MAUSAM, **57**, 1 (January 2006), 141-150

551.515.2 : 551.509.313 : 551.501.75

QuikSCAT scatterometer wind data impact on tropical cyclone forecasts by a mesoscale model

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सार – इस अध्ययन में मेसोस्केल निदर्श (एम. एम. 5) का उपयोग करते हुए उष्णकटिबंधीय चक्रवात विश्लेषणों और पूर्वानुमानों पर क्विकस्केट स्केट्रोमीटर आँकड़ों के सकारात्मक प्रभाव का उल्लेख किया गया है। क्विकस्केट के आँकड़े विशेष रूप से इसलिए भी मूल्यवान हैं क्योंकि वे उष्णकटिबंधीय चक्रवातों के मुश्किल से प्राप्त होने वाले आँकड़ों के क्षेत्रों में ही नहीं बल्कि मेघाच्छन्न और वर्षा की स्थितियों में भी उपलब्ध रहते हैं। इस अध्ययन के लिए उपयोग किया गया निदर्श एम. एम. 5 पाँचवीं पीढ़ी के एन. सी. ए. आर. / पेन स्टेट मेसोस्केल निदर्श के नाम से जाना जाता है। क्विकस्केट स्केट्रोमीटर पवन आँकड़ों के प्रभाव को समझने और उसकी जाँच करने के लिए 1999 से 2003 की अवधि के दौरान कुछ उष्णकटिबंधीय चक्रवातों के लिए स्केट्रोमीटर आँकड़ों का समावेशन सहित और बिना समावेशन के प्रतिरूपण किया गया है। चक्रवाती स्थिति हेतु उस समय विद्यमान कुछ पोतों पर लिए गए आँकड़ें और कुछ तटीय अथवा द्वीपों के केन्द्रों पर प्राप्त किए गए आँकड़ें ही उपलब्ध हैं। प्रेक्षण द्वारा प्राप्त किए गए आँकड़ों का एम. एम. 5 में सम्मिलित करने के लिए अलग–अलग समयों पर लिए गए क्विकस्केट के कुछ पासें उपलब्ध हैं। आँकड़ों को सम्मिलित करने के लिए इन अतिरिक्त आँकड़ों से प्रारम्भ में लिए गए आँकडों में वृद्धि हुई है। इनसे प्राप्त हुए परिणामों से यह पता चला है कि स्केट्रोमीटर आँकड़ों के समावेशन से प्रारम्भिक क्षेत्र वास्तविक स्थिति के अधिक निकट था। पूर्वानुमान जाँच से यह भी पता चला है कि उपग्रह से प्राप्त किए गए आँकड़ों के समावेशन से 48 घंटे की अवधि तक का पूर्वानुमान देने में सुधार हुआ है।

ABSTRACT. This study describes the positive impact of QuikSCAT Scatterometer data on tropical cyclone analyses and forecasts using a Mesoscale Model (MM5). QuikSCAT data is especially valuable because they are available in the data sparse genesis regions of tropical cyclones, and because they are available in cloudy and rainy conditions. The model used in the study, MM5 is known as fifth generation NCAR/Penn State Mesoscale model (MM5). In order to understand and investigate the impact of QuikSCAT Scatterometer wind data, simulation with and without assimilation of scatterometer data has been performed for a few tropical cyclone cases during the period 1999 to 2003. For a cyclonic situation, data of few ships of opportunity and of some coastal or island stations are only available. For the assimilation of observed data into MM5, a few passes of QuikSCAT at different times are available. These additional data strengthen the initial data for assimilation. The results showed that the initial field with the inclusion of scatterometer data was nearer to the actual situation. In the prediction experiment, it was also shown that the inclusion of satellite data improved the prediction up to 48 hrs.

Key words – Mesoscale model (MM5), QuikSCAT, National centre for environmental prediction (NCEP), Newtonian relaxation, Four dimensional data assimilation (FDDA), Meteosat imageries, Special sensor microwave imager (SSM/I).

1. Introduction

One of the main challenges in the study of tropical cyclones is understanding and prediction of their genesis, especially the development of organized cloud clusters [*i.e.*, one or more mesoscale convective systems (MCSs)] into a warm core vortex. The difficulty in making progress in this area has reflected the genesis process involving three scales of motion (cloud resolving scale, mesoscale, synoptic) and the need to observe each of these in detail, from upscale growth and intensification of a complex, dispersed system into a single, coherent vortex.

A high resolution mesoscale model is a useful tool for prediction of tropical cyclone genesis, intensity and movement. Problem in the use of mesoscale model is to get a high density initial condition. Presently almost all mesoscale models get their initial state from the global analysis field (*e.g.*, NCEP, ECMWF or NCMRWF). This global field gets interpolated from coarse resolution to mesoscale resolution. These interpolated fields may not represent the actual mesoscale feature. Therefore additional a synoptic data assimilation has to be done to get realistic mesoscale features. The asynoptic data from microwave remote sensing is most useful for mesoscale assimilation.

