2. Atmospheric and Oceanic Environment Modeling

Study of Basin-Scale Ocean Circulation related to Global Chlorophyll Distribution

Contact Person | Laboratory head, Masahiro Endoh
Meteorological Research Institute,
Tsukuba, 305 Japan

(Research Organization) | Yoshiteru Kitamura, Goro Yamanaka, Atsushi Obata, Tatsuo Motoi and Yoshifumi Nogi
Meteorological Research Institute

Keywords | global ocean circulation model, surface mixed layer, chlorophyll, satellite ocean color data, spring bloom

1. Background

Recently, effects of human activity are expanding to the global ocean scale. Necessity of evaluating anthropogenic effects is increasing. Satellite ocean color data is an important indicator of ocean surface content of chlorophyll or phytoplankton as oceanic primary productivity, which is affected by the oceanic nutrient distribution related to the environmental deterioration. Therefore we need to develop useful satellite ocean color data set to evaluate the ocean environment.

2. Objective

In order to prepare useful satellite oceanic chlorophyll data for evaluation of the ocean environment, it is necessary to realize relationship between global chlorophyll distribution and global ocean circulation as a physical factor which affects biochemical environment of the ocean.

As the first step, we develop a global ocean circulation model which resolves processes influencing the chlorophyll distribution, such as circulation in the surface layer, depth of the surface mixed layer, upwelling of deep water and so on. Next, we compare horizontal structure of the surface mixed layer reproduced by this model, with the global satellite-derived chlorophyll distribution.

3. Method

A numerical model employed is a standard global ocean circulation model with realistic bottom and coastal topography and resolution of 2.5° x 2° x 21 levels (Endoh et al., 1994(1)). Embedded in the model is a turbulent mixed layer model which has a closure scheme of level 2 (Mellor & Yamada, 1982(2)) with 5 meters resolution in the upper 20 meters. It gives a set of turbulent mixing coefficients of temperature/salinity and momentum, which actually mixes water in the vertical direction and predicts new temperature/salinity and current. The model is driven by the monthly mean climatological wind stress (Hellerman & Rosenstein, 1983(3)), monthly mean temperature and seasonal mean salinity (Levitus, 1982(4)) after equilibrium calculation with the annual mean climatology forcing as reported in (1). Using the CGER's Supercomputer, the calculation was carried out for 11 years until it reaches to a quasi-steady state with seasonal variation. We define the surface mixed layer depth as the depth where the downward temperature deviation in a vertical grid column reaches 0.5 °C measured from the sea surface, and have discussed the seasonal variation of the global distribution of the surface mixed layer depth in the 11th model year in the last report (Endoh et al. 1994(5)).

In the study of the 1994 fiscal year we investigate global relationship between the seasonal variation of the surface mixed layer depth in our model and that of the surface chlorophyll concentration from the satellite ocean color data which is derived monthly from the Coastal Zone Color Scanner data from November 1978 to June 1986 (Ishizaka & Takahashi, 1993(6)). Comparison of these data is made in terms of the *Sverdrup(1953(7))'s critical depth*, which is defined as the depth where the phytoplankton production integrated downward from the sea surface balances the integrated destruction in the well-mixed layer. It is proposed as a useful criterion for spring bloom of phytoplankton in (7) by the analysis at the particular observational station. The critical depth is practically controlled by the insolation at the sea surface and the visible light extinction coefficient of sea water. The global distribution of optical water types of Jerlov (1976(8)) is used for the extinction coefficient in this study. The seasonal variation of the mixed layer depth in the in-situ observed data (4) is also compared with that of the satellite-derived chlorophyll data for the verification of our model.

4. Results

By means of the method introduced in the preceding section, we discuss influence of the seasonal variation of the mixed layer depth on the spring bloom of phytoplankton, especially in the northern hemisphere because of relatively abundant satellite data amount in this region.

