Global Environment Research Account for National Institutes

Long-term Monitoring of Carbon Flux and Promotion of a Data Network in Asian Terrestrial Ecosystems (Abstract of the Final Report)

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1. Introduction

In the 21st century, climate change has become an important environmental problem for which immediate measures are required. Atmosphere as well as terrestrial and oceanic ecosystems must be monitored by long-term integrated observations. Evaluation of carbon dioxide (CO_2) exchange in terrestrial ecosystems is important in formulating policies to prevent climate change, as specified by the targets of the Kyoto Protocol. There are various types of ecosystems in Asia, and they play an important role in the global environment. A tower flux observation is a typical technique used for measuring CO_2 flux in terrestrial ecosystems. The Forestry and Forest Products Research Institute, National Institute for Agro-Environmental Sciences, National Institute of Advanced Industrial Science and Technology, National Institute for Environmental Studies, and several other institutions and universities have monitored carbon flux in Japan for many years. These observations have been conducted for different studies using individual funds. Data have already been collected for the past 11–18 years from various sites. AsiaFlux, a regional research network studying CO_2 exchange in Asia, was established in 1999 and has since developed observation support and data sharing. However, observation systems have not been standardized and compared because of insufficient funds; data sharing has therefore not progressed sufficiently.

2. Research Objective

CO_2 balance in terrestrial ecosystems has been monitored via tower flux observations. Data obtained have been used to improve and verify various models. This research was aimed at promoting long-term and high-quality monitoring, as well as data sharing (Fig. 1). Eight flux sites in Japan and three in other parts of Asia, which were established by independent administrative agencies, were reorganized as long-term monitoring sites. These sites are located in areas that differ from each other with respect to vegetation, climate, and terrain. Data from these sites were used to compare and standardize observation systems. The observation systems are efficient and stable devices for long-term monitoring, and suitable to Asian conditions.

3. Methods

The current state of observation systems and analytical methods at each site was noted to provide feedback for standardizing the observation systems. The sites were maintained for long-term observation and data were collected. Systems were examined on the basis of reports obtained for each site and an observation manual was developed. While concentrating on data quality and sharing, comparative measurements of sensible heat, water vapor, and CO_2 fluxes were

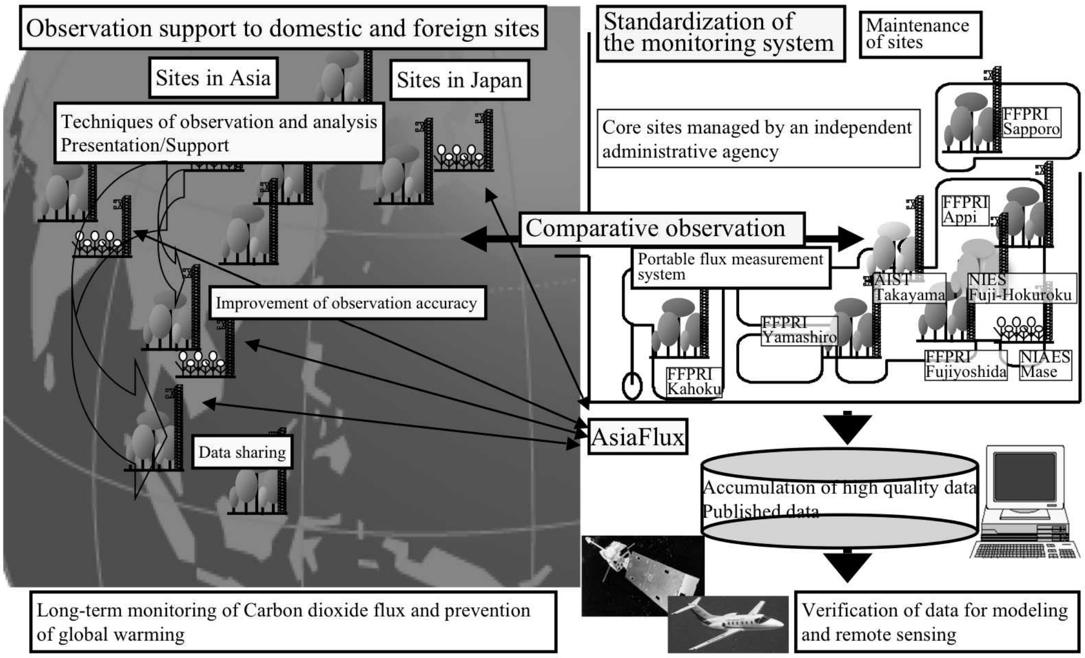

Fig. 1 Project concept

conducted at Fujiyoshida, Mase, Fuji-Hokuroku, Takayama, and Lambir (Malaysia) sites.

