The Statistical Characteristics of Wave Height Data Measured by an Altimeter Loaded on the Satellite, GEOSAT

by

Yoshitaka Ogawa*, Guner Ozmen** and Iwao Watanabe***

Summary

This paper describes the characteristics of the wave height measured by an altimeter on the satellite, GEOSAT. At first, comparison for checking the accuracy of GEOSAT data is made with Ocean Wave Charts and Coastal Wave Observation offered by the Japan Meteorological Agency(JMA).The effects of temporal and spatial differences on the GEOSAT data are discussed. The accuracy of them in the coastal area where sea state is much dependent on location is checked. It is found that the GEOSAT gives wave data in reasonably good agreement with sea truth data in the coast as well. Next, the wave height distributions made from them are compared with existing ones to examine availability of the altimeter data for getting the global wave statistics. Lastly long term prediction of the wave load on a ship are tried to examine how difference of the wave height distribution affects the predicted load. It is found that the difference in wave height distribution results in difference in long term prediction of ship response.

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1. Introduction

It is important to have an accurate knowledge on the characteristics of the ocean waves when estimating the seakeeping performance of ships at sea. The Ship Research Institute has been making efforts to summarize wave statistics in the oceans for years to this end. The works by Yamanouchi et al.[1]and Takaishi

* Ship dynamics division
** Faculty of Marine Sciences, Karadeniz Technical University, Trabzon, Turkey
***Director of the Special Research
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et al.[2] are typical examples among them. They summarized the statistics of wind and wave data in the North Pacific Ocean. Their works mainly relied on the weather reports from voluntary ships in service when compiling the wave statistics.

There are other sources of wave data other than ship data. Buoy measurement, wave hindcasting and remote sensing data from satellites are the source of the wave information currently available. There are advantages and disadvantages among them according to the nature and origin of data. For example, the probability of high wave height of the ship report is thought to be smaller than other data sources because ships tend to try to avoid the storm seas. On the other hand, a buoy measurement is considered to be one of the best source of information since it measures waves mechanically, however it has a disadvantage of limited number of deployments for vast area of the oceans.

Recently, it became possible to measure wave height by the altimeter on a satellite. Although the altimeter has a shortcoming that it is not able to measure the wave direction and wave period, it has a merit to cover wide range of the ocean in short time because it turns around the earth within hours. But there are questions on the nature and the reliability of measured wave heights by the satellite. Examinations are necessary before using them as a reliable data source. Dobson[4] and Carter[5] checked the quality of satellite data in the relation to the offshore buoy data. They concluded the individual altimeter data agrees well with the buoy data. Young[6] indicated the global wave height distribution using the GEOSAT data.

In this paper, the characteristics of wave height data measured by an altimeter on the satellite GEOSAT is described. Comparison with respect to spatial and temporal variation are made with other wave sources such as measurements by offshore buoys, coastal wave robots and wave charts compiled by the Japan Meteorological Agency (JMA). Comparison was also made with commonly used wave distributions for several areas in the Pacific Ocean and discussions were made on reasons of the difference among them.

2. GEOSAT Mission

The satellite GEOSAT was launched in March 1985. Its main purpose was to measure the marine gravity field with a high precision. After first 18 months of the classified geodetic mission, the satellite's orbit was altered in October 1986 to a 17 day repeat pattern. The GEOSAT Exact Repeat Mission (ERM) commenced on the 8th of November 1986 and continued until the satellite failed in January 1990 [5]. It was during this second stage that the wave information had been successfully extracted from the altimeter on board. Therefore wave data from the 8th of November 1986 is used in this paper.

3. Altimeter Data

An altimeter irradiates a microwave towards the sea surface, and measures the return pulse. Since the altimeter pulse is scattered by the wave elevation, return pulse is rounded or broadened, as shown in Fig. 1. The broadness of the return pulse is related to significant wave height (SWH) in the spotted sea area. [7]

There are some mechanisms that may contaminate the measured data and cause the source of error. One of them is the existence of the water vapor in the air. According to the GEOSAT handbook[8], the water vapor affects to the microwave. The affection is large both in the Polar region because of sea ice and in the tropical regions because of much rainfall. Radiometer data is needed to correct vapor effects in altimeter data. Unfortunately the GEOSAT did not include the water vapor radiometers since the primary mission of GEOSAT was to map the marine Geoid and the limited loading weight did not allow the instrument not directly related to the mission. The correction was made by using the radiometer data measured by another satellites, i.e. those of the Tiros Operational Vertical Sounder (TOVS) and the Special Sensor Microwave Imager (SSMI) were used. Those satellites were operated during GEOSAT missions, TOVS was incorporated from the beginning of the GEOSAT mission through to July 8th, 1987. SSMI was used during the remainder of the GEOSAT mission.

