B-6.4.4 Modeling of Global Carbon Cycle

Contact person **Naohiro GOTO**
Research Associate
Department of Ecological Engineering
Toyohashi University of Technology
tempaku-cho, Toyohashi,441-8580, Japan
Tel:+81-532-44-6915 Fax:+81-532-44-6929
E-mail: goto@eco.tut.ac.jp

Total Budget for 1996-1998 **18,844**yen (FY 1998 : 5,856yen)

Key Words Carbon dynamics, Mathematical model, Soil ecosystems

Abstract Recent increase of atmospheric CO_2 is mainly attributed to the disturbances of global carbon dynamics caused by anthropogenic activities including excessive usage of fossil fuel and deforestation. Soil ecosystems have been focused on as a key of "missing sink problem". Also the climate change itself would affect the soil ecosystems through change of soil respiration rates due to increase of temperature. To make clear the overall scheme of carbon dynamics in the soil ecosystems, a carbon dynamics model is proposed which is, in principle, a substantial model based on mass balance and kinetics of carbon. Soil was divided into twelve typical types and the soil respiration rate system of each soil was described in terms of local soil types. The terrestrial surface was divided into meshes of latitude 0.5 x longitude 0.5. Calculations were carried out for all the meshes and for each mesh. This procedure provides the soil carbon dynamics based on the present geographical information. The model could simulate the soil carbon dynamics with reasonable accuracy and it also can predict effect of climate change on soil carbon dynamic.

1. Introduction

Increase of atmospheric CO_2 is caused by anthropogenic activities such as burning fossil fuel and deforestation. These activities disturb natural carbon dynamics and then the subsequent increase of atmospheric carbon dioxide concentration is considered to be a main cause of anticipated global warming in the future. Numbers of meteorological works have pointed out that serious climate changes will occur when the atmospheric CO_2 concentration doubles. For the prediction of transient behavior of carbon dioxide in the atmosphere, carbon exchanges between the atmosphere and the terrestrial vegetation and between the atmosphere and the ocean are to be clearly defined. The carbon dynamics in terrestrial ecosystems, however, are expected to be affected by the climate change. To estimate carbon exchanges between the atmosphere and the terrestrial ecosystems and to assess the impact of climate changes on carbon content, it is necessary to describe the holistic picture of carbon dynamics in the terrestrial ecosystems by means of a mathematical model that accounts for the dominant factors in ecosystems.

2. Research Objective

The terrestrial ecosystems have an important role in global carbon dynamics. Especially soil ecosystems are great carbon budget and have been focused on as a key of "missing sink problem". The objective of this research is to construct a mathematical model, which describes soil carbon dynamics, and to predict the effect of climate change on the soil ecosystems by using the model.

3. Research method

3.1 Carbon Dynamics Model

A carbon dynamics model in terrestrial ecosystems is based on the simplified material balance concept as shown in Fig. 1. Terrestrial ecosystem is composed of 5 types of vegetation and 12 types of soil. The terrestrial ecosystem is divided into two compartments and subsequent four sub compartments as follows:

(I) Biomass compartment composed of living cells, Leaf and Trunk

(II) Soil organic compartment composed of dead cells, Dead Biomass and Humus

Carbon exchanges kinetics among these four sub compartments and the atmosphere compartment are described.

3.2 Vegetation Distribution Model

In the present model, only three vegetation types are considered: Tropical Forest, Temperate Forest, and Boreal Forest. These vegetation types have different kinetic. Dominant vegetation at a certain point is determined by calculation using climate parameters, such as temperature, precipitation, solar intensity, soil characteristics, etc. As a first approximate, the carbon storage in biomass are considered here to be the determining factor. For calculation of distribution on the earth, the global land area is divided into meshes, composed of latitude 0.5 x longitude 0.5. In all meshes, calculations were carried out for the biomass carbon storage of the three vegetation types based on the climate condition and soil distribution data (EPA, 1992) for each mesh until reaching the steady state. By comparing the calculated biomass carbon storage of the three vegetation types in one mesh, we assumed that the vegetation with the maximum carbon storage is the vegetation that dominates the mesh. If the carbon storage of the dominant vegetation is less than 0.5 (kgC/m^2), the mesh is classified into Desert/Semi-desert and if less than 5.0 (kgC/m^2) and above 0.5 (kgC/m^2) the mesh is classified into Grassland. This judgment is executed in all meshes and the global vegetation map can be provided.