The main objective of this study is to evaluate the impact of QuikSCAT wind data on tropical cyclone analyses and forecasts. Although some work has been done on the assimilation of QuikSCAT wind data on tropical cyclone analyses and forecasts, it has to be studied for a number of cases to arrive at a firm conclusion. In order to understand and investigate the impact of QuikSCAT Scatterometer wind data, simulation with and without assimilation of scatterometer data has been performed for a few tropical cyclone cases formed over Bay of Bengal during the period 1999 to 2003.

2. Model

The fifth generation NCAR/Penn state mesoscale model is a non-hydrostatic, terrain following sigma coordinate, limited area model designed to simulate or predict mesoscale and regional scale atmospheric circulation (Dudhia, 1993). It can be configured to run from global scale to cloud scale in one model. It has multiple nesting capability. The model can be run in 2-way and 1-way nesting mode. It has options for a wide variety of advance physical parameterization schemes. The model can be run using routine observations and has provision for 4-dimensional data assimilation (FDDA). The model was run with 30 × 30 km horizontal resolution with a single domain. Twenty three unevenly spaced full sigma levels were used in the vertical, with the maximum resolution in the boundary layer. Thirty minute averaged terrain/land use data were interpolated to the 30 km model grids.

3. Earlier studies

A number of studies were conducted to simulate or study the cases of cyclones using mesoscale and regional scale models. However, very few have attempted to study the assimilation of satellite derived winds into the mesoscale models to study their sensitivity. Dudhia (1993) was able to simulate an Atlantic cyclone using non-hydrostatic version of the MM5 model. Evans (2000) had studied the assimilation of satellite derived winds into the Community Hurricane Modeling System (CHUMS) using MM5 FDDA procedure. He found that the impact of the FDDA on the forecast resulted in degradation of cyclone track prediction. Tahara (2000) in his study on the impact of QuikSCAT winds in JMA Global model found out positive impacts on forecasts over southern hemisphere and small positive impacts over northern hemisphere and tropics. Randhir Singh *et al.*, (2001) concluded that the MM5 model was able to provide successful cyclogenesis and improvement in the track. Das (2002) had studied the case of super cyclone formed over Bay of Bengal during 25-31 October 1999 and crossed the coast of Orissa on 29 October. He found out that the track of the cyclone predicted by MM5 model output was close to the track given by IMD and better than the T 80 forecast. The study also showed that the position of the cyclone was not well defined because there were not enough satellite data over Bay of Bengal during the period of cyclone. A few case studies have been made earlier with scatterometer data for simulation of isolated cyclone cases (Rambabu, 2004).

4. Data and methodology

A single domain run (SDR) option at 30 km resolution is set over Indian region. The input data *i.e.*, initial and boundary conditions are taken from the NCEP (AVN)/NCEP (FNL) (0.75 × 0.75 degree Latitude – Longitude grid) analysis and forecasts. The NCEP data used for the study is from 13 – 19 October 1999, 24 – 30 October 1999, 24 – 28 October 2000, 11 – 17 October 2001 and 09 – 18 May 2003. The control run is performed with NCEP data without assimilation of additional QuikSCAT data and the experimental run is performed with the assimilation of additional QuikSCAT data. The QSCAT data used for the assimilation is as follows:

(*i*) 13 – 14 October 1999, 16 – 17 October 1999

(*ii*) 24 – 25 October 1999, 27 – 28 October 1999

(*iii*) 24 – 25 October 2000, 26 – 27 October 2000

(*iv*) 11 – 12 October 2001, 15 – 16 October 2001

(*v*) 09 –10 May 2003, 15 – 16 May 2003

The Meteosat imageries and SSM/I data of the same period are used for model verification. According to [Stoffelen and Beukering (1997)] the impact of QuikSCAT data in MM5 depend on:

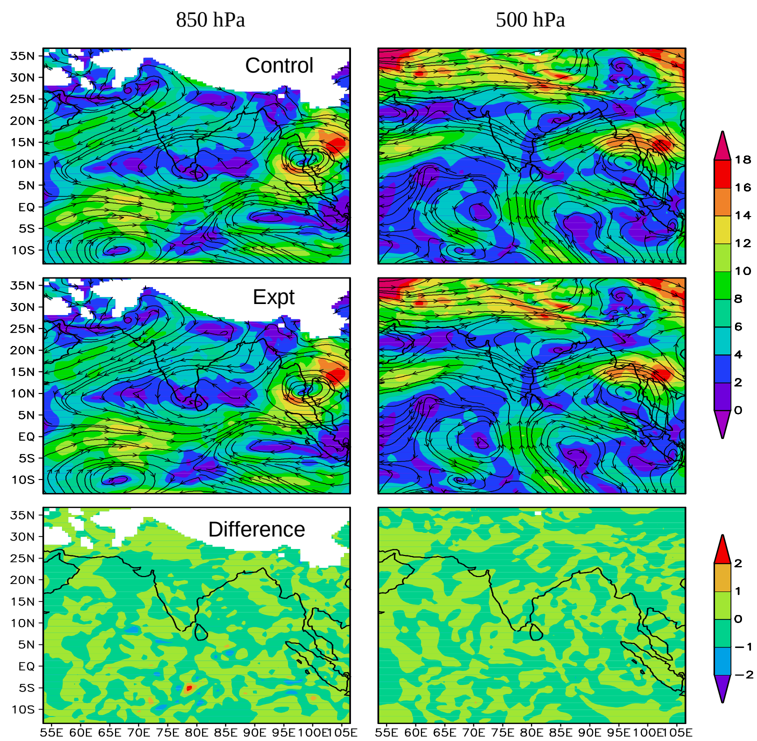
(*i*) The quality of the scatterometer winds presented to the analysis

