CHARACTERIZATION AND USE OF MSG AMVS IN THE ITALIAN WEATHER SERVICE REGIONAL NWP SYSTEM

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ABSTRACT

Atmospheric Motion Vectors (AMVs) have been an integral part of the Global Observing System for many years, and their use has been shown to have a beneficial impact for the quality of NWP analysis and forecast fields. The Italian Weather Service (IWS) has been using AMVs operationally since 2003 in its data assimilation system (DAS), with consistently positive impacts (Bonavita and Torrisi, 2004) . The increased spatial and temporal resolution of the MSG derived Atmospheric Motion Vectors, together with their improved accuracy, has further enhanced their usefulness in NWP applications, but it has also highlighted the need for a careful characterization of their error structure. The quality and error characteristics of the EUMETSAT MSG AMVs have been studied with respect to both short-range forecast fields of the IWS Regional Forecasting Model and to the European radiosounding network. These findings have been put to the test in forecast impact trials. Results to be presented demonstrate the usefulness of the proposed approach and the continuing benefit that is to be gained in NWP applications by a judicious use of AMVs, even in comparatively well observed areas of the Earth.

1. INTRODUCTION

The operational production of Atmospheric Motion Vector (AMV) observations derived from higher resolution MSG sensors and the continuing evolution of the methods used for their extraction and height assignment has led to the availability of high quality, near real time data for the initialization of Numerical Weather Prediction (NWP) models. On the other hand the larger data volumes available with respect to MET7-derived products pose new practical problems in order to to make effective use of this wealth of information in an operational setting. More specifically, the continous drive to use these observations at higher spatial resolutions means that systematic biases with respect to forecast fields need to be corrected, low quality observations need to be carefully screened, spatial error correlations taken into proper account.

To this end a preliminary step is the error characterization of the AMV observations both in terms of their perceived accuracy and the spatial structure of the errors. This work has been carried out at the IWS for MSG AMVs derived from the visible and water vapour channels and the results have been verified through assimilation experiments in the CNMCA regional NWP system.

The structure of the paper is as follows: A short description of the CNMCA regional NWP system is given, then the metodology used for computing the error characteristics of AMV is described and the main findings are presented. Results from limited impact studies are finally illustrated together with a short description of current research activities.

2. THE CNMCA NWP SYSTEM

At CNMCA an intermittent, 6-hourly, data assimilation system based on a variational objective analysis scheme (Bonavita and Torrisi, 2005) and the EURO_HRM prognostic model is currently operational.

In standard notation (Ide at al., 1997) the objective analysis component computes the maximum likelihood estimate of the atmospheric state ($\boldsymbol{x}_a$) by minimization of the following cost function of the state vector $\boldsymbol{x}$:

$$J(\mathbf{x}) = 0.5[\mathbf{y} - H(\mathbf{x})]^T\mathbf{R}^{-1}[\mathbf{y} - H(\mathbf{x})] + 0.5[\mathbf{x} - \mathbf{x_b}]^T\mathbf{P}_b{}^{-1}[\mathbf{x} - \mathbf{x_b}] \qquad (1)$$

i.e., minimizing a scalar distance of the analysis vector from both the observations and the first guess fields, based on their respective perceived accuracies. The CNMCA implementation solves the minimization problem in “observation space” (“3D-PSAS” algorithm, Cohn et al., 1998) through a parallel, preconditioned conjugate gradient descent method. A linear balance is imposed on the mass and wind fields through the use of the thermal wind constraint in spherical geometry.

Standard synoptic observations are assimilated (TEMP, PILOT, SYNOP, SHIP, BUOY) together with a large variety of a-synoptic ones (AMSU radiances,AMDAR, AIREP, AMV, Wind Prof, QUIKSCAT, ERS2).

The numerical model used to produce the first guess fields is the EURO High-Resolution Regional Model (EURO_HRM) of CNMCA. The EURO_HRM is a modified version of the Deutscher Wetterdienst hydrostatic, primitive equations, EM/DM model (Majewski, 2001). The model is run on a Euro-Atlantic domain (Fig.1) at 0.25° horizontal grid spacing and 40 vertical levels extending up to 10 hPa.

The assimilation cycle is run with a 4-h data window around the analysis nominal time. Twice daily (at 00Z and 12 Z), an extended run (+72h) of the EURO_HRM model based on the assimilation cycle analysis is performed.

