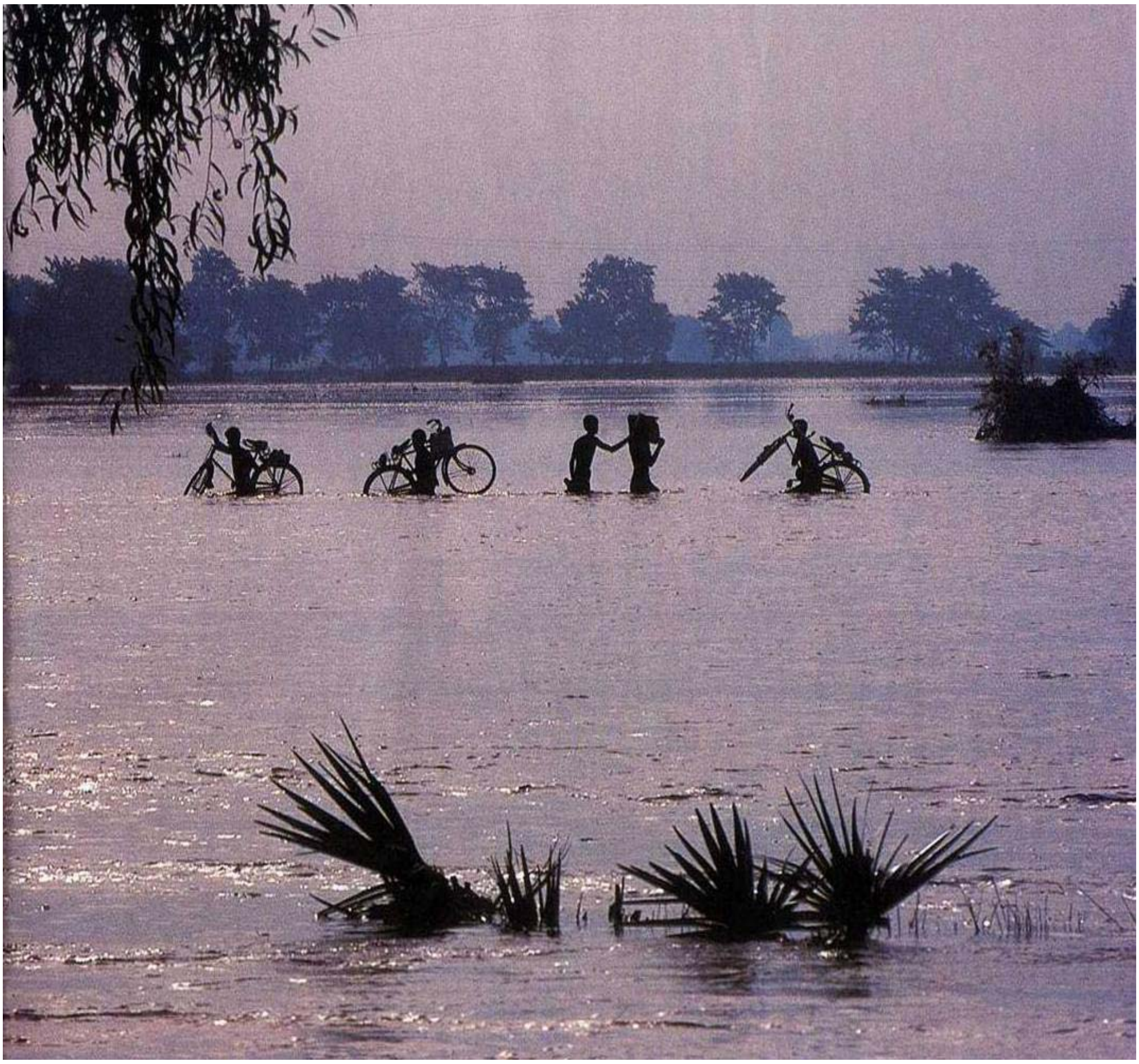

MILAC

Marine Impacts on Lowlands Agriculture and Coastal Resources.

A Contribution to Natural Disaster Reduction by WMO Regional Associations, Tropical Cyclone Programme, Technical Commissions, and IOC GOOS Regional Alliances.

Part I: Proposed actions.
Part II: The rationale.

Photo: Swapan Nayak.

Part I: Proposed actions.
Marine Impacts on Lowland Agriculture and Coastal Resources. (MILAC)

MILAC Chained Pilot Projects.

Introduction.

MILAC aims to contribute to Natural Disaster Reduction (NDR) in coastal lowlands where marine impacts from Tropical Cyclones cause severe damage to population, agriculture, freshwater, environment, and infrastructure in general. MILAC therefore calls for the participation of a number of organizations leading to increased synergy from having them work together.

A MILAC strategic document has been endorsed by EC-LIV and subsequently submitted to Cg-XIV. As well, an excerpt on this issue is attached to this document stemming from the 2003 meeting of Presidents of WMO Technical Commissions. The present document provides a strategic, action-oriented approach comprising the following consecutive steps:

- identification of the socio-economic problems (connected with tropical cyclones);
- establishment of a comprehensive solution to mitigate problems within a NDR framework;
- development of new and revision of existing policies;
- provision of tools (i.e. observations and numerical models) for the solution;
- testing and implementation of tools;
- integration of tools and policies within an overarching (regional) system for natural disaster mitigation.

Summary.

It is foreseen that this approach be undertaken at the regional level, with the intent that regional pilot projects be linked. This “chain of projects”, separated by regions, would become a vehicle for exchange of experience and knowledge on tools and data for the purpose of NDR. Regions will prioritize problems specific to their needs, so problems and solutions are expected to differ, but some elements being common.

Each region will undertake a problem identification that may include the following elements;

- Tropical cyclones climatology including extremes in the region;
- Regional demographics and infrastructure;
- Significance and sensitivity of agro- and aqua-culture;
- Significance and sensitivity of water supplies;
- Miscellaneous and mixed cause impacts
- Identification of hazardous areas.

A typical result from such a study could be an increased understanding of the risk associated with storm surge hazard in a region. The risk assessment may point to the need to revise current approaches to managing use of hazard-prone lands, managing water resources, and planning of agriculture. Another typical conclusion may be to seek the establishment and preparedness of emergency evacuation mechanisms for populations at risk and agricultural livestock, equipment, and materials.

Actors.

Although each regional MILAC project should have its autonomous management, there are supporting actors who will facilitate cross-regional exchange of approaches, concepts, tools, and resources. In fact one could figure two classes of actors; one being the internal regional experts, the other being those who can facilitate inter-regional transfers of knowledge and resources.

