# A Japanese study on carbon cycling: its outline

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## 1. Background

Although there is uncertainty, global warming will be the most serious problem for us. Increasing of carbon dioxide (CO2) in the atmosphere is outstanding for these several ten years and it is one of the causes (green house gases) of global warming. The global warming will cause very drastic environment changes, which never happened before on the earth, and serious changes on the terrestrial ecosystem. Therefore monitoring of CO2 flux or carbon balance is one of most important problem, and its reality must be made clear urgently. Necessity of carbon balance evaluation was pointed out in the second meeting of Inter-governmental Panel on Climate Change (IPCC) in 1990, and CO2 emission control was discussed in the Kyoto COP3 summit in last December.

On the other hand, progress of earth observation and computer technology is going to improve accuracy of land cover mapping spectrally and spatially. Although the global vegetation index (GVI) of NOAA AVHRR data has been used for global study, there were several problems with GVI data due to its data processing procedure (Goward et.al. 1993). However, finer resolution mosaics has been created by improved data processing procedure, and the problems with GVI is going to be removed. There are some international plans for satellite launches with earth observation sensors such as MODIS on EOS-AM, GLI on ADEOS-II. They have more channels and finer resolution than AVHRR. It would be possible to improve global land cover maps using those data. The data would be also helpful for carbon flux estimation. Therefore, it is an urgent requirement to understand the carbon circulation mechanism and patterns in global scale using updating technology.

Although carbon balance has been studied intensively comparing with other elements such as nitrogen, it is not very clear still now. It was recognized that the ocean was very huge sink of CO2, but carbon balance estimation couldn't tell unknown sink of CO2 at that time. On the other hand, a role of temperate and boreal forests in the northern hemisphere as CO2 sink is becoming clear nowadays, and they say that it may absorb big amount of carbon, which can compensate the missing sink. As seen in the history of carbon balance study, it must be very important to evaluate land and ocean at the same time.

A Japanese carbon flux mapping study, which is called 'Study on global carbon cycle and the related global mapping' (tentative English title), has been organized sponsored by the Science and Technology Agency of Japan under such backgrounds. It covers both the terrestrial and ocean ecosystems.

## 2. Outline of the study

The land part of study is explained hereafter. The study is composed of 2 phases, the productivity mapping phase and the carbon flux mapping phase. The objective is global mapping of net primary production (NPP) and some parameters, which affect on NPP, with satellite remote sensing in the first 3-year phase. It will be basic information about carbon cycling. We will execute field surveys to understand mechanism of carbon cycling and to improve mapping accuracy in the eastern Eurasia and Oceania, where we selected as intensive test sites.

### 2.1 Flow of the study

We take two approaches to estimate global NPP patterns (Fig. 1). There may be some methods for global mapping of NPP. Most promising and simple method is classifying terrestrial ecosystem in detail and allocate an unit value, which would be determined based on past study or results of the project, to each vegetation types. It is called as bulk method in this study and will be utilized to know rough patterns of NPP distribution.

Satellite remote sensing is very effective for large area mapping and many vegetation maps have been produced. Advanced multi-channel satellite data would make global vegetation map more accurate. However, spectral similarity of different vegetation types and variation of phenological-sepctral patterns year by year will cause inconsistency in classification results. And this method cannot show effects of climate changes on NPP.

Due to such problems, we also study a precise method based on process studies of carbon flux in different major vegetation. Continuous measurements of carbon flux will be executed to understand the process, and measurement methods will be improved and systematized. One of primary objective is to develop any process models, which use satellite data directly or indirectly. Vegetation changes would be monitored by satellite data, effects of environmental changes will be monitored by process models. Although basic models have been produced, it would be a hard task to improve models.

### 2.2 Production and Carbon Flux

Green plants fix CO2 in the air by photosynthesis to their body, and emit CO2 by respiration. CO2 is also released from soils as the result of respiration by roots and bacteria (soil respiration). Total photosynthesis is called gross primary production (GPP) and plants consume the production for respiration (PR). Difference of GPP and PR is called net primary production (NPP). NPP shows uptake of $CO2$ by plants, and it can be measured as follows.

$$NPP = \Delta W + L \qquad (1)$$

where $\Delta W$ is biomass growth of plants and L is litters from plants to soil in a year. On the other hand, it is necessary to take into account of soil respiration (SR) to know CO2 flux and it is shown as follows.

$$NEP = NPP - SR \qquad (2)$$

NEP is called net ecosystem productivity, and it shows CO2 flux (Oikawa, 1991). Therefore it is very important to estimate the amount of CO2 uptake by plants and release by soil to estimate CO2 flux in the terrestrial ecosystems.

