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SIXTH INTERNATIONAL WORKSHOP on TROPICAL CYCLONES

Topic 0.3 : **Observations and Forecasts of Rainfall Distribution**

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Abstract

Tropical cyclone rainfall rate and distribution is a most important issue for tropical cyclone landfall area. High impact weather and extreme events will be closely connected with rainfall brought about by landfalling tropical cyclones. There are several parts of rainfall observation forecasting techniques and physical processes etc. to be included in this report.

Remotely sensed observation is a most important means for quantitative precipitation estimation (QPE) of the tropical cyclone rainfall. It includes TRMM.SSM/I, AMSU and infrared and visible data from satellite as well as the doppler radar reflectivities. On the other hand, conventional surface observation, dense spread rain gauges and automated weather stations can provide tropical cyclone rainfall basic data. To mix together those data from different sources with certain data processing techniques could provide quantitative precipitation estimation (QPE) with a certain error.

A variety of forecasting techniques have been employed in quantitative precipitation forecasting (QPF) associated with landfalling tropical cyclones. Limited area models or meso scale models have been developed and used in operational forecast by many tropical cyclone forecasting centers around the world. Remotely sensed data assimilation has improved the initialization of the model and the rainfall forecasting accuracy for some of the forecasting centers. Furthermore, ensemble forecast method has been designed and employed for rainfall forecast in some of the centers as well. The effectiveness and improvements of ensemble forecasting would be evaluated in near future. Statistical scheme and statistical combined with dynamical approaches have also been used in tropical cyclone rainfall forecasting which could provide certain basic background to QPF. Empirical model is quite valuable for the forecast of rainfall distribution and intensity of landfalling tropical cyclones. Some rainfall mechanisms or physical concepts are being considered in model design.

Some studies on tropical cyclone rainfall have been carried out in different institutes. Some valuable mechanisms related to rainfall distribution and intensity are found from those researches which are related to boundary layer transfer, surface and topography effect, meso scale system genesis and growth, energy fluxes and budget, extratropical transition (ET) processes, interaction between different motion scale or between different latitude systems etc. This would back up the improvements of tropical cyclone rainfall forecasting.

0.3.1 **Introduction**

Tropical cyclone landfall involves several important issues including structure / intensity change and track turning when it approaches coastal area, sustention and decay over land, storm surge, wind strength and rainfall. Landfalling tropical cyclone rainfall is one of the most complex issues. Interaction among ocean, atmosphere and land topography should be considered when tropical cyclone approaches the coastal area.

Most of the severe disasters or catastrophes were often caused by heavy rainfall of a landfalling tropical cyclone which could result in flash flooding, reservoir collapses and debris flow to threaten the loss of lives and properties. Especially in recent two years, extreme weather events and disasters from landfalling tropical cyclone occurred in both Pacific and Atlantic coastal regions frequently, such as super typhoons Rananim (2004), Haitang (2005), Matsa (2005) and Saomai (2006); super hurricanes Ivan (2004), Jeanne (2004) and Katrina (2005), Rita (2005) etc. Some of the damage was caused by heavy rainfall from those typhoons and hurricanes. In this connection, accurate forecasts and warnings on tropical cyclone rainfall will play an important role for disaster prevention and preparedness.

Tropical cyclone rainfall forecasting techniques are much more lagging behind to the track forecast. But significant progress has been made in recent years because the remotely sensed techniques and numerical model as well as the data assimilation techniques have been developed speedily. Several years ago, forecasts on rainfall distribution and intensity associated with tropical cyclone landfall depended on the forecaster's subjective estimation along with their experiences. But now, the quantitative precipitation forecast (QPF) of tropical cyclone has been developed in many forecasting centers around the world.

0.3.2 **Tropical Cyclone Rainfall Observations**

Remotely sensed data from satellite and radar are quite effective to reflect the rainfall of intensity and distribution. The Tropical Rainfall Measuring Mission (TRMM) is the first meteorological satellite loading Precipitation Radar (PR). It together with on board Visible and Infrared Scanner (VIRS) and TRMM Microwave Imager (TMI) provide a powerful capability to observe cloud precipitation. 19 landfalling tropical cyclones were selected to study the rainfall observation (Cheng 2006) with TRMM PR data measuring average area percentage (A.P) and the precipitation intensity (API) for different type of precipitation. The results show that the precipitation from both convective and stratiform are nearly the same probability density functions before and after tropical cyclone landfall. Their case studies also show that the precipitations derived from digital reflectivity of TRMM were agreeable well with that from ground radar observations.

