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A SERIES OF IMPACT TESTS ON NEW SATELLITE WIND TYPES

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Abstract

A series of impact tests on satellite winds has been conducted. The trials were set up using the suite control system and used the analysis correction method of assimilation. Three trials were run to test the impact of using satellite wind types that were not assimilated into the UKMO global NWP model (the Unified Model, UM). The first tested the use of Meteosat-5 satellite winds. Meteosat-5 was moved to cover the Indian Ocean region in 1998 as part of the INDOEX mission and thus fulfils a useful role in a relatively data-sparse region. For this trial, NWP index decreased by 0.3% yet the same forecast fields verified against observations yielded an index increase of 0.4%. On the basis of the observation index increase and the fact that these winds are providing data in areas where currently there are very few, the operational assimilation of Meteosat-5 winds was initiated in February 1999. The second test looked at the impact of assimilating water vapour winds derived from the Japanese satellite GMS. These winds increased both the NWP index and the observation index by 0.2%. They were switched on operationally in March 1999. A test on the use of high-resolution visible winds from Meteosat-7 (stationed at 0 degrees) yielded a neutral result for both NWP and observation index. However, these winds were thinned before use, and it is thought that in this state they merely reinforce the low-resolution winds currently assimilated. A further impact test is planned to test these visible winds at a much greater resolution than thinning currently allows. They are not yet used operationally.

INTRODUCTION

Satellite winds, or atmospheric motion vectors, are currently transmitted operationally on the global telecommunication system (GTS) from five geostationary satellites: GOES-8 and GOES-10, operational at 75 and 135°W, respectively; INSAT stationed at 74°E; GMS at 140°E; Meteosat-7 at 0° (prime mission), and Meteosat-5 at 63°E in support of the INDOEX mission over the Indian Ocean.

Satellite winds have been used by the UKMO for over 10 years. Recently, there have been many refinements to the processing of satellite winds, and also innovations with regard to the channels used to derive vectors; they are now retrieved from infrared (IR), water vapour (WV) and visible (VIS) imagery. Their resolution, both spatial and temporal, has been increased in some cases. Currently, the UKMO is making use of only a subset of these winds. The operational use of satellite winds at UKMO in October 1998 is outlined as follows:

Meteosat-7 (prime mission)

IR winds used except below 700 hPa in the northern hemisphere extratropics (NH) over land
All WV winds used
VIS winds used except below 700 hPa in the NH over land
No high-resolution visible winds used

GOES-8, -10

IR high-resolution winds used except below 700 hPa in the NH over land, thinning applied
No WV winds used

GMS-5

IR winds used except below 700 hPa in the NH over land
No WV winds used
VIS winds used except below 700 hPa in the NH over land

Meteosat-5 (INDOEX)

No winds used

INSAT

No winds used

This list is notable for all the types of wind that are currently not used. In an effort to try and make use of more different types of wind and those from different satellites, the UKMO set up a programme of impact testing. This report outlines the results from the first three impact trials conducted.

IMPACT TRIALS

General description

The first trial tested the use of Meteosat-5 satellite winds from over the Indian Ocean, the second assimilated winds derived from the water vapour channel of GMS, and a third tested the assimilation of high-resolution visible winds from Meteosat-7. Using the suite control system (SCS) two simulations of the operational global UM were run for each impact trial. One was the control version, which was as close as possible in set up to the operational model valid at the time of the experiment. The other was modified from the control suite, and included switching on observations for assimilation that were not used in the operational model. The first two tests (Meteosat-5 and GMS water vapour) used an analysis correction (AC) control run that had already been executed by the variational analysis team in testing the VAR model (July-August 1998). For the third (Meteosat high-resolution visible), both control and test fields had to be generated for the test period (October-November 1998) since a control run was not available from previous work. The trials were run for a minimum of two weeks, with a three-cycle spin-up before initiating the actual trial. All were run at full UM global resolution, with only the 12Z run generating a full 5-day set of forecasts.

Meteosat-5 impact trial (MET5)

Due to the lack of conventional observations assimilated over the Indian Ocean (see Fig. 1 for a typical 12Z set of observations, valid 20 January 1999), it was decided that satellite winds from Meteosat-5 should be tested first. Meteosat-5 was previously the operational geostationary satellite at 0 degrees, from which satellite winds were routinely assimilated into the UM. Therefore, the wind production method used by Meteosat-5 is fully acceptable to the UKMO, as is the satellite itself. The operational transmission of satellite winds from Meteosat-5 began in July 1998. Figure 2 shows a subset of Meteosat-5 winds, the IR winds, valid at the same time as those observations shown in Fig. 1. An extra 456 observations are available, a large number of which are over the ocean.

The trial initially ran from 15 to 31 July 1998, but was then extended to 6 August 1998 to verify results for a further week, and assimilated Meteosat-5 IR, WV and VIS winds with the same accept/reject conditions as the current operational 0 degree Meteosat satellite (Meteosat-7). Wind observations at all upper-level pressure ranges (950 to 150 hPa) were assimilated. Results given below are for the initial 2-week trial; results for the 3-week trial are not significantly different.

