SPECIAL PROJECT FINAL REPORT

All the following mandatory information needs to be provided.

Project Title:	Limited Area Ensemble Kalman Filter
Computer Project Account:	SP ITLEKF
Start Year - End Year :	2007 - 2014
Principal Investigator(s)	Lucio TORRISI, Francesca MARCUCCI
Affiliation/Address:	CNMCA- Italian Met. Service
Other Researchers (Name/Affiliation):	

The following should cover the entire project duration.

Summary of project objectives

(10 lines max)

The SPITLEKF main goal was to investigate methodologies to improve analysis and forecast skill of operational limited area NWP models through the use of an ensemble data assimilation algorithm based on a variation of the Ensemble Kalman Filter approach (LETKF). This is an important current research topic in meteorology and many competing approaches are currently under study and experimentation.

Summary of problems encountered

(If you encountered any problems of a more technical nature, please describe them here.)

No real problem was encountered, neither technical nor conceptual.

Experience with the Special Project framework

(Please let us know about your experience with administrative aspects like the application procedure, progress reporting etc.)

We are familiar with the Special Project framework and we appreciated this way to proceed.

Summary of results

(This section should comprise up to 10 pages and can be replaced by a short summary plus an existing scientific report on the project.)

The operational CNMCA data assimilation cycle [1][2] is based on the Ensemble Kalman Filter (EnKF) approach, in particular the LETKF version (Hunt et al.2007)[3] has been chosen. The CNMCA-LETKF scheme is running on the Mediterranean-European domain with 40 ensemble members plus a control run, having a 0.09° grid spacing (~10 km) and 45 vertical levels. The COSMO-ME deterministic run is initialized from the LETKF control state analysis. The system is operational since june 2011.

First years of the project have been spent for the implementation of the algorithm and for the migration from HRM to COSMO model (www.cosmo-model.org).

<u>Radiances assimilation</u>

During the project a big effort have been spent in the assimilation of radiances. The major problem is that the vertical localization of satellite radiances is less straightforward to implement than for other observation types in a local algorithm, such as LETKF, because these data are an integrated observation sampling a significant layer of the atmosphere. At the beginning only radiances from AMSU-A and MHS sensors has been tested in the CNMCA operational data assimilation system. The assimilation of these satellite radiances has been tested applying different localization strategies. In the operational configuration the Maximum Based Method (Fertig et al. 2007) has been chosen as localization strategy: radiances are treated as single-level observations and the radiance is assigned to the pressure level obtained by a weighted average using the levels where the normalized weighting function is larger than 0.8.

In order to evaluate the impact of the AMSU-A-radiances two COSMO-LETKF systems, one with and the other without the assimilation of AMSU-A were run. The relative difference (%) in RMSE are computed against IFS analysis for 00 UTC COSMO runs from 16-09-2012 to 05-10-2012. A clear positive impact of AMSU-A assimilation (negative values) has been observed in the whole column both for temperature (Fig.1) and wind vector (Fig.2) forecasts.

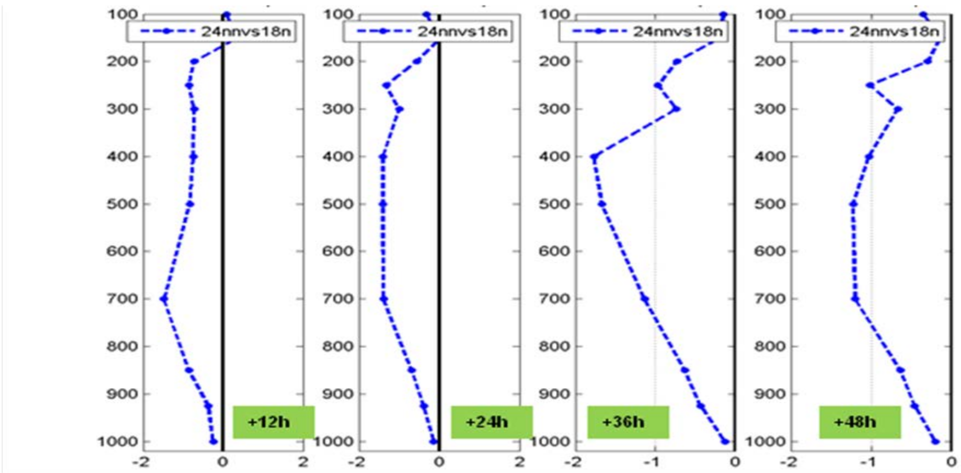

Fig.1: Relative difference (%) in RMSE computed against IFS analysis for 00 UTC COSMO runs from 16-09-2012 to 05-10-2012 for temperature forecasts due to the assimilation of AMSU-A.

