Recent progress in using satellite winds at the German Weather Service

A. Cress

Deutscher Wetterdienst, Frankfurter Strasse 135, 63067 Offenbach am Main

ABSTRACT

Atmospheric motion vector (AMV) wind fields - derived from tracking cloud and water vapour image sequences - provide the only global tropospheric wind information for numerical weather forecast models and therefore make an important contribution to the global observing system, particularly over the oceans or polar regions, were there are either no other or only very few conventional wind observations. Additionally, space-bourne scatterometer data provide near surface wind observations (both wind speed and direction) over the global oceans with high temporal and spatial resolution under most weather conditions. Results of various impact studies demonstrate the positive benefit of using AMV and scatterometer wind products in the data assimilation system of the German Weather Service (DWD). Currently, the DWD uses AMV wind data from 5 geostationary satellites (GOES 11/12, METEOSAT 7/9, MTSAT-1R and 2 polar satellites (MODIS from TERRA and AQUA). Since mid 2009, scatterometer wind data from QuikScat and ASCAT are used routinely.

Monitoring of AMV wind vectors, product upgrades and the evaluation of new wind products which have the potential to improve the quality of analyses and forecasts, are ongoing tasks at DWD. This presentation will give an overview of recent progress in the assimilation of AMV and scatterometer data at the German Weather service. Polar winds have been recently derived by CIMSS and EUMETSAT from infrared AVHRR imagery from the NOAA and METOP satellites. Having in mind, that the MODIS instrument is already operating beyond its lifetime and that no mission is planned to replace the MODIS WV channel instrument in the near future, the AVHRR winds can be used to either supplement MODIS winds through additional spatial and temporal resolution or to replace the winds after the instrument stops working. Several month long impact experiments showed a comparable quality between MODIS and AVHRR polar winds and a slightly positive impact on both hemispheres and Europe could be detected. In addition, direct-broadcasting MODIS winds are available now to improve the timeliness of polar winds in the assimilation resulting in a greater coverage for the early cut-off run at DWD. Furthermore a larger number of polar winds can be used in the assimilation run resulting in a small but consistent positive impact on both hemispheres in spring and summer. In addition, results of an impact study, initiated by the International Wind Working Group, demonstrating the positive impact of wind vectors derived from geostationary and polar satellites for the winter 2007/2008, will be presented. The assimilation of scatterometer data from QuikScat and ASCAT requires a careful data selection with regard to rain and ice contamination and in case of QuikScat a bias correction is needed. In general, using the scatterometer data lead to improved analysis and forecast impact in regions were there are only few other wind observations (Southern Hemisphere, Tropics) or in areas with large impact weather systems (tropical cyclones or extra tropical low pressure systems). Additionally, first results of using scatterometer data in the regional forecast model COSMO-EU will be presented.

I Introduction

Atmospheric motion vector wind observations are derived from the changing positions of typical structures (automatic pattern recognition) in three consecutive images made by geostationary or polar orbiting satellites in the infrared, visible and water vapour channels within a certain time period. The so derived wind vectors are assigned an altitude based on radiation temperature of the cloud measured by selective channels. Finally, each wind is assigned a quality index which supplies information regarding the spatial and temporal consistency of winds and to a background field (usually a short-range forecast). Errors can occur not only in pattern recognition but also in height assignment. Such errors substantially reduce the quality of the wind data and their usefulness in data assimilation. Winds in a large area are sometimes subject to the same or similar errors, and similar errors can remain uncorrected over a long time period. When, this happens, the AMV winds contain spatially and temporally correlated errors, which, as yet, can not be accounted for in modern data assimilation systems. Additionally, redundant wind measurements are produced by observing the same tracer in different spectral channels. Consequently, the winds are usually thinned out spatially and temporally before they are used. In addition, winds with an inadequate quality index (QI) are not used at all. Also the assumption, that clouds were conservative randomly distributed within and floating with the airflow, to estimate a unbiased AMV wind is certainly only a first approximation to the real physical behaviour of clouds and depict a serious limitation of using AMV wind fields in NWP systems**.** Currently, the DWD uses AMV wind vectors from 5 geostationary satellites (GOES 11/12, METEOSAT 7/9, MTSAT-1R and 2 polar satellites (MODIS from TERRA and AQUA).

