CHAPTER 50

Estimation of Typhoon-Cenerated Maximum Wave Height along the Pacific Coast of Japan Based on Wave Hindcasting

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Abstract

Wave hindcastings in the West Pacific Ocean and at selected locations along the Pacific coast of Japan by the use of two wave prediction models are conducted for 118 typhoons which occurred from 1940 to 1991 to estimate maximum wave height at each point during a typhoon. Combination with maximum wave height data in the concerned area for 125 typhoons from 1934 to 1983 obtained by Yamaguchi et al.(1987a, 1987c) results in data sets of maximum wave heights caused by 243 typhoons from 1934 to 1991. Spatial distribution of the most extreme wave height and wave height for return period of 100 years, and their variation along the Pacific coast of Japan are re-examined on the basis of statistical analysis of the data and compared with the Yamaguchi et al. results (1987a, 1987c), in which case there is little change in the distribution except for the Western Kyushu coast. In addition, maximum wave height along the coast of the Japan Sea is evaluated in a similar manner.

1. Introduction

As the coastal areas of Japan facing the Pacific Ocean and the East China Sea have been heavily damaged by attacks of huge waves generated by powerful typhoons, the reasonable estimation of the typhoon-generated extreme waves around the Japanese coast is essential to planning and design of coastal protection systems for mitigation

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of wave-induced coastal hazards. The extreme waves expected in 50 or 100 years in the concerned sea area or location are usually evaluated based on statistical analysis of wave data hindcasted for many severe storms over a long term period of more than 30 years rather than measured wave data, because acquirement of measured data which is acceptable in quality and quantity is difficult.

Yamaguchi et al.(1987a, 1987c) estimated the spatial distribution of maximum significant wave height generated by typhoons in the West Pacific Ocean and around the Pacific coast of Japan, based on wave hindcasting for 125 typhoons in the past 50 years using two kinds of spectral wave prediction models. But re-estimation of probable extreme waves around the Pacific coast of Japan is required, because in recent years abnormally high waves and the consequent severe coastal hazards have been brought about by successive attacks of powerful typhoons such as Typhoons 8712 and 9119.

In this paper, wave hindcastings in the West Pacific Ocean and at selected locations along the Pacific coast of Japan by the use of two wave prediction models are conducted for 118 typhoons which occurred from 1940 to 1991 to estimate maximum wave height at each point during a typhoon. Combination with maximum wave height data in the concerned area for 125 typhoons from 1934 to 1983 obtained by Yamaguchi et al.(1987a, 1987c) results in data sets of maximum wave heights caused by 243 typhoons from 1934 to 1991. Spatial distribution of the most extreme wave height and wave height for return period of 100 years, and their variation along the Pacific coast of Japan are re-examined on the basis of statistical analysis of the data. In addition the most extreme wave height along the coast of the Japan Sea is also evaluated based on wave hindcastings for intense storms with use of the wave prediction models and their statistical analysis.

