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WMO's programme on tropical cyclone

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सार — विश्व मौसम संगठन के उष्णकटिबन्धीय चक्रवात कार्यक्रम का प्रतिपादन चक्रवात से प्रभावित विश्व के अनेक देशों को चक्रवातों के मॉनीटरिंग, पूर्वानुमान और आपदा निवारण तथा तत्संबंधी तैयारी करने के लिए, उनकी क्षमता को बढ़ाने के माध्यम से उष्णकटिबंधीय चक्रवातों के दुष्प्रभावों को कम करने के लिए, सहयोग देने हेतु किया गया था। इस शोध पत्र में उन सभी तथ्यों की चर्चा की गई है जिनके कारण इस क्षेत्र में उल्लेखनीय प्रगति हुई है। इन तथ्यों में कार्यक्रम का संगठन एवं संरचना, इसकी प्रणालियाँ तथा प्रौद्योगिकियाँ, इसकी प्रशिक्षण क्रियाविधि एवं उष्णकटिबंधीय चक्रवात बेसिनों के देशों में परस्पर क्षेत्रीय सहयोग सम्मिलित हैं। विशिष्ट उष्णकटिबंधीय चक्रवात अनुसंधान और तत्संबंधी प्रचालनात्मक मामलों के बारे में बताया गया है।

ABSTRACT. The Tropical Cyclone Programme of WMO was established to assist the many affected countries of the world in mitigating the impacts of tropical cyclones, through the development of their capabilities in monitoring, forecasting and disaster prevention and preparedness. The paper discusses the factors which have together led to significant progress in this regard. These include the organization and structure of the Programme, the systems and technologies in place, and the mechanisms for training and regional cooperation among the countries of the tropical cyclone basins. Specific tropical cyclone research and operational issues of concern are also presented.

Key words — Tropical Cyclone Programme (TCP), Regional Specialised Meteorological Centres (RSMC), National Meteorological Services (NMS), Global Telecommunication System (GTS).

1. Introduction

Tropical cyclones are among the most destructive natural hazards around the globe. They are characterized by very strong winds, heavy rains and associated storm surges, floods and landslides. While they assume different names in different parts of the world, such as, tropical cyclones, hurricanes and typhoons, they represent the same meteorological phenomenon. Each year around the globe, approximately 80 tropical cyclones reach the storm intensity stage with measured or estimated maximum sustained winds of 17 m/s or stronger. Of these about two thirds reach the hurricane stage with maximum sustained winds of over 33 m/s. Almost all tropical cyclones form over warm tropical waters and of these, 87 per cent are spawned within 20^{o} latitude of the equator (see Fig. 1). In most basins, tropical cyclones appear to have a peak frequency of formation during late summer or early autumn. This corresponds to the period of maximum sea surface temperatures, although other factors, such as, vertical wind shear are also important.

The socio-economic impact of tropical cyclones, which directly affect about 70 countries is considerable. During the past 20 years, these storms have been responsible for the death of over half a million people and affected about 150 million people. The damage caused in one year globally may exceed US $ 6 billion. A single cyclone has been known to set back social and economic advancement of a small developing country by many years. Most of the casualities have