(*ii*) The density of scatterometer winds

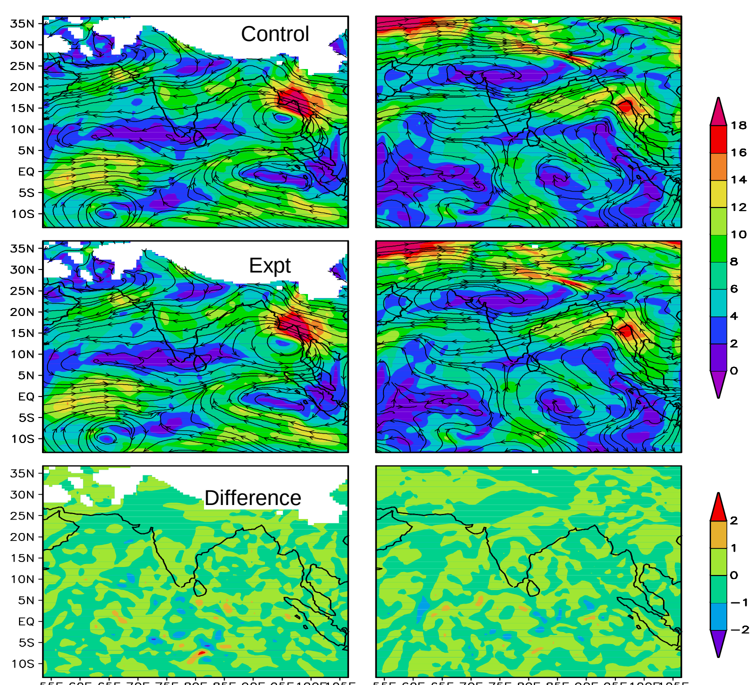
(*iii*) The way the data are projected into the model and

