RECENT DEVELOPMENTS IN THE USE OF SATELLITE WINDS AT THE UK MET. OFFICE

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ABSTRACT

Impact trials carried out for July 1998 to test Meteosat-5 and GMS water vapour satellite winds showed small positive impacts, and operational changes to The Met. Office's global operational numerical weather prediction (NWP) system were subsequently made in spring 1999. Since then, a set of impact trials attempting to make use of satellite winds at a higher resolution than previously has been carried out. It was found that assimilating winds at a resolution of 2º results in a neutral impact, whereas assimilating at resolutions closer to model resolution (92- and 125-km) produces small negative impacts. The average forecast RMS error increased by 0.4 and 0.3%, respectively, even though use was made of EUMETSAT's quality indicator in the thinning of these winds. To provide a context within which to set these results, a trial was run using no satellite winds, which resulted in a degradation of forecast RMS error of 1.8% when verified against independent observations. This last result confirms that the current operational use of satellite winds is providing a significant enhancement to the forecast.

1. Introduction

Since the 4th Winds Workshop in October 1998, The Met. Office has carried out a series of impact trials in order to try and improve the use of satellite winds in its operational global NWP model, the Unified Model (UM). Improvements and modifications to the current set of satellite winds transmitted worldwide have been outlined and highlighted in the proceedings from the most recent Winds Workshops (EUMETSAT, 1997, 1999). These include the repositioning of Meteosat-5 in support of INDOEX, the generation of water vapour winds by the Japanese GMS satellite, the generation of high-resolution winds from both Meteosat and GOES, and also the transmission of winds with a quality indicator (QI) attached from Meteosat. Tests were carried out on Meteosat-5 and GMS WV winds in 1998, and, within the past year, attempts have been made to make use of high-resolution winds, including those containing a QI.

Currently (February 2000) use is made of infrared, water vapour and low-resolution visible winds from Meteosats-5, -7 and GMS-5, and infrared winds from GOES-8 and -10 (thinned to 2º). No satellite winds are used at heights below 700 hPa (low level) over land in the northern extratropics, and GMS-5 water vapour winds are not used between 400 and 700 hPa (medium level).

Other types of "satellite wind" are in use at The Met. Office: winds derived from scatterometer measurements and those from the microwave imager, SSM/I. The term satellite wind or satwind is used here to signify those data derived from geostationary imagery; winds from scatterometer or SSM/I will be named as such. Recent changes in the use of these latter winds included the switching off of scatterometer winds in December 1999 as a Y2K precaution. The Met. Office had been carrying out its own retrieval and dealiasing of ERS data since August 1993, to the benefit of the forecast system. However, this benefit had recently been negated by an error in the sea-ice check, which was introduced in January 1998 and rectified in September 1999. An impact trial on ESA-produced winds with extra quality control on the wind directions yielded neutral impact (Candy *et al.*, 1999). Scatterometer winds will be reintroduced within the operational 3DVAR assimilation system in late 2000. SSM/I wind speeds have been used operationally since October 1999. They showed a similar positive impact to scatterometer winds (largest in the southern extratropics) but there exists some redundancy between the two observation types.

2. Data assimilation developments

In March 1999 The Met. Office changed from the previous analysis correction (AC) scheme to a three-dimensional variational assimilation (3DVAR) system (Lorenc *et al.*, 2000). ATOVS data from NOAA-15 were assimilated simultaneously. In October 1999, direct assimilation of radiances from satellite sounders was introduced, as were SSM/I wind speeds. There were also changes to the background error covariances and to the use of surface pressure observations. Together these changes were the most significant to the data assimilation system for many years and they resulted in forecast improvements throughout the globe, but particularly in the southern extratropics (see Fig. 1).

