On the precipitation monitoring and prediction of typhoon in Central Weather Bureau, Taiwan

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***ABSTRACT*:**

The Central Weather Bureau (CWB) of Taiwan issues typhoon analyses, forecasts, and warnings, 24 hours prior to a typhoon with a sustained wind strength of Beaufort scale 7 (34 knots) is expected to invade Taiwan or Kinmen and Matsu islands within a range of 100 km. Recently, more reasonable forecasts, extended forecast lead times, and new generation of products and services are made possible due to the advances in observational capabilities, numerical weather prediction systems, and forecaster tools and other auxiliary systems. Some scientific limitations remain, however. This article briefs the CWB's current procedure for precipitation monitoring and prediction of typhoon, and highlights recent improvements and addresses upcoming challenges.

KEYWORDS: Central Weather Bureau, precipitation monitoring and prediction of typhoon

1. Introduction

Taiwan is prone to the invasion of the Tropical Cyclones (TCs) generating in the western North Pacific. Climatologically, 3 to 4 typhoons invade Taiwan every year (Fig. 1). Typhoons may bring human losses and property damage, yet they are the major water resource for Taiwan, without the passage of typhoons, Taiwan would suffer draught (Wu and Kuo, 1999). Therefore, improving typhoon forecasts (including the track, rainfall, and wind) is one of the major responsibilities of the Central Weather Bureau (CWB). This paper discusses the current workings of the nation's typhoon warning program, highlighting the recent and on-going improvements occurred.

2. CWB typhoon monitoring operations

The procedure of the CWB to issue typhoon warnings is as follows:

(1) Typhoon sea warning: A sea warning will be issued when the typhoon's radius of sustained winds of 34 knots or greater is anticipated to touch the 100 km sea area of Taiwan, Penghu, Kinmen, and Matsu (TPKM) in 24 hours; and then be updated 3 hourly. Additional warnings will be announced whenever essential (Fig. 2a).

(2) Typhoon land warning: A land warning will be issued if the typhoon's radius of sustained winds of 34 knots or greater is going to hit the land of TPKM in 18 hours; and then be renewed every 3 hours.

Additional warnings will be announced whenever necessary (Fig.2b).

(3) Termination of a typhoon warning: A typhoon land warning will be terminated when the typhoon's radius of sustained winds of 34 knots or greater leaves the land area of TPKM. A typhoon sea warning will be terminated when the typhoon's radius of sustained winds of 34 knots or greater leaves the coastal area in TPKM. The warnings can also be terminated when the typhoon dissipates or changes its direction.

It is worth mentioning that when a typhoon forms near the coastal area of TPKM, or when the size, speed, and direction of a typhoon has any sudden change, a sea or land warning, or both when necessary, will be released regardless of the above-mentioned schedule.

The tools and systems used for monitoring typhoons in the CWB are stated below.

2.1 QPESUMS

The CWB has cooperated with US NOAA/NSSL (National Oceanic and Atmospheric Administration/ National Severe Storms Laboratory) to develop a web-based convective/severe weather monitoring system called QPESUMS (Quantitative Precipitation Estimation and Segregation Using Multiple Sensors) since 2002. The QPESUMS system integrates multiple observation data, such as radar reflectivity, satellite, surface observation, lightning data, and geographic information system (GIS) to provide real-time evolution of convective weather systems, the latest quantitative precipitation estimation (QPE) information, and 0-1 hour quantitative precipitation forecast (QPF). All the products are displayed on QPESUMS' webpage (Fig. 3), and the information is updated every 10 minutes. Up to now the webpage products have been referred by over 40 central government organizations, emergency operations centers of the county municipal governments, and research centers in real-time. In recent years, the CWB focuses on the generation of customized QPESUMS web-pages (customer-oriented precipitation-related products) according to the operational needs from the disaster prevention and mitigation agencies to optimize the application and usage of the meteorological information.

2.2 Satellite Observations

The imagery of the visible(0.47-1.1 μ m wavelength) and infrared (IR, 10-12 μ m) channels of the Japanese geostationary satellite, MTSAT (Multi-functional Transport SATellite), are used to locate the center position and intensity of TCs based on Dvorak empirical methods according to the cloud patterns and the distribution of the brightness temperature (Velden et al., 2006).

