USE OF SATELLITE WIND VECTORS IN THE ITALIAN WEATHER SERVICE NUMERICAL WEATHER PREDICTION SYSTEM: CURRENT STATUS AND PERSPECTIVES

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ABSTRACT

The increase of the spatial and temporal resolution of satellite-based wind observations, together with their improved accuracy, has greatly enhanced their usefulness in NWP applications, also in areas relatively well covered by the conventional synoptic network. Two types of satellite wind data are currently ingested in the Italian Weather Service regional 3D-Var data assimilation system: surface winds retrieved from the QuikScat scatterometer on board the Seawinds polar satellite and High Resolution Atmospheric Motion Vectors from Meteosat 7 and 5. The present paper describes the assimilation methodology, use of the Eumetsat MPEF Quality Indicator and wind observation error statistics. Impact trials have been conducted for both types of observations, showing consistent improvements in forecast quality, especially from the AMVs dataset.

1. INTRODUCTION

The quality and quantity of satellite derived wind observations which are currently available for the initialization of numerical weather prediction (NWP) models has been steadily increasing over the last decade. This confronts the data assimilation community with the challenge of making effective use of this wealth of information while keeping the computational cost of the objective analysis algorithms within the strict requirements of operational schedules.

Observing System Experiments (OSEs) have been performed at CNMCA in order to gauge the relative impact of some of these new sources of data. The data used in the present OSEs were: retrieved surface winds from the Seawinds scatterometer on board the Quikscat polar satellite and Atmospheric Motion Vectors (AMVs) from METEOSAT 7 and METEOSAT 5 geostationary satellites. From geostrophic adjustment considerations (Kalnay, 2003; Daley, 1991) it is apparent that winds tend to be the most effective source of information for providing initial conditions for all but the shallower vertical modes. The experimental datasets provide very high spatial and/or temporal resolution wind observations, which should be most useful in data sparse regions like the oceans or desert areas. Considering the analysis and integration domain of the CNMCA NWP system (Fig.1), it is apparent that we are dealing with a relatively well covered region in terms of conventional networks. However, large data gaps in the conventional synoptic network are evident in large parts of the domain in desertic and oceanic areas, so that it is reasonable to expect an improvement of the analysis and forecasts quality as a consequence of the use of more homogeneously distributed measurements.

2. THE CNMCA DATA ASSIMILATION SYSTEM

At CNMCA an intermittent, 6-hourly, data assimilation system based on a variational objective analysis scheme (Bonavita and Torrisi, 2004) and the 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 $\boldsymbol{x}$:

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

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. Fast gravity waves are then filtered out of the analysis fields through an adiabatic implicit nonlinear normal mode initialization step (Temperton and Roch, 1991).