4. Results and Discussion

(1) Maintenance of monitoring sites and standardization of the observation systems

(a) Maintenance of monitoring sites

Site information, observation systems, and analysis procedures were classified for long-term monitoring. The type of data logger and gas analyzer (open and/or closed) used at each site varied; however, the analysis procedures were similar.

(b) Continuance of long-term observation

[Sapporo] Annual net ecosystem exchange (NEE) ranged from 80 to 360 gC m^{-2} y^{-1} during five years (2007–2011). The gross primary production after a disturbance, which was a large typhoon in 2004, decreased 10% and the ecosystem respiration increased by a factor of 1.5 relative to the situation before the disturbance. Although the Sapporo Forest site, where the 4-year average NEE was –443 gC m^{-2} y^{-1}, had absorbed carbon dioxide before the typhoon, the site would have released carbon dioxide because the typhoon damaged trees and increased the amount of coarse woody debris. The annual carbon release was greatest in 2010 among the last five years. Air temperature in spring was lower than usual and the beginning of the leafing stage was delayed in 2010. As a result, the amount of carbon absorption in June was small and total carbon release was greatest. The biomass of dwarf bamboo (*Sasa kurilensis* and *S. senanensis*) rapidly increased in the three years following the disturbance, and understory trees gradually grew in the last few years. Long-term monitoring is required to study the recovery.

[Appi] We continued eddy covariance-based CO_2 flux and meteorological observations in a cool-temperate deciduous forest on the Appi Plateau of Japan. Annual NEE showed maximum net CO_2 uptake in 2011 among the five years: annual NEE from 2007 to 2011 was respectively –88, –280, –288, –212, and –380 gC m^{-2} y^{-1}. In 2007 and 2010, the amounts of net CO_2 uptake decreased owing to insect damage and high summer temperatures, respectively. The length of the growing season in 2011 was 155 days and the shortest as well as the length in 2010.The mean air temperature in the 2011 growing season (15.9°C) was second only to that in 2010 (16.9°C). Although previous observations revealed that seasonal net CO_2 uptake decreased with increasing air temperature in the growing season, the observational results for 2011 showed a different trend.

[Mase] The Mase site is located in central Japan, and as a flux-monitoring site situated in paddy fields, it has the longest period of data starting from August 1999. By adding data for the five years from 2007 to 2011, we clarified the interannual variability of CO_2 exchange and factors affecting the CO_2 budget in the growing season. To solve a problem that is inherent to the open-path eddy covariance (OPEC) system and becomes apparent in the fallow season, we compared the open- and closed-path eddy covariance systems and improved the quality control procedure for eddy covariance data. We also developed a standard data processing program for the OPEC system and applied it to three paddy flux sites including the Mase site. The program is particularly well designed in terms of quality control, and it can be used for cropland and grassland sites, especially in monsoon Asia, because such sites generally employ the OPEC system and have frequent rainfall in the growing season.

[Fujiyoshida] We continued meteorological and flux measurements in a cool-temperate, secondary evergreen red-pine forest at the Fujiyoshida forest meteorology research site in central Japan between 2007 and 2011. Annual NEEs for each of the five years were –446, –331, –436, –516, and –443 gC m^{-2} y^{-1}, respectively, and the maximum deviation of annual NEE from the five-year-average exceeded 100 gC m^{-2} y^{-1}. The monthly net uptakes of CO_2 (NEP = –NEE), except for January and February, were positive (CO_2 absorption), and the maximum daily net uptake of about 5 gC m^{-2} d^{-1} occurred in May during the five years. Between June and September, there were clear depressions in net CO_2 uptake synchronized with periods of lower solar radiation due to the long rainy season. Variations in monthly NEEs were larger between April and September than in other months. These results suggest that year-to-year change in meteorological conditions from spring to summer or early autumn affect annual NEE in a complex manner.

