Water Environmental Prediction System with Satellite Data

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A near-real-time simulation system using satellite data has been developed for use in oil leaks, blue tide movement and environmental assessment in coastal areas. An example of simulation for Tokyo Bay using temperatures and wind data observed by a satellite is demonstrated in this paper.

1. Outline

Mitsubishi Heavy Industries, Ltd. (MHI) has developed the prototype of a real-time simulation system to simulate and forecast the movement of seawater. This system is designed to serve necessary emergency countermeasures by rapidly predicting and evaluating the impacts of accidents like the recent oil leak caused by a tanker in coastal areas.

This system can predict not only the impact of oil leaks, but also seasonal environmental changes such as blue tide movement — a great concern to fisheries — and changes in seawater currents caused by river outflows due to a heavy rain, change in water quality due to mass movements of bay water forced by strong winds, and the large-scale drift of jellyfish population.

In addition, evaluating the extent of changes in water currents and environmental changes due to various construction works along bay coast provides important information for decisions on measures related to the works.

2. Function and operation method of the simulator

This simulation system is distinguished from others by utilizing the data transmitted from an earth survey satellite and combining the distributions of sea surface temperatures, chlorophyll concentrations (water quality index), etc. in the simulation in order to improve the reproducing reliability of the actual seawater conditions. In other words, this simulator computes bay water currents for about 15 days, the minimum time required to conform to a tide cycle from one spring tide to the next via a neap tide, and then reflects the horizontal and vertical distributions of the water temperatures and densities which influence the water currents according to each season.

Further, it can simulate the rapid increase of a river outflow caused by unusual weather such as a typhoon, or the change of a water current due to a deflective blow. It also has a function to simulate water pollution indexes such as DO (dissolved oxygen) and COD (chemical oxygen demand) by combining data on the cyclic processes of materials like phosphorus with data on the water current.

3. Water environment prediction system

The method of predicting such impacts by applying average figures for each season is effective for prior evaluations like environmental assessments. However, when predicting impacts due to unexpected accidents like oil leaks and planning to support emergency countermeasures, there are limitations in the method of simply applying the averages of atmospheric data and marine meteorology. Hence, a more precise prediction method must be established.

The system demonstrated here is an integrated system developed to instantly reflect real-time monitored data in the prediction output.

Fig. 1 shows the configuration of the system. Its main component systems include the receiving device for observed data relating to atmospheric and marine meteorology, the data processing and display system, the data storage and management system, the predicting simulation system, and the telecommunication system.

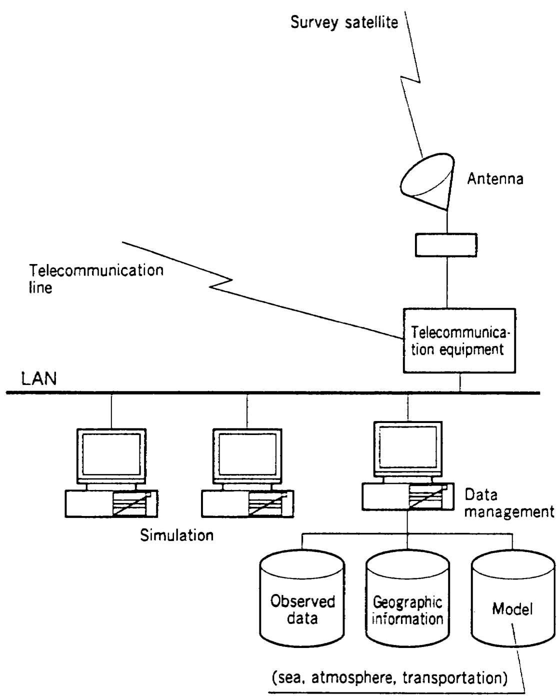

Fig. 1 Water environment prediction system
This figure shows the basic composition of the system to receive and process observed data.

The observed data are classified into two categories: data observed by the satellite and data obtained at sea level. From fixed-point observatories like buoys, time series data such as the current velocities, temperatures, and densities of the seawater are obtained. The data observed by the satellite can cover a wide range spatially but are discrete in time series. On the other hand, the data obtained from the fixed-point observatories are highly accurate, dense, and continuous in time series but very non-dense and discrete spatially.

Of course, the observed data cannot be used as they are:

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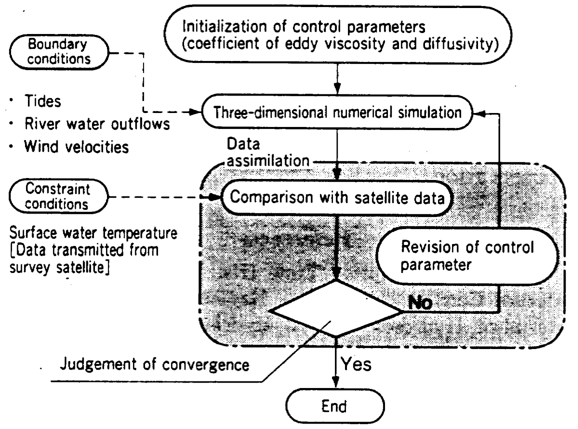

Fig. 2 Simulation flow chart
This is a calculating flow chart for use when applying assimilation.

appropriate processing and display of data according to each predicting purpose are crucial. The data processing and display system demonstrated here also controls data qualities.

