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Note

Application of Realtime Monitoring of Oceanic Conditions in the Coastal Water for Environmental Management

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This study describes the realtime monitoring system for water quality conditions in coastal waters. Some issues on the data quality control and quality analysis are examined along with examples of erroneous data. Three different cases of database produced by the realtime monitoring system are presented and analyzed, namely 1) hypoxic condition, 2) over-saturated D.O. and 3) short-term variability of temperature and D.O. In utilizing the realtime database, D.O. prediction and warning models are developed based on autoregressive stochastic process. The model is very simple, yet, powerful and useful with its ability to send warning messages to users in various levels from governmental administrative staff to local fisherman, and give them some allowances to cope with the situation.

Key words: Realtime, Monitoring, Water Quality, Coastal Waters, Hypoxic, Dissolved Oxygen, Temperature, Short-term Fluctuation, Wireless Internet

INTRODUCTION

The first step to understanding the oceanic phenomena is to observe the conditions in the ocean. Traditional observations have relied on the ship-borne measurements such as hydrographic profilings using bottles, CTD, echo sounding, and nettings for plankton and fish samplings. Costly charges for shiptime and human labor have set a big obstacles to frequent observations so that information required for immediate actions and responses are practically impossible. Moreover, some of the phenomena of significant public concerns such as harmful algae bloom and hypoxic conditions occur with short time scales which traditional method could not properly detect.

In the recent years, occurrences of the hypoxic and anoxic conditions in the coastal waters have been reported in many sites. Among those, many studies focused on the Chinhae Bay (Yang, *et al.*, 1984; Hong, 1987; Hong, *et al.*, 1991; Cho, *et al.*, 2002) with a few others are on the other areas such as Choi, *et al.* (1991) in the Buk Bay, Lee (1993) in the Wonmun Bay and Ro (2002) in the Chunsu Bay and Aengang Bay.

However, cutting-edge technology equipped with sensors and wireless communication devices provide challenging opportunity for oceanographic applications in the coastal waters. In addition to this, data streams from *in situ* sensors connected to host computer with web and MySQL can be displayed on the web pages on realtime basis and will be very useful to users from local management agencies and fisherman.

Data production of oceanic conditions on the realtime base with high resolution (within a few hour time lag) will provide great challenges and opportunities for the management and studies of health-related and ecosystem problems. Among those, harmful algal bloom (red tide), monitoring of the release of toxic materials into coastal water body, and occurrence of hypoxic conditions in aqua-fishfarms and shellfish culturing sites will be benefitted with this kind of new database.

This study will focus on the system development of the realtime monitoring of oceanic conditions, data quality issues and its application in understanding oceanic phenomena.

DESCRIPTION OF THE REALTIME MONITORING SYSTEM

The realtime monitoring site is seen in Fig. 1a and system is configured (Fig. 1b) as follows;

1) water quality sensors (temperature, salinity, dissoved oxygen, pH, turbidity, chlorophyll, etc) with a data logger,

