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Field Comparison of Different Types of Sea-Bed Installed Directional Wave Gauges

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1. INTRODUCTION

Methods for measuring wave height and direction varies throughout the world, depending on wave climate and local traditions. In Japan, bottom mounted systems have long been the standard for coastal areas with water depth less than 50m, and extensive studies in the 1980s and 1990s refined the systems to a level where the full wave directional spectrum could be measured. These systems take a multi-parameter approach to the problem by taking into account pressure fluctuation, orbital particle velocity, and surface elevation to generate a spectrum that covers the full range from 1 second wind waves to 1000 seconds tsunamis.

In this study, we introduce the results from three different bottom mounted systems installed in the same offshore area within 20m horizontal distance where wave conditions are almost constant, all using acoustic techniques in combination with pressure. The detail implementation is different in each system and the purpose is to analyze how the differences impact the characteristics of the observed wave spectra (Nagai.et.al., 2003b).

2. FIELD TEST

2.1 NOWPHAS and DWDM

NOWPHAS (Nationwide Ocean Wave information network for Ports and HArbourS) , the Japanese coastal wave observation and analysis system, has been operated since 1970 by the Ports and Harbors Bureau of the Ministry of Land, Infrastructure and Transport and its associated agencies including the Port and Airport Research Institute (PARI);e.g. (Nagai et al.1994;Nagai 2002). Fig. 1 shows network of the NOWPHAS in March 2003.

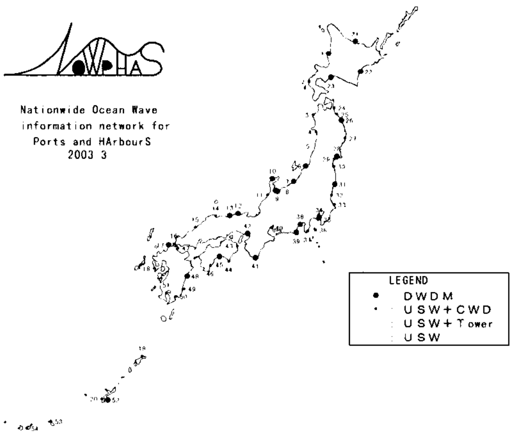

Fig.1. Location of the NOWPHAS Wave Stations.

At fifty-four stations coastal wave observation data are being obtained and sent to PARI by telecommunication line. Annual NOWPHAS coastal wave information is available from the PARI's

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Technical Notes; e.g.(Nagai et al.2003a). The Omaezaki-off field test site is the No.39 station shown in the Fig. 1, where routine wave observation is being conducted using the newly developed DWDM (Doppler-type Wave Directional Meter) at water depth 23m since 1997.

Development and nationwide installation of the DWDM was recently completed as shown in the Fig. 1. DWDM, a new type of wave gauge, was put into practical use in 1995 after long years' cooperation research among PARI, JAMSA (JApan Marine Surveyors Association), and Kaijo Co. DWDM enabled us to obtain directional spectrum information with one single seabed installed sensor by application of the Doppler Principle of the acoustic signal in the sea. DWDM made directional and infra-gravity wave observation possible with one single seabed installed sensor (Takayama et al.1994; Hashimoto et al.1996), without installing very expensive wave gauge array system (Nagai et al.1997).

Photo.1 shows the seabed installed DWDM sensor, and Fig. 2 shows the observation principle of DWDM. Ultrasonic signal output vertical direction takes the same rule to the traditional USW (Ultra-Sonic Wave gauge) sensor. In addition, three components of oblique directional signal output are for the directional wave measurement. By applying the Doppler effect each oblique directional water particle velocity in arbitrary layer can be obtained. Therefore, directional wave information of deep-sea condition is available by DWDM, while traditional combination system of USW and CWD (Current meter type Wave Directional meter) is to observe only in shallow water condition where seabed water particle horizontally moves.

