Numerical simulation of surface wind and rainfall fields caused by a typhoon

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Abstract

A typhoon is the most significant meteorological event for natural disasters in the hydrosphere, which are caused by strong winds, heavy rain, river floods, storm surges and high waves. It is an important research theme for coastal engineers to develop the numerical simulation technique for strong wind and heavy rainfall fields caused by a typhoon. This study first carried out a simulation of strong wind fields by using a simple typhoon model of gradient-wind field reproduced with the Schloemer’s atmospheric pressure distribution model. Then a meso-scale typhoon model MM5 was employed to simulate both surface wind and rainfall fields caused by typhoons, which were compared with the gradient-wind field of simple typhoon model for Typhoon T9918 in the Suohnada Sea, Japan and the observed precipitation in the Korean Peninsula during Typhoon T0215. It is concluded that MM5 works well in both simulations of surface wind and rainfall fields caused by a typhoon.

Keywords: typhoon, surface wind, rainfall, numerical simulation, meso-scale meteorological model, MM5, MASCON model.

1 Introduction

Strong wind and low atmospheric pressure of typhoon generate storm surges and high waves that are the main causes of beach erosion and damages of coastal structures. It is an important task for coastal engineers to simulate the field of external forces of typhoon for coastal disasters and impact of coastal environment. Atmospheric pressure distribution of typhoon can well be simulated by a concentric circle distribution (e.g. Schloemer’s model...
(Mitsuta [1])) and its wind field is reproduced by a gradient wind assumption where the pressure gradient, centrifugal force and Coriolis’s force are in balance. The surface wind field can then be reproduced with sum of the gradient wind and typhoon moving wind together with artificial correction of inflow angle to introduce the effects of land surface friction. Such a simple model of wind and pressure field of typhoon has been applied for surface wind simulation for many practical purposes (Mitsuta [1]). MASCON (Mass Consistent Model) is also employed to correct the wind fields which are affected by land topography (Dickerson [2]).

Recently meso-scale meteorological models, such as MM5, have been employed to simulate the surface wind and pressure fields for engineering purposes. MM5 can also simulate the precipitation field accompanied with a typhoon in the watershed that causes rainfall runoff and river flood resulting in the sediment and material transport to the coastal ocean through river networks.

This paper discusses an applicability of numerical models for surface strong wind simulation caused by typhoon and a possibility of heavy rainfall simulation by the meso-scale meteorological model, MM5 [3].

2 Model outline and computational method

The outline of the model used and simulation method are explained below.

1) Simple Typhoon Model: Using Schloemer’s concentric circle atmospheric pressure distribution of typhoon, a gradient-wind field can be reproduced. A simple typhoon model employed this wind field together with correction of inflow angle and wind speed reduction due to surface friction. Mitsuta and Fujii’s simple typhoon model (Mitsuta [1]) was employed in this study. MASCON model is additionally used to correct wind velocity field which is affected by land topography. These two models will be called “simple typhoon model” and “MASCON model” in this paper.

2) Meso-Scale Meteorological Model, MM5: The Pennsylvania State University and National Center for Atmospheric Research (NCAR) have developed the Meso-scale Model (MM5) which is based on a non-hydrostatic, primitive equation model with a terrain-following $p - \sigma$ coordinates (Grell et al. [4]). The vertical full-sigma of 23-level is used from surface pressure level up to 100 hPa in all domains in the computation of this study. High-resolution Blackadar planetary boundary layer scheme composed of four stability regimes, including free convective mixed layer, is adopted. For cumulus processes, the “Grell’s parameterization” was used, that is based on rate of destabilization or quasi-equilibrium, simple single-cloud scheme with updraft and downdraft fluxes and compensating motion determining heating/moistening profile. This scheme is useful for smaller grid sizes 10-30 km, tends to allow a balance between resolved scale rainfall and convective rainfall. Shear effects on precipitation efficiency are considered. For moisture scheme, “simple ice” scheme was employed that adds ice phase processes to cloud and rain water fields predicted explicitly with
microphysical processes. No super-cooled water and immediate melting of snow below freezing level were assumed in this scheme.

(3) Background Data for MM5: Global weather reanalysis data by NCEP/NCAR was employed for rainfall simulation in the Korean Peninsular caused by T0215. GPV (Grid Point Value) data by the Japan Meteorological Agency was used for surface wind simulation of T9918. Typhoon bogussing was also used in the largest computational domain of MM5 (Davis and Low-Nam [5]).

