FORECASTING AND WARNING OF TROPICAL CYCLONES IN CHINA

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ABSTRACT

With the development of the global economy, the impact of tropical cyclones has become far-reaching. Thus they are a fundamental issue to be addressed both nationally and globally. The socio-economic impact is particularly noticeable in developing countries, especially China. This paper begins with the effects of cyclones on regional and global economies. Then a brief introduction to the past and current situations and progress in cyclones forecasting and warning in China are presented. Finally the paper gives recommendations about improving and perfecting the tropical cyclone forecasting and warning systems.

Keywords: Tropical cyclones, Forecasting, Warning, China

1 INTRODUCTION

China is one of the countries affected most severely by tropical cyclones. Generally speaking, every year about 27-28 tropical cyclones form over the northwestern Pacific Ocean and South China Sea, and seven of these make landfall over China's coastal areas. There is also a slightly increasing number of those reaching land. Tropical cyclones are the most disaster-inducing weather systems over the Southeast China coastal area from early summer to autumn every year. They often bring a large number of casualties and great damage to the coastal areas with gales, torrential rains, and storm surges during their landfall. They may also cause great damage to inland areas when they interact with middle-latitude synoptic systems during northward motion after landing. On the other hand, tropical cyclones are an important water resource for some Southeast China areas during summer. The intense rainfall that accompanies the storms relieves drought conditions in these areas. Therefore, exact and timely forecasting and warning is of significant importance in the struggle against tropical cyclones in order to mitigate their impacts on the population. In China, because tropical cyclone forecasting and warning have always been of major concern to all levels of government and other organizations, great progress in monitoring, forecasting and forewarning these cyclones has been made.

2 IMPACT OF TROPICAL CYCLONES ON REGIONAL AND GLOBAL ECONOMIES

On the one hand, the high wave of globalization seems to be engulfing almost all corners of our world. On the other hand, weather, climate, and water affect all human activities in general and societal security and national economy in particular. Therefore, the impact of natural disasters induced by the weather, climate, and water events are of increasing concern to the world as a whole. Based on the statistics for the past decade, over 80% of all natural disasters are meteorological in origin. In the 1950s, the total annual loss as result of all natural disasters including severe weather events, earthquakes, and volcano eruptions was 4 billion USD, and the figure increased to 40 billion USD in the 1990s, of which 65% of the economic losses and nearly half of the casualties were results of meteorological and related disasters.

According to data from the World Meteorological Organization (WMO), the top ten natural calamities that threaten human survival are tropical cyclones, earthquakes, floods, thunderstorms and tornados, snow storms, snow slides, volcanic eruptions, heat waves, mud-rock flows, and storm surges. Among these, the death toll of tropical cyclones is the greatest, especially in Asia where damage from tropical cyclones is very severe.

Statistics indicate that the direct annual economic loss as result of tropical cyclones' invasions is about 26.38 billion Yuan RMB with a annual death toll of 440 from 1988 to 2005 (Figures 1 & 2). In 2005, eight tropical cyclones made landfall over China. Six of these became typhoons and two were severe tropical storms. The fastest central wind velocity (59.5m/s) was recorded when Typhoon Khanun (0515) made landfall. Four of six typhoons caused 10-20 billion Yuan RMB of direct economic loss. In these disasters, over 100 people died in Typhoons Talim (0513) and Longwang (0519), and the loss from the cyclones was 39% of that year's total (Figure 3). In contrast, from January to September 2006, seven tropical cyclones made landfall over China's coastal areas, and more than 71 million people and 28,900 km^2 of farmland were affected. 1,261 people were killed, and 420 people were missing. 670 thousand houses were destroyed and 1,360 thousand houses were damaged. Direct economic losses were about 76.4 billion RMB Yuan (Figures 1 & 2).

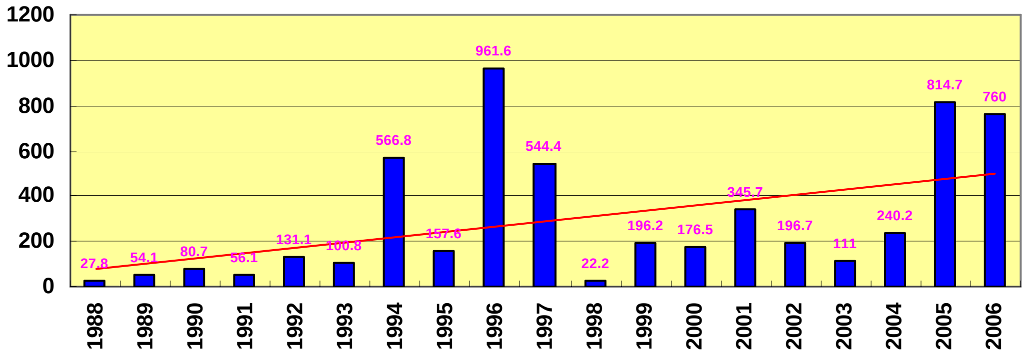

Figure 1. The direct economic loss induced by tropical cyclones in China from 1988 to Oct. 2006 (unit: 0.1billion RMB)