Other data obtained from sensors of the polar orbiting satellites, such as SSMI (Special Sensor Microwave Imager) and SSMIS (Special Sensor Microwave Imager/Sounder), are referred to reveal the positions of the typhoon circulation center in different vertical levels. The imagery of

89GHz from AMSU-B and precipitation intensity derived from AMSR-E of EOS-AQUA are helpful to identify the structure and the precipitation pattern of typhoons.

2.3 Dropsonde Observations

The GPS dropsonde are used to reveal the wind and thermodynamic structure of the typhoon circulation (Fig. 4). Dropsonde data also provide direct measurements of surface winds. With the insertion of dropsonde data, the accuracy of the track forecast by TWRF (Typhoon WRF) is improved by 7.6%, on the average, for cases from 2008 to 2011. For some cases, the track forecast may be improved by 40-50% in the first 36 hr (Fig. 5).

3. CWB typhoon forecast operations

Typhoon prediction in the vicinity of Taiwan encounters two major challenges: (i) the lack of traditional observational data over the western North Pacific, and (ii) the influence of Taiwan's Central Mountain Range (CMR, as shown in the middle picture of Fig. 14) on the typhoon circulation. Because of the influence of CMR, the geographical distribution of winds and rainfall intensity for a typhoon approaching Taiwan is highly sensitive to the track and approaching angle (with respect to the orientation of CMR) of the storm. Accurate forecasts of distribution of winds, rainfall, and the ensuing storm surge, over Taiwan are then highly dependent on accurate typhoon track forecasts. The typhoon forecast decision-support systems at CWB are briefed below.

3.1 WINS

An US AWIPs-like operation system called WINS (Weather Integration and Nowcasting System, see Fig. 6) is the backbone auxiliary system for routine and typhoon weather monitoring and forecasting system, which integrates meteorological information, including surface and upper-air observations, satellite imagery, radar data, and outputs from the numerical models.

3.2 TWRF

The Weather Research and Forecasting (WRF) modeling system applied to the TC forecasts in the western North Pacific has been developed since 2010 in the CWB, and is called TWRF (Typhoon WRF, Song et al., 2010). The TWRF provides objective forecast guidance for TC forecasts at CWB to construct real-time forecasting of typhoon track and rainfall prior to and affecting Taiwan Recently, the improvement and performance of TWRF (Hsiao et al., 2010) is obvious enough, such that the joint typhoon warning center (JTWC) of the US Navy has asked CWB to offer the TWRF track forecasts for her operation needs. The typhoon track information from TWRF will be provided starting from the typhoon season of 2012. The comparison for TC track forecast errors of TWRF, NCEP-GFS, JMA-GFS, UK-GFS, and US Navy NOGAPS in 2011 is shown in Fig.7.

3.3 TAFIS

The TAFIS (Typhoon Analysis and Forecast Integration System) is a graphic-based man-and-machine interactive application tool which can display typhoon tracks from observations and numerical models, and provide other necessary information for operational typhoon forecast. It can also produce official typhoon warning products and forecast error statistics for evaluation. It is able to show more than 30 TC tracks from different numerical models and different official track forecasts in western North Pacific (Fig. 8a) at the same time. TAFIS has become the major tool used for the official typhoon track forecasts in CWB since 2004. The CWB forecasters can selectively load any typhoon track from a specific numerical model or collectively select a few of the tracks provided by different models (objective guidance) or from other operation centers (subjective guidance). The "consensus" of all the selected tracks could be obtained automatically and some adjustment on the "consensus" based on the experience of the forecasters can be made manually. The final decision of the typhoon track, intensity and the probability of strike can be posted on the webpage directly via the TAFIS (Fig. 8b) for public reference.

3.3 PARE, ISWIS and WPPSII

The PARE (Pattern Analog Risk Evaluation) is an assistant tool for forecasters to search in weather events archive for matching the current (on-going) meteorological conditions. It can be used for general weather pattern searching and for a specific typhoon weather pattern searching in the archive. Users need to key in the parameters such as the temperature, rainfall and so on, in a specific region, describing the weather pattern. The PARE will then display the weather maps of the previous cases that satisfy the assigned meteorological parameters. The fields of temperature, wind, precipitation etc., are also revealed for weather forecast reference. Fig. 9 shows the display and operating interface of PARE.

