ARCP Programme Final Report




Project Reference Number: ARCP2015-01CMY-Miyata

Toward CarboAsia: integration and synthesis of ecosystem flux data in tropics/subtropics and croplands in Asia by activating regional tower-based observation networks

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Final Report submitted to APN

1. Part One: Overview of Project Work and Outcomes

Non-Technical Summary

With the support by APN, we have launched ‘CarboAsia’, a strategic project that fills the critical data gaps in tropical/subtropical forests and croplands in Asia for assessing carbon budget of terrestrial ecosystems covering the whole monsoon Asia. Information and observation data of the tower-flux sites have been integrated into the AsiaFlux database, a free-access and sustainable database. After the re-processing through the standardized protocols, those data are currently being used to fill in the critical gaps in data-model integration and synthetic analysis. Despite the complexity and heterogeneity in terrestrial ecosystems in Asia, the updated datasets have been used successfully for site-level model intercomparisons and spatial upscaling along with remote sensing data. We now can provide independent estimations of spatio-temporal variations in terrestrial CO_2 fluxes in Asian regions. The resultant estimates of spatial and temporal variations are, however, subject to further scrutiny with other independent methodologies and longer time series of field data as well as the quantification of uncertainties. The workshops and training & seminars as well as other capacity building/development activities held under the framework of AsiaFlux have met the demands of Southeast and South Asian countries, thereby activating or revitalizing the regional observation networks in those regions.

Keywords

Flux, Carbon budget, Tropical Asia, Cropland, Terrestrial ecosystem

Objectives

1) To integrate standardized tower flux data in Monsoon Asia into the AsiaFlux database to fill the critical data gaps in tropical/subtropical forests and croplands in Asia.

2) To scrutinize those data to elucidate inter-annual and site-to-site variabilities in carbon budget in terrestrial ecosystem in Asia in close collaboration with investigators on terrestrial biosphere modelling and satellite remote sensing, thereby making major contribution to the first AsiaFlux report on ‘the Asian Carbon Budget and Implications for the Global Carbon Cycle’.

3) To hold workshops and training courses by utilizing the framework of AsiaFlux to cultivate next generation of leaders and stewards and to encourage and revitalize tower-based flux observation networks in Southeast and South Asia.

Amount Received and Number of Years Supported

The Grant awarded to this project was:

US$ 45,000 for Year 1, US$ 40,000 for Year 2, and US$ 40,000 for Year 3

Activity Undertaken

During the project period, we had three workshops and three seminars (Appendix A1).

In order to promote interdisciplinary collaborations, the three workshops in Seoul (Korea), Los Baños (Philippines) and Pune (India) were jointly held with other international communities/projects such as HESSS (Hydrology delivers Earth System Science to Society), GRA (Global Research Alliance for Agricultural Greenhouse Gases), iLEAPS (Integrated Land Ecosystem-Atmosphere Processes Study) and ISPRS (International Society for Photogrammetry and Remote Sensing). In these workshops, we had sessions on tropical/subtropical forest, croplands, and data-model integration and synthetic analysis. The three seminars in Mymensingh (Bangladesh), Cat Tien (Vietnam), and Taipei (Taiwan; mini-workshop) were focused on specific topics required for promoting CarboAsia, *i.e*. methane flux measurement, monitoring in tropical ecosystem, and utilization of remote sensing, respectively. Through these activities, e the principal investigators (PIs) of tower-flux sites have been encouraged to share their observation data and the associated information for CarboAsia.

With the support from manufacturers of the instruments, technical training courses on eddy covariance flux measurement and data processing were held five times as pre-conference capacity development activities for the participants mainly from newly established tower-flux sites to ensure data quality. Furthermore, young scientist meetings were held in the three workshops to provide young participants with opportunities to talk with invited Asian and non-Asian senior scientists who have accomplished respected careers as leading scientists in AsiaFlux community. Young participants were provided with travel support (Appendix A2) by using the APN fund and co-fundings (Appendix A3).

Results

Information and observation data of the tower-flux sites submitted by site PIs were integrated into the AsiaFlux database (https://db.cger.nies.go.jp/asiafluxdb/), a free-access and sustainable database. During the project period, the number of the tower-flux sites registered to the AsiaFlux database has been increasing steadily, and reached 101 sites in total, with 125 site-year data from 34 sites as of November 2015. Forty-one site-year data from 13 sites were added to the database during the project period, and among them, 14 site-year data were provided from tropical/subtropical forest sites and 4 site-year data from cropland sites. All of these data are currently being used to fill in the critical gaps in data-model integration and synthetic analysis.

Despite the complexity and heterogeneity in terrestrial ecosystems in Asia, the updated datasets have been used successfully for spatial upscaling along with satellite remote sensing data. We now can provide independent estimations of spatio-temporal variations in terrestrial CO_2 fluxes in Asian regions. The resultant estimates of spatial and temporal variations are subject to further scrutiny with other independent methodologies and longer time series of field data as well as the quantification of uncertainties.