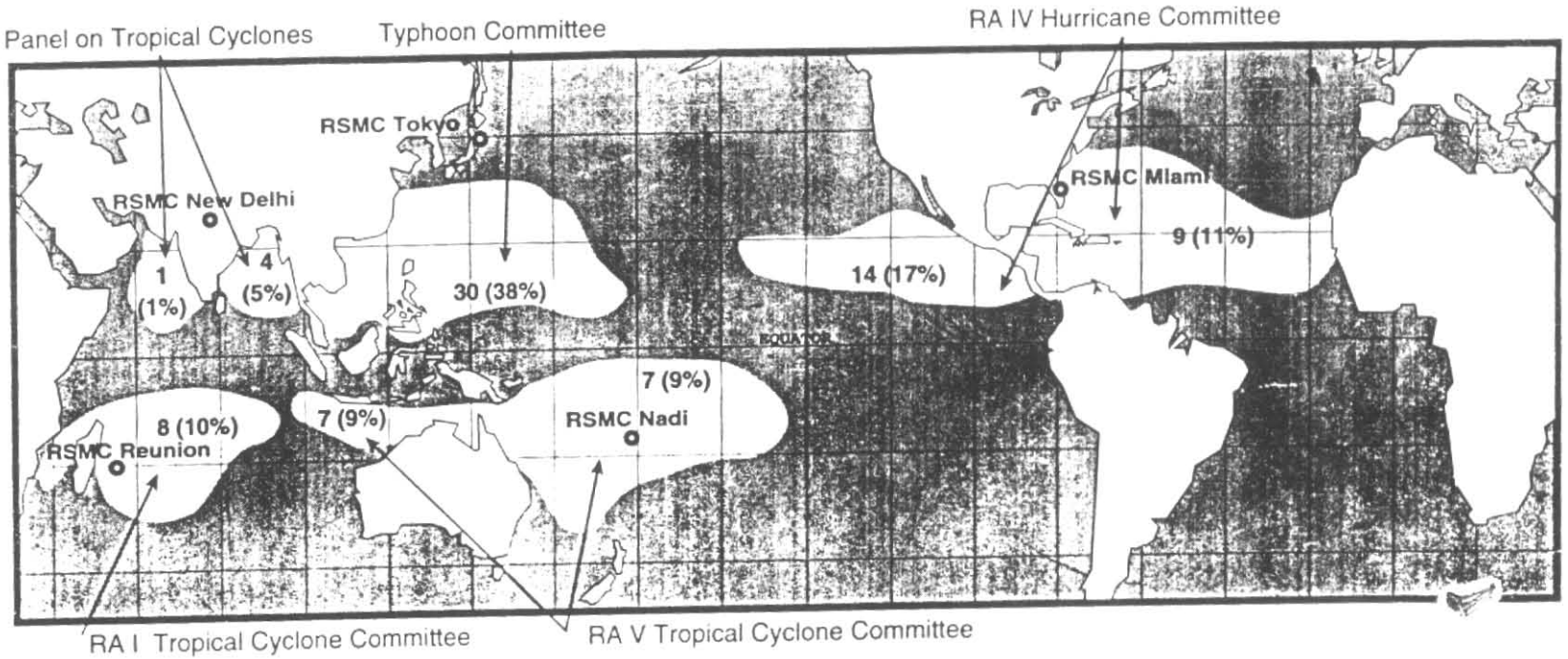

Fig. 1. Average annual numbers, percentages of the total number and areas of formation of tropical cyclones. Regional tropical cyclone bodies and associated regional centres are also indicated

occurred in developing countries which have inadequate warning and preparedness systems. Many of these lives could have been saved, and suffering and property damage greatly reduced, if adequate warning and disaster preparedness arrangements had been instituted more widely. The experience in USA, Jamaica and more recently in Bangladesh, shows that where effective warning and disaster preparedness systems have been established, the loss of life is significantly reduced. It is also estimated that up to 40% of the property damage could be averted.

2. United Nations and the WMO tropical cyclone programme

The responsibility of the World Meteorological Organization (WMO) and to a large extent that of its predecessor, the International Meteorological Organization, has been for over 120 years, amongst others, to facilitate world-wide cooperation in the making of meteorological, hydrological and other geophysical observations related to meteorology and to encourage the applications of the science of meteorology for the benefit of people around the globe. In view of its mandate, WMO, therefore, has always been on the forefront of advancing research, promoting training and supporting the establishment of cyclone forecasting and warning systems in countries affected by these phenomena. At the regional level, in 1964, the United Nations Economic Commission for Asia and the Pacific (ESCAP), then called the Economic Commission for Asia and the Far East (ECAFE), in collaboration with WMO, initiated the establishment of the intergovernmental Typhoon Committee to promote and coordinate efforts to minimize typhoon damage in the Western North Pacific region. The Committee became operational in 1968.