(*iv*) The meteorological regime encountered during the experiments

(a) 24 hr forecast of Horizontal wind vector

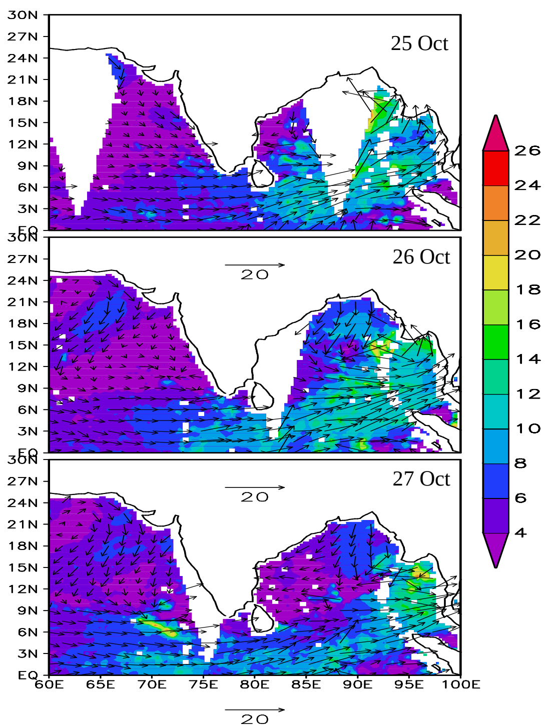


(b) 48 hr forecast of Horizontal wind vector

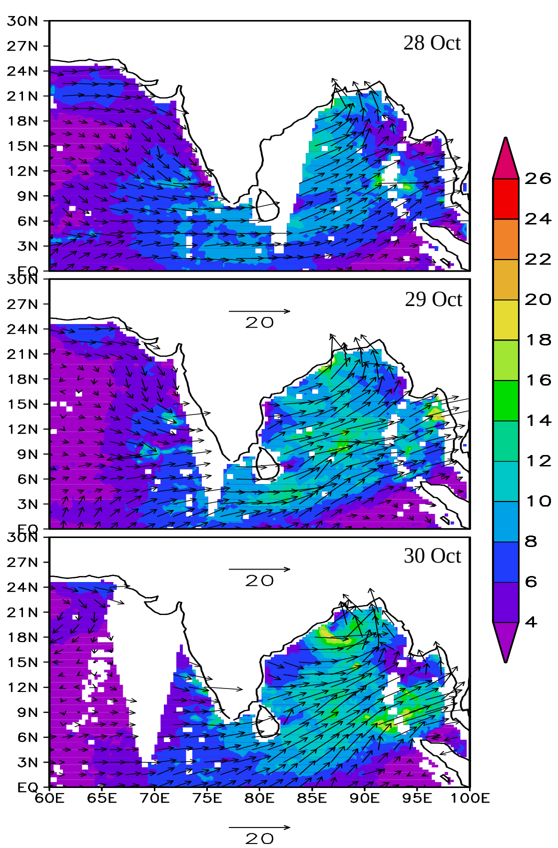


Figs. 1(a&b). Forecast wind vector at 850 hPa and 500 hPa. (a) 24 hr and (b) 48 hr

(a) 25 - 27 October 1999



(b) 28 - 30 October 1999



Figs. 2(a&b). Analysis with QSCAT wind data

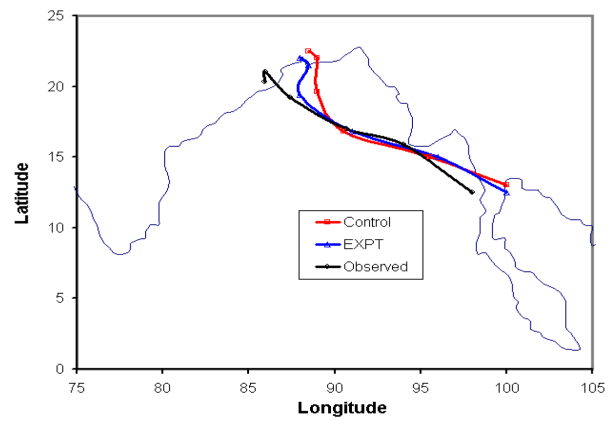


Fig. 3. Comparison of cyclone 25-31 October 1999 tracks

The domain selected for running the model covers a large area of collected QSCAT winds and the full cyclone area to allow for the evaluation of any forecast improvement over land. The domain grid uses a horizontal grid spacing of 30 km roughly equivalent to the observational spacing of the QSCAT winds (25 km). The results based on the study of five cases of cyclones during the period 1999 to 2003 are presented in this report. The positions and intensities of these cyclones are based on India Meteorological Department (IMD) weather summaries. Due to their proximity to the east coast of India, the TCs discussed here were well monitored. These tropical cyclones can usually only be identified in their early life by QuikSCAT scatterometer observations, due to the very sparse coverage of conventional data in this region.

The following tropical cyclone cases have been studied for assessing the impact of scatterometer wind data on their forecasts:

(*i*) Very severe cyclonic storm over the Bay of Bengal (15-19 October 1999)

(*ii*) Super cyclonic storm over the Bay of Bengal (25-31 October 1999)

(*iii*) Cyclonic storm over the Bay of Bengal (25-28 October 2000)

(*iv*) Cyclonic storm over the Bay of Bengal (14-17 October 2001)

(*v*) Very severe cyclonic storm over the Bay of Bengal (10-19 May 2003)