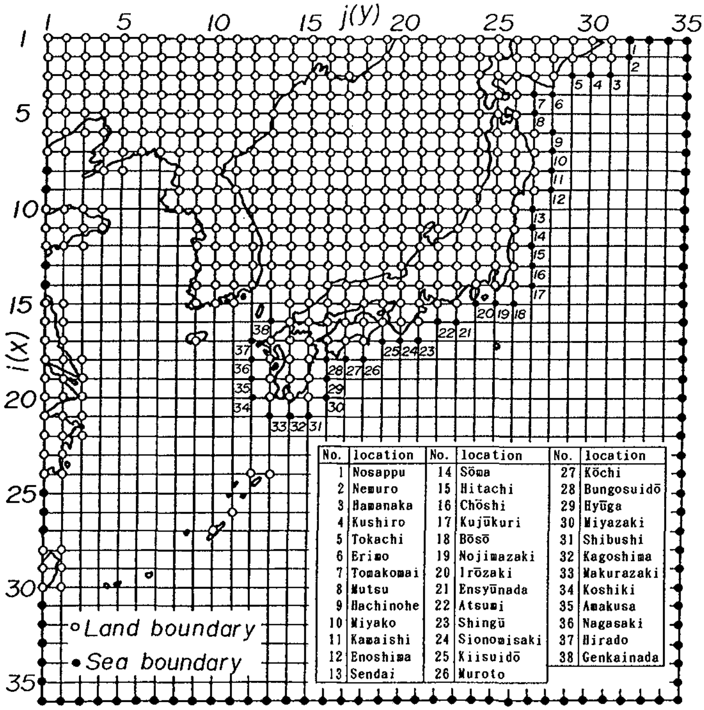
2. Outline of Wave Hindcast System

(1) Wind hindcast model

A parametric typhoon model is used for the estimation of typhoon-generated winds. The model computes the spatial distribution of wind speed and wind direction in a typhoon by composing axisymmetyrical gradient wind components and wind components related to the movement of a typhoon. The exponential function is assumed for the pressure distribution in a typhoon. The model parameters such as central pressure, position of typhoon center, radius to maximum winds and wind inflow angle are given every 6 hours, and wind field every 1 hour is estimated through a linear interpolation of the typhoon parameters. Correction factor to wind speed at the height of 10 m is 0.60.

(2) Wave hindcast model

The wave prediction models developed by the authors are used in the wave hindcasting. The first model referred to as the grid model(Yamaguchi et al., 1987a) is a coupled discrete model belonging to the second generation model which solves the energy balance equation on a regular grid. The grid with a spacing of 80 km is used for the estimation of spatial distribution of deep water extreme waves in the West Pacific Ocean shown in Fig. 1.



No.	location	No.	location	No.	location
1	Nosappu	14	Sōma	27	Kōchi
2	Nemuro	15	Hitachi	28	Bungosuidō
3	Hamanaka	16	Chōshi	29	Hyūga
4	Kushiro	17	Kujūkuri	30	Miyazaki
5	Tokachi	18	Bōsō	31	Shibushi
6	Erimo	19	Nojimazaki	32	Kagoshima
7	Tomakomai	20	Irōzaki	33	Makurazaki
8	Mutsu	21	Ensyūnada	34	Koshiki
9	Hachinohe	22	Atsumi	35	Amakusa
10	Miyako	23	Shingū	36	Nagasaki
11	Kamaishi	24	Sionomisaki	37	Hirado
12	Enoshima	25	Kiisuidō	38	Genkainada
13	Sendai	26	Muroto		

Fig. 1 Coarse grid used in wave hindcasting with grid model.

The second model referred to as the point model (Yamaguchi et al., 1987b) is a decoupled propagation model classified into a category of the first generation model in which the evolution of directional spectrum is traced along a wave ray for individual spectral component

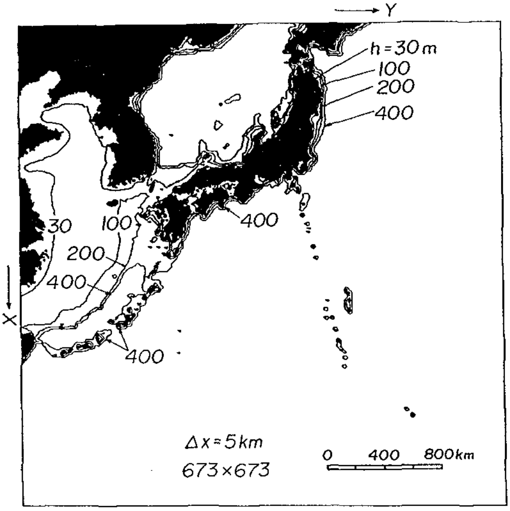
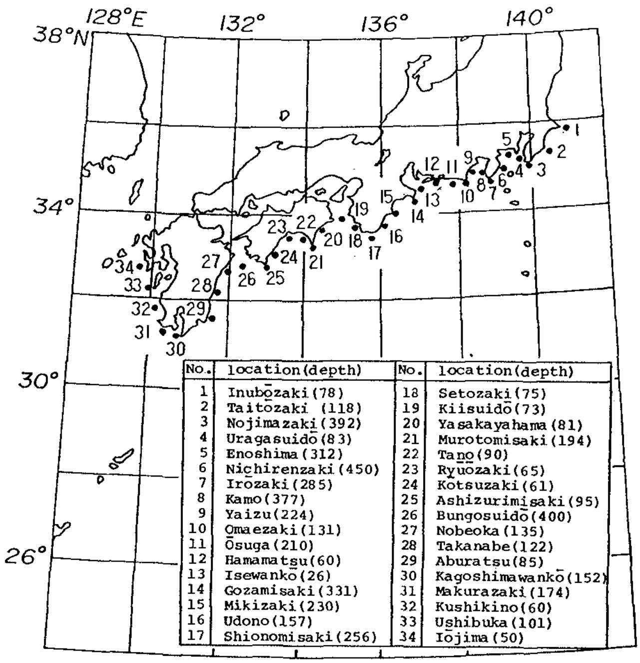


Fig. 2 Computation area used in wave hindcasting with point model and contour plot of water depth.



