

Bay undulations excited by the typhoon 0423 in Japan

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(Received 30 November 2009)

Abstract

A storm surge of the typhoon 0423 generated bay undulations in Japan on October 20–21, 2004 and the bay undulations were analyzed using the records observed at 9 tide stations during one day from 12:00 (JST) on October 20. The sea level deviations from the ordinal tidal levels were decomposed into amplitude spectra for every 6 hour with overlapping of 3 hours. Noticing the dominant periods we examined a relation between the dominant period and the wind direction, and summarized that the bay undulations are excited by the wind parallel to the bay direction and the amplitude increases with the duration time but not depends on the wind strength. The straight bays tend to show a rapid response to the wind direction.

Key Words : typhoon0423, bay undulations, wind, seiche

Introduction

The typhoon 0423, being generated on the west Pacific, passed through Japan on October 20–21, 2004. This typhoon brought a heavy rainfall in Japan and killed 99 persons including missing persons (2008 Chronological Science Table, Maruzen publishing). Since the typhoon landed in Shikoku and traversed the central Japan with a low velocity, many bays were controlled by a low atmospheric pressure for a comparatively long time. The low pressure with a strong wind brought high tides in bays and excited bay undulations. On the other hand Japanese bay has a potential of tsunami. It is well known that the resonance of tsunami to a bay brings a high sea level in the bay (e.g. Kato et al.,1961). Noticing the importance of tsunami resonance Abe (2005a,b,2006,2009a,b) determined dominant periods of bays on his seiche observations. The bay undulations are generated with some characteristic periods. It is interesting to compare the dominant periods of the typhoon with those of the seiche.

Observation data

Sea levels observed at 9 tide stations are main data used in the analysis. The tide stations are located at Honshu and Shikoku in Japan and the names are Kochi, Murotomisaki, Osaka, Owase, Maizuru,

Nagoya, Toyama, Uchiura and Tokyo. All of them are situated in the heads of the bays except for Kochi in the mouth. The analysis will be conducted for time series of one-minute interval from 12:00 on October 20 to 12:00 on October 21 (JST). Secondary data are meteorological ones about the typhoon, atmospheric pressure, wind and tide. Generally the meteorological observatories are distant from the tide stations. Then the meteorological observatory nearest to the tide station is used as the reference station. They are Kochi, Murotomisaki, Osaka, Owase, Maizuru, Nagoya, Toyama, Mishima and Tokyo for Kochi, Murotomisaki, Osaka, Owase, Maizuru, Nagoya, Toyama, Uchiura and Tokyo tide stations, respectively. The meteorological and tide data are downloaded from an internet homepage of Japan Meteorological Agency and are used. Third data are dominant periods of bays. They are referred from papers of Abe (2005b, 2006, 2009a,b).

Analysis

At first sea levels observed at tide stations of an intake-pipe method are corrected for the response to the sea level oscillation. All the tide stations except for Kochi are the tide stations. The correction is conducted on the method same as Satake et al. (1988) and a average recovery time of 269 s prepar-

ed by Abe (2003) is used to correct the response. In the next time the ordinal tidal level is referred from data of Japan Meteorological Agency and interpolated for every minute using a quadratic equation and the deviation is calculated between the observed sea level and the predicted one. In the third step amplitude spectra are calculated for the sea level difference as the time series. The spectra is calculated in the same method as Abe (2005a) used. Total length of the time series from 12:00 on October 20 (JST) to 12:00 on the next day is divided into 7 series of 6 hours with an interval of 3 hours. Thus, the time sequence of the dominant period is examined through passing of the typhoon.

Result

Trail of the typhoon and tide stations used in this article are shown in Figure 1. Response corrected sea levels with the predicted tidal levels are shown for

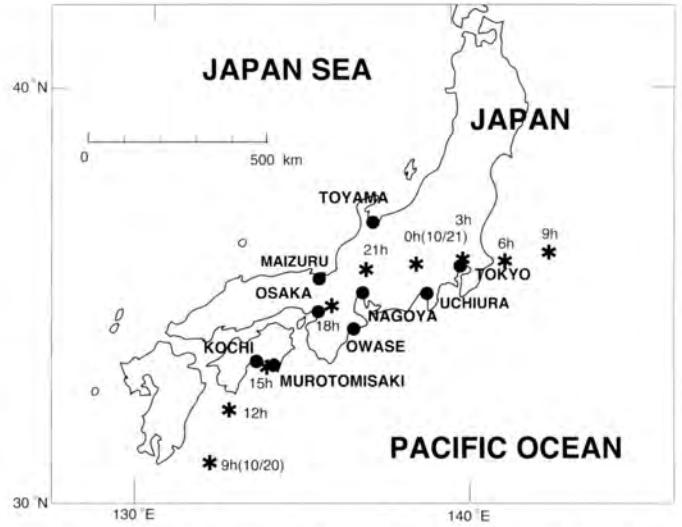


Figure 1, Central position of typhoon 0423 (asterisk) observed at time interval of 1 hour and tide stations used here (solid circle).

