THE STORM SURGES IN THE SEA OF YATSUSHIRO GENERATED BY TYPHOON BART (9919)

by

Nadao Kohno[1), Masami Okada[2) and Tatsuo Konishi[3)

ABSTRACT

In September 1999, TY BART struck the western part of Japan and generated enormous storm surges. These storm surges caused dreadful disasters, including 13 killed people along the coast of the Sea of Yatsushiro in western part of Kyusyu.

JMA made a field survey of the storm surge in this area, and analyzed its mechanism by hindcast simulation. As a result, we can reasonably estimate the storm surge in the northern part, the highest surge part of the Sea of Yatsushiro, but in the middle west side, the estimation was much smaller than the field survey results. This may be due to the effects of ocean waves and low accuracy of wind fields used in the calculation.

KEY WORDS： storm surges
Typhoon BART
wave set-up
local gust

1. INTRODUCTION

Typhoons sometimes make great impacts to coastal area and islands in Japan, and enormous storm surges sometimes occurred by striking typhoons.

In September 1999 TY BART (9918) struck the western part of Japan and generated storm surges. And dreadful disaster occurred: In Yamaguchi-Ube airport, breakwaters were destroyed by storm surge, and most area were inundated (Pic.1). And in the coast of the Sea of Yatsushiro in western part of Kyusyu, 13 people were killed by storm surges.

Pic.1 Inundation at car park of Yamaguchi-Ube air port

In this paper, we briefly introduce TY BART and storm surges caused by it, and focus the storm surge in the sea of Yatsushiro, comparing the field survey results with numerical simulation. And also discuss about the effect of ocean waves and local winds.

2.TYPHOON BART

(1) The Course of TY BART

Fig.1 shows the best track of TY BART. At 9 o'clock on 17 September 1999, Tropical

1) Research Scientist, Typhoon Research Department, Meteorological Research Institute, JMA, Nagamine, Tsukuba, Ibaraki, 305-0052, Japan
2) Head, Matsushiro Seismological Observatory, JMA, Matsushiro, Nagano, 381-1232, Japan
3) Head, Marine Division, Kobe Marine Observatory, JMA, Kobe, Hyogo, 651-0073, Japan