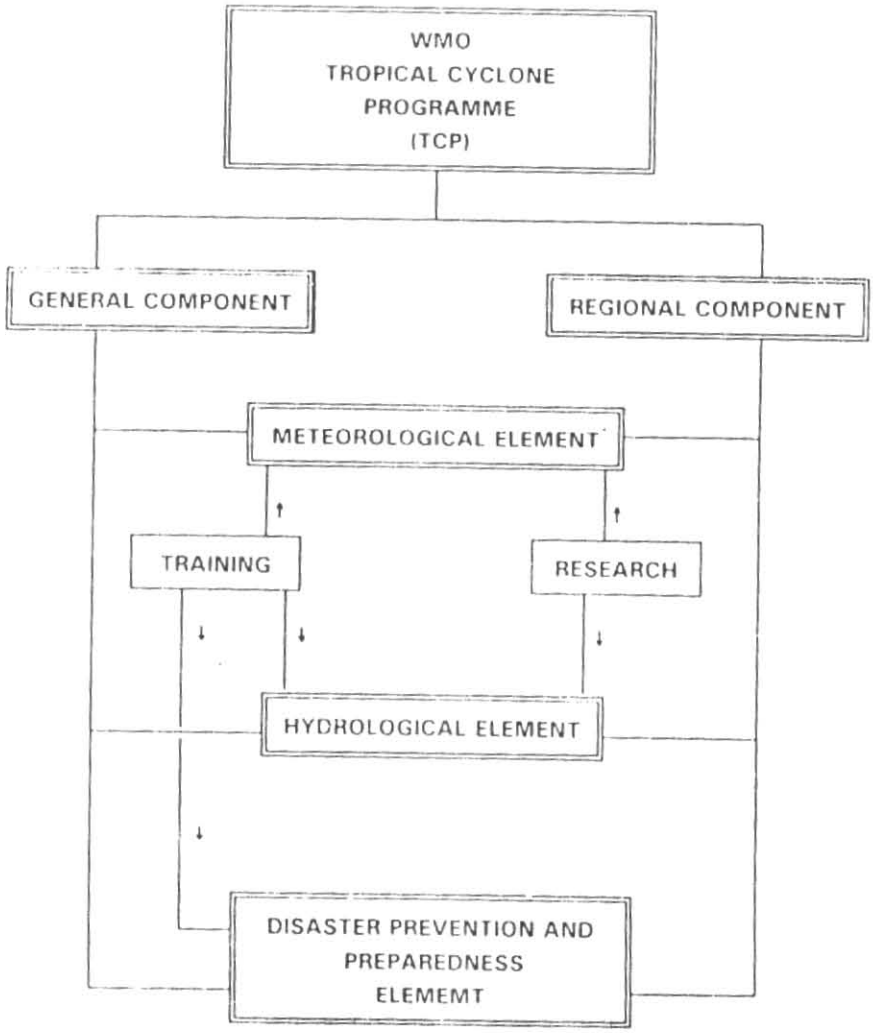

Fig. 2. The structure of the Tropical Cyclone Programme (TCP)

Following the worldwide concern at the series of tropical cyclone disasters and particularly, the loss of some 300,000 lives and considerable material damage in Bangladesh in 1970, the United Nations General Assembly adopted Resolution 2733 (XXV) - Peaceful Uses of Outer Space. The resolution called for international action to mitigate the harmful effects of such disasters and requested WMO to mobilize scientists to study the phenomena, and Member countries to implement WMO's World Weather Watch Programme. In view of its long-standing experience, WMO was able to respond promptly and effectively. The Sixth Congress of the World Meteorological Organization (Geneva 1971) established the WMO Tropical Cyclone Project which included the Typhoon Committee and an intergovernmental Panel on Tropical Cyclone for the Bay of Bengal and the Arabian Sea. In 1977, the thirty-second session of the UN General Assembly welcomed the actions taken by WMO and adopted another resolution, UN Res/32/196 A - Peaceful Uses of Outer Space, calling on WMO to intensify its efforts in the mitigation of tropical cyclones, taking into account the development and use of satellites for tropical cyclone surveillance. Subsequently, WMO's Eighth Congress (1979) reviewed the achievements of the Tropical Cyclone Project and upgraded it to the WMO Tropical Cyclone Programme (TCP).

In 1987, WMO's Tenth Congress decided that there should be a phased enhancement of the Programme with a shift in emphasis towards improving the capabilities of the national Meteorological and Hydrological Services to provide better forecasts and more effective warnings with substantial improvements at the interface with the user community.

In 1990, the United Nations launched the International Decade for Natural Disaster Reduction (IDNDR) which is a global effort aimed at reducing loss of life and damages by ensuring widespread use of proven disaster mitigation methods, and to mobilize the scientific and engineering communities to improve warnings and damage reduction methods, and to adapt them for different regions. In recognizing the humanitarian, social and economic dimension of the TCP and its great potential for substantial contributions to the goals of the IDNDR, WMO's Eleventh Congress in 1991 adopted a Plan of Action for the IDNDR and included the contribution of the TCP to this global effort. In particular, a project to substantially upgrade the warning system in the South- West Indian Ocean was developed and is being successfully implemented.

