IMPROVEMENTS IN FORECASTS AT THE MET OFFICE THROUGH REDUCED WEIGHTS FOR SATELLITE WINDS

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ABSTRACT

Following results presented by the Met Office at the 5th International Winds Workshop in Australia, there was some concern that the Met Office's global NWP model might be overfitting to satellite wind observations (satwinds). Sensitivity trials of the Met Office-assigned satellite wind observation error were carried out: doubling and quadrupling the error, and rejecting satellite winds entirely from assimilation, for a period in spring 2001.

Upon taking a weighted subset of forecast parameters (the NWP index) and verifying against sonde and surface observations, it was found that the no-satwinds trial gave a negative impact, and the quadruple observation error impact had degraded tropical forecast parameters while improving extratropical forecasts. The double observation error trial appeared to give most consistent improvements without any significant degradations. It was decided that the latter change would be most likely to improve the Met Office global NWP model. A further trial in summer 2001 again showed a benefit to Met Office forecasts of doubling the observation error, and an operational change was made in October 2001 to that effect.

Further impact trials were carried out to test the use of winds derived from GOES water vapour imagery (GOES WV winds) and winds transmitted by EUMETSAT from the Meteosat satellite in BUFR code. The BUFR-coded winds are transmitted at much greater temporal and spatial resolution than currently used Meteosat SATOB-coded winds. The tests were carried out for autumn 2001, and although neither gave as large a positive impact as the double observation error trials above, the Meteosat BUFR winds are promising enough for a second-season trial to be run; the same is true of GOES WV if time permits.

1. Reduced Weighting through the use of Observation Errors

Satellite winds, the atmospheric motion vectors deduced from sampling the movement of tracers in geostationary satellite imagery, are routinely used to initialise numerical weather prediction (NWP) models. Therefore, it is important to make an estimate of their errors. The relative values of observation and background errors determine how closely the assimilation system will pull towards the observations when producing an analysis from which to run the forecast. Set up in response to a request from the Coordination Group for Meteorological Satellites (CGMS), the EUMETSAT web site (http://www.eumetsat.de/en/dps/mpef/windsuse.html) gives the values of satellite wind observation errors used at some global NWP centres around the world. There are significant differences in these values. An investigation by Tsuyuki (2000) showed that, in some cases, a difference in assimilation method (3D or 4D variational assimilation) was the reason; in others either an outdated or a fixed set of errors were applied. Some centres prefer to use an exaggerated observation error for satellite winds in order to reduce their weight in assimilation.

The Met Office was using low observation errors compared with other NWP centres at the time of Tsuyuki's investigation (September 2000; see Table 1). These errors are routinely produced using a year's worth of observation-background statistics; they are considered to be a reasonable estimate of the satellite wind observation error, if the observation and background error are assumed to be comparable. They are applied to all satellite winds, regardless of satellite or channel.

This work was prompted by earlier impact trials of high spatial-resolution satellite winds at the Met Office that had not shown the positive impact hoped for. It had also been found that operational satwinds had the potential to degrade the short-term (6-hour) forecast of some atmospheric parameters. It was deduced that the satwinds were being given too much weighting in the assimilation, i.e. that the estimated observation errors were too low. Impact trials were run at the Met Office to estimate the impact on the forecast of using larger observation errors.

Table 1. Wind component observation errors (m/s) used at some global NWP centres, assigned at different model levels, valid September 2000