all the tide stations in Figure 2. Spectral amplitudes

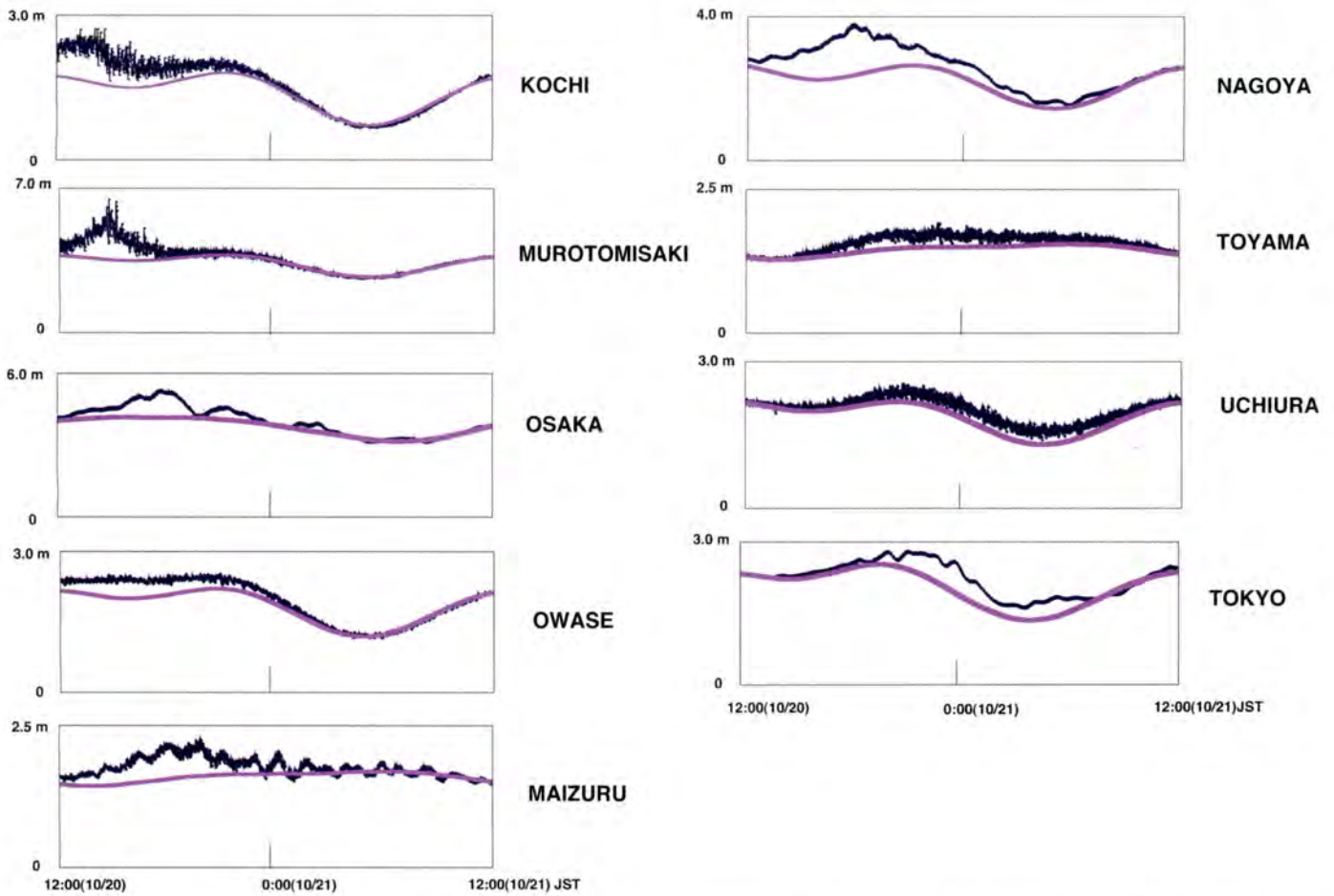


Figure 2, Sea levels (response corrected) observed at each tide station (solid line of violet), and predicted tide (solid line of dark red).