Workshops and seminars, which were held mostly in developing countries in Southeast and South Asian countries, attracted more participants and presentations from those countries than expected (Appendix A1), and participants in the technical training courses were almost full of the capacity. The young scientist meetings, newsletters, and the AsiaFlux mailing list have also functioned well. All of these activities contributed to stimulate and revitalize the regional observation networks. For further details, please refer to Section 3.3 in the technical report.

Relevance to the APN Goals, Science Agenda and to Policy Processes

Capacity development activities in our project were relevant to Goal 1 (supporting regional cooperation in global change research on issues particularly relevant to the region) and Goal 3 (Improving the scientific and technical capabilities of nations in the region) in the Third Strategic Plan (2010-2015) of APN.

The project results on integration and syntheses of terrestrial ecosystem flux data in tropics/subtropics and croplands in Asia are directly related to "Changes in the carbon cycle and the water cycle" in the APN Scientific Research Agenda 2 (Ecosystems, Biodiversity, and Land Use). The results are also relevant to "Source and sink fluxes of greenhouse gases" in Agenda 2 because measurement of methane flux was included in implementing our project.

Although spatial upscaling of the carbon budget has to be investigated further, updated and accurate estimates of carbon budgets on national and regional levels based on standardized flux observation networks is expected to contribute to the next IPCC (Intergovernmental Panel on Climate Change) Assessment Report, and to give scientific backgrounds for decision makers to take effective greenhouse gas management strategies for implementing the Paris Agreement of COP21 (United Nations conference on Climate Change).

Self-evaluation

The flux monitoring tower sites established in tropical/subtropical regions and the associated institutes have been augmented into the existing infrastructure of AsiaFlux. These sites have already begun to make important contributions to AsiaFlux database, and those data are currently being used to fill in the critical gaps in data-model integration and synthetic analysis. The data are also provided for public use mostly by Asian scientists. Results of detailed site-level intercomparison and spatial upscaling along with remote sensing data will contribute to the first AsiaFlux report on "Asian Carbon Budget and Implications for the Global Carbon Cycle" (Appendix A6).

Our capacity development and networking activities met the requirement of Southeast and South Asian countries and are welcomed by young scientists in those countries, and thus contributed to activate or revitalize the regional observation networks. Our activities also attract attention of public sectors. For instance, APRIL, an Indonesian pulp and paper company, which has recently initiated tower flux observation with interest in the global environmental change, participated in our mini-workshop in Taipei to request collaboration.

All of these results indicate our project is mostly successful, and we will certainly attain the three objectives of the project mentioned above.

Potential for further work

With three-year support by APN, 'CarboAsia', a strategic project by AsiaFlux, got a successful start. CarboAsia initiated the capacity development not only in human resources but also in infrastructural, institutional and procedural dimensions by augmenting several national networks, activities, data production and information sharing into the AsiaFlux framework. These dimensions in capacity building/development are not the final product but an ongoing process, and therefore deserve further efforts and persistent supports.

There is still one particular concern which requires special attention and priority support, that is the mismatch between 'the rapid advances in data collection/sharing' and 'appropriate applications of modern statistical and modelling tools.' Future efforts must address inherent challenges of making useful translations and predictions from complex data such as deciding the usefulness and robustness of data and models, selecting a best model or combination of models, avoiding overfitting, and incorporating uncertainties.

To promote the CarboAsia project further and to address the above-mentioned issue, we are planning to have the AsiaFlux workshop in 2017 in China in collaboration with International Ecological Society (INTECOL), and in 2018 in Indonesia, where rapid land use change as well as climate change in recent years attract scientific and social attention.

Publications [please write the complete citation]

1) Kim, W., Miyata, A., Ashraf, A., Maruyama, A., Chidthaisong, A., Jaikaeo, C., Komori, D., Ikoma, E., Sakurai, G., Seoh, H.-H., Son, I. C., Cho, J., Kim, J.-H., Ono, K., Nusit, K., Moon, K. H., Mano, M., Yokozawa, M., Baten, Md. A., Sanwangsri, M., Toda, M., Chaun, N., Polson, P., Yonemura, S., Kim, S.-D., Miyazaki, S., Kanae, S., Phonkasi, S., Kammales, S., Takimoto, T., Nakai, T., Iizumi, T., Surapipith, V., Sonklin, W., Lee, Y., Inoue, Y., Kim, Y., Oki, T., 2015. FluxPro as a realtime monitoring and surveilling system for eddy covariance flux measurement. *Journal of Agricultural Meteorology*, **71**, 32-50.

2) Ichii, K., Ueyama, M., Kondo, M., Saigusa, N., Kim, J., Alberto, M. C., Ardö, J., Euskirchen, E. S., Kang, M., Hirano, T., Joiner, J., Kobayashi, H., Marchesini, L. B., Merbold, L., Miyata, A., Saitoh, T. M., Takagi, K., Varlagin, A., Bret-Harte, M. S., Kitamura, K., Kosugi, Y., Kotani, A., Li, S.-G., Machimura, T., Matsuura, Y., Mizoguchi, Y., Ohta, T., Yasuda, Y., Zhang, Y., Zhao, F., New data-driven estimation of terrestrial CO_2 fluxes in Asia using a standardized database of eddy covariance measurements, remote sensing data, and support vector regression, *in review*.

