6.7 Storm Surge Model

6.7.1 Introduction

Since Japan has suffered from many storm surge disasters over the years, accurate and timely forecasts and warnings are critical to mitigating the threat to life and property from such storm surges. Japan Meteorological Agency (JMA), which has the responsibility for issuing storm surge warnings, has operated a numerical storm surge model since 1998 to provide basic information for the warnings.

6.7.2 Dynamics

Storm surges are mainly caused by the effect of wind setup due to strong onshore winds on sea surface and inverted barometer effect associated with pressure drop in a low pressure system. To predict the temporal and spatial variations of sea level in response to such meteorological disturbances, the storm surge model utilizes two-dimensional shallow water equations. The shallow water equations consist of vertically integrated momentum equations in two horizontal directions:

$$
\begin{aligned}
\frac{\partial M}{\partial t} - fN &= -g(D+\zeta)\frac{\partial(\zeta-\zeta_0)}{\partial x} + \frac{\tau_{\mathrm{sx}}}{\rho_{\mathrm{w}}} - \frac{\tau_{\mathrm{bx}}}{\rho_{\mathrm{w}}} \\
\frac{\partial N}{\partial t} + fM &= -g(D+\zeta)\frac{\partial(\zeta-\zeta_0)}{\partial y} + \frac{\tau_{\mathrm{sy}}}{\rho_{\mathrm{w}}} - \frac{\tau_{\mathrm{by}}}{\rho_{\mathrm{w}}}
\end{aligned}
\tag{6.7.1}
$$

and the continuity equation:

$$
\frac{\partial \zeta}{\partial t} = -\frac{\partial M}{\partial x} - \frac{\partial N}{\partial y} \tag{6.7.2}
$$

where *M* and *N* are volume fluxes in the x- and y-directions, defined as:

$$
\begin{aligned}
M &= \int_{-D}^{\zeta} u\,\mathrm{d}z \\
N &= \int_{-D}^{\zeta} v\,\mathrm{d}z
\end{aligned}
\tag{6.7.3}
$$

f is the Coriolis parameter; g is the gravity acceleration; D is the water depth below mean sea level; ζ is the surface elevation; ζ_0 is the inverted barometer effect converted into the equivalent water column height; ρ_{w} is the density of water; τ_{sx} and τ_{sy} are x- and y-components of wind stress on sea surface; and τ_{bx} and τ_{by} are stresses of bottom friction, respectively. For computational efficiency, non-linear advection terms are omitted.

The equations are solved by numerical integration using an explicit finite difference method.

6.7.3 Meteorological forcing

The fields of surface wind and atmospheric pressure are required as external forcing for the storm surge model. A simple empirical model of tropical cyclone (TC) structure is used for TC cases, while the grid point values (GPV) predicted by the Mesoscale Model (MSM) and the Regional Spectral Model (RSM) are used for extratropical cyclone cases.

The simple empirical model of TC is introduced in order to take into account the error of TC track forecast and its influence on storm surge forecasting. Although the performance of TC forecast has been improved steadily, the mean position error in TC track forecast at this writing is still around 100km for 24-hour forecast (JMA, 2006). This implies that there is probably a large spread of possible forecast values of surface wind and atmospheric pressure at a certain location and the spread makes accurate storm surge prediction difficult even for 24-hour forecast. To take into account the influence of TC track uncertainty on the occurrence of storm surge, we conduct five runs of the storm surge model with five possible TC tracks. These five TC tracks are prescribed at the center and at four points on the forecast circle within which a TC is forecast to exist with a probability of 70% (Fig. 6.7.1), and used to make meteorological fields with an empirical TC model.

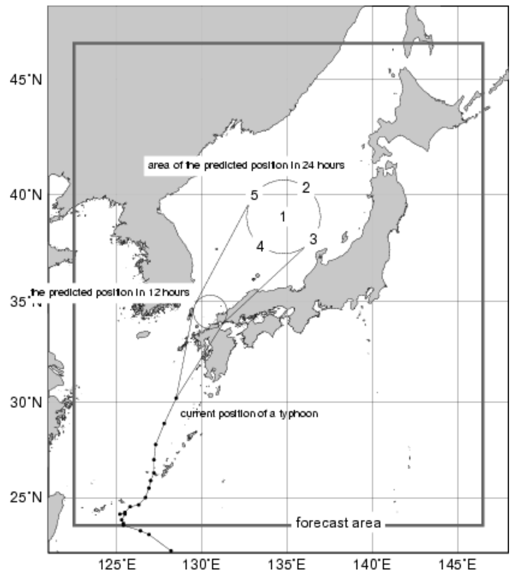

Fig. 6.7.1 The model area and forecast TC tracks.
Numerals in and on the forecast circle of TC position represent TC tracks used in the storm surge forecasting.

The simple empirical model utilizes the Fujita's empirical formula (Fujita, 1952) that represents the radial pressure distribution in a TC:

$$P = P_\infty - \frac{P_\infty - P_c}{\sqrt{1 + (r/r_0)^2}} \tag{6.7.4}$$

and the gradient wind relation. In eq. (6.7.4), P is the atmospheric pressure at r distance from the center of a TC, P_∞

is the atmospheric pressure at an infinitely distant point, P_c is the pressure at TC center and r_0 is the scaling factor of the radial distribution of the pressure. The surface wind field is estimated by using the gradient wind relation and the above pressure profile. To represent the asymmetry of wind field in a TC, the moving velocity vector of the TC multiplied by a weight that decays exponentially with the distance from TC center is added to the gradient wind. Analysis and forecast information on TC, such as center position, central pressure and maximum wind are applied to these formulas to synthesize the wind and pressure fields (Konishi, 1995).