3. MET8 AMV WINDS ERROR CHARCTERISTICS

Atmospheric motion vectors (AMV) are derived from sequences of well navigated and calibrated geostationary satellite images. This derivation is mostly an automatic procedure, using consecutive infrared, visible or water vapor images. Whichever channel is used, a tracer is selected from the central image, and then tracked in the two other images by calculation of cross-correlations coefficients. The displacement yields the average motion of the tracer over the time span covered by the image sequence, which is assumed to equal the wind at that location.

The AMVs are available within the useful field of view of the satellite, usually up to 60 degrees from the subsatellite point, and provide the main source of remotely sensed winds for NWP.

AMVs from Meteosat image data are produced routinely by the operational Meteorological Product Extraction Facility (MPEF) at Eumetsat in Germany (Schmetz et al., 1993, Buhler and Holmlund, 1993, Holmlund, 2004).

The Eumetsat AMVs undergo quality control before being disseminated on the GTS in BUFR or SATOB format. The internal quality control scheme performs a selection so that each wind vector is associated with a quality indicator (QI). The QI is based on a set of tests for consistency against neighbours (in time and space), a forecast field and different channels.

There are different wind products, depending on channel, resolution, quality and type of encoding. Redundant wind measurements are produced by observing the same tracer in different spectral channels.

In the present work BUFR encoded high resolution Meteosat 8 AMVs (Fig.3) in the visible (HRV) and cloudy water vapor channels (HWW) have been collected for a 9 months period (April to December 2005) together with RAOB colocated winds and EURO_HRM short range (+6h) forecasts. Wind observations were considered to be colocated if their horizontal separation was below 150 Km and vertical mismatch below 15 hPa.

The results of the RAOB-AMV colocations are summarized in fig. 3,4. Water vapour wind speeds in the upper troposphere show a negative bias which seems to be connected to underestimation of the zonal wind component. Lower tropospheric AMVs are mainly derived from the visible channels and do not show significant biases. The small fraction of water vapour and visible AMVs which are assigned to middle tropospheric pressure levels present significant biases and RMS errors. This seems to be an indication of possible problems in the underlying height assignment algorithm. The colocation statics also point to a RMS error of around 2.5m/s for the HRV wind components and 4.5 m/s for the HWW wind components and these results have led the authors to lower the expected errors of the AMV winds in the IWS DAS to 3 m/s (HRV) and 5 m/s (HWW), down from 4 and 6 m/s respectively.

Statistics of AMV vs EURO_HRM 6 hour forecasts for both wind speed and wind components (not shown) present qualitatively similar results to the AMV-RAOB colocations.

These findings have been tested in a limited data assimilation impact experiment in which static bias correction and screening of mid-tropospheric (450-700 hPa) AMV winds have been applied. Results (fig. 5) show a moderate improvement in the medium-upper tropospheric wind field forecast.

The spatial structure of the AMVs errors has been investigated. In the CNMCA data assimilation system AMV observation are currently assumed to be spatially uncorrelated and thinned at 1 degree horizontal resolution and 20 hPa in the vertical, selecting the wind vectors with the highest QI (current QI thresholds are 0.65 for High Resolution Visible winds and 0.80 for High Resolution Water Vapor winds, following EUMETSAT recommendations). Taking into consideration the AMV derivation process, it is clear that the assumption of null horizontal correlations is not justified and observation thinning is a necessary, though sub-optimal way of reducing the observations mutual correlations. Using again the RAOB-AMV colocations and the fact that sounding observations can be assumed to be spatially uncorrelated, the correlated part of the error can be attributed to the AMV winds. Results (Fig. 6,7) show isotropic spatial autocorrelations for the wind components, while cross correlation seems to be negligible. The isotropic component of the autocorrelation for both HRV and HWW winds has been fitted with a simple SOAR function ($(1+r/L)exp(-r(L)$), obtaining decorrelation lengths in the 150-170 Km range (not shown).

4. IMPACT STUDIES AND CURRENT DEVELOPMENTS

In the current DAS implementation at the IWS, AMVs are assumed to be horizontally uncorrelated observations. In view of the results shown above, it is important to thin the data in order to reduce the mutual correlation of the winds while retaining at the same time most of the information content of the data. Theoretical work (Liu and Rabier, 2003) points to an optimal thinning distance which corresponds to mutual correlations of the order of 0.2-0.3. Since the absolute values of these correlations are difficult to accurately estimate at the relevant length scales, a series of sensitivity experiments has been performed over a limited period (16/04/05 – 05/05/05) varying the thinning lengths used for AMVs in the objective analysis. Results for the visible winds (not shown) seem to be generally insensitive to the thinning lengths used in the experiments. This could be an indication of the low information content of these winds but it could also be an artefact due to the choice of the experiments' period and its representativity. For cloudy water vapour winds results (Fig. 8) seem to point to an "optimum" thinning length of around 100 Km, but also in this case they need to be confirmed with trials in different periods.

