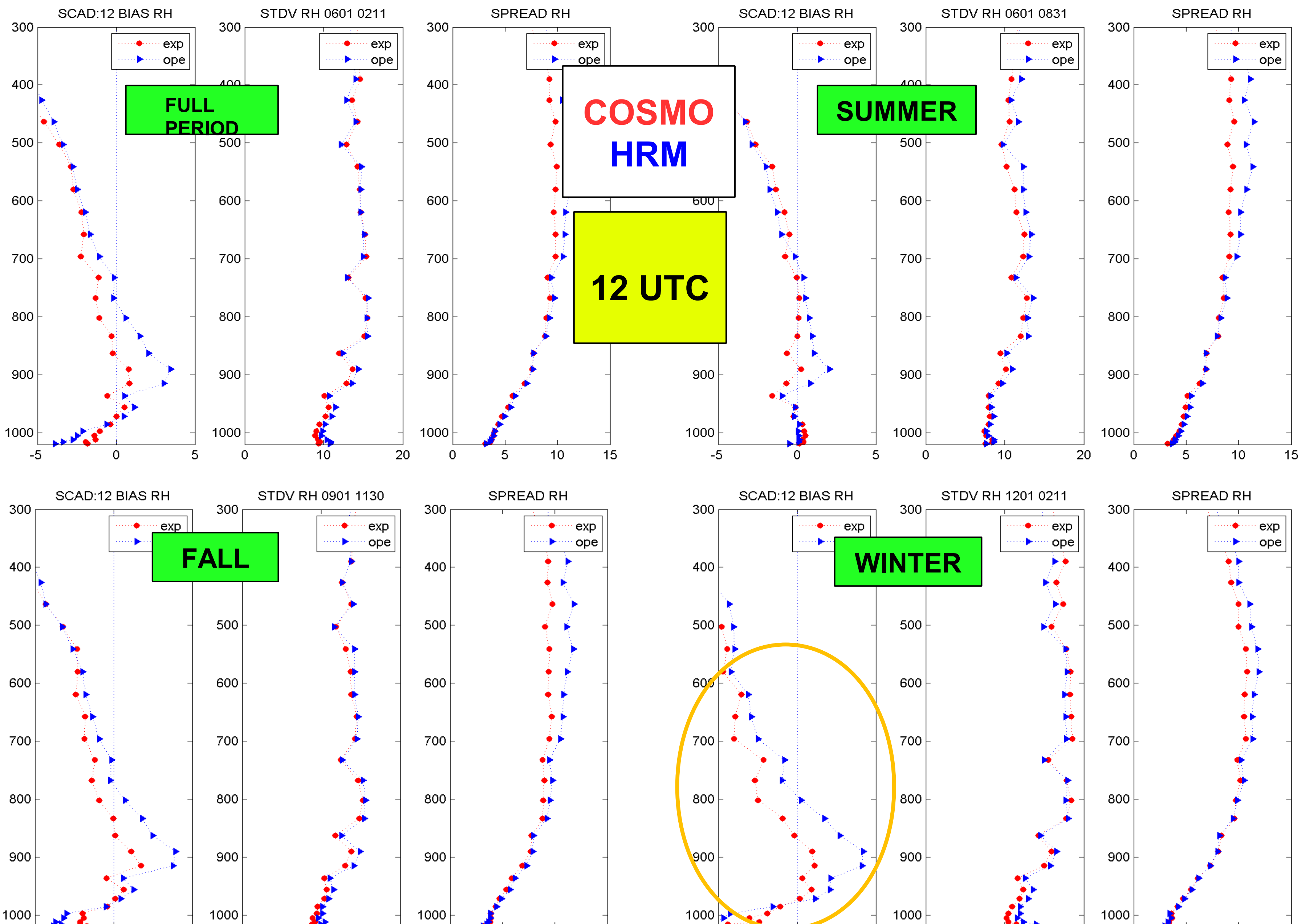
REL.HUMIDITY OBS INCR STATISTICS



REL.HUMIDITY OBS INCR STATISTICS

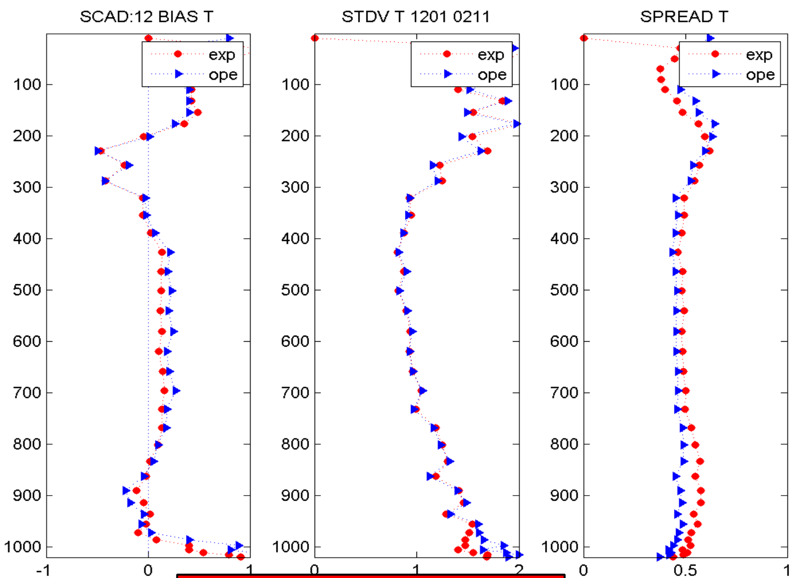


REL.HUMIDITY OBS INCR STATISTICS

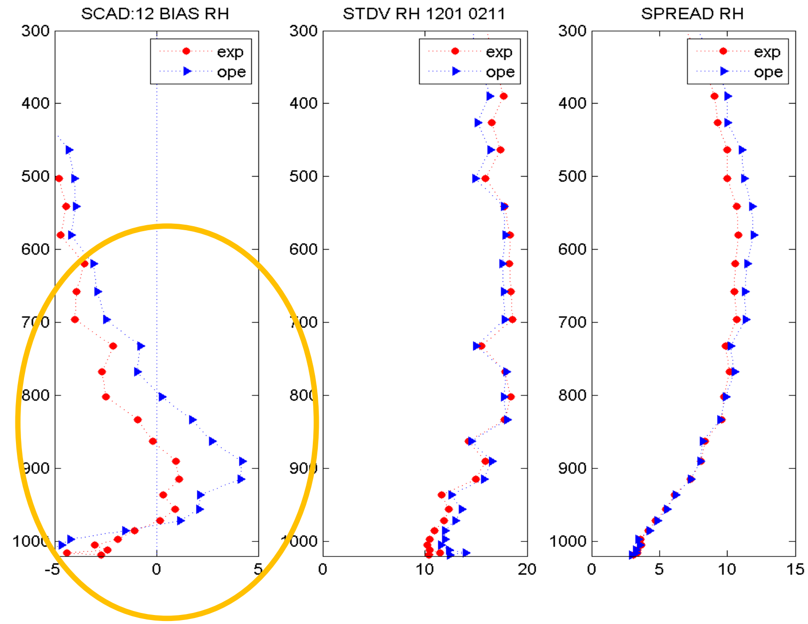


OBS INCR STATISTICS: **WINTER**

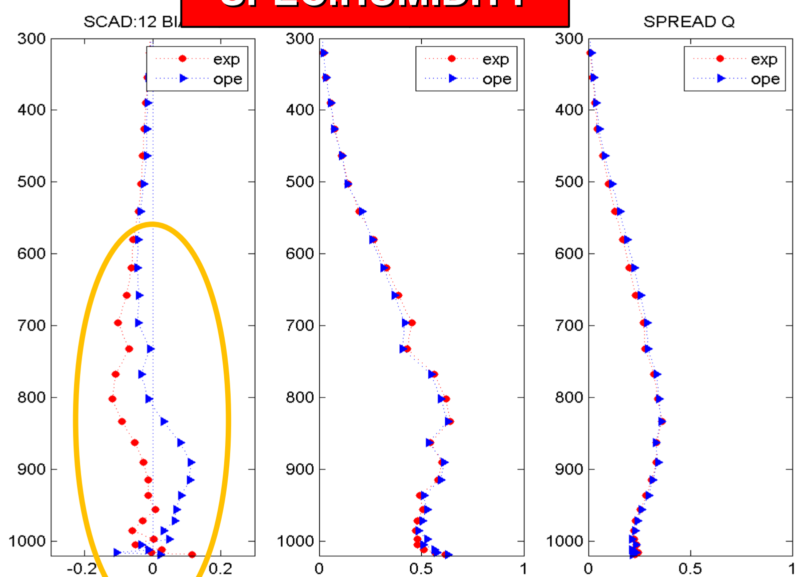
TEMPERATURE



REL.HUMIDITY

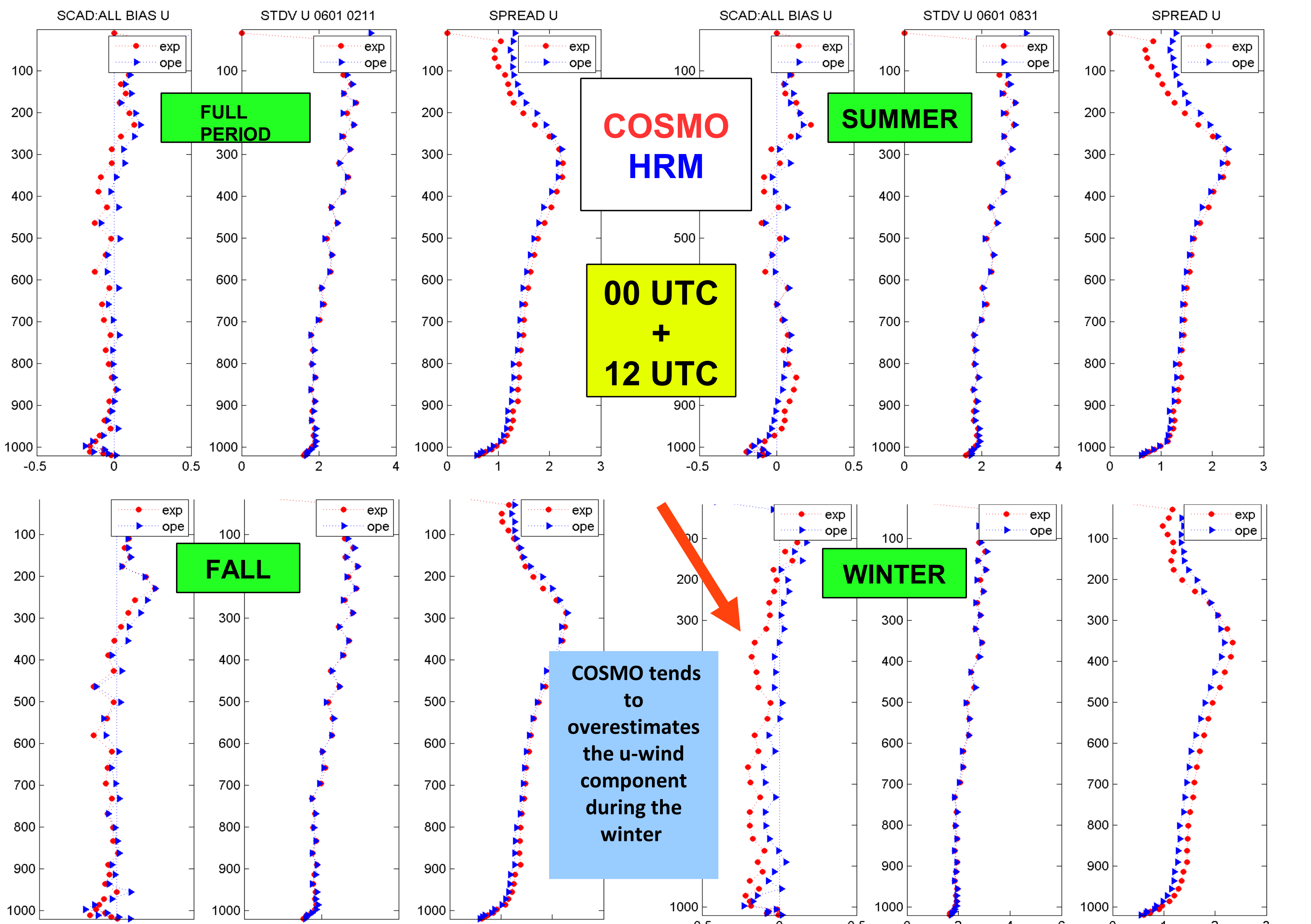


SPEC.HUMIDITY

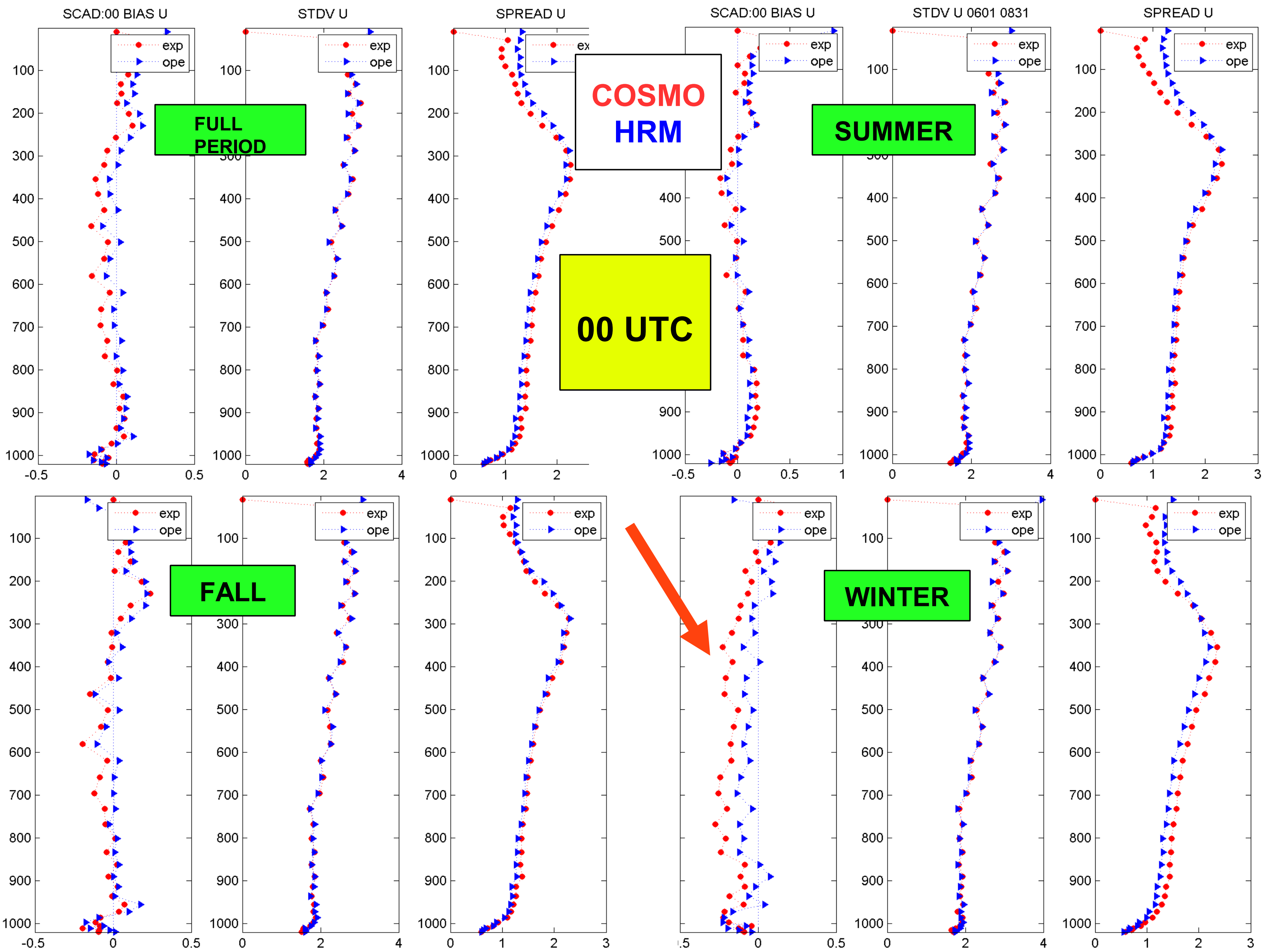


AT 12 UTC MAIN CONTRIBUTION TO RH BIAS COMES FROM SPEC.HUMIDITY

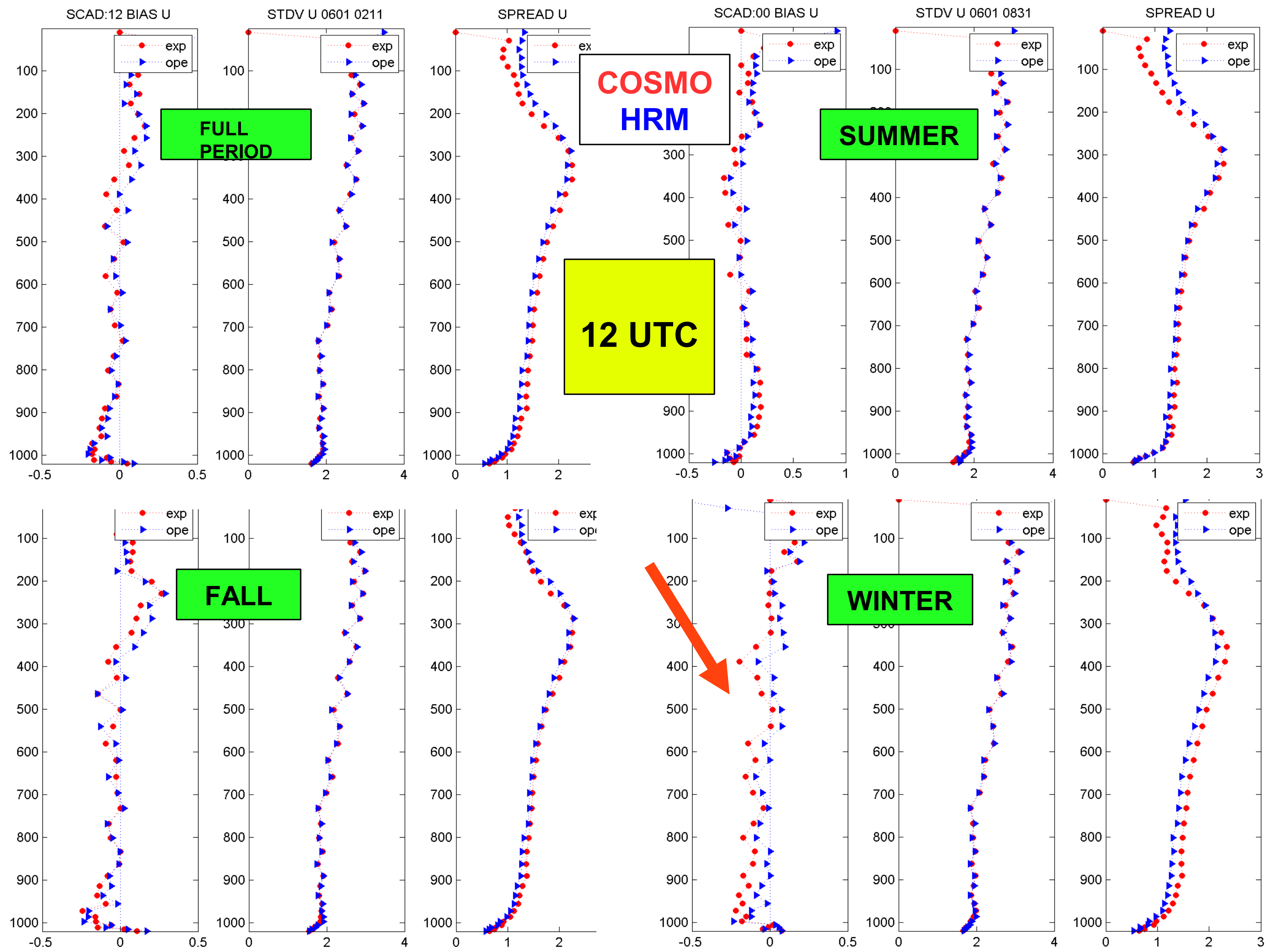
U-WIND OBS INCR STATISTICS



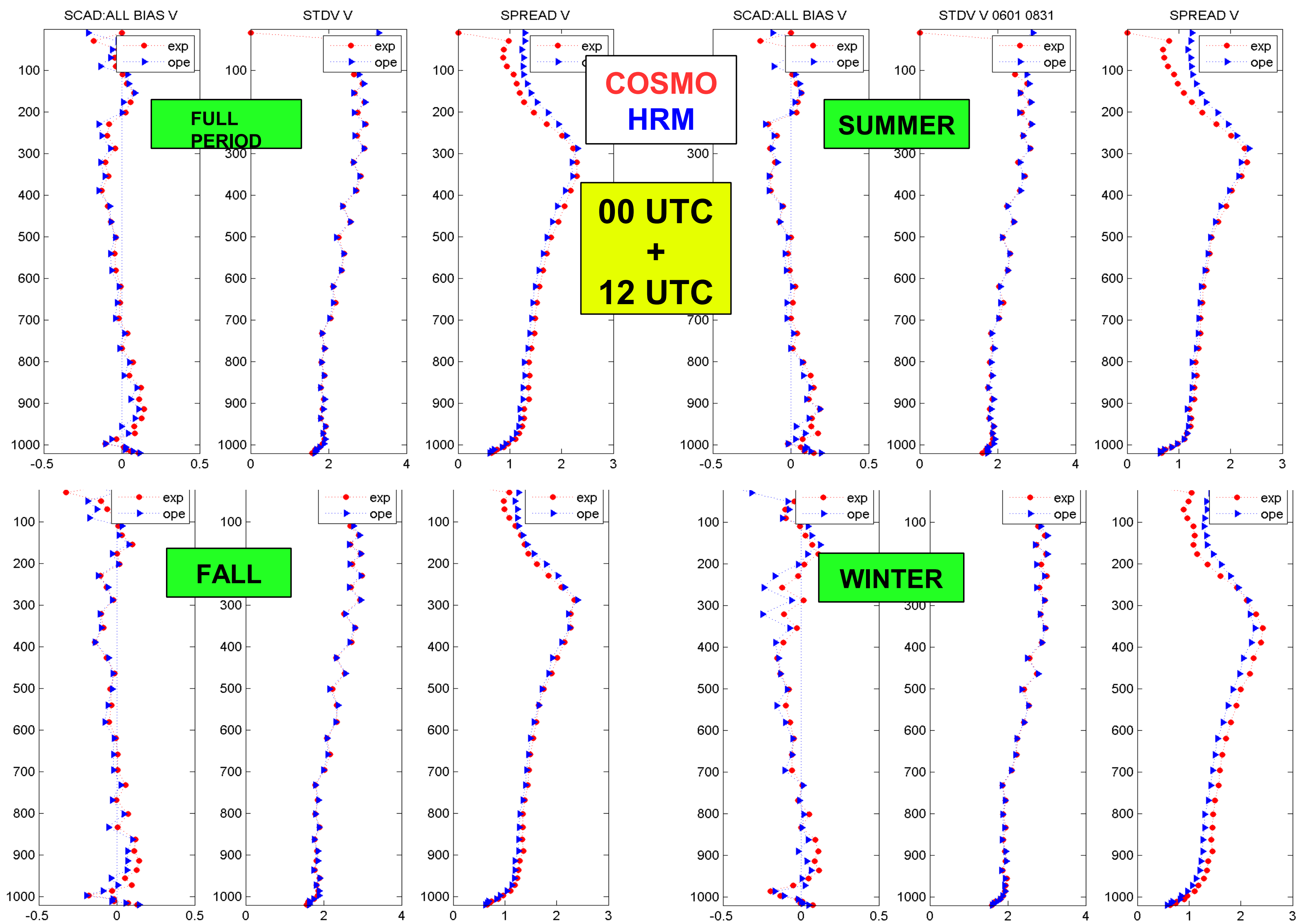
U-WIND OBS INCR STATISTICS



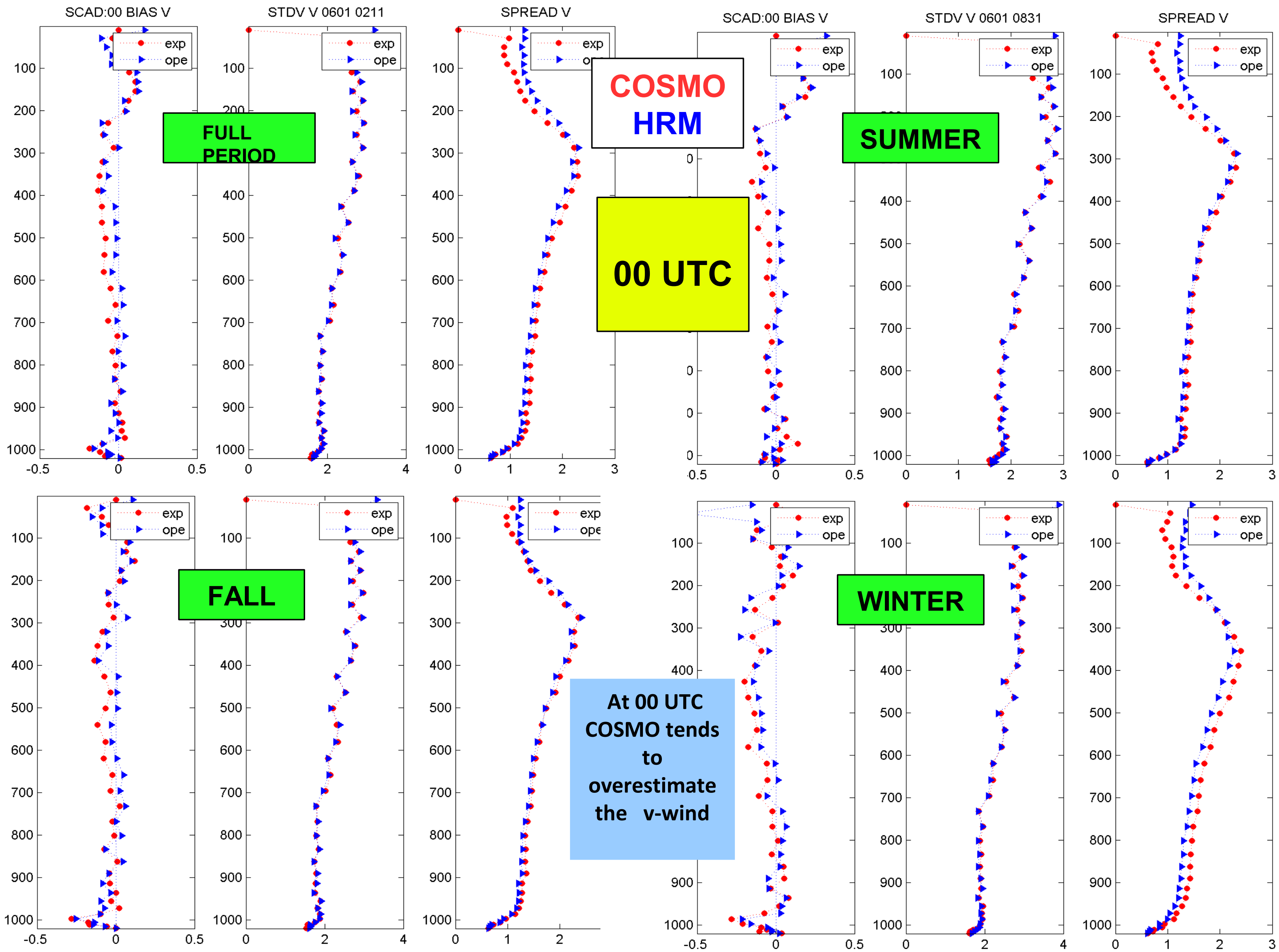
U-WIND OBS INCR STATISTICS



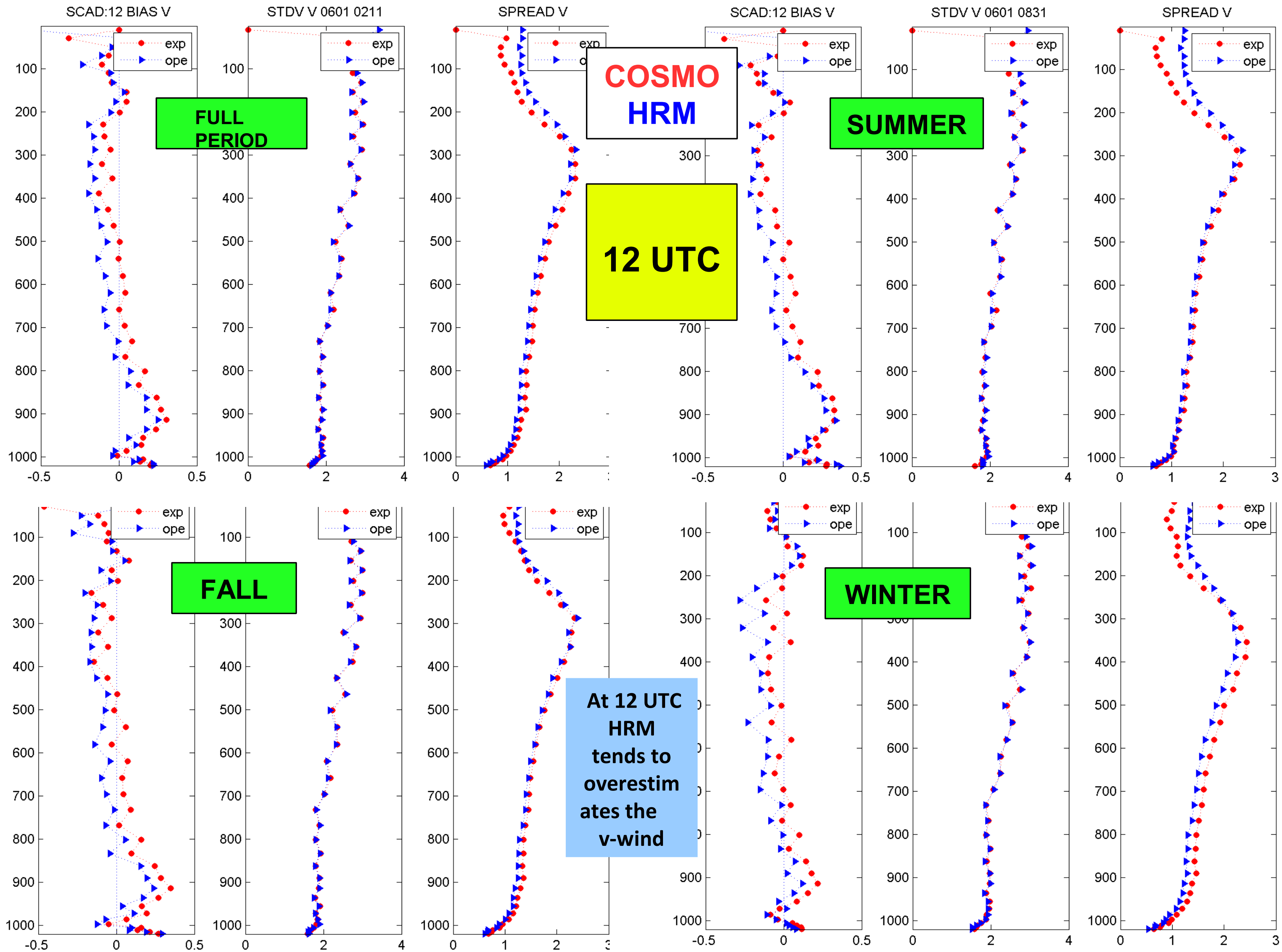
V-WIND OBS INCR STATISTICS



V-WIND OBS INCR STATISTICS



V-WIND OBS INCR STATISTICS



NEW COSMO SETTINGS

OBS. INCR. STATISTICS

tkhmin=0.7, ltkesso=.TRUE.

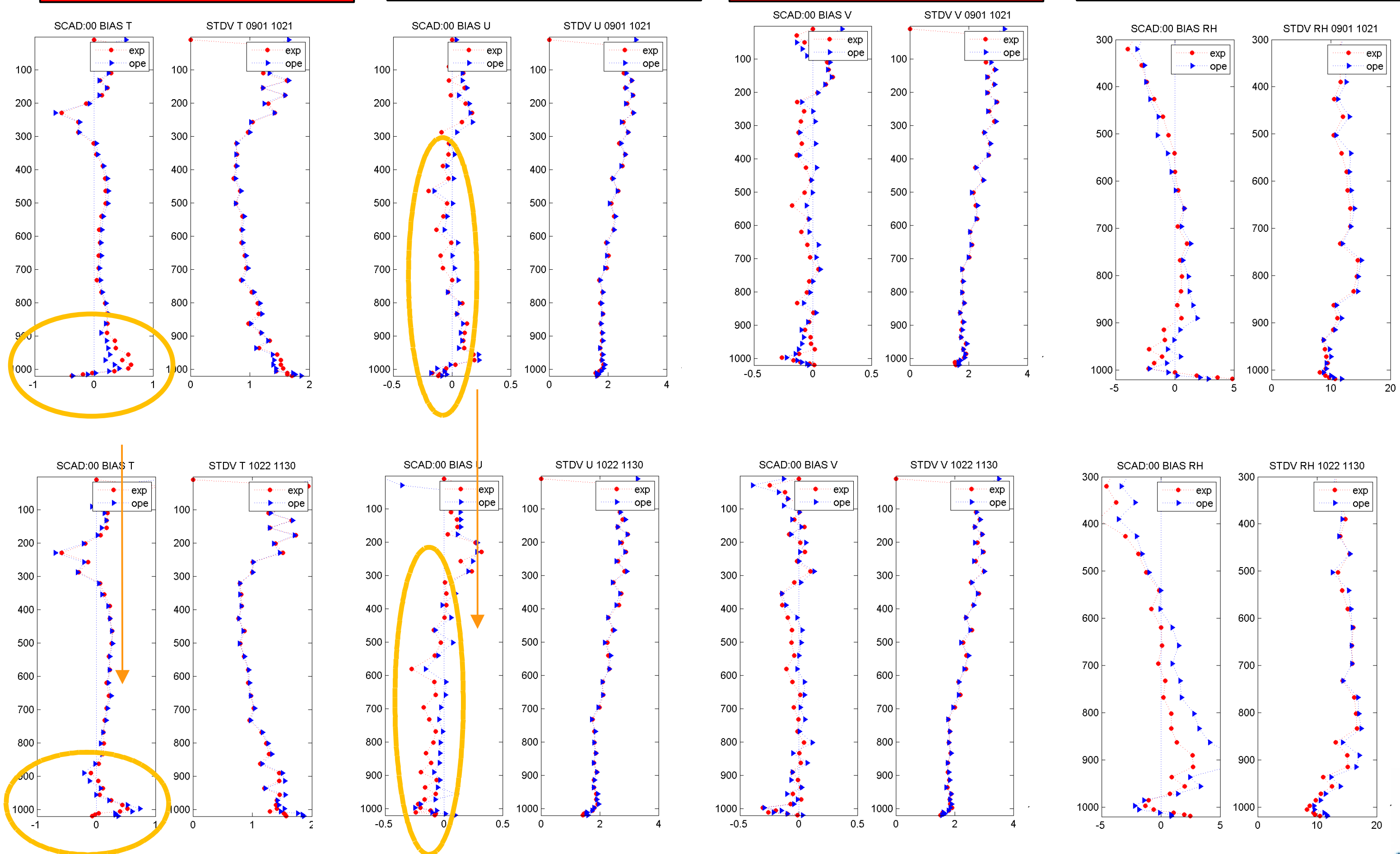
00 UTC

OLD
1sept-21oct

COSMO
HRM

NEW
22oct-30nov

TEMPERATURE | **U-WIND** | **V-WIND** | **REL. HUMIDITY**



NEW COSMO SETTINGS

