MODIS WINDS: LATEST RESULTS AT THE MET OFFICE

Mary Forsythe[(1)], **Howard Berger**[(1,2)]

[(1)] Met Office, Fitzroy Road, Exeter, EX1 3PB, UK
[(2)] Cooperative Institute for Meteorological Satellite Studies (CIMSS), Madison, WI, USA

ABSTRACT

The MODIS winds, developed at the Cooperative Institute for Meteorological Satellite Studies (CIMSS), have shown potential as a useful new dataset for NWP models. The winds provide information in the data-sparse polar regions and complement the conventional low and mid-latitude geostationary atmospheric motion vectors (AMVs).

Over the last 2-3 years several centres, including the Met Office, have been running assimilation experiments and monitoring the MODIS winds, but not always with consistent results. In an attempt to improve our understanding and to identify possible sources of error, the Met Office participated in a special monitoring period (MOWSAP) during November 2003 – January 2004. Monitoring of the CIMSS and NESDIS MODIS datasets shows better agreement of the NESDIS MODIS winds with the Met Office model background. MODIS winds produced from the 2 satellites, Aqua and Terra, show similar biases and root mean square vector differences, although there are some differences in their distributions. We also continued to run assimilation experiments with the MODIS winds in the global Met Office model. The most recent experiment, assimilating NESDIS MODIS winds, is the first MODIS experiment at the Met Office to show neutral to positive impact in both the northern and southern hemispheres.

1. INTRODUCTION

Until the development of the MODIS wind dataset by the Cooperative Institute for Meteorological Satellite Studies (CIMSS) 2-3 years ago, the only wind observations available for global NWP in the polar regions (polewards of 65° latitude) were a few radiosonde and aircraft reports. The MODIS winds provide important new information in the data-sparse polar regions and have the potential to greatly improve polar wind analyses, which should in turn improve global forecasts. MODIS wind assimilation experiments at several centres including the European Centre for Medium Range Weather Forecasting (ECMWF) and the Global Modelling and Assimilation Office (GMAO), NASA, have indeed shown improvements in polar analyses and forecast skill (Bormann & Thépaut, 2003; Key et al., 2003).

The MODIS winds, like the well-established geostationary AMVs, are produced by tracking clouds or areas of water vapour through consecutive satellite images. Although the geostationary and polar winds are produced using the same method, there are several important differences. In general, there is a much longer time lag between the valid time of the observations and their arrival time at NWP centres, restricting their usage in forecast models. Another major difference is the longer time interval between consecutive images. For the MODIS polar winds the interval is approximately 100 minutes, longer than the 10-30 minute intervals used for geostationary AMVs and much longer than the optimal 5-10 minutes for cloudy tracers determined by experiments at EUMETSAT and CIMSS (e.g. Velden et al., 2000; de Smet, 2002). With the MODIS winds there are also complications due to the different viewing geometries of successive orbits and difficulties with height assignment due to the low atmospheric water vapour amounts and thin clouds that are typical of the Arctic and Antarctic (Key et al., 2003). In view of these difficulties, it is perhaps unsurprising that not all assimilation experiments using the MODIS polar winds have produced positive results (Velden et al., 2003).

In an attempt to understand the mixed results from different centres and to gain a better idea of the errors in the MODIS data, a special monitoring period (MOWSAP) was established during November 2003 to January 2004. As one of the participating centres, we began monitoring the MODIS winds in October 2003. Over the last year we have also continued to run forecast impact experiments with the MODIS winds in the global Met Office model. In this paper, we will use the results of our assimilation experiments, monitoring and investigations to address some questions regarding the MODIS winds including how the winds from Terra and Aqua compare and whether the new NESDIS MODIS winds are better than the original CIMSS dataset. We also show how reducing the time delay of the MODIS winds, through the use of direct broadcast, could benefit the Met Office.

2. HOW DO THE WINDS FROM TERRA AND AQUA COMPARE?

The MODIS polar winds are produced using imagery from two polar-orbiting satellites: Terra and Aqua. The benefits of using data from both satellites can be seen in the data coverage plots (see Figure 1). With data from both satellites, there is almost complete polar coverage in a 6-hour assimilation window.