No.	location(depth)	No.	location(depth)
1	Inubōzaki(78)	18	Setozaki(75)
2	Taitōzaki (118)	19	Kiisuidō(73)
3	Nojimazaki(392)	20	Yasakayahama(81)
4	Uragasuidō(83)	21	Murotomisaki(194)
5	Enoshima(312)	22	Tano(90)
6	Nichirenzaki(450)	23	Ryūozaki(65)
7	Irōzaki(285)	24	Kotsuzaki(61)
8	Kamo(377)	25	Ashizurimisaki(95)
9	Yaizu(224)	26	Bungosuidō(400)
10	Omaezaki(131)	27	Nobeoka(135)
11	Ōsuga(210)	28	Takanabe(122)
12	Hamamatsu(60)	29	Aburatsu(85)
13	Isewankō(26)	30	Kagoshimawankō(152)
14	Gozamisaki(331)	31	Makurazaki(174)
15	Mikizaki(230)	32	Kushikino(60)
16	Udono(157)	33	Ushibuka(101)
17	Shionomisaki(256)	34	Iōjima(50)

Fig. 3 Locations selected for wave hindcasting with point model.

focusing on a single position. The high topographical resolution grid with a spacing of 5 km is used in the point model to estimate the effect of shallow water on extreme waves in the nearshore region, as indicated in Fig. 2. Fig. 3 shows location of 34 selected points where wave hindcastings are conducted along the coastal region of Western Japan.

In hindcasting, 20 frequency components from 0.045 to 1.0 Hz and 19 directional components from 0 to 360 degrees are used in the grid model and 23 frequency components from 0.035 to 0.5 Hz and 37 directional components from 0 to 360 degrees are used in the point model. At the land boundary the directional spectrum is set at zero, and at the open boundary the directional spectrum computed from the product of frequency spectrum based on the Ross model(Ross, 1976) and an angular distribution is given in both models.

3. Typhoons Selected for Wave Hindcasting

In this study, 118 intense typhoons are newly selected for wave hindcasting by surveying the published reports. They include annual reports of wave data with ocean buoys deployed around Japan by the Japan Meteorological Agency, annual reports of wave data acquired with sonic-typc wave gauge around the coastal area of Japan by the Harbor Construction Bureau, Ministry of Transport, a report of Typhoon Summary of Japan 1940-1970 edited by the Japan Meteorological Association and a report of Tropical Cyclone Tracks in the Western North Pacific 1951-1990 edited by the Japan Meteorological Agency. Extremes of typhoon-generated wave height are estimated based on the results of wave hindcasting for the 243 typhoons from 1934 to 1991, in which case wave hindcastings for the 125 typhoons from 1934 to 1983 have already been carried out by Yamaguchi et al.(1987a, 1987c).

Fig. 4 shows tracks of the 243 typhoons with those of the 125 typhoons used in wave hindcasting by Yamaguchi et al.(1987a, 1987c). Tracks of the 243 typhoons cover a wide area of the West Pacific Ocean far more densely than tracks of the 125 typhoons. Yearly consecutive typhoon data is available only for the period of 42 years from 1950 to 1991, because the typhoon data preceding the period are limited to huge typhoons which caused severe damages. Data of annual maximum wave height used in extreme wave statistics are those estimated for the 221 typhoons which occurred over the period of 42 years.

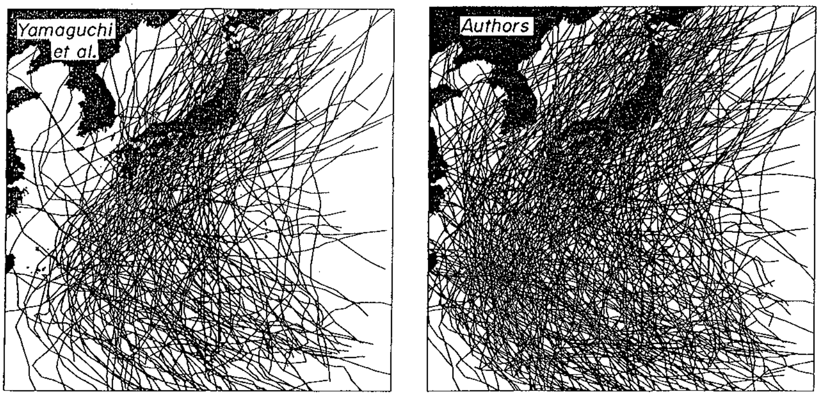


Fig. 4 Tracks of typhoons used in wave hindcasting.