The ISWIS (Interactive Smart Weather Identification System) is an advanced tool used to automatically search for historical weather events which resemble the current atmospheric condition. For instance, ISWIS is able to display the past weather maps similar to the on-going weather maps, such as the 500-hPa weather map et al., such that the forecasters are able to make more reasonable decision on weather forecast. This automatic matching function is the essence of the system, such that the effort to search for the similar weather events (such as typhoons) in the past is greatly saved. The ISWIS can also make forecast verifications.

The WPPSII (Wind and Precipitation Prediction System, generation II) is an operational system for generating typhoon wind and precipitation forecasts in CWB. The system contains four major functions: (1) Introducing the wind and precipitation forecast guidance information from observational and climatological data bank including the numerical models; (2)

Providing an easy-editing interface for forecasters to produce the county-wise, 12-hourly precipitation and 3-hourly wind forecasts in table or in figure formats; (3) Verifying the official and the numerical forecasts in real-time.

The track forecast is determined based on the objective guidance from numerical model forecasts, such as the CWB GFS (Global Forecast System), TFS (Typhoon Forecast System), TWRF, and the other numerical forecasts from ECMWF, NCEP, NOGAPS, UK and JMA, and the subjective forecasts, such as the official forecast from USA, Japan, Korea, etc. With the use TAFIS, ISWIS, PARE, WPPSII, and applying the associated forecasters' experience, the official CWB typhoon track and intensity forecast is issued. A sample of the official typhoon forecast of track, wind and precipitation, is shown in Fig. 10, 11, and 12, respectively.

4. Tropical Cyclone Forecast verification

The official track forecast errors of CWB and some operational milestones from 1994 to 2010 are shown in Fig.13. The main tendency of the errors is decreasing because of the development and of the assisting tools and the improvements from numerical models.

The precipitation forecasts in typhoon affecting period are determined base on the information from the climate statistical precipitation with the similar historical typhoon track which matches the forecast track, the precipitation with the similar tracks and structures of historical typhoon cases by analog method, the numerical models' forecasts, and the experience for the terrain effect of Taiwan. The figures products for precipitation are shown as Fig. 6.

5. Upcoming Challenges

Due to the lack of observations over the waters surrounding Taiwan, the errors inherent in the numerical models (such as, the insufficient representation of the physical process of the atmosphere in the models), and so on remain as challenges and obstacles for typhoon forecast improvement in Taiwan.

On the other hand, the complex terrain in Taiwan also plays an important role on the movement (speed and direction) and intensity of typhoons. The unique CMR in Taiwan tends to deflect the typhoon tracks and change their intensity. The processes of track and intensity change involve multiple scale interactions between weather systems, which are not well known yet. They bring about the difficulties on typhoon track forecasting for Taiwan.

For Taiwan, the accuracy of typhoon precipitation forecasts is heavily dependent on the accuracy of track forecasts. Although the typhoon track error of the CWB official forecasts is compatible to the average of the international official forecasts, a 20-30km difference in the landing positions of typhoon on Taiwan could result in a totally different rainfall accumulation pattern on this island due to a complicated interaction between typhoon and CMR (Fig. 14). Consequently, the current precipitation forecasts are not accurate enough to satisfy the needs for the operations of disaster mitigations and preventions.

The CWB of Taiwan will continue to make effort towards the refinement of typhoon real-time monitoring and forecasts by introducing or developing more remote sensing techniques, such as the introducing of dual-polarization radar QPE techniques and the QPE derived from both geostationary and polar orbiting satellites, along with a more efficient integration of the operational systems and processes.

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REFERENCES

Chen, D.-S., L.-F. Hsiao, T.-C. Yeh, Y.-R. Guo, K.-N. Huang, C.-T. Fong, J.-S. Hong, B. Kuo, 2010: Recent Improvement of Typhoon WRF (TWRF) Model for Operational Typhoon Prediction at Taiwan. *Asia Oceania Geosciences Society Conference*, Taipei,

Sisko, S. R. Stewart, A. N. Tribble, 2009: Advances and Challenges at the National Hurricane Center. *Weather and Forecasting*, 24, pp. 395-419.

Hsiao, Lin-Feng; et al., 2010: A Vortex Relocation Scheme for Tropical Cyclone Initialization in Advanced Research WRF. *Mon. Wea. Rev*., 138, 3298-3315.