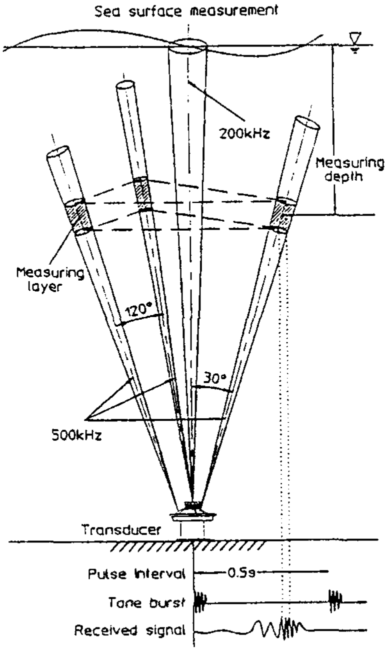

Fig.2. Observation Principle of the DWDM.

2.2.1 AWAC (Acoustic WAve and Current rofiler produced by Nortek Co.)

AWAC's directional wave observation principle is similar to the DWDM; e.g.(Allender,et.al.1989). AWAC measures four wave components, seabed water pressure fluctuation and three components of oblique current velocity shown in the Fig. 2. Photo.2 shows the seabed installed AWAC sensor during the field test term. AWAC sensor was installed on the circular horizontal table, which keeps the sensor in correct location without inclination. Electro power was supplied from a battery put in front of the sensor.

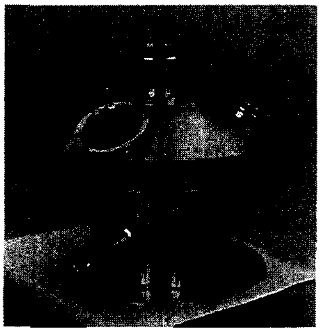

Photo.1. Seabed Installed Sensor of the DWDM.

Photo.2. Seabed Installed Sensor of the AWAC.

2.2.2 DL2(produced by Kyowa-Shoko Co.)

DL2 is the most popular self recording type wave gauge used not only in Japanese coast but also used for the Japanese international technical cooperation projects all over the world such as the Turkish Port Hydraulic Research Center Project; e.g.(Nagai 2000). DL2 measures four wave components, acoustic water surface elevation, two components of horizontal water particle velocity, and pressure fluctuation. Photo.3 shows the seabed installed DL2 sensor during the field test term.

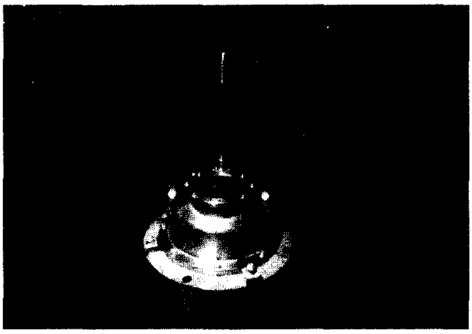

Photo.3. Seabed Installed Sensor of the DL2.

Table 1 shows observation items of each wave gauge used in the field test. Methods of wave data analysis applied in each wave gauge are shown in the Table 2. Significant wave heights and periods obtained by AWAC are based on frequency spectrum analysis, while ones by DWDM and DL2 are based on wave-to-wave zero-up-cross analysis.

3. Representative Wave Height, Period and Direction

3.1 Significant wave height

Fig. 3 shows time history of the observed significant wave heights obtained by each wave gauge during the test term. Fairly good agreement is observed, which certifies the high reliability of coastal wave observation by each sensor. Very high wave condition around September 10th caused by an attack of the Typhoon No.0115 is included during the field test term. The maximum observed significant wave height was almost the same value about 6m in each wave gauge.

Very slight difference can be seen in the Fig. 3 around September 22nd and October 8th among the three records. During these terms AWAC's results differ to the DWDM's and DL2's ones, when the observed wave period was relatively short as shown in the Fig. 4. Frequency banded wave expression can explain the differences.