When no TC exists around Japan, the storm surge model predicts a single scenario by using the meteorological fields predicted by MSM and RSM. For the computation period before 15 forecast hour, fields computed by MSM are used, while those by RSM are used after 15 forecast hour.

6.7.4 Specifications and products of the model

Table 6.7.1 gives the specifications of the storm surge model. The horizontal resolution of the model is one arc-minute in longitude and latitude, corresponding to about 1.5km by 1.9km. The model area covers the entire Japan (refer to Fig. 6.7.1). The model runs four times a day, i.e. six-hourly, and provides 33-hour prediction of storm surges for about 280 locations on Japanese coasts.

Table 6.7.1 Specifications of the storm surge model

area	23.5 – 46.5°N, 122.5 – 146.5°E
grid resolution	1 arc-minute (E-W: 1.5km, N-S: 1.9km)
forecast hour	33 hour
initial time	00, 06, 12, 18UTC
forecast member	5 scenarios (in the case of TC) 1 scenario (in the case of extratropical cyclone)

The model computes only storm surges, i.e. anomaly from the level of astronomical tides. However, storm tides (storm surge plus astronomical tide) are also needed in issuing a storm surge warning. Astronomical tides are predicted by using harmonic analyses of sea levels observed at tide stations beforehand. After the computation of the storm surge model, the level of astronomical tide for each station is added to the predicted storm surge.

Then the results are sent to local meteorological observatories that issue storm surge warnings to their responsible areas.

Fig. 6.7.2 shows the time series of storm surge at Takamatsu tide station on August 30-31, 2004 when Typhoon CHABA (T0416) passed the western part of Japan. This typhoon caused storm surge disasters in the coastal areas in the western part of Japan, especially those surrounding Seto Inland Sea. Fig. 6.7.2 also shows the storm surge predictions initialized at 09JST on August 30, about 12 hours before the peak surge occurred. As described above, five forecast runs were carried out for the five different possible TC tracks and the results are denoted by the five different kinds of lines in the figure. The heights of the forecast peak surges show a good agreement with the observation.

(a) (b)

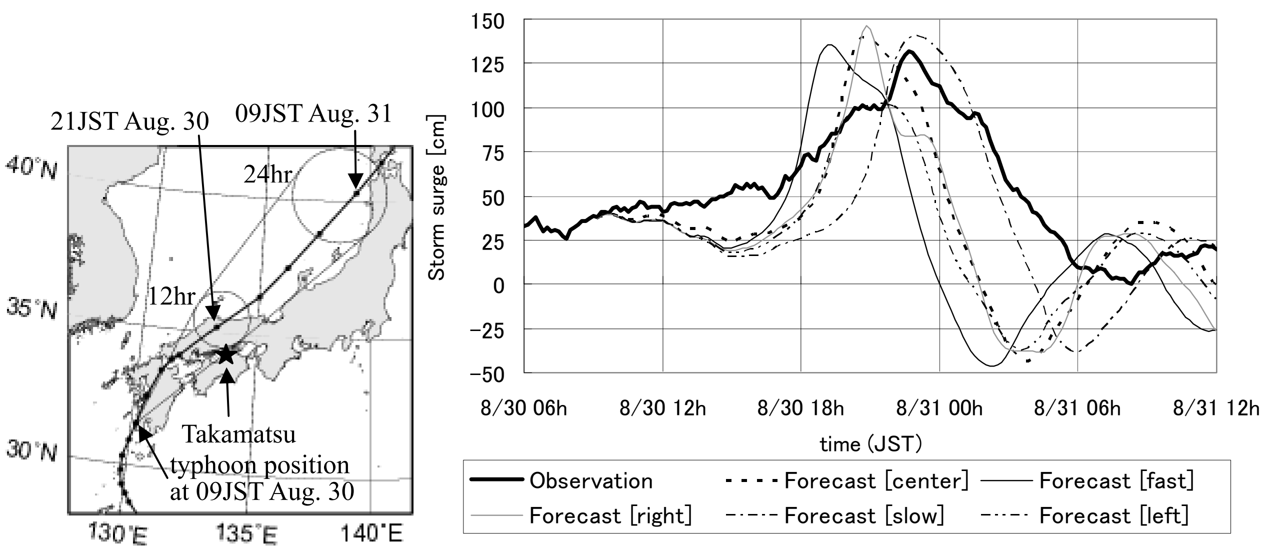

Fig. 6.7.2 Track of Typhoon CHABA (T0416) and time series of storm surge at Takamatsu.

(a) Track of the typhoon. The thick line is the analyzed track and dots on the line show six-hourly positions. Two circles indicate the areas of possible typhoon center position with 70% probability for 12-hour and 24-hour forecasts.

(b) Observed and predicted storm surges for Takamatsu tide station. The five thin lines depict the time series predicted for the five different typhoon tracks.

References

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