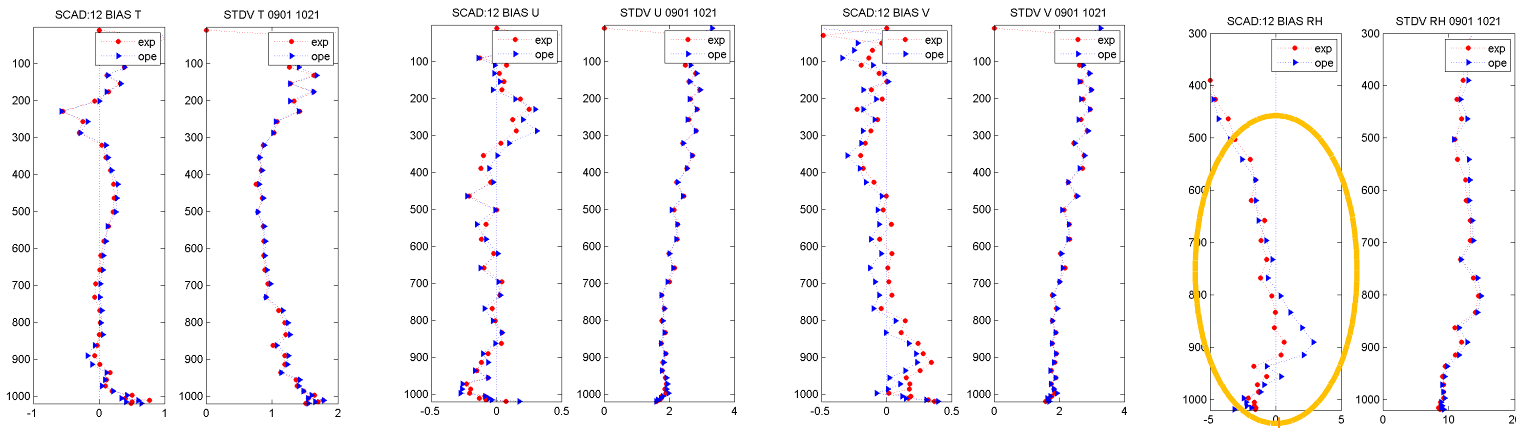
OBS. INCR. STATISTICS

tkhmin=0.7, ltkesso=.TRUE.

12 UTC

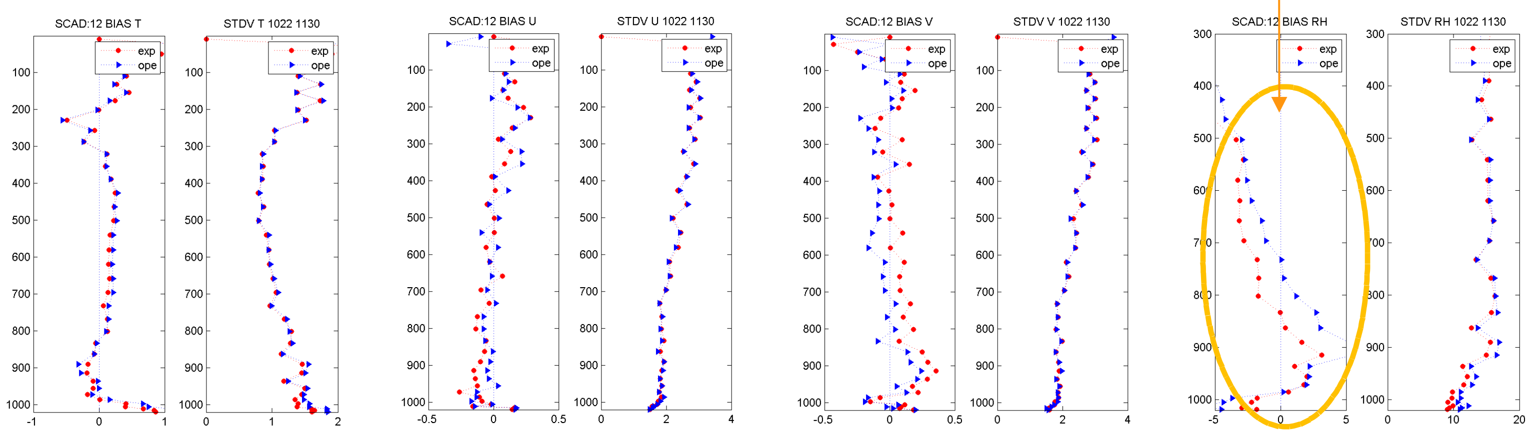
TEMPERATURE | **U-WIND** | **V-WIND** | **REL. HUMIDITY**

OLD
1sept-21oct



COSMO
HRM

NEW
22oct-30nov



Summary of Results

From observation increment statistics :

Nocturnal larger negative temperature bias near the surface in COSMO-LETKF background ensemble mean in fall as observed during the spring

- The prognostic TKE scheme is too diffusive → tkhmin decreased
- The new settings improves the performance of COSMO-LETKF background ensemble mean

Diurnal larger positive humidity bias in the middle-lower troposphere using COSMO model as during the spring

- COSMO-LETKF tends to moisten the troposphere more than the HRM-LETKF.

Slight u-wind over-estimation at 00UTC in the winter period in COSMO model

- Probably due to the changes in COSMO-LETKF.

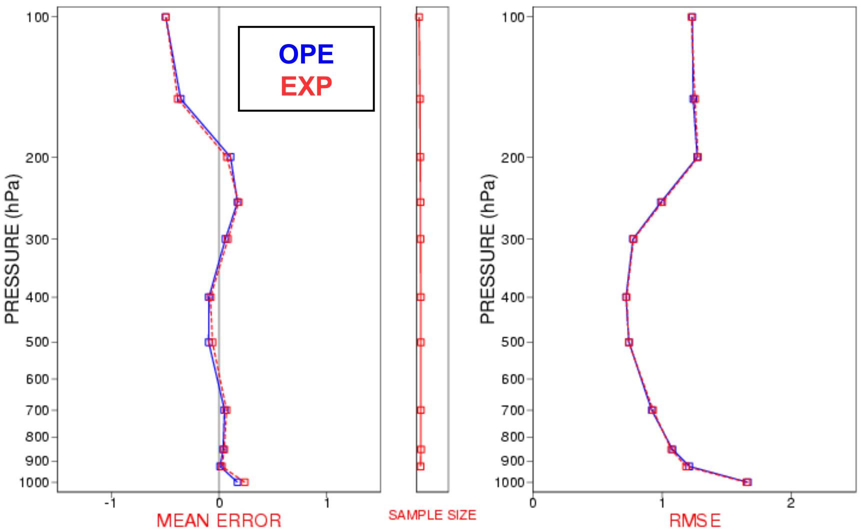
Deterministic forecast is verified against conventional observation

from 1 jun 2012 to 11 feb 2013

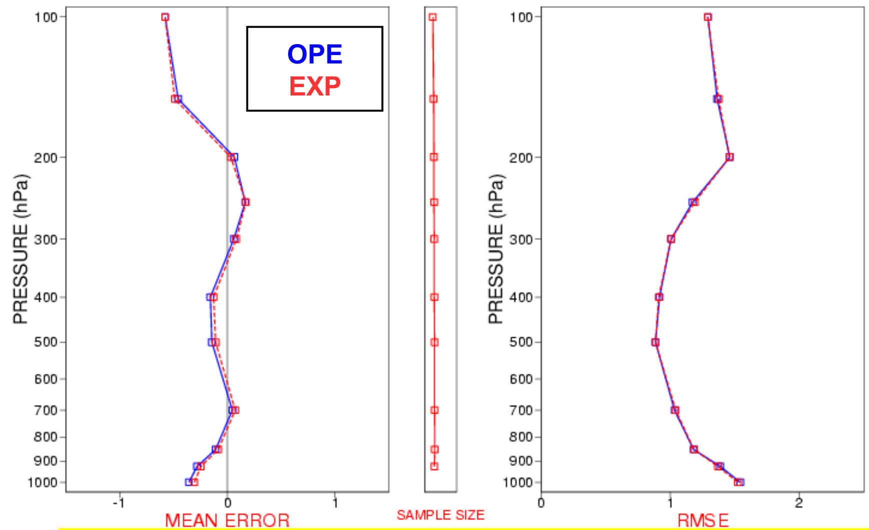
(00 UTC FCST)