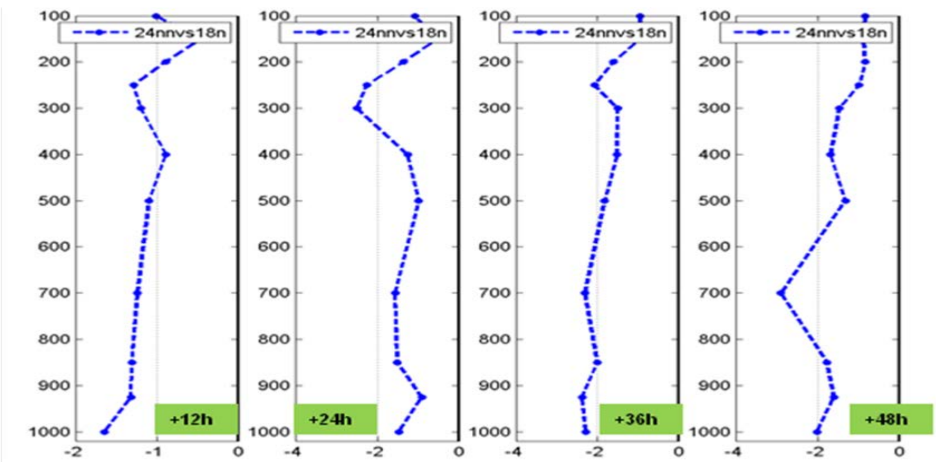

Fig.2: Relative difference (%) in RMSE computed against IFS analysis for 00 UTC COSMO runs from 16-09-2012 to 05-10-2012 for wind forecasts due to the assimilation of AMSU-A.

The assimilation of MHS radiances have been also introduced in the operational system because their clear positive impact on forecasts for all variables (Fig.3).

Other aspects of data assimilation (e.g. quality control, radiance bias correction, etc.) has been investigated to have a further positive impact in the operational NWP system.

In order to improve the specification of land surface emissivity the “dynamical land emissivity retrieval” method proposed in Karbou et al. (2005) has been implemented in the operational system. The method is applied both to AMSU-A and MHS data: AMSU-A channel 3 and MHS channel 1 are used to estimate the emissivity for the other sounding channels. A clear positive impact is observed looking at the observation increment statistics, especially for AMSU-A observations (Fig.4), and at the relative difference in rmse computed against IFS analysis for different variables and forecast lead times (Fig.5) for the assimilation of both AMSU-A and MHS radiances.