Level (hPa)	1x 10^3	850	700	500	400	300	250	200	150	100
BoM	3.0	3.0	3.0	3.0	6.0	6.0	6.0	6.0	6.0	6.0
CMA	2.5	2.5	2.5	2.5	5.0	5.0	5.0	5.0	5.0	5.0
CMC	3.8	3.8	3.8	3.8	7.5	7.5	7.5	7.5	7.5	7.5
DWD	3.0	3.0	3.0	3.0	6.0	6.0	6.0	6.0	6.0	6.0
ECMWF	2.0	2.0	2.0	3.5	4.5	5.0	5.0	5.0	5.0	5.0
JMA	3.0	3.0	3.0	3.0	3.2	3.5	3.7	3.9	4.1	4.5
MetF[1]	2.8	2.9	3.1	3.9	4.3	4.6	4.8	5.1	5.1	5.1
MetO	1.3	1.7	2.0	2.5	3.3	3.3	3.3	3.3	3.6	5.5
NCEP[2]	3.9	3.9	3.9	3.9	6.1	6.1	6.1	6.1	6.1	6.1
NCEP[3]	1.8	1.8	2.1	3.0	3.0	3.0	3.0	3.0	3.0	3.0
USNavy	2.8	2.8	3.8	4.8	5.8	6.5	6.5	6.5	6.5	6.5

[1]Meteo-France's Meteosat wind values, [2]current winds, [3]new GOES values.

1.1. Impact Trials

Using the Met Office operational global NWP system, three impact trials were conducted for the period 10 March - 18 April 2001. A low-resolution run of the operational model was used as the control.

Control: 288 x 217 horizontal resolution global model, 30 vertical levels, 6-h 3D VAR assimilation. The satellite wind observation errors used are shown in Table 2, and have been in operation at the Met Office since 1997.
Trial 1: As for the control, but with more recently calculated (year 2000) satellite wind observation errors doubled, as shown in Table 2.
Trial 2: As for the control, but with more recently calculated (year 2000) satellite wind observation errors quadrupled, as shown in Table 2.
Trial 3: As for the control, but with satellite winds not used in the assimilation. (A "no satellite winds" trial.)

Table 2. Wind component observation errors (m/s) used for the control, Trial 1 and Trial 2 model runs, assigned at different model levels

Level (hPa)	1x 10^3	850	700	500	400	300	250	200	150	100	70
Control	1.3	1.7	2.0	2.5	3.3	3.3	3.3	3.3	3.6	5.5	5.4
Trial 1	3.6	2.8	4.0	4.8	6.2	6.2	5.6	5.8	6.6	11.8	11.8
Trial 2	7.2	5.6	8.0	9.6	12.4	12.4	11.2	11.6	13.2	23.6	23.6
Trial 3	Satellite winds rejected entirely from assimilation										

1.2. Results

Forecast parameters contributing to the Met Office's NWP index

The NWP index is the primary tool used at the Met Office for assessing whether an impact trial has improved the forecast compared with a control run. Figure 1 is a bar chart of the changes in percentage root mean square (RMS) error for the trials vs control for the forecast parameters contributing to the NWP index. A negative bar indicates that the error has decreased, and is a positive result for the trial. An RMS forecast error difference of 2% or more is considered a significant change. The forecasts are verified against independent observations.