Velden, C. S., B. Harper, F. Wells, J. L. Beven II, R. Zehr, T. Olander, M. Mayfield, C. “Chip” Guard, M. Lander, R. Edson, L. Avila, A. Burton, M. Turk, A. Kikuchi, A. Christian, P. Caroff, P. McCrone, 2006: The Dvorak Tropical Cyclone Intensity Estimation Technique: A Satellite-Based Method that Has Endured for over 30 Years. *Bulletin of the American Meteorological Society.*87, pp. 1195-1210.

Wu, C. C., and Y.-H. Kuo, 1999: Typhoons affecting Taiwan: Current understanding and future challenges. *Bull. Amer. Meteor. Soc.*, **80**, 67-80.

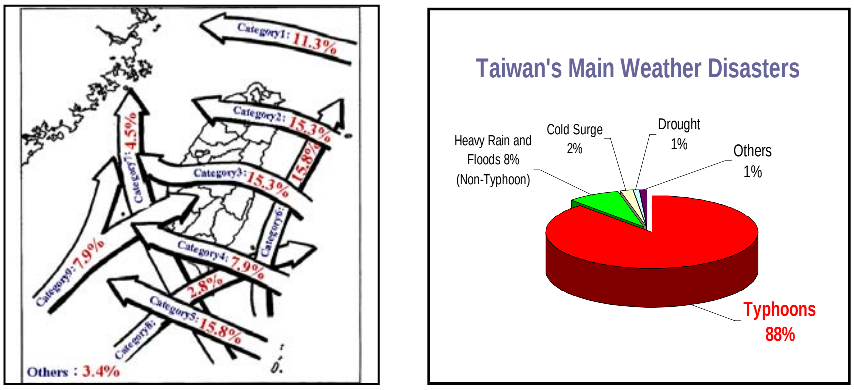

Fig. 1 Left: Nine major categories of paths of typhoons invading Taiwan; Right: Statistics of weather disaster damage in Taiwan show an annual average of NTD17 billion losses, of which 88% were caused by typhoons.

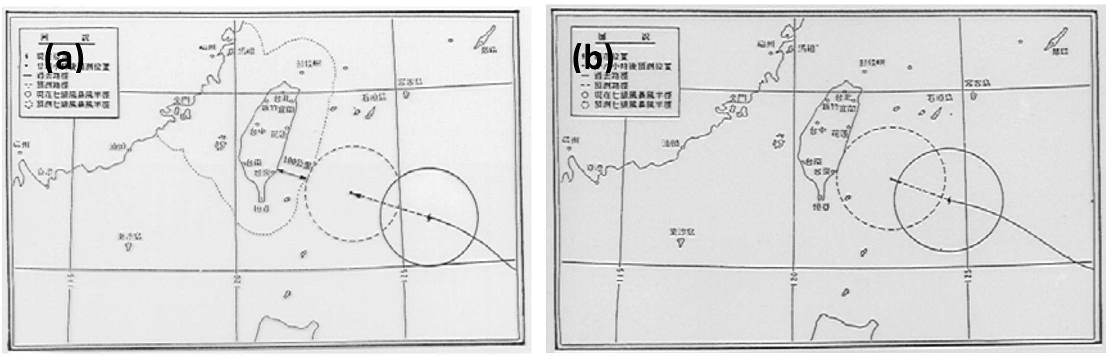

Fig. 2 Illustration of how the typhoon warning is issued. (a) A sea warning will be issued when the typhoon's radius of sustained winds of 34 knots or greater is anticipated to touch the 100 km sea area of Taiwan, Penghu, Kinmen, and Matsu (TPKM) in **24** hours; (b) A land warning will be issued if the typhoon is going to hit the land of TPKM in ***18*** hours.

