THE CASE STUDY OF THE STORM SURGES IN THE SETO INLAND SEA CAUSED BY TYphoon CHABA

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Typhoon Chaba in 2004 made landfall on the southeastern Kyushu and went through Chugoku (western part of Japan’s Main Island) on 30 August, causing large storm surges in the Seto Inland Sea (SIS). The highest tides yet were recorded at tide stations in Takamatsu and Uno Ports. We analyzed the tidal data and simulated this case with numerical storm surge models.

The results revealed that the wind set-up basically played a key role in causing the large storm surges. However, the maximum storm surge (MSS) in Takamatsu did not occur when the typhoon was the nearest to the city, but about 2 hours later. Since the time of MSS approximately corresponds to the high spring tide time, the record breaking storm tide was observed there. We also investigated the degrees of the contribution of two main factors of storm surges, i.e. inverted barometric effect and wind set-up, in each area. As a result, it turned out that the peak times of each effect were influenced by the geographical feature, as well as the wind field and the position of the typhoon, and had different characters in areas. It also turned out that the Kammon Strait, which is very narrow and supposed to be negligible, had an important role on sea water inflow into the SIS.

Keywords: topographic effect; wind set-up; numerical simulation; TY Chaba

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INTRODUCTION

Storm surges generated by typhoons have often brought large disasters in the coast of Japan. Especially, in the case of Typhoon (TY) Vera, which caused 5,098 dead or missing in 1959, most of the casualties were brought by the storm surges. The countermeasures to storm surges have developed progressively after this disaster. However, serious storm surges still occurred. In 1991, large storm surges were generated in the western part of the Seto Inland Sea (SIS; shown in Fig. 1) by TY Mireille (Konishi, 1994; Konishi and Tsuji, 1995). However, severe disaster did not occur since the maximum storm surge (MSS) occurred just in low tide. In 1999, the storm surges by TY Bart led to serious disasters; 13 people were directly killed by storm surges in Yatsushiro Sea, and Yamaguchi-Ube airport in the Suoh-Nada (western part of the SIS) was unavailable by inundation (JMA, 2000; Kohno, 2000). The tracks of these two typhoons are almost the same and both of them generated large storm surges in Yatsushiro Sea. Recently, intense typhoons have frequently hit Japan since 2000, and serious disasters sometimes happened. In 2004, as many as ten named tropical cyclones made landfall on Japan, which is quite extraordinary since usual number is two or three. Several tropical cyclones brought disasters due to storm surges. Especially, TY Chaba generated large storm surges in the SIS, and the coincidence of MSS with the peak time of high tide caused the highest storm tide records at Takamatsu and Uno (central part of the SIS). More than 8,300 houses are inundated above the floor level only in Kagawa Prefecture, and total damages were quite enormous as 16,799 houses inundated above the floor level.

FIGURE 1 – MAP OF THE WESTERN PART OF JAPAN AND THE SETO INLAND SEA (SIS). THE WHOLE AREA OF THE SETO INLAND SEA FROM THE SUOH-NADA TO THE OSAKA BAY IS AN INLAND SEA. THE POINTS OF TIDE STATIONS ARE ALSO SHOWN.
Although large storm surges sometimes occurred in the SIS due to typhoon passages as mentioned above, most cases happened in the Suoh-Nada (western part of the SIS) or the Osaka-Bay (eastern part of the SIS), and they rarely occurred in the central part of the SIS. TY Chaba is applicable to the latter case. This case is also characterized by the fact that the MSS occurred a few hours later than the time when the typhoon was nearest. Therefore we have investigated the mechanism of this storm surge with a concern to the effects of sea topography and the sequence of typhoon position, mainly based on a numerical model.

TY CHABA (0416) AND STORM SURGES IN THE SIS
1. OUTLINE OF TY CHABA (0416)

A tropical depression (TD) was formed in the sea around the Caroline Islands at 06UTC (all times are expressed in UTC hereafter) on 18 August 2004. It moved slowly westward and developed into a Tropical Storm Chaba at 12UTC on 19 August. Chaba continued to move westward and was upgraded into a Typhoon at 18UTC on 21 August. Then it turned toward the northwest at the southwestern edge of sub-tropical high on 23 August. The typhoon continuously intensified during this period and developed to the strongest level as central pressure of 910hPa and the maximum wind speed of 56m/s at 18UTC on 23 August.