<u>*Northern Hemisphere*</u> <u>*Southern Hemisphere*</u>

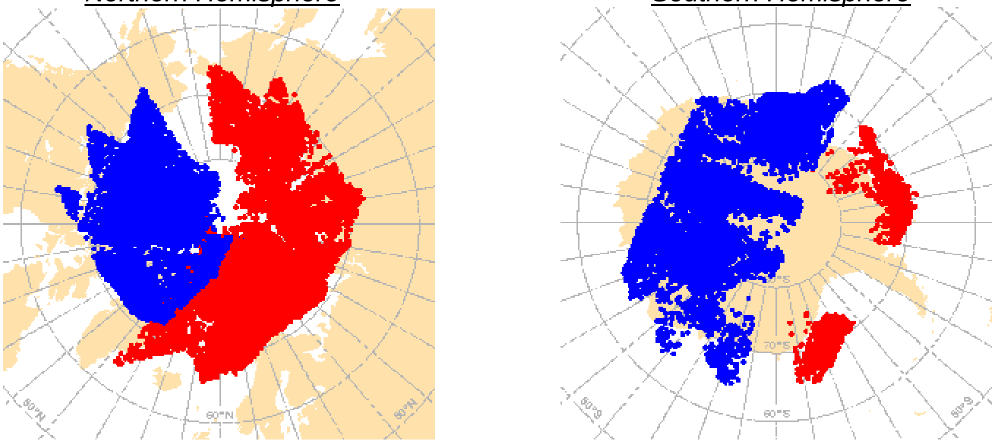

Figure 1: Location of all NESDIS MODIS winds valid between 0900 and 1500 GMT on the 24th January, 2004. Winds from Terra are shown in red; winds from Aqua are shown in blue. Note the almost complete polar coverage for the 6 hour assimilation period.

Assimilation experiments at ECMWF using CIMSS Aqua MODIS winds on top of their operational Terra winds initially showed disappointing results. The Met Office also obtained negative impact assimilating CIMSS data from both satellites. In view of these results, we decided to test the robustness of our strategy to use winds from both Aqua and Terra, repeating our original experiment with data from Terra only and Aqua only (see Table 1 for more details).

MODEL DETAILS	Low resolution (100 km) Met Office Unified Model (Cullen et al., 1997)
DATA ASSIMILATION	3D-VAR (Lorenc et al., 2000)
PERIOD OF EXPERIMENT	11th May – 5th June 2003
BLACKLISTING	All clear-sky water vapour (CSWV) winds All winds below 400 hPa over land All IR winds below 700 hPa over sea All cloudy WV winds below 550 hPa over sea
THINNING BOX SIZE	140 km x 140 km x 100 hPa
EXPERIMENT DETAILS	CONTROL: No MODIS winds TRIAL A: Winds from Aqua and Terra TRIAL B: Winds from Terra only TRIAL C: Winds from Aqua only

Table 1: Details of the CIMSS MODIS assimilation experiments at the Met Office.

The results of the single satellite experiments were very similar, with both showing negative impact in the southern hemisphere, but less so than the original experiment using data from both satellites together (see Figure 2). Percentage root mean square differences of greater than 2% are considered significant.