The tropical cyclone quantitative precipitation estimation (QPE) has been developed and put into operational use with Fy-2C satellite digital products by NSMC[1)] China since 2005. The relationship between tropical cyclone precipitation measured by surface observation and digital data from Fy-2C was set up. TBB data and cloud classification can be utilized to analyze the development and distribution of convective cloud bands and rainfall distribution. SSM/I and AMSU data are also useful to estimate the potential maximum rainfall of the landfalling tropical cyclones. They set up the cloud profile data base with microwave data. Surface precipitation can be calculated from a cloud profile selected from the profile data base which is analogous to the observed one.

Radar reflectivities have widely been used to estimate the rainfall intensity and distribution of tropical cyclones. Some techniques have been developed to find the relationship between radar rainfall and true rainfall. The rainfall could be calculated from certain algorithms from relationship between radar reflectivities and observed rainfall. But the algorithms vary with different locations and rainfall properties.

Some methodologies blending rain gauge data and radar data have been developed to estimate the rainfall rate and distribution (C. Velasco-Forero 2006)

[1)] National Satellite Meteorological Center

However, a lot of uncertainties still exist in precipitation estimation with either satellite data or radar reflectivities. The sources of these errors are various from both systematic and random errors. Those road blocks should be overcome through further development.

0.3.3 **Tropical Cyclone Rainfall Forecast**

Limited area model or meso scale model with advanced data assimilation has become a major methodology for tropical cyclone quantitative precipitation forecast (QPF). A non-hydrostatic meso scale model (MSM) is being run in Japan Meteorological Agency (JMA) to predict several phenomena such as heavy rainfall. The result is used by Very Short Range Forecast (VSRF) of precipitation which provides 6-hour quantitative precipitation forecast updated every 30 minutes (Hara 2006). The rainfall forecast is based on extrapolation of latest observed precipitation in first 3 hours then the model results is combined with extrapolation in the later half. The weight of MSM prediction is increased in the forecast time afterwards since the extrapolation capability is rapidly decreased. JMA has upgraded MSM in March 2006. The horizontal resolution was increased from 10km to 5km. Daily runs were increased from 4 times to 8 times.

Another QPF scheme was developed by Shanghai Typhoon Institute. They use the satellite IR/TBB data blending with hourly rain gauge data to found the QPE method for landfalling tropical cyclones. Based on QPE, very short term of 3 hour tropical cyclone rainfall forecast can be implemented with extrapolation.

Rainfall ensemble forecasting systems have been designed and developed in many meteorological centers around the world. It could provide the probability of the occurrence on strong rainfall amounts. A super ensemble prediction system based on non-hydrodynamic meso scale model (MM5) has been developed by Institute of Plateau Meteorology China for rainfall forecast. The multi-physical perturbation scheme and multi-initial condition perturbation method were adopted to focus on the uncertainty of heavy rainfall event forecast in East Asia.

Statistical-dynamical approaches are also employed in some of the forecasting centers which could provide rainfall forecast as well. NCHMF[1)] Vietnam has developed a model output dynamic (MOD) approach which utilizes dataset of the output from numerical prediction model and rain observational data. MOD provides 6 hourly rain amount and its distribution forecast.

Statistical methods could provide a longer period (1-2 days) rainfall trend forecast or accumulated amount precipitation forecast with some techniques to select some analogue cases from data base. Certain criteria such as season, track and landfalling spot, topography characteristics etc. need to be set to select the analogue samples. The rainfall accumulated amount and its geographical distribution and other information from the analogue cases with certain data processing techniques could provide tropical cyclone rainfall forecast. Statistical methods also can provide a climatic background for rainfall forecast, such background can be derived from the historical data statistics. The basic background from statistics is valuable to the tropical cyclone rainfall forecast.