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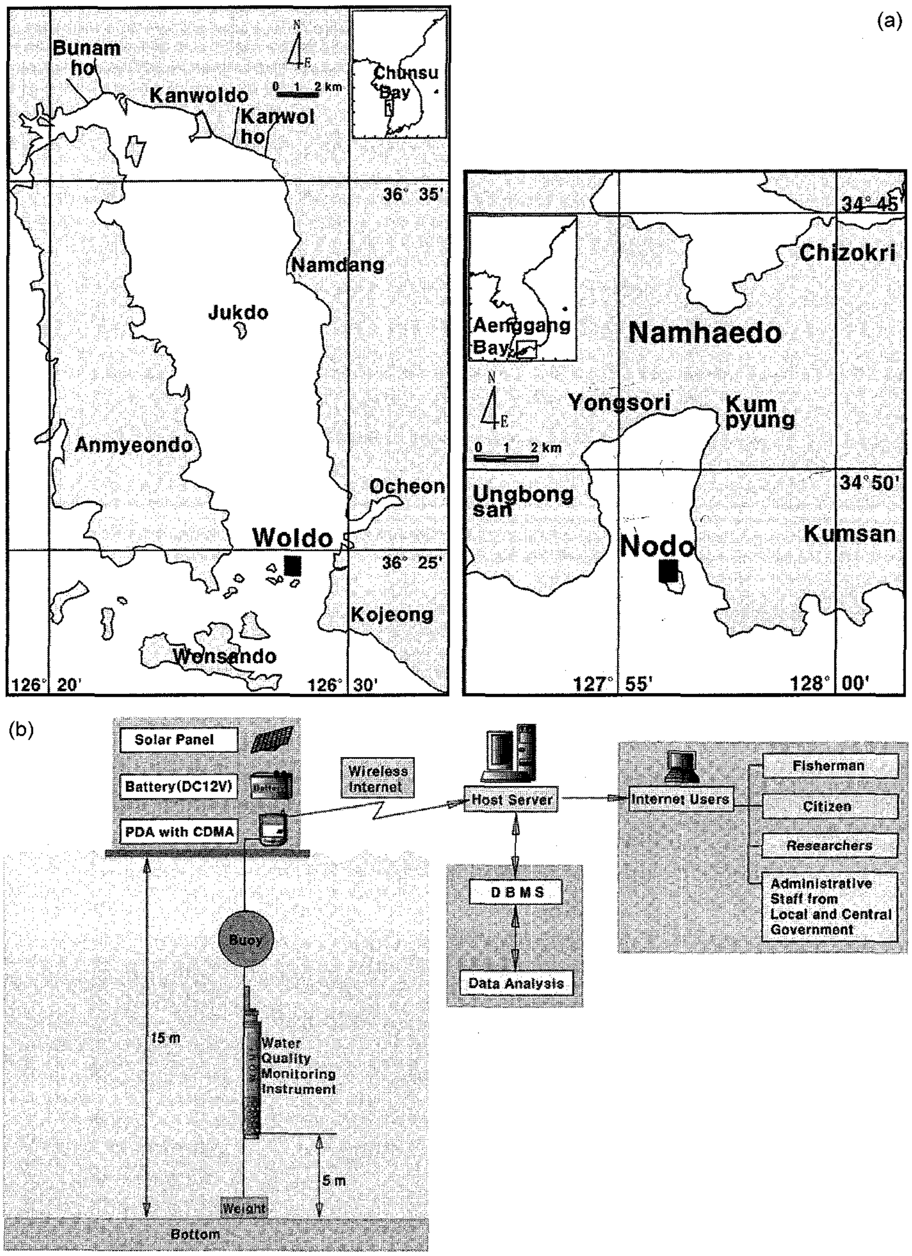

Fig. 1. (a) Realtime monitoring site (Woldo, Chunsu Bay; Nodo, Aengang Bay), (b) Schematic system configuration of the realtime monitoring of oceanic condition in coastal waters.

2) HPC (handheld personal computer) with CDMA communication module and OS (Window CE 3.1),

3) solar panel with regulator and battery,

4) host computer (Linux with Apache and MySQL database daemons),

5) controlling and communication software on HPC and processing software on host computer.

The realtime production of data stream and display on the Internet web page are made possible in continuous functions of various system elements. The sensors *in situ* and data logger connected to HPC via RS 232 port transmit data stream to HPC which stores them in specific files and upload them to a host computer through ftp. At this steps, three control parameters such as sampling time interval (sti), file saving cycle (fsc) and ftp cycle can be arbitrarily defined at user's command. In our case, sti, fsc and ftpc are 10, 60, 60 minutes. In an extreme case, sti, fsc and ftpc were tested with 1, 10, 10 minutes and yielded satisfactory results. Host computer should be running 24 hour a day without interruption for any anonymous users. It is continuously receiving new data files through ftp and stores the data in the database with MySQL which will serve the data at the order of user's searching in terms of parameter and period. The searched database can be displayed as