The typhoon kept its intensity till 18UTC on 26 August, moving to northwest, and gradually weakened. The typhoon moved to west again in the sea east of the Nansei Islands and turned to the north-northeast in the sea south of Kyushu.
The typhoon made landfall at Kushikino at about 00UTC on 30 August, with central pressure 950hPa, the maximum wind speed 41m/s, and the radius of storm wind extended to 230km east. The best track of TY Chaba around Japan is shown in Fig. 2. The typhoon passed through Kyushu and moved northward in the Suoh-Nada, and made landfall again at around Hohfu. As the TY Chaba approaching, Chugoku, Shikoku, northern and central part of Kinki were gradually covered by storm winds. The typhoon passed Tottori at about 12UTC with slightly weakened intensity (central pressure 960hPa and the maximum wind speed of 31m/s), and became to move faster in the Sea of Japan. The typhoon made landfall again at Hakodate at 03UTC on 31 August, and transformed into an extra-tropical cyclone in the east of Hokkaido at 06UTC.

Strong winds were observed in the areas the typhoon passed nearby. In Okayama, the maximum wind of 21.1m/s (SW) and the maximum gust of 38.5m/s (SW) were observed at 15:20 and 12:51UTC on 30 August, respectively; those were the highest records there.

2. STORM SURGES IN THE SIS BY TY CHABA

The main storm surges in the SIS by TY Chaba occurred from 30 to 31 August. Fig. 3 shows the time series of hourly storm surges (the each storm surge is defined by detracting astronomical tide from observed sea level) observed at tide stations. The magnitudes of the MSSs are generally about 1-1.5m.

![Figure 3 - Storm Surges Observed at Several Tide Stations in the Seto Inland Sea](image)

The more east the observation point is located, the later the MSS was observed (Table1). For example, in the western part of the SIS, the MSS of 1.33m in Moji was observed at 06:36. The MSSs in Hiroshima and Matsuyama occurred at 09:35 (1.49m) and 08:49 (1.40m), respectively. MSSs in Takamatsu and Uno were observed after 13UTC, 4 hours later than that
in Matsuyama. The MSS of 1.33m was observed at 13:23 in Takamatsu, and 1.37m at 13:16 in Uno. In Kobe and Osaka, that are in the eastern part of the SIS, the MSSs were observed just before 15UTC: 1.34m at 14:42 in Kobe and 1.32m at 14:30 in Osaka.

**TABLE 1 – THE MAXIMUM STORM SURGES (MSS), THE MINIMUM SEA LEVEL PRESSURES (MSLP) AND THE DIFFERENCE OF TIME**

<table>
<thead>
<tr>
<th>Tide station</th>
<th>MSS (m) and time (UTC)</th>
<th>MSLP (hPa) and time(UTC)</th>
<th>difference of time (min.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moji</td>
<td>1.33 (06:36)</td>
<td>969.5 (06:30)</td>
<td>6</td>
</tr>
<tr>
<td>Hiroshima</td>
<td>1.49 (09:35)</td>
<td>972.1 (10:16)</td>
<td>-41</td>
</tr>
<tr>
<td>Matsuyama</td>
<td>1.40 (08:49)</td>
<td>972.8 (08:49)</td>
<td>—</td>
</tr>
<tr>
<td>Uno</td>
<td>1.37 (13:16)</td>
<td>978.1 (10:48)</td>
<td>148</td>
</tr>
<tr>
<td>Takamatsu</td>
<td>1.33 (13:23)</td>
<td>978.1 (11:01)</td>
<td>132</td>
</tr>
<tr>
<td>Himeji</td>
<td>1.57 (14:50)</td>
<td>982.7 (13:13)</td>
<td>97</td>
</tr>
<tr>
<td>Kobe</td>
<td>1.34 (14:42)</td>
<td>987.5 (14:05)</td>
<td>37</td>
</tr>
<tr>
<td>Osaka</td>
<td>1.32 (14:30)</td>
<td>988.1 (13:42)</td>
<td>48</td>
</tr>
</tbody>
</table>

Fig. 4 shows the water levels at several tide stations. The magnitudes of the storm surges are not so different among these points, but the magnitudes of the storm tides are different each other because the timing of the astronomical tides are different each other. Since the time of MSSs were the same as that of low tide in Moji, storm tides did not become so high; the maximum tides were observed about 6 hours earlier than the time of MSS (around 00:30), this was mostly contributed by high tide, not the storm surge. The maximum storm tides of 2.58m (Matsuyama) and 2.69m (Hiroshima) were observed at 11:56 and 12:56 respectively, 2-3 hours earlier than the high tides. The maximum storm tide there results from combination of storm surge and astronomical tide. The maximum storm tides were observed in Takamatsu and Uno at 13:42 and 13:47, respectively, only 30 minutes later than MSS. Moreover, since it was period of spring tide, water levels at high water were higher than usual. This also led to the highest record of maximum tides as 2.46m (Takamatsu) and 2.54m (Uno). This extraordinary high storm tide caused enormous disasters, and more than 12,000 houses were flooded to over floor level in these coastal areas. The maximum storm tides were observed at 12:24 in both Kobe and Osaka to the east of Takamatsu, which was about 2 hours earlier than the time of MSSs.