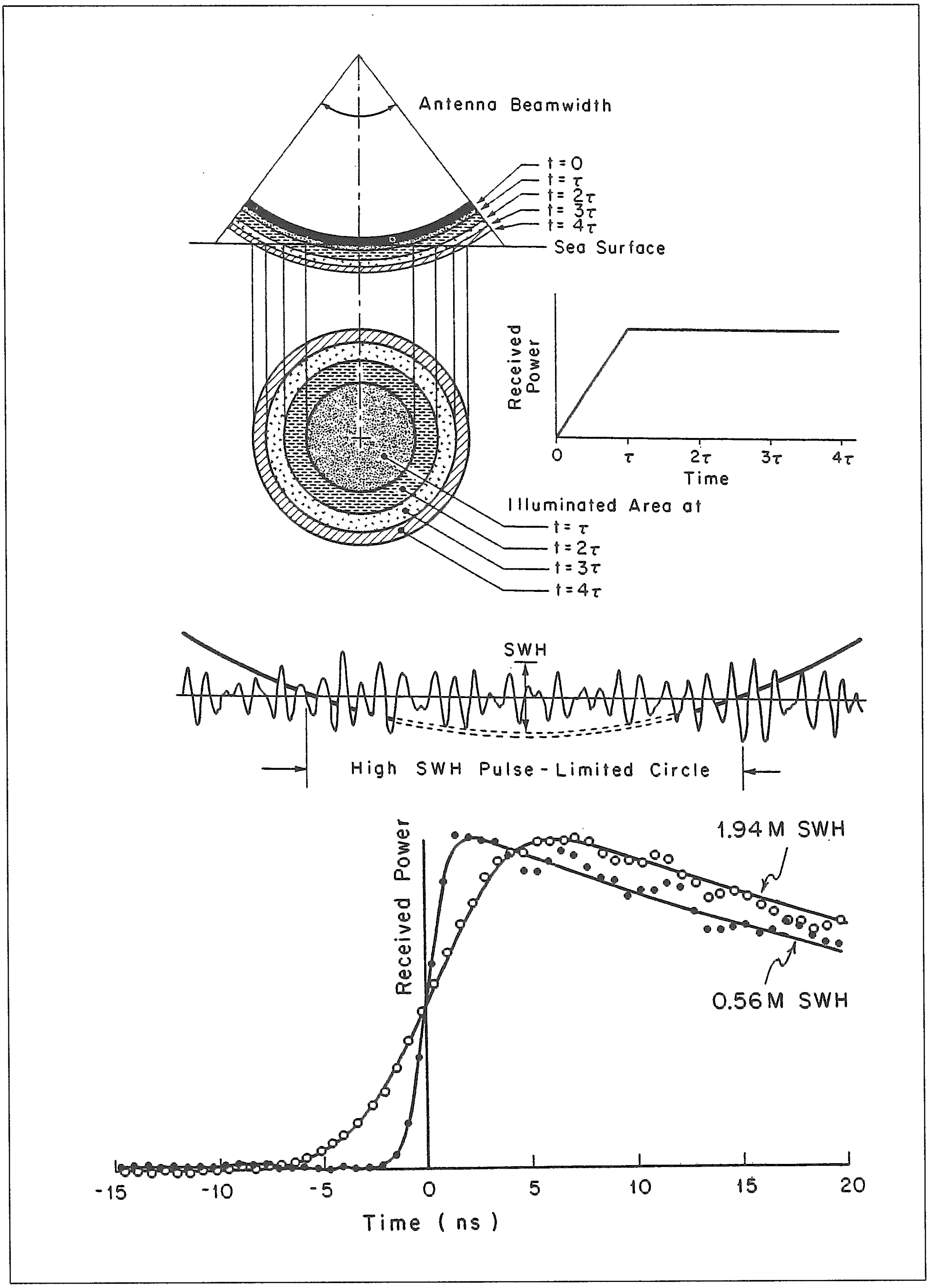

Fig. 1 The Interaction of a Pulse of Radar Energy from a Altimeter with the Surface of the Ocean[7]

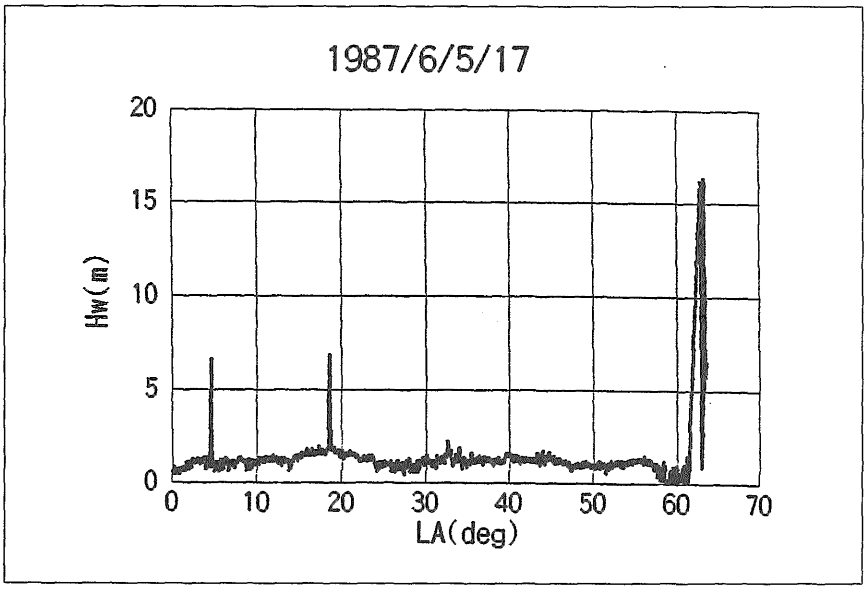

Fig. 2 Time History of Wave Height Measured by GEOSAT

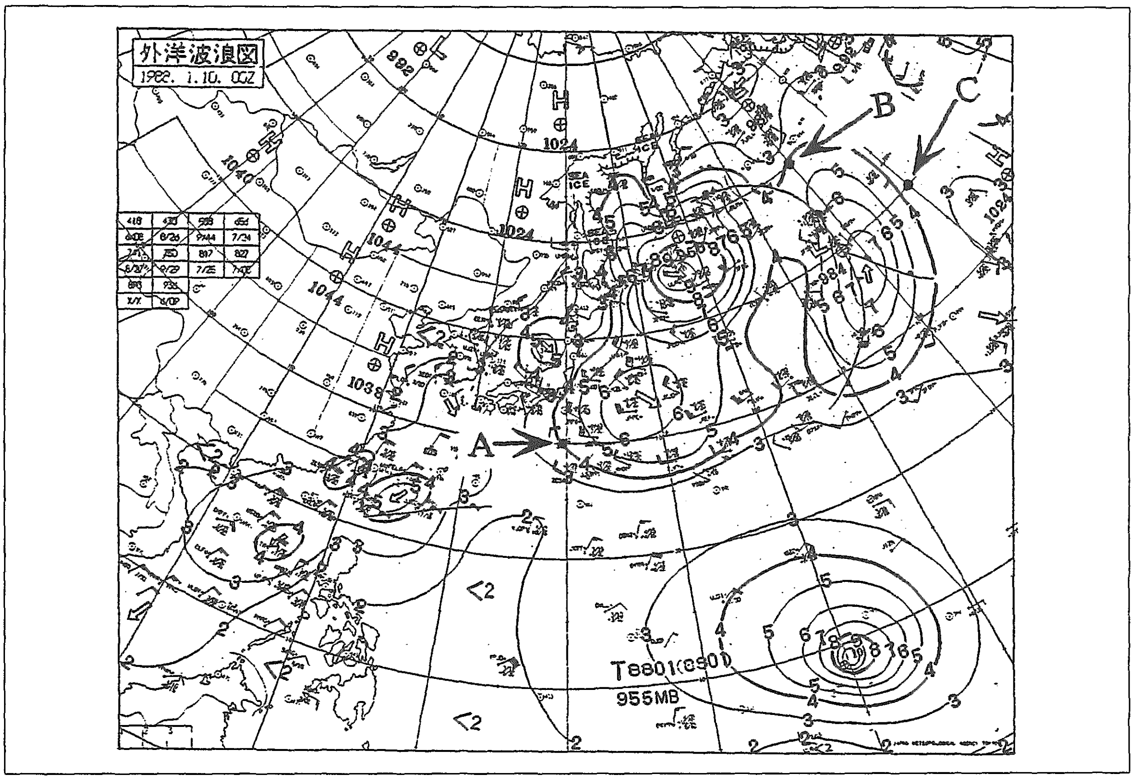

Fig. 3 Ocean Wave Charts (January 10th 1988) [10]

