B-6.4.2 Development of local CO_2 circulation models and elucidation of role of land ecosystem

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Abstract

To investigate how physical and biological interactions between the land surface ecosystems and the atmosphere influence the seasonal and interannual variations of atmospheric CO_2 concentration in a regional scale, a numerical simulation using a physical regional climate model including a sophisticated biological land surface model was performed. The interannual variations of CO_2 concentration computed by the model indicated the similar characteristics to those observed over Japan. It was suggested that in this experiment period the interannual variations of downward short wave radiation at the land surface were mainly responsible for the interannual variations of photosynthesis activities. The interannual variations of photosynthesis activities influenced the interannual variations of net CO_2 flux between the land surface and the atmosphere, and those influenced the interannual variations of CO_2 concentration in the lower troposphere over Japan(Meteorological Research Institute).

Carbon balance in Monsoon Asia was simulated using a regional model termed Sim-CYCLE which was based on the production theory established by Monsi and Saeki (1953)[1). Terrestrial ecosystems of Monsoon Asia (land total 20.6 million km^2; that is 15% of the global total land area; a spatial resolution of 0.5 degree longitude-latitude) are classified into 28 biome types. C4 plants occupy major parts of plant biomass in hot and arid grasslands, and thus they are discriminated from C3 plants, because of the large difference in physiological properties between the two plant types. Carbon fluxes such as gross primary production (GPP), net primary production (NPP) and net ecosystem production (NEP) were simulated by Sim-CYCLE(University of Tsukuba).

Key Words regional climate model, biosphere-atmosphere interaction model, CO2 flux,

net ecosystem production, Monsoon Asia

(1) Numerical simulation study of relations between climate and carbon dioxide cycle in a regional scale(Meteorological Research Institute)

1. Introduction

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

The CO_2 circulation is deeply influenced by land surface ecosystem, and especially through local weather and climate. Thus, we need to simulate CO_2 circulation after modeling local weather and climate.

In this study, we firstly perform long-term integration of local CO_2 circulation model. The model results are compared with inter-annual variation of atmospheric CO_2 concentration observed by airplane by the Tohoku University(Nakazawa et al.(1993)[2)]). As a result, we can estimate an atmospheric CO_2 concentration at each pressure-height level. 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.

2. Research Method

Firstly, a local CO_2 circulation model over the Japan island is integrated for several years, and then diurnal, seasonal and year to year variation are estimated by use of their computation, and then they are compared with observation by airplane observation etc. Secondly, by analysing their results, the role of land ecosystem in CO_2 exchange processes between the biosphere and the atmosphere was explored with stress of relationship to transient local weather and climate. In particular, it is explored what is important parameter in CO_2 budgets in the global scale, and is the role of land surface ecosystem in CO_2 budgets in the global scale.

A local CO_2 circulation model in which the seasonal variation of land ecosystem is prescribed as an external parameter and exchanges of heat, water, CO_2 between the biosphere and the atmosphere are represented (Fig.1) and also its horizontal resolution is 30km. The model is integrated for the Japan island area for several years:1986～1991. The model represents 15 plant species; broadleaf-evergreen forest(with grass), broadleaf-deciduous forest(with grass), mixed forest(with grass), needleleaf-evergreen forest(with grass), needleleaf-deciduous forest(with grass), grass land, crop land, broadleaf-deciduous forest(with bamboo grass), mixed forest(with bamboo grass), city area, mixed forest, needleleaf-evergreen forest, needleleaf-deciduous forest, tundra, desert. Objective analysis data such as JMA-GANAL for meteorological variables and airplane observation data by the Tohoku University for atmospheric CO_2 concentration data are used, respectively, as the boundary conditions. In particular, for atmospheric CO_2 concentration data spatially constant value averaged in the upper troposphere and in temporally observed trend for several years. Then computed results (Fig.2) are compared with AMEDAS (Automated Meteorological Data Acquisition System) etc. for regional weather and climate, and year to year variation of atmospheric CO_2 concentration observed by use of airplanes by the Tohoku University (Nakazawa et al. (1993)[2] and Nakazawa and Aoki(1998)[3]) for atmospheric CO_2 concentration.