We classifies terrestrial vegetation into 3 major groups as follows. Terrestrial vegetation would be classified into 2 types by its structure, trees and herbs. Herbs would be classified into two types, natural herbs and agricultural crops by difference of human interaction. The biggest difference between trees and herbs is that trees have woody parts, which are large in volume and non-assimilatory. Trees and many of natural herbs are perennial plants, and they start growing drastically using nutrient in their roots in early spring in temperate and boreal zones. On the other hand, many of crops are replanted and harvested year by year by human. Thus those would cause big differences in the process of carbon cycling. Therefore we separate terrestrial ecosystems into forest, natural herbs (grasslands and wetlands) and crops (Fig. 2).

It is pointed out that classifying vegetation into same functional types is favorable for ecosystem modeling (Gitay and Noble, 1997). Such classification using satellite data would be necessary, however we have to remind that classification, which based on production types, would be very difficult by satellite data alone. Combination of satellite and environmental information would be necessary to derive better vegetation type maps.

2.3 Classification of vegetation

Ground truth collection is one of hard task for global classification. Vegetation type maps are necessary, but each map would be produced by different classification system. There may be inconsistency of categories among maps, and then high-resolution satellite imagery will become an important ground truth data.

As pointed out widely, the idea of scaling up would be important (Ehleringer and Field, 1993). Since Landsat TM covers important spectral channels, its data could be used to produce simulation data of low resolution imagery of advanced sensors. If it is so, any analysis methodology for TM data could be applied to low resolution data. We would employ 2 level categories in the global vegetation classification (Fig. 3). The level 1 categories may be classified using low-resolution satellite data alone, and idea of scaling-up would be utilized there.

Although satellite data is effective for large area classification, it would be very difficult to classify vegetation types in detail. Since each plant grows in its ideal environment, and environmental information will be mandatory for level 2 classification.

2.4 Linkage of satellite data and process

Optical satellite sensors measure reflectance from the ground and their data include information about plant biological status, which has close relationship with photosynthesis or productivity. Thus satellite data may be very effective for NPP estimation. It has been recognized that there is a near linear relationship between sum of the normalized vegetation index (NDVI) and productivity of different ecosystems in the continental scale.

NDVI is very well studied, and it was demonstrated that NDVI had a linear relationship with fAPAR and curvilinear relationship with LAI. Although many ecological models use LAI to describe production, this fact shows disadvantage of utilizing satellite data to estimate LAI. On the other hand, sunny and shade leaves have different photosynthetic capacity, LAI may not be a suitable parameter for production modeling. There would be any possibility to utilize fAPAR as an input parameter in production models.

It is impossible to measure soils under dense vegetation canopy directory by remote sensing. therefore it is necessary to know the relationships between soil respiration and environmental factors in global scales. Even soil cannot be observed, decomposition speeds of leaves are relating with not only climate but also leaf materials, vegetation types are very important information for soil respiration study.

We selected at least one measurement site for the 3 major ecosystems to measure reflectance spectra and biological parameters, which relating with production, respiration and carbon flux (Fig. 4). Various parameters, which relate on production and respiration, will be measured. Relationships between seasonal variation of reflectance spectra and productivity are one of interest to use satellite data for process models.

2.5 Process study

Some process models describe carbon flux as movements of carbon between compartments. There are some methods to measure total carbon flux and movement of carbon between compartments as shown in Fig. 5. Each method has its own advantages and disadvantages, and they may give different outputs. Thus it is very important to improve methods and to systematize community level measurements for accurate measurements. On the other hand, since biological process is controlled by environment, environmental effects on carbon flux must be analyzed in not only compartment level but also community level. Measured flux between compartments will be used as a basic information to understand process and to improve process models. Those measurements are basics for modeling.

## 2.6 Global mapping

Developed algorithms will be modified and combined for global mapping of NPP and carbon flux at the end of the first 3-year and second 2-year term respectively. As described before, we have selected two approaches for NPP mapping, and the bulk method is much promising to derive any results, although there is hard limitation for improving accuracy. The precise method is much favorable due to its flexibility and reality description. However, there are many problems to be solved before applying the precise method in the global scale.

Key points for the mapping are summarized as follows.

