B-1.9 A Study of Modeling of Local CO_2 Circulations

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Abstract

A Biosphere-Atmosphere Interaction Model(BAIM) for use within physical climate models (two vegetation layers and three soil layers) was developed. In general, the fluxes simulated by the model agreed well with those observed. In particular, clear differences between the results using the parameters for C3 plants and those using the parameters for C4 plants appeared in the net carbon dioxide fluxes.

CO_2 and H_2O fluxes were measured over an artificial grassland composed of 31 herbaceous species; eight among them belong to C4 plants of graminoid. Above-ground biomass was also measured. A multi-layer canopy model well simulated the observed daily and seasonal variations of CO_2 and H_2O fluxes over the grassland.

Key Words : Climate model, Biosphere model, CO_2 flux, C3 plants, C4 plants

1. Introduction

It is an especially important and basic issue to make clear the mechanism of carbon dioxide (CO_2) circulations and budgets in the study of global warming. The so-called " CO_2 missing sink issue " shows that we have not had sufficient knowledge of CO_2 circulations. Unless we can make clear the problem, it is difficult to draw the future image of the global warming phenomenon.

The CO_2 circulations are deeply influenced by ecosystems, and especially through local weather and climate. Thus, we need to simulate CO_2 circulations after modeling local weather and climate in a model study of CO_2 circulations.

In this study, we firstly construct the model of the relationship between local weather and surface hydrology processes including land ecosystems. Secondly, we numerically simulate daily variations of atmospheric CO_2 concentration by estimating CO_2 fluxes in the model. As a result, we can estimate the atmospheric CO_2 concentration. By doing so, it will be possible to evaluate the role of processes associated with so-called " CO_2 missing sink" and their relative degree of importance.

Vegetation plays an important role in the global energy, water, and carbon cycles through its evapotranspirative, photosynthetic and respiratory activities. Recently, realistic biosphere models were presented by Dickinson[1] (1984) and Sellers et al.[2] (1986) for use in GCMs. Several studies have been conducted to investigate the interactions between land surface processes and atmospheric phenomena using these models (Dickinson and Henderson-Sellers[3], 1988; Sato et al.[4],1989).

The energy, water and CO_2 exchanges between vegetated surface and atmosphere have been studied by many researchers in the scale of plant canopy (e.g... Horie[5], 1981; Ohtaki[6], 1985; Baldocch[7], 1994; Fan et al.[8], 1995). The energy and mass fluxes over natural vegetation are, however, not yet readily predictable. For example, grasslands in the mid latitude consist of C3 and C4 plants, and the contribution of C3 and C4 plants to the above-ground biomass often changes with season and climatic conditions.

Generally, C4 plants have a higher optimum temperature for photosynthesis and higherwater use efficiency than C3 plants, and the effects of atmospheric CO_2 concentration on the plant biomass and net primary production are different between C3 and C4 grassland (Oikawa[9],1995). The geographic distribution and ecophysiological responses of C3 and C4 plants have been investigated in several grasslands in the world (Hattersley[10], 1983; Cavagnaro[11], 1988; Kalapos[12], 1991). However, the effects of the changes in the biomass of C3 and C4 plants on the energy and mass fluxes over the canopy have not been well understood. Long-term field measurements are thus required to obtain more information about energy and mass fluxes relating with spatial and temporal variations in plant species.

2. Research 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 CO_2 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 "CO_2 missing sink", and their degree of relative importance.

On the other hand, the aim of the present study in University of Tsukuba is to measure CO_2 flux by the gradient method over a grassland containing C3 and C4 plants. The seasonal change in CO_2 flux measured by the gradient method was analyzed from the ecological and meteorological point of view over an artificial grassland containing C3 and C4 plants in University of Tsukuba. The three dominant species of the grassland belonged to the Gramineae; Festuca elatior (C3)dominated in early spring, and Imperata cylindrica (C4) and Andropogon virginicus (C4) grew during early summer and became dominant in mid-summer (Fig.3).

3. Results and Discussion

3.1 Development and Verification of a Biosphere-Atmosphere Interaction Model(BAIM) for use within physical climate models.