4. Estimation of Maximum Wave Height

(1) Spatial distribution of maximum wave height

Superimposing maximum wave height obtained from hindcasted wave heights every 1 hour for the 243 typhoons at a point produces the most extreme wave height from 1934 to 1991 at the point. Fig. 5 shows spatial distribution of the most extreme wave height estimated by the wave hindcasting using the grid model of Yamaguchi et al. (1987a) and the authors' revised results. As the typhoon-generated extreme wave height at a point is strongly dependent on tracks of powerful typhoons which passed over near the point, it varies remarkably from place to

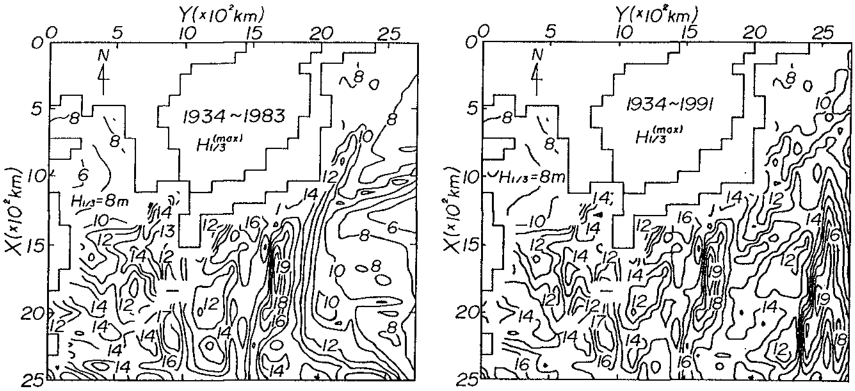


Fig. 5 Spatial distribution of the most extreme wave height.

place. Differences between both the results are seen at the southeast and southwest parts of the computation area and the western part of Kyushu Island. Especially, maximum wave height along the western part of Kyushu Island is replaced from 12-13m to 14 m associated with Typhoons 8712 and 9119.

(2) Alongshore distribution of the most extreme waves

Fig. 6 illustrates alongshore distributions of the most extreme wave height and frequency of occurrence of waves more than 10 m high estimated from wave data hindcasted with the grid model and observed data. Name and number of the location indicated along the horizontal axis in the figure are given in Fig. 1. In a qualitative sense, alongshore distribution of extreme wave height looks similar, but in a quantitative sense, hindcasted results give much higher estimation than observed results except for the northern part of the Japanese coast such as Sendai or Tomakomai where the most extreme waves are frequently generated by strong monsoon winds in winter. The reasons are that the wave model does not take into account the shallow water effects, that the grid system of poor topographical resolution is used in the wave hindcasting and that the period of wave observation is too short compared to the period of wave hindcasting. The most extreme wave height estimated by Yamaguchi et al.(1987a) is updated 2 m near Nagasaki by Typhoons 8712 and 9119, and updated 1 m near Chōshi by Typhoon 8913. Maximum of the most extreme wave height exceeding 15 m is observed at the sea area near Shionomisaki.

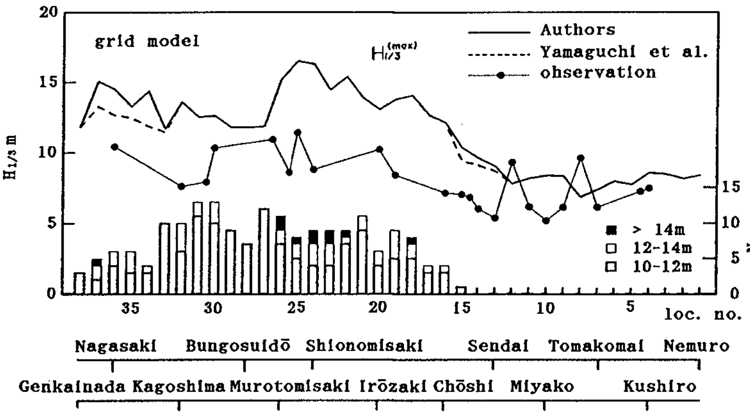


Fig. 6 Variation around the Pacific coast of Japan of the most extreme wave height and frequency of occurrence of waves more than 10 m high estimated from wave data hindcasted with grid model and observed wave data.

In addition, Fig. 7 shows alongshore distributions of the most extreme wave height estimated from wave hindcasting with the point model. Name of location corresponding to the figure along the abscissa is summarized in Fig. 3. The most extreme wave height and occurrence rate of high waves estimated with the point model are relatively lower than that with the grid model and varies significantly from location to location, because the point model can take into account the topographical effect in much more detail than the grid model.