Salient features of the 3DVAR system are that it is performed at half the horizontal resolution of the operational forecast model (in spectral terms it is a T107 analysis) and no special account is taken of asynoptic data (plans are currently in hand to amend this). The 3DVAR system allows use of nonlinearly related observations (such as satellite radiances) and an improved covariance model controls the spreading of observational increments. For example, in the tropics there is less vertical spreading of wind and temperature increments (Ingleby, 2000). In general the system extracts more useful information from observations but it appears also to be more vulnerable to poor quality data. Thus, if one aspect of the quality control system is wrong, then it can negate the benefit of using a particular observation type (e.g. scatterometer winds). Observation errors should be regularly monitored to ensure that up-to-date estimates are used within the assimilation system. For the trials outlined below, the observation errors used at different levels for satellite winds are:

Level (hPa):	1000	850	700	500	400	300	250	200	150	100	70
Error (m/s):	1.3	1.7	2.0	2.5	3.3	3.3	3.3	3.3	3.6	5.5	5.4

A full discussion on background errors is given in Ingleby (2000).

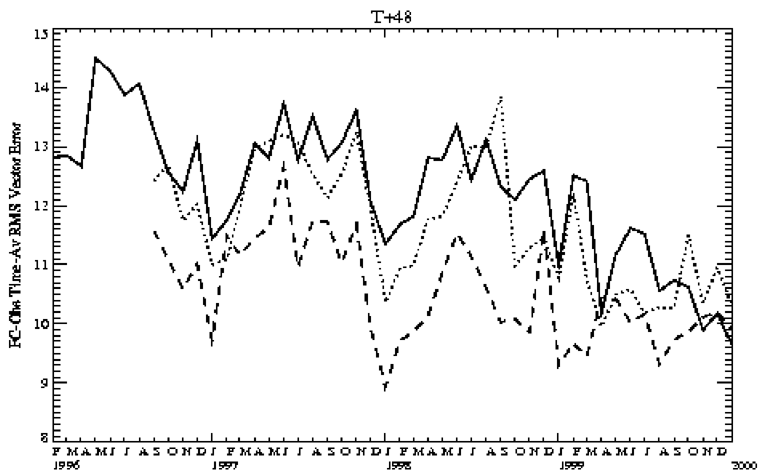

Figure 1. RMS verification of T+48 forecasts against radiosonde 250-hPa wind (m/s) for region 30-90º south: The Met. Office (solid line), ECMWF (dashed line) and NCEP (dotted line). (Courtesy of D. Matthews, The Met. Office.)

3. Impact trials

In response to the repositioning of Meteosat-5 for INDOEX over the Indian Ocean, an impact trial valid for July 1998 was run. Verifying the forecasts against observational data showed an improvement in an averaged skill score of 0.4%. This improvement was good enough for the use of Meteosat-5 winds to be made operational in the UM in February 1999. Following this, an impact trial on the use of GMS water vapour (WV) winds at high level (heights above 400 hPa), valid for July 1998 was carried out, and showed an improvement in skill score of 0.2%. Again, this resulted in an operational change, and high-level GMS WV winds were switched on in March 1999. The skill score is described briefly in section 4 of Lorenc *et al.* (2000). It places most weight on short-range (24-hour) forecasts and mean sea-level pressure.

Two subsequent trials on the use of high-resolution visible winds from Meteosat gave results that were not so encouraging. The first, using these winds thinned to one per 2 x 2º box, run during October 1998, gave a neutral result. The second, which attempted to make more use of these winds by using one per 92-km box, as well as increasing the use of GOES IR winds to this density (they are used operationally at one per 2 x 2º box) gave different results depending upon the season. Two separate trials were run. The first, valid for March 1999, showed an insignificant increase in skill score against observations (0.03%) and the second, valid for June 1999, showed a decrease in skill score of 0.3%. Due to the negative nature of the combined trials, the operational use of GOES winds remained as before, and high-resolution Meteosat visible winds were not introduced operationally. A more in-depth account of all the above trials is given in Butterworth (2000).

The transmission of Meteosat satellite winds in BUFR code, along with the QI, means that more flexibility is now possible in the use of Meteosat winds. The QI is computed at EUMETSAT during routine quality control of satellite wind observations (Holmlund, 1998), and is based on a set of five tests for consistency against neighbours and a forecast field. The QI can range from 0 to 1, and for normal satob transmissions of low-resolution winds, only those winds that have a QI above 0.8 are transmitted. In BUFR code, however, all winds with QI>0.3 are transmitted, thus allowing the NWP centre to determine its own requirement with respect to quality. The BUFR winds are also produced every 90 min (with the exception of visible winds, which are produced every 3 hours).