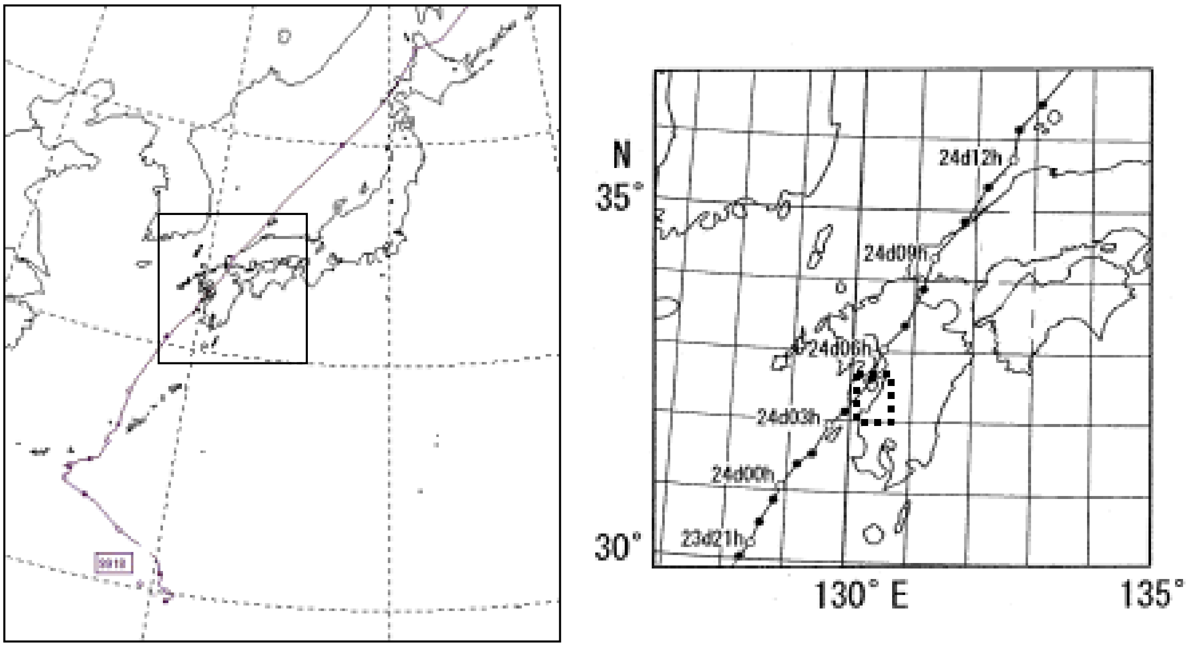

Fig.1 The best track of Typhoon BART (9918)

The left map shows the gross track of TY BART. The right map shows the close up of Kyusyu district. The rectangular in broken lines shows the location of the Sea of Yatsushiro.

Depression (TD) was formed in the east of Philippine, and developed to TY BART at 09:00 on 19, about 400km south of the Okinawa Island

After it stayed in the sea around Okinawa Islands during a few days, it turned to move northeastward and upgraded to the strongest stage in the sea west of the Okinawa Island at 21:00 on 21 (central pressure 930hPa, maximum wind speed 45m/s, gale wind area of wind speed over 25m/s extend 110 nautical miles) . It passed through Shimokoshiki Island in Kagoshima Prefecture around 03:00 on 24, and then through Amakusa Island. It made a landfall on the northern part of Kumamoto Prefecture at around 06:00, also on Ube in Yamaguchi Prefecture before 09:00 on 24 (central pressure 960hPa, maximum wind speed 40m/s), after passing through the northern Kyushu. It continued to move northward over the Japan Sea. Typhoon became extra-tropical cyclone at 12:00 on 25.

The map in the right of Fig.1 is close up at Kyusyu area. TY BART passed the western side of Kyusyu on 24. The Sea of Yatsushiro locates central western side of Kyusyu, which is within the area of rectangular in dot lines, just right to Typhoon path, and typhoon was nearest during 4 to 5 a.m.

(2) Data of TY BART

Strong southerly winds greater than 30m/s were observed over the western part of Japan along with typhoon. Especially, in Kyushu and Cyugoku area, where typhoon passed by, observed more than 40m/s winds.

Table 1 lists intensity of the typhoon at 6 o'clock, when the typhoon was near the sea of Yatsushiro. As historical records, at Ushibuka observatory in Kumamoto Prefecture, the highest wind gust of 66.2m/s was observed at 03:17 on 24 in the observatory's statistics since

1949. And at the Kashima villege of Shimokoshiki Island, village government observed the maximum wind gust of even 83.9m/s at 3:42, though it was not official data.

Table.1 Data of TY 9918 BART
(6:00 24 / Sep.)

Surface pressure	950 hPa
Maximum wind	40m/s
Radius of storm wind	150km
some records of maximum gust wind	
Ushibuka	66.2m/s (3:17)
Shimokoshiki	83.9m/s (3:42)

As TY BART had maintained the intensity passing through Japan, extensive damages by the strong gusts, storm surges, wind waves, and heavy rainfalls were generated. Unfortunately, it was around the highest season of daily-mean sea level and high water in the whole year when the typhoon hit Japan. It reinforced the disasters by storm surges.

In Kumamoto, 16 persons were killed, including 13 dead people directly by the storm surge, 143 houses were razed and 1,609 houses were partially damaged. And 1,881 were inundated. Especially 921, about half of this inundation, were above floor. It means storm surges may be high in Kumamoto.

Pic.2 shows the flooded situation at Matsuai area of Shiranui town, just faces to the innermost part of the Sea of Yatsushiro, where 12 people killed, a few hours later its storm surge peak. The waters were still piled up, and some houses are inundated.

3.FIELD SURVEY RESULTS

JMA made a field survey* of the storm surge in the Sea of Yatsushiro, a week later the storm surge occurred.