Remote Sensing:

1) Reasonable classification by functional types of production.
2) Estimation of photosynthetic parameters.
   PAR, light use efficiency, LAI etc.

Process:

1) Determination for unit values for the bulk method.
2) Establishment of systematic measurement methods especially for forest community.
3) Analysis of relationship between parameters.
4) Improvement and simplification of models.

To make utilize remote sensing data successful, basic corrections such as geometric correction and atmospheric correction are very important. Although the former will be study and improve correction method in this project, the latter is out of scope at the moment.

Finally, the results will be merged with the ocean group result to make clear global carbon flux. The map will be produced with 8 km resolution.

## 2.7 Frame

Ten institutions are involved in the land group of this project. Roles of those institutions are briefly summarized in Fig. 6. This study has cooperation with IGBP DIS and TEMA. Most institutes have any international cooperative institution in China, Mongolia, Korea and

Australia. There is an international flux network to exchange information, and we are planning to contribute on it.

## 3. Conclusion

As described above, current technological improvements make global analysis possible. There are many activities to understand global ecosystem using advanced technologies. However, we still needs ground measurements over the world for validation of study. It is very hard task for each research group to derive ground data in various places. Thus international cooperation is already mandatory in global studies.

Global warming causes drastic environment changes, which never happened in the earth history. The human society needs various efforts to prevent global warming to keep sustainable development. It would be our duty to observe and record current earth for the future.


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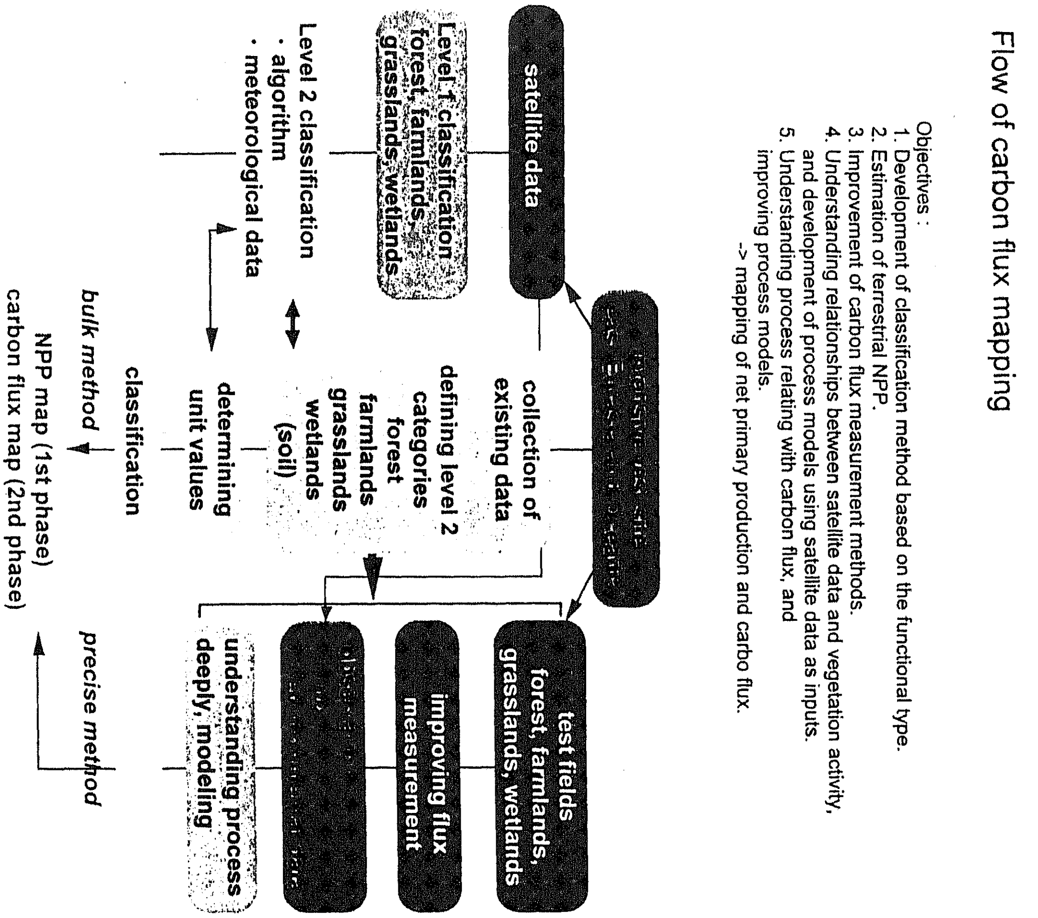



Fig. 1 flow of the study.