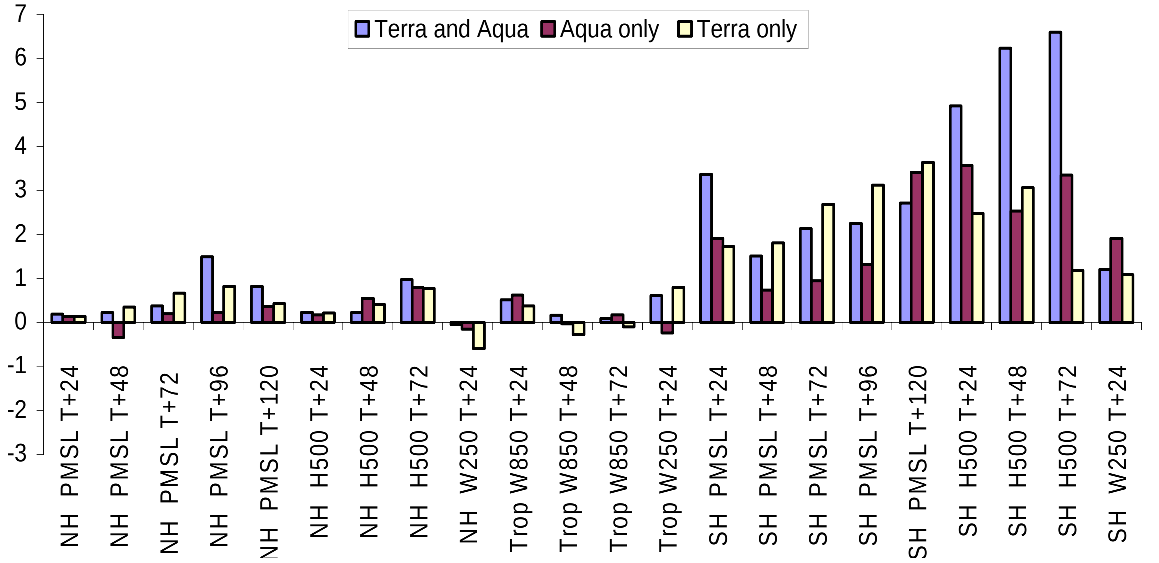

Figure 2: Changes in % root mean square difference between the experiments and control over the course of the trials for certain forecast parameters (pressure at mean sea level (PMSL), 500 hPa geopotential heights (H500), 850 hPa and 250 hPa wind fields (W850 and W250)). Forecasts are verified against selected observations. Positive root mean square differences indicate a negative impact compared to the control trial without MODIS winds. Note, in particular, the poor impact in the southern hemisphere (SH).

In addition to the assimilation experiments, we also compared monitoring statistics for the two satellites against the Met Office model background. The statistics show some differences, notably a greater number of SH winds from Aqua (see Figure 3), but the average speed bias and root mean square vector differences are comparable (see Table 2).

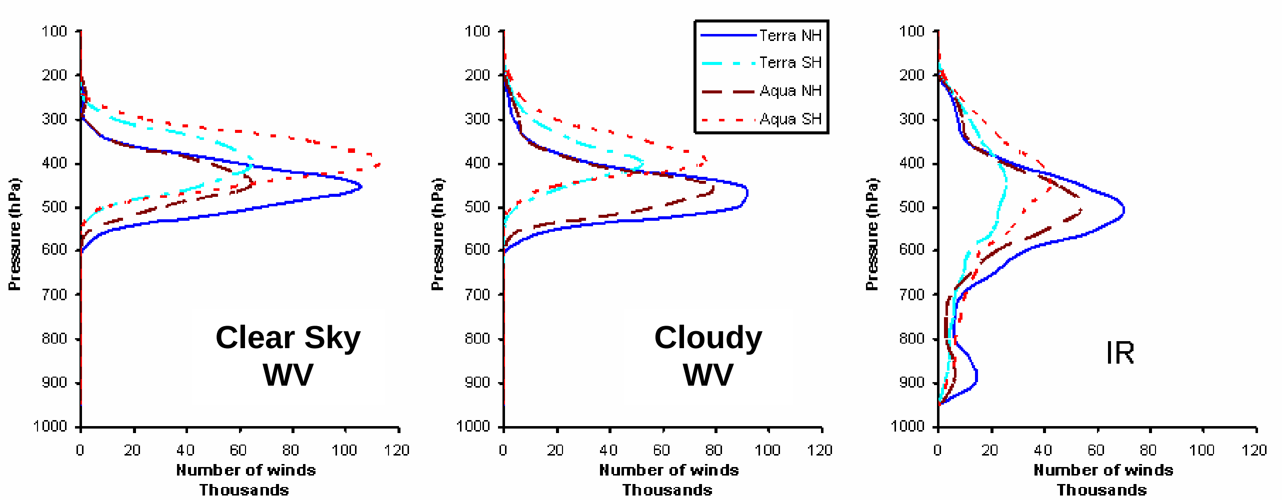

Figure 3: Line plots showing the number of NESDIS MODIS winds produced in February 2004 in each 50 hPa pressure bin. Note that for Terra, many more winds are produced in the NH than the SH, whereas for Aqua the numbers are more similar except for clear sky water vapour winds where more winds are produced in the SH. Also notice the peak in number of winds at lower pressures for the SH compared to the NH. This distribution is probably related to seasonal climatology.

