THEMATIC SESSION B4
CYCLONE AND TSUNAMI

Chairperson: Prof. S. K. Dube
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ABSTRACTS

DISASTER MANAGEMENT AND VULNERABILITY REDUCTION PLAN IN RESPECT OF CYCLONES FOR THE COASTAL REGIONS OF ANDHRA PRADESH

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The study has been undertaken for evolving a Disaster Management Plan (DMP) for cyclones and associated storm surges for mitigation in the nine coastal districts of Andhra Pradesh (AP) State. The study was initiated by the Govt. of Andhra Pradesh under the World Bank financed project "Andhra Pradesh Hazard Mitigation and Emergency Cyclone Recovery Project" (APHM & ECRP) following the 1996 cyclone with the objective of reconstruction of infrastructure in its nine coastal districts.

The objective of this study is to prepare a long term DMP coveringdisaster risk identification (Hazard and Assessment of Physical Vulnerability, Social Vulnerability and Economic Vulnerability), Disaster Risk Reduction (Mitigation and Regulation) and Disaster Risk Transfer (Relief and Insurance)

Physical Vulnerability (PV)

The backbone of a DMP is the determination of PV due to cyclones, for each coastal district separately, using Mandal as the smallest geographical unit. In this study the determination of PV for each mandal of the coastal districts of AP has been based on the frequency of cyclones affecting AP. The determination of PV due to storm surges is, however, difficult due to incomplete and less precise observational data on storm surge. Even when storm surge height estimates are available for specific cyclones, it is very difficult to break this down to the mandal level. For this reason, to determine storm surge vulnerability, we adopted a more scientific approach.

Based on historical cyclone data, through a simple statistical analysis, Delta P (Pressure deficit) was determined for cyclones land falling on the AP coast, for return periods of 2, 5, 10, 25 and 50 years. The 50 year value was used as an input to the Storm Surge Model. The Storm Surge Model developed by IIT-Delhi was run with this Delta P value for a set of synthetic tracks. These tracks were made up by composting actual tracks, ensuring that each coastal district is covered. The results of the computer models, calibrated with actual observed surge data for each region of the coast, provided maximum probable surge amplitudes on a 50 year return basis at the mandal level. The maximum probable total water levels have been determined by superimposing the tidal amplitudes and wind wave setup on the surge amplitudes. The total water levels determined in this manner could be used for coastal zone management including cyclone mitigation.

A generally world-wide accepted procedure in determining the extent of land inundation by a storm surge is to assume that, a water level of 5 m at the coastline would have an impact up to the 5 m land contour. A 10 m water

level would impact up to the 10 m contour. This is a conservative approach and may somewhat over-estimate the extent of inundation. However, for Coastal Zone planning purposes this is desirable and hence adopted.

Social Vulnerability (SV)

SV has been worked out for physically vulnerable mandals. By using the vast data, provided by Government of AP, on social factors in the state, 11 social factors have been considered for assessing SV. Each factor was allocated suitable points. A number of maps have been made for each affected mandal. By clicking on a given mandal, all these maps can be seen in GIS format and in tabular form.

INTERANNUAL VARIATION OF CYCLONIC DISTURBANCES LAND FALLING OVER INDIA

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The cyclonic disturbances cause very often devastation due to heavy rainfall, strong wind and storm surge. A study is under taken to find out characteristics of interannual variation like co-efficient of variation, trends and periodicities etc. in the annual frequencies of different categories of disturbances such as depressions, cyclonic storms, severe cyclonic storms, total cyclonic storms and total cyclonic disturbances landflaling over different coastal states of India based on the data of 115 years (1891-2005).

About 68% of the disturbances developing over the Bay of Bengal have landfall over east coast and about 30% of the disturbances developing over the Arabian Sea have landfall over west coast. Out of total disturbances having landfall over east and west coasts, about 85% and 44% cross Orissa and Gujarat coasts respectively.

While the frequency of severe cyclonic storms crossing Andhra Pradesh coast shows significant increasing trends, the frequencies of cyclonic storms crossing Orissa, West Bengal and Gujarat coasts show significant decreasing trends. The sixth order polynomial trends could be well fitted to the frequencies of different categories of disturbances crossing the coasts during this period.

The quasi-biennial oscillation (QBO) is significantly observed in the frequency of cyclonic storms crossing Orissa coast. The cyclonic storms crossing Andhra Pradesh and Tamil Nadu coasts show significant cycles of 5-6 years.

The severe cyclonic storms crossing Andhra Pradesh coast exhibits QBO and that crossing West Bengal coast shows QBO as well as 4-5 cycle of oscillation. There is no periodicity in the frequency of disturbances landfalling over other coastal states.

