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MM5 simulation of the 1999 Orissa Super Cyclone : Impact of bogus vortex on track and intensity prediction

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सार – इस अध्ययन में 29 अक्तूबर, 1999 को उड़ीसा के तट पर आए महाचक्रवात के प्रतिरूपण के लिए एन. सी. ए. आर/पी. एस. यू. एम. एम. 5 मेसोस्केल निदर्श (ग्रेल इत्यादि 1995) का उपयोग किया गया है। इस निदर्श में चक्रवात की प्रारंभिक अवस्था और उसकी परिसीमाओं की अवस्थाओं के रूप में राष्ट्रीय मध्य–अवधि मौसम पूर्वानुमान केन्द्र टी. 80 के प्रचालनात्मक विश्लेषणों का प्रयोग किया गया है और तूफान की अवधि में 3 दिन तक का पूर्वानुमान तैयार करने के लिए इस निदर्श को 72 घंटे की अवधि के लिए समाकलित किया गया है। इस अध्ययन का उद्देश्य चक्रवात के मार्ग पर कल्पित भ्रमिल के प्रभाव का मूल्यांकन करना और चक्रवात की तीव्रता का पूर्वानुमान लगाना है।

ABSTRACT. In this study NCAR/PSU MM5 mesoscale model (Grell *et al*. 1995) is used to simulate the super cyclone that struck the Orissa coast on 29th October 1999. The model makes use of the operational NCMRWF T 80 analysis as initial and boundary conditions and is integrated up to 72 hr for producing 3-day forecast of the storm. The aim of this study is to assess the impact of bogus vortex on track and intensity prediction.

Key words – Super cyclone, Physical parameterization and Bogusing.

1. Introduction

In this study NCAR/PSU MM5 mesoscale model (Grell *et al*. 1995) is used to simulate the super cyclone that struck the Orissa coast on 29th October 1999. The model makes use of the operational NCMRWF T80 analysis as initial and boundary conditions and is integrated up to 72 hr for producing 3-day forecast of the storm. The aim of this study is to assess the impact of bogus vortex on track and intensity prediction. In a similar study Singh *et al*. (2005) make use of MM5 mesoscale model and the NCEP reanalysis to simulate the super cyclone. Wind speed and location of the tropical cyclone obtained from the best track data are used to define maximum wind speed and center of the storm respectively, in the initial analysis. Using this scheme, the 24-hour, 48-hour and 72-hour forecast errors for this case on the average were reduced to 59 compared to for the non-vortex initialized case.

Part -I of the study concentrated on the impact of various physical parameterization schemes on the tropical cyclone intensification and track prediction. It was noted that from among the 12 experiments using four cumulus parameterization schemes and three boundary layer schemes, three experiments simulated tropical cyclone tracks close to the observations. All the 12 experiments features large differences in the cyclone positions, intensity and rainfall at the time of landfall. While the differences in the predicted tracks of the cyclone could be attributed to the differences in the physical parameterization schemes, error in the initial description of the location and intensity of the system can cause huge errors in the predicted tracks of the cyclone. Accurate representation of the vortex in the model initial analysis is crucial for prediction of track and intensity of the tropical cyclones. In the coarse resolution operational T80 model analysis the vortex is often broad, weak and misplaced particularly when the system is over the data sparse oceanic region. To improve the storm representation the use of bogus vortices is often adopted (Trinh and Krishnamurti 1992; Kurihara *et al*. 1993; Leslie and Holland 1995). Kurihara *et al*. (1993) proposed a scheme to improve the representation of a tropical cyclone in the initial condition of a high-resolution hurricane model. A crudely resolved tropical cyclone in the large-scale analysis is replaced by a vortex that is properly specified for use in the prediction model. Appropriate filters are used to remove the vortex from the large-scale analysis so that a smooth environmental field remains. The new specified bogus vortex takes the form of a deviation from this environmental held so that it can be easily merged with the latter field at the correct position. The methodology used in this study follows this approach and is discussed in detail in the following section.

