

Framework for Multi-Weather Hazard Early Warning System in Myanmar

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Abstract

The paper presents a framework for a multi-weather hazard early warning system for application over the Bay of Bengal primarily focusing on Myanmar. The early warning system consists of an observational component based on observations from the Indian Ocean observing System (IndOOS) and a prediction component based on the Regional Environment Simulator (RES). IndOOS consists mainly of an assemblage of Earth observing satellites for key environmental parameters in addition to a complementary in situ observations network. The Regional Environment Simulator (RES) is a coupled system of numerical simulation models for meteorology, physical oceanography, land surface, vegetation, hydrology, coastal dynamics and urban environment. The developed system is supposed to have a major role in predicting, forecasting and issuing of early warnings to reduce the risk in case of extreme weather events in Myanmar.

1. Introduction

Natural disasters have been increasing every year due to various factors such as urbanization, population growth, destruction of natural environment and climate change. Asian region accounts nearly 90 % of the total affected people in the world. This human suffering is happening more in developing countries, especially poverty-stricken countries, catastrophic natural disasters cause enormous amount of economic losses, which sometimes exceed the Gross Domestic

Product (GDP) of these countries. Natural disasters have negative consequences in inhibiting the promotion of sustainable development. Therefore, it is essential to conduct comprehensive disaster measures in Asian region (ADRC, 2002). Countries around the Bay of Bengal (Figure 1) are threatened by severe hazards due to variety of extreme weather events. Extreme weather events include droughts, floods and associated landslides, storms, cyclones, ocean and coastal surges, heat waves and cold snaps. Haggag (2009) showed that the big killer in all of these hazards is the storm surge due to tropical cyclones; the emerging consensus among climate scientists is that the trend toward stronger and more destructive storms appears to be linked to global warming, and specifically to the impact of global warming on higher ocean temperatures, which drives convection energy and moisture into these storms and makes them more powerful. In the Bay of Bengal, even with the present sea-level and weather conditions, the area is prone to some of the most disastrous coastal flooding in the world caused by storm surges associated with tropical cyclones (Murty et al., 1986). A Category one/two cyclone hitting the low-lying, densely populated coasts of the Bay of Bengal countries could still be devastating. The triangular shape of the Bay of Bengal acts to funnel storm surge waters into the coastal areas, and the very shallow bottom of the bay allows the surge to pile up to very high heights (Murty and Neralla, 1992).

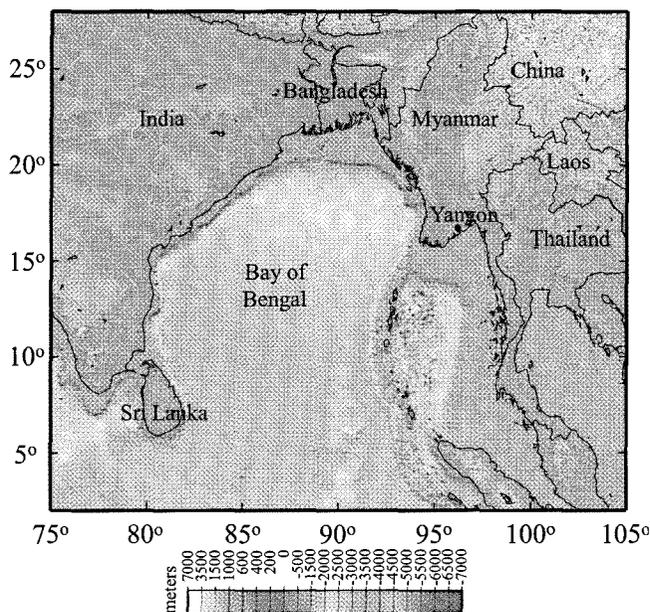


Figure 1: Bathymetry/topography map of the Bay of Bengal surrounding area.

A disaster unfolded in Myanmar in early May 2008, as Cyclone Nargis swept over the Irrawaddy River delta, pummeling the area with high winds, storm surge and heavy rains. The cyclone made landfall in the country on May 2nd in 2008, causing catastrophic destruction and at least 138,000 fatalities with a further 1.5 million people were severely affected by this cyclone (Webster, 2008). Lin et al. (2008) showed that Nargis rapidly intensified from a category-1 storm (The Saffir-Simpson hurricane wind scale) to a category-4 storm just in 24 hours before landfall. The cyclone moved ashore in the Irrawaddy division of Myanmar near peak intensity and after passing near the major city of Yangon, the storm gradually weakened until dissipating near the border of Myanmar and Thailand. The storm made landfall at the mouth of the Irrawaddy River, where the interaction of water and land lying right at sea level allowed the combined effects of waves and surge to deliver maximum penetration of sea water over land.

