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EXTENDED ABSTRACT

NUMERICAL MODEL FOR STORM SURGES

by Takao Yamashita and Isao Bekku

Disaster Prevention Research Institute, Kyoto University
Gokasho, Uji, Kyoto 611, Japan

yamashit@rs01.dpri.kyoto-u.ac.jp

INTRODUCTION

Storm surges are defined as abnormal changes of sea surface elevation whose periods range from several hours to days. The generation mechanism is separated into two. One is sea water suction due to atmospheric depression and the other is wind-driven sea water circulation. The former is a forced long-wave motion which is accompanied by a typhoon. The later is water circulation with a vertical distribution which is driven by strong wind blowing on the sea surface, including wind wave effects (roughness and Stokes drift). In both the motions, the hydrostatic assumption may be allowed because of the smallness of vertical acceleration compared with horizontal acceleration. Storm surges are generated by strong wind and atmospheric pressure gradients whereas tsunamis are generated by ground motions caused by earthquakes, land sliding and volcanic eruption. Tsunamis can be described by a series of free long waves whose periods range from ten minutes to several hours. However storm surges are more complicated phenomenon in which forced and free wind waves, wind-driven sea water circulation and water elevation forced by moving depression are combined together

For describing storm surges with hydrodynamic equations, nonlinear advection and propagation, generation, dissipation, excitation, and Coriolis' effect should be incorporated, because it has an extremely wide range of variation in its motion. Generation can be described with both surface friction due to wind, and atmospheric pressure gradient. Dissipation effects are vertical and horizontal mixing. Excitation can be expected by the gradient of radiation stresses (excess momentum due to wave motion). Nonlinear advection may play an important role under the condition of very shallow water such as storm surge propagation on tidal flats and dry lands (flooding). Moreover the vertical distribution of currents is important for wind-driven circulation. It is too difficult to get a solution of the hydrodynamic equations which contains all these effects. Rather, we use some assumptions to make the problem simpler to get the solution easily and precisely. However, when we simulate storm surge motion from the deep sea to extremely shallow water, we need different types of models (depth-averaged, three dimensional version with several turbulent models) for numerical computation.

The intensity of a storm surge depends on both sea bottom topography and land topography. A notable example is the difference between storm surges in the Bay of Bengal and in the bays of Japan. The Bay of Bengal has a larger scale of the continental shelf whose dimension is larger than the diameter of cyclone. A high and long-period surge is generated in such a wide area because the huge amount of wind-induced sea water circulation moves with the cyclone and piles up water at the coastline. In contrast, storm surges in the closed small basin such as bays of Japan, whose dimensions average 20-40m in depth, 60km in length, and 10km in mouth-width, and where the continental shelf connecting with the bay is narrow (order of 20-30km) are restricted in development. However, the Kuroshio current may affect the tidal level along the coastline causing abnormal mean sea level changes whose magnitude ranges from 10 to

60cm. Forerunners of storm surges along Japan's coast may also be a part of this abnormal tide.

This paper shows numerical modeling for storm surges in both the Bay of Bengal and in Osaka bay, considering differences of sea bottom topography, land topography, ocean currents and wind-wave characteristics.

NUMERICAL MODELS

Atmospheric Model

The pressure fields in the typhoon can be formulated with enough accuracy by Schloemer's equation. The radius of the maximum cyclostrophic wind speed is very important to simulate the atmospheric pressure fields. The method of objective analysis may be effective in the case of hindcasting. However, some kinds of meteorological formulation for the maximum wind radius may be needed for prediction.

Yoshizumi's formula is employed to estimate the wind field in the friction layer of the moving cyclone.the wind fields in the area which is surrounded by mountains are affected by both small-scale roughness such as trees and houses and large-scale land topography itself. However the wind fields evaluated by the typhoon model, such as Yoshizumi's model, can not consider the latter effect. We then used the MASCON (mass conservation) model in this paper to consider the effects of attenuation and acceleration of wind velocity due to land topography.

Oceanographic Model

The hydrodynamic model is based on the depth-averaged mass and momentum conservation equations. A time-fractional numerical scheme is used to solve the basic equation by the finite difference method following Benque et al(1982) by Yamashita et al (1990). The time-fractional finite difference method used here consists of three calculation steps of advection, diffusion, and propagation which are computed by an effective numerical scheme in each step. In the nonlinear advection computation the method of characteristics (the Two-Point Fourth-Order Scheme) is employed in the time step of n+1/3. For the computation of diffusion due to horizontal mixing and Coriolis' effects and propagation due to pressure gradient and shearing stresses, the ADI (Alternating Direction Implicit) scheme and the iterative ADI schemes are used in the time step of n+2/3 and n+1, respectively.