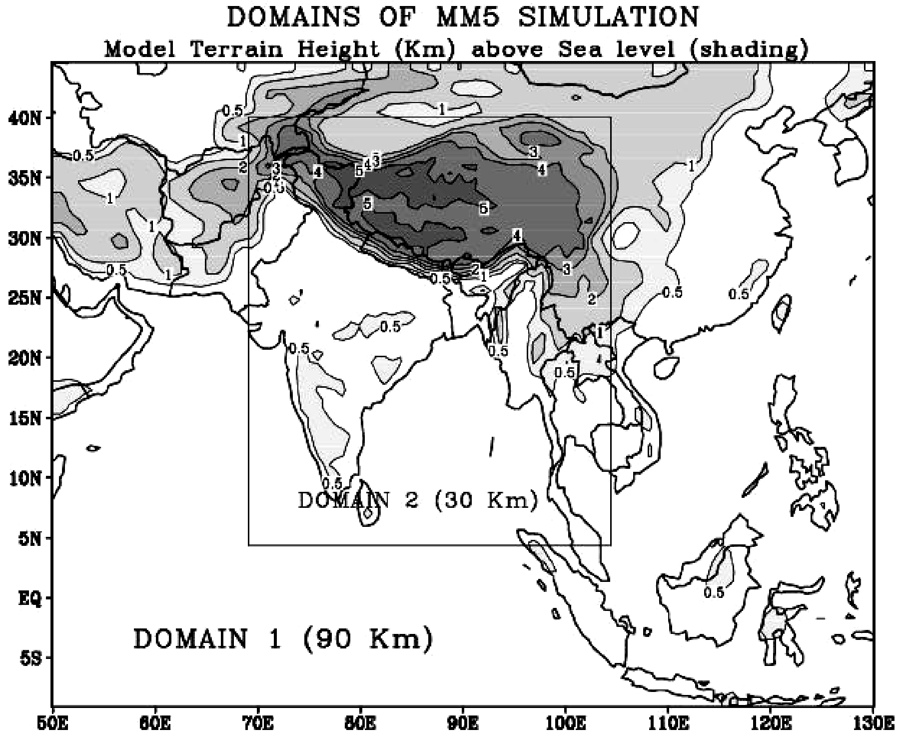


Fig. 1. Geographical domains used in the MM5 experiments

2. Model description and experiments

The MM5 mesoscale model (Version 3.6) has *U*, *V*, *T*, *q*, *Ps* as prognostic variables with semi-implicit time integration scheme. It is a non-hydrostatic (NYH) model with a two-way nesting. NYH effects may be negligible for scales larger than 100 km, and the hydrostatic (HY) assumption is a good approximation down to scales of 10-15 km. However for these scales the dynamical effects, excluding the HY assumption start to become non-negligible and the use of NYH models is necessary. The model uses fourth order horizontal diffusion for inner domains and second order diffusion for the coarse domain. The model uses staggered Arakawa B-Grid in the horizontal direction. In this study we have used 40 vertical levels (Sigma-Hybrid). The time steps of model integration for two domains domain 1 and domain 2 are 270 and 90 seconds respectively. The model uses USGS (Interpolated depending on resolution) with 25 categories for Vegetation/ Land use. Explicit treatment of cloud water, rainwater and ice has been performed using Dudhia (1996). Cloud radiation interaction has been allowed between explicit cloud and clear air. The initial and lateral boundary conditions are obtained from operational global T80/L18 model of NCMRWF.

2.1. *NCAR-AFWA Bogusing scheme*

NCAR-AFWA Bogusing scheme modifies the vorticity, geostrophic vorticity, and divergence, then solves for the change in non-divergent stream function, geopotential and velocity potential, respectively and computes the modified velocity field. The procedure is discussed in detail in the report Davis and Low-Nam (2001) and also in Singh *et al*. (2005). A brief description of the scheme broken into two components is given here.

(*i*) *Detection and extraction of tropical cyclone from the first guess* - First guess information is generally available on coarse resolution. The vortices contained in the analysis are too broad and weak. Initialization of a high resolution model from these analysis leads to a storm that typically maintains its physical characteristics from the initial time. If the storm starts out with a radius of maximum wind (RMW) of, say 200 km, the RMW tends to remain near this value for and extended period during the forecast until the model is able to produce scale contraction and associated intensification of the vortex. This often requires 1-2 days. To improve intensity prediction it is necessary to insert an initial vortex that is closer to the observed storm intensity after removing the vortex in the analysis.

