Establishment and data analysis of sea-state monitoring system along Taiwan coast

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Abstract: Taiwan Island is at the joint of Eurasian Continent and Pacific Plate, under threatening of typhoons and northeasterly strong winds. Consequently, enormous human lives and properties are lost every year. It is necessary to develop a coastal sea-state monitoring system. This paper introduces the coastal sea-state monitoring system (CSMS) along Taiwan coast. The COMC (Coastal Ocean Monitoring Center in National Cheng Kung University) built the Taiwan coastal sea-state monitoring system, which is modern and self-sufficient, consisting of data buoy, pile station, tide station, coastal weather station, and radar monitoring station. To assure the data quality, Data Quality Check Procedure (DQCP) and Standard Operation Procedure (SOP) were developed by the COMC. In further data analysis and data implementation of the observation, this paper also introduces some new methods that make the data with much more promising uses. These methods include empirical mode decomposition (EMD) used for the analysis of storm surge water level, wavelet transform used for the analysis of wave characteristics from nearshore X-band radar images, and data assimilation technique applied in wave nowcast operation. The coastal sea-state monitoring system has a great potential in providing ocean information to serve the society.

Keywords: coastal sea-state monitoring, moored buoy, wave monitoring of radar technique, EMD, wavelet transform, data assimilation

There is complicated and diverse marine environment around Taiwan Island, which is at the joint of Eurasian Continent and Pacific Plate. It is dominated by subtropical island climate, frequently suffering from deluge due to typhoon or tropical depression during

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summer and fall and it's threatened by long wave erosion resulting from northeast monsoon in winter. At the abnormal sea statues, such as non-typhoon or tropical depression, there is also severe disaster in its coastal region.

For the purpose of sustainable development and utilization of marine resources, it is no doubt for Taiwan to develop effective protections from coastal disasters and a comprehensive coastal warning system. Since the 1990s, Taiwan initiated to construct hydrological observation system aiming at raising the overall level of coastal observation technology, improve the quality of coastal hydrological data, and set up primary coastal disaster warning system. Coastal Ocean Monitoring Center (COMC) of National Cheng Kung University in Taiwan undertook the project. COMC, established in 1998, is an affiliated research center of National Cheng Kung University, hoping to research observation technology in the marine environment, develop key technologies of relative equipment, improve domestic marine and meteorological technology, cultivate marine research personnel, and set up operational observation systems [1-5].

In this paper, it will illustrate the coastal sea-state monitoring system (CSMS) in Taiwan, giving much more details in data buoy, pile station and radar monitoring station. Further, the data application methods in CSMS are reviewed, including empirical mode decomposition (EMD) used for the analysis of storm surge water level, wavelet transform used for the analysis of wave characteristics from nearshore X-band radar images, and data assimilation technique applied in wave nowcast operation. Here, an operational typhoon wave nowcasting model and a coastal disaster warning system will also be included as well.

1 Coastal sea-state monitoring system

1.1 Monitoring network

Introducing the observation technology from NOAA, COMC is aiming to establish strict DQCP of air-sea observation technology applied in Taiwan coasts to improve the accuracy of the observation data. It has assembled R & D, manufacturing, distribution, data quality management, maintenance, calibration and service together into an integrative operational system, which passed through ISO 9001 certification. The modern and automatable observation system is self-control and independent, holding no limitation of foreign manufacturers. Coastal sea-state monitoring network (CSMS) consists of observation pile, data buoy, water lever gauge, coastal automatic weather observation system, and remote sensing systems. In all, CSMS owns 43 monitoring stations, including 14 data buoy stations, 11 tidal stations, 14 weather stations, 2 observation piles and 2

X-band radar stations[4] (Fig. 1).