Table 1. Observation Items of Each Wave Gauge

Wave Gauge	Observation Items
1)DWDM	Surface Motion(Acoustic) Seabed Pressure Fluctuation Three Components of Oblique Current Velocity
2)AWAC	Seabed Pressure Fluctuation Three Components of Oblique Current Velocity
3)DL2	Surface Motion (Acoustic) Seabed Pressure Fluctuation Two Components of Horizontal Seabed Current Velocity

Table 2. Data Processing Methods of Each Wave Gauge

Wave Gauge	Significant Wave Parameters	Directional Spectrum Estimation
1) DWDM	Zero-Up-Cross Method of the Sea Surface Motion	Modified EMLM Method (Hashimoto,etal.1996)
2) AWAC	Integrated Value of the Frequency Spectrum	Modified EMLM Method (Allender,et.al.1989)
3) DL2	Zero-Up-Cross Method of the Sea Surface Motion	EMEP method (Hashimoto,etal.1994)

3.2 Wave period and direction

Fig. 4 shows time history of the observed significant wave period, and Fig. 5 shows time history of the observed mean wave direction. Fairly good agreement is also observed in these figures, although there exist following exceptional differences among the three records in each figure. In the Fig. 4 observed significant wave period by AWAC was relatively shorter than the one by DWDM and DL2 around September 10th during the high wave condition due to the Typhoon. Mean wave direction obtained by AWAC extraordinary differs to one by DWDM and DL2 during very short term in September 10th and October 10th.

4.SPECTRUM ANALYSIS

4.1 Directional spectrum

Fig. 6 is an example of observed directional spectrum comparison at 0:00 on September 10th in high wave condition due to the Typhoon. Horizontal axis shows wave energy incident direction, and the vertical axis shows frequency. Double-peaks shaped spectrum was observed by each sensor, with low frequency (less than 0.1 Hz (longer than 10 seconds corresponding period)) component from SE direction, and high frequency (more than 0.15Hz (shorter than 6 seconds corresponding period)) component from E direction. The former main peak was almost the same among the three types of wave gauges. But the second high frequency peak of AWAC was a little different to the DWDM and DL2 in the direction and in the frequency, which shows difficulty of high frequency wave component analysis by AWAC based on the pressure observation.

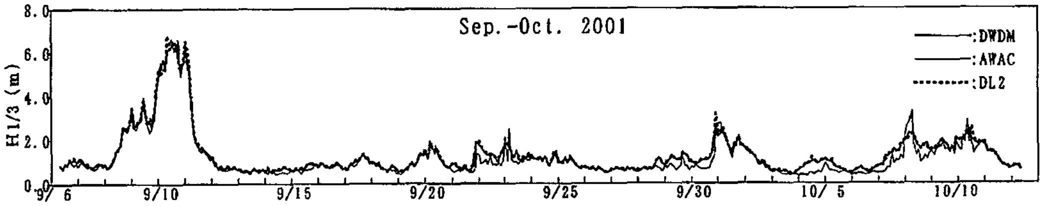

Fig.3. Time Series of the Observed Significant Wave Height.

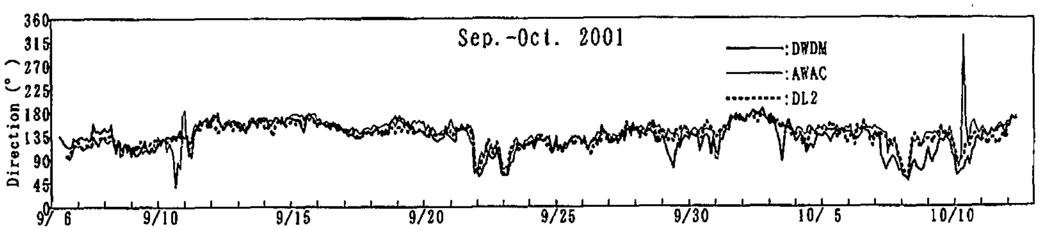

Fig.4. Time Series of the Observed Significant Wave Period.

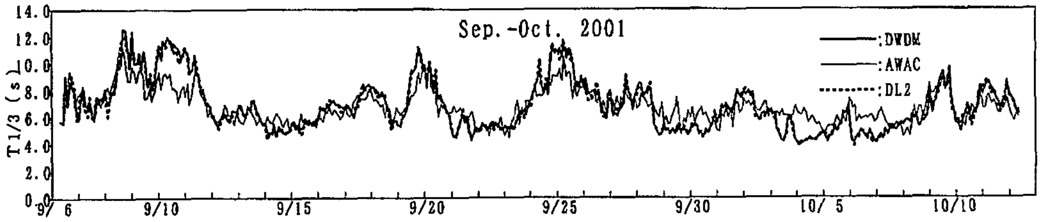

Fig.5. Time Series of the Observed Mean Wave Direction.