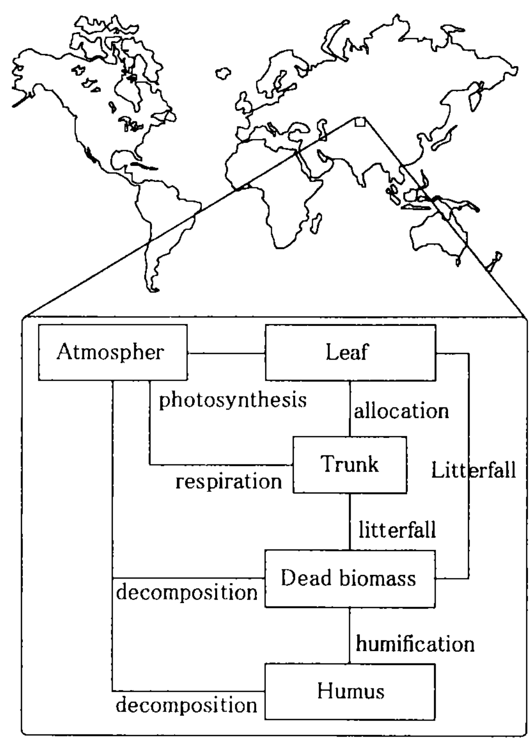

Fig. 1 Model Scheme

4 . Result

Table 1 shows global vegetation area, biomass carbon storage, soil carbon storage, net primary production (NPP: difference between photosynthesis and respiration) and soil respiration (sum of dead biomass and humus decomposition) in current climate condition and 2 x CO_2 climate condition (Meteorological Research Institute, 1996). Calculation was done by using the current climate condition and soil distribution data until reaching the steady state. NPP equaates with soil respiration in steady state condition.

As shown in Table 1, biomass carbon storage increases by 9.9 % (391.5→430.1 GtC), soil carbon storage increases by 12.7 % (1234.7→1391.7) and NPP and soil respiration increases by 22.0 % (128.5→1391.7). Increase in NPP is caused by increase in temperature and atmospheric CO_2. This NPP increase is brought into increases of biomass carbon storage, soil carbon storage and soil respiration. The carbon storage in the terrestrial ecosystems increase by 195.1 GtC, 12.0 % (1626.3→1821.8 GtC). This means that the terrestrial ecosystems absorb 195.1 GtC due to doubling atmospheric CO_2. 80 % of the absorption is caused by soil ecosystems.

Areas in tropical forest, temperate forest and grassland increase those in boreal and desert/semi-desert decline by climate change. This tendency is the same as carbon dynamics in the terrestrial ecosystems. This means that global warming is negative feedback for boreal forest. Taking only temperature effect into account, NPP and Soil respiration should increase by global warming, but those in boreal forest and desert/semi-desert decrease. It is because soil water condition becomes worse.

Table 1 Global vegetation area, biomass carbon storage, soil carbon storage, net primary production (NPP) and soil in current climate condition and 2 x CO_2 climate condition

Current		Tropical	Temperate	Boreal	Grassland	Desert, Semi-desert	Total
Area	10^6 km^2	9.7	9.3	12.5	27.0	73.1	131.7
Carbon storage							
Biomass	Gt	95.4	99.9	108.6	87.1	0.5	391.5
Soil	Gt	179.4	352.4	347.1	348.6	7.2	1234.7
Total	Gt	274.8	452.3	455.7	435.8	7.7	1626.3
NPP and Soil respiration	Gt/yr	34.2	23.6	19.0	50.8	0.9	128.5

CO_2 X 2		Tropical	Temperate	Boreal	Grassland	Desert, Semi-desert	Total
Area	10^6 km^2	13.0	11.9	9.6	26.2	70.9	131.7
Carbon storage							
Biomass	Gt	127.7	131.0	88.2	82.9	0.3	430.1
Soil	Gt	220.7	561.1	281.0	324.4	4.6	1391.7
Total	Gt	348.4	692.1	369.2	407.3	4.9	1821.8
NPP and Soil respiration	Gt/yr	49.4	26.9	15.5	64.4	0.5	156.7

Fig. 2 shows distribution maps of the soil carbon storage in current climate and CO_2 X 2 climate, and Fig. 3 shows those of the soil respiration in same conditions. As shown in Fig. 2 the soil carbon storage in Northeast Asia and North America increase. As shown in Fig. 3 the soil respiration in Southeast Asia increases. These concluded that the effect of global warming on global soil dynamics is dependent on region.