The real time operational forecasting on rainfall rate and distribution in many forecasting centers would have a comprehensive manner. Based on tropical cyclone accurate intensity and track forecast, rainfall climatic background should be checked over. Numerous numerical models such as global model, limited area model, ensemble model etc. produce the products related to tropical cyclone rainfall prediction which should be put into comparison and checked with the satellite remotely sensed data, radar relfectivities, densely distributed rain gauge data and other QPE products. Anyway, the forecaster’s practical experiences and empirical concept are still valuable to tropical cyclone rainfall forecast. The final decision is usually made from the result of comprehensive consideration with those

[1)] National Center of Hydrological and Meteorological Forecast

QPF and QPE products.

Rainfall forecast will not be convertible to flood forecast if without hydrological model. There are several important uncertainties in the hydrological model forecast. Rainfall distribution and rate forecast and surface runoff / precipitation amount are the sensitive initial conditions for hydrological model to predict flood. It shows that flash flood forecasts are heavily dependent on tropical cyclone rainfall rate and distribution forecast.

0.3.4 **Physical Processes for the Tropical Cyclone Rainfall**

The rainfall intensity and distribution associated with landfalling tropical cyclones are closely related to the flowing physical processes.

0.3.4.1 **Moisture Supply**

Basic factor of the tropical cyclone rainfall is the moisture transportation which usually can be distinguished from the satellite images or radar reflectivities. Tropical cyclone heavy rainfall would be stronger with a moisture supplying channel connected than that without a moisture channel.

Typhoon Meari (2004) made landfall in Kyushu Japan at 08:30 (JST) 29 Sep. Heavy rainfall was occurred in Kii Peninsula even 500km far away eastward from the center of Meari. A set of numerical simulation was performed (Murata 2006) with Japan Meteorological Agency Non-Hydrostatic Model (JMANHM) with grid spacing of 5km. Five sets of initial data were used: 2100 JST 27 Sep. and 0300,0900, 1500, 2100, JST 28 Sep. The results show that the heavy rainfall was well simulated in two experiments and weak rainfall in other three. The major difference between the two group simulations is the group with heavy rainfall reproduced have relatively large amount of precipitation water compared with another group of simulation. It suggests that moisture plays a critical role in the occurrence of the heavy rainfall in both real and model atmosphere.

Huge lakes, rivers, enormous reservoirs in land surface are also the sources to transfer the moisture to landfalling tropical cyclone when it covers those water source areas. A numerical investigation (Shen W. Ginis 2002) showed that the water surface over land would be favorable to decrease the decaying rate of the landfalling hurricanes. The decaying rate of the landfall tropical cyclone over water surface on land would have direct ratio with the water depth.

On the other hand, a numerical simulation (Ying li et al. 2005) also showed that the moisture flux transfer of boundary layer over saturated wet soil ground would be favorable to landfalling tropical cyclone sustaining over land. Those land surface processes transfer the latent heat energy to the remnant of landfalling tropical cyclones which are also favorable to increase the rainfall of the cyclone over land. This is a rainfall feedback effect to increase further precipitation.

0.3.4.2 **Extratropical Transition (ET)**

Some investigations exhibit that heavy rainfall caused by a weak remnant of landfalling tropical cyclone may exceed the rainfall caused by strong typhoon in its landfalling stage. It is uncertain that the rainfall has direct ratio with tropical cyclone intensity.

Many cases demonstrate that landfalling tropical cyclone would be dissipated sooner or later except it obtains baroclinic energy from the mid-latitude in an extratropical transition process.

Interaction between the tropical cyclone and mid-latitude weather system is an important topic including tropical cyclone extratropical transition. Observational and numerical simulation studies (Lei, 2004, Zeng 2002) showed that a tropical depression produced 304mm/24h rainfall exceeding most of the rainfall from typhoons. This rainfall was created in the interaction between the tropical depression and cold wave from the mid-latitude or in the process of extratropical transition of the tropical depression. Other study (Ying Li 2005) showed that the heaviest rain (1062/24 hours) of the remnant of typhoon Nina occurred under the interaction between the cold air and the remnant of Nina. The rainfall rate was much great than the rainfall produced by super typhoon Nina in the landfall stage. Those studies show that the remnant of a landfalling typhoon would be revival or resuscitating in its ET process. It would heavily increase rainfall.