		Terra		Aqua	
		Speed Bias	RMSVD	Speed Bias	RMSVD
CSWV	NH	-0.7	5.9	-0.5	5.3
	SH	-0.9	6.3	-1.0	6.3
Cloudy WV	NH	-0.6	5.5	-0.6	5.5
	SH	-0.8	7.1	-1.0	6.9
IR	NH	-0.6	5.3	-0.5	5.3
	SH	-0.4	5.8	-0.5	5.7

Table 2: Speed bias and root mean square vector difference statistics for Terra and Aqua for February 2004, calculated against the Met Office model background. Statistics are calculated separately for each channel and hemisphere.

Based on the monitoring and experiments we believe that the winds from Aqua and Terra are of comparable quality and any future strategy at the Met Office will utilise winds from both satellites.

2.1. Where to go from here? – modified quality control

The first three MODIS wind assimilation experiments at the Met Office, described in the previous section, all show neutral to slightly negative impacts in the northern hemisphere and tropics and a very large negative impact in the southern hemisphere, particularly in the 500 hPa height field. In an attempt to improve performance some modifications to the quality control were made and the May 2003 trial was re-run. The main differences were the inclusion of clear sky water vapour winds, an increase in the thinning box size and the modification of the blacklisting criteria (see Table 3 for details).

	Original MODIS experiment (TRIAL A)	New MODIS experiment (TRIAL D)
Channels used	IR, Cloudy WV	IR, Cloudy WV, CSWV
Blacklisting	All winds below 400 hPa over land All IR winds below 700 hPa over sea All WV winds below 550 hPa over sea	All winds below 400 hPa over land All winds below 600 hPa over sea ice
Thinning box size	140 km x 140 km x 100 hPa	250 km x 250 km x 100 hPa

Table 3: Differences in quality control between the original and new CIMSS MODIS assimilation experiments.

The results of the new MODIS experiment were encouraging. Overall the impact in the northern hemisphere was slightly positive relative to a control with no MODIS winds. The negative impact in the southern hemisphere, although still evident, was reduced. An example is shown in Figure 4, where the root mean square differences between forecast 500 hPa height fields and sonde observations in the southern hemisphere is reduced for the new experiment.

3. TWO MODIS PRODUCTS: THE ARRIVAL OF THE NESDIS MODIS WINDS

All the assimilation experiment results discussed so far have been using the CIMSS MODIS winds. Recently a second product has become available from NESDIS. Early comparative studies of the two products (e.g. Daniels, 2003) uncovered unexpected differences. The production processes at CIMSS and NESDIS are very similar. However, a significant improvement in the statistics against rawinsondes was noted for the NESDIS MODIS winds. The improvement probably relates to a few technical differences in the processing at the two centres. One major difference is a more accurate first guess used in the tracking at NESDIS. At CIMSS the Navy/NOGAPS models was used without time interpolation and at NESDIS the NCEP/GFS model was used with time interpolation (Daniels, Pers. Comm.). A second difference is the image used for tracer selection. At CIMSS the first image was used until recently and at NESDIS the middle image is used. This second difference is now thought to be the dominant factor.