3 Simulation of strong wind field

Storm surges and waves due to Typhoon T9918 in the Suohnada Sea were simulated by the developed atmosphere-ocean coupled model, in which three types models, (simple typhoon model, MASCON model and MM5) were used for reproducing the wind and atmospheric pressure at the surface caused by typhoon. Figure 1 shows the track of T9918. Computed period is from 0:00 to 23:00 on September 24, 1999 and computational domain is 131-133W and 33-34N. For the MASCON model, horizontal grid size is 1min and vertical grid size is 10m (120x85x201 grid points). For MM5 computation, 4.5km mesh size in the horizontal spacing (109x64 grid points) and 23 layers in the vertical spacing were employed.

![Figure 1: Estimated tracks of the Typhoon T9918.](image-url)

Figure 2 shows the surface wind fields computed by the simple typhoon model and corrected by MASCON model. Figure 3 shows comparison of surface
wind fields computed by MASCON model and MM5. It is found that surface pressure computed by MM5 is not in concentric circle and westerly wind component is enhanced in the MM5 simulation.

Figure 2: Surface wind fields computed by the simple typhoon model and corrected by MASCON model in the Suohnada Sea.

Figure 3: Comparison of surface wind fields computed by MASCON model and MM5.
To evaluate these simulated sea surface wind fields, storm surge simulations using these wind fields may be effective way. Comparison between simulations and observation of storm surge height in Hiroshima Bay are shown in Figure 4. We can recognize that the time series in surge height simulated by the wind fields of MM5 can reproduce observations with the good agreement. This result concludes that MM5 is better than simple typhoon model or MASCON model for simulation of surface wind field in the sea and bay surrounded by complicated land topography.

Figure 4: Comparison between simulations and observation of storm surge height in Hiroshima Bay.

4 Simulation of heavy rainfall field

Heavy rainfall due to Typhoon T0215 caused severe flood damage in the east coast of the Korean Peninsular. Its MM5 simulation was conducted in this study by using background meteorological analysis data of NCEP/NCAR with 1 degree mesh. Three nesting of computational domain of 27km, 9km, and 3km and four-dimensional nudging were used together with typhoon bogussing only in the largest computational domain. For parameterization of stable rainfall, the Grell scheme was selected and the simple ice scheme was used for convective rainfall simulation in the MM5 simulation.

To simulate the effects of the Taeback mountain range on the rainfall characteristics, the smallest horizontal grid size was set in 3km considering cumulus parameterization. In Figs 5-7, total precipitation distributions are shown. The last figure shows this computation for rainfall simulation predicts the total precipitation of 900mm in Kangneung area. Figure 8 shows the comparison between simulation (dark bars) and observation (light bars) of time series of...
precipitation intensity at Kangneung. It can be concluded that prediction of changes in precipitation intensity is still difficult for MM5 simulation even though the total precipitation can be reproduced with good agreement.

Figure 5: Total precipitation distributions in the computational Domain 1.

Figure 6: Total precipitation distributions in the computational Domain 2.
Figure 7: Total precipitation distributions in the computational Domain 3.

Figure 8: Comparison between simulation (dark bars) and observation (light bars) of time series of precipitation intensity at Gangneung.
5 Conclusions

This study first carried out a simulation of strong wind fields by using a simple typhoon model of gradient-wind field reproduced with the Schloemer’s atmospheric pressure distribution model. Then meso-scale typhoon model MM5 was employed to simulate both surface wind and rainfall fields caused by typhoons, which were compared with the gradient-wind field of simple typhoon model for Typhoon T9918 in the Suohnada Sea, Japan and the observed precipitation in the Korean Peninsular during the Typhoon T0215. The main results are listed below.

(1) Surface wind field simulated by MM5 is better than that simulated by the simple typhoon model or MASCON model.
(2) MM5 can simulate total precipitation of heavy rain caused by typhoon when we suitable employ the bonus typhoon and 4-dimensional nudging.
(3) Simulation of the intensity of precipitation is still difficult for MM5 simulation.

This study will be extended to a meso-scale water circulation model together with material transport to simulate fluid motion in the hydrosphere, which will be utilized for environment assessment and disaster prevention researches. For this purpose, a watershed runoff model and a land surface model interacted with meteorological model will be introduced to the atmosphere-ocean coupled model developed in this study.

References