# 2. Atmospheric and Oceanic Environment Modeling

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

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### 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 one of the most efficient indicators of ocean surface content of chlorophyll or phytoplankton as oceanic primary productivity, which is affected by the nutrient distribution sometime related to the environmental deterioration. Therefore we need to develop useful ocean satellite data set to evaluate the ocean environment.

### 2. Objective

For preparing useful ocean satellite chlorophyll data for evaluation of the ocean environment, it is necessary to realize the relationship between global chlorophyll distribution and global ocean circulation as a physical factor which affects the 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(4)). Embedded in the model is a turbulent mixed layer model which has a closure scheme of level 2 (Mellor & Yamada, 1982(3)) 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.

### 4. Results

In this study, the model is driven by the monthly mean climatological wind stress (Hellerman & Rosenstein, 1983(1)), monthly mean temperature and seasonal mean salinity (Levitus, 1982(2)) after equilibrium calculation with the annual mean climatology forcing as reported in (4). Using the CGER's Supercomputer, the calculation is carried out for 11 years until it reaches to a quasi-steady state with seasonal variation.

Fig.1 and Fig.2 indicate global distributions of the surface mixed layer depth in February (winter in the northern hemisphere) and in August (summer in the northern hemisphere) of the 11th model year, respectively. We defined 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.

Fig.1 (winter in the northern hemisphere) shows that deep mixed layers develop in the Kuroshio current region, Gulf Stream and extension regions of these western boundary currents, and also in the northern part of the Mediterranean Sea. These deep mixed layers are formed by strong vertical mixing due to cooling of the surface saline water. In other regions except the Antarctic Circumpolar Current, wind driven Ekman mixed layers are seen and these depths are about 40 meters in average. In the central area of the equatorial Pacific, surface mixed layer is deeper than the observed climatology. It may be caused by well known overestimation of easterly wind stress in the original Hellerman and Rosenstein's data set.

In the North Pacific, deep mixed layer occupies mainly western mid-latitudes. On the other hand, in the North Atlantic, deep mixed layer extends to the whole mid-latitudes. The difference is due to different eastward transports of saline water by the western boundary currents.

Wind driven Ekman mixed layer with the depth of about 40 meters extends over the whole North Pacific in summer (Fig.2). In the winter Antarctic Circumpolar Current, depth of the mixed layer exceeds 200 meters over the large region. Especially, mixed layers are deeper in the western boundary current (Agulhas, East Australian current and these extension) of the subtropical gyre in the southern hemisphere.

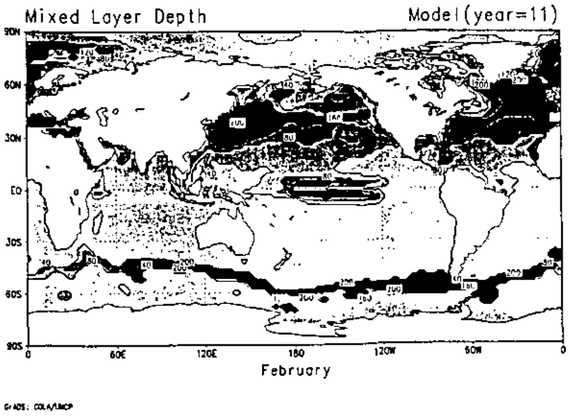


Fig.1 Distribution of the surface mixed layer depth in the model (February). Contours indicate 40, 80, 120, 160 and 200 m deep.

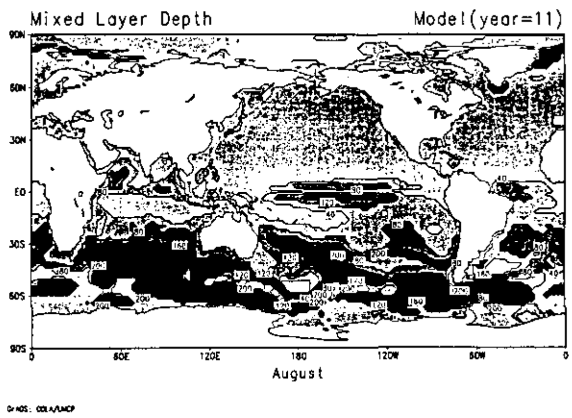


Fig.2 Distribution of the surface mixed layer depth in the model (August). Contours indicate 40, 80, 120, 160 and 200 m deep.

