MAUSAM, **54**, 1 (January 2003), 237-246

551.501.75 : 551.501.86 : 551.509

Impact of high resolution satellite wind vector data on NCMRWF assimilation and forecasting system

V. S. PRASAD

National Center for Medium Range Weather Forecasting

Mausam Bhavan Complex, Lodhi Road, New Delhi-110 003, India

e mail : vsprasad@ncmrwf.gov.in

सार – हाल ही में, राष्ट्रीय मध्यम अवधि मौसम पूर्वानुमान केंद्र में क्विकस्कैट प्रकीर्णमापी से उच्च विभेदन वायुमंडलीय गति वेक्टर डाटा और महासागर सतह पवन वेक्टर उपलब्ध कराए गए हैं। इन नए आँकड़ों को राष्ट्रीय मध्यम अवधि मौसम पूर्वानुमान केंद्र में चल रहे भूमंडलीय डाटा को सम्मिलित करने और पूर्वानुमान तंत्र में इन नए डाटा सेटों को सम्मिलित करने का प्रयास किया जा रहा है। इस शोध–पत्र में प्रेक्षणात्मक तंत्र प्रयोग के माध्यम से नए डाटा सेटों के प्रतिघात को निर्धारित करने का प्रयास किया गया है। विभिन्न विषयपरक स्कोरों और परिसंचरण विशिष्टिताओं के संदर्भ में इस प्रतिघात का परीक्षण किया गया है। पूर्वानुमान की शैली में और सिनॉप्टिक परिसंचरणों में भी हुए कुछ सुधार से नए डाटा सेटों के परिणामों के समावेशन का स्पष्ट पता चलता है।

ABSTRACT. High resolution Atmospheric Motion Vector (AMV) data and Ocean surface wind vectors from QuikScat scatterometer have recently become available at NCMRWF. Efforts are on to assimilate these new data sets in Global Data Assimilation and Forecasting (GDAF) system operational at NCMRWF. In this study an attempt is made to quantify the impact of the new data set through an Observational System Experiment (OSE). The impact has been examined in terms of various objective scores and the circulation features. It is clearly seen that the inclusion of the new data set results in some improvement in the forecast skill, also in reproduction of synoptic circulations in better way.

Key words – Scatterometer, Ocean surface wind vectors, Atmospheric motion vector (AMV), Global data assimilation, Observational system experiment (OSE), Medium range weather forecasting, Remote sensing.

1. Introduction

The global meteorological observing system is extremely expensive and in the present economic conditions conventional observations such as radiosondes are beginning to be considerably reduced. At the same time new and advanced satellite systems are becoming available. The operational Global Data Assimilation and Forecasting (GDAF) system, which uses both conventional and satellite measurements, determines how accurately the initial atmospheric state can be prescribed and thereby influences the accuracy of the forecast to a large extent. Hence there is an urgent need to investigate the importance of different observing systems for Numerical Weather Prediction performance through Observing System Experiments (OSE). The OSE's are conducted to evaluate the impact of specific observations or class of observations on analyses and forecasts. Such experiments have been performed for selected type of conventional data and for various types of satellite data as they become available. In these studies the impact of a specific observing system is assessed by comparing extended data assimilation and regular forecasts based on the total GDAF system, with those generated excluding/including the particular observing system under investigation. In general the earlier OSE's have clearly brought out that, the satellite sounding temperatures and Atmospheric Motion Vector winds (AMV) are very important components of the observing systems in the southern hemisphere, with mixed results for the northern hemisphere extratropics (Halem *et al*., 1982, Mo *et al*., 1995). Experiments to evaluate the usefulness of SSM/I wind speeds have demonstrated significant improvement to ocean surface wind analyses in the tropics and southern hemisphere (Atlas *et al*., 1991). Documenting the impact of various data within a Data Assimilation System (DAS) is extremely valuable and comparison with similar studies for other DAS can eliminate the dependency of the results on the assimilation system. They will help to judge the relative importance of various observing systems and to find any redundancy in them.

In the Indian context, it is more important to evaluate the impact of satellite data as India is surrounded by large data sparse oceanic region where the remote sensing data is the only source of meteorological information currently

TABLE 1

Typical distribution of SATOB & high resolution AMW received at NCMRWF for a period 1-7 April, 2002