[Fuji-Hokuroku] We continued long-term observations of CO_2/H_2O flux in a deciduous needleleaf forest (a larch plantation) of the Fuji-Hokuroku Flux Research site. The phenology of larch clearly reflects the seasonal pattern of NEE observed at the site. Periods of opening leaves and falling leaves likely vary depending on temperature. Variations in the length of the growing season affect the annual uptake of CO_2. During the growing season of the vegetation, NEE changes in response to short-term change in light availability. At the Fuji-Hokuroku site, to ensure consistency of observed parameters, various sensors are periodically calibrated by rounding multiple sensor-sets. We are attempting quantitative evaluation of the temporal change in leaf phenology using phenology cameras installed on a tower.

[Takayama] Measurements of CO_2, H_2O, and heat fluxes, meteorological parameters, the atmospheric CO_2 concentration, soil environmental parameters, soil respiration, stable isotopes, and ecosystem phenology have continued at the Takayama site. In 2011, the temperatures from winter to spring were lower than normal. Although the beginning and end of the rainy season were earlier than normal, the solar radiation in August was less than normal owing to rainy and cloudy conditions. The beginning of net CO_2 absorption was delayed owing to a delay of budding associated with the lower temperatures in spring. The monthly NEP for August was lowest in 2011 among the five years of 2007–2011 owing to reduced photosynthetic activities associated with less solar radiation. Hence, the annual NEP was second lowest in 2011 among the five years. From the result, it was suggested that the year-to-year change in meteorological conditions from spring to summer complexly govern that in annual NEP at the Takayama site. For long-term measurement with higher quality, the measuring system needs to be further improved using information and communication technologies.

[Yamashiro] Meteorological and flux measurements were conducted in the warm temperate broadleaf forest at the Yamashiro flux site from 2007 to 2011. Various respirational processes (e.g., soil respiration, root respiration, and course-wood-debris respiration), ecosystem phenology, and biomass change were also continuously measured at the site. The phenology of *Quercus serrata* reflects the seasonal pattern of NEP observed at the site. Annual NEP gradually increased from 2000–2003 (120 gC m^{-2} y^{-1}) to 2009–2011 (170 gC m^{-2} y^{-1}) following recovery from the disturbance of Pine welt disease in the 1980s. NEP of 2010 was slightly less than that in 2008 and 2009 because of high temperatures during the summer. Temporal NEP changes at this site were controlled by a combination of interannual changes in environmental factors and changes in tree growth after the large disturbance.

[Kahoku] We continued micrometeorological and eddy flux measurements at the Kahoku forest meteorological research site in Kyushu. This site is located in a planted coniferous forest (Japanese cypress (*Chamaecyparis obtuse*) and Japanese cedar (*Cryptomeria japonica*)) and is the most southern site among the sites in Japan. Similar seasonal patterns of carbon exchange were observed from 2007 to 2011; there was maximum CO_2 uptake in spring and lower CO_2 uptake in summer. Lower CO_2 uptake in summer might be due to less solar radiation during the monsoon season (from June to July) and greater ecosystem respiration in August.

[Jiangdu] We conducted meteorological and flux measurements in a rice–wheat double-cropping field at the Jiangdu site in Jiangsu Province, eastern China, for five years from 2007 to 2011, and clarified the temporal variation in CO_2 exchange on daily, seasonal, and interannual scales and quantified differences in the CO_2 budget between rice and wheat cropping seasons. The annual NEE at the Jiangdu site, where crops were cultivated almost throughout the year, was on average 3.4 times that at the single-cropping Mase site, and interannual variations in the annual NEE at the Jiangdu site were found to be quite small. However, the quantification of carbon flow in burning harvest residue and how different management of harvest residue affects CO_2 flux in the subsequent season require further investigation.

[Mymensingh] We conducted meteorological and flux measurements in a double-rice-cropping paddy field at the Mymensingh site in northern Bangladesh for the five years from 2007 to 2011, and clarified the temporal variation in CO_2 exchange on daily, seasonal, and interannual scales including non-cropping seasons. This is the first long-term study of CO_2 exchange in paddy fields in South Asia, and it therefore provides useful data for crop science and studies on biosphere–atmosphere interactions. Unfortunately, there were unexpected problems with the flux measurement system in the mid-growing seasons of 2009 and 2010, which resulted in several long-term data gaps. From the experience, we have learned that it is important to prepare a backup system for long-term measurements, especially those made at foreign sites.