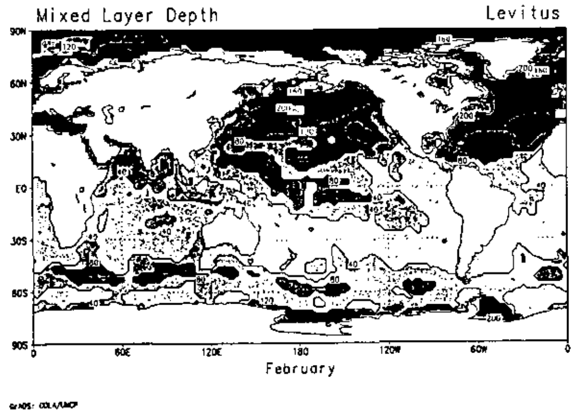


Fig.3 Distribution of the surface mixed layer depth (February) estimated from the Levitus climatology. Contours indicate 40, 80, 120, 160 and 200 m deep.

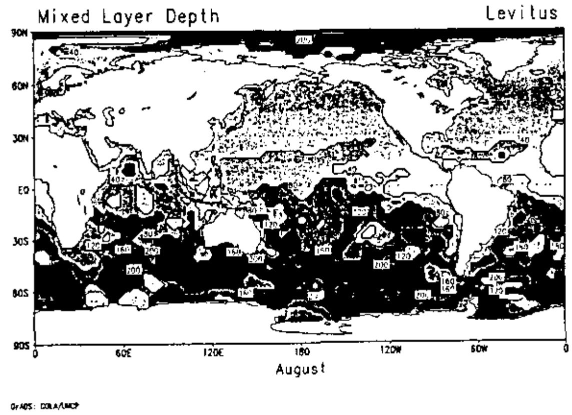


Fig.4 Distribution of the surface mixed layer depth (August) estimated from the Levitus climatology. Contours indicate 40, 80, 120, 160 and 200 m deep.

In Fig.3 and Fig.4, global distributions of the surface mixed layer depth in the Levitus climatology are shown in February and August, respectively. Comparing Fig.1 with Fig.3 (February), or Fig.2 with Fig.4 (August), model and climatology are similar to each other in terms of the basin-scale pattern of distributions of the surface mixed layer depth.

## 5. Summary

A global ocean circulation model with a turbulent closure mixed layer model is integrated for 11 years with climatological monthly mean forcing. In accordance with analysis of the in-situ observed temperature data, the global ocean circulation model well simulates that mixed layers for the winter convection season in the North Pacific are deepest in the western subarctic/subtropical region, while in the North Atlantic, deep mixed layers extend to the whole higher latitudes. In the Southern Oceans, basin-scale convective mixed layer is deepest along the Antarctic Circumpolar Current.

In the future study, spatial and seasonal variations of model surface mixed layer will be compared with those of global chlorophyll distribution derived from satellite ocean color data. Upgrade of the closure scheme in the mixed layer model from level 2 to level 2.5 is also planned.

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

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Keywords

Acid Rain, Long-range Transport, Numerical Model, Deposition, Transformation

1. Background and objective

Recently, more than 23 million ton/ year of SOx is released into the atmosphere over the East Asia, and it is to be feared that they are transported in long distance and acid deposition affects biosphere. In the East Asia, however, observation network of acid deposition is not developed. Therefore one has no method to estimate amount of acid deposition except using numerical model.

To understand transport process of atmospheric pollutants related with acid rain and to estimate amount of acid deposition , a long-range transport numerical model which has transformation and deposition of pollutants by precipitation is developed. Recent investigations reveal that in-cloud scavenging such as cloud nucleation of pollutants through the process of cloud formation greatly contributes wet deposition process. Using 2-dimensional cloud model, Flossmann[1] calculated deposition process of marine aerosols by cloud. Karamchandani and Venkatram[2] estimated formation process of surfeit in clouds by model. In this study, the developed long-range transport numerical model will be improved by following ways:

- adding in-cloud scavenging effects,
- increasing the resolution of meteorological model to evaluate clouds in the model,
- developing a method giving us results of high resolution while maintaining wide model area of the East Asia.