The simulation system consists of components for input, analysis, and display. As shown later, this system is characterized by being provided with a condition-setting function based on the data assimilation, as one of the functions of the input component, beside the general input-output functions. For the condition-setting function, this system has a mechanism to link with the observed data. The telecommunication system serves mainly to communicate the observed data. The data from the satellite can be received by wireless directly from the satellite and the data from the fixed-point observation can be received by wireless through a communication satellite.

4. Water-environment-predicting function by numerical simulation

Usually, for numerical simulation to predict water environmental changes, the input data consist of the averages obtained by analysis of observed data on water qualities and atmospheric and marine meteorology. However, in order to predict impacts due to an event, the momentary changes of atmospheric and marine meteorology must be reproduced in real-time by a computer.

Here, we present an example of a simulation for prediction of the currents including the wind effects in Tokyo Bay, by means of the data assimilation technology. The information primarily required to predict impacts is water currents in the bay. In the event of a catastrophe such as an oil leak, all the impacts to the specified places are dominated by the water currents in the bay. The observed data used for the simulation include the wind directions and velocities, together with the sea surface temperature distribution obtained by the survey satellite, NOAA. The wind velocities are received hourly. On the other hand, the surface temperature distribution from NOAA is delivered daily in the form of images rendered at a nearly constant visual angle[1].

The collection of the initial conditions and coefficient values required for numerical simulation from observed data discrete both in space and time is termed data assimilation. In the numerical simulation, the input data such as the coefficient of eddy viscosity are determined to minimize the difference between calculated results and observed data on the sea surface temperature distributions by comparing them in discrete time series but dense spatially, using an adjoint method .

Fig. 2 shows an outline of the data assimilation procedure adopted in this system[2]. This procedure is to calculate the water flow by inputting the wind directions, wind velocities, tide changes, and river outflows using the observed sea surface temperature distribution as a constraint condition. The system is based on a three dimensional transient calculation code which takes account of the density distribution dependent both on salt concentrations and water temperatures. **Fig. 3** shows a comparison of the sea surface temperature distribution simulated by the assimilation procedure and that observed by the satellite. Naturally, they conform well. **Fig. 4** shows the water flow corresponding to the sea surface temperature distribution obtained by the simulation shown in Fig. 3. From Fig. 4, it can be seen that a northward wind generates the water currents toward the west on the sea surface layer and toward the northeast along the bottom layer. In other words, it causes a circulating flow between these layers in Tokyo Bay. Therefore, along the coast from the north end of the bay through Chiba Prefecture, there is an upwelling where the low-temperature water-mass of the bottom layer comes up to the surface.

The sea surface current not conforming to the wind direction is generated by the effect of the earth rotation. This is generally termed the Ekman drift current. Stratification appears in summer, and once such currents are generated in Tokyo Bay, the anoxic water of the bottom layer comes up to

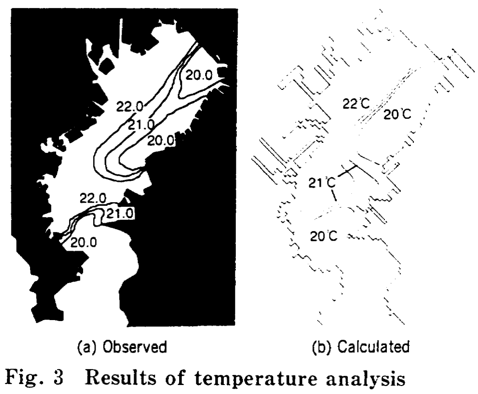

Fig. 3 Results of temperature analysis
The site surface temperature distribution can be reproduced precisely by applying the data assimilation.

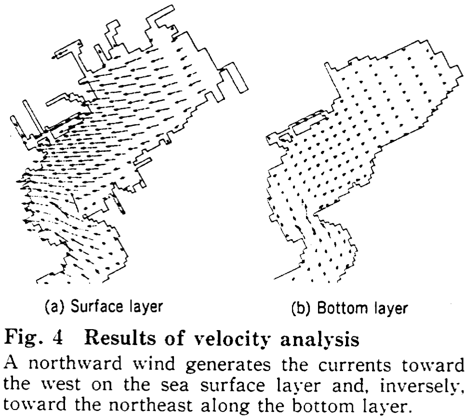

Fig. 4 Results of velocity analysis
A northward wind generates the currents toward the west on the sea surface layer and, inversely, toward the northeast along the bottom layer.

the surface layer, posing a serious threat to marine organisms. Since the water from the bottom layer may contain a large amount of sulfur oxides, it sometimes gives off a luminous blue glow at its upwelling — a phenomenon known as a blue tide. This system has precisely demonstrated why the blue tide is generated in summer along the coast from the north end of Tokyo Bay through Chiba Prefecture.

5. Conclusion

A prototype of the water-environment-prediction system using the observed data of an actual sea area has been developed. This system improves the reliability of the real-time predictions attained by numerical simulations based on observed data. As an actual example, a simulation of the currents of Tokyo Bay has been demonstrated by applying the sea surface temperature distribution data obtained by the survey satellite, NOAA. The accuracy of the real-time simulation can be further increased by applying the assimilation procedure of the current velocity data obtained by the fixed-point observation.

References

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