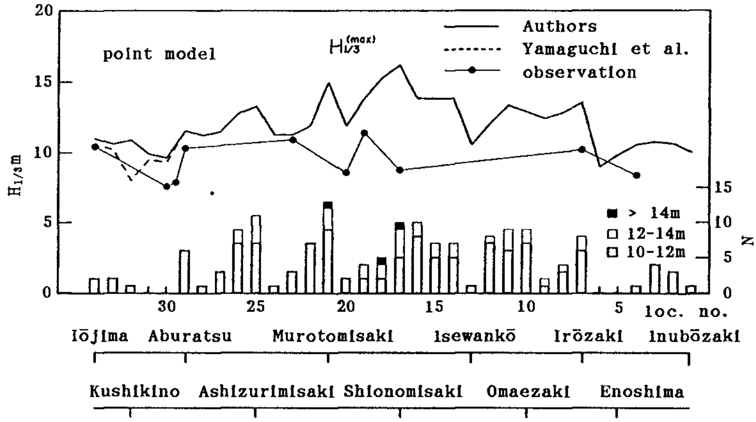


Fig. 7 Variation around the Pacific coast of Western Japan of the most extreme wave height and frequency of occurrence of waves more than 10 m high estimated from wave data hindcasted with point model and observed wave data.

Alongshore distributions of the most extreme wave height estimated by both the grid model and the point model and observed wave data are compared in Fig. 8. Notation of the abscissa is the same as Fig. 6. Extreme wave height estimated by the point model gives a consistently smaller value than that of the grid model and varies remarkably from location to location, as the point model can take into account the effect of water depth variation and topography by usage of fine computation grid. The most extreme wave height estimated with the point model shows a closer value to the observed extreme wave height than the result with the grid model. As mentioned before, the most extreme wave height observed near Sendai and Tomakomai exceeds the estimate with the grid model. This suggests that the most extreme wave height in northern Japan is caused by not only typhoons but also by monsoons.

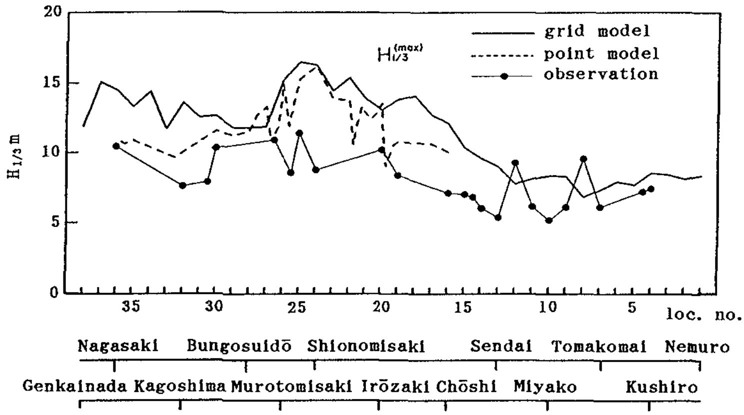


Fig. 8 Variation around the Pacific coast of Japan of the most extreme wave height estimated from wave data hindcasted with both grid model and point model and observed wave data.

(3) Wave height for return period of 100 years

Yearly variations of the annual maximum wave heights at Irōzaki estimated with the grid model and point model and the corresponding observed data are shown in Fig. 9. Both hindcasted results agree relatively well with the observed data, because Irōzaki is exposed directly to open sea and water depth of the installed wave gauge of 50 m is enough to measure deep water waves. Maximum wave height varies remarkably from year to year due to strong annual change of powerful typhoons attacking the Pacific coast of Japan, in which cases the severest sea state occurred in the nineteen-fifties and the nineteen-sixties.

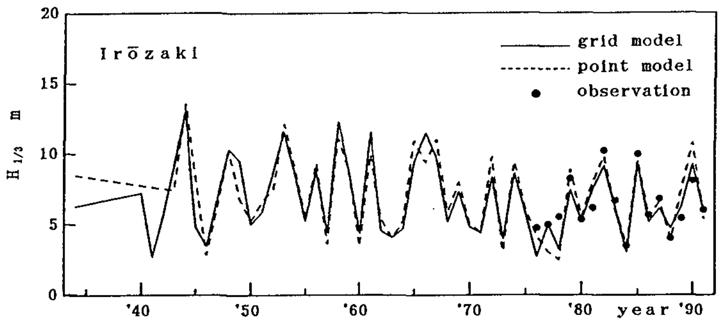


Fig. 9 Yearly variation of annual maximum wave height at Irōzaki.