By this model, we will understand transport process of pollutants in long time period and estimate acid deposition over the East Asia.

2. Method

The model consists of two parts: one is a weather forecasting part which predicts meteorological variables, and the other is an advection-diffusion part of pollutants which uses meteorological variables forecasted by the former part as input data.

2-1. *Weather Forecasting Part*

This part of the model is almost the same as the routine weather forecasting model of the Japan Meteorological Agency (JMA). Details of this model are described in a technical report issued by the Numerical Prediction Division of JMA[3, 4]. Two meteorological models (finite difference limited area model over Asia region, and spectral limited area model around Japan) are nested to gain high resolution over focused area. The nesting method is the spectral nesting (Kida *et al.*[5]). The boundary values of the outer model is given by global analysis by JMA.

The primitive equations in $\sigma$-coordinates and the polar stereographic projection at 60°N are used in the model.
The calculation domain of the second model (Asian model) and the topography in the model are shown in Fig. 1.

The domain is covered horizontally by the Arakawa's B grid (73 x 55). The grid size is 127 km at 60°N. The inner-most model (Japan Spectral model) has a resolution of 40 km at 60°N. It has 19 layers in the vertical direction.

As the vertical eddy diffusion, we employ the closure model of level 2 (Mellor and Yamada[6] ). At the lowest layer, Monin-Obukov's similarity theory is applied to determine vertical fluxes from the lower boundary. The surface temperature is predicted.

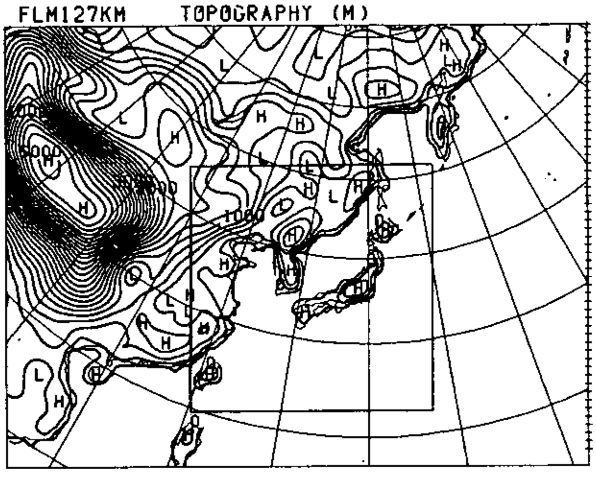


**Fig. 1.** Domain and the topography of the outer model. Inner frame indicates the area of the inner model.

We use two types of parameterization for precipitation process in the model: the large-scale condensation parameterization and the moist convective adjustment. The former prevents supersaturation and the latter keeps the atmospheric lapse rate between the dry adiabatic and the moist adiabatic lapse rate.

2-2. *Advection-Diffusion Part*

Advection and diffusion of pollutants are described by a random-walk model in the same coordinate systems as in the weather forecasting part. Winds, precipitation and diffusion coefficients used in the random walk model are predicted by the weather forecasting model. The variables are stored at every one hour integration of the forecast model.

The equations of the random walk model are:

$$\begin{cases} \dfrac{dX}{dt} = u \\ \dfrac{dY}{dt} = v \\ \dfrac{d\sigma}{dt} = \dot{\sigma} + R \end{cases},$$

where $X$, $Y$, and $\sigma$ are positions of a particle in the three-dimensional space.
A random variable $R$ is defined as

$$R = \pm\sqrt{\frac{2K_z}{\delta t}},$$

where $K_z$ is the vertical diffusion coefficient derived from the forecast model, $dt$ is the time interval in the random walk model, and the sign of the right-hand-side is chosen randomly for each particle and each time step.

A simplified Runge-Kutta method is employed for time integration of three-dimensional advection terms with a long time step $dt$ = 10 min for the outer domain. We employ the Euler-backward scheme for random vertical diffusion terms with shorter time step $dt$ = 2 min in order to avoid artificial convergence or divergence of particles at the layer where $K_z$ varies abruptly. Each time step in the inner domain is decreased to 2/3 of the outer domain.

A particle is assumed to be deposited by a dry process if following two conditions are satisfied: the height of the particle is lower than a prescribed critical height $H_{dep}$= 0.99 in $\sigma$-coordinate, and a number given randomly for each particle and each time step is smaller than a value $P_{ddep}$ defined as

$$P_{ddep} = \frac{V_{dep}\delta t}{H_{dep}},$$

where $V_{dep}$ is the dry deposition velocity.