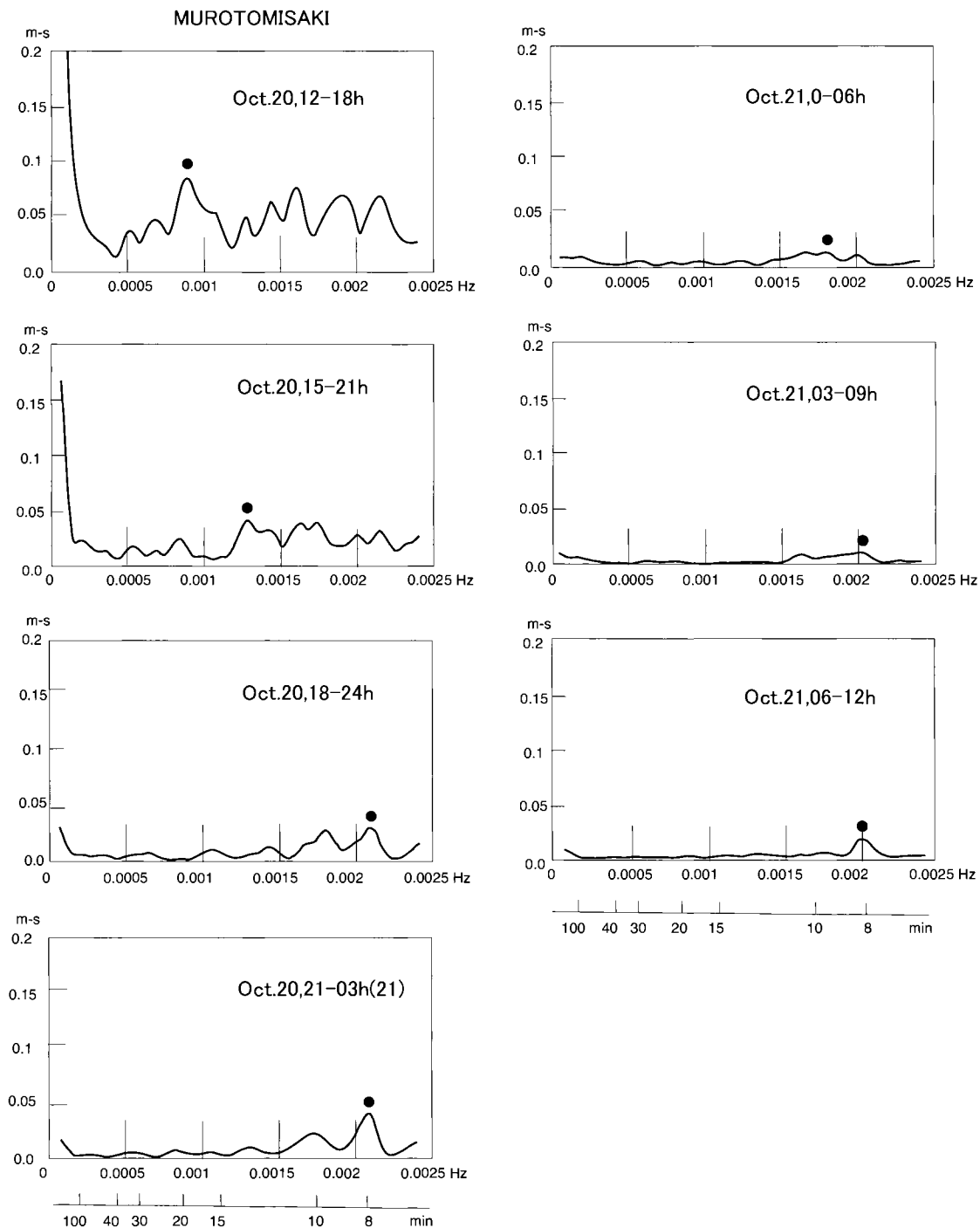


Figure 3, Example of amplitude spectra obtained at Murotomisaki tide station for each 6 hour. Solid circles indicate the dominant frequencies (periods).

were calculated for the sea-level deviations and a part of them are shown in figure 3 and 4. A dominant period (frequency) was obtained from each spectrum as a period of the maximum spectral amplitude. These results show that the dominant periods are not fixed but variable through the processes.