5. CONCLUSION

Carbon dynamic model was proposed to describe carbon storage and soil respiration. Carbon balance equation and growth kinetic equations were provided accounting for photosynthesis rate, Litterfall rates and respiration rate. By using this model, the global carbon dynamics in the current climate condition were described well, and prediction was also made on the change of the global soil carbon storage and soil respiration for doubling CO_2 climate condition. On the basis of the results of the model calculation, it is anticipated that the soil carbon storage increases when the CO_2 concentration increases. The most significant reason for such results might be the temperature change caused by the greenhouse effect.

In the present work, special attention was paid upon the soil carbon dynamics in steady state. The soil carbon dynamics is slow than that of biomass carbon dynamics. Difference of response to climate change among the two is solved by model calculation in non steady state. Improving the present model, the carbon dynamics in the terrestrial ecosystems can be quantitatively estimated in non steady state.

REFERENCES

EPA, Global Ecosystems Database, EPA Contract No. DW13934786-01-0, 1992.

Goto N. et al., Ecological Modeling, 74 (1994) 183

Goto N. and M. Suzuki, Toward Global Planning of Sustainable Use of the Earth, Elsevier, Amsterdam、(1995) 135

Meteorological Research Institute, CD-ROM on Global Warming Projection, 1, Japan Meteorological Agency , 1996