Current developments and research activities are aimed at increasing the use of AMV observations in the IWS DAS. In particular, error characterization of clear air water vapour AMVs (WVW) is undergoing. These winds are attractive because they complement nicely the geographical and vertical coverage provided by the HWW and HRV winds. On the other hand their derivation makes the issues of height assignment even more problematic than for the other AMVs, and some work to derive a proper observation operator is envisaged.

Another are of current development work is aimed at making a more frequent use of the AMVs in the DAS. To this end, an experimental 3-hourly data assimilation cycle has been set up and is run in parallel to the current operational 6-hourly cycle. Verification results obtained so far have been mainly neutral. However AMV observation errors and thinning lengths used in the 3-hour cycle have been deduced from the 6-hourly error statistics and these could clearly be sub-optimal for the present case. Ongoing work is currently being devoted to collecting 3-hour colocation statistics.

5. CONCLUSIONS

Inclusion of satellite derived winds from Meteosat 8 AMVs has proved beneficial for the forecast skill of the CNMCA Regional NWP system. However observations are to be carefully monitored, bias corrected and sometimes screened to prevent spurious errors from entering the objective analysis and this work needs to be performed separately for the different channels. AMVs show an isotropic spatial correlation with characteristic length scales around 150-170 Km. This demands that thinning be performed in AMV usage in data assimilation. In order to find the optimum thinning distance some impact experiments have been performed. Results were inconclusive for HRV winds while for HWW winds the best skill scores were obtained with 100 Km thinning length. Due to their limited time span the statistical significance of these results need to be confirmed.

Current development activities are focused on the error characterization of clear air water vapour AMVs and increased temporal use of AMV observations.

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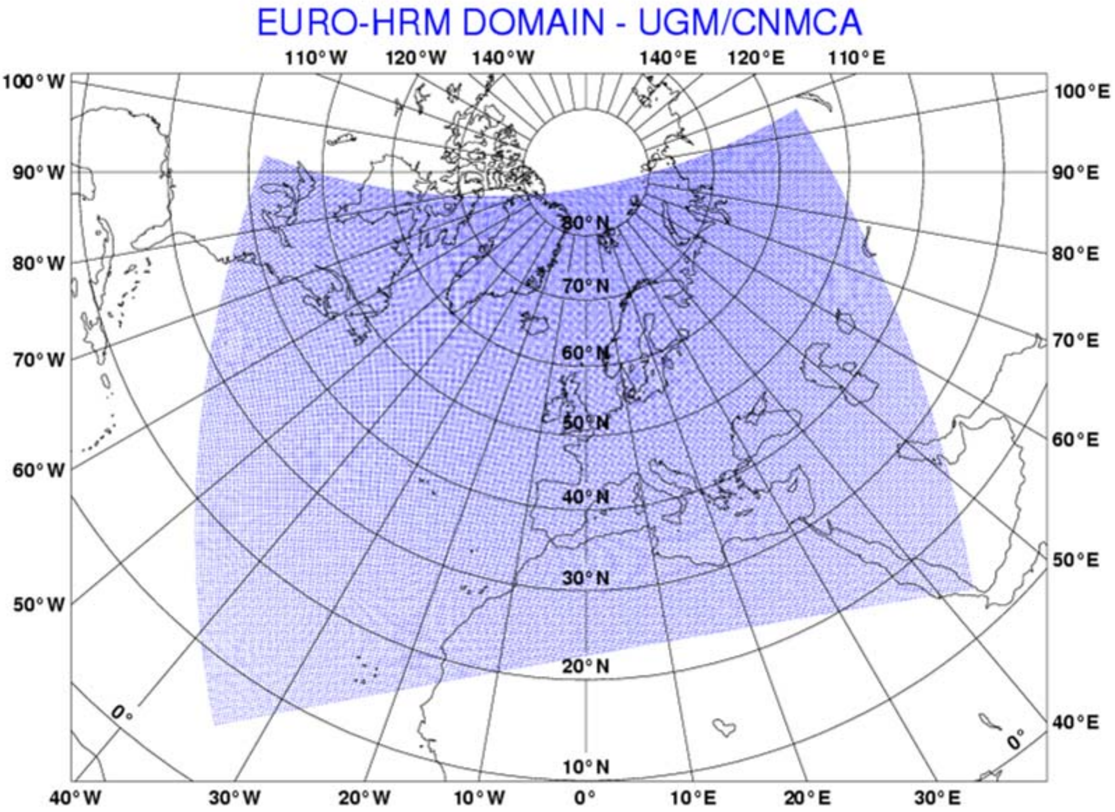