Within each region and each project one will typically find :

- TCP RSMC's providing meteorological forcing data;
- GOOS Regional Associations, in particular those covering the tropics;
- WMO Regional Associations (6, with 4 in the tropics);
- CAgM regional experts, OPAG 3 on Climate Change and Natural Disasters in Agriculture;
- CHy experts;
- JCOMM regional experts;
- Other WMO Technical Commissions;
- NDR organizations and regional politicians.

Between each project/region, facilitation of transfer mechanisms would be driven by;

- WMO Secretariat and GOOS Project Office;
- JCOMM/GOOS CB and Services;
- I-GOOS & GRA Federation.
- CAgM and CHy.
- NDR global bodies.

Actions.

A brief outline of actions is given, for each step followed by an illustrating example as perceived for a South China Sea (SCS) country (*in cursive*).

1. **Establishment of regional inter-organizational fora with the task to define the problem to be approached.**
   Such a forum would consist of;
   - the proper regional NDR body;
   - the most relevant GRA;
   - the most relevant WMO RA(s);
   - others as appropriate.
   SCS example: *The actual NDR body would be a national committee for NDR, the GRA would be the upcoming SEAGOOS. The WMO RA would be RA V.*

2. **With participation of TCP, JCOMM and others to "define the problem".** In one region it may be found most appropriate to prioritize population safety due to flooding, demographics and infrastructure. In another area it may be found more important to secure freshwater resources exposed to marine impacts from storm surges. Different objectives will lead to different strategies, however there remains a large potential for synergy.
   SCS example: *There would be a meeting in one of the capitals of the region, conducted by the regional NDR body, SEAGOOS, TCP and JCOMM, attended by national GRA and JCOMM representatives and the forum defined above. Possible*

outcomes may be to prioritize activities of high importance, such as population evacuation, structural protective measures such as dredging and dikes, and protection of freshwater reservoirs and sewage treatment plants. Another possibility could be that solutions in one region would not be realistic in another. Priorities could include the development and implementation of policies on acceptable land use practices in hazard prone areas, or providing improved services to reduce losses to the agricultural community. This underlines the importance of the involvement of the regional/national NDR bodies in the planning process.

3. **Establishment of a solution strategy to mitigate the problems.**

   If the problem is inaccurate early warnings or warnings that do not provide sufficient lead time to permit the evacuation of large populations , then the strategy would be to seek better 1 – 5 days forecasting tools and deliver mechanisms for forecast products in accordance with NDR requirements. If the problem is escalating losses for events of similar magnitude occurring over several years, then more comprehensive solutions that include forecasting with other non-structural and structural solutions could be considered. If the problem is the need for better management and planning of freshwater resources and agriculture, then the strategy will be to combine hindcasts with medium long term forcasts.

   SCS example: *Storm surge and wave models would be sought for the purpose of short-medium term forecasting. A monitoring network could be defined to support forecasting.*

4. **Developments of tools to implement the strategy.**

   Numerical models for storm surges and coastal waves are fed by atmospheric forcing input from numerical weather prediction models operated at all RMSC's. This means that ALL areas doing MILAC projects need to have access to atmospheric forcing data, and they may ALL need to have wave, storm surge, and hydrological models. These models can be run in hindcast or forecast mode depending on the problem that is to be solved. The need for enhanced modelling capabilities calls for;
   - further improvement of model suites through inter-regional comparison of results;
   - adding specific models for mitigation purposes associated with agricultural and water resource management practices;
   - inverse modelling aiming at defining the optimal ocean observing network in support of improving model performance; and
   - the development of cost/benefit assessments 'before or after' incidences;

   While the basic tools (observations, data management, models to predict or hindcast) are important, they are still un complete in relation to most purposes. The 'error bars' are likely to be large, and their characteristics (e.g., accuracy) need to be provided to and better understood by NDR bodies, who are taking actions and decisions based on these inputs.
   SCS example: *Models would be installed and tested, and an inter-regional group would start working on improvements. An ocean monitoring network could follow, consisting of either in-situ or remotely sensed observations.*

5. **Testing and implementation of tools.**
   Observation/monitoring networks must be operated in a responsible manner with high regard to Quality Assurance. Numerical models must be tested and their accuracy established. Ensemble techniques are applied to give the best estimates of error bars.
   SCS example: *Experiments and early warning systems could be arranged. There should be agreements on regional shares of responsibilities.*

6. **Integration of tools in an overarching system for NDR.**
   If a regional NDR official body is present, it must be negotiated with them how to introduce the MILAC tools output into their procedures in a situation of disaster. This relates to delivery mode, updating according to proximity of the TC etc.
   SCS example: *NDR organizations of the region should be aware of the activities at an early stage and be prepared to include the setup in their infrastructure.*

7. **Inter-linkage of MILAC regional projects.**
8.

   Overarching bodies such as the International Secretariat for Natural Disaster Reduction, the GRA Federation, JCOMM and TCP, will facilitate the exchange of plans, knowledge and experience gained through meetings, reports and web sites.

Actors and their roles

The following table indicates successive steps to be taken in MILAC projects, and indications of actors and roles. Not all perceived partners have confirmed their interest.

MILAC	WMO TC's	WMO RA's	IOC/GOOS bodies	Others
General concept and Promotion	CAgM, CHy, JCOMM , the Tropical Cyclone Programme.	I, II, III, IV, V	GOOS Africa, IOGOOS and "SEAGOOS" GOOS Carribb.	NDR contacts
MILAC steps:				
1. Regional fora		***TBD***	TBD	TBD
2. Problem definition	Compilation of advice inputs	Focal advisers	Focal advisers	TBD
3. Solution strategy	Recommended by TC's	Advising	Joint advice	
4. Tools and links developmts. Including CB.	By TC expertise	Observing	Supporting expertise	
5. Preimple-mentation/testing	By TC expertise	**Observing/accepting**	Supporting expertise	NDR observation

6. Mitigation sys-tem, sustained and integrated	Liaising with partners and operators	Partners	Partners	Local comm.-unities and NDR
7. Overarching linkage	TCP, JCOMM and future GRA network			WMO IOC/GOOS
MILAC support:				
1. Funding	Promotion via WMO Secr. (TBD.)	Seeking regional sources	Seeking regional sources	NDR sources
2. Awareness	Submission to Congress and joint TC/RA meetings?	Internal meetings	Internal meetings	With IOI and local comm-unities.

Table 1.

Target areas/regions.