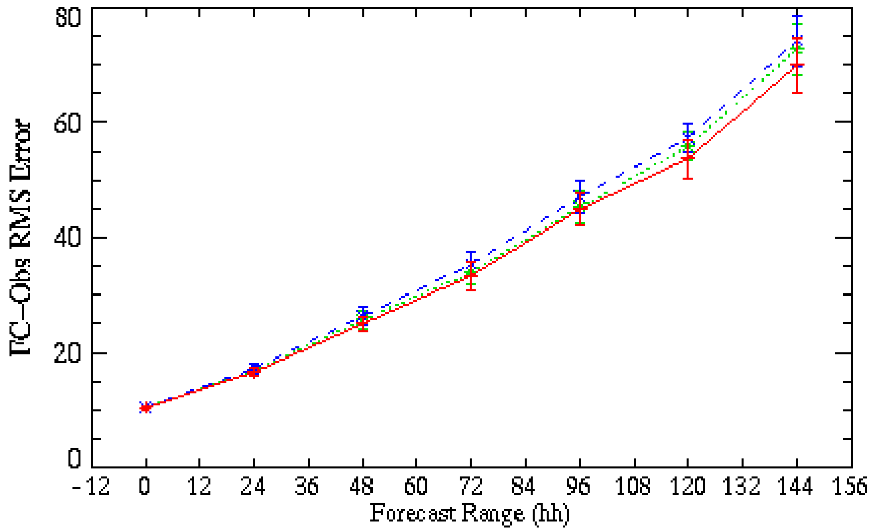

Figure 4: 500 hPa heights in the southern hemisphere (20S-90S): forecast minus sonde observation root mean square differences averaged over the course of the trial (12th May – 4th June) as a function of forecast range. The solid red line is the control, the dotted green line is the new MODIS trial and the dashed blue line is the original MODIS trial. The new quality control reduces the root mean square differences, but the impact is still negative.

Before running assimilation experiments with the NESDIS MODIS winds, we compared statistics of the NESDIS and CIMSS products against the Met Office model background. Figure 5 shows a time series plot of root mean square vector differences between the CIMSS and NESDIS MODIS datasets and the Met Office model background for the first week of February, 2004. The statistics shown are for the infrared medium level northern hemisphere winds from Terra only. In general, the NESDIS MODIS winds show substantially smaller root mean square vector differences against the Met Office model background. Other channel, satellite, level and hemisphere combinations show similar results.

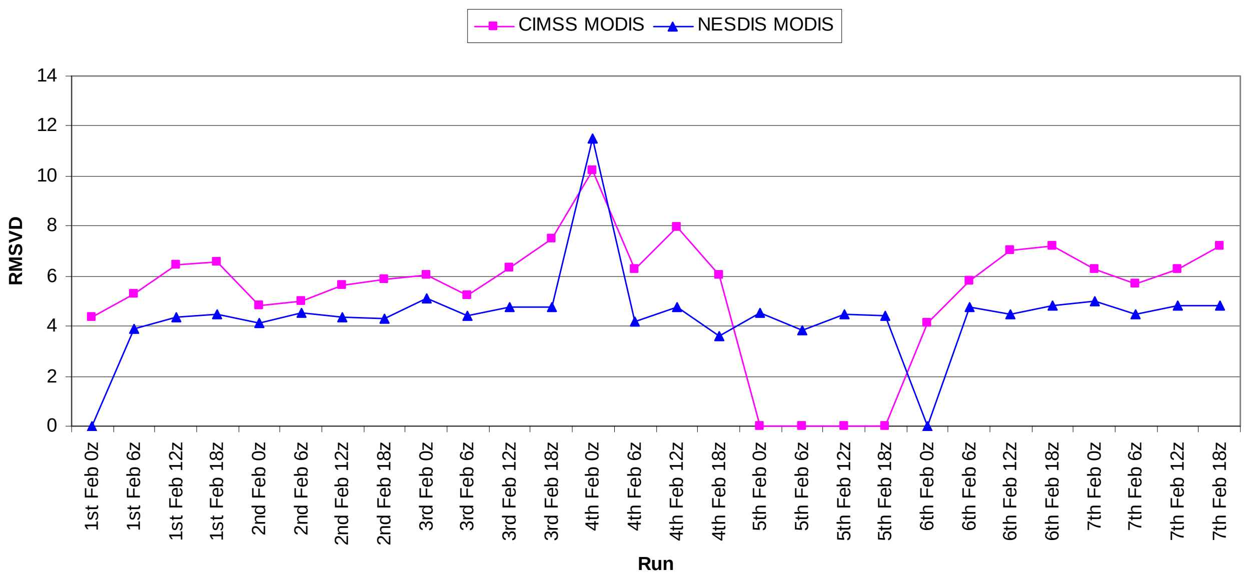

Figure 5: Time series of the root mean square vector differences between the MODIS observations and the Met Office background for the first week of February 2004. The statistics shown are for the IR, medium level, NH Terra winds produced by each centre. Note the lower root mean square vector differences for the NESDIS MODIS winds throughout the period. The poor results for the 0z run on the 4th February is anomalous and requires further investigation.