A Biosphere-Atmosphere Interaction Model (BAIM) for use within physical climate models was developed (Fig.1). BAIM has two vegetation layers and three soil layers, and the temperature of each layer and moisture stored for each layer are predicted. In the presence of snow on the ground, the snow layer is divided into a maximum of three layers, and the temperature and the amount of snow and water stored in each layer are predicted. BAIM can estimate not only the energy fluxes but also the carbon dioxide flux between the land surface ecosystem and the atmosphere. The photosynthesis processes for C3 plants and C4 plants are adopted in the model.

Off-line verifications of BAIM in a snowless condition were made using the point micro-meteorological data observed at a grassland. In general, the fluxes simulated by the model agreed well with those observed(Fig.2). In particular, clear differences between the results using the parameters for C3 plants and those using the parameters for C4 plants appeared in the net carbon dioxide fluxes.

To investigate the influence of variations in the values of parameters related to the property of vegetation, sensitivity tests of the model were conducted. By changing the values of the parameters by ±50%, the maximum variations of the time-averaged fluxes were obtained. The values of net radiation flux, sensible heat flux, latent heat flux, and soil heat flux were about $\pm 15 W/m^2$, $\pm 8 W/m^2$, $\pm 9 W/m^2$, and $\pm 1 W/m^2$, respectively. The maximum variations of the time-averaged value of net carbon dioxide flux were about $\pm 5 \mu mol/m^2/s$ for C3 parameters and $\pm 7 \mu mol/m^2/s$ for C4 parameters.

The energy fluxes and carbon dioxide fluxes were also influenced strongly by changes of the soil wetness. As the soil wetness decreased, the net radiation flux, the latent heat flux, and the carbon dioxide accumulation rate decreased, and the sensible heat flux and the respiration rate increased. The accurate estimation of the soil wetness is very important to accurately estimate the energy fluxes and the carbon dioxide flux.

3.2 A Model and Observational Study of CO_2 and H_2O Exchange Between Atmosphere and Grassland Ecosystem

On the other hand, the aim of the present study in University of Tsukuba is to measure CO_2 flux by the gradient method over a grassland containing C3 and C4 plants. The seasonal change in CO_2 flux measured by the gradient method was analyzed from the ecological and meteorological point of view over an artificial grassland containing C3 and C4 plants in University of Tsukuba. The three dominant species of the grassland belonged to the Gramineae; Festuca elatior (C3)dominated in early spring, and Imperata cylindrica (C4) and Andropogon virginicus (C4) grew during early summer and became dominant in mid- summer(Fig.3).

Data of the surface heat budget were used to analyze the CO_2 and H_2O exchange between the grassland and the atmosphere. From August to October in 1993, CO_2 flux decreased even under the same solar radiation conditions. The monthly values of water use efficiency, i.e..., the ratio of CO_2 flux to H_2O flux decreased from 5.2 to 2.9 $mgCO_2/gH_2O$ from August to October, while the Bowen ratio increased from 0.20 to 0.30, and the ratio of the bulk latent heat transfer coefficient CE to the sensible heat transfer coefficient CH was maintained around 0.40-0.50 during the same period.

The increase in the Bowen ratio was explained by the decrease in monthly mean air temperature from 22.3°C in August to 16.6°C in October without considering biological effects such as stomatal closure on the individual leaves. The nearly constant CE/CH ratios suggested that the contribution ratio of canopy resistance to the aerodynamic resistance of the canopy did not change remarkably, although the meteorological conditions changed seasonally. The decrease in the water use efficiency, however, suggested that the photosynthesis rate decreased on the individual leaves from August to October under the same radiation conditions.

Diurnal variations of CO_2 exchange were simulated by the multi-layer canopy model which took the differences in the stomatal conductance and photosynthetic pat way between C3 and C4 plants into account. The results suggested that the decrease in the net canopy CO_2 exchange from August to October was induced partly by the relative decrease of the contribution of C4 plants to the canopy photosynthesis, and also by the decrease of net photosynthesis on the individual leaves in both C4 and C3 plants, which could be due to aging of the leaves. Further studies are required to develop a methodology of observing and predicting the seasonal changes in the characteristics of CO_2 and H_2O fluxes over vegetated surfaces, based on photosynthetic and transpirative processes on the scale of individual leaves.