In order to investigate the relation of storm surges to the relative position of typhoon, the time of MSS and the time when the minimum sea level pressure (MSLP) was observed, which corresponds to the time when the typhoon mostly approached, are listed in Table 1. The easterly wind was predominant in the western part of the SIS as the typhoon was approaching, and the sea level became higher from early stage in the Suoh-Nada. Around the Suoh-Nada
area, the times of MSSs were almost the same as the time of the MSLP, since the typhoon passed through the Suoh-Nada. For example, in Moji, the time of MSS (1.33m) was only 6 minutes later than MSLP time. After the typhoon passed and made landfall at Chugoku region, the predominant wind turned to westerly in the wake of typhoon, and large storm surge area shifted to the eastern part of the SIS gradually. The MSS was observed at almost the same time of MSLP in Matsuyama, but was 41 minutes earlier in Hiroshima. At the points to the east of Matsuyama, the MSSs were observed later than the time of the MSLP.

![Graphs showing observed sea levels at several stations in the Seto Inland Sea.](image)

**FIGURE 4 – THE OBSERVED SEA LEVELS AT SEVERAL TIDE STATIONS IN THE SETO INLAND SEA.** The observed sea levels are indicated by a solid line; the broken line represents the astronomical tide. The arrows show the time of the minimum surface pressure.

It is notable that the times of MSS in Takamatsu and Uno were more than 2 hours later...
than the times of the MSLPs, but in Himeji and Osaka, located in further east of Uno, the
difference of times between MSS and MSLP became smaller again. This indicates that the
storm surge area did not move monotonously to east while the typhoon was simply leaving
northward.

NUMERICAL METHODS

The simulation was basically carried out with a two-dimensional (2D) storm surge
model whose equations are momentum flux and continuity of water mass under the rotating
field with gravitational acceleration. We also calculated with the Princeton Ocean Model
(POM) developed by Blumberg and Mellor (1987) later.

The surface pressure field $P_s$ is defined by the formula of Fujita (1952), using the
parameters of the 3 hourly JMA best track data. The gradient wind derived from this profile
gives the symmetrical surface wind, and the surface wind is defined to be asymmetrical by
adding a typhoon moving speed to this gradient wind with a constant inflow angle of 30
degrees. The surface stress was determined with this surface wind. The surface and bottom
drag coefficients $C_{da}$ and $C_{db}$ are defined empirically as

$$C_{da} = 3.2 \times 10^{-3}$$
$$C_{db} = 2.5 \times 10^{-3}$$

The coastal boundary was assumed to be a “rigid wall” and no inundation or dry-up
were considered. The boundary of open sea was assumed to maintain a static balance with the
surface pressure, and a deviation from the statically balanced level makes inflow or outflow
current as a gravitational wave.

The computational area was set from 32°N to 35°N and from 130°E to 136°E, which
covers the whole SIS, and the horizontal grid resolution was 1 minute (corresponds to a
physical distance of 1.85km in latitude and 1.55km in longitude). The domain and sea
topography used in the calculation are shown in Fig. 5. The calculation time step was 2
second, which completely satisfies the CFL condition since even the largest water depth does
not exceed 1,000m. This grid resolution was not enough to express the Kanmon Straits, and
sea water could not pass through. However, the gross characteristic of the storm surge in the
SIS is supposed to be expressed adequately since the amount of sea water flow via channels
such as the Bungo Channel, which is well represented, is far larger than that of the Kanmon
Straits.
We conducted the simulation from the static initial state. Considering the earlier part being spent for spin up, we started the calculation from 00UTC on 29 August, two days before the typhoon hit the SIS.

**SIMULATION RESULTS**

Fig. 6(a) shows the simulated storm surge distributions as well as the surface winds used in the calculations. The observation of winds is not so dense in this area, especially in the sea, for intensive comparison. Therefore, the surface winds of the hourly objective analysis, which is based on the operational Meso-Scale Model (MSM) prediction as a first guess and modified with the wind profiler observation, and shown in Fig. 6 (b), will be used for discussion in the next section.

