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ASSIMILATION OF WATER VAPOR RADIANCES FROM GEOSTATIONARY IMAGERS IN 4DVAR

Christina Köpken[1], Graeme Kelly, Jean-Noël Thépaut
ECMWF (European Centre for Medium-Range Weather Forecasts)
Reading, United Kingdom

1. INTRODUCTION

While the direct assimilation of radiances from sounding instruments on polar orbiting satellites is well established for numerical weather prediction (NWP), data from geostationary imagers have primarily been used either in the form of atmospheric motion vectors derived from tracking features in the imagery or in the form of cloud top information.

Here, the approach of directly assimilating radiances from geostationary imagers within the 4-dimensional variational assimilation system (4DVAR) of ECMWF is described. Currently, emphasis is being put on using radiances from the water vapour (WV) channel. They provide valuable information on the upper tropospheric humidity field which is in the ECMWF assimilation only constrained by WV radiances from the polar orbiting NOAA satellites (channel HIRS-12) and radiosondes (being scarce over the tropics and oceans and only used up to 300 hPa). Additionally, the 4DVAR can take advantage of the high frequency observations from geostationary platforms by extracting information on the wind field from the movement of WV patterns in a sequence of images. The assimilation of geostationary radiances became operational at ECMWF on 9 April 2002 using WV radiances of the European Meteorological satellite METEOSAT--7 (Köpken et al., 2002). The WV radiances are used in the form of area averaged clear sky radiances or brightness temperatures (called CSR or CSBT). For satellites from the METEOSAT (MET) series, the CSR are processed by EUMETSAT (European Organization for the Exploitation of Meteorological Satellites, Germany). Following the encouraging results with these CSR data, a similar product for the two GOES satellites has been derived and distributed since November 2001 by the Cooperative Institute for Meteorological Satellite Studies (CIMSS; Schreiner et al., 2003). These data are currently evaluated and being used in assimilation tests both at ECMWF and at the National Center for Environmental Prediction (NCEP; Sue et al., 2003).

After a short description of the data and data quality issues (Section 2), examples of assimilation results and forecast impact will be shown in Section 3 before giving an outlook on ongoing work in Section 4.

2. DATA QUALITY CONTROL AND ASSIMILATION

For assimilation purposes the imager radiances are processed to area averages of clear-sky radiances (cloud detection being done by EUMETSAT and CIMSS) with a resolution of about 50 km and 80 km for the GOES and METEOSAT data, respectively. Before assimilation, a thorough monitoring of the observed brightness temperatures (TB) in comparison to corresponding values computed from the model's short range forecast profiles (first guess, FG) has been carried out in order to detect systematic problems and set up data selection and control criteria. Monitoring, as well as assimilation, is done with the operational model (IFS, Integrated Forecasting System) running globally at a resolution of about 40 km, with analysis increments being computed at about 125 km. The radiative transfer model used is RTTOV-6 in an improved version (Matricardi et al., 2001). The monitoring shows for METEOSAT WV CSBT a distinct positive bias of about 2-3 K compared to the model, while the

[1] *Corresponding author address*: Christina B. Köpken, ECMWF, Shinfield Park, Reading RG2 9AX, UK.
Email: Christina.Koepken@ecmwf.int

GOES-8 (10) CSBT have only a small bias of about 0.7 K (1.4 K). Other WV radiances from the High Resolution Infrared Sounder (HIRS) and the Advanced Microwave Sounding Unit (AMSUB) agree to within 1 K with the model FG. To correct for such biases and to bring the different satellites used to a common level, the observations (OBS) are bias corrected using a regression with model predictors. The coefficients are derived from statistics of OBS minus analysis (AN) differences in the vicinity of radiosondes accumulated over typically about four weeks. The time series of observation minus FG departures show furthermore for METEOSAT anomaly features occuring around local midnight, being strongest during the eclipse periods. They are linked to the intrusion of solar stray light (Köpken et al., 2001) and affected data are excluded from assimilation. The blacklisting depends on time of day and year and is based on two years of monitoring. For the GOES satellites, particularly for GOES-8, a systematic diurnal minimum is visible in the departures and is probably linked to a calibration anomaly caused by the heating of the satellite at local midnight (Johnson and Weinreb, 1996). GOES-8 (10) CSBT are therefore also excluded for currently 4 (2) hours close to local midnight.