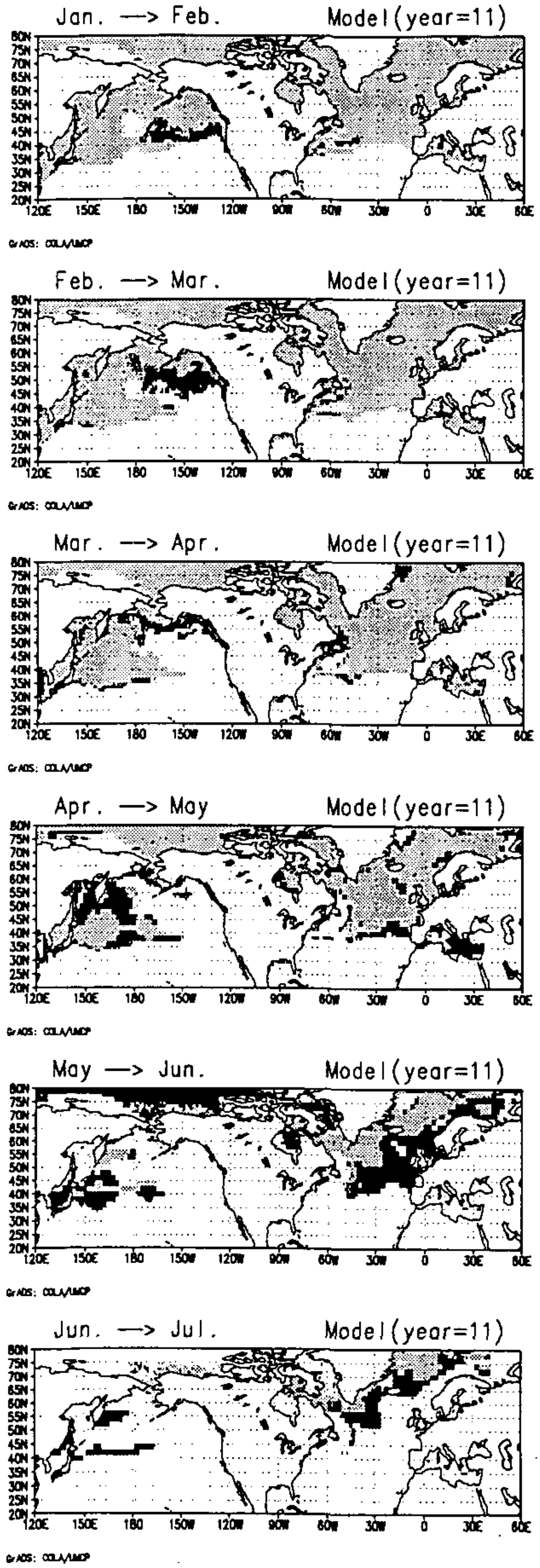

Fig. 1 Seasonal variation of the surface mixed layer depth in the model in terms of the Sverdrup(1953)'s critical depth. The black indicates the region where the mixed layer depth becomes shallower than the critical depth from the previous month to the current month. The gray area shows the region where the mixed layer depth is deeper than the critical depth in both months or the region where the mixed layer depth becomes deeper than the critical depth from the previous month to the current month. The white area shows the region where the mixed layer depth is shallower than the critical depth in both months.

In Fig. 1, the region where the mixed layer depth in the model becomes shallower than the Sverdrup's critical depth from the previous month to the current month in winter and spring seasons, is shown by the black. It is expected to be the region of the spring bloom where the light's condition for photosynthesis is just satisfied in the current month in terms of the Sverdrup's hypothesis. Gray area indicates the region where the mixed layer depth is deeper than the critical depth in both months or the region where the mixed layer depth becomes deeper than the critical depth from the previous month to the current month. White area is the region where the mixed layer depth is shallower than the critical depth in both months. In Fig. 2, the region where the surface chlorophyll concentration from the satellite data increases by more than 100 % from the previous month to the current month, is shown by the black. This area may be regarded as the region of the spring bloom.

At the mid- and high latitudes of Fig. 1, the mixed layer depth in the model becomes shallower than the critical depth, mostly in the spring season when the condition for the spring bloom is satisfied for photosynthesis. This is consistent with the fact that the wind driven shallow mixed layer grows remarkably with the increase of insolation at the sea surface in spring. In the North Pacific, conditioning for the spring bloom in the western region is later than that in the eastern region. Conditioning occurs almost in the same time of the year over the whole basin in the North Atlantic. These features are well compared to the basin-scale pattern of the spring bloom in Fig. 2, though the conditioning for the spring bloom in the model is later than the bloom in the satellite ocean color data by one/two months in the western region of the North Pacific and in the North Atlantic.

The basin-scale pattern of the spring bloom is considered to be due to following mechanism. The deeper mixed layer is formed in winter in the region where the intensified winter convection occurs with the cooling of the saline water advected by the Kuroshio or the Gulf Stream as the western boundary current of the subtropical gyre. The deeper mixed layer results in the later spring shallowing. Therefore, due to difference of zonal extent of the saline waters, the Kuroshio affects only the western region of the basin while the Gulf Stream affects the whole zonal scale of the basin, which leads to the difference of the basin-scale pattern of the spring bloom between the basins.

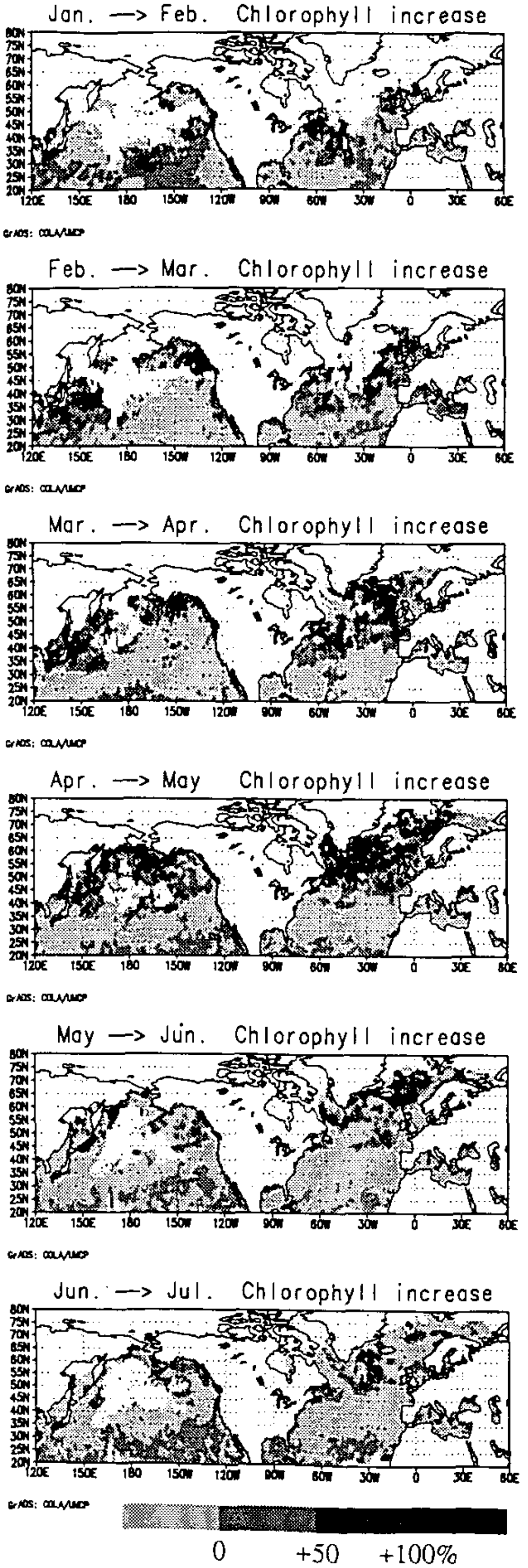

Fig. 2 Seasonal variation of the sea surface chlorophyll concentration from the satellite ocean color data. The black indicates chlorophyll increase of 100 % or more from the previous month to the current month.