Figure 1: CNMCA Regional model (EURO-HRM) domain of integration.

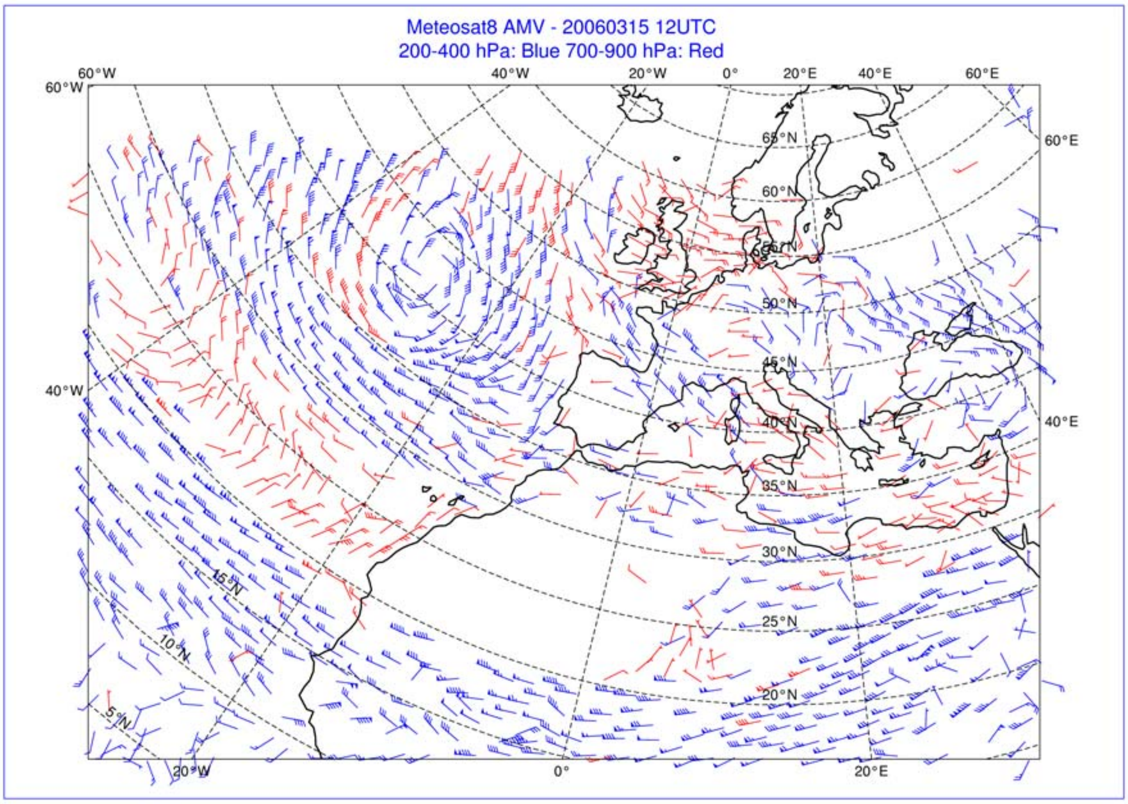


Figure 2: Example of METEOSAT 8 AMVs in the upper (blue) and lower (red) troposphere from High Resolution Water Vapour and Visible channels over the CNMCA Regional NWP system domain.