The limited number of channels available on the imagers makes a perfect cloud detection difficult. Histograms of OBS minus FG departures show normally a distinct skewness towards colder differences. This is illustrated in Figure 1 showing a scatter plot of departures for the WV channel versus those of the IR channel. An increased number of negative OBS-FG in the WV channel occurs especially for negative OBS-FG values in the IR window, which is indicative of cloud influence. To minimize risk of cloud contaminated OBS being used in the assimilation, a threshold check is imposed on IR departures (over sea) as well as on the percentage of clear pixels used in the CSBT average (over land). Additionally, a FG check and a variational quality control are done. Data are thinned to 1.25° (matching roughly the resolution of analysis increments at 125 km). During data thinning, the points having the highest IR CSBT are selected.

3. INFLUENCE OF WV RADIANCES AND FORECAST IMPACT

To illustrate the structure of increments from WV radiances, Figure 2 shows a vertical cross section through relative humidity increments from an experiment where the only observations used are METEOSAT-7 WV CSBT. The vertical extent of the increments, typically between 100 and 700 hPa, and their peak, typically at 300 to 400 hPa, reflect the sensitivity (weighting function) of the WV channel. This is modulated by the FG error correlation functions (based on forecast error statistics) which shift the vertical extent and peak slightly downwards. As can be seen e.g. at 39°N in the cross section, increments may even extend down to the surface, although the WV channel itself does not contain information about the low atmosphere. Such increments arise from correlations in the FG errors between higher and low levels. The two example profiles given in Figure 3 show this effect: the main peak of increments is located at 250 and 400 hPa, respectively, but small increments (a few percent in relative humidity) occur also at the surface. It is likely that physical parameterizations in the model, e.g. convection, are sensitive to these increments. A new formulation of the humidity analysis is being developed (Holm et al., 2002) and initial tests indicate that it reduces these near-surface increments.

Figure 4 shows in the top panel the mean change in the upper tropospheric humidity (here relative humidity at 300 hPa) due to the assimilation of GOES WV CSBT based on a four weeks 4DVAR assimilation experiment. Within the area covered by GOES-8 and -10, there is characteristically a decrease in humidity in the convective areas of the Inner Tropical Convergence Zone (ITCZ) and the Southern Pacific Convergence Zone (SPCZ) while humidity is increased in adjacent areas (changes being about 2-10 %). The scattered humidity changes outside the GOES areas are caused by a slightly different evolution of weather patterns between the assimilation experiment and the control. The humidity changes in and around the ITCZ are also found over the Atlantic when assimilating METEOSAT-7 CSBT. This influence of the WV radiances is consistent with the model being known to have a too static and hence too moist ITCZ. The increments caused by the geostationary WV CSBT are also consistent with other radiances, as illustrated in the bottom panel: HIRS-12 observations show also higher TB than the model (corresponding to drier/warmer upper troposphere) in the ITCZ and SPCZ.

Figure 5 illustrates the potential of 4DVAR to exploit the movement of WV patterns as observed by the imagers to correct model dynamics in the upper troposphere. The top panel shows the wind vector increments of a 4DVAR analysis of 1st April 2002 using only METEOSAT-7 WV radiances, the bottom panel the corresponding wind field of the FG at 300 hPa. In this case, the influence of the CSR is particularly marked in the region of the trough around 25°N/18°W (west African coast) and at 15°S/10°E (central African coast) and 15°S/20°W (equatorial Atlantic). Wind increments show coherence over a deep vertical layer appropriate to the layer sounded by the WV channel. They occur primarily in the METEOSAT disk area. However, especially in the jet stream areas outside the western edge of the disk, increments extend further upstream. This is linked to 4DVAR using data from the following 12 hours to correct the initial state at the beginning of this observation time window. In such a single case, the quality of the increments is difficult to assess due to insufficient observational coverage especially over the tropical and ocean areas.

Statistics of OBS minus FG differences based on longer experiments, however, show a small improvement in some experiments for tropical wind observations from pilots and aircraft. This indicates a positive influence of the used sequence of WV radiances on the wind field. While the fit of the FG to other temperature observations is unchanged, a closer agreement to other radiance OBS, e.g. HIRS-12 and AMSU-B, is achieved and shows a consistent use of the different radiances in the system.

The impact of the geostationary WV radiances on forecast quality may be assessed in terms of anomaly correlation (between forecast and analysis anomalies compared to a climate) and root mean square errors of forecasts compared to the verifying (e.g. operational) analysis. The impact of both METEOSAT and GOES data is generally positive to neutral depending on the area considered. It should be noted, however, that the forecast impact was found to depend noticeably on the bias correction used. A careful tuning of the used radiances from different satellites is therefore important. A typical forecast impact is given in Figure 6. It is based on a 4 weeks assimilation experiment with GOES-8 and -10 WV CSBT and shows scores for the geopotential at 200 hPa for the extra tropical northern and southern hemispheres for forecasts from one to ten days verified against operational analyses. There is a small but statistically significant positive impact on the southern hemisphere while for the northern hemisphere as a whole this experiment was neutral. Impact over the northern Pacific and northern America was found to be positive for GOES CSBT.