MULTI-HAZARD EARLY WARNING SYSTEM: CONCEPTUAL REVIEW

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The impact of Tsunami underlined the crucial role of Early Warning in Disaster Preparedness and substantial attention is given now to strengthen Early Warning capacities. The concept of multi-hazard Early Warning System (EWS) has been invoked by many Disaster Management Professionals and Practitioners to be the model for Early Warning. The concept is driven on the idea that Early Warning System if developed for a high impact, low frequency hazard such as Tsunami will not be cost effective and therefore a multi-hazard System need to be considered. The concept is supported by the fact that a number of other hazards such as Cyclone, Flood, Drought, Epidemics etc. have a common pattern in their Early Warning Systems characterized by four distinct phases (detection, monitoring, communication/dissemination and response capability). The observation that there can be substantial similarities in these phases and therefore a multi-hazard System (if adequately integrated) will be more effective than individual scattered Systems. The argument supporting this mechanism views Early Warning to be beyond the domain of scientific agencies (detecting and monitoring functions) and requires specialized skills in decision making, delivery mechanism, monitoring response and compliance of user groups. This concept however is yet to be fully analyzed and comprehensive review of effectiveness of this system is needed. This paper will be an attempt to develop conceptual framework for a multi-hazard

Early Warning System, analyze issues about implementing such mechanism given the diversity of various agencies involved, how such integrated system can be compared with the present system of Early Warning in India.

REBUILDING LIVES: POST TSUNAMI RECOVERY AND RECONSTRUCTION IN ANDAMAN & NICOBAR ISLANDS

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The earthquake followed by devastating Tsunami of 26th December 2004 was not only responsible for thousands of deaths, extensive damages to the infrastructure and loss of human lives, but also dislocated the communities from their neighborhood, affected their means of livelihood and socio-cultural linkages. The tsunami damaged about 8000 hectare of crops and plantation and destroyed 10000 houses. The damages have been assessed to the tune of Rs. 3300 crores.

The disaster of tsunami is being perceived as opportunity for reshaping the lives of people by creating an environment with ample employment opportunities thorough the implementation of various relief packages announced by the government of India and also through the recovery efforts by other NGOs and the local self governments. However the communities have differential capacities to respond, accept and adapt to the changes intended or perceived to be beneficial to them and are influenced by cultural and ideological forces and sometimes driven by purely rational economic choices.

The paper discusses the approaches of the administration, community and NGOs in rebuilding not only the physical infrastructure but also the efforts made in restoration of the social and fabric of the community and promoting the culture of disaster prevention and preparedness which involves close interactions and intensive debates/discussions among the stakeholders for assessing and projecting both the short term and long term needs and strategies with ecological sensitivity and good environmental management practices. One of the major accomplishments under the short term recovery process has been the construction of about 10,000 intermediate shelters for housing the tsunami affected families in a time period of 4 months before the onset of heavy monsoon in 2005. The paper documents this challenging task and other complex issues associated with the permanent housing for the tsunami victims, livelihood restoration, nature and extent of compensations, introduction of new technologies and initiatives in livelihood sectors particularly the farm sector and the issues of transparency and inclusion in the rehabilitation process.

REHABILITATION AND CHANGE IN THE AFTERMATH OF TSUNAMI: A RETURN TO LITTLE NICOBAR ISLAND

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After the tsunami of December 26th 2004 the southern Nicobar Islands were revisited, a place where I had previously conducted ethnographic research. My research was aimed at understanding methods that the 'Payuh' [residents of Pulomilo, Kondul, Little Nicobar Islands] employed to use their surrounding environment of forests and coastline toward sustenance. This focussed on food articles they sourced from the forest, sea and places the Payuh chose to reside at. It was evident that the Payuh designed livelihood and their island through an understanding of their forests and seas, manipulating livelihood through opportunity and living with the security of tradition they were accustomed to. The tsunami was a disaster that caused untold destruction and has disrupted the placid lives of islanders, some of whom I had worked with. I never realised how it would put me in a fix as to how I could put knowledge gained through previous research to use, in aiding the rehabilitation of people who had become a part of my life's experience. This was a journey that I embarked on without any prior experience in 'disaster management', but that which I took on confident of being able to converse with and create an understanding between myself and the Payuh. In this process I watched as the Payuh were exposed to the local administrative machinery that they rarely if ever came into contact with. In all their experience and history, this was the first time the Payuh, like many other indigenous islanders of the Nicobars were being exposed en masse to a

rehabilitation effort and the world outside of their hamlets; this was an experience that would not have occurred if not for the tsunami. It exposed many chinks in the dialogue with native islanders such as incomplete governmental records on the islanders and in understanding tribal communities with sensitivity, while not accounting for the socio-ecological resilience of these islanders within the framework toward recovery and rehabilitation. It unfortunately also delayed the process to recovery and threatened to bring on a dominant system of governance in place of their former self-reliance. In this process, amongst the Payuh many new social and economic linkages were created and some social networks were under duress. I attempt to outline these as I understand the past being different to the present and possible outcomes that may be bolstered to mitigate future impacts through the present developmental process. I also briefly write on the process that team members and I undertook in the rehabilitation effort.

IMPORTANCE OF INTEGRATED COASTAL ZONE MANAGEMENT IN INDIA

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Coastal systems are more vulnerable and prone to the effects of natural hazards. The tsunami that struck several nations in the Indian Ocean on December 26, 2004 destroyed the lives and livelihoods of several coastal communities in India and resulted in significant damage and destruction of properties and infrastructure. A number of lessons were learnt from the 2004 Tsunami with respect to Infrastructure Management, Policy/Planning and Community Preparedness. While tsunamis are rare, the coastal communities in India are also exposed to other phenomena like cyclones, coastal erosion, floods etc. and the people of the coastal communities lack adequate development and livelihood opportunities.