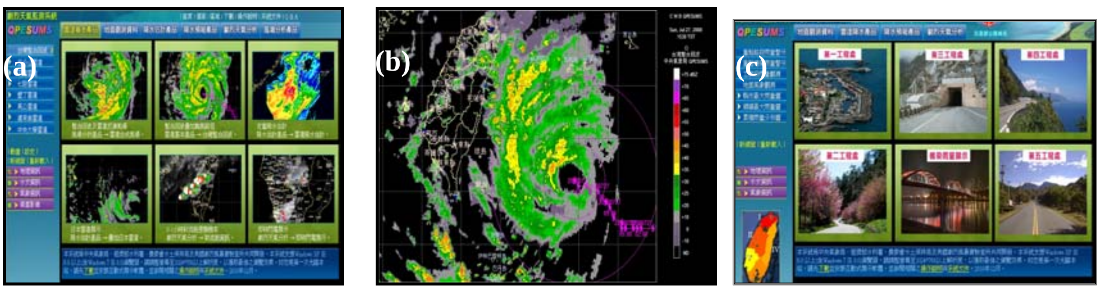

Fig.3 Illustration of the QPESUMS system. (a) Homepage of the professional QPESUMS system; (b) Radar mosaic reflectivity at 1530LST July 27^{th} 2008 (Typhoon Fung-Wong); (c) Customized QPESUMS system for Directorate General of Highways (DGH)**.**

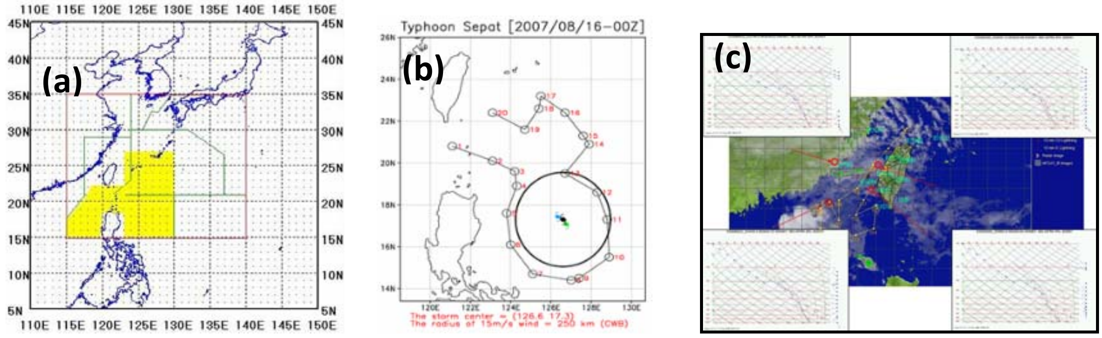

Fig. 4 Illustration of dropsonde operation. (a) The area in yellow is the area with dropsonde mission; (b) The points of drop for a typhoon case; (c) Thermodynamic structure of the weather system shown by the dropsonde data.

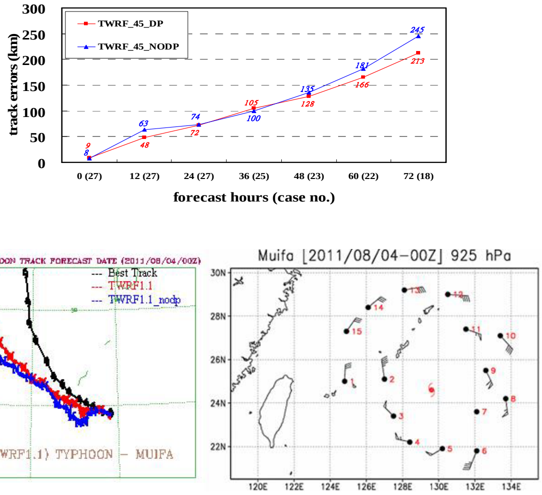

Fig. 5 Upper panel: With the assimilation of dropsonde data, the accuracy of the track forecast by TWRF (Typhoon WRF) is improved by 7.6%, on the average, for cases from 2008 to 2011; Lower panel: A typhoon case, dropsonde insertion result in a major improvement (by 40-50%) of track forecast by TWRF in the first 36hr.

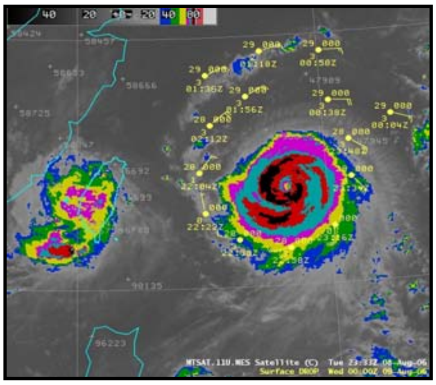

Fig.6 The WINS (Weather Integration and Nowcasting System) is an interactive computer system that integrates meteorological information, including surface and upper-air observations, satellite imagery, radar data, and outputs from the numerical models.