References

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Besides the collaborators' institutes, the following institutes and organizations supported the project. Cat Tien National Park, Vietnam; Indian Institute of Tropical Meteorology, India; Chi-Sing Irrigation Association, Taiwan; Chi-Seng Water Management Research & Development Foundation, Taiwan; and Taiwan Agricultural Engineering Society.

2. Part Two: Technical Report

Preface

In the technical report, we describe the progress in the CarboAsia project funded by APN, placing the focus on how tower flux data were integrated into the AsiaFlux database to fill the critical data gaps in tropical/subtropical forests and croplands in Asia, and what we found on inter-annual and site-to-site variabilities in ecosystem carbon budgets in Asia through the integrated analyses of tower flux data, ecosystem modelling and satellite remote sensing. We also describe how the networking activities conducted in the CarboAsia project stimulated and revitalized tower-based flux observation networks in Southeast and South Asia.

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1. Introduction

As an essential component of Integrated Global Carbon Observing System (IGCO) (Ciais, *et al.*, 2010), eddy covariance terrestrial ecosystem flux measurement should be enhanced with improved access to its database. Integration of the standardized flux data from a variety of biome types is also crucial for validating the upscaling of carbon budget with modelling and remote sensing.

AsiaFlux, the flux monitoring tower network for carbon and water cycles in terrestrial ecosystems in Asia, is implementing a strategic plan, CarboAsia (the carbon budget assessment covering the whole Asian terrestrial ecosystems), to fill the critical data gaps in tropical/subtropical forests and croplands in Asia. Through the CarboAsia project supported by APN, we have held several workshops, seminars and training courses under the framework of AsiaFlux. These activities have encouraged and activated the tower-based flux observation networks in Southeast and South Asia, thereby promoting data integration and syntheses in close collaboration with investigators on terrestrial biosphere modelling and satellite remote sensing.

The three main objectives of the project are 1) to fill the critical data gaps in tropical/subtropical forests and croplands in Asia into the AsiaFlux database by facilitating the tower-based flux observation networks in Southeast and South Asia; 2) to scrutinize these data to elucidate inter-annual and site-to-site variabilities in ecosystem carbon budgets in Asia through the integrated analyses of tower flux data, ecosystem modelling and satellite remote sensing, and 3) to hold workshops and training courses to cultivate next generation of leaders and stewards who will continue pursuing the vision of AsiaFlux, which is to serves as the "Science Frontier" in carbon, water and energy cycles, developing and transferring scientific knowledge.

The current project will make major contribution to the report that will be prepared by AsiaFlux on ‘the Asian Carbon Budget and Implications for the Global Carbon Cycle’ (Appendix A6).

2. Methodology

2.1. Filling the data gaps in subtropics and tropics

In order to fill in the critical data gaps in subtropical and tropical regions, first we need to establish flux towers with pertinent objectives and purposes appropriate for resolving concerns of local and regional communities. The importance of the establishment of flux tower network in tropical and subtropical regions is promoted through various settings such as regular AsiaFlux Workshops (AFWS), seminars/mini-workshops with more specific focus, intensive hands-on Training Course on flux-monitoring and data processing, along with numerous strategic meetings led by AsiaFlux Science Steering Committee.

These flux towers must be equipped with appropriate instrumentations, operated and maintained by specially trained scientists for reliable data collection and acquisition. Then, following the standard protocols, the data must be post-processed with corrections, quality controls and gap-filled with the site-specific methodologies. Consistently pre-processed database of eddy-covariance flux observation is a prerequisite for any analyses, integrations, data-driven upscaling, and comparisons. The training course is offered strategically before AFWS and seminars particularly for participants from newly established tower-flux sites. They learn fundamental theories of tower-based flux measurement, instrumentation, handling and processing eddy covariance data (flux calculation, quality control, assessment and gap-filling) and analysis, which are necessary for data integration. The AsiaFlux's Short Course Workgroup guides and supports these training courses.

2.2. Data integration, analysis, and synthesis

2.2.1. Site-level analysis and comparison

The site information and observation data collected from the individual sites are integrated into the AsiaFlux database (https://db.cger.nies.go.jp/asiafluxdb/). First, the data submitted to the AsiaFlux database will go through a process of quality control to scrutinize any overlooked data that are not acceptable or questionable (*e.g.*, spikes, outliers). Then, CO_2 fluxes and other biophysical data are re-processed with standardized protocols for individual sites to minimize the potential biases due to differences in data processing methodologies and gap-filling strategy to produce the final seamless datasets. Once the datasets are prepared for each site, then, comparison analysis is conducted for the datasets obtained with various methods (*e.g.*, friction velocity-, light-response curve-, and advection-, and/or model-based). Accordingly, the most appropriate data can be selected and provided as the final dataset for users.