There is substantial consensus now that managing coastal zones require an integrated approach capable of bringing together diverse perspectives while framing any Coastal Zone Management Plan. Integrated Coastal Zone Management (ICZM) concept is a planning and coordinating process which aims at optimum development and resource management. It can prove to be an effective general framework for dealing with coastal issues including resource management and disaster risk reduction.

This paper tries to put forth certain recommendations for risk reduction in coastal areas within the ICZM framework based on findings from Tamil Nadu after Tsunami 2004. The paper seeks to integrate these findings into developing an effective ICZM policies related to its development of plans and programmes, participation, training and capacity building.

AN ECOSYSTEM APPROACH FOR MANAGING ENVIRONMENT, HEALTH IN THE TSUNAMI AFFECTED SLUM: A CASE OF ANJUKUDISAI, CHENNAI

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An ecosystem is a system whose members benefit from each other's participation via symbiotic relationships (positive sum relationships). It is a term that originated from biology, and refers to self-sustaining systems. Many projects in the world are successfully completed by adopting the so called ecosystem approach taking in account various stockholders to amicably solve the various issues like environment, health and livelihood of community.

Anjukudisai is a small area located on the banks of Coovum river, inhabited by daily wage workers primarily in fish market. The slum was also affected by the December 2004 Tsunami. The Department of Geography, University of Madras, Department of Environmental Sciences, York University, Canada, Corporation of Chennai, Exonora (NGO) and other agencies are the stake holders working in this community particularly for the welfare of the livelihood, water, environment and health. The various programmes were conducted in this study area since December 2004. In the slum the women work as maidservants. The residents have no permanent source of income. Hygiene level is poor and the garbage is dumped in Coovum. The clogging drains bring an unpleasant odour and are a natural habitat for worms, insects and rodents. The toilets are not maintained properly. Some of the issues

pertaining to Anjukudisai are basic hygiene, child labor; the people in Anjukudisai were reluctant, indifferent and arrogant. An unwelcome attitude was there. There was no priority on health and hygiene.

The team members started the community participation with the children. They were actively involved in all the aspects. Similarly a PAR process integrating with the critical issues of the youths was initiated. As a first step we wanted to identify the needs and priorities of the youth. Our PAR work was based on the belief that the youth have the knowledge, vision and capacity to create social transformations. Participatory change in built on relationships, building friendships, trust and showing a sincere interest in the lives and concern of the youth. From the outset, we believed that the direction and pact of the work should come from the grass roots. These people and not, us control decision, plans and actions. We strive to stay out of decision working roles. To get the community participation of the adults, the youth-adult partnership will be established based on the non-hierarchical relationship of caring and respect. Youths will provide impetus, creativity and act as equal partners in making decision. Adults help to extract community resource, facilitating team dynamics and support for community development. To summarize, the efforts of the project team with the community members started giving dividends. The potential leaders identified would take care of the community effectively and efficiently.

The full paper will envisage the concept of ecosystem approach in detail and its impact on Tsunami affected community in the Anjukudisai Slum.

PREDICTING CYCLONE TRACKS IN THE NORTH INDIAN OCEAN: AN ARTIFICIAL NEURAL NETWORK APPROACH

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Predicting cyclone tracks in the Indian Ocean has been a challenging problem. In this paper, we used past 12 hours of observations (2 positions, at 6 hourly intervals and the present position) to predict the position of a cyclone 24 hours in advance in terms of latitude and longitude. For this purpose we adopted an artificial neural network approach using 32 years (1971-2002) of tropical cyclone best track analysis over the Indian Ocean. The mean absolute error between the estimated and actual latitude (longitude) is 0.75 (0.87) degrees with correlation coefficient of 0.98 (0.99) for the prediction data set that was not used for developing the model. The mean error of estimation of the distance between the best track and the predicted positions is 137.5 km. Forecasts for 12, 36, 48, 60 and 72 hours were also attempted.

NUMERICAL SIMULATION OF THE INTENSIFICATION AND MOVEMENT OF TROPICAL CYCLONES OVER BAY OF BENGAL: A CASE STUDY

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Prediction of the intensification and movement of tropical cyclones is important for the planning of disaster mitigation. Numerical models are used to provide quantitative prediction of both the intensification and movement. The numerical predictions are sensitive to model physics and dynamics, which are related to the horizontal and vertical resolution of the model. The parameterization of the physical processes such as convection, energy transfer in the planetary boundary layer and cloud microphysics are hypothesized based on resolution. In this study a review of the tropical cyclone prediction as sensitive to the physical processes and horizontal resolution is made.