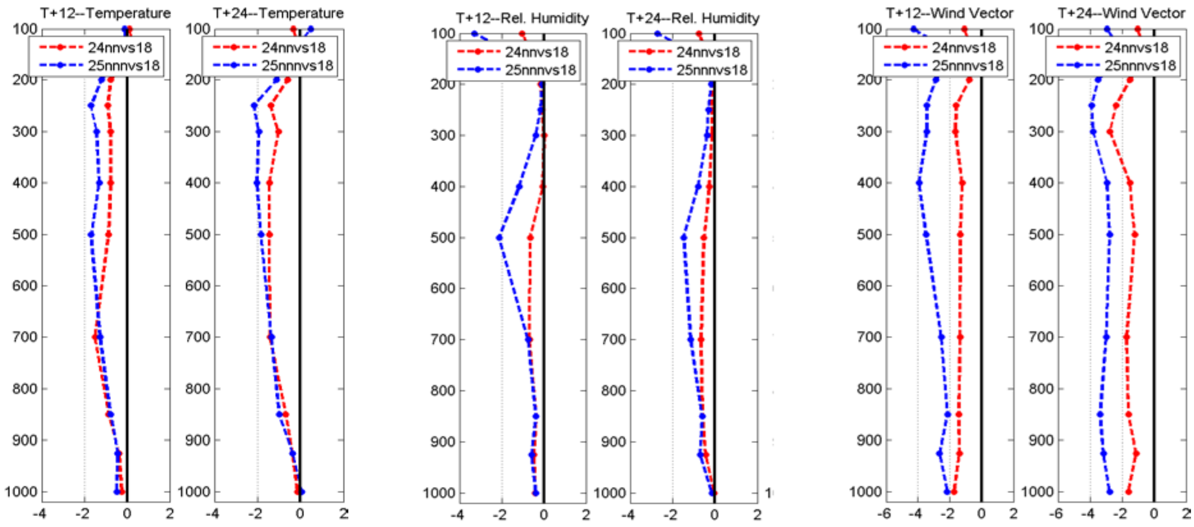

Fig.3: Relative difference (%) in RMSE computed against IFS analysis for 00 UTC COSMO runs from 16-09-2012 to 05-10-2012 with respect to NO-RADIANCES case, for temperature, rel. humidity and wind vector for T +12h and T+24h forecast. In blue impact of assimilation of both MHS and AMSU-A, in red assimilation of AMSU-A only. Negative values mean positive impact.

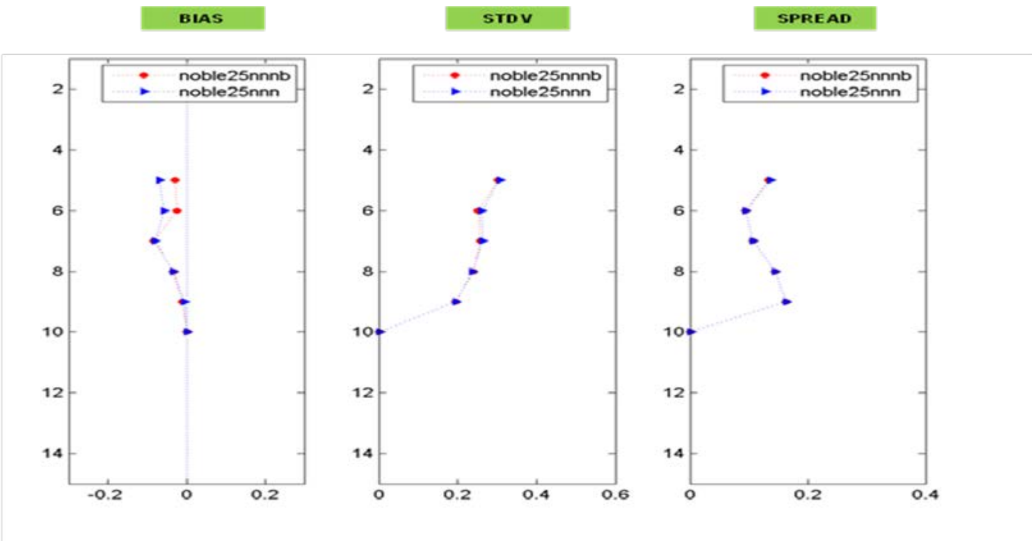

Fig.4: AMSU-A observation increment statistics (bias, stdv and spread) for the period 16-09-2012 to 05-10-2012.