(this picture is quoted from http://www.comc.ncku.edu.tw/Englishsite/station/Monitor.htm)

Fig. 1 Distribution of China Taiwan coastal meteor-oceanographic monitoring stations

1.2 Data buoy

Data buoy is a monitoring station that is working in marine the environment, with reference to the methods of observation from NOAA. It is based on hydrodynamic environmental characteristics around Taiwan to design and refine the domestic CSMS (Patent No. 087358). Data buoy has the dish shape, with diameter 2.5 m, height 4.95 m, weighs about 1 300 kg and it is equipped with three solar batteries and six storage batteries, which build up the power supply systems for energy self-sufficiency. Allowing for the security of observe operations and vessels at sea, data buoy has also set warning lights and navigational radar transmitter. Meanwhile, because of the advantage that data buoy is equipped with anchor chain that connects with the bottom anchor fixed on the seabed, it is able to float freely within a certain range for a variety of oceanographic observation operations. Data buoy is also a multifunctional work platform arranged on any depth in the ocean, ranging from a few meters to as deep as several thousand meters for a variety of measuring instruments that can be installed for long-term observations on the sea. The data obtained will be sent to the monitoring center via two real-time transmission systems, radio and satellite and its quality will be ensured through DQCP.

Data buoy owns the capability of measuring wave condition, wind (including wind speed, wind direction, and gust), pressure, lapse rate, water temperature and so on. It obtains each wave parameter by means of detecting acceleration of water particle in various directions. The sampling operation is conducted every 1 h, with sampling frequency 2 Hz. When it comes to abnormal sea state, such as typhoon and hurricane, there will be an adjustment in frequency. It is also feasible to add the measurements for velocity, water quality, precipitation and other kinds of observation instruments because of the merit of modular design in CSMS. In addition to monitor oceanographic data, data buoy obtains latitude and longitude information through Global Positioning System (GPS). COMC employs 13 coastal data buoys and 1 deep ocean data buoy.

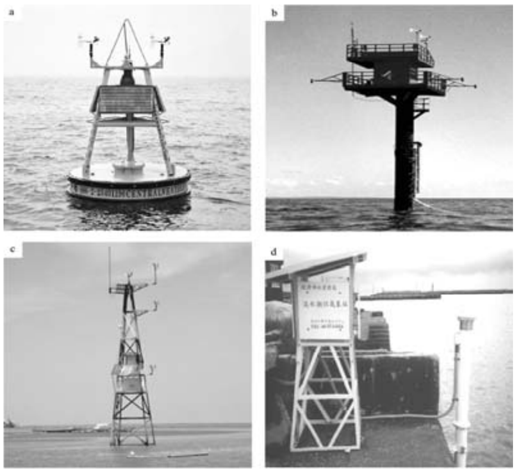

Fig. 2 Four kinds of coastal meteor-oceanographic monitoring systems, including a. Data buoy b. Pile station c. Weather station d. Tidal station

1.3 Pile station

Pile station is a fixed observation platform in marine environment, with independent power supply systems, communication transmission equipments and data collection systems. In general, the observation platform is about 10 m above the mean sea level to conduct the ocean and atmosphere observations. It shares the similar function with Data buoy, and yet with only one difference that the moored pile is feasible in any depth whereas the pile station is set on a flat and sandy seabed in nearshore areas only, when taking into consideration the cost of construction.

One chief negative factor that influences the observation results is the comparatively large tidal range in Taiwan Straight and for that, the sampling time which is 10 minutes fails to be in the range in which time factor can be neglected. Fig. 3(a) shows wave observation sequence at the presence of tide, with sampling time of 10 minutes, the sampling frequency of 2 Hz, and a total of 1 200 points. Fig. 3(b) shows the results affected by the system or the external factor. Therefore, further improvements are desirable [4].

1.4 Radar monitoring station

Using X-band radar to monitor sea state is one of the sea-state monitoring methods developed in Taiwan in recent years (Fig. 4 and Fig. 5). The system employs the 20MHz high-speed sampler to capture radar signals that will be digitized and then analyzed, forming wave field image involving spatial resolution 7.5 m / pixel by the computer. From image processing and wave theory, the sea-state spectrum parameters can be obtained and transformed into wave parameters in the next step, matching with data transmission systems to control center to process DQCP [2, 4, 7].

The feasible observation range for the radar system is about 3.5 km - 5 km radius of a circular area. Based on the radar image analysis, both the time series of wave parameter and surface velocity value and direction will be acquired. The system will lose its accuracy in extreme weather such as heavy rain and thus further improvements are desirable (Fig. 6).