A high resolution mesoscale model NCAR MM5 is used to predict the intensity and movement of the Orissa super cyclone, the most intense cyclonic storm experienced over Bay of Bengal, with an estimated minimum central sea level pressure of 912 hPa and associated maximum wind of 140 knots. This storm was first identified as a low-pressure area over southeast Bay of Bengal on 25 October 1999, later intensified as super cyclone at 15 UTC of 28 October. The cyclone had northwest movement with its landfall near Paradip (20.5N, 86E) on the east coast of India around 0500 UTC on 29 October.

In this present study, a set of experiments were conducted to study the effect of the horizontal resolution. For this purpose NCAR MM5 is designed to have a fixed domain covering Bay of Bengal and neighboring region and with the chosen

parameterization schemes of KF2 scheme for convection; MRF scheme for PBL; and Simple Ice scheme for explicit cloud physics processes. Five experiments were performed, with a single domain with varying horizontal resolutions of 90, 60, 30, 20 and 10 km. Two separate experiments were performed with interactive nested two domains of 90 and 30 km resolutions and 3 domains of 90, 30 and 10 km resolutions. All the experiments were performed with the model integrations starting from 00 UTC of 25 October for 120 hours i.e. up to 00 UTC of 30 October 1999. The results from the single domain experiments indicate that the model simulated cyclone has stronger intensification with increasing resolution i.e. resolutions varying from 90 to 10 km. The minimum central surface pressure and maximum surface wind predicted from these experiments vary from 980 hPa and 34 m/sec at the 90 km resolution to 951 hPa and 55m/sec at 10 km resolution. Contrastingly the results from two domains experiment, the predicted minimum CSP (central surface pressure) and maximum surface wind (MSW) are 954 hPa and 55 m/sec, which are stronger than the single domain experiment with 30 km which predicted minimum CSP and MSW as 969 hPa and 44 m/sec. Similarly the predicted cyclone has stronger intensity in the 3-domain experiment as compared to single domain with 10 km resolution.

All the single domain experiments show nearly the same track indicating that horizontal resolution may not have any impact on the track prediction. It is noted that the predicted track agrees with the observations up to 48 hours and then deviates northward and eastwards with increased vector error from 48 to 120 hours. In all the single domain experiments the flow from the boundaries seem to influence the region of cyclone track after 48 hours contributing to a turn towards north and eastwards, with increasing vector errors. Contrastingly the prediction of the track improves in the 2-domain and 3-domain experiment provides the best track nearly agreeing with the observations.

The time variation of the different terms in the vorticity equation is examined to understand the dynamics of intensification and movement. The analysis at 850 hPa level shows that the intensification of the cyclone is dominated by the relative vorticity component of the stretching term and horizontal advection becomes significant after mature stage. From the estimates at 500 hPa level, the movement of the storm is noted to be due to the horizontal advection as well as the relative vorticity component of the stretching term. The change of movement towards north and northeast in the single domain experiment seem to be influenced by sudden change of the tilting term to negative values. These observations indicate that the formation of convection, contributing to increased vertical variation of the vertical velocity is a major factor for the intensification of the tropical cyclone where as the horizontal advection becomes significant only after the storm attains its maturity.

An analysis of the potential vorticity (PV) at 500 hPa is also made in order to study the relationship of PV anomalies with the movement. It is noted that the PV anomalies are positive (negative) towards the forward (rear) half of the storm, there by indicating that the PV anomaly gradient from negative towards positive clearly agrees with the movement of the storm. This result indicates that the distribution of the PV anomalies can be used as a predictor for the tropical cyclone movement.

TSUNAMI TRAVEL TIME ATLAS FOR THE INDIAN OCEAN

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The increasing intensity of economic exploitation of coasts leads to socio-economic consequences arising from the hazardous action of tsunami waves generated from submarine seismic activity and other causes. As of now (November 2006) the only Tsunami Warning System (TWS) that is in existence is for the Pacific Ocean, which began in the late 1940's. Following the recent disastrous tsunami of 26th December 2004 in the Indian Ocean, the nations around the Indian Ocean rim are now working together to establish a tsunami warning system which should become operational in near future. One of the most basic information that an Indian Ocean tsunami-warning center should have at its disposal is information on tsunami travel times to various coastal locations surrounding the Indian Ocean rim, as well to several island locations. Devoid of this information, no ETA's (expected times of arrival) can be included in the real-time tsunami warnings.

The importance of ETA for tsunami warning system motivated in the development of a comprehensive atlas comprising 250 representative coastal locations from 35 countries, showing the feasibility of developing a TWS in a relatively short time-span. Our objective here is an attempt to present a Tsunami Travel time (TTT) atlas (using 250 past energetic events), which is a pre-cursor in developing an information dissemination center in the long

term. It is expected this TTT atlas will serve as a valuable information database to reduce warning time in event of tsunami in the Indian Ocean and promote awareness among the population dwelling in the littoral belts of the south-Asian countries.

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EARLY WARNING SYSTEM CAPABILITIES IN INDIA METEOROLOGICAL DEPARTMENT

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Due to its unique geo-climatic conditions Indian subcontinent experiences a variety of natural hazards around the year. Major types of natural hazards which affect this region are tropical cyclones, floods, droughts, earthquakes, landslides, avalanches etc. Past records show that 60% of Indian landmass is prone to earthquakes of various intensities, 40 million hectares prone to floods, 8% of the total area prone to cyclones and 68% of the area is susceptible to drought. Therefore, it is important to monitor, forecast and provide early warnings about the impending hazards so that effective measures could be undertaken to prevent/minimize loss of life and damages to property due to these disasters.