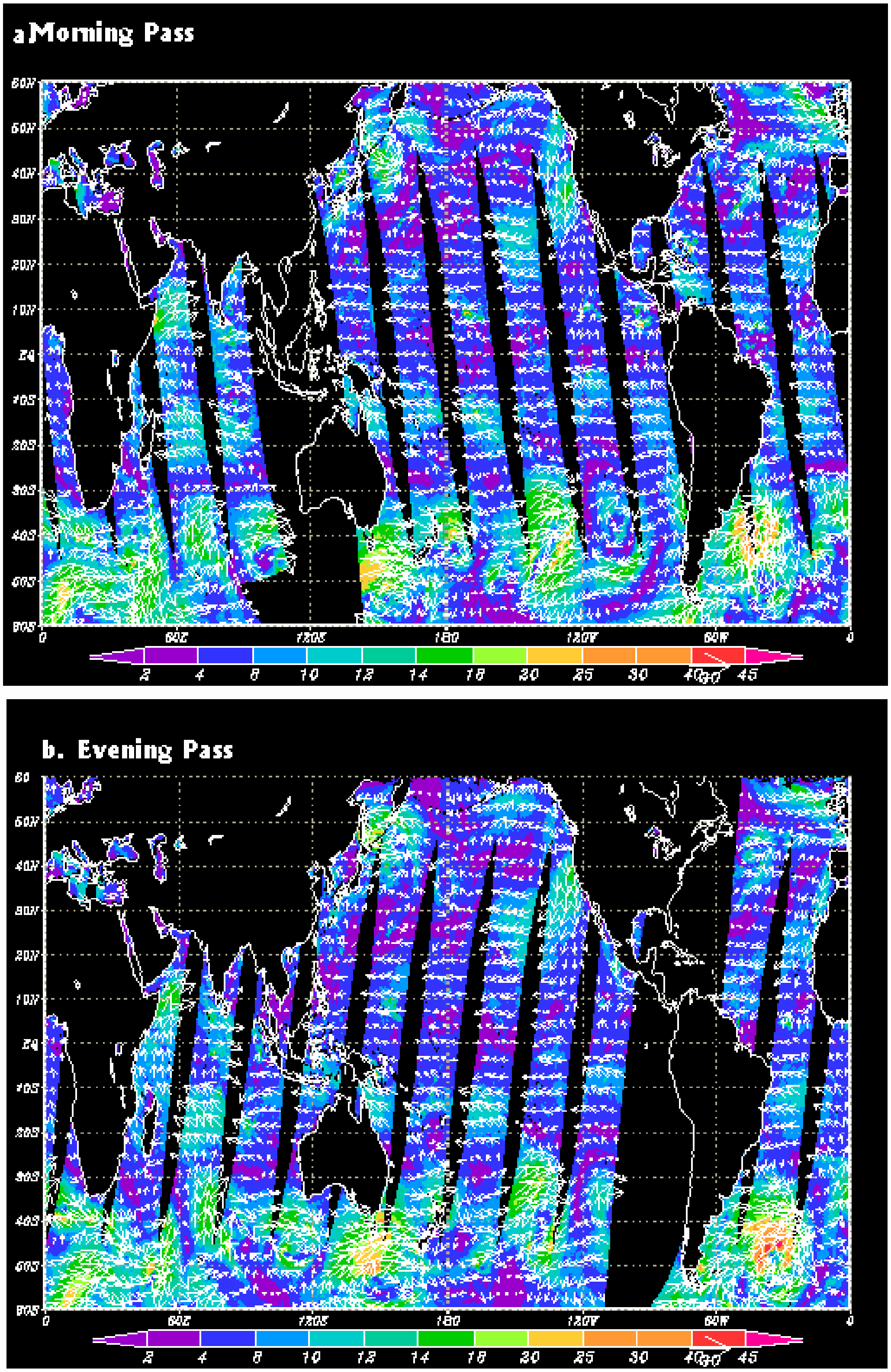
Time &Date	High Resolution CMV winds				GTS winds			
	Total	MET 5& 7	GMS	GOES	Total	MET	GMS	GOES
0001042002	18472	4732	4656	9084	4133	2191	1290	652
0002042002	33511	7431	3496	22584	4320	2053	1271	996
0003042002	39297	4018	3318	31961	3202	2030	516	656
0004042002	15638	2215	4222	9201	4113	2136	1271	706
0005042002	18105	8986	5473	3646	3981	2265	1318	398
0006042002	17469	8609	3715	5145	3844	2106	1313	425
0007042002	16233	8071	3638	4524	2941	473	1180	1288

available. Further, the circulation characteristics of the atmosphere and ocean of the tropical Indian Ocean region are known to be quite different from the rest of the tropics. As such the impact of any kind of non-conventional data over this region on analysis forecast system might differ from other regions. Earlier studies conducted at NCMRWF with temperature sounding data has proved the importance of such data in improving the weather forecasts. But the impact of the data on the synoptic structure of the circulation fields could not be brought out due to coarse (500 km) resolution (Bohra *et al*., 1998). Experiments with higher horizontal resolution temperature sounding data (120 km) by Prasad *et al*., (1999, 2000) has suggested some improvement on synoptic scales. Experiments with SSM/I measured Total Perceptible Water Content (TPWC) suggest that it has great potential to improve the moisture content not only in initial state of the atmospheric circulation but in forecasts as well (Prasad *et al*., 2001). Joshi *et al*., (1998) studied the impact of ERS-1 scatterometer wind data on medium range forecasting. They have clearly brought out that the inclusion of scatterometer data over Indian Ocean area has been able to produce the tropical circulation with better details. Further, it was thought that the combination of scatterometer data, atmospheric motion vectors (*i.e.* both cloud motion vectors and water vapour winds) from geostationary satellites provide a unique opportunity for proper depiction of synoptic scale system. In this study the impact of the satellite-based operational wind observing systems, *viz*., the high resolution Atmospheric Motion Vector (AMV) and the Ocean surface wind Vectors from QuikScat together, is quantified through OSE.