3.1. The Quality Indicator

Before quality control decisions based on the QI can be made within the data assimilation system, it must be verified that the QI itself is an independent measure of quality which can be used by the assimilation system. The QI contains information from another NWP model (the ECMWF model is used for the forecast check), and it is possible that a high QI measured by the EUMETSAT quality control system will not equate to a high quality when compared against our system. To this end, a week's worth of data were collected (25 October - 1 November 1999), and for each separate wind type, in different latitude regions and at different levels, the QI was compared against the observation-background differences found during observation preprocessing. Figure 2 shows some typical results. The winds were divided into QI bins of 0.01, and then plotted with the average wind speed bias and vector RMS computed for the set of winds within that bin. Number of winds in each bin and the averaged background wind speed is also shown. It is reassuring that, generally, as the QI increases, the measures of quality for bias and vector RMS improve (i.e. the bias tends closer to zero, and the vector RMS decreases). For lower values of QI (0.3 - 0.5) the signal tends to be more noisy, and for the cases of medium-level cloudy WV winds and clear-sky WV winds, the signal is not clear enough that we would currently consider testing these winds with the current assimilation system.

3.2. Details of impact trials

Two impact trials at different resolutions were run to test the use of the QI and increased resolution satellite winds. The tests ran from 26 November to 26 December 1999, using a low-resolution version of the current operational UM. Changes made in the use of satellite winds were as follows:

- Satob-coded winds from Meteosat were switched off.
- BUFR-coded winds from Meteosat were switched on, constituting high-resolution visible winds, high-resolution water vapour winds (cloudy only at high levels) and standard-resolution infrared winds.
- BUFR winds were only used for validity time closest to the operational runtime, i.e. every 6 hours, and not every 90 min.
- All satellite winds, and not just the high-resolution data, were subject to thinning.
- One trial at a thinning resolution of one wind per 92-km box was run. A second trial at a thinning resolution of one wind per 125-km box was run.
- The choice of wind within a thinning box was that closest to the centre of the box for GOES and GMS winds.
- The choice of wind within a thinning box was that with the highest QI for Meteosat, subject to a certain minimum threshold.