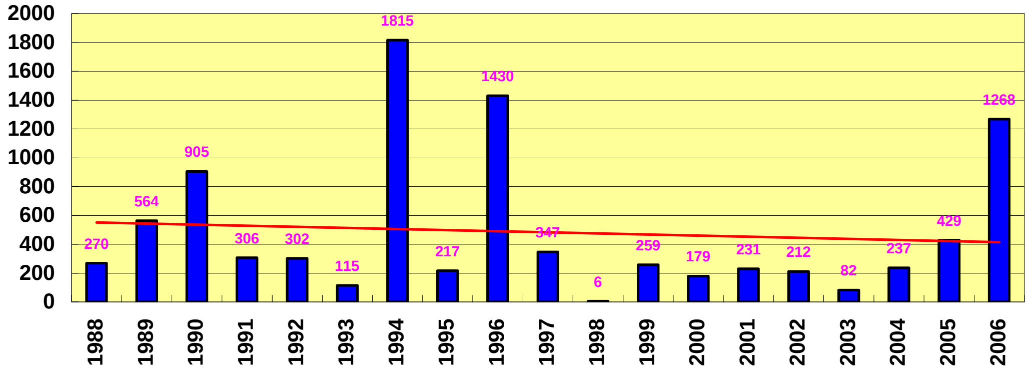

Figure 2. Loss of life from tropical cyclones in China from 1988 to Oct. 2006 (unit: person)

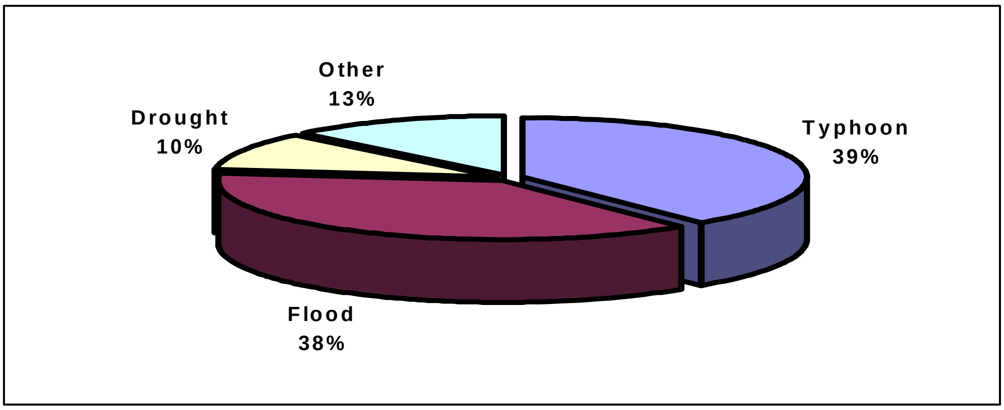

Figure 3. The percentage of direct economic loss from different natural disasters in China in 2005

In general, since the 1950s, along with the improvement of tropical cyclone monitoring capabilities and forecasting skills and because of the effective measures being taken by the government at various levels, the casualties, crop losses, and damage to homes have been decreasing. On the contrary, with the growth of a national economy, the total annual economic loss caused by disasters related to tropical cyclones has been increasing in China. Specifically, compared with annual direct economic losses from 3 to 4 billion Yuan in the 1980s, since the 1990s, economic losses have exceeded 10 billion Yuan RMB. For example, Typhoon Herb (9608) led to an economic loss of 65.27 billion Yuan RMB. Moreover, Typhoon Rananim (0413) gave rise to a direct economic loss of 20.14 billion Yuan RMB. Typhoon Matsa (0509) caused an economic loss of 17.72 billion Yuan. Severe Tropical Storm Bilis (0604) led to an economic loss of 34.83 billion RMB Yuan, and Super Typhoon Saomai (0608) caused an economic loss of 19.65 billion RMB Yuan.

In other areas of the globe, such as Bangladesh, Japan, Philippines, and India in Asia and countries around the Caribbean Sea and North America, tropical cyclones and concomitant gusts, heavy rains, and storm surges often appear. Some tropical cyclones quite often bring about even more serious disasters (Table 1). In November 1970, a severe storm in Bangladesh killed 300,000 people within 3 days. In April 1991, the storm and surges hit 16 of Bangladesh's total 60 communities. The stricken population reached 10 million; 140,000 persons lost their lives, and the direct economic loss was about 3 billion US$.