Fig. 2 shows the storm tide results from the field survey. The values are regulated above

Pic.2 Flooded situation at Matsuai area,
Shiranui town, facing to the Sea of Yastushiro

TP, the mean sea level of Tokyo Bay, which correspond to 0m level of usual maps. (We measured these values with the base of local sea surface. As the level of the base for field survey, we use the astronomical tide level of Yatsushiro port estimated by JMA.) The values with the mark × are derived from inundation traces, and values with the mark ★ are maximum values observed at tidal station during the typhoon period. The additional mark > means that values are lowest limit, because water ran up the breakwater etc.

At the northern part of the sea of Yatsushiro, the highest tide of this sea was found. In all points of the area, the levels of

---

*Field survey was carried out during 4 to 7 October 1999, just a week later the storm surge occurred, by research group of JMA. The results in detail are reported in JMA (2000).
The research group members are as follows:
Masami Okada (Chief), Nadao Kohno
(Mteteorological Research Institute)
Tatsuo Konishi (Vice –Chief), Chiharu Nagai
(JMA headquarters)
Ryohei Okada, Daisuke Ueno
(Nagasaki Marine Observatory)
Toshiaki Yonekura, Kazunori Masaki, and related members
(Kumamoto Local Observatory)

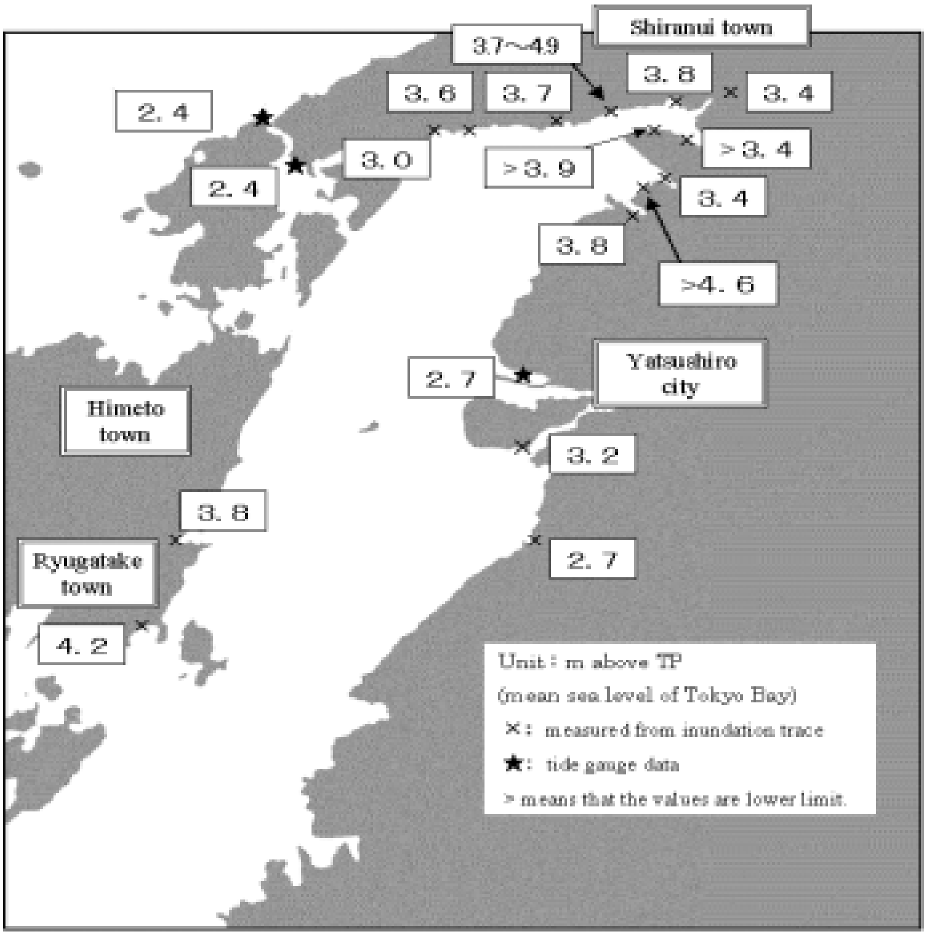

Fig.2 Field survey result of the storm tides by the TY BART.