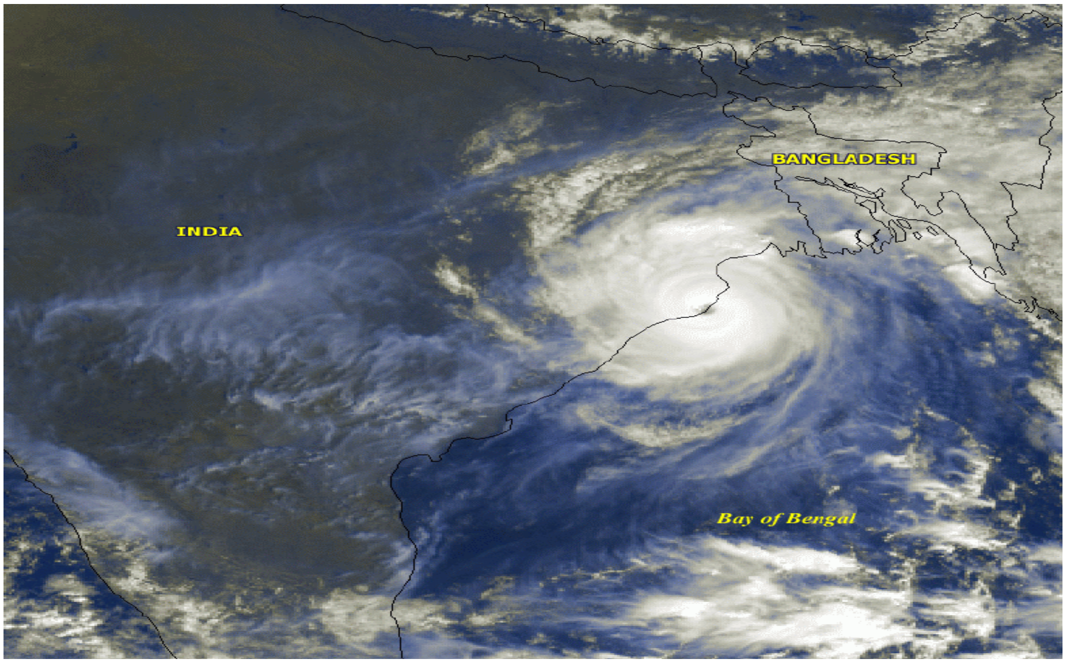


Fig. 4. METEOSAT Imagery at 0500 UTC, 29 October 1999

5. Results and discussion

Out of the five cases studied, only two cases are described in detail.

(*i*) *Super cyclonic storm over the Bay of Bengal (25-31 October 1999)*

A well marked low pressure area lay over Gulf of Thailand and neighbourhood on 24 October associated cyclonic circulation extended up to lower tropospheric levels. Moving westwards, it concentrated into a depression over north Andaman Sea and neighbourhood at 1200 UTC of 25 October, near Lat. 12.5° N / Long. 98.0° E.

Starting at 1200 UTC on 24 October 1999, a 72 hr simulation was carried out with and without FDDA of Satwinds. Figs. 1(a&b) shows the 24 and 48 hr forecast circulation at 850 hPa and 500 hPa. The model is able to generate a strong convergence in the 24 hr forecast and more organized convergence in 48 hr forecast. It also indicated the movement of the system to westnorthwest direction. Study showed that there were not enough QSCAT data over the area of the low pressure on 24 October. Hence, the centre of the cyclone was not well defined in the initial condition.

The model was further integrated from the 0000 UTC of 27 October 1999 to simulate the movement of the cyclone. Figs. 2(a&b) shows the analysis of QSCAT wind data between 25 – 30 October. The model simulated wind patterns are broadly in agreement with QSCAT actual wind patterns. The accumulated rainfall valid for 29 October for both control and experimental runs shows the rainfall of the order of 24-27 cm over coastal Orissa, which increased to 34-37 cm for 30 October forecast. The QSCAT inclusive run shows slight improvement in maximum precipitation accumulation than control run and match with the actual observations of IMD. The SSMI rainfall analysis for 29 and 30 October broadly agrees with the model simulation.