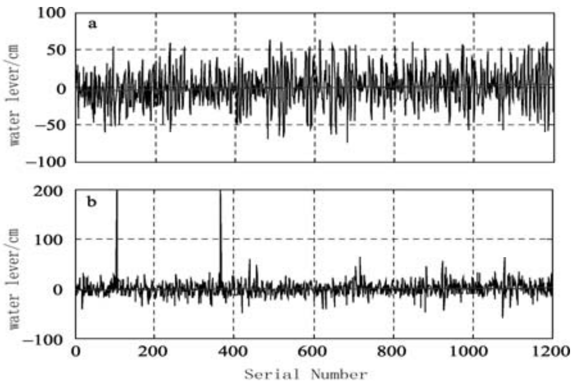

Fig. 3 Observed noise by pile station

Fig. 4 Mobile coastal radar monitoring system

Fig. 5 Fixed coastal radar monitoring system

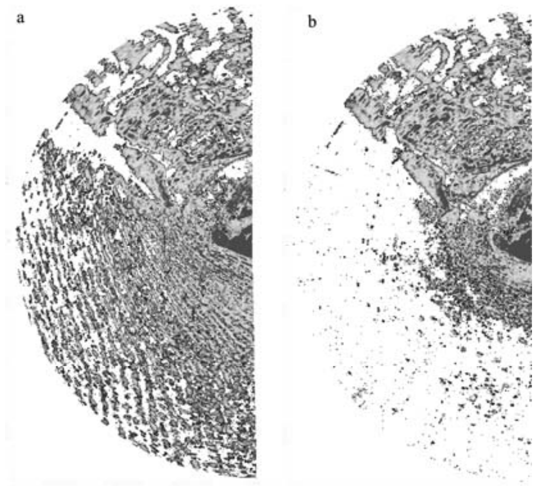

Fig. 6 Radar images

(a) with heavy rain interference, (b) without heavy rain interference

2 Data quality check procedure and standard operation procedure

In the observation process, because of noise of the sensor, encoding and decoding during transmission data, data monitoring stations will receive incorrect data inevitably. Moreover, extreme data which is measured in the harsh climatic conditions and very similar with incorrect data in features are very valuable, scarce and should be cherished. Therefore, it is the key issue to separate the incorrect data and remove it. There are several rules to follow. To begin with, data quality check procedure (DQCP) is to ensure that observational data must be in line with the equipment specifications or physical characteristics. It is well accepted that the temporal and spatial variation of observed data is gradual. According to that principle, if the variation overtaking its common limitation or data from adjacent spatial measuring points can not be explained through physical points of view, the data can be judged as incorrect data. Furthermore, there are relationships between different items. For instance, by virtue of similar relevance of temperature and time, various forms of regression analysis can be conducted.

Three points mentioned above in DQCP are known as the rationality, continuity and relevance of the data, respectively. To a large extent, all data quality is analyzed and discriminated by those who possess highly experienced skill. The operation process chart is shown in Fig. 7.

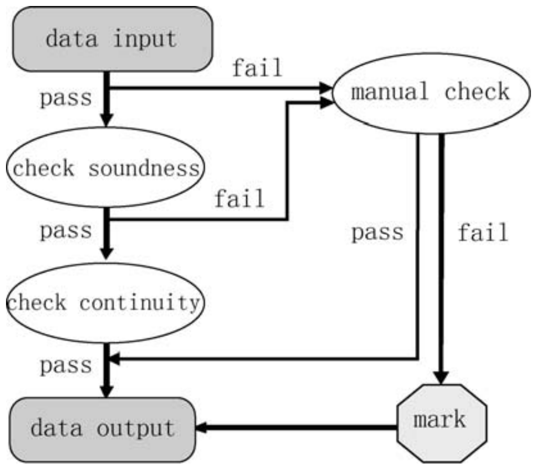

Fig. 7 Data quality check procedure

To ensure the ultimate quality, observing process must comply with the standard operation procedure (SOP). Setting up SOP can reduce manual negligence and avoid technology loss caused by the floating of personnel. Since the entire observed process was guaranteed by the International Organization for Standardization (ISO) 9001 in 1990, the international standard operating procedures have been implemented [8].