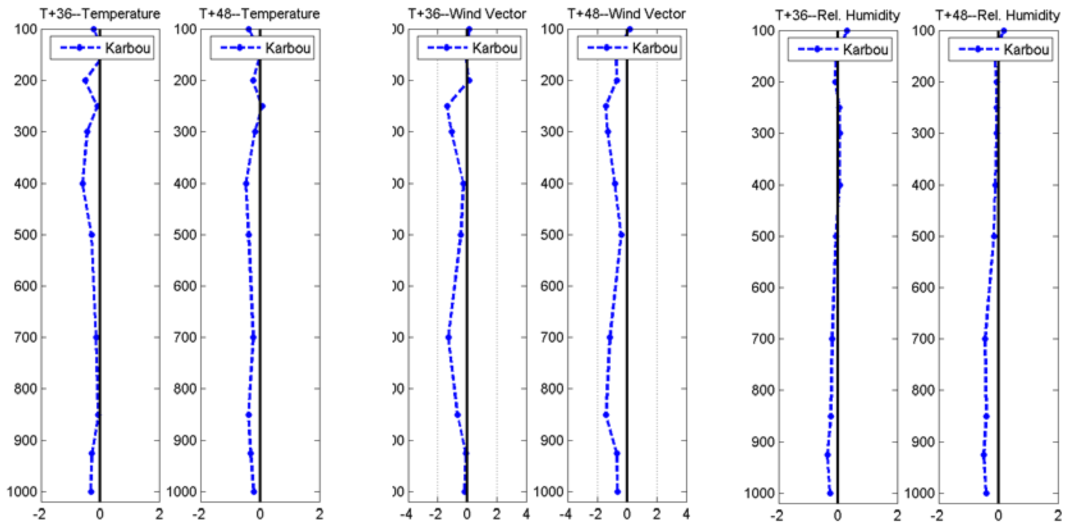

Fig.5: Relative difference (%) in RMSE computed against IFS analysis with respect to the configuration without dynamical emissivity retrival (MHS+AMSU-A assimilation) for 00 UTC COSMO runs from 16-09-2012 to 05-10-2012.

<u>Forecast Sensitivity to Observations</u>

Because of the continuous increase of the observation ingested in the algorithm, it is important to know which observations have large impact on the analyses and forecasts and avoid using observations which have no impact or even negative impact. Estimation of forecast sensitivity to observations without performing data-denial experiments can be performed using different methods. The formulation of Kalnay et al. [4] was applied to the CNMCA Ensemble Data Assimilation System to estimate the observation impact. Figure 6 illustrates the impact of the different types of assimilated observations on 6 hour forecasts in term of the moist total energy reduction. Looking at the total general impact plot (central panel), the largest contributions are from aircrafts and radiosoundings observations, as expected, because of their large amount. In the singular impact plot (impact normalized by the number of observations) the largest value is obtained for AMV observations.

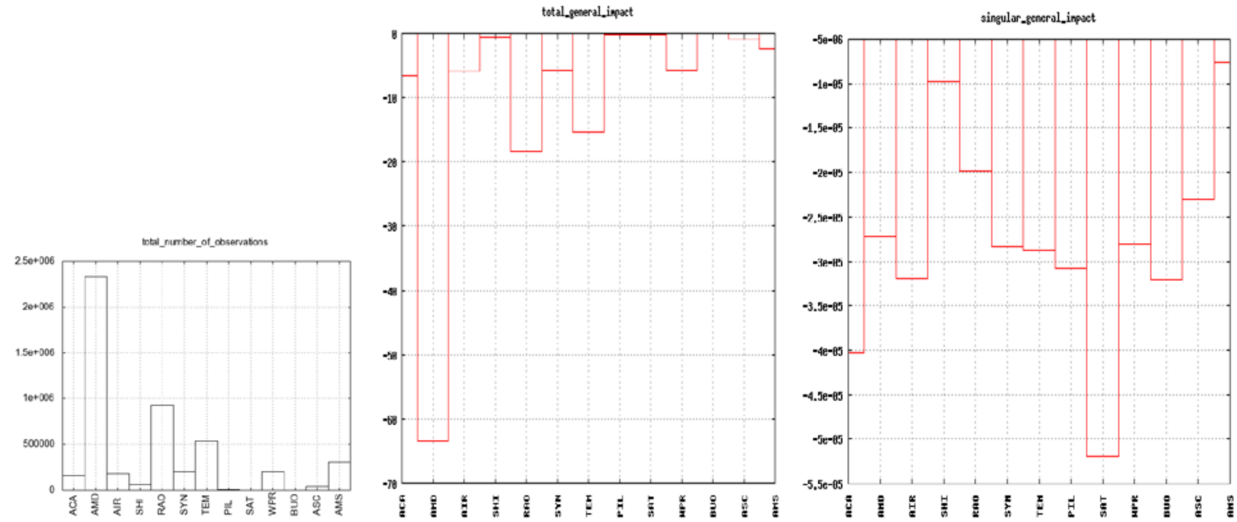

Fig.6: Observation statistics in the period 17 july -17 aug 2013 (left panel). Singular (right panel) and total observation impacts (central panel); in the x-axis there are the classes of observations while numbers in y-axis represent the forecast error reduction due to each class of observations (moist total energy, J /Kg) in the period 17 july -17 aug 2013 computed with FSO technique.

