Buoy and Radar Observation Network around Taiwan

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Abstract –**The Coastal Ocean Monitoring Center (COMC) was assigned by the government offices to establish an coastal ocean monitoring network around Taiwan. It is composed by Data Buoys, Radars, Tide Stations and Coastal Weather Stations. All field stations are operational and have real time data transmission function. The purpose of this paper is to present the frame of this observation network and show observation results especially during past typhoons. This paper focuses on the introduction of Data Buoy and Radar systems. The hardware and analysis method of Data Buoy and Radar System are presented in this study.**

I. INTRODUCTION

Ocean is pregnant with cradle of origin of life, and human survival and development also depend on it. A lot of economic activities take place in the coastal area, for instance shipping trade, fish drag for cultivating, subsidiary island industry, etc. Engaged in regional development of coast must primarily face the dangerous environment and the external force of ocean, which include wind, wave, flow, temperature and salt, etc. They are the main factors for the engineering design and also can lead the project to be success or failure. Those factors are related to the environmental external forces and changed randomly all the time with the meteorological phenomena. They often cause ocean disaster problems which are dangerous to the people's lives and properties.

Besides the ocean disaster problems, the topics of the marine environment pollution have been paid attention too, most marine pollution sources could be spread and drifted with the influence of external forces , such as wind , wave , flowing. Recognizing marine environment could predict the movement characteristic of the pollution sources; reduce the impact of the marine environment pollution. Recent years, the topic continuing development forever in the ocean is respected gradually, a lot of international organizations are established in succession, work hard for promoting the marine protection of resources. We must know well about marine environment, and ensure the safety of maritime activity.

Because the features of ocean waves are extremely random, and the characters of ocean waves are effected by meteorological, hydrological, oceanographic and topographical factors directly or indirectly, they often can not be fully understood only by theoretical or numerical approaches. Field measurement must be performed to increase the knowledge of waves. The observing results of marine and meteorological have been applied in many different kinds of fields. For the purpose of ocean and coastal engineering, it needs wave data for determining the safety and the possible working days of the engineering. The ships need the marine and meteorological information for determining the most appropriate itinerary on the sea. For researching purpose, marine and meteorological data are often applied for understanding the characters of ocean waves.

Taiwan is located in edge of West Pacific Ocean and the south-east sea of Asia mainland. It is in the important position to against the abominable sea state cause by natural. Recently more than ten typhoons attack subtropical area of West Pacific Ocean and induce damaging wave, storm surge, huge wind and so on. These factors will induce serious damages on property and life. Therefore the field data of Taiwan is necessary for studying the typhoon's character and hazard warning.

Coastal Ocean Monitoring Center (COMC) of the National Cheng Kung University was established in response to the need for more meteorological and oceanographic information. We develop and operate the observation network that are primarily located in near-shore areas to provide real-time marine meteorology data around Taiwan. The purpose of this paper is to present the observation network. The observing resules of typhoon cases are also discussed in this paper for verifying the capability of this observation network.

II. INSTRUMENTS

2.1 Data Buoy

Data buoy is adapted in any depth of water, the design chart of data buoy is shown as Fig. 1. It acquires instant high quality oceanic environment data from monitored items which was selected according to flexible demand by long term execution automatically on the sea.The observation system with high scalability provides different monitoring items following by demand projects. The basic observation items of data buoy are shown as follows,

- The height, frequency and direction of wave.
- The spectrum of wave direction.
- The temperature of surface water
- Wind speed 、wind direction
- Air temperature
- Air pressure

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The system of data buoy is expandable, some selected items are also observed by data buoy. The selected observation items are shown as follows,

- A profile of flow velocity and flow direction
- Water Quality. (Do mg/L、pH、Turbidity、Chlorphy11、Nitrade-Nitrogen、Salinity、Silicates、Phosphate)。