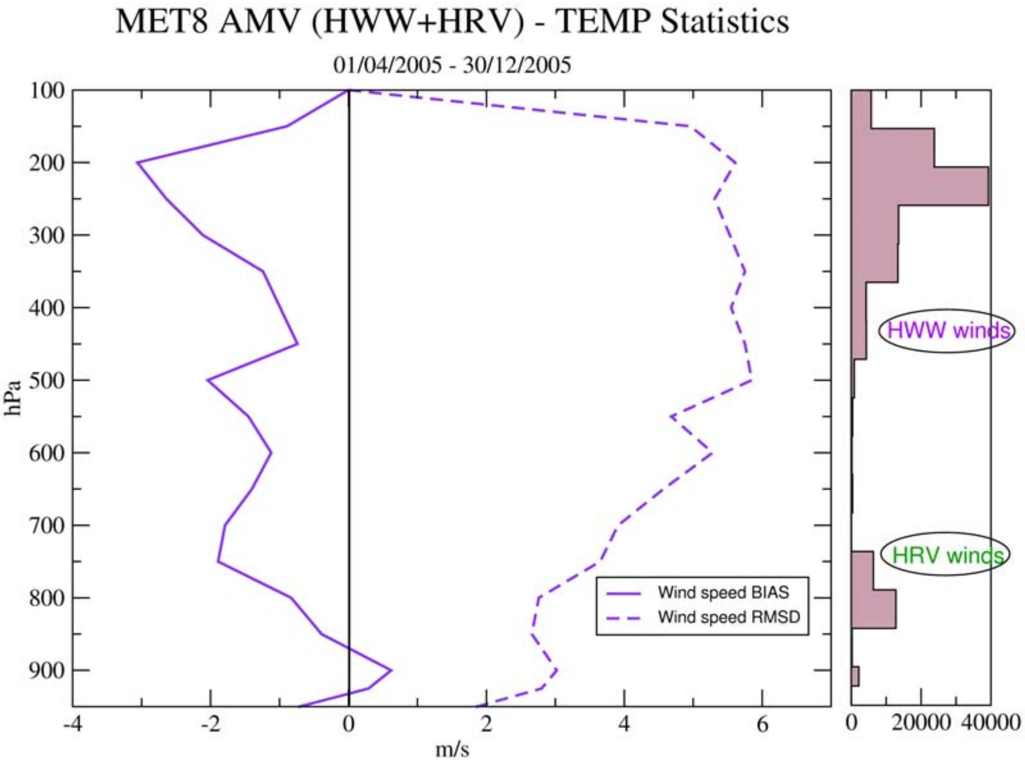


Figure 3: MET8 AMVs wind speed bias (solid) and RMS difference (dashed) with respect to colocated RAOB wind observations.