Last year developments

During last year the following developments have been done:

1. Assimilation of ATMS radiances and further improvement of the use of AMSU-A and MHS observations;

2. Assimilation of MODE-S observation and GPS total zenith delay;

3. Implementation of a self-evolving additive noise technique and experimental test for a better tuning of the model error representation.

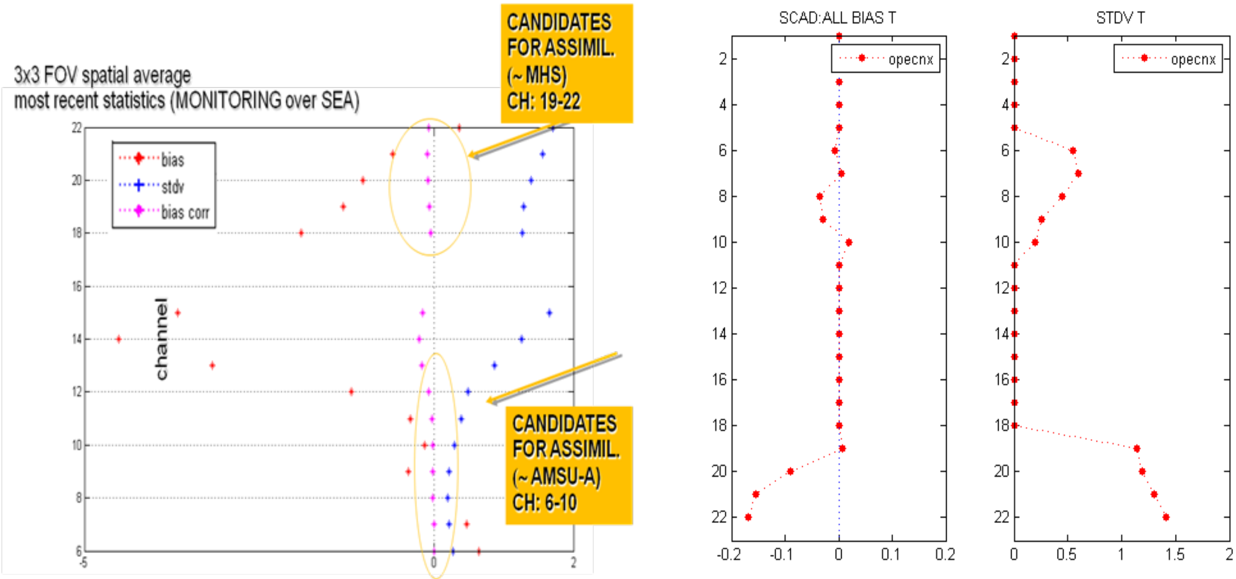

Fig.7 ATMS monitoring statistics over sea (left panel) and bias and standard deviation (right panel) of the observation increment with respect to first guess temperature field for ATMS experimental assimilation cycle

Monitoring of the ATMS radiances suggest their assimilation over sea for all channels with small bias (as shown in Fig.7, left panel) and also over land for channel 9 and 10. Results of the assimilation of the selected ATMS channel are shown in term of observation increment statistics for the 20 days testing period 12 august-3 september 2014 (Fig.7, right panel).

GPS total zenith delay are also good candidates for the assimilation because the observed small bias and low standard deviation of the observation increment statistics (Fig.8). GPS assimilation has been tested from 11 january to 30 january 2014 showing a mixed impact (not showed).

MODE-S aircraft observation have been monitored and then assimilated for one month test period. In the assimilation test the same AMDAR wind errors have been used, but the temperature ones have appropriately increased, because of their poorer quality, as found in the monitoring. Observation increment statistics results for MODE-S assimilation are shown in Fig.9.