In 2004, 10 tropical cyclones landed in Japan. The severest of them was the Typhoon Songda (0418), which killed at least 17 persons, with 19 lost and 718 injured. It also caused power cuts, transportation suspension, and about 20,000 persons displaced. In October, another Typhoon Tokage (0423) hit Japan again, causing at least 66 deaths, with 22 lost and 340 injured; 57 houses collapsed, 3,400 buildings were destroyed, and there were many landslides. In the Philippines in 2004, 9 tropical cyclones either landed or affected the country. Severe Tropical Storm Muiha (0425) caused 48 ships to sink, 61 deaths, 80 lost, 101 injured, 27,000 houses collapsed, and the stricken population reached 60,000. In America, 9 tropical cyclones landed on mainland USA. Hurricane Ivan hit islands in the Caribbean and then moved on to southeastern USA. (Figure4), killing at least 43 persons. In Grenada, 90 percent of the buildings suffered some degree of damage. In an earlier time, the eastern US was hit by severe hurricanes Charley and Frances, which caused great economic loss. In the same month, the severe tropical cyclone Jane hit Puerto Rico, Dominica, and Cuba successively, killing at least 1,128 persons, with 1,251 lost and a direct economic loss of several hundred million US$.

Table 1. A list of major casualties around the world caused by tropical cyclones or hurricanes and associated storm surges. Source: Dr. S. K. Dube, Technical Report of Working Group on Tropical Cyclone, 31st WMO/ESCAP Tropical Cyclone Committee Meeting, and the Centurial Tropical Cyclone Website, a project on landing TC monitoring and forecasting techniques, Chinese Academy of Meteorological Sciences.

Year	Country/Territory	Number of Casualties
1970	Bangladesh	300,000/500,000
1737	India	300,000
1886	China	300,000
1923	Japan	250,000
1876	Bangladesh	200,000
1897	Bangladesh	175,000
1991	Bangladesh	140,000
1922	China	Over 70,000
1833	India	50,000
1864	India	50,000
1822	Bangladesh	40,000
1905	China	26,000
1780	Antilles Islands (West Indian Islands, L.A)	22,000
1965	Bangladesh	19,297
1999	India	15,000
1963	Bangladesh	11,520
1961	Bangladesh	11,466
1985	Bangladesh	11,069
1906	China	Over 10,000
1971	India	10,000
1977	India	10,000
1966	Cuba	7,196
1900	United States	6,000
1960	Bangladesh	5,149
1960	Japan	5,000
1972	India	5,000

In 2005, seven tropical cyclones hit the US mainland - three as tropical storms (Arlene, Cindy, and Tammy) and four as hurricanes (Dennis, Katrina, Rita, and Wilma). This put the 2005 season in a tie for second place for storms making landfall, just behind the 1916 and 2004 seasons, when eight named storms hit land. Hurricane Katrina swept across Mississippi (Figure 5), Alabama, and western Florida. The majority of homes and businesses along the western Mississippi coastline were either damaged or destroyed. In New Orleans, meanwhile, about 80% of the city flooded after a storm surge breached several levees. Inland effects included high winds and some flooding in the states of Alabama, Mississippi, Florida, Tennessee, Kentucky, Indiana, Ohio, and Georgia. A preliminary estimate was approximately $125 billion in damage/costs, making this the most expensive natural disaster in U.S. history; approximately 1,833 deaths - the highest U.S. total since the major 1928 hurricane in southern Florida.

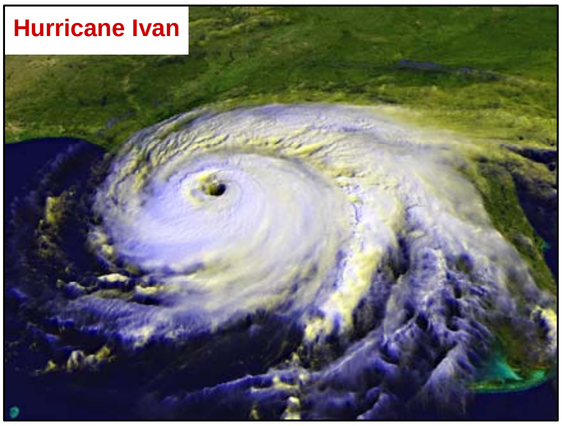

Figure 4. The terrible Hurricane Ivan on 15 Sept. 2004

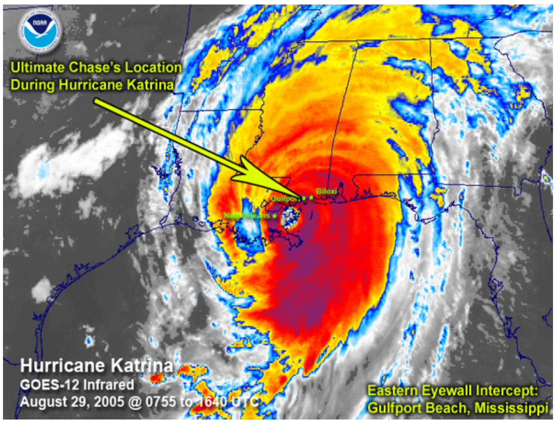

Figure 5. Hurricane Katrina's Landfall: Gulfport Beach, Mississippi, August 29, 2005

3 PROGRESS OF TROPICAL CYCLONE MONITORING IN CHINA

Currently, with consistent efforts made over many years, substantial progress has been made in tropical cyclone monitoring using such methods as satellites, radar, and Automatic Weather Stations (AWS).