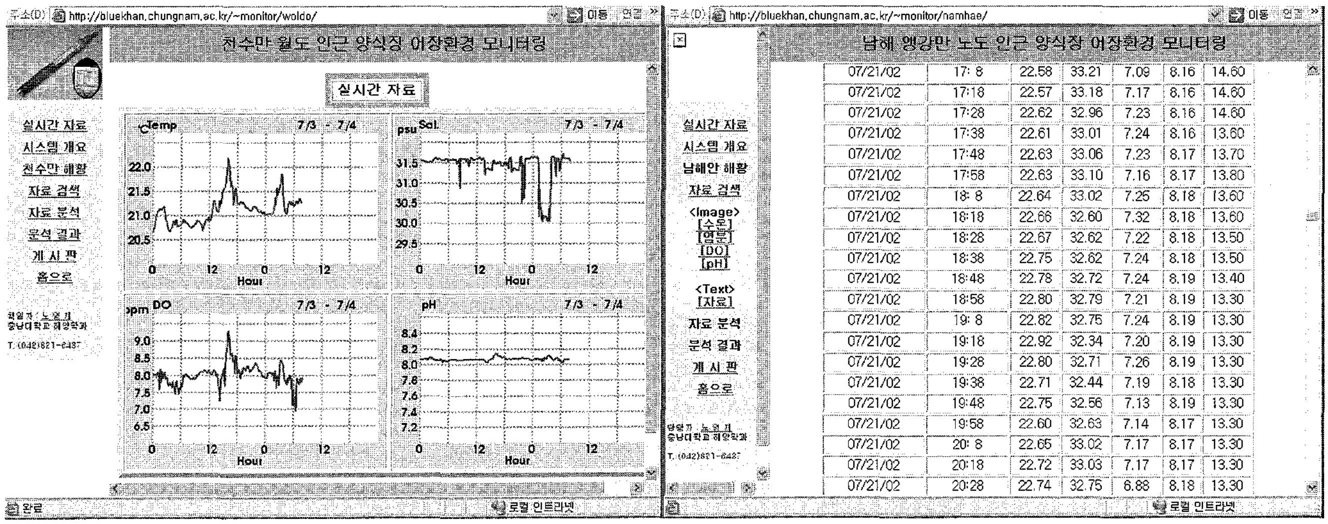

Fig. 2. Examples of realtime display on graphic mode (left) and on text mode (right).

graphic on the web and/or provided in text mode (Fig. 2). To display realtime data on line, skill is needed with a graphic engine which produces graphic images and script to load them on web. In addition to this basic software, high level software is desired for more complicated applications such as prediction of occurrences of any episodic events (hypoxic condition, over-saturated condition, low saline condition, etc) and sending warning messages to designated users. Details of the technical information for the realtime monitoring system can be referred to Ro (2002).

ISSUES ON DATA QUALITY CONTROL

In any oceanographic measurements, the first step we are concerned with is careful planning for the data quality control. It is strongly required when you produce data based on autonomous monitoring system remotely operating in offshore waters. In managing the realtime monitoring system and data production, many practical problems are involved such as 1) sensor contamination due to variety of sources, 2) system mulfunction due to power supply, connections among sensors, HPC and cables, 3) loss of data transmission due to bad telecommunication environment. Any of these problems affect the data production rate and quality.

In practices, we set up a rule for regular cleaning and recalibration of sensors nominally every two weeks. Cleaning sensors will involve disassembling all the sensor probes from the system and cleaning them. Brushes and ultra-sonic cleaning have been used to remove debris, dirts, particles and living organism attached. Bio-fouling on underwater equipment is one of most difficult problems to tackle with and is most severe in warm season for the period of May to September. D.O. sensor requires very special attentions and cares in using membrane and keeping electrode non-contaminated. Other cares should also be exercised to maintain the power supply system of solar panel, battery and regulator in enhancing data production rate. Many incidents of bad connection through underwater cable between sensor and HPC occurred to fail data production. We also experienced the loss of produced data due to Internet access problem of host computer in that high traffic load on Internet in University campus hindered the ftp access from remote HPC and finally shut down of the HPC. This problem is inherently occurring in using Internet line. In our study, this problem were circumvented and relaxed by using a commercially available host computer off campus which provides faster and more stable access for ftp.