The log-normal distribution with three parameters is fitted to the data of annual maximum wave height for the period of 42 years from 1950 to 1991, in which the estimation of parameters is due to the moment method. Fig. 10 shows an example of the fitting. At Irōzaki, wave heights with a return period of 100 years are 13.8 m and 13.5 m for the data hindcasted with the grid model and point model, and 11.9 m for the observed data. Observed data give a smaller estimation of extreme wave height, because the observation period is short compared to the wave hindcast period and the observed waves are affected by bottom topography in rough sea condition even if the wave gauge is installed at the point of 50 m deep.

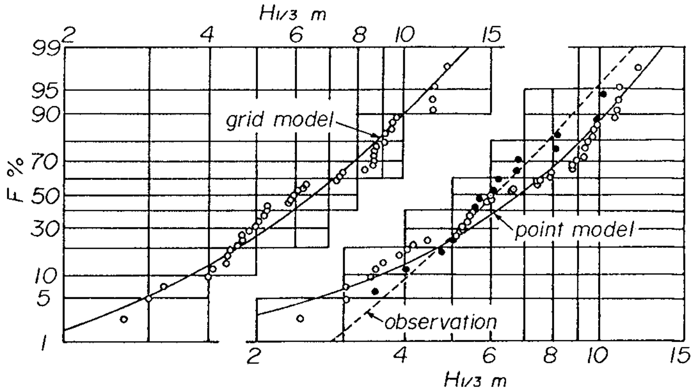


Fig. 10 Fitting of log-normal distribution to annual maximum wave height data at Irōzaki.

Fig. 11 describes the spatial distribution of wave height for a return period of 100 years over the West Pacific Ocean and the East China Sea. The spatial distribution is estimated by the fitting of log-normal distribution with three parameters to the annual maximum wave height data obtained from wave hindcastings by use of the grid model for the period from 1950 to 1991. Being similar to the spatial distribution of the most extreme wave height in this area, return wave height over 19 m is observed in the offshore sea area and return wave height becomes smaller around the Japanese coast, especially in the northern part because of the decay in typhoon intensity.

Fig. 12 illustrates alongshore distributions of wave height for a return period of 100 years estimated from wave data hindcasted with the grid model and observed wave data. Name of the location corresponding to the number along abscissa in the figure is given in Fig. 1. Except near Nagasaki, the present results are similar to

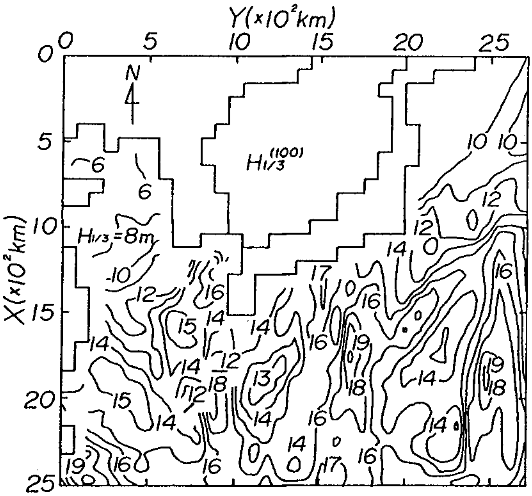


Fig. 11 Spatial distribution of wave height for return period of 100 years.

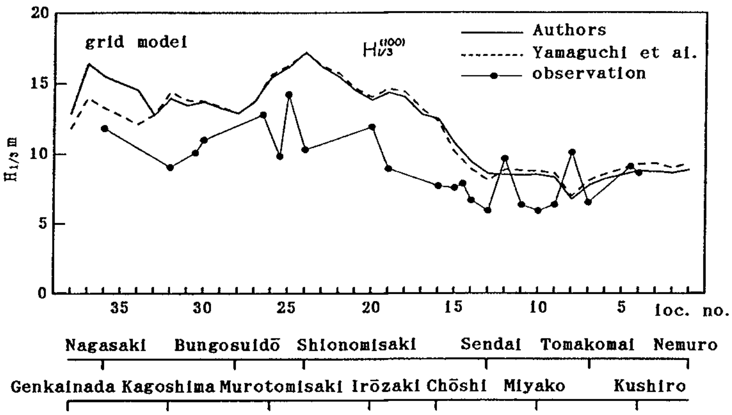


Fig. 12 Variation around the Pacific coast of Japan of wave height for return period of 100 years estimated from wave data hindcasted with grid model and observed data.

the results of Yamaguchi et al.(1987a), despite the fact that the number of annual maximum wave height data and cases of typhoon for wave hindcasting increased from 34 to 42 and from 107 to 221 respectively.