4. Verification of GEOSAT Data

4.1. Abnormally High Waves

It was found that the wave height measurement in the North Pacific Ocean in 1986 and 1987 contained significant wave height over 15m which was considered to be unrealistic. It was also found that these data existed only at the high latitude region, near the equatorial and near coastal zones. Fig.2 shows a sample of time history of wave height near the 15m wave height. The high wave record looks like noise. The other cases with abnormally high waves showed similar results. Therefore, it can be said that wave record with 15m wave is false record caused by some kinds of noise.[9]

4.2 Comparison with Ocean Wave Charts

In this chapter, the GEOSAT data are compared with Ocean Wave Charts published by the JMA . The Ocean Wave Chart is produced combining the numerical wave forecasts, ship weather reports, ocean buoy data and some sort of experience by experts in the JMA. The chart is produced once a day at 9 am JST. Fig. 3 shows an example of the Ocean Wave Chart. The black circles in the figure indicate the locations A, B and C selected for the comparison. The comparison has to be made in the form of temporal and spatial average because otherwise the satellite path is too scarce for meaningful results. Therefore it was decided to take all the GEOSAT data in the vicinity area of each location and make daily average. The vicinity

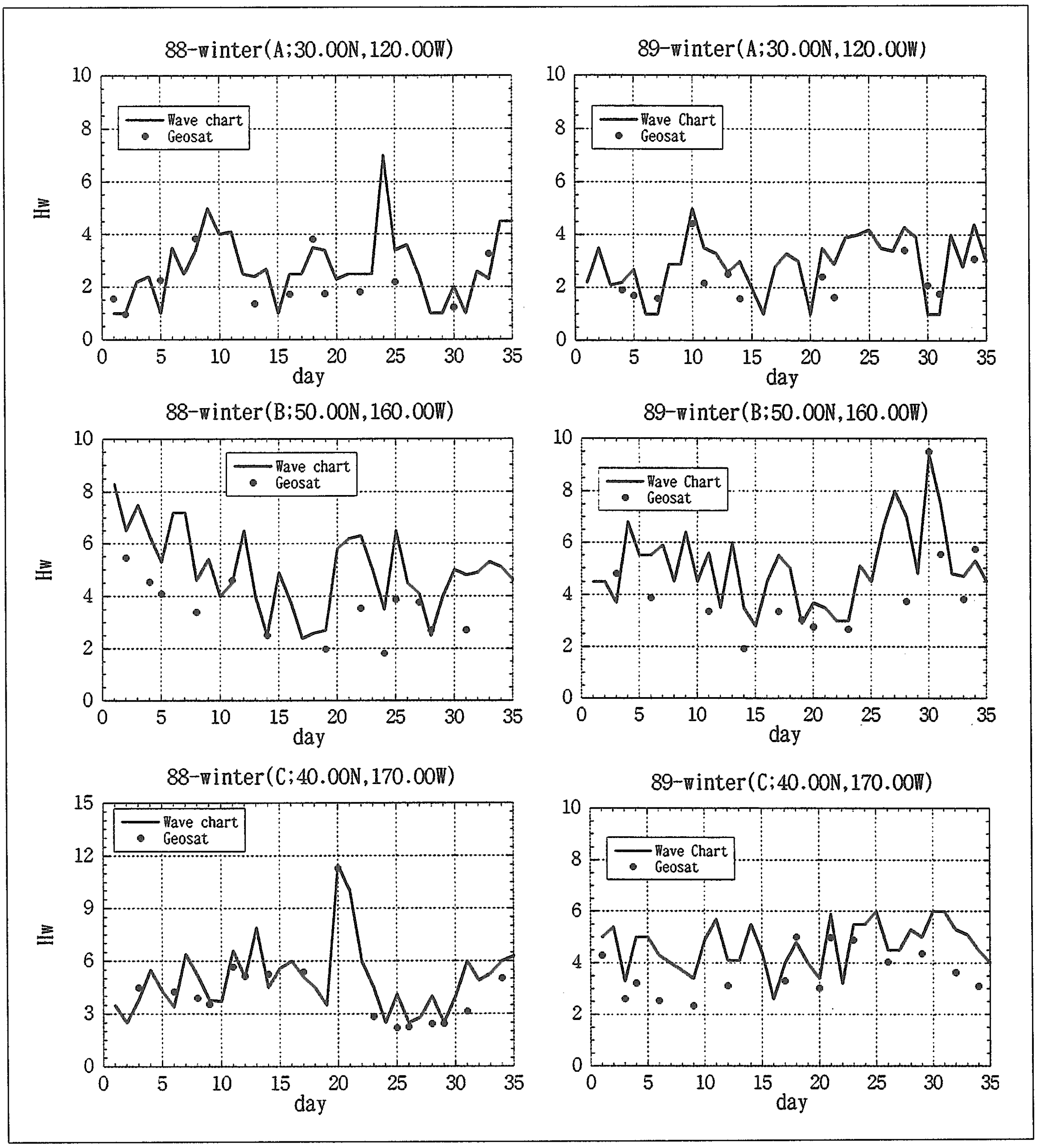

Fig. 4 Comparison of Daily Trend of Significant Wave Height with Ocean Wave Charts