FORECAST VERIFICATION SCORES 1jun 2012 – 11feb 2013

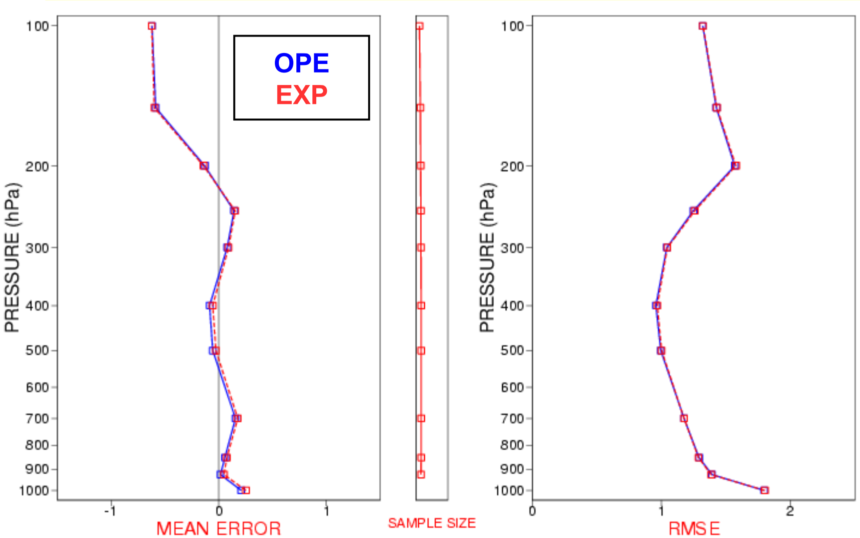
Temperature 00UTC FC+12h



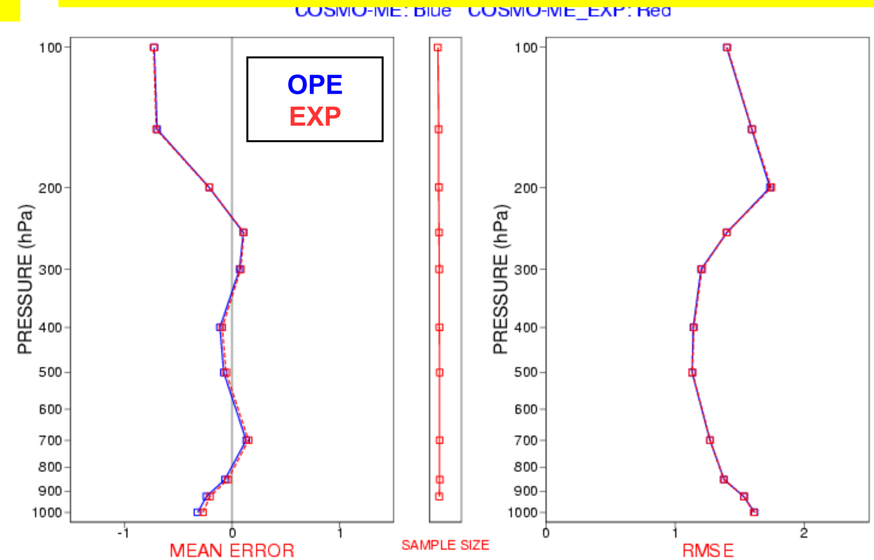
Temperature 00UTC FC+24h



Temperature 00UTC FC+36h



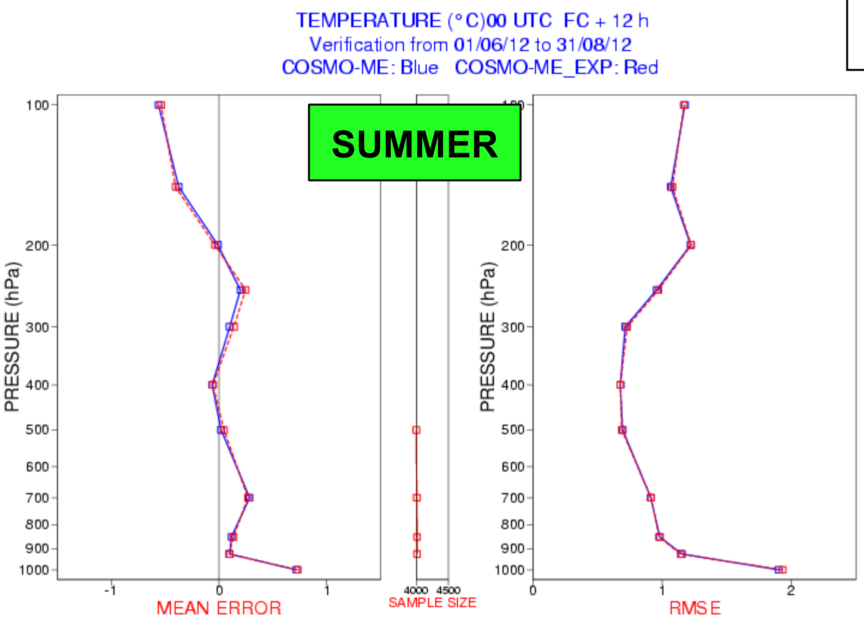
Temperature 00UTC FC+48h

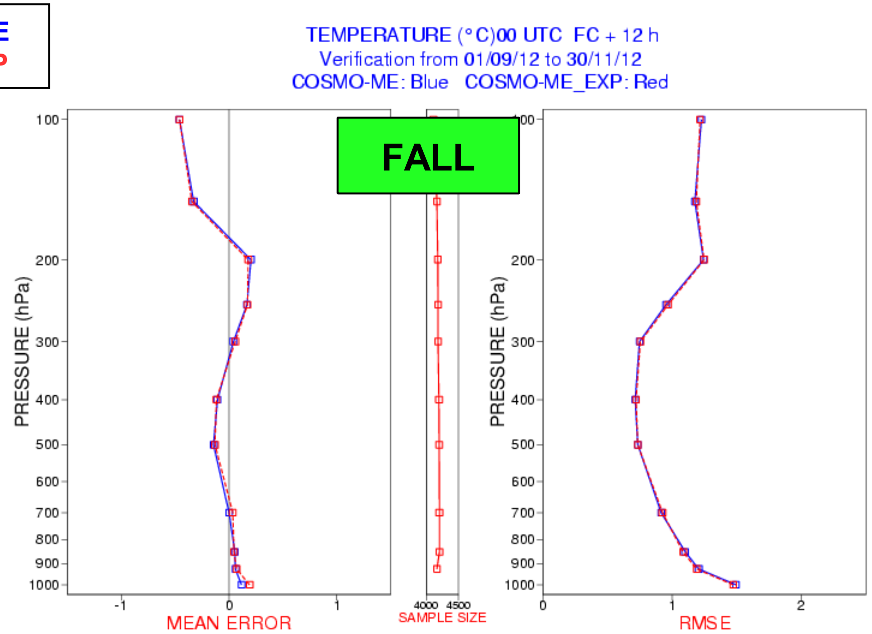


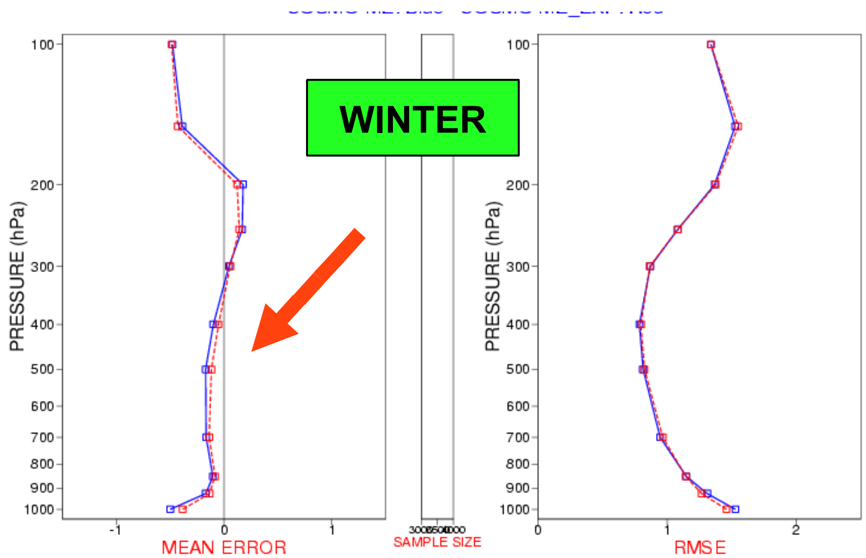
FORECAST VERIFICATION SCORES

Temperature 00UTC FC+12h

OPE
EXP

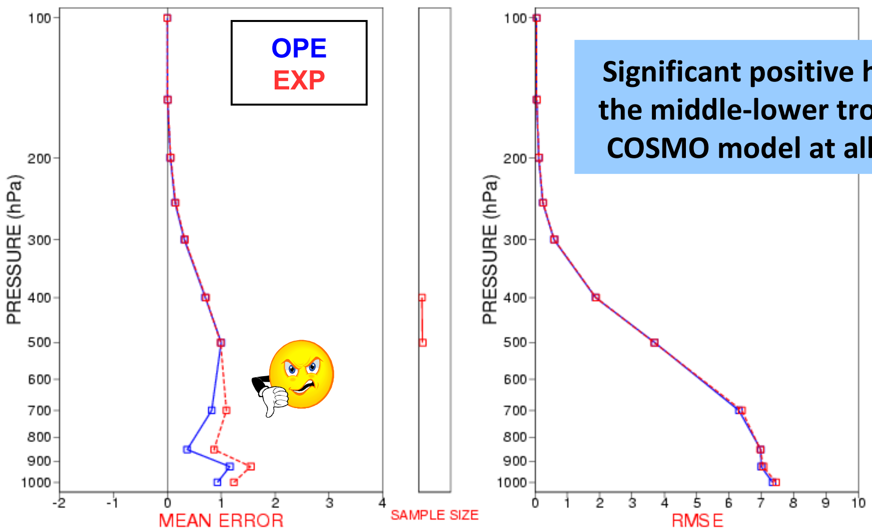




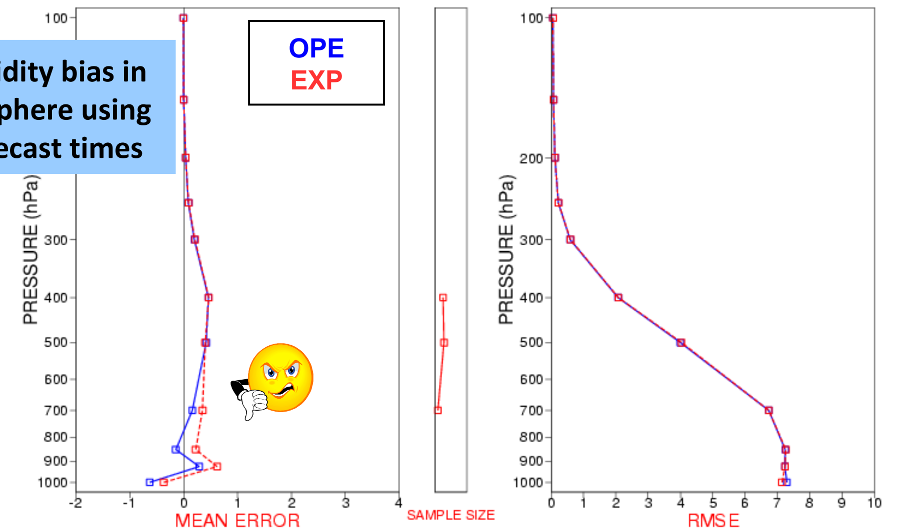


FORECAST VERIFICATION SCORES 1jun 2012 – 11feb 2013

Spec. Humidity 00UTC FC+12h

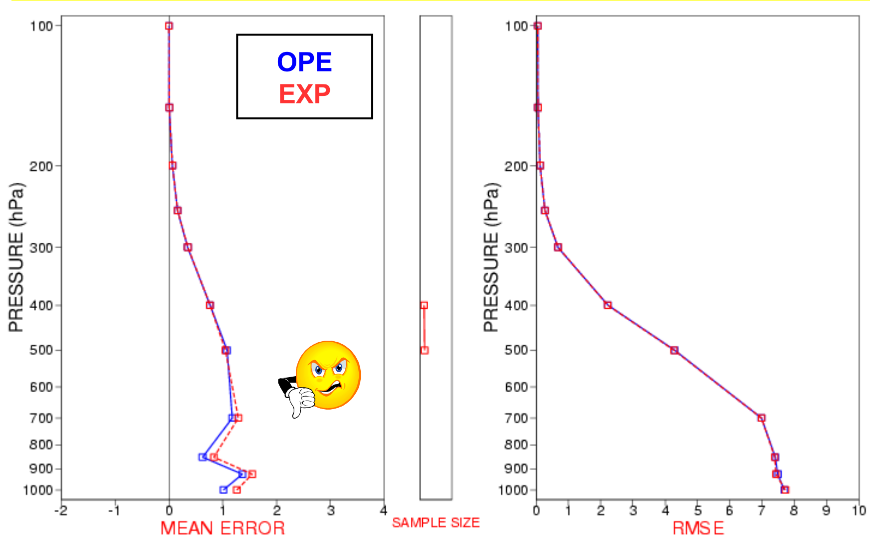


Spec. Humidity 00UTC FC+24h

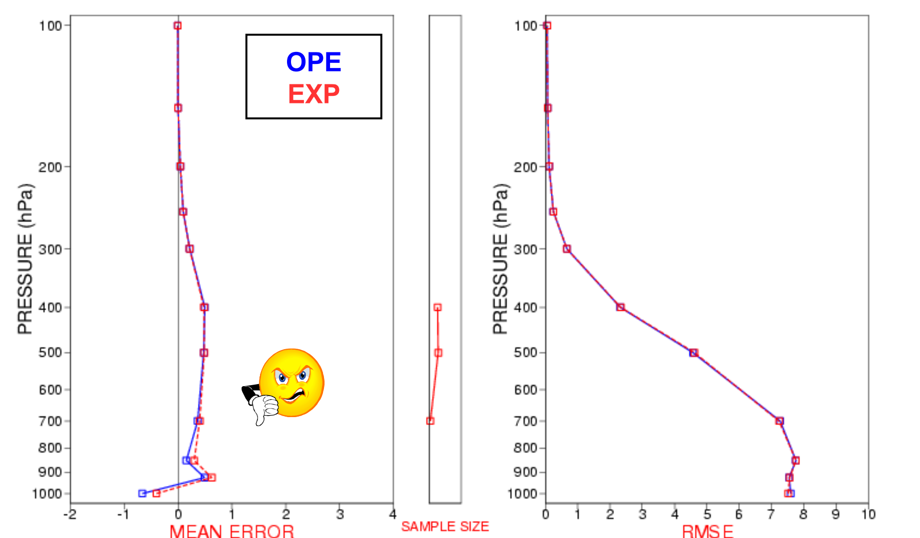


Significant positive humidity bias in the middle-lower troposphere using COSMO model at all forecast times