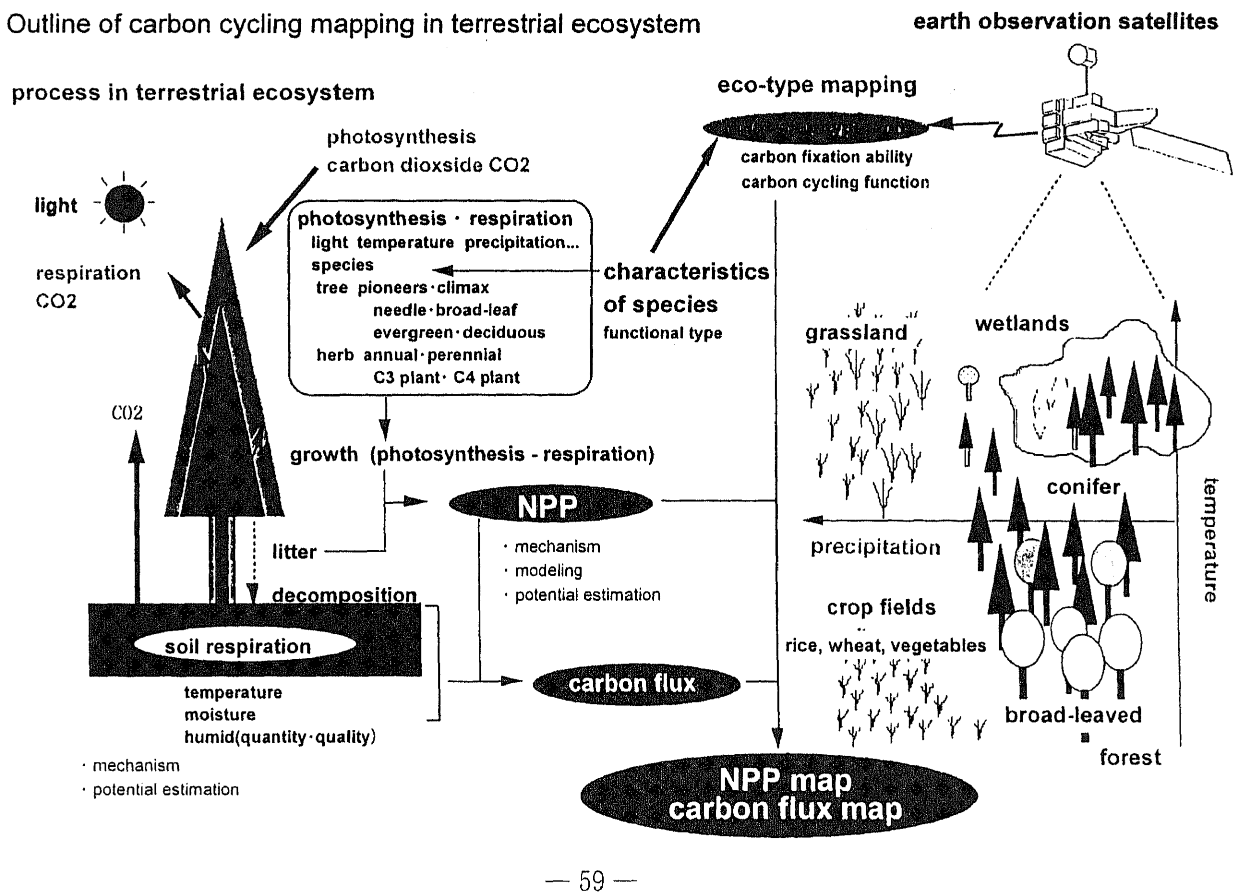



Fig. 2 Out line of carbon cycle mapping in the terrestrial ecosystem.