Seasonal variation of the surface mixed layer depth in the in-situ observed temperature data is also compared with that of the surface chlorophyll concentration from the satellite data. Conditioning for the spring bloom in the Levitus climatology (4) is shown in Fig. 3 in the same manner as that in Fig. 1 for the model. Comparing Figs. 2 and 3, similar features of the basin-scale pattern of the spring bloom in each basin are confirmed as seen in the model (Fig. 1). Conditioning for the spring bloom in the Levitus climatology occurs from March to May in the western region of the North Pacific and in the North Atlantic at the mid- and high latitudes, which well corresponds to the spring bloom period in the satellite data.

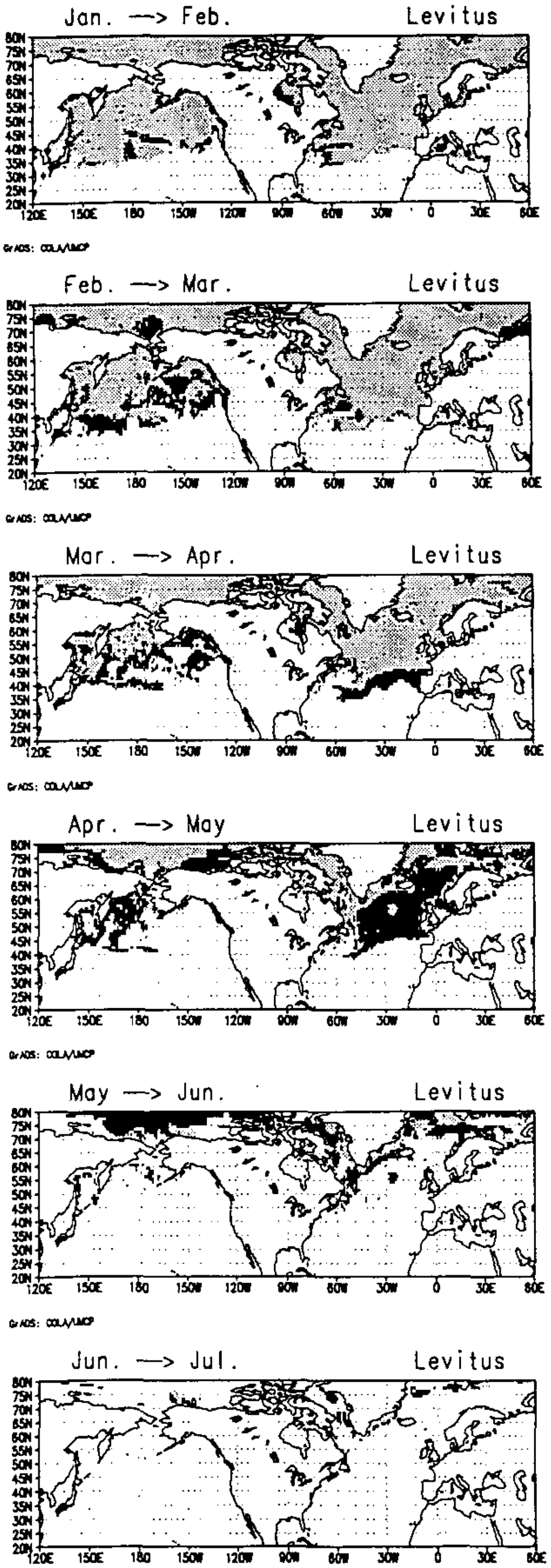

Fig. 3 Seasonal variation of the surface mixed layer depth in the Levitus climatology in terms of the Sverdrup(1953)'s critical depth. The black indicates the region where the mixed layer depth becomes shallower than the critical depth from the previous month to the current month. The gray area shows the region where the mixed layer depth is deeper than the critical depth in both months or the region where the mixed layer depth becomes deeper than the critical depth from the previous month to the current month. The white area shows the region where the mixed layer depth is shallower than the critical depth in both months.

5. Summary

Seasonal variation of the surface mixed layer depth [1] in a global ocean circulation model (with a turbulent closure mixed layer model) with climatological monthly mean forcing and that [2] in the in-situ observed temperature data, are compared with seasonal variation of the satellite ocean color data (the sea surface chlorophyll concentration). It is shown that at the mid- and high latitudes shallowing of the mixed layer depth from winter to spring season well explains basin-scale features of spring bloom of phytoplankton in terms of the Sverdrup(1953)'s critical depth for conditioning of photosynthesis.

In future study, interannual variation of the surface mixed layer depth in the model with the forcing of climate variation will be compared with that of sea surface chlorophyll concentration derived from the satellite ocean color data and the in-situ observational data.

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Development of the Transport, Transformation and Removal Model for Acidic and Oxidative Pollutants in the East Asia

Contact person

Junji Sato
Applied Meteorology Research Department
Meteorological Research Institute
Japan Meteorological Agency

(Research Organization)

Takehiko Satomura
Hidetaka Sasaki
Shunji Takahashi
Kikuo Okada

Keywords

acid rain, long-range transport, numerical model, deposition, transformation

1. Background

Nowadays a large amount of energy is being consumed in consequence of the rapid progress of industrialization in the East Asia. More than 23 million ton/year of SO_x is produced and released into the atmosphere, and they affect biosphere after transported in long distance. The acid deposition thus becomes a serious problem. In the East Asia, however, observation network of the acid deposition is not developed. Therefore it is very difficult to estimate amount of the acid deposition except using numerical models.