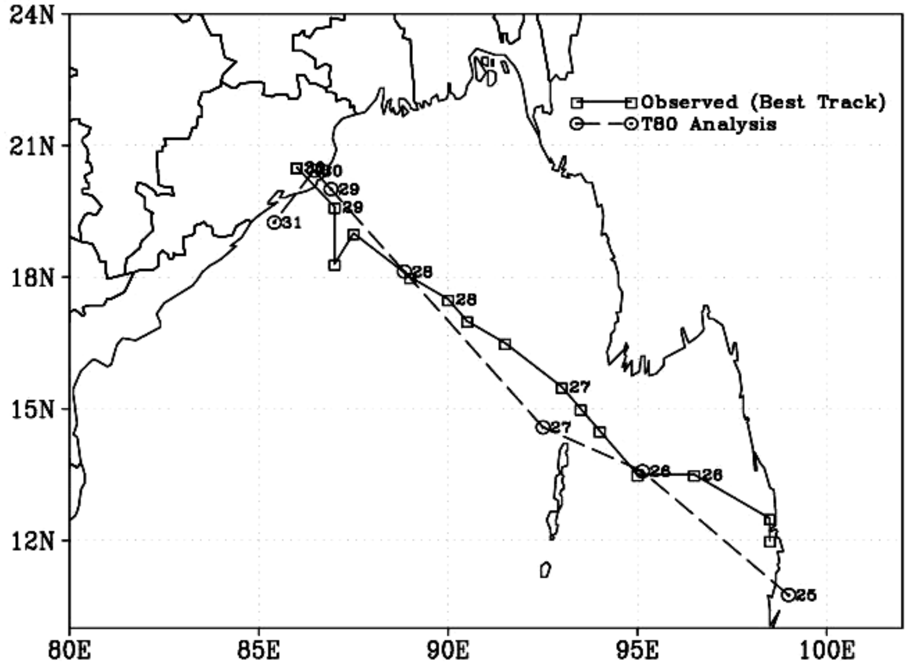


Fig. 2. Observed track of the Orissa Super Cyclone 1999 during 25 -31 October 1999. Cyclone track as captured in the T80 analysis is also shown

(*ii*) *Computation of bogus vortex and blending with the modified background field* - The scheme uses the input data on storm location and estimated maximum winds and constructs a storm profile based on the assumptions of axisymmetry, fixed RMW (90 km), mass and wind fields in nonlinear balance, nearly saturated core and maximum winds of the bogus storm are a predetermined fraction of observed/estimated maximum winds.

With 25th October 1999 initial conditions the model is integrated for 3 days with combination of Kain-Fritch (KF) scheme for cumulus parameterization and Blackdar PBL (Zhang and Anthes 1982) scheme. Pielke (2001) gives a brief description of all the cumulus parameterization schemes and are not described here for brevity. The five experiments are carried out to study the impact of bogus vortex on track prediction and storm intensification. The simulations are carried out in two nested domains at 90 and 30 km horizontal resolution (Fig. 1). All the results presented in this study are from domain 2 for 30 km resolution.

3. Results

3.1. *Super cyclone track prediction*

Fig. 2 shows the track of the super cyclone from early stages of genesis on 25th to 31st October 1999. The observed track corresponds to the best track data provided by the India Meteorological Department (IMD). The track in NCMRWF T80 analysis is also shown. Although the track in the T80 shows high departure on 27th, the deviation is minimal on 28th and 29th until landfall. Further the analysis correctly captures the southward migration of the storm after remaining anchored to the coast.