The table below shows perceived areas of interest to MILAC projects, with indications of actors and status of initiatives already taken. WMO RA's are existing intergovernmental bodies. GOOS RA's have either recently been given formal status, or are under development leading to a formal status. A possible GOOS RA Network Development may help to consolidate the chain of GOOS RA's.

Area	Project name or acronym	GRA's and RA's, RSMC's involved	Perceived focal body or nation	Perceived priority problem	Status of development
South China Sea	TBD	SEAGOOS RA V RSMC X	Thailand	Waves/surge Forecast in TC	SeaCamp programme Ongoing training
Indian Ocean	TBD	IOGOSS, RA II RSMC X	India	Erosion and flooding fc Biodiversity	Pending
Western IO	WIOMAP	RA I RSMC X	Kenya	Ocean fc	Full proposal In submission
West African	TBD	GOOS Africa RA I RSMC X	Nigeria	Storm surge fc	Draft proposal via JCOMM CB
Carribbean	TBD	GOOS Carr RA III and IV RSMC X	???	Storm surge fc with TC's	???
Others i. e. NE Pacific		RSMC ?			

Table 2.

Funding strategy.

Some initial actions should be derived from synergy. When items and their costs are outlined within a comprehensive plan, items must be covered primarily by external sources and should not be dependent on the regular budgets of IOC and WMO.

Coordination Mechanism

A facilitating mechanism could be the newly established Resourcing Team under JCOMM CB.

List of acronyms (in order of appearance).

(If not explained in the text).
EC-LIV : WMO Executive Council 53 (year 2002)-
Cg – XIV : WMO 14th Congress (2003).
TCP : Tropical Cyclone Programme.
TCP RSMC : Regional Center for monitoring and forecasting of Tropical Cyclones.
CAgM : WMO Commission for Agricultural Meteorology.
OPAG: Open Programme Area Group.
CHy: WMO Commission of Hydrology.
SEAGOOS: South East Asia GOOS.
RA: WMO Regional Associations (6 in total).
GRA: GOOS Regional Alliances (In similarity to WMO RA’s)
IOGOOS: Indian Ocean GOOS.

Attachment:

Excerpt from the Joint meeting of President of WMO Technical Commissions, February 2003.

4.5 The meeting discussed the proposal for a cross-commission project "Marine Influences and Impacts on Lowland Agricultural and Coastal Resources" presented by Mr J. Guddal, co-president of JCOMM. It noted that CAgM and CHy as well as some Regional Associations and Regional GOOS Alliances have already been involved in preparation of this proposal. **Mr Guddal also, in the same context, emphasized the potential, implicit roles of the Tropical Cyclone Programme.B** The meeting recalled that in accordance with the decision made at 2002 PTC meeting the draft project proposal "Natural Disaster Reduction in Coastal Lowlands" had been submitted to EC-LIV and approved by the Council as a draft project proposal (Annex II to paragraph 2.3.12, EC-LIV). It agreed that **the** new initiative should be considered as further development of approved project proposals, in particular with respect of impact on lowland resources and should be treated as a demonstration project.

4.6 The meeting recognized that all commissions could be involved in these activities. In the discussion the president of CHy pointed out that the contribution of CHy to the new project could be through already existing projects on flood management. He mentioned also that at regional level some projects concerning flash flood forecasting were being implemented in Central America and Mozambique. The President of CAS suggested as the main possible contribution of CAS to the project the development of forecast systems for severe weather events. The President of CCl referred to the role that the Regional Climate Centres could play in providing products for use in regional forecast applications. The Vice-president of CIMO stressed the need to ensure reliable telecommunications links and appropriate observation systems in order to assure the availability of essential information. The President of CAeM mentioned that a possible contribution of CAeM could consist of AMDAR and other aircraft data used in better identifying and forecasting severe weather phenomena, and in this specific case tropical cyclones. The Acting president of CBS referred to the work that the Commission had done through PWS to establish a web site titled Severe Weather Information Centre at severe.worldweather.org.

4.7 The meeting recommended to integrate the new initiative with the project proposals approved by the EC-LIV and prepare in collaboration with the co-president of JCOMM a document based on proposed project to bring this issue to the Fourteenth Congress.

Part II: The Rationale for MILAC.

Marine Impacts on Lowland Agriculture and Coastal resources

Introduction

The tropical cyclone constitutes one of the most destructive natural disasters that affects many countries around the globe causing tremendous loss of lives and property. The impact of tropical cyclones is greatest over the coastal areas which bear the brunt of the strong surface winds, and flooding from rainfall at the time of landfall. In their cloudy arms and their tranquil core, wind blows with lethal ferocity, and the ocean develops devastation surge, inundating vast coastline.

Tropical cyclones, hurricane and typhoons are the regional names for what is essentially one and the same phenomenon. Depressions in the tropics which develop into storms are called tropical cyclones in the south west Indian Ocean, in the Bay of Bengal and Arabian sea, in parts of the south Pacific and along the northern coasts of Australia; these storms are called typhoons in the north west Pacific and are known as hurricanes in the Caribbean, in the south east of the United States of America and in Central America. In the Phillipines they are called bagious.

Compared to the extra-tropical cyclones, tropical cyclones are moderate in size and their worst winds do not approach tornado velocities. The associated winds often exceeding 200 kmph, rainfall exceeding 50 to 100 cms in 24 hours and worst of all, very high storm tides (storm surge combined with astronomical tides) often exceeding 20 feet bring worst human disasters over the coastal areas where they strike. Today records are available for the wind speed of 317 kmph gusting to 360 kmph, rainfall of 117 cm in 24 hours and storm surge of 41 feet in association with tropical cyclones. The lowest pressure of 870 mb ever recorded on the earth was in association with a tropical cyclone (Typhoon `TIP') in the Pacific which formed in 1979.

2. Climatology of tropical cyclones

A thorough knowledge of climatology of tropical cyclones is very much essential for cyclone forecasting, risk assessment and for planning long-term mitigation measures for cyclone disaster management. Almost all tropical cyclones form over warm tropical waters (SST $\geq 26.5\,^0$C) of the tropical oceans except over the south Atlantic and south Pacific, east of 140^0 W. Tropical cyclones are most commonly observed in the northern hemisphere from May to November and in southern hemisphere from December to June. The frequencies of tropical cyclones, however, vary from ocean to ocean. The annual average frequency ranges from 5.6 (the least) in the north Indian Ocean to about 30 (the highest) in the northeast Pacific. About 70 per cent of the tropical disturbances which later develop into tropical storms form in the northern hemisphere. Approximately 80 tropical cyclones attain maximum sustained winds of 20-25 ms $^{-1}$ over the globe per year. About half to two-third of these disturbances develop into the severe stage with a core of hurricane winds (wind speed 64 kts or more).