Spec. Humidity 00UTC FC+36h



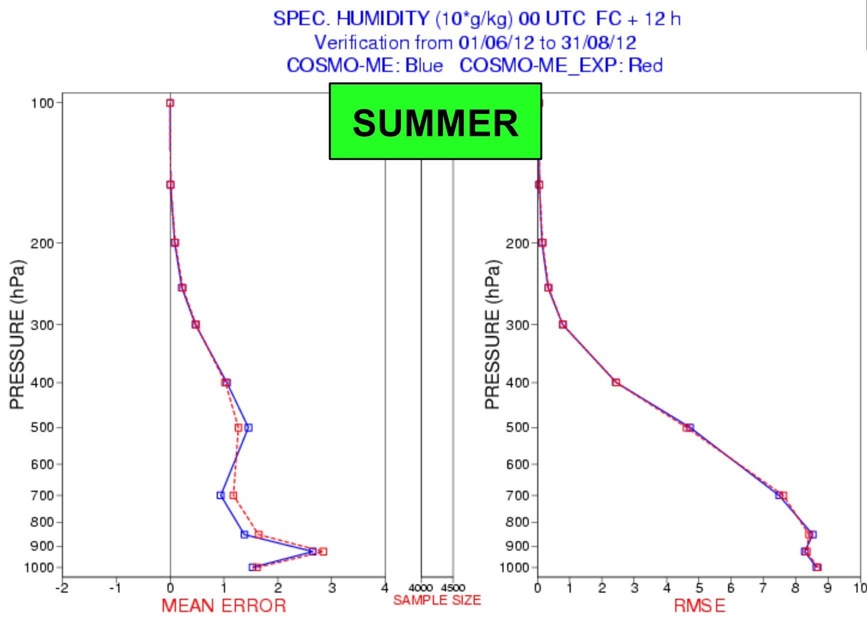
Spec. Humidity 00UTC FC+48h

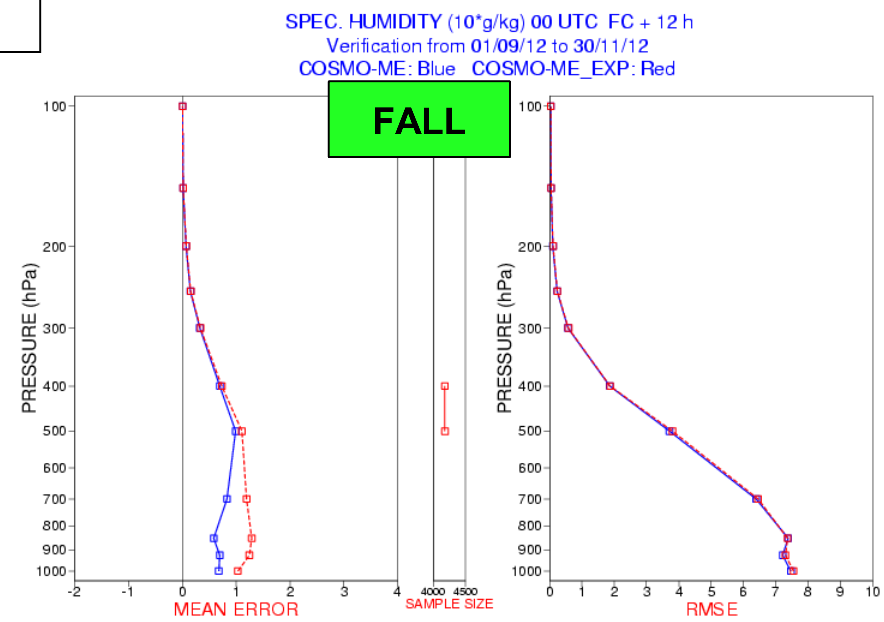


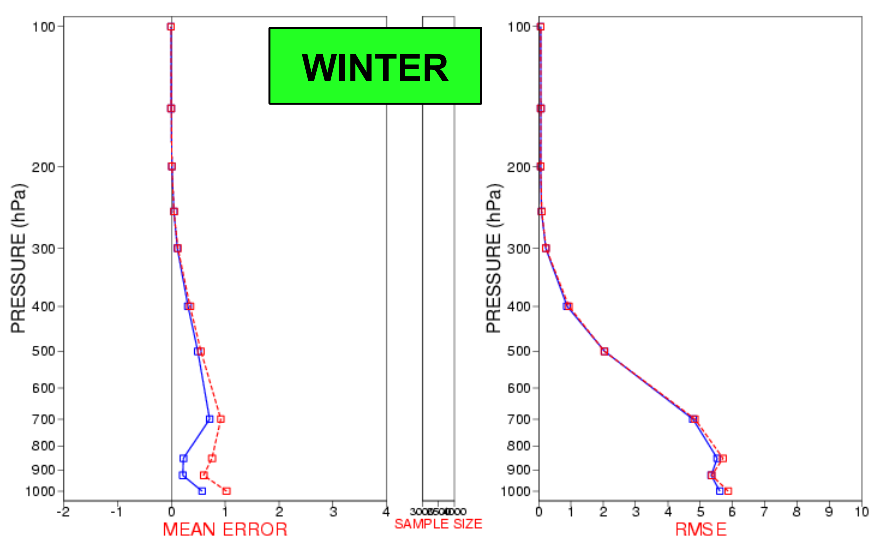
FORECAST VERIFICATION SCORES

Spec. Humidity 00UTC FC+12h

OPE
EXP



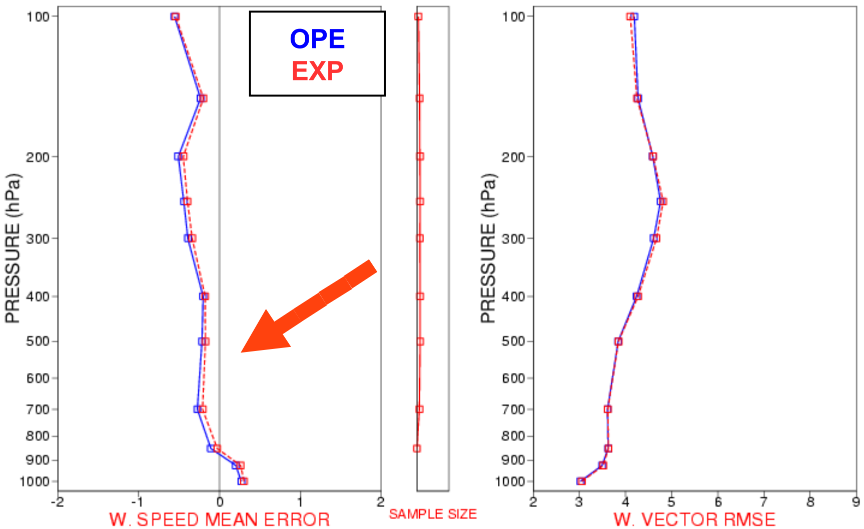




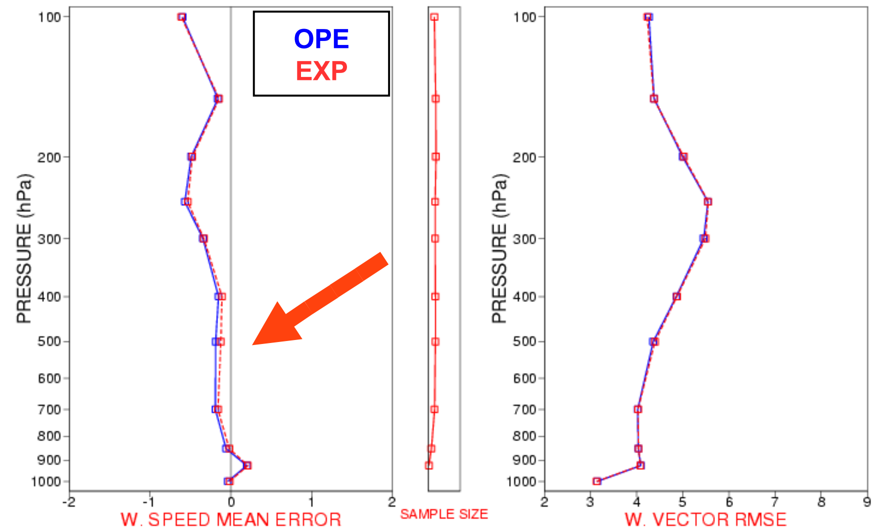
FORECAST VERIFICATION SCORES

1jun 2012 – 11feb 2013

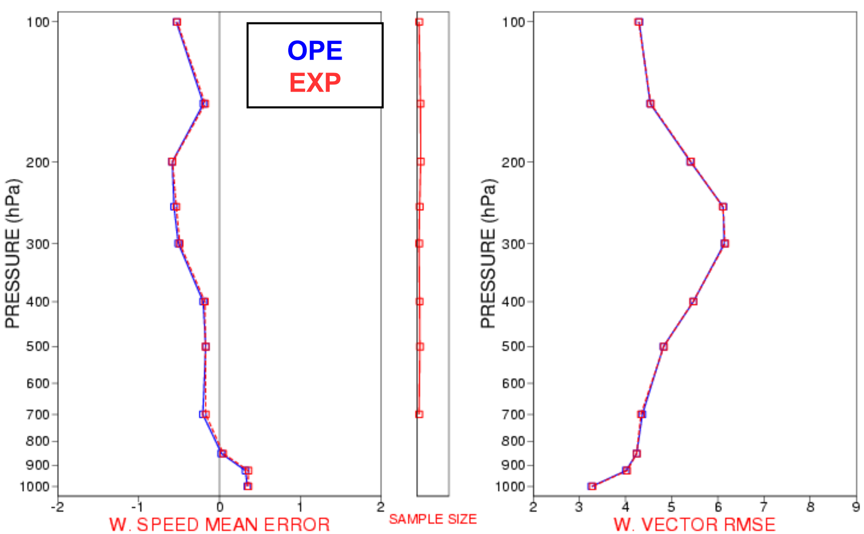
WIND 00UTC FC+12h



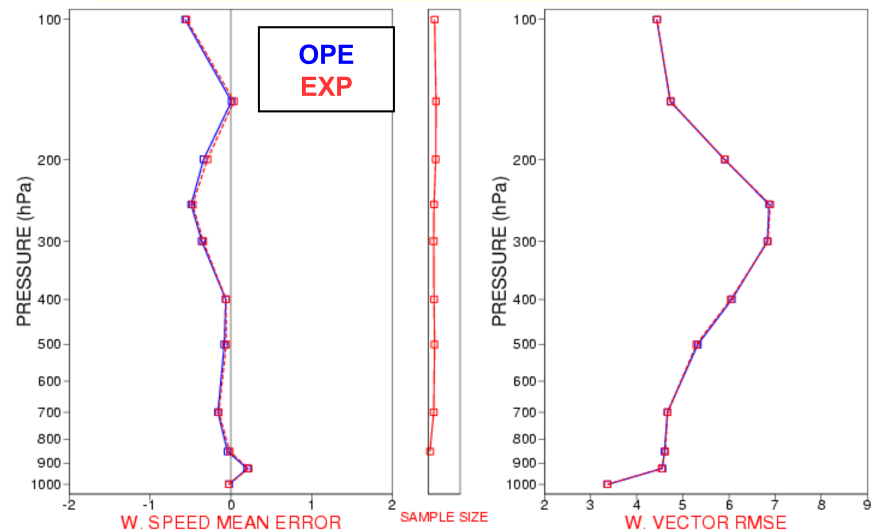
WIND 00UTC FC+24h



WIND 00UTC FC+36h



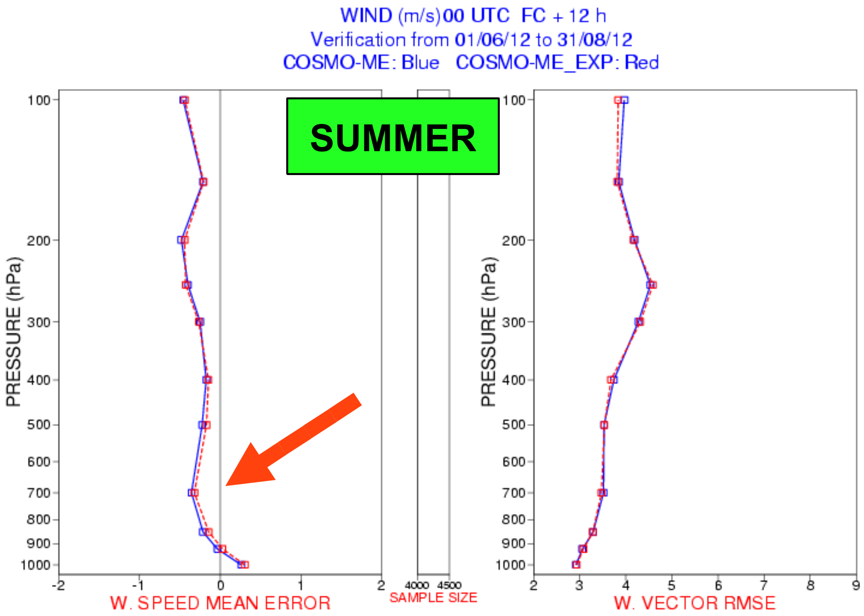
WIND 00UTC FC+48h

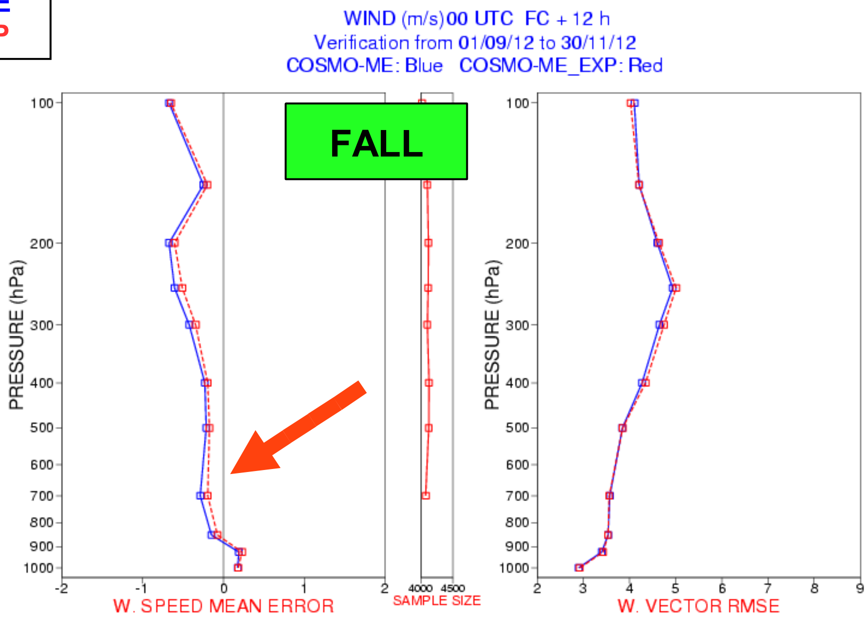


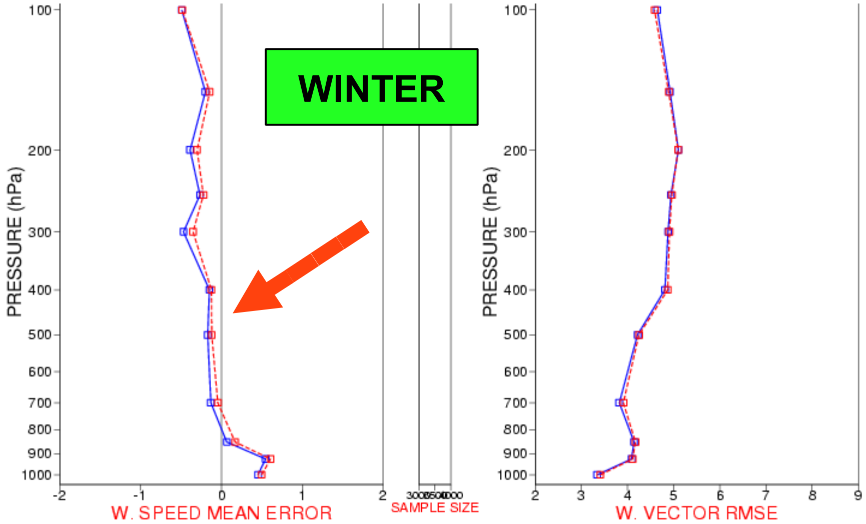
FORECAST VERIFICATION SCORES

WIND 00UTC FC+12h

OPE
EXP

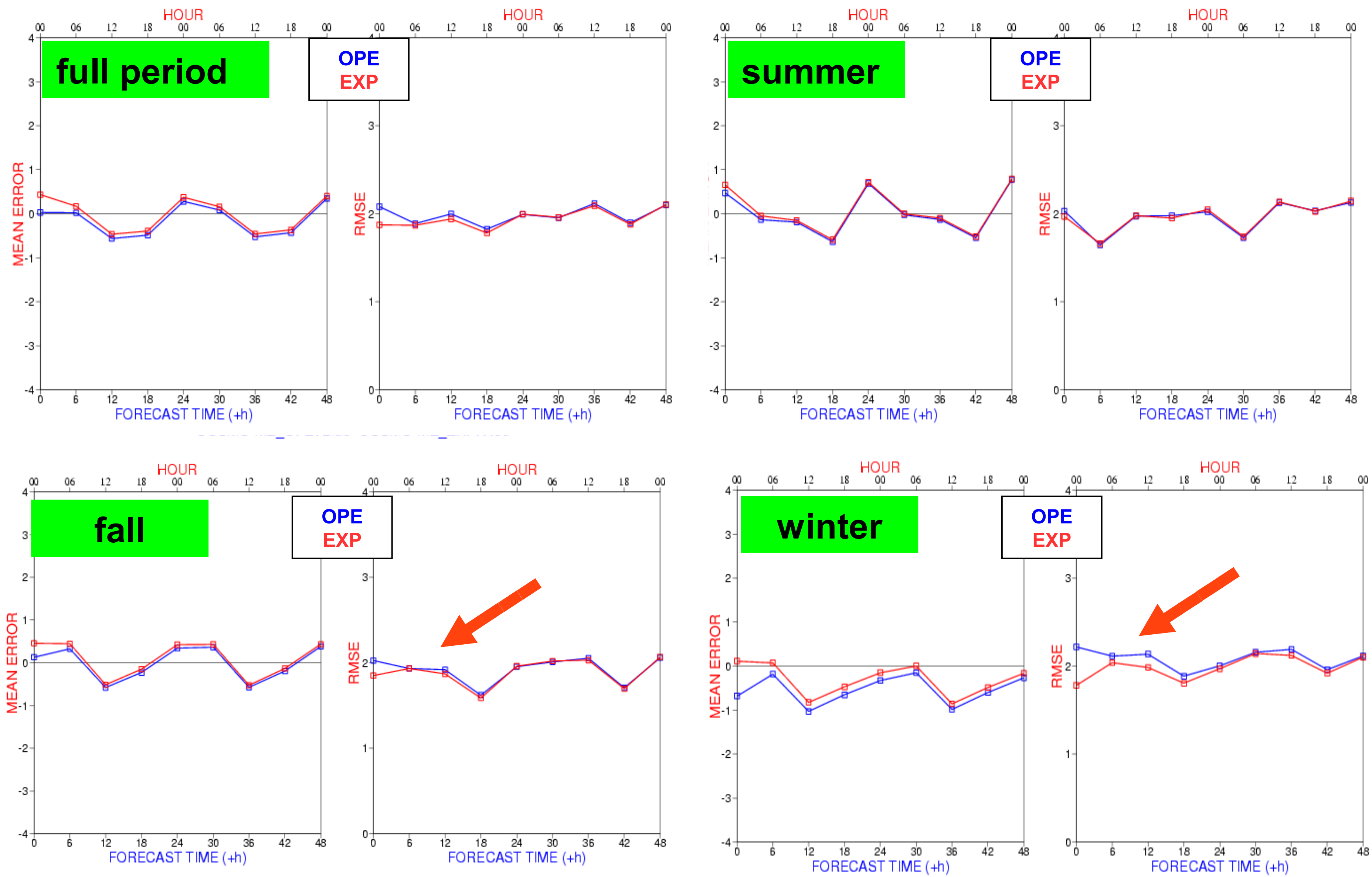






FORECAST VERIFICATION SCORES

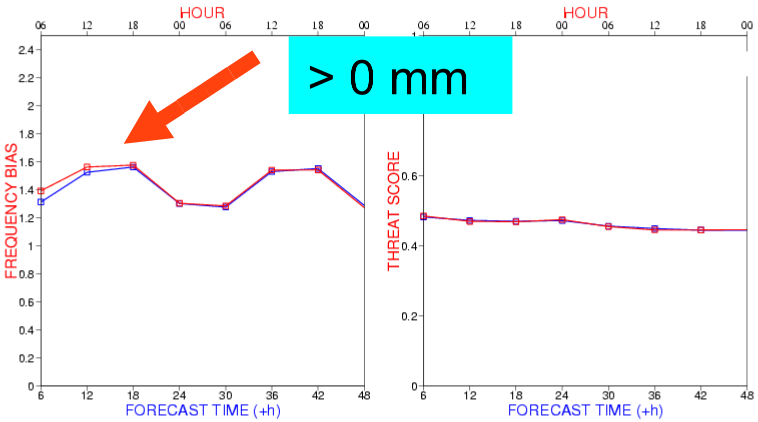
T2m 00UTC RUN



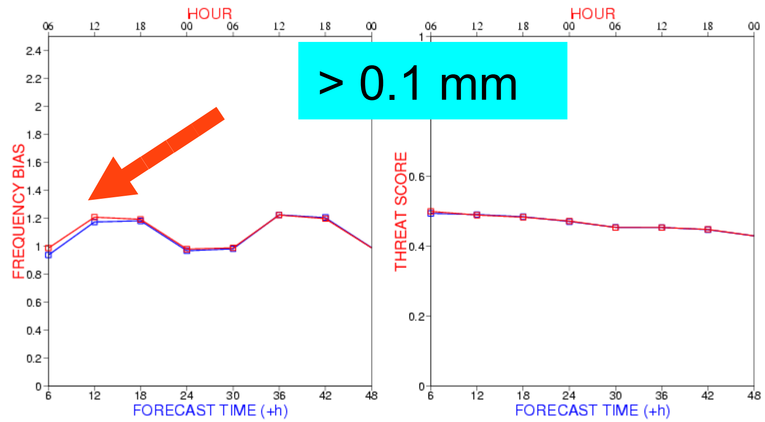
FORECAST VERIFICATION SCORES

6h accumulated PRECIPITATION 00UTC RUN

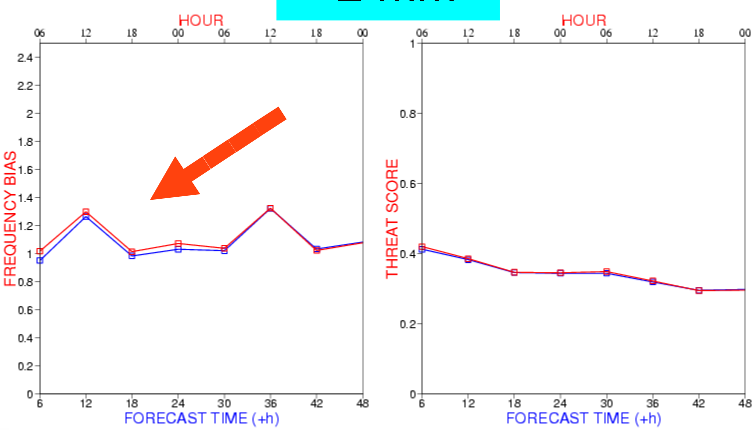
> 0 mm



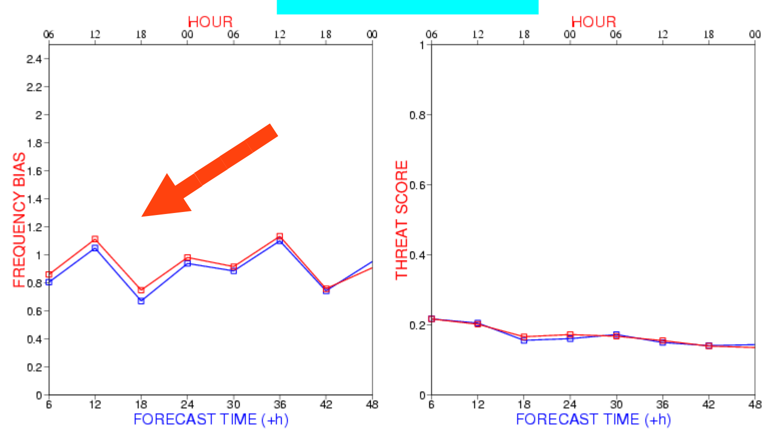
> 0.1 mm



> 2 mm



> 10 mm



Summary of Results

From forecast verification :

- **Slight wind speed bias reduction with COSMO-LETKF**
- **Slight overestimation of precipitation**
- **After changing in the COSMO-LETKF settings: slight improvement in temperature bias**

COSMO LETKF TEST ON BC CHANGE

- **OPE: EPS Perturbations 24 h older**
- **EXP: MOST RECENT EPS Perturbations (12h OLDER)**

Radiosoundes obs increment statistics
(obs -BG ensemble mean)
on 40 pressure levels

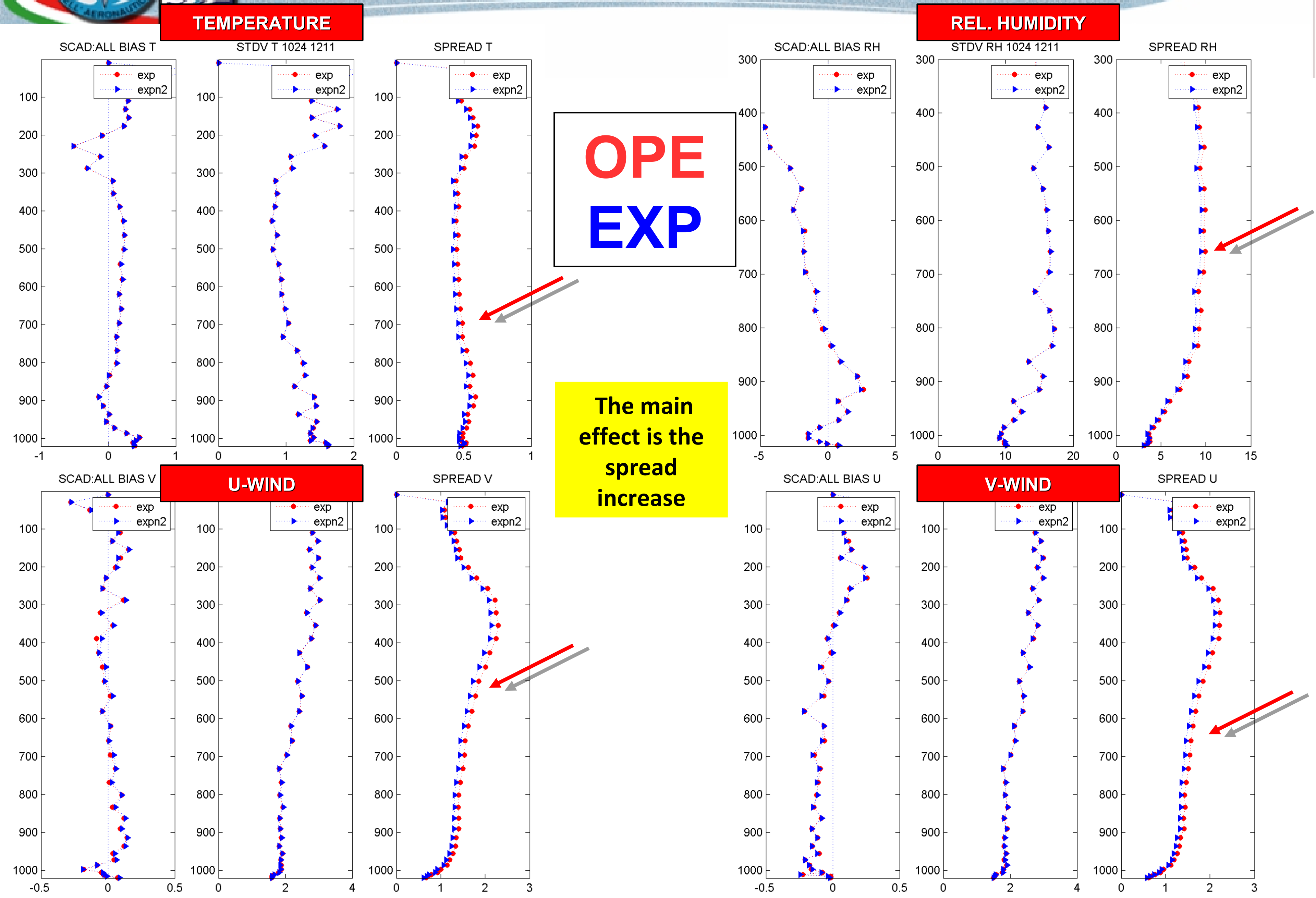
From 23 OCT 2012 to 12 DEC 2012

(00 and 12 UTC)

COSMO-LETKF 40 MEMBERS: BC CHANGE

OBS.INCR.STATISTICS

24 OCT 2012 to 12 DEC 2012

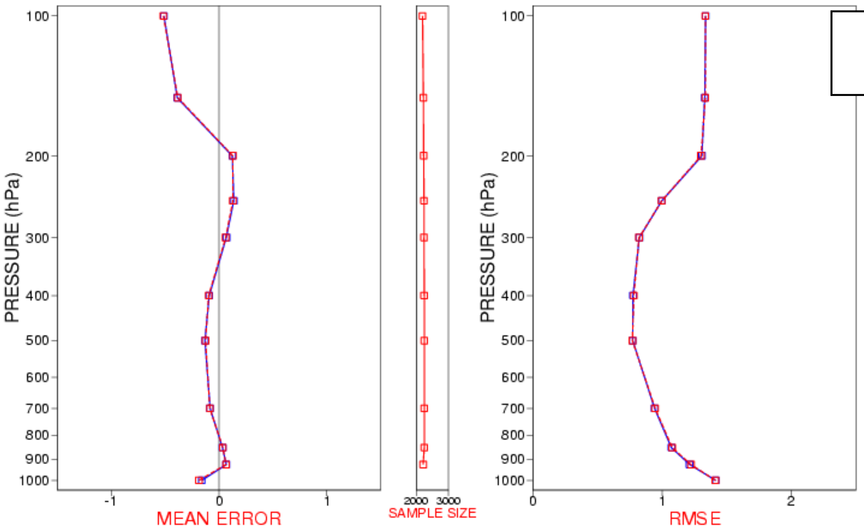


COSMO-LETKF 40 MEMBERS: BC CHANGE

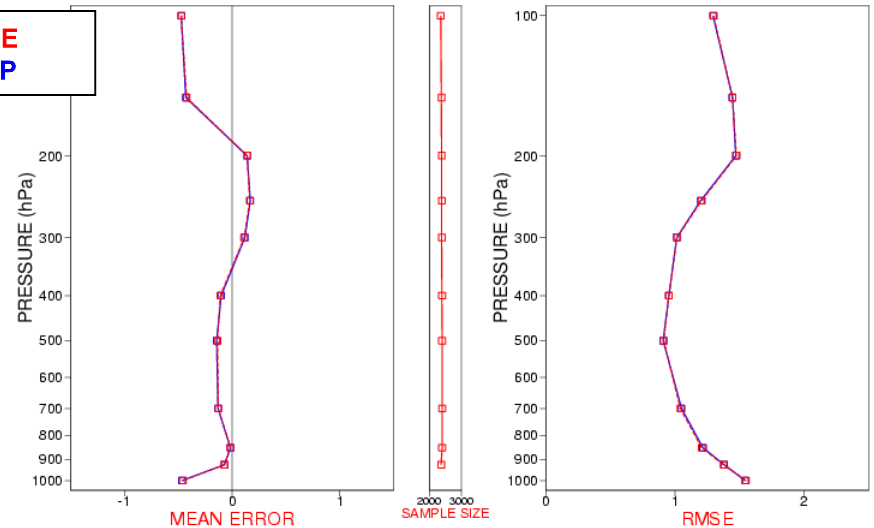
VERIFICATION SCORES 24 OCT 2012 to 12 DEC 2012

