Disaster Mitigation Warning System of Coastal Hazards

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Abstract: A disaster mitigation warning system includes the field monitoring network subsystem, data management subsystem and numerical forecasting subsystem. The real time measurement data are essential for the calibration of the numerical forecasting subsystem. To obtain real-time, long-term and non-break-off field data, the monitoring network subsystem must be reliable, robust and could be served by rapid response maintenance. On the other hand, to ensure the correctness of the data, the quality control procedure, which is one of the most important components in the data management subsystem, should be firstly established according to the theoretical foundations and then applied to the observations routinely.

To issue the disaster mitigation warning, the numerical model is applied to forecast the sea state. With the uncertainties of the numerical model in current stage, the experienced experts are required to response the warning system. A well designed graphical user interface, which integrates the information from measurements and numerical prediction of all the weather center, is important for being imported, visualized and compared with the varied data.

To improve the field monitoring network subsystem, the support by the technical teamwork, which possesses innovative R&D and disciplinary routine operation capability, is indispensable. The R&D improves the instrumentation reliability by integration of the latest monitoring technologies, as well as the data quality by establishing and renewal of data quality procedures. Discipline acts to ensure the working efficiency so as to reduce the personal negligence in daily routine operations. The integration of professionals from Oceanography, Meteorology, Hydrology, Electronic and Computer Science aspects to form a technical teamwork plays the key part of successfully establishing, implementing and operating of the Coastal Watch Network.

Key words: coastal monitoring; ocean environment

1 Foreword

Coastal zones, which consist of the coasts, the coastal waters and the estuarine systems, are affected by the nearshore hydrographic and the marine meteorological factors. With the rapidly increasing human activities in coastal zones, such as the exploitations of fishery resources and oil/gas reserves, the recreations, the navigations and the waste discharges, the realization of the natural phenomena in the coastal zone is of necessary prerequisite. While assuring safety of these various activities, how to concurrently prevent destruction to the natural environment relies on sufficient knowledge of coastal environment. Traditionally, physical model or numerical model built on fluid dynamics is the most common methodology employed in understanding coastal environment. These methods have their advantages such as low manpower and budget requirement and short execution time. Nonetheless considering coastal environment's tremendously complicated regional factors and any given model's actual boundary condition requirement in terms of operation or calculation are essential to deploying in-situ meteorological and oceanographical obser-

vation. On the other hand, according to the prevailing International Ocean Law and relevant regulations, all nations have obligations to monitor and preside over its territorial seas in exercising its jurisdiction, all of which provide evidence for the essentiality of coastal monitoring.

In contrast to field observation on land, ocean poses particular hardships: the severe waves, intense sunlight and high humidity and salinity not only subject the crew to dangers, the adverse environment and lack of communication and power supply, but also challenge instrument operation. Fortunately the advance in wireless communication technology, embedded calculation and control technology has progressively materialized unmanned, automated ocean environment monitoring. The so-called "Green Data" ocean environment data can be obtained almost realtime at time series via wireless transmission, making related routine operation feasible.

In considering the operational monitoring for coastal environments, meteorological observation can be adopted as an analogy: the monitoring processes include data access of digitalized environment factors, realtime data transmission, data quality control, data report and data assimilation technology in the application of numerical models, all of which are essential issues to planning and deploying operational coastal environment monitoring as shown in Fig. 1. The present paper intends to address the aforesaid issues, and introduce marine disaster warning system.