3.1 Satellite Remote Sensing

As in many other countries, China depends mainly on satellites for tropical cyclone detection. So far, China has launched four polar-orbiting meteorological satellites (FY-1 series) and three geo-stationary meteorological satellites (FY-2 series). The FY-1C has been functioning for nearly five years, and the FY-1D has been operating normally for about three years. The FY-2B has been put into a geo-stationary orbit for two years, and the FY-2C has just been put into operation in 2005. These two series of meteorological satellites constitute the tropical cyclone monitoring network in China (Figures 6 & 7).

For more 30 years, China has had a satellite data receiving and processing system, which receives and handles different satellite data on a timely and accurate basis, and a number of products have been developed for tropical cyclone characterization and applications. All this information has become a useful tool for tropical cyclone detection and monitoring. The regional and global satellite data, which has been accumulating for years serves as a solid basis for tropical cyclone–related research and data sharing.

3.2 Weather Radar

Weather radar is one of the key means of monitoring and forecasting tropical cyclones. Considering its higher temporal and special resolutions and its timely and accurate detecting capacities, weather radar has proven to be a very effective tool for tropical cyclone monitoring and forecasting. According to requirements for its operational development, the China Meteorological Administration (CMA) has worked out a national weather radar deployment plan in coordination with relevant authorities, in which 158 Doppler weather radar sets are planned for China, in which jointly installed weather radar sets will act as a unified radar network to share radar observations, ensure timely acquisition of radar data, and make full use of radar resources in a comprehensive manner. Based on quality control, all weather radar data can be shared nationally through high-speed information networks. Up until now, 105 sets of Doppler radar have been installed and put into operation (Figures 8 & 9).

3.3 Automatic Weather Stations

With substantial support from local governments, CMA has mobilized financial resources to establish several AWS networks for meso- and small-scale meteorological observations and some automatic rain-gauges at provincial levels within the CMA framework. Our operational practices demonstrate that AWS and other automatic instruments have played a key role in pinpointing tropical cyclone tracks and landing times. Up until now, 12778 sets of AWSs have been put into operation (Figure 10).

Furthermore, other tropical cyclone monitoring technologies like AMDAR, GPS, wind profiler soundings (Figure 11), and mobile meteorological offices have been utilized for just this purpose. The set-up and operating of mobile meteorological offices have significantly improved in-situ meteorological observations and on-the-spot service capabilities.

