# Exclusion of a coastal effect from tsunamis recorded at ports in the use of the observed seiche

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**Abstract.** The exclusion of coastal effects from tsunamis was tried by using the spectra of water levels with quiet sea conditions. Normalized tsunami spectra were obtained by dividing observed tsunami spectra by background spectra as the coastal effect. Applied tide stations are Kouzushima, Tosashimizu, and Ayukawa in Japan. The analysis used 5 to 35 tsunamis. The results at Ayukawa show that every tsunami is composed of a combination of a fundamental mode of 0.43 mHz (39 min per period) and the higher modes. Characteristics of tsunamis appear in different excitations of each mode. For example, the first mode is most predominant for the 1952 Kamchatka tsunami, the second mode for the 1968 Tokachi-oki tsunami. Excitation for the first mode depends on the azimuth angle of the epicenter and the azimuth dependence shows the maximum at 35° from the north. This result suggests that Kinkazan Island, located in the same direction to the tip of Oshika peninsula, excites the fundamental mode. As a result of the exclusion, we found a shelf effect on the shallow sea surrounding Kinkazan Island. The refraction of tsunamis on slopes off the island and peninsula contributes to the amplification at Ayukawa tide station for north tsunamis.

## 1. Introduction

The greater part of a tsunami consists of a local oscillation excited in the sea nearest a tide station (Omori, 1902). In counting the time intervals of waves in tide gage records of tsunamis observed at the Ayukawa tide station, Omari indicated predominant periods of 23–25 and 7.1–7.8 min. The predominant periods of long waves as the secondary undulations in bays and ports were measured by Honda *et al.* (1908). The long-period wave as seiche was also excited by a strong wind (Ichie, 1956; Nakano and Unoki, 1962). After introducing spectral analysis, predominant periods in the spectra were discussed. Takahashi and Aida (1963) found predominant periods of 8.5 and 20–22 min for Ayukawa and 21, 40 min for Tosashimizu in several tsunamis. Aida (1982) discussed the role of the seiche in a tsunami. It is necessary to exclude a seiche that is a coastal effect in order to obtain source spectra from the tsunami spectra observed at a tide station. Rabinovich (1997) proposed the separation of source effect and topography effect by using the background spectra. It is interesting to apply this method to tide stations such as Ayukawa and Tosashimizu where the same predominant periods were frequently observed in various tsunamis.

## 2. Background Spectra

By using a pressure gage of handy type, water levels at quiet sea conditions were observed at coasts nearest to the Kouzushima tide station in Izu Islands,

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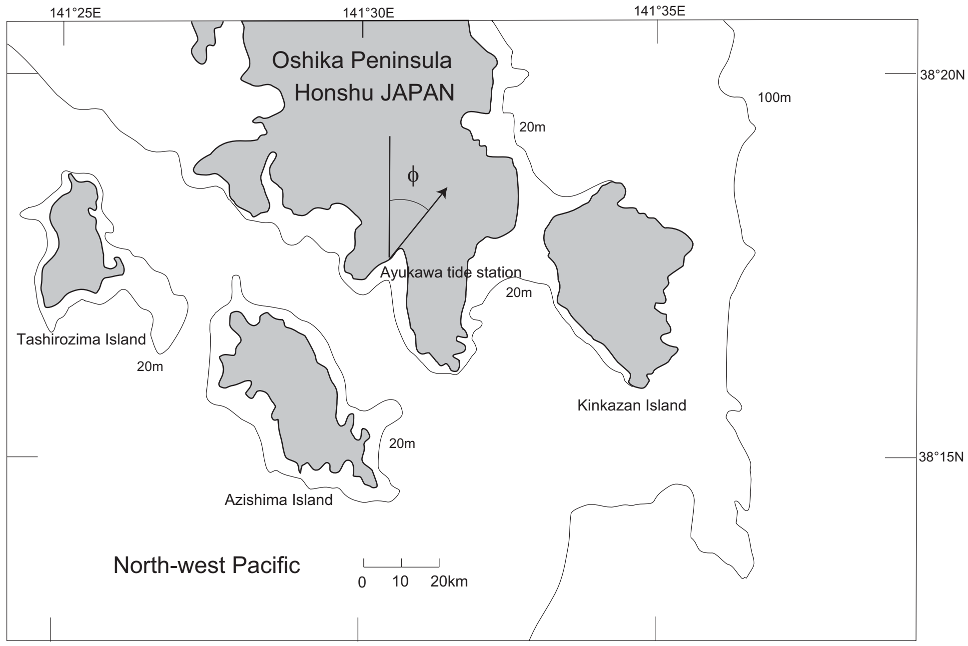