2. Data set description

2.1. *High resolution AMV wind*

The satellite derived wind products at comparatively lower resolution from major operational geostationary meteorological satellite such as Meteosat, GMS, GOES and INSAT are operationally made available through GTS in SATOB code and are being used in GDAF system at NCMRWF. These winds are deduced from the sequential imagery provided by the above satellites. The components of the AMV's include a velocity vector and its vertical level (pressure level) to which it belongs. The vertical level/pressure level of the velocity vector is estimated by suitable methods as appropriate for the observational function of imagery channels used. The main problem in the AMV production is the assignment of correct height to these winds. Thin clouds are best tracers of wind flow at single level but assigning them with correct height is especially difficult due to some known uncertainties. In order to cope up with this problem of the height reassignment methods and stringent quality control methods have been developed by using short range forecasts from numerical models (Stewart *et al*.,1985; Hayden and Purser,1995; Uchida, 1991; Holmlund, 1993; Prasad, 1997; Prasad *et al*., 2002). These studies resulted in developing automated techniques for wind extraction at very high density and subsequent objective Quality Control (QC) techniques. The QC procedure involves a iterative preliminary objective 3-D analysis of the wind data and a re-evaluation of the originally assigned heights using a short range forecast from a GDAF system as background fields. These automated techniques are able to produce wind vectors of good quality (Laurent, 1993; Veldon, 1996; Holmlund, 1993; Schemtz *et al*., 1993). Evaluation of these winds can be accomplished through two approaches;statistical validation against the collocated rawinsondes and numerical model impact studies. Earlier studies have shown that these winds are comparable in quality with RMS values in the range of 6.5 to 8 m/sec and speed biases less than1 m/sec (Laurent, 1993; Hayden *et al*., 1994). Focus of this study is on the impact of these new wind data on NCMRWF GDAF system. The high-resolution winds have become available to NCMRWF recently. Table 1 depicts the number of low resolution



Figs. 1 (a&b). Typical distribution of a single day QuikScat data (Example 10 June, 2002)

TABLE 2

Collocation statistics of QuikScat retrievals and *in-situ* surface observations

Observation time (UTC)	Indian Ocean			Tropics			Global		
	Spead bias	Spead RMSE	Wind vector RMS	Spead bias	Spead RMSE	Wind vector RMS	Spead bias	Spead RMSE	Wind vector RMS
0000	-0.34	1.4	1.87	-0.31	1.33	1.82	-0.16	1.32	1.88
0600	-0.37	1.39	1.99	-0.37	1.39	1.99	-0.13	1.49	2.03
1200	-0.12	1.38	1.91	-0.13	1.33	1.88	-0.04	1.36	1.92
1800	-0.32	1.39	2.01	-0.32	1.39	2.01	-0.08	1.5	2.05

observations that are available in SATOB code and that of the high resolution AMV's for 0000 UTC cycle for about seven day period in April 2002.

2.2. *Scatterometer winds*

The QuikScat is a specialized microwave radar that continuously measures both the speed and direction of winds near the ocean surface in all weather conditions. NCMRWF started receiving the level 3 data set of this QuikScat satellite. The data consists of daily grided values of scalar wind speed, meridional (*U*) and zonal (*V*) components of the wind velocity and pseudo-stress (wind speed squared) for both the ascending pass (6AM LST equator crossing) and descending pass (6PM LST equator crossing). The satellite has a swath width of 1800 kilometers and thereby provides about 90% coverage of Earth's Ocean per day at 25 km horizontal resolution. Figs. 1(a&b) shows a typical distribution of the coverage of the QuikScat data in ascending and descending modes respectively. The quality of these winds for April 2002 period is evaluated by comparing with that of collocated buoy data observations, that are available through GTS (Table 2). This clearly shows that the quality of the data is of good quality with Mean Wind Speed RMS of 1.3 m/s and Wind Vector RMS error (WVRMS) of 1.9 m/s. The incorporation of QuikScat data was one of several recent upgrades made to the European Centre for Medium-Range Weather Forecast and analysis system. They have clearly shown that these upgrades have resulted in a definite improvement in forecasts of atmospheric conditions over the southern hemisphere and in the upper atmosphere and their ability to forecast tropical cyclone tracks has also been enhanced.