2. Objective

To understand transport process of atmospheric pollutants related with acid rain and to estimate amount of the acid deposition, a long-range transport model which includes transformation and dry/wet deposition processes of pollutants has been developed. Recent investigations reveal that the in-cloud scavenging such as cloud nucleation of pollutants through the process of cloud formation greatly contribute the wet deposition process. Using two dimensional cloud model, Flossmann[1] calculated deposition process of marine aerosols by cloud. Karamachandani and Venkatram[2] estimated formation process of sulfate in non-precipitation cloud by model. The objective of this study is to develop a precise transport model, and to estimate the amount of the acid deposition in the East Asia.

3. The improvement of model

Since the details of the long-range transport model are explained in this report on 1993, the model description is left out here. In order to append the in-cloud scavenging process of acidic pollutants to the long-range transport model, the model is improved by following ways:

- increasing the spatial resolution of the meteorological model to evaluate clouds more accurately in the model,
- developing a method keeping the model resolution high while maintaining wide model area of the East Asia.

The fine mesh limited area model over the Asian region (FLM) which was employed operationally for weather forecasting in the Japan Meteorological Agency (JMA) is replaced with the spectral asian model, and the spectral limited area model around Japan with higher resolution (JSM) is nested in the Asian spectral model through the spectral boundary coupling method (Kida et al.[3]). The detail of coupling method is described by Sasaki et al.[4]. Furthermore, in order to make the wet deposition process more precise, the model is also improved to provide the three dimensional distributions of cloud and rain drops for the calculation of interaction processes among precipitation, cloud and pollutants.

The climatological value is used as initial condition for the prediction of the surface temperature which greatly affects the structure of atmospheric boundary layer.

3. Results

To verify the performance of the improved meteorological model, long-term integration is conducted. The calculated results are compared with the observed and analysis data. The predicted sea-level pressure and movement of depression are almost in accord with them of the Japan Meteorological Agency operational global objective analysis data sets (GANL). Figure 1 shows an example of the predicted distribution of precipitation (a) and corresponding cloud distribution from geostationary meteorological satellite (GMS) visible imergery (b). It is seen from Fig. 1 that the predicted distribution of precipitation agrees with cloud in location. However, the model sometimes predicts the precipitation under a thin clouds. This provides us useful information to determine the threshold of precipitation.

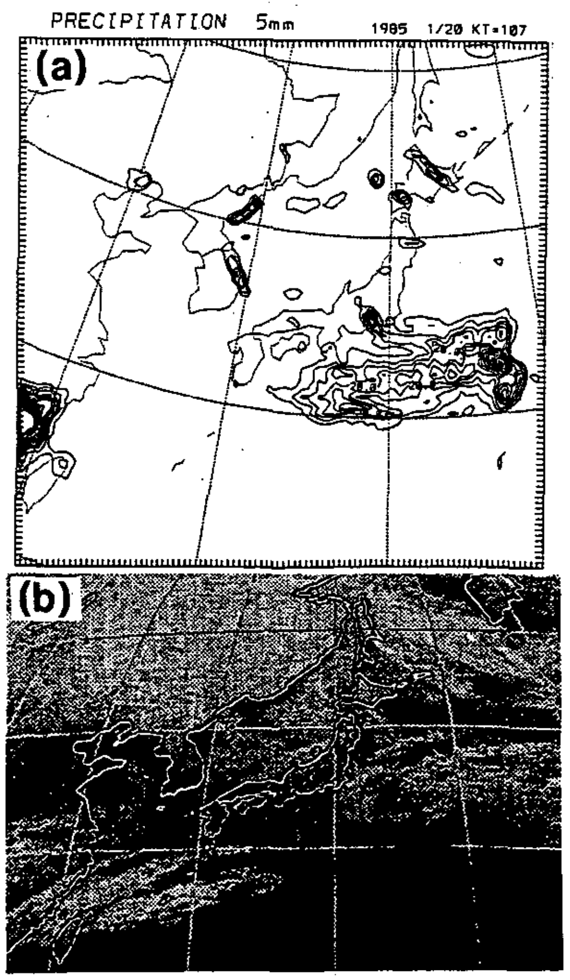

Fig. 1 The distribution of precipitation by the model simulation (a) and the observed cloud distribution (b).

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A Study of Modeling of Local CO_2 Circulations

Contact Person: Laboratory Head, Yasuo Sato
Applied Meteorology Research Dept., Meteorological Research Institute,
1-1 Nagamine, Tsukuba, Ibaraki 305, Japan

Research Organization: Hidetaka Sasaki, Takehiko Satomura, Akira Yamamoto, Kazuyo Adachi
Applied Meteorology Research Dept., Meteorological Research Institute,
Kazuo Mabuchi, Takashi Koide, Masaru Chiba, Kiyotaka Shibata
Climate Research Dept.,Meteorological Research Institute,
Takehisa Oikawa, Nobuko Saigusa
Institute of Biological Sciences, University of Tsukuba

Key Words: Carbon Cycle, Local Meteorology, CO2 Flux, Climate Model, Surface Hydrology, Plant Physiological Process

1. Introduction

It is an especially important and basic issue to make clear the mechanism of carbon dioxide(CO2) circulations and budgets in the study of global warming. The so-called "CO2 missing sink issue" shows that we have not had sufficient knowledge of CO2 circulations. Unless we can make clear the problem, it is difficult to draw the future image of the global warming phenomenon.

The CO2 circulations are deeply influenced by ecosystems, and especially through local weather and climate. Thus, we need to simulate CO2 circulations after modeling local weather and climate in a model study of CO2 circulations.

In this study, firstly we construct the model of the relation of local weather and surface hydrology processes including land ecosystems. Secondly, in the model, we numerically simulate daily variations of atmospheric CO2 concentration by estimating CO2 fluxes. As a result, we can estimate the atmospheric CO2 concentration. By doing so, it will be possible to evaluate the role of processes associated with so-called "CO2 missing sink" and their relative degree of importance.