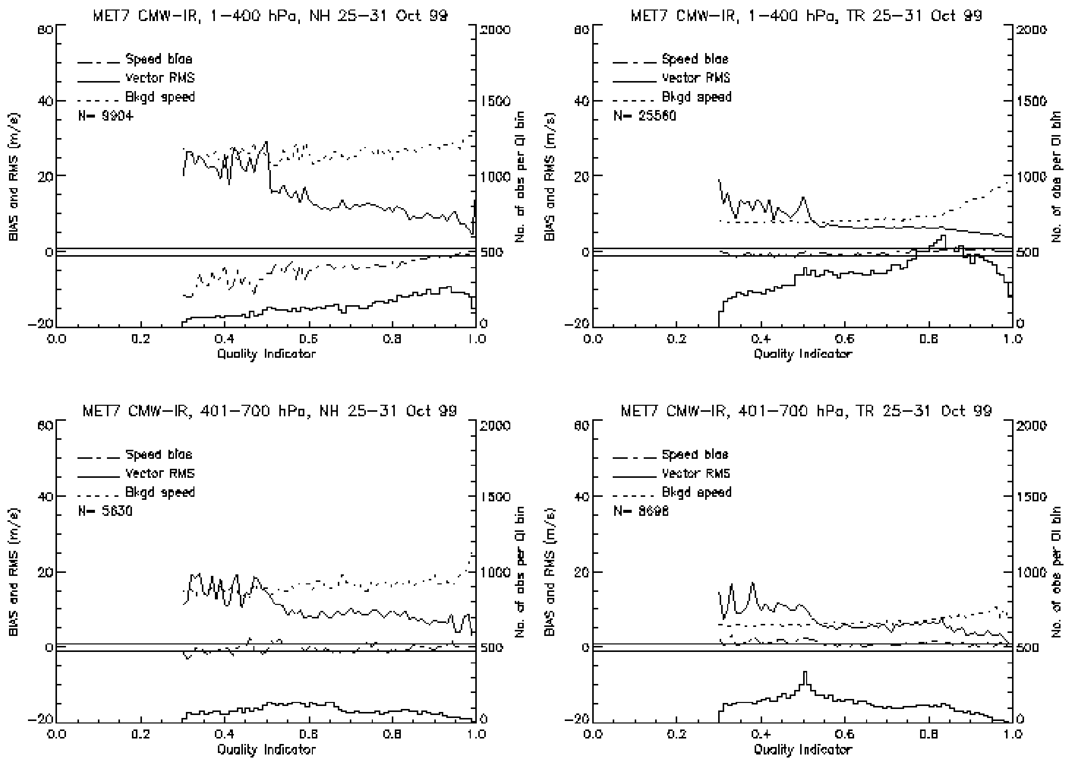

Figure 2. Quality indicator vs observation-background statistics for Meteosat-7, infrared cloud-motion winds. Top panels: high-level winds; bottom panels: medium-level winds; left panels: northern extratropics; right panels: tropics. Solid line: vector RMS; dot-dashed line: wind speed bias; dotted line: background wind speed, all relating to the left-hand scale. The number of winds in each 0.01 QI bin is also plotted, relating to the right-hand scale.

Since winds with QI above 0.3 are transmitted, it is necessary to impose a threshold limit on the winds that are allowed into assimilation. Based on the figures showing QI in relation to observation-background quality statistics, the following thresholds were chosen:

Tropics, all winds	all levels	0.90
Visible winds	low level	0.60
Water vapour winds	high level	0.80
Infrared winds	high level	0.85
Infrared winds	medium level	0.60
Infrared winds	low level	0.70

The high threshold chosen for tropical winds is not based on the QI plots (since these showed tropical winds to be quite reliable at QIs much less than 0.9), but on the experience of impact trials at ECMWF (Rohn *et al.*, 1999). Those trials found that a stringent threshold should be placed on tropical winds, due to the scarcity of other observations and to avoid over-dependence on satellite winds. With regard to volume, it was found that moving from the current operational use of satellite winds to 92-km resolution resulted in double the number of satellite winds being assimilated (from *ca* 7000 to 15000 per model run).

4. Results

The forecasts were verified from 1 to 25 December 1999, allowing a generous 4-day spin-up before comparison. In each case, a set of forecast parameters were verified for the test run and the control run, both against the analysis produced by each run, and against independent observations valid for the forecast time. Forecast parameters include geopotential heights, wind, temperature and relative humidity at a range of levels (850-100 hPa), and mean sea-level pressure, all at a range of forecast times, from T+24 to T+144 h. The RMS forecast error was measured for each case, and the value of percentage change in RMS forecast error computed, whereby a positive change is a degradation from control to test, and a negative change an improvement. The percentage changes in RMS forecast error averaged in latitude bands are given in Table 1, as is the number of observations available for verification for each model run.

Table 1. Percentage change in RMS forecast error for the two trials at different resolutions, and number of observations available for verification in each latitude band. A positive change is a degradation in the forecast from control to test.

	Verification vs analysis	Verification vs observations	Obs available for verification
92-km resolution			*Surface*
NH	+0.8	+0.1	3160-3280
Tropics	+1.2	+0.4	650-850
SH	+1.4	+0.6	620-670
Average:	+1.1	+0.4	
125-km resolution			*250-hPa wind*
NH	+0.9	+0.3	310-340
Tropics	+0.8	+0.3	70-95
SH	+1.1	+0.4	70-95
Average:	+0.9	+0.3	

It can be seen from Table 1 that both trials show a negative impact from the changes introduced in the test runs. Overall, the result is worse for the 92-km resolution trial than the 125-km, yet within latitude bands the northern extratropics verifies better for the 92-km trial. Verification against observations is considered to be a better measure of forecast error, since they are independent of the forecast being verified. Analyses retain some influence due to previous forecasts and do not provide an independent reference, especially in data-sparse regions. However, a closer inspection is still needed to pinpoint the locations of the changes that are being made to the forecast by introducing the new winds and the new thinning procedures.