2.2.2. Data and model comparison

Ecosystem models are widely used to estimate terrestrial CO_2 fluxes at local, regional and continental scales. Although multiple models have been used to estimate terrestrial CO_2 budget in Asia, these models are rarely evaluated with AsiaFlux observations. Such evaluation will help not only to better understand current status of model performance, but also to identify future tasks for model improvements and data requirement. Hence, multiple terrestrial ecosystem models are evaluated with the updated AsiaFlux observation datasets. The outputs of CarboEastAsia-MIP projects (Ichii *et al*., 2013) are used, and the participating models include BEAMS (Sasai *et al*., 2005), Biome-BGC (Thornton *et al*., 2002), Carnegie-CASA (Field *et al*., 1995), CLM3.5 (Oleson *et al*., 2008), LPJ (Sitch *et al*., 2003), TRIFFID (Cox *et al*., 2001; Suzuki and Ichii, 2010), and VISIT (Ito, 2008). Monthly and site averages of gross primary productivity (GPP), and net ecosystem exchange (NEE) from observation, empirical upscaling, and ecosystem models are compared (Ichii *et al.*, *in review*).

Inter-annual and site-to-site variabilities in carbon budget components can be also examined by comparing the results of spectral analysis of the time series of those components. Spectral analysis is an effective tool to describe the complex variability patterns in long time series at different time periods. The spectral characteristics can represent the possible frequencies of processes according to their importance or magnitude (Platt and Denman, 1975).

2.2.3. Spatial upscaling

Empirical upscaling is an approach for synthesis-based on-site observation and satellite remote sensing. The advantages are that it combines purely and empirically driven estimation with remote sensing data, and provides an independent estimation of spatio-temporal variations in terrestrial CO_2 fluxes. In spatial upscaling, empirical regression algorithms is used with individual sites data along with remote sensing observations, and a machine learning algorithm (*i.e.*, Support Vector Regression, SVR) (*e.g*. Yang *et al*. 2007; Ueyama *et al*. 2013). First, a model is established at a site level using AsiaFlux data and remote sensing data and its evaluation is conducted using the data that are not used for model establishment. Then, spatial CO_2 fluxes are calculated using remote sensing data for the 2001-2014 period. The MODIS (Moderate Resolution Imaging Spectrometer) products used include Normalized Difference Vegetation Index (NDVI), Enhanced Vegetation Index (EVI), Land Surface Temperature (LST), Land Cover, Leaf Area Index (LAI), Fraction of Photosynthetically Active Radiation absorbed by a canopy (FPAR), and Solar Radiation (Ichii *et al*., *in review*).

2.3. Activation of national/regional networks

AsiaFlux has 20 study sites (and potentially more) in South Asian countries, but most of them have been dormant or started observation quite recently. To encourage those sites to continue long-term flux monitoring and to submit observation data for synthesis, we stimulate and reactivate the existing national networks through the above-mentioned regular workshops, seminars and training courses. Key collaborators are encouraged to organize a national network if not exist. For countries with only a few study sites, AsiaFlux augments them with neighbouring countries to form a regional network.

3. Results & Discussion

Key findings, interpretation, importance, and the related discussion are summarized here by the following order: (1) data integration, (2) data analysis and synthesis (including site-level analysis and comparison, data and model comparison, and spatial upscaling), and (3) activation of networks in Southeast and South Asia.

3.1. Data integration

The network of AsiaFlux tower flux sites cover climatological and ecological diversities in monsoon Asia: It ranges from tropical forest near the equator to the Siberian Taiga in the subarctic, and from wetlands near sea level to prairies on the Tibetan Plateau (Fig. 3.1). The present APN-funded project focused on tropical/subtropical forest and croplands, where the flux sites are relatively scarce, and therefore the number of available flux data are limited.