Space-borne scatterometer date provide accurate near surface wind observations (both wind speed and direction) over the global oceans with high temporal and spatial resolution under most weather conditions. With an intensification of satellite data usage at the DWD, the implementation of wind observations from the Seawinds scatterometer aboard the QuikScat satellite and from the ASCAT scatterometer aboard the Metop satellite is being worked on. Whereas the Seawinds scatterometer, which operates at KU-band frequency, is very sensitive to rain and ice contamination, which makes a careful elimination of poor quality data necessary, the C-band ASCAT scatterometer wind measurements are relatively independent of rain conditions and only ice contamination has to be eliminated. Therefore a whole new processing chain for both scatterometer data has to be setup at the DWD. Results of various impact studies demonstrate the positive benefit of using AMV and scatterometer wind products in the data assimilation system of the German Weather Service (DWD). Since mid 2009, scatterometer wind data from QuikScat and ASCAT are used routinely.

II Experiment design

Using the global assimilation and forecasting system of the DWD several impact studies for different time periods (winter and summer) were conducted to estimate the potential benefit of AMV wind observations, to test the impact of new wind products (AVHRR winds vectors, direct broadcasting Modis winds) and to investigate the potential impact of the scatterometer wind data from QuikScat and ASCAT. All experiments were compared to the operational forecasts (Control) – in general not using the wind data tested in the experiment – using a verity of conventional (synops, radiosonde , aircraft, buoy) and satellite (AMSU-A form the NOAA Satellites, Metop and Aqua) observations. In general, the DWD uses AMV wind observations only over sea and at synoptic times (00, 06, 12, 18 UTC), with the exception of polar Modis winds (every 3 hours and also over land). Winds derived from the visible channel are used only below 700 hPa and winds from the water vapour cloudy channel only above 400 hPa. AMVs tracked from clear-sky atmospheric motions in the water vapour channel are not used at all. The assimilation processing chain of AMVs at DWD consists of several steps. First a static filtering is conducted through QI thresholds, separately for channels, tropospheric layers and geographical regions and only wind data which exceed the QI thresholds are remain active. Second a thinning step is used in order to take into account the high spatial correlation of the AMV winds. To accommodate the various horizontal resolutions and spatial correlations of the extra-polar and polar AMV wind measurements, two different thinning box widths, ~180 km and ~60 km, were introduced into the processing steps of the assimilation procedure.

In the following quality and impact of different AMV wind products from different satellite processing centres will be described in more detail. Additionally, monitoring and impact results of scatterometer wind observations will be discussed.

III Impact of AMVs in the NWP system of DWD

Results of different impact studies demonstrate the positive benefit of using AMV wind products in the NWP system of the DWD. Fig. 1 compares the impact on forecast quality of an experiment not using any AMV wind vectors in the assimilation (no-AMV All), to a control forecasts using all available observations, to an experiment not using winds from all geostationary satellites (no-AMV Geo) and to an experiment not using polar wind vectors (no-AMV Pol). The No-AMV All experiment shows fairly consistent degradation in forecast quality for the tropical atmosphere and on the Southern

Hemisphere, whereas the forecast impact is much smaller on the Northern Hemisphere, due to a better observation density of, especially conventional (radiosonde, aircraft, synops, buoys) data on the Northern Hemisphere which mask the potential benefit of AMV wind vectors considerably. In the absence of other satellite data, the AMV wind vectors show a much bigger benefit. The impact is largest on the upper tropospheric wind field decreasing with decreasing height and smaller for other fields like geopotential height. Denying only AMV wind vectors from geostationary satellites lead to a similar degradation in forecast quality as not using any AMVs. Obviously, using only polar winds can not compensate for the loss of information content, the AMV wind vectors of the geostationary satellites release to the assimilation system. The loss of polar AMV winds lead to a substantial loss of analysis and forecast quality on the Southern Hemisphere. The impact on the Northern Hemisphere is quite neutral, whereas a small positive impact is observable also on the forecast quality in the tropics.