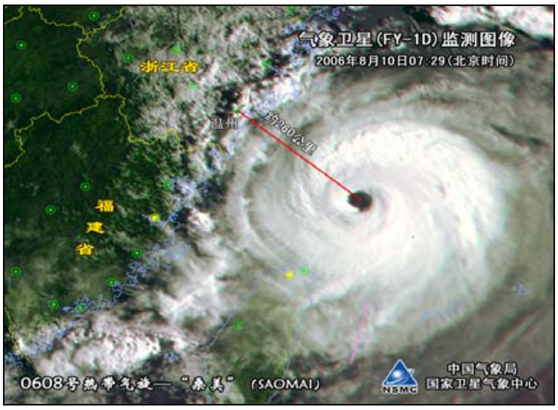

Figure 6. FY-1D Image at 23:29UTC on Aug. 9, 2006

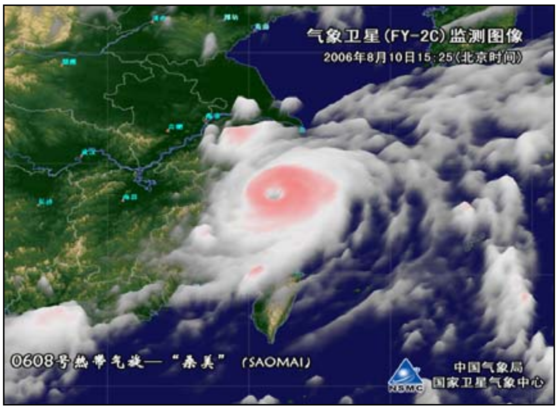

Figure 7. FY-2C Image at 07:25UTC on Aug. 10, 2006

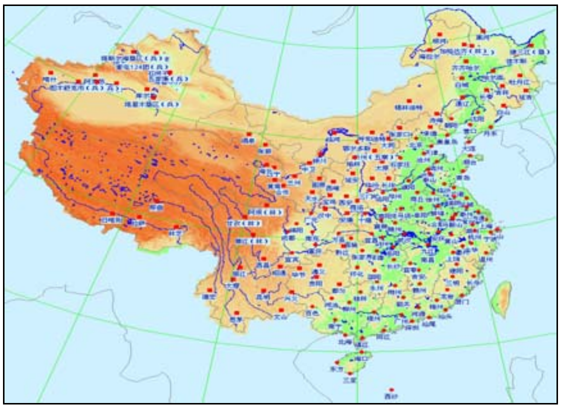

Figure 8. China's Doppler Radar deployment plan

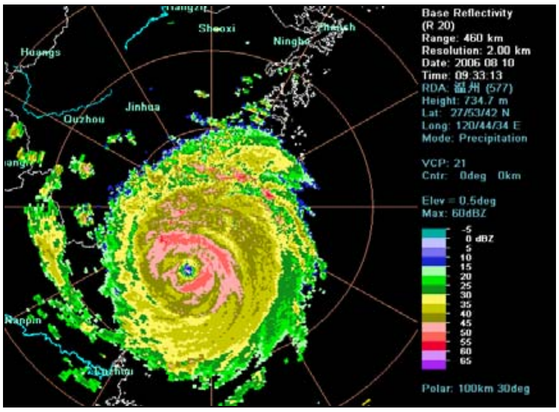

Figure 9. Wenzhou Radar at 09:33UTC on Aug.10, 2006

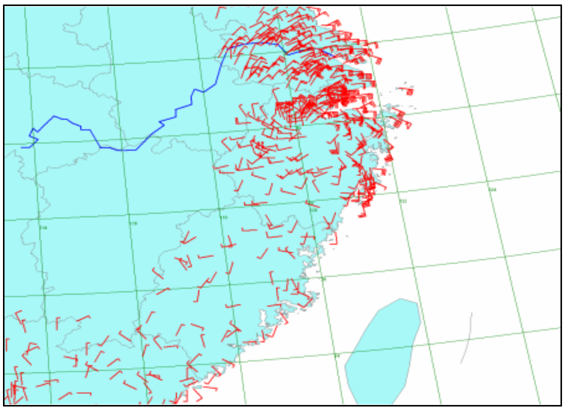

Figure 10. China's AWSs net (every 10 minutes)

Figure 11. Wind Profiler System

4 PROGRESS IN OPERATIONAL TROPICAL CYCLONE FORECASTING

4.1 Tropical Cyclone Track Forecasting

The operational tropical cyclone track forecasting, at almost all national forecast centers, was once based on forecasters' experience and their synoptic judgments. Since the 1990s, with increasing improvements in tropical cyclone numeric prediction skills, particularly with improved tropical cyclone ensemble forecast techniques built upon multiple dynamic models, operationally subjective tropical cyclone track forecasting has witnessed considerable progress, and track errors have been greatly decreasing on an annual basis (Figure 12). For now, in operationally subjective tropical cyclones track forecasting: the 24 hour error is 140 km; the 48 hour error is 250 km, and the 72 hour error is about 380 km.

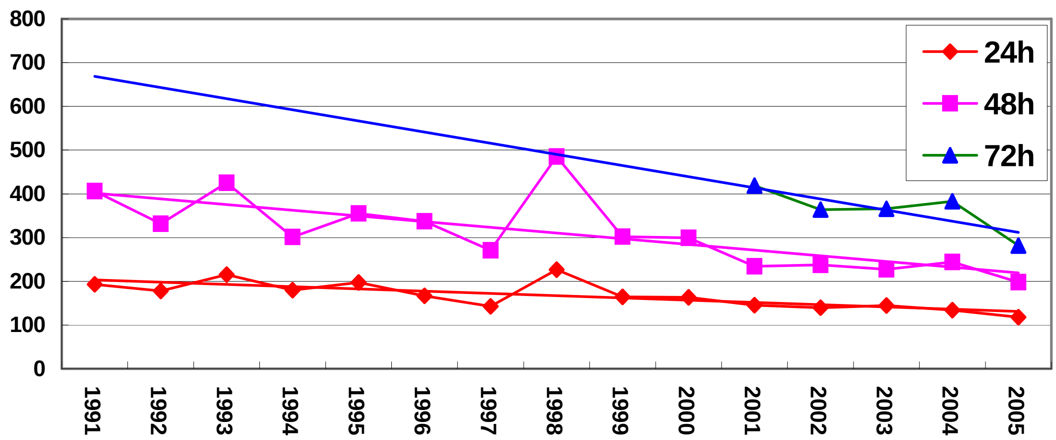

Figure 12. CMA mean TC track forecast errors within 24, 48 and 72 hours from 1991 to 2005 (unit: km)

4.2 Tropical Cyclone Intensity Forecast

All weather forecast centers have been working on improving operational tropical cyclone intensity forecasts for the past two decades. They have developed new dynamic models for improved intensity forecasts, Geophysical Fluid Dynamics Laboratory (GFDL, US), Global Forecasting System (GFS, US), US Navy Operational Global Atmospheric Prediction System (NOGAPS, US), and UK Meteorological Model (UKMET, UK), while continuing to use climate persistence methods (Statistical Interpretation by CMA and Statistical Hurricane Intensity Forecast model (SHIFOR) by NHC/NOAA), and the Statistical Hurricane Intensity Prediction Scheme (SHIPS) by NHC/NOAA. At present, the mean tropical cyclone track forecast errors within 24, 48, and 72 hours vary from country to country, approximately 10, 15, to 20h Pa respectively (Table 2).