Figure 3 shows where the differences in analysis between test and control are taking place for mean sea-level pressure. The data are averaged for 1 - 25 December 1999, for the runs at 12 UTC, and the RMS difference between test and control is shown. It is apparent that the biggest changes are taking place in the south Atlantic and southern Indian ocean, under the Meteosat sphere of influence. With regard to upper-level parameters, Fig. 4 shows an equivalent field for the u-component of the 250-hPa wind. This time, the changes are more widespread over the Meteosat regions. Figures 3 and 4 indicate that no major changes were made to the analyses by the introduction of more GOES data due to the increased resolution, and this finding is apparent in fields of other forecast parameters. The auto-editor system at NESDIS reassigns the observation heights to give a better fit to the NCEP forecast (Nieman *et al*., 1997). This appears to improve their accuracy and their fit to our short-range forecasts, but at the cost of introducing information from another NWP system.

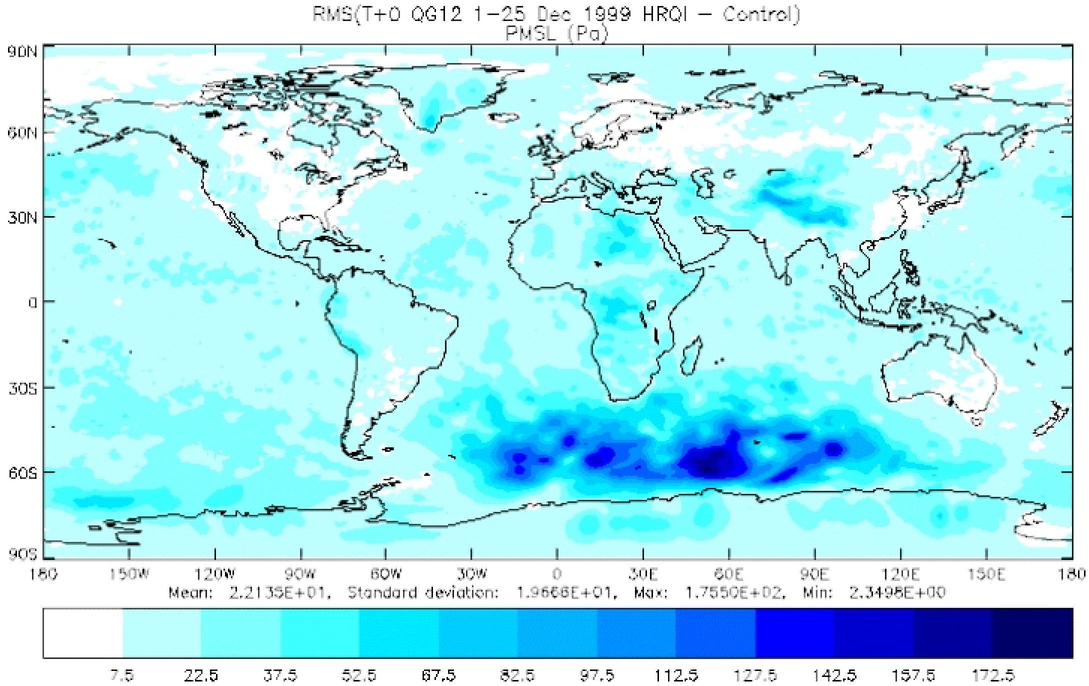

Figure 3. RMS difference (test - control) of mean sea-level pressure (Pa), averaged for 1 - 25 December 1999, model runs at 12 UTC only, for the 92-km resolution trial.