4. CURRENT AND FUTURE WORK

Current work concentrates on introducing the GOES WV CSBT into operational usage. This would extend the coverage with geostationary WV radiances to cover nearly the whole tropical and much of the mid-latitude regions. Further improvements are expected from a reformulation of the ECMWF humidity analysis in terms of scaled relative humidity which will improve increment structures and allow a better weighting of observation and first guess information due to an improved description of model humidity errors. Additionally, work is ongoing at EUMETSAT and CIMSS to add new quality indicators qualifying the reliability of the clear-sky radiance information. This will allow to enhance quality checks of the data for residual cloud contamination.

In future, enhanced imagers with several additional channels in the visible, infrared, and water vapor bands will become available. This ranges from the recently launched European Meteosat Second Generation (MSG) satellite to the Advanced Baseline Imager (ABI) on the GOES follow-on satellites and to the much more comprehensive measurements which can be expected from the planned advanced sounders in geostationary orbit, like the Geostationary Imaging Fourier Transform Spectrometer (GIFTS). But already in the near future, the additional visible and infrared window channels on MSG will considerably improve the cloud detection possibilities and hence the quality of clear-sky radiances. Additionally, the information of two humidity sounding channels at the high time resolution of the geostationary imager will provide more vertical information useful both for the definition of the humidity fields and, in the 4DVAR context, for the indirectly derived wind increments.

5. REFERENCES

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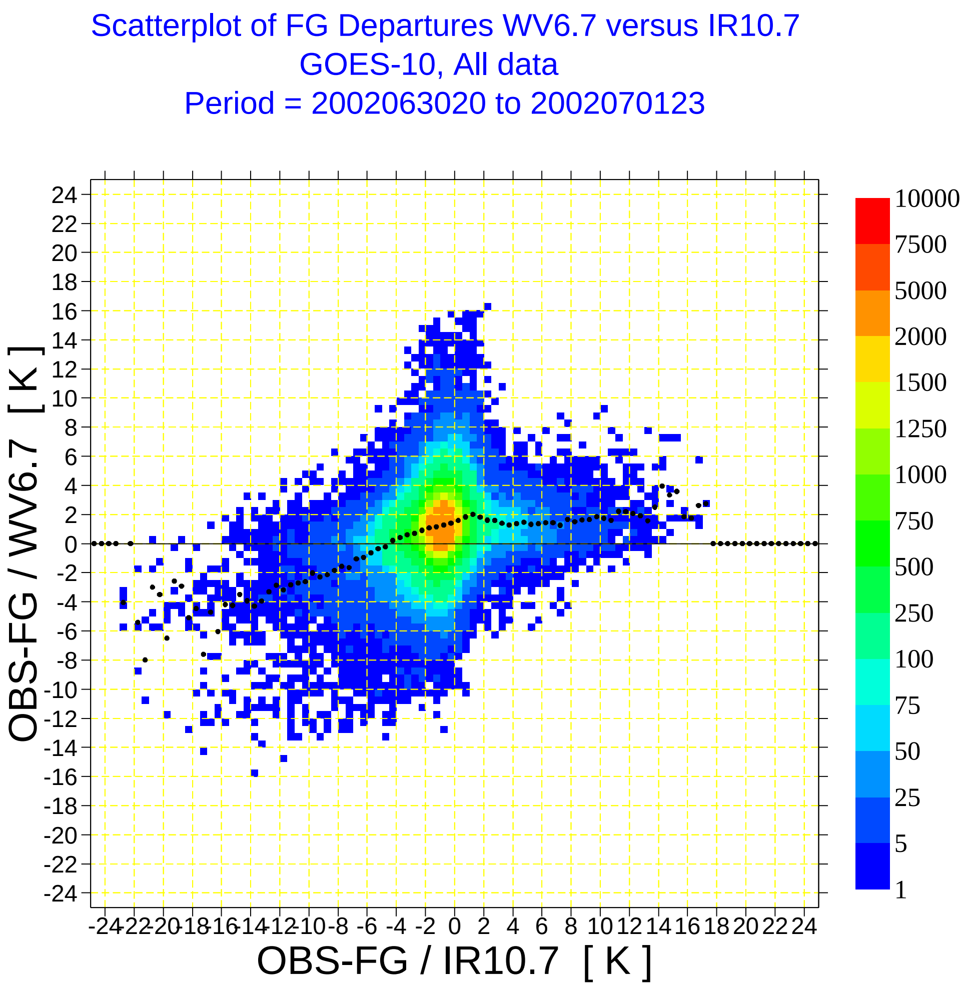