Fritz (2009) concluded that the high fatalities of Cyclone Nargis were due to lack of implementation of a cyclone education program, development of flood and vulnerability maps, construction of cyclone-safe buildings to serve as shelters and lack of implementation of an improved warning system and evacuation plans in Myanmar. Other neighbor countries to Myanmar have implemented modern monitoring and early warning systems to save their citizens lives from similar natural disasters. The cyclone warning service of India Meteorological Department (IMD) is more than a century old. IMD has developed the infrastructure to originate and disseminate the cyclone warning at appropriate levels. The cyclone warning service in Bangladesh has considerable advances in the last two decades. An evidence can be seen in the relatively low number deaths experienced with recent cyclone Sidr in 2007 (3046 fatalities) compared to cyclone Gorky in 1991 (140,000 fatalities). The relatively low number of death fatalities due to Sidr is considered a consequence of the advances in early warning system and government cyclone preparedness plans (Paul, 2009). Close attention has been paid to the development of early warning system in China over the last four decades. Several executive disaster management agencies have established their specific monitoring and early warning system that considerably used to reduce disaster related damage (Kueppers, 2002). Thailand Meteorological Department (TMD, <http://www.tmd.go.th/en/>) supplies weather forecasts and publicizes disaster warnings for Thailand by using modern technologies in monitoring and forecasting activities. TMD fulfills the requirement from administration and management in natural disasters mitigation by building the people's awareness toward natural disasters; enable them to perform correct surviving practices; and reduce effects from natural disasters.

The objective of this article is to set a framework for a weather hazard early warning system in the Bay of Bengal primarily focusing on Myanmar. The early warning system consists of the recently implemented Indian Ocean Observing System (IndOOS, McPhaden et al., 2009); using both satellite and in situ observation, and the established Regional Environmental Simulator (RES, Haggag, 2009) to provide effective and timely forecasts on weather hazards in the Bay of Bengal. Indian ocean countries supported with the international community are currently implementing a sustained Indian ocean observing system for the study of oceanographic and climatic phenomena in the basin across timescales that range from synoptic weather events to climate change (Meyers and Boscolo, 2006; McPhaden et al., 2009). The RES is a coupled system of numerical simulation models for meteorology, physical oceanography, land surface, vegetation, hydrology, coastal dynamics and urban environment. The RES has been developed to simulate mesoscale water, material transport and energy circulations in continental and coastal areas. RES has proven an adept at dealing with several environmental issues including natural disasters in marine coasts, estuarine as well as in terrestrial ecosystems.

The paper is organized as follows: section 2 briefly describes the history of weather hazard and the current status of warning in Myanmar. Section 3 describes the framework plan for establishing an early warning system in Myanmar. Sections 4 and 5 present the observation and numerical components of the proposed system. The potential applications of the system are discussed in section 6. Finally, section 7 concludes and summarizes the contents of the article.

2. Background of weather hazard in Myanmar

Paul (2009) reported that only 5% of cyclones form in north Indian Ocean, but loss of lives and property is about 85% of the global total. The frequency of tropical cyclones is much higher over the Bay of Bengal when compared with the Arabian Sea. Highest frequency is seen during the pre-southwest monsoon season (March-May) and during the post-southwest monsoon (September-November) seasons (Sadhuram et al., 2004). Figure 2 shows the percentage probability of occurrence of tropical storms in the north Indian Ocean. Ninety percent of the tropical storms occurred before and after the monsoon time while limited number of storms coincides with the monsoon. The source of data in Figure 2 is UNISYS hurricane dataset (<http://weather.unisys.com/hurricane/>) including a total of 187 tropical storms from 1975 to

2009. These storms/monsoon depressions move toward the East Coast of India, a few of them take re-curved and hit Bangladesh and they rarely hit Myanmar coasts.

Willige and Carayannis (2009) explained Myanmar's high vulnerability to natural disasters that results from its unique geographic location and geomorphology. Myanmar borders the Bay of Bengal to the southwest and the Gulf of Martaban and the Andaman Sea along its southern periphery as shown in Figure 1. The country's extensive coastline of about 1,930 km (1,199 mi) and its extensive lowland areas make it particularly vulnerable to all types of marine and terrestrial disasters. Table 1 presents a summary of the twentieth century and most recent natural disasters in Myanmar in the period from 1901 to 2009; the data is based on information from ADRC (2002) and updated with the most recent facts from Cyclone Nargis in 2008. Table 1 shows that tropical storms and floods are the major natural hazard that threatens Myanmar compared to other types of hazards. Tropical cyclone Nargis is blamed for at least 138,000 fatalities, more than 1.5 million of affected people and around 10 billion USD damages. The destruction due to natural hazards, mainly tropical storms, is a serious concern along the coastal regions of Myanmar; in particular, the low lying deltaic regions of Irrawaddy River delta are most vulnerable to hazards. The current situation of weather monitoring and forecast technology in Myanmar is rather outdated, even compared to neighbor countries, and insufficient to provide safe environment for social and economical development in the country. The earlier discussion showed the relevance for rapid implementation of an early warning system for weather hazards using available observation and prediction technologies.