The long term average of tropical cyclones in the north Indian Ocean (the Bay of Bengal and the Arabian Sea) is 5.6. This is about six per cent of the global total. The frequency of tropical cyclones in the north Indian Ocean is the least in the world. On an average, 2-3 out of six tropical cyclones intensify to severe cyclones. The frequency of tropical cyclone is more in the Bay of Bengal than in the Arabian Sea. Quite different from other oceans, tropical cyclone frequency in north Indian Ocean is by-modal in character having a primary peak in November and secondary one in May. There are two distinct seasons of tropical cyclones in the north Indian Ocean. One is from May to June and the other is mid-September to mid-December. May, June, October and November are known for several tropical cyclones and often have the inner core of hurricane winds and the calm centre - the Eye. They usually form between latitudes 10^0N and 14^0 N. Although the cyclonic storms have occurred in the monsoon season, the real severe ones are rare in this season. Cyclones during the monsoon season are generally marked by well distributed rainfall which often leads to floods in different parts of the country.

After moving in a westerly direction in the earlier stages, they often recurve towards the north and north-east. The region of strongest winds associated with these storms usually lies to the north of the centre. One of the destructive features of the storms in the Bay of Bengal is the 'Storms Surge', which commences a couple of hours before the centres strike the coast.

The annual average of severe cyclonic storm with a core of hurricane winds in the north Indian Ocean is very small (about 2.5 per year). Year to year variation of tropical cyclones in this area, however, is quite large. It has been observed that during the 99 year period, the frequency of tropical cyclones has varied from one in 1949 to 10 on four occasions. The variations are random and there is no trend of periodicity.

Cyclones which move west, northwest or even north strike the east coast of India. Some of the Arabian Sea cyclones strike west coast of India mainly Gujarat and north Maharashtra coast. Out of these storms that develop in the Bay, over 58 per cent of them approach or cross the east coast in October and November. Only 25 per cent of the storms that develop over the Arabian Sea approach west coast. In the pre-monsoon season, the corresponding figures are 25 per cent over the Arabian Sea and 30 per cent over the Bay of Bengal. An important feature is that along the vast stretch of Indian coast, there are a few preferred zones which are more vulnerable (both in the east and west coast) to tropical cyclones.

The average life period of tropical cyclones in the north Indian Ocean is about 2.5 days as against the world average of six days which means, compared to other oceanic areas, the tropical cyclones in the north Indian Ocean are short lived.

The radial dimension of tropical storms vary from 50-100 km radius to 2000 km radius. Over the Indian seas about 17% of the storms have diameter between 3 to 5 degrees and 65% between 5 to 10 degrees indicating that the majority of the storms have diameter within 1000 km and are moderate in size.

3. The destructive power of tropical cyclone and infrastructure for protection

The destructive power of a tropical cyclone can be shown in three principal effects – strong winds, flooding and storm surges. A disaster prevention and preparedness system must include warnings and protective measures against each of these effects. Winds are a fundamental property of tropical cyclones and various other causes.

3.1 Strong winds

The winds of a tropical cyclone are very strong and gusty and may persist for many hours, even for a day or two. It is most important for everyone to understand that when the centre or eye of the storm passes over a place, the strong winds from one direction give away to a fairly short period of quite conditions which are then followed by a resumption of strong winds from the opposite quarter.

The damaging effects of the wind in a tropical cyclone are produced by a combination of their strength, their gustiness and their persistence. Any structural defects in a building, however firm and solid it may appear, can eventually be revealed by gusty winds of gale force.

3.1.1 Infrastructure for protection against winds

In a tropical cyclone the winds are very strong and unusually gusty and may persists as such for periods up to two or three days. If a weak point in a building once gives way, the wind damage must be expected to increase rapidly. It is therefore most important to tie the roof, walls and foundations all together and to cover the windows with strong shutters. The structure itself should also be anchored firmly to its foundations. It is also recommended that windows be opened on the lee side in order to permit the equalization of air pressures, a helpful procedure since the suction or pull of the wind is often greater than its direct force. If these measures are taken, the roof will resist uplifting forces and the structure will be prevented from overturning and disintegrating.

In determining the appropriate building codes, engineering designers should be provided with the available statistics for a locality on wind velocity, gustiness and the variation of wind with height. As a general rule any structure in an area where tropical cyclone may make their landfall should be capable of withstanding the loads generated by winds of at least 120km per hour. For an important building, such as a hospital, a school, etc., the design strength should be such that the critical wind load would have only a very small probability of occurrence during the lifetime of the structure. In this way a good margin of safety is provided; for less important buildings a lower margin may be used, as with the general rule suggested below.

In coastal areas, where the possibility of storm surges must be recognized, it is necessary to provide protection against the surge. This can be done by confining building to higher elevations or by building on concrete pillars embedded in the ground so that the "ground floor" of the structure is above the highest water levels to be expected. The latter type of structure increases substantially the risk of wind damage unless additional strengthening is provided.

3.2 River floods from tropical cyclone rains

Tropical cyclones nearly always give very heavy rains as they move inland from the ocean. At any one station the total rainfall during the passage of a tropical cyclone may exceed 250 mm, all of which may fall in a period as short as 12 hours or may be spread over a period of 48 hours. In either case there could be a high risk of river flooding which could lead to loss of life by drowning and to heavy damage.

In the forecasting and warning aspects of flood risk there must be the closest co-ordination between the Meteorological and the Hydrological Services, which will be working in concert with the water authorities and local officials. The meteorologists, besides forecasting the intensity, movement and evolution of the tropical cyclone, will also prepare *forecasts of rainfall, its time of onset, duration and the amount expected. Forecasting rainfall amounts is one of the most difficult tasks in meteorology.*

3.2.1 Infrastructure for protection against floods

In flood prone areas the first stage of protection against flood is by means of dikes, embankments, temporary reservoirs, etc. Additional requirements which should be incorporated in building codes in order to combat the effects of floods include the following:

(a) *Proper anchorage to prevent buildings floating away from the foundations;*
(b) *Adequate elevation of basement and first floor of buildings;*
(c) *Sufficient strength to withstand water pressure and water moving at high speed;*
(d) *Elimination of use of materials which deteriorate when exposed to water;*
(e) *Prohibition of installation of equipment, e.g. electrical equipment, chemical materials, boilers, at levels which might create a hazard if the items became submerged.*

Flood proofing designs are based on the studies of hydrological and associated meteorological data and take into account such factors as speed of water flow, rate of rise and fall of flood water, flood depth and duration, debris load and wave action.