Temporal variations of the dominant period in all the stations are shown with the wind direction in Figure 5. Time of the spectrum is represented by the central value of the total sampling time between start and finish. Dominant periods with amplitude less than 0.01m-s were neglected in the figure. It is

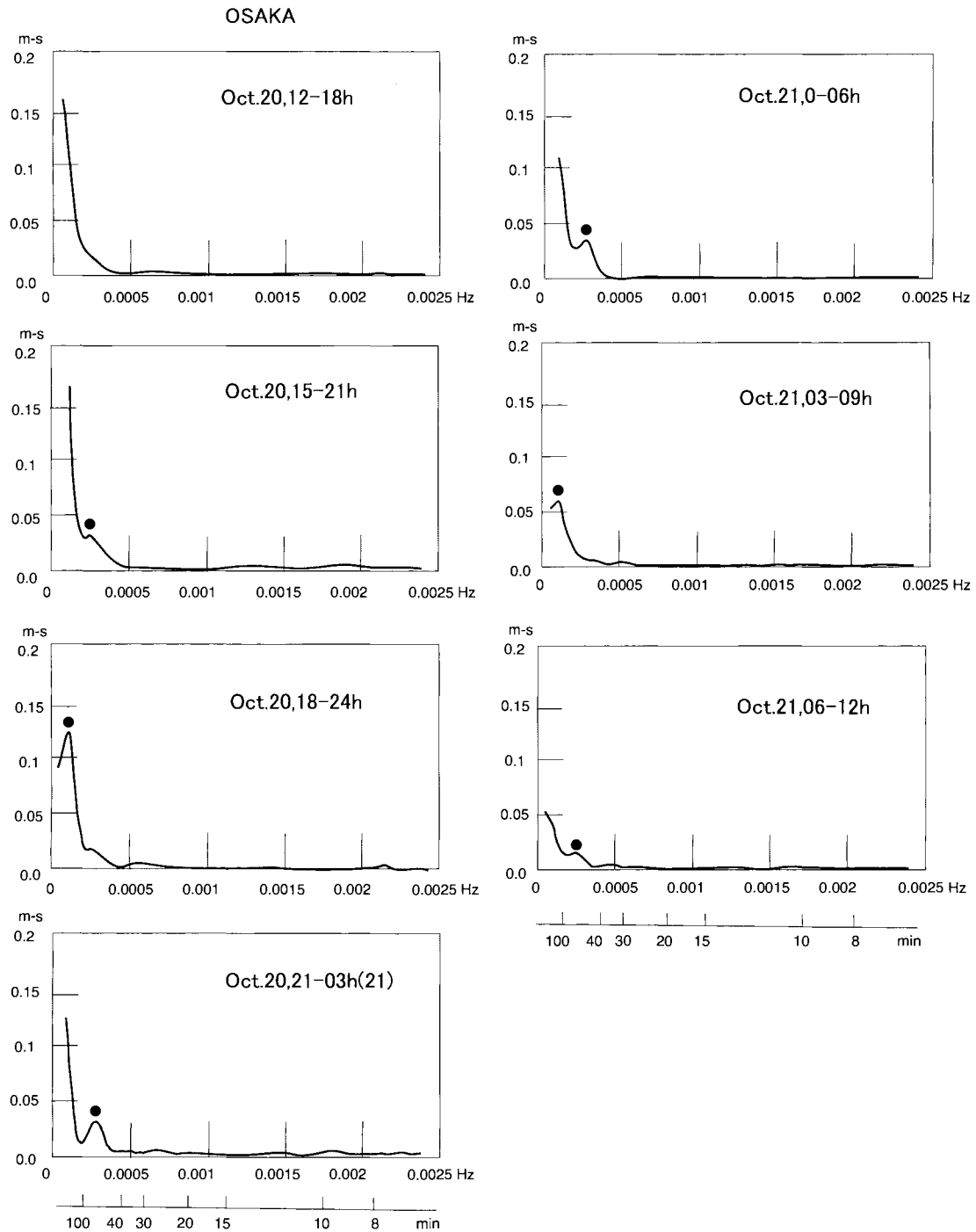


Figure 4, Amplitude spectra obtained at Osaka tide station. The comment is the same as that of Figure 3.

remarkable that dominant periods became longer with the duration time of wind having the same direction in Osaka, Nagoya and Toyama. The dominant periods in the seiche are 69, 93 and 104 minutes for Osaka, Nagoya and Toyama, respectively (Abe, 2005b,2009b). They are located in large bays

commonly. This fact shows that the long period component is developed with long duration time of a stable wind. It is also interesting that dominant period tends to converge into a small value with a lapse time in comparatively small bays or ports. The decrease was observed at Murotomisaki, Owase and