GMS water vapour impact trial (GMSWV)

Water vapour winds from the Japanese satellite, GMS, have been transmitted for a couple of years. However, these were never assimilated as a matter of course since the winds themselves were produced using pure water vapour images. Water vapour winds assimilated currently from Meteosat-7 are cross-referenced with IR imagery to ensure that clouds are present, and thus are "cloudy" WV winds, as opposed to the "clear-air" WV winds transmitted from GMS. The main difference seen on receipt of these data is that the GMS WV winds are set at pressures between 500 and 150 hPa, whereas Meteosat WV winds range from 400 to 150 hPa. By deciding to test GMW WV winds at heights above 400 hPa only, there is a degree of reassurance that we are actually seeing cloudy WV winds, and not the clear-air WV winds. The latter winds are problematic since what the tracers represent is not clearly defined (possibly movement of a broad layer rather than a tracer more clearly defined at one level similar to other satellite wind types).

The trial ran from 15 to 31 July 1998, covering some of the same period as the Meteosat-5 impact trial and using the same control run for verification.

Meteosat high-resolution visible wind impact trial (METHRV)

The resolution of the visible channel on the Meteosat satellite is twice that of the infra red channel (2.5 vs 5.0 km at sub-satellite point), yet initially the satellite winds produced from visible imagery were at the same resolution as the IR winds (using 32x32 IR-sized pixel search and target areas leads to an approximate resolution of 150 km for IR and regular VIS satellite winds). EUMETSAT have recently instigated the production of high-resolution visible winds, i.e. at full resolution for the visible channel. Not only are more wind vectors produced, but they are also produced in areas where low-resolution tracking does not pick up any tracers at all. It is estimated that there is an eight-fold increase in number of vectors from low to high resolution (Ottenbacher *et al.*, 1997). High-resolution winds are also transmitted every 3 hours during daylight, whereas low-resolution winds are transmitted every 6 hours coinciding with global model run times. Visible winds are only transmitted at low levels (below 700 hPa), preferentially over the sea (since the contrast in the visible channel between low-level cloud and surface is much more defined over sea than over land), yet some vectors are retrieved over land. These are prior rejected within the OPS if in the northern hemisphere extratropics.

The trial ran from 23 October to 7 November 1998. Only winds valid for 6, 12 and 18Z were assimilated, since asynoptic wind vectors would strictly need four-dimensional variational assimilation to produce the best benefits. However, a background field interpolated to the appropriate time should, in the future, be able to make use of the asynoptic data within 3-D VAR assimilation. In accordance with the current strategy on thinning of high-density IR winds from the GOES satellites (one wind only assimilated per 2x2 degree, 100-hPa volume), MetHRV winds were also thinned to this density before assimilation. On average, for the 12Z run, this resulted in an extra 700 (MetHRV) winds being assimilated, an average of 24% of the total winds assimilated for those days. The actual number of MetHRV winds transmitted that are valid for assimilation into a 12Z run is of the order of 6000 (includes winds timed at 9Z).

RESULTS

Assessment of the results of the impact trials was based mainly on calculation of the NWP index for control and test runs. This was backed up by calculation of the NWP index as if it were based on validating against observations (surface and upper-air) rather than each forecast verifying against its own analysis, as is the case with calculation of the NWP index. Both verification measures are objective, but their interpretation is different, particularly in data-sparse areas. The advantage of measuring the "observation" NWP index is that it is independent of the analysis fields for the control and test runs. Introducing extra observations into an assimilation can make the forecast more structured and thus less likely to be compared successfully against its own analysis. Thus, while a drop in NWP index can be seen for a test run, a corresponding increase could be seen against observations.

Other information used to gain insight into the effect of assimilating these extra wind types were forecast error RMS plots, verifying against analysis or observations out to T+120 hours. These were averaged for the 12Z runs covering the trial period. The areas of the changes made to the analysis and forecast fields were viewed by looking at, for example, control and test global fields of mean sea-level pressure, u- and v-component wind fields at upper levels, and the specific differences between control and test runs.

Table 1 shows a summary of the changes in NWP index and observation index for the three impact trials.

Table 1. Scores of NWP index and index against observations of control and test runs, plus the percentage change from control to test

	NWP index			Upper-air obs index (0.52 weighting)		Surface obs index (0.48 weighting)		Overall %change wrt obs
	Control	Test	%Change	Control	Test	Control	Test	
MET5	79.8274	79.5879	-0.300	58.1030	58.6915	79.6580	79.4211	+0.384
GMSWV	79.8274	79.9696	+0.179	58.1030	58.4758	79.6580	79.4215	+0.193
METHRV	80.3207	80.3672	+0.058	66.3949	66.3939	79.7151	79.7149	-0.001

MET5

A decrease in NWP index of 0.30% was seen from control to test run. Inspection of the details show that the main contributor to this drop was in the 250-hPa T+24 wind field in the tropics. Low-level winds in the tropics improved slightly. Conversely, comparison of the forecast fields against observations showed an increase in observation index of 0.38%, with verification against surface observations being slightly negative and against upper-air observation being very positive. Against observations the greatest improvement was seen in the 850-hPa T+24 wind fields in the tropics.

An indication of how these scores translate throughout the forecast is given in Fig. 3, which shows a comparison of the control (solid line) and test (dashed line) bias and RMS forecast errors for 250-hPa wind in different areas of the globe for control and test against observations. Similar figures for other forecast parameters have been plotted. Generally, any difference between test and control is very small in this kind of plot.