Rainfall increase due to interaction between tropical cyclone and cold wave occurs not only in mid-latitude but in lower latitude as well. It is indicated that tropical cyclone would bring about large amounts of rainfall if it is associated with cold air invasion in Viet Nam. The heaviest rainfall occurs when the time of tropical cyclone landfall coincides with cold air (northeast monsoon) invasion or this invasion occurs 12-24 hours after the tropical cyclone landfall (Duong 2006).

Appropriate cold air intrusion would provide remnant vortex with baroclinic potential energy converting kinetic energy and increasing potential instability. It would be favorable to increase rainfall. On the other hand, rainfall of tropical cyclone would be suppressed if more strong cold air was intruded. It could fill up the remnant.

0.3.4.3 **Topographic Effect**

Coastal topography and mountainous range play an important role for rainfall associated with landfalling tropical cyclone. Topography convergence strengthening ascending motion in the mountain slope against wind would be a basic contribution to rainfall increase. There are three precipitation systems associated with typhoon Meari (2004) made landfall in Kyushu Japan at 08:30 JST 29 Sep. A sensitivity experiment was conducted with the model mentioned in (0.3.4.1). In the sensitivity experiment, the model topography over Kii Peninsula was removed. The simulating result showed that one of the three precipitation systems over Kii Peninsula area was disappeared and other two still existed. It is suggested that one of the precipitation system is associated with interaction with the mountain topography (Murata 2006).

Asymmetric distribution of rainfall of landfalling tropical cyclone is related to coastal topographic effect. Huge rainfall area would occur in the region against the typhoon wind and less rainfall in the lee side region. Thus, the asymmetric rainfall distribution appears. Contrary, numerical simulation (Liang et al. 2002) shows that high rainfall could be occurred in the lee side of the coastland if proper cold air is brought by peripheral winds of the tropical cyclone to increase the instability in the area.

Anyway, mountainous range with certain conditions could increase the rainfall. But large roughness and friction of the land surface would consume the energy of tropical cyclone and lead to dissipation.

0.3.4.4 **Meso Scale Convective System**

A major part of heavy rainfall would be produced by strong meso scale convective systems even micro scale systems such as tornadoes. Statistical or observational studies show that those systems are subject to occur in the front or right front quadrant of the cyclone. Serial meso scale strong convective system activities would occur under the interaction among the proper cold air, mountainous range and remnant vortex itself. Strong convergence in low layer with strong vorticity, increased potential instability and upper level divergence that would be helpful the genesis and growth of meso scale convective systems. Tropical cyclone would be intensifying if a meso scale vortex merges with it (Chen, Luo 2004). Heavy rainfall would be increased in the merging process.

0.3.5 **Summary**

Remotely sensed data from TRMM, VIRS, AMSU, SSMI Doppler radar reflectivity blending rain gauge data are quite efficient for the quantitative precipitation estimation of landfalling tropical cyclones. Uncertainties still exist in the rainfall amount from remotely sensed observation. Technical improvements need to be implemented for the future work.

Quantitive precipitation forecast of landfalling tropical cyclones has been developed. Limited area models or meso scale models are the major efficient means to predict very short range precipitation in 6 hours combined with extrapolation. Ensemble rainfall forecasting techniques are developing to improve the model forecast, empirical models and statistical schemes or statistical-dynamical combined approaches are also used in operational forecast and tropical cyclone rainfall climatological background can provide a valuable reference to the operational forecast.

Physical processes of tropical cyclone rainfall have been studied by the research community. Moisture transportation, boundary layer fluxes transfer, extratropical transition, topographic effects, genesis and growth of meso scale convective systems are playing an important role to affect the rainfall caused by landfalling tropical cyclones.

0.3.6 **Recommendations**

To improve the rainfall quantitative estimation and forecast associated with the tropical cyclone landfall, the following recommendations need to be addressed.