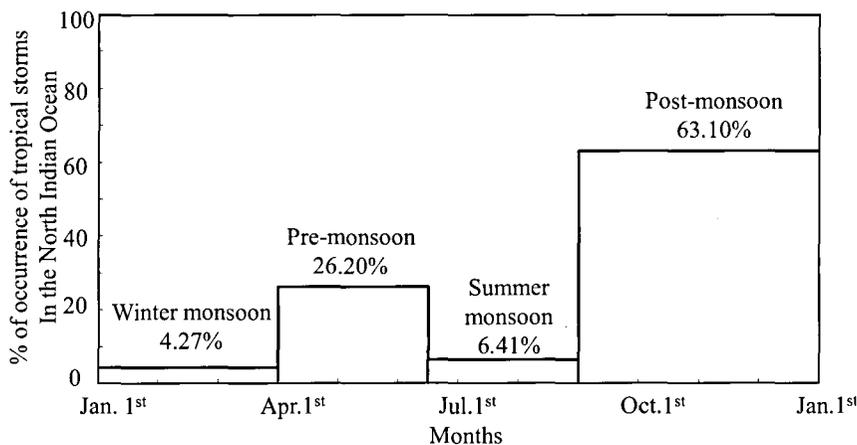


Figure 2: Probability of occurrence of tropical storms in the Bay of Bengal.

Table 1: Summary of natural disasters in Myanmar (1901-2009).

Disaster Type	Count of Disasters No.	Sum of Killed	Sum of Total Affected	Sun of Damage US\$ (x1000)
Tropical Storm	15	145,982	2,570,689	10,000,000
Flood	12	317	2,197,697	553,915
Earthquake	6	1342	136	37,100
Wild fire	2	8	78,588	11,000
Epidemic	2	10	800	-

3. Multi-weather hazards warning system

The severity of the impacts of weather hazards in Myanmar can be affected by the implementation of an early warning system that can effectively participate in minimizing the number of people located in vulnerable regions. The idea is simply based on the principal that human efforts cannot prevent or affect the presence of hazard itself, but human effort can effectively reduce the size of vulnerability to hazards. Figure 3 shows the concept of risk reduction through controlling the size of vulnerability rather than the size of hazard itself. A major challenge that faces scientists is that exposure to such natural hazards is expected to increase in the future due both to growth in population density in low-lying coastal areas and the effects of global climate change which require additional efforts in reducing the size of vulnerability to reach acceptable risk level.

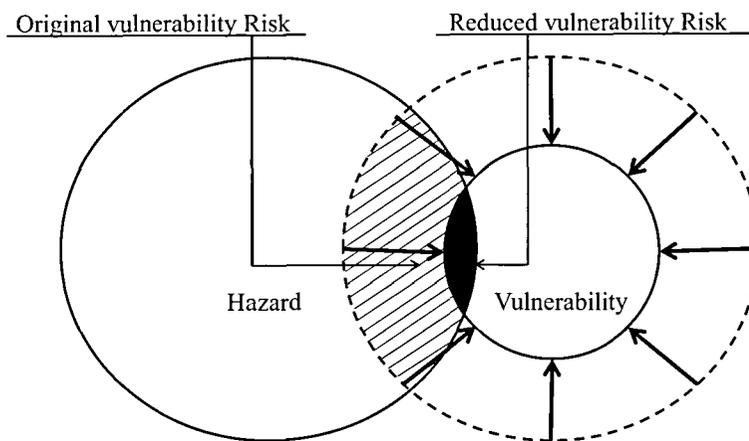


Figure 3: Schematic showing the concept of risk reduction through controlling the size of vulnerability.

The multi-weather hazards warning system is a tool that can participate in reducing the size of vulnerability and hence reducing of risk levels in Myanmar. It aims to use of the established observation infrastructure of the IndOOS, including remote sensing measurements, moored buoys, surface drifters and sea level gauges, along with the established Regional Environment Simulator to provide an effective and timely forecasts on natural hazard in the Bay of Bengal (e.g. storm surges and floods, and high waves) primarily focusing on Myanmar. Figure 4 presents a flowchart diagram for the proposed early warning system. Figure 4 emphasizes the strong complementary relationship between observational and numerical components of the system. Remote sensing measurements are the backbone of the system. Remote sensing is the first mean that provides information of the existence of an extreme weather event in the domain of interest covered by the early warning system. Based on the continuous interpretation of the remote sensing measurements, it can be decided whether to proceed further in the warning process or to issue a normal situation announcement. No doubt that availability of real time or near real time data is vital for the success of the system. In case of having a possibility to extreme situation, the oceanic and meteorological in situ observations in the coverage area are to be collected, processed and analyzed for further use in the system. The remote sensing measurements and the in situ observations datasets will be assimilated in the RES models that will enable the system to better forecast ocean