OPE
EXP

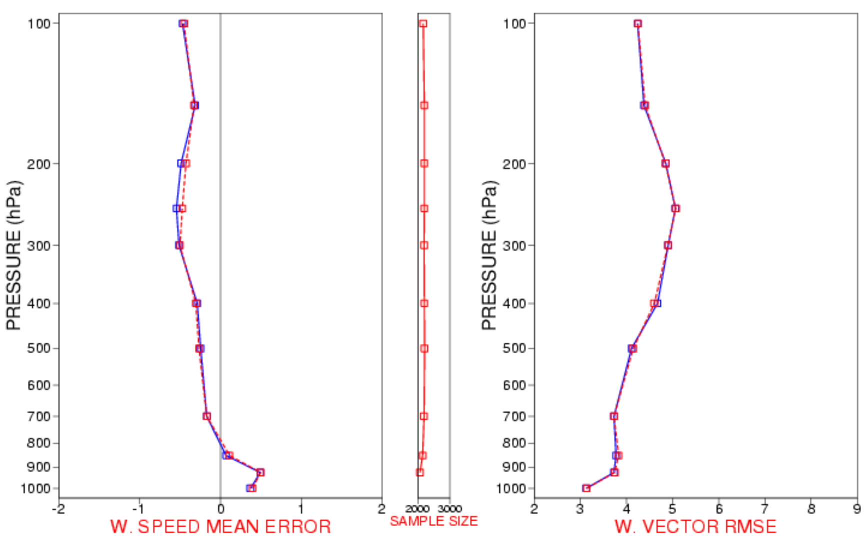
Temperature 00UTC FC+12h



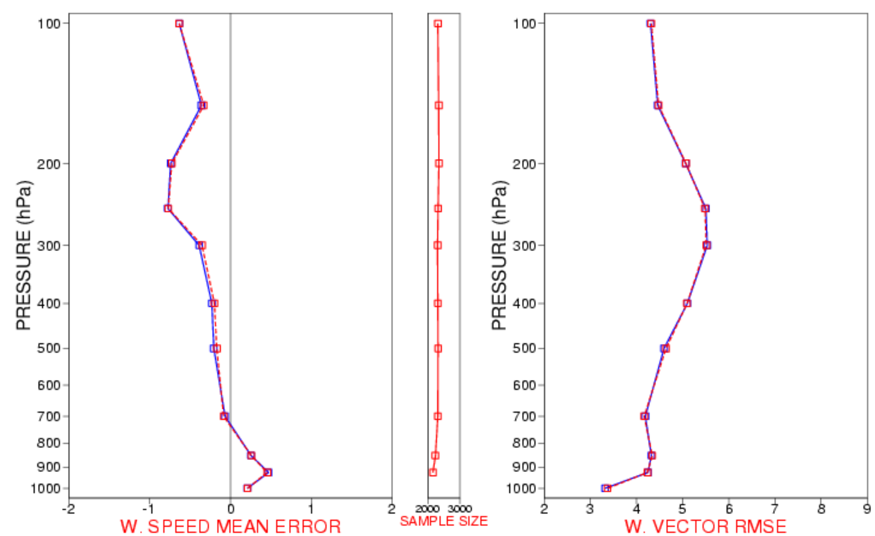
Temperature 00UTC FC+24h



Wind 00UTC FC+12h



Wind 00UTC FC+24h

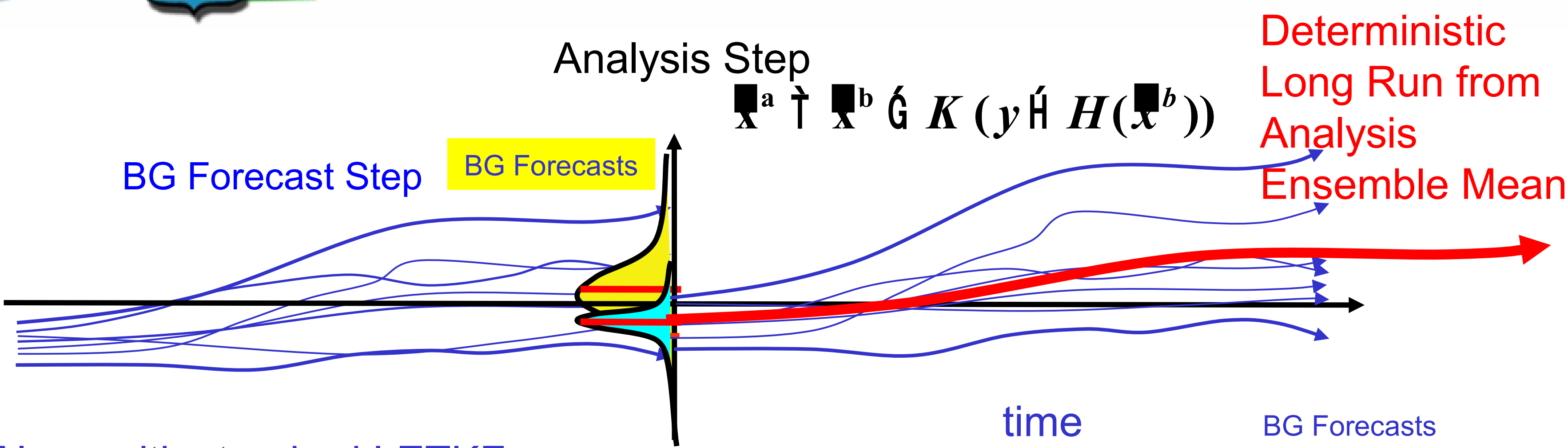


Future Developments

- Assimilation of AMSU A-B/MHS (with “multi-step” approach) and IASI retrievals
- Study of the impact of different observations with FSO technique (Kalnay et al)
- Use of KENDA and contribution to its improvement
- Tests with shorter assimilation window
- Further tuning of model error representation (tuning of cov. localization, self-evolved additive noise, bias correction, etc.)
- Further tests of the Short-Range EPS based on COSMO-ME LETKF

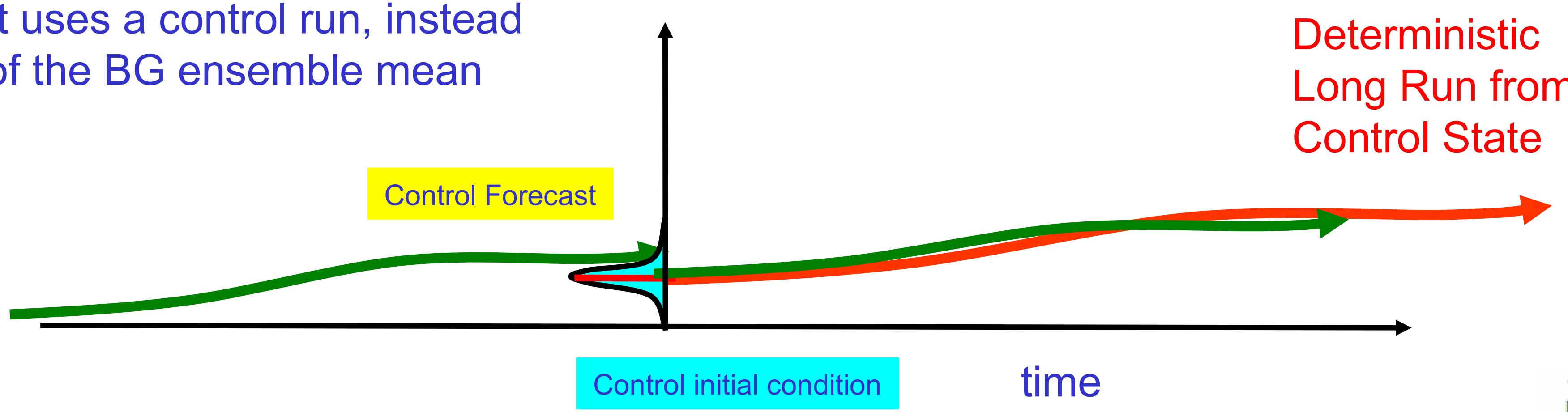
Thanks for your attention !

Deterministic Run from LETKF

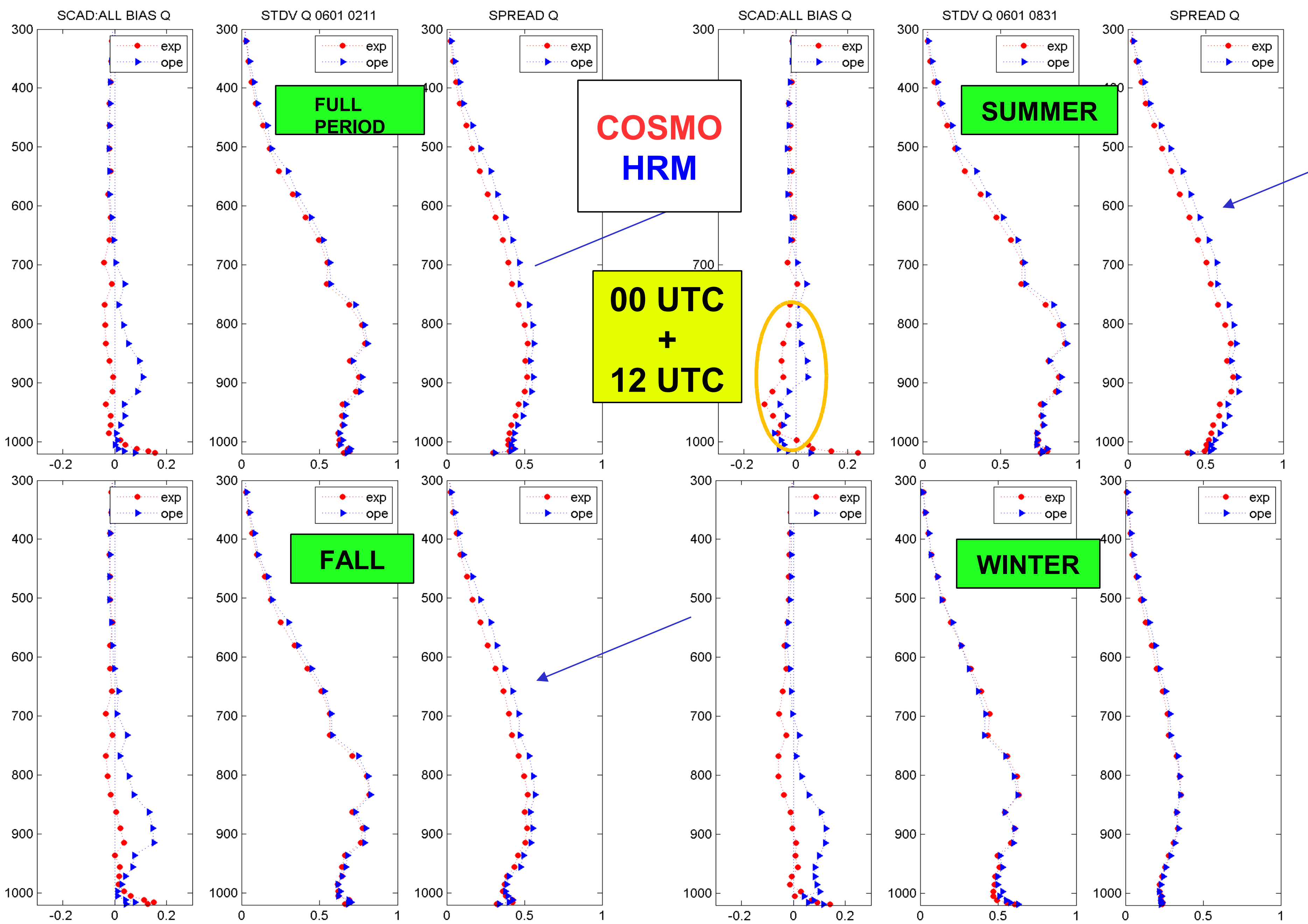


Along with standard LETKF analysis, a control state LETKF analysis is computed. It uses a control run, instead of the BG ensemble mean