In a general study of the protection of buildings against flood, data on the factors mentioned above would be supplemented by statistics on rainfall duration and intensity for the area concerned and also by information on local topography and on the soil's capacity to hold water. This study should enable responsible authorities at national, regional or local level to determine a regulatory flood, that is, the flood expressed as a height of water level above mean sea-level which would have a probable frequency of once every 50 or 100 years. The concept of a so-called Regulatory Flood Datum is then applied, consisting of the regulatory flood plus an arbitrary safety factor which may differ from one area to another according to local conditions.

3.3 Storm surges

A tropical cyclone can cause arise of several metres in the level of the sea along the coast with the result that large areas inland may be inundated. These effect have accounted for some of the greatest disasters associated with tropical cyclones. The death toll of more than 200000 lives in Bangladesh in November 1970 was caused by a storm surge variously estimated at a level between three and nine metres.

The main meteorological factors governing a storm surge are the wind field in the tropical cyclone and the sea-level pressure at the centre which in the more vigorous tropical cyclones may be 100 mb lower than the pressure in the area surrounding the storm. In general, the most severe storm surges are associated with a large pressure difference inside and outside the storm and with an extensive area of very storn winds which also affect the swell and the height of the waves. Other factors on which hydrographic advice and data are required are the state of the tide all along the coastline, including times of high tide, the nature of the tide and the topography of the sea bed near the shore. Very high storm surges result from a combination of strong winds, high spring tides and a gently sloping ocean floor. Bays and other inlets along the coast are particularly vulnerable to storm surges. Another critical situation may occur at the mouth of a coastal river when the flood crest due to rainfall occurs at the same time as the storm surge and produces even higher water levels.

3.3.1 Infrastructure for protection from storm surge

Coastal embankments susceptible to storm surges should be designed specifically to withstand the expected storm surge water heights and forces, the combined action of wind and waves, and overtopping from the storm surge water. Furthermore, coastal embankment projects in deltaic areas should be planned in conjunction with other development projects such as highways, harbour and reclamation projects in order to avoid duplication of investment costs.

An advanced and carefully planned system of storm surge protection has been developed at Osaka, Japan, in one of the most densely populated areas of Asia. The present storm surge prevention project consists of the construction of embankments, locks, pumping stations and the lifting of bridges lowered by land subsistence. The large locks that now protect Osaka from a storm surge caused by a typhoon were constructed as an alternative to raising the height of the existing embankment for reasons of cost and time, and to minimize the effects on traffic.

4. Population changes in vulnerable areas

It has been realized in recent years, that in the coastal area of countries which are vulnerable to tropical cyclones the population is increasing much faster than the national average. The high rate of population growth results from the attraction of coastal areas for living and recreation. But for zoning laws and building codes the growth rate would be much higher. In these areas there is an even grater need for public awareness of danger than in those communities where the population is relatively stable and where a fair proportion of the inhabitants have personal experience of the dangers that are brought by a tropical cyclone.

It will be evident that in the planning of disaster preparedness an assessment should be made of population trends in vulnerable areas. Such an assessment would indicate the areas where the regulations governing future development and building should be strictly enforced in order to avoid a high risk of a major catastrophe. The assessment would also help to provide planning guidance on the requirements for escape routes and the arrangements to be made for evacuation.

5. Significance and sensitivity of water supplies

Rise in sea level associated with storm surges could inversely impact fresh water supplies in some coastal areas. Saline water profiles in river mouths and deltas would be pushed further inland, and coastal aquifers would face an increased threat of saltwater intrusion. The intrusion of saltwater into current freshwater supplies could jeopardize the quality of water for some domestic industrial and agricultural users. Salt water intrusion from sea threatens the ecology of the coastal zones as well as its use as a fresh water source. The heavy rain associated with cyclonic storm guarantees longer water availability period and provides possibilities for off-site extra storage in rivers, lakes and artificial reservoirs (on farm or at subcatchment level) for the benefit of improved rural water supply and expanded or more intensive irrigated agriculture and inland fisheries.

Disaster planners in sensitive regions can take steps to improve the ability of fresh water resources systems to recover from the adverse effects of cyclonic storm.

Among the steps that can be taken:

(i) Disinfection of existing drinking water sources susceptible to infections, particularly water borne diseases such as gastroenterities, dyscentry, cholera, etc. should be carried out through bleaching powder or chlorine tablets.

(ii) *Supply of safe and portable drinking water which is a precious commodity in cyclone affected areas. It should be transported to the remote affected areas by railways/road transports to the nearest rail/road junction and subsequently by tankers to the affected areas.*

6. Significance of sensitivity of agro and aquaculture

6.1 Damage to agriculture and fisheries sector

The tropical cyclone causes irreparable damage to the agriculture, ranches and forests. The loss to an agriculture systems can be categorised as

i) Destruction of vegetation, crops, orchards and livestock.
ii) Damage to irrigation facilities like canals, wells, tanks.
iii) Long term loss of soil fertility from saline deposits over land flooded by sea water.
iv) Damage to the fisheries sector like loss of fishing boats, fishing gear and pots at sea.

6.1.1 Agrometeorological loss associated with some devastating cyclones

For most developing countries, agricultural production losses represent a significant part of the damage caused by cyclonic disasters. Damage caused to agriculture (and forests) by the high winds depends on the velocity of the winds and their duration. The higher the wind speed and the longer the duration of the strong winds, the heavier the damage. Typhoons have been known to inflict severe damage to agriculture : for example in south Hainan on 2 October 1989, some 25 million timber and rubber trees were blown down (WMO, 1994 - Salinger) and in Mauritius on 6 February 1995, the main agricultural product, sugar, was reduced by about 30%. Also a typhoon which struck Thailand on 4 November 1989 wiped out some 150,000 hectares of rubber, coconut and oil palm plantations and other crops.

In Mozambique, it was reported that more than 100 people died while 30,000 others were affected by the cyclone which struck the country in January 1984, through the destruction of their agricultural crops; the total damage was estimated at US $75 million. The crops which suffered most in Thailand are rice, upland crops and fruit and total area losses comprise nearly 160, 000 ha of these commodities annually. At the same time, the timber variety of rain forests suffer losses of monetary values $30-450 million and areal losses of 4800 to 76000 ha annually. In USA, annual crop losses are approximately $50 million. In Philippines livestock losses of about $4 million (for 1991) and crop losses of about $5 million (for 1992) have been reported. In Vanuatu, crops affected annually are coconuts ($165, 000 to $826, 000 losses) with an area damaged of 50, 000 – 100, 000 ha; cocoa ($41, 000 – 226, 000) with an area damaged of 10, 000 – 20, 000 ha and garden crops ($816, 000 to $4, 110, 000) with an area damaged of 500 – 1000 ha (Bedson, 1997).