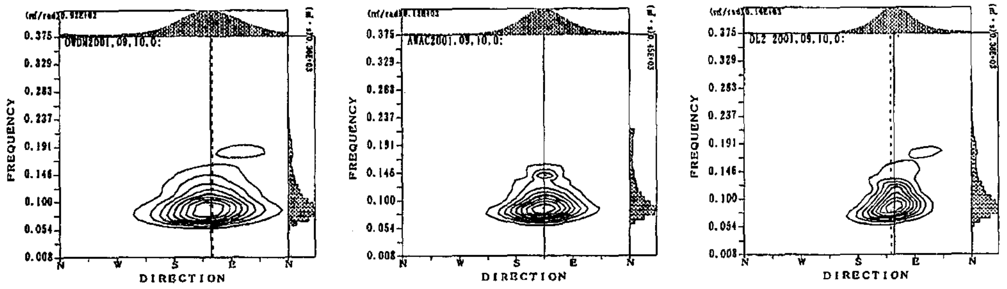

Fig.6. Example of the Directional Spectrum Comparison.

4.2 Frequency banded wave expression

In the Japanese NOWPHAS system,frequency banded wave expression was recently applied to understand directional wave characteristics, for directional spectrum such as the Fig. 6 has too much information for engineers to understand wave essential characteristics as time series or as wave climate; e.g.(Nagai et al.2000;Nagai et al.2002a;Nagai et al.2002b). The concept of the frequency banded wave power is defined in the following equations.

Significant wave height can be related with total wave power which is defined as the frequency integration of the power spectrum in the frequency range from 0Hz to infinite high frequency, as the equation (1) and (2) shows.

$$H_{1/3} = 4m_0^{1/2} \tag{1}$$

where

$$m_0 = \int S(f)df \qquad (0 < f < \infty) \tag{2}$$

Frequency banded wave height is defined by selecting the integration any frequency range as the equations (3) and (4), where and b2 is the corresponding spectrum frequency range between fl and f2.

$$H_b = 4m_b^{1/2} \tag{3}$$

$$m_0 = \int S(f)df = 0.5\sum a_i^2 \qquad (i = b_1, b_2) \tag{4}$$

Frequency spectrum can be obtained from the observation wave profile by applying FFT method, in the form of sum of scattered frequency number i, as the equation (5) shows, where NOWPHAS wave data analysis is based on 2048 water surface fluctuation data with sampling interval of 0.5s, as each one wave observation data sampling time is fixed as 20 minutes (1200s).

$$f_i = i/1024 \qquad i = 1,1024 \tag{5}$$

In the NOWPHAS system, obtained frequency spectrum is expressed after smoothing by taking average values of every eight numbers of frequency. So, the total smoothed frequency number is reduced to 128 from the original 1024 in the equation (5).

$$f_n = n/128 \qquad n = 1,128 \tag{6}$$

With the concept of the frequency banded wave height it is possible to reduce the number of parameters to explain the frequency spectrum. Table 3. shows frequency bands division and band names.

Table 3. Frequency Bands Division and Spectrum Number

Band Names	Obtained Spectra No.	Frequency (Hz)	Period (s)
f1	1 - 4	1/128 - 4/128	32.0 -128.0
f2	5 - 8	5/128 - 8/128	16.0 - 25.6
f3	9 - 12	9/128 - 12/128	10.7 - 14.2
f4	13 - 16	13/128 - 16/128	8.0 - 9.8
f5	17 - 30	17/128 - 30/128	4.3 - 7.5
f6	31 - 128	31/128 - 128/128	1.0 - 4.1