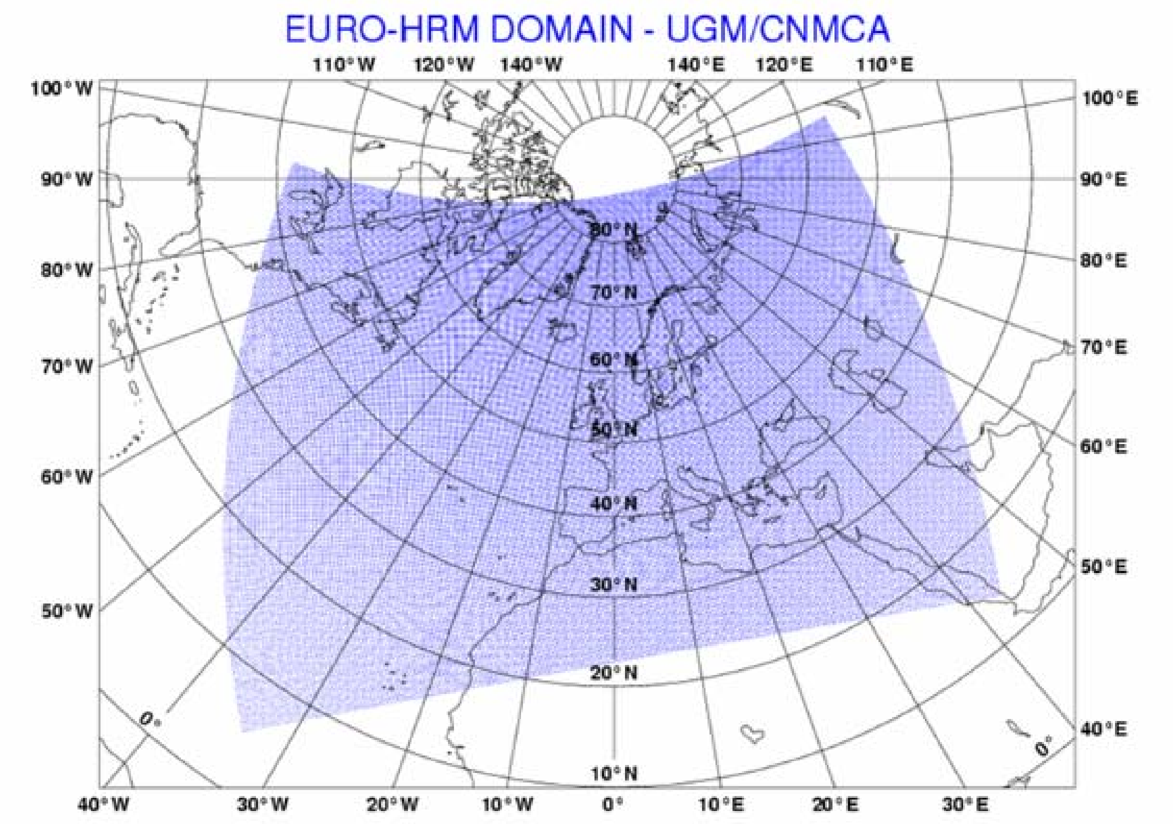

Figure 1: CNMCA Regional model (EURO-HRM) domain of integration.

The numerical model used to produce the first guess fields is the High-Resolution Regional Model (HRM) of CNMCA. The 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 31 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 HRM model based on the assimilation cycle analysis is performed.

3. QUIKSCAT WINDS

Wind data from satellite scatterometers, such as SeaWinds on Quikscat, provide accurate sea-surface wind vector information with a high spatial resolution coverage compared to conventional data (Fig. 2). The Quikscat data coverage is such that developing oceanic storms are likely hit, thus accurately depicting their position and amplitude.

The normalized radar cross-section σ^o on the ocean surface roughness is measured by a scatterometer. Since the sea surface roughness is driven by the wind, the latter can be inferred from radar data. The gravity-capillary (Bragg) waves are the dominant contribution to the radar backscatter. The wind-to-backscatter relationship is generally referred to as the geophysical model function (GMF). The empirically derived forward model function (GMF) relates the state variables (wind speed and wind direction) to the observations (radar backscatter).

