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Application of artificial neural networks in typhoon surge forecasting

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Abstract

A typhoon-surge forecasting model was developed with a back-propagation neural network (BPN) in the present paper. The typhoon's characteristics, local meteorological conditions and typhoon surges at a considered tidal station at time $t-1$ and t were used as input data of the model to forecast typhoon surges at the following time. For the selection of a better forecasting model, four models (Models A–D) were tested and compared under the different composition of the above-mentioned input factors. A general evaluation index that is a composition of four performance indexes was proposed to evaluate the model's overall performance. The result of typhoon-surge forecasting was classified into five grades: A (excellent), B (good), C (fair), D (poor) and E (bad), according to the value of the general evaluation index. Sixteen typhoon events and their corresponding typhoon surges and local meteorological conditions at Ken–fang Tidal Station in the coast of north-eastern Taiwan between 1993 and 2000 were collected, 12 of them were used in model's calibration while the other four were used in model's verification. The analysis of typhoon-surge forecasting results at Ken–fang tidal station show that the Model D composing 18 input factors has better performance, and that it is a suitable BPN-based model in typhoon-surge forecasting. The Model D was also applied to typhoon-surge forecasting at Cheng-kung Tidal Station in south-eastern coast of Taiwan and at Tung-shih Tidal Station in the coast of south-western Taiwan. Results show that the application of Model D in typhoon-surge forecasting at Cheng-kung Tidal Station has better performance than that at Tung-shih Tidal Station.

Keywords: Typhoon surge; Surge forecasting; Back-propagation neural network; Evaluation index

1. Introduction

Violent tropical storms sweeping over the Pacific Ocean from the Philippine Islands to Taiwan, Japan, Korea and/or the south-western coast of China are usually called typhoons. Most typhoons occur between July and October. A strong typhoon usually brings strong winds and heavy rains, causes severe surges and floods, and then results in significant loss of life and property. On average, Taiwan suffers about three to four typhoons annually. Typhoons usually cause significant different effects between the east coast and the west coast of Taiwan due to the shielding from the Central Mountain Range having a highest elevation of 3996 m. In general, typhoons act more severely on the east coast than on the west coast because most of typhoons landing on the Taiwan Island are approaching from the offshore of the east coast. Typhoon's intensity used to degrade after landing on the east coast and further degrade after passing over the Central Mountain Range. According to the Central Weather Bureau (CWB) of Taiwan, the moving tracks of low-pressure center of typhoons against Taiwan could be divided into seven categories, as shown in Fig. 1.

As a typhoon is approaching toward Taiwan, its strong wind and low atmospheric pressure often cause storm surges (abnormal rise in the water level near the coast) which could result in severe damage on coastal areas, especially on the low-lying lands around river mouths due to the double effects of the river floods by typhoon-brought rains and the backward uplifting sea-water floods by storm surges. For example, during the Typhoon Herb event in August 1996, spring tides and storm surges concurrently occurred, and resulted in severe damage on the harbor structures and seawalls in Keelung, Suao and Hualien in

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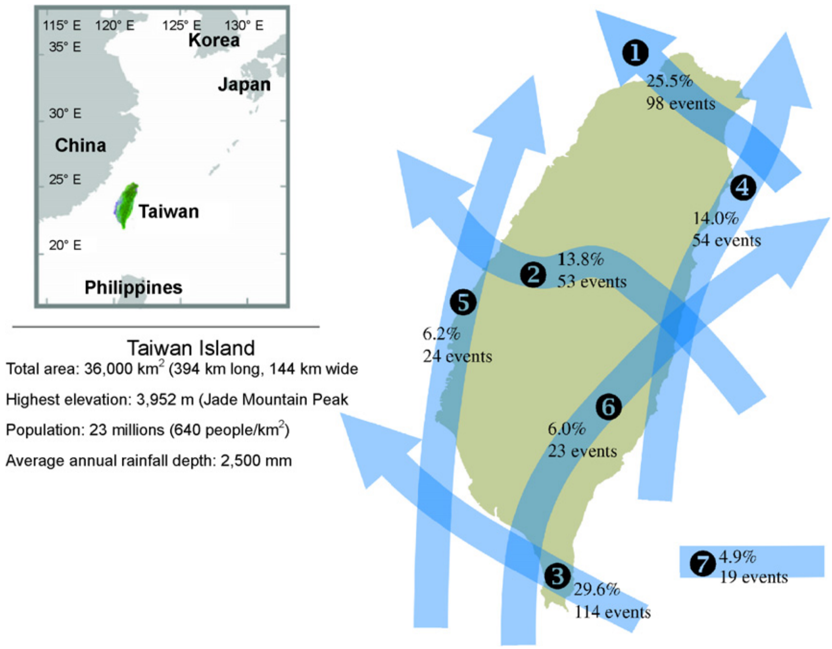