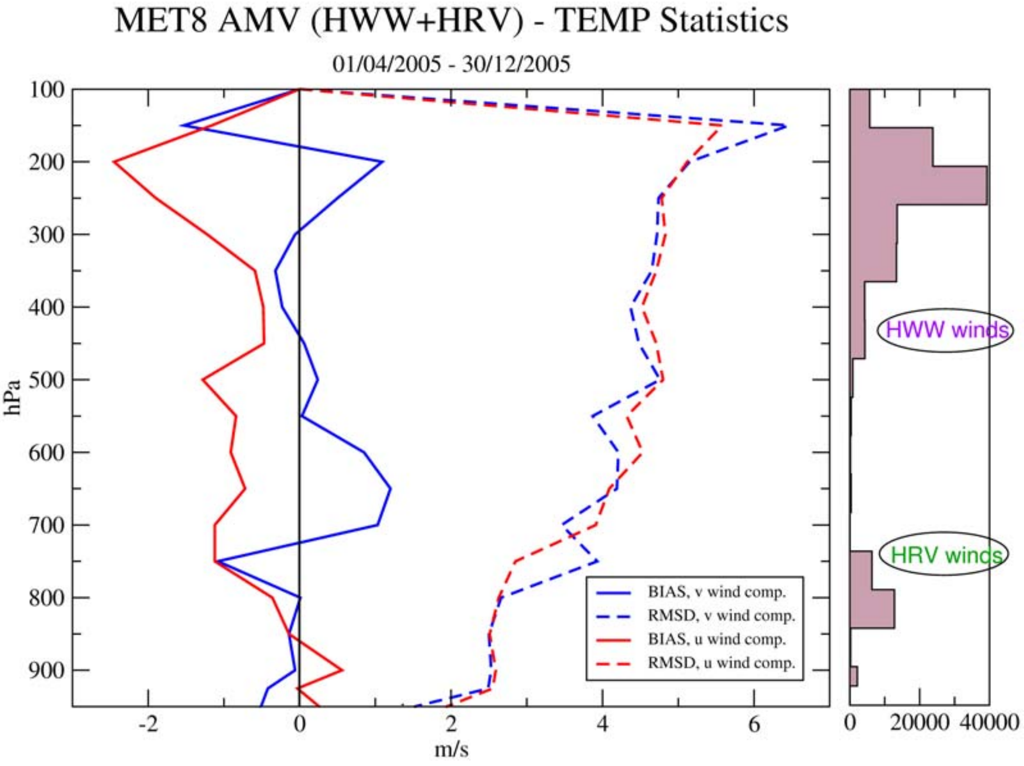


Figure 4: MET8 AMVs wind components bias (solid) and RMS difference (dashed) with respect to colocated RAOB wind observations.

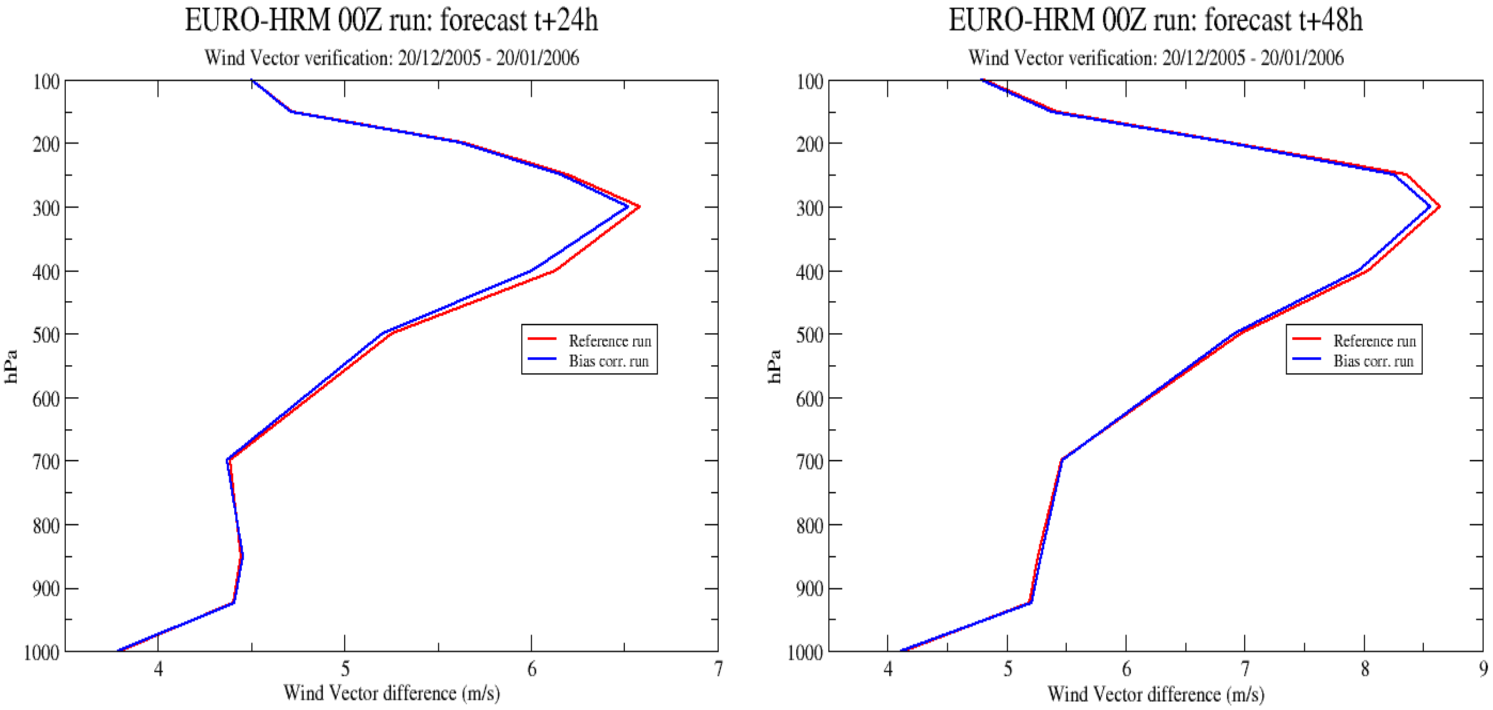


Figure 5: Wind vector RMSE of EURO-HRM t+24, t+48h forecasts from CNMCA 3DVar analysis with (red) and without (blue) the bias correction and observation screening. Verification against European RAOB observations.