3.Results

Analyzing the model results, following things can be concluded. The model could reproduce the seasonal variations of meteorological variables and the heat and the water budgets at the land surface in each year. The interannual variations of atmospheric CO_2 concentration(Fig.2) calculated by the model indicated a similar characteristic phenomenon of stepwise increase in the lower troposphere to those observed over Japan. These results suggested that this characteristic phenomenon was attributed to the interannual variations of photosynthesis activities which were influenced by the interannual variations of the climate around the Japanese Islands. The examinations of the principal elements that influence the photosynthesis activities suggested that the interannual variations of downward solar radiation at the land surface in this experiment period were mainly responsible for those of photosynthesis activities, which influenced the interannual variations of net CO_2 flux between the land surface and the atmosphere, and those influenced the interannual variations of an atmospheric CO_2 concentration in the lower troposphere over Japan.

(2) Simulation of carbon balance in Monsoon Asia region using a carbon dynamics model (University of Tsukuba)

1. Introduction

The Asian-Australian area is governed by the monsoon circulation, which is the most constant large wind system. In this great monsoon circulation, winds blow outward from Asia and inward onto Australia during the winter of the Northern Hemisphere, with a reversal of the circulation during the summer. Such a seasonal wind direction change produces dry and wet seasons regularly and then determines the types and dynamics of terrestrial ecosystems in Monsoon Asia. In Monsoon Asia, land cover change is the most intensive because the density of human population is highest in the world and is ever-growing at a high rate. Ongoing global warming will accelerate land cover change, which positively feedbacks global warming.

2. Research Method

On the basis of these backgrounds, carbon balance in Monsoon Asia region was simulated using a regional-scale model termed Sim-CYCLE which was based on the production theory established by Monsi and Saeki (1953)[1). As shown in Fig. 3, terrestrial ecosystems of Monsoon Asia (land total 20.6 million km^2; that is 15% of the global total land area; a spatial resolution of 0.5 degree longitude-latitude) are classified into 32 biome types, where warm grasslands have the largest area, followed by irrigated croplands, hot deserts, paddy fields and so on, reflecting the typical monsoon climate. To be noteworthy, the paddy fields, where one of the three major crops, rice is intensively produced and a huge amount of methane are evolved by their side-effects, have the largest area in the world. In addition, C4 plants occupy major parts of plant biomass in hot and arid grasslands, and thus they are discriminated from C3 plants, because of the large difference in physiological properties between the two plant types. Carbon fluxes such as gross primary production (GPP), net primary production (NPP) and net ecosystem production (NEP) were simulated by Sim-CYCLE.

3.Results

Figure 4 illustrates the distribution of NPP and plant biomass in Monsoon Asia, estimated from the steady state simulation under long-term mean climate condition. The areas having higher NPP values more than 10 Mg C/ha/y are drawn around the equator, which is mainly occupied by tropical and seasonal rain forests. On the other hand, such extremely unproductive areas as the Gobi and the Taklamakan deserts are widely found in the middle latitudinal zone of the inner continent. Summing up all values, we obtained that regional NPP and plant biomass are 8.7 Pg C/y and 84.8 Pg C, respectively. From the global point of view, they are about 16%, which is proportional to its area. C4 plants mainly distributed in arid grasslands are estimated to produce 0.71 Pg C/y in NPP, which corresponds to about 8% in regional NPP, although their biomass occupies tiny portion. Currently, the agricultural ecosystems including the paddy fields may produce such a significantly high fraction of NPP as 24%, which is more than two times compared with the global mean fraction. This is one of the most important characteristics in Monsoon Asia region, and this fraction will be inevitably increased more and more in the next century at the expense of tropical rain forests influenced by the high pressure of ever-increasing human population in this area. Such land use change will induce one of the most serious impacts on the human being in the next century.

Transient carbon balance change in Monsoon Asia was also predicted(Fig.5) under the assumption that an atmospheric CO_2 concentration increases with an annual rate of 1% (doubling after 70 years) and that a resultant rising CO_2 induces climatic perturbation projected by three representative GCMs (GISS, GFDL, and MRI).