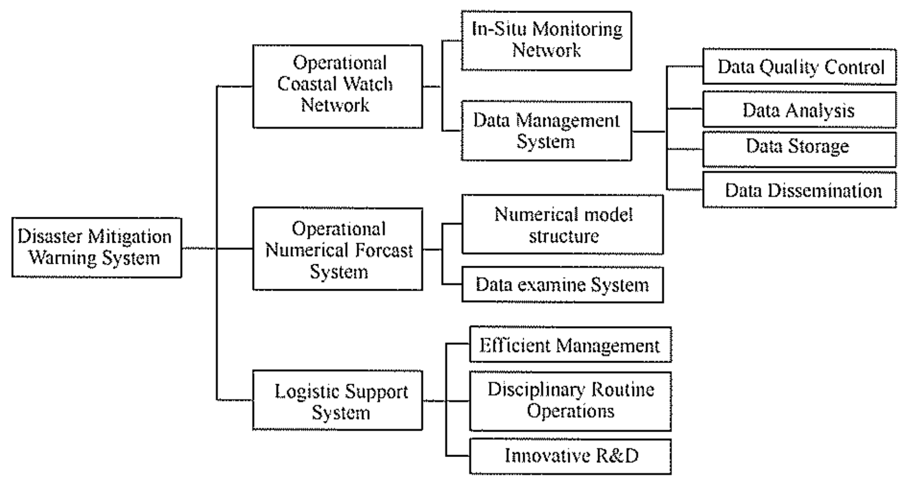

Fig. 1 The Framework of operational disaster mitigation warning system

2 Ocean environments monitoring system

Generally speaking, coastal environment observations can be distinguished into two major categories: one is short-term observation of research or engineering orientation; the other is long-term operational routine monitoring as shown in Fig. 2. The object of long-term operational monitoring is to build national marine meteorology and coastal hydrology database to satisfy present and potential future needs, which include navigation, weather prediction, fisheries, ocean and coastal engineering design and planning, water sport safety, coastal hazard warning, disaster mitigation and coastline management, etc. From these needs a guiding principle for developing a comprehensive marine environment monitoring system can be derived, namely the system shall be able to operate on long-term basis in building sustained regional marine environment database, while concurrently capable of realtime data transmission in providing data for marine weather and weather prediction, and that when weather changes drastically, capable of issuing warning to reduce damage, allowing relevant authorities to rapidly and effectively make disaster prevention and rescue decisions.

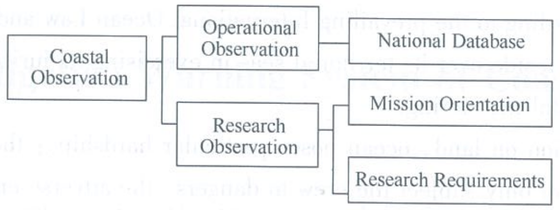

Fig. 2 Categorization of coastal observations

Based on the said guiding principle, the coastal environment monitoring system should suffice to monitor all Met-Oceanographical factors the end users may require, and present these data in quick, easy-to-understand format to the end users. The potential users might require the data for the following applications i. e. the pollutant surveillance, fish cultivation monitoring, sea-bathing beach water quality monitoring and hazard rescues operation. In such way, meteorological factors, water quality, ocean dynamics, sedimentations as well as marine biological/ecological status are of essential importance. Furthermore, as hazardous weather systems such as typhoons approach, the system shall accept remote control to shorten the time interval to increase the monitoring intensity. On the other hand, to maintain the integrity of long-term database, the marine environment monitoring system shall have high sea resistance to forestall any potential interruption.

The criteria for determining observing coastal environment factors should take into account the end data user's needs and budgeting. The basic observation items should include: wave height, period and direction, tidal elevation, surface current, wind speed and direction, air temperature, water temperature and barometer. Considering the facts that since the wave and marine meteorological factors are extremely varyed with time, they have the priority to be observed. If budget allows more detailed investigations concerning marine ecology may be carried out, such as directional wave spectrum, current profile as well as salinity, turbidity, pH, DO, alkalinity, nutrient saline and chlorophyll. As the automatic observation technologies on some of the items are not available or mature ready for operational use, developments and integration of sensor technologies should be promote.

3 In-situ realtime monitoring network

On technical level, coastal marine environment monitoring system comprises two subsystems: In-situ realtime monitoring network subsystem and data management subsystem. Of the two the former transmits the data measured on the field to the data centre. The latter undertakes data quality control, database pooling, operational prediction and data report service at the data centre.

The approaches of coastal marine monitoring could be categorized as the remote sensing and In-situ measurements, as shown in Tab. 1. The satellite remote sensing has its limitations on the operational monitoring due to its long return periods. The airborne operations are comparably costly. As the underwater wireless data communications are restricted, the bottom mount instrumentations are not capable of delivering the data in realtime. Considering the previous mentioned requirements of operational coastal watch network, the data buoy is regarded as the most frequently used instrumentations. The moored data buoy has the following characteristics over other methods to be regarded as the main observation method: ① data buoy can be applied in water depths ranging from thousands to tens of meters; ② floating on the surface, buoy can fully benefit from satellite communication and broadband wireless data transmission technology for deployment in any ocean region; ③ data buoy need not depend on submarine

lifeline to provide energy, and has sufficient buoyancy to carry the weight of various instruments, equipped with high expendability.