3. Experiment design

In the existing operational analysis-forecast system, all types of data received on GTS at hourly interval and satellite retrieved geophysical parameters from SSM/I and ATOVS are used in the assimilation cycle. But for the experimental period starting from 20 March, 2002 the assimilation cycle is repeated by including both the high resolution AMV and QuikScat winds and is continued up to 30 April, 2002. Starting from 25 March, 2002 (0000 UTC) onwards forecast experiment up to 120 hours are carried out with different initial conditions of 0000 UTC till 30 April, 2002. Over the QuikScat and SSM/I overlapping areas the data from the QuikScat is given preference and SSM/I rainfall rates are utilized to flag heavy rainfall areas. The analyses and forecasts thus generated by using wind vector data are compared with the corresponding operational archives. The impact is examined in terms of anomaly correlation coefficients, RMSE and skill scores.

4. Results and discussion

Forecasts produced from the above experimental analyses produced by using the high resolution wind vectors are compared with operational forecasts as well as with radiosonde observations in order to assess the impact of the data. The forecast fields are verified against model analyses by using certain standardised verification procedures recommended by World Meteorological Organisation's Commission for Basic Systems (CBS) (WMO Manual No.485). Four latitude dependent domains are considered *viz*, northern hemisphere, southern hemisphere, tropical and Indian region, in order to examine the regional impacts. The impact is examined in terms of RMSE, anomaly correlation, S1 skill score and wind vector RMS error for the whole month of April, 2002. The monthly mean averages of these scores for height field all along the forecast length (0-120 hr) are presented in Tables 3. These scores are computed at different levels for different regions as per CBS guidelines. The impacts are rather modest, as might be expected since the wind data coverage over the mid latitudes is limited. The impact is more positive for the hemisphere domains as compared to the tropics or Indian region.

TABLE 3

RMSE statistics of height field for the month (April 2002)

Forecast period (hour)	Northern hemisphere						Southern hemisphere						Tropics				Indian region			
	MSLP		500hPa		250hPa		MSLP		500hPa		250hPa		850 hPa		250 hPa		850 hPa		250 hPa	
	Op. Fcst.	OSE	Op. Fcst.	OSE	Op. Fcst.	OSE	Op. Fcst.	OSE	Op. Fcst.	OSE	Op. Fcst.	OSE	Op. Fcst.	OSE	Op. Fcst.	OSE	Op. Fcst.	OSE	Op. Fcst.	OSE
24	1.9	1.9	18.7	18.1	26.5	25.4	3.3	3.1	27.0	26.2	34.3	33.3	11.3	11.1	12.0	11.9	15.2	15.2	17.6	17.9
48	3.3	3.2	33.4	31.7	45.5	42.8	5.6	4.9	45.9	44.1	60.4	58.5	11.6	11.7	15.8	15.6	15.3	15.4	24.6	23.9
72	4.6	4.5	48.6	46.5	65.3	61.9	6.4	6.3	62.5	59.5	83.3	79.4	14.1	13.6	19.5	19.2	20.7	19.4	29.6	28.8
96	5.9	5.8	63.8	62.1	84.6	81.9	7.5	7.4	76.3	74.2	102.9	100.6	14.8	14.7	24.1	23.0	21.4	20.9	33.9	30.9
120	7.0	6.9	77.9	76.9	103.6	101.7	8.3	8.2	87.8	87.1	118.5	119.4	15.1	14.9	29.0	26.9	20.8	20.5	38.9	36.8

TABLE 4

Mean monthly ACC for the month (April 2002)