structure and weather conditions in the coverage area at suitable temporal and spatial resolutions. The spatial resolutions of the different models in RES are planned to cover coasts, shelves, slopes and the shallow water regions surrounding Myanmar. The forecasts include wind speed, storm surge, rainfall, coastal and near-shore currents, wave spectrum and rivers discharges. Based on the forecasts, hazard maps can be prepared to determine the regions vulnerable to direct weather hazard or weather related hazards (wind hazard map, storm surge hazard map and flood hazard map). Real-time data delivery constitutes an important, if not crucial aspect of the early warning system. Optimal use of this information is only ensured if all data are available at all times as they provide the basis for determining the existence of extreme weather event and enable the assimilation of real world data in the numerical models.

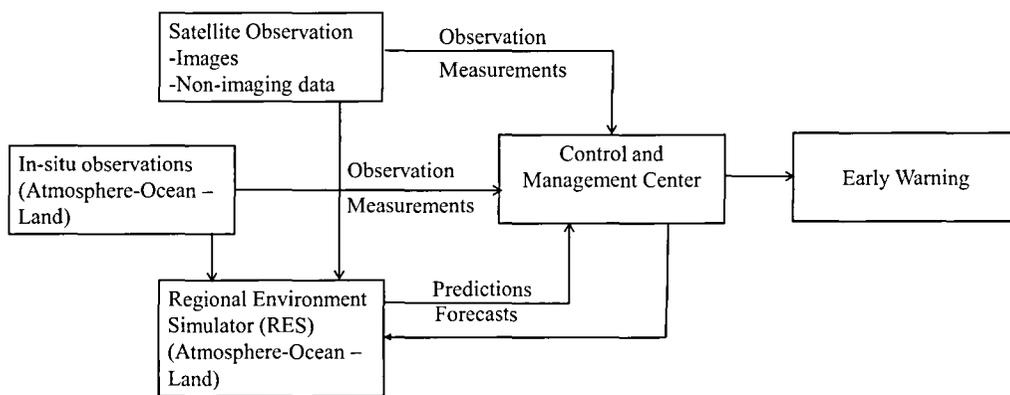


Figure 4: Schematic diagram of the multi-weather hazard early warning system.

Another two factors that determine the effectiveness of the early warning system are related to the level of rescue infrastructure that is not in the scope of the discussion in this article. The first of the two factors is the availability of communication methods by which the early warning can reach to the people in vulnerable regions in a timely manner. This depends on the level of the communication technology in Myanmar. The second factor is the availability of safe shelters that are easily accessed by people in vulnerable regions.

4. Indian Ocean Observing System (IndOOS)

The Indian Ocean Panel (IOP) was established in 2004 to design and guide the implementation of a sustained Indian Ocean observing system for forecast of oceanographic and climatic conditions in the basin (Meyers and Boscolo, 2006). Indian ocean countries supported with the international community is currently implementing a sustained Indian ocean observing system (IndOOS) for the study of oceanographic and climatic phenomena in the basin across timescales that range from synoptic weather events to climate change (Meyers and Boscolo, 2006; McPhaden et al., 2009). The IndOOS consists mainly of an assemblage of Earth observing satellite for key environmental variables such as sea level height and its anomalies, sea surface temperature (SST), ocean surface wind in addition to an in situ observation networks including the Argo global float array, the Research Moored Array for African-Asian-Australian Monsoon Analysis and Prediction (RAMA, McPhaden et al., 2009), surface drifters, tidal gauges, and biogeochemical observations. Satellite observations of oceanic surface properties provide the framework for the observing system.

The in situ observations are complementary and provide subsurface data that complement and enhance interpretation of satellite data. Most of the oceanic phenomenology cannot be resolved without satellite data; likewise, in situ observations are used to maintain calibration of satellite data.

The scientific drivers for implementing the IndOOS are improved description, understanding, modeling and ability to predict: seasonal and intraseasonal monsoon variability, Indian Ocean zonal dipole mode, decadal variation and warming trends in the upper Indian Ocean, southern Indian Ocean and climate variability, oceanic circulation and heat budget and biogeochemical cycling (McPhaden et al., 2009). In addition to the oceanographic measurements from IndOOS, the meteorological measurements particularly at moorings will be extremely valuable to data assimilation issues concerned with weather forecasting and reanalysis providing accurate initial conditions determination for the RES.