2. Method

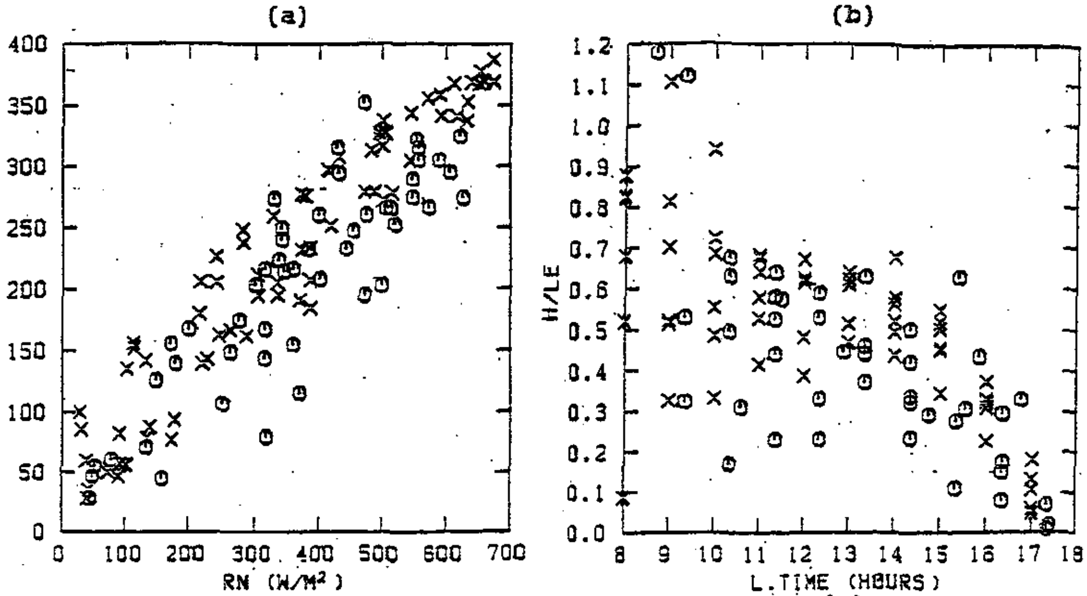
Firstly, we develop a high-quality nested local climate model. Secondly, we develop a simple surface hydrology model including plant physiological processes for use in a 3-dimensional local climate model. In that model, we treat explicitly CO2 fluxes between the atmosphere and land surface ecosystems according to daily variations of local weather. Thirdly, we will simulate the local CO2 circulations and budgets with use of the developed model. Lastly, through analyzing results of the model simulations, we will investigate the role of variety of processes associated with the so-called "CO2 missing sink", and their degree of relative importance.

3. Results.

We developed a 3-dimensional nested local climate model to explicitly treat CO2 fluxes between the atmosphere and land ecosystems according to daily variations of local weather. As the first case, two models are nested. The outside model is results of a global general circulation model or ordinary global meteorlogical observations. The inside model is the Japan Spectral Model (JSM) with the resolution of DX=30km; its region size is about 2500 x 3000km2.

On the other hand, a simple surface hydrology model including plant physiological processes was developed for use in a 3-dimensional local climate model. By giving boundary atmospheric conditions, the model was tested in comparison with observed data (Verma et al.(1986)) in a deciduous forest of North America for 6 days in August when they were fine weather during daytime except one day and in a grassland site in the University of Tsukuba for April to November in 1993 and 1994. Figures 1a,1b,1c show the results of this model for the case of a deciduous forest. Fig.1a is a relation of upward latent heat flux versus downward net radiation flux. It contains the data for observed 6 days. A sign (○) denotes the observed values, whereas a sign (×) the computed.

Computed latent heat fluxes tend to be larger than observed fluxes around about the timespan near local



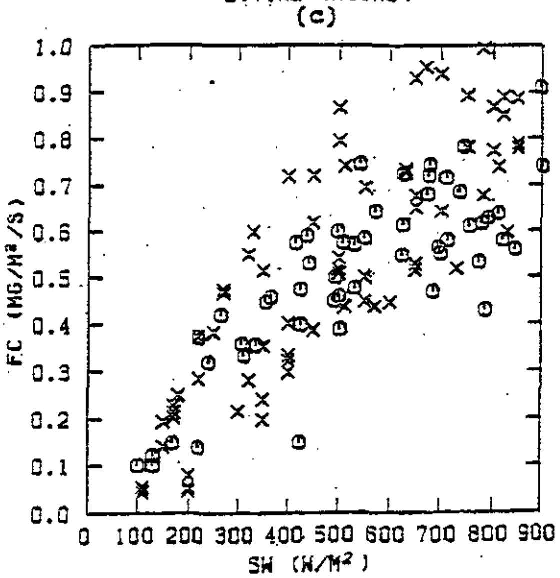


Fig. 1a Upward latent heat fluxes versus downward net radiation. A sign (○) denotes observed values, whereas a sign (×) denotes computed values.
1b Daily variation of the daytime Bowen ratio.
1c Daytime net carbon dioxide absorption versus downward solar radiation .

noon when there have much net radiation fluxes; the fraction of latent heat fluxes versus net radiation fluxes is at around 0.4 ~ 0.6, it is a similar result in comparison with observed. Fig 1b shows the temporal variation of the Bowen ratio during daytime. Although their values vary day by day, generally speaking, they tend to decrease from about 0.5 in the morning to about 0.1 in the evening. This tendency is almost the same as observed. Fig 1c shows daytime carbon dioxide net absorption versus downward solar radiations. Generally speaking, their values show reasonable values, although the model tends to be greater than that of observed from the morning to noon.