Inspection of the global time-averaged plots of the upper-air wind fields provide information on where the assimilation of these winds is affecting the analysis and forecasts. Figure 4 shows the T+0 (analysis) difference (control - test) fields of the u-component of the 850-hPa wind field, averaged over all three weeks of the test period. (Differences are more easily seen in the u-component field due to the stronger wind speeds zonally.) In this case the Indian Ocean between western India and the horn of Africa provides the area of contention. Inspection of the control and test fields individually shows that the difference is due to an adjustment in the formation of the monsoon jet, with the test fields "smearing out" the jet itself and making the impact of the jet on the Indian continent less intense.

The T+24 forecast fields for the u-component of the 850-hPa wind field are given in Fig. 5. By this time the difference between test and control is less marked, but is still present in the region defined above. Differences off the south coast of South America are considered to be spurious due to the lack of assimilated observations in this area.

Global plots of 250-hPa T+0 and T+24 winds fields show that the difference is due to the fact that the test fields, with Meteosat-5 winds assimilated, keep the formation of the jet more consistent at upper levels. The upper-air observation index scores this field very slightly positive, in contrast to the NWP index, which scores it negative.

Milton (1998) states "In July 1998 the intensification of the low level Indian Monsoon flow is apparent in the zonal average mean error as too strong westerlies north of the equator and too strong easterlies to the south". The assimilation of Meteosat-5 winds seems to go some way towards rectifying the former systematic error; wind vector plots of observations and background fields show the observations have more diffuse westerlies north of the equator, when compared with the background field.

Since this impact test took place during the summer monsoon season, it was expected to show up the greatest differences between the test and control fields. The differences should not be so great at other times of the year.

GMSWV

Both NWP and observation index scores from the test on GMS WV winds show an overall positive result (0.18 and 0.19% respectively), making this test more straightforward to analyse in terms of benefit than the MET5 test.

The NWP index reports that the main improvements are in mean sea-level pressure in the extratropics out to T+120, with a slight degradation in the 250-hPa T+24 wind field in the tropics. In contrast, upper-air observations report improvements in all tropical wind forecasts, but with a slight reduction in 250-hPa wind fields in the southern hemisphere. Surface observations report reductions in mean sea-level pressure. To a certain extent, the two indices are contradicting each other within their calculations, while both giving an overall positive score to the assimilation of GMS WV winds.

The percentage changes in indices are lower than in the MET5 tests, and this translates to less dramatic global difference plots. The areas that are affected by the assimilation of (high-level) GMS WV winds are in the Indian Ocean at high levels (this test was independent of the MET5 test, and assimilation of winds at the western edge of the GMS full disk region affect the eastern Indian Ocean), high-level wind fields at the western edge of South America, and again at lower levels (wind, mean sea-level pressure) off the south coast of South America. The differences involved are small compared with those seen in the MET5 test, showing that the assimilation of GMSWV winds, while improving the NWP and observation indices, is not making any significant adjustment to the mean analysis fields.

METHRV

Essentially, the index scores from the METHRV test show a neutral result, with just minor changes to the components of the indices. Inspection of global fields show that the adjustments to the analysis field of mean sea-level pressure are taking place mainly in the tropical and south Atlantic, but that the differences are minimal. With regard to the wind fields, there is no significant difference at high levels (e.g. 250 hPa), but at low levels (e.g. 850 hPa) assimilation of METHRV winds is adjusting the wind fields of the southwestern edge of Africa, an area where persistent marine stratocumulus clouds causes problems for wind retrieval algorithms (Fig. 6). This is already a contentious area between the UM background field and regular low-resolution visible winds, and assimilation of METHRV is adjusting the UM. However, overall the change is slight. The influence of Meteosat-7 in parts of the western Indian Ocean can also be seen in the same figure.

At T+24, the small analysis differences seen in the PMSL and high-level wind fields have been spread out and further minimised, however the 850-hPa wind field still shows some differences in the regions described above (Fig. 7).

It is thought that, although a reasonable number of METHRV winds are being assimilated in addition to the regular winds, these are only reinforcing the data that are already being assimilated. Another reason for the neutral result is probably the thinning applied to these high-resolution data, so that they are not being assimilated at very high resolution.

For full details and complete results of these impact trials, UKMO readers can access http://www-nwp/~frbp/home.html and the trials pages listed there.

CONCLUSION

MET5

Meteosat 5 is a tried and tested satellite, as are the wind production methods used by EUMETSAT. In view of this, and the facts that assimilation of Meteosat-5 winds fill a significant data void in the Indian Ocean area, and that verification against observations show an improvement when assimilating these winds compared with the control field, it was decided by WGOS (Working Group for the Operational Suite) that these winds should be assimilated operationally within the UM, despite the predicted drop in NWP index. Meteosat-5 winds became operational in February 1999.

GMSWV

Since the results that came out of the GMWV impact trial were much less contentious than those from the MET5 test, it was decided that there could be benefit from assimilating these observations in the format conducted within the impact trial, i.e. at high levels only. (Continuous monitoring has show that medium-level GMSWV winds have a very high background-flagging rate and large biases when compared with the UM background fields.) GMS WV winds became operational within the UM in March 1999.

METHRV

Although small positive impact from assimilating METHRV has been seen at other centres (e.g. Ottenbacher *et al.*, 1997), it was thought that in this case we nullified any benefit that we might have gained by over-thinning these winds. With this in mind, these winds have not been made operational as yet, but we intend to conduct another impact trial in which the thinning for both METHRV and high-density GOES winds is much reduced. It is thought that this future trial should produce some change in the analysis and forecast fields, for better or worse.