The traditional, small scale fisheries are also hit by cyclones. In monetary terms, the losses incurred by livestock raising, forestry and fisheries mostly remain below those suffered by crop agriculture. In this respect, Madagascar is quite representative. Following several cyclone occurrences in 1983-84, the FAO Office for Special Relief Operations (OSRO) estimated that crop losses represented 85% of the total damage to the agricultural sector, whereas the damage to infrastructure and equipment (drainage and irrigation channels, fishing gear etc.) barely reached 15%. Livestock losses were negligible (OSRO, 1984). A rather different impact pattern occurs in small islands like Antigua and Barbuda where fisheries constitute the backbone of the economy. After hurricane "Hugo" in 1989, 47% of the losses occurred in fisheries, but crop losses still represented almost 40% of the total damage (OSRO, 1989).

It is worth mentioning the losses affecting cash crops which constitute a major source of export earnings in a number of developing countries. In Nicaragua, it is reported that direct loss of export crops due to hurricane "Juana" ("Joan") in late 1988 amounted to 21% of the total losses in the agricultural sector(MIDINRA, 1988). Coffee and bananas suffered a direct loss of their fruits and mechanical damage to their plants. Nonetheless, food crop losses were estimated to be higher (35%), while the livestock sector was less affected (8%) of which one fifth was poultry.

Two broad categories of effects on the agricultural sector can be identified : direct and indirect effects. Direct effects to a farmer could be, for example, the loss of his current crop and damages to his irrigation facilities. Indirect effects appear progressively, as a result of low income, decrease of production, and other factors related to the cyclone disaster. The farmer may well have to pay high prices for seeds because of increased demand and the disruption of the transportation system. He might also lose a portion of future harvest because of a storm surge related salinization of soils or the destruction of perennial plantation crops which sometimes take 5 to 10 years to establish again. Indirect effects are difficult to quantify and therefore, they are often termed "invisible" effects. Conditions conducive to the development of pests and diseases are to be regarded as indirect effects. In fact, the conditions which trigger pests and diseasedevelopment are rarely directly harmful per se. They are usually a combination of moisture or temperature conditions which do not directly affect crops. Typical examples are desert locust outbreaks or increased disease incidence on sugarcane after hurricanes. Plants weakened by adverse weather are much more susceptible to cryptogamic diseases or pest attacks, like the explosion of "coconut black beetle" populations on strong wind damaged coconut trees. As for example, it takes 30 years for certain timber varieties after hurricane "Allen" (August, 1980) hit Jamaica (FAO, 1982), but more frequently from 6 months or 1 year (banana) to 4 to 5 years (coffee and sugarcane). Even for crops that regenerate easily after partial damage, harvesting is usually made difficult by the "abnormal" morphology, thus further reducing yield expectations.

6.1.2 Salt Deposition in coastal areas

The effects of strong winds associated with tropical cyclones in coastal areas is seen with stunned and sculptured trees bearing unmistakable evidence of the strong winds. In addition to the battering effects of winds, there is an important effect of damage by air-borne sea salt within perhaps a few hundred meters from the coast. Winds which blow from coastal seas sprays a lot of salt on the coastal areas, making it impossible to grow crops which are sensitive to excessive salt.

A rise in the ecstatic sea level will result in the territorial extension of coastal salinity under the direct or indirect influences of saline sea water. The inundated crop fields due to storm surge suffer loss of fertility due to salt deposition, even after the sea water has receded. The land take a few years to regain its original infertility. The period of high water last from about 6 hours to several days in case of poor drainage and may leave the soil saline and unfit for crops. Salt water intrusion also affects some of fish species in the coastal zone, several of which are believed to be so weakened that they are granted protection. Saline soils are dominantly observed in coastal areas in India. Sea level rise would adversely affect the 7000 km coastal belt of India, comprising 20 Mha of coastal ecosystem, increasing coastal salinity and reducing crop productivity.

7. Miscellaneous and mixed cause impacts

Tropical cyclones are responsible for large casualties and considerable damage to property and agricultural crop. The destruction is confined to the coastal districts; the maximum destruction being within 100 kms to 150 kms from the centre of the cyclone and to the right of the storm track where wind is from ocean to land. The principal dangers from cyclones are : (1) fierce winds, (2) torrential rain and associated flooding, (3) high storm tides (combined effect of storm surge and astronomical tides) leading to coastal inundation.

Most of the casualties are caused by coastal inundation by storm tides. The penetration varies from 10 to 20 kms inland from the coast. Heavy rainfall and floods come next in order of devastation. Death and destruction purely due to winds are relatively small. The collapse of buildings, falling of trees, flying of debris, electrocution, aircraft accidents and disease from contaminated food and water in the post-cyclone period contribute substantially to loss of lives and destruction of properties. The available statistics the world over shows that the tropical cyclone are far ahead of any other disaster as killer accounting for about 64% of the total lives lost. The 80-100 tropical cyclones that occurs each year caused an annual average of 20,000 deaths over the period 1964-78. The average economic loss per cycle per year was about 60 millions US dollars. When a cyclone hits an U.S. coast like that around the Gulf of Mexico, the loss can be as high as 2000 million U.S. dollars .

Apart from the serious calamity of loss of human life and injuries, the impacts of a severe cyclone on a coastal district are :

1. Shoreline erosion.
2. Damage to off-shore and on-shore installations .
3. Damage to roads, railway tracks and other public utilities.
4. Damage to electric supply systems.
5. Damage to telecommunication systems.

7.1 Some economic and social consequences

The factors discussed above - damage from wind, rain, flood, storm surge and sea waves - may be regarded as representing the direct impact of tropical cyclones. The losses and damage attributable to these factors can be assessed in terms of deaths and injuries to the population, buildings and installations destroyed or in need of repairs, destruction of crops and livestock, etc. However, there are additional , perhaps indirect, consequences which cause losses to individuals, industry, community or the nation. The magnitude of these effects can be very large and they can not be ignored. Some of these aspects are discussed briefly below.

Losses in productivity

A tropical cyclone can lead to disruptions to the work force and to other activities and results in substantial losses in productivity. Factories and warehouses may be out of commission for varying periods and many man-hours may be lost because of breakdowns in land, sea and air traffic impending the movement of people and supplies, and because of diversion of labour to disaster relief and restoration. In agriculture there can be large losses in primary production on account of delays in the recovery of arable land that has been inundated.