2.1. *Objectives of the Tropical Cyclone Programme*

The objectives of the Tropical Cyclone Programme have evolved considerably over the years. In its present form, the TCP is designed to assist Member countries in their effort to mitigate tropical cyclone disasters by strengthening their capabilities to provide timely warnings of the occurrence and impact of tropical cyclones and associated phenomena, such as, floods and storm surges, as well as to organize and execute the related disaster prevention and preparedness measures.

Thus the programme has been encouraging and assisting the concerned WMO Member countries to :

(*i*) provide reliable forecasts of tropical cyclone tracks and intensity, and related forecasts of strong winds, quantitative forecasts or timely assessments of heavy rainfall, quantitative forecasts and simulation of storm surges, along with timely warnings covering all tropical cyclone-prone areas;

(*ii*) provide forecasts of floods associated with tropical cyclones;

(*iii*) promote response to warnings and carry out activities at the interface between the warning systems and the users of warnings, including public information, education and awareness;

(*iv*) provide the required basic meteorological and hydrological data and advice to support hazard assessment and risk evaluation of tropical cyclone disasters and

(*v*) establish national disaster preparedness and prevention measures.

2.2. *Structure of the Programme*

The Tropical Cyclone Programme is composed of two components - a *general component* and a *regional component*. The activities pursued under each of these components may be further divided into three principal *elements - meteorological, hydrological, and disaster prevention and preparedness*. The programme also covers specialized *training and research* (See Fig. 2).

A short description of the organizational structure is given below:

(*i*) The *general component* is concerned with methodologies and its chief aim is to provide

information, scientific knowledge, guidance and transfer of technology to assist Member countries, mainly through the medium of publications, such as, manuals and reports. The work under this component facilitates the development of improved systems within the overall programme and encompasses the broader aspects of training for the programme.

(*ii*) The *regional component* is mainly concerned with the development of coordinated operational systems among groups of Member countries (tropical cyclone regional bodies) in distinct geographical areas subject to tropical cyclones. The object of this component is to improve the combined capability of these Member countries to mitigate the cyclone damage sustained by each individual Member through fruitful regional cooperation and coordination.

2.3. *Regional tropical cyclone bodies*

Since tropical cyclones vary from basin to basin with respect to size, intensity, tracking and frequency, it is more effective to deal with measures at the regional level to improve forecasting and warning systems.

To assist Member countries of tropical cyclone-prone basins in their collective efforts to mitigate tropical cyclone disasters, much of the work of the TCP is being carried out by five groups of countries pursuing cooperative and coordinated programmes through the following regional tropical cyclone bodies:

- ESCAP/WMO Typhoon Committee (Western North Pacific Ocean);
- WMO/ESCAP Panel on Tropical Cyclones (Bay of Bengal and Arabian Sea);
- RA I Tropical Cyclone Committee for the South-West Indian Ocean;
- RA IV Hurricane Committee; (North Atlantic Ocean, Caribbean Sea, Gulf of Mexico and Eastern North Pacific Ocean) and
- RA V Tropical Cyclone Committee for the South Pacific and South- East Indian Ocean.

The first two bodies are inter-governmental and the other three are working groups of WMO Regional Associations (Fig. 1). Each of these bodies undertake its tasks within the framework of the three principal elements, mentioned earlier, namely; *meteorology, hydrology,* and *prevention and preparedness*:

(*i*) The *meteorological* element, which is based on WMO's World Weather Watch (WWW), is primarily concerned with the provision of basic meteorological data and analyses and other processed products required for tropical cyclone forecasting and the application of the appropriate techniques to ensure accurate forecasts and timely warnings.

(*ii*) The *hydrological* element is concerned with the basic hydrological data required for flood forecasting and the application of the appropriate techniques to ensure accurate forecasts and timely warnings. It is carried out in close coordination with WMO's Hydrology and Water Resources Programme. Within the Asia and the South Pacific regions, this element is also implemented in close cooperation with ESCAP.