**Figure 1**: A map of the region nearest to the Ayukawa tide station. Azimuth angle $\phi$ is defined as the angle of the earthquake epicenter to a tsunami source.

Tosashimizu in Shikoku, and Ayukawa in Honshu. The observations were conducted for 2 hours on sunny or rainy days without wind on 26–27 July 2000 for Kouzushima, 24–25 August 2000 for Tosashimizu, and 3 November 2000 for Ayukawa. Comparing the spectra with those of tsunamis observed at the same stations it was found that the same predominant periods as the tsunamis are observed. Thus, the use of water levels in quiet sea conditions as the background is justified.

The amplitude spectra were calculated using the Goertzel method after eliminating the tide level. Sampling time is 6 hours including the initial motion with a time interval of 1 min, and the result was shown from 0.02 mHz to 2.4 mHz with an interval of 0.02 mHz for passing it through a running mean filter. In the same condition as the tsunami, the background spectra was calculated using tide gage records of the same days as the pressure gage measurement. This is for the purpose of keeping the same response function of the tide gage to both the spectra. The response of a tide gage was studied by Satake *et al.* (1988). The effect of a tide gage response is negligible when taking the spectral ratio. Normalized tsunami spectra were obtained by dividing the observed spectra by the background spectra (Rabinovich, 1997).

## 3. Results at Ayukawa

Data for background spectra water levels recorded at Ayukawa tide station on 3 November 2000 and data for tsunami spectra water levels of 35 tsunamis recorded at the same station for the period from 1894 to 1999 were used. As for the records, recent ones were obtained from the Ishinomaki meteorological observation station and old ones were referred to from tsunami records written on CD-ROM by the Japan Weather Association or many published documents (e.g., Omori, 1902). The location is shown in Fig. 1. Some examples of tsunami spectra are shown in Fig. 2. Two examples of spectra under atmospheric disturbances and one example in a quiet day are shown in Fig. 3. By comparing tsunami spectra with the spectra under the atmospheric disturbances there is little difference between them. The same thing is said for the comparison of tsunami spectra with the spectra of the quiet sea. This is proof that tsunamis excite the same seiche as a wind disturbance or some other force. It is noticeable that almost the same spectral peaks at 0.67–0.88 mHz (19–25 min in period) are predominant for tsunamis, atmospheric disturbances, and quiet conditions. The period of 19–25 min is the most predominant period for 94% of all tsunamis.

The normalized tsunami spectra are shown in Fig. 4. As the dividing effect of background spectra having the peak at 0.67 mHz the peak height of 0.83 mHz decreased and a peak at 0.43 mHz predominates in the normalized spectra of the 1952 Kamchatka tsunami. As a result, the relative levels between both the peaks become inverse. As a typical example, the 1897 Miyagi-oki tsunami spectral peaks oscillate with almost the same frequency interval. This result shows that tsunami spectra, except for the coastal effect, consists of a first mode of 0.41 mHz and the higher modes, and the higher modes were equally excited. According to this oscillating spectra we call the first peak the first mode, the second peak of 0.84 mHz the second mode, the third peak of 1.18 mHz the third mode, the fourth peak of 1.47 mHz the fourth mode, the fifth peak of 1.77 mHz the fifth mode, and the sixth peak of 2.2 mHz the sixth mode. In other tsunamis, the most predominant modes are the first mode for the 1952 Kamchatka tsunami, the second modes for the 1968 Tokachi-oki tsunami and the 1995 North Chilean tsunami, the fifth mode for the 1933 Sanriku tsunami, and the fourth mode for the Iriyanjaya tsunami. As shown in Fig. 4, tsunamis near observing tide stations excite various modes, north tsunamis excite lower modes, and distant south tsunamis excite second, fourth, and fifth modes. Excitation of the first mode depends on the azimuth angle of the earthquake epicenter generated by the tsunami, which is shown in Fig. 5. The definition of azimuth angle is shown in Fig. 1. The maximum value is obtained at the angle of 35° for the 1952 Kamchatka tsunami. Sources of high level concentrate at the angle of about 40°. The tips of Oshika peninsula and Kinkazan Island are in this direction. This suggests that the tsunami arrived at Ayukawa tide station and refracted around the island and the peninsula. A numerical harmonic analysis taking the real topography into account using a finite element method explains the large amplification at Ayukawa tide station for sinusoidal incidence with a frequency of 0.5 mHz in sinusoidal wave incidence (Abe, 1986). This frequency is close to that of the first mode. Thus, it is concluded that the fundamental mode results from a natural oscillation on a local shelf formed by a slope of Kinkazan Island. This shelf is two-dimensional and different from a large-scaled one-dimensional shelf.