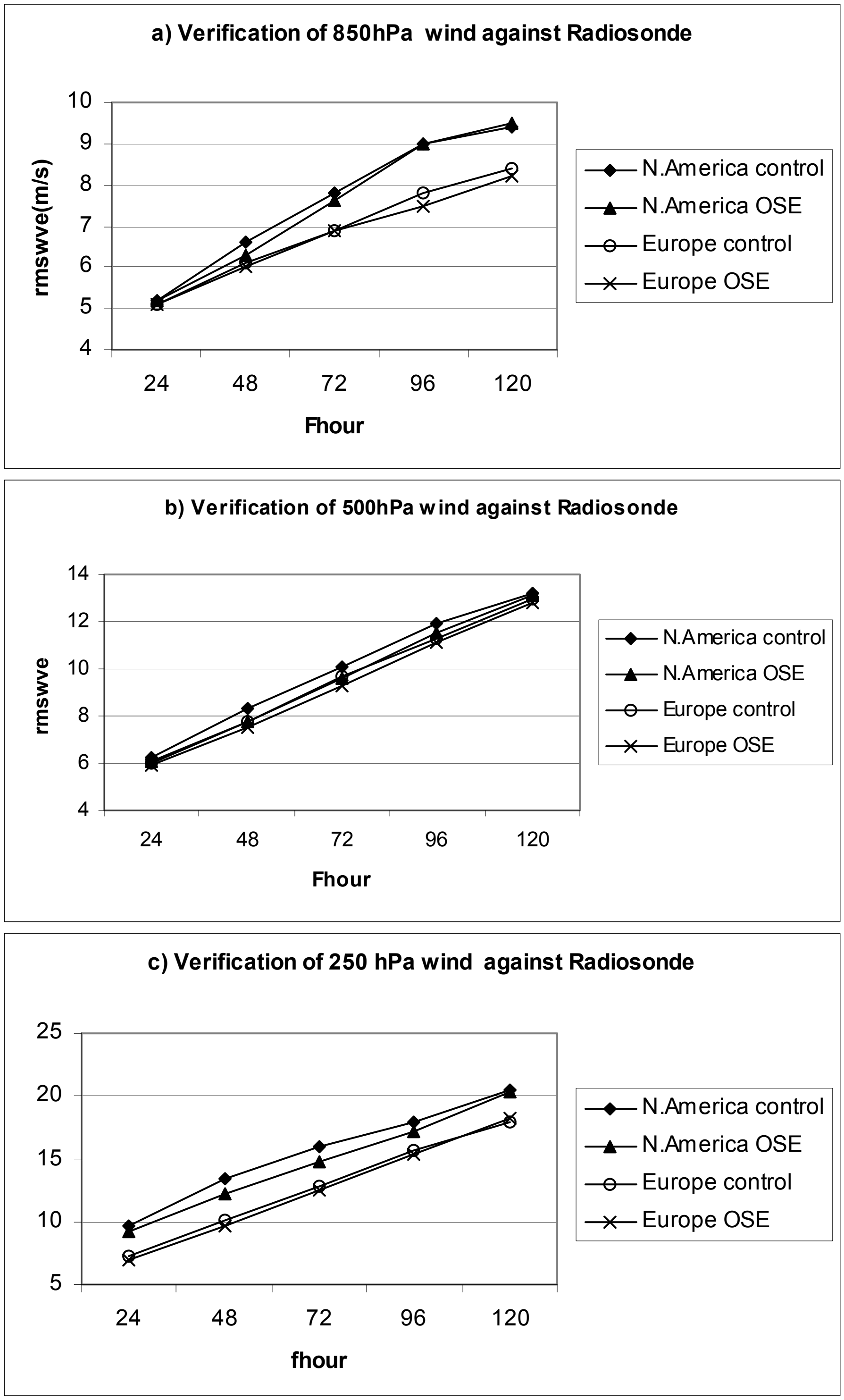
Forecast period (hour)	Northern hemisphere						Southern hemisphere						Tropics				Indian region			
	MSLP		500hPa		250hPa		MSLP		500hPa		250hPa		850 hPa		250 hPa		850 hPa		250 hPa	
	Op. Fcst.	OSE	Op. Fcst.	OSE	Op. Fcst.	OSE	Op. Fcst.	OSE	Op. Fcst.	OSE	Op. Fcst.	OSE	Op. Fcst.	OSE	Op. Fcst.	OSE	Op. Fcst.	OSE	Op. Fcst.	OSE
24	95	95	96	96	96	96	90	91	94	95	95	96	60	63	77	79	72	73	88	87
48	93	93	94	94	94	95	87	88	91	92	92	93	74	76	81	83	76	76	89	89
72	89	90	90	91	91	92	81	83	86	88	87	89	69	71	81	82	76	75	92	92
96	85	85	85	85	86	87	78	79	83	84	84	85	64	65	79	80	75	73	91	92
120	79	80	79	80	81	82	74	75	79	79	80	79	62	64	76	79	71	69	88	89

TABLE 5

Mean monthly S1 Skill scores for the month (April 2002)