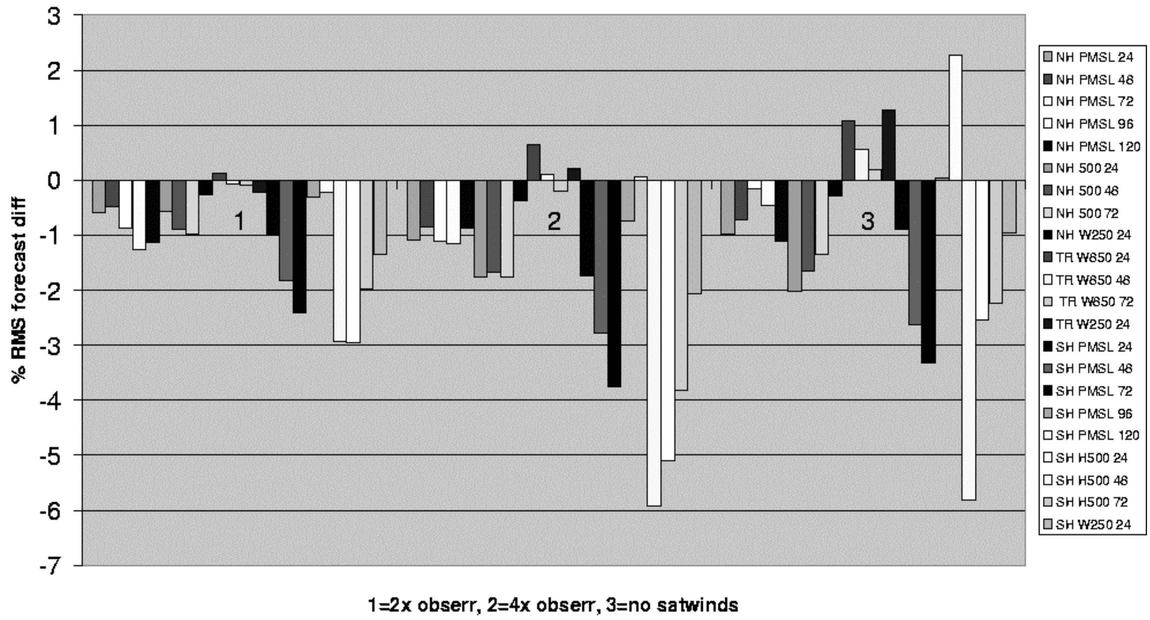


Figure 1. Changes in %RMS forecast error for trials 1, 2 and 3. The values are averaged over the period of the trials. Key: NH=northern hemisphere, TR=tropics, SH=southern hemisphere, PMSL=pressure at mean sea level, (H)500=geopotential height at 500 hPa, W850, W250=wind at 850, 250 hPa, 24/48/72/96/120 refer to forecast times in hours. The parameters are ordered as listed from the left of each grouping.

Trial 1: The double observation error trial has improved the overall forecast, and has significantly improved some southern hemisphere parameters. While both NH and SH forecasts have been improved, there has been little change in tropical forecasts. Taken as a weighted average of the combined parameters, trial 1 increased the NWP index by 0.4% (baseline value = 113.0), a positive result.

Trial 2: The signal seen for trial 1 in Fig. 1 is exaggerated for the quadrupled observation error trial. Some astounding improvements in the SH are offset by a degradation in tropical wind forecasts and an indication of a negative impact on long-range SH PMSL (pressure at mean sea level). Trial 2 increased the NWP index by 0.5%.

Trial 3: It may be supposed that if we followed the logic above to the extreme, and used infinitely large observation errors, then we would see a further exaggeration of the impact characteristics for trials 1 and 2. By rejecting satellite winds entirely from the assimilation, we have effectively done this. The results for trial 3 seen in Fig. 1 show that all tropical wind forecasts are degraded when no satellite winds are used in the assimilation. The large SH improvements have effectively reached a plateau and in some cases the improvement has decreased in magnitude from Trial 2. Forecasts of long-range (120-h) PMSL in the SH have been markedly degraded, although short-range PMSL forecasts have improved. Trial 3 decreased the NWP index by 0.1%, a negative result overall, since the combined weighting of (degraded) tropical forecast parameters is larger than that of the SH forecast parameters.

Changed fit of background field to observations

Another way of verifying trial output is to look at how the background field (the 6-h forecast) has changed to fit observations at the validity time. We have changed the analysis in the trial, and, if it has been improved, we would expect the background field to have a better fit to the observations. The following statistics are found by taking the RMS difference between observations and background for the control, then repeating the calculation for the trial, and calculating the percentage change between the two. Details given are for trial 1 (double observation error).

Aircraft: The fit to background is unchanged with respect to Airep and Amdar observations.
Sonde: Neutral for most reports. However, the background field fits sonde temperatures closer at 500 and 700 hPa (by changes in %RMS difference of 1.3% and 1.8%, respectively), and sonde winds closer at 250 and 500 hPa (by 1.4% and 1.1%, respectively).
Surface reports: The fit of the background is significantly closer to most PMSL reports from different platforms (up to 1.9% for ships, and 3.7% for buoys). The background 10-m wind field had a worse fit to ship and buoy reports, but the change was less than 1%.

