D-3.3 Modelling of Physical-Biological Processes in the Central Japan Sea with Assimilation of Satellite Data (Final Report)

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Abstract We compared ocean color remote sensing data and optical buoy data from the Japan Sea with results of a simple 1-dimensional physical-biological model. First, we observed three-months time-series of weather, vertical structure of temperature, and sea surface phytoplankton pigment concentration from a moored optical buoy system. The buoy system was developed by the National Space Developmental Agency of Japan and moored from August 25 to November 26, 1993, at the Japan Sea, off Hamada, Shimane. Solar radiation decreased and mixed layer developed during the three months, and sea surface phytoplankton pigments were highest at the early November.

We developed a coupled 1-dimensional turbulence-, optical-, primary production-, ecosystem-model with data set of the buoy. The turbulence model generally reproduced the development of mixed layer. Coupled optical-turbulence model indicates that the phytoplankton affects to the mixed layer dynamics and the heat balance. We used the coupled model with forcing of data from weather station to simulate one-year change of surface pigment concentration off Hamada detected by Coastal Zone Color Scanner. The model well reproduced the time changes of surface phytoplankton pigment concentrations. Autumn bloom was initiated with the introduction of nutrients by the development of mixed layer, and ended by the light limitation caused by deep mixing. On the other hand, spring bloom started with the warming of surface water with high nutrient concentration and ended with depletion of nutrients.

Key Words Ocean Color Remote Sensing, Optical Buoy, Physical-Biological Model, Chlorophyll, Phytoplankton

1. Introduction

Recently, human activities are expected to start to affect to the large scale ocean, such as continental shelf area, and it is required to evaluate the influences. However, the frequency of traditional observation methods is not enough for the evaluation because the ocean is huge and spatial and temporal variabilities are large. Remote sensing from space is expected one of the most effective method for monitoring ocean environment, and it is required to explore the method for environmental evaluation with the data. In this study, a physical-biological model is used with ship observation data, satellite two-dimensional data, and buoy time-series data to analyze the phytoplankton dynamics in the Japan Sea as a test case.

2. Buoy Data

Three-month (August 25 - November 26, 1994) time series of ocean color as well as water temperature were measured by optical buoy system moored off Hamada, in the Japan Sea[1-2]. This buoy system was developed by National Space Development Agency of Japan for verification of Ocean Color and Temperature Sensor (OCTS) on Advanced Earth Observation Satellite (ADEOS) be launched on August 1996. Physical data showed decrease of surface water temperature and development of mixed layer during three-months. Calculation of heat flux[3] from the buoy meteological data indicated that the decrease of solar irradiance and of atmospheric temperature and the increase of wind stress caused the development of mixed layer.

Concentration of chlorophyll a calculated from downward irradiances with three band algorithm proposed for OCTS[4] showed less change during first two months and gradual increase with peak at the middle of November. This general trend was also seen by the chlorophyll fluorescence, except the fluorescence increased about one-order after a typhoon. This increase of fluorescence was caused by the damage of cleaner system of window of fluorometer. Both downward irradiances and fluorescence indicated a rapid decrease of chlorophyll a few days after the buoy deployment, and this decrease may be caused by rapid change of water mass around the buoy. Calculation of nutrient input to the mixed layer with the development of the mixed layer indicated that the increase of chlorophyll was caused by nutrient supply. Sveldop's critical depth theory[5] indicated that further deepening of mixed layer caused the light limitation and resultant decrease of chlorophyll after November.

3. Comparison of Buoy Data with Vertically 1-D Model

Vertically 1-D model was developed for the comparison with the buoy data. Buoy data was used as forcing of the model with heat flux and wind stress. Physical model is Mellor and Yamada Level 2 turbulence model[6] with the program of Dr. Endoh of the Meteological Research Institute[3]. The model reproduced decrease of surface temperature and deepening of mixed layer by the buoy observation. However, the model could not reproduce the increase of temperature below the mixed layer and resulted that the shallower mixed layer depth than the observation. This may be caused by luck of turbulence below the mixed layer created with 1-dimensional assumption as well as the luck of advection in this region.