Results of development and tests of horizontally uniform multi-layer canopy model developed by Institute of Biology, University of Tsukuba are stated hereafter. To investigate the characteristics of environmental dependence, we developed a multi-layer canopy model over a grassland ecosystem. The model is an extension of the multi-layer canopy model by Kondo and Watanabe (1992) by incorporating the differences of stomatal responses and photosynthetic model between C3 and C4 plants. Figure 2 shows observed daily variation of net CO2 fluxes on a grassland in the University of Tsukuba and computed values by the model. In this calculation, we assumed two cases about plants; that is, one is composed of all C3 plants,the other is composed of all C4 plants. Generally speaking, computed results have good coincidence with the observed except one day: October 11-th in 1993. A reason of the difference is dintinct: the model does not take defoliation into account.

Although the model validation has been limited to several kinds of plant, soil, and also a certain season, diurnal variations of heat and water budgets of the model showed reasonable results. Diurnal variation of CO2 flux also showed reasonable patterns as compared with observations. Calculated daily variation of CO2 flux reaches its peak value of about 1.0 mg/m2/s during daytime, which value corresponds to the observed values.

On the other hand, a precise horizontally uniform multi-layer canopy model was developed at the

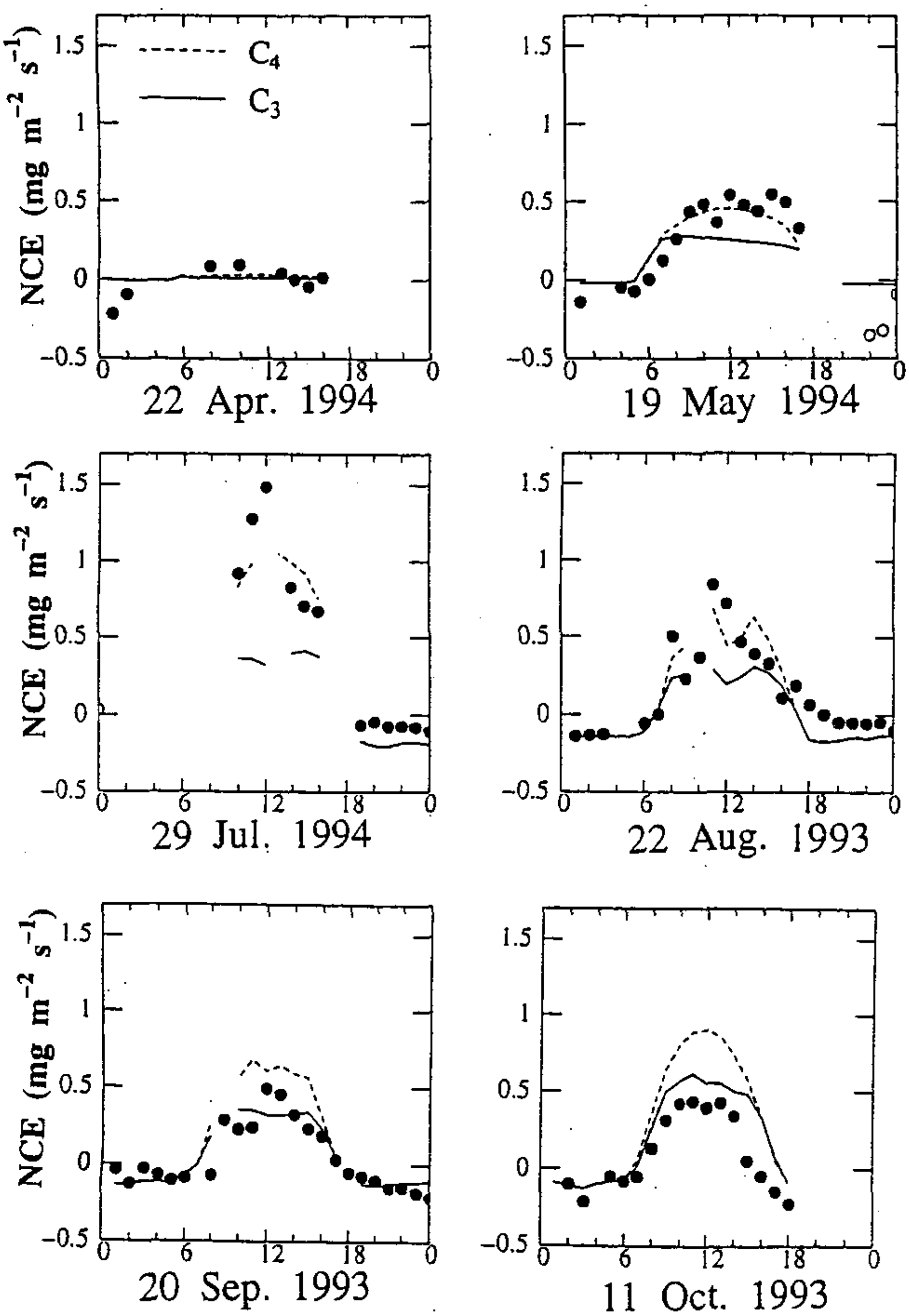


Fig. 2 Daily variations of carbon dioxide fluxes on a grassland. A sign (○) denotes an observed value. Solid and broken lines denote the computed values for C3 and C4 plants, respectively.

University of Tsukuba and applied to a grassland ecosystem. The results for the cases of each month were shown in Figure 2. These model results agreed reasonably well with observations. Using these results, we can check the validity of the parameters of the simple surface hydrology model by the MRI.