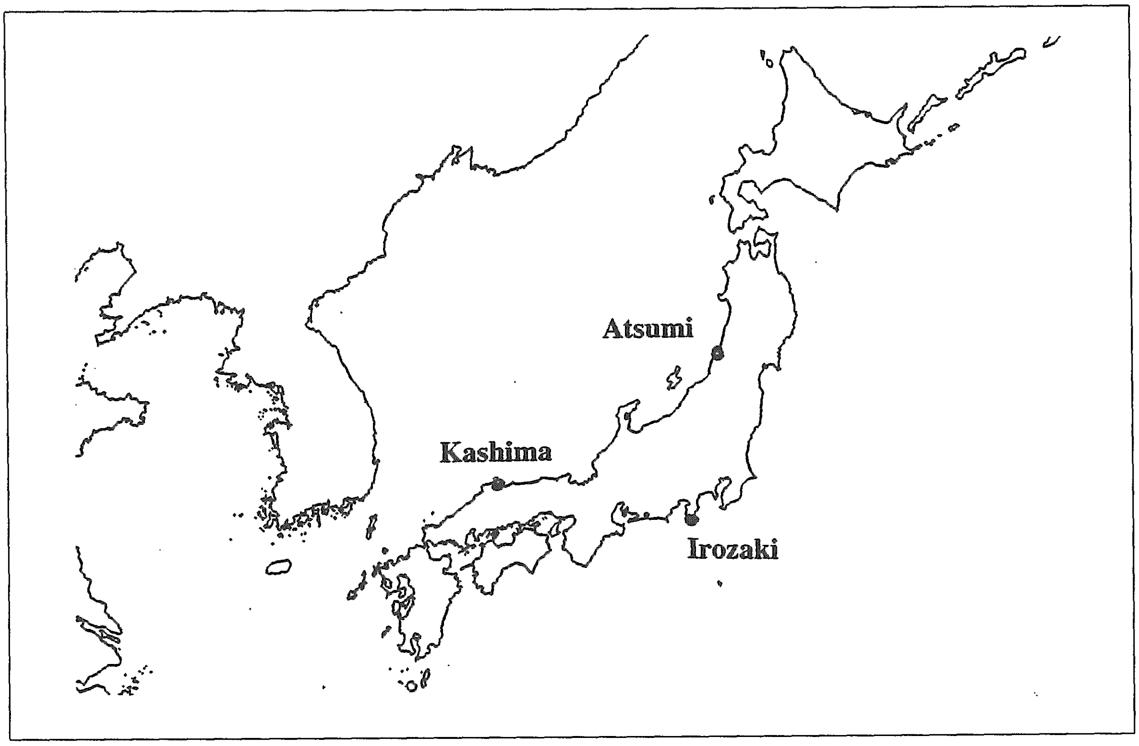

Fig. 5 Selected Location for Comparison

area was assumed the square area with 2° in latitude by 2° in longitude surrounding the selected point. This enabled us to accumulate data during 2 or 3 orbit paths for the day. The averaging minimize statistical variability of the altimeter data.

Variation of daily mean of the significant wave height at the locations A, B and C from January 1 (day 1) to February 3 (34) in 1988 and 1989 are shown in Fig. 4. Solid lines indicate the value taken from Ocean Wave Charts and the symbols indicate those from the GEOSAT data. They are in good agreement qualitatively. But they also show several discrepancies, for example, on location B. There are two reasons for them. One is time lag between the time of measurement by the GEOSAT and the time of the chart compiled. Namely the chart is complied once a day whereas the GEOSAT measurement is made whenever the satellite is flying over the area for the day. Therefore there may be hours time difference at the largest. The other reason is that the vicinity area assigned for averaging the satellite data is too wide for the data to be statistically stationary. The region of 2° in latitude by 2° in longitude for averaging the satellite data is enough in reducing the spatial difference according to Carter[11]. The results here confirm his statement in general but it also shows that there is still room for improvement.

4.3. Coastal Effects

In coastal region, the land may cause unwanted influences on the irradiated pulse when included in the footprint of the pulse and may become source of errors in the wave height estimation process. Thus the wave height data measured in the coastal effects are examined by comparing to sea truth data given by coastal buoy robots.

There are networks of wave robots equipped with the ultrasonic wave sensor in the coastal line of Japan deployed by the Japan Meteorological Agency (JMA). Three locations among them are selected for comparison, as shown in Fig. 5. The wave measurement by the robot is made every three hours at the each site. The daily trends of significant wave height for each site are shown in Fig. 6. The figure shows the variation of daily mean wave height from day 275 (October 1) to day 365 (December 31) in 1988. The coastal wave robot data are shown by the solid lines and GEOSAT data are shown by the symbols respectively. The wave height by the GEOSAT has been derived by averaging all the results obtained in a day inside 2° in latitude by 2° in longitude enclosing the wave robot location. The area was selected to exclude the coast. The GEOSAT data and the buoy data are in good agreement in most cases but they show differences in several cases. Typical example is the case of day 303 in Kashima as shown in the middle graph of the figure. The difference is considered due to the temporal difference because the robot shows closer value when the averaging is made for data with nearer time of GEOSAT measurement. The modified robot data of day 303 in Kashima is shown by a cross symbol in Fig. 6. It has been confirmed that the degree of the agreement is improved when correction is made in the same way for the rest of cases.

As the results of these comparisons, it may be said that the GEOSAT data have an acceptable reliability in the coastal area when care is taken to the temporal and spatial differences.