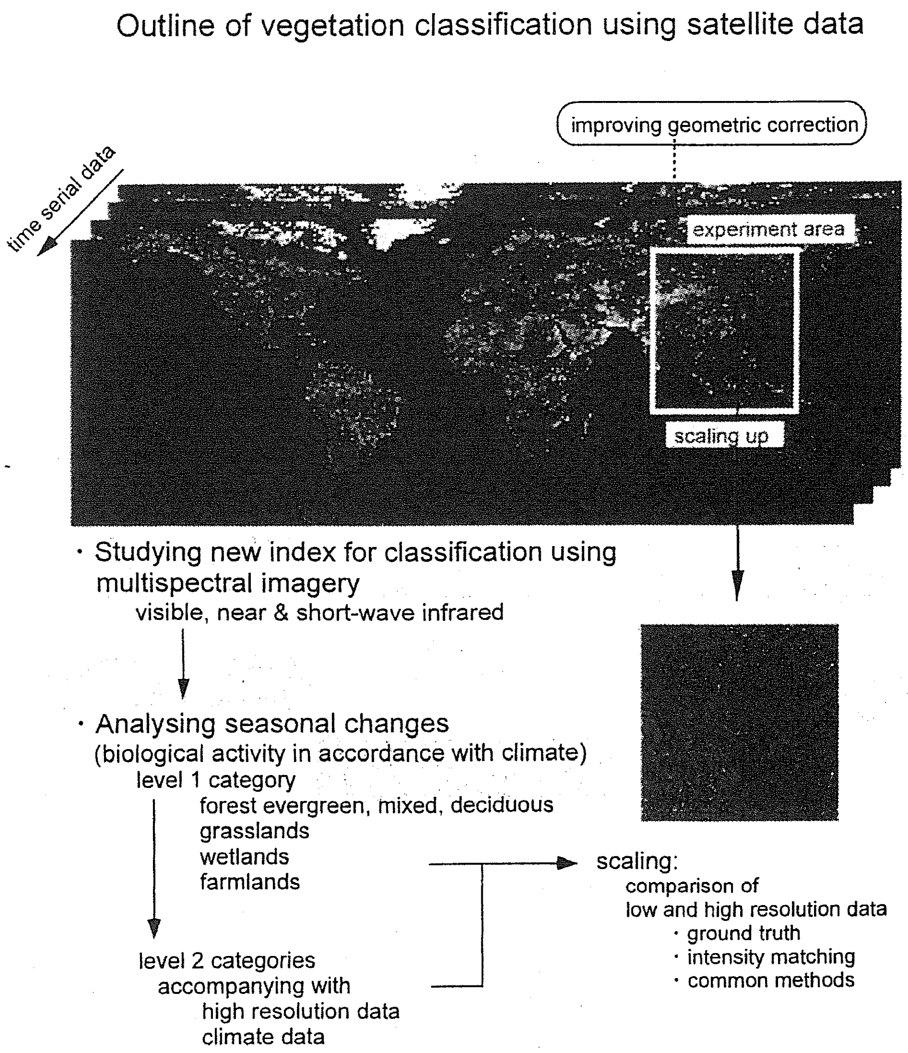



Fig. 3 Outline of vegetation classification using satellite data.