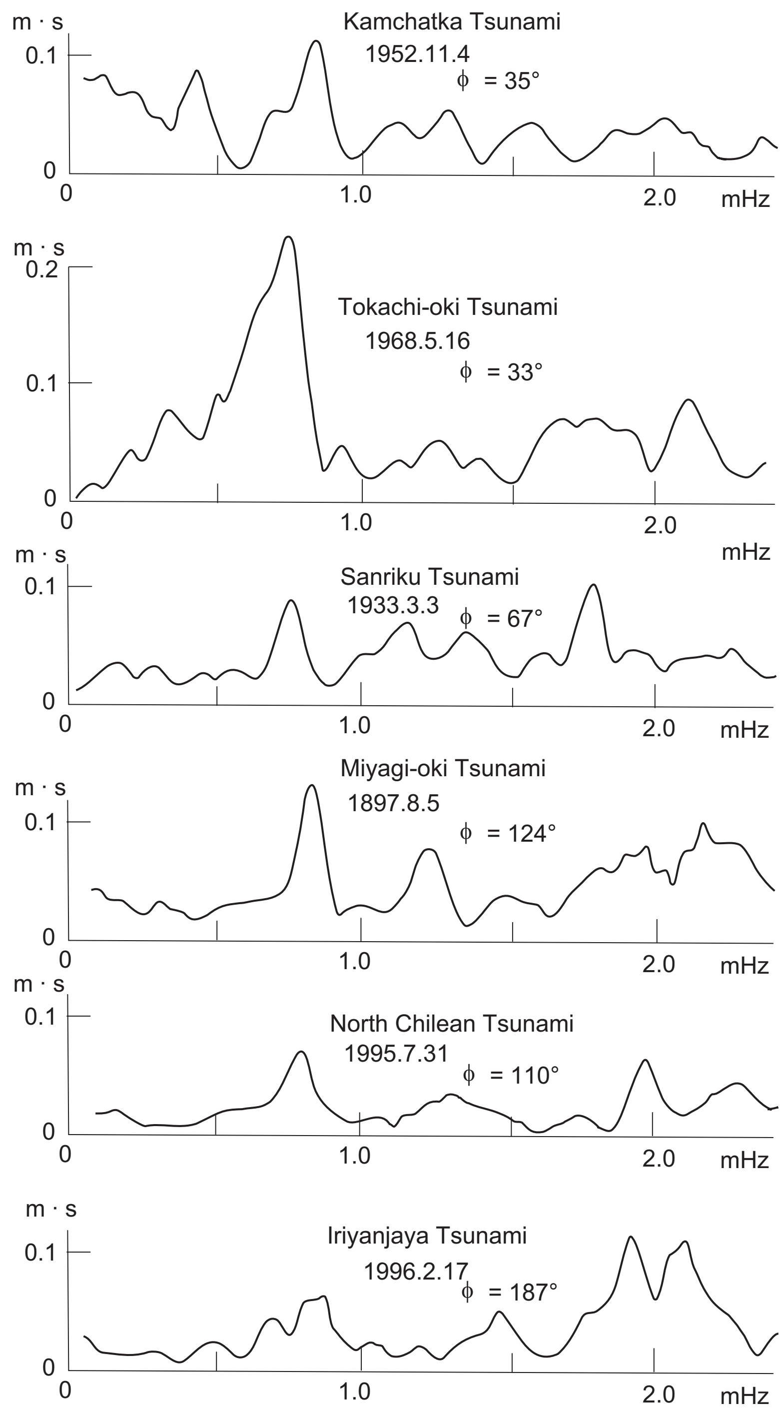


**Figure 2**: Examples of tsunami spectra observed at Ayukawa. Azimuth angle $\phi$ is defined in Fig. 1.

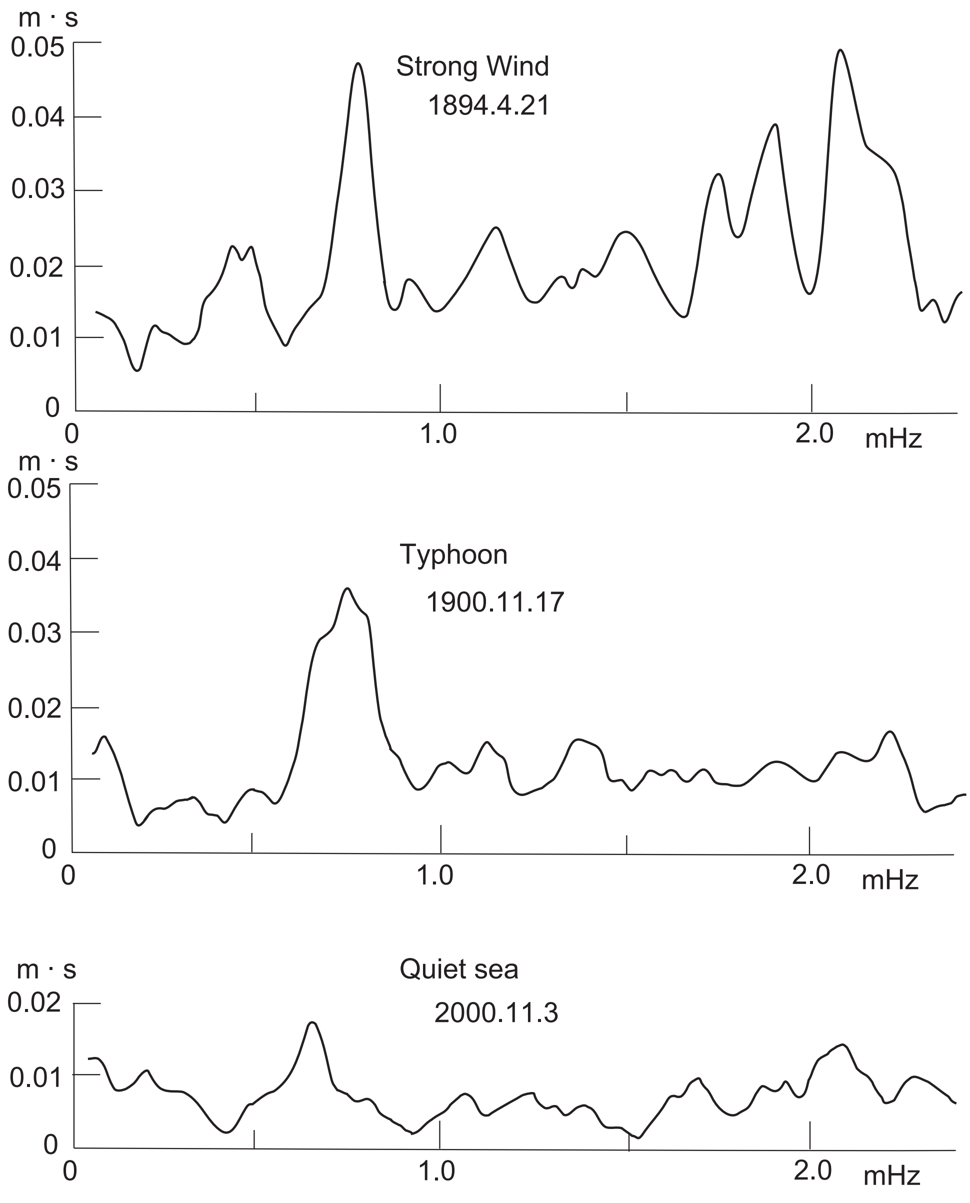


**Figure 3**: Spectra observed at Ayukawa under atmospheric disturbances (top, middle) and one of a quiet sea (bottom) which is used as the background spectra.