Although some of the effects are relatively small, the results show a positive impact in the improved fit of some background parameters to independent observations. A surprising aspect is that the mean sea-level pressure has been changed so much for the better. The fact that the background is fitting closer to sonde wind reports at high levels is a positive aspect, given the well-documented slow bias of satellite winds at high wind speeds.

Satellite winds: In contrast to the results presented above, the fit of the background fields to satellite winds has been degraded. We expect that an improved analysis leads to an improved background, which should give a better fit to *all* observations, regardless of any change in the processing of those observations. What we assume as the observation error is irrelevant to the real observation error and only the background has changed. The fact that the 6-h forecast from an improved analysis is further from satwinds, but closer to other observation types, suggests that the satwind errors at T+6 are correlated with those at T+0. This could also be explained in terms of an inherent local bias leading to local corrections of error in both space and time. Table 3 outlines the percentage change between the fit for the control and trial 1.

Table 3. Control-trial 1 RMS averaged fit of background to satellite winds (% difference). Negative values indicate a reduced fit of trial 1 backgrounds fields to the satellite winds indicated compared with the control

IR WINDS:	High-level	Medium-level	Low-level	WV High	VIS Low
Met-5	-4.6	-7.5	-6.2	-5.5	-3.5
Met-7	-5.0	-7.9	-5.9	-6.4	-8.8
GMS-5	-3.6	no winds	-1.6	-7.1	-2.0
GOES-8	-3.4	-4.9	-1.9	NA	NA
GOES-10	-4.9	-6.3	-2.1	NA	NA

There are significant differences in the changed background fit to satwinds from different channels, levels and originating satellite. However, it is not clear that any immediate conclusion can be drawn from these differences. Each subtype of satwind has different quality characteristics (biases) when compared with the Met Office background field; the meteorological situation must play some part in any suspected temporal correlation; and the satellite operators have varying levels of processing involved in the production of their winds.

1.3. Conclusion

It was clear that some improvement could be made to the Met Office NWP global model by increasing the satellite wind observation errors. A further trial was run with doubled observation errors for a different season (July 2001), which confirmed the above results, although with slightly more variability in tropical winds. An operational change to the Met Office model was implemented in October 2001: the satellite wind observation errors were changed to those given in Table 2 for trial 1.

It is not entirely satisfactory that such large observation errors are used for satellite winds, since these do not appear to be the "true" values of the errors. As mentioned in Tsuyuki (2000), if very strict quality control is used on the original wind dataset to produce a small subset for assimilation, then lower errors could be more applicable. Conversely, if one chooses to assimilate a large dataset, then larger errors are more appropriate to guard against the negative effects of systematic biases or possible error correlations.

Bormann (2002) has recently studied the spatial structure of satellite wind observation errors in an attempt to calculate the extent to which satellite wind observation errors are correlated. He finds that there are significant spatial error correlations for distances up to about 800 km, for all types of satellite wind. Broader correlations are found in the tropics, and there is evidence for larger correlated errors in winter compared with summer. Within variational assimilation systems, an assumption is made that observation errors are uncorrelated; this avoids the inversion of large matrices with off-diagonal elements and makes the mathematics easier. It is also generally true for unconnected observations, e.g. radiosonde data from independent stations around the globe. If this assumption is not true, and this seems to be the case for satellite winds over distances less than 800 km, then the assimilation is not optimal. The use of large observation errors for satellite winds goes some way towards compensating for this effect; another method would be to assimilate them at much lower resolution.