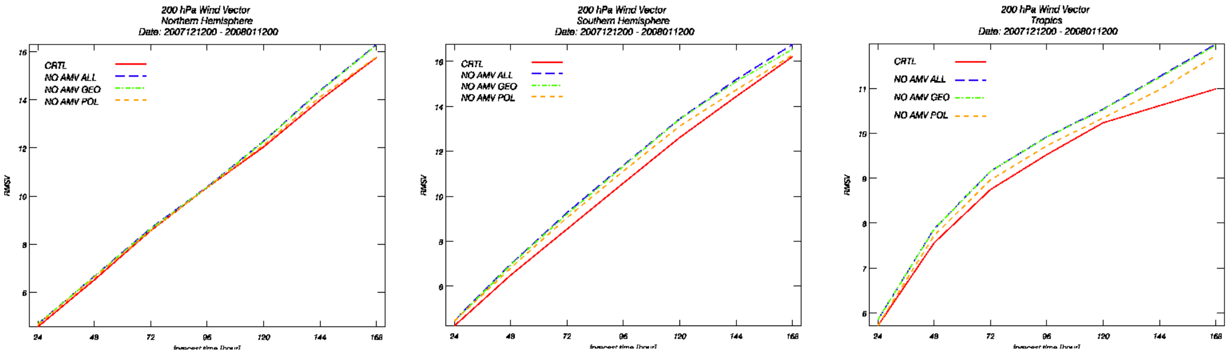

Fig. 1: RMS of 200 hPa wind vector error versus forecast time for the Northern Hemisphere (left), Tropics (middle) and the Southern Hemisphere (right) for the Control and for an experiment not using any AMVs (blue), an experiment not using AMVs from geostationary satellites (green) and an experiment not using polar AMVs (yellow) averaged over the winter period 12th Dec. 2007 – 12th Jan. 2009.

The global distribution of the difference in the RMS of the T+48h forecast error for the 500 hPA geopotential height with and without AMV wind vectors is presented in Fig. 2. The largest error differences are observed in the extra-tropics, where most of the winds are assimilated, whereas in the tropics – where blacklisting is much stricter, the differences in forecast errors are smaller. The largest benefit of assimilating AMV wind vectors is found in the Pacific and Indic Oceans and the smallest benefit in the Atlantic area. Additionally, a strong positive benefit is also obvious in the northern polar region and over parts of Antarctica by assimilating AMV wind vector data. By contrast, the areas of the coast off South America and the north-eastern part of the North Pacific show a small negative impact on the 500 hPa geopotential height field, partly due to a problem with using wind vectors from the MTSAT-1R during the AMV denial trails and partly due to problems receiving AMV wind observations over parts of South America and the surrounding oceans.

IV Use of AVHRR polar wind vectors in the global model GME

In mid of 2008, a new polar wind product became available via EUMETCAST, consisting of polar vector winds derived from AVHRR imagery of polar-orbiting NOAA satellites (NOAA 15/16/17/18) and METOP processed by CIMSS (Key, 2008, Dew, 2008). The wind estimation procedure of AVHRR winds is very similar to that of MODIS winds with the one major drawback that no WV channel is available on AVHRR. Therefore, no WV winds are available, which accounts for about 2/3 of the MODIS wind data. This limits the retrievals to cloudy areas, so the number of wind vectors produced is significantly lower than for MODIS. Furthermore, the height assignment for the remaining IR winds is poorer as no semi-transparency correction can be performed. Having in mind, that the MODIS instrument is already operating beyond its lifetime and that no mission is planned to replace the MODIS WV channel instrument in the near future, the AVHRR winds can be used to either supplement MODIS winds

