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Opportunities and challenges for extended-range predictions of tropical cyclone impacts on hydrological predictions

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SUMMARY

An opportunity exists to extend support to the decision-making processes of water resource management and hydrological operations by providing extended-range tropical cyclone (TC) formation and track forecasts in the western North Pacific from the 51-member ECMWF 32-day ensemble. A new objective verification technique demonstrates that the ECMWF ensemble can predict most of the formations and tracks of the TCs during July 2009 to December 2010, even for most of the tropical depressions. Due to the relatively large number of false-alarm TCs in the ECMWF ensemble forecasts that would cause problems for support of hydrological operations, characteristics of these false alarms are discussed. Special attention is given to the ability of the ECMWF ensemble to predict periods of no-TCs in the Taiwan area, since water resource management decisions also depend on the absence of typhoon-related rainfall. A three-tier approach is proposed to provide support for hydrological operations via extended-range forecasts twice weekly on the 30-day timescale, twice-daily on the 15-day timescale, and up to four times a day with a consensus of high-resolution deterministic models.

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1. Introduction

1.1. Background

Especially in the mountainous terrain of Taiwan, floods, debris flows, and landslides are usually induced by the heavy rainfall associated with tropical cyclones (TCs) (Wu and Kuo, 1999; Wu et al., 2002; Tsai and Lee, 2009; Lee et al., 2011). In August 2009, Typhoon Morakot produced almost 3000 mm rainfall over three days as it approached and slowly passed by Taiwan. The rainfall-induced hazards caused 619 deaths and over USD 500 million agriculture losses (Lee et al., 2011).

Despite these destructive effects, TC rainfall is a major water resource in Taiwan. Over 50% of the water resources in southwestern Taiwan come from TC rainfall. Whereas the annual average rainfall in Taiwan is more than 2000 mm, the non-uniform spatial and temporal rainfall distribution and limited reservoir capacity may lead to serious shortages in agricultural water supplies (Huang and Yuan, 2004; Chen et al., 2009). If deficient rainfall occurs during the Mei-yu season, the water storage in the reservoirs in summer can be very low if the typhoon-related rainfall is also deficient, and the Water Resources Agency in Taiwan may need to limit water usage. By contrast, abundant rainfall during Mei-yu plus multiple typhoons may lead to dangerously high water levels during the typhoon season. Thus, predicting both the typhoon-related rainfall and the absence of such rainfall is a challenging issue for water resource management and reservoir operations (Chang and Chang, 2001).

As indicated by the Joint Typhoon Warning Center (JTWC) best-tracks from 1980 to 2010 in the western North Pacific basin (Fig. 1), the Taiwan area (here defined as 21–26°N and 119–125°E) is one of the most active TC regions in the basin. However, large interannual variations in the numbers of TCs exist, with a maximum of nine in 2004 and a minimum of one in 1983 (Fig. 2a). Whereas about 29% of the years during 1980–2010 have the average (and median) five TCs in the Taiwan area, the distribution about the average is rather uniform (Fig. 2b). Even in an active year, the occurrence of a tropical cyclone in the immediate Taiwan area must be considered a rare event.

In addition to the total number of TCs during a season, the first TC that would pass or form in the vicinity of Taiwan after the end of Mei-yu season is also an important factor for water resource management. Broadly defining the Mei-yu season as 15 May to 30 June, the length (days) after 30 June of the first TC gap (i.e., no TC track passing or forming in the Taiwan area) during 1980–2010 is shown in Fig. 3a. While the average first TC gap is 25.2 days and the median is 17 days, the distribution of first TC gaps is highly skewed. About 55% of the years have a TC passing by or forming in the Taiwan area within 20 days after the end of the Mei-yu season. If the Mei-yu rainfall has been plentiful and the water levels in the

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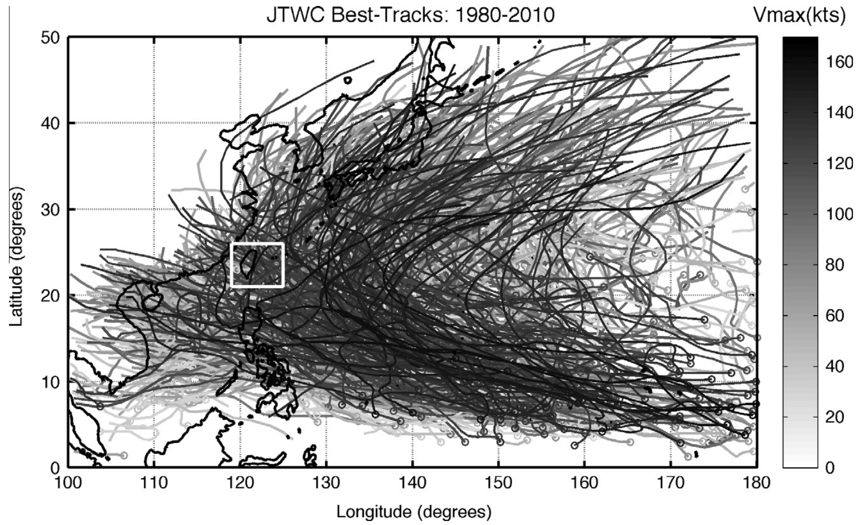