Major concerns of produced database will be its data quality. High-frequency data production does not guarantee good data quality. Thus, special attention and analysis should be paid and carried out to test the quality and data management. It will be described in details in next section.

EXAMPLES OF THE ERRONEOUS DATA

In the course of producing data for water quality conditions in Korean coastal water bodies in Chunsu Bay and Aengang Bay in western and southern respectively since April, 2001, many difficult situ-

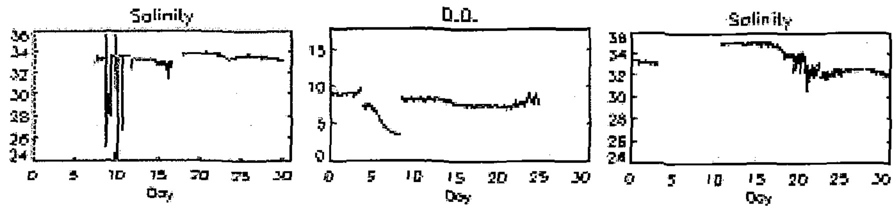

Fig. 3. Three categories of errors such as 1) random, 2) systematic, 3) system malfunction.

ation with the seemingly erroneous data has been experienced. Potential users of the produced data as well as planner of the monitoring system in the future should be aware of the fact that data can not be free from errors. Here, some types of data with errors are presented. Data with errors can be classified in three categories such as 1) random error, 2) systematic error with gradual degradation, 3) system malfunction. Figs. 3 show the examples for data with errors corresponding to three categories. The cause of errors are not always clear nor evident due to variety of sources. Those come to contribute in a single and/or combination modes such as bio-fouling of sensors, pollution or oxidation of electrode probes as results of membrane breakage, contamination of sensors with foreign matters such as debris and/or particles.

Several steps are needed to check the erroneous data such as

1) to define window function for upper and lower limit for particular parameters,

2) to use statistical parameters such as mean and standard deviations to define outliers,

3) to estimate smooth data by using a simple moving average or more sophisticated band-pass filter.

All of produced raw data should pass the quality test procedures defined above and will be identified either passed or bad. Flag valuse is endowed for each raw data where value of 1 is assigned as good and readily usuable and value of 0 is given to bad and unusable and value of 0.5 is given to data which require further inspection and correction for later useage. Once data is identified as bad, it should be removed from the database and will not be used in estimating basic statistics. Later, removed data points need to be interpolated depending on particular analysis.

ANALYSES OF THE DATABASE

Three different cases of database obtained based on the realtime monitoring system are presented and analyzed.

Highly anoxic condition

The D.O. data were measured in July, 2001 in Chunsu Bay using realtime monitoring system (YSI 6000, USA). The measured depth is 2 meter above bottom and its mean depth is 7 meter. Fig. 4a shows extraordinary and surprising hypoxic conditions. For the period of one month in July, 2001, the maximal D.O. concentration was 10.6 ppm and minimal value is less than 0.1 ppm representing highly anoxic condition. Hypoxic conditions were periodically occurred in response to tidal condition (in ebb tidal current). Probability of Hypoxic conditions under 3 ppm is 3.7% (160 out of 4288 measurements). These phenomena are extremely critical and alarming in local fishery farming, since those condition in this area were reported to occur in summer season repeatedly resulting in massive death of culturing fishes in the past. The mechanism of the occurrence of hypoxic condition in Chunsu Bay is beyond the scope of this paper. Readers may refer to detailed interpretation through numerical modeling approach by Choi and Ro (2003). Briefly, they tried to develop a D.O. budget model where source and sink terms are parameterized with simple assumptions. It is indicated that sediment oxygen demand (SOD) plays a dominant role in forming hypoxic condition when critical shear stress causes resuspension of organic sediment into water column at ebb tide and subsequent SOD outweighs oxygen source from photosynthesis and reaeration from surface interface. Coupled water quality model should be developed in conjunction with hydrodynamic model so that correct estimates of oxygen budget items can be made.