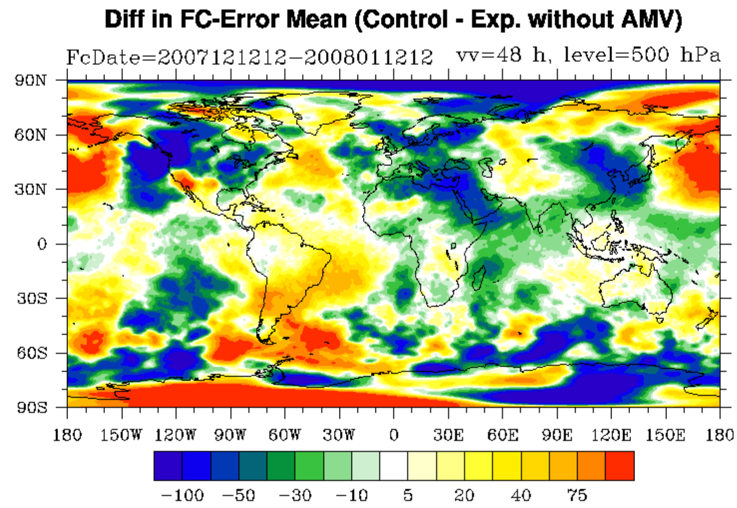

Fig. 2:Difference in mean 500 hPA geoptotential height T+48 hr forecast error for te AMV denial experiment and Control. Green-blue colours indicate benefit from assimilating AMV wind vector data.

through additional spatial and temporal resolution or to replace MODIS winds after the instrument stops working.

Using the global assimilation and forecasting system (GME) of DWD, an impact experiment for the period 1 Oct. - 31 Oct. 2008 was conducted to estimate the quality and potential benefit of AVHRR winds. The experiment was compared to operational forecasts (Control), using a variety of conventional (synop, radiosonde, aicraft, buoy) and satellite (AMSU-A from the NOAA satellites, METOP, AQUA and various AMV winds) observations. In the impact experiment, the AVHRR winds were treated in the same way as the MODIS winds in the Control run.

The impact of additional AVHRR wind vectors on the quality of the global analyses shows only small differences over the northern polar regions, whereas the South Pole area depicts larger differences with a tendency to higher wind velocities over the Antarctic peninsula and decreasing wind speeds along the coastal areas and over the Wedell Sea (not shown). The vertical distribution of RMS departures and biases of radiosonde observations from the first guess and analysis fields for the experiment using additional AVHRR wind vectors and the Control are compared in Fig. 3, separated for the North and South Pole regions. A pronounced reduction of the wind speed bias occurs in the mid-tropospheric levels of the southern polar region, whereas the northern polar area shows only a small bias reduction in the upper troposphere. A reduction in wind speed RMS departure from the first guess field can be seen in the whole troposphere but more prolonged over the southern polar region than over the northern polar area. Additionally, the fit of MODIS observations to the first guess and analysis within the area of influence by AVHRR winds increased slightly (not shown). The overall impact of using AVHRR wind vectors is neutral to slightly positive, depending on season and weather situation. For the experiment in October 2008, a small positive impact is obvious for the Northern Hemisphere and Europe and mainly neutral for the Southern Hemisphere and the Tropics (Fig. 4). The positive impact on the Northern Hemisphere and Europe is not caused by a single forecast event but by a period of a few days, where the use of AVHRR winds leads to a slightly increase in forecast quality, especially for the Atlantic/European area.