India Meteorological Department (IMD), the National Meteorological Service provider plays a key role in combating various natural hazards that affect India. It has a well-established and time-tested system to monitor and forecast different high impact weather systems. A good network of meteorological observatories (both surface and upper-air) is operated and maintained by IMD. The conventional observations are supplemented by satellite and radar observations. In addition, the observations from ships and buoys are of immense importance in the analysis and forecasting of tropical cyclones which invariably forms over data sparse tropical oceans. All these

observational data are exchanged nationally and internationally through Global Telecommunication System (GTS) on real time basis.

The present forecasting technique is primarily synoptic, a subjective method, but the forecaster makes use of the guidance available by different numerical models (regional as well as global) in addition to the various products from radars and satellites. The weather forecasts/warnings are communicated to agencies engaged in disaster management, passed on to AIR, TV and print media and put on IMD's website. Cyclone advisories in respect of cyclones which originate over Bay of Bengal and Arabian Sea are even sent to neighbouring countries under World Meteorological Organization (WMO) programme.

The dissemination of weather warnings is a major responsibility which in the present system is restricted to conveyance of the impending adversity to the press for further dissemination in print or electronic form. In addition, authorities in the likely affected Districts and State Capitals as well as the monitoring cell of the Ministry of Home Affairs are directly informed through special messages. In addition there is a dedicated Cyclone Warning Dissemination System with terminals along the coastline where the message is passed on through VSAT in real time. It is the present endeavor to add new communication techniques like mobile SMS and Internet to increase the outreach. The paper further discusses the major initiatives IMD has undertaken to strengthen and upgrade its observational, forecasting and communication system for providing improved support in disaster prevention /mitigation activities.

CYCLONE MONITORING, FORECASTING AND WARNING SYSTEM IN INDIA

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Indian subcontinent is affected by a number of severe weather systems like tropical cyclones, floods, droughts, severe thunderstorms, heavy snowfall, avalanche etc. Monitoring and forecasting such weather hazards are important to minimize the damages to the property and loss of precious lives. India Meteorological Department (IMD), the National Weather Service agency is entrusted with the responsibility of making systematic observations of weather and climate and providing weather forecasts/ warnings to various user agencies. IMD is also mandated with seismological monitoring and earthquake precursor studies.

IMD in its more than 125 years of existence, has many major landmark achievements to its credit in modernizing and upgrading its observational and forecasting capabilities. It has systematically upgraded its observational network and the telecommunication system by inducting / adopting the various technological advances that have taken place both in ground and space based observational techniques and communication systems. IMD has at present, a reasonably good observational network comprising of surface and upper-air observations, and X-band and S-band weather radars. Recently, IMD has installed 5 Doppler Weather Radars (DWRs) along the east coast at Chennai, Shriharikota, Machilipatnam, Kolkata and Visakhapatnam with the major objective of monitoring and tracking tropical cyclones more accurately and thus to provide better support to the disaster management agencies. IMD also plays an active role in the

INSAT programme carried out by Department of Space and has strongly supported and encouraged the BUOY programme being carried out by Department of Ocean Development.

Weather forecasting is a big challenge especially over Indian domain due to various constraints like sparse data, weak dynamic balance and dominance of mesoscale systems. To improve its weather forecasting capabilities, IMD has made use of the advances in numerical weather prediction system and runs a regional analysis and forecasting system covering the southwest monsoon domain. It also operates a sophisticated regional model for predicting the track and intensity of tropical cyclones. IMD is an active partner in various research programmes and field experiments aimed at improving our understanding of different weather systems affecting Indian region. IMD is constantly responding to the new demands in forecasting requirements with due scientific sincerity.

The present paper briefly discusses the monitoring, prediction and warning system in IMD in respect of Tropical cyclones which form over north Indian Ocean and affect India and neighbouring countries. It is well known that amongst many of the natural hazards, tropical cyclones are rated as the most destructive weather hazards. The devastating impacts of tropical cyclones are primarily due to the strong winds, heavy rains and storm surge associated with them. It is therefore important to develop techniques to accurately monitor and predict the strength and movement of a tropical cyclone, so that timely warnings may be issued to the public and various agencies engaged in disaster management. IMD has built up a credible cyclone monitoring, forecasting and warning system over the years. A tropical cyclone formation is detected from its incipient stage and tracked

continuously. Cyclone warning messages are issued to all the concerned government agencies, marine sectors, local population and media through a variety of communication means. The paper discusses in detail the cyclone prediction and warning system alongwith the limitations in the present observational and prediction system. Major initiatives taken up by IMD to improve its forecasting capabilities for monitoring and forecasting tropical cyclones are also discussed in the paper.