Storm surges are little detected in the whole area before the typhoon reached Kyushu and a gale wind started. In the Suoh-Nada, large storm surge area is generated by strong easterly wind ahead of the approaching typhoon (06UTC on 30 August). As the typhoon had passed the Suoh-Nada and moved northeastward, the wind turned to westerly, which led the large storm surge area to move eastward (10UTC). Around 13UTC, although the typhoon had already moved away northward, a large storm surge is notable in the central sea to the west of a narrow Straits (just where Takamatsu and Uno exist). After that, although the typhoon continued to leave further, westerly wind continued to blow, and storm surge shifted eastward, to the Osaka Bay around 15UTC on 30 August.

The calculated MSSs at several points are listed in Table 2. According to Tables 1 and 2, all the calculated MSSs are favorably compared with observation and every error are within 0.30m. However, there are almost 1 hour differences in peak time at some points. This may mainly come from the error of meteorological data input, e.g. assumed pressure field.
FIGURE 6 – HORIZONTAL DISTRIBUTION OF (A) THE SIMULATED STORM SURGE AND THE MODEL WIND, AND (B) THE SURFACE WIND OF THE HOURLY OBJECTIVE ANALYSES. THE SHADES INDICATE SIMULATED STORM SURGES (m), AND THE CONTOURS IN THE LEFT COLUMN SHOW THE MODEL SURFACE PRESSURE. THE BARBS IN BOTH COLUMNS SHOW THE WINDS (LONG FLETCHING IS 10m/s, AND SHORT 5m/s).

DISCUSSION

Generally speaking, storm surges are mainly caused by two factors: the inverted barometric effect and the wind set-up. Both of the effects are easily estimated to some extent by assuming the static balance. In addition, it is also known that the dynamical effects such as
the resonance of the moving speed of meteorological disturbance and surface water movement as ocean long wave may cause large storm surges (e.g. Arakawa and Yoshitake, 1935). Since the numerical simulation model enables to include such dynamical effects without any simplification of topography, we will be able to proceed to discuss how the two main effects functioned in the simulation.

To detect these effects, we carried out two additional simulations: One is that only the wind effects are considered by setting the pressure force in the second term on the right side of (3.1) to $\zeta_0 = 0$ (hereafter we refer to as the “wind calculation”), and the other is that only the pressure effects are considered by setting the wind stress in the third term on the right side of (3.1) to $\tau_a$ to 0 (hereafter we refer to as the “pressure calculation”). We represent I as the control calculation, II as the “wind calculation”, and III as the “pressure calculation”. The MSSs by every calculation are listed in Table 2.

### TABLE 2 – THE RESULTS OF THREE CALCULATIONS. SIMULATED MAGNITUDES OF THE MAXIMUM STORM SURGES (MSS), GIVEN MSLP WITH THE OCCURRENCE TIME IN PARENTHESES. CONTRIBUTION RATIO OF THE WIND SET-UP IN THE MSS, CR, DEFINED AS THE MSS IN II DIVIDED BY THAT IN I IS ALSO LISTED.