The field survey was carried out during 4 to 7 October 1999. Most values (marked ×) were estimated from inundation traces. Some values （marked ★） are the extremes of observations at tidal stations.

storm tide are above 3m, which mean that this is quite a high storm surge case in Japan, because the highest record of the storm tide in Japan was 3.9m above TP.

The tides tend to be higher toward east. The lowest place is the most western point (which is Funatsu area of Misumi town), and its value is 3.0m. The water levels derived from inundation traces gradually become higher toward east, and in Matsuai area of Shiranui town, it records 3.7 to 4.9m. The opposite side of this area also has high values. In the innermost part the values are decreased to 3.4m. But this is the value of the water flowing up against river. And this value is the lower limit. So we may consider that these decrease don't have significance in general distribution.

According to the witness by residents, the storm surge occurred at 5:30 to 6:00 around Matsuai area. This is 2 hours before the time of high water, so these high sea levels may be caused by storm surge itself. The storm surges reached to 3.5m, It is comparable to the case of Ise bay by TY5915, the highest historical record in Japan and its value is 3.5m at Nagoya tidal station.

In the eastern side, the water levels become also higher toward north, the inner part. And they decrease along with southward. At the Yatsushiro port, we can get reliable data, by tide gauge. The maximum value at this point was 2.7m, slight lower than inner parts. Near to this point, the value we measured was also 2.7m, so it coincides well.

In the central western part, on the contrary, around Ryugatake town and Himeto town, have high inundation level traces, though this part is open to sea relatively. This part is close to the path of the typhoon, and by witness, storm surges occurred about 04:00 to 05:00, along with typhoon approach. The high surge ceased at about 6 a.m. in Himeto, but it continued to 8 a.m. in Ryugatake,.

4. NUMERICAL SIMULATION

(1) Outline of Calculation

We analyzed its mechanism by numerical simulation. As ocean model, we use Princeton Ocean Model (POM) by Blumberg and Mellor (1987). It is σ-coordinate 3D primitive equation model, and useful for extensive expression in shallow water depth areas for storm surge calculation. We set the horizontal grid resolution as 20 seconds, and 12 levels in vertical.

Fig.3 shows the computational area which covers whole area of the Sea of Yatsushiro and water depth in（m）. ★ shows the location of tidal station at Yatsushiro port, and ● and ■ show the point of Matsuai area and Ryugatake respectively. This sea is almost closed, though connected to Ariake Sea and the East China Sea, with small channels. It extends from SW to NE about 60km, with the width 20km. The mean water depth is just 38m, and less than 10m in northern part. (mean depth in northern part is only 7m.) The tide change is large as 4m at Yatsushiro port.

As meteorological input, we make idealized surface pressure and wind fields from analysis. From the operational analysis we get some parameters like typhoon position and intensity and so on. And we suppose pressure distribution with the aid of Fujita's formula,

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

Where, P_c ; center pressure P_∞ ; field pressure and r_0 ; radius of gale winds.

Wind fields **W** are derived using this profile, supposing gradient wind relation. And we set the inflow angle as 30 deg. and also add the asymmetry by typhoon movement, like this.

$$-\frac{v^2}{r} - fv = -\frac{1}{\rho}\frac{\partial P}{\partial r}$$

$$\mathbf{W} = C_1 \left\{ \mathbf{V} + \mathbf{C} \cdot \exp\left(-\pi \, r / r_e \right) \right\}$$

Where, C_1 and **C** are coefficients.

As initial condition, we start calculation with static state. We previously calculated 18 hours for spin up.