References

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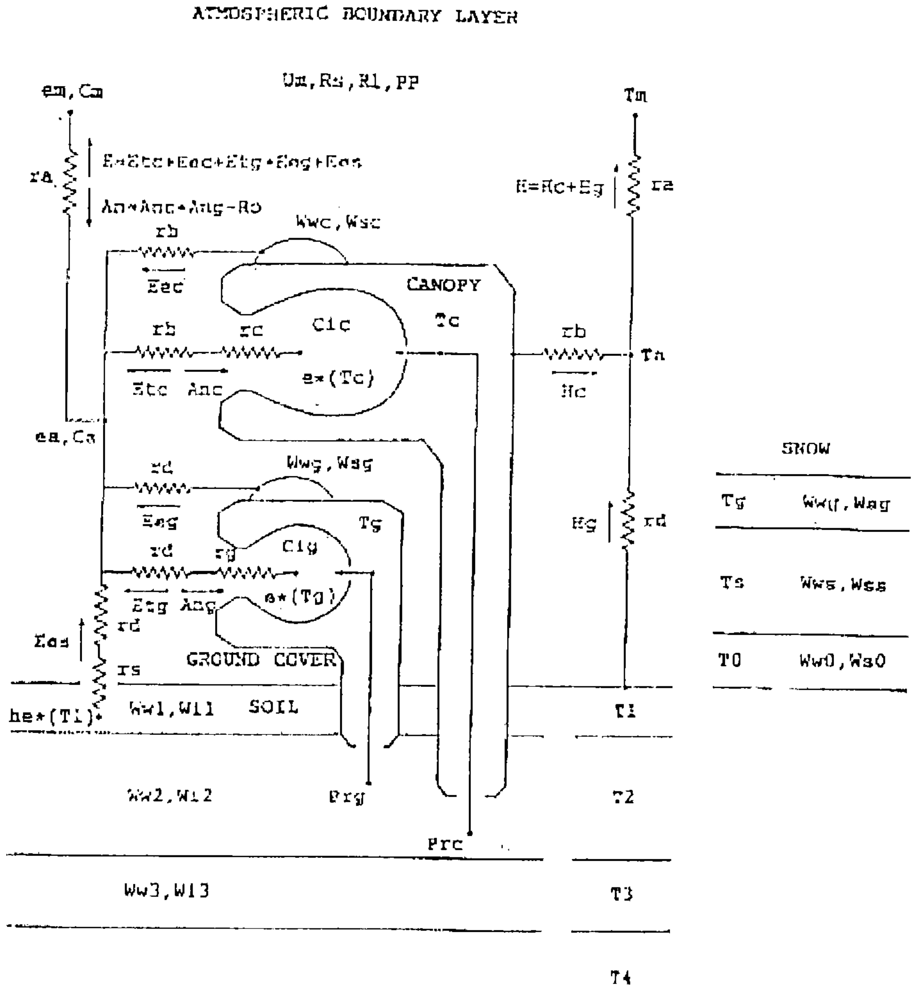

Fig.1 A block diagram of the Biospher-Atomosphere Interaction Model (BAIM).

On the left-hand side, 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.

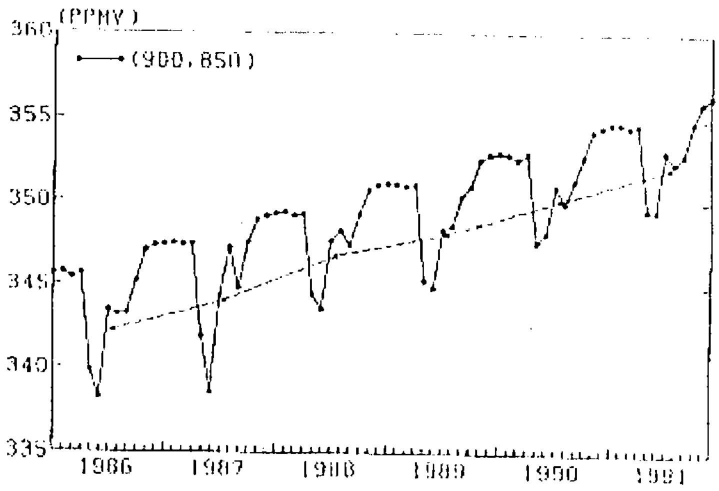

Fig.2 Interannual variation of atmospheric CO_2 concentration (ppmv) in the lower troposphere computed by the local CO_2 circulation model