In Part-I a detailed analysis was carried out to obtain best combination of cumulus and boundary layer parameterization schemes that resulted in a prediction of the super cyclone track closer to the observed track. It was found that the combination of Kuo-MRF, BM-Blackdar and KF-Blackdar produce cyclone tracks close to the observations. However all the experiments with Kuo suggested lack of intensification in the storm. To study the impact of introduction of bogus vortex in the initial analysis MM5 simulation experiments are carried out with KF-Blackadar configuration. MM5 was integrated for 72-hour forecasts with initial conditions from 25th, 26th, 27th, 28th and 29th of October 1999. The errors in the predicted tracks are computed relative to the best track positions of IMD at 6-hour interval. The results are presented in Table 1. The impact of error in the location of the system in the initial analysis can be clearly seen. For MM5 runs starting on 25 and 26th the errors are small in the beginning and the errors generally increase with forecast time. In this case without Bogusing the predicted

TABLE 1

Tropical cyclone track prediction errors (km) in the MM5 simulations of the super cyclone relative to IMD best track (Track errors in km)

Date of IC		Day-1 (24-hours lead time)				Day-2 (48-hours lead time)				Day-3 (72-hours lead time)			
	0000	0600	1200	1800	0000	0600	1200	1800	0000	0600	1200	1800	0000
						Without Bogusing							
25th Oct	-	51	234	284	113	224	273	227	173	144	142	141	170
26th Oct	99	54	84	157	219	357	394	325	314	369	494	532	482
27th Oct	440	503	478	478	458	413	438	352	496	598	598	598	598
28th Oct	353	289	262	356	272	360	360	360	360	360	360	360	360
29th Oct	70	102	291	329	369	428	430	430	465	-	-	-	-
Average	226	200	270	321	286	356	379	339	362	377	399	408	402
						With Bogusing							
25th Oct	-	56	56	56	69	69	69	137	137	137	137	273	273
26th Oct	63	63	63	76	76	76	141	141	141	141	275	275	275
27th Oct	57	57	57	70	70	70	138	138	138	138	273	273	273
28th Oct	57	57	57	71	71	71	140	140	140	140	275	275	275
29th Oct	58	58	58	74	74	74	142	142	142	-	-	-	-
Average	59	58	58	69	72	72	126	160	160	139	240	274	274

track errors do not show a systematic increase or decrease. In the MM5 run starting on 27 and 28th the errors are rather very large in the initial analysis itself and they also show slight increase with time. Errors in the initial position of the system are indicated in the first column. For 25th October 1999, 0000 UTC and for 1st November 1999 the observed data on the location of the system was not available and hence the track error computations for these dates and hours are missing in the Table 1. A cursory glance at the Table 1 suggests that the errors in the predicted tracks grow with increasing forecast lead time. Further the errors also vary with changing initial conditions. With the initial conditions of 25th October 1999 and without Bogusing the errors are 113, 173 and 170 km in 24-hour, 48-hour and 72-hour forecasts respectively, which is lowest in the entire set of experiments. However in the run with initial conditions of 27th October 1999 and without Bogusing the errors are 458, 496 and 598 km in 24-hour, 48-hour and 72-hour forecasts respectively. On 27th October 1999 the initial position of the storm itself shows large error of 440 km which has caused large errors in the predicted track of the cyclone. On average errors are 286, 362 and 402 km in 24-hour, 48-hour and 72-hour forecasts. The MM5 run with initial conditions corresponding to 25th October 1999 features track errors much lower than the average errors.

3.2. *Introduction of bogus vortex*

The representation of the cyclonic system in the initial analysis can be improved by introducing "bogus vortex". MM5 makes use of the bogusing technique of Davis and Lownam (2001). The MM5 runs are repeated by including bogus vortex to assess the impact of bogusing on the track prediction. For this purpose the position of the system and reported maximum wind from 25th - 29th of October 1999 are prescribed based on the best track data obtained from the IMD. While preparing the initial analysis the observed location of the system is specified at 11.2° N/99.2° E with maximum observed winds of 12.85 m/s based on the best track data provided by IMD. Further the radius of maximum wind (R_{max}) is specified at 180 km (~2 times the grid resolution) and the radius of search for locating the vortex in the analysis is specified as 400 km.