Figure 1: Scatter plot of brightness temperature differences of WV (6.7 μm) CSBT minus model first guess versus differences of IR CSBT (10.7 μm) minus model first guess for data from GOES-10 between 21 UTC 30 June and 23 UTC 1 July 2002.

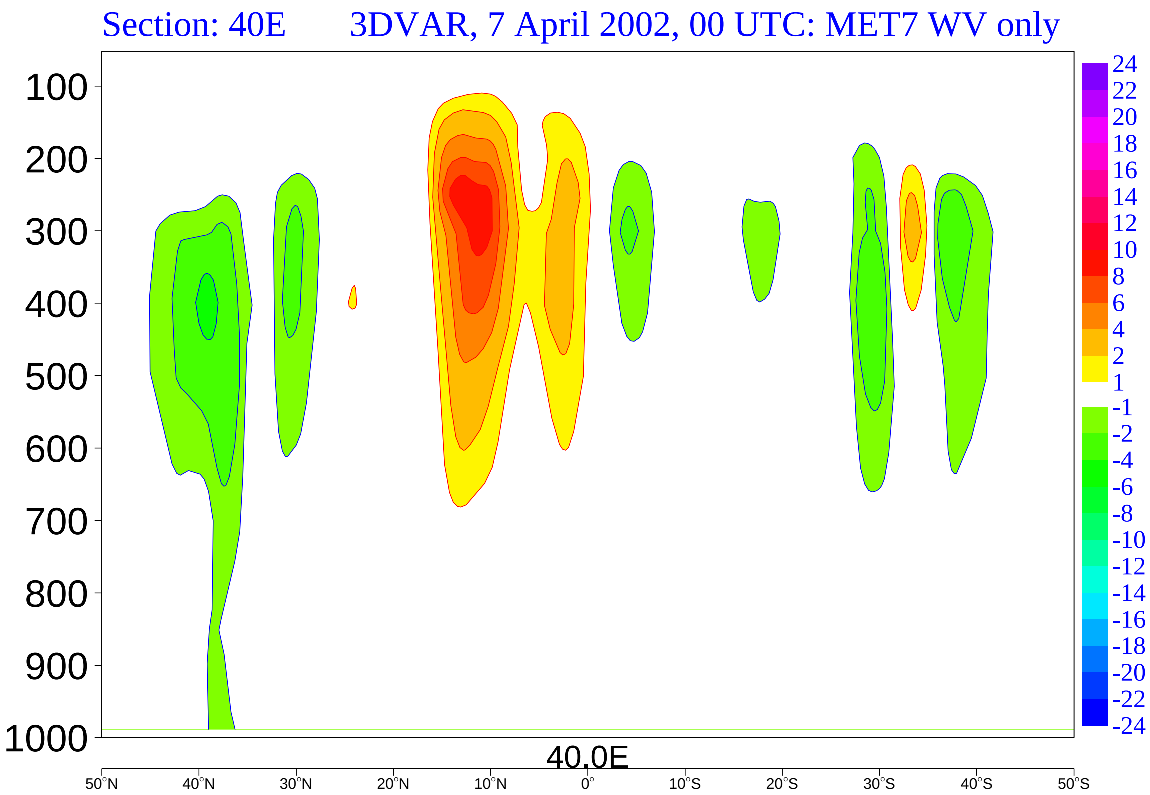
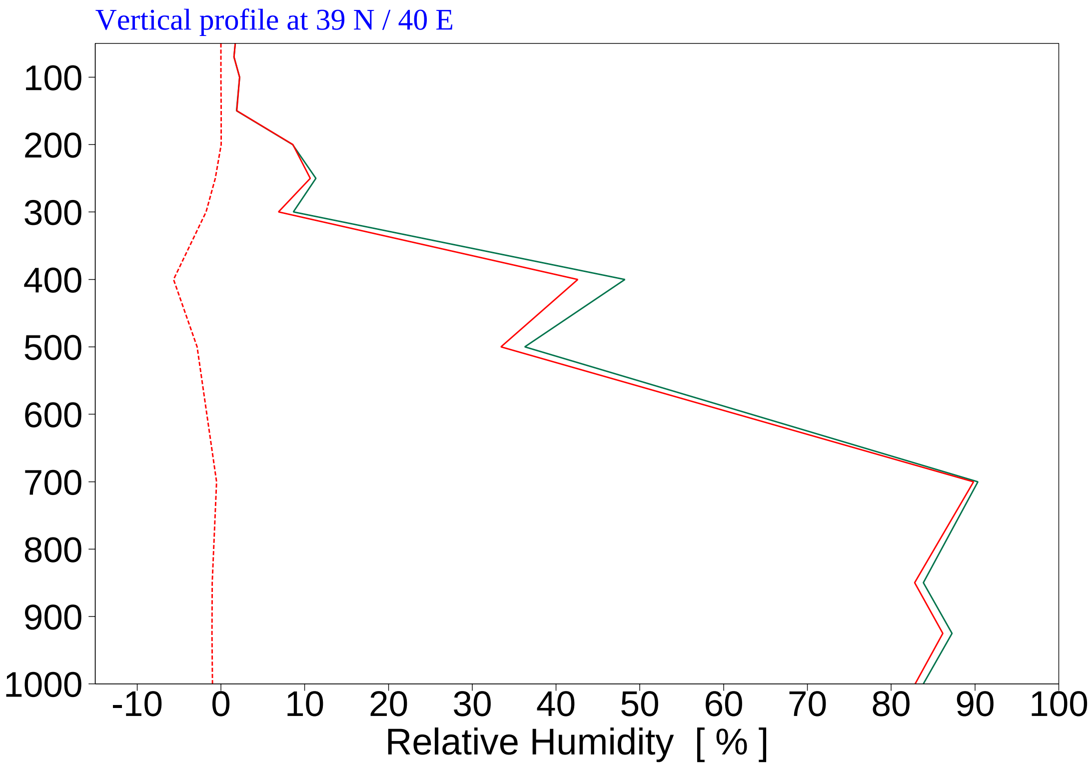