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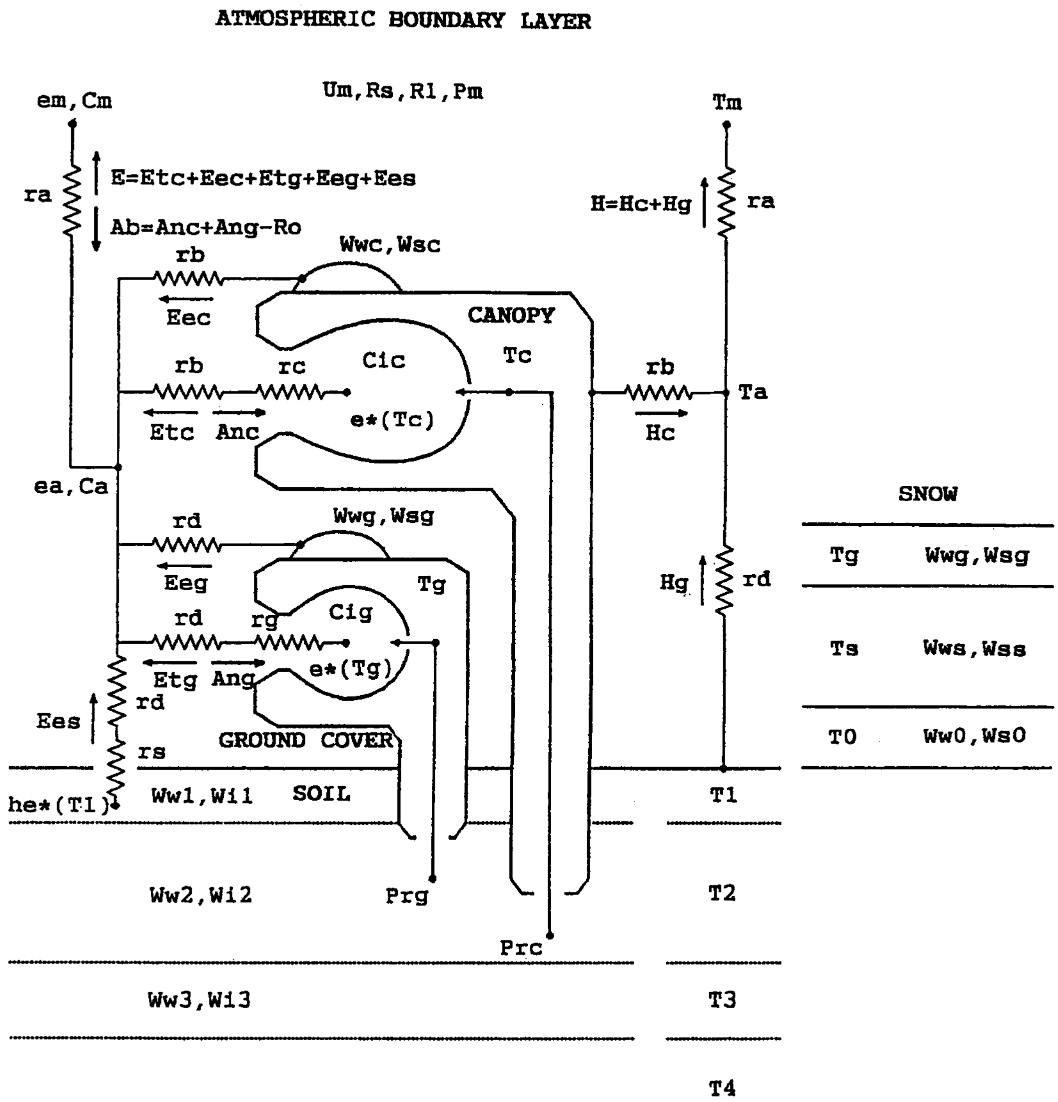


Fig.1 A block diagram of the Biosphere-Atmosphere Interaction Model (BAIM). On the left-hand side, the transfer pathways for latent heat flux and carbon dioxide flux are shown. On the right-hand side, the transfer pathways for sensible heat flux are shown. Explanations of symbols are described in the text.