<table>
<thead>
<tr>
<th>Tide station</th>
<th>MSS(m) in I</th>
<th>MSLP (hPa)</th>
<th>MSS (m) in II</th>
<th>MSLP (hPa)</th>
<th>MSS (m) in III</th>
<th>MSLP (hPa)</th>
<th>CR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moji</td>
<td>1.61 (05:40)</td>
<td>969 (07:20)</td>
<td>1.35 (05:20)</td>
<td>969 (07:20)</td>
<td>0.52 (08:40)</td>
<td>969 (07:20)</td>
<td>84%</td>
</tr>
<tr>
<td>Hiroshima</td>
<td>1.44 (10:10)</td>
<td>969 (10:20)</td>
<td>1.01 (08:50)</td>
<td>969 (10:20)</td>
<td>0.70 (11:10)</td>
<td>969 (10:20)</td>
<td>66%</td>
</tr>
<tr>
<td>Matsuyama</td>
<td>1.15 (10:30)</td>
<td>978 (10:00)</td>
<td>0.70 (10:20)</td>
<td>978 (10:00)</td>
<td>0.50 (11:00)</td>
<td>978 (10:00)</td>
<td>60%</td>
</tr>
<tr>
<td>Uno</td>
<td>1.19 (12:40)</td>
<td>983 (12:00)</td>
<td>0.89 (12:20)</td>
<td>983 (12:00)</td>
<td>0.49 (14:00)</td>
<td>983 (12:00)</td>
<td>74%</td>
</tr>
<tr>
<td>Takamatsu</td>
<td>1.08 (13:30)</td>
<td>985 (12:00)</td>
<td>0.76 (12:50)</td>
<td>985 (12:00)</td>
<td>0.47 (14:20)</td>
<td>985 (12:00)</td>
<td>69%</td>
</tr>
<tr>
<td>Himeji</td>
<td>1.47 (13:50)</td>
<td>985 (13:20)</td>
<td>1.16 (13:30)</td>
<td>985 (13:20)</td>
<td>0.46 (15:20)</td>
<td>985 (13:20)</td>
<td>78%</td>
</tr>
<tr>
<td>Kobe</td>
<td>1.40 (14:30)</td>
<td>990 (13:40)</td>
<td>1.11 (14:20)</td>
<td>990 (13:40)</td>
<td>0.36 (15:50)</td>
<td>990 (13:40)</td>
<td>79%</td>
</tr>
<tr>
<td>Osaka</td>
<td>1.62 (14:40)</td>
<td>991 (14:00)</td>
<td>1.35 (14:30)</td>
<td>991 (14:00)</td>
<td>0.37 (15:50)</td>
<td>991 (14:00)</td>
<td>82%</td>
</tr>
</tbody>
</table>

### 1. THE INVERTED BAROMETRIC EFFECT

The results of III show that all the MSSs appeared after the time when the typhoon was nearest; especially the delay became large in the Hiuchi-Nada and the Osaka Bay, that is, Uno, Takamatsu, Himeji, Kobe and Osaka. The reason is supposed that the eastward movement of water piled up in the western part of the SIS was prevented at the narrow part of the east channel surrounded by the ellipse in Fig. 7 (a). In order to verify this hypothesis, a calculation with an experimental topography as shown in Fig. 7 (b) was conducted. (The channel part is enlarged and changed to the sea with 20m depth.) The result showed that the times of the MSS in the west of the Iyo-Nada were hardly changed. On the one hand, those in the east of
the Iyo-Nada became earlier and the delay of time decreased (not shown). For example, the
time became earlier about 20 minutes in Takamatsu and Uno, and about 40 minutes in the
Hiuchi-Nada at most.

FIGURE 7 – (a) THE ORIGINAL TOPOGRAPHY, (b) THE TEST ONE WHERE THE EAST
CHANNEL IS EXTENDED.

If the static balance is assumed, the amount of surge by inverted barometric effect can
be estimated to be 30 - 40cm from the minimum surface pressure, that are generally 10cm
smaller than the MSSs of III. The reason of this difference may be that sea water was
preferably piled up, due to the inertia of sea water and the narrow strait as an “obstacle”.
Therefore, the dynamical inverted barometric effect with an influence of sea topography is
likely to give larger MSS than only static one would give in this area.

2. THE WIND SET-UP

Fig. 8 shows the amplitudes of the MSS at every grid point and surface wind
corresponding to the occurrence time of the calculation I. This distribution reveals several
clusters of large storm surge area and wind direction. The storm surge in each area behaves as
if the area is a bay, where large storm surge is generated in the most inner part by an inflow
wind. By considering this characteristic, we divide the SIS into 6 local seas as shown in Fig. 8.

FIGURE 8 – THE MAXIMUM STORM SURGES (m) CALCULATED IN EVERY GRID AND WIND
AT SAME TIME.

(1) the sea opening to east with the Kanmon Straits as a wall (the Suoh-Nada)
The wind set-up is extremely predominant due to its shallow water depth. The inflow of sea water from the Bungo Chanel also influences on the storm surges.

(2) the sea opening to south with the north coast of Hiroshima (the Hiroshima Bay)

Since the typhoon passed nearby and the duration of southerly wind was long, the wind set-up continued longer than other areas.

(3) the sea opening to southwest, closed by islands around Imabari (the Iyo-Nada and the Aki-Nada)

The wind set-up is not so predominant due to deep water. However, the coincidence of the time of the maximum inverted barometric effect and that of the wind set-up causes large storm surge.

(4) the sea opening to west, closed by the narrow channels (the Hiuchi-Nada)

The maximum of the inverted barometric effect appeared about 2 hours later than the minimum surface pressure. The reason of the delay is that flow of the sea water was reduced by the narrow east edge of the Aki-Nada.