Figure 2: Vertical cross section of increments of relative humidity (analysis minus first guess, in %) for a 3DVAR experiment in which only METEOSAT WV CSBT are assimilated (example 7 April 2002, 00 UTC; vertical axis is pressure in hPa).



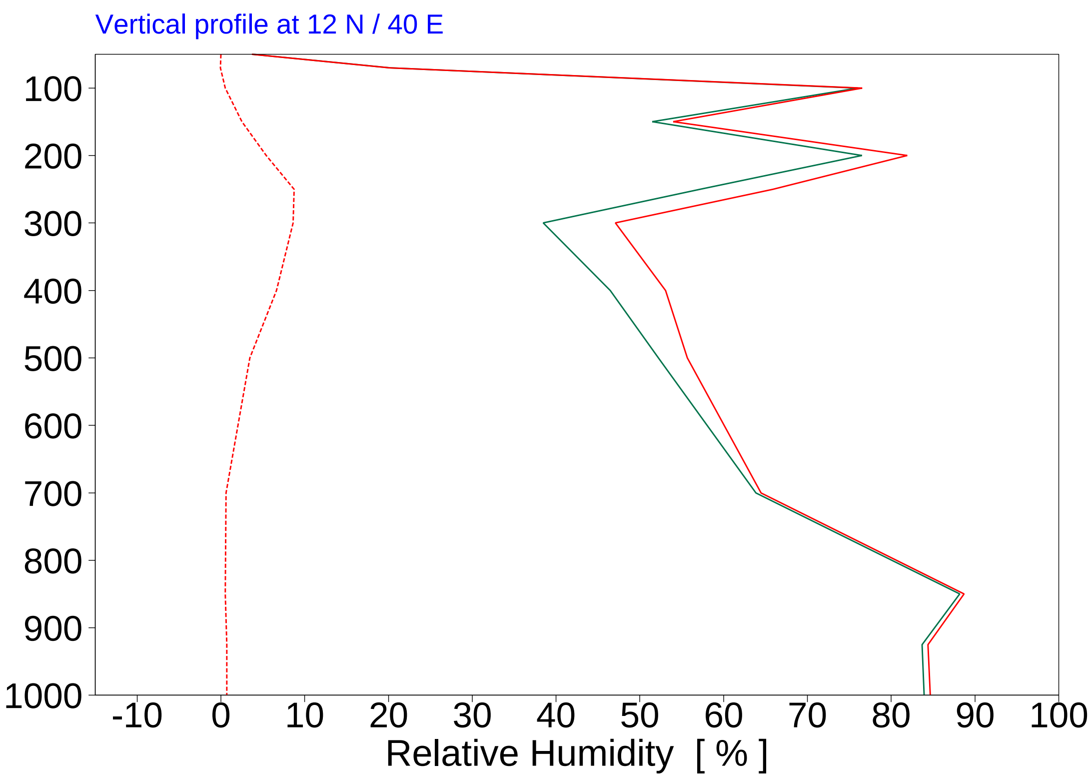
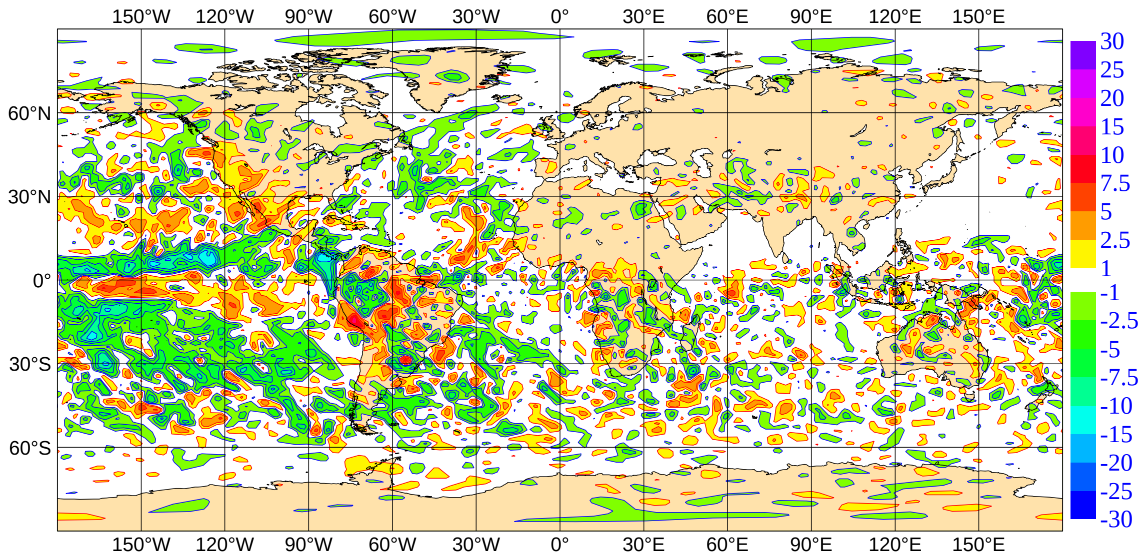


Figure 3: Examples of vertical profiles of relative humidity increments (left red dashed line, in %) taken at 39 degrees N (top panel) and 12 degrees N (bottom panel) from the section displayed in Fig. 1. Also shown are the corresponding relative humidity profiles of the analysis (red line) and the first guess (green line). Vertical axis is pressure in hPa.