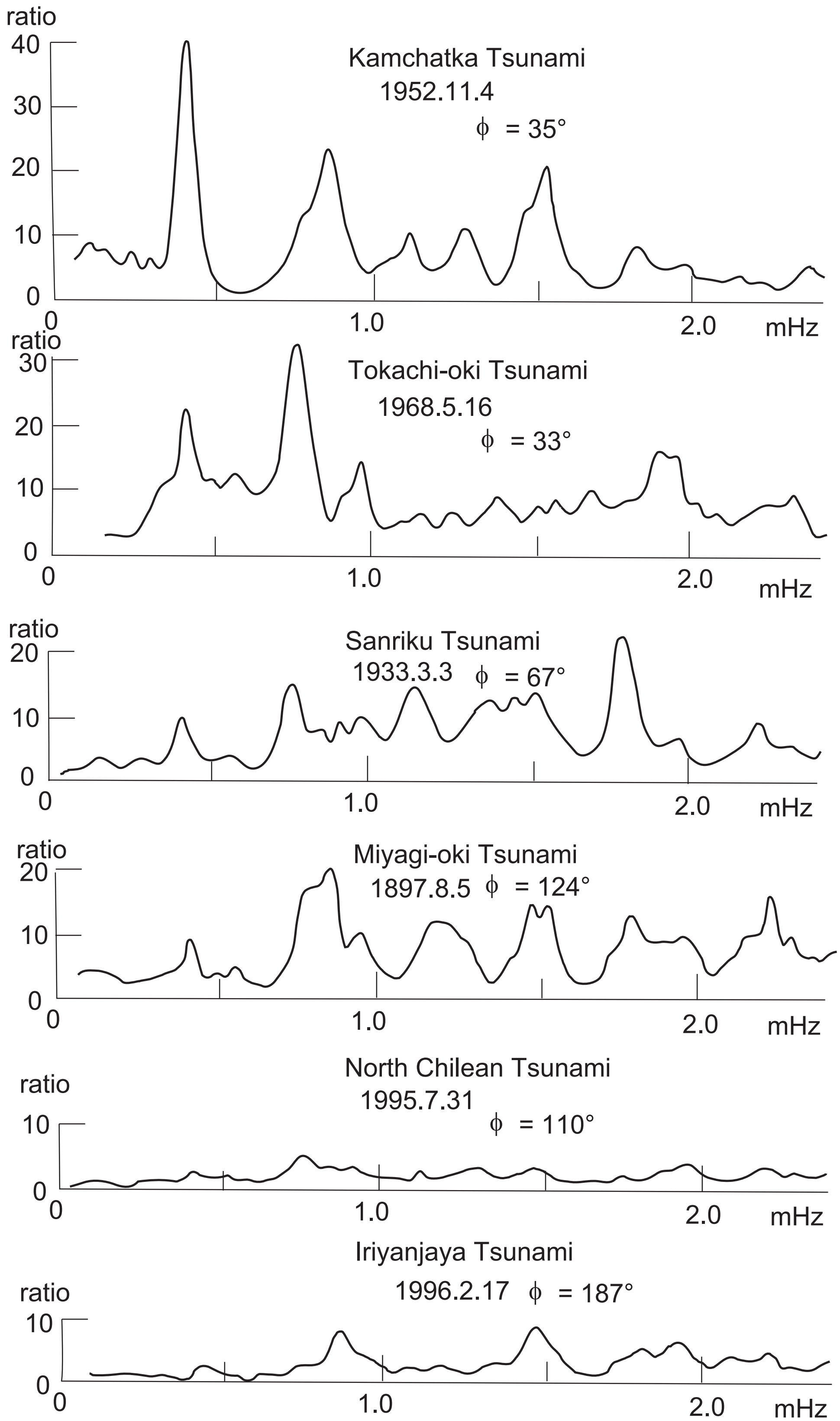


**Figure 4**: Examples of normalized spectra observed at Ayukawa. Azimuth angle $\phi$ is defined in Fig. 1.

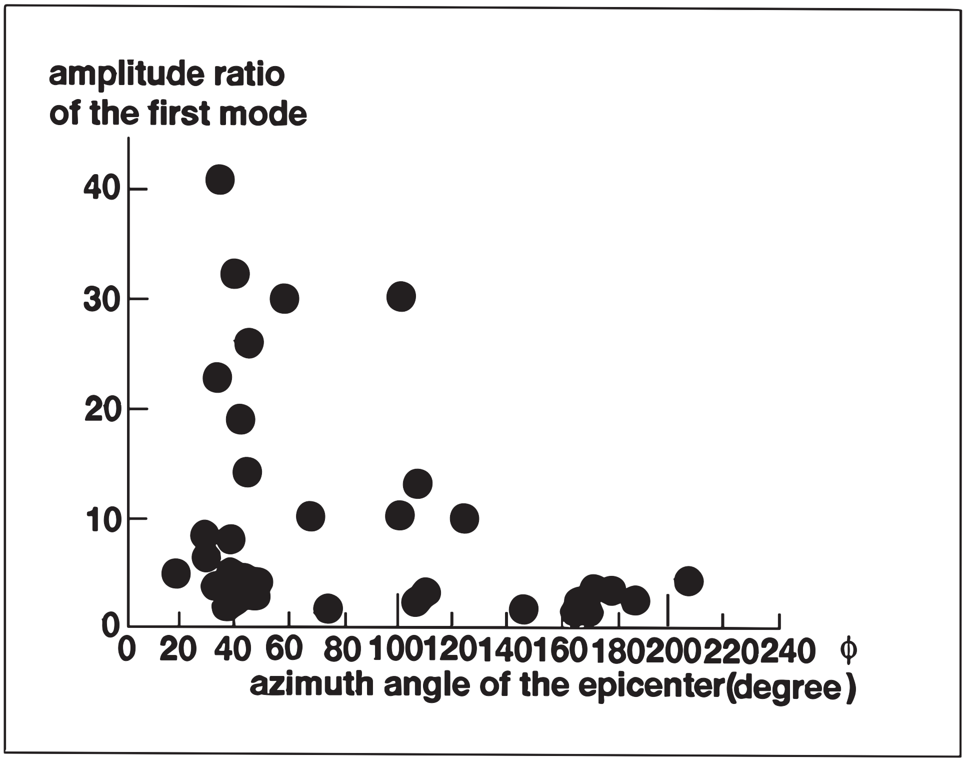


**Figure 5**: Azimuth dependence of amplitude ratio of the first mode in the normalized spectra.

## 4. Discussion

Abe (1996a, b) described the focusing effect of islands during the 1993 Hokkaido Nanse-oki tsunami and the 1983 Nihonkai-chubu tsunami. Islands act as a convex lens to a tsunami incidence. This explains the amplification of a tsunami on the opposite side of the incidence. The Ayukawa tide station is located nearest to Kinkazan Island and for the island opposite to tsunamis from the Pacific Ocean including northern Japan and Kamchatka. Tsunami sources are located to induce the focusing effect for a relative position of Kinkazan Island and the Ayukawa tide station. The large amplification at the azimuth of 35° in the first mode is attributed to the focusing effect of the island. Refraction around the island to tsunamis incident from the northeast is also assumed from an expansion of an equi-depth line of 100 m to the south, as shown in Fig. 1. The same focusing effect around the peninsula is also expected.

We have no criteria to determine the best background spectra. In this article, we did not discuss a statistical meaning of the selected background spectra. Uncertainty of the background spectra and its effect on the normalized spectra are future problems.

## 5. Conclusion

The observed spectra of tsunamis were normalized using the background spectra. The results at the Ayukawa tide station showed a predominance of 0.4 mHz (42 min) in many of the tsunamis. This mode predominated at the azimuth angle of 40° and was explained as a kind of shelf oscillation of north tsunamis refracted by Kinkazan Island.

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