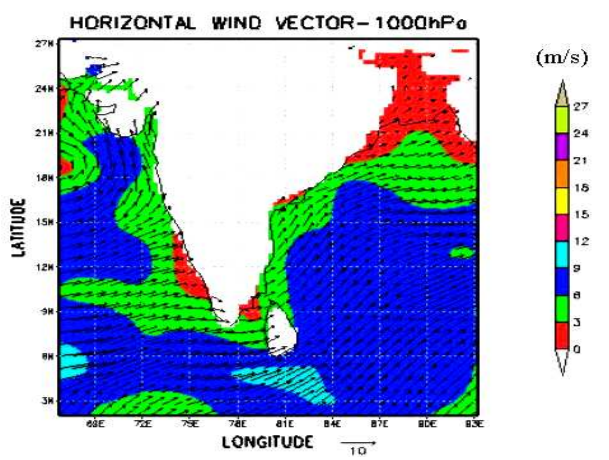


Fig. 5. Analysis - 0000 UTC, 11 October 2001

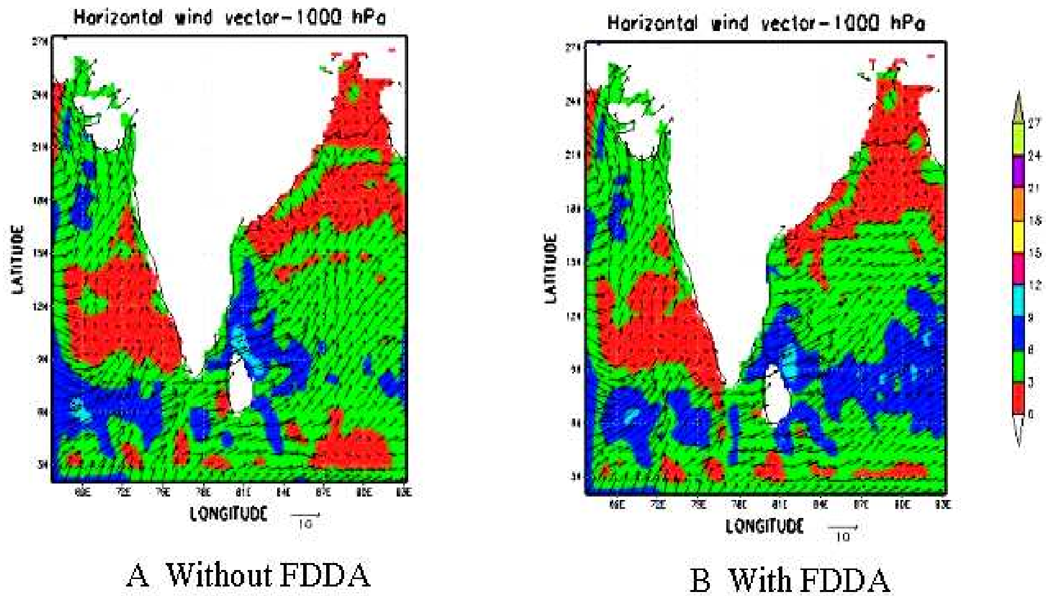


Fig. 6. 24 hr forecast - 0000 UTC, 12 October 2001

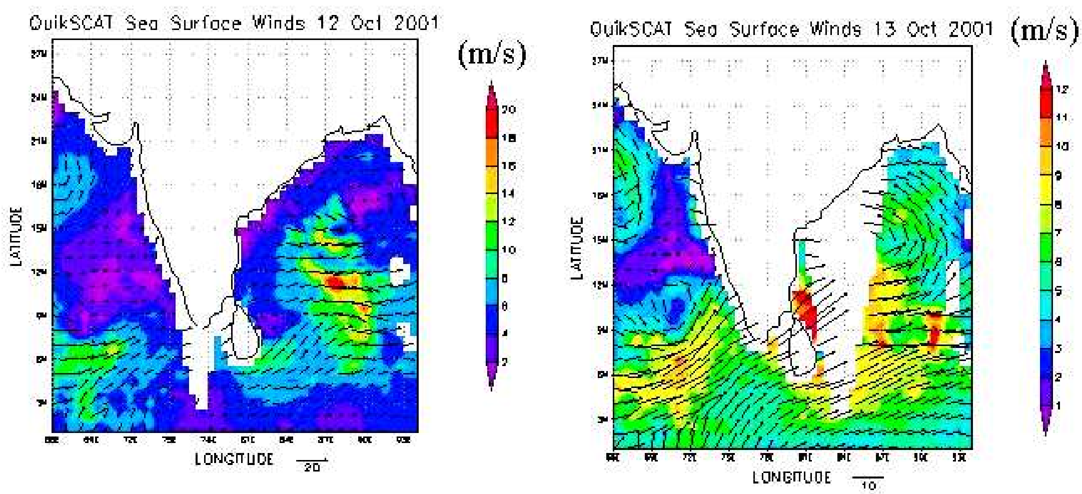


Fig. 7. Analysis of QSCAT winds, 12 and 13 October 2001

The track of the cyclone prediction based upon the initial condition of 24 October 1999 is shown in Fig. 3. The track based on the experimental run (with SCAT) was close to observations and was better than the control run forecast. The difference in track prediction between the IMD observed track and model simulated tracks are mainly due to the fact that there is an offset of around 150 km in the initial position between IMD data and model (NCEP) data. The Meteosat imagery shown at Fig. 4 depicts the characteristics of the super cyclone with a clear eye over the coastline at the time of crossing the coast at 0500 UTC on 29 October.

(*ii*) *Cyclonic storm over the Bay of Bengal (14-17 October 2001)*

A low pressure covering west-central and adjoining southwest Bay off Tamilnadu-South Andhra coast formed on 14 October morning. It concentrated into a depression at 1200 UTC of 14 October near Lat. 13.5° N / Long. 84.0° E. Moving in a westerly direction, it rapidly intensified into a deep depression at 0900 UTC of 15 October near Lat. 13.5° N / Long. 81.5° E. Thereafter, moving in a northwesterly direction, it further rapidly intensified into a cyclonic storm at 1200 UTC of 15

TABLE 1

Comparison of tropical cyclone location and intensity prediction with and without QuikSCAT data