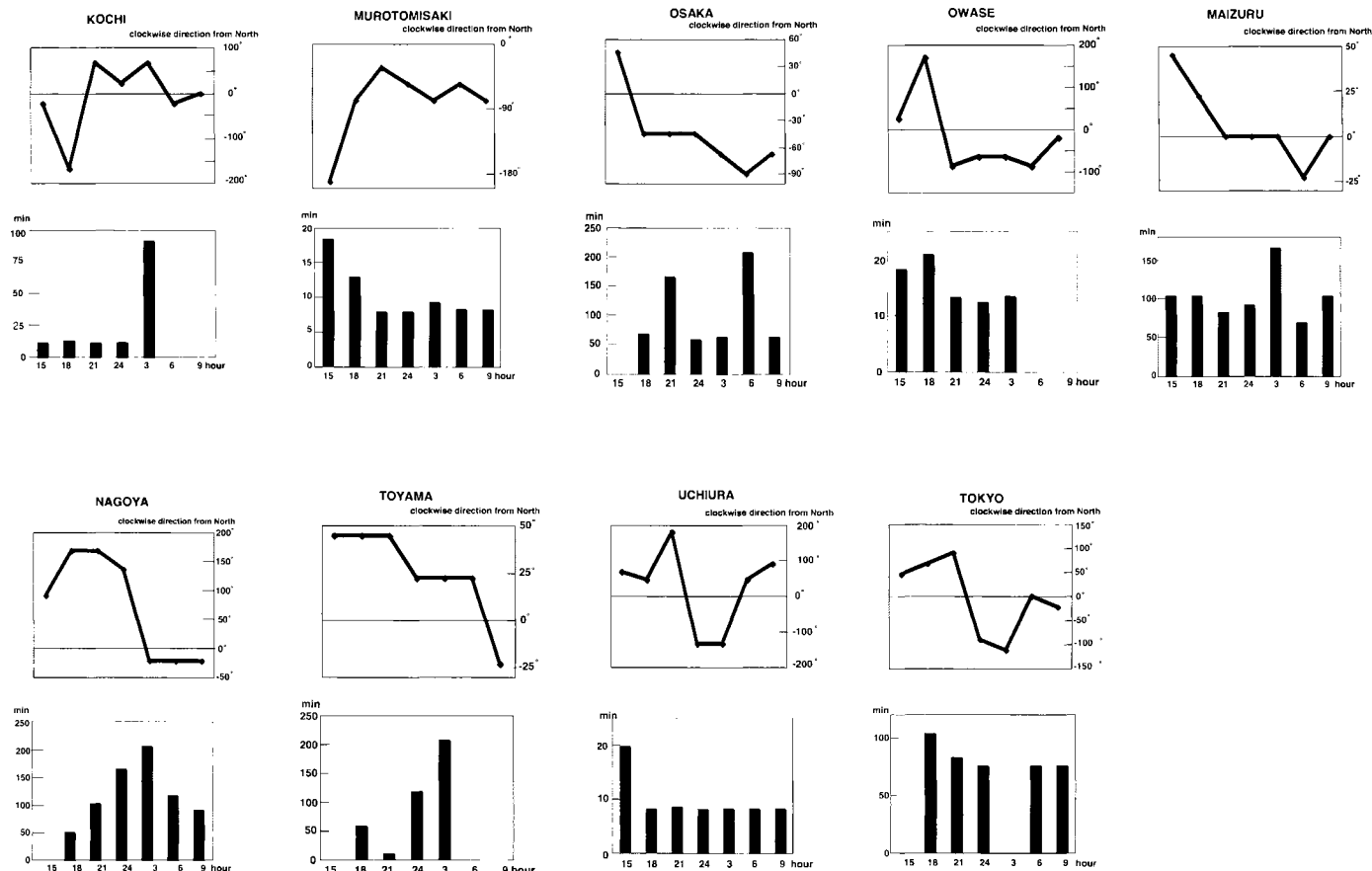


Figure 5, Time variations of dominant periods (bar graph) and wind directions (line graph) at each tide station. The wind data was referred from data observed at the nearest meteorological observatory.