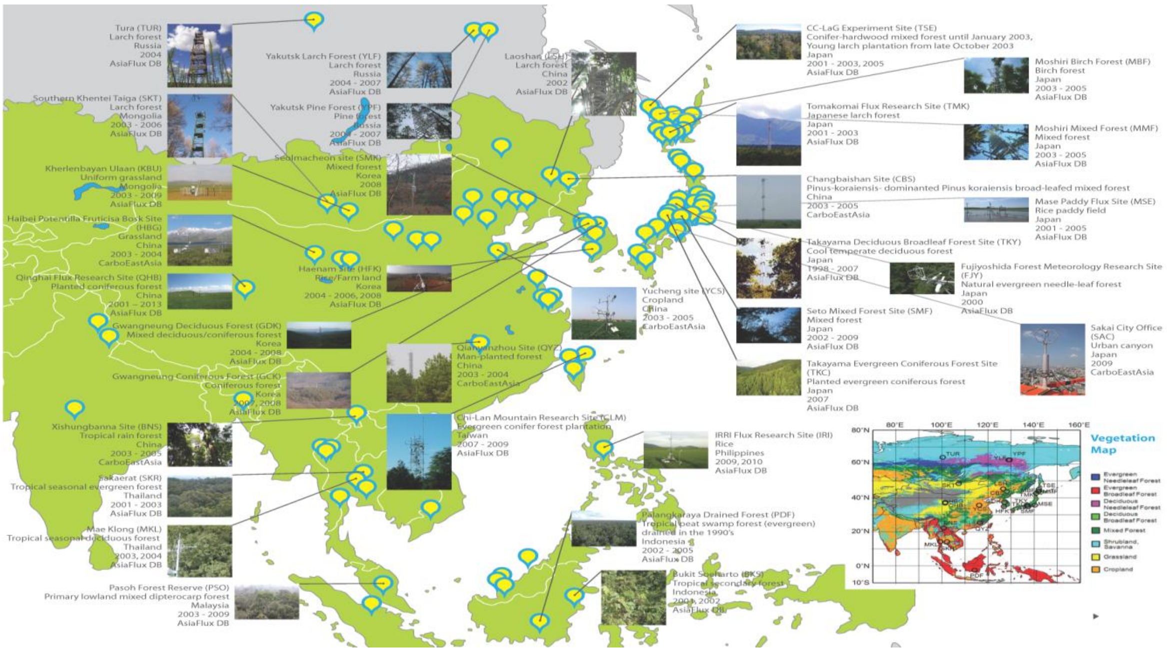


Figure 3.1 Flux monitoring sites in Asia as of August 2013.

During the project period, the number of flux study sites registered to the AsiaFlux database has been increasing steadily to reach 101 sites in total as of November 2015. Out of the 13 new registered sites, 2 are located in Southeast Asia and 3 in South Asia (Fig. 3.2 left).

The AsiaFlux database has 125 site-year datasets from 34 sites as of November 2015 (Fig. 3.2 right). Among the 41 site-year data from 13 sites added during the project period, 14 site-year data were provided from *t*ropical and subtropical forest sites (3 from Thailand, 7 from Malaysia, 3 from Taiwan and 1 from China) and 4 site-year data from cropland sites (3 from China and 1 from Japan). Further data are expected to come from Philippines, Vietnam, Malaysia, Bangladesh and India.

The datasets integrated into the AsiaFlux database were not only used in the synthetic data analysis in the present project but also provided for open use. Recently, the number of downloaded datasets has increased up to 200 and 450 per month, and more than 80% of the download was made by Asian users (Fig. 3.3), indicating the integrated datasets meet increasing demand for flux data in Asia and are welcomed by scientific communities, especially those in Asia.

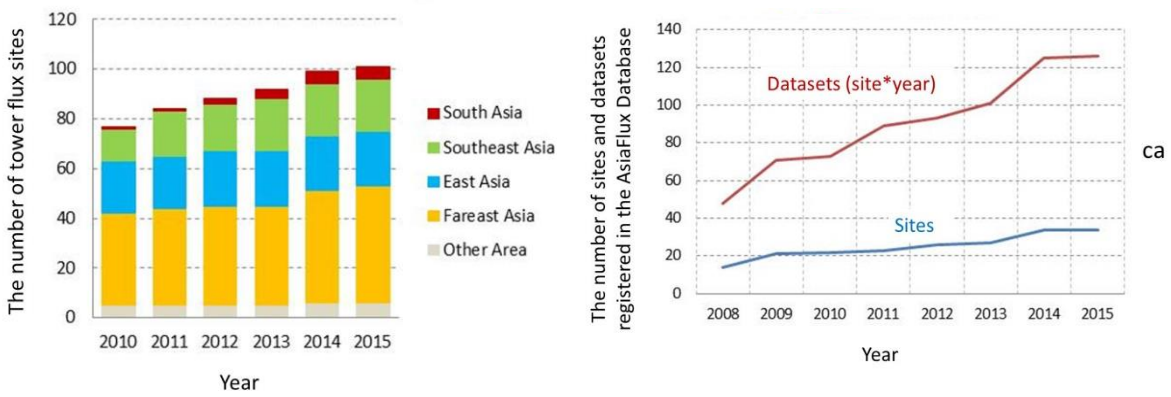


Figure 3.2 Increase in the number of tower flux sites (left) and datasets registered in the AsiaFlux database (right) as of November 2015.

It is, however, recognized that the number of integrated datasets is still not satisfactory when compared with the number of the study sites. With requests of the global scientific community, it is required to continue our efforts for integrating more datasets, especially from tropical/subtropical forests and croplands in Asia, even after the APN-funded project is over.

Understanding of site PIs on data sharing has gradually been improved to have the consensus, for instance, to promote inter-site comparison and synthetic studies for rice fields. Showing the results of synthetic studies in this project will advance the understanding further, and encourage and motivate site PIs to submit their data to the AsiaFlux database. FluxPro (Kim *et al*., 2015), an advanced data integration system, will also be a useful tool for data integration, and it potentially has practical application to terrestrial ecosystem flux monitoring on a scale of monsoon Asia.

3.2. Data analysis and synthesis

3.2.1. Site-level analysis and comparison

In Fig. 3.4, the examples of the site-level comparisons between different data processing methodologies are shown for the GCK coniferous forest site (left) and the HFK cropland site (right) in Korea. Three methods used for the final datasets are: friction velocity-based correction (u*), light-response curve-based correction (LRC), and advection filtering-based correction (VGm). The results are presented for GPP, RE (ecosystem respiration) and NEE for both sites based on the averages for eight years' data (in g C m^{-2} d^{-1}). They demonstrate that (1) the results from the three methods are different in both patterns and magnitudes and (2) the differences varied from year to year and from site to site depending on the degree of heterogeneity of the vegetation and the complexity of the site topography. Therefore, caution should be exercised to choose the best selection and/or combination of these datasets for more accurate applications (*e.g*., Kang *et al*., 2014).