The core of control system inside the buoy is an operational chip with low-consumed in power developed by COMC independently. It includes the modularized analog-digital convert, power supply, system control processor, data analysis and storage. It provides automatic observation, data analysis and data transmitting. The observation system equips with a variety of transmitting types in radio, GSM, GPRS and satellite to delivery those data to receiver stations on land to satisfy the demand about disaster warning system and forecasting. The system equips several monitoring items:

- Coastal and Oceanic engineering in deign, construction and operation
- Meteo-Oceanography observation in harbor navigation
- Monitoring in ocean pollution.
- Investigating in Fisheries Resource.
- Researching in Atmosphere and Ocean Sciences

Provide the concrete solution about ocean observation environments to all users. Concerning the wave monitoring by data buoy, both the inertia gyros and GPS systems are integrated to provide six degree of freedom the accelerations, velocities and inclinations on 3 axes. The recorded buoy movements with wave are used to yield wave directional spectrum via cross-spectrum analysis, describing wave energy's distribution characteristics on frequency and propagation direction. The directional spectra provide greater precision in building wave forecast model and the application of data assimilation technology. The wave direction spectrum is illustrated in Fig. 2.

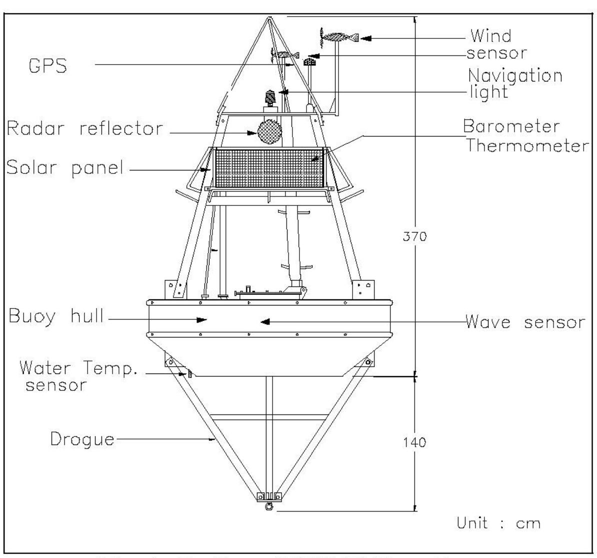

Fig. 1. Outline of COMC Data Buoy

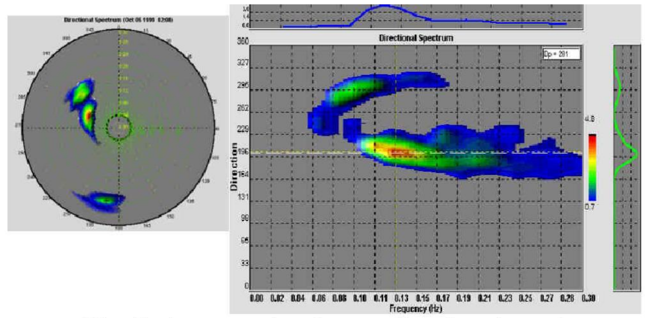

Fig. 2. An example of wave directional spectrum

2.2 Radar

While ordinary measurements of waves and currents by an in-situ instrument are used for a time variation of wave height/current at a point, remote sensing techniques gives information over a broader area. There are two methods of wave/current measurement used in remote sensing. They are the space borne sensors such as SAR and microwave altimeter, and the ground base radar such as X-band radar and HF Doppler radar. As the space borne sensors have properties of global measurements, large size footprint, and lower resolution of the order of a few ten meters to a few kilometers. On the other hand, ground based radar is suitable for monitoring the waves in near offshore or shallow zones, with the wave field of a few ten meters to a few hundred meters. For the data requirements of coastal engineering, coastal area protection and management and oceanic recreation, the interesting area is always within several kilometers to the land and high measurement resolution requirement. The ground based X-band radar is therefore the adapted wave and current measurement tool. The ground based X-band radar is used for measurement of reflectivity from the sea clutter at similar wavelengths to the sensors based on Bragg scattering. X-band radar using microwave frequency band (0.01-1 m), which can measure the Bragg scattering from the sea clutter with wavelengths of 0.5-50 cm. The X-band radar wave measurement system includes data acquisition and image process units. Nowadays, using X-band radar to measure wave and current has been commercialized, such as the WAve MOnitoring System (WaMoS), developed by GKSS research center in Germany (Ziemer and Dittmer, 1994) and the Marine Radar Wave Extractor (WAVEX), developed by the MIROS AS Company in Norway (Grønlie, 1995). In Taiwan, the Coastal Ocean Monitoring Center also self-constructed an X-band wave/current measurement system which is shown as Fig. 3 and Fig. 4.