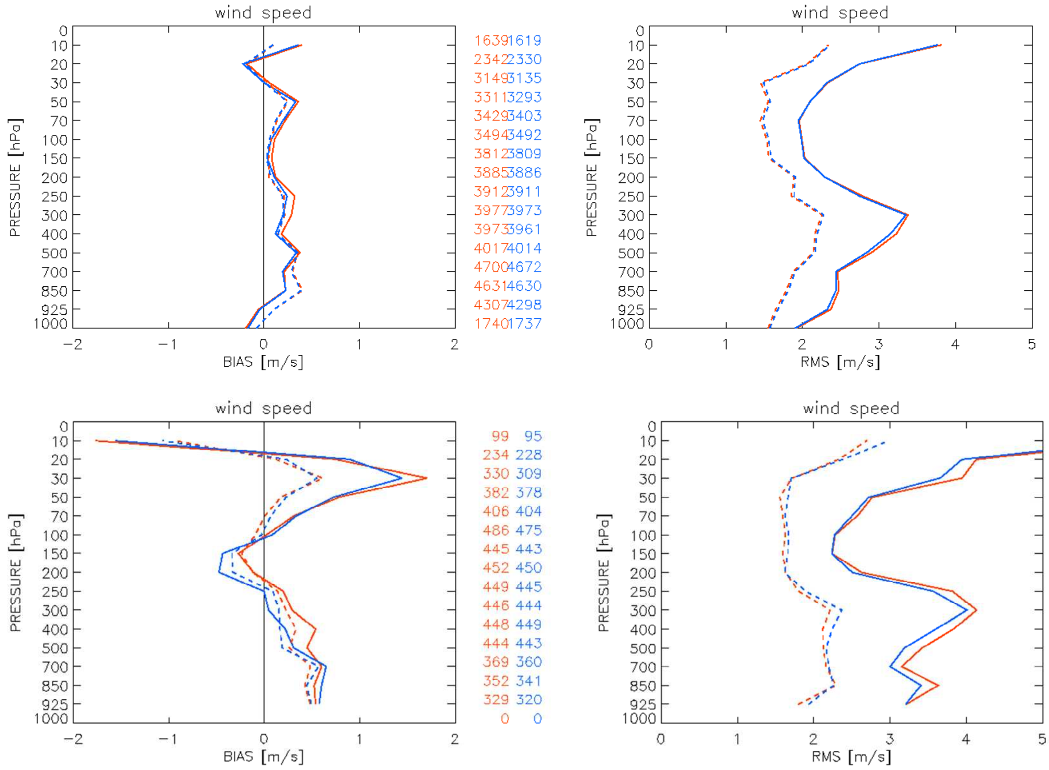

Fig.: 3: Comparison of bias (left) and RMS (right) of used radiosonde observation departures from first guess (solid) and analysis (dashed) for the Northern (above) and Southern (below) Hemisphere for the Control (red) and an experiment using AVHRR wind vectors (blue). The numbers indicate the observations which are used in the experiment and the Control run, respectively. The averaging time period is October 2008.

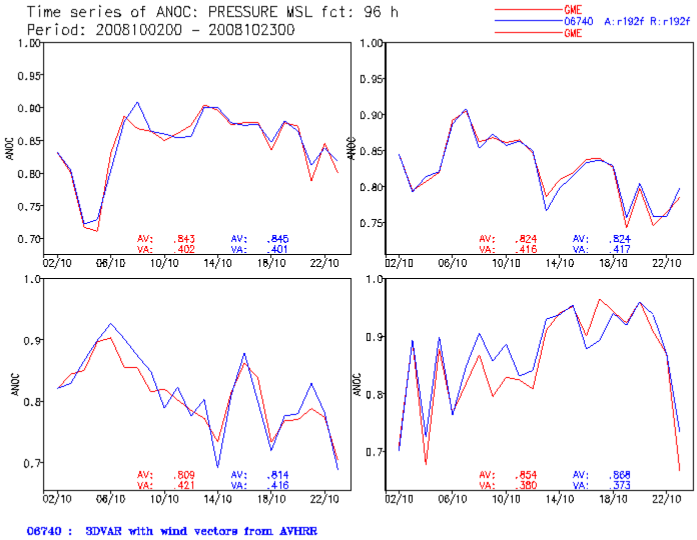

Fig. 4: Time series of anomaly correlation coefficients for 96 hours forecasts of sea level pressure for the experiment using AVHRR polar wind vectors (blue) and Control (red) and the regions Northern Hemisphere (upper left), Tropics (upper right), Southern Hemisphere (lower left) and Europe (lower right).