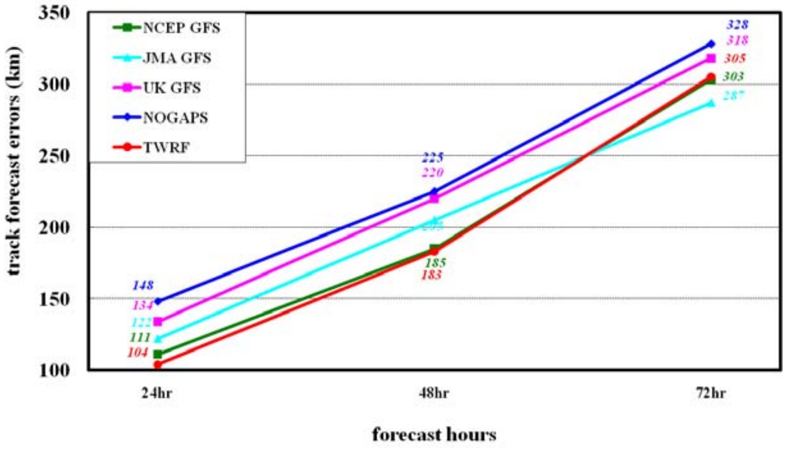

Fig.7 TC track forecast errors of CWB-TWRF, NCEP-GFS, JMA-GFS, UK-GFS, US Navy NOGAPS for 24, 48, and 72 hr in 2011

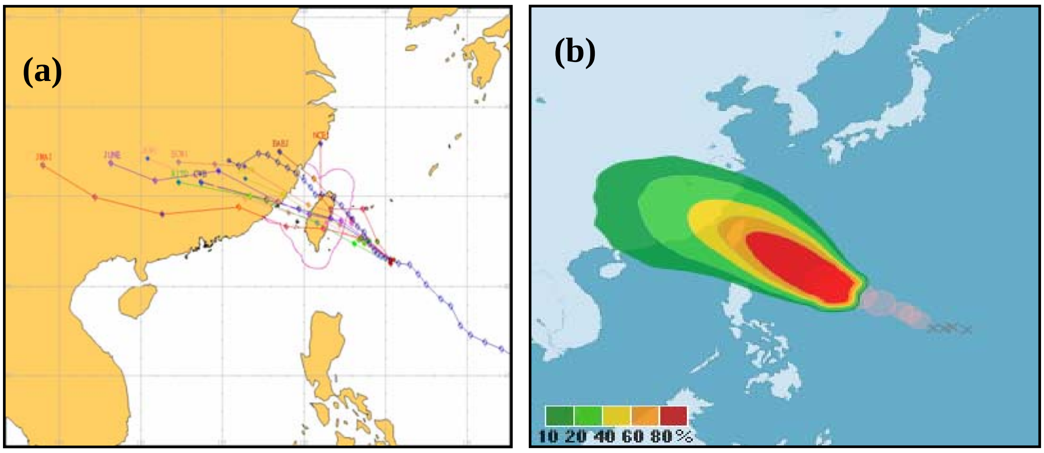

Fig.8 Illustration of TAFIS displays. (a) TAFIS can display typhoon tracks from observations and numerical models, and provide other necessary information for operational typhoon forecast. (b) The probability distribution of a typhoon strike generated by TAFIS.