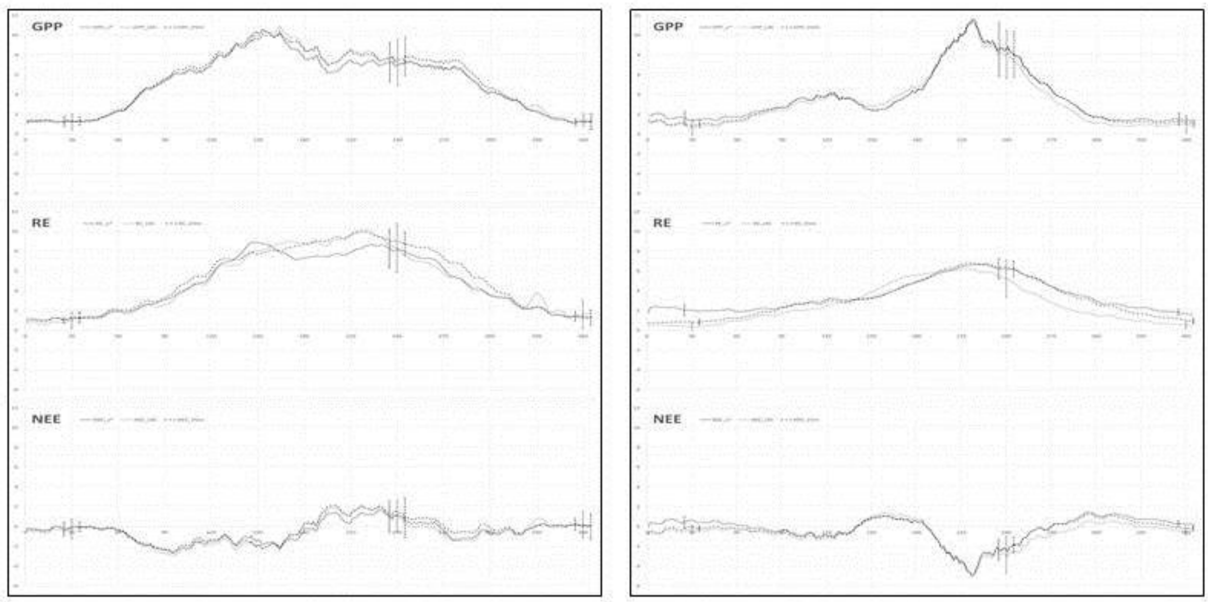


Figure 3.4 Comparisons of seasonal variations of GPP, RE, and NEE between different data processing methodologies for GCK coniferous forest (left) and HFK cropland (right) in Korea.

3.2.2 Data and model comparison

The CarboEastAsia-MIP outputs tends to underestimate high end of GPP for monthly and site-mean (Fig. 3.5). Although observed GPP reaches up to 15 g C m^{-2} d^{-1} at monthly scales, model simulation only reaches to 8 g C m^{-2} d^{-1}. Models also do not reproduce both monthly and site mean NEEs (Fig. 3.5c, d)). Comparison of performance of estimation between empirical upscaling (SVR) and CarboEastAsia-MIP (Model) show clearly better performance of empirical upscaling estimations. These results suggest further requirement of model improvements using observations. Potential causes of model-data mismatch are (a) model parameters are not calibrated well against observation, (b) site-specific information (*e.g*. disturbance history, cropland calendar) are not included in the models.