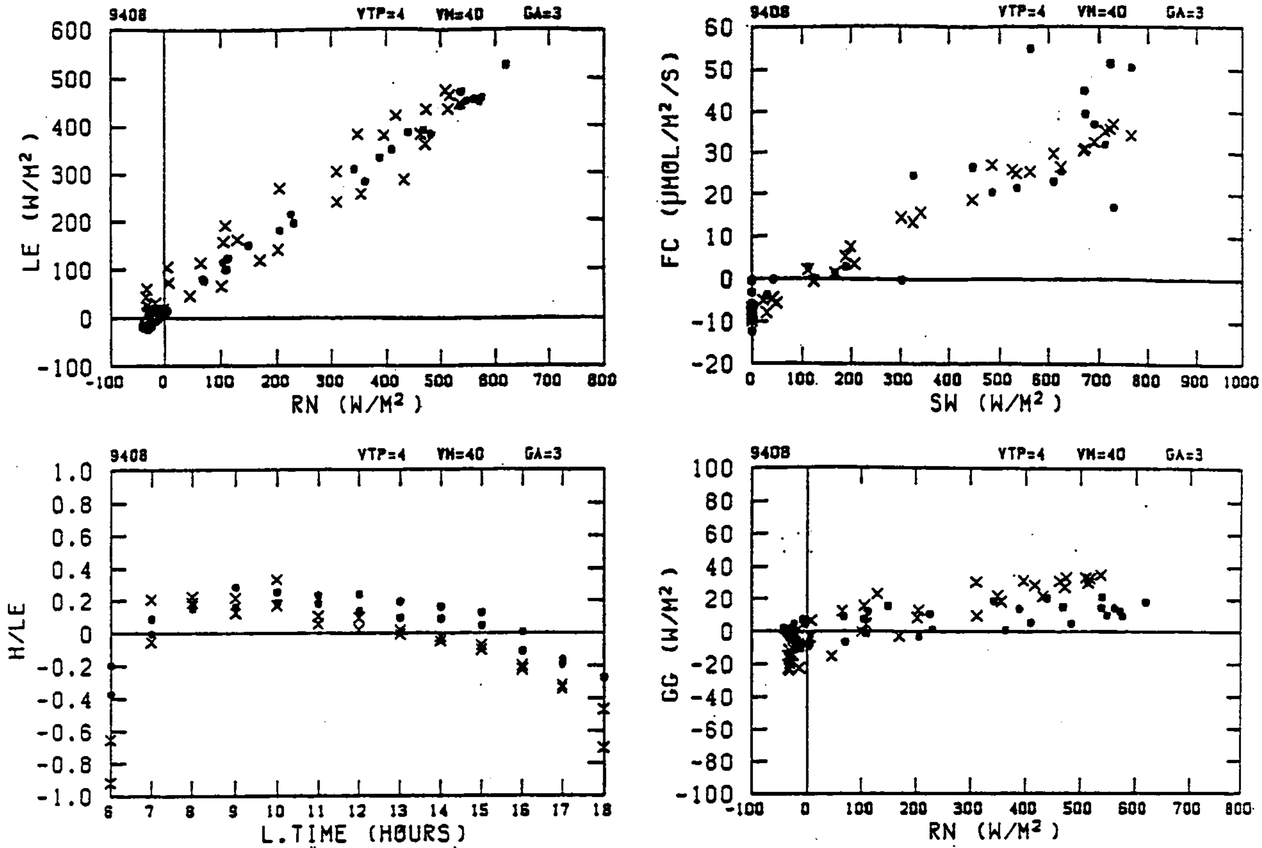
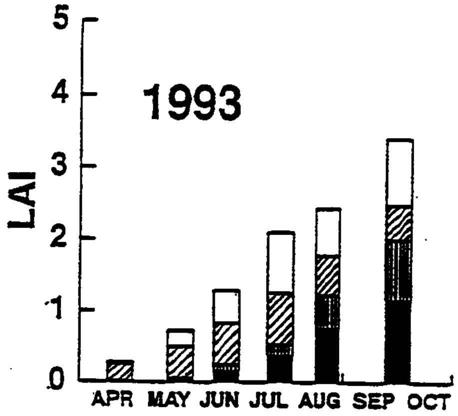


Fig.2 The comparison of observed and calculated fluxes in Aug. Circles are the observations and x symbols are the calculations using the parameters for C_3 plants. LE, latent heat flux (upward flux is positive); RN, net radiation flux (downward flux is positive); H/LE, the Bowen ratio; L.TIME, local time; FC, net carbon dioxide flux (downward flux is positive); SW, downward shortwave radiation flux (observed value); GG, heat flux into the soil (downward flux is positive).