4.1. Satellite observations

Satellite remote sensing is the main pillar of the IndOOS. Remote sensing provides horizontal distribution maps of the surface variables, such as sea surface temperature, sea surface height, and ocean color, as well as several meteorological parameters such as surface wind, precipitation, heat and fresh water fluxes. Until recent days, our understanding to the phenomenology in the Indian Ocean was limited to satellite observations due to scarcity in the in situ observations in the basin. One of the ways remote sensing can be used in studying the ocean is by depicting sea surface height anomalies (SSHA). $SSHA = \text{observed SSH} - \text{Average SSH as observed by altimetry satellite}$. The SSH is directly related to the ocean upper layer depth of warm water, which is a key ingredient in tropical storms strengthening. The higher the SSHA the warmer the layer of water; thus, if the SSHA is high, one can estimate that the potential exists for a tropical system to further develop. There are four altimetry satellites currently in service: Jason-1 and Jason-2 with a relatively short repeat cycle (10 days), able to observe the same spot on the ocean frequently but with relatively widely-spaced ground tracks (315 kilometers at the equator), Envisat with a longer repeat cycle (35 days) but tighter ground track spacing (90 kilometers at the equator) and ERS-2 on the same track of Envisat but with a small time-lag.

NASA's QuikScat satellite and its SeaWinds scatterometer launched in June 1999, QuikScat data help scientists detect tropical storms, understand their wind fields, estimate their intensity and track their movement. These data fill a large void in surface wind information over the open ocean basins. QuikScat has been used at several hurricane prediction centers for estimation of TC intensity and the radius of certain wind speeds. SST information is crucial in studying tropical systems. Warm water is essential for further storm development. In order for a tropical storm to develop, the water must be 26°C or warmer (Chaston, 96). Warmer water means warmer air above it which means higher dew points, consequently giving the tropical storm more energy to be released in the heat of condensation during cloud and precipitation development.

4.2. In situ observations

The in situ observation component of IndOOS is based on established technologies available for large scale ocean monitoring. The experience gained in monitoring activities in the Pacific Ocean (TAO/TRITON, McPhaden et al., 2001) and the Atlantic Ocean (PITRA, Bourles et al., 2008) provided the platform for the IndOOS planning, implementation and operation. The in situ observation instruments consists of mooring (for subsurface temperature, salinity, currents and surface weather variables), Argo floats (for subsurface temperature and salinity), expendable bathythermograph lines XBT lines for upper ocean temperature observations), surface drifters (for sea surface temperatures and sea surface currents) and sea level stations as shown in Figure 5.

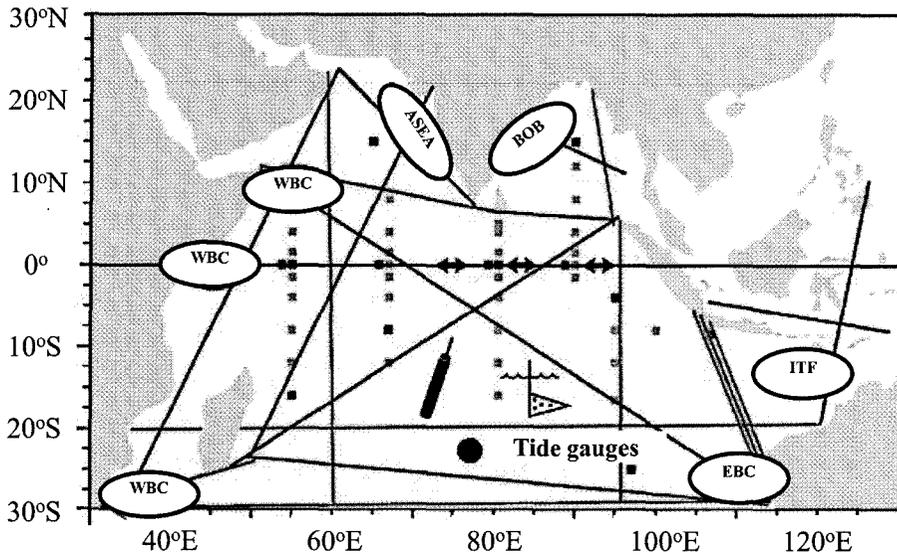


Figure 5: The in situ components of the IndoOS, with moored buoys network, Argo floats, XBT lines, surface drifters and sea level gauges.