Tab. 1 Methods of coastal environment observation

	Payload	Observations
Remote Sensing	Satellite Airborne	SAR Altimeter Scattermeter Stereophotography
	Lane Based Marine Radar	X - band Radar Images
In-Situ Measurement	Platform Data Buoy Ship	Directional Wave Spectrum Tide Current Marine - Meteorological Factors Water Quality Bio/Ecological Factors
	Bottom Mount	Waves Current Profile Sedimentation

Concerning the wave monitoring, the six degree of freedom accelerations and inclinations that record buoy movement with wave can yield wave directional spectrum via cross-spectrum analysis, describing wave energy's distribution characteristics on frequency and propagation direction, providing greater precision in building weather forecast model and the application of data assimilation technology.

Data transmission from interruption in extremely adverse sea conditions due to excessive signals from moisture and spray, planning of the monitoring system should be emphatic of multi-route data transmission mechanism, allowing data to choose one channel from wireless transmission, GSM wireless communication, broadband bluetooth communication or satellite communication to send the data back to the control centre as shown in Fig. 3.

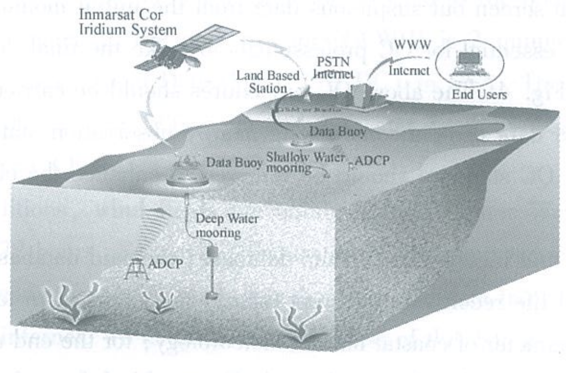

Fig. 3 The multi-routes real-time data transmission

4 Analysis & management of realtime monitoring data

Once field data is sent back to the centre, data analysis and management should directly commence. All raw data should be sorted first, subject to data spectrum analysis, statistical analysis and quality control, compiled and then reported to relevant authorities and policymakers. In the procedural flow above, data quality control is the most critical step.

In the course of monitoring, as sensor would pick up miscellaneous signals coupled with data encoding and decoding during the transmission together with other uncertainties, inaccurate numeric data is invariably included in the received data. Particular attention should be given to the fact that if the inaccurate data is applied in the design of engineering applications or calibration of forecast model, it will not only lead to error judgment, but also put the public's lives and properties in jeopardy due to wrong decision-making. On the other hand the extreme data monitored in adverse weather conditions are rather identical to invalid data in their format features; these extreme numeric data are hard to come by and valuable, thus how to correctly remove invalid data from precious extreme data is critical.

In addressing the said goal, there are two strategies to uphold high data quality and accuracy: in active undertaking, to 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, to 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.

Fundamentally professional researchers skilled in data analysis should administer all data quality control; these QC personnel must have extensive field background and well acquainted with instrument characteristics, electronic circuitry, data analysis theories and marine meteorological characteristics to have the competency of judging data quality control accurately. To alleviate manpower burden, enhance data QC efficiency, high-performance computing capacity may be employed to screen out suspicious data from the initial monitor database, and mark them out accordingly. However it remains essential for QC professionals to make the final determination concerning data accuracy; the flow is presented in Fig. 4. The above QC procedures should be carried out daily. In case of data drifting caused by aged sensors, the data comparisons among nearby observation stations should be implemented for longer period. Annually, all the QC standard should be renewed to enhance the efficiency and performance of QC procedures.

Once QC data are analyzed and incorporated in the database, the said database besides storing monitored data shall also contain all the sensors' life records and current instrument statuses. In terms of subsequent data application, given the strong regional character of coastal marine meteorology, for the end user's convenience, data display should be structured on Internet coalesced with coastal area's Geographic Information System (GIS) to achieve optimal data application.

All of the procedures of the QC can not change or modify the original data but generate a series of flags. The database will store all of the original data sets and the QC generated flags. According to the stored information, the situations of the data or sensors can be performed easily.