Uchiura. Dominant periods of the seiche are 8, 36 and 17 minutes, respectively (Abe, 2005b,2006, 2009a). The stable value in the period suggests a formation of standing wave in bays or ports. The convergent value is equal to the dominant period of the seiche in Murotomisaki. It is important to describe that a discontinuous lengthening of dominant period is generated in a long duration of the same wind-direction. The sudden change to the long period is seen in Kochi, Maizuru and Tokyo with seiche dominant periods of 93, 89 and 69 minutes, respectively (Abe,2006,2009a,b). Wind vectors corresponding to the maximum spectral amplitude in each station are shown in Figure 6. Except for Maizuru the maximum spectral amplitude was observed nearest to the central position of the typhoon. It is interesting that the directions of wind vector are parallel to the bay axes in most cases. Detail of the relation is shown in Figure 7. A direction of the bay or port is defined as a

direction of the straight line from the head to the mouth as shown in the figure. The maximum amplitudes were attained under the wind against the bays in Nagoya and Toyama. A relation of the direction between the bay and the wind is shown in Figure 8. A wind direction is defined from the lee side to the windward side and the bay direction, defined from the head to the mouth, is shown in the figure. A low correlation group in the figure belongs to non straight (curved) bays like Kochi, Owase and Uchiura. Another figure in Figure 8 is for a relation between the maximum spectral amplitude of bay undulations and bay axis components of the wind velocity at the maximum. The bay axis component is defined as cosine of differential angle between the bay direction and the wind direction. Correlation relations exist between the wind direction and the bay direction but not exists between the maximum amplitude and the velocity component of wind. In

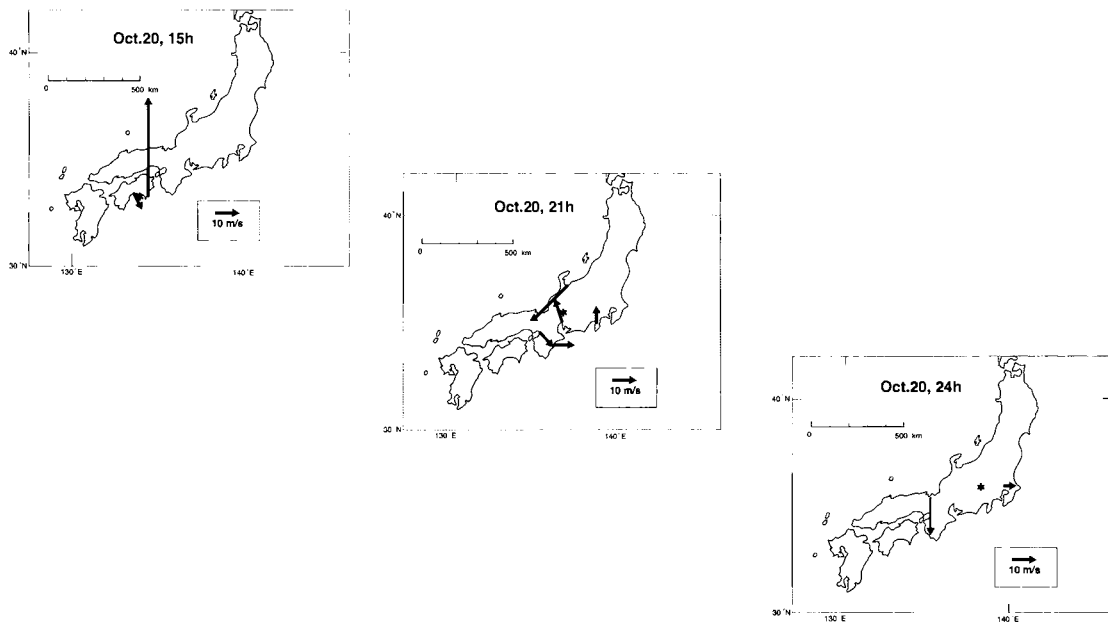


Figure 6, Wind vectors at a time of the maximum spectral amplitude with the central position of the typhoon 0423. The figures are arranged in a sequence of time from the upper left to the lower right.