IV Use of direct broadcasting (DB) polar wind vectors

Direct broadcasting Modis winds have been received at DWD since 2008. The data are received and processed directly at different direct broadcasting stations in the Arctic and Antarctica region and immediately transmitted via Eumetcast to the different NWP centers in order to improve the otherwise poor timeliness of the global NOAA/NESDIS MODIS wind product. On average, at latency of 3-5 hours is typically observed at DWD for the NESDIS MODIS product, which is considerably reduced in case of the DB Modis winds. On average, the DB Modis winds are 2-3 hours early available in our data base system. Timeliness is particularly crucial for NWP centres with short cut-off assimilation times for its main forecast runs. For instance, the DWD has a cut-off time of 2:15 hours after 00 or 12 UTC for its main forecast runs, and data which arrive later can only be used in its assimilation cycle, to improve the first guess, and not for the assimilation of its main run. The latency of the NOAA/NESDIS Modis wind product means, that typically no Modis winds can be used in the analyses for the main forecast runs at DWD. Using the DB Modis winds improves the latency considerably, leading to the use of several Modis wind vectors in the analyses of the main forecast runs.

Using the global assimilation and forecasting system (GME) of DWD, an impact experiment for the period 26 Apr. - 31 May 2009 was conducted to estimate the quality and potential benefit of DB Modis winds. The experiment was compared to operational forecasts (Control), using a variety of conventional (synop, radiosonde, aicraft, buoy) and satellite (AMSU-A from the NOAA satellites, METOP, AQUA and various AMV winds) observations. In the impact experiment, the DB Modis winds were treated in the same way as the MODIS winds in the Control run.

A continuous monitoring of the quality of DB Modis winds could not find any degradation in quality compare to the NOAA/NESDIS Modis winds (not shown). Using the DB Modis winds lead to small but consistent positive impact on the forecast quality of the global model at DWD in both hemispheres and Europe (Fig. 5). The positive impact on the forecast quality for Europe is not due to a specific synoptic situation but rather to a continuous improvement of forecast quality over the whole period.