(*iii*) The *prevention and preparedness* element is concerned with all other structural and non-structural measures required to ensure the maximum safety of human life and the reduction of damage to a minimum. In this connection, WMO's role of assisting its Member countries to ensure coordination of measures to protect life and property is performed in close cooperation with the UN Department of Humanitarian Affairs, the International Federation of Red Cross and Red Crescent Societies, the International Decade for Natural Disaster Reduction Secretariat and appropriate regional bodies, such the Asian Disaster Preparedness Centre (ADPC) and the Caribbean Disaster Emergency Response Agency (CDERA), which have special expertise in these fields.

2.4. *Training and Research*

Training and research activities within the Tropical Cyclone Programme are considered in the context of the three principal elements. Training is generally conducted within each of the individual regional tropical cyclone bodies, but sometimes, it is conducted on a multi-regional basis and occasionally in cooperation with other agencies connected with the three elements. The TCP has a planning and/or supporting role in tropical cyclone-related research and promotes such activities in cooperation with the WMO Tropical Meteorology Research Programme (TMRP).

3. Regional cooperation programme

Each of the five regional tropical cyclone bodies has adopted a regional cooperation programme, in which major emphasis is placed on improving tropical cyclone and flood forecasts, provision of timely early

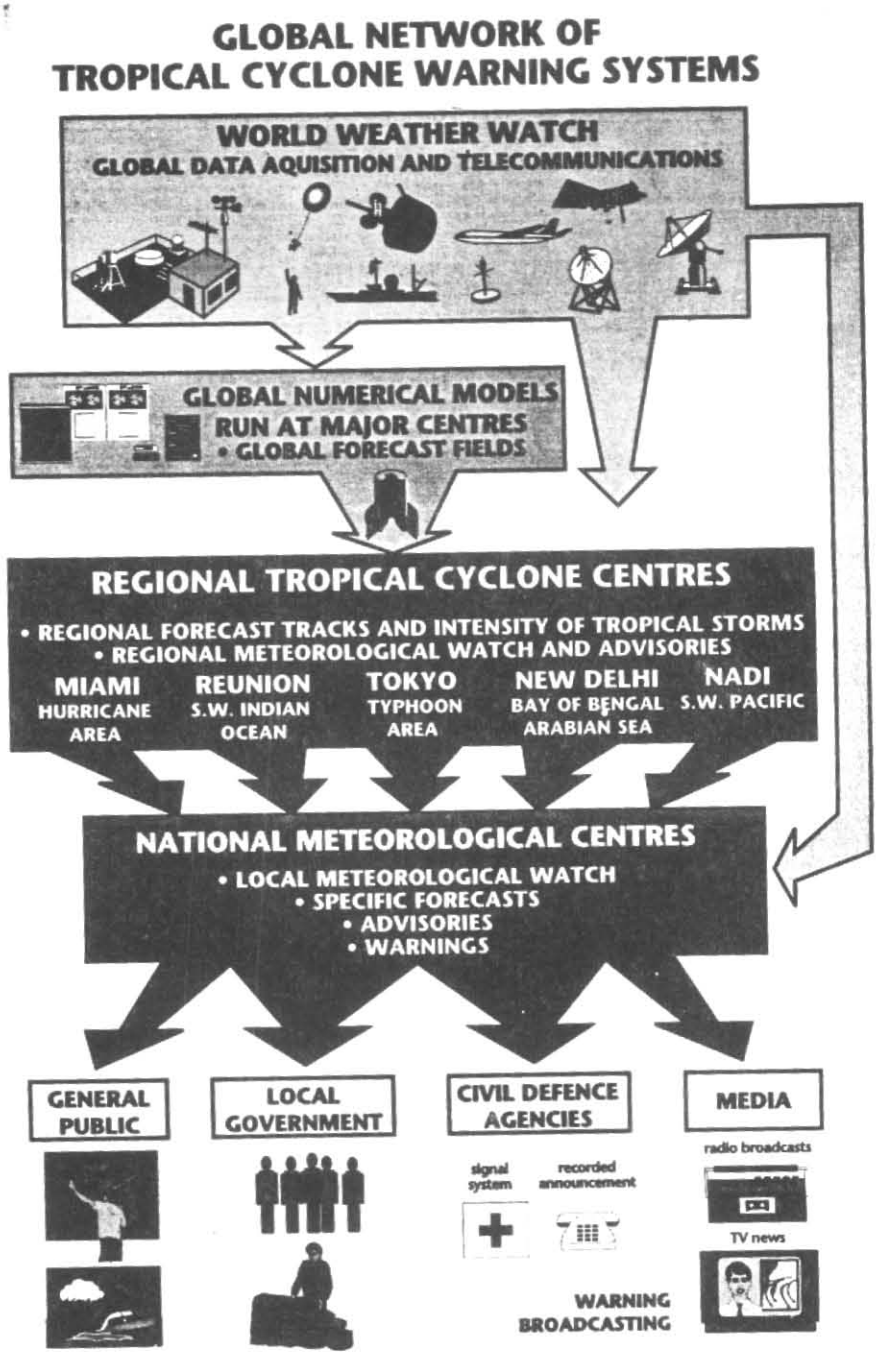

Fig. 3. Global network of tropical cyclone warning systems

warnings and establishment of the necessary disaster preparedness measures in order to minimize the impacts of tropical cyclones on their Membership. Each regional cooperation programme includes :

— a *tropical cyclone operational plan*, which is designed to ensure the most effective current cyclone forecasting and warning system through coordination and cooperative arrangements; and,

— a *technical plan* for upgrading facilities and services, coordination of disaster mitigation procedures, and regional training and research activities and requirements.

These plans are reviewed and updated at each session of the respective tropical cyclone bodies. A core feature of these plans is the Regional Specialized Meteorological Centres (RSMCs), located in Tokyo, New Delhi, La Reunion, Miami, and Nadi, corresponding to each of the bodies mentioned above. The centres carry out specialized functions and provide tropical cyclone advisories to Member countries of their respective regions. The collaboration that exists between RSMCs and national warning centres is an outstanding example of international and regional cooperation and collaboration.

3.1. *WMO/ESCAP Panel on Tropical Cyclone*