Min: -5.1310 Max: 5.6063 Mean: -0.225122

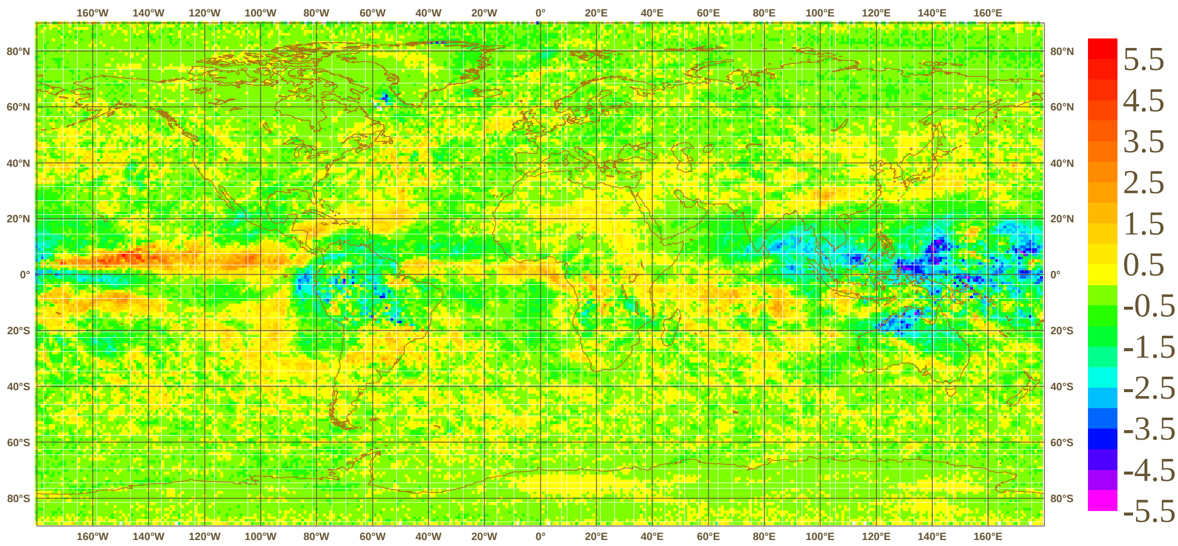


Figure 4: Top: Mean difference in analyzed relative humidity (in %) at 300 hPa between the experiment assimilating GOES WV CSBT and the control. Average is from 1 February to 3 March 2002 for 00 UTC analyses. Bottom: Mean difference of HIRS channel 12 (NOAA-15, bias corrected) minus first guess as brightness temperature (in K) averaged onto a 1° grid over the period 1 to 28 February 2002.