Over-saturated dissolved oxygen

The database obtained in August, 2002 in Aengang Bay (Fig. 4b) shows another extraordinary condition which is in opposite contrast to hypoxic condition, ie, over-saturated dissolved oxygen condition. This over-saturation of D.O. can not be existent in natural condition without additional source of oxygen. It was

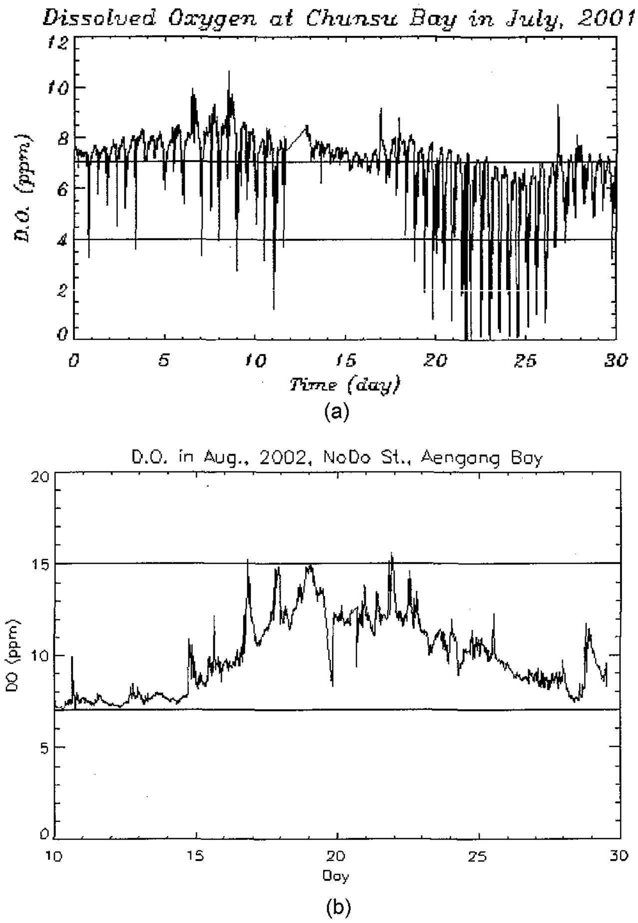

Fig. 4. (a) Time series plot for the D.O. concentration (hypoxic condition) for the period of July, 2001 in Chunsu Bay, (b) Time series plot for the D.O. concentration (oversaturated conditon) for the period of Aug., 2002 in Aengang Bay.

reported that harmful algal bloom so called red tide was first observed on August 8th, 2002 in Aegang Bay and lasted until the end of the month when Typhoon Russa passed through the Bay and the red tide was dispersed and subsidized. The monitoring system could capture the over-saturated D.O. condition with the incoming tidal current during daytime. Over-saturation persisted for two or three hours with the values exceeding 200% of saturation concentration calculated as a function of temperature and salinity. In the literature, it is known that the active photosynthesis produce oxygen in euphotic layer under favorable solar light condition (Yang, *et al.*, 1984). Of course, the rate of oxygen production will be a function of algal concentration, nutrients and ligh condition which need to be monitored simultaneously in the future. However, this example demonstrates that D.O. concentration can play as a parameter to be used for red tide monitoring and warning system. In next section, a warning model is presented.

Variability of temperature and D.O. within monthly record

Figs. 5 show the time series of temperature and D.O. for the period of July 12 – 24, 2002 in Aengang Bay. In 12-day record, it is noticeable that diurnal and semi-diurnal components play important roles in their variability, while short-term components whose period is less than 3 hour also contribute significantly to their short-term variability. To be noteworthy, spike-like signals both in temperature and