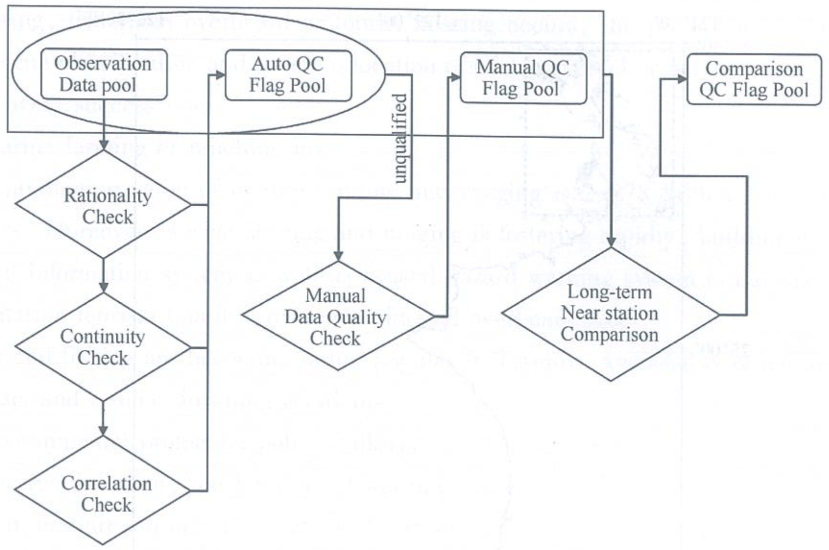

Fig. 4 Data quality control flow chart

5 Marine weather data forecast system description

Waves, tides and currents are the causations of marine hazards in Taiwan region. To setup the numerical forecasting system, open public source that code recognized by the academic societies are the better choices as the kernel of prediction in the operational mode. For instance: ① for near shore wave model, NCEP's wave watch model (NWW Ⅲ) might be adopted; ② coastal wave model may consist SWAN wave model, ③ the Princeton Ocean Model might be adopted in tide and current model; ④ In the storm model it may employ the current Central Weather Bureau model. Those models are technically maintained by the developing group and users' groups. Therefore the removal of bugs and updates can be found and modified quickly. Normally, SWAN is used to forecast the coastal wave field and NWW Ⅲ is used for near shore wave forecasting. Both the two models for coastal wave forecasting are setup in nested grid system. The output of NWW Ⅲ model is used as the boundary conditions for SWAN model. Fig. 5 shows the calculation domain, the grid size for NWWIII is 2 minutes and the water depth is using ETOPO2 maintained by National Geophysical Data Center (NGDC) in USA. The grid size for SWAN here for example in the North-East coastal of Taiwan is 500 meter and the water depth is obtained from National Center for Ocean Research (NCOR) in Taiwan, China.

The Forcing boundary conditions, wind fields are obtained from Center Weather Bureau (CWB) every 12 hours and the forecast period is 72 hours. For saving the size of the data and reduce the lost data during data transmission, the technique for data code/decode is used. For the large size data transmission it is difficult to have other means for data transmission but internet. To keep the completeness of the data is much important and should be automation.

6 Marine hazard warning

The engineering of warning system is a critical means to effectively mitigate disaster damages. As technologies

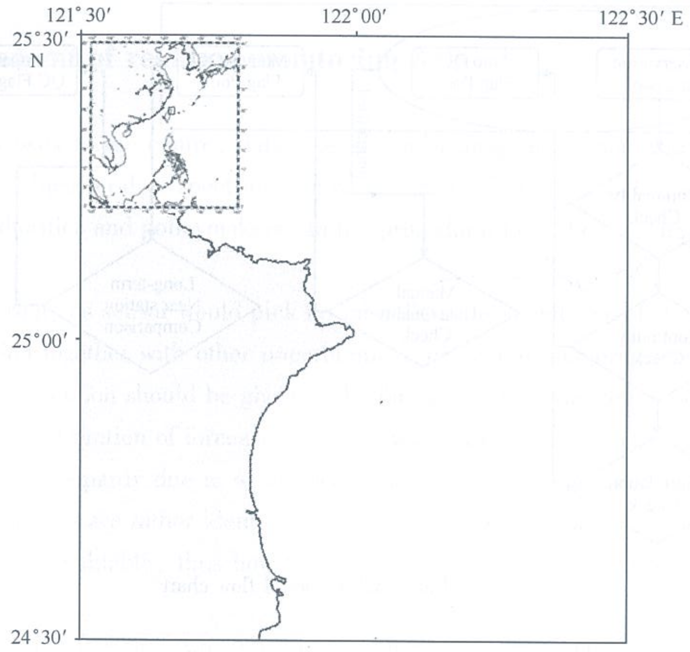

Fig. 5 Numerical model calculation domain.

for monitor and surveillance, data transmission, forecast and calculation progressively developed, to a certain extent information of disaster occurrence and evolution can be quickly sent to the prevention and rescue decision-makers as well as the concerned public, and through direct assessment, arriving at effective rescue decision to prevent losses and accelerate rebuilding.