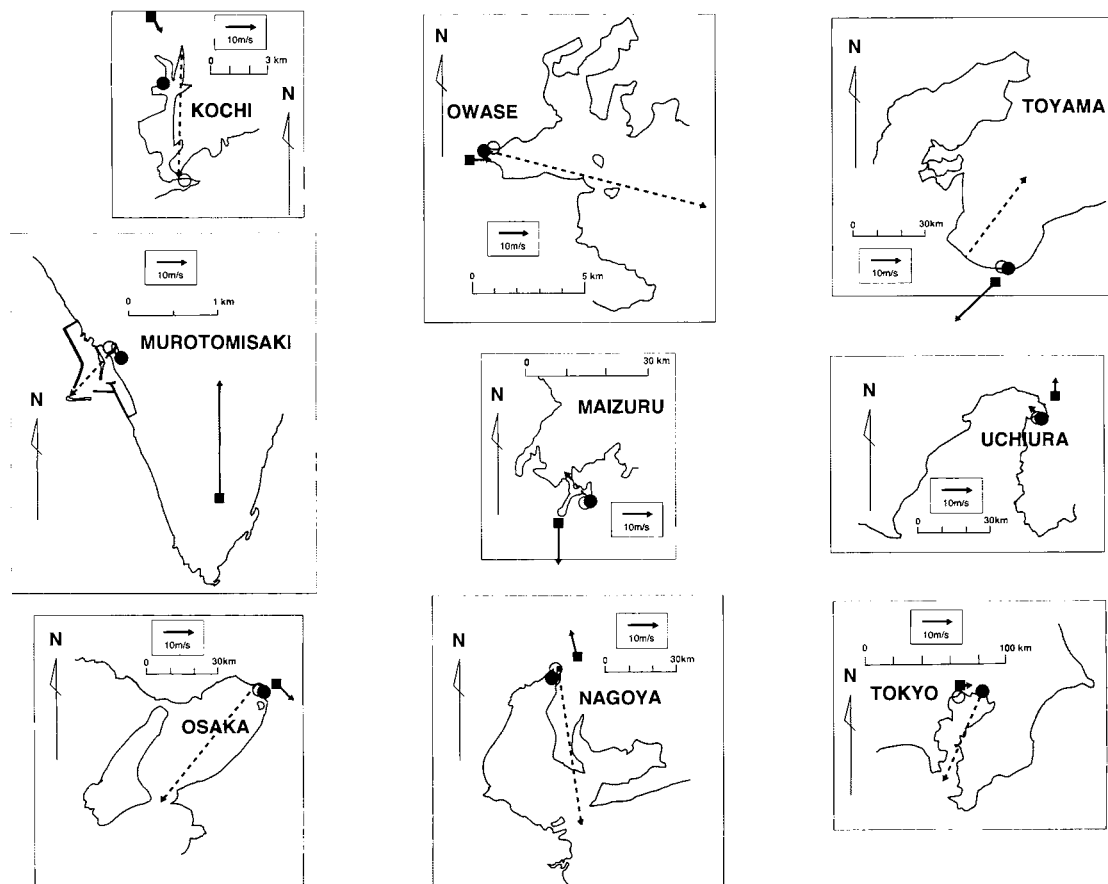


Figure 7, Wind vectors at a time of the maximum spectral amplitude (solid arrows) same as Figure 6. Relative locations of tide station (open circle), seiche observation point (solid circle) and meteorological observatory (solid rectangle). Definition of the bay direction is shown with dotted arrows.

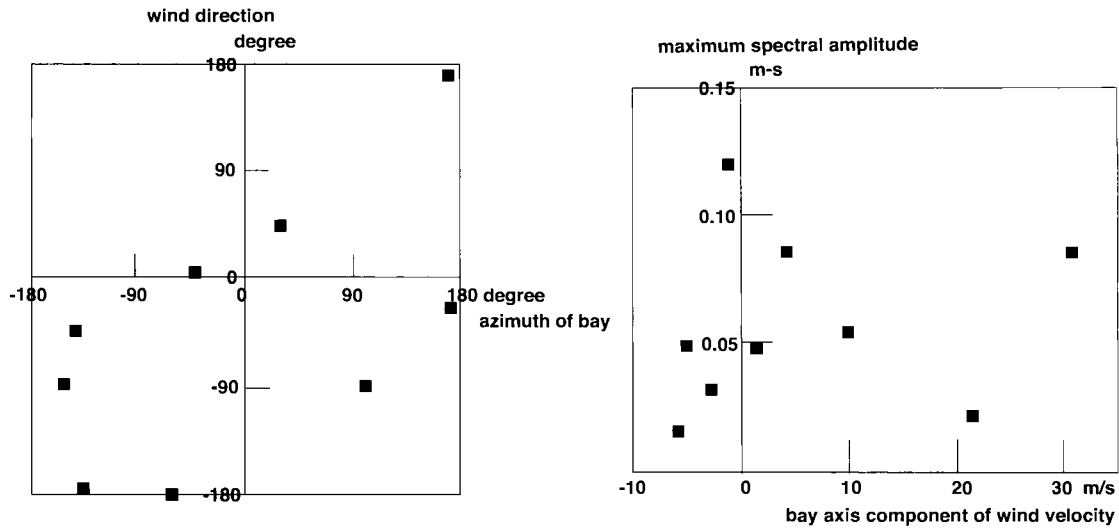


Figure 8, Relation between the bay direction and the wind direction for the maximum spectral amplitude (left) and the maximum spectral amplitude versus cosine of direction difference between bay and wind (right).

the latter case Osaka and Toyama contribute to decreasing the correlation coefficient. A high correlation would be obtained if we exclude two data of Osaka and Toyama from the figure. Both the figures should be unified under the importance of the same direction between the wind and the bay.