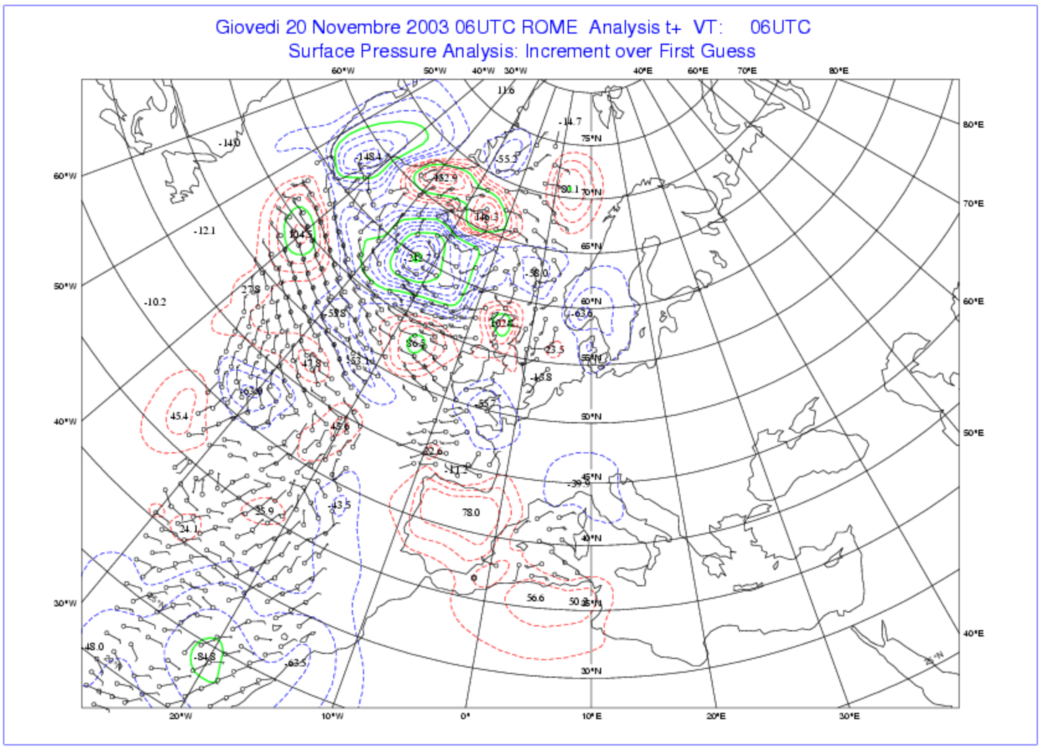

Figure 2: Example of KNMI retrieved winds from Quikscat data and their impact on the surface pressure analysis, 20th November 2003 06UTC.

The SeaWinds instrument is a conically scanning pencil-beam Ku-band scatterometer. It uses a rotating 1-meter dish antenna with two spot views, a H-pol view and a V-pol view at incidence angles of 46˚ and 54˚ respectively, that sweep the surface in a circular pattern. Due to the conical scanning, a Wind Vector Cell (WVC) is generally viewed when looking forward (fore) and a second time when looking aft. As such, up to four views emerge: H-pol fore, H-pol aft, V-pol fore, and V-pol aft, in each WVC. The 1800-km-wide swath covers 90% of the ocean surface every 24 hours with a resolution of 25 km. On the other hand, the wind retrieval from SeaWinds data is not trivial, since the number of views and their azimuth angles vary with the subsatellite cross-track location.

In the wind retrieval procedure (Portabella and Stoffelen, 2004) a set of radar backscatter measurements (observations) in each cell is inverted into a set of ambiguous wind solutions. The inversion output is then used, together with some additional information (from NWP models) and spatial consistency constraints, to select one of the ambiguous wind solutions as the observed wind for every WVC. This is called ambiguity removal (AR), and in contrast with the inversion, which is performed on a WVC-by-WVC basis, the AR procedure is spatially filtering many neighbouring WVCs at once. An important aspect of wind retrieval is the quality control (QC). The goal of the QC is to detect and reject poor-quality retrieved winds, produced by

WVC contaminated by sea ice, confused state sea, rain. The Weather Service of the Netherlands (KNMI) generates a near real time 100 km resolution QuikScat wind product (BUFR format) developed for assimilation in numerical weather prediction models, which includes inversion, QC and ambiguity removal. A so-called "Index of selection" is encoded in the QuikSCAT wind BUFR files, in order to select the wind vector extracted by the 2D-Var Ambiguity Removal performed at KNMI.

At CNMCA KNMI-produced wind vectors are assimilated at their full nominal resolution. These data have been considered as conventional surface wind observations: the observation operator consists of a spatial interpolator of the post-processed surface wind forecast field of the HRM model. This field has proven to be an accurate predictor of the Quikscat product. The observation minus background statistics show no appreciable bias in both (u,v) components and a RMS wind vector difference of around 3m/s. These wind observation increments are then ingested, together with all the other available surface pressure and wind reports, in a multivariate (surface pressure and wind vectors) 2D-Var objective analysis of the surface pressure field. An example of the surface pressure analysis increments thus obtained is given in Fig.2.

4. METEOSAT AMV WINDS

Atmospheric motion vectors (AMV) are derived from sequences of well navigated and calibrated geostationary satellite images. This derivation is mostly an automatic procedure, using three consecutive infrared, visible or water vapor images typically taken at half hourly intervals (or less, as is the case with the new Meteosat 8). The use of water vapor images to calculate winds means that information can be obtained in clear, as well as in cloudy, regions of the atmosphere. 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 within that hour, 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. Typically the AMV horizontal density is of synoptic scale (~100 km). The AMV quality control in the data assimilation system is necessary to decide which data are acceptable for inclusion in the NWP model. In certain cases, tracer motion may not equate to the wind (Convective, orographic clouds).

The height level of the vector needs to be assigned and this is done by comparing the measured cloud-top temperature with external information such as a forecast model temperature profile. Representativity problems are usually less severe than those associated with other types of point data, since the observing technique implies that a volume measurement roughly comparable to the model resolution is provided.