The Panel on Tropical Cyclones for the Bay of Bengal and the Arabian Sea was established in 1973 as an intergovernmental body under the sponsorship of WMO and in collaboration with ESCAP. The Meteorological Centre in New Delhi which has been designated as the RSMC with activity specialization for tropical cyclones ensures the provision of advisory services to the countries concerned (Fig. 1). As the Bay of Bengal area is extremely vulnerable to the very high storm surges and storm tides caused by tropical cyclones, the Panel has formulated a detailed and comprehensive storm surge project and action plan as part of its programme.

4. Operational tropical cyclone warning systems

The successful implementation of the Tropical Cyclone Programme rests on a symbiotic interaction of a number of systems operating at various levels. At the global level, the cyclone warning and related activities of the national Meteorological Services are coordinated by the World Meteorological Organization (WMO) and are integrated into its World Weather Watch (WWW) and Tropical Cyclone Programmes. The WWW is a unique global system which enables each national Meteorological Service to obtain in real-time and continuously the data and information it requires, from both, within and beyond its national boundaries. The WWW ensures that meteorological observations from land-based stations, aircraft, ships and buoys, and from geostationary and polar- orbiting meteorological satellites are exchanged globally through the WWW Global Telecommunications System (GTS) using satellite, cable and radio transmissions. These data are received at World, Regional and National Meteorological Centres, and processed by a variety of techniques including the use of numerical models of the atmosphere. The analyses and predictions produced by these centres are also disseminated through the GTS (Fig. 3).

At national level, the responsibility for the provision of warning service to the local population and for the coastal waters rests, in principle, with the Meteorological Service of that country. Primary responsibility for warnings for a specified area on the high seas and for civil aviation is assigned to selected National Meteorological Services (NMS). In preparing the warnings, the NMS rely on the GTS for its data as well as on the relevant WMO RSMCs with activity specialization in tropical cyclones for specialized products and advisories.

One of the principal aims of the RSMCs within the TCP is therefore to promote the development of appropriate techniques, the provision of a wide variety of products, including numerical weather prediction (NWP) products, in a timely manner, and to offer appropriate guidance on the use of products by decision-makers at the national level. Thus a symbiotic relationship is developed between each national warning centre and the respective RSMC for the preparation of timely and high-quality warnings for use at national and regional level.