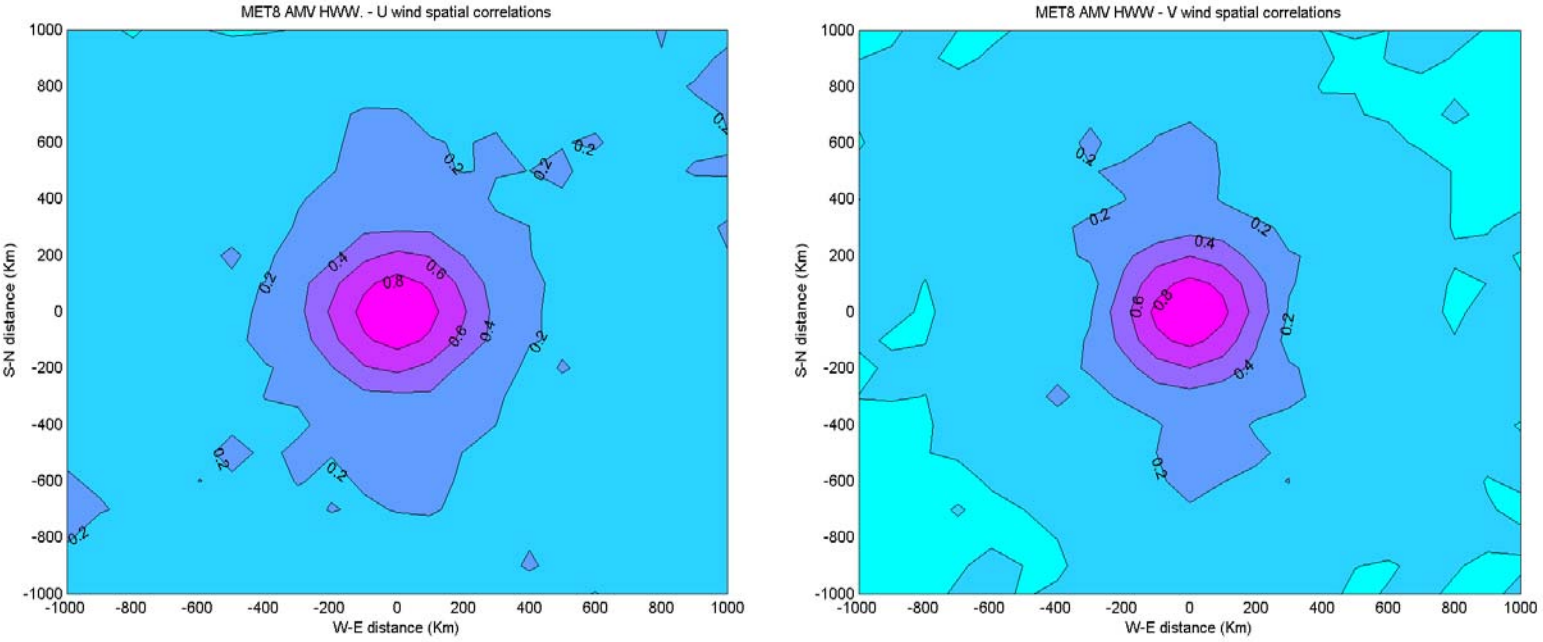


Figure 6: MET8 HWW AMV wind components, normalized spatial autocorrelations.