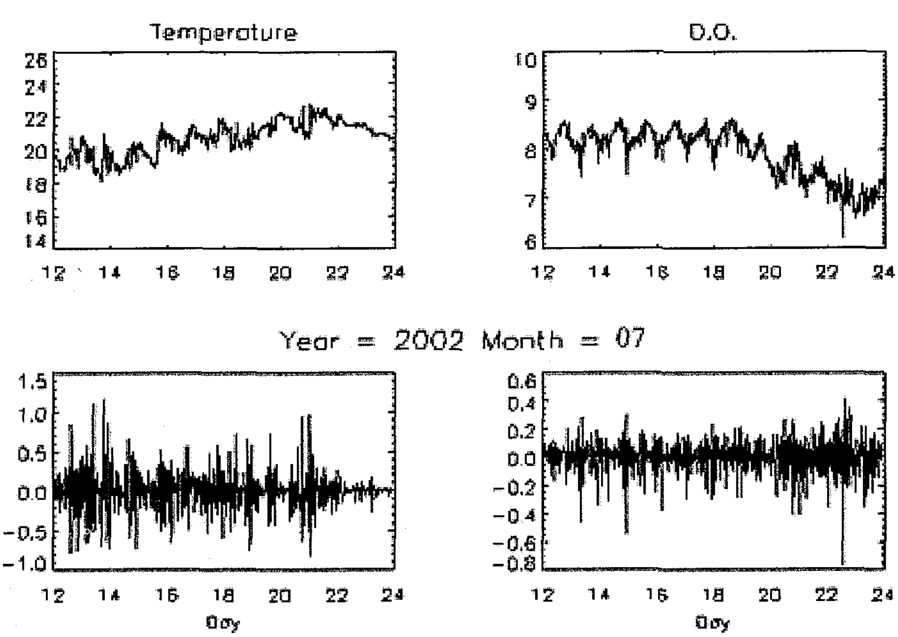

Fig. 5. Time series plots for temperature and D.O. (upper panel) for the period of July 12-24, 2002 in Aengang Bay. Lower panel represents time rate of change of temperature and D.O. for the same period (parameter/sec).

D.O. anomaly whose magnitudes exceed 1.0°C for temperature and 0.5 ppm for D.O. intermittently occur which would act as impact to local ecology. Consider the cases where mean temperature is high and short-term fluctuation is over 1°C which will result in high temperature beyond the marine organism's tolerance limit. On the other hand, negative D.O. anomaly may cause hypoxic condition within very short time scale.

Interestingly enough, one can also recognize the linear trend existing in temperature and D.O. variation. These processes are readily understood, if one consider seasonal variability in that temperature is slowly warming up toward summer season and accordingly D.O. concentration is decreasing. Rate of temperature increase for the period of July 14-21, 2002 is 0.322°C/day, while the rate of D.O. decrease is -0.245 ppm/day.

DEVELOPMENT OF D.O. PREDICTION AND WARNING MODELS

For practical application, development of the warning model for episodic events such as hypoxic condition in water column and/or harmful algal bloom (hab) is very much desired. However, it has not been possible due to lack of high-frequency realtime data. In this study, two-way steps are taken in that firstly, a simple stochastic model is developed to predict the occurrence of such critical episodes by using incoming realtime D.O. data stream every 30 minutes and secondly, a warning model is set up based on the model prediction.

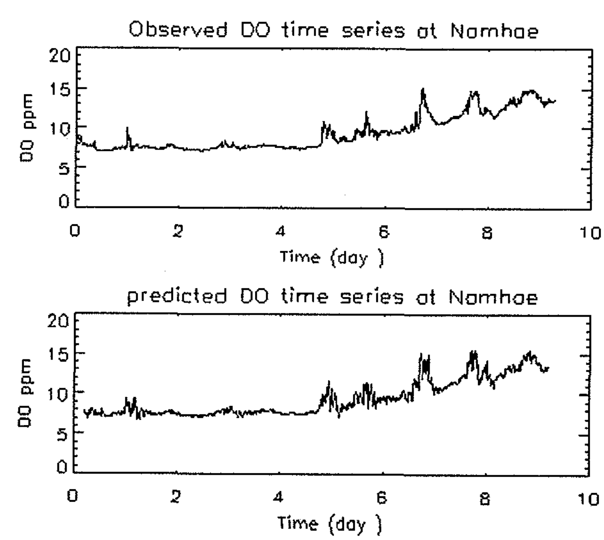

Fig. 6. Comparison between oberved D.O. concentration versus predicted one based on a stochastic model.