Figs. 3(a-c) shows the sea level pressure (hPa) and 850 hPa winds (m/s) valid for the 0000 UTC of 25th October 2005 in the initial analysis (*i*) without introduction of bogus vortex (*ii*) after the introduction of bogus vortex and (*iii*) the difference between the two. It can be noted that the introduction of bogus vortex has resulted into a better description of the vortex in the initial analysis. The difference between the two shown in Fig. 3(c) suggests that the introduction of the bogus vortex has decreased the sea level pressure by over 5 hPa and provided enhanced cyclonic circulation. Similarly the bogus vortex in introduced into the initial analysis corresponding to all the four dates of 26th, 27th, 28th and 29th of October 1999. Using the new set of initial analysis MM5 was run for preparing the 72 hour forecasts and the predicted track of the cyclone is computed as described

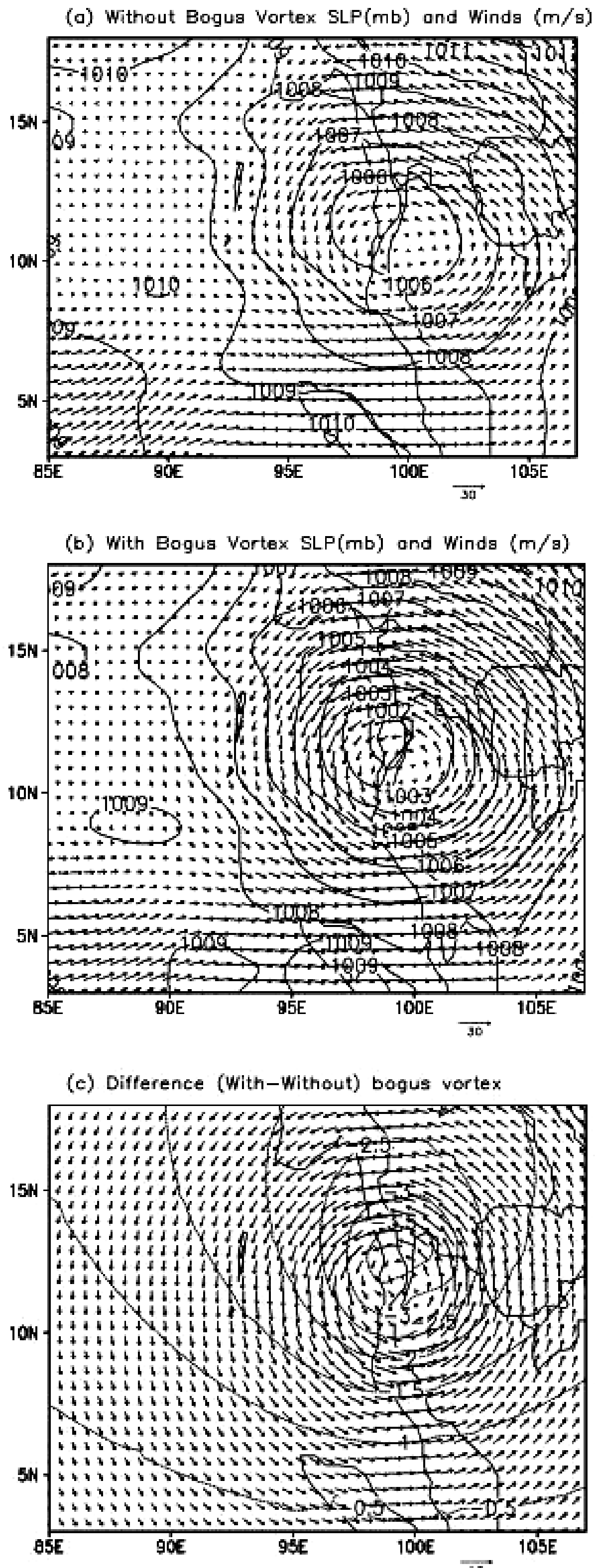
TABLE 2

Central sea level pressure (hPa) in the MM5 simulations of the super cyclone

Date	Day-0	Day-1	Day-2	Day-3
		Without Bogusing		
25th Oct	1005	1006	1002	988
26th Oct	1002	998	995	990
27th Oct	1002	1000	998	998
28th Oct	1000	998	998	998
29th Oct	1000	998	998	996
Average	1001	1000	1000	993
		With Bogusing		
25th Oct	1000	998	994	992
26th Oct	998	996	993	989
27th Oct	1000	998	998	994
28th Oct	1000	998	995	990
29th Oct	999	998	993	988
Average	999	998	995	991

before. The errors in the predicted tracks are given in Table 1. The errors in the initial analysis have decreased. After the introduction of bogus vortex the average error in the initial position of the storm is reduced to 61 km compared to the earlier case without bogus vortex. Although the track errors show increase on Day-2 and Day-3, the magnitudes are much smaller compared to value of errors in the case without bogusing. On an average the predicted tracks feature errors of 72, 160 and 274 km in the 24-hour, 48-hour and 72-hour forecasts respectively.