2. GOES WV and Meteosat BUFR Wind Trials

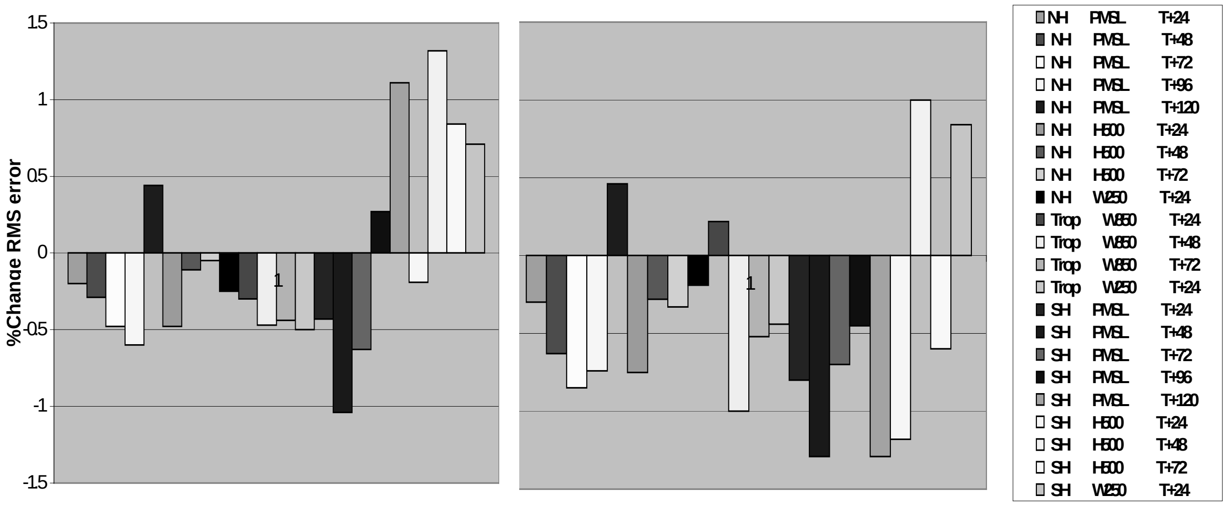
These trials were run from 25 September to 20 October 2001. A low-resolution run of a future operational model (incorporating the New Dynamics; Cullen *et al*., 1997) was used as the control. The details and differences for each run are as follows:

Control: A 288 x 217 horizontal resolution grid-point global model, 30 vertical levels, 6-h 3D-VAR assimilation
GOES WV: As Control, but allowing GOES WV winds into processing (thinning) at 2 degrees, 100 hPa, together with GOES IR. This has the effect of allowing for the possible replacement of GOES IR winds with GOES WV winds within the processing, as well as the addition of GOES WV winds in regions where no IR winds are being transmitted. There are no preferences set in the thinning; the wind closest to the centre of the thinning box is chosen.
Met BUFR: As Control, but replacing Meteosat SATOB-coded winds with BUFR-coded winds for IR, WV and VIS winds. Implicit in the use of Met BUFR winds is the use of the quality indicator (QI), a value appended to the wind report by EUMETSAT. Heavy spatial thinning was applied to the winds at 2 degrees, 100 hPa (like GOES), since previous trials at higher resolution had failed to produce any positive impact, and only those winds within 3 h of the synoptic run time (00, 06, 12, 18Z) were used, so that no advantage was made of the higher temporal resolution of these winds. The wind with the highest QI inside the thinning box was chosen for assimilation.

2.1. Trial Results

Figure 2 displays the percentage change in RMS error for a set of forecast parameters for each of the two trials when verified against independent observations. A negative change is a positive result for the trial. It can clearly be seen that, on balance, the Met BUFR trial is providing a more positive impact than the GOES WV trial, and it is not so detrimental to the forecasts in the southern hemisphere. These forecast parameters are weighted to produce the NWP index, and an increase in the NWP index is a positive impact. The GOES WV trial increased the NWP index by 0.05% on a baseline value of 115.0, the Met BUFR trial increased it by 0.25%. Comparison with Fig. 1 shows the changes in forecast fields made by these trials are much smaller than those made in the observation error trials of section 1.

Figure 2. Changes in %RMS forecast for the GOES WV trial (left) and the Met BUFR trial (right) for certain forecast parameters. The values are averaged over the period of the trials. See Fig. 1 for key.



Results of an investigation into the fit of the changed background fields (T+6 forecasts) to other observation types, are given below.