As boundary conditions, we set static balance to surface pressure at open boundary. Since this sea is almost closed to open ocean,

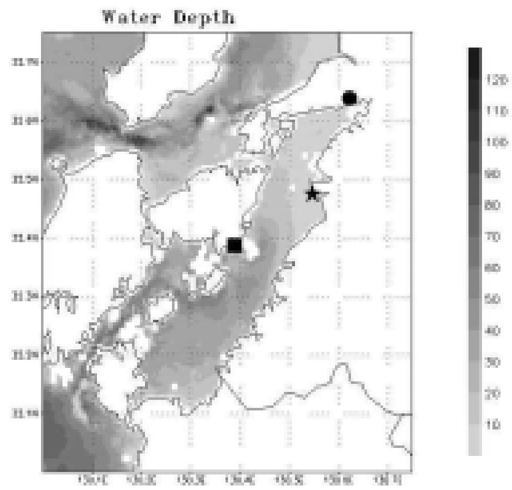

Fig.4 Water depth in the Sea of Yatsushiro
Some marks are the locations of ★: Yatsushiro tidal station, ●: Matuai area, ■: Ryugatake point, respectively.

therefore this may not be critical to general features. At the land boundary, we considered rigid wall, and no inundation was considered. Nor we considered astronomical tide, we just calculate storm surge heights.

We set the drag coefficients in calculation Cs = 3.2×10^{-3} at sea surface, and : Cb = 2.6×10^{-3} at sea bottom. Cs looks like slight large, but it fits the calculation results so we adopt it empirically.

(2) Comparison with Observation

At first we compare the calculation with observation at Yatsushiro tidal station. Fig. 4 shows the time series from 21:00 on 23 to 15:00 on 24 September. Thick dot line shows the observation and full lines exhibit calculation. Also, thin dot line of astronomical tide and broken line of the calculation at Matsuai point are shown as a reference. Though the calculation is lower than observation from 02:00 to 03:00 on 24, and calculated storm surge starts slightly faster than observation, the general feature resembles.

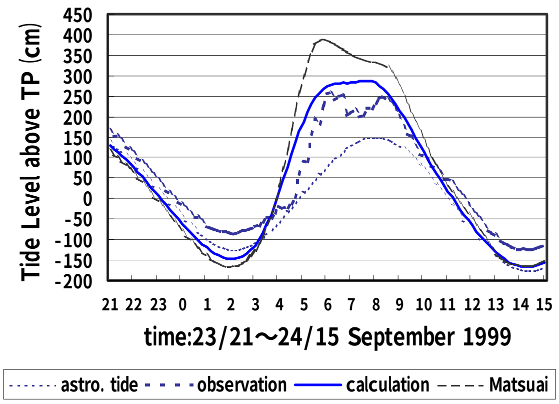

Fig.4 Tide level at Yatushiro Port

Tide level are estimated by adding the astronomical tide values to the storm surges. The estimation at Matsuai point are also plotted in broken line.

Such differences may be caused by input wind errs, because wind speed is too strong compared with observation when the typhoon approached to this area. But wind speeds when the typhoon center passed through, were almost equal to observation, so the calculation when the typhoon was near to Yatsushiro is not far from feasibility.

We can recognize two surges at about 06:10 and 08:20, both in abservation and calculation. Analyzing the topography of Sea of Yatsushiro, there is a normal mode which has two nodes around the northern part of this Sea, and the period is about 140 minutes. The second surge is consistent with this mode, and we may regard it as the seiche. The calculation of present model can estimate the seiche though it is not enough quantitatively.

(3) Horizontal distribution

Fig.5 shows the hourly horizontal distributions of storm surges. During the typhoon approached, waters accumulate in western part by easterly wind. After the typhoon passed and it turned to SW wind fields, waters were put into NW part. The sea width become narrower and depth become shallower at inner part, the deviation of water level become high.

The peak of surge is above 3.5m at 06:00, and is reasonable considering the field survey results.

On the other hand, model simulation could not depict detailed features such as remarkable high traces of the storm surge in the west- coast of the Sea of Yatsushiro.

(4) Summary

In general, our calculation results coincide with that of field survey results ;

・Maximum surge was above 3m, which means this case was one of the highest storm surge cases in Japan.