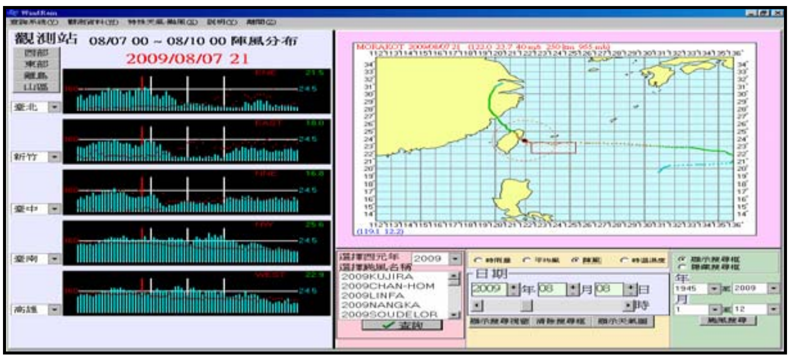

Fig.9 The display and operating interface of PARE

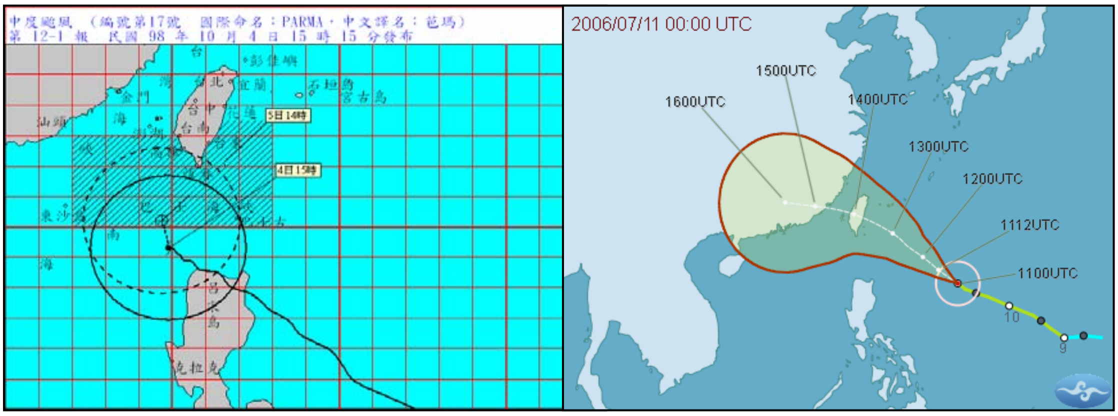

Fig. 10 The CWB's official typhoon track forecast. Left: Deterministic track forecast diagram on warning message; Right: Potential track area (PTA) diagram

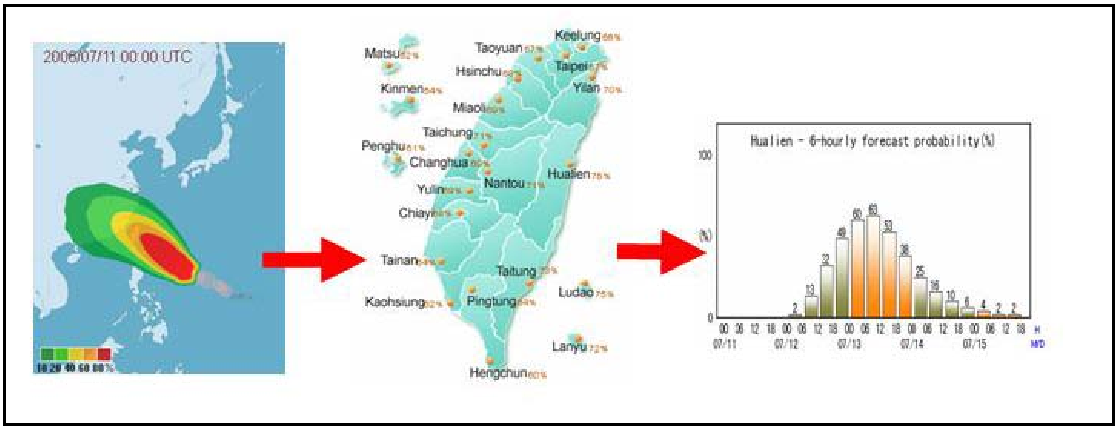

Fig. 11 The CWB's official typhoon wind forecast. Left: The wind speed plot for the next 120 hours; Middle: The wind speed at major cities over Taiwan Island and the surrounding islands for the next 120 hours; Right: The 6-hourly wind speed at Hualien City for the next 120 hours.

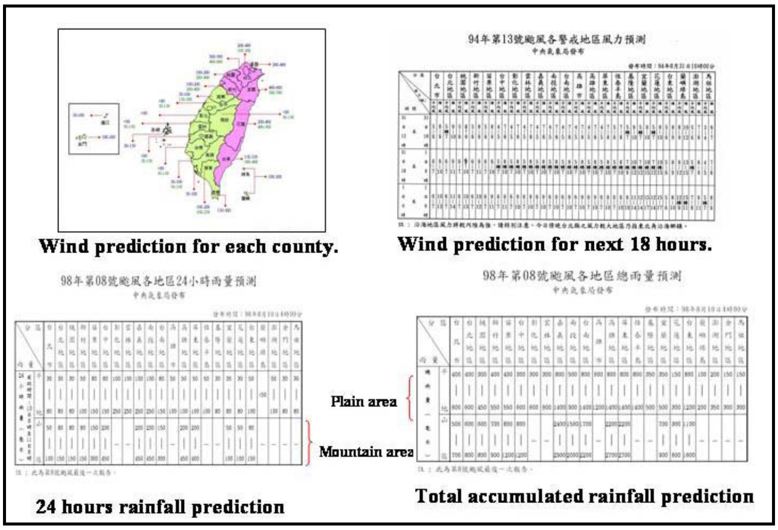

Fig. 12 A sample of the CWB's wind and rainfall forecast sheets.