The wave field is computed by the so-called 2nd generation spectral model to estimate roughness on the sea surface and Stokes drift. The computational domain of the wave field is much bigger than that of the storm surge computation. Usually the area of the South-West Pacific Basin is used for wave field computation (wave height, period and direction).

CASE STUDIES

Storm surges in Bangladesh in the Cyclone of 1991

The most notable difference in storm surges between in the Bay of Bengal and in the bays of Japan is the scale of the continental shelf. The continental shelf in the Bay of Bengal has the scale same as the diameter of a cyclone; which is defined as twice the maximum wind radius.

The continental shelf geometry off Bangladesh is peculiar in the formation of the "step" that is an area shallower than 10 m deep and 80 km wide. This "step" is on the continental shelf whose width is of the order of 100 km. Cyclones generate huge storm surges in such an area because of a strong wind-induced circulation of an enormous amount of sea water. In addition to these factors, ilarge area of low ground caused so many flooding disasters that a heavy toll of lives has been taken. Thus it is very important to include the flooding computation in the storm surge simulation in

Bangladesh. In this paper, the numerical model is applied to the simulation of the storm surge in April 1991.

Storm Surges in Osaka Bay by Typhoon 9426

The Kii Channel and Osaka Bay (**Fig.1**) form the most important estuary in Japan which has been developed for many years. Recently, many artificially-reclaimed islands, such as the Kansai International Airport, Port Island and Rokko Island, have been constructed.

For numerical simulation of storm surges in this area, the Kuroshio (anomaly of tide level with a magnitude of 10 to 60 cm) and land topography effects on the wind field have to be considered. The storm surge caused by Typhoon 9426 is small, but meteorological and sea-state observations have been made at many facilities; Storm Surge Observation Tower (DPRI, Kyoto University), Kansai International Airport, many tide stations and meteorological stations. This will be good information for checking the fields of winds, waves, surges and currents.

A numerical hindcasting of this typhoon has been carried out in this study. Time-series of winds observed and computed at Shirahama and Osaka by Yoshizumi wind models with and without MASCON model are shown in **Fig.2** and 10m-height-wind field differences between two wind models is shown in **Fig.3**. **Figure 4** shows the comparison between observation and computation of storm surges at Shirahama and Osaka. It is observed that forerunners (about 20 to 30cm high) are generated and a dumping effect in surge height is simulated in the results computed using the Yoshizumi wind model with the MASCON model.

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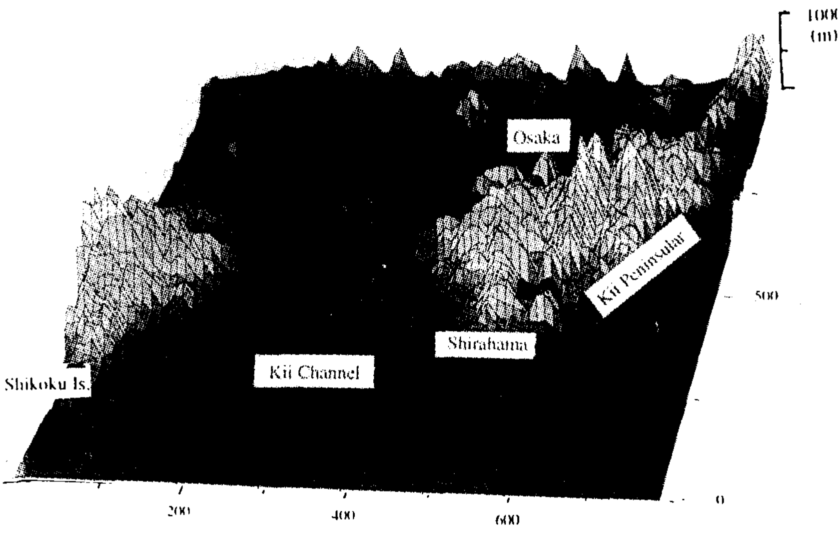