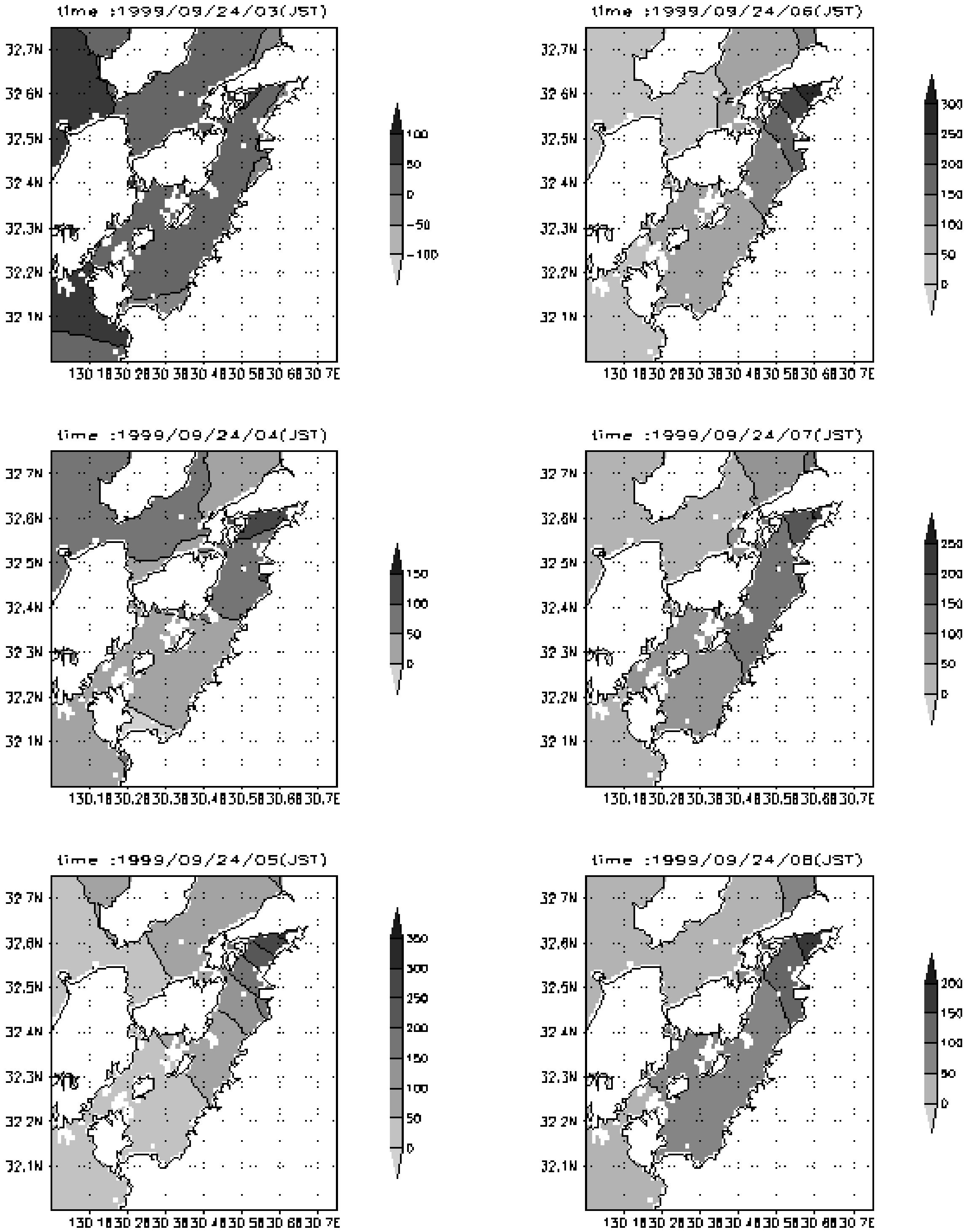

Fig.5 Hourly horizontal storm surge distributions

・At the northern part, storm surges tend to become high toward east, due to strong SW wind and geographic features of the Sea of Yatsushiro.

・The seiche was excited by back current in Yatsushiro, though our calculation could not simulate enough. The reason may be that we did not consider the astronomical tide dynamically, and winds used in calculation are almost constant during this period.

Therefore our simulation also shows fairly good correspondence to observation, except for central western part of the Sea of Yatushiro.

5.DISCUSSION

We would like to consider what make the difference of storm surge at central part, that is, around Ryugatake town and Himeto town.

This may be due to (1) the effect of ocean waves and (2) local variability of wind fields used in the calculation.