Wet deposition of the pollutants was estimated every one hour in the outer domain and 40 min in the inner domain. The particles are deposited on the surface with a probability of $P_{wdep} = C_{dep} \cdot dt \cdot$RR, where $C_{dep}$ is the wet deposition rate, $dt$ the estimated duration of wet deposition (one hour and 40 min in the respective domain) and RR is a precipitation factor.

The precipitation factor RR is defined as:

- for particles at grid points
  RR=1 if the predicted precipitation rate is greater than 0.05 mm/hour,
  RR=0 otherwise,
- for particles between grid points
  RR is interpolated horizontally using RRs around the particle.

3. Results

In order to verify the effect of the spectral nesting method on the calculation of long-range transport, a simulation is performed in case of the Chernobyl nuclear power plant accident and the results are compared to the observation in Europe. As the observation data, the data distributed in the ATMES workshop[7] are used.

To examine the behavior of pollutants at the nesting boundary, the source of the pollutants is located in the outside of the inner model. Figure 2 shows simulated distribution of $I^{131}$ in the air at 00 UTC on 1986.05.01., and indicates no significant problem around the nesting boundary.

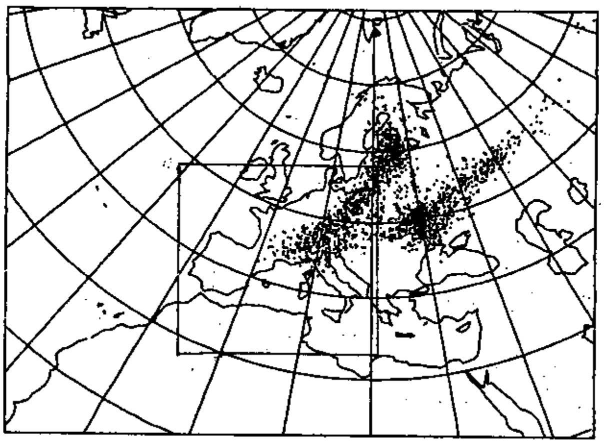

**Fig. 2.** Simulated distribution of $I^{131}$ in the air at 00 UTC on 1986.05.01. Inner frame indicates the area of the inner model.

Next, we evaluate the nesting model statically by the following 4 cases:

- only the outer model is used, averaged concentration is calculated over 254×254 km (case 1),
- only the outer model is used, averaged concentration is calculated over 80×80 km (case 2),
- the inner model is nested, averaged concentration is calculated over 254×254 km (case 3),
- the inner model is nested, averaged concentration is calculated over 80×80 km (case 4).

The averaged time is 24 hours running mean. The results are shown in Table 1.

It is found in this table that nesting method is better than the non-nesting model both in RMSE and hit number. Comparing the different averaged areas, RMSE in the models with 80 km square averaging area are smaller than with the 254 km area, although hitting number in the models with 254 km square averaging area are larger with 80 km area. This indicates that narrower averaging area represents more locality and predicts better concentration of pollutants at the costs of increasing number of no-hit events.

**Table 1.** Root mean square error and number of hit, no-hit and false alarm of model for $I^{131}$ over Europe.

| Case | RMSE | Hit | No-hit | FA |
|---|---|---|---|---|
| 1 | 0.994 | 348 | 129 | 4 |
| 2 | 0.874 | 277 | 203 | 1 |
| 3 | 0.905 | 397 | 76 | 8 |
| 4 | 0.818 | 314 | 165 | 2 |

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# A Study of Modeling of Local $CO_2$ Circulations

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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 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 predict 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 prosseses including land ecosystems. Secondly,in the model, we numerically simulate daily variations of atmospheric CO2 concentration by estimating CO2 flux. 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 CO2 missing sink and their relative degree of importance.

2. Method

Firstly,we develop a high-quality multi-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 ecosystems according to daily variations of local weather. Thirdly, we simulate the local CO2 circulations and budgets with use of the developed model.

Lastly,through analyzing results of the model simulations,we investigate the role of variety of processes associated with CO2 missing sink, and their degree of relative importance.