4.3 Results and Discussion

Fig. 7 is the result of the frequency banded spectrum analysis of the three different selected characteristics terms during the field test. Frequency banded wave height change is shown in the Fig. 7 in the four different frequency ranges f2 (corresponding wave period in between 15 and 30 seconds), f3 (corresponding wave period in between 10 and 15 seconds), f4 (corresponding wave period in between 8 and 10 seconds) and f5 (corresponding wave period in between 4.3 and 8 seconds), by three types of wave gauges respectively. Wave characteristics of following each term can be expressed as follows;

4.3.1 Wave condition from September 8 to 10

During these three days, significant wave heights gradually increased by reaching the maximum value on September 10th, due to the attack of the Typhoon No.0115. Low frequency banded wave heights of f2 and f3 indicated two peaks during the three days, the first lower peak was during the night from September 8th to 9th, and the second higher peak was around noon of September 10th. Nevertheless, in the higher frequency bands of f4 and f5 only the latter peak appeared without existing the former one.

This means that on September 8th and 9th, only swells existed in the sea area without high wind waves. And in such conditions, in each frequency band, time history of frequency banded wave heights obtained by three different wave gauges agreed quite well. On the other hand, on September 10th when the frequency banded wave height showed the peak value in each frequency band, AWAC's results slightly differs to the DWDM's and DL2's ones, especially in the high frequency band f5. The difference is supposed to be the wave height estimation principles shown in the Table 2. For AWAC wave data analysis is based on the seabed pressure fluctuation, precision of the surface wave estimation should decrease in high frequency band; e.g.(Hashimoto et al.1993), while DWDM and DL2 measure direct acoustic water surface movement.

In addition, during 10:00 and 18:00 on September 10th, AWAC's wave direction in every frequency band differs to DWDM's and DL2's one counter-clockwise. And at 22:00 on the same day, AWAC's wave direction in every frequency banded differs to DWDM's and DL2's one clockwise. This explains the extraordinary mean wave direction by AWAC on September 10th in the previously shown Fig. 5. Although the reason of this extraordinary difference was not yet clear with 100% reliability, we cannot deny a possibility that AWAC seabed sensor fixing was not sufficient and the sensor might move during the high wave condition term. The same extraordinary wave direction change was also observed on October 10th in the Fig. 5 Another field test with more stable AWAC seabed sensor fixing condition may be recommendable, if possible.

4.3.2 Wave condition from September 21 to 23

During these three days, frequency banded wave height was totally in very low level in lower frequency bands f2, f3 and f4, while in higher frequency band f5, two peak wave heights about 2m were observed at 0:00 on September 22 and at 0:00 on September 23. During this term, significant wave heights in the Fig. 3 and the f5 frequency banded wave heights in the Fig. 7 agreed quite well in the double peaked shape. AWAC's result slightly differs to the DWDM's and DL2's ones, possibly due to less precision of the surface wave estimation from the seabed pressure data.

4.3.3 Wave condition from October 7 to 9

During these three days, frequency banded wave height differed in each frequency band. Significant wave height peak in the morning on October 8th shown in the Fig. 3 corresponds to the higher frequency band f5, when no peak can be seen in the lower frequency bands. This means that this peak was due to short period wind waves from the NE direction. In the lower frequency bands f2 and f3, peak frequency banded wave height was observed from 0:00 to 8:00 on October 9th from the SSE direction, which can be supposed to a swell arrival from the southern direction. Therefore, typical double-peaked directional spectrum should appear during this term.

Frequency banded wave heights quite well agreed among the three types of sensors in lower frequency bands f2, f3 and f4. But in the higher frequency band f5, AWAC's result slightly differs to the DWDM's and DL2's ones.

5. CONCLUDING REMARKS

In this paper authors introduced field simultaneous observation by three types of seabed installed wave gauges, such comparison test was very rare due to difficulty of practice. Significant wave heights and periods obtained by each type of wave gauges showed good agreement during the test term, in both high wave conditions with significant wave heights bigger than 6m and low wave conditions with wave heights lower than 0.5m. Nevertheless, in the high frequency band, AWAC results slightly differs to the DWDM and DL2 results, for AWAC wave data analysis is based on the seabed pressure fluctuation, while DWDM and DL2 wave data analysis is based on direct acoustic water surface movement. In addition, two times during the test term, AWAC showed some extraordinary wave direction change with some unknown reason. Another field test with more stable AWAC seabed sensor fixing condition may be recommendable, if possible.