Source: Meyers and Boscolo 2006

The main element of IndoOS in situ instruments is the basin-scale moored buoys array known as the Research Moored Array for African-Asian-Australian Monsoon Analysis and Prediction (RAMA, McPhaden et al., 2009). The array provides well resolved data on the interannual variations, particularly with regard to mixed-layer dynamics focusing on the top 500 m of the ocean where most of the interactions between the ocean and atmosphere take place. The array is made up of a total of 46 moorings for measurement of temperature, salinity, currents, basic weather variables and surface fluxes. The moorings are divided into 38 surface mooring and 8 subsurface moorings. Five of the eight subsurface moorings are Acoustic Doppler Current Profilers for equatorial and coastal boundary currents located along the equator and in the upwelling zone off the coast of Java. The array is designed to resolve the most energetic variations in the ocean and interactions with the atmosphere. The current profilers are located where geostrophy cannot be used to estimate currents. The flux moorings provide data to calibrate flux estimates from satellite data; and they are located in regions where flux climatology is poorly known. According to McPhaden et al., (2009), so far 47% of the array is completed with 22 of the 46 moorings deployed. It is expected that by the end of the year 2012, the array could be fully implemented. The array data are sent to shore via the Argos satellite system. The data are post-processed and pasted online (http://www.pmel.noaa.gov/tao/data_deliv/deliv-nojava-rama.html) for public distribution based on the principle of free, open, and timely access to all types of data.

The Argo network in the Indian Ocean is a part of the global Argo network to measure temperature and salinity profiles to a depth of ~2000 m. The design of the Argo network is based on experience from the present observing system, on recent knowledge of variability from the TOPEX/Poseidon altimeter, and on the requirements for climate and high-resolution ocean models. A 450 Argo floats are to be distributed over the Indian Ocean at average 3-degree spacing. Floats will cycle to 2000 m depth every 10 days, with 4-5 year lifetimes for an individual instrument. The Argo profiles are essential for research on the role of ocean circulation in climate variability and change, from interannual

to multidecadal time-scales. Combined with satellite altimetry the data are essential for generating the products of operational oceanography. All Argo data are publically available in near real-time via the Global Data Assembly Centers (GDACs) in Brest, France and Monterey, California after an automated quality control (QC), and in scientific quality controlled form, delayed mode data, via the GDACs within six months of collection.

Surface drifters, sea level gauges, XBT lines and biogeochemical observations are other major elements of the IndOOS in situ observations plan. Surface drifters typically provide measurements of sea surface temperature, surface velocity and other parameters. Drifting buoy data include the buoy position, date, time and in many cases include other variables such as surface and subsurface water temperature, air pressure, air temperature, wind speed and wind direction. The International Buoy program for the Indian Ocean (IBPIO) planned to cover the Indian Ocean with 160 drifters following the standard coverage density of one drifter in average in 5-degree spacing. The current number of surface drifters in the Indian Ocean is about 60 north of 40°S (Meyers and Boscolo, 2006). Maintaining a sustained record for sea level in the Indian Ocean is essential requirement for climate observing efforts as well as tsunami warning efforts. As the installation phase of the sea level stations comes to end (UNESCO, 2006), the major challenge is sustained operation and continuous upgrading of the network to ensure real time data transmission to tsunami and climate warning system. Real-time and delayed sea level data from the Indian Ocean is available from the University of Hawaii Sea Level Center (UHSLC, <http://ilikai.soest.hawaii.edu/uhsdc/data.html>). The design of biogeochemical observations is still at an earlier stage compared to other observation in IndOOS. However, in the near future the biogeochemical measurements need to be implemented to study the uptake and storage of CO₂ and the biogeochemical responses to variation in environmental conditions.

5. The Regional Environment Simulator (RES)

RES is a coupled model system developed and maintained by the Earth Environment Simulator Laboratory at the Graduate School for International Development and Cooperation, Hiroshima University (Haggag, 2009; Lee, 2007; Kim, 2005). RES is used to simulate water, material transport and energy circulations in continental and coastal areas with a horizontal scale that ranges from regional to mesoscale. RES is applicable for the studies of natural disasters in coastal and estuarine areas such as tropical cyclones, storm surges, high waves, floods inundation, heavy rainfall, etc. The coupled model system, as shown in Figure 6, consists of the atmosphere, land-surface, hydrology, ocean-wave, and ocean-current models. The model used in RES to represent the atmospheric circulation is the Pennsylvania State University and National Center for Atmospheric Research Fifth Generation Mesoscale Model (PSU/NCAR-MM5; Grell et al., 1996). The land surface is represented by the detailed multi-layer land surface model (SOLVEG; Nagai, 2002, 2003, and 2005). Basins hydrology and water quality is represented by Hydrological Simulation Program-FORTRAN (HSPF) (Bicknell et al., 1997). The ocean waves are represented by the third-generation ocean wind-wave model of NOAA, WAVEWATCH III (WW3; Tolman, 2002) and Simulating Waves Nearshore (SWAN), and the ocean currents are represented by the Princeton Ocean Model (POM; Mellor, 2004). Additional models that can extend the RES application field include estuary circulation model, coastal models, dynamic vegetation model, and urban air quality model.