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 neighbors (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. A typical METEOSAT 5-7 product distributed in BUFR code contains up to 2000 winds together with the associated QI.

In the present study BUFR encoded high resolution Meteosat 5-7 AMVs (Fig.3) in the visible and water vapor channels were used. Wind vectors are thinned at 1 degree horizontal resolution and 20 hPa in the vertical, selecting the wind vectors with the highest QI. QI thresholds used in the trials have been similar to those currently used in many NWP Centers (0.65 for High Resolution Visible winds, 0.80 for High Resolution Water Vapor winds; see EUMETSAT “Usage of Wind Products from Geostationary Satellites at Major NWP Centers”, available online at www.eumetsat.de). Winds are not used over land north of 35° N, considering the dense synoptic network available there, but are retained south of 35° N in order to cover the vast desertic North Africa area.

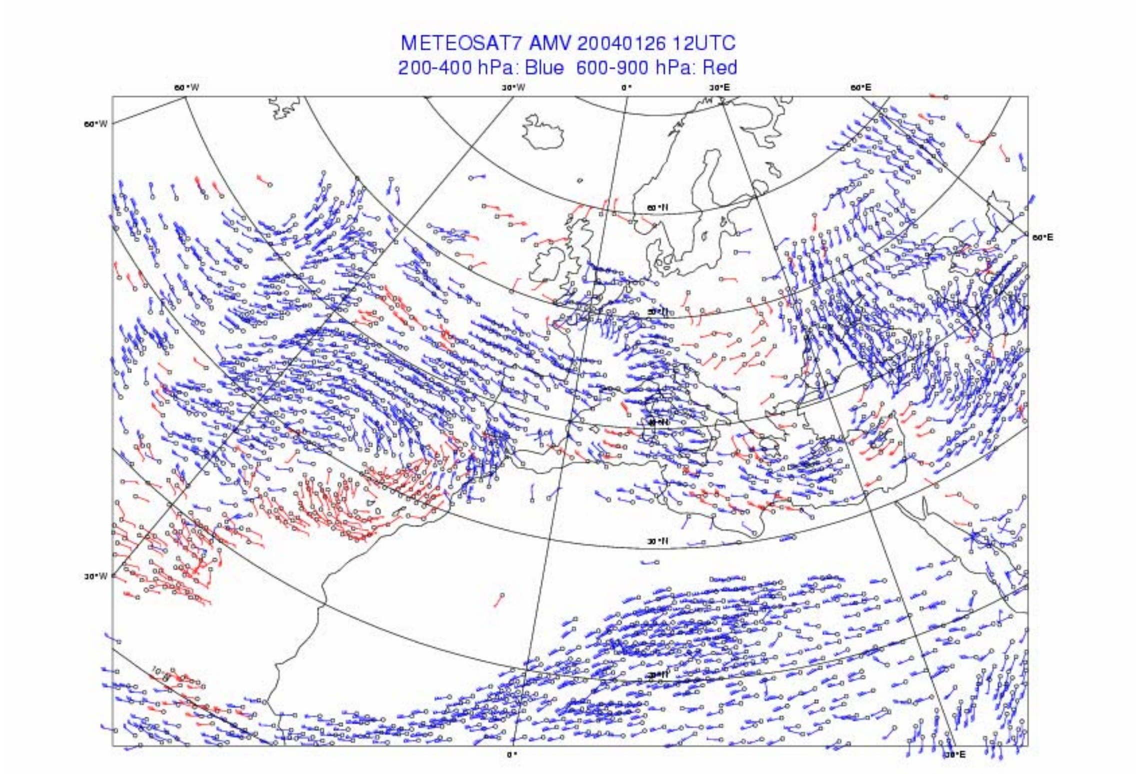

Figure 3: Example of METEOSAT 7 AMVs in the upper (blue) and lower (red) troposphere from High Resolution Water Vapour and Visible channels over the CNMCA Regional NWP system domain.