Aircraft: For the GOES WV trial, aircraft temperature reports between 300 and 1000 hPa fit closer to the background by 1.5%. The Met BUFR trial was neutral against this observation type. Most aircraft reports are transmitted over the continental US, so it is not surprising that only the GOES WV trial changed the fit to background.

Sonde: The GOES WV backgrounds fit better to 50-hPa sonde heights (by 1.0%), but worse to 50-hPa sonde temperatures (by 2.2%). Information from such low pressures is not to be relied upon too much. GOES WV backgrounds fit closer to 100-hPa wind profiler reports (by 1.1%). Met BUFR trial backgrounds fit closer to sonde 250-hPa wind reports (by 1.1%), 50-hPa heights (1.2%), but had a worse fit to 50-hPa temperatures (by 2.4%).

Surface reports: The GOES WV backgrounds fit better to pressure reports from land stations (by 1.1%). Met BUFR backgrounds fit closer to those same reports by 1.6% and to those from buoys by 1.1%.

Satwinds: The GOES WV backgrounds showed a worse fit to GOES-10 IR winds by 6.3%, and to GOES-8 by 35.4%. In line with the discussion in section 1.2, the worse fit can be assumed to be a result of temporally correlated errors, but the differences between satwind types cannot be easily explained. Perhaps, in this case, the differences can partly be attributed to fewer GOES-10 WV data during the period being tested (due to the Camex observation experiment). Also, some GOES-10 WV winds were being labelled as IR winds due to a transmission problem at NESDIS. Therefore, some GOES-10 WV data were already being assimilated inadvertently in the Met Office global NWP model. The fit to other satwind types was neutral. In the Met BUFR trial, the current Meteosat operational winds (in SATOB format) were all rejected, so there were no data for the fit to Meteosat; the fit to other satwind types was neutral.

The results above show that there has been no degradation in the analyses and short-term forecasts with respect to other observation types. The backgrounds fit closer to some sonde and surface reports, so we can be confident that the changes trialled would not cause any degradation in the operational forecast system.

Figure 3 gives an indication of the geographical locations of the changes made to the analysis fields. Each plot shows the trial-control u-component of the wind at 250 hPa, averaged for the period of the trial (upper: GOES WV-control, lower: Met BUFR-control). It is intuitive and obvious that the strongest changes to the analysis fields of 250-hPa u-wind are made in the GOES and Meteosat fields of view. However, these changes do propagate throughout the trial to cover the globe. Note that the maximum and minimum differences are not very great (~3 to -4 m/s). On a day-to-day basis, the changes were much larger.

2.2 Conclusions

We tested the assimilation of Meteosat BUFR and GOES WV winds in autumn 2001. In terms of the Met Office NWP index, the replacement of Meteosat SATOB-coded winds with BUFR-coded winds gave a positive result. Small positive changes were made to most of the main forecast parameters in all latitude and forecast ranges (more positive in the southern hemisphere), especially pressure at mean sea level. Inspection of analysis fields showed the greatest trial/control differences in high-level wind fields to be in the Meteosat fields of view. These changes propagated around the rest of the globe, but were confined mostly to the tropics and southern hemisphere. The improved analyses resulted in a closer fit of the background (6-h forecast) to reports from other observation types; an encouraging result.

The GOES WV trial was neutral when measured by the NWP index. There are small improvements in nearly all northern hemisphere and tropical parameters (apart from long-range mean sea-level pressure); the positive (if small) tropical wind verification is particularly encouraging. However, the larger degradation in forecasts for the southern hemisphere is not a good sign. Measurement of the fit of the background fields to other observation types showed that the background fit closer to some reports; there was no significant worsening. Trial-control analysis differences of the high-level zonal wind speed component showed the main changes to have taken place in the eastern tropical Pacific Ocean.