The wave and current analysis of a X-band radar system is on the point view of that ocean waves should follow the wave dispersion relationship. The X-band radar image data set which use for wave and current measurement purpose are always 32 or 64 image sequences and has 3~5 km radius for each image. Normally, a sub-image which has size of 1 x 2 km is cut for wave and current analysis (Borge et al., 1999). This is the spatial representation of wave and current of such a certain sub-image area. Since remote sensing has capability of measurement in large domain, the spatial distribution of wave and current needs to be presented, especially at the coastal non-homogeneous area. Therefore, the purpose of this paper is to estimate the spatial distribution of wave and current fields from coastal marine radar image sequences. The extracted currents from radar images are compared with the in-situ current data obtained from GPS drifting buoy measurement.

The method for calculating ocean waves and surface currents from marine radar is based on the spatial and temporal structure analysis, the flow chart is shown as Fig. 5. Radar images are generated by the interaction of electromagnetic waves with the sea surface ripples at grazing incidence. Radar backscatter is presented as gray value. For wave and current analysis, a sub-image has to be extracted from the full radar image. This sub-image is then transformed into image wavenumber spectrum by transformation theory, such as 3D Fourier transform. Young et al. (1985) proposed that energy associated with ocean waves can be separated from the background noise energy by applying the wave dispersion relation as a filter. Ocean waves are dispersive under the certain relationship between wavenumber and frequency. During this approach, the surface current speed can be estimated by an iterative method. Gangeskar (2002) used the same idea and derived a cost function as (2.1) and (2.2) to estimate the current speed and direction.

$$J = \sum\sum\sum (\Delta\omega)^2 E(\omega, k_x, k_y) \tag{2.1}$$

$$\Delta\omega = \omega - \sqrt{g|\vec{k}|} - k_x U_x - k_y U_y \tag{2.2}$$

$E(\omega, k_x, k_y)$ is the radar image spectrum, U_x and U_y are the x and y components of $\bar{U}$ respectively. By minimize the cost function, the current can be estimated by (2.3).

$$\begin{bmatrix} U_x \\ U_y \end{bmatrix} = \begin{bmatrix} \sum E k_x^2 & \sum E k_x k_y \\ \sum E k_x k_y & \sum E k_y^2 \end{bmatrix}^{-1} \begin{bmatrix} \sum\left(\omega - \sqrt{g|\vec{k}|}\right) k_x \\ \sum\left(\omega - \sqrt{g|\vec{k}|}\right) k_y \end{bmatrix} \tag{2.3}$$