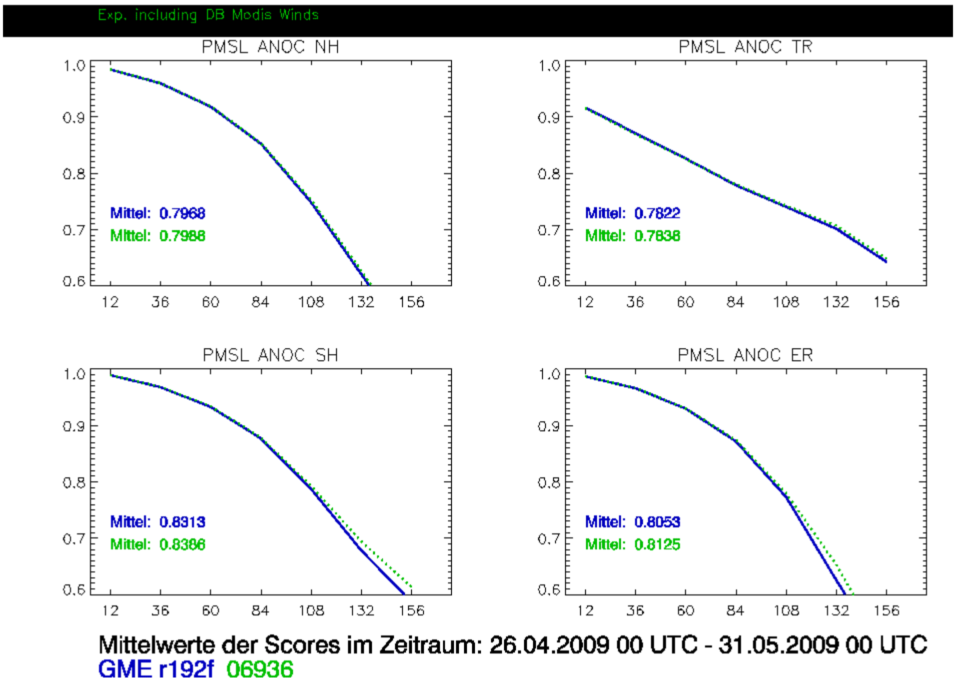

Fig. 5: Anomaly correlation coefficient of the mean sea level pressure for the Control run (blue) and an experiment using DB Modis wind vectors (green) averaged over 36 forecasts for Northern Hemisphere (upper left), Tropics (upper right), Southern Hemisphere (lower left) and Europe (lower right).

V Assimilation of scatterometer wind data into COSMO-EU

Space-borne scatterometer data provide accurate near surface wind observations (both wind speed and direction) over the global oceans with high temporal and spatial resolution under most weather conditions. The high temporal and spatial resolution makes this data source also an interesting observation system for limited area models with an integration domain partly of oceanic areas. The assimilation of scatterometer wind data requires careful data selection with respect to rain and ice contamination.

Therefore a new processing chain at DWD is established taking into account a rain-flagging algorithm developed at KNMI, a careful elimination of land or sea ice contaminated wind vectors and, in case of scatterometer winds from QuikScat, a bias correction for observed wind speeds. This leads to a substantial increase in wind speed correlation between wind data from QuikScat and collocated first guess wind speed data from 0.66 for all data to 0.82 for quality controlled data.

In order to use scatterometer data in the COSMO-EU nudging scheme one single wind vector has to be selected out of the up to four wind vectors supplied by the data producers. All quality control and bias correction steps developed for use in the global model GME were also taking into account in the COSMO-EU assimilation environment. In several idealized test case studies the 10-m wind vector information provided by the scatterometer data are widely rejected by the COSMO-EU unless the mass field is explicitly balanced. Therefore a new COSMO-EU version was developed, were starting from 10-m wind analysis corrections surface pressure corrections are derived which are in geostrophic balance with the 10-m wind analysis increments. After the implementation, the new model system now