Marine hazards are one of the gravest disasters for Taiwan region, broadly pertaining to tides, waves and other natural or manmade phenomena existing at the interface between the atmosphere and the ocean that result in damages and losses of lives, properties or environment. The marine hazards common in Taiwan region include shipwreck, tidal flooding, seawater in-flood, coastline erosion, embankment damage, etc. When these hazards occur, the relevant authorities, business units and private rescue organizations are restrained by the caprice of marine weather changes in their rescue efforts and subsequent undertakings to take appropriate response measures, often missing the critical response timing that results in spreading of damages. It follows that Taiwan is hard pressed for a standardized marine weather warning system to provide hazard warning and reference basis for rescue decision-making.

The importance and urgency of building a coastal hazard warning system can be illustrated from the aspects of hazard losses prevention and potential benefits in terms of shipping, disaster rescue, environmental protection, tourism and fishery.

(1) Reduce disaster losses, increase fishery safety

According to statistics of fishing boat shipwreck and victimized fishermen, during the period from 1995 to April 1998 due to natural disasters, 119 ships sunk, 631 boats sustained damages and 19 went missing; 124 fishermen died from falling overboard or ship sinking, 6 sustained heavy injuries, 11 sustained minor injuries and 104 fishermen were missing in sea. If typhoon passage and weather forecast can be accurately predicated based on marine weather monitoring losses of lives and properties may be reduced, and thus cut down burden on the society.

(2) Facilitate sea rescue operations, increase search and rescue success rate

When boat missing, fishermen overboard or tourist missing occurs, the prediction system can provide rescue organizations with rescue classification and possible location of missing vessel or personnel to lock on range of rescue in enhancing the recovery success rate.

(3) Reduce marine farming or ranching loss

Taiwan's 1997 production value of marine farming and ranging is 2.878 billion NTD; marine conditions are critical to the industry. Moreover as cage farming and ranging is fostering rapidly, building coastal monitor and surveillance network and information system as well as coastal hazard warning system is increasingly pressing.

(4) Enhance marine tourism quality, reduce accidental overboard risk

Water activities and fishing are becoming rather popular in Taiwan. Availability of marine conditions serves to propel relevant tourism and reduce drowning accidents.

(5) Uphold environmental protection policy, alleviate ecological impact

With oil-leak marine pollution, the building of warning system will serve to project the passage of leak in administering prevention measures to mitigate ecological impact.

Operational marine weather warning system should provide the functions of: ① realtime weather data, monitor weather changes; ② precision predication (forecast) of weather activities, grasp of future sea conditions; ③ data storage and management; ④ data display and solution analysis; ⑤ report mechanism. In terms of realtime monitor station's data transmission, to achieve realtime monitoring, data sharing system and standard transmission format should be regulated, compiling all extant domestic realtime monitor station data with the Central Weather Bureau's weather monitor and report centre as the national marine data hub in integrating all existing weather monitor resources.

In terms of database management, realtime database should be built as the core module of integrating weather monitor data and warning data. The system shall be capable of high performance management of massive data to ensure efficiency and stability of data input, output, enquiry and display. With hazard warning display, as marine weather changes are highly regional, the warning system should be designed conflating geographic information system and marine weather data to provide display of space and property data. Additional function modules may also be added in the future such as hazard prediction module and expert data system to assist decision-maker process and analyze data as basis for assessing marine weather conditions, decide rescue solution. Regarding realtime data enquiry and weather hazard warning communication subsystem, Internet may be employed to provide users quick access of realtime data, while concurrently report the prediction results and decision information to the various levels of governing authorities via multiple transmission channels. The report system is shown in Fig. 6.