The turbulence model was coupled with optical model as a next step. Both non-spectrum model[7] and spectrum model[8] was tested for the experiment. The result of the model indicated that the phytoplankton actually changed the heat budge on the surface mixed layer; higher phytoplankton concentration resulted higher surface temperature with lower sub-surface temperature and resulted lower heat flux to the ocean.

Finally, a simple phytoplankton growth model with a primary production model[8] based on photosynthesis quantum yield and with a linear decrease term was coupled. This model showed increase of phytoplankton with the deepening of mixed layer depth during three months; however, the decrease of phytoplankton for November was not reproduced because the deepening of the mixed layer was not enough.

4. Comparison of Satellite Data with Vertically 1-D Model

Results of the 1-D model was compared with the data of ocean color satellite data. Satellite data is the monthly composite of 1978-1986 Coastal Zone Color Scanner data[9], and it was shown that the two maxima of phytoplankton pigment presented as spring (April) and autumn (October-November) bloom. In order to compared with this 1 year data, the model was forced by data from Hamada meteological station and the initial condition was the data taken at the buoy position for the deployment.

The model results showed that the surface decreased with deepening of mixed layer from October to March. The surface water temperature increased and stratification started early April. Predicted surface phytoplankton pigment concentration increased November and gradually decreased until the pigment jumped on April. Predicted vertical distribution of chlorophyll showed subsurface maximum until the surface pigment increased and decrease of mixed layer chlorophyll with deepening of mixed layer until March. After the increase of surface chlorophyll during April, the subsurface chlorophyll maximum developed. These changes of the pigment concentrations are consistent with the predicted nutrient concentrations. The nutrient concentration was low at the surface until the surface chlorophyll reached the maximum on November and gradually increased in the mixed layer.

Analysis of growth rate of the phytoplankton showed that the positive growth only at the subsurface maximum during low surface nutrient condition and only at the surface in the mixed layer from November to April. The critical depth was also calculated from the model, and it is shown that the critical depth was far deeper than the mixed layer before pigment concentration increased. However, critical depth shallowed and mixed layer deepened and they were almost same after the pigment concentration reached the maximum on the last November. Critical depth and mixed layer deepened together until April when the mixed layer suddenly shallowed.

Those changes of chlorophyll, nutrient, growth, mixed layer and critical depth indicate that following story. Deepening of mixed layer at the late summer broke the subsurface chlorophyll maximum and supplied nutrient in the mixed layer and resulted increase of surface chlorophyll. Further deepening of mixed layer induced the decrease of chlorophyll concentration in the mixed layer mostly because low light induced no growth and deepening of mixed layer dilute the chlorophyll. The spring bloom was caused by the sudden development of stratification at the surface and depletion of nutrient developed the subsurface chlorophyll maximum.

There are several problems remained for this model. First of all, the development of mixed layer from summer to autumn was relatively well reproduced; however the development of stratification from spring to summer was not reproduced. This is probably because of the inherent problem of the turbulence model as well as one-dimensionality. This may be concurred with development of assimilation technique of buoy data into the physical model. Second problem is that the model did not take into account the regeneration of nutrient. This caused the rapid decrease of total mass in the model system. It is required to develop the regeneration model. Furthermore, there are number of possibilities that the magnitude of model pigment concentration did not exactly correspond to the satellite and buoy data. Obviously further refinement of the model is necessary.

5. Conclusion

With this study, usefulness of combination of ship, buoy, satellite data with a physical-biological model to understand the natural variability of phytoplankton pigment was shown. There are number of parameters that are only available with the measurements from ship; however the time and space coverages are limited. Buoy and satellite are powerful new tools to take the data of remote area with the extension of time and space; however the measurable parameters are limited. A numerical model is necessary for combining of information from ship, buoy, and satellite data and for reproducing the consistent natural variability of ecosystem.

Unfortunately, it was not possible to use satellite data coincided with buoy and ship observations for this study. However, new ocean color and temperature sensor (OCTS) will be on-board of ADEOS, which will be launched on August, 1996. The satellite will also measured wind velocity and direction above ocean surface. Combined use of these remote sensing data with ship and buoy data and analysis with physical-biological model similar to the one developed in this study, are useful and necessarily to evaluate how human activity affect to the large scale ocean.

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