Fig.1 Land topography of Osaka Bay and Kii Channel

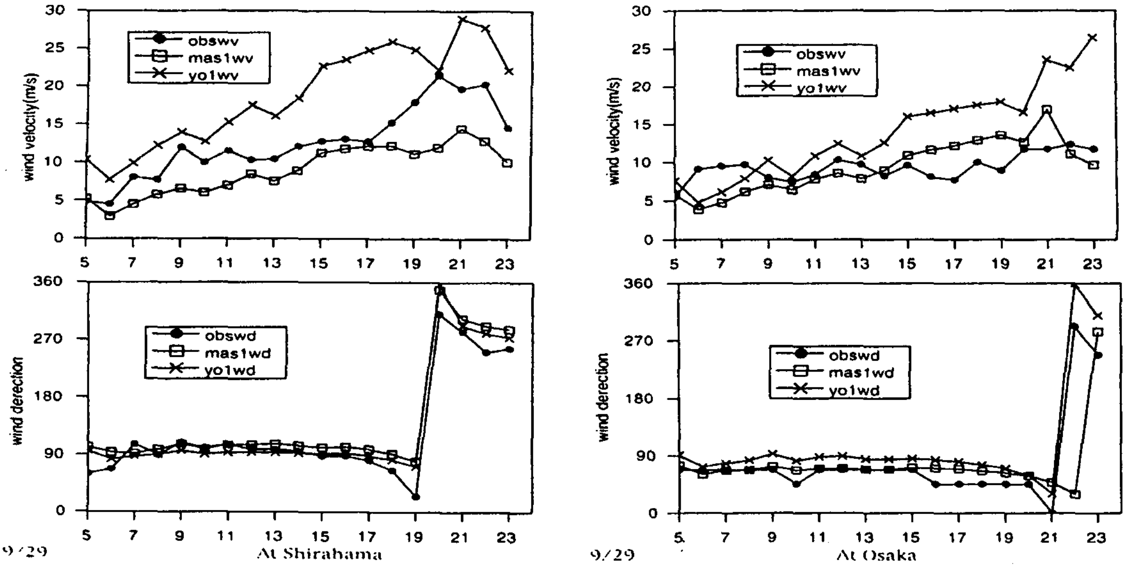

Fig.2 Time series of winds observed and computed at Shirahama and Osaka by Yoshizumi wind models with and without MASCON model

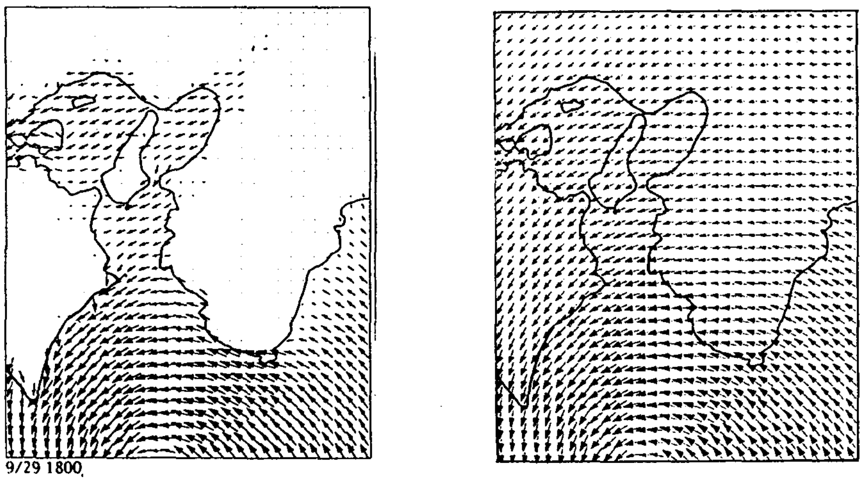

Fig.3 Wind fields at 10m height in the computation domain estimated by Yoshizumi wind models with (left) and without(right) MASCON model

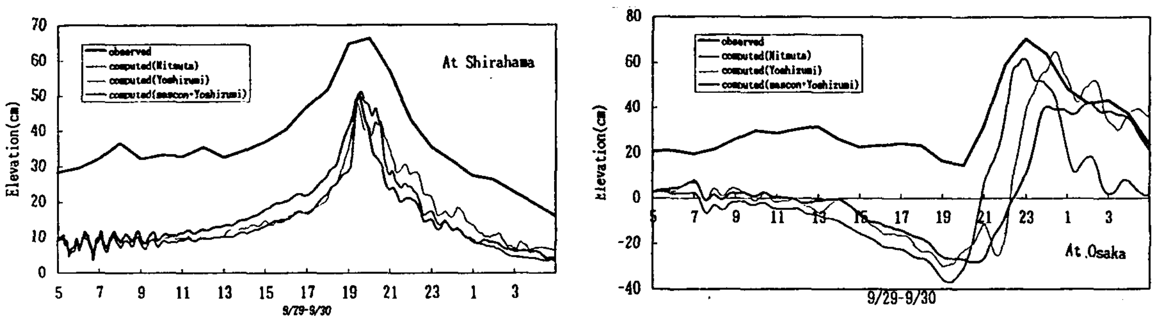

Fig.4 Time series of storm surges observed and computed at Shirahama and Osaka