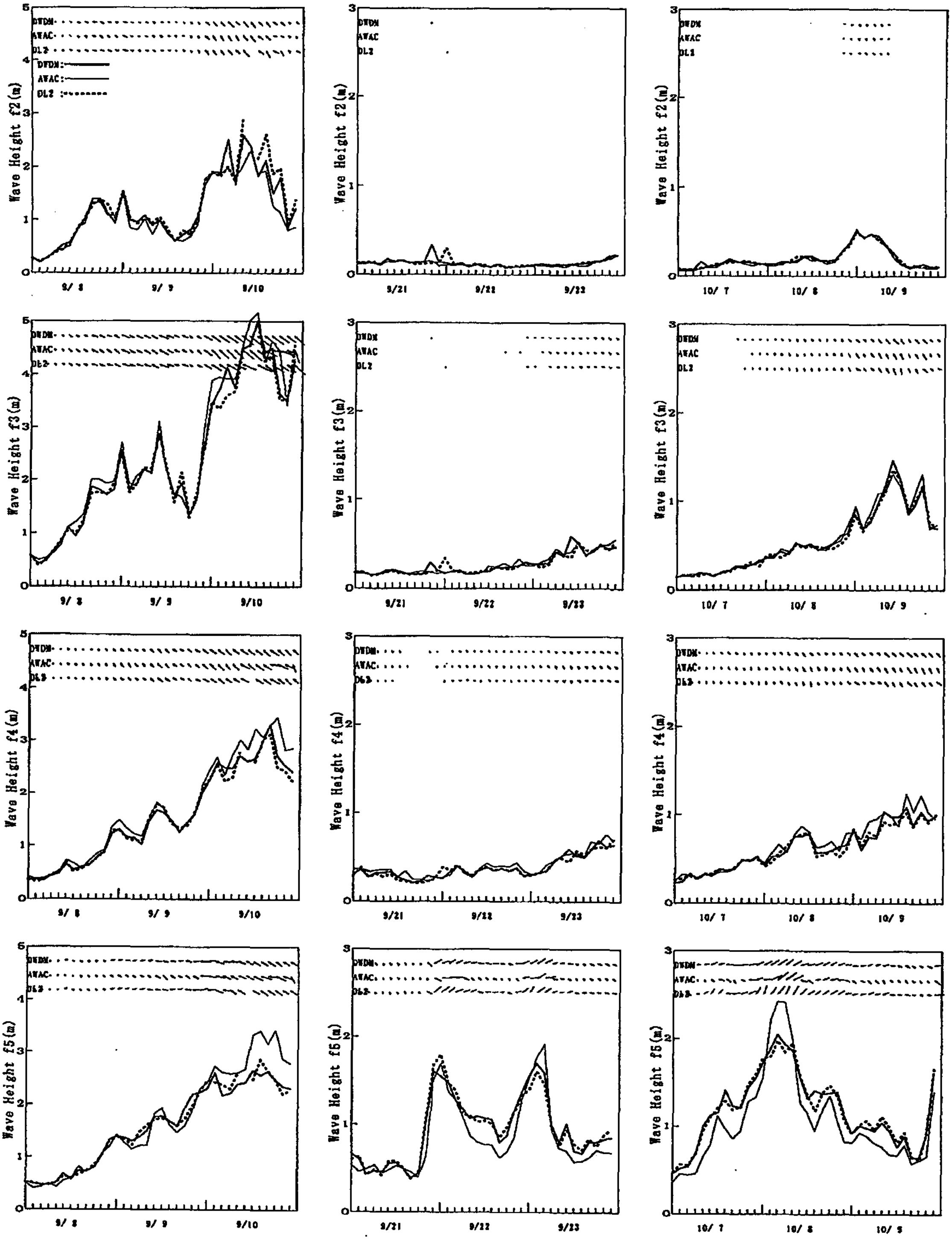

Fig.7. Time Series of the Frequency Banded Wave Height and Direction.

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