Based on the results of our monitoring and the monitoring results and advice from other centres, we decided to start assimilation experiments with the NESDIS MODIS product. The trial set-up was based on the final CIMSS MODIS experiment (Trial D), but with a slight modification to remove all water vapour winds below 400 hPa. Otherwise the main difference is the season tested, as the NESDIS MODIS winds were not available in May 2003. The details of the NESDIS MODIS experiment are shown in Table 4.

MODEL DETAILS	Low resolution (100 km) version of Met Office Unified Model (Cullen etal., 1997) with 38 vertical levels
DATA ASSIMILATION	3D-VAR (Lorenc et al., 2000)
PERIOD OF EXPERIMENT	24th January – 17th February 2004
BLACKLISTING	All Cloudy WV and CSWV winds below 400 hPa All IR winds below 400 hPa over land All IR winds below 600 hPa over sea-ice
THINNING BOX SIZE	250km x 250 km x 100 hPa
EXPERIMENT DETAILS	CONTROL: No MODIS winds TRIAL E: NESDIS Winds from Aqua and Terra

Table 4: Experiment details for Trial E using NESDIS MODIS winds.

The results of the latest experiment are the best so far (see Figure 7), with neutral to slightly positive impacts in all three latitude bands (NH, TR and SH). This improvement is probably due to the use of NESDIS MODIS winds instead of CIMSS MODIS winds, but could also be due to seasonal differences. The difference in season may be particularly critical for polar data where winter and summer may produce large contrasts in verification. We plan to run a second season trial during a southern hemisphere winter to ensure the MODIS winds are still beneficial.

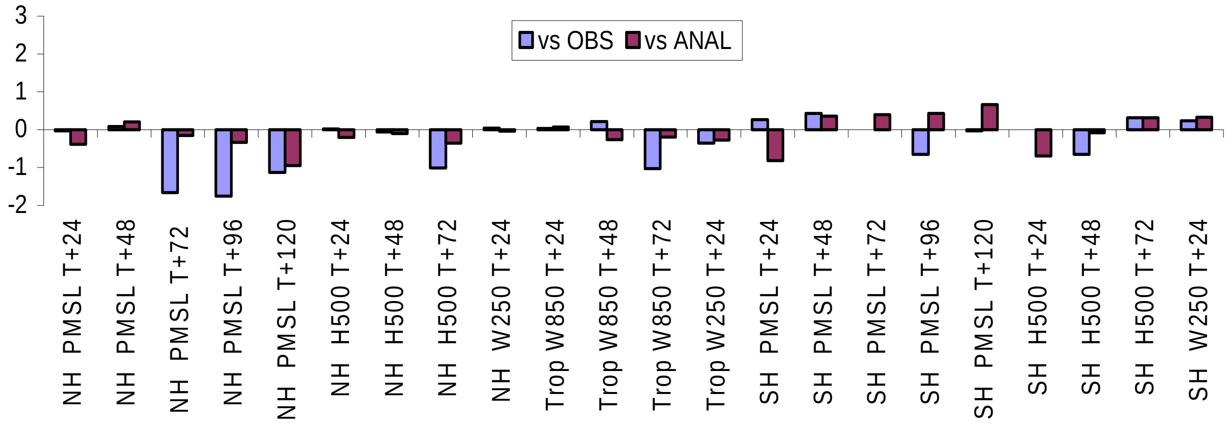

Figure 7: Changes in % root mean square differences between the NESDIS MODIS experiment and control over the course of the trials for certain forecast parameters (pressure at mean sea level (PMSL), 500 hPa geopotential heights (H500), 850 hPa and 250 hPa wind fields (W850 and W250)). Forecasts are verified against observations (blue) and analyses (red). Negative % root mean square differences indicate a positive impact compared to the control trial without MODIS winds. Overall the impact is neutral to positive, with most impact seen in the NH at medium range.