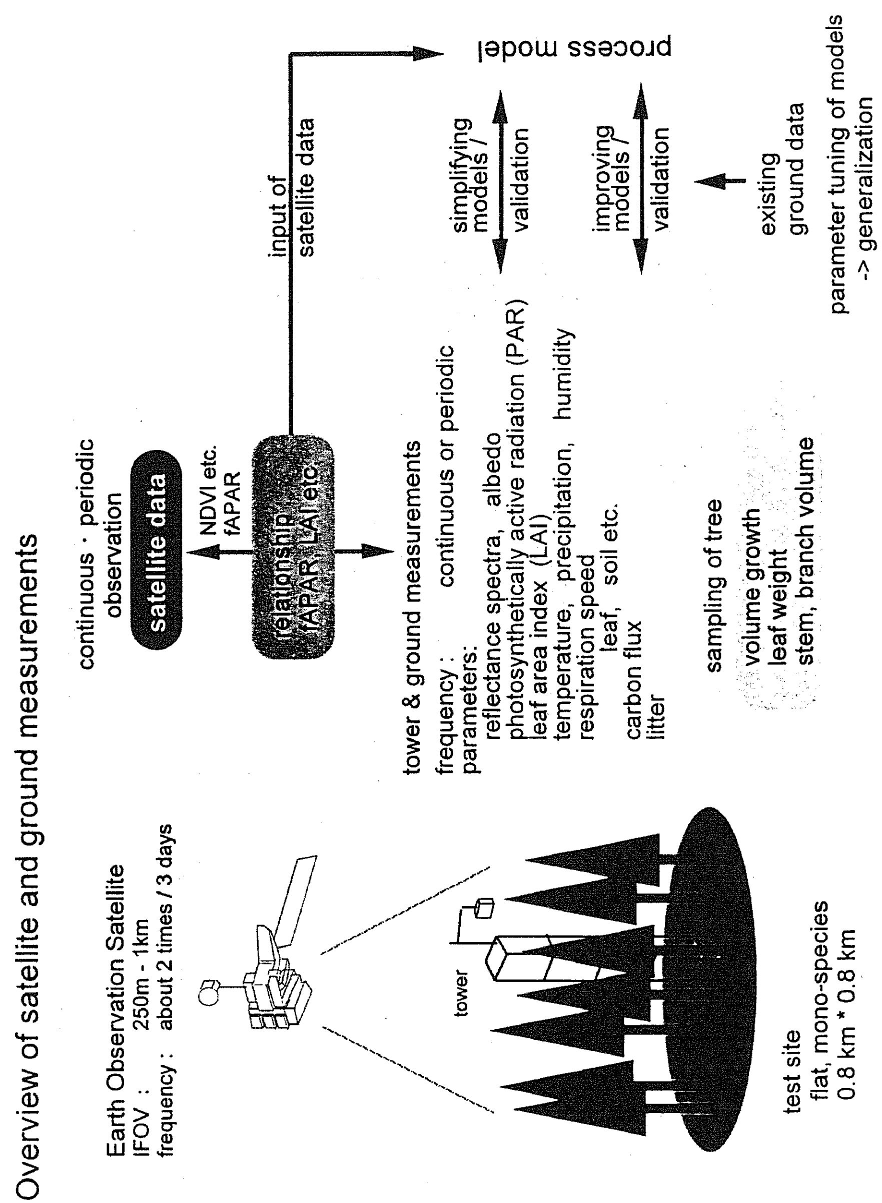



Fig. 4 Over view of satellite and ground truth measurement.