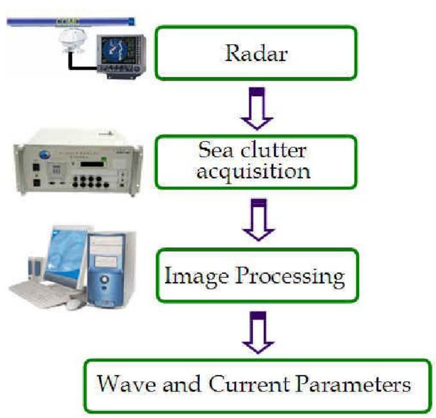

Fig. 3. The process for acquiring wave and current information from radar system

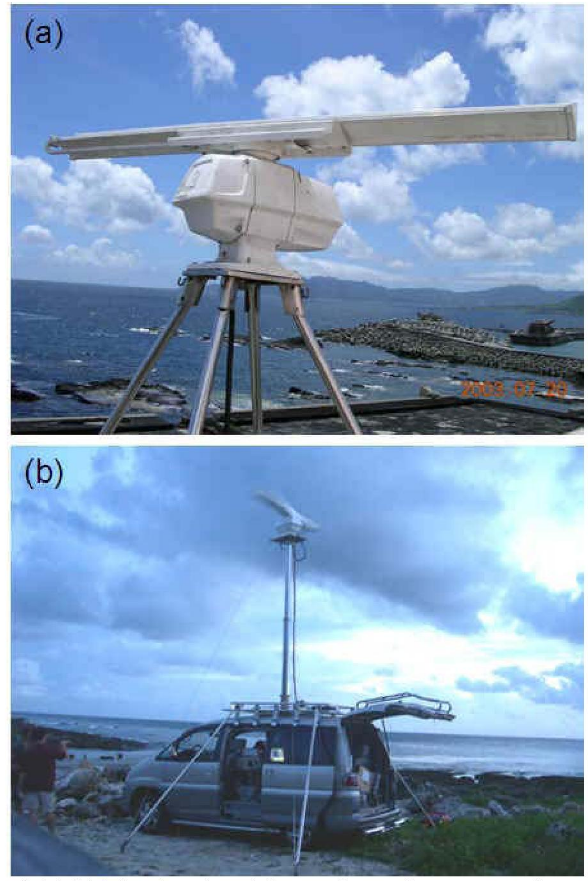

Fig. 4.(a)(b) Fixed and mobile marine radar wave and current measurement system

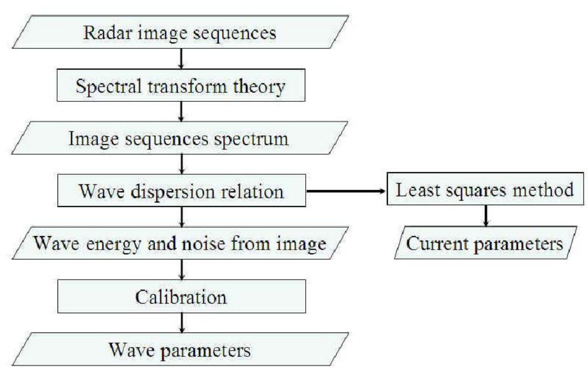

Fig. 5. The flow chart of radar images processing

III. OPERATIONAL NETWORK

3.1 Field stations

Up to now nine data buoys and two radar stations are operating around Taiwan by COMC which is commissioned by government units such as Central Weather Bureau for marine weather forecasting, Water Resources Agency for coastal hazards mitigation, Tourism Bureau for oceanic activities safety and so on. The basic information and locations of these stations are listed in Table 1 and Fig. 6. Among of them, the Siao Liouciou data buoy locates at the most depth about eighty meters. Next year a data buoy is designed to launched in the western Pacific with water depth ranging from 4,000 m to 5,000m.

Table 1 Basic information of monitoring stations

Category	Station	Location	Water depth (m)	Data from
Data buoy	Longdong	121°55'28"E, 25°05'54"N	32	1998/10
	Gueishandao	121°55'30"E, 24°50'57"N	22	2002/05
	Suao	121°52'33"E, 24°37'29"N	23	1999/09
	Hualien	121°37'52"E, 24°02'07"	36	1997/05
	Eluanbi	121°49'22"E, 21°54'08"N	40	2000/11
	Siao Liouciou	120°20' 21"E, 22°18'49"N	82	2003/09
	Dapeng Bay	120°26' 13"E, 22°25'02"N	26	2002/11
	Hsinchu	120°52'46"E, 24° 46'47"N	17	2000/01
	Kinmen	118°24'48"E, 24°22'48"N	25	2000/07
Radar station	Suao	121°50'0.4", 24°43'8.5"	-	2005/08
	Eluanbi	120°50'55'E, 21°54'18'N	-	2004/10

Fig. 6. Coastal ocean monitoring network around Taiwan

3.2 Real time data process and QC

Real-time meteo-oceanographic data are essential to the weather forecast, the fishery operation, the safety of nautical sports/leisure activities and the planning and the execution of the rescue operations. A multi-path data transmission system is developed by using latest telecommunication techniques including radio telemetry, satellite communication, mobile phone and internet to ensure the long-term reliable real-time data transmission as shown in Fig.7.

