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Optimization of multi-model ensemble forecasting of typhoon waves

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Abstract

Accurately forecasting ocean waves during typhoon events is extremely important in aiding the mitigation and minimization of their potential damage to the coastal infrastructure, and the protection of coastal communities. However, due to the complex hydrological and meteorological interaction and uncertainties arising from different modeling systems, quantifying the uncertainties and improving the forecasting accuracy of modeled typhoon-induced waves remain challenging. This paper presents a practical approach to optimizing model-ensemble wave heights in an attempt to improve the accuracy of real-time typhoon wave forecasting. A locally weighted learning algorithm is used to obtain the weights for the wave heights computed by the WAVEWATCH III wave model driven by winds from four different weather models (model-ensembles). The optimized weights are subsequently used to calculate the resulting wave heights from the model-ensembles. The results show that the optimization is capable of capturing the different behavioral effects of the different weather models on wave generation. Comparison with the measurements at the selected wave buoy locations shows that the optimized weights, obtained through a training process, can significantly improve the accuracy of the forecasted wave heights over the standard mean values, particularly for typhoon-induced peak waves. The results also indicate that the algorithm is easy to implement and practical for real-time wave forecasting.

Keywords: Wave modeling; Optimization; Forecasting; Typhoon waves; WAVEWATCH III; Locally weighted learning algorithm

1. Introduction

Prediction and understanding of ocean waves are extremely important for ocean-dependent industries, such as shipping and fisheries, as well as for coastal protection and coastal zone management. In particular, the highly energetic waves induced by typhoon events can cause enormous damage to property, infrastructure, and human lives (Doong et al., 2012; Liu et al., 2008). The catastrophic consequences of typhoon-related events have often been seen and reported in Taiwan in recent years. Although it is almost impossible to completely avoid the damage caused by typhoons, more accurate prediction and forecasting of typhoon-induced waves play an important role in mitigating and minimizing the impacts from the typhoons. However, the hydrological and meteorological interactions are complex, and the uncertainties arising from both weather and hydrodynamic modeling systems due to the forcing conditions, modeling techniques, and physical parameters can make wave prediction and forecasting rather difficult and challenging. In recent years, ensemble approaches have been widely used to improve quantification of the uncertainties arising from the modeling systems and physical parameters. In wave modeling, ensemble approaches can be generally classified into two types: parameter ensemble approaches and model ensemble approaches. In both types, a

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particular wave model is selected to transform the atmospheric forcing conditions into wave fields, but the atmospheric forcing conditions can be generated in different ways. The parameter ensemble approach generates wave ensembles through the wave model, which is driven by the ensembles of forcing conditions (usually winds and atmospheric pressure) from a weather model using equally perturbed physical parameters. For example, in the works reported by Chen et al. (2010) and Zou et al. (2013), the tide-wave model POLCOMS/ProWAM (Osuna et al., 2004) was used to produce the ensemble results of waves, tides, and storm surges from 50 ensembles of wind field and atmospheric pressure as the surface forcing. Then, statistical analysis was carried out to quantify the uncertainties arising from the model results of both hydrodynamics and morphodynamics. The model ensemble approach, in contrast, uses the ensembles of surface forcing conditions generated from different weather models, each of which is calibrated to its optimal operational conditions for a particular region or globally to drive the wave model to produce the wave ensembles for statistical analysis. In the work of Fan et al. (2013), the WAVEWATCH III model was used to transform the wind fields obtained from four weather models, namely the National Centers for Environmental Prediction (NCEP) Aviation model (AVN), Japan Meteorological Agency model (JMA), non-hydrostatic forecast system (NFS), and weather research and forecasting model (WRF), developed by different research institutions, to model ocean waves in the coastal waters of Taiwan for real-time wave forecasting. Their results showed that the mean wave heights of the waves generated by four wind fields in general agreed with the field observations from the wave buoys deployed off the Taiwan coasts. However, it was clear that, during typhoon events, the peak wave heights were generally underestimated by the standard equally weighted averaging method. As the peak wave height during the typhoon events can be one of the most important parameters in the decision- and policy-making processes since it represents the worst-case scenario, it is desirable to improve the methodology currently used to generate more accurate peak wave heights during the typhoon events. To this end, in this paper, a locally weighted learning algorithm is proposed to optimize the weights and used to calculate the resulting wave heights from each model-ensemble, so that the behavior of the wave model in response to each wind field can be better captured and understood, leading to improved typhoon wave forecasting. This study used the computed wave heights presented in Fan et al. (2013) for three typhoon events that occurred in 2011 and 2012 to illustrate the proposed methodology.