Table 2. JMA mean tropical cyclone forecast errors in tropical cyclone intensity forecasts

Root Mean Square Errors (RMSEs) of 24-, 48- and 72-hour Operational Central Pressure Forecasts (hPa)			
Year/time	24h	48h	72h
2000	13.0	N/A	N/A
2001	10.9	15.6	N/A
2002	10.8	15.3	N/A
2003	11.0	15.3	18.5
2004	11.4	16.1	18.6
2005	12.8	17.0	19.0

4.3 Strong Wind and Heavy Rain Forecasting

At present, the CMA has no objective methodology for operational forecasts of strong wind and heavy rain induced by tropical cyclones. The local weather bureaus in areas affected by tropical cyclones have to, according to their own needs, develop quasi-theoretical and quasi-empirical techniques or diagnostic statistical methodologies to forecast the intensities and locations of strong wind and heavy rain. However, in the U.S.A., where potential hurricane impact is severe, a real-time in-situ analysis and warning system based on ground radar, surface data, and GIS information has been developed. Meanwhile, research efforts are being made to estimate rainfall by unconventional means including satellites, ground and airborne radar, and the impact of microphysical processes on precipitation. Finally, attempts have been made to use Numerical Weather Prediction Models (NWP) to operationally forecast wind and rain associated with hurricanes.

5 IMPROVEMENT IN THE OPERATIONAL TROPICAL CYCLONE WARNING SYSTEM

Some progress in operational tropical cyclones warning and service systems have focused on the following during recent years in China:

5.1 Regulations on Meteorological Disaster Prevention

The China Meteorological Administration issued, subject to the approval of the national government:

- A Contingency Plan for Significant Meteorological Disaster
- The Procedure for Issuing Unexpected Meteorological Disaster Early Warning Signals (trial)
- The Guidance on Meteorological Disaster Early Warning Signaling and Preventative Actions
- Provisional Rules on News Release of Major Meteorological Information
- Rules on Collection, Survey and Evaluation of Meteorological Disasters.

In this connection, the CMA has also worked out a 4-level warning signal and associated rules for issuing (Figure 13), set up a regular (monthly) new release system for meteorological information and for disasters and a direct reporting and evaluation system for meteorological disasters. In the framework of Meteorological Law, CMA has prepared Regulations on Meteorological Disaster Prevention.

Figure 13. China's operational 4-level tropical cyclones warning signals system

5.2 Revision of the Grade Standard of Tropical Cyclones

The CMA organized a revision of the China National Grade Standard of Tropical Cyclones from 2005 to the beginning of 2006. The revised standard has been taken and put into operational TC forecasting and warning since June 15, 2006 (Table 3). The revised standard plays an important role in strengthening operational tropical cyclone forecasting and warning and improving public and governmental awareness and measurements for prevention and preparedness against tropical cyclones in China.

Table 3. Revised Grade Standard of Tropical Cyclones in China

Grade of Tropical Cyclone	Maximum Sustained 2 minute Wind Speed	Wind Scale
Tropical Depression（TD）	10.8-17.1m/s	6-7 level
Tropical Storm（TS）	17.2-24.4m/s	8-9 level
Severe Tropical Storm (STS）	24.5-32.6m/s	10-11 level
Typhoon（TY）	32.7-41.4m/s	12-13 level
Severe Typhoon （STY）	41.5-50.9m/s	13-14 level
Super Typhoon（Super TY)	⩾51.0M/S	⩾ 15 level

5.3 Investigation after a Tropical Cyclone landing

The amount of disaster or breakage induced by tropical cyclones, especially the destruction produced by gale force wind, differs according to the intensity and landing site of the storm. It is very important to understand the variation in disaster or losses related to tropical cyclones of different intensity levels. Therefore, in September 2006, the CMA initiated an investigation of tropical cyclones making landfall in China from 1996 to 2006. This work is responsible for drafting a literal referenced description of the degree of disaster or loss related to the different levels of tropical cyclones. This work is still under development.

6 RECOMMENDATION FOR THE NEXT STEP

6.1 Observing Systems for Tropical Cyclones

China started applying meteorological satellites to tropical cyclone remote sensing in the 1980s. Satellite information including derived satellite data has been used for tropical cyclone monitoring ever since. This capability enables China to receive, process, and archive satellite data from both home and abroad. However, compared with advanced international standards, China still lags behind in its satellite remote-sensing technologies, data acquisition, and processing. There is still much room for improvement in this area. On the application side, major gaps exist in producing quantitative satellite products to satisfy operational application requirements, and our quantitative applications are rather weak. Problems still exist in the fields of radar data transmission and radar products applications. There are a number of issues to be tackled in AWS data quality control, data collection, etc. In addition, because of the availability of massive tropical cyclone data such as that from the new-generation Doppler radars, lightning positioning systems, GPS/MET observations, wind profilers, a greater stress has been put on the existing communication networks.