Once field data is sent back to the centre, data quality control (QC) should directly commence in order to promise the high quality data. There are two strategies to upholding high data quality and accuracy: in active undertaking, discover problems from daily monitor operation, sustain in the research and development of relevant instruments and data analytical calculation, improve system precision and stability, and in passive approach, build data quality control theory and methodology, regulate QC standards to ensure data accuracy. Data QC theory is predicated on a few standpoints, namely the monitored data must comply with instrument specification or physical property; changes of monitored values in time and space are gradual, and are correlated with other data items such as wind and wave. These three standpoints in quality control theory are known as data rationality, continuum and correlation.

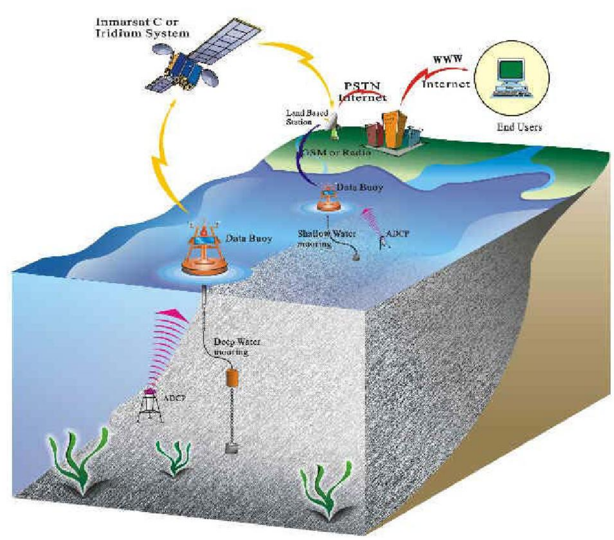

Fig. 7. The Multi-routes Real-Time Data Transmission

IV. RESULTS

4-1 Typhoon observations

After experienced a couple of typhoons, the data buoy systems have proven their reliability and importance. For example, typhoon Bills in August 2000 and typhoon Aere in August 2005 were fully recorded by the data buoys. A 12-

meter significant wave height was then measured at Suao station during these two typhoons, is illustrated in Table 2.

Table 2 The max significant wave height of data buoy stations in the monitoring network around Taiwan

Buoy Data Station	Typhoon name / Time	$(Hs)_{max}$
Huailien	Cass / 1997.08.29-08.30	11.94m
Hsinchi	Xangsane / 2000.10.30-11.01	6.40 m
Lungdong	Nocten / 2002.10.24-10.26	7.86 m
Suao	Talim / 2005.08.30-09.01	12.5 m
Eluuanbi	Dujuan / 2003.08.29-09.04	11.45m
Kinmen	Sanvu / 2005.08.11-08.13	4.84 m
Tapen Bay	Haitang / 2005.07.16-07.20	6.43 m
Turtle Mountain Island	Dujuan / 2003.08.29-09.04	7.31 m
Xiao Lioucliou	Sanvu / 2005.08.11-08.13	6.54 m

The radar images which are observing during Typhoon season are shown as Fig. 8. According to the wave and current analysis method introduced in previous chapter, a large enough sub-image which has 1 x 2 km size and covers data buoy is cut for analysis. Traditionally, the results are always compared with in-situ data buoy measurements to assess the accuracy. As shown in Fig. 9, the average error of wave data is around 9%. For some certain purpose, this error range is still acceptable.