PREDICTION OF TRACK AND INTENSITY OF TROPICAL CYCLONES OVER THE BAY OF BENGAL WITH MESOSCALE MODELS

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Tropical cyclones are one of the nature's most violent manifestations and potentially the deadliest meteorological phenomena. The Bay of Bengal tropical cyclone disaster is the costliest and deadliest natural hazard in the Indian sub-continent. It has a significant socio-economic impact on the countries bordering Bay of Bengal, especially India, Bangladesh and Myanmar. So, timely and reasonably accurate prediction of track and intensity of these storms can save loss of lives and damage to properties.

The genesis and movement of the Bay of Bengal tropical cyclones are unique in nature compare to other region of cyclones. The high resolution mesoscale model MM5 is customized over the basin through a large number of numerical experiments with different parameterization schemes in different model horizontal resolutions. The optimal configuration of the model with improved initial condition through vortex initialization and assimilation of satellite data is used to simulate all severe cyclonic storms (eight) over the Bay of Bengal during the period 1995-1999. The simulation results of these storms are illustrated with performance/forecast skill of the model. The intensity of the storms both in terms of central pressure and strength of maximum surface wind is simulated with reasonable good accuracy. The model simulated track of the storms followed the observed

track closely and track forecast errors indicate reasonably good accuracy of the model performance.

In recent years, Weather Research & Forecast (WRF) Modeling System, developed by the Mesoscale and Microscale Meteorology Division of NCAR, USA, is designed to be a flexible, state-of-the-art atmospheric simulation system which is suitable for abroad range of applications. Improved cumulus and boundary layer parameterization schemes and planetary boundary layer physics etc. are the key points to capture the mesoscale features in prediction of the tropical cyclones.

During 26-29 April 2006, a very severe tropical cyclone known as Mala developed over Bay of Bengal and crossed the Arakan coast of Myanmar on 29 April 2006. In the present study, two state-of-the-art mesoscale models MM5 and WRF have been used to evaluate the performances of both the models in the simulation of Bay of Bengal cyclone Mala. The model is initialized at 12 UTC 26 April 2006 with the Global Forecasting System (GFS) analysis and is being integrated up to 96 hrs i.e. up to 12 UTC 30 April 2006. The lateral boundary condition of the model is provided from GFS forecast. A number of important fields' viz. central pressure / pressure drop, winds, rainfall etc. are verified against observations / verification analysis. The vector displacement error in track forecast is also calculated in comparison to the observed track provided by the India Meteorological Department. Both the mesoscale models could simulate most of the features of the cyclone Mala with reasonably good accuracy. The WRF could simulate intensity in terms of pressure drop at the center and maximum wind speed much higher and close to observed values than MM5. The precipitation forecast with WRF system found to be more realistic with respect to observed rainfall derived from TRMM/SMI products (from NASA

website), both in terms of amount and pattern of distribution. However, MM5 failed to reproduce the same. The system moved much faster in MM5 simulation with large vector displacement errors while the WRF could simulate the track of Mala with much greater accuracy. Thus, the WRF model have much better forecast skill in respect of track, intensity and associate rainfall compared to simulate results of the MM5 model.

SIMULATION OF TROPICAL CYCLONE MALA OVER BAY OF BENGAL WITH MESOSCALE MODEL HWRF

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Tropical cyclone is one of the most devastating and deadliest weather phenomenon worldwide. It is a result of organized intense convective activities over warm tropical oceans. In the recent years mesoscale models are extensively used for simulation of genesis, intensification and movement of tropical cyclones.

The National Oceanic and Atmospheric Administration (NOAA) / National Centers for Environmental Prediction (NCEP) Environmental Monitoring Center developed a sophisticated mesoscale model known as Hurricane Weather Research and Forecasting (HWRF). The model utilizes the Nonhydrostatic Mesoscale Model (NMM) dynamic core of the Weather Research and Forecast (WRF) modeling system with rotated-E coordinates for computational efficiency. The WRF-NMM is designed to be a flexible, state-of-the-art atmospheric simulation system which is suitable for abroad range of applications. The model is planned to be operational for hurricane prediction at National Hurricane Center (NHC). The moving structure of inner nest along with the automatic tracking system of tropical cyclones and diagnosis of its intensity and structure enhances the importance of HWRF.

During 26-29 April 2006, a very severe tropical cyclone known as Mala developed over Bay of Bengal and crossed the Arakan coast of Myanmar on

29 April 2006. In the present study, the state-of-the-art mesoscale model HWRF has been used to simulate the tropical cyclone Mala. The model is initialized at 12 UTC 26 April 2006 with the Global Forecasting System (GFS) analysis and is being integrated up to 96 hrs i.e. up to 12 UTC 30 April 2006. The lateral boundary condition of the model is provided from GFS forecast. The horizontal resolution of 20 km for the coarser domain and 6.6 km for the nested domain along with the vertical 23 sigma levels is considered for the present study. The model includes cumulus convection (SAS), planetary boundary layer of NCEP Global forecast system which is well tested by NCEP for WRF-NMM and radiation parameterization (GFDL). A number of important fields' viz. central pressure / pressure drop, winds, rainfall etc. are verified against observations / verification analysis. The vector displacement error in track forecast is also calculated in comparison to the observed track provided by the India Meteorological Department. The model could able to capture most of the features of the cyclone Mala with reasonably good accuracy. The model simulated intensity in terms of central pressure, pressure drop and surface wind strength are higher than the observed values at the peak intense stage of the storm. The movement of the storm 'Mala' is little slower in model simulation than the observation and there is a delay landfall of 12 hrs. The location of landfall of 'Mala' in model simulation shifted towards the north-west compared with the observed landfall location. The results indicate that, model simulation may be improved with improved initial conditions as the initial track error of 65 km is there in the model simulation. The model could able to capture the intensification and dissipation of the storm, though the intensity of the storm is over predicted.