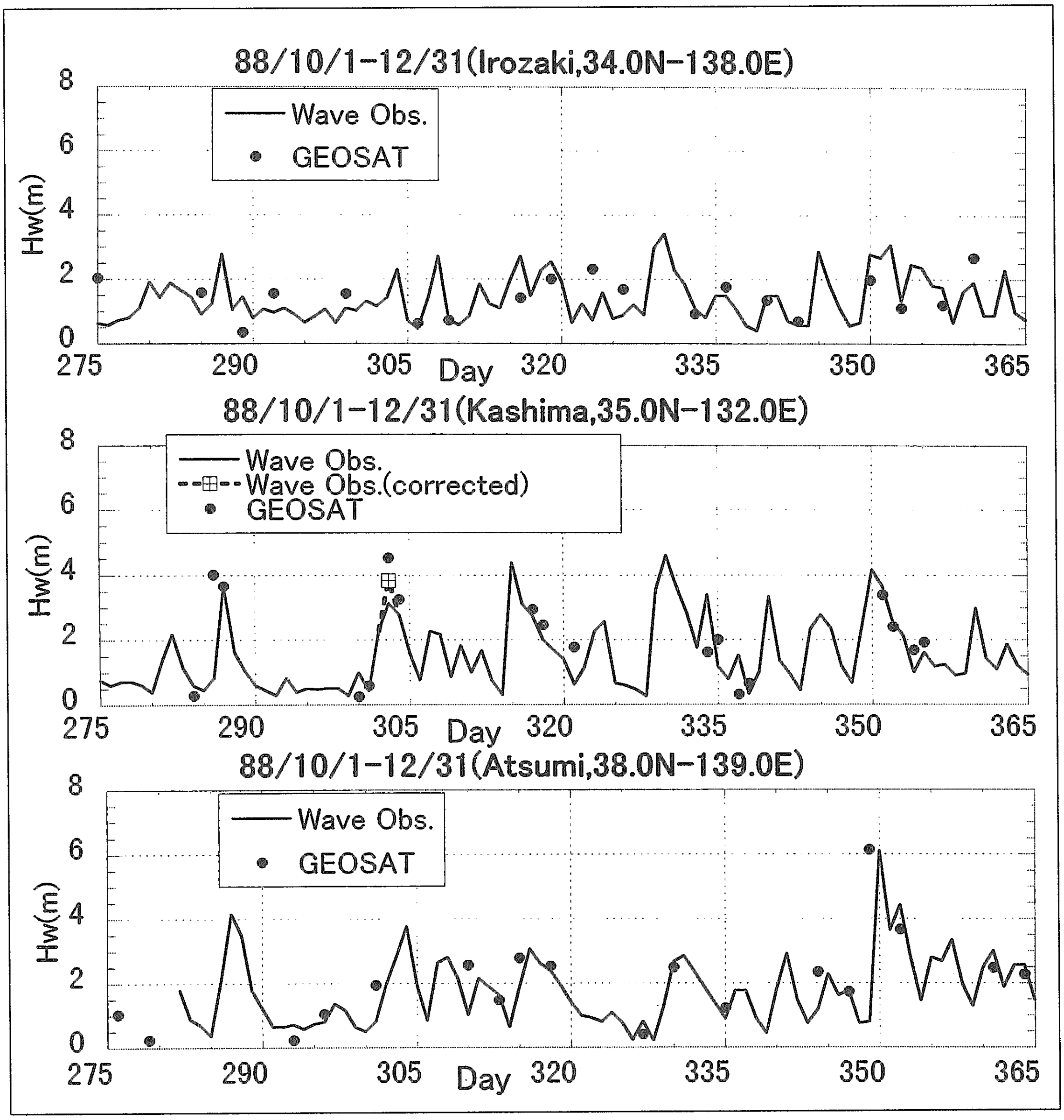

Fig. 6 Comparison of Daily Trends of Significant Wave Height by Wave Robots

4.4. Comparison with Offshore Buoy Measurement

There are many offshore buoys deployed in the oceans mainly by meteorological agencies. They are considered to be unbiased and the most reliable in gathering wave information since they measure waves by mechanical or electronic instruments. According to the result compared with individual buoy data[4,5], it is concluded that the GEOSAT data agree well with them. But these works covers only limited sea states and periods. For use of ship design, wave data covering all kinds of sea states and season is needed to compile statistically reliable information. Therefore, the wave height by the GEOSAT in various kinds of sea states was compared with those of buoys is made in the form of wave height distribution.

Fig. 7 shows location of the typical buoys deployed in the North Pacific Ocean by NOAA. Fig. 8 shows the wave height distribution derived from the GEOSAT and buoy measurement. The distributions shown here are annual, summer and winter distributions. The mean and the standard deviations of the wave height distributions are shown in Table 1. It is seen that the mean wave height by the GEOSAT for annual and summer agree well with those of buoy data although they are a little smaller than those of buoys. But the mean wave height in winter by the GEOSAT shows a larger difference from that of buoys.
It was noticed that in these cases the sea state was making appreciable variation to the time. It may be considered that temporal leaning of measurement of the GEOSAT follows this variation less successfully than the buoy does, which was measuring at the constant interval. This affected the statistical characteristics.

4.5 Verification of Wave Height Distribution

The comparison in the form of cumulative distribution of wave height is made with the other data sources in this section. The results obtained from the offshore buoys, wave hindcast, ship reports and Global Wave Statistics (GWS) are used[3,12]. Area near North America in the North Pacific Ocean is selected for comparison (latitude N40° ~N50° , longitude W130° ~W170 °). Fig. 9 shows cumulative distribution of the area for annual, summer and winter. The cumulative distributions obtained from the buoy data is a combined result by four buoys, i.e. Buoy No. 46001, 46002, 46003, 46004, 46005 and 46006 which are located in the area. The figure