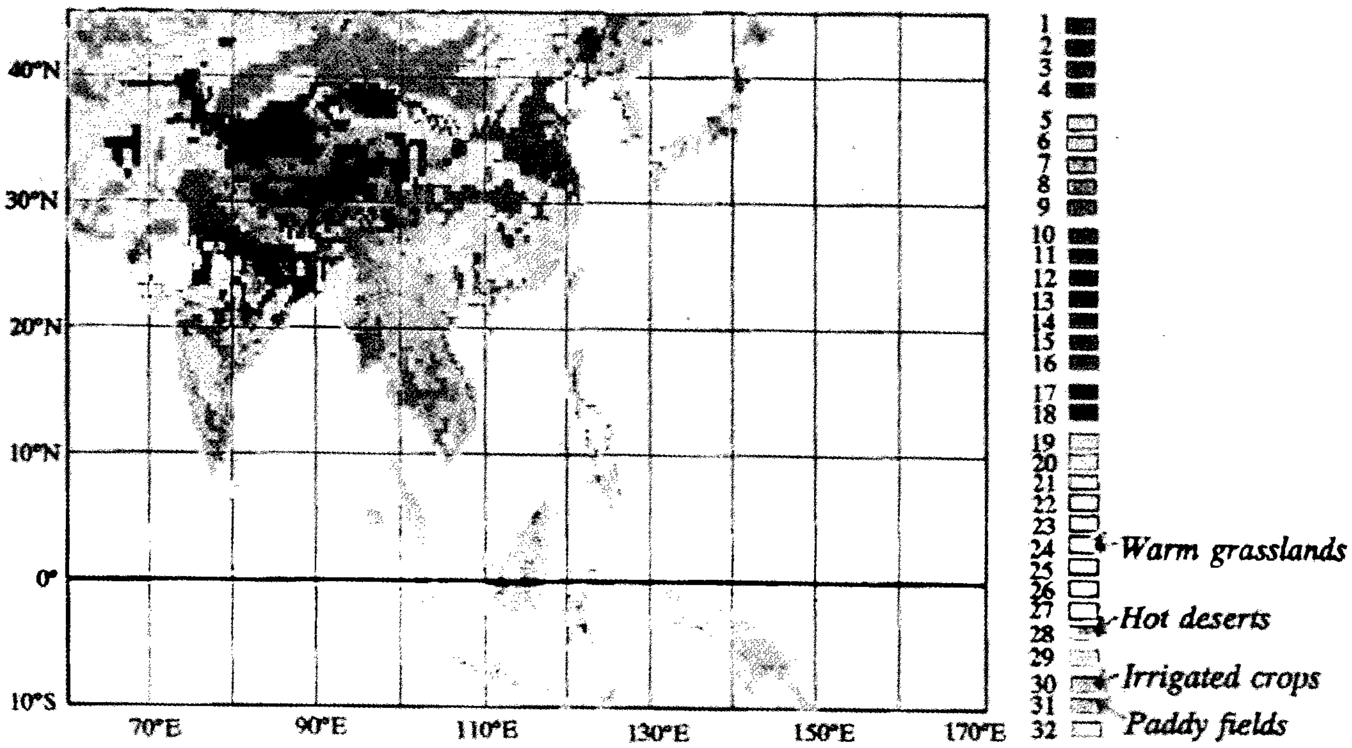

Fig.3 Biome distribution of Monsoon Asia.

Table 1. Estimated carbon storage and productivity in Monsoon Asia. C4 plant contribution is in parenthesis.