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Ecosystem model in Tokyo Bay Part I: Modeling of circulation

Contact Person — Masataka Watanabe
Division of Water and Soil Environment
National Institute for Environmental Studies

Research Organization
Masataka Watanabe — NIES
Shigeki Harada — NIES
Tsuyoshi Takayama — Univ. of Tsukuba
Yuji Ishikawa — FALCON Co.
Yoshinori Miyazaki — Univ. of Tsukuba

Keywords — Tokyo Bay, Density current, Tidal current, Wind driven current

1.Introduction

High concentrations of phosphorus and nitrogen as well as organic matter contaminated the enclosed seas in Japan. Degradation of water quality due to eutrophication have severely affected aquaculture and natural living resources. Bottom water anoxia has increased both temporally and spatially. It is important to understand the complex interactions between nutrient loads, eutrophication and anoxia. A coupled model of hydrodynamic and ecosystem is essential for prediction of eutrophication. Since hydrodynamic transport is an important factor in determining the distribution of the various ecological constituents, the three dimensional circulation model has been developed. The model results were verified with continuous field data of velocity, salinity and temperature for 40 days obtained between September - October, 1989.

2. Description of Model Simulation

The circulation and salinity model used in this investigation was the three dimensional model developed by Blumberg and Mellor (1983, 1987), Blumberg and herring (1987), and temperature model was extended by Watanabe (1994).

Horizontal grid size was 1 km X 1 km and vertical resolution was 10 vertical grid points using a depth-conforming vertical coordinate (sigma system) which was sufficient to resolve surface wind-mixed and bottom tidal mixed boundary layers. The major source of freshwater discharges were from Tsurumi river, Tama river, Sumida river, Arakawa river and Edo river (Fig. 1), and

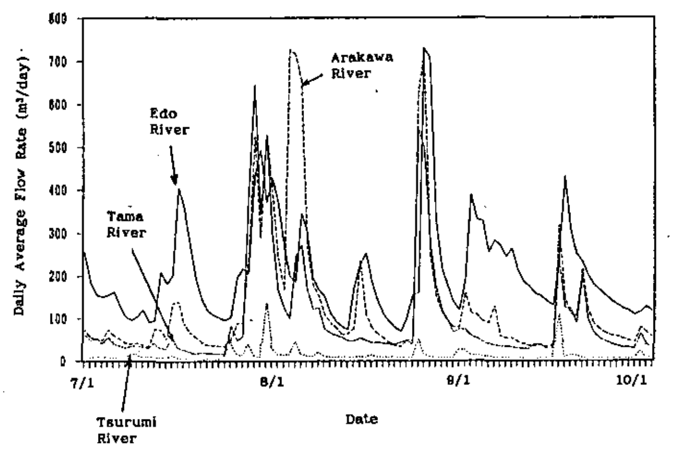


Fig. 1 Daily average flow rates of Tsurumi River, Tama River, Edo River and Arakawa River

upstream of 10 km was included as computational domain. Duily averaged freshwater discharges of these rivers (Ministry of Contruction) were imposed. Tidal forcing was given from harmonic constrants obtained at Jogashima and Iwaibukuro tide gauge stations (Table 1). Meteorological conditions such as daily averaged air temperature, solar radiation, cloud cover, relative humidity, wind velocity were obtained from monthly report of meteorology (Meteorology Agency).

Table 1 Harmonic constants at Jogashima Tide Gauge Station

	phase (°)	amp (cm)
K2	171.0	4.6
M2	146.0	38.0
S2	171.0	17.0
O1	159.0	18.0
P1	177.0	7.3
K1	177.0	22.0
SA	180.0	9.0

Initial distributions of temperature and salinity were obtained from water quality data base of Environment Agency.

Boundary conditions of temperature and salinity at open ocean were obtained from water quality data base of Fishery Agency (Kanagawa Prefecture). Simulation was conducted for 115 days from July 1 1989 to October 21, 1989, and time step Δt was 10 sec.

3. Simulation results and comparison with observation

In order to compare observed and computed results, continuous current observation conducted by Oshima et al., (point D in Fig 2; Hydrographic Department, Maritime Safety Agency, 1989) and field data on anoxic condition in Tokyo Bay (points 1-8 in Fig 2; Environment Agency, 1989) were used.

Fig. 3 shows comparisons of computed and observed vertical temperature and salinity distributions on September 25, 1989. The model simulates very well the observed temperature and salinity distributions. At stations 5 and 6 the effect of freshwater discharge from Arakawa river was well simulated and strong salinity stratification was maintained. We compare in Fig. 4 computed and observed energy spectra at station D (Fig. 2)