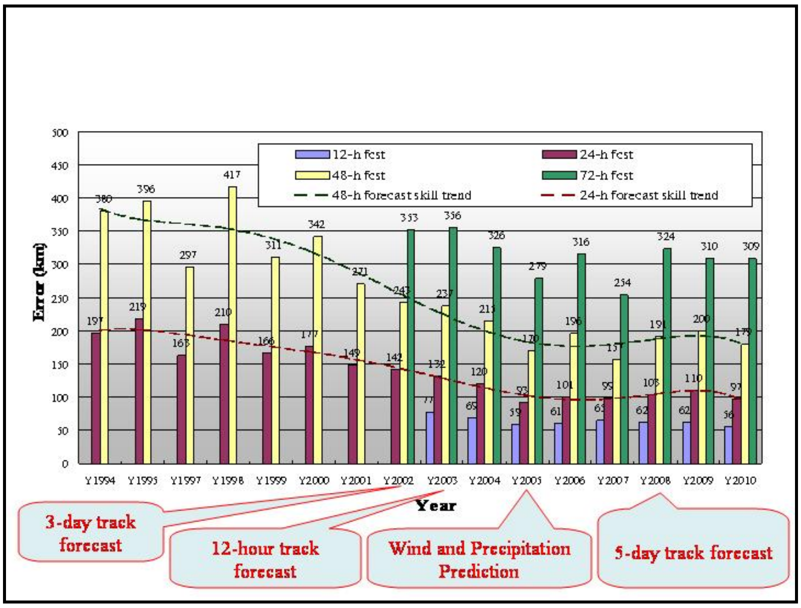

Fig.13 The typhoon track forecast skills and milestones of CWB from 1994 to 2010

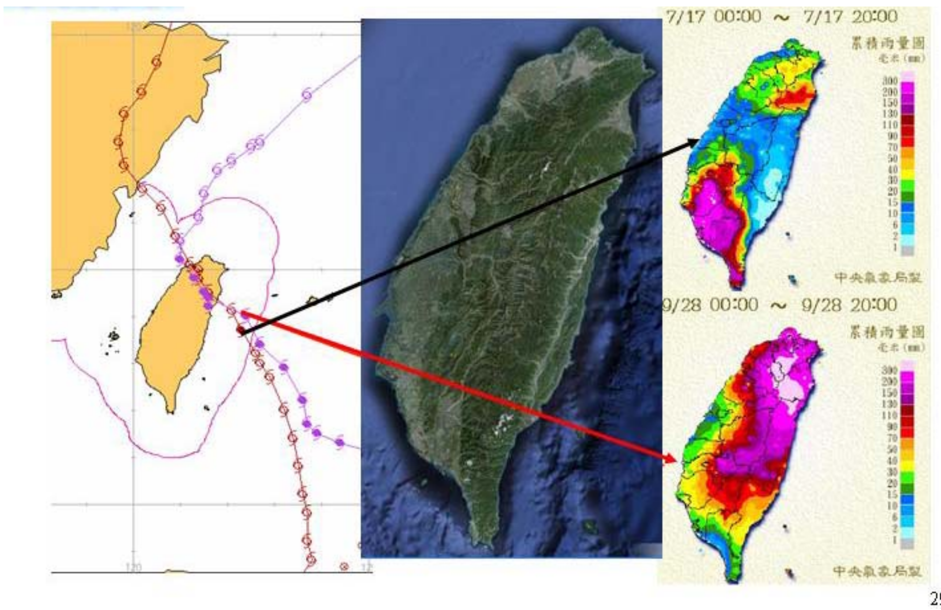

Fig. 14 A "small" difference in the tracks (left) of typhoons landing on Taiwan could result in a totally different rainfall accumulation pattern (right) on this island due to a complicated interaction between typhoon and Central Mountain Range (middle).