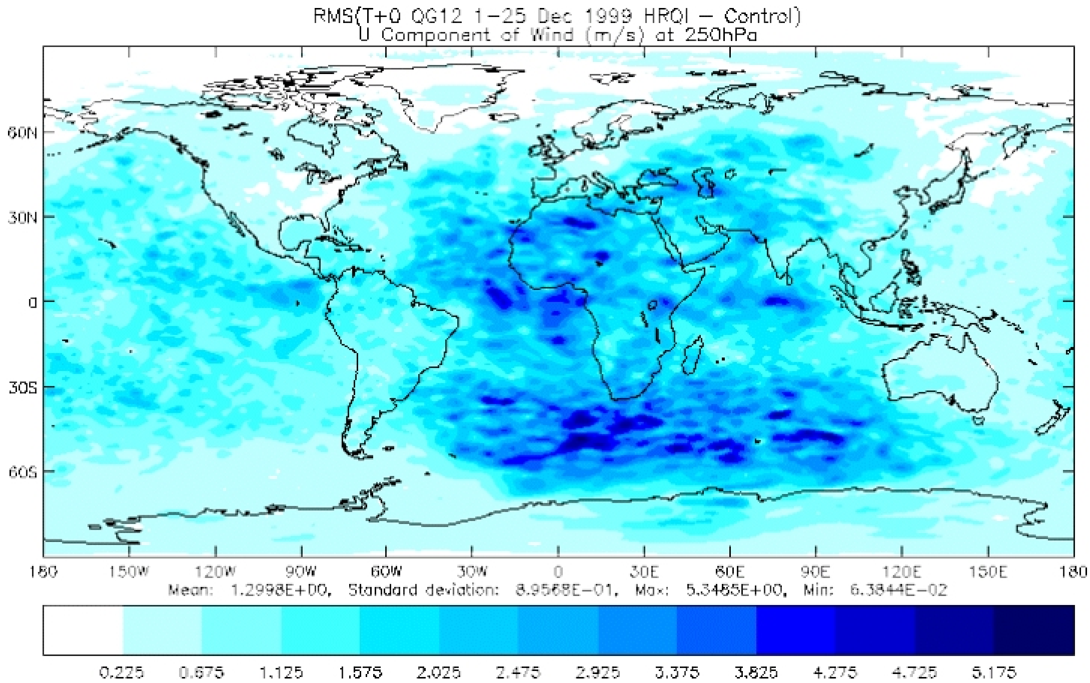

Figure 4. As Figure 3 but showing the u-component of the 250-hPa wind field (m/s).

Although the results for both trials were negative overall, the average change in percentage forecast RMS error was not very large. Of the forecast parameters that were compared against observations, mean sea-level pressure in the southern extratropics for the 92-km resolution trial showed the most sustained difference, with significant increases in forecast RMS error of 2.6, 2.7 and 3.4% at forecast times of T+72, 96 and 144 h, respectively. The biggest single changes in forecast RMS error were in the southern extratropics for 850-hPa geopotential height at T+96 and 250-hPa wind field at T+144 (both 3.9%). The 125-km resolution trial displayed a similar pattern of differences.

In order to try and place these results in context, a further trial was carried out in which all satellite wind observations were removed from the test run. In this case the control is the current operational system, which assimilates Meteosat, GOES and GMS winds at low resolution. Table 2 shows the results averaged for 1 - 25 December 1999. Against analysis, the global forecast has improved by 0.4% upon the removal of satellite winds from the system, while verifying against observations shows that the forecast is degraded by 1.8%. The improvement in forecast against analysis in the tropics is dominated by T+24 forecasts. Since persistence gives a good forecast in the tropics, adding observations here nudges the forcast away from persistence and so the verification against analysis is worse at short range. The use of satellite winds in the tropics becomes more positive at longer ranges. Due to the reasons described above, verification against observations is considered to be a better measure of impact.

Table 2. Percentage change in forecast RMS error for the "no satwind" test. A positive result implies a benefit from using the satwinds.

	Verification vs analysis	Verification vs observations
NH	+0.4	+0.9
Tropics	-2.2	+1.8
SH	+0.5	+2.7
Average:	-0.4	+1.8

Against observations, it can be seen that overall the forecast in the southern extratropics has degraded the most, by 2.7%. The biggest single changes in forecast RMS error were in the southern extratropics for mean sea-level pressure (T+144, 11.9%) and for 100-hPa wind fields in the tropics (T+24, 12.1%).

Although many forecast parameters exhibited sustained degradation throughout the forecast range when no satellite winds were used (e.g. tropics, 100- and 250-hPa wind fields, 100-hPa temperature fields; southern extratropics, 50- and 250-hPa wind fields, 250- and 850-hPa geopotential height), mean sea-level pressure in the southern extratropics displayed the largest changes, as seen in Fig. 5. These results confirm that satellite winds are a valuable part of the observing system used in data assimilation. An interesting result to come from this trial found that in the northern extratropics the satellite winds were actually degrading the short-term (24-hour) forecast when verified against radiosondes, particularly over Europe and Asia, however this was more than compensated by the benefit seen at longer forecast ranges. The implication of the degradation at short-range is that we may be overfitting the satellite winds, and perhaps need to increase the assigned observation errors.