[Sakaerat] Flux observation data were collected up to March 2012 at the Sakaerat tower site, Thailand, and they are currently being processed and analyzed. As a result of improving the observation facilities and instruments used in previous years, we made CO_2 flux measurements without long data gaps throughout the rainy season of 2011. In the Indochina region including Thailand, where there are tropical seasonal forests, the ecosystems are more active in the rainy season. The success of the monitoring in the rainy season allows discussion of the effects of climate change on the carbon budget in such a region with greater accuracy. The data availability will be further improved through remote monitoring and using an automated alert of the observation system by introducing Information-Communication Technology, and by developing human resources while enhancing cooperation between National Institute of Advanced Industrial Science and Thai collaborators, in the next phase of the project.

(c) Intercomparison of radiation sensors and development of a calibration strategy

We built a calibration facility for various radiation sensors on the rooftop of a building at the National Institute for Environmental Studies. We updated reference radiometers to enable traceability against the world standard. We carried out the first comparison experiment of longwave radiometers in September 2010. We compared each radiometer against a reference radiometer that was calibrated at the World Radiation Centre of World Meteorological Organization immediately before the comparison. We also compared our result with reference data recorded by the Aerological Observatory of Japan Meteorological Agency, only approximately 300 m from our calibration facility. The scheme of this radiometer calibration would be helpful in ensuring the quality and long-term consistency of our radiation measurements.

(d) Standardization of the observation systems

Common methods for both measurement and data analysis are essential when comparing CO_2 fluxes among the sites. However, the differences in topography and vegetation affect observation and analysis systems. We proposed a common data format for designing standard analysis programs.

(e) Compilation of a flux observation manual

The Japanese edition of a flux observation manual was released online in FY2008 and an English edition was released online in FY2009. The editions have since been revised and their contents improved. The English edition was printed in FY2011 and distributed to applicants and relevant organizations. We posted a questionnaire on the Internet using Computer Gateway Interface scripts. Questionnaire data indicated that users belong to a broad fields of research, not only meteorology and hydrology but also ecology, forestry, geochemistry, and environmental engineering. Access-log analysis indicated that the Web pages were accessed from not only Asia but also Europe and the Americas. The website received views from many nations.

(f) Data sharing

The Global Earth Observation System of Systems was adopted with a 10-year implementation plan and is the basis for promoting data sharing. Data sharing is advanced at each institute according to such policy. The extent of data sharing among observation sites varies; nevertheless, the publication of data will progress gradually. Several sites in this project have cooperated with AsiaFlux and/or JaLTER.

(2) Comparative observation using a portable flux observation system

The compatibility of measurement data is essential in realizing the research potential of measurement networks. In general, there is no single method that can be recommended, and various kinds of site-specific procedures have been developed and carried out for tower flux measurements. To improve tower-flux data accuracy and to promote comparative data analysis and data sharing within the Asia region, a portable eddy covariance carbon flux measurement system was taken to four forest sites and one paddy field site, and carbon dioxide fluxes were compared between the portable system and the routine measurement system at each site six times in total. The portable flux observation system consists of a closed-path infrared gas analyzer, sonic anemometer, data logger, and other peripheral devices.

As a result, the carbon-dioxide eddy covariance fluxes obtained by the routine measurement systems at the four sites were evaluated as being adequate, being comparable to the fluxes measured by the portable measurement system. Root-mean-squares of differences in the half-hourly fluxes recorded by the routine measurement systems at the four sites and the portable system were less than 2.6 μmol $m^{-2}s^{-1}$, and relative errors were less than 23.4%. These relative errors were within ranges given in past references, which reported random errors in carbon-dioxide fluxes measured from towers. Our analysis of the data comparing the routine measurements and portable measurements suggests there are some problems, and we have proposed the improvement of routine measurements.

A user manual for the portable flux observation system was published. This manual is available to users of the potable system, including beginners in flux observations.