To predict the D.O. values in the near future, a simple stochastic model is developed assuming prognostic values such as D.O. obey auto regressive process so that

$$x(t) = \sum_{i}^{n} w_i x(t - i\Delta t) + e_i$$

where x represents autoregressive process such as concentration of dissolved oxygen. w_i, e_i represent weights and errors associated with predicted x at time t. This model will predict the x at time t by using previous n observations (latest 5 hours) with optimally chosen n numbers of weights, w_i by minimizing the estimated errors, e_i.

Figs. 6 show the example of time series of observed versus predicted values of D.O. Fig. 7a shows the time series of observed D.O. with upper and lower limits of D.O., while in Fig. 7b show the warning signal issued at the time the observed value exceeded

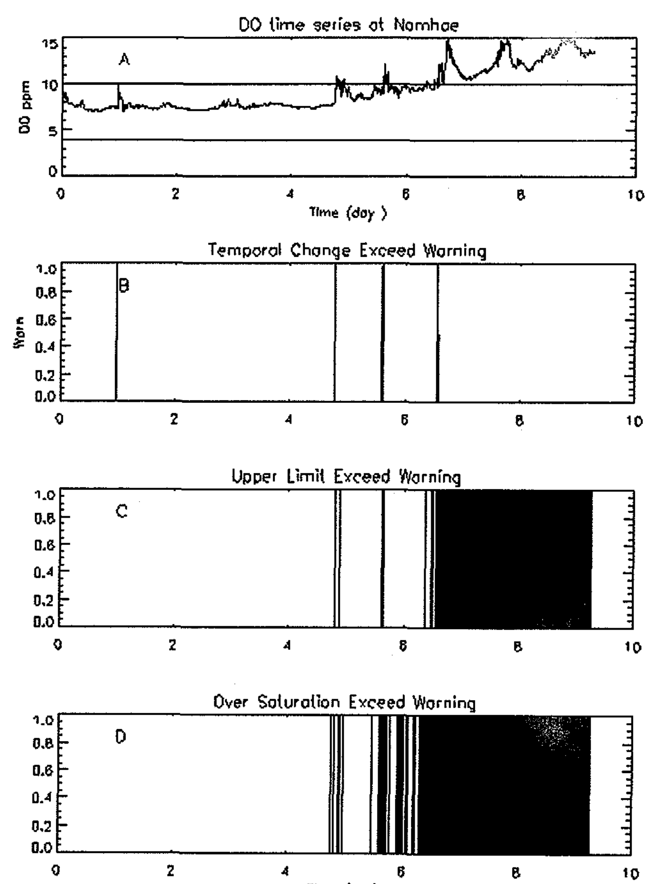

Fig. 7. A warning model with different conditions; (a) upper and lower limits of D.O, (b) threshold value of time rate of change, (c) upper limits, (d) 30% of theoretical D.O. saturation level.

threshold value of time rate of change, in Fig. 7c upper limits, in Fig. 7d shows the 30% of theoretical D.O. saturation level as a function of temperature and salinity. In practice, a warning signal will be issued if the predicted value meet any conditions of threshold value of rate of change, upper and lower limits, over- and under-saturation levels.

SUMMARIES

In this study, a system for realtime monitoring of water quality conditions in coastal waters is described in terms of system configuration. Issues on the QC/QA for the database produced from the monitoring system are examined along with the some notions from experiences of maintenance and error analyses.

Advantage of establishing the monitoring systems are obvious in several aspects; 1) from the scientific point of view, short-term fluctuations of processes of time scale less that a few hours, say three hours, in coastal waters are associated with wind, wave, mixing and diffusion. These processes are the subjects which remain still poorly understood, yet most important for local water quality and ecosystem. 2) from practical point of view, realtime monitoring will be very useful to provide information and warning messages at the right time to users of various arena such as environmental managers, local aqua-culture fisherman, and governmental administrative staff. In this study, we demonstrated the usefulness of realtime monitoring system and address data quality issues. Establishing network of such autonomous realtime monitoring system across main coastal water bodies would be highly recommended for national environmental management plan.

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