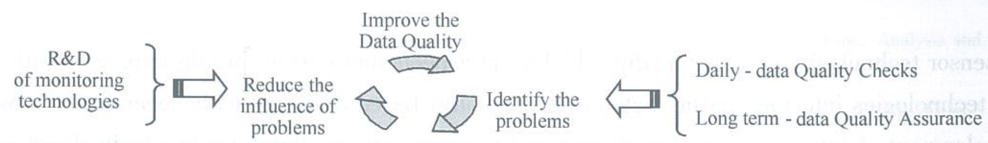

Fig. 6 Localized technical support from teamwork

7 Logistics to coastal environment monitoring warning system

Coastal environment monitoring and warning system covers field bathymetric survey, building of monitor stations, station operation, station maintenance, troubleshooting, instrument calibration, realtime data transmission and monitor quality control, regulating of data QC standards, issuance of annual data report, production of typhoon report, database management and maintenance, information report service system engineering and service, educational promotion and coordination with organizations and public, sustained development of surveillance system and induction of advanced technology, and operational forecast. The scope of undertaking as listed above is extensive, and the execution is complicated. The most critical element to building a long-time uninterrupted monitoring network lies with that the instrumentation system must have reliable stability, sound sea weather resistance, and once damage or breakdown occurs, able to receive immediate repair. On the other hand to receive high quality data, the data QC procedure and standards should be regulated according to theoretical principles, and gingerly executed thereafter.

Examination of Taiwan's technical status and marine instrument market scale reveals that most ocean instruments are imported; relevant calibration and repair technologies are lacking so that the instruments have to be sent abroad for repair, which is time consuming and involves tedious processes. In terms of procurement, the attention is directed at the price tag with little concern to risk and internal cost issues as lack of instrumentation technology can cause interruption of monitoring and unreliable data quality. The modicum market scale cannot entice researchers to develop local instruments, resulting in high technician turnover rate, inability to command technical details, and hence is impossible for instrumentation technology to entrench.

It follows obviously that coastal environment monitoring and warning system requires a localized technical team to back it up, and that the team must be equipped with innovative technology integration and R&D capabilities together with stringent, disciplined competency in surveillance execution and repair maintenance. Innovative capability is applicable in developing the latest sensor, communication technologies and digital analytical calculation, standardized digital module development, regulating and updating data QC standards, integrate Internet database application technology, GIS application technology, etc. Meanwhile the stringent, disciplined competency will serve to provide quick response to instrumentation repair, and forestall data quality degeneration due to human negligence. Hence this technical team should accrue professionals in the fields of oceanography, marine meteorology, hydrology, electronic mechanical engineering, information technology, structure, and materials to engineer the three primary technological infrastructure covering R&D, operational observation and systemic warehousing, administrative management. The cultivation and integration of such manpower is the key to successful building of the surveillance and warning system.

8 Future developments

As the sensor technologies of water quality, biological aspects and current profile improve rapidly, the integration of these technologies into the coastal watch network could be carried out in the near future. Besides, in the technical development of future coastal surveillance and warning system, there are two main directions: one is remote distance sensing, and the other lies with data assimilation technology's application in numerical nowcast model. Remote sensing utilizes different frequency sections of electromagnetic waves as medium, which can be picked up by such airborne bases as satellite and aircrafts' projecting radar onto ocean surface in obtaining wide extensive space of marine environment data. However, if considering from the standpoint of operational automatic time series monitoring and budget requirement, application of coastal-based radar promises higher potential. Coastal-based radar system uses cheap navigation X-band radar to beam signal onto sea surface and accept reflected waves, and through analyzing the inter-functioning between radar waves and ocean waves and ocean waves' modulating charac-

teristic due to current, the spatial wave field and current field distributions can be calculated from the backscatter images. Furthermore, as navigation radar can be controlled to survey in auto-spiral format, sequential order of return images may be obtained. These features enable coastal-based radar to enrich the information of data. Such a system will be vital to future field monitor surveillance and marine research.

In the aspect of data assimilation application relative to research approach of employing conventional numerical model to improve forecast accuracy, consideration should be given to improving the physical mechanism, the data calculation methodology and calculator precision, and data assimilation technology be applied from a varied perspective in improving precision of numeric data forecast. This technology subject the realtime monitored marine environment data via various methods to subjective and objective analyses, and then incorporated in the calculation grid's corresponding calculation points for the optimization of realtime data model in attaining comprehensive status report and enhancement of forecast accuracy. In the past the greatest limitation of data assimilation technology is lacking of realtime monitor data. Today the increasing monitoring density is laying down groundwork for the development of data assimilation technology. So that in the event of accident occurrence such as oil leak, the nowcast module would be able to project the passage of the oil spill, enabling timely information to the decision-makers.

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