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Ensemble forecasting of typhoon rainfall and floods over a mountainous watershed in Taiwan

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SUMMARY

In this study, an ensemble meteorological modeling system is one-way coupled with a hydrological model to predict typhoon rainfall and flood responses in a mountainous watershed in Taiwan. This ensemble meteorological model framework includes perturbations of the initial conditions, data analysis methods, and physical parameterizations. The predicted rainfall from the ensemble meteorological modeling system is then used to drive a physically distributed hydrological model for flood responses in the Lanyang basin during the landfall of Typhoon Nanmadol (2011). The ensemble forecast provides track forecasts that are comparable to the operational center track forecasts and provides a more accurate rainfall forecast than a single deterministic prediction. The runoff forecast, which is driven by the ensemble rainfall prediction, can provide uncertainties for the runoff forecasts during typhoon landfall. Thus, the ensemble prediction system provides useful probability information for rainfall and runoff forecasting.

1. Introduction

Typhoons are one of the most important severe weather systems in Taiwan. The heavy rainfall and strong winds that are associated with typhoons can cause tremendous damage in Taiwan. On average, three to four typhoons make landfall in Taiwan each year. Due to the disasters and high social impacts that result from typhoons, accurate typhoon forecasting is a priority of operational weather forecast centers in the western North Pacific, especially in Taiwan.

Typhoon track forecasts are primarily based on the guidance from numerical weather prediction (NWP) models. However, the NWP models are inherently limited due to the predictability limits that result from the intrinsic chaotic nature of the atmospheric system. Consequently, future weather states are sensitive to small errors in the initial state (Lorenz, 1963). Errors in initial conditions (ICs) and in model physics result in forecast uncertainties in the NWP models (Tribbia and Baumhefner, 1988). One approach for reducing these uncertainties is the use of ensemble forecasting (Epstein, 1969). An ensemble forecast that explicitly represents these uncertainties would provide useful quantitative information regarding the probability of the weather systems (Murphy, 1990).

Convection-allowing models use grid sizes that are small enough to simulate convective processes explicitly. In contrast, the models with coarse horizontal grid sizes must use a cumulus parameterization scheme to represent the effects of subgrid-scale convective processes (Weisman et al., 1997; Kain et al., 2006). Kain et al. (2008), Weisman et al. (2008), and Clark et al. (2010) indicated that the convection-allowing NWP models with fine horizontal grid spacing provide value-added predictions for severe convective storms and their associated heavy rainfall.

Several operational centers, including the European Centre for Medium-Range Weather Forecasts (ECMWF), the National Centers for Environmental Prediction (NCEP), the Japan Meteorological Agency (JMA), and the United Kingdom Meteorological Office (UKMO), provide valuable operational ensemble predictions at a

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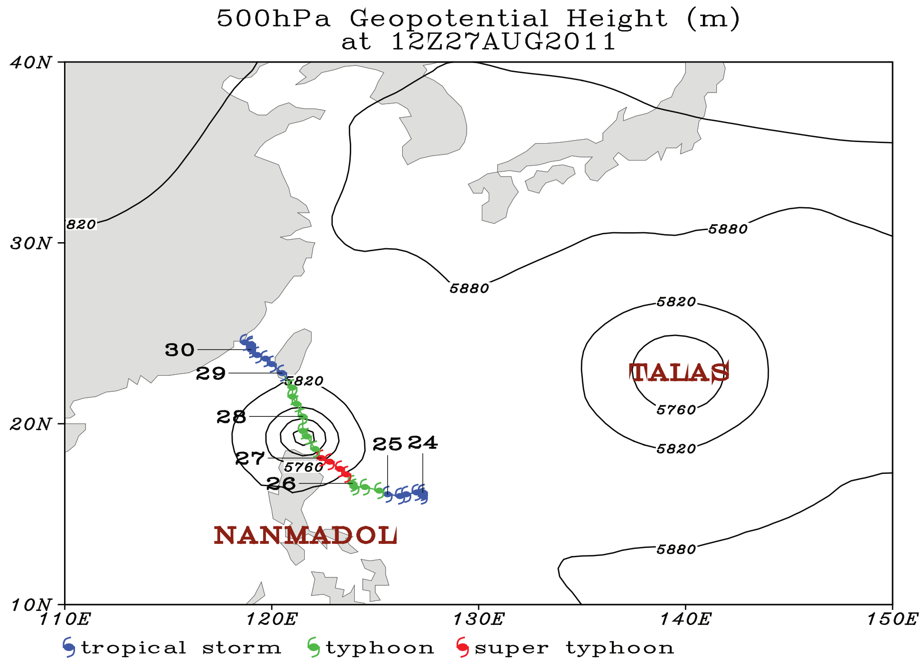

Fig. 1. 500-hPa geopotential height at 1200 UTC 27 August 2011 from the analysis of NCEP GFS (with a contour interval of 60 hPa). CWB best-track positions for Typhoon Nanmadol are plotted every 6 h from 1200 UTC 23 to 1800 UTC 30 August with labels indicating the date of August 2011 at 0000 UTC.

