Global Environment Research Account for National Institutes

Sensor Network and Data Processing Automation for Evaluating Carbon Cycle Changes in Terrestrial Ecosystems (Abstract of the Final Report)

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1. Introduction

During the 21st century, climate change has been recognized as a critical environmental problem. Long-term integrated observations of the atmosphere, the oceans, and the terrestrial ecosystems are indispensable for assessing global warming and facilitating policy decisions. In 2003, a 10-year implementing the Global Earth Observation System of Systems was proposed, and new initiatives in International Earth Observations were implemented. In December 2004, the Council for Science and Technology Policy in Japan submitted a report entitled “Earth Observation Promotion Strategy.” The scientific working group of the Office for Coordination of Climate Change Observation commented on the importance of developing of a comprehensive and integrated system for observing climate change. The necessity of continuously performing research on climate change and its influences and accumulating additional scientific knowledge was affirmed by recent decisions in meetings of the cabinet and the Conference of Parties (COP21). In these reports, the necessity of carbon cycle observations in the Asia–Oceania region was emphasized. Long-term observations in terrestrial ecosystems are necessary because the influence of climate change is uncertain, and flux observations are among the *in situ* observation methods that are required to clarify the debate.

2. Research Objective

Carbon cycle monitoring sites in terrestrial ecosystems (*in situ* observation points using towers) were established worldwide. Most of the sites are located in America and Europe, with a smaller number located in Asia. More observation sites are required in Asia because of the complex topography, climate, ecosystems, and land use. In dynamic ecosystems, long-term observations are important in resolving the uncertainty in the influence of the carbon cycle. Four institutes, namely, the Forestry and Forest Products Research Institute (FFPRI); the Institute for Agro-Environmental Science, NARO (NIAES); the National Institute of Advanced Industrial Science and Technology (AIST); and the National Institute for Environmental Studies (NIES), have been monitoring domestic and foreign sites since the 1990s. Close cooperation has promoted sharing and improved data quality. The use of new technology is necessary to achieve and maintain high precision in observations. Furthermore, automated observation systems save labor and offer a distinct advantage in long-term observation efforts.