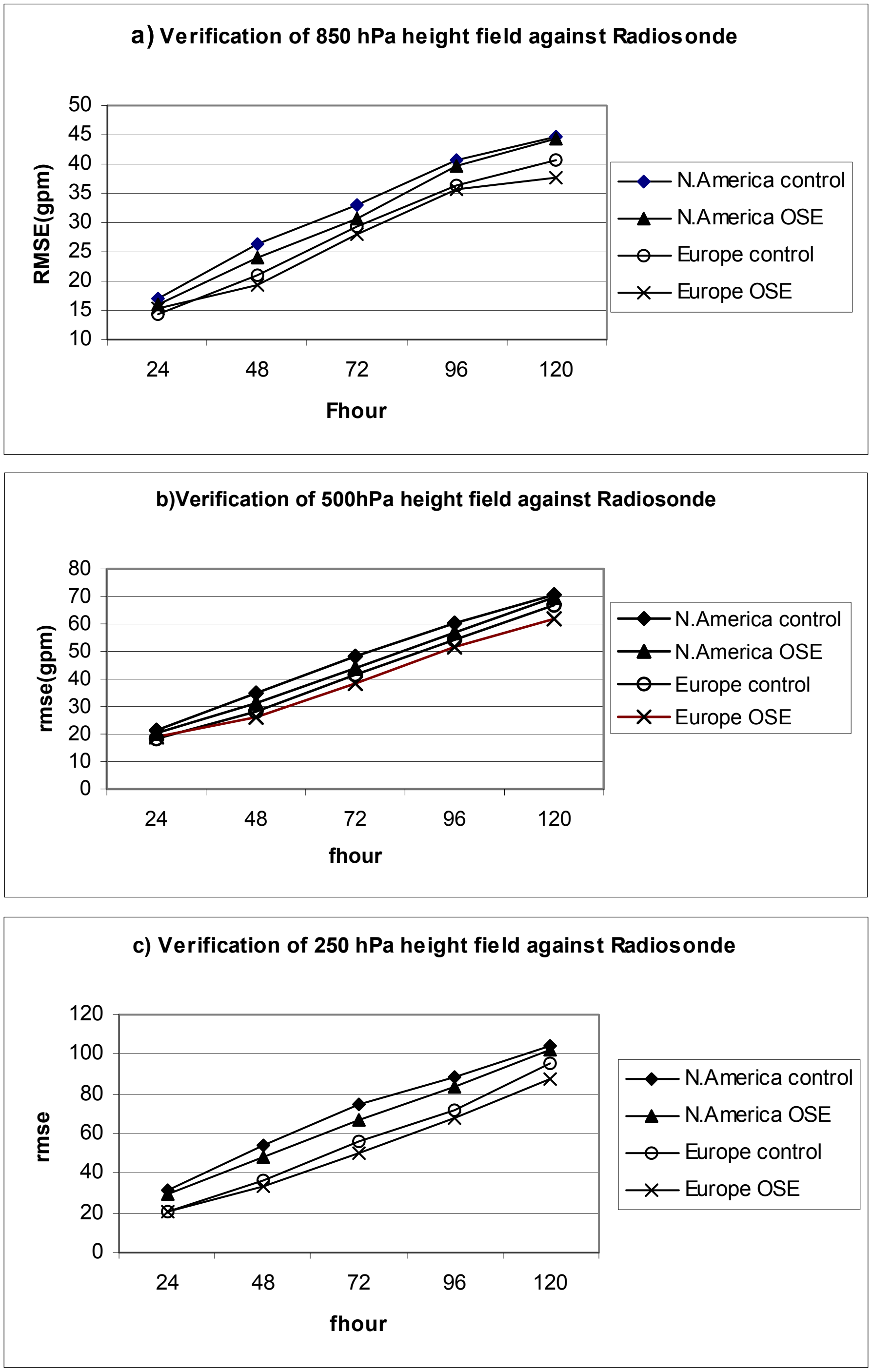
Forecast period (hour)	Northern hemisphere						Southern hemisphere						Tropics				Indian region			
	MSLP		500hPa		250hPa		MSLP		500hPa		250hPa		850 hPa		250 hPa		850 hPa		250 hPa	
	Op. Fcst.	OSE	Op. Fcst.	OSE	Op. Fcst.	OSE	Op. Fcst.	OSE	Op. Fcst.	OSE	Op. Fcst.	OSE	Op. Fcst.	OSE	Op. Fcst.	OSE	Op. Fcst.	OSE	Op. Fcst.	OSE
24	27.5	27.6	20.1	19.8	18.1	17.7	28.4	28.1	20.5	20.4	18.0	17.8	51.5	51.7	34.8	35.8	41.6	41.8	24.0	24.2
48	41.8	41.3	31.8	30.8	28.3	27.4	43.0	42.3	32.5	31.9	29.2	28.8	64.6	64.1	46.3	46.7	51.8	51.6	31.2	31.2
72	52.5	51.7	41.3	39.8	36.4	35.1	52.2	51.6	41.2	40.2	37.1	36.5	67.9	67.2	50.3	50.4	55.6	54.9	33.9	34.3
96	61.5	60.8	49.3	48.2	42.9	41.9	58.7	58.2	47.4	46.7	43.0	42.9	69.6	68.9	53.0	52.7	57.9	58.0	36.9	35.9
120	68.7	68.2	55.7	55.0	48.7	48.0	62.9	63.3	51.9	51.9	47.4	47.8	71.4	70.6	55.4	54.9	59.3	58.7	39.2	38.9