Personal and domestic losses

A tropical cyclone can cause many losses of personal and domestic nature. The loss of personal belongings, such as clothing and furniture, can be a specially severe blow to families whose financial reserves are small. In the domestic area, breakdowns in public utilities can lead to losses significantly. All these losses, may be great in some homes and small in others, and could be a substantial financial loss to a community as a whole.

7.2 Beneficial impact of cyclonic storms

The effect of the cyclonic storms is not always baneful; benefits centre principally on the precipitation associated with them which may have considerable value to agriculture. The extra precipitation due to cyclonic storms on land would help increase plant growth leading to an improved protection of the land surface and increased rainfed agricultural production. Ryan (1993) mentioned some important aspects of benefits of Tropical cyclone in Australia. Increased water availability in water critical region makes agricultural production less susceptible to dry period. Sugg (1968) estimates that nine major hurricanes in the United States since 1932 terminated dry conditions over an area about 622,000 sq. km(240,000 sq. miles). Hartman et. al. ,(1969) estimated the change in total crop value brought on by these storms occurring in different months. The losses in crops for two of the storms were $54 million and $1 million ; for the third storm there was an increase in total crop value of $8 million.

8. Forecasts and warnings of tropical cyclones

When the possibility of a tropical cyclone threatening the country is recognized, the Meteorological Service would carry out the following procedures:

(a) Preparation of routine forecasts and other advisory messages in order to keep the responsible authorities informed about the tropical cyclone's intensity, its location and anticipated movement;

(b) The issue as appropriate of warnings of dangerous winds, high storm surges, torrential rains and river flooding.

Forecasts, as distinct from warnings, would normally be issued at fixed times, at intervals of 6 or 12 hours or, of course, more or less frequently according to individual requirements. Warnings are issued when the tropical cyclone poses a threat to lives and property. As the tropical cyclone continues to approach, warnings would be updated, normally becoming more specific in such matters as time and place of landfall, maximum wind strength to be expected, time of onset of rain and the expected intensity, and the coastal areas most liable to storm surge. By arrangement with the authorities, warnings should be so worded or labelled as to indicate clearly the nature of the action that should be considered by those to whom the warning is issued.

The warning service should study the needs of its customers, preferably by direct consultation. First, there are the authorities responsible for implementing the disaster preparedness measures and the general public but there are, in addition, many special interests. The warnings may need to be expressed differently and be for different time periods according to various customers' requirements. The fishing fleet, for example, may be more than a day's sailing from safe harbour and would clearly need much earlier warning than the home owner, who might be concerned only to place shutters over his windows. The operators of off-shore oil rigs have numerous problems in preparing for a tropical cyclone and a comprehensive service covering wind speed and direction, state of sea, swell and other parameters is required.

9. Disaster preparedness and mitigation measures

Disaster preparedness is seen in action in the short term or emergency measures which come into force when conditions such as those of a tropical cyclone approach and bring with them the threat of a disaster. These measures remain in force until some time after the conditions have passed, because emergency action is required not only on the approach of a tropical cyclone, but also when it is actually present with all its force over an area and then in the aftermath.

In an integrated disaster plan there are two categories of measure. One category is of permanent nature, known as prevention, includes a structural component – levees, dams, reservoirs, etc. – and a non-structural component – land use and zoning, building codes, etc. The other category, known as preparedness, consists of emergency measures which, however, must also be planned well in advance. Each of these categories is essential and should be viewed not so much as a separate undertaking but entirely as a supplementary part of an overall system for protecting life and property.

9.1 Structure of disaster preparedness

The effective mitigation of the impact of tropical cyclones upon a country depends to a great extent upon the provision at national levels of an adequate framework incorporating policies, programmes and guidance to enable action to be taken at community level where the emergency organization must function at high efficiency and have regard to all the fine details in the plans to be implemented. Indeed, planning and the implementation of plans from a continuous process from national to community levels. In emergency the major tasks are apt to fall upon communities. It is at this level that evidence will be found whether the overall planning has been sufficiently comprehensive and co-ordinated to develop the necessary high degree of motivation among the responsible people as well as among the general public in carrying out the whole range of measures which the emergency demands.

In order to emphasize the importance of the planning and action roles at the local level, it may be mentioned that in the United States plans are made for improving the capability at local government level for rapid and effective response to save lives and protect property in the event of any threatened or actual emergency. In adopting this objective it is realized that local communities must not be left to fend for themselves using their own resources but must receive government help in planning, in all requirements to implement plans and, as required, during an actual emergency.

It would be appropriate for each local authority to set up a permanent Disaster – preparedness Committee. This would function within the framework of the Disaster-preparedness Board and in co-operation with the Board's subcommittees and working groups. The local Disaster-preparedness Committee would include representatives of the following bodies:

Local authority (nominated members of the town council);
Civil Defence;
Police;
Public Works;
Public health and medical service;

Fire service;
Utilities (transport, electricity, gas, water, post and telegraphs);
Education;
National Red cross.

The terms of reference and functions of the committee should be clearly set out and would include such matters as the following :

- *(a)* *To keep the population and its property, installation, etc. constantly prepared for an emergency arising from a tropical cyclone or other natural phenomena;*
- *(b)* *To keep under view, and to take all appropriate action on, matters likely to reduce danger and devastation from tropical cyclones;*
- *(c)* *To supervise generally the warning system and the organization for dealing with emergencies;*
- *(d)* *To direct and control rescue and relief work;*
- *(e)* *To maintain liaison with the press, radio and television and to organize programmes of public information and education;*
- *(f)* *To organize a survey of deaths, injuries and damage after each emergency and to take action on the lessons to be learned.*

Once established, the committee should meet as often as necessary until a satisfactory disaster-preparedness plan has been drawn up and action for implementation is proceeding smoothly. Thereafter, the committee should meet regularly and should invariably hold a meeting as the tropical cyclone season approaches. The committee should visit all components of the preparedness organization and ensure that all necessary arrangements have been made for co-ordination collaboration and teamwork. Particular attention should be given to the warning system and its capabilities.

9.2 Evacuation

In almost any natural disaster, certainly one which is associated with a tropical cyclone, it becomes necessary to move people from a dangerous area to one that is safe or at least relatively so. It is therefore necessary as a part of the disaster-preparedness planning to formulate detailed plans so that people may be moved in good time, smoothly and efficiently.