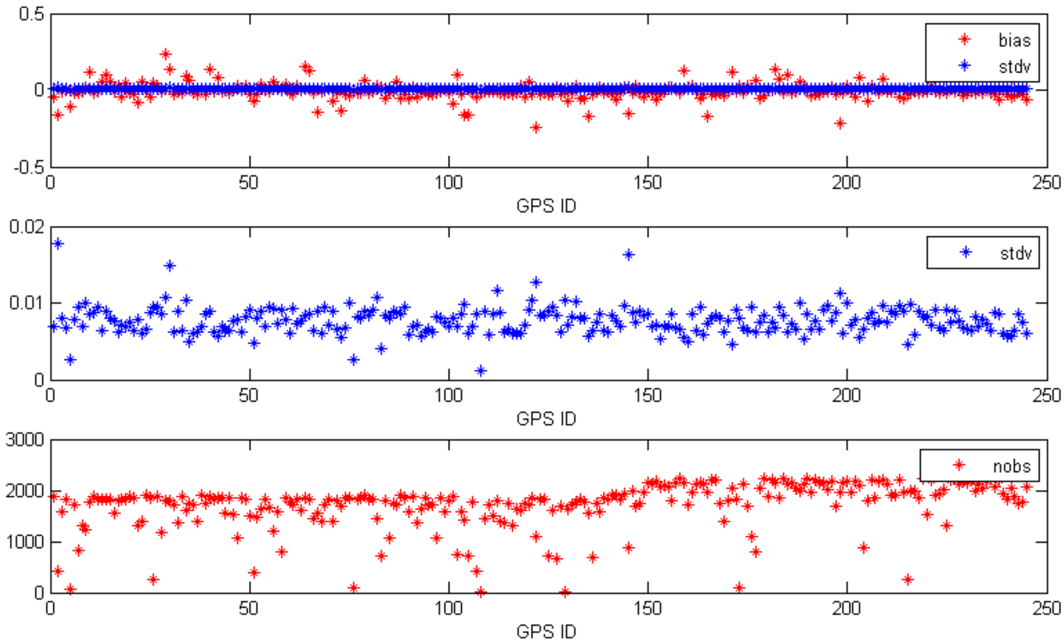

Fig.8 Italian GPS station monitoring statistics from 1st to 28th february 2014

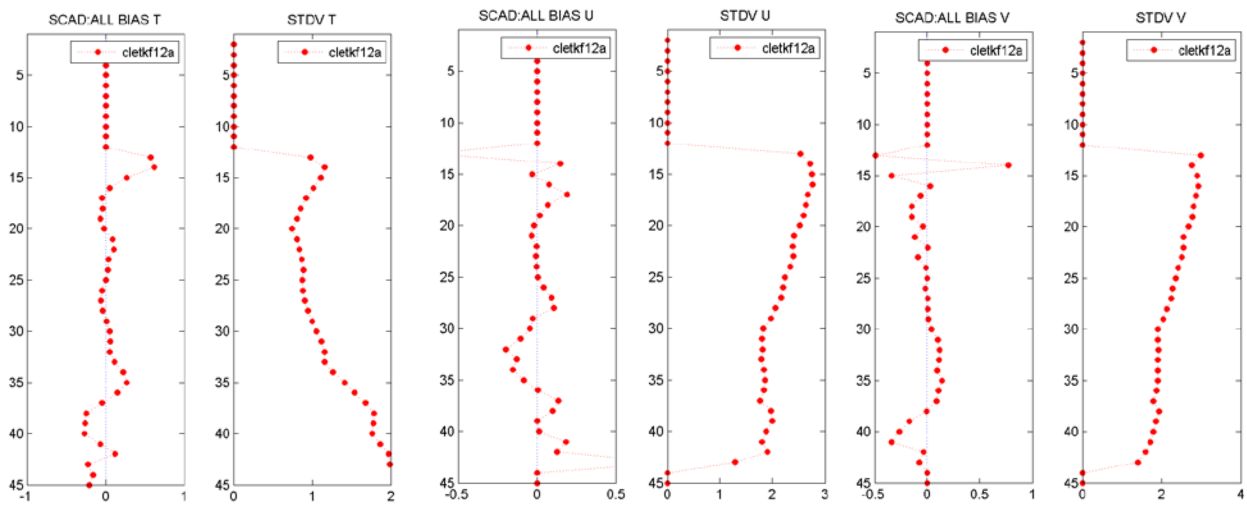

Fig.9 MODE-S observation Increment statistics (bias and standard deviation) for the assimilation test from 10-nov 2014 to 10 dec 2014.