4.1. *Activities in support of tropical warning systems*

In order to enhance the tropical warning systems worldwide, a number of activities are promoted in the context of Tropical Cyclone Programme. The examples below indicate the range and nature of some of these activities:

(i) Improvement of the meteorological observing networks and systems, by promoting the installation of radars, buoys, upper air sounding stations, automatic weather stations, satellite data receiving stations and tide gauges.

(ii) Establishment and/or upgrading of meteorological telecommunications including the use of satellite-based circuits, the establishment of highspeed links and the automation of centres.

(iii) Enhancement of the capabilities of national and regional centres for improved forecasting and warning of tropical cyclones and storm surges.

(iv) Installation and upgrading of flood forecasting systems in an increasing number of river basins and monitoring these systems using a specially

designed Management Overview of Flood Forecasting Systems (MOFFS).

(*v*) Promotion, with the cooperation of other agencies, the establishment of a wide range of disaster prevention and preparedness arrangements and measures, including risk assessment, evacuation, dissemination and response to warnings and public education.

(*vi*) Research in meteorology with emphasis on the application of research results to operational use.

(*vii*) Development and implementation of special projects, such as the Typhoon Operational Experiment (TOPEX), regional computer networks, the Special Experiment Concerning Typhoon Recurvature and Unusual Movement (SPECTRUM) and storm surge forecasting models.

(*viii*) Training of personnel through courses, seminars, workshops, exchange programmes, study tours and on the job training. A large part of the effort under the TCP is devoted to human resources development. As an example of training activities, a series of 10-week training courses on tropical meteorology and tropical cyclone forecasting for senior forecasters from around the world is organized biennially by the USA in cooperation with WMO.

5. Global climate change and tropical cyclones

A symposium on global climate change and tropical cyclones was organized by WMO and the International Council of Scientific Unions (ICSU) as part of the Third WMO/ICSU International Workshop on Tropical Cyclones (IWTC-III) (Mexico, 1993). The symposium concluded that direct first-order effects of global Sea Surface Temperature change on tropical cyclone frequency and intensity should not be expected. It further noted that even though the possibility of some minor direct effects of global warming on tropical cyclone frequency and intensity can not be excluded, they would effectively be "swamped" by large natural variability.

The WMO/UNEP Intergovernmental Panel for Climate Change in its Second Assessment Report issued in December 1995, noted that warmer temperatures will lead to a more vigorous hydrological cycle and suggesting a possibility for more extreme rainfall events. The report noted, however, that knowledge was currently insuffient to be specific about any changes in occurrences and geographical distribution of tropical cyclones. Because of the importance of this topic, the WMO Commission for Atmospheric Sciences (CAS) has established a special project which will carry out further assessments of climate change effects on tropical cyclones.

6. Issues requiring urgent attention in the future

6.1. *Research*

Improvements to tropical cyclone forecasts and warnings will require advances in research. In this respect, IWTC-III proposed that highest priority should be accorded to research aimed at the following:

(*i*) Improvement in tropical cyclone position forecasts, at 72 hours, 48 hours and 24 hours, by as much as 20%;

(*ii*) improvement in the basic understanding and forecast accuracy of tropical cyclones structure and their structural changes including rapid changes in intensity, and in wind and precipitation distributions;

(*iii*) identification of the physical mechanisms of propagation of tropical cyclones under various environmental flow conditions;

(*iv*) modelling efforts that further the understanding of motion due to the interaction between the tropical cyclone and its environment;

(*v*) evaluation of all tropical guidance methods in terms of the synoptic situations, storm characteristics (size, intensity, etc.) and translation speed and direction, to facilitate the choice of the most appropriate guidance by operational forecasters;

(*vi*) application of the ensemble forecast techniques to tropical cyclone track forecasting;

(*vii*) provision of a better understanding of the coupling between motion, intensity change and wind structure change; and,

(*viii*) inclusion of the effects of orography and other boundary conditions on tropical cyclone motion.

6.2. *Operational forecasts*

The accuracy of operational forecast depends not only on advances in research but also on the availability

of relevant data and facilities. In turn, the usefulness of these forecasts is a function of the close collaboration with relevant national authorities involved in disaster preparedness. In this regard, the IWTC-III had made the following recommendations:

(*i*) better communication capabilities are needed for centres to receive data and imagery (including Special Sensor Microwave image (SSM/I)), and disseminate warnings in a timely and effective manner. Every effort should be made to have all regional centres connected to high speed GTS circuits.