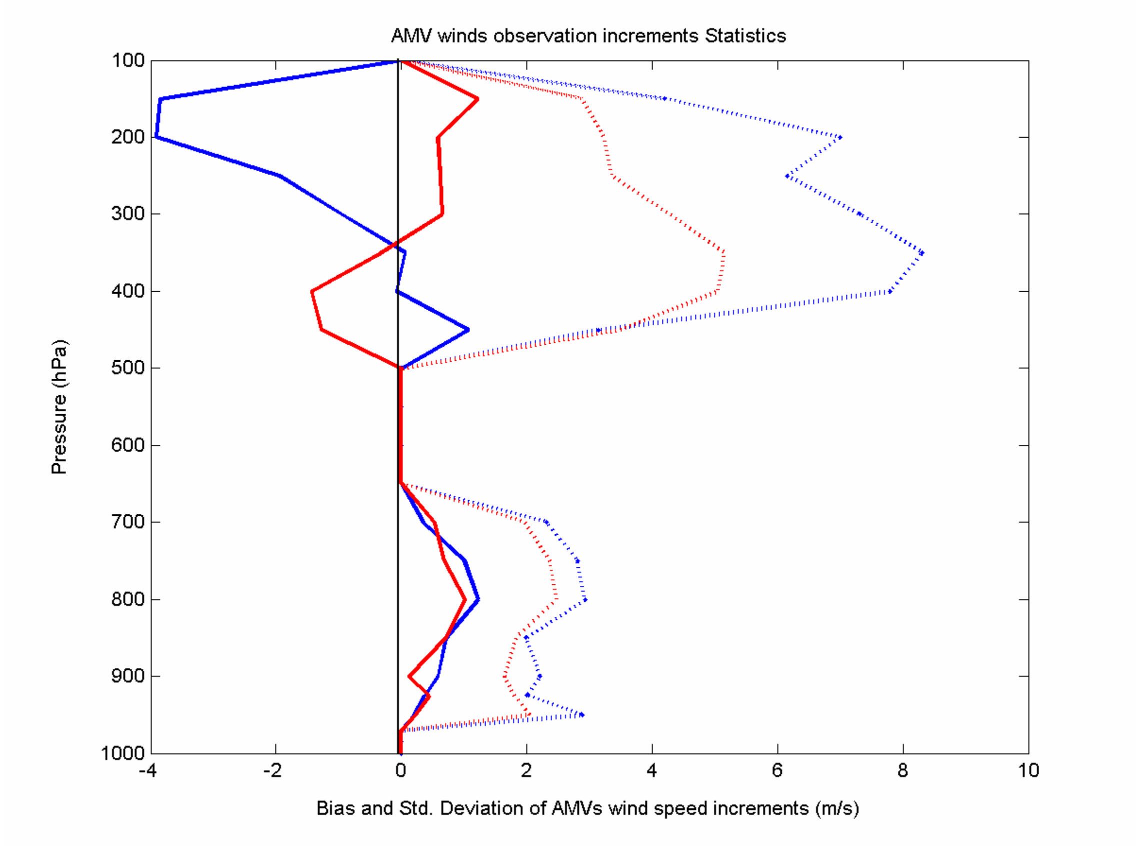

Figure 4: AMVs wind speed bias (solid) and standard deviation (dashed) with respect to the t+6h EURO-HRM first guess field. Red lines for height adjusted observations.

Assumed wind components observation errors are in the range 4-6 m/s, increasing with height. As pointed out by many authors (see, for example, ECMWF, 2000), AMVs winds tend to underestimate the jet intensity in the extra tropics, and this feature was confirmed by a consistent negative bias near jet pressure levels found in the statistics of the observation increments with respect to the model first guess field (Fig.4). Since one of the most uncertain parts of the AMV wind product is the reported height, where forecast fields information is also used, it was decided to adjust the “observed” pressure of the winds by the minimization of a simple cost function *J* which measures the discrepancy between the AMV data and the model first guess corresponding values:

$$J = \left(\frac{u_0 - u_{fg}}{\Delta u}\right)^2 + \left(\frac{v_0 - v_{fg}}{\Delta v}\right)^2 + \left(\frac{p_0 - p_{fg}}{\Delta p}\right)^2,$$
$$\Delta u = \Delta v = 3ms^{-1} \qquad (2)$$
$$\Delta p = 60\,hPa$$

where $u_{o/fg}$,$v_{o/fg}$ and $p_{o/fg}$ are the observed/first-guess values of wind components and pressure. This simple pre-processing step has led to an effective reduction of both the observation increments bias at upper and lower levels and their associated standard deviations (Fig.4). The usefulness of the height adjustment step has been also confirmed by a limited forecast impact study (not shown here) where two parallel data assimilation cycles were run, with and without the height corrections. Slight but consistent improvement of forecast accuracy (~0.2-0.3 m/s in wind vector STDV at +24h) was found especially near jet level.