In this coupled model system, calculations of the models are carried out as independent parallel processes and a model coupling program (model coupler) controls these processes and data exchanges among models using Message Passing Interface (MPI). This coupling method is very convenient for the construction of this kind of complicated coupled model. The modifications of models are easy, simply adding some modules for data exchanges to each model code without changing each model's original structure. RES has proven an adept at dealing with several environmental issues including natural disasters in marine coasts, estuarine as well as in terrestrial ecosystems. The atmosphere land

surface interactions within RES have been proved to play a significant role in enhancing heavy rainfall intensities over land. The RES showed a great improvement in reproducing the observed heavy rainfall over Kyushu Island in July 2006 compared to the original parameterization in MM5 model. The Japan Meteorological Agency's wind profiler network data has been assimilated into the meteorological model of RES to improve the rainfall simulation in the atmosphere land surface hydrology coupled model. RES has been proved a capability in the assessment of surface meteorological stations and filling the gap of observations-limited areas through its application in the simulation of tropical cyclone Gonu that hits Oman in 2007. The wind-wave-current interactions in the RES have been applied to the simulation of cyclone Nargis that had a landfall in the Irrawaddy delta of Myanmar in 2008. An additional whitecapping wave breaking stress was introduced to consider the energy transfer from wind to current through wave breaking.

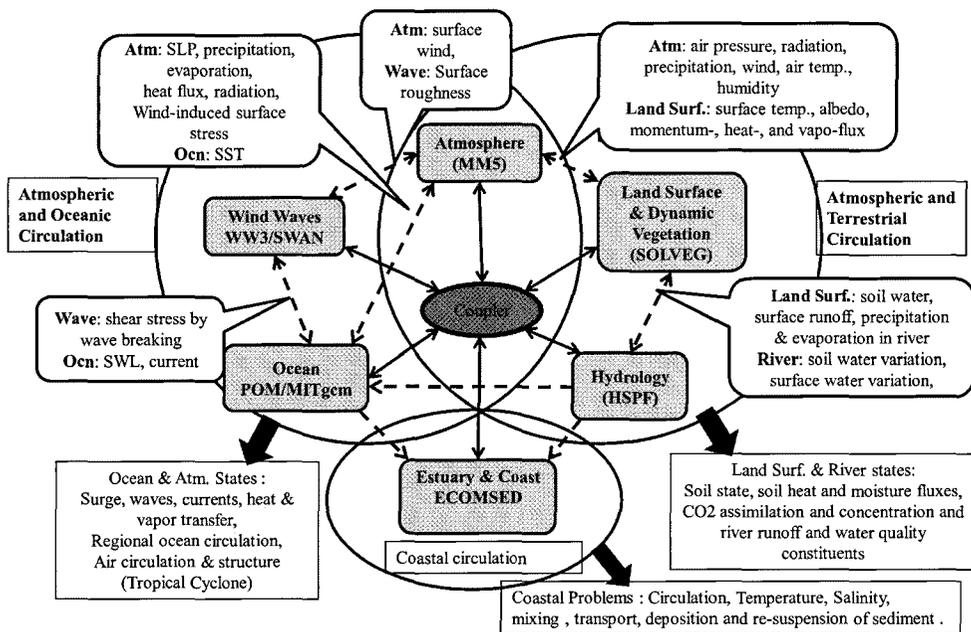


Figure 6: Data exchanges and interactions among coupled models. The data exchanges are performed via MPI controlled by the model coupler.

6. Applications and expectations

The targeted application of the developed system is mainly to provide early warnings for extreme weather events threatening Myanmar. Meanwhile, the system can be a basis for an operational forecasting system for weather, ocean and river that can provide daily forecasts, or even shorter times, covering all of Myanmar. This is to be done through the assimilation of the in situ observations and validated remote sensing data in the ocean and atmosphere models of the RES for better representation of ocean and atmosphere structure in the North Indian Ocean (present and future state of ocean).

The assimilation of QSCAT data in the MM5 model will improve the model initial fields, mainly in cases of

tropical cyclones in which the QSCAT provides data nearer to the actual positions compared to background reanalysis data. In addition to QSCAT, the in situ meteorological observations (particularly at moored buoys) will be very precious to data assimilation issues concerned with weather forecasting. Incorporation of SST from remotely sensed satellite microwave measurements, like TRMM's TMI, in atmospheric modeling is expected to show advances in weather forecasting, especially in tropical cyclone position, track and intensification. The performance of ocean circulation model in the northern Indian Ocean is to be improved via incorporation of in situ temperature/salinity profiles measurements for initial and boundary conditions. Remotely sensed sea surface height can be used to enhance surface height variability by providing better initial conditions for water level.