	Location	Intensity	
		Circulation	Max wind speed (m/s)
Case I (13-14 October 1999 & 16-17 October 1999)			
24 hr forecast			
Control	Not seen	Not seen	6
Experiment	Not seen	Not seen	7
Observed	13.2° N, 92.8° E		8
48 hr forecast			
Control	Not seen	Not seen	6
Experiment	Trough is seen	Trough is seen	8
Observed	14.0° N, 90.0° E		11
72 hr forecast			
Control	15.0° N, 86.0° E	Weaker	15
Experiment	15.5° N, 86.0° E	Moderate	17
Observed	17.5° N, 86.5° E		20
Case II (24-25 October 1999 & 27-28 October 1999)			
24 hr forecast			
Control	13.0° N, 100.0° E	Moderate	9
Experiment	12.5° N, 100.0° E	Strong	10
Observed	12.5° N, 98.0° E		12
48 hr forecast			
Control	15.0° N, 95.5° E	Strong	18
Experiment	15.2° N, 96.0° E	Strong	19
Observed	15.9° N, 94.0° E		20.5
72 hr forecast			
Control	16.8° N, 90.5° E	Strong	22
Experiment	16.8° N, 91.0° E	Strong	24
Observed	17.0° N, 90.7° E		31
Case III (24-25 October 2000 & 26-27 October 2000)			
24 hr forecast			
Control	12.5° N, 94.5° E	Moderate	8
Experiment	12.5° N, 94.0° E	Strong Convergence	10
Observed	14.0° N, 92.5° E		10
48 hr forecast			
Control	13.5° N, 89.0° E	Strong	10
Experiment	14.0° N, 89.0° E	Strong	12
Observed	16.8° N, 89.3° E		14
Case IV (11-12 October 2001 & 15-16 October 2001)			
24 hr forecast			
Control	13.7° N, 84.5° E	Weaker	20
Experiment	13.5° N, 84.5° E	Strong Convergence	18
Observed	13.5° N, 83.0° E		13
48 hr forecast			
Control	13.8° N, 82.0° E	Strong circulation	28
Experiment	13.8° N, 82.4° E	Strong circulation	24
Observed	13.8° N, 80.4° E		18
60 hr forecast			
Control	14.2° N, 80.0° E	Weaker	27
Experiment	14.1° N, 80.0° E	Slightly weaker	22
Observed	15.0° N, 79.0° E		13
Case V (09-10 May 2003 & 15-16 May 2003)			
24 hr forecast			
Control	7.0° N, 88.5° E	Moderate	12
Experiment	7.0° N, 89.0° E	Strong	14
Observed	6.0° N, 91.0° E		14
48 hr forecast			
Control	11.0° N, 86.0° E	Stronger	20
Experiment	10.2° N, 86.5° E	Stronger	22
Observed	10.0° N, 87.5° E		24
72 hr forecast			
Control	13.5° N, 84.0° E	Intense	24
Experiment	12.5° N, 84.5° E	Intense	27
Observed	11.0° N, 86.0° E		32

October near Lat. 13.7° N / Long. 81.0° E. It moved in a northwesterly direction and made a landfall near Nellore around 0000 UTC of 16 October. The maximum intensity of the system reported was T2.5 from 1200 UTC of 15 October to 0300 UTC of 16 October. The lowest estimated central pressure was 996 hPa at 0000 UTC of 16 October.

Starting at 0000 UTC on 11 October 2001, a 60 hrs simulation was carried out with and without FDDA of Satwinds. Control run used data from the NCEP global aviation (AVN) model initialized at 0000 UTC, 11 October 2001. Fig. 5 shows the initial flow at 1000 hPa. From the figure the absence of convergent flow in Bay of Bengal is noted. In Fig. 6 (24 hr forecast) a weak convergent flow has developed and this weak flow has been intensified into a strong cyclonic circulation (48 hr forecast). The model simulated low pressure system without FDDA is compared with model simulation with FDDA for 24 hr and 48 hr forecasts. The intensity and the position of the low pressure system is well simulated in the experimental run compared to the model simulation without FDDA. Convergence patterns are stronger in the QuikSCAT assimilated simulation at the leading edge of the low pressure system. These simulated forecasts are also compared with observed fields (QuikSCAT) for 12 October and 13 October 2001 (Fig. 7). In the case of simulation, the intensity of the low pressure area is weak and is seen to the north of its position in comparison to the analysed field. The time series of model simulated minimum sea level pressure (MSLP) averaged over a box of latitude 15° - 16° N and longitude 85° - 86° E for 60 hr run for both control and experimental runs (Fig. 8) shows that the model is able to simulate the deepening of low pressure.

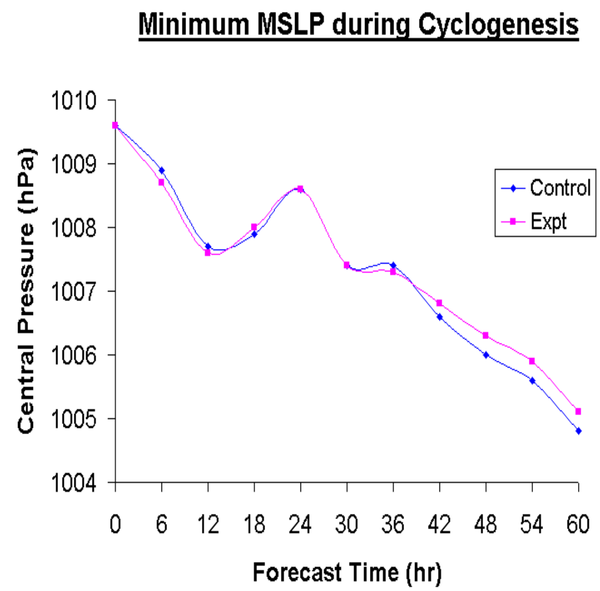


Fig. 8. Time series of Model Simulated MSLP (Initial time 0000 UTC, 11 October 2001)

Fig. 9 shows the comparison between the simulated track with and without satwinds and actual track as seen in the analysed field. The track of cyclone was well simulated by the experimental (with satwinds) forecast of the model. Inclusion of satwinds in this case has resulted in improvement in the track prediction.