An importance of wind direction is understood from comparison of appearing time between the minimum atmospheric pressure and the maximum spectral amplitude. It is shown in the bottom of Figure 9. The top in the figure is for one between the minimum atmospheric pressure and the maximum deviation of sea level. The maximum deviation is connected to the minimum atmospheric pressure in a close relation. The maximum spectral amplitude is not closely connected to the minimum atmospheric pressure. Thus it is concluded that the element to connect the maximum amplitude is the wind direction.

Finally a correlation of the dominant periods between the seiche and the bay undulation is treated. The relation is shown in Figure 10. Tide stations contributing to the low correlation are Kochi, Toyama and Osaka. At Toyama the dominant period of the seiche (104 min) was not developed in spite of the almost parallel direction between the bay and the wind. It was an exceptional case. In other tide stations dominant periods of the typhoon approximately coincide to those of the seiche.

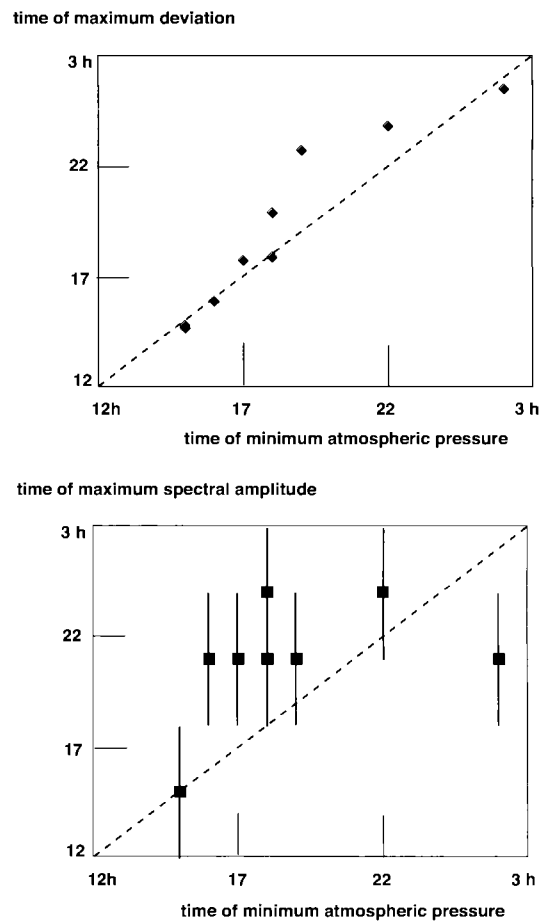


Figure 9, Comparisons of appearing times (JST) between the minimum atmospheric pressure and the maximum deviation (top) and between the minimum atmospheric pressure and the maximum spectral amplitude (bottom).

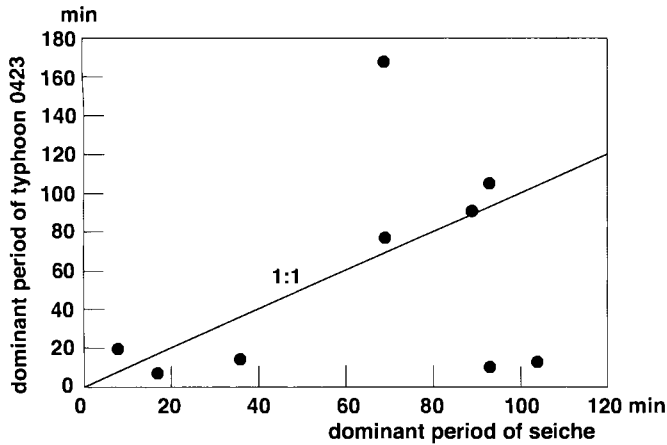


Figure 10, Correlation of dominant periods between the seiche (x axis) and the typhoon 0423 (y axis).

Conclusion

Spectral analyses of a storm surge in the typhoon 0423 revealed that bay undulations are excited by the wind parallel to the bay direction and develop themselves with the duration. Straight bays are effective in the excitation. Dominant periods same as the seiche are observed in the storm surge with a high probability.

Acknowledgement

Author is grateful to prepare tide gauge records for Japan Meteorological Agency.

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