The forecasting system over Myanmar includes totally three domains, geographical locations of the domains are presented in Figure 7. The center of the coarse domain (Domain 1) is located at 17.5°N, 90°E. The Lambert Conical Conformal (LCC) map projection is used in the model coordinates. The total area of Domain 1 is about 16×10^6 km² with a grid spacing is 18 km. The second-nesting domain (Domain 2) covers almost all of the eastern part of the Bay of Bengal with a grid size of 6 km. The third nesting-domain (Domains 3) is selected such that it covers the area of Myanmar. In normal weather conditions the system is used to make forecast of waves, sea level, rainfall intensity and river discharge over Myanmar. The system is to be executed on a daily basis with lead time for forecast of 3 days. In case of extreme weather events (cyclones), the system is to be used to make forecast of cyclone position, track and intensity over the region, waves, storm surge, rainfall intensity and river discharge in addition to other meteorological parameters obtained during normal conditions. Due to the high temporal variability of weather condition, the system is to be executed 6 hours for coming 72 hours (lead time: about 3 days).

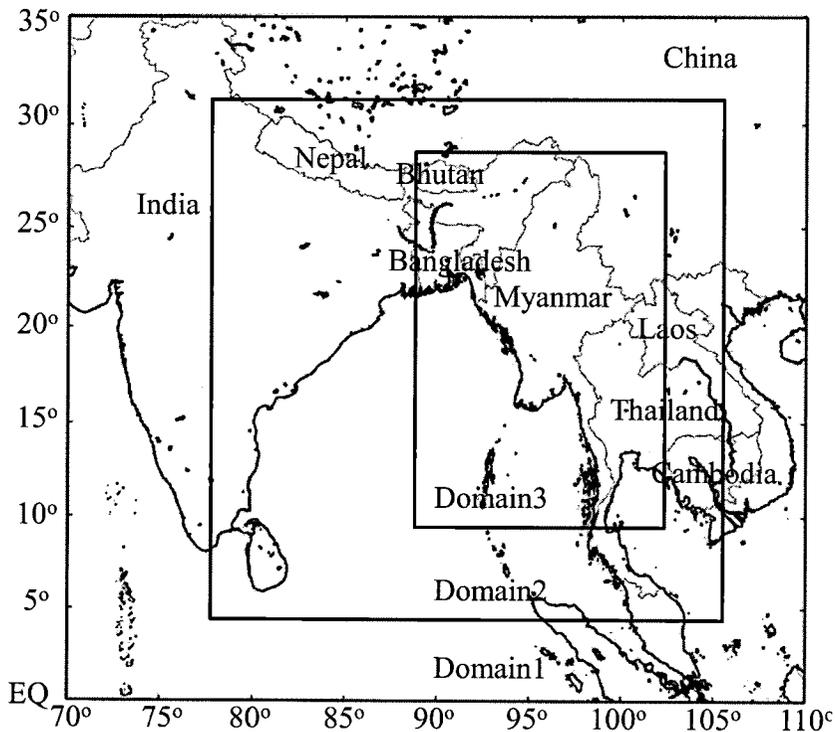


Figure 7: Area covered by the early warning system with three nested domains.

8. Conclusions

However the number of natural disasters in Myanmar is relatively low compared to other countries in the Bay of Bengal, the geographical and topographical conditions in Myanmar make people living in the low laying coastal areas of Myanmar subjected to major threats because of extreme weather hazard. The political and economical conditions that faced Myanmar in the last five decades lead to a delay in the degree of development in different fields compared to neighbor counties (e.g. India, Thailand). Meteorological, ocean, and hydrological sciences are among the practical science fields in which Myanmar needs to take quick steps for the sake of saving their people lives from expected increased future hazards consequences.

This article presented a basic framework for an early warning system over Myanmar that is based on using the monitoring network of the recently implemented Indian Ocean Observing System (IndOOS), including in situ and remote sensing measurements, and the Regional Environment Simulator group of models that is recently developed in Hiroshima University. IndOOS is a sustained on-going ocean observing system in the Indian Ocean developed to compensate the data scarcity in the basin and to advance the scientific understanding of the ocean and atmosphere phenomenology in the basin. IndOOS consists of a constellation of satellite measurements for sea surface height, ocean wind and sea surface temperature, and in situ network of oceanographic-meteorological observations. The RES is a coupled modeling system for atmosphere, ocean, land surface and hydrology that can be employed in weather forecasting and prediction. This article has set the framework guidelines for the complementary usage of IndOOS and RES to obtain an environmental perdition tool to fill the gap of inexistence of weather perdition and warning system in Myanmar.

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