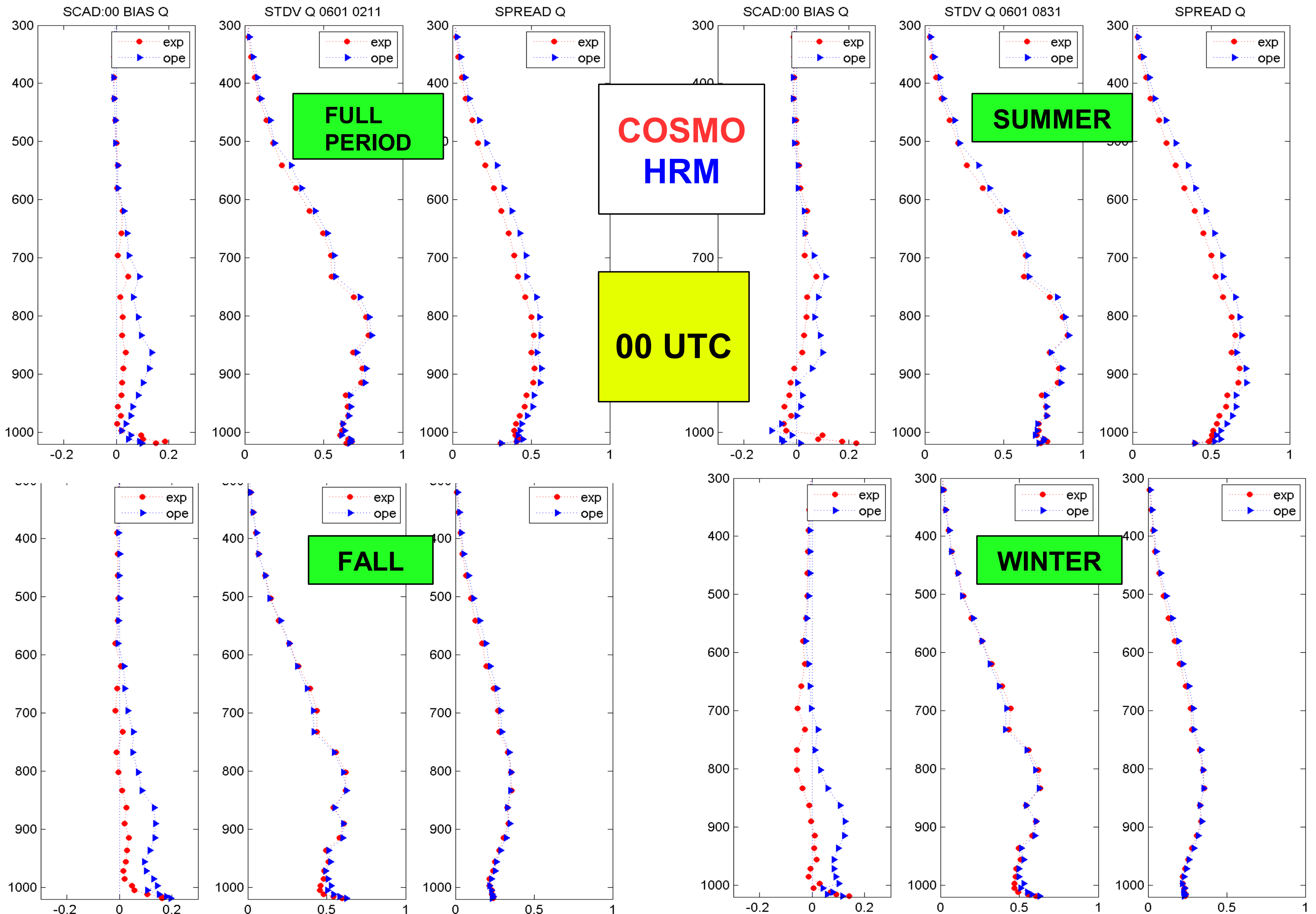
$$x_c^a = x_c^b + K(y - H(x_c))$$



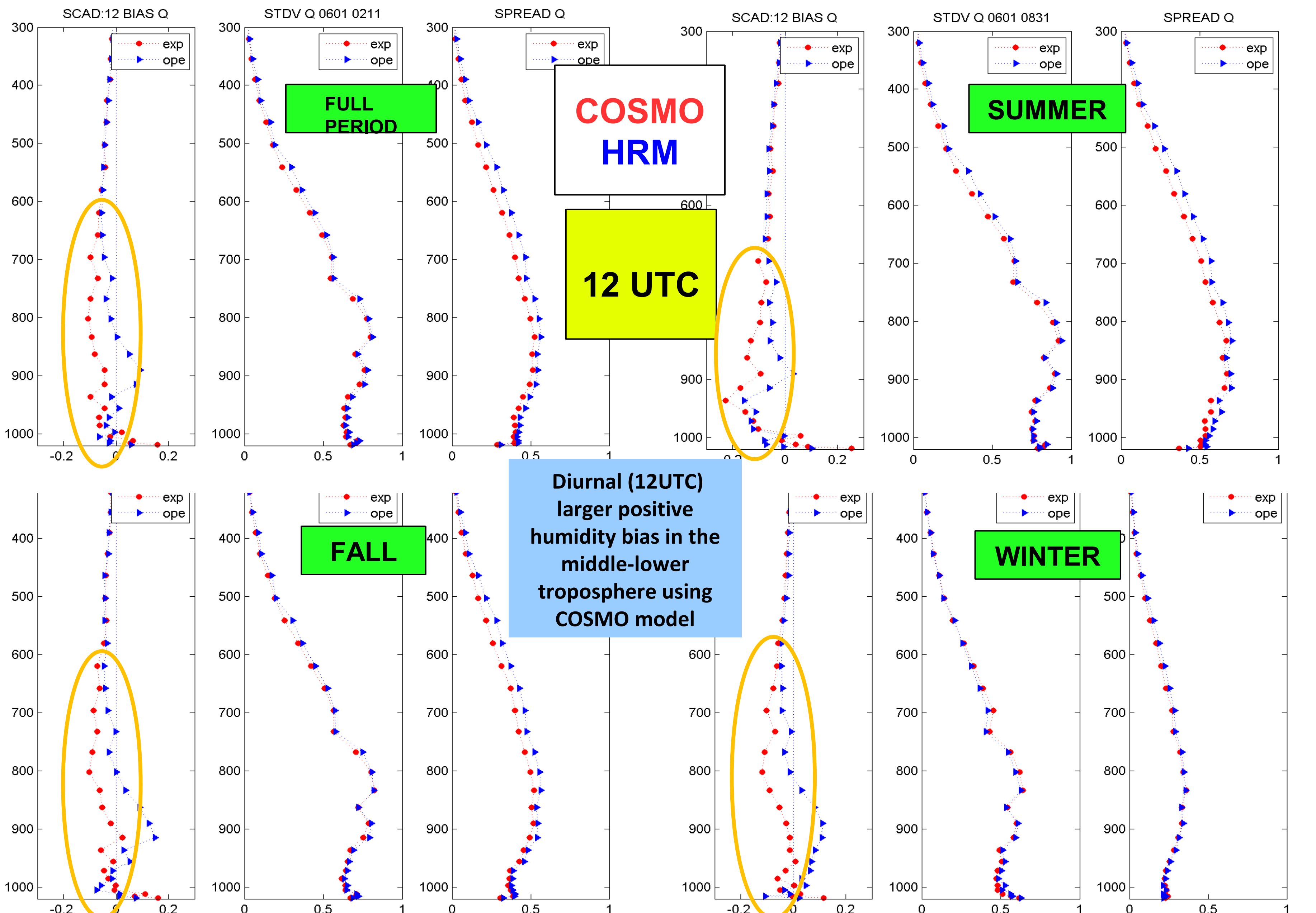
SPEC.HUMIDITY OBS INCR STATISTICS



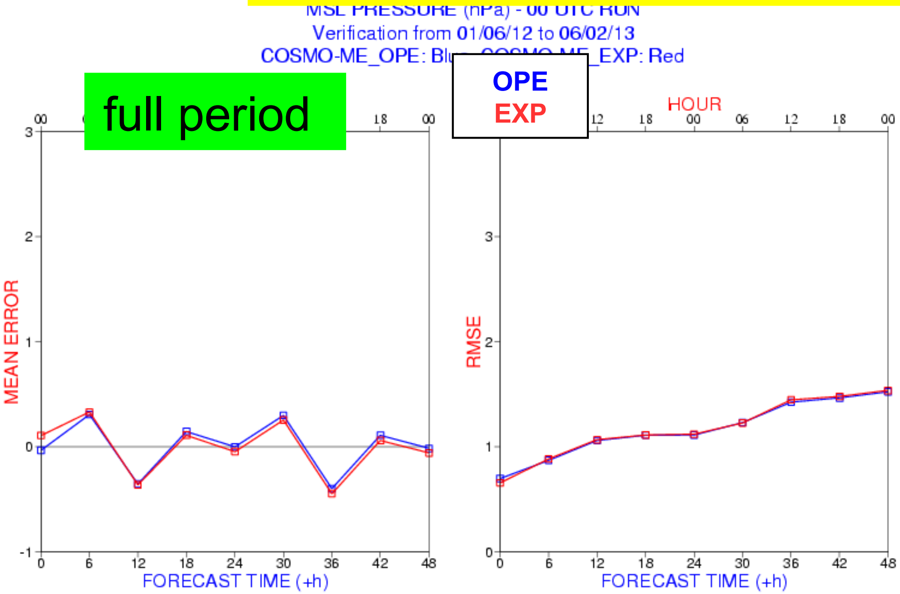
SPEC.HUMIDITY OBS INCR STATISTICS

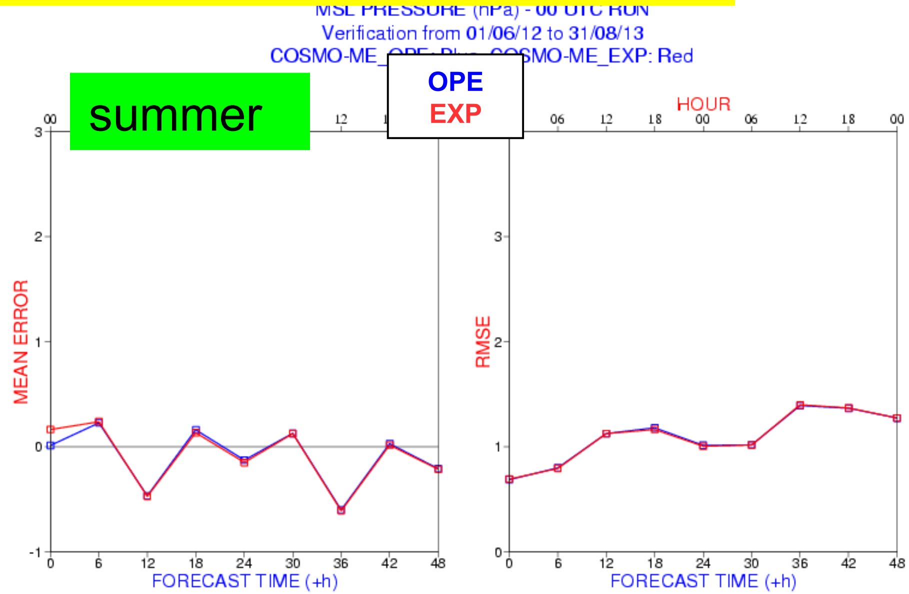


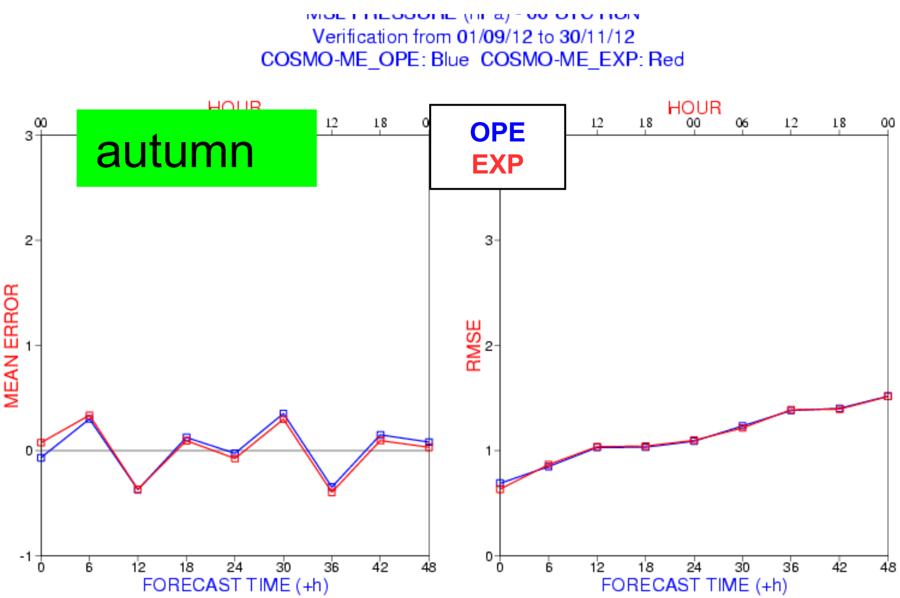
SPEC.HUMIDITY OBS INCR STATISTICS

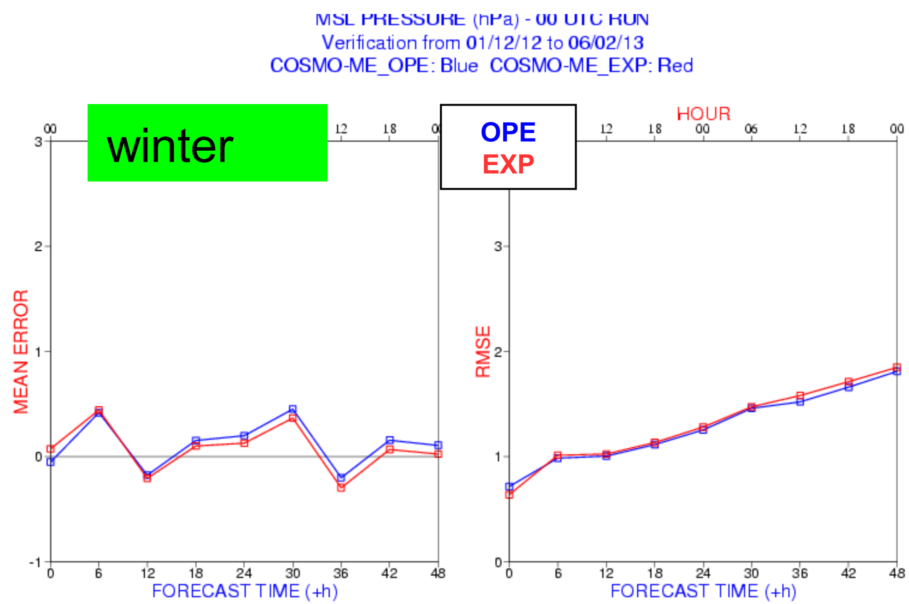


MSLP pressure 00UTC RUN

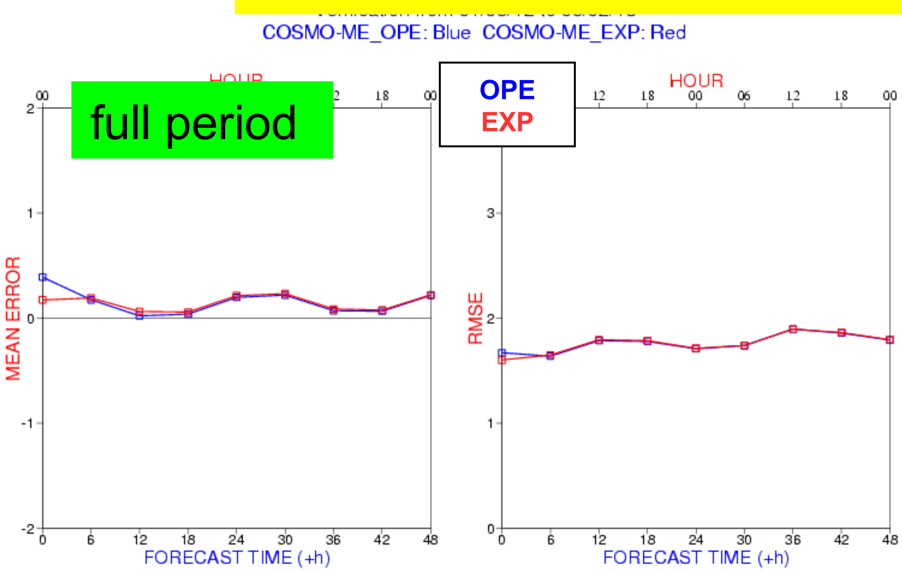


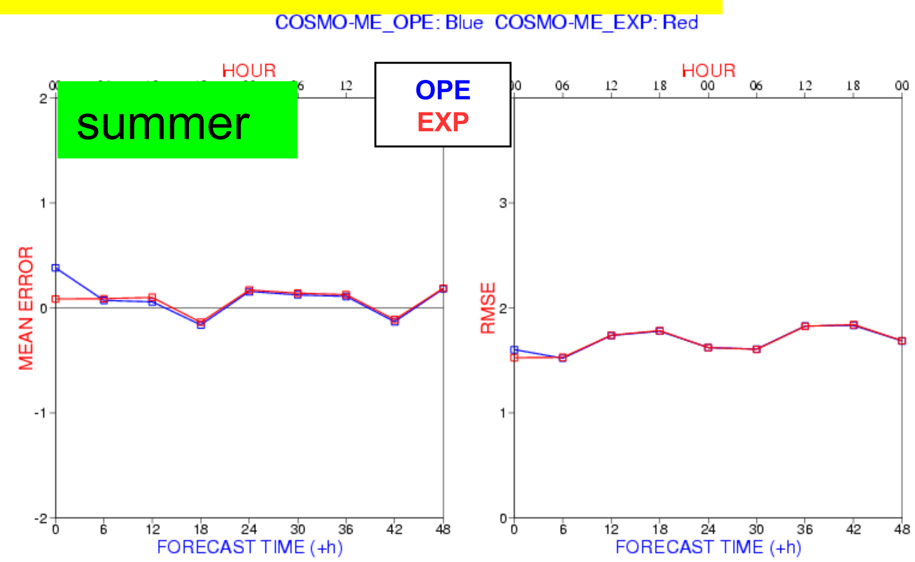


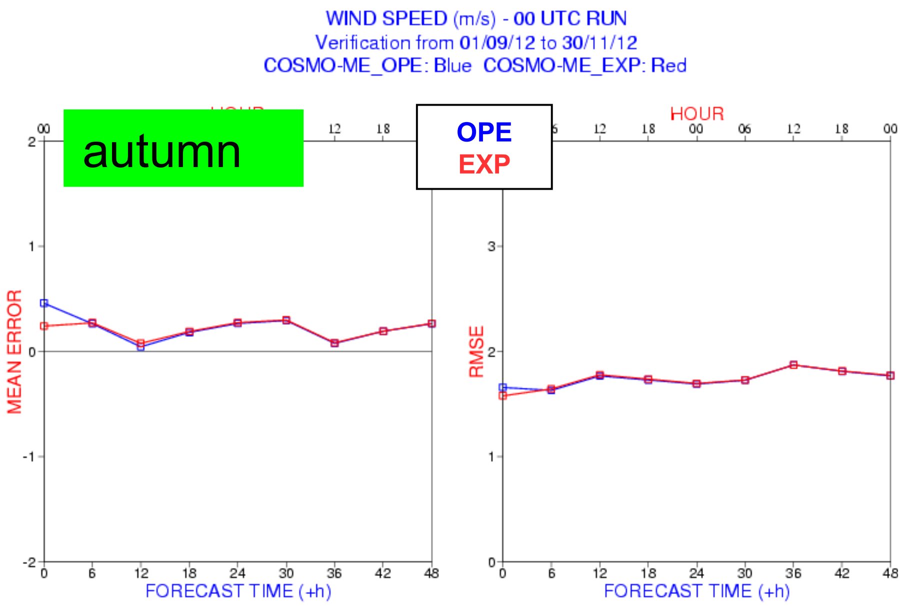


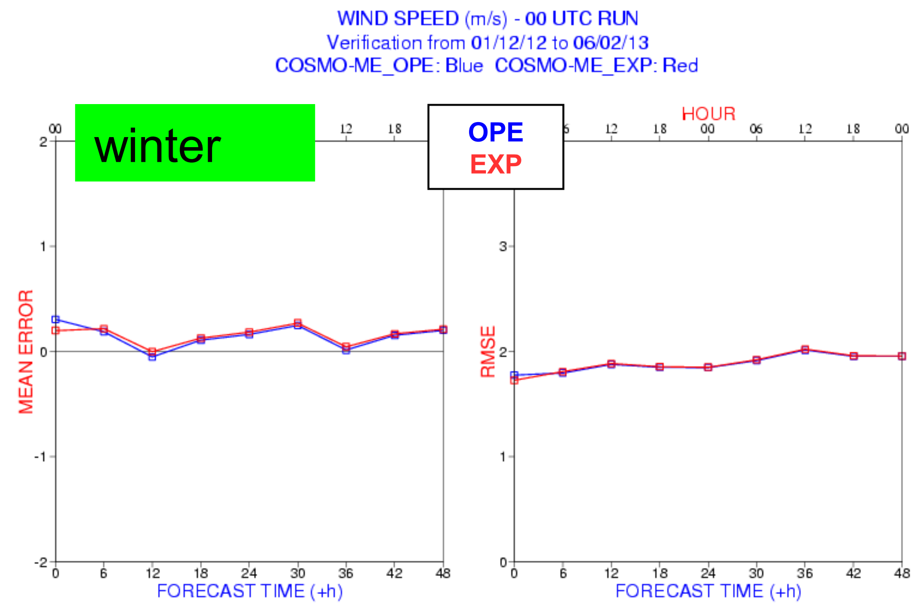


10m WIND SPEED 00UTC RUN



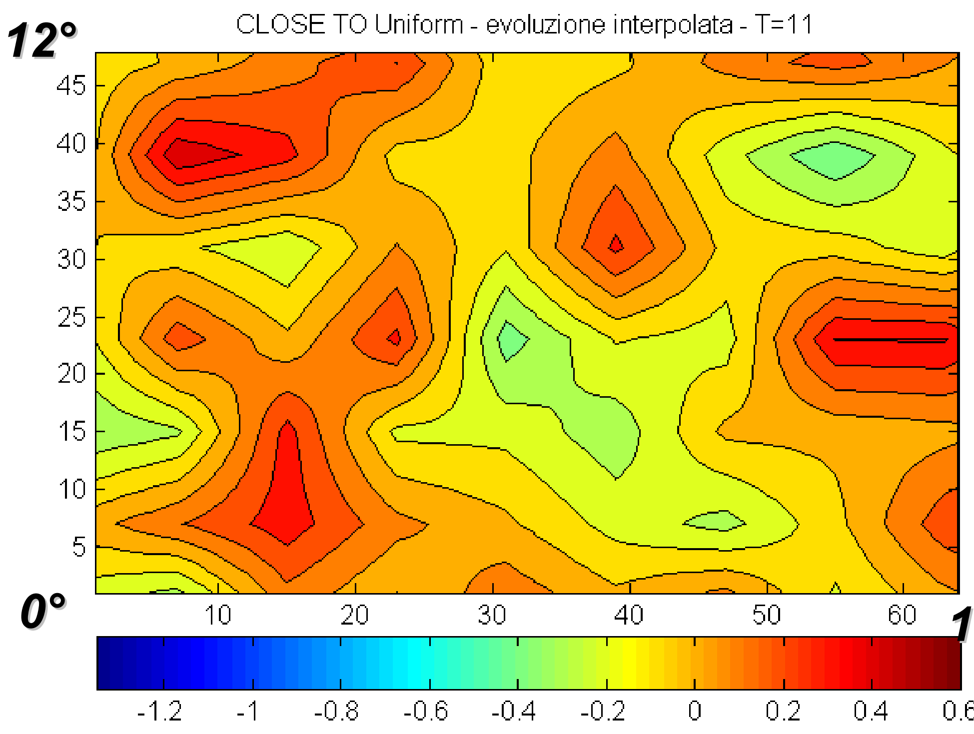






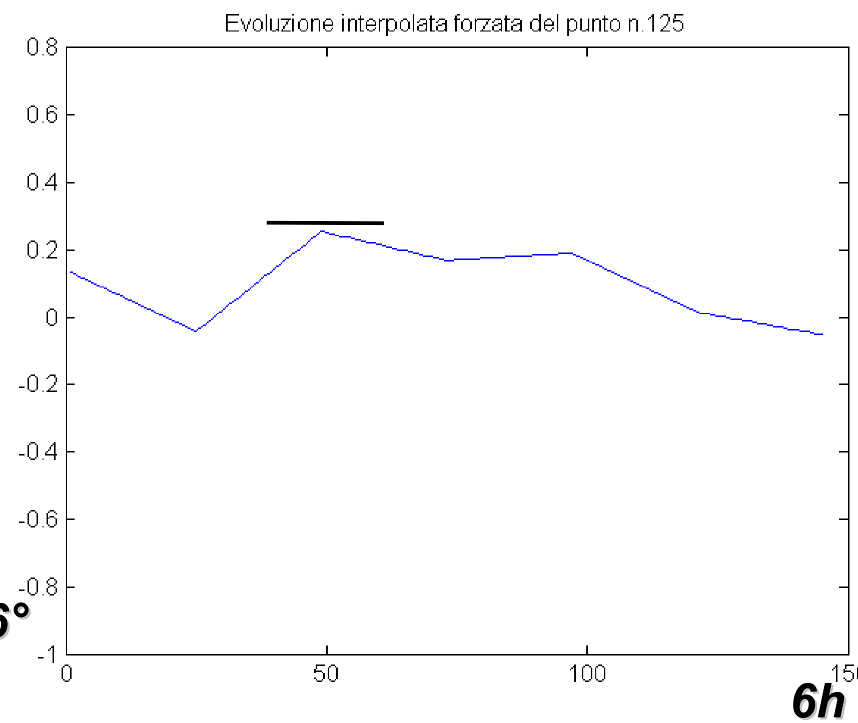
Modified Version of Stochastic Physics

Spatial pattern



Bilin. Interpolation from coarse grid

Temporal pattern

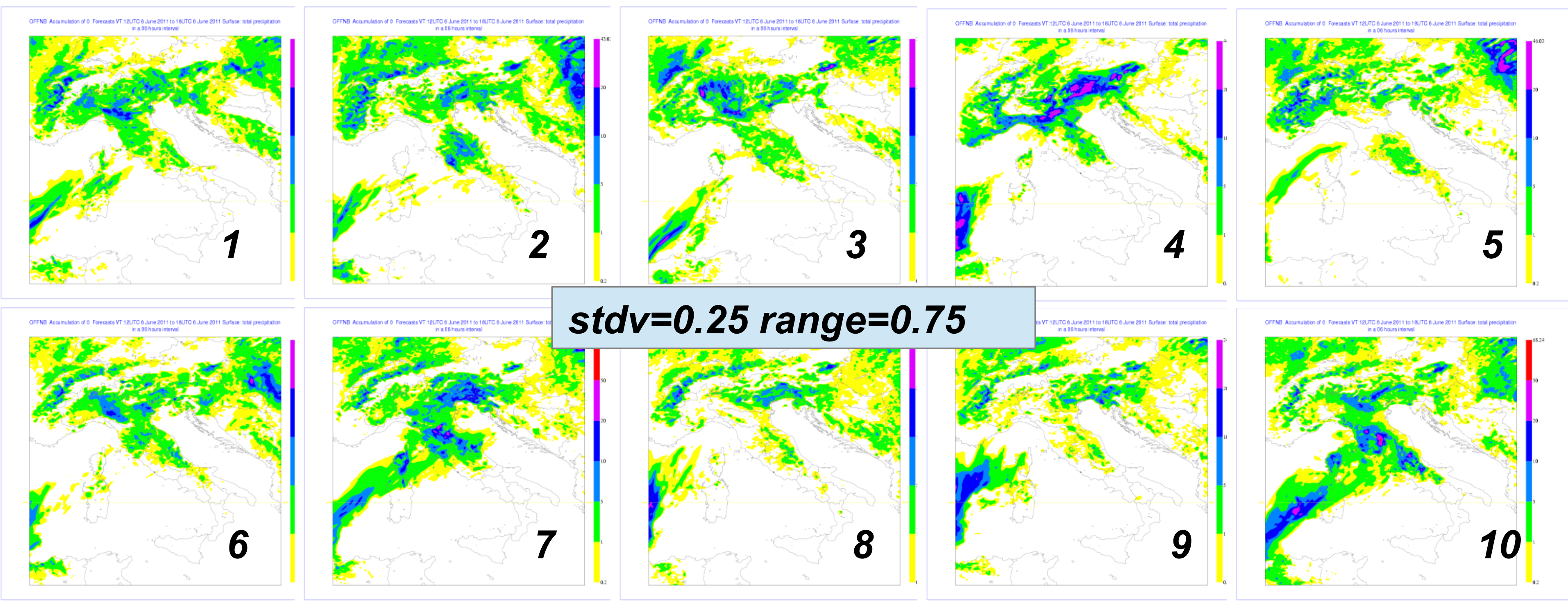


Lin. Interpolation from coarse grid

LETKF:
account of model error / additive inflation

05 June 2011 00UTC

6h Accumulated Precipitation (T+36 - T+42h)



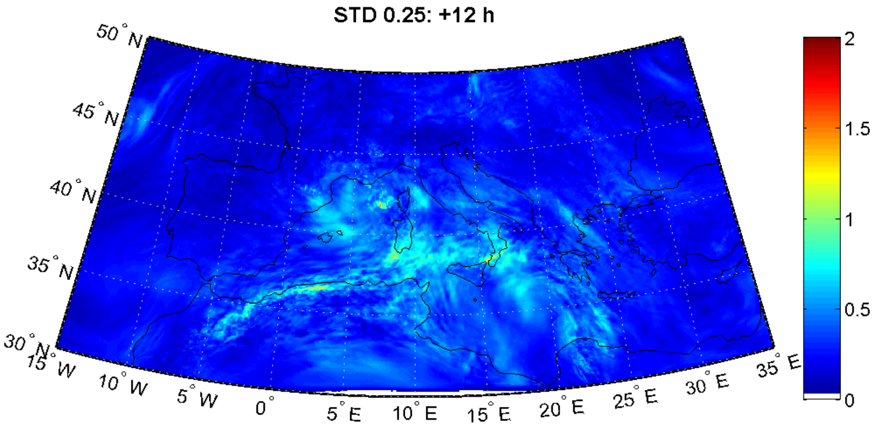
LETKF: account of model error / additive inflation