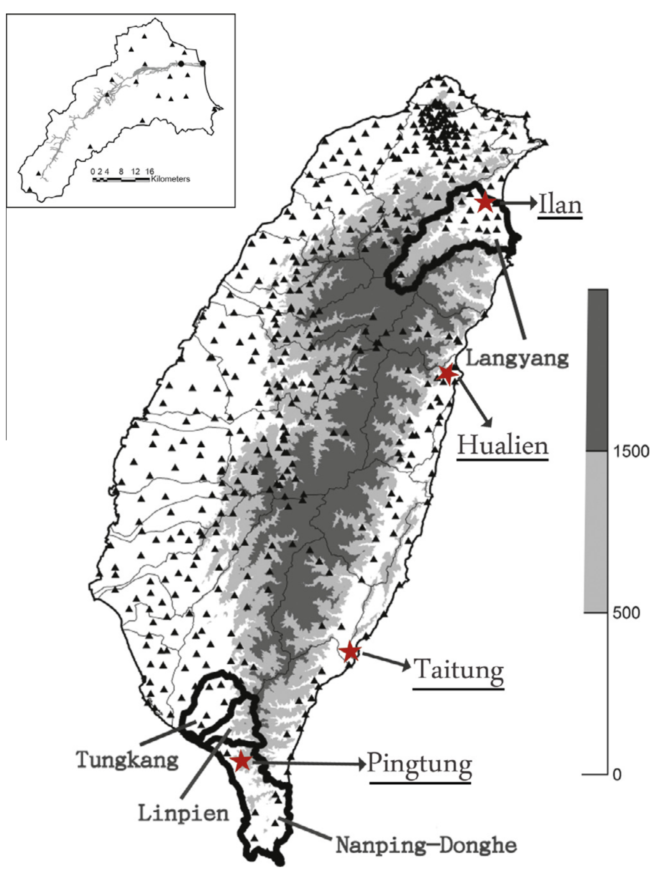

Fig. 2. Taiwan topography with gray shading at 500 and 1500 m. 512 rainfall stations including conventional and automatic rainfall and Meteorological Telemetry System stations (triangle symbols) are plotted. Contours indicate the boundaries of 33 river basins on Taiwan. Four basins (dark black contours) are the targeted areas discussed in Sections 5 and 6. The insert illustrates the Lanyang basin over northeastern Taiwan with rain-gauge (triangle symbols) and flow (closed circles) stations. Star symbols denote the cities of Ilan, Hualien, Taitung, and Pingtung.

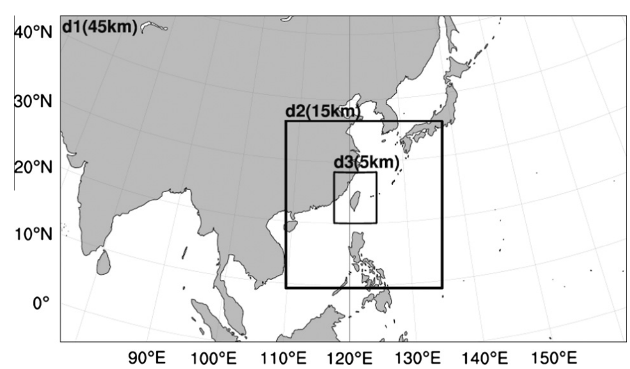

Fig. 3. Three nested domains for ensemble members.

global scale (Buizza, 2007; Bowler et al., 2008; Yamaguchi et al., 2009; Hamill et al., 2011). Regional scale ensemble prediction systems have been developed in research and operational modes to address the need for detailed and high-impact weather forecasting with higher spatial resolution (Du et al., 2009; Yamaguchi et al., 2009; Clark et al., 2010).

Previous studies have indicated that ensemble forecasting is promising for predicting tropical cyclones (hurricanes/typhoons). Krishnamurti et al. (1997) examined the ensemble forecasts of three hurricanes in 1979, and obtained useful track forecasts with reduced spread. Yamaguchi et al. (2009) showed that the ensemble mean track forecasts for typhoons in the western North Pacific in 2007 had a 40-km error reduction in the 5-day forecasts compared to the deterministic model forecast. Snyder et al. (2010) demonstrated that the NCEP global ensemble forecast system was significantly more accurate for forecasting Atlantic tropical cyclone (TC) tracks between August and September in 2006.

Although these ensemble forecasting results are encouraging, the ensemble meteorological forecasting system has not been coupled with a hydrological model for typhoon-related flood forecasting for mountainous watersheds in Taiwan. The hydrological responses of most watersheds in Taiwan are fast and complicated