Key words: Tropical cyclone, Mesoscale model, Track, Intensity

TSUNAMI TRAVEL TIME PREDICTION USING NEURAL NETWORKS

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Neural Networks are inspired by biological nervous systems. Composed of elements operating in parallel, the network function is determined primarily by connections (weights) between elements. A neural network can be trained to perform a particular function by adjusting the values of these weights between elements. Commonly neural networks are adjusted or trained so that a particular input leads to a specific target output. The network can be trend based on a comparison of the output and the target until the network output matches the target within a specified error level (supervised learning). For this study, different combination of input was used to trend the network. The trend network can be validated with the data that has not been used for training. If this system performs well with the validation data, the system can be deployed real time to perform the specific job.

Neural networks can be trend to solve problem that are difficult for conventional computers. Neural network have been trend to perform complex functions in diverse fields of application, which include non-linear regression, classification, identification, pattern recognition and control systems. The supervised training methods are commonly used, but other networks can be obtained from unsupervised training techniques, which can be used where there are no input/output pairs as such but only input data. This for instance may be used to identify groups of data.

The present work reports the development of the non-linear technique based on Artificial Neural Network (ANN) for prediction of Tsunami travel time in the Indian Ocean. The expected times of arrival (ETA) computation involve 250 representative coastal stations, encompassing 35 countries. A travel time model is developed using ANN approach. The ANN model uses non-linear regression where a Multi-layer Perceptron (MLP) is used to tackle the non-linearity in the computed ETA. The back-propagation feed forward type network is used for training the system using resilient back-propagation algorithm. The model demonstrates a high degree of correlation, proving robustness in development of real time Tsunami warning system.

PREDICTING CYCLONE TRACKS IN THE NORTH INDIAN OCEAN: AN ARTIFICIAL NEURAL NETWORK APPROACH

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Predicting cyclone tracks in the Indian Ocean has been a challenging problem. In this paper, we used past 12 hours of observations (2 positions, at 6 hourly intervals and the present position) to predict the position of a cyclone 24 hours in advance in terms of latitude and longitude. For this purpose we adopted an artificial neural network approach using 32 years (1971-2002) of tropical cyclone best track analysis over the Indian Ocean. The mean absolute error between the estimated and actual latitude (longitude) is 0.75 (0.87) degrees with correlation coefficient of 0.98 (0.99) for the prediction data set that was not used for developing the model. The mean error of estimation of the distance between the best track and the predicted positions is 137.5 km. Forecasts for 12, 36, 48, 60 and 72 hours were also attempted.

IMPACT OF SEA SURFACE TEMPERATURE IN MODULATING MOVEMENT AND INTENSITY OF TROPICAL CYCLONES

By

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It is well accepted that sea surface temperature (SST) plays dominant role in the formation and intensification of tropical cyclones. A number of observational / empirical studies were conducted at different basins to investigate the influence of SST on intensification of tropical cyclones and in turn, modification in SST by the cyclone itself. Though, a few modeling studies confirmed the sensitivity of model simulation / forecast to SST, it is not well quantified, particularly for the Bay of Bengal cyclones. The present study is designed to quantify the sensitivity of SST on mesoscale simulation of an explosively deepening storm over the Bay of Bengal, i.e., Orissa super cyclone (1999). A number of numerical experiments are conducted to investigate the influence of SST in simulating Orissa super cyclone using mesoscale model MM5. Numerical experiments are carried out with SST provided from climatological SST, NCEP skin temperature, observed SST (satellite derived). It is observed that NCEP skin temperature and observed SST over the Bay of Bengal are 1-2oC warmer than climatological SST but cooler by nearly 1oC along the coastline at model initial state. Observed SST shows a number of warm patches in the Bay of Bengal compared to NCEP skin temperature. The results obtained from experiments indicate that sea surface temperature has significant impact in model simulated intensity and

track of the cyclonic storm. It is noticed that SST has significant influence in modulating intensity of the storm and is more pronounced at the severe intense stage. It is also observed that the storm reaches its peak intensity over the warmest SST region. The results indicate that the intensification and dissipation of the storm is better simulated with observed SST. It is also observed that SST has notable influence in model-simulated track of the storm as well with its tendency to move towards warmer ocean surface.