CMA's response strategies concerning observation systems are as follows:

- Strengthening operational observation by satellites. The second group of two FY-2 satellites will be launched, i.e. FY-2D and FY-2E. The two satellites will maintain continuous operations until 2012, to ensure stable meteorological satellite observations and services.
- Accelerating the deployment of a radar network. A nationwide weather radar observation network will be set up, which is based on the S-band and C-band Doppler weather radars as the major components, while other types of weather radars are also interconnected with a view to improving tropical cyclone monitoring.
- Increasing AWS coverage. In order to improve tropical cyclone monitoring, appropriate considerations have been given to increase AWS deployment, particularly in islands (those far away from the coast have a higher priority) and coastal areas of higher tropical cyclone and torrential rain occurrences.

6.2 Data Transmission and Sharing

At present, the traditional GTS network still plays an important role in providing meteorological services. With almost 10 years' worth of effort, meteorological telecommunication in China has been developed into a new stage supplemented by a Very Small Aperture Terminal (VSAT) system that is based on satellite telecommunications. In recent years, a broadband communication network based on public communication networks has been under construction. It has already played an important role in tropical cyclone monitoring and early warning. The national main telecommunication network is in transition from a dedicated meteorological network toward a combination of public and private networks, from narrowband to a broadband network, and from single to multiple applications, in order to meet the demand for data exchanges and sharing. Modern communication technologies such as broadband networks and satellite communication and mobile phone short-message services have proven to be effective means for visual discussions, data transmission, and rapid dissemination of tropical cyclone information for the future.

6.3 Joint Experiment in Relation to Tropical Cyclones

For some years, the development of observation technologies and the wider application of remote-sensing data have given impetus to operational tropical cyclone forecasting and scientific field experiments on tropical cyclone landfalls at a regional level. At present, outfield tropical cyclone experiments and related research programs on tropical cyclone landfalls are constantly emerging around the globe, including TOST, CBLAST, ATCCIP, DOTSTAR, CLATEX, and the accomplished TCLP. All these experiments lead to further understanding of such characteristics as the tropical cyclone boundary layer in the context of strong wind, changes of meso-scale structure and intensities, etc., which unveils new observations of the inner structure of a tropical cyclone and promotes the development of operational tropical cyclone intensity forecasts during the process of tropical cyclone landfall. However, tropical cyclone field experiments cannot be conducted continuously because of technical reasons or lack of funding. It is, therefore, necessary to strengthen international cooperation in tropical cyclone field experimentation within the region or in a larger area, in order to reveal, as soon as possible, the physical mechanism governing the movement and intensity of tropical cyclones.

6.4 The Impact of Climate Change on Tropical Cyclone Activities

At present, there is still no certainty of how global climate change will impact global and regional tropical cyclone activities, but past studies indicate that global warming might reduce, to some extent, tropical cyclone activities globally, while tropical cyclone intensity in the future may become stronger. In recent years, strong tropical cyclones have hit the U.S., Japan, and China more frequently, which, perhaps, is an important signal of the impact of global warming on tropical cyclone activities. Of course, the trend deserves further attention by meteorologists from various countries and needs to be further proven on a scientific basis.

6.5 Research on Monitoring and Forecasting Tropical Cyclones

There are a number of difficulties and challenges in theoretical research on operational tropical cyclone forecasts. For example, an effective method is lacking for forecasting abrupt changes of tropical cyclone motion and speed including abrupt changes in its structure and intensity and the unexpected increase of associated heavy rainfall during the landfall. Future tropical cyclone research should emphasize:

- The 3-dimensional inner structure of a tropical cyclone. The evolution of a tropical cyclone is closely related to its structure. With the development of detection technologies such as satellites, radar, etc., more refined meso-scale and small-scale structures inside the tropical cyclone, including the characteristics of the tropical cyclone boundary layer, will be revealed. These will be helpful in improving forecasting capability.
- The mechanism behind the abrupt changes of tropical cyclone tracks and intensities. Several theories have been proposed addressing the abrupt change of tropical cyclone tracks. NWP can also be effective in forecasting unexpected tropical cyclone tracks. Comparatively speaking, it is more difficult to forecast tropical cyclone intensity changes than to predict tropical cyclone tracks. Moreover, intensity changes often lead to abrupt track changes. However, there is little research on the mechanism of abrupt tropical cyclone track changes, and the research in this area should be strengthened.
- The impact of the interactions between weather systems at different scales and between atmospheric

circulations at different latitudes upon tropical cyclones. Current research on such impacts still hinges on factors or phenomena analysis. Further research should be carried out on physical processes and mechanisms.