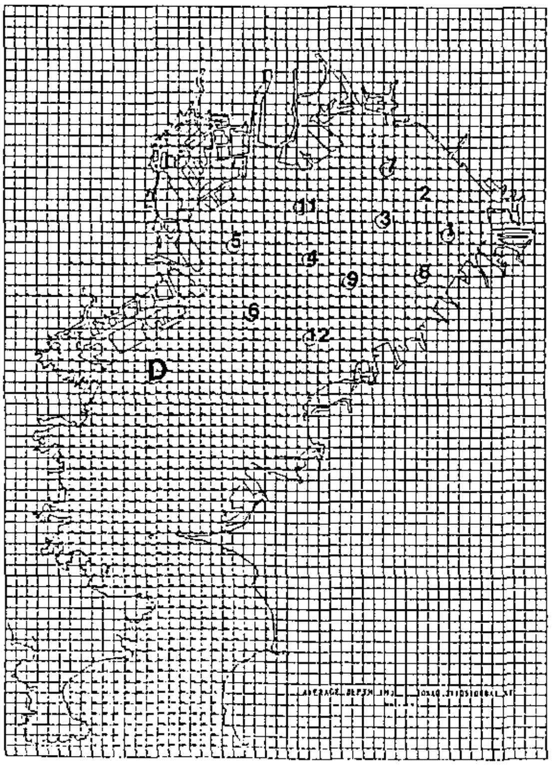


Fig. 2 Measurement points for temperature, salinity and velocity

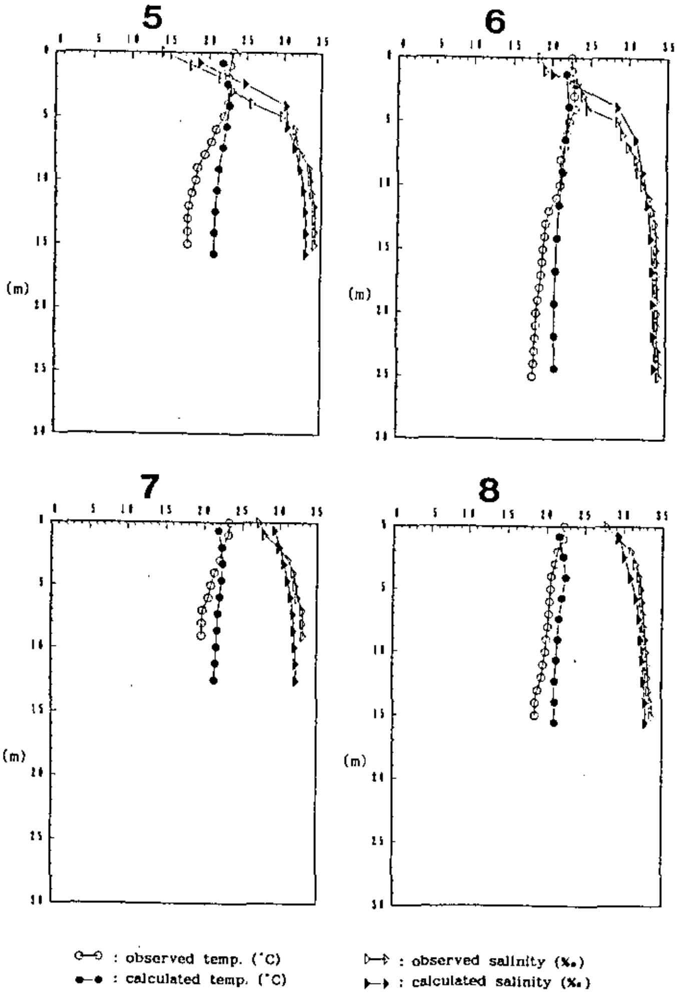
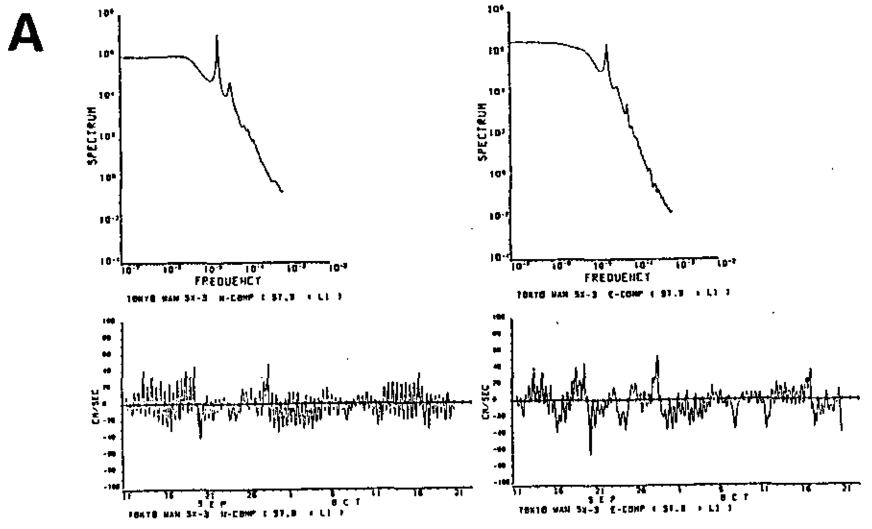


Fig. 3 Comparisons between observed and calculated distributions of temperature and salinity on September 25, 1989



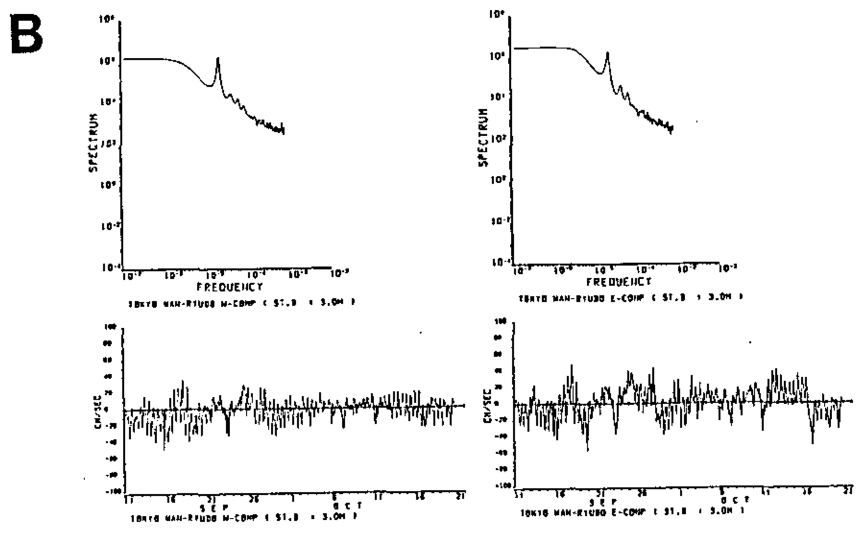


Fig. 4 Energy spectra of (A) simulated surface currents (N-S component and E-W component) at station D, (B) observed surface currents (N-S component and E-W component) at station D

where 40-day observations were available. Model energy bands at diurnal and semidiurnal compare quite well with observations. The simulated energy spectra at high frequency are less than observed energy spectra, and this suggests that the model's grid sizes might not be sufficiently refined to correctly resolve small-scale eddies and shear dispersion processes in Tokyo Bay. However, energy spectra at low frequency are well simulated and this circulation model provides satisfactory fluxes for ecosystem analysis.

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