3 Methods of data analysis

3.1 EMD analysis of storm surge

Effective analysis of observational data is an essential part of that system. During Typhoon period, storm tide level change plays a key role in disaster warning, and during that time, observation data includes both astronomical and meteorological tide. The storm surge lever which people focus on is obtained through harmonic analysis, filtering out the astronomical tide. One month is the shortest monitoring time period and in general, under that condition, the astronomical tide effect can be almost eliminated. However, there are still periodic water level signals in the storm surge level obtained. Through the application of other new data analysis methods, Empirical Mode Decomposition method (EMD), these problems mentioned above can be avoided.

EMD is a new data processing method, put forth by Huang [9]. EMD is capable of picking out the original signal in different frequency ranges of energy components directly, and expressing the original signal in terms of a batch of Intrinsic Mode Function (IMF).

The analysis data was from the Shuitou tide station in China Taiwan, and time was from September 23 to October 2, 2008, among which Typhoon Jangmi was from September 26 to 29. Harmonic analysis is shown in Fig. 8, and EMD analysis is in Fig. 9 and Fig.10. The comparison of two results indicates that periodic signal that is not influenced by typhoon still exists in harmonic analysis while that does not occur in EMD, only reflecting the storm surge water level. This finding allows us to place emphasis on the soundness and accuracy in analyzing the storm surge water lever. In addition, due to the need of comparatively short length of observation time period, this EMD method is more applicable robustly. EMD analyzes observational data from a new perspective, in the field of unsteady signal analysis.

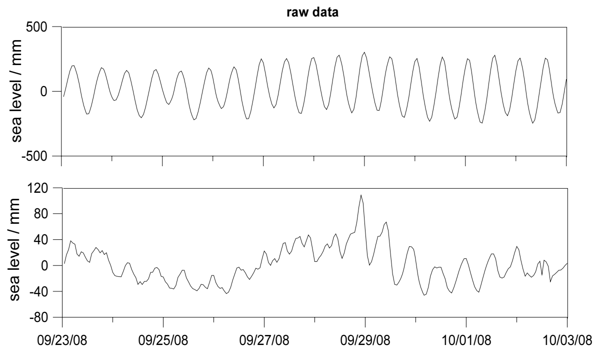

Fig. 8 Sea level of observed raw data and storm surge water level produced by harmonic analysis