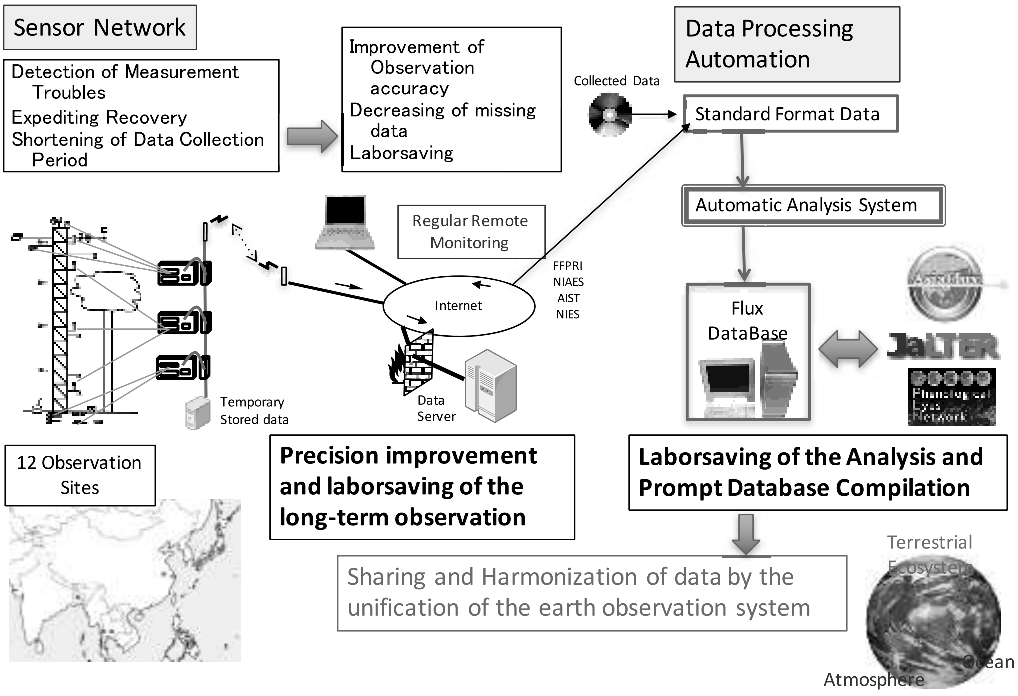

Fig.1 Conceptual diagram of an integrated climate change observation system

3. Methods

We constructed a sensor network using information and communication technology for real-time monitoring. Methods for precise observation and prompt data sharing were developed (Fig. 1). As a result, the long-term carbon cycle in terrestrial ecosystems can be observed in detail.

4. Results and Discussion

(1) Construction of a high-precision observation system using the sensor network

(a) Sensor network in AIST

The AIST team has performed long-term monitoring of CO_2 flux and more than 40 meteorological parameters at 3 tower sites: Takayama (TKY) in Japan and Sakaerat (SKR) and Mae Klong (MKL) in Thailand. Throughout the project, each of the 3 tower sites went online by a method suitable for the site. We established a connection between the towers and the server in the AIST Tsukuba office, which enabled automatic data acquisition, data transport, and near-real-time data processing, including estimations of CO_2 flux. We have also installed a malfunction alert system that monitors instruments operating unattended in towers on the network. As a result, we have reduced recovery time due to instrument failure and decreased data losses without increasing the frequency of visits to the tower sites for routine inspection and maintenance of instruments.

(b) Sensor network in NIAES

NIAES has been performing remote flux monitoring using a sensor network of Asian agricultural flux monitoring sites, including Mase (MSE) in eastern Japan and Mymensingh (MYM) in northern Bangladesh. This sensor network consists of a multi-site flux monitoring and surveilling system, a portal site for flux site management, and a satellite-flux-meteo database. Major components of the NIAES sensor network have been constructed, and almost all of the data from MSE and MYM are now acquired in real time. We have continuously operated the NIAES sensor network and accumulated observational data from MSE for 5 years and from MYM for 4 years. A time series of NEP data from MSE showed year-to-year variability in the annual peak of the ecosystem's CO_2 uptake, whereas NEP data fromt MYM showed seasonal variations, with double peaks corresponding to double cropping of rice. After implementation of the sensor network, long-term periods of missing data disappeared and the frequency of on-site maintenance visits was reduced.

(c) Sensor network in FFPRI

Five FFPRI Fluxnet observation sites were connected to the Internet in March 2014. The Sapporo and Fujiyoshida sites were connected using a wireless local area network. The Appi, Yamashiro, and Kahoku sites were connected using the mobile phone communications networks (NTT Docomo 3G or 4G). Most preexisting observation equipment was replaced with new devices that have telecommunication functions. The new observation system enabled continuous monitoring through the Internet. At the Sapporo site, continuous monitoring through Internet access decreased the number of working hours and the rate of data gaps. At the Appi site, we performed quasi-real-time data collection between the site and laboratories using online sensor network. We were able to detect instrument trouble early and were able to understand its impact in observations. Online checking shortened the duration of missing data and reduced the maintenance necessary to obtain measurements. At the Fujiyoshida site, the sensor network system is equipped with 5 network cameras, an automated snow gage, and an automated rain gage for continuous monitoring. Using this monitoring system, we reduced the number of trips for maintenance. Because the Kahoku site utilizes narrowband transmission, meteorological variables and the vertical CO_2 profile are synchronized with the cloud storage service every 2 hours. With these changes, the time and labor necessary for maintenance of the sensor network has been reduced because we can detect sensor problems before visiting the sites. Direct data processing on the network enhances data quality and speeds up data publication.