Correlation methods have been extensively used to account for the spatial similarities between two sets of forecasts of an operational global model. The correlation is usually evaluated between anomaly patterns in which the climate value of a variable is subtracted from its instantaneous value at each grid point which is normally addressed as the anomaly correlation coefficient (ACC). Greatest ACC magnitude occurs when the model climate anomaly and the true climate anomaly occur in phase (100%) or exactly in out of phase (−100%), while small or zero values can occur when the anomalies are out of phase. Table 4 shows the variations of ACC scores in



Figs. 2(a-c) Mean monthly RMSWVE (fcst *vs* Radiosonde): (a) 850hPa, (b) 500 hPa and (c) 250 hPa

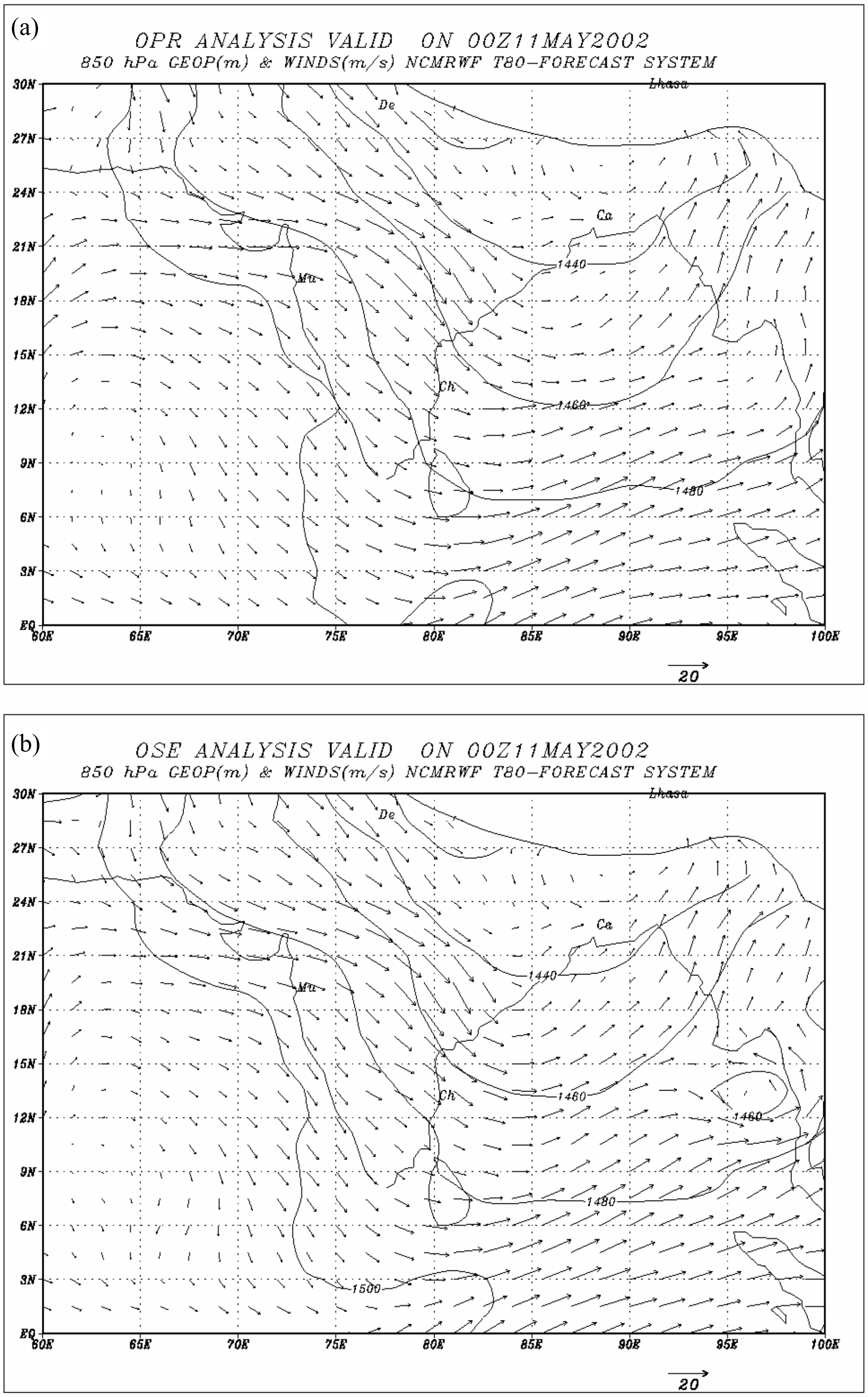
respect to height field. Over southern hemisphere and tropics ACC score clearly demonstrates a clear improvement through out except in the case of 120-hour 200 hPa forecast. The response over the Indian region is



Figs. 3(a-c) RMSE (fcst *vs* Radiosonde) scores for height component : (a) 850hPa, (b) 500 hPa and (c) 250 hPa

mixed. On the other hand, improvements in ACC magnitude are not much remarkable in northern hemisphere for mean sea level pressure (MSLP) and 500 hPa levels. However at 250 hPa level some improvement in ACC scores is noticed.