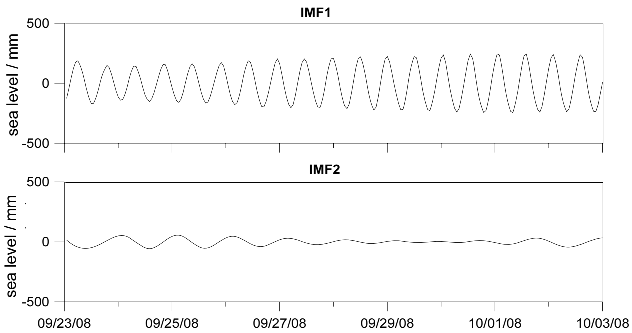

Fig. 9 IMF of EMD during analyzing storm surge water level

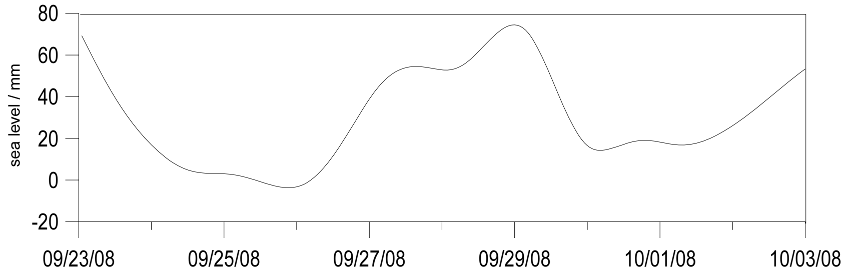

Fig. 10 Storm surge water level produced by EMD

3.2 Wavelet transform in radar image processing

The X-band radar observation system, developed independently by COMC of Cheng Kung University in Taiwan is a remote sensing system. Wave conditions, including wave direction, wave length, and wave height are able to be calculated by wave spectrum that is also obtained from wave image processing which dominates the accuracy of the result and applicability of the system directly. Fourier Transform (FT) is the common algorithm used to derive wave spatial spectra from radar images. FT is acceptable in the analysis of radar images in deep water regions. But, in shallow water regions, the nearshore wave fields are not expected to be spatially homogeneous and temporally stationary due to the wave shoaling, so the performances of FT are not satisfactory when applied.

In the investigation of land-based radar, FT may lead to spatial ambiguity of wave characteristics in nearshore images, and one can not clearly know the wave information about wave fields. Apparently, in revealing the characteristics of whole wave fields, this approach has no capability of presenting wave shoaling, refraction, and so on. The COMS employs wavelet transformation (WT), to process the non-homogeneity of the image to make it available for nearshore observation, which has made key contribution in the subject of wave refraction and wave shoaling [7,11].

Wavelet transform (WT) is to estimate inner product between a mother wavelet function with different scales, positions and directions, and signals to obtain images' frequency energy characteristics corresponding to different spatial and time domains [11].

Fig. 11 and Fig. 12 show the wave spectrum of observation image that is in the water area near Kenting in Taiwan where obvious wave shoaling and wave refraction occur, and it was expressed by WT. The sub-images extracted from nearshore region have dimensions of 128 pixels × 128 pixels, and spatial resolution is 7.5 m/pixel, in which six parallel space locations along the inshore direction are selected for WT analysis. The nearshore non-homogeneity of wave field expressed by 2D WT is more transparent than that expressed by 2D FT .From the information in the domain, the shoaling represented by variation of wave length and direction is clear [12,13].

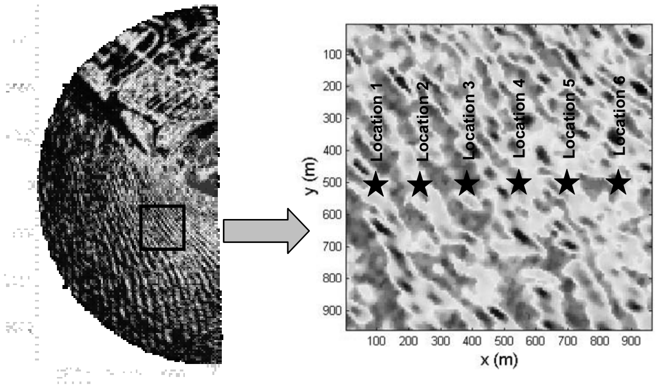

Fig. 11 Analyzed radar image detected in Kending, China Taiwan

3.3 Data assimilation technique in wave nowcasting

With the wide range of application of data assimilation in the field of meteorology, scientists in oceanography try to apply it in the spheres of wave forecast and nowcast, yet impeded by the lack of high-quality data at first. Establishment of monitoring network of operational wave monitoring and its constant and steady function in Taiwan have provided an absolutely perfect chance for its advanced development. The main difference between the application of data assimilation in numerical model and the conventional method lies in that the conventional method is to use the model to hindcast, compared with the filed data to adjust the parameter setting in the model, while data assimilation integrates operational numerical wave model and operational observation system, applies real-time data to adjust the sea state in order to improve the accuracy of model (Fig.13-15) [15].

Optimal interpolation is widely accepted by most operational systems of data assimilation when considering feasible operation and refinement of the data assimilation in the future. In the foresting model developed by COMS, instead of the use of traditional statistical wave height for data assimilation, it employs the wave directional spectrum initially [14].