(*ii*) expanded access to two-dimensional depth-average numerical storm-surge models with high resolution bathometry (and topography) remains a high priority. When such models become available to a particular country and region, attention should be given to develop for each basin an atlas of realistic storm surge cases including composite sets of Maximum Envelopes of Water (MEOW). Centres are also strongly encouraged to archive storm tide and surge data for validation purposes.

(*iii*) Meteorological Centres should seek opportunities to assist:

— disaster preparation agencies in the identification of communities vulnerable to tropical cyclones, and in the preparation of any documentation for mitigation plans;

— in the preparation of relevant data on which commercial companies and civil authority may base accurate risk assessments; and

— municipalities in the drafting of building codes to properly account for the likelihood of encounters with highly destructive tropical cyclones.

In order to implement the priority actions related to research and operational forecast, WMO (through its Commission for Atmospheric Sciences) and ICSU have instituted a "tropical cyclone disasters" project in the context of IDNDR, aimed at:

(a) Providing active support for, and coordination of research programmes aimed at improved understanding and prediction of all aspects of tropical cyclones, including: motion, structure, rainfall, ocean interaction (waves and storm surge, oceanic mixing), extratropical interactions, seasonal variability and climate-change implications.

(b) Investigating new and innovative ways of observing tropical cyclones and of incorporating all available observations into numerical analysis and forecast systems.

(c) Investigating ways in which tropical cyclone warning and response might be improved, especially in developing countries.

7. Conclusions

Since the inception of the Tropical Cyclone Programme, major achievements have been made in satellite monitoring of the tropical oceans, improvement in communication facilities and the upgrading of tropical cyclone warning services in a large number of countries especially the developing ones. The programme for the upgrade in warning services has so far been accomplished through the transfer of technologies by way of specialized training, field experiments (such as the Special Experiment Concerning Typhoon Recurvature and Unusual Movement (SPECTRUM)) and other special projects, the improvement in equipment (such as computers, radars and satellite receivers) and the publication of scientific guidance material, coupled with intensive regional cooperation in operational and technical matters. A feature of this has been the establishment of one RSMC with activity specialization in tropical cyclones in each of the tropical cyclone ocean basins, to provide scientific guidance to national warning centres. The TCP has continually cooperated with other Programmes of WMO in encouraging tropical cyclone research and in fostering the exchange of knowledge between the research and operational communities.

In general, the accuracy of track forecasts and the timeliness of warnings have been steadily improving, though not rapidly, with most of the advances coming during the last fifteen years. That is true even in the advanced Meteorological Services with the state-of-the science in tropical cyclone forecasting methods and services. There is obviously an urgent need to speed up the progress and improve the accuracy of cyclone forecasts, particularly of unusual movement, sudden changes in intensity, and long-range position forecasts. In order to achieve this, the need to improve conventional observations will remain a priority, requiring strong national support. With such a large ocean surface, future improvements in and the

availability of aircraft and satellite-derived data over tropical oceans (such as Special Sensor Microwave image (SSM/1) data and vertical soundings), particularly in the vicinity of tropical cyclones, can be expected to provide the major contributions in the determination of the environmental structure, and thus in the improved predictability of these systems.

Advances in forecasting, the increasing availability of affordable modern technologies and facilities, and the enhancement of the TCP specialized training for tropical cyclone forecasters around the world, will continue to lead to improved forecasting and warning capabilities in developing countries. However, to maximize the effectiveness of warnings, National Meteorological and Hydrological Services (NMHS) must strive towards significantly high standard presentation of weather information to the public and other users, particularly those on tropical cyclones. In addition, improved communication and coordination between the NMHSs and national emergency response agencies must be achieved. In countries where this is done, the number of deaths from tropical cyclones has shown a steady decline over the years, even though material damage remains high. Addressing these issues will continue to be a priority of the Tropical Cyclone and other Programmes of WMO.

The success to-date in implementing the network of tropical cyclone warning systems is based on sustained actions at the national, regional and international levels. Therefore, the World Meteorological Organization, through its Tropical Cyclone Programme, will continue its efforts to remove existing weaknesses in the systems and to work towards narrowing the gap between the developing countries affected by tropical cyclones and those with the appropriate experience and expertise. This activity deserves continued support and attention at national and international levels.