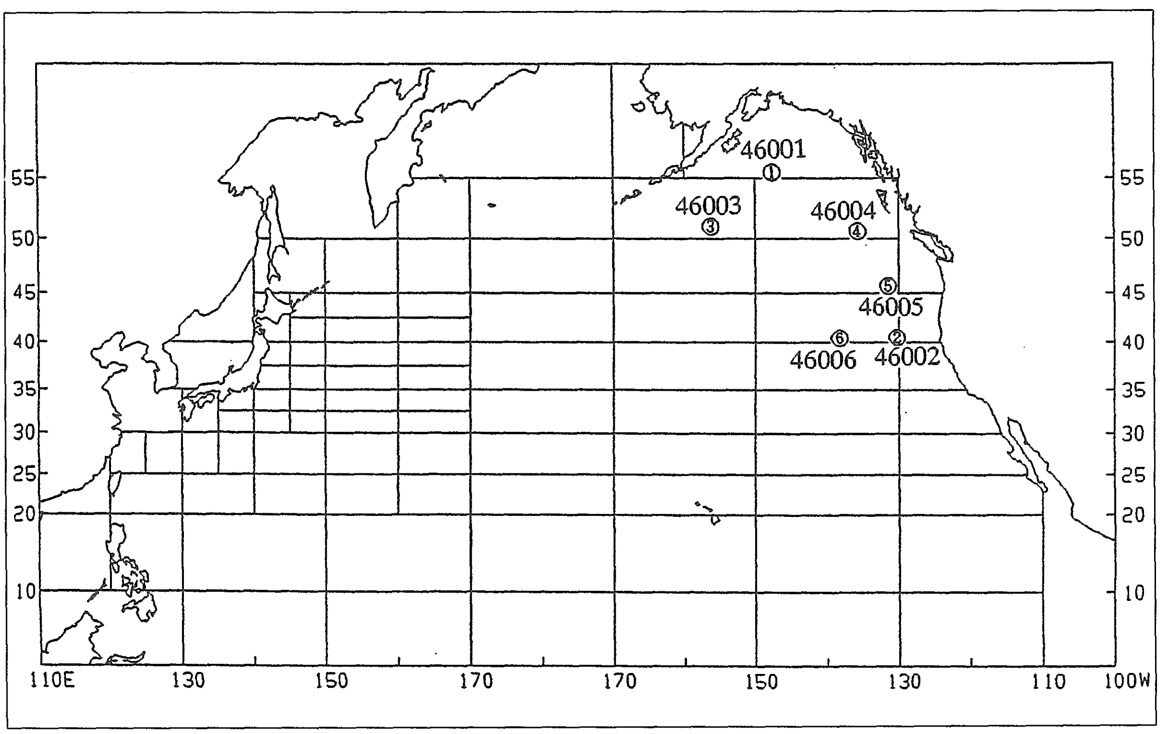

Fig. 7 Map of Buoy Location

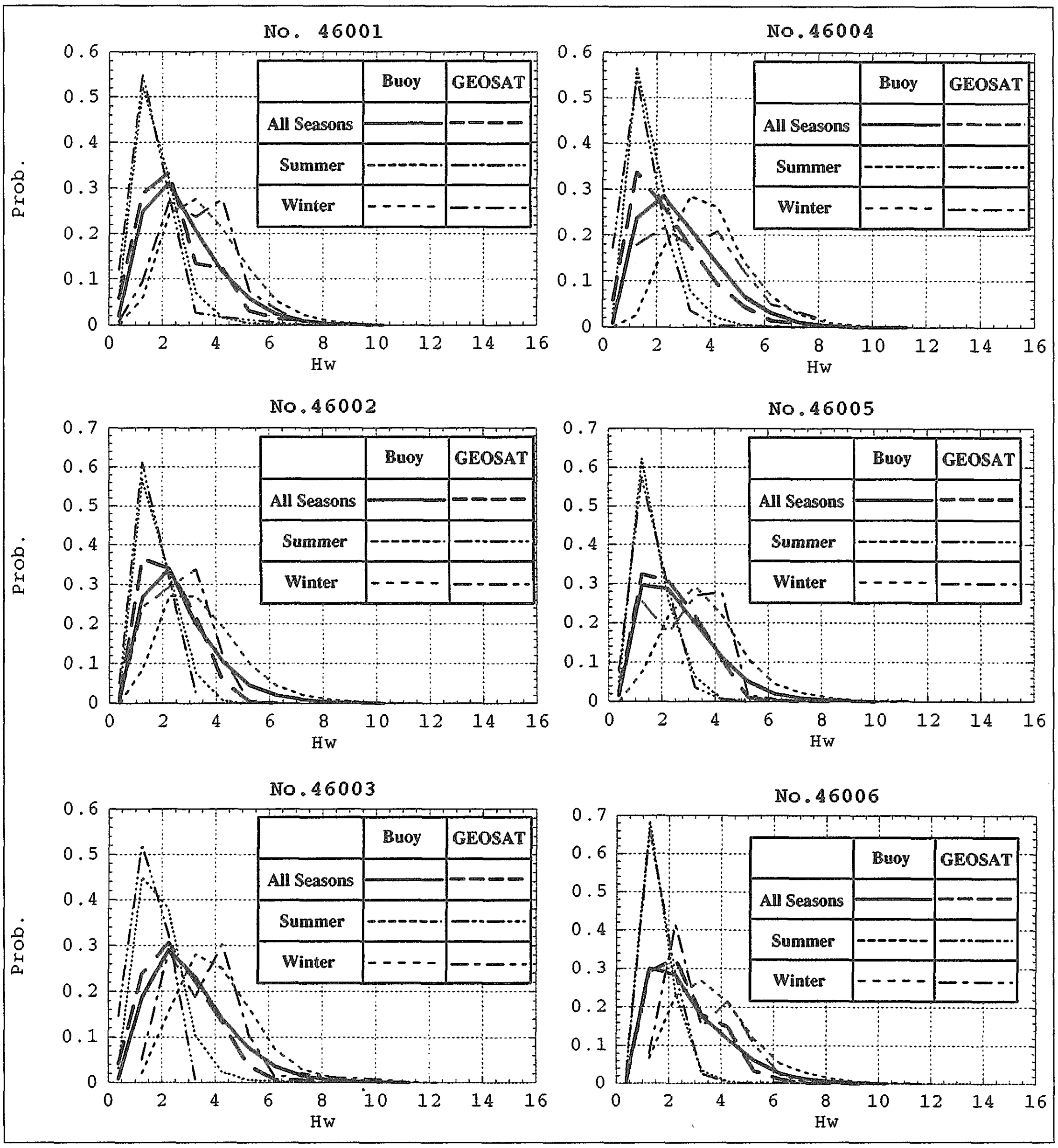

Fig. 8 Comparison of Probabilistic Distribution with Buoy

Table 1 Comparison of Mean Wave Height and Standard Deviation with Buoy Data (unit : m)

Average	Buoy No.	46001	46002	46003	46004	46005	46006
Buoy	annual	2.77	2.68	3.10	2.92	2.68	2.76
	summer	1.73	1.73	1.93	1.77	1.62	1.54
	winter	3.67	3.51	4.12	3.99	3.64	3.74
Geosat	annual	2.47	2.20	2.66	2.43	2.38	2.61
	summer	1.54	1.56	1.46	1.48	1.67	1.59
	winter	3.31	2.60	3.68	3.49	2.90	3.24
Standard deviation	Buoy No.	46001	46002	46003	46004	46005	46006
Buoy	annual	1.46	1.41	1.58	1.53	1.47	1.56
	summer	0.84	0.69	0.89	0.83	0.72	0.61
	winter	1.49	1.55	1.54	1.49	1.52	1.62
Geosat	annual	1.44	0.95	1.41	1.45	1.16	1.29
	summer	0.76	0.59	0.65	0.96	1.08	0.65
	winter	1.29	1.01	1.61	1.72	1.21	1.42