(d) Sensor network in NIES

We have established and improved networking in the long-term observation system for meteorological and ecological monitoring in the Fuji-Hokuroku Flux Observation Site (FHK), which is expected to reduce labor and enhance the robustness of the data accumulation. Our objectives are to collect measurements data from various sensor outputs rapidly and to control the measurement system in the observation site from a remote location. The FHK site is located in a deciduous needle-leaf forest that has clear seasonality in vegetation phenology. Variation in CO_2 exchange fluxes is closely related to the phenology. We have been developing a technique to capture and to digitalize the phenology of forest stands by using spectrometric radiation sensors and digital imaging devices. The infrastructure of the sensor network is extremely valuable for acquiring digitalized ecosystem information for the rapid assessment of climate impact. Accumulating high-quality observation data without data interruption by using sensor networking will be helpful in investigating long-term changes in atmosphere-biosphere CO_2 budget.

(e) Comparative analysis of the carbon budget

We performed a comparative analysis of the annual carbon flux among observation sites distributed in Asia from subarctic to tropical zones. The ecosystem includes forests and rice fields. Gross primary production showed a complex change in solar radiation. Changes in ecosystem respiration were similar to changes in air temperature. In spite of the complex relationships, Respiration increased with the increase in gross primary production.

(2) Development of automated technology for efficient data sharing

(a) Use of FluxPro

Using the “FluxPro” software developed for the automated processing of eddy covariance and meteorological data obtained from remote sites, we have connected the Asian agricultural flux monitoring sites into a network. FluxPro processes raw data transmitted from remote sites through the Internet every hour. It displays fluxes, their uncertainties, spectra, cospectra, and other statistical parameters of turbulence on a website. FluxPro data processing is simple so that its output can be used in immediate surveillance of the monitoring sites. As of March 2017, FluxPro is used at 18 monitoring sites in Asia and is operated online at 10 of the 18 sites. All of the output data from FluxPro can be accessed through the Internet in nearly real time, thereby reducing the effort necessary for monitoring and surveillance of the monitoring sites and the early detection of sensor problems. Furthermore, by simultaneously processing data from multiple sites, FluxPro enables the comparison of fluxes between the monitoring sites in real time, thus providing us with insights for new studies by utilizing the monitoring network. With growing concerns about the Internet security, it was necessary to reduce risks in Internet communication between the FluxPro application server and servers located in the other domains. One approach was to take advantage of Hypertext Transfer Protocol (HTTP) in place of Secure Shell (SSH) in comminutions with data collection servers. Otherwise we used a direct connection between the FluxPro application server and the data logger at the measurement site. Another approach was to relocate the FluxPro web server to an official web server associated with the research organization and managed for Internet security by professional staff. This enabled the research staff to minimize the time and effort necessary to manage individual web servers for FluxPro.

(b) Use of a data logger for onsite computation of eddy-covariance fluxes

As an alternative approach to achieving flux monitoring, we developed a program that computes the eddy covariance fluxes of CO_2 and H_2O in real time on a commercial data logger. The performance of the program was compared with that of published software programs used on data from maize fields. The calculated fluxes were consistent among programs. Because practical onsite and real-time quality control procedures for flux measurements were unavailable, we developed a quality control procedure that utilizes sensor disability signals. Filtering sensor-disabled signals significantly improved the detection of anomalous fluxes during rainy periods. By slightly modifying the source code, we can adapt the framework of our program to other combinations of data from sonic anemometers and gas analyzers.

(c) Network usage for data preservation and sharing

To prevent data loss caused by equipment trouble or disaster, we established a backup system that stores data at multiple locations. A common data format was used to ensure continuity in data maintenance and efficient use of data. It also reduced the effort necessary to collect and treat data for the open database.

(d) Metadata arrangement for sharing, integrating, and presenting data

Meteorological observations are publicly available on the websites of each institute and on Asiaflux. It is important to properly manage the metadata and to ensure rapid access to shared data. The Data Integration and Analysis System project is presently working for the Promotion Strategy for Earth Observation, and our observation sites have offered metadata to the project. This report shows complete data on the meteorological and carbon budget from 2011 through 2015. Older data are accessible on the websites.