Table 2 shows central sea level pressure in the initial analysis and the forecasts based on the initial conditions of all the five days from 25th to 29th October 1999. The experiment without bogus vortex shows central sea level pressure in the initial analysis (Day-0) excess of 1000 hPa on all days. On introduction of the bogus vortex however the central sea level pressure has slightly decreased in the initial analysis. Although the decrease is marginal it must be noted that the 24-hour pressure drop in the MM5 run with bogus vortex has improved. In these experiments the introduction of the bogus vortex into the analysis does not lead to much intensification of the system. With 25th October initial condition and without bogus the lowest pressure of 988 hPa was reached on Day-3 (28th October) and with 26th October initial condition it was 990 hPa (29th October) with the observed central pressure of 986 hPa and 912 hPa respectively in the IMD estimated values. Similarly with bogus vortex the lowest central pressure reached was 992 hPa (observed 986 hPa) on 28th October and only 989 hPa (observed 912 hPa) on 29th October.



Figs. 3(a-c). Sea level pressure (hPa) and 850 hPa winds (m/s) in the initial analysis of 0000 UTC of 25th October 1999 (a) without bogus vortex, (b) with bogus vortex and (c) the difference (with-without) between the two

The large difference in the simulated and observed central pressure showing marginal intensification in simulation is most probably due to not so good forecast in the NCMRWF global model on the large scale storm did not intensify from the observed initial condition based even on 27th October as well as based on 28th October. We also notice that the initial specification of the bogus vortex on 27th agrees with the observed but on 28th and 29th October the bogus vortex central pressure is about 1000 and 999 hPa respectively whereas the observed ones were 986 hPa and 912 hPa respectively. These are very large differences between the bogus central pressure and observed central pressure. Perhaps the bogusing technique was not responding to the maximum winds prescribed. This question is being looked into.

4. Summary

The aim of this exercise is to study the impact of tropical cyclone bogusing using asymmetric vortex on the prediction of tropical cyclone track. The study uses the MM5 mesoscale model and the NCAR-AFWA Bogusing Scheme. 1999 Orissa super cyclone is chosen for the study. MM5 simulations of the cyclone are carried out with initial conditions starting from 25th October to 29th October. With each of the initial conditions 72 hour forecasts are generated. From each of the runs, tropical cyclone tracks are computed based on the location of lowest sea level pressure. The tracks obtained from the MM5 simulations are compared with the best track data available from IMD. Using the observed and simulated track data of the tropical cyclone predicted track errors are computed. Similar exercise is also carried out after the initial data is modified by introducing the bogus vortex to obtain track errors relative to the best track data. It is found that the introduction of bogus vortex significantly improves the location of the system in the initial conditions In this study it was found that the average error in the initial position of the system was 226 km and on introduction of the bogus vortex the error decreased to 60 km. Similarly errors in the storm location in Day-1, Day-2 and Day-3 forecasts decreased significantly after introduction of bogus vortex. Introduction of bogus vortex also showed some impact on the intensification of the storm although marginal.

This exercise suggests that the by introducing the asymmetric vortex in the initial analysis prediction of the track of the system can be improved significantly. The improvement in the prediction of storm intensity is marginal. This could be mainly attributed to the methodology of introducing the bogus vortex into the initial analysis. It could also be attributed to the inherent assumptions of bogusing and choice of the radius of maximum wind R_{max}. The results could be sensitive to the choice of R_{max}. Detailed investigation of methodology of bogusing and the impact of inherent assumptions of the bogusing schemes needs to be done. It is also important to carryout similar analysis for several cyclonic storms of the Bay of Bengal as well as Arabian Sea which is being planned at NCMRWF.

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