Acknowledgements

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Ottenbacher A, M Tomassini, K Holmlund and J Schmetz (1997) Low-level cloud motion winds from Meteosat high-resolution visible imagery. *Weather and Forecasting* **12**, 175-184.

Figures, Tables.

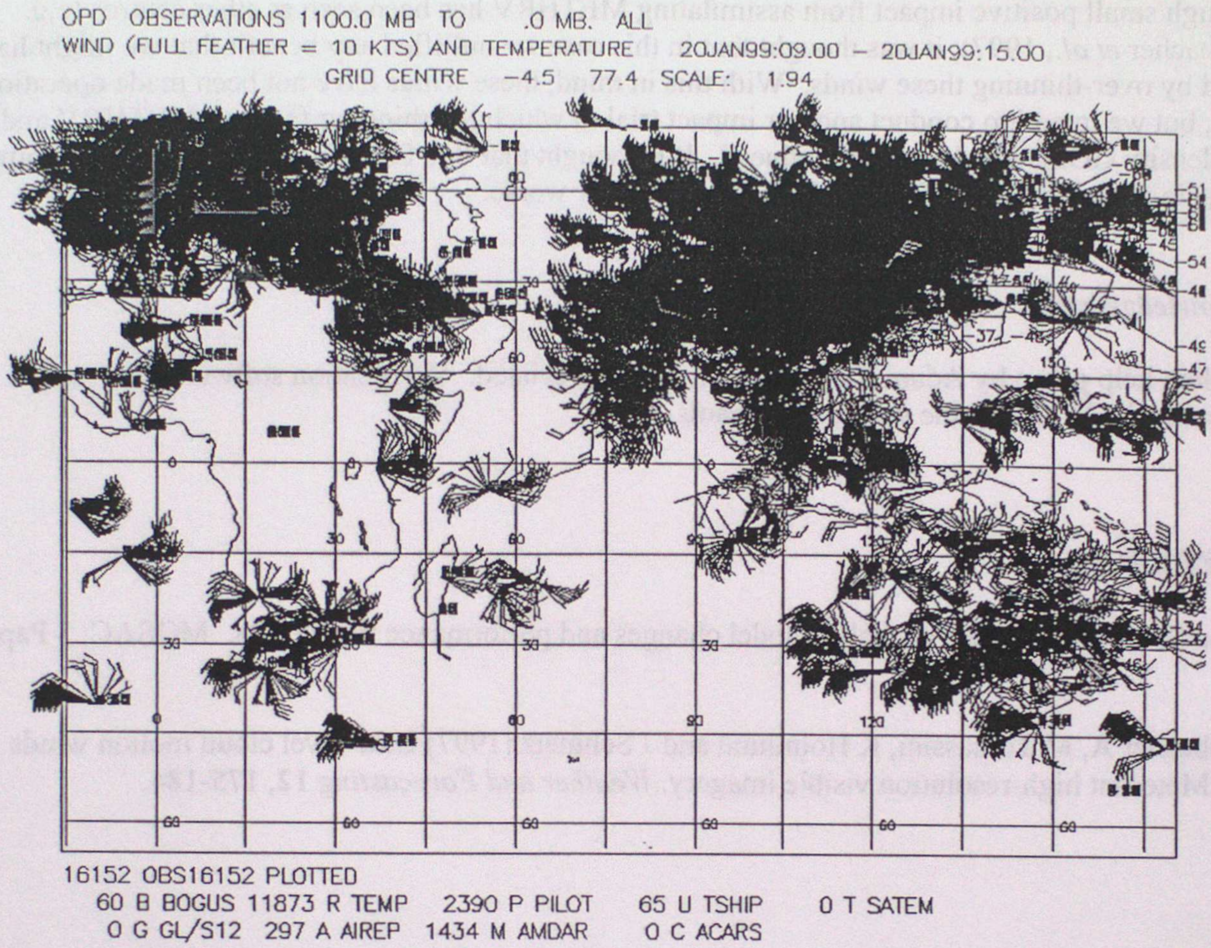

Fig. 1. Conventional observations for a sample time of 12Z 20 January 1999.