Compared with the traditional forecasting models, there is a significant improvement in the foresting accuracy since the wave spectral data assimilation is applied in the model. In addition, data assimilation captures real-time data that is from deep sea buoy, more than 200 km off Taiwan Island. When typhoon arrives near the buoy, there will be 4 to 5 hours ahead of typhoon arrival for operational numerical wave model to nowcast, indicating that it will serve the nearshore sea-state warning and possess remarkably practical value [15, 16]. Zheng and Feng [16] have primarily proved the high potential of the nowcasting idea for

Fujian coast region. Further, Feng [17] gave the description in details on nowcasting model for East China sea via data assimilation method, in which the real-time spectra along Taiwan coast is used to update the initial wave fields.

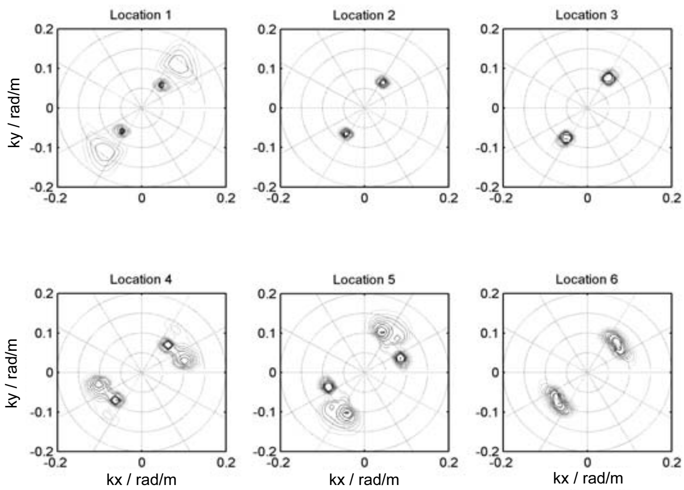

Fig. 12 Wave number spectra calculated by 2D-FT at six different locations

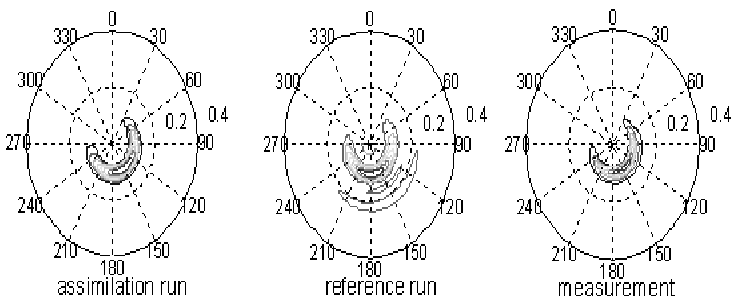

Fig. 13 Performance of 2D spectra calculated by model compared with measurement data

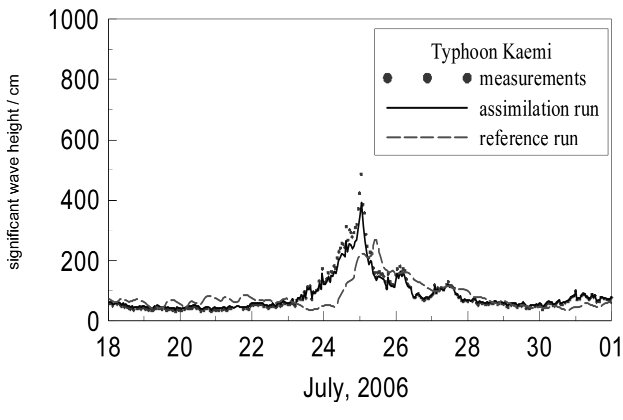

Fig. 14 Time series of SWH calculated by model compared with measurement data

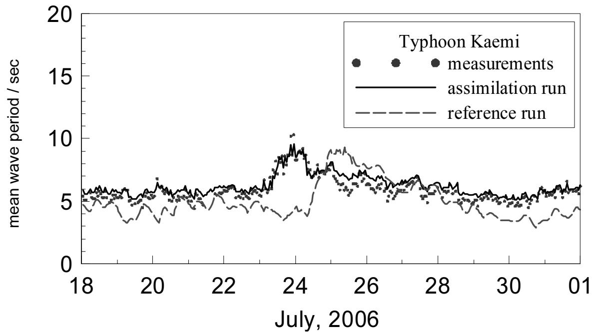

Fig. 15 Time series of mean wave period calculated by model compared with measurement data