5. IMPACT STUDIES

In order to gauge the impact of the different observation types two OSEs were performed.

Parallel data assimilation cycles were run, one making use only of the standard synoptic observations available (TEMP, PILOT, SYNOP, SHIP, BUOY plus WIND Profiler data) while the other ingested the new observation type as well. Once a day two extended EURO-HRM model runs to +48h from the 00Z analysis fields were performed. Forecasts fields have been verified against observations from the European upper air network and surface synoptic observations covering the whole integration domain. Mean error and RMSE of surface variables (two meter temperature, ten meter wind, mean sea level pressure), as a function of forecast time (every 6 hours), have been computed. Temperature and wind vertical profiles of mean error and RMSE at the standard pressure levels for t+12, t+24, t+36 and t+48 forecast steps have been also calculated.

Results are now given in detail.

1. QUIKSCAT Surface Winds Experiments

Sample results from a statistical comparison in the period 8 December 2003 – 14 January 2004 are plotted in Fig. 5. Red and blue lines represent scores for the runs with and without the ingestion of Quikscat data, respectively. No significant differences are found (not shown) in the RMSE and ME vertical profiles of temperature and wind vector. A slight positive impact in the surface parameters is found for the mean sea level pressure starting from T+18h onwards. Though the absolute value of the gain in forecast skill is small (~0.1hPa), it must be considered that the conventional surface network in place in the analysis domain is relatively dense even in oceanic areas. The fact that Quikscat winds, which are mostly available over the analysis domain only twice a day (around 06 and 18 UTC), are able to provide even a marginal positive impact is, from our point of view, remarkable and a clear indication of their potential in more sparsely observed oceanic areas.

2. AMV Observing System Experiment

The statistical evaluation of the impact of Meteosat 5-7 AMV winds in the CNMCA NWP system was performed during the period 16th December 2003 - 31st of January 2004. The ME and RMSE vertical profiles of temperature and wind vector for forecasts T+24h and +48h are plotted in Fig. 6. Red and blue lines give the scores with and without the ingestion of AMV winds, respectively.

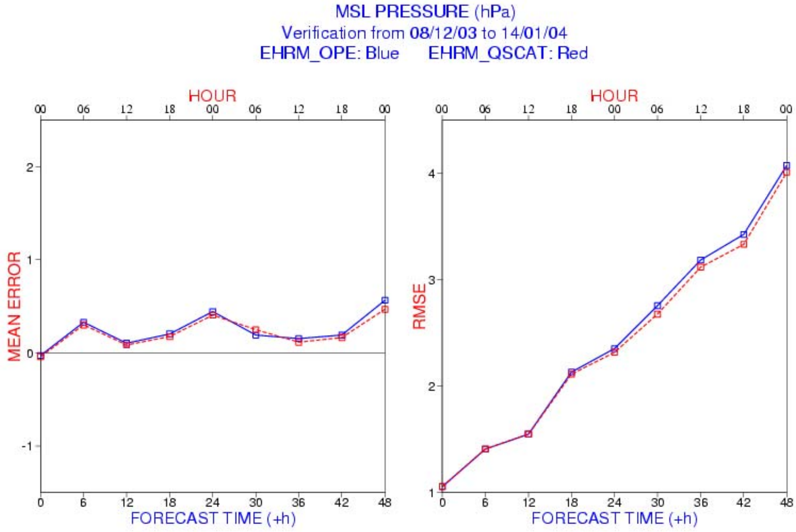

Figure 5: Mean errors and RMSE of EURO-HRM MSL pressure forecasts from CNMCA 3DVar analysis with (red) and without (blue) the ingestion of Quikscat retrieved winds verified against lowland SYNOP observations.