3. Results.

We developed a 3-dimensional multi-nested local climate model to explicitly treat CO2 fluxes between the atmosphere and land ecosystems according to daily variations of local weather. The 4 models are nested. The most outside model is a global general circulation model. The second most outside model is the Fine-mesh Limited-area Model(FLM) and this model was nested to the Meteorological Research Institute(MRI) spectral General Circulation Model(GCM).

The third most outside model is the Japan Spectral Model(JSM) with the resolution of DX=40km, and then this model was nested to the FLM. Finally, the most inside model is the other JSM with the resolution of DX=10km, its region size is about 2500 x 3000km2, which was nested to the JSM of DX=40km. We performed a long-term integration for one-month in January,and simulated the local climate over Japan. By investigating the distribution of accumulated precipitation, we could simulate the asymmetric feature of precipitation about the backbone mountain range in Japan Islands,that is,the Japan Sea side of Japan Islands had much rain, whereas the Pacific Ocean side had less rain,and also the Setonaikai(the Inland Sea of Japan). (Fig.1)

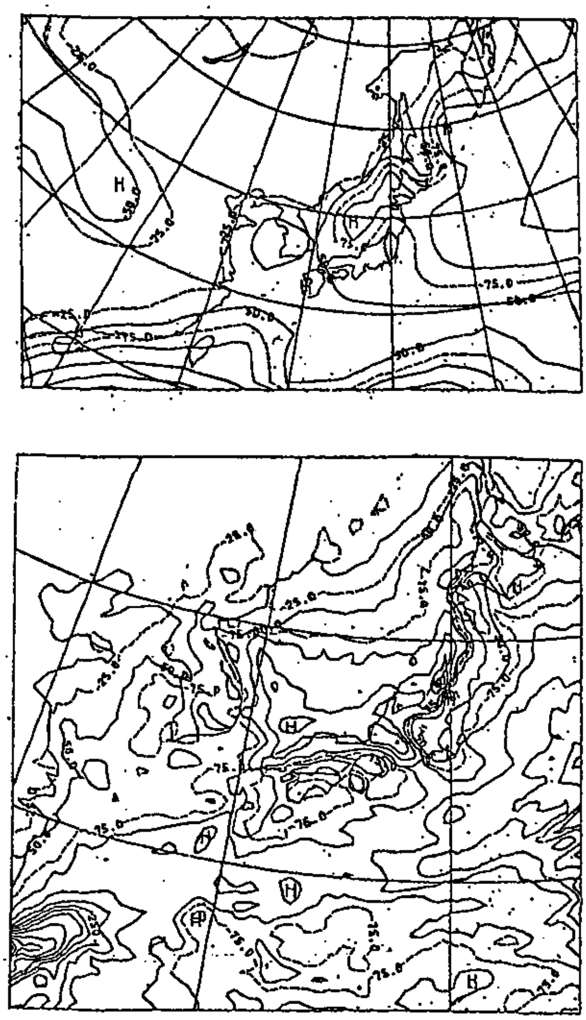

Fig.1 Computed total precipitation by the GCM (upper panel) and the local climate model(lower panel). Contor interval is 25mm.

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,this model was tested in comparison with observed data in a mixed forest of Musashino hills in June. Model results are shown in Figures 2 and 3.

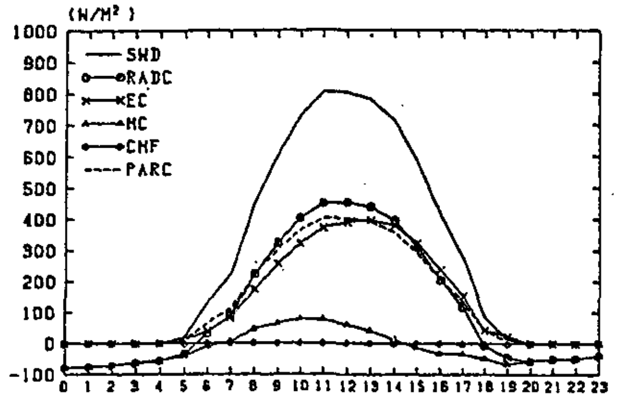


Fig.2 Heat and water budgets in a mixed forest in a clear sky in June. RADC:Net radiation (Downward is positive.), HC:Sensible heat flux (Upward is positive.), EC:Latent heat flux(Upward is positive.)