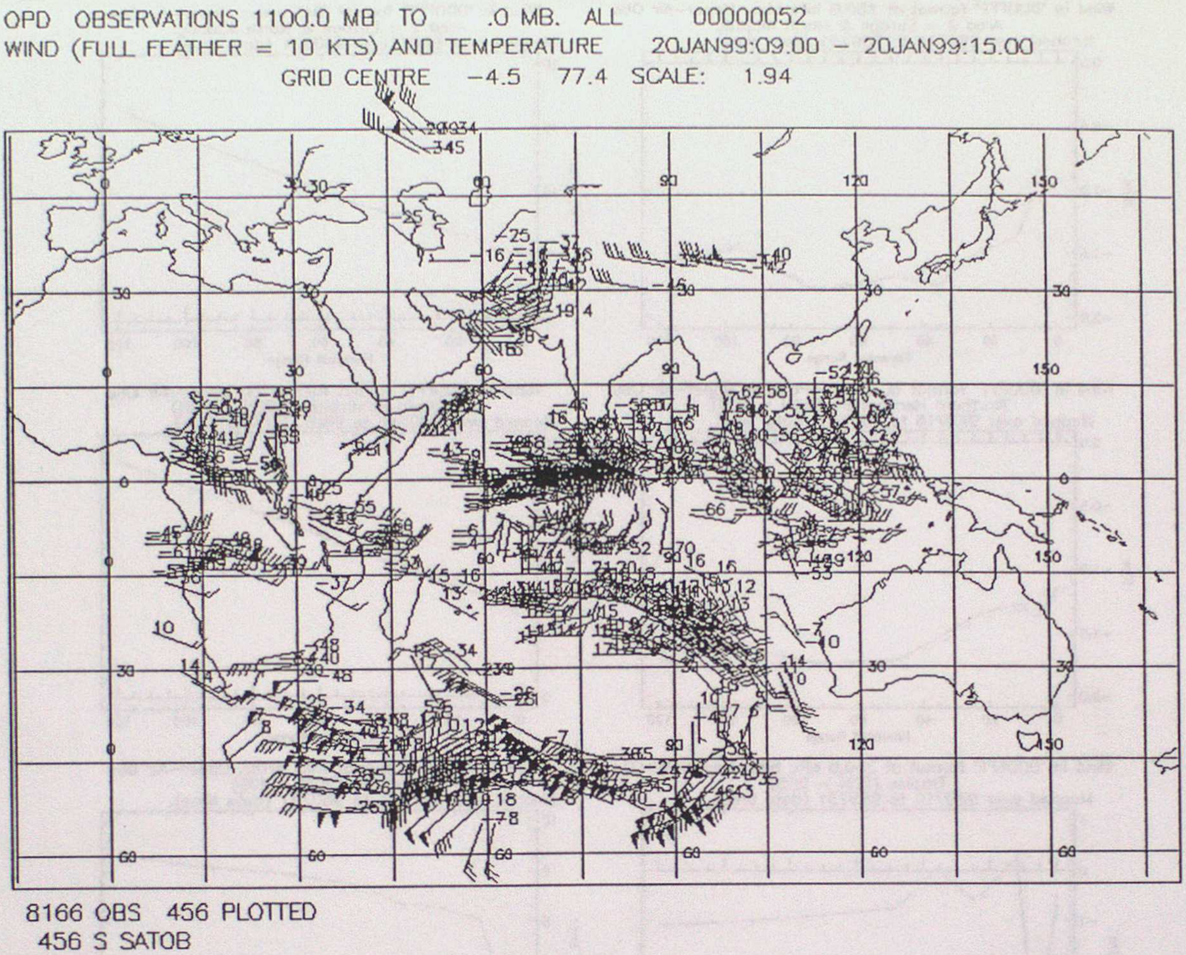

Fig. 2. Meteosat-5 IR satellite wind observations for a sample time of 12Z 20 January 1999.