To verify the current results from radar, three experiments of drifting GPS buoy were done in Apr, 2005. The GPS buoy is free drifting at the sea surface. By the received GPS position and time, the Lagrange sea surface current is known. The non-homogeneous property at the coastal ocean can also be identified from the results because of the unsteady current speed and direction. Simultaneous radar measurements are also done. The current result of close sub-image from radar measurement is used to compare with in-situ current from drifting GPS buoy, as shown in Table 3. It is found the average errors are 0.09 m/s on current speed and 5.9 degree on current direction.

Table 3 Comparison of current from radar with GPS buoy

Experiment No.	Radar sub-image	Current speed (radar/GPS buoy) unit: m/s	Current direction (radar/GPS buoy) unit: degree
Experiment #1	sub-image 1	0.46 / 0.54	320 / 324
	sub-image 2	0.42 / 0.48	315 / 311
	sub-image 3	0.40 / 0.42	295 / 292
	sub-image 4	0.36 / 0.34	280 / 278
Experiment #2	sub-image 1	0.35 / 0.60	310 / 323
	sub-image 2	0.35 / 0.63	312 / 314
Experiment #3	sub-image 1	0.29 / 0.30	310 / 322
	sub-image 2	0.35 / 0.35	310 / 317
average		0.09 m/s	5.9^{o}

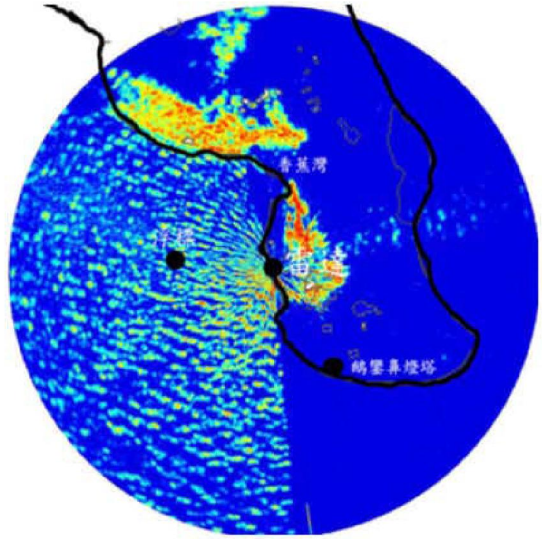

Fig. 8. Radar images with different sea states

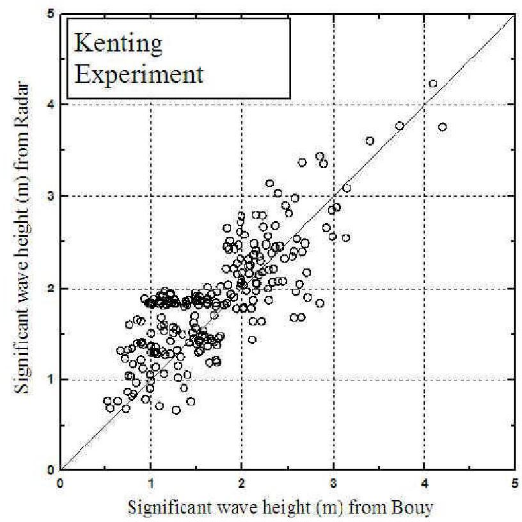

Fig. 9. Long-term comparative result of significant wave height between marine radar and in-situ data buoy

4-2 Model verification

Observation and remote sensing play important roles to realize the ocean environment. It is pity sometimes they are limited to the forbidding status of ocean and meteorology. Therefore, the in-suit data is difficult to obtain. Furthermore the monitoring station network is not probably to coverage the whole interesting area. For this reason, the method to utilize numerical simulation can plan to mend the deficiency in this respect. The numerical simulation has comprehensive, instant and predictable characteristics. It can also achieve data assimilation by combining with observation data. In the way it can improve the accuracy and practicability of the wave model even more. The wave models adopted here are NWWIII (NOAA Wave Watch III) and SWAN (Simulation Wave Nearshore) wave model. NWWIII model is used for the estimation of open ocean condition and SWAN model is applied to carry out the nearshore estimation. The technique of data assimilation achieved here is optimal interpolation method which describes as below.