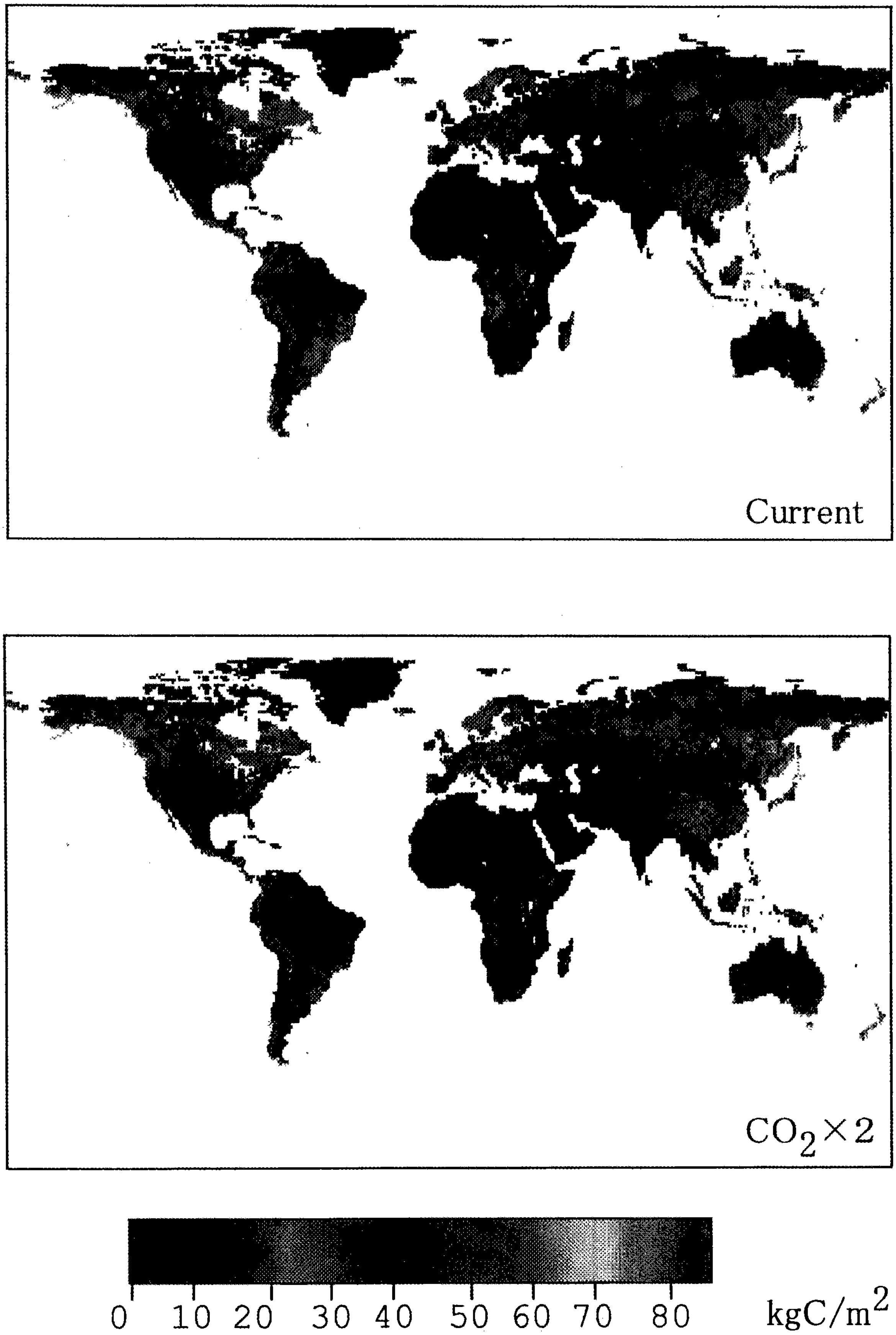

Fig.2 distribution map of soil carbon storage

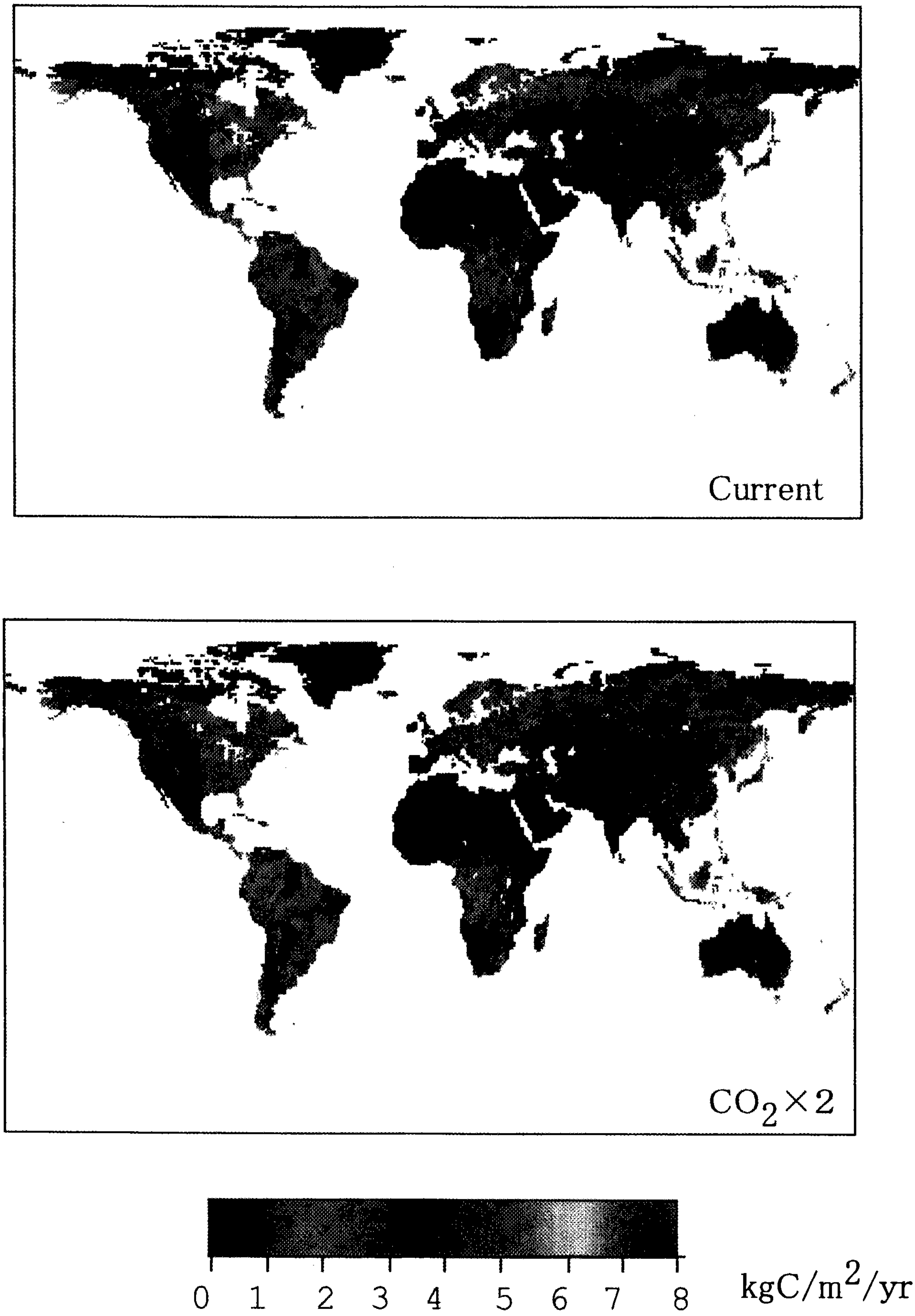

Fig.3 distribution map of soil respiration