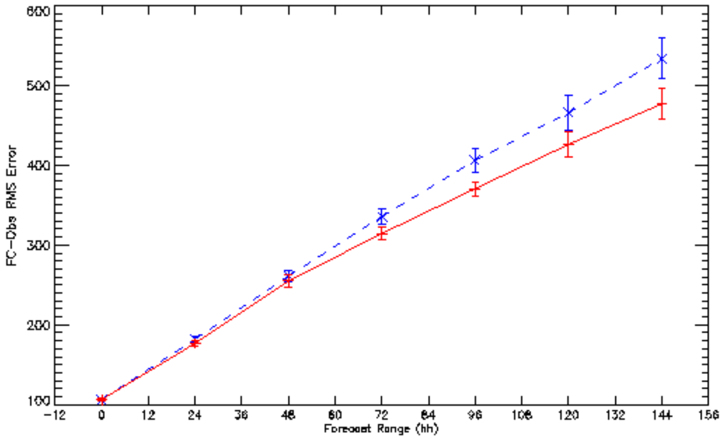

Figure 5. Forecast - observation RMS error for mean sea-level pressure (Pa), verified against surface observations for the southern extratropics (20-90 S), vs forecast range for control (solid line) and no satwind test (dashed line).

A greater selection of RMS forecast error changes for the 125-km resolution trial and the no satellite winds trial is given in Table 3.

Table 3. Percentage change in RMS forecast error for a selection of forecast parameters. Results for the 125-km resolution trial and the no satellite winds trials are shown. A positive change indicates a degradation from the control run to the test run. Changes vs both analysis and observations are given.

			125-km resolution		No satellite winds	
Area	Field	Range	vs anal	vs obs	vs anal	vs obs
NH	PMSL	T+24	0.75	1.85	1.09	0.01
NH	PMSL	T+48	0.16	1.16	1.10	1.98
NH	PMSL	T+72	0.82	0.46	0.47	1.24
NH	PMSL	T+96	1.30	1.69	0.81	0.39
NH	PMSL	T+120	1.14	1.35	1.55	5.69
NH	H500	T+24	1.73	2.14	0.04	-1.13
NH	H500	T+48	0.39	-0.45	1.59	2.88
NH	H500	T+72	0.88	-0.34	0.89	2.15
NH	W250	T+24	1.39	0.32	-0.12	-0.29
Trop	W850	T+24	0.63	0.32	-16.13	0.54
Trop	W850	T+48	0.47	0.15	-10.52	1.31
Trop	W850	T+72	0.73	0.17	-7.05	1.74
Trop	W250	T+24	-1.81	0.73	-15.76	8.61
SH	PMSL	T+24	0.09	-0.12	-1.81	2.96
SH	PMSL	T+48	0.58	0.97	0.54	2.42
SH	PMSL	T+72	0.72	2.24	3.11	6.75
SH	PMSL	T+96	0.92	2.16	3.80	9.56
SH	PMSL	T+120	1.50	0.69	5.13	9.32
SH	H500	T+24	0.41	-1.56	-3.47	-1.22
SH	H500	T+48	0.24	-0.75	2.30	4.13
SH	H500	T+72	0.65	0.10	5.32	6.59
SH	W250	T+24	1.07	-0.91	-7.26	2.78

5. Conclusion

The use of satellite winds at resolutions approaching model resolution does not improve the forecast, at least in the current configuration. Making use of extra quality information supplied by EUMETSAT is not sufficient to overcome the negative impact of assimilating so many winds. As a follow-up to the tests on high-resolution winds, an impact test using no satellite winds was also carried out. In comparison, the use of winds at 92-km resolution resulted in an average forecast RMS error degradation of 0.4% against observations (equivalent to 0.4% degradation in skill score). The use of no satellite winds resulted in an average forecast RMS error degradation of 1.8% (equivalent to 1.9% degradation in skill score), illustrating that the use of satellite winds is enhancing the forecasts, particularly in the tropics and southern extratropics. The smaller enhancement in the northern extratropics due to the use of satellite winds is to be expected in the light of the density of conventional observations in this region. Since there is some evidence that we are overfitting the satellite winds, a trial using increased observation errors is being trialled. Height assignment may also be part of the problem, and this will be investigated.

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