The dominant wind direction is south while Takamatsu is open northward. Therefore, it is not reasonable to explain this storm surge simply by the local wind set-up. There may be possibility of any seiche being excited by own topography scale, but no such oscillation is detected. We consider that the storm surges in the Hiuchi-Nada was caused mainly by the accumulation of sea water, prevented from moving eastward at the narrow channel between Takamatsu and Uno.

(5) the sea opening to south with the north coast of Himeji (the Harima-Nada)

The wind set-up functioned well since the sea opens to south and southwest and water depth is shallow.

(6) the sea opening to south with the north coast of Osaka (the Osaka Bay)

The character is almost same as those of the Harima-Nada.

3. THE EFFECT OF WIND ACCURACY

The calculation results show good agreement with observation, but there are still different points. These problems essentially may come from the wind fields, which are deduced from the ideal profiles of pressure. The real structure of a typhoon is so complicated and the wind in the core area is far from being uniquely determined. Moreover, the wind is modulated by the topography, and the wind distribution is usually not simple. The “errors” of wind fields surely bring error in storm surges estimation.

Therefore, we conducted a storm surge simulation with more realistic winds, that is derived from is the Numerical Weather Prediction (NWP) GPVs. These GPVs were calculated by the Non-Hydrostatic Model (NHM) of JMA with the grid resolution of 5km (Saito et al., 2001), and we interpolated them for the storm surge model. The simulation was carried out with POM with 12 vertical layers, though we could not detect any significant effect of 3D calculation itself, at least our calculations.
Fig. 9 shows the time sequence of storm surges at Takamatsu by these results. However the results showed that the MSS is almost same among them though the storm surges were certainly improved especially before and after the MSS. This may be because that wind field at central part of typhoon is adequately estimated even in the gradient wind but not around typhoon. The wind around typhoon may be much influenced by environmental condition, and thus dynamical estimation should be desirable.

![Graph showing time series of storm surges at Takamatsu](image)

**FIGURE 9 – THE TIME SERIES OF STORM SURGES AT TAKAMATSU. OBSERVATION (OB S), CONTROL RUN BY THE GRADIENT WIND (CNTL), CALCULATION BY THE NWP GPV(MSM), AND FINE MESH CALCULATION BY NWP GPV (MSM-F) ARE SHOWN.**

4. THE EFFECT OF THE KANMON STRAITS

We also simulated with a finer grid resolution of 30 seconds, also shown in Fig.9. In this case, we can express the Kanmon Straits as open. The results with 30 seconds resolution apparently show closer profiles to observation, especially in the low surge part. The main reason of this modification is likely to come from the inflow from the Kanmon Straits, since this improvement did not appear if we close the Kanmon Straits.

We assumed that the gross characteristic of the storm surge in the SIS was adequately expressed since the Kanmon Straits seemed to be negligible to small. However, according to our calculation the water inflow via the Kanmon Straits was not negligible and played important role on water supply.

CONCLUSION

The mechanism of the storm surges in the SIS caused by TY Chaba in 2004 was investigated and our conclusions are summarized as follows:
(1) The storm surges by TY Chaba are mainly caused by the wind set-up effect, since the water depth in the SIS is generally shallow.

(2) The SIS is divided into six areas in terms of the characteristics of the storm surge caused by TY Chaba. Each area is characterized by the preferred wind direction, relative importance of wind set-up effect and piling up of the sea water.

(3) The time of the MSS was different among the areas. The time is almost the same as the time when the typhoon was nearest in the western part, although it delayed in the eastern part, especially the delay of time in the Hiuchi-Nada was over 2 hours. This indicates that storm surges in the SIS have good chances to occur after a typhoon passing away by the influence of sea topography. The timing of MSS was also influenced by the change of wind directions along with the typhoon movement.

(4) The fact that storm surges in the SIS occurred after a typhoon passing away, should be strongly kept in mind for adequate timing of warning. Since it is rather common for a typhoon to pass along the same course as TY Chaba, that made landfall in Kyushu and passed into the Sea of Japan, it is likely that similar storm surges also happen frequently. Therefore we will research other storm surge cases to detect the mechanism as well.

Acknowledgements

The authors would like to express their sincere gratitude to Dr. Ohno, the Director of the Takamatsu Local Observatory, for his helpful comments and continuous encouragement. Some of data used in this research are collected in the “Urgent research about typhoons made landfall on Japan in 2004” of MRI, and the authors also show thanks to the organizations concerned for providing their data.

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