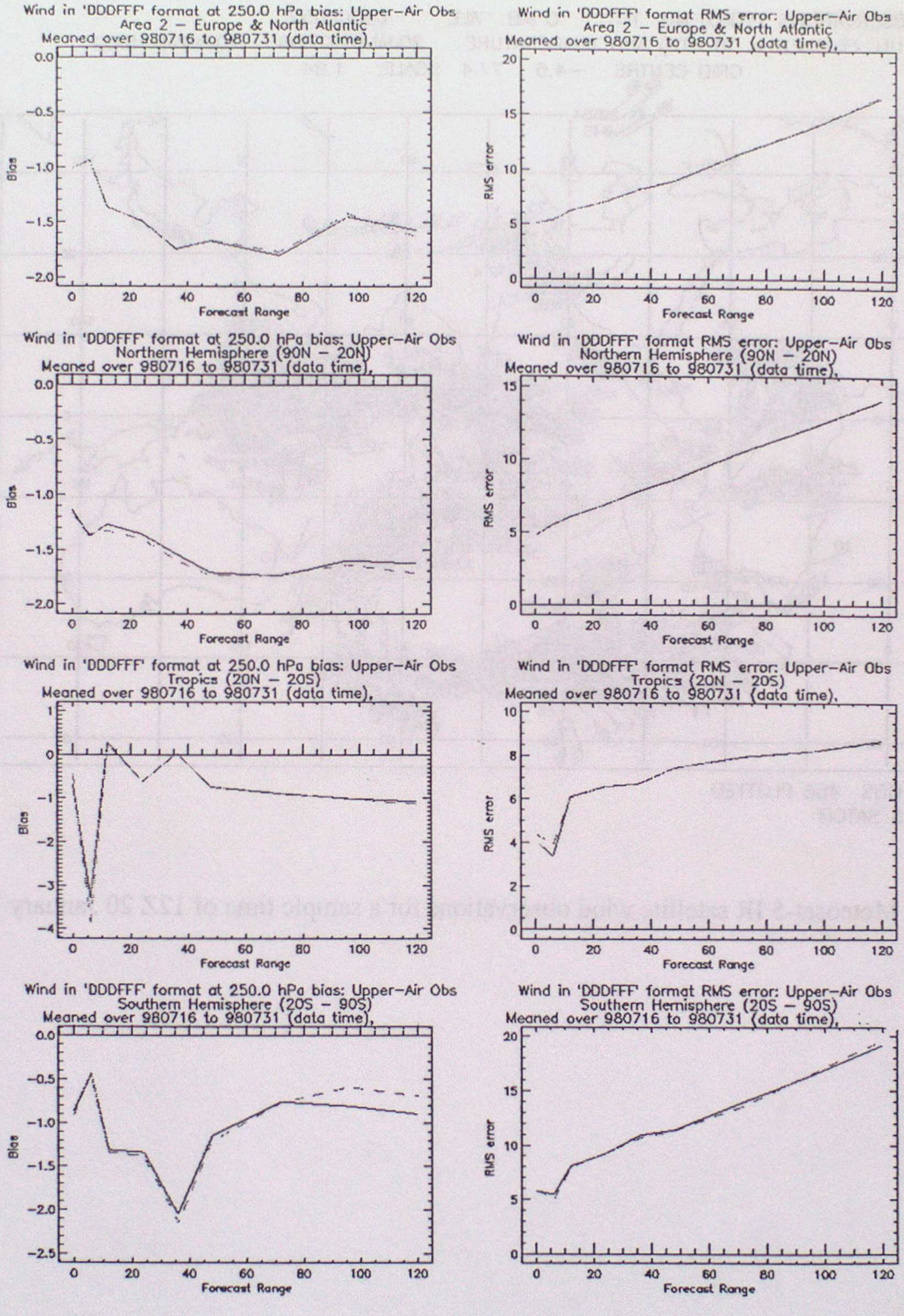

Fig. 3. Comparison of the control (solid line) and test (dashed line) bias and RMS forecast errors against upper-air observations for 250-hPa wind in different areas of the globe (MET5).

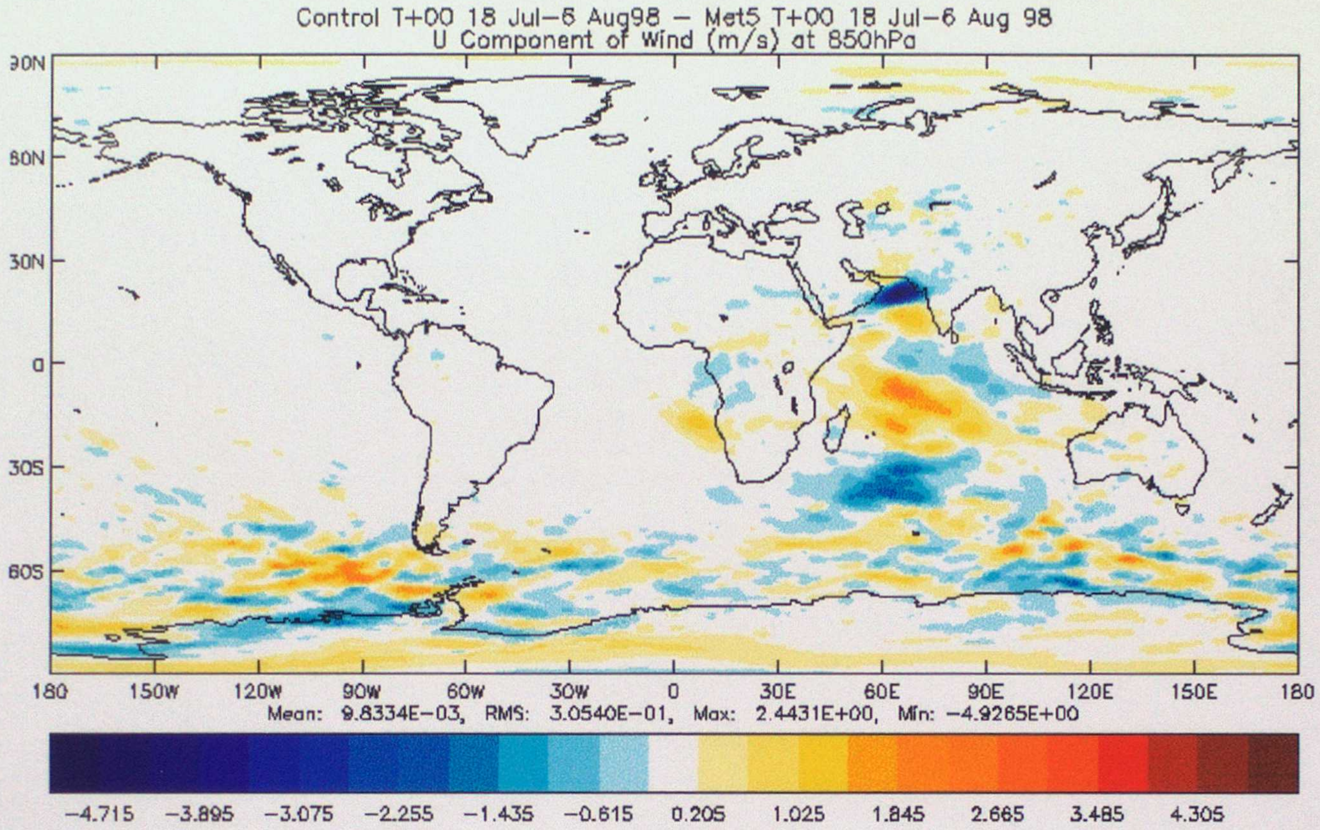

Fig. 4. Meteosat-5 trial: T+0 difference fields of 850-hPa u-component wind, 18 Jul-6 Aug 98.