(1) The Effect of Ocean Waves

As for the effects of ocean waves, it is clearly possible that such effects as wave run-up, wave set-up will occur. In general, wave set-up factor directly affect the sea surface level, and it may play a significant role in the storm surges along coastal islands beaches facing the open ocean, where high waves tend to hit. To check it, we calculated wave conditions in the Sea of Yatsushiro with numerical model.

Fig. 6 shows the time sequence of wave heights at Ryugatake and Himeto. Also tidal levels are plotted at both points.

In the central part of the Sea of Yatsushiro, wave heights developed to 2~3m. These values are not so high values comparing with high waves in ocean. The wave heights of 2~3m are not sufficient for accounting for high trace by wave set-up.

But it is impossible for waves to become high in such closed and shallow waters in general, and then these relatively low values

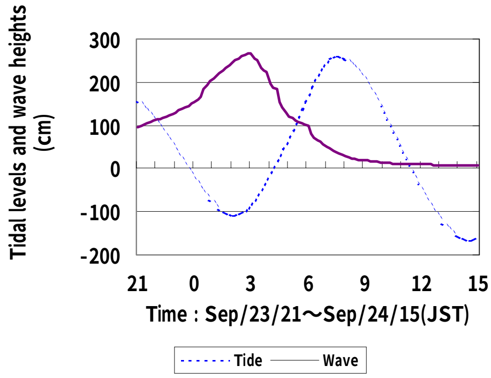

Fig. 6 Time sequence of wave heights and tidal level at Ryugatake points.

Full line shows wave heights and dot line shows tidal levels.

are reasonable. Therefore we could not explain the difference only by the effect of wave set-up.

How about wave run-up then？ By the witness of residents, storm surge started as early as 3:30 at Ryugatake and 4:30 at Himeto, which is just around the time when wave heights were highest, tough tidal levels were still low.

Continuous wave run-up may accumulate vast of waters and result to high sea inundation traces. Kawai (2000) estimated the time needed to compile the water by wave run-up, in this area. It needs a few hours, but if the sea level become high it shorten to half an hour. It may be one of reasons, though we need further research about it.

(2) Accuracy of Wind Fields.

Also by the witness of residents, the peak of storm surge at this area was around 04:00 to 05:00, and ceased at 07:00 to 08:00. The time of end coincides with that of astronomical tide. But in its peak time, neither wave heights nor tidal levels were high. We need another reasons.

In our calculations, we use idealized wind fields derived from idealized pressure profiles. Thus it is impossible to take into consideration both the topographical effects and the local wind fields, especially around the typhoon center.

On the other hand, the center of the typhoon passed over the middle west side of the Sea of Yatsushiro, just near these towns, and thus the local wind field may have affected the storm surge at this area.

From a meteorological radar observation, severe rain band passed through this area, just during 04:00 to 05:00. Of course, we can not directly connect radar echo with wind speed, but strong winds accompanied with such rain bands.

The observation by the local government of Ryugatake town, also recorded the maximum gust wind of 48.8m/s at about 4:20.These data suggest that severe local winds blew, and affected the storm surges in their peak. Though it is circumstantial, it is feasible that such local winds cause extraordinary storm surges at this area.

6.CONCLUSION

We analyzed the mechanism of the storm surges at the Sea of Yatsushiro, both with field survey results and numerical simulation.

We may fairly account for the mechanism at the northern parts. But in the central parts, the features of storm surges are much different from usual cases.

To account for such a special case, we must consider the local wind fields, especially detailed features of winds around a typhoon center. And also we need consider the effects of ocean waves.

REFERENCES

Blumberg, AF and GL Meller(1987) A description of a three-dimensional coastal circulation model, in Three-Dimensional Coastal Ocean Models, Vol.4, American Geophysical Union, pp208.

JMA (2000) Report on the storm surges by Typhoon BART (No.9918) in September 1999, Japan. Technical Report of JMA, 122.
(in Japanese)

Kawai, H (2001) Storm surges in Yatsushiro-kai Sea and Suou-nada Sea caused by Typhoon 9918. Umi to Sora (Sea and Sky), 76, 215-220.
(in Japanese)