Fig. 1. Location of Taiwan, and seven categorized moving tracks of typhoons against Taiwan from 1897 to 2005.

the north-eastern Taiwan. In addition, storm surges at river mouths in western coasts of Taiwan had caused uplifting effects on river floods and resulted in severe inundation in coastal areas. Therefore, it is imperative to find a reliable method or model to predict the height of typhoon surge for coastal managements and hazards prevention.

The variation of sea-water level includes astronomical tides and meteorological tides. The meteorological tides are referred to typhoon surges during the actions of typhoons. Typhoon surges that are lack of periodic property are mainly caused by the lower atmospheric pressure and strong winds brought by typhoons, and could be influenced by environmental conditions along their moving paths. Typhoon surges are significantly different from astronomical tides having periodic property of rising and falling. The typhoon surge deviation $H(t)$ at time t in a considered tidal station during a typhoon event can be expressed as the difference between the measured sea water level $y(t)$ and the estimated astronomical tide level $Y(t)$, i.e.

$$H(t) = y(t) - Y(t). \tag{1}$$

Traditional harmonic analysis has been used to estimate the astronomical tide variations for few decades, but it requires a long length of (at least 29 days) observed tidal records to calibrate its harmonic parameters (Doodson, 1957, 1958). For areas lack of sufficient length of tidal records, one can use a new and efficient method that combines the Kalman filter technique with the harmonic analysis to estimate the astronomical tides (Jan et al., 1995; Yen et al., 1996).

The numerical simulation technique, statistical (empirical) analysis and artificial neural network have been used in typhoon surge forecasting or simulation. A numerical simulation model of typhoon surges is a combination of hydrodynamic equations, coastal topographical data, boundary conditions and a specified typhoon model (Hansen, 1956; Kawahara et al., 1982; Jelesnianski et al., 1992; Liu, 1997; Abohadima and Rabie, 2002). Therefore, accurate and detail hydrodynamic equations, topographical data, typhoon model, boundary conditions, as well as elaborate and time-consuming calculations are needed for the numerical simulation models. Unfortunately, we usually do not have accurate and detail topographical data and boundary conditions. Statistical frequency analysis has been used to estimate the maximum storm surge deviation under various recurrence intervals (Tsai et al., 2000). Some researchers have statistically analyzed the relation of the typhoon surge deviations and the typhoon characteristics (such as pressure at the center of typhoon, wind velocity and storm radius, etc.) to establish empirical formulas for typhoon surge estimation (Jan et al., 2006). Simply taking the sea-surface wind velocity as a primary input factor; Marzenna (2003) developed a wind-induced surge-forecast model; Basing on an artificial neural network (ANN). Lee (2006) took local meteorological conditions nearby the considered tidal station, such as the local wind speed, wind direction, atmospheric pressure and astronomical tidal levels as input factors, and then employed a back-propagation neural network (BPN) to establish a typhoon-surge forecasting model. A typhoon surge is caused by a typhoon, therefore a rational typhoon-surge forecast model should include the characteristics of typhoon itself. The present paper is aimed to develop a rational typhoon-surge forecast model with a BPN. Typhoon's characteristics, local meteorological conditions, and typhoon-surge heights at previous hours at the concerned tidal station are