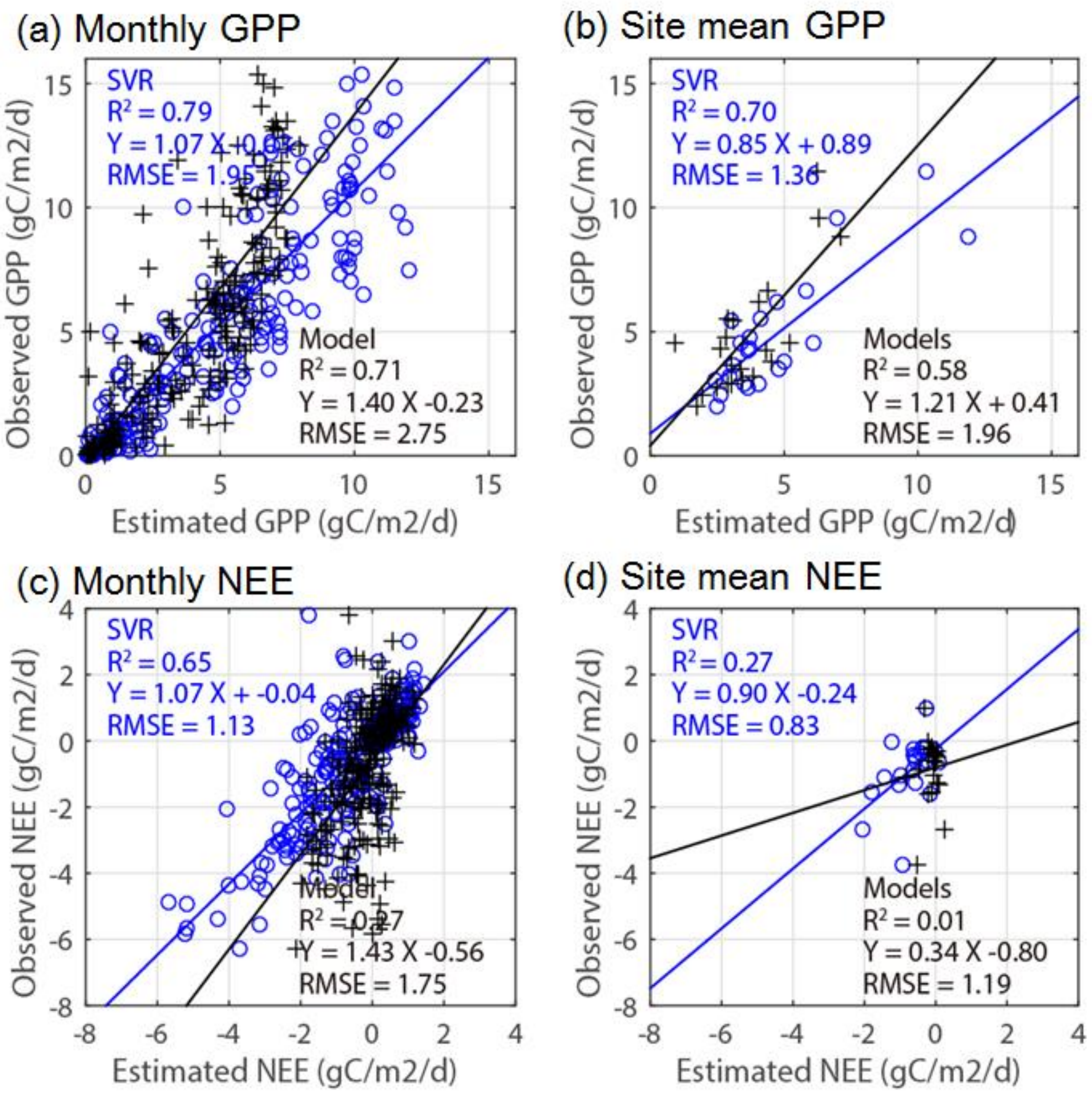


Figure 3.5 Scatter plot of observed and estimated CO_2 fluxes at 22 sites in the CarboEastAsia DB. As estimated CO_2 fluxes, empirically upscaled estimation (spatial upscaling) and CarboEastAsia-MIP outputs (model outputs) are shown for comparison. Multi-model averages are used as model outputs.

Other ways to examine model performance includes the comparison of spectral characteristics of the time series of both measured and modelled. Table 3.1 shows the results of the variance spectra for GPP and NEE for two AsiaFlux sites: (1) a tropical peatland forest (PDF site) in Indonesia and (2) a single-cropping rice paddy (MSE site) in Japan. Overall, notable spectral peaks were with the periods of 12, 6, 4, and 3 months. For example, the observed data at PDF showed that annual cycles explained approximately 20% of the total variances of the observed GPP and NEE. Such a spectral peak and its contribution were reproduced well by the models such as LPJ but were overestimated by VISIT, for example. For other spectral peaks (*e.g*. 6, 4, and 3 months) and their contributions, most models either overestimated or underestimated the contributions. For cropland, annual cycles explained 36 to 51% of the total variance of GPP and NEE, and an additional 30% by semi-annual period. Part of such differences was attributed to the mismatch of site-specific information between the observation and the model (*e.g.* management options, disturbance history, *etc*.). These results may be used to identify the weaknesses and strengths of the models in order to reduce uncertainties.

Table 3.1 Characteristic peaks in variance spectra and their corresponding accumulated contribution (in percentage) to total variance for monthly values of gross primary productivity (GPP) and net ecosystem exchange (NEE) of CO_2 in PDF site (*i.e.*, peatland forest in Indonesia) and MSE site (single-cropping rice paddy in Japan). The periods of spectral peaks with less than 1-month difference are categorized into one period.

PDF Forest Site: (2002-2005) (%)		Accumulated contribution to to total variance			
Period:	(year)	1	1/2	1/3	1/4
GPP	Obs.	17	43	72	93
	BGC	37	-	73	-
	LPJ	18	35	77	97
	SEIB	21	73	85	-
	VISIT	50	85	-	-
NEE	Obs.	23	-	88	96
	BGC	15	-	65	-
	LPJ	37	-	87	98
	SEIB	9	52	71	95
	VISIT	45	84	-	-

MSE Rice Paddy Site: (2001-2006) (%)		Accumulated contribution to to total variance			
Period: (Year)		1	½	1/3	1/4
GPP	Obs.	51	80	96	-
	BGC	80		97	98
	LPJ	77	91	96	-
	SEIB	67	-	96	-
	VISIT	81	95	-	98
NEE	Obs.	36	67	94	97
	BGC	70	90	95	97
	LPJ	52	81	95	97
	SEIB	45	77	-	-
	VISIT	55	80	-	97

3.2.3. Spatial Upscaling using AsiaFlux data and Remote Sensing

Empirically upscaled SVR model performs reasonably if all available sites in Asia are included (Fig. 3.6). GPP at both 8-day and site mean performs better than NEEs presumably because NEE is a net result of complex processes, which is not observed by remote sensing. Croplands and sites in sub-tropical/tropical regions show larger discrepancies in estimating GPPs, especially in cropland for site-mean (Fig. 3.6b). The modeled estimates show a poor agreement with the measured in the high GPP regions in cropland at 8-days. Also noted is an apparent difficulty in sub-tropical/tropical forests in the estimation of NEE (Fig. 3.6c).