(a) Field scientific experiments on landfalling tropical cyclones should be implemented. The scientific objectives of those experiments could focus on rainfall, high winds, structure and structure change of a landfalling tropical cyclone including its boundary layer variation. Various satellite observations, doppler radar, wind profiler, densely deployed rain gauge, aircraft observation and other advanced devices could be employed in the program. The field experiments should be continued for several years with international technical cooperation. Field experiments could acquire sufficient data from various sources for theoretical and applied study to get better understanding on tropical cyclone rainfall mechanism and developing forecasting techniques.

(b) A demonstration program should be developed on landfalling tropical cyclone forecast and warning including rainfall forecast. The program attempt to obtain advanced techniques for tropical cyclone quantitative precipitation estimation and forecasting and complete a valid warning system which could be extended to other forecasting centers concerned.

(c) A numerical model comparison project should be conducted with international cooperation. The project could improve the meso scale model and ensemble forecasting techniques as well as the tropical cyclone rainfall QFE and QPF.

(d) A roving seminar on tropical cyclone rainfall estimation and forecasting should be encouraged. This sort of seminar would efficiently help those relevant forecasting centers to develop and improve current rainfall forecasting techniques.

(e) Special workshops or symposia need to be organized on tropical cyclone QPE and QPF with WMO funding.

(f) In recent years, a variety of remotely sensed data from satellites and radars are increased rapidly. Those data should be shared with or made available as widely as possible to most of the forecasting centers around the regions impacted by tropical cyclones. Those are the basic information to develop the QPE and QPF of tropical cyclone rainfall.

Bibliography

Akihiko Murata, 2006: A cloud-resolving numerical simulation for characteristic rainfall induced by typhoon Meari (2004), Team member report on topic 0.3 of Sixth International Workshop on Tropical Cyclones

C. Velasco-Forero, et al., 2006: An automatic methodology for estimation of rainfall fields blending radar and rain gauges data in real time, 2nd International Conference on Quantitative Precipitation Forecasting and Hydrology Proceedings, P. 26

Chen Lianshou, Lou Zhexian, 2004: Interaction of typhoon and meso scale vortex, Advances in Atmospheric Sciences, Vol 21. No4, 515-528

Cheng Minghu, et al., 2006: The studies of landfalling tropical cyclone using TRMM and HK radar data, Team member report on topic 0.3 of IWTC-VI

Duong Lien Chau, 2006: Team member report on topic 0.3 of Sixth International Workshop on Tropical Cyclones

Feng Hanzhong, et al., 2006: Verification of precipitation prediction from meso scale ensemble system for the upper basin of Yangtze River, 2nd International Conference on Quantitative Precipitation Forecasting and Hydrology. Proceedings, P.68

Kwan-Yin Kong, 2002: Anomalous intensification of the remnants of tropical storm Allison over land, 25th Conference on Hurricane and Tropical Meteorology. San Diego CA, American Meteorological Society

Lei Xiaotu, 2004: A case study on the heavy rain in Shanghai induced by a tropical depression on 5 Aug. 2001, Proceedings on WMO International Workshop on Tropical Cyclone Landfall Processes, 157-159

Liang Xudong, Duan Yihong, Johnny C. L. Chan, 2002: Convective Asymmetries associated with tropical cyclone landfall, ACTA Meterologica Sinica, Vol. 60 (Supplement), 26-35 (in Chinese)

Li Ying, et al., 2005: Numerical study on impacts of boundary layer fluxes over wetland on sustention and rainfall of landfalling tropical cyclone, Acta Meteorologica Sinica, 63(5), 683-693

Shanghai Typhoon Institute, 2006: Team member report on topic 0.3 of IWTC-VI

Shen W. Ginis, 2002: A numerical investigation of land surface water on landfalling hurricane, J Atmos Sci., 789-802

Tabito Hara, 2006: The operational non-hydrostatic meso scale model for quantitative precipitation forecasts at JMA, 2nd International Conference on Quantitative Precipitation Forecasting and Hydrology, Proceedings, P.36

Zeng Zhihua, Chen Bomin, Gao Quanping, 2002: Simulation of influence of “urban heat island” on torrential rain in Shanghai on 5 Aug. 2001, ACTA Meteorologica CINICA, Vol 60 (Supplement) 58-64 (in Chinese).