Present research mainly covers tropical cyclone tracks and intensity and seasonal forecasting as well as the impact on human life. Advanced detecting technologies such as aircraft reconnaissance and dropsonde, wind profiler and Doppler radar, and satellites provide useful tools for research. Research on tropical cyclone tracks has placed emphasized weather detection, numerical research, and ensemble forecasts based on dropsondes. Research on tropical cyclone intensity focuses on wind field retrievals from airborne Doppler radar observations, the impact of air-sea interactions on tropical cyclone intensity changes, and 3-D tropical cyclone structure simulations. With respect to the impact of tropical cyclones, great efforts have been made in establishing and improving the real time surface analyzing and warning system based on radar and surface data and the Geographical Information System (GIS). Meanwhile, research on precipitation forecast and the impact of different microphysical processes on precipitation has been conducted by using advanced means including satellites, ground based and airborne radar, etc. Furthermore, research on tropical cyclone landfalls aims at improving numerical tropical cyclone prediction systems through field experiments, reducing tropical cyclone track and intensity errors by 20%, and further improving the validity and accuracy of tropical cyclone-induced strong wind and its range forecasts, including the validity and accuracy of tropical cyclone warnings and Quantitative Precipitation Forecasts.

6.6 An Operational Platform for Tropical Cyclone Forecasting

A new-generation tropical cyclone forecasting platform will include the following functions:

- Historical Database Retrieval System for accessing meteorological elements and atmospheric fields of tropical cyclones;
- Identification of the best track. The best tropical cyclone track will be calculated automatically according to the locations and intensities of the tropical cyclone center defined by various measurements provided by satellite, Dvorak technology, aircraft and dropsonde observations;
- Production of tropical cyclone track forecasts. After inputting the best track into the system, the numerical models and an ensemble forecast system should generate tropical cyclone track products. Then, a final track forecast could be made by combining these results with the forecasters’ judgments and experience;
- Tropical cyclone intensity forecast. A final intensity forecast could be made on the basis of the tropical cyclone intensity output from the numerical models and relevant statistical models, taking into consideration the factors that affect tropical cyclone intensity as well as the experience of the forecasters;
- Warning issuance. An assessment of tropical cyclone-related disasters will be made, and then tropical cyclone warnings will be prepared for dissemination of tropical cyclone warning products and relevant information;
- Tropical cyclone warnings standardization and verification.

6.7 Risk Management for Tropical Cyclones

The existing tropical cyclone disaster assessment and decision-making systems are inadequate in terms of the timely reception of complete information about disasters related to tropical cyclones. The assessment of tropical cyclone disasters is often undertaken long after the event has taken place. Disaster information via satellite has not been analyzed and utilized in a timely fashion. Therefore, decision-making authorities cannot be well informed with timely disaster information about the affected areas, which are badly needed for taking proper and effective mitigation measures to reduce the loss of lives and properties. On the other hand, the current disaster assessment methods seem to be too simple and primitive.

Therefore, assessment for disasters related to tropical cyclones should be further enhanced in order to improve disaster risk management. Moreover, the emergency preparedness and response system for tropical cyclone disasters as well as the relevant data exchange networks should be strengthened in order to provide improved forecasting and services. Meteorological establishments at all levels in China will enhance the disaster assessments and fully demonstrate our professional and technological capabilities to better incorporate meteorological investigations and assessments on high-impact disasters into the governments' natural disaster prevention and mitigation system, according to the Meteorological Law of the People's Republic of China.

The risk management and assessment system for disasters related to tropical cyclones should include the following:

- Research on tropical cyclone behavior;
- Analysis of the capacities of prevention and mitigation against disasters in populated, economically developed areas;
- Development of a disaster information database;
- Research on disaster damage assessment methodology;
- Comprehensive assessment of the multi-disasters induced by tropical cyclones;
- Verification of the usefulness of forecasting;
- Response strategies for disaster prevention and mitigation.

6.8 Early Warning System for Tropical Cyclones

The current operational tropical cyclones forewarning system will be further improved, and timely and user friendly modern warning and forecasting services will be developed, in order to provide governments and relevant authorities at all levels and the general public with tropical cyclone forecasts and information about associated disasters including response strategy services. Guided by the concept of "public meteorology, security-oriented meteorology, and natural resource-oriented meteorology," the CMA will meet the evolving demands of socio-economic development on a public meteorological service, and it will expand the coverage of meteorological early warnings, establish interactions with the agencies such as water resources, civil aviation, land resources, agriculture, construction, safety supervision, and media improve the coordinated emergency response mechanism, and incorporate the meteorological service into the government's public service system.

6.9 Public Awareness of Disaster Preparedness and Mitigation

The increasing public awareness of preparedness and mitigation of disasters related to tropical cyclones should include the following:

- Professional training;
- Management training;
- Outreach and education to increase public awareness.

Public awareness and knowledge about combating tropical cyclone-induced disasters and the public's active participation in preventing and combating these disasters are key components of disaster preparedness and mitigation. However, insufficient knowledge about tropical cyclone disasters and a small sense of participation often serve as a bottleneck that restricts effective efforts in preventing and mitigating tropical cyclone-induced disasters.

6.10 International Cooperation

The relationship among international organizations, such as WMO, the WMO/ESCAP Typhoon Committee, and WMO/ESCAP Panel on Tropical Cyclones, the government and its administrative departments, education and research institutions, monitoring, forecasting, and warning operative departments of tropical cyclones must be enhanced, and effective regional cooperation and exchange mechanisms for monitoring, forecasting, and warning technology and measurements to mitigate the disasters of tropical cyclones must be established.

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