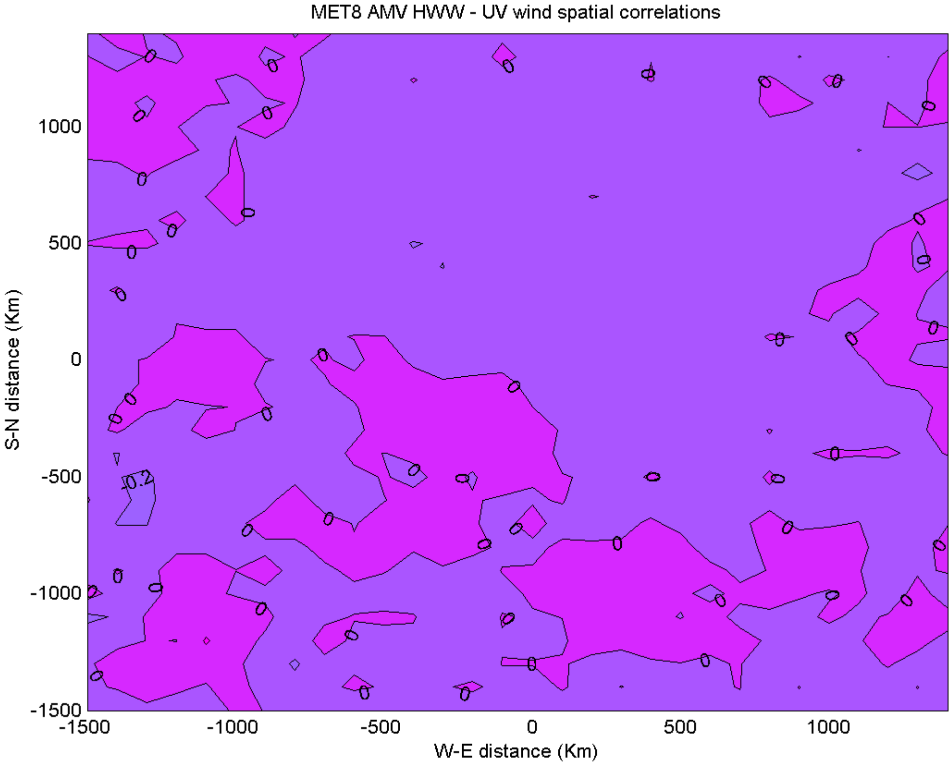
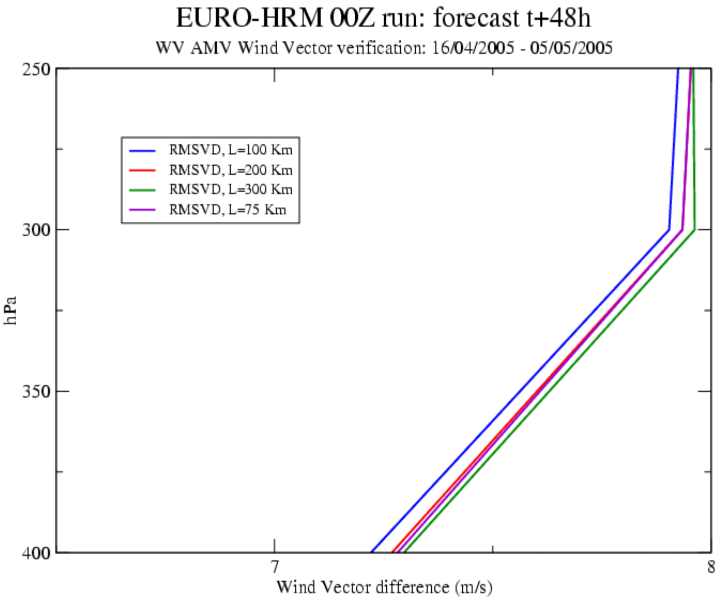


Figure 7: MET8 HWW AMV wind components spatial cross-correlations.



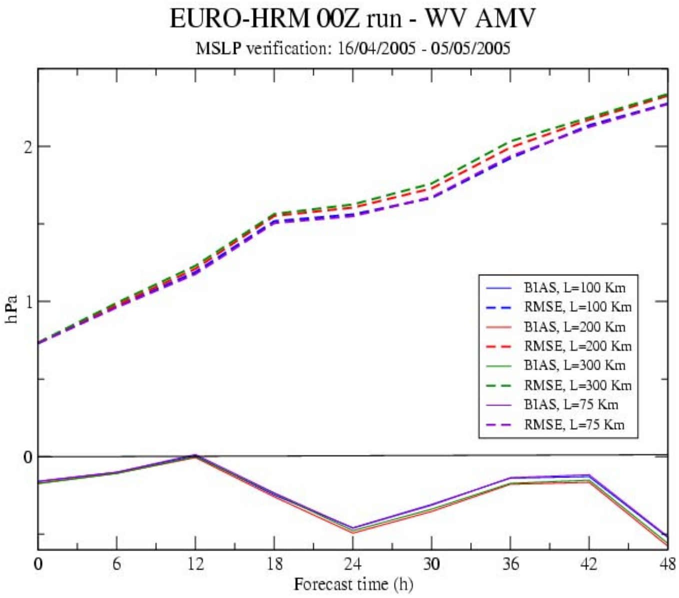


Figure 8: MET8 HWW AMV, t+48h EURO_HRM forecast errors with different thinning lengths (see legends for details).