	Area	Plant C	Soil C	GPP	NPP
	$10^3\ km^2$	Pg C	Pg C	Pg C/year	Pg C/year
tundra	1846.3	0.74	44.86	0.45	0.21
wooded tundra	129.9	0.23	3.16	0.06	0.03
northern taiga	0.0	0.00	0.00	0.00	0.00
main taiga	521.4	1.16	5.25	0.09	0.06
southern taiga	0.0	0.00	0.00	0.00	0.00
cool conifer	258.1	2.97	6.50	0.23	0.16
cool mixed	262.1	3.57	6.37	0.27	0.18
warm deciduous	972.1	11.61	21.42	1.41	0.88
warm mixed	328.6	3.60	5.93	0.31	0.19
warm conifer	32.9	0.57	0.93	0.05	0.03
cool forest/field	232.1	2.35	3.06	0.24	0.13
cool field/woods	78.3	0.52	0.77	0.05	0.03
warm forest/field	770.9	9.04	8.85	1.02	0.55
warm field/woods	577.5	3.76	4.51	0.46	0.24
tropical dry forest	550.5	5.61	4.73	0.79	0.37
tropical seasonal	1240.4	13.21	13.10	1.84	1.00
equatorial evergreen	1097.5	15.50	12.20	1.84	1.01
tropical montane	398.0	4.32	4.65	0.53	0.29
semiarid woods, scrub	15.7	0.05	0.08	0.01	0.00
succulent thorns	139.2	0.05 (0.03)	0.48	0.07 (0.06)	0.02 (0.02)
highland shrub	143.9	0.08	0.50	0.01	0.00
med. grazing	0.0	0.00	0.00	0.00	0.00
cool grass/shrub	794.6	0.30 (0.07)	3.14	0.15 (0.06)	0.04 (0.02)
warm grass/shrub	3257.6	2.03 (0.94)	19.65	2.03 (1.42)	0.94 (0.64)
tropical savanna	42.1	0.05 (0.02)	0.25	0.07 (0.05)	0.02 (0.02)
crops, irrigated	2387.9	0.74	18.08	1.80	1.03
paddy lands	1907.3	0.78	11.87	2.02	1.11
marsh, swamp, bogs	419.0	1.25	5.82	0.24	0.11
hot desert	2036.2	0.30 (0.04)	1.53	0.12 (0.04)	0.02 (0.01)
cool desert	140.5	0.05	0.27	0.03	0.01
coastal edged, mangroves	48.1	0.33	0.43	0.06	0.03
ice	0.0	0.00	0.00	0.00	0.00
total	20628.8	84.78 (1.10)	208.40	16.25 (1.64)	8.70 (0.71)

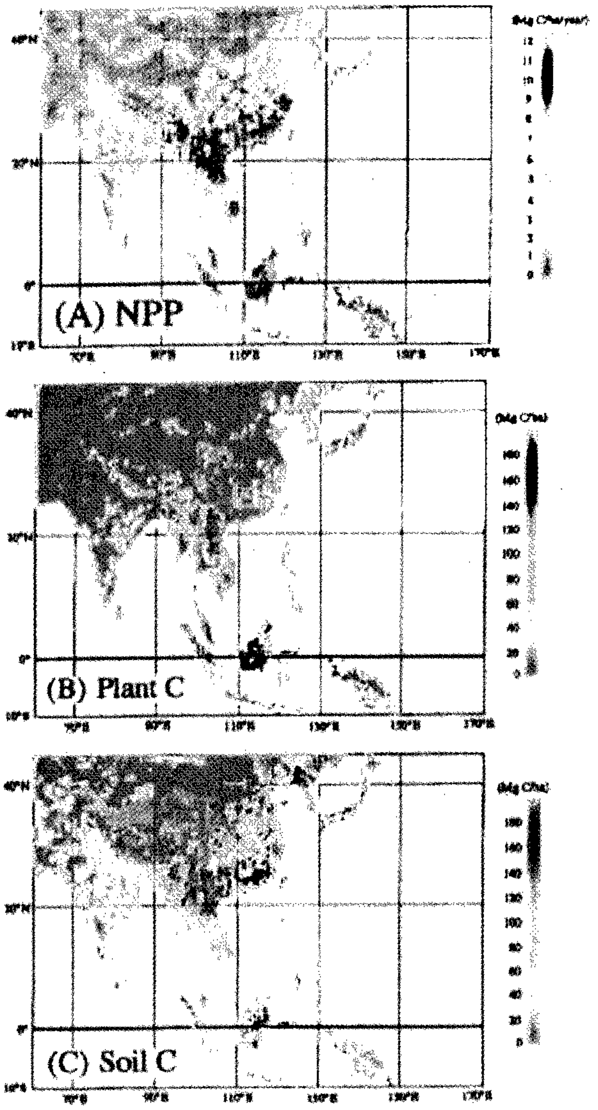

Fig.4 Regional distribution of (A) NPP (B) Plant C (plant carbon), and (C) Soil C (soil carbon), in Monsoon Asia, estimated by the equilibrium run.

Fig.5 NPP in Monsoon Asia at the 70th year predicted by Sim-CYCLE (based on MRI climate change scenario)