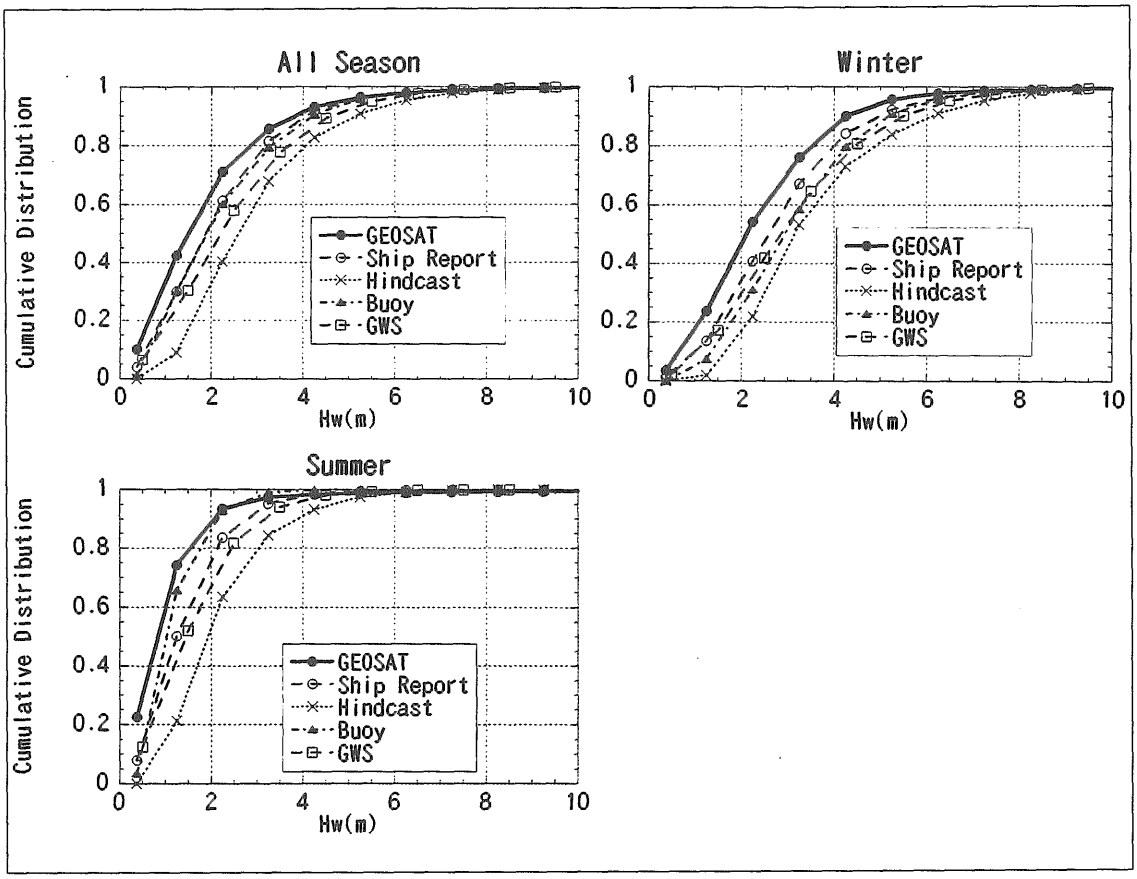

Fig. 9 Comparison of Cumulative Distribution with Various Data Sources

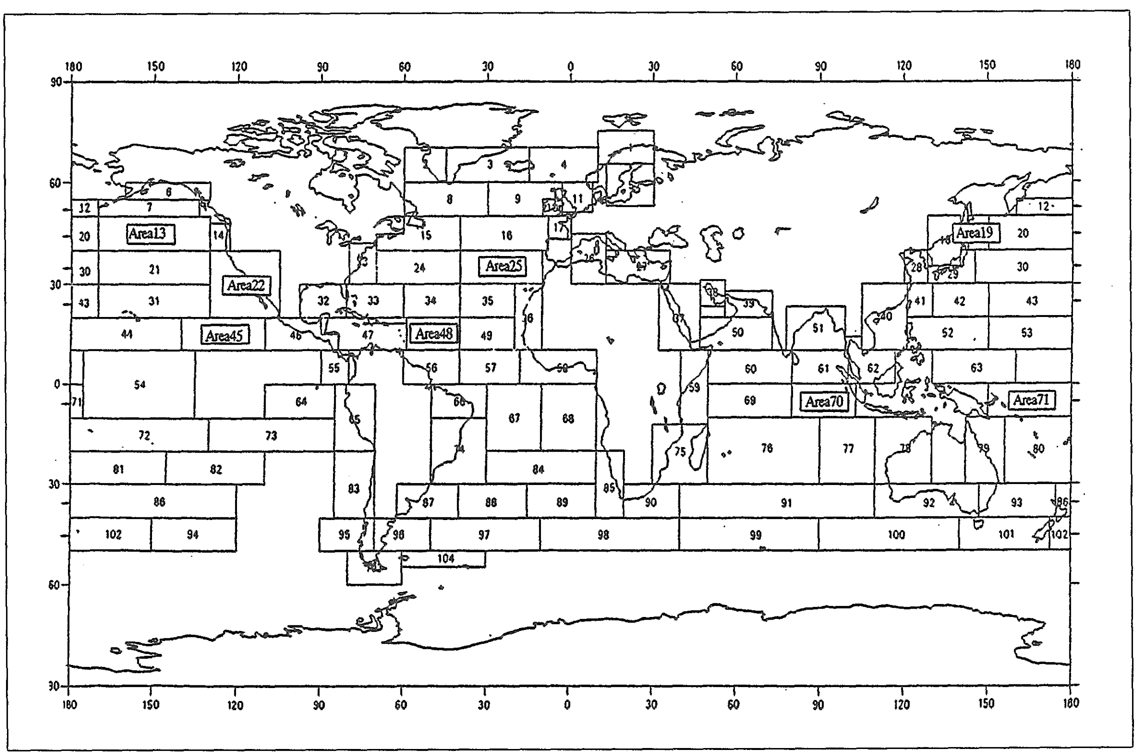

Fig. 10. Map of Sea Area used for Comparison with Global Wave Statistics

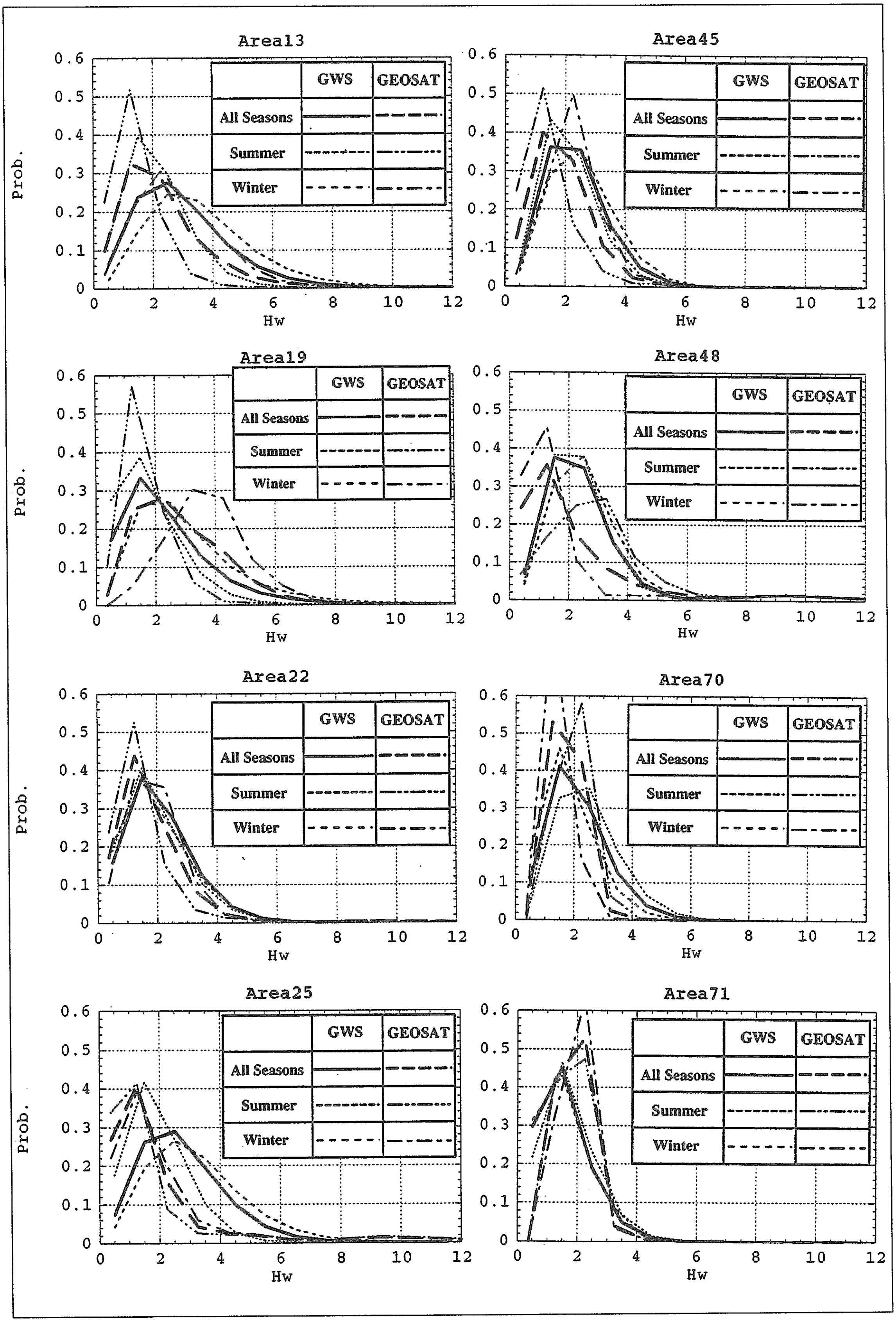

Fig. 11 Comparison of Probabilistic Distribution with Global Wave Statistics

Table 2 Comparison of means Wave Height and Standard Deviation with GWS

average	area13	area19	area22	area25	area45	area48	area70	area71
geosat(annual)	2.315	2.784	1.801	2.022	1.858	2.230	1.749	1.909
GWS(annual)	2.976	2.350	2.081	2.777	2.333	2.261	2.127	1.536
geosat(summer)	1.459	1.588	1.547	1.963	1.448	3.183	2.014	1.997
GWS(summer)	2.121	1.746	1.944	1.922	2.142	2.261	2.476	1.715
geosat(winter)	2.864	3.730	1.994	2.157	2.262	1.757	1.428	1.993
GWS(winter)	3.619	3.088	1.995	3.258	2.567	2.476	1.808	1.531
standard deviation	area13	area19	area22	area25	area45	area48	area70	area71
geosat(annual)	1.592	1.465	1.493	2.382	1.185	2.414	0.723	0.747
GWS(annual)	1.636	1.616	1.170	1.521	1.040	1.016	1.057	0.913
geosat(summer)	1.175	0.824	1.522	2.576	1.258	2.244	0.776	0.911
GWS(summer)	1.127	1.127	1.142	1.058	0.975	0.936	1.102	0.942
geosat(winter)	1.602	1.332	1.421	2.348	0.989	2.327	0.626	0.668
GWS(winter)	1.796	1.966	1.235	1.720	1.106	1.027	0.964	0.944

shows that there is wide variety of the wave height distribution according to the data sources. Among them, that of the GEOSAT gives a slightly higher probability than those of other sources but wave hindcast gives considerably lower value. It has been pointed out that the wave hindcast tends to give higher wave height data compared to the ship reports and the buoy data [13]. Nevertheless it is also true that there is no reasonable way at hand to resolve the differences among the distributions and that much efforts are necessary to this end.

5. Comparison with GWS

The characteristics of wave height measured by the altimeter have been discussed in the previous chapters. One of the advantages of wave measurement by satellite is that it can cover wide area with the same instrument in short time of period. In this chapter, the GEOSAT data are examined to see if they can describe wave condition worldwide by comparing with the GWS which is one of the most widely used statistical wave charts with widest coverage over the oceans.

The sea areas selected for comparison, as Fig. 10 shows, are the North Pacific Ocean, the Indian Ocean and the North Atlantic Ocean. Fig. 11 shows wave height distributions given byGEOSAT and GWS for the areas. Table 2 shows comparison of mean wave height and standard deviation of wave height distribution in the areas. Although the distributions shown in the figure look like varying without any tendency, it is seen from the table that the average values of the GEOSAT data show the same regional variation to the selected