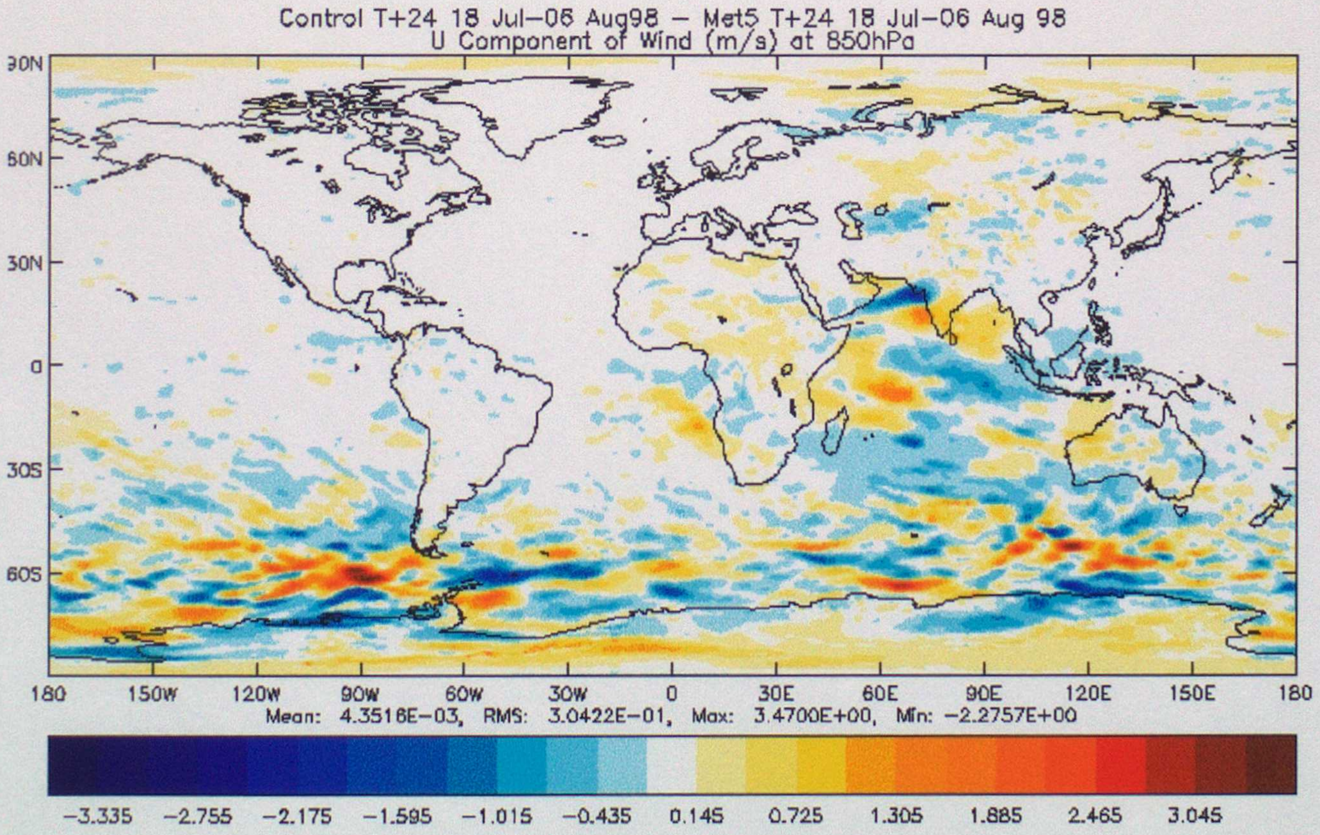

Fig. 5. Meteosat-5 trial: T+24 difference fields of 850-hPa u-component wind, 18 Jul-6 Aug 98.