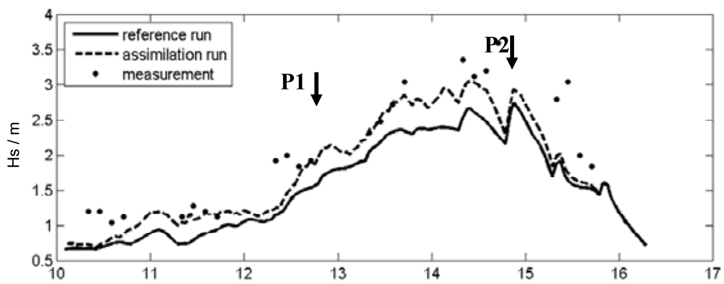

Fig. 16 SWH in nowcasting model at Beishuang station during Typhoon Sinlaku

4 Social application and its future development of CSMS

There is a wide range of application for CSMS: on one hand, it is used in real-time monitoring of marine environment; on the other hand, it offers long term hydrological data [18]. The system produces forecasting wave field every 12 h for the next three days, which will not only serve to provide the basis for decision-making and enable the public to understand the wave climate around the island of Taiwan, but also integrate other coastal hydrological data and information for disaster prevention and maritime salvage. During the typhoon warning period, the implementation of 24 h monitoring of sea states will provide the latest information. The real-time sea state information effectively updates the efficiency of coast disaster prevention, thus alleviating disaster losses. As an evidence of that, figure16 displays the measured wave heights during Typhoon Krosa[19]. Following the purpose of sustainable and scientific coastal development, COMC will make CSMS further go through for its unremitting development and improvement. Henceforth, COMC will promote the advanced observation techniques and setup a variety of sites, including remote sensing, image observation, deep sea observation techniques, dealing with newly emerging issues in marine system, such as abnormal sea state of the oceanographic hydrographic fields. At the same time, CSMS also focuses more on data analysis, exploring deep marine science areas and releasing the observation news for public. It is the imperative responsibility for both the government and scientists to develop more comprehensive coastal disaster warning systems and make more and more people benefited from this.

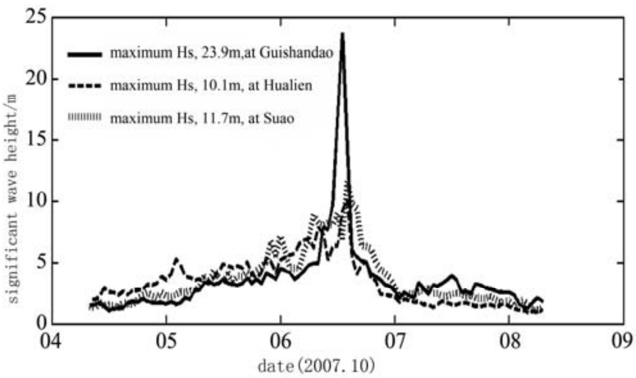

Fig. 16 Freak wave (24 m) during Typhoon Krosa measured by Guishandao buoy

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台湾近海水文观测体系的构建及其数据分析方法

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摘 要：台湾岛地处亚欧大陆和太平洋交界处，台风、东北季风等所引起的海洋灾害频繁，所以建立完备的海洋水文观测体系显得尤为重要。中国台湾自主建置完成的近海水文观测体系由资料浮标站、观测桩、潮位站、岸边气象站、雷达测波站等多种近海水文观测系统构建组成；同时，为确保观测体系的准确性和规范性，还建立了数据品质管理系统和标准化作业模式。在近海水文观测数据的分析方面，尝试应用新的数学分析方法，如通过EMD(empirical mode decomposition)方法探讨风暴潮水位变化，利用小波转换从雷达观测影像中分析近岸波浪信息，以及发展数据同化技术将观测数据应用于作业化波浪现报、预报模式。此外，近海水文观测体系在社会应用方面有着很大的发展潜质。

关键词：近海水文观测；资料浮标；雷达测波；EMD；小波分析；数据同化