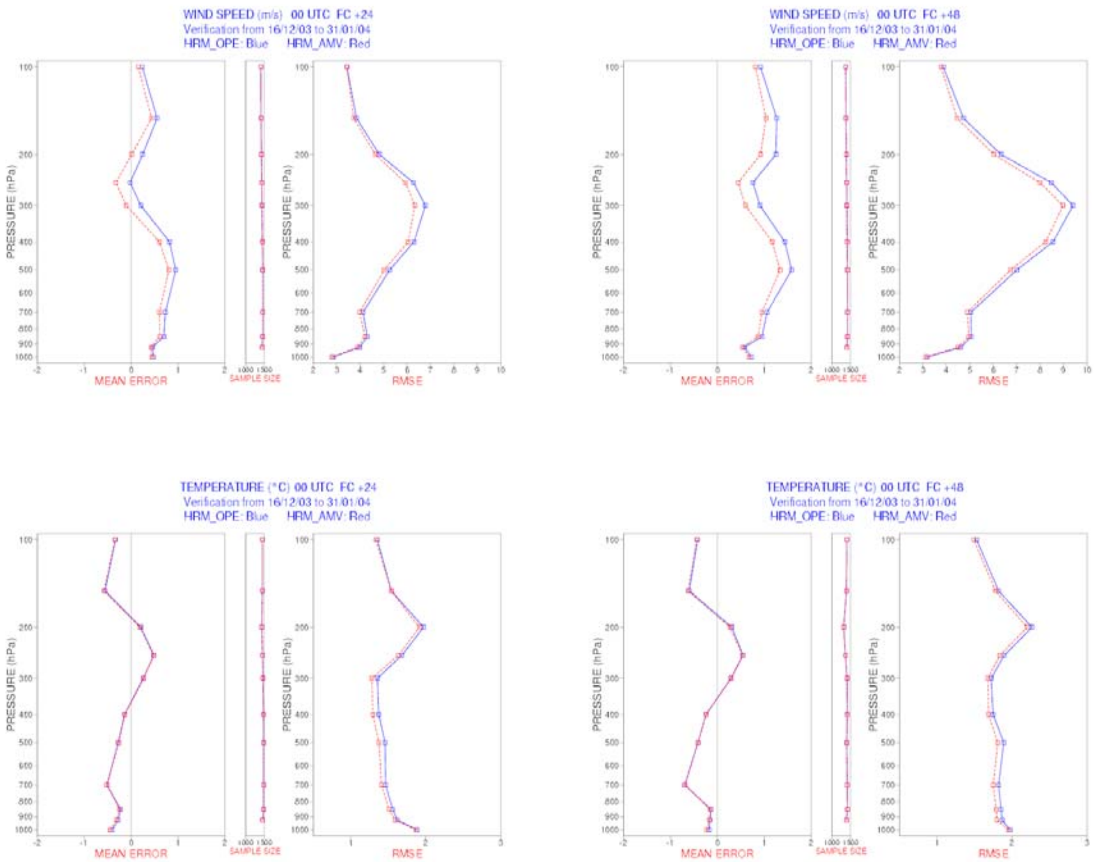

Figure 6: Wind speed and temperature mean error and wind vector and temperature RMSE of EURO-HRM t+24, t+48h forecasts from CNMCA 3DVar analysis with (red) and without (blue) the ingestion of Meteosat 5 and 7 AMV data verified against European RAOB observations.

The AMV winds have a clear positive impact in the temperature and wind vector accuracy in the 200-900 hPa layer, where the bulk of the observations are found. Particularly noticeable is the reduction of the wind vector RMSE around jet level (200-400hPa layer). A significant impact is also found on the wind speed ME, which indicates the effectiveness of these observations in ameliorating the model bias.

6. CONCLUSIONS AND FUTURE DEVELOPMENTS

Inclusion of satellite derived winds from near surface QuikScat scatterometer observations and upper level Meteosat AMVs has proved beneficial for the forecast skill of the CNMCA Regional NWP system. However observations are to be carefully monitored to prevent spurious biases from entering the objective analysis. In the case of AMVs a light observation thinning is also required to prevent numerical instability problems in the minimization step and also to be able to make the commonly used assumption of statistically independent observation errors.

Encouraged by these results work is now in progress towards the inclusion of more satellite derived wind products. For the surface analysis we are implementing the operational procedures for the ingestion of the recently revived ERS2 data. The ERS2 scatterometer winds should be an effective complement to the QuikScat data considering that the satellite crossing times are shifted about 5 hours with respect to the QuikScat ones. For the upper level analysis, Meteosat Second Generation (MSG) AMVs have become available early this year and are now used in an experimental data assimilation cycle at CNMCA. Their effective use requires special consideration in view of the much larger amount of data due to the increased temporal and spatial resolutions. Preliminary results, however, indicate a 3-5% wind vector RMS error reduction in the t+24h forecasts based on the experimental cycle with respect to the operational one.

7. REFERENCES

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