500 hPa Temperature Spread for 10 members

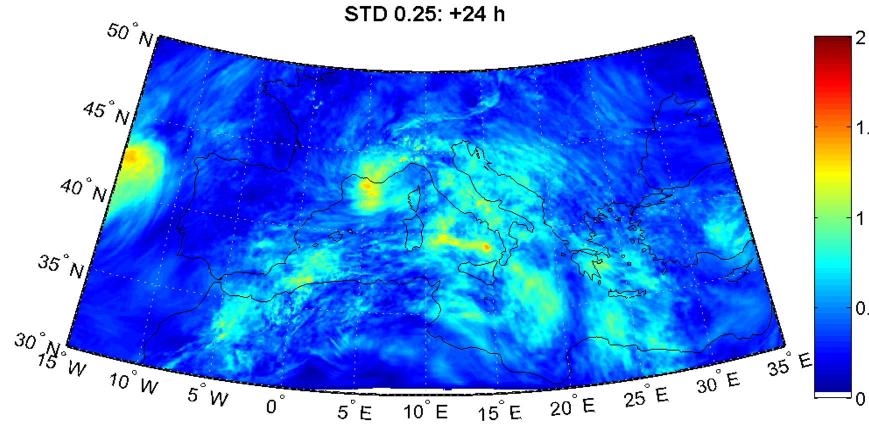
stdv=0.25 range=0.75

05 June 2011 00UTC

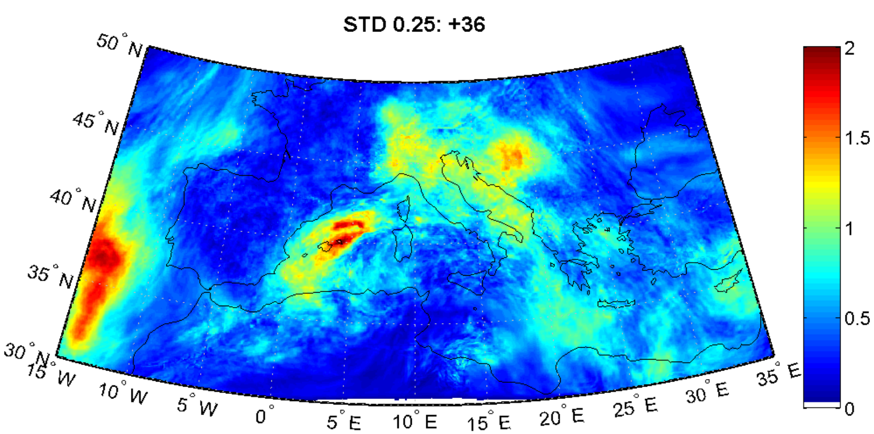
T+12h



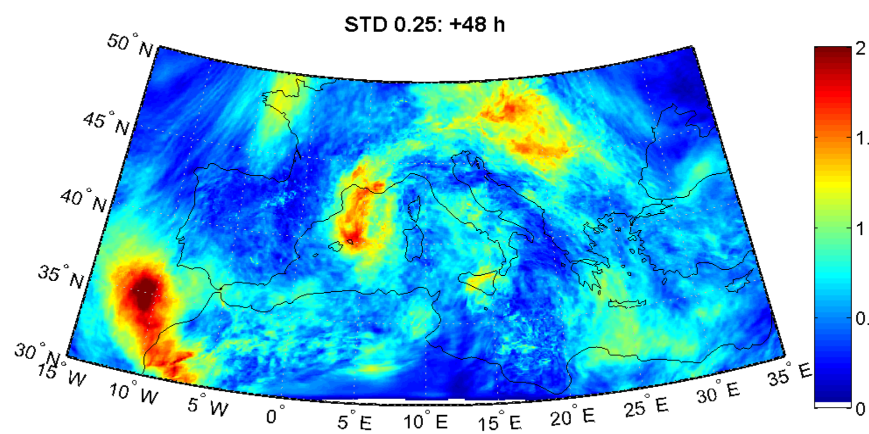
T+24h

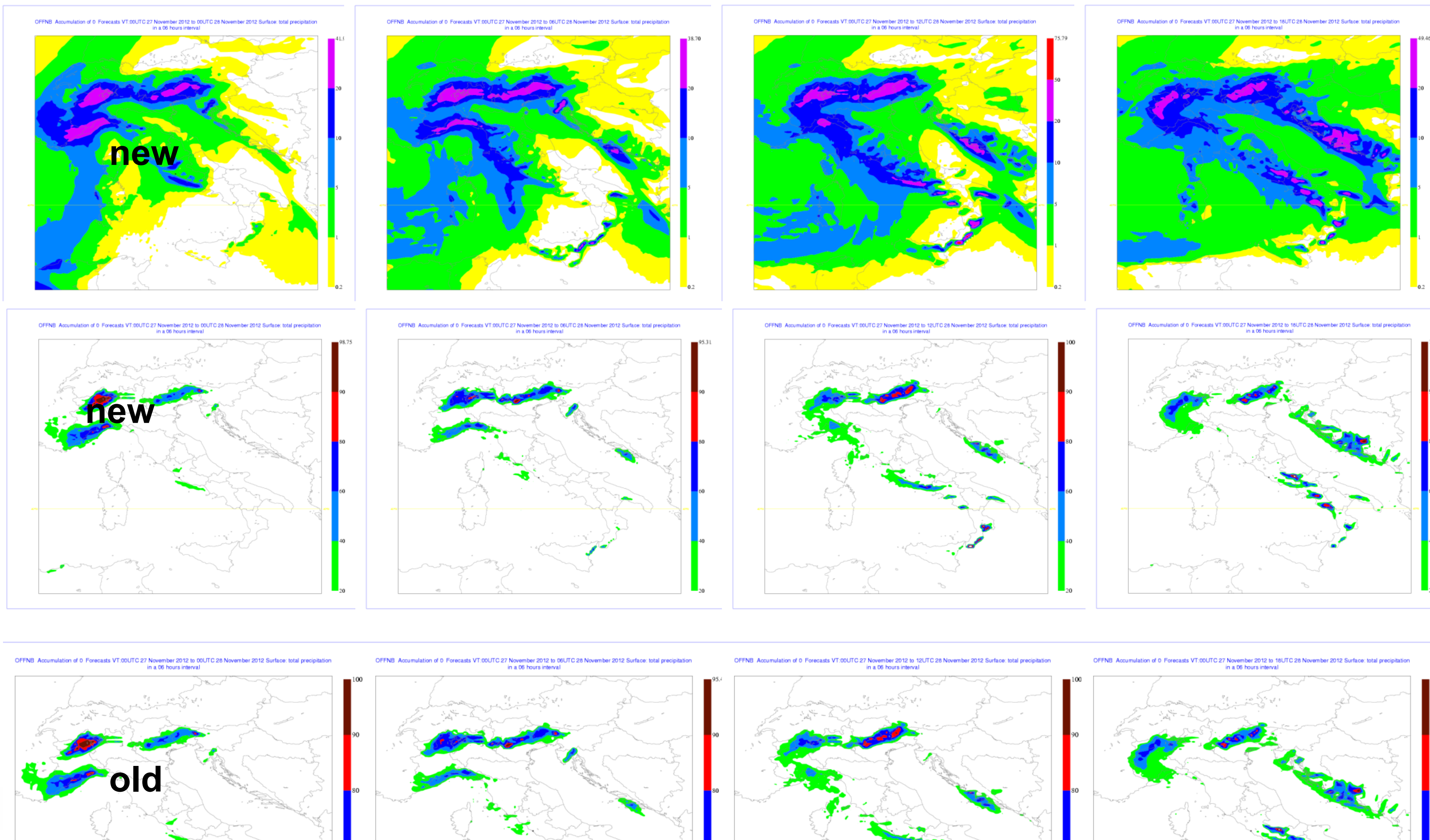


T+36h



T+48h





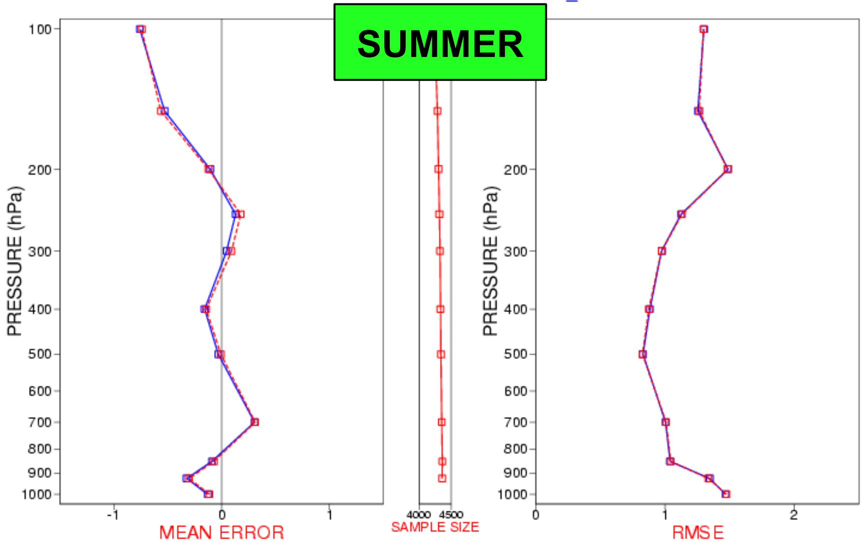
OFFNB Accumulation of 0 Forecasts VT:00UTC 27 November 2012 to 00UTC 28 November 2012 Surface: total precipitation in a 06 hours interval
OFFNB Accumulation of 0 Forecasts VT:00UTC 27 November 2012 to 06UTC 28 November 2012 Surface: total precipitation in a 06 hours interval
OFFNB Accumulation of 0 Forecasts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

FORECAST VERIFICATION SCORES

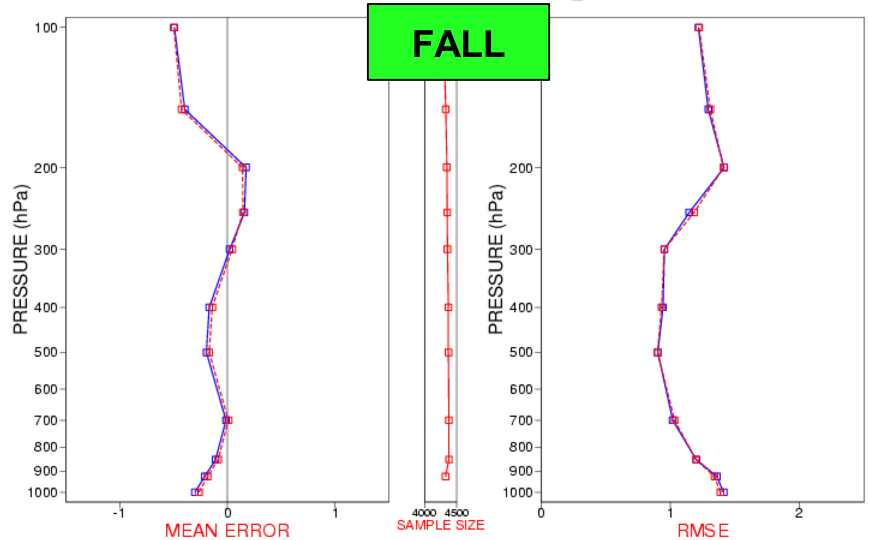
Temperature 00UTC FC+24h

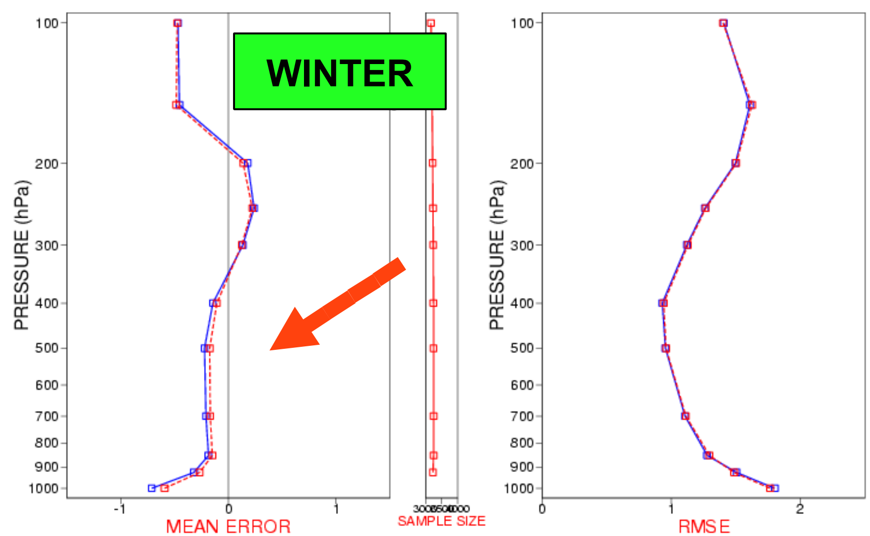
OPE
EXP

TEMPERATURE (°C)00 UTC FC + 24 h
Verification from 01/06/12 to 31/08/12
COSMO-ME: Blue COSMO-ME_EXP: Red



TEMPERATURE (°C)00 UTC FC + 24 h
Verification from 01/09/12 to 30/11/12
COSMO-ME: Blue COSMO-ME_EXP: Red



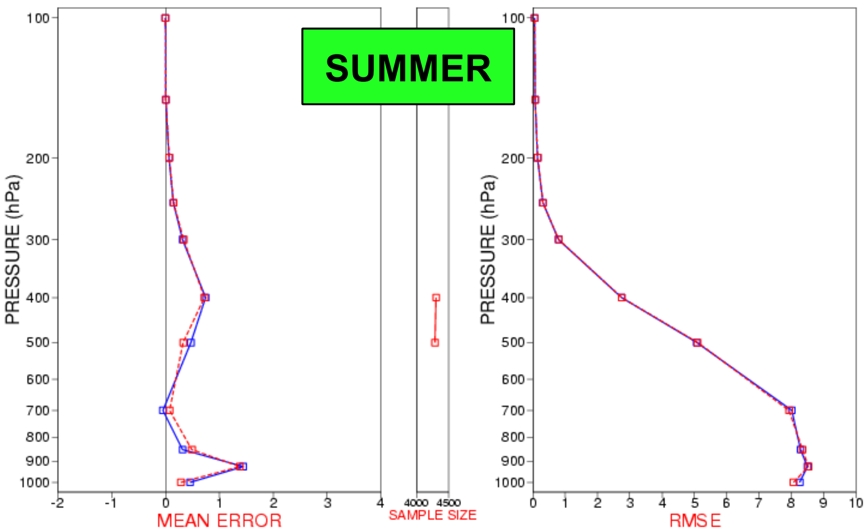


FORECAST VERIFICATION SCORES

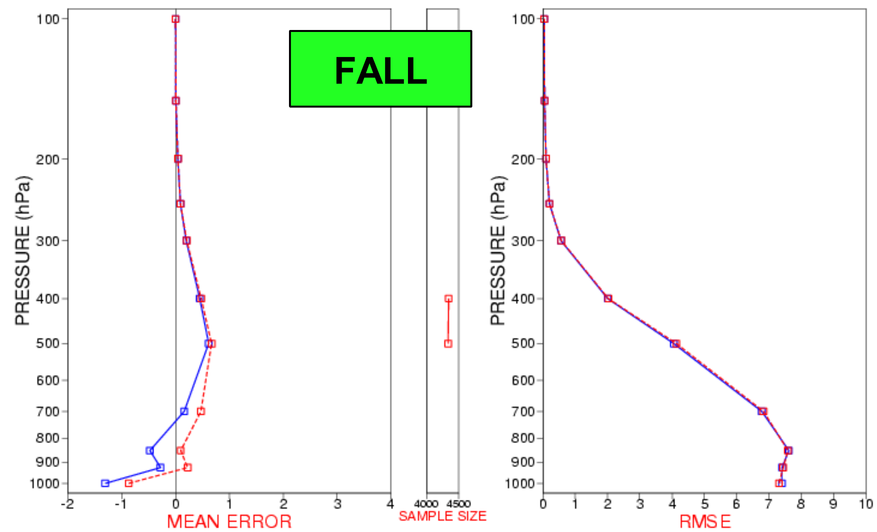
Spec. Humidity 00UTC FC+24h

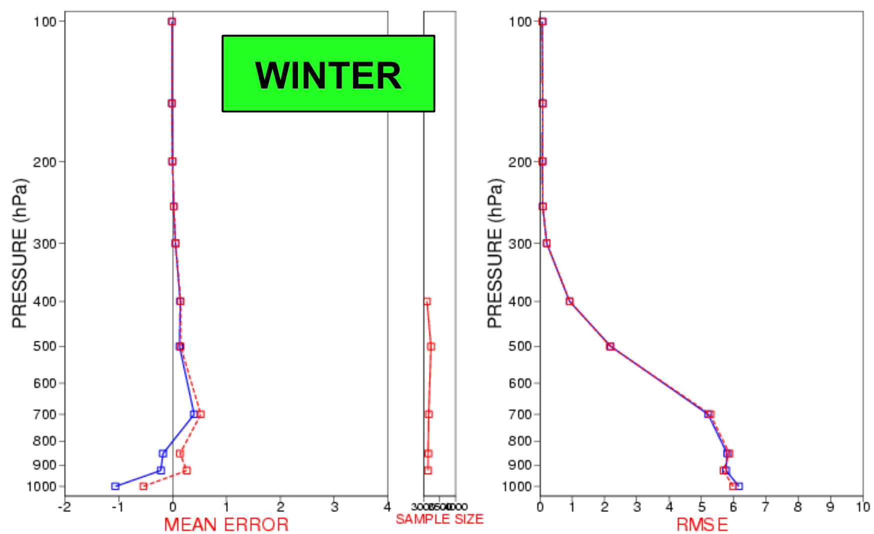
OPE
EXP

SPEC. HUMIDITY (10*g/kg) 00 UTC FC + 24 h
Verification from 01/06/12 to 31/08/12
COSMO-ME: Blue COSMO-ME_EXP: Red



SPEC. HUMIDITY (10*g/kg) 00 UTC FC + 24 h
Verification from 01/09/12 to 30/11/12
COSMO-ME: Blue COSMO-ME_EXP: Red