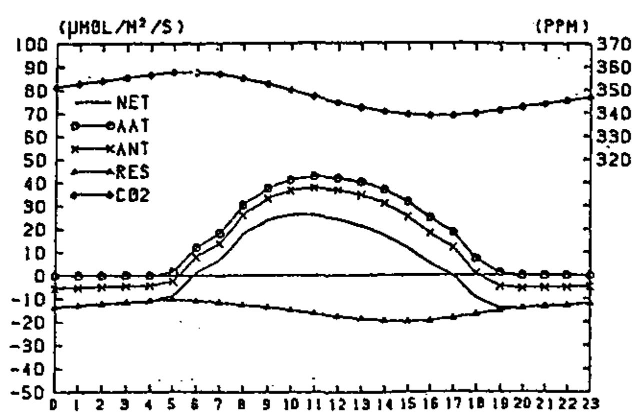


Fig.3 $CO_2$ flux(Downward is positive.) in a mixed forest in a clear sky in June. NET: net $CO_2$ absorption, AAT: total $CO_2$ absorption, RES: total respiration.

As is shown in the figures,observed sensible heat flux reaches its peak value of about 50w/m2 at 10-11 AM; latent heat flux reaches its peak value of about 400-450w/m2 at 2-3 PM. 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 literatures. Calculated daily variation of CO2 flux reaches its peak value of about 4gCO2/m2/h in the daytime, which value corresponds to the observed values in the previous literatures(Monteith(1976), Jones(1992), Miyaji(1993)).

On the other hand, a precise horizontally uniform multi-layer canopy model was developed at the University of Tsukuba and applied to a grassland ecosystem. This model is the multi-layer canopy model(Kondo and Watanabe(1992)) extended by incorpolating CO2 diffusion process. The results for the case of October are shown in Figures 4 and 5.

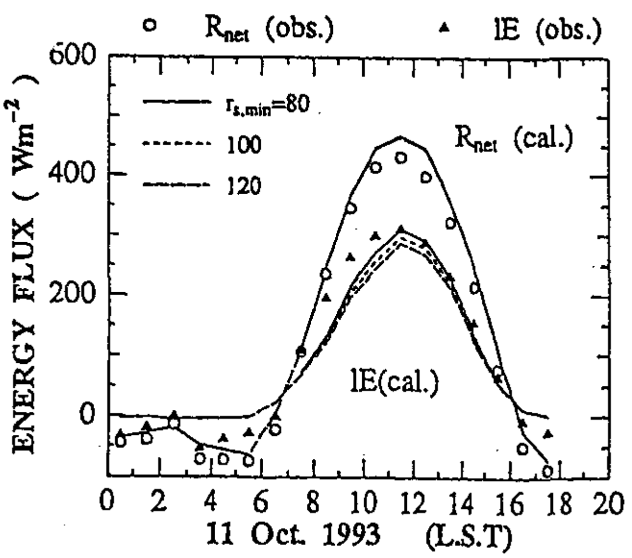


Fig.4 Time variations of net radiation and latent heat flux

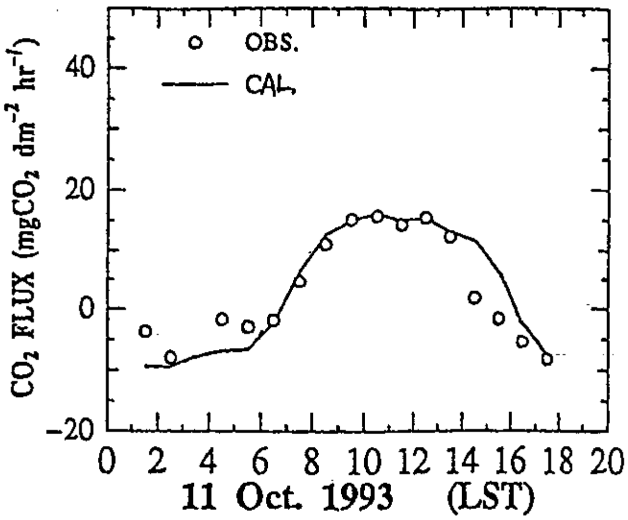


Fig.5 Time variation of CO2 flux

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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