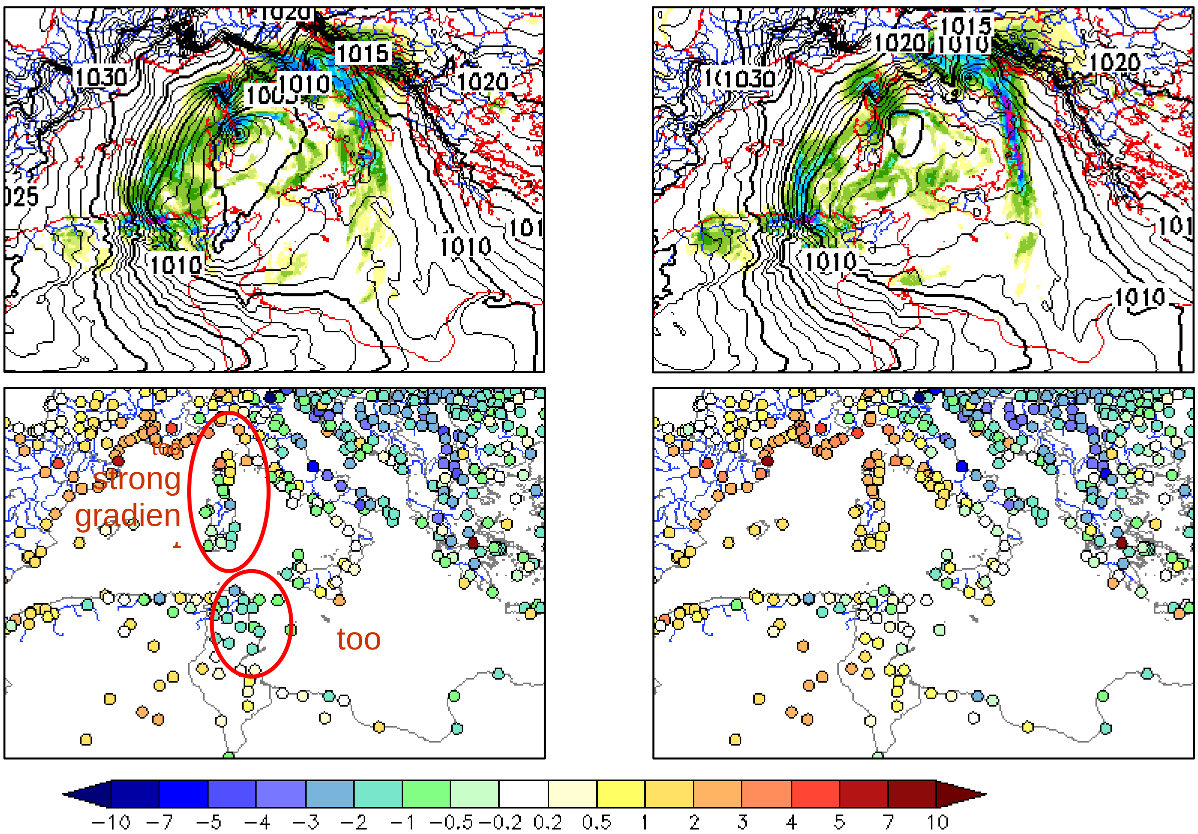

Fig: 6: Comparison of a 9-hour forecast of mean sea level pressure and precipitation for a control run not using any scattererometer data (upper left) and an experiment using scatterometer (QuikScat and ASCAT) observations (upper right). Additionally, the lower panels show the mean sea level differences to SYNOP observations for the corresponding experiments accepts the scatterometer data predominantly. Several case studies and an experiment over a longer time period in summer 2009 were conducted to estimate the possible impact on the forecast quality of COSMO EU. In Fig. 6 a case study for 9^{th} May, 2008 is illustrated, where a low pressure system in the Mediterranean causes heavy rain in Corsica, Sardinia and Tunisia. The control experiment not using any scatterometer data deepens the low pressure system, with a maximum off the coast of Corsica to much, leading to an overemphasized rain fall in Corsica and Sardinia, whereas the experiment using scatterometer data is able to reduce the gradient off the coast of Corsica substantially, leading to more realistic rain fall amounts in Corsica and Sardinia and reducing the observed bias compared to the SYNOP observations over Corsica, Sardinia and Tunisia considerably. The positive benefit of using scatterometer data in the regional COSMO EU model could also be confirmed in an almost month long experiment (not shown), especially for the 10m wind field and the sea level pressure, leading to an operational use of scatterometer data in the regional COSMO EU model as well as in the global model of DWD.

VI References

Holmlund, K., 1998: The utilization of statistical properties of satellite-derived Atmospheric Motion Vectors to derive quality indicators. Weather and Forecasting, 13. 1093-1114.

Dew, G., 2008: AVHRR polar winds derived at EUMETSAT: Current status and future developments. In Proceedings of the 9th International Winds Workshop, Annapolis.

Key, J., Santek, D., Velden, Ch., Daniels, J., Dworak, R., 2008: The polar wind product suite. In Proceedings of the 9th International Winds Workshop, Annapolis.