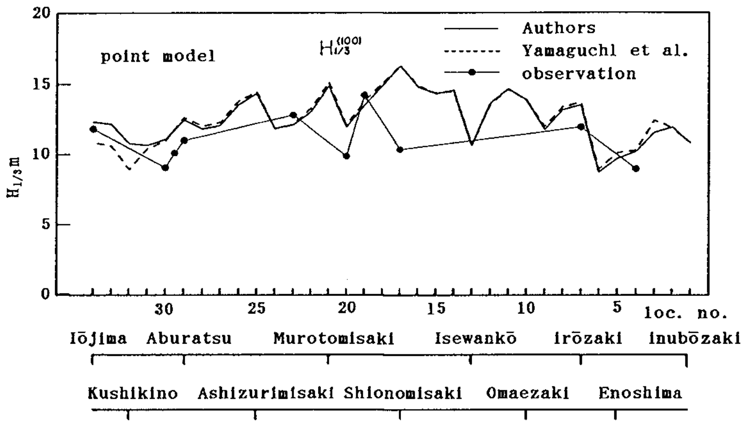


Fig. 13 Variation around the Pacific coast of Western Japan of wave height for return period of 100 years estimated from wave data hindcasted with point model and observed wave data.

Fig. 13 shows alongshore distributions of wave height for a return period of 100 years estimated with the point model by the authors and Yamaguchi et al. (1987c), which includes the corresponding results based on observed data. Name of numbered location is indicated in Fig. 3. Hindcasted results produce smaller estimates at Ryūōzaki and Kiisuido than observed results. But, the reliability of the observed results is relatively low, because the number of annual maximum wave height data used in extreme analysis is less than 10 at these points.

Alongshore distributions of wave height for a return period of 100 years evaluated with three kinds of wave data are given in Fig. 14. Return wave height estimated from the results hindcasted with the grid model varies from 9 m to 17 m and is greater than the other results because of poor topographical resolution of the grid system used in wave hindcasting. But at the open coastal locations, both models produce comparative results. Return wave height based on the point model using the grid system with high topographical resolution varies greatly from location to location, which is in closer agreement with that estimated with observed data. It should be noted that at most locations, the return wave height evaluated with observed data takes a lower value than that with hindcasted data, because the observation period is far shorter compared to the hindcast period.

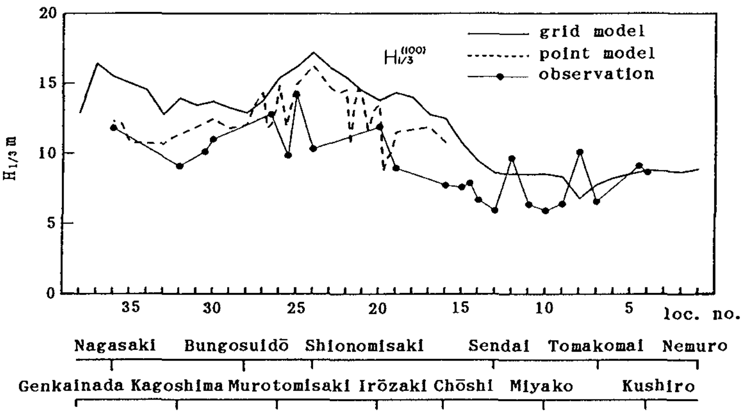


Fig. 14 Variation around the Pacific coast of Japan of wave height for return period of 100 years estimated with both grid model and point model and observed wave data.

5. Estimation of Maximum Wave Height along the Coast of the Japan Sea

Finally, maximum wave height along the coast of the Japan Sea is briefly discussed to contrast the characteristics of the maximum wave height along the Pacific coast. To evaluate maximum wave height along the coast of the Japan Sea, wave hindcasting for 143 storms which occurred from 1962 to 1991 is carried out with the same spectral wave prediction models as mentioned before. Wind distributions are estimated by weather map analysis, as high waves in the Japan Sea are predominantly generated by winter monsoons. The weather map analysis consists of a spline interpolation onto regular grid of irregularly-distributed atmospheric pressure data and an application of the Bijvoet wind model(1957).