There are three phases of a possible disaster during which the transfer of people to a safer area may take place:

- *(a)* In advance of the arrival of the tropical cyclone or other natural phenomenon. *In this phase action would be taken on the basis of warnings that have been issued and for this reason the control of the evacuation should be a part of the whole operational system and in close touch with the warning sources. During this phase weather conditions must be expected to deteriorate rapidly with rising winds and heavy rainfall. Flooding may begin in the most vulnerable area.*
- *(b)* During the emergency itself. *This requirement for evacuation could arise if some delays or breakdowns had occurred during the earlier phase discussed in (a) above, or if it were seen that unexpected dangers had presented themselves, e.g. the destruction of buildings thought to be safe, flood water reaching a significantly higher level than forecast, a storm surge occurring farther along the coast than was considered likely, and so on.*
- *(c)* In the aftermath of the emergency. *In this phase the amount and complexity of the evacuation problem would depend on the severity of the disaster and its impact upon inhabited areas.*

In the planning of evacuation reference should be made to vulnerability studies. These studies should show the hazardous area and also indicate the conditions when potential dangers become real. For example, the vulnerability analyses would clearly point to the areas which would be inundated in the event of flood waters reaching a given level; the effects of storm surges of given heights on coastal areas would also be available.

In combination with the results of the vulnerability studies there should be a thorough survey of the area for which the concerned authority has responsibility. It would then be feasible to prepare maps and diagrams showing:

(a) Areas to be evacuated and time required for the operation to be carried out;
(b) Areas/places/buildings to be used as shelters;
(c) Assembly points and routes to be used in transferring people from a particular area to the specified safety area or place or building.

10. Development of numerical models for storm surge and their testing and implementation

Storm surges are generated by wind stresses and, to a lesser extent, falling atmospheric pressure that produces a rise in water level at the rate of approximately 1cm per hPa fall in pressure. Coastal bathymetry can also affect storm surge intensity. Shallow coastal bathymetry tends to amplify the storm surge while topographic features can channel the coastal currents.

Astronomical tides, storm surges and wave set-up interact nonlinearly to produce total sea levels that are lower than the sum of the individual contributions. This is due to the friction of the ocean floor that has a retarding effect on the flow proportional to the square of the coastal current. For this reason, it is preferable to integrate the effects of all contributions to coastal currents and sea levels in a dynamical model simulation rather than adding the effects of some components seperately at a later stage. As a case study, a numerical model which is applied over the gold coast Broadwater on the east coast of Australia by Mclnnes et al., 2002 has been described in the following paragraphs to see how a particular model can be run in hindeast or forecast mode to follow the strategy.

The model used in this study include the coastal ocean model, GCOM2D, the atmospheric model, RAMs for generating the meteorological conditions accompanying the storm events, and the third generation spectral wave model WAM.

10.1 Storm surge and wave setup results

Three fine mesh model simulations were conducted. The first incorporated tidal forcing only, the second had tides and wind forcing and the third also contained wave radiation stresses. Comparing the modelled and observed sea levels at the Seaway reveals that a slight phase difference is evident and is consistent with that seen on the coarse resolution tides-only simulation. The modelled sea level heights are also underestimated by about 0.1 m. The underestimation of sea levels by the model, particularly in the last 12 hours, may be due to an underestimation of the wind strength along with a shift to northeasterlies in the atmospheric model simulation that was not seen in the observations.

To investigate the contribution due to wave setup, the sea level results from the tides and surge simulation at the Seaway (east coast of Australia) were subtracted from the full simulation that also included wave radiation stresses. The contribution due to the storm surge was obtained by subtracting the sea levels due to tides-only from the tides and surge simulation. The result indicates that the storm surge contributed between 0.10-0.15 m to the total sea level. This finding is consistent with the results of a study into the relative contributions of storm surge and wave setup to the sea levels recorded along the NSW coast during severe east coast low events.

The storm surge and wave setup made their largest contribution to the water levels during the first half of the simulation. It is likely that the storm surge and to a lesser extent, the wave setup were underestimated due to errors in the modelled wind field.

During the latter half of the simulation, fresh-water runoff was the main contributor to the sea levels in the Broadwater. This particular event highlights the fact that rainfall has the capacity to considerably worsen the impact of extreme storm tide events in this region. As a consequence of this, future efforts to determine the risk of severe floods in the Broadwater should incorporate freshwater runoff in combination with wave setup and storm surge to be inclusive of all the major physical processes. A simulation of the 1974 flood event with present day bathymetry produced sea levels that were between about 0.3 and 0.4 m lower than those attained with the 1974 bathymetry. This illustrates the effectiveness of deepening the Seaway channel to minimise the flooding from future flood events in which severe runoff is the major contribution.

This study represents the first step towards the development of an integrated modelling system that links together a range of models representing the various contributions to coastal flooding. This study has focussed on the ability of the coastal ocean model GCOM2D to model severe flood events with contributions due to wave setup and rainfall runoff. A hydrological model can be linked to the system so that modelled rainfall can be routed through the catchment to provide fluxes for GCOM2D.

REFERENCES

Bedson, G.; 1997. Specific aspects of Natural disasters which affect Agricultural production and forests, particularly wildland fires, Severe local storms and hurricanes. CagM Report No. 73, WMO, Geneva.

FAO, 1982. Salvage and rehabilitation in the forestry sector of the hurricane affected areas of the eastern region, Jamaica. FAO, Rome, pp.16.

Hartman, L. M., David, H. and Giddings, M., 1969. "Effects of hurricane storm on Agriculture". Water Resources Research, 5(3), pp. 555-562.

Mclnnes, K. L., Hubbert, G. D., Abbs, D. J. and Oliver, S. E., 2002. A numerical modelling study of coastal flooding. Meteorol. Atmos. Phys. 80, pp. 217-233.

MIDINRA, 1988. Danos en el sector agropecuario provocados por el huracan "Juana". Evaluation preliminar. Managua, Nov. 1988, pp. 39

OSRO, 1984. Madagascar, Evaluation de la situation agricole a la suite des cyclones. OSRO. TCP/MAG/4404, FAO, Rome, pp. 43.

OSRO, 1989. Evaluation of the agriculture situation in eastern Caribbean countries affected by hurricane "Hugo". OSRO 03-89-E, FAO, Rome, pp. 63.

Ryan, C. J., 1993. Costs and benefits of Tropical Cyclones, Severe Thunderstorms and Bushfires in Australia. Climatic Change 25, pp. 353-367.

Sugg, A. L., 1968. "Beneficial aspects of the tropical cyclone". J. Appl. Meteorol., 7(1), pp. 39-43.

WMO, 1994. climate variability, Agriculture and forestry (authors: Salinger et al.), Tech. Note No. 196 WMO, Geneva.