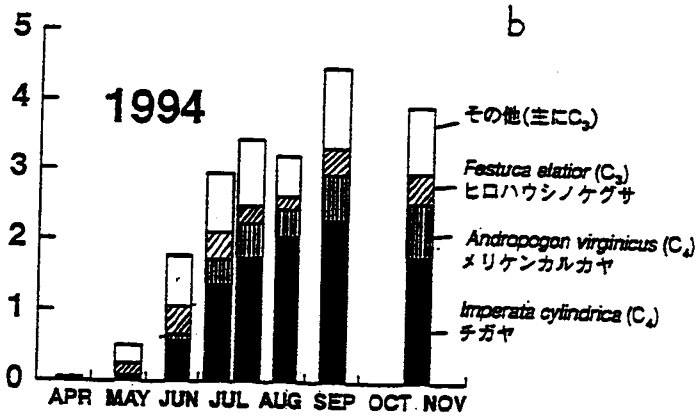


Fig. 3 Seasonal Variation of Leaf Area Index, a:1993, b. 1994.

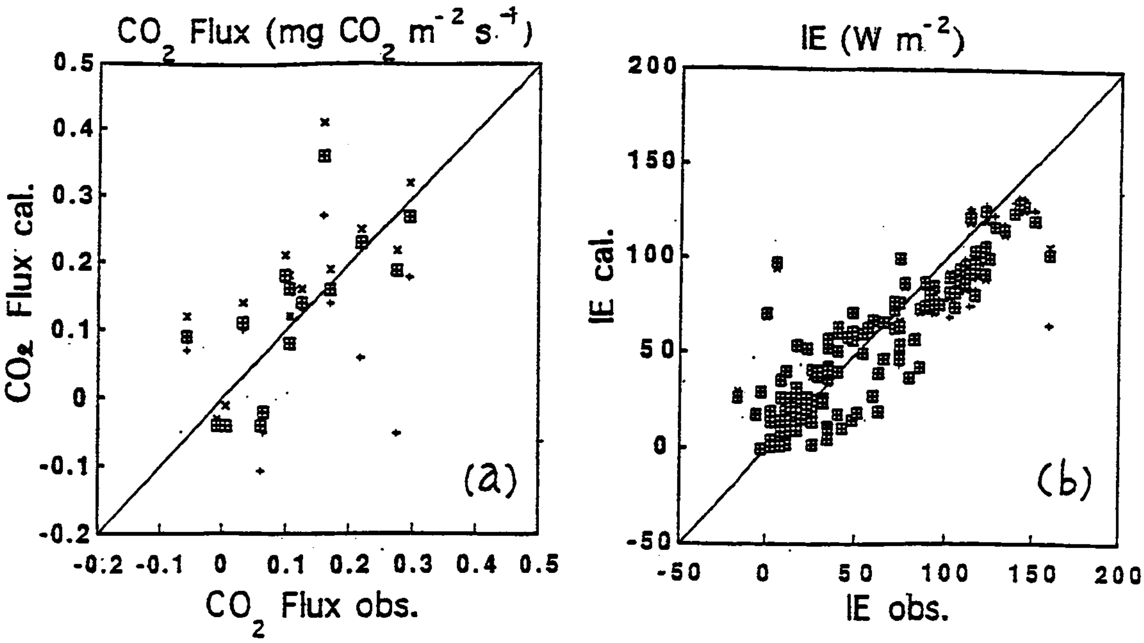


Fig. 4 A comparison of computed CO2 flux(a) and latent heat flux(b) with those observed. +: C3 plants, x: C4 plants, ⊞: C3, C4 mixed grasslands.