Keywords: sea surface temperature (SST), tropical cyclone, intensity, track and heat flux

HYDROLOGICAL ASPECTS OF CYCLONIC DISTURBANCES INFLUENCING ORISSA

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Orissa experiences flood very often during monsoon season due to the westward moving cyclonic disturbances over the northern part of the Bay of Bengal as it gets vigorous monsoon condition (actual rainfall more than 4 times of the normal) due to these disturbances. Hence, an attempt is made to find out the interannual variability in the rainfall over Orissa in relation to the frequency of occurrence, intensity and movement of these disturbances from 100 years (1901-2000) data. The basic objective of the study is to find out the contribution of interannual variability in the characteristics of cyclonic disturbances to the extreme events like flood and drought over Orissa.

On an average, 4 cyclonic disturbances influence rainfall over Orissa during monsoon season. The variability of both rainfall and cyclonic disturbances is above normal since 1960s leading to more floods and droughts over Orissa during recent years. Both the seasonal rainfall over Orissa and the frequency of cyclonic disturbances during monsoon season show quasi-biennial oscillation of 2-2.8 years period. There is no significant impact of elNino-southern oscillation (ENSO) on interannual variability of

both the seasonal rainfall over Orissa and the frequencies of cyclonic disturbances affecting Orissa.

The comparison of tracks of cyclonic disturbances during excess and deficient monsoon years over Orissa during 1980-1999 indicates that most of the cyclonic disturbances move westwards across Orissa (preferably north Orissa) during excess years. They mostly move across extreme south Orissa coast or further south or across Gangetic West Bengal/Bangladesh during deficient years.

The adverse impact of significant decrease in cyclonic disturbances since around 1980 could not be compensated by the increase in monsoon lows resulting in significantly less than normal rainfall over Orissa in main monsoon month of July.

EVALUATION OF THE QUASI-LAGRANGIAN MODEL FOR CYCLONE TRACK PREDICTION IN BAY OF BENGAL AND ARABIAN SEA

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Quasi-Lagrangian model (QLM) for cyclone track prediction is the operational limited area model used in India Meteorological Department for providing numerical guidance in cyclone forecasting operations. QLM is specially tailored for providing cyclone track forecasts using the methodology of a synthetic vortex superimposed on gridded fields to correct the location and intensity of the vortex in the initial fields. QLM has a horizontal resolution of 40 km and 16 sigma levels in the vertical. It is integrated in a domain of about 4400x4400 km2 area that is centered on the initial position of the cyclone.

The special feature of the QLM is an idealized vortex, which is generated from the current storm parameters; and a Dipole, which is generated based on the estimated storm speed and direction. Mathur (1991) introduced the concept of superimposing dipole winds on the idealized vortex in westward moving storms to overcome the problem of poleward drift in the model forecast tracks. The synthetic vortex thus obtained is incorporated in the background initial analysis by a merging process. The basic data sets required for running the experiments are obtained from the global T-80 model operationally run at National Centre for Medium Range Weather Forecasting (NCMRWF), New Delhi.

The original version of the model adapted in IMD was providing the cyclone track forecasts upto 36 hours. Subsequently the model in collaboration with SAARC Meteorological Research Centre (SMRC), Dhaka was upgraded to provide track forecasts upto 72 hours. The modified version was further tested for some historical cyclones in the Bay of Bengal and Arabian Sea for the period 2000-2004. In these track prediction experiments it was observed that while the westward moving storms were forecasted well, the superimposition of the dipole winds in the case of northward moving storms introduced a general westward bias in the forecast tracks.

Recently, the QLM code have been modified to receive inputs from a global analysis and forecast system in the grid point form and thus to delink the model from the spectral form of inputs, with which the original version of model was tied up. The modified model was used to test its success using some past historical cases of tropical cyclones which hit the east coast of India and Bangladesh coast. In the present study, a number of experiments have been conducted on northward moving and recurving storms as they constitute a difficult forecast problem. In the present experiments we used the idealized vortex without dipole winds. Track prediction experiments were performed with the basic data sets drawn from the ECMWF Re-analysis (ERA-40), NCEP GDAS & GFS. The use of GFS data is of particular significance in these experiments in view of its potential in the real time forecasting operations. The case of 'MALA' in April 2006, the most recent cyclone in Bay of Bengal was experimented upon with real-time GFS data. Performance evaluation in terms of qualitative comparison of the model simulated and actual tracks on the one hand and quantitative

comparisons with forecast error statistics in various forms indicated that while the forecast errors are reasonable, the direction of movement of the storms, largely northward and recurving northeastward in the cases under study, is well captured by the model. The mean error works out to 153 km for 24 hour forecast, 226 km for 48h forecast and 344 km for 72h forecast. Two facts emerge from these statistics: (a) the mean errors in all the forecast ranges are negative except in the 72 hour range, which indicates a slow bias in the predicted speed of movement; and (ii) the RMSE Angular Deviations are small, being within 20 degrees for all forecast ranges except in the 12 hour range. An early indication about the most likely direction of movement and the most likely part of the coastline to be struck by the storm, 48 to 72 hours in advance, when the storm is located in the southern parts of Bay of Bengal and has the possibility of striking any part of the long coastline from the extreme south of India through Bangladesh to Myanmar, may be considered a good numerical guidance for the forecasters. The results of these experiments are discussed along with recent advancements in the field and IMD's future plans for improving the tropical cyclone prediction system.

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