The impact of the new data sets is also measured in terms of S1 score (Tweles and Wobus, 1954). This score ranges from 0 to 200, with low score being better than a high score. S1 scores for height field are shown in Table 5. It can be seen that a clear improvement in terms



Figs. 4(a&b). Analysed fields of wind/height at 850 hPa for 11 May, 2002 (0000UTC) [Units :ms^{-1} for wind, gpm for height,contour interval; 20gpm] (a) Operational and (b) OSE

of the reduction in S1 score magnitudes is found in majority of cases with the incorporation of high resolution wind data.

Monthly average of wind vector RMS error are presented in Table 6. In this case also positive impact is observed in both the hemispheres. But over the Indian

TABLE 6

Mean monthly wind vector RMSE for the month (April 2002)

Forecast period (hour)	Northern hemisphere				Southern hemisphere				Tropics				Indian region			
	500 hPa		250hPa		500 hPa		250hPa		850 hPa		250hPa		850 hPa		250hPa	
	Op. Fcst.	OSE	Op. Fcst.	OSE	Op. Fcst.	OSE	Op. Fcst.	OSE	Op. Fcst.	OSE	Op. Fcst.	OSE	Op. Fcst.	OSE	Op. Fcst.	OSE
24	4.4	4.4	6.5	6.4	5.1	5.0	7.0	6.9	2.8	2.9	4.9	5.2	3.7	3.7	5.8	5.8
48	7.2	6.9	10.2	9.8	8.4	8.1	11.6	11.3	3.8	3.9	7.1	7.2	4.8	4.8	7.8	7.8
72	9.5	9.2	13.3	12.7	10.8	10.4	14.9	14.6	4.4	4.4	8.3	8.3	5.3	5.3	9.1	9.2
96	11.6	11.3	15.9	15.5	12.6	12.2	17.6	17.5	4.8	4.8	9.1	9.0	5.7	5.6	10.3	10.1
120	13.3	13.2	18.4	18.1	13.9	13.7	19.6	19.8	5.0	5.0	9.8	9.8	5.8	5.7	11.1	11.1

region no improvement is observed in the initial 3 days and some improvement is seen for the 4th and 5th day. This may be due to utilization of Meteosat-5 data in the operational suite. The major improvements are observed over North America and Europe and are shown in the Figs. 2&3. The Fig. 2 shows the variations of the monthly mean wind vector RMSE with respect to radiosonde data over Europe and North America and Fig. 3 shows the similar plot for height field. They demonstrate the improvement of the forecasts throughout the forecast length even with respect to *in-situ* observations. This improvement is observed all over the globe but it is well marked over North America and Europe. As shown in Table 1 the number of high resolution wind incorporated over this region is much more than other parts (GOES and METEOSAT-7 coverage) of the globe.

The value of an observing system is most easily demonstrated when an energetic event is reproduced only by one observing system at correct location. In order to demonstrate such an example, a case of a low pressure over North Andaman Sea on 11 May, 2002, is examined. A well marked low pressure area developed over South Andaman Sea on 10 May, 2002. This system intensified into a deep depression (centered near 14.0° N/96.0° E) on 11 May. The operational GDAF system is not able to reproduce such a circulation as shown in the Fig. 4(a) . The assimilation cycle is repeated after incorporation of high resolution wind vectors from 8 May, 2002 (0600 UTC) and continued up to 0000 UTC of 13 May, 2002. The experimental analysis is able to bring out the above system at correct location and almost of same intensity [Fig. 4(b)]. Thus, it is found that the inclusion of high resolution AMV could lead to depiction of synoptic circulations well and could also lead to the correction in the positional displacement of weather system.

5. Conclusions

Based on the analysis of the results presented above, the following general comments can be made :

(*i*) Quantitative assessment of the impact of high resolution wind vector data through the estimation of various objective scores *viz.*, RMSE statistics, ACC scores and S1skill scores clearly demonstrated some improvement in the forecast skill after inclusion of the above stated additional data in the GDAF system.

(*ii*) The high resolution data is also contributing towards improving the quality of analyses on the synoptic scales, which is demonstrated through improved positioning of a cyclonic circulation systems.

Acknowledgements

Author is grateful to Chris Veldon, University of Wisconsin for providing high resolution AMV winds and Quikscat data are produced by Remote Sensing systems and sponsored by the NOAA climate change program. Thanks are due to Sri G.R Iyengar for many useful discussions and for his contribution in the sensitive evolution of the model forecasts. The encouragement given by Dr. R. K. Paliwal and Head, NCMRWF to carry out this study is greatly acknowledged. The views expressed herein are of the author and do not necessarily reflect the views of the organization affiliated to.

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