The performance of data assimilation is mostly developed with least square method. The aspect of this method is to minimize the deviation between observed and numerical value. In early days, there were several methods to achieve data assimilation. One of the methods called subjective analysis was to interpolate the observed value directly to the computational grid point. This is the way to initialize the initial wave condition. Later, in order to overcome the disparity in space distribution of observed value, Panofsky (1949) used the curve fitting method to interpolate the observed value to the grid point. This kind of method is called objective analysis. However in the area where it is sort of observed data, to utilize the curve fitting method will cause the discontinous question. So in 1955 scholars, such as Bergthorsson, etc., included the idea of the background field into the objective analysis. Moreover, Cressman in 1959 utilized the error difference between observed and numerical values to be the criterion of convergence. This method was called successive correction method. In addition, Gandin in 1963 further utilized the concept of least square method. He calculated the minimization of variance of observed and numerical value, and superposed the results linearly through the weight ratio. The factors of weight ratio include the observed value, the error of computation results and the correlation function. This method is called optimal Interpolation method the mostly used in the 80's. Now it becomes the operational assimilation method gradually.

It is with the concept of least square approach to perform the optimal Interpolation method. It utilizes minimum variance estimation method to obtain the linear analysis form, which expressed as following:

$$H_i^A = H_i^P + \sum_{j=1}^{Nobs} W_{ij}(H_j^O - H_j^P)$$

Here N_{obs} is the number of observation station. H^O is the observed wave height, and H^P is the first guess value of wave height for numerical computation. H^A is the analysis value after data assimilation achieved. W_{ij} is the optimal weight ratio for each station. The symbol i expresses the grid point and j expresses the station number. The performance of data assimilation are achieved as shown as Fig. 10 and Fig. 11.

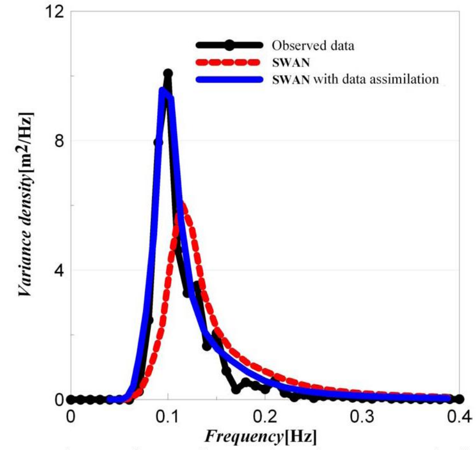

Fig. 10. Comparison of one dimensional spectrum before and after achieved data assimilation

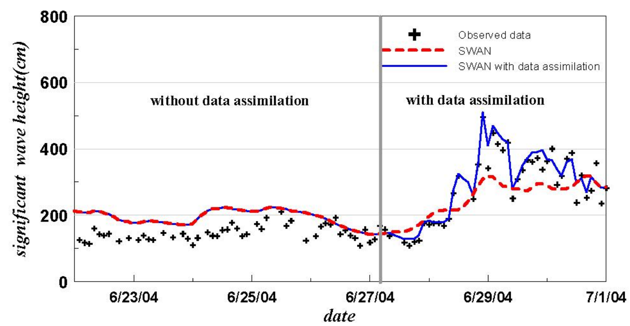

Fig. 11. Comparison of wave height time series before and after achieved data assimilation.(The right hand side of grey line is SWAN achieved with data assimilation as shown in the blue line and the left hand side is SWAN run without data assimilated.)

V. SUMMARY

An operational coastal ocean monitoring network around Taiwan which composed of Data Buoy, Radar and other instruments was setup. Real-time data and sea-state image sequences are observed for coastal hazard mitigation. The design, manufacture, deploy and maintance are executed by COMC of National Cheng Kung University at Taiwan. The Buoy and Radar were tested by severe typhoons and collected significant data and images. The max. significant wave height recorded is up to 12m. From the radar image sequences, the spatial wave and current fields are extrcted. They are verified as correct measurements. All the data from the netowrk are real-time transmitted to government office and opened for all international researchers.

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