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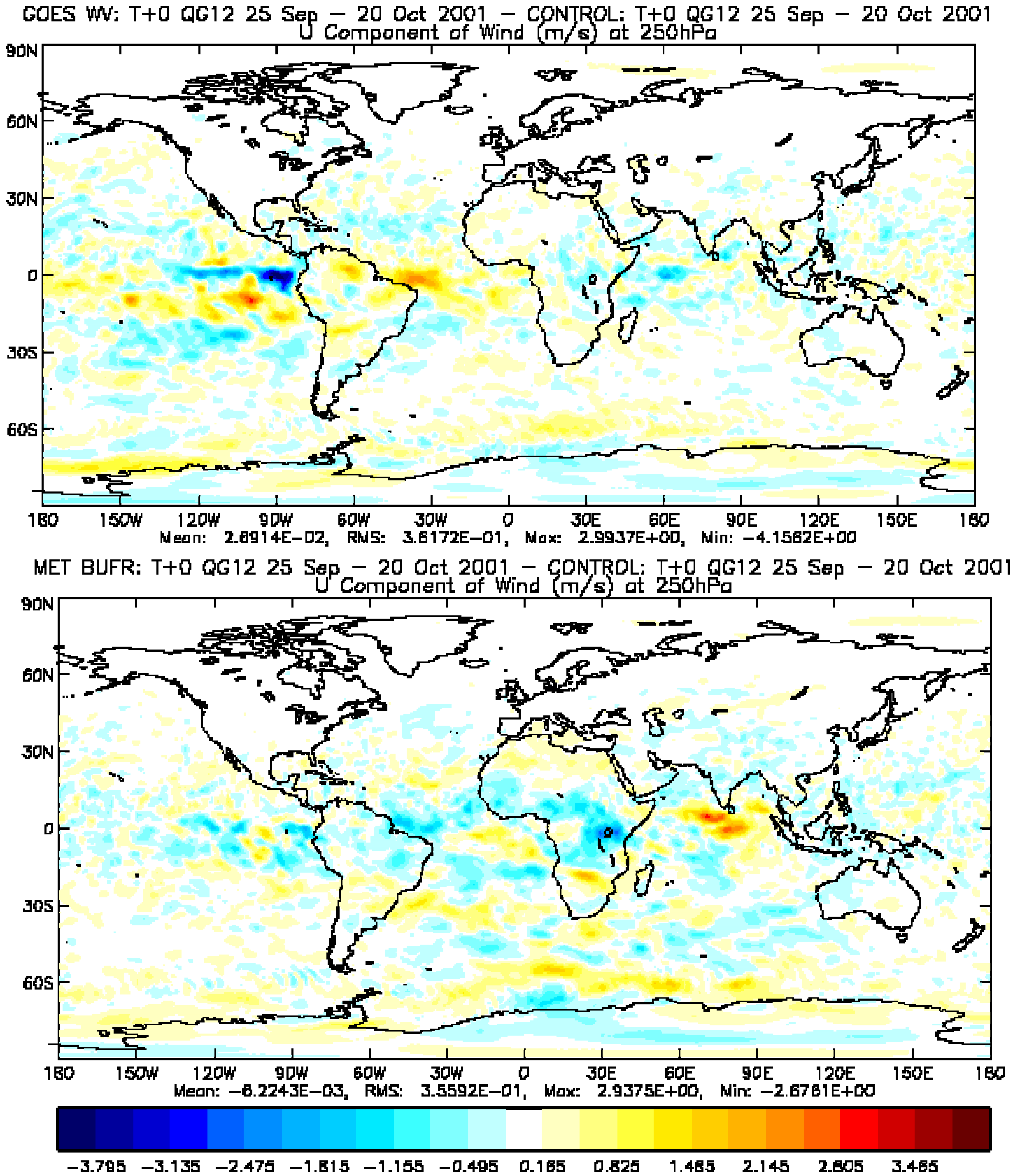

Figure 3. Mean analysis field difference (trial - control) of the u-component of the wind at 250 hPa. Top: GOES WV, bottom: Met BUFR. The analysis differences are averaged over the period of the trial.