2. Wave model and computational domains

As stated in Fan et al. (2013), the WAVEWATCH III model was selected to predict waves from the surface wind forcing. For the sake of clarity, the wave model and its computational domains are briefly described here. The WAVEWATCH III wave model is a third-generation wave model developed at the National Oceanic and Atmospheric Administration/National Centers for Environmental Prediction (NOAA/NCEP) (Tolman, 1997, 1999, 2009) in the spirit of the WAM wave model (WAMDIG, 1988; Komen et al., 1994), which has been widely used to simulate wave fields using the wind data from various weather models.

In the work of Fan et al. (2013), a nested computational framework, as shown in Fig. 1, was used. The waves computed from the left-side coarse-grid domain were used to provide the boundary conditions for the right-side fine-grid domain. The resolutions of the coarse and fine grids were 0.5° (about 55 km) and 0.25° (about 27.5 km), respectively. The modeling system was driven by the wind fields from four weather models, namely, AVN, JMA, NFS, and WRF. The modeling system was applied to three typhoon events, Typhoon Jelawat, which occurred in 2012, and Typhoons Meari and Nanmadol, which occurred in 2011, as part of their operational forecasting. With four wind fields used as the surface forcing, the model generated four ensembles for waves. The wave heights of four wave ensembles were averaged using the standard arithmetical averaging method (i.e., equally weighted, 1/4). Their results, in general, showed agreement between the averaged wave heights and the measurements at a number of selected locations. However, it was clear that the averaged peak wave heights during those typhoon events were underestimated. Those peak waves, which in fact have the most

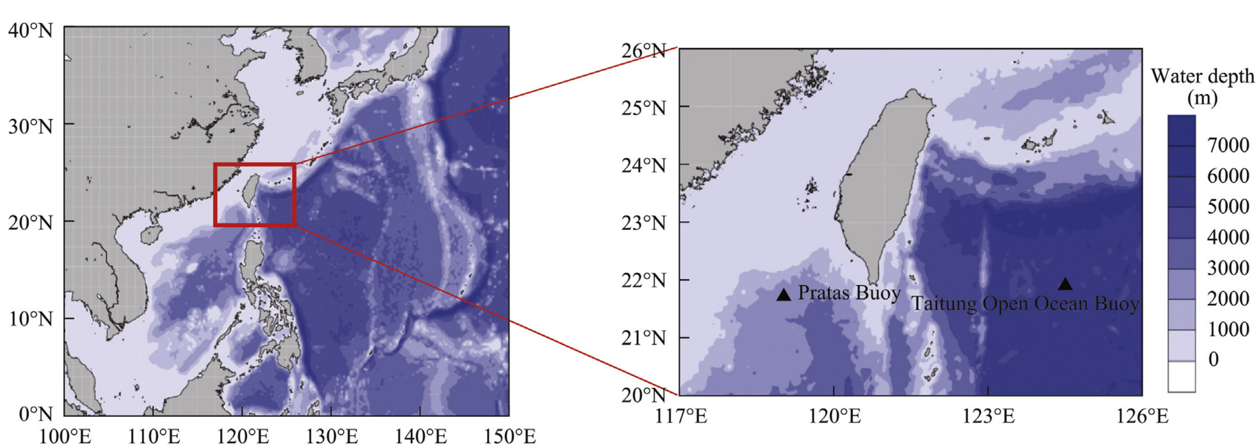

Fig. 1. Nested computational domains for WAVEWATCH III model and locations of wave buoys.