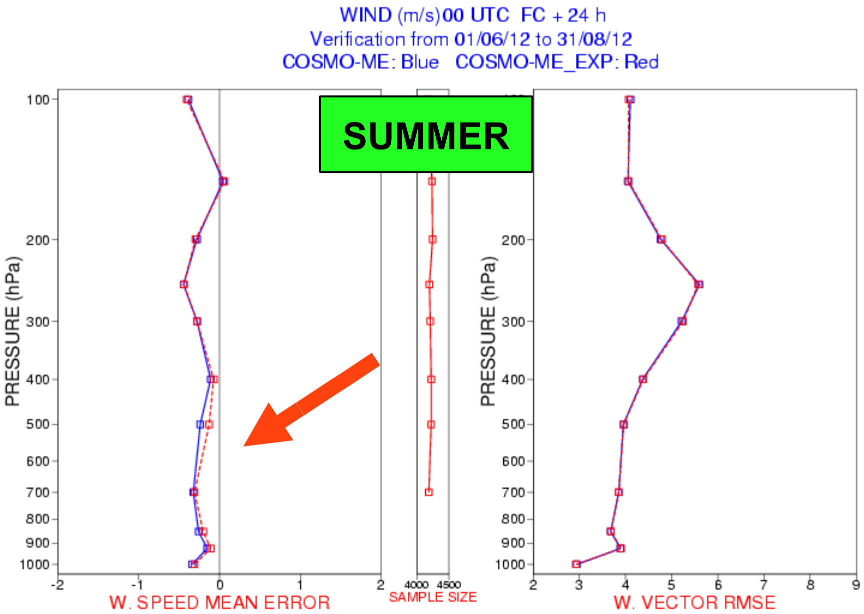


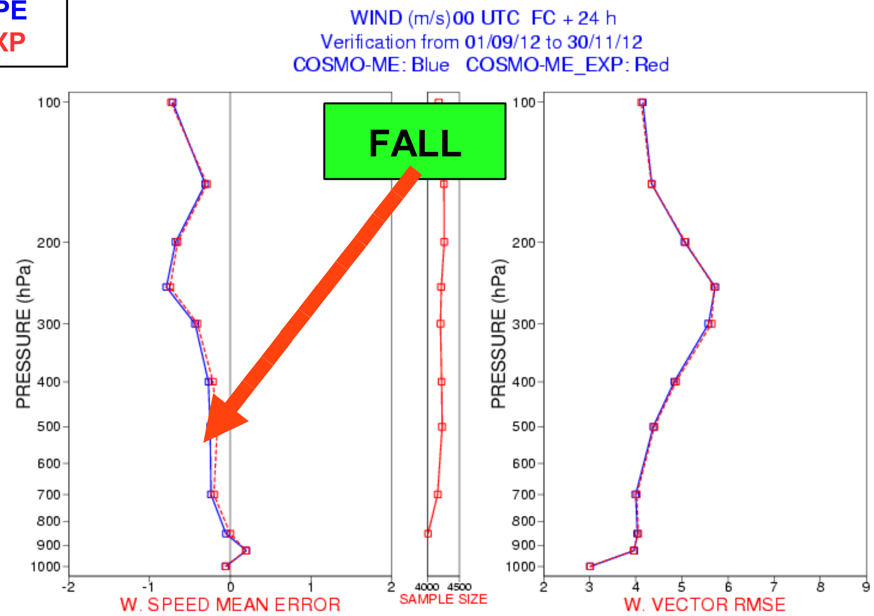


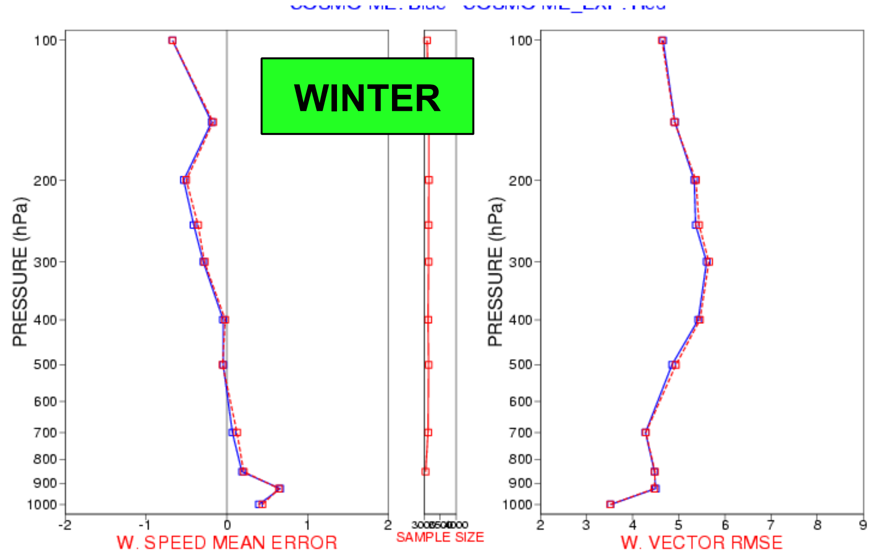
FORECAST VERIFICATION SCORES

WIND 00UTC FC+24h

OPE
EXP



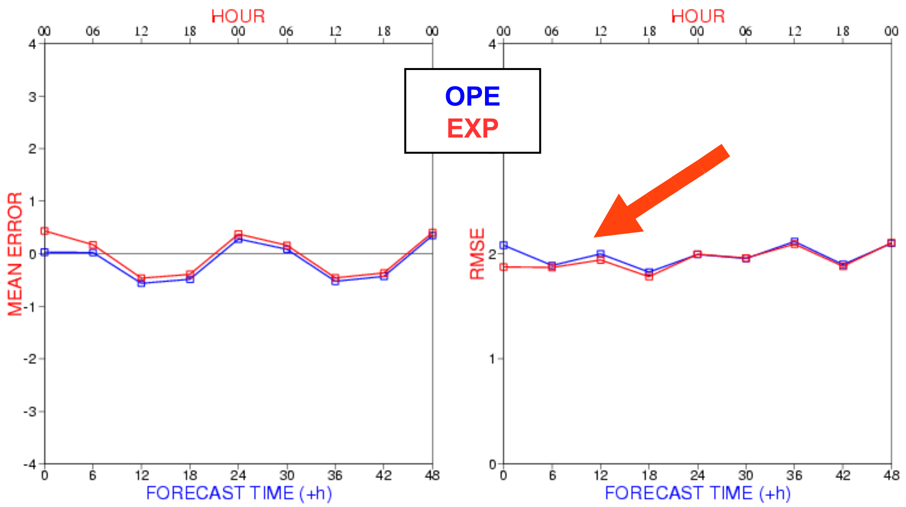




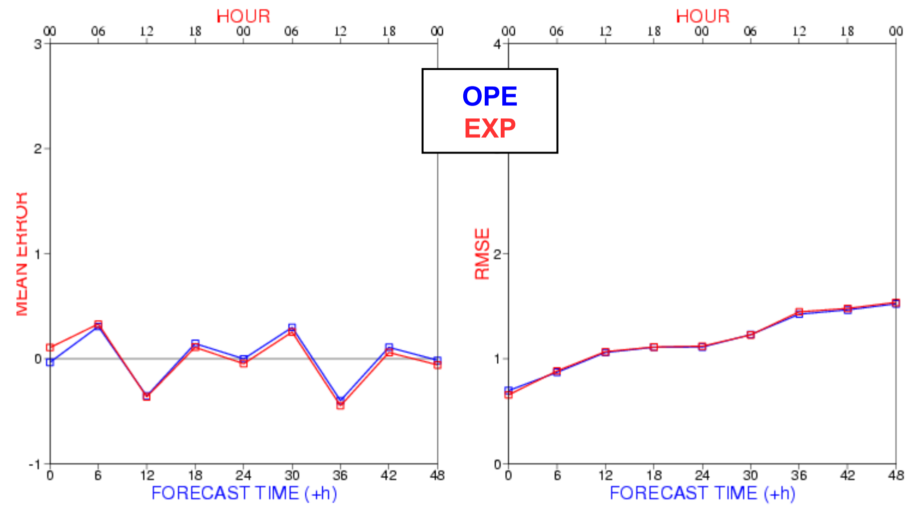
SURFACE FIELDS

FORECAST VERIFICATION SCORES

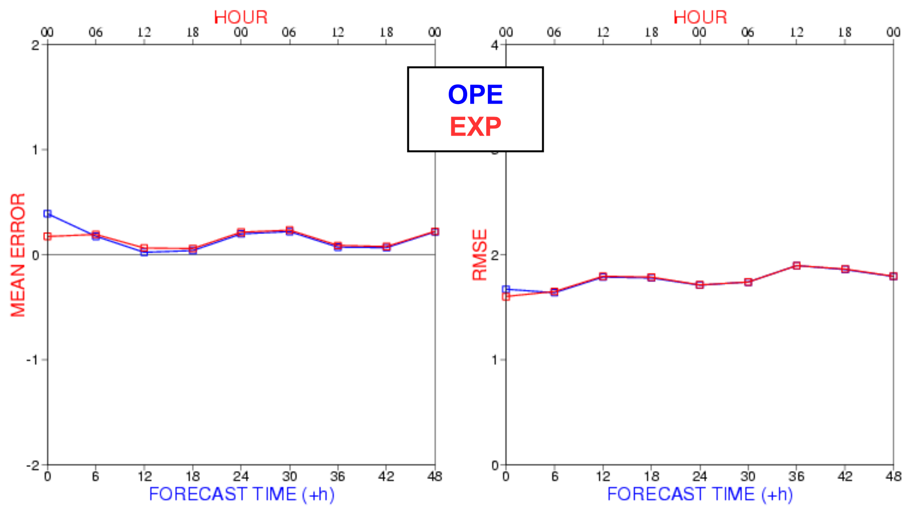
T2m 00UTC RUN



MSLP pressure 00UTC RUN



WIND SPEED 00UTC RUN



Stochastic Physics

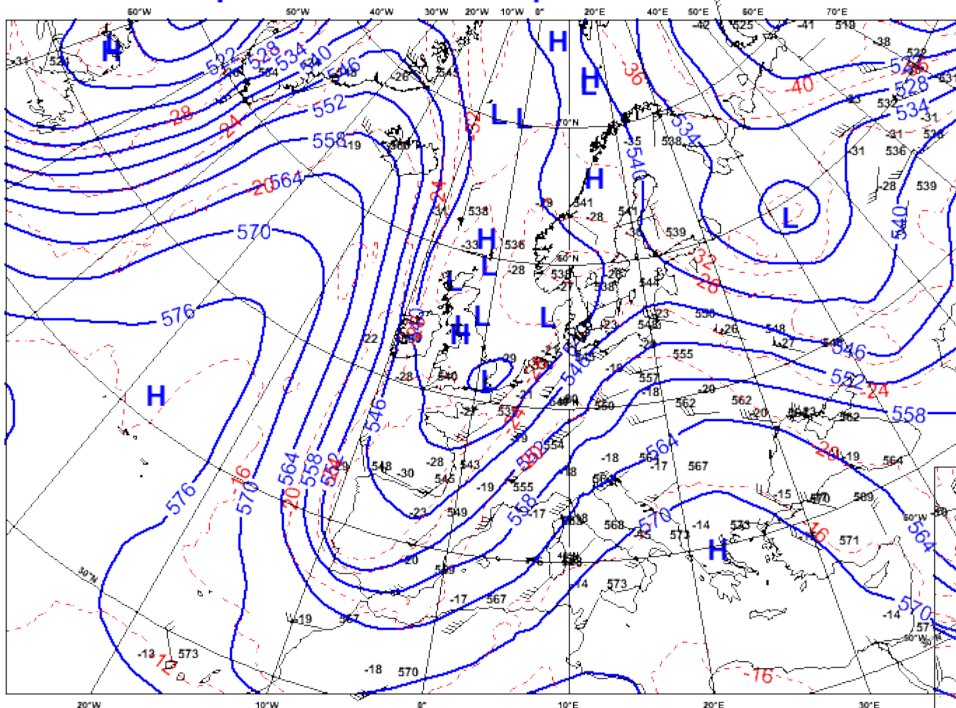
$$X_p=(1+r\ \mu)X_c$$

Modified Version (in blue, differences from Buizza et al, 1999)

- For all variables (u,v,T,qv), the random numbers r are drawn from a uniform distribution in a certain range [-0.5,0.5] or a gaussian distribution with stdv (0.1-0.5) bounded to a certain value (range= ± 2-3 stdv) on a coarse horizontal grid every n time-steps
- A tapering factor μ is used to reduce r close to the surface and in the stratosphere (Palmer et al, 2009)
- The perturbations of T and qv are not applied if they lead to particular humidity values (exceeding the saturation value or negative values)
- Spatial correlation is imposed using the same r in a whole column and drawing r for a coarse grid with spacing DL (boxes); then they are bilinearly interpolated on the finer grid to have a smooth pattern in space
- Temporal correlation is achieved by drawing r every n time steps (Dt); then they are linearly interpolated for the intermediate steps to have a smooth pattern in time
- Coarse grid SW corner is different for each member

COSMO-ME EPS

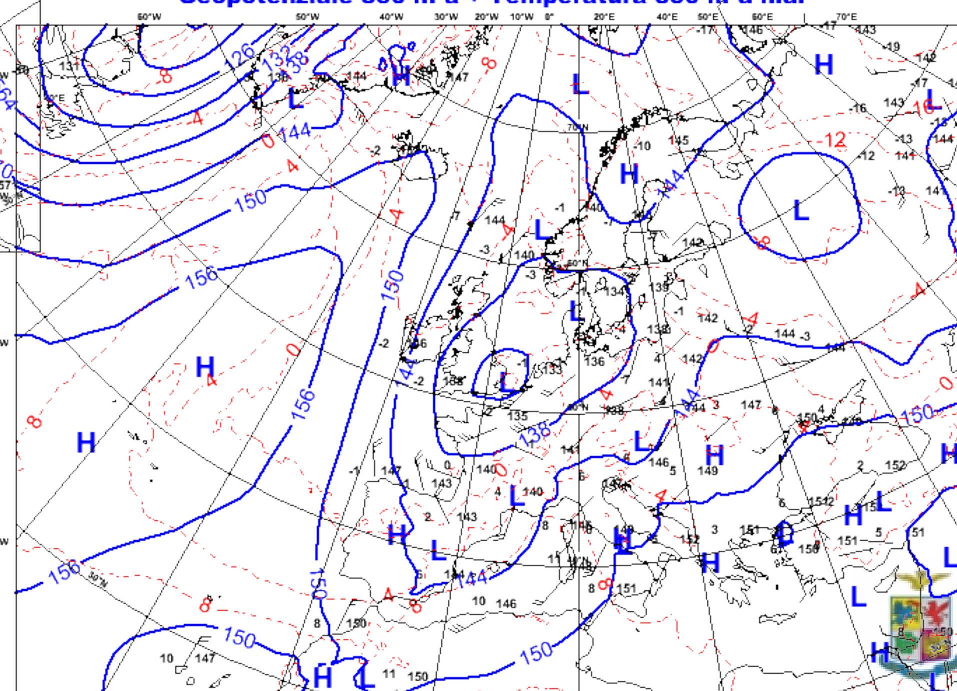
ROME Analysis VT:Martedi 27 Novembre 2012 00UTC
Geopotenziale 500 hPa + Temperatura 500 hPa n.a.



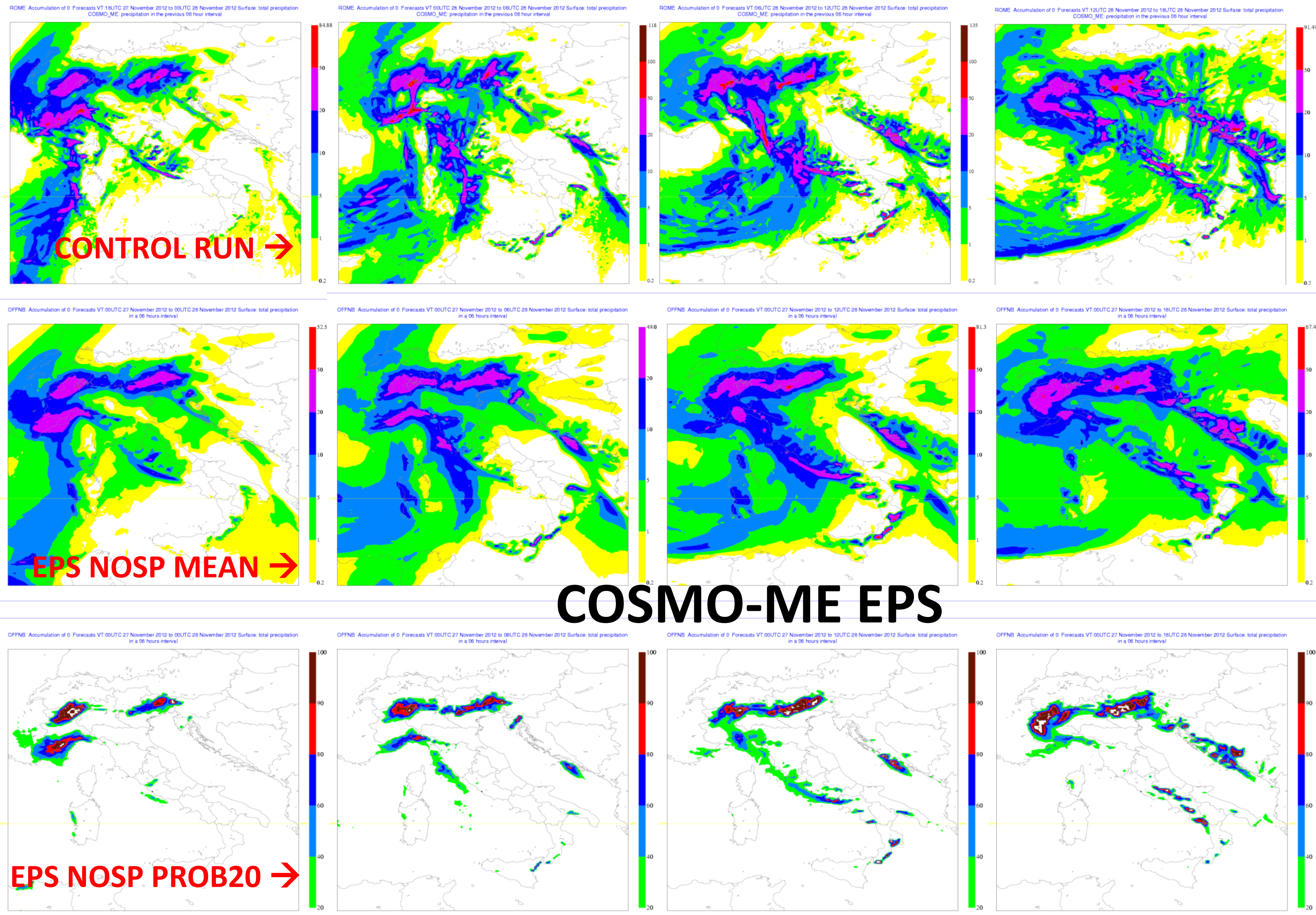
40 members with 0.09° grid spacing, $\frac{1}{28}$26km ($\frac{1}{28}$18hPa) model top, 45 vertical levels, IC from CNMCA LETKF, BC from deterministic IFS perturbed by ECMWF EPS

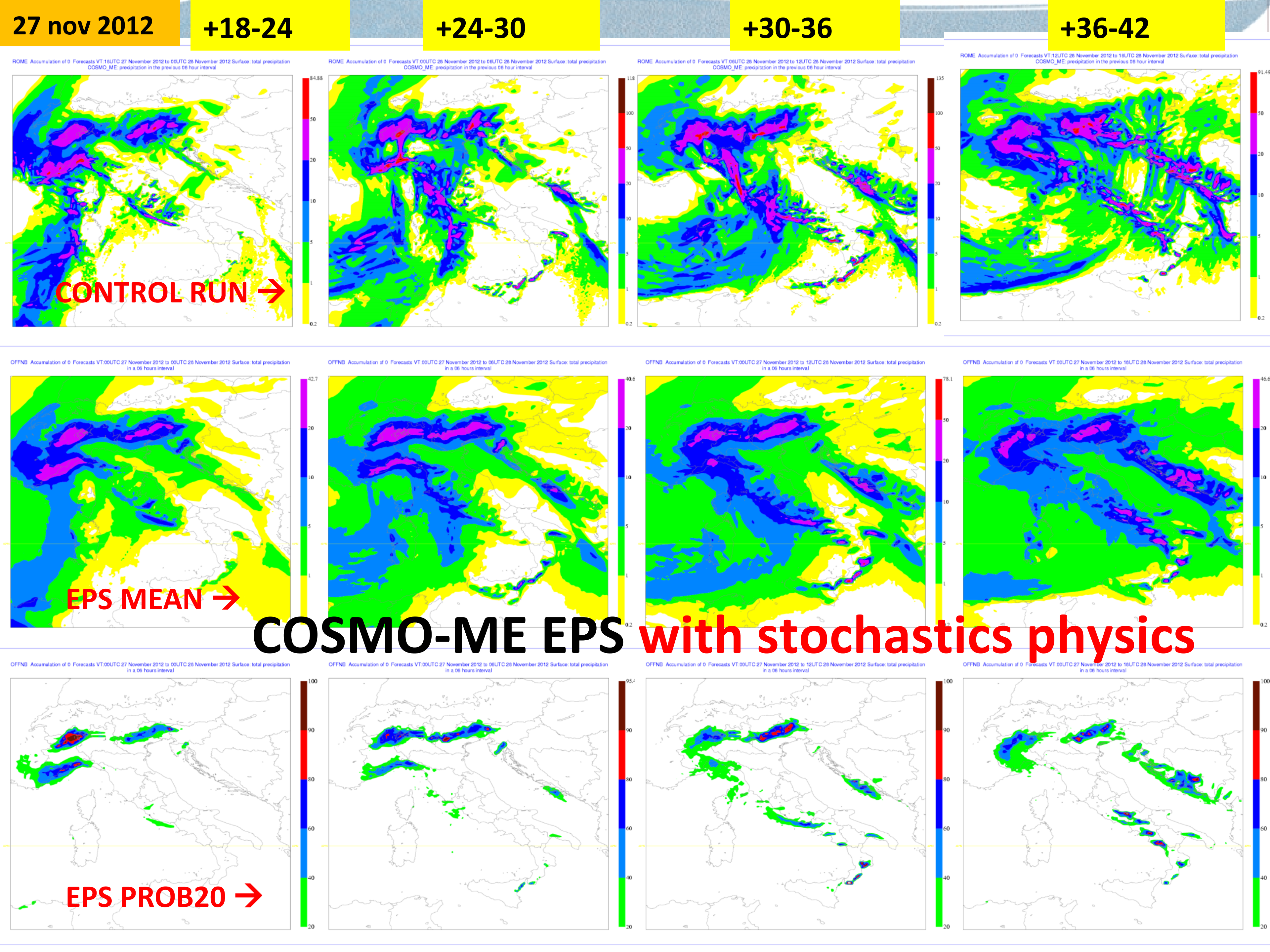
27 nov 2012 00 UTC

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

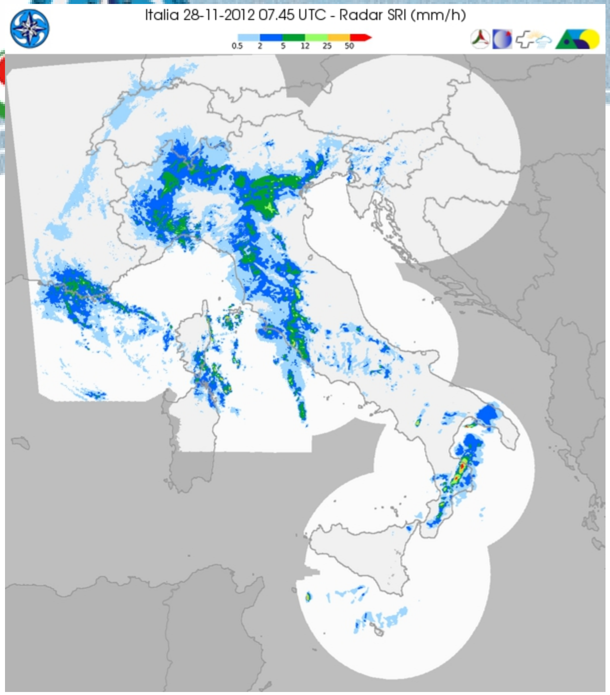


27 nov 2012 | +18-24 | +24-30 | +30-36 | +36-42

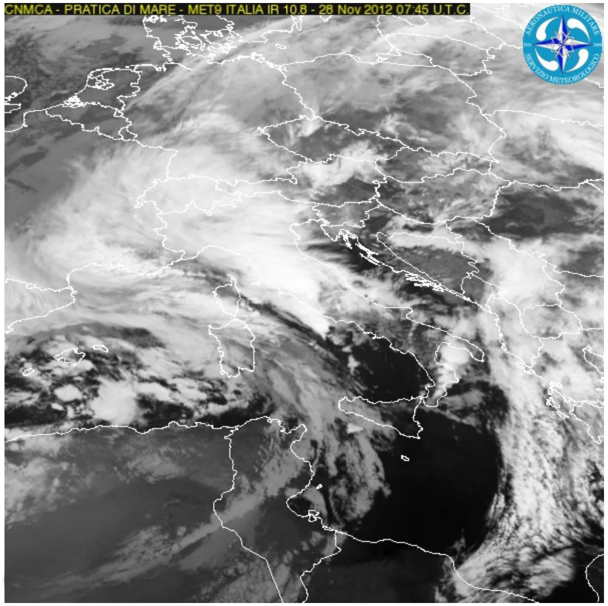



27 nov 2012
+18-24
+24-30
+30-36
+36-42
CONTROL RUN →
EPS MEAN →
EPS PROB20 →
COSMO-ME EPS with stochastics physics

COSMO-ME EPS with and w/o stochastics physics

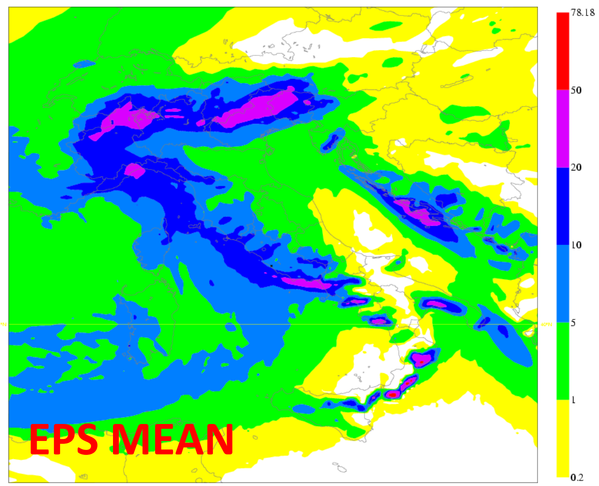


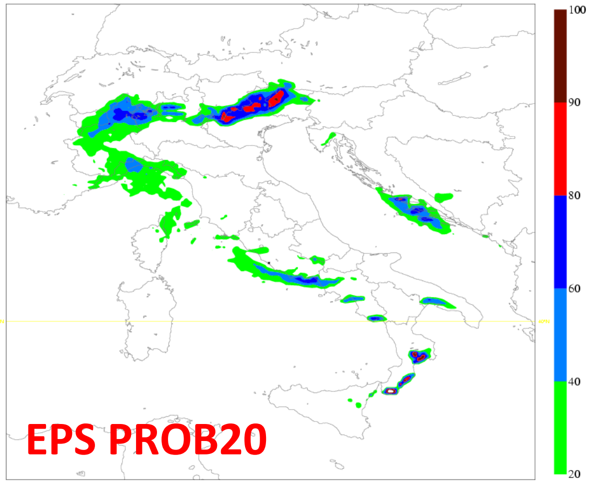
28 nov 2012 07:45 UTC



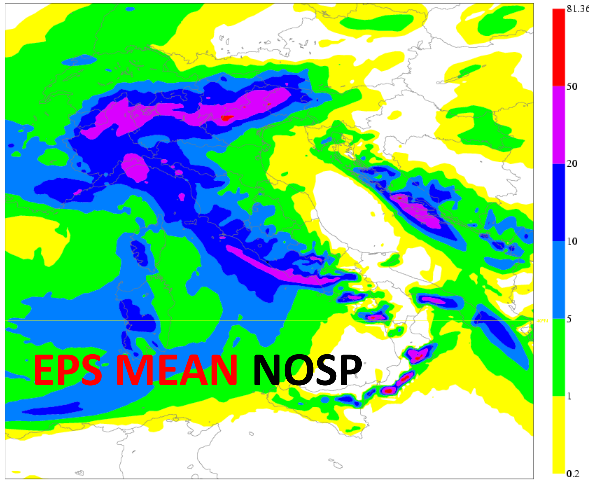
FORECAST 30-36h

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 12UTC 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