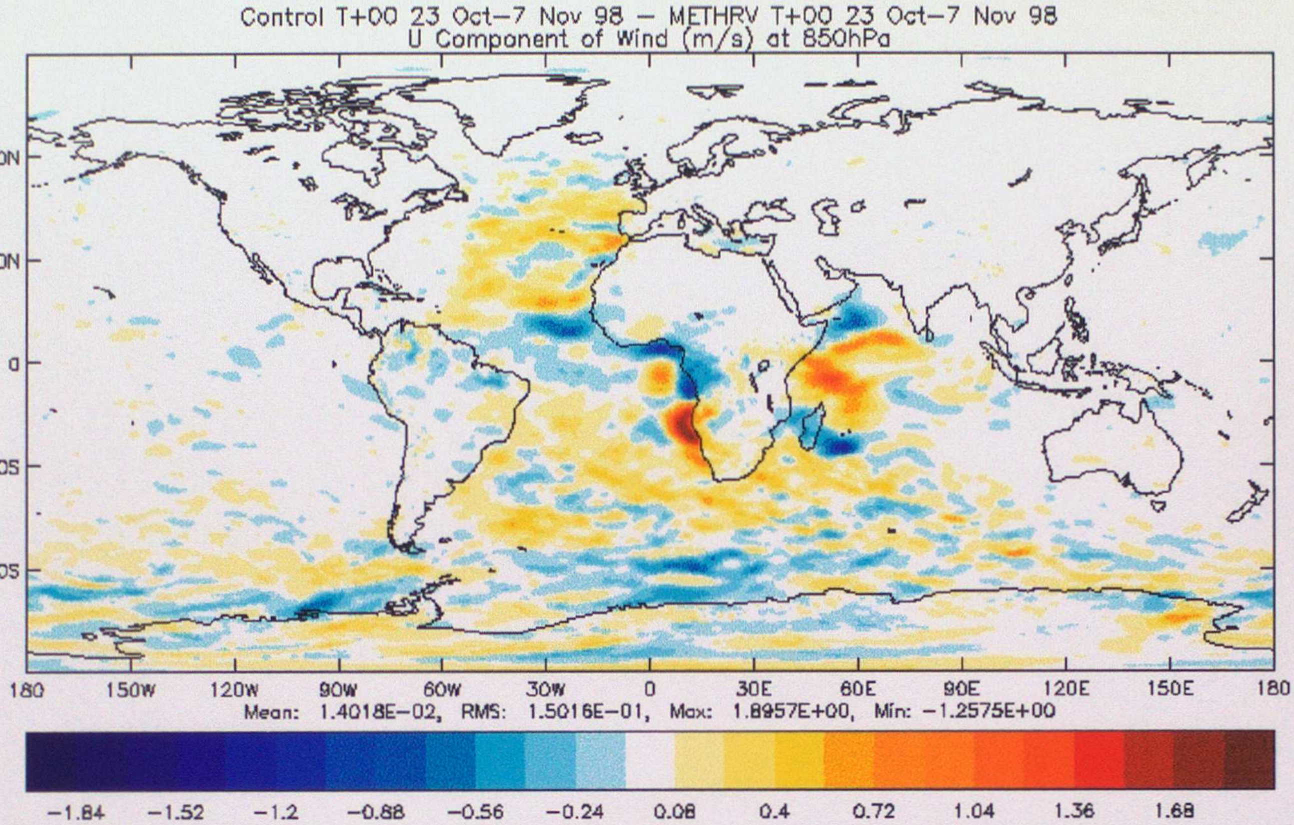

Fig. 6. Meteosat Hi-Res VIS trial: T+0 difference fields of 850-hPa u-component wind, 24 Oct - 7 Nov 98.

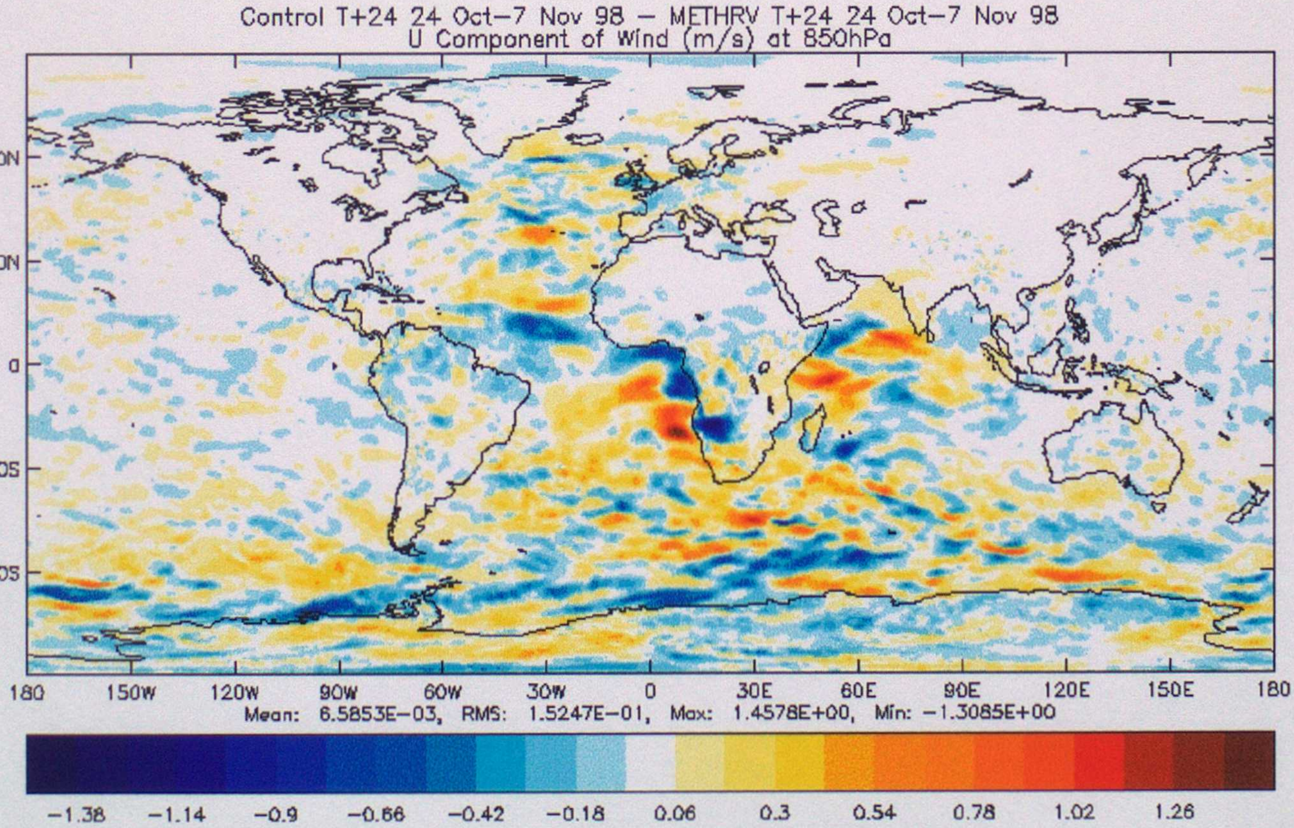

Fig. 7. Meteosat Hi-Res VIS trial: T+24 difference fields of 850-hPa u-component wind, 24 Oct - 7 Nov 98.