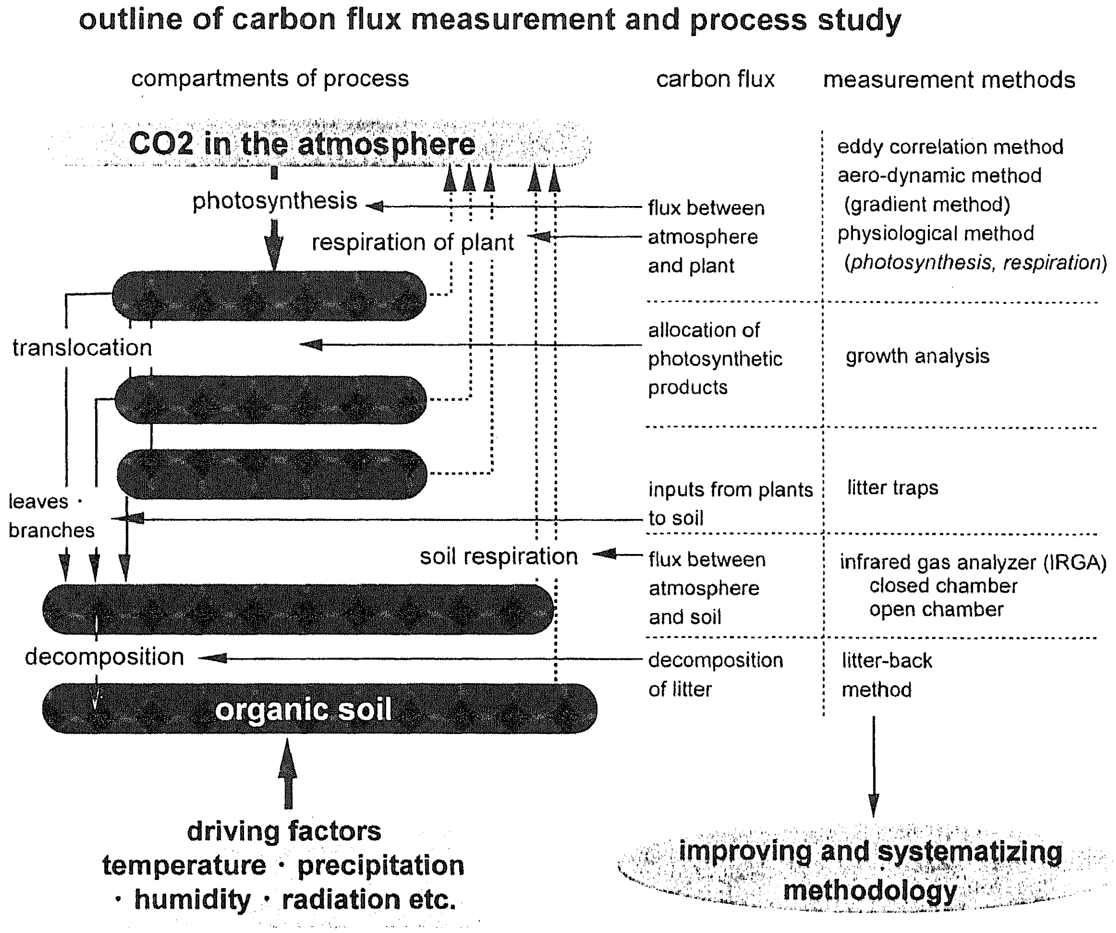
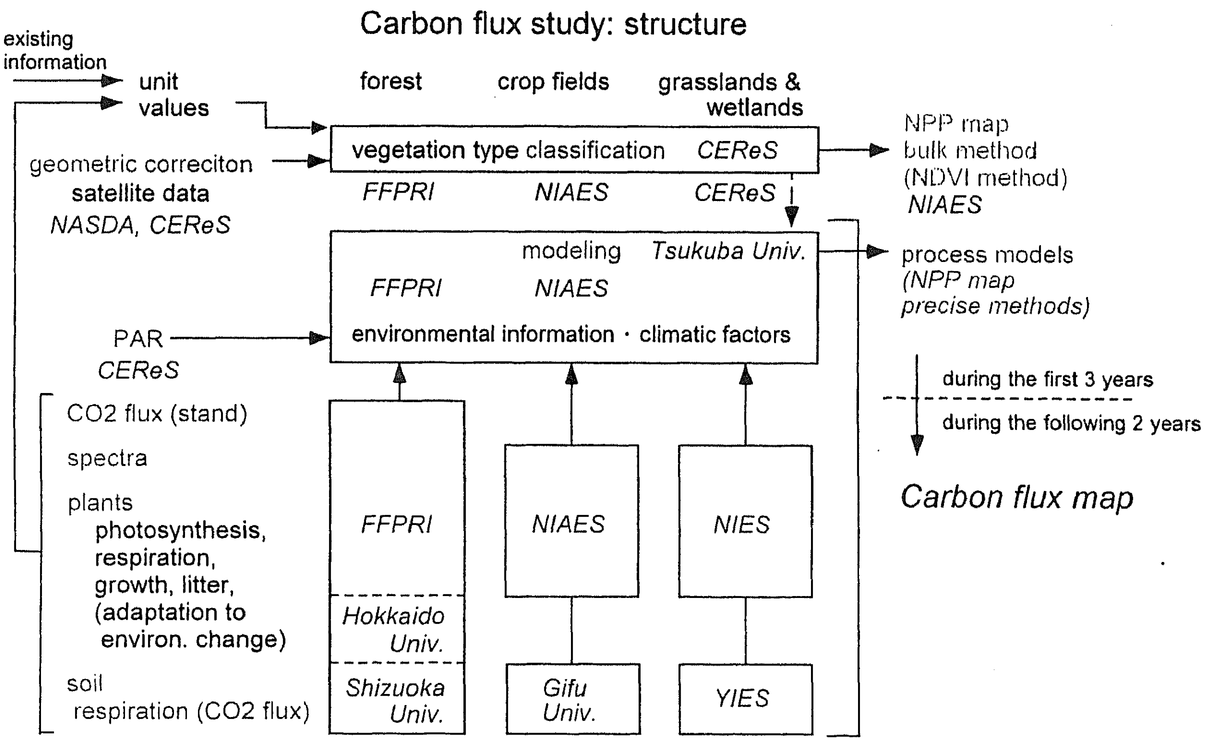



Fig. 5 Outline of carbon flux measurement and process study.




**Institutions:**

*FFPRI*: Forestry and Forest Products Research Institute
*NIAES*: National Institute of Agro-Environmental Sciences
*NIES*: National Institute for Environmental Studies
*NASDA*: National Space Development Agency of Japan
*YIES*: Yamanashi Institute of Environmental Sciences
*CEReS*: Center for Environmental Remote Sensing
Gifu University
Hokkaido University
Shizuoka University
Tsukuba University

Fig. 6 Carbon study: structure.