In the CNMCA-LETKF system a combination of multiplicative inflation (Relaxation to prior spread [5]) and additive noise (based on ECMWF-EPS perturbations) is operationally used to prevent the filter divergence, due to sampling and model error. Recently, a flow-dependent additive inflaction has been implemented and tested. The perturbations are derived by a suitable scaling of the "zero-mean" differences of lagged ensemble forecasts giving a self-evolving and flow-dependent additive noise. Differences of 18h and 6h or 12h and 6h ensemble forecast members have been compared. A positive impact with respect to no-additive setup is observed for both configuration, but a small improvement is appreciated if the perturbations are computed using differences of 12h and 6h forecast (Fig.10).

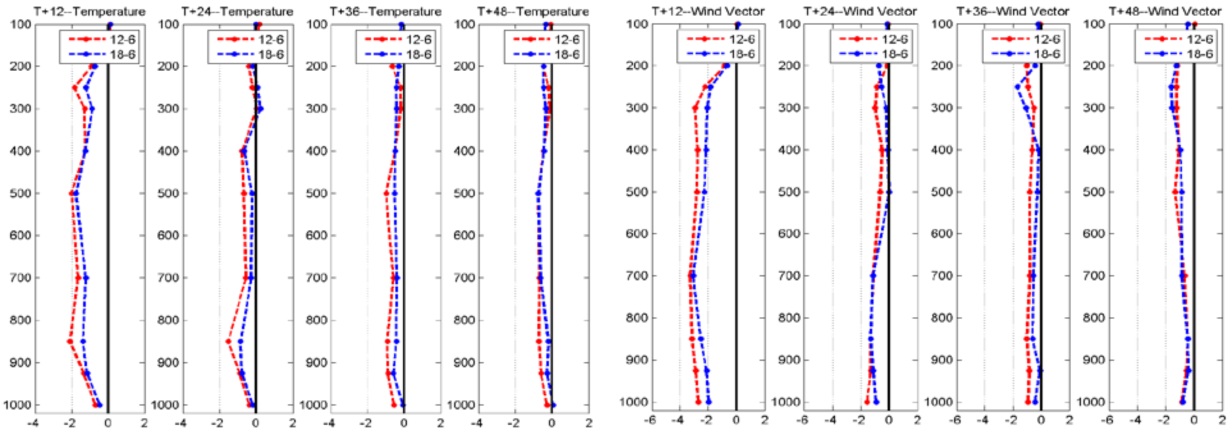

Fig.10 Relative difference (%) in RMSE, computed against IFS analysis, with respect to NO-ADDITIVE run for 00 UTC COSMO runs from 21-oct 2013 to 10 nov 2013 (blue lines for 18-6h differences, red lines for 12-6h differences)

List of publications/reports from the project with complete references

[1] Bonavita M, Torrisi L, Marcucci F. 2008. The ensemble Kalman filter in an operational regional NWP system: Preliminary results with real observations. *Q. J. R. Meteorol. Soc.* 134: 1733-1744.

[2] Bonavita M, Torrisi L, Marcucci F. 2010. Ensemble data assimilation with the CNMCA regional forecasting system. *Q. J. R. Meteorol. Soc.* 136: 132-145.

[3] Hunt, B. R., E. Kostelich, I. Szunyogh. “Efficient data assimilation for spatiotemporal chaos: a local ensemble transform Kalman filter”, *Physica D*, 230, 112-126, 2007

[4] Kalnay, E., Ota, Y., Miyoshi, T. and Liu, J. 2012. A simpler formulation of forecast sensitivity to observations: application to ensemble Kalman Filters. Tellus A, vol. 64.

Future plans

(Please let us know of any imminent plans regarding a continuation of this research activity, in particular if they are linked to another/new Special Project.)

A new project has been started on 2015 as continuation of the SP ITLEKF project. The goal of the proposed study is to improve the existing short-range ensemble prediction system based on the Ensemble Kalman Filter (EnKF) approach (CNMCA-LETKF) for the data assimilation component (estimation of the initial conditions) and the COSMO regional model for the prognostic one.