In an attempt to obtain positive impact from the MODIS winds, the quality control has become very strict and as much as 98% of the winds are thrown away. This is not ideal. We may run further experiments relaxing some of the quality control. Another possible option is to superob the winds (Berger et al., 2004).

3.1. Looking ahead: improvements in the modis winds

Development work is ongoing at CIMSS and NESDIS to improve the MODIS winds. Some of these improvements include: developing the parallax correction, use of alternate Aqua and Terra passes, production of winds across the day boundary, modification to the size of the search area and improvements in timeliness of the wind product. The developments should help to reduce any dependence on first guess, improve the quality of the winds and reduce the time lag between observation valid time and receipt time.

The reduction in lag time is possible through the use of direct broadcast. It is thought that the time lag could be reduced for some passes by 2-4 hours. At the Met Office, our main forecast model starts just under 2 hours after analysis time. Very little MODIS data make this strict cut-off. Currently, the MODIS winds are only influencing the forecasts through the background field, which is generated from update model runs beginning 7 hours after analysis time. If timeliness were to improve through the use of direct broadcast, we should be able to start including at least some MODIS winds in our main forecast runs. See Table 5 for an example of how timeliness could improve MODIS wind usage at the Met Office.

RUN	WINDOW	CUT-OFF	No. extracted	%	Observation times of extracted winds
12z main	900-1500	1400	0	0	/
12z update	900-1500	1900	16030	85	900-1400
12z main	900-1500	1530	5568	29	900-1000
12z update	900-1500	2030	18875	100	900-1500

Table 5: An example of number and percentage of MODIS winds extracted for the main and update forecast runs. The example is from 2nd December 2003 for CIMSS MODIS data. The first two rows show the current usage of the MODIS winds in the two forecast runs. In this case, the main forecast data cut-off does not allow any MODIS winds into the assimilation. The update cut-offs allow 85% of the data to be used. The last two rows illustrate how an improvement in timeliness by 90 minutes might improve the number of winds available for the two runs. In this case 29% of the winds are used in the main run and 100% in the update run.

The development work is very promising for the future of the MODIS winds. The Met Office supports these efforts to increase the quality and timeliness of the MODIS winds.

4. CONCLUSIONS

From the monitoring, assimilation experiments and investigations carried out at the Met Office we can make the following conclusions:

1. The winds from Aqua and Terra are of comparable quality although there are some differences in the proportion of winds reported over each pole, with Terra generally providing more winds over the North Pole and Aqua more over the South Pole. At the Met Office we plan to use the MODIS winds from both satellites.
2. Some benefit was observed in our forecasts when clear sky WV winds were included, the blacklisting was modified and the thinning box size was increased. The new method does reject the majority of winds. Further experiments may be carried out to test whether any of the restrictions can be relaxed. The MODIS winds are also a possible candidate for superobbing.
3. Monitoring at the Met Office of the new NESDIS MODIS wind product shows lower biases and root mean square vector differences against our model background compared to the CIMSS MODIS product. This result agrees with rawinsonde comparisons. Also, although there is no direct comparison due to the use of a different trial season, the NESDIS MODIS winds perform better when assimilated, in particular improving the impact on forecasts in the southern hemisphere. The main benefit of the MODIS winds remains in the northern hemisphere at longer forecast range (T+72 onwards). We plan to run a second assimilation trial with the NESDIS MODIS winds during the northern hemisphere summer. If this is successful, the winds may become operational in early 2005.
4. We are grateful to CIMSS and NESDIS for the hard work they have put in to developing the MODIS wind product and look forward to future improvements. We have illustrated in this paper how a reduction in the time lag before the data becomes available may benefit our assimilation system. Positive impact has been observed for direct broadcast ATOVS data and these are now used operationally at the Met Office (Candy et al., 2004).

5. ACKNOWLEDGEMENTS

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