areas as is given by GWS in qualitative manner. It is true that the difference between the distribution forms by the GEOSAT data and GWS is large in most of the areas selected. It is so not only in the area where the effect of coastal and water vapor is considered appreciable but also in the open sea area where these effects are considered to play little role. The temporal and spatial effects of the GEOSAT data may explain parts of the difference. But it must be reminded at the same time that the wave height data of GWS is neither free from bias because they are estimated using wind fields instead of direct measurement of the wave. Therefore, it takes more researches to specify reasons of these differences only by this comparison.

6. Effect of the Difference of Wave Height Distribution to the Long Term Prediction

From the practical viewpoint, It is important how the wave height distribution affects wave loads in the long term life of ships. Thus long term prediction of ship response is carried out for checking the effects of difference of these wave height distribution using Fukuda's method[14]. The area selected for comparison is the area 13 in the North Pacific Ocean which is enclosed by 130° W and 170° W in longitude and by 40° N and 50° N in latitude. The comparison is made for two wave scatter diagrams. One is the scatter diagram taken for the area from GWS and the other is the scatter diagram made from the wave height distribution of the GEOSAT data in the area and the wave period distribution of GWS. The transfer function of the relative wave height at midship of a tanker used as the example model is shown in Fig. 12. Comparison of long term prediction is shown in Fig. 13. Difference of two estimated value at Q=10-8 is about 10%. This difference is not negligible for ship design purpose. It is said that the occurrence of maximum wave height, the tail of the distribution, has significant influence on extreme values derived by the long term prediction. The accumulation of satellite data is needed to utilize more reliable wave height distribution.

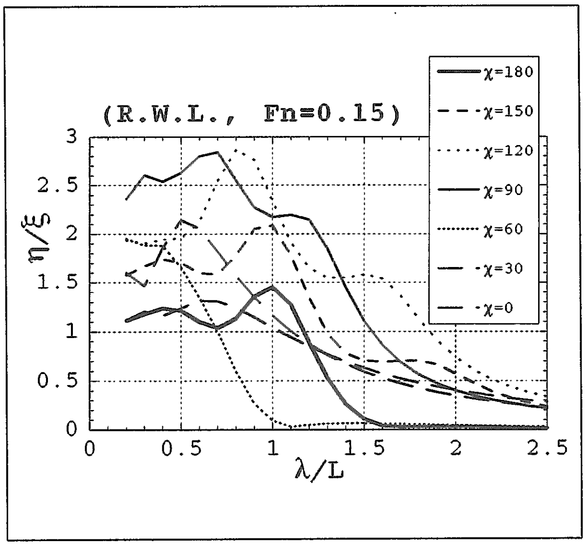

Fig. 12 Response Function of Relative Wave Height at Midship

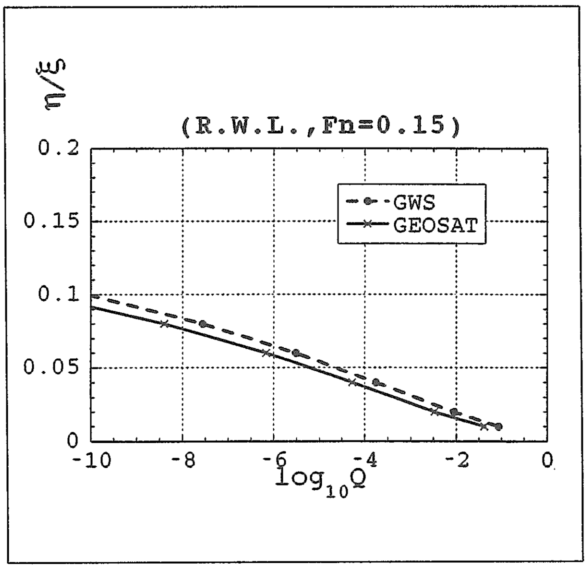

Fig. 13 Comparison of Long Term Estimation

7. Conclusions

The characteristics of the GEOSAT data are discussed by comparing with existing wave data. The following conclusions can be made.

(1) The altimeter data have acceptable reliability not only in the open sea but also in the coastal area.

(2) Statistical value of altimeter data is useful if care is taken to the temporal and spatial differences.

(3) The difference between altimeter data and GWS data is large. More data accumulation and study are needed to clarify the reasons of the differences in detail.

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