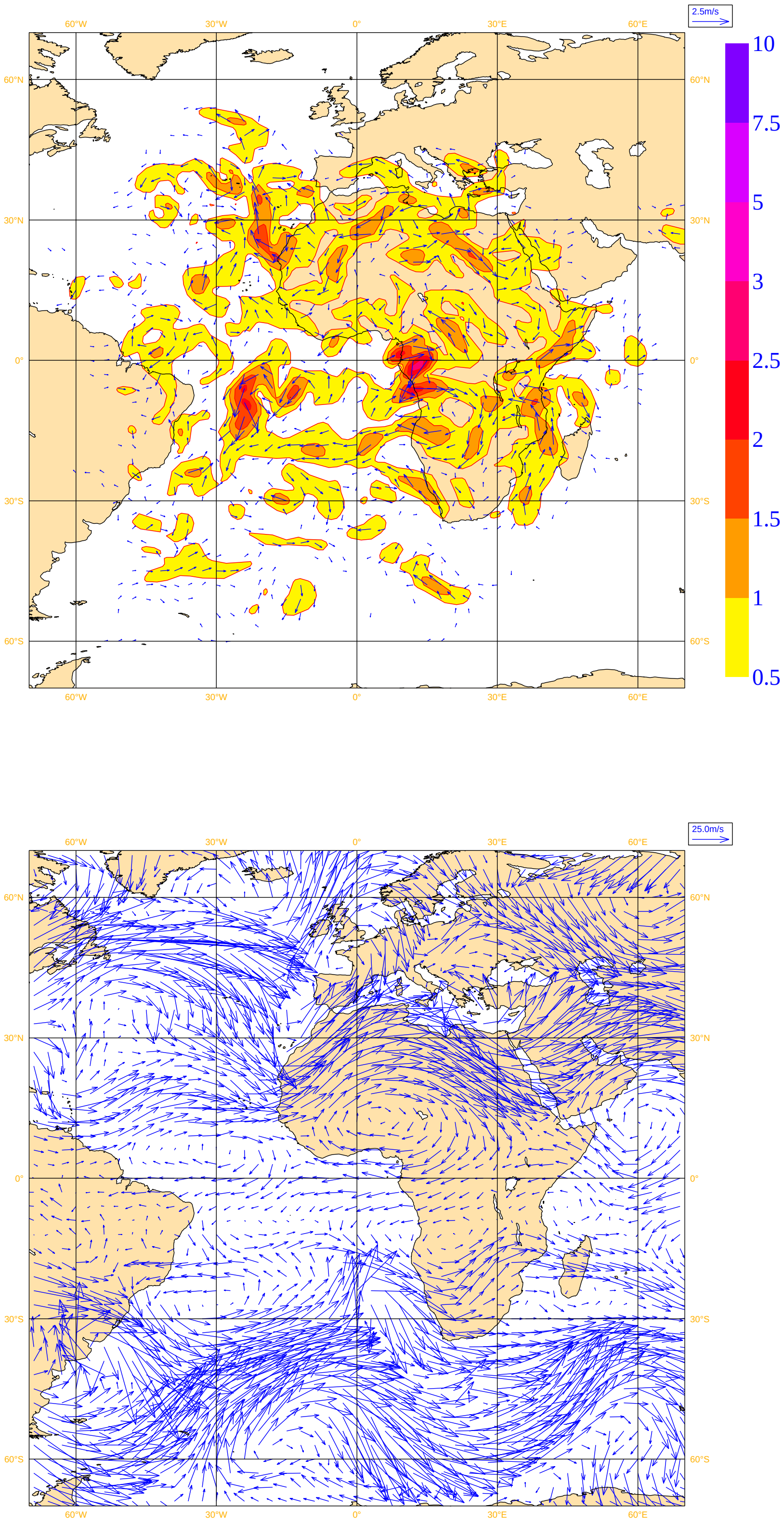


Figure 5: Top: Wind vector increments at 300 hPa (analysis minus first guess, in m/s; scaling vector at top right is for 2.5 m/s, shaded areas give wind speed of difference vectors in m/s) for a single cycle 4DVAR analysis 1 April 2002 3 UTC. Bottom: Corresponding first guess field of wind vectors at 300 hPa (scaling vector at top right is for 25 m/s).

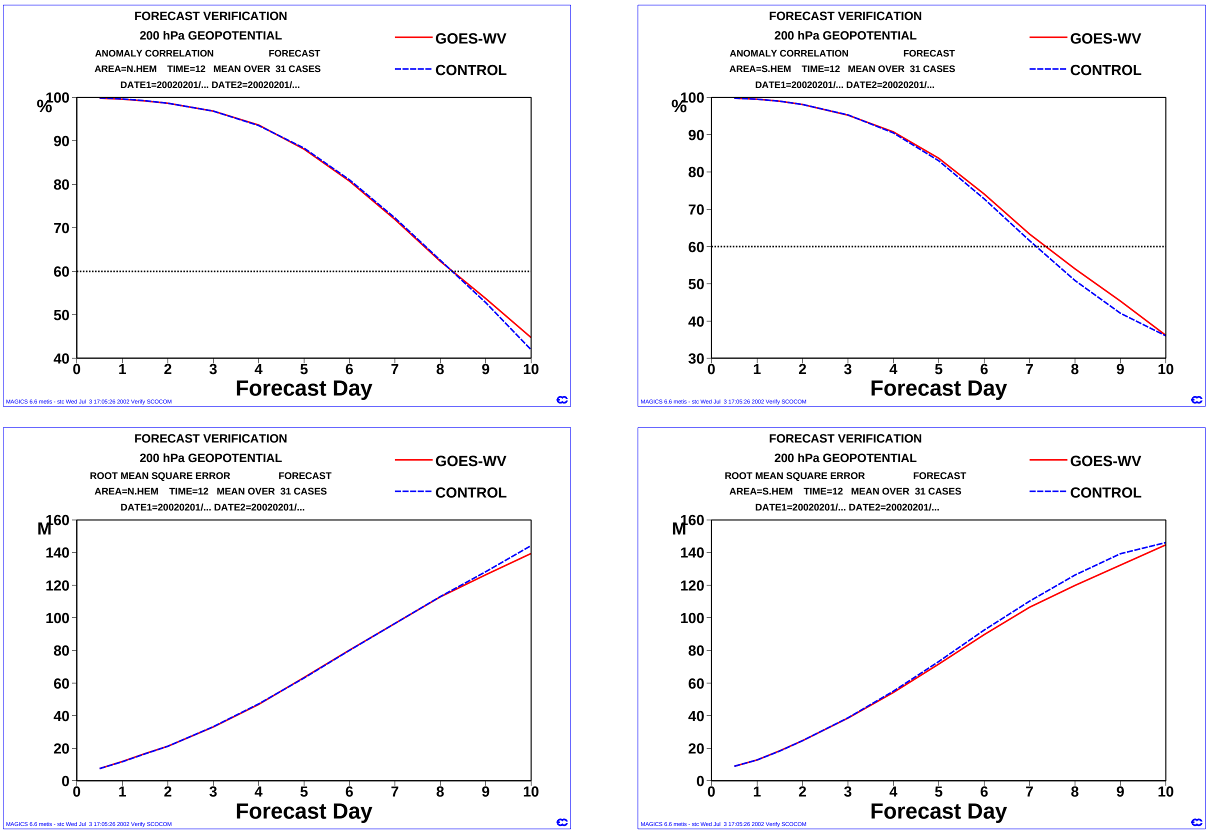


Figure 6: Anomaly correlation (top) and root mean square error (bottom) of 200 hPa geopotential for forecasts up to 10 days verified against operational analyses for the experiment with assimilation of GOES WV CSBT (red solid line) versus the control (blue dashed line). Left panels are for the Northern hemisphere (> 20 degrees N), right panels for the Southern hemisphere (< -20 degrees S). The average comprises 31 cases from 1 February to 3 March 2002.