Fig. 1. JTWC best-tracks during 1980–2010. The white box (21–26°N, 119–125°E) is defined as the Taiwan area in this study.

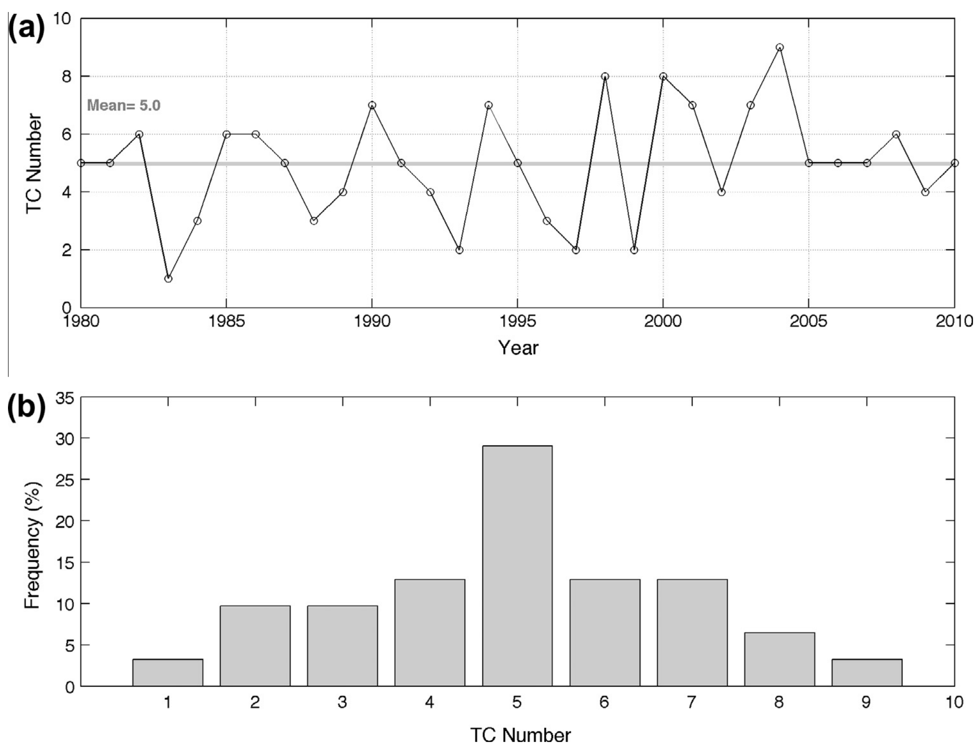

Fig. 2. (a) Annual variations in the number of TCs with maximum intensity ⩾25 kt in the Taiwan area (21–26°N, 119–125°E) during 1980–2010. (b) Frequency (%) distribution of annual number of TCs in which both the mean and median number of TCs is five.

reservoirs are high, the threat of flooding may be raised. By contrast, in 30% (15%) of the years, the first gap was longer than 30 (50) days.

These analyses indicate that using the average numbers of TC in the season is not sufficient in estimating the potential TC-related rainfall impacts for water resource management decisions. As indicated above, the distribution in time is also an important factor for water resource management. Although a drought event is a combination of water resources, water usages, and water management problems, the major drought events are usually related to the amount of typhoon rainfall and its major locations (Hsu et al., 2011). For example, a serious drought event occurred in Taiwan during 1993 (the first TC gap was about 75 days; Fig. 3a) due to the lack of typhoon (only two TCs in the Taiwan area; Fig. 2a) rainfall in the major reservoir catchment areas during that summer. The government limited the agricultural water supplies to support the domestic use, and the drought event was not relieved until April 1994 with heavy spring rainfall (Hsu et al., 2011).

1.2. Present typhoon forecast products

Hydrological predictions for hazards such as flooding, debris flows, and landslides first of all require an accurate typhoon track forecast both for the location of the rainfall and for the duration, which crucially depends on the translation speed. Forecasting the track is particularly difficult as the typhoon circulation interacts

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