Fig. 15 shows alongshore distribution of the most extreme wave height estimated from the wave data hindcasted for intense meteorological disturbances over 30 years from 1962 to 1991 with both the grid model and the point model and the observed wave data of shorter period. Usually, annual maximum wave height along the Japan Sea coast does not change so greatly as that along the Pacific coast, because in most cases it is generated by winter monsoons with weak yearly variation and the Japan Sea is a semi-closed and limited basin. The most extreme wave height along the coast of the Japan Sea ranges from 6 m to 10 m and is about 5 m lower than that along the southern Pacific coast shown in Fig. 8 due to the limited sea area.

Sheltering effect of waves by Sado Island can be observed from Naoetsu to Sakata by comparing the estimates with the grid model and point model. Grid system with a grid distance of 40 km used in the grid model is too coarse to resolve the presence of Sado Island and consequently the grid model overestimates the wave conditions in the coastal sea area of Hokuriku district behind Sado Island.

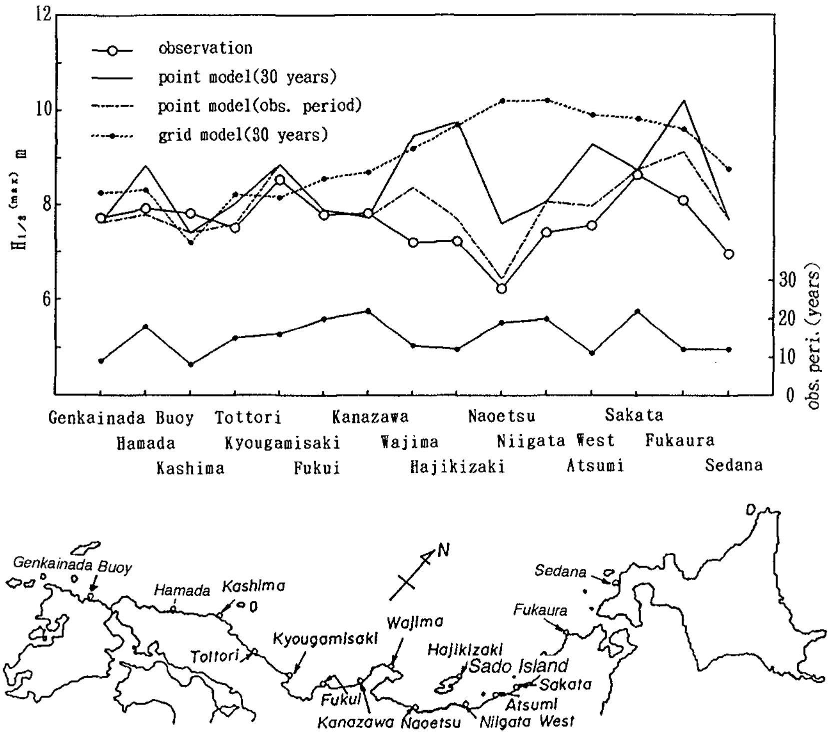


Fig. 15 Variation around coast of the Japan Sea of the most extreme wave height estimated from wave data hindcasted with both grid model and point model and observed wave data.

6. Conclusions

The most extreme waves expected in 100 years in the West Pacific Ocean and around the Japanese coast were evaluated based on statistical analysis of the wave data hindcasted with the use of two kinds of wave prediction models for the 243 typhoons which occurred from 1934 to 1991. It is deduced that maximum wave height around the Japanese coast exceeds 15 m. The most extreme wave heights along the Japan Sea coast were also estimated in similar manner. The result is that the wave height ranges from 6 m to 10 m which is about 5 m lower than that along the Pacific coast for the reasons of a limited sea area with restricted fetch and monsoon-dominated wind conditions in the sea area.

7. Acknowledgements

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References

Bijvoet, H.C.(1957): A new overlay for the determination of the surface wind over sea from surface weather charts, KNMl, Mededelingen en Verhandelingen, Vol. 71, pp. 1-35.

Ross, D.B.(1976): A simplified model for forecasting hurricane generated waves, Bull. American Meteorol. Soc., 113.

Yamaguchi, M. et al.(1987a): Estimation of alongshore distribution of typhoon-generated maximum wave height around the Japanese coast based on wave hindcasting, Proc. JSCE, No. 381/lI-7, pp. 131-140 (in Japanese).

Yamaguchi, M. et al.(1987b): A shallow water prediction model at a single location and its applicability, Proc. JSCE, No. 381/11-7, pp. 151-160 (in Japanese).

Yamaguchi, M. et al.(1987c): Alongshore distribution of extremes of typhoon-generated waves around the Pacific coast of Western Japan on the basis of wave hindcasting, Proc. JSCE, No. 387/II-8, pp.281-290 (in Japanese).