6. Conclusions

The Scatterometer derived data available over Indian Ocean region have been used in this study for their impact on forecasting during a tropical cyclone period. For assimilation of the satellite data for Numerical Weather Prediction a few passes at different times are available. This additional data strengthened the initial data sets for assimilation, where otherwise data of a few ships of opportunity and of some coastal stations or island stations are available. In this case the inclusion of QuikSCAT data improved the initial field. In the prediction experiment, it was shown that the inclusion of QuikSCAT data improved the prediction up to 48 hrs. Beyond 48 hrs, the forecasts are nearly identical suggesting that the forecast lateral boundary condition, which is same for both the experiments, has become an important influence over the limited area. The rainfall prediction of the model is monitored by superimposing the Meteosat imageries. The model is able to provide spatial distribution of mean rainfall.

The MM5 model realistically captured the formation of low pressure system and its progression in four out of five cases considered. It is also found that with the addition of QuikSCAT wind data the cyclone track in experimental run is closer to observations than the control run and the improvement is of the order of 50-100 km, closer to observations. The results of the tropical cyclone location and intensity prediction are summarized in Table 1. It is to be noted that the model has run with the initial and boundary conditions from NCEP global model output and there is an error of about 100-150 km in the initial position between NCEP and IMD observations.

It is expected that more impact on the forecast will be possible if this data are used along with other satellite data, especially moisture information over the data sparse region. In the present study no vertical coupling was put in the assimilation system. This coupling on the basis of other satellite products like Atmospheric Motion Vectors (AMVs), temperature profiles and humidity profiles

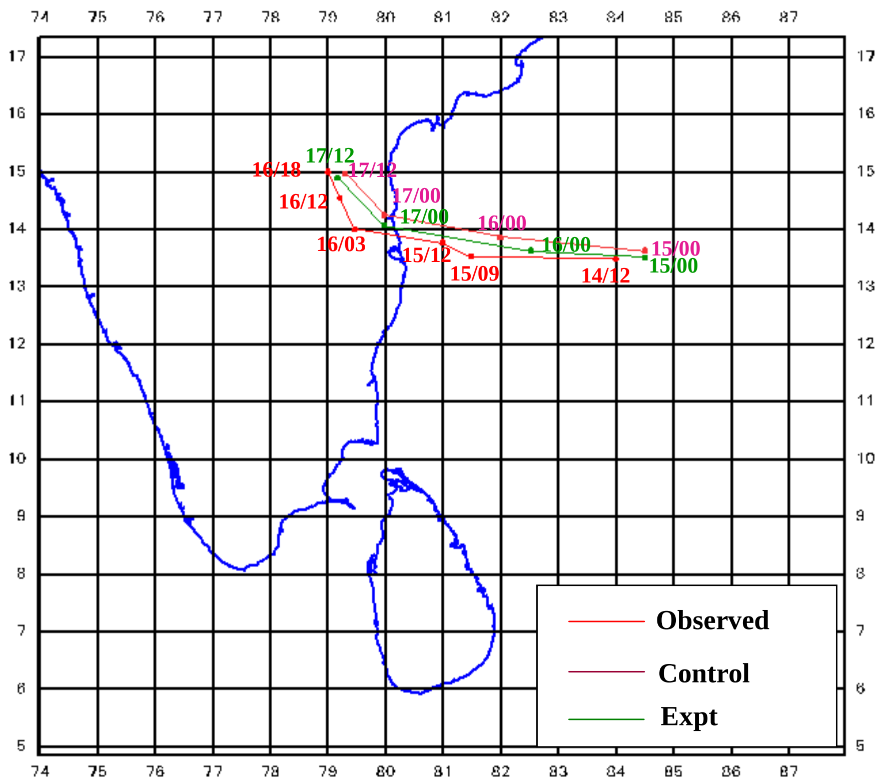


Fig. 9. Comparison of cyclone tracks of 14-17 October 2001. The number following the date of the cyclone track refers to the time (UTC)

provide a unique opportunity for a proper formation of vortices. This may be very much useful for short range forecasting. Also, the QuikSCAT wind data has to be tested with many more cases to assess its reliability of assimilation in a mesoscale model for tropical cyclone forecasts for operational purposes.

Acknowledgements

The author would like to thank Commodore Mahitosh Misra, Principal Director Naval Oceanology and Meteorology (PDNOM), Naval Headquarters, Commander R.T.T. Antoni, Joint Director Naval Oceanology and Meteorology (JDNOM), Naval Headquarters and Commander CS, Panda, Officer-in-charge, School of Naval Oceanology and Meteorology for providing constant encouragement during the course of study. Author is also grateful to Dr. Pradip K. Pal, Scientist, SAC/ISRO for valuable suggestions during the completion of this study.

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