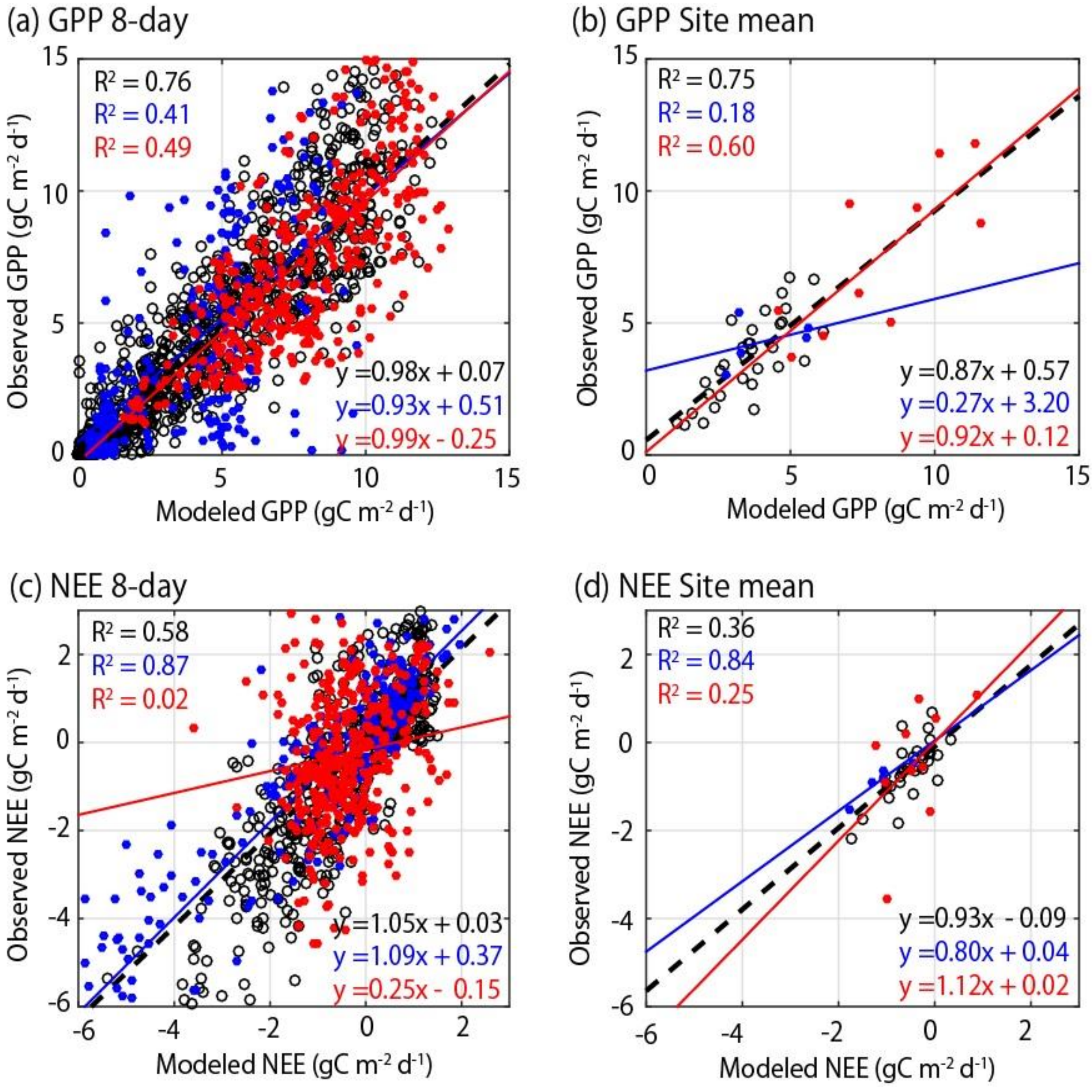


Figure 3.6 Scatter plots of the comparison between the observed and the empirically upscaled CO_2 fluxes. (Black, blue, and red colors represent all sites, cropland sites, and tropical/subtropical sites, respectively.)

Geographic variations in GPP show reasonable patterns that are consistent with climate gradients. The highest GPPs (> 3.0 kg C m^{-2} yr^{-1}) are distributed over southeast Asia regions. High GPPs (> 2.0 kg C m^{-2} yr^{-1}) are also distributed over humid temperate regions across East Asia. Low GPPs are distributed over semiarid regions in China and Mongolia. Estimated NEE shows that most of Asian regions act as CO_2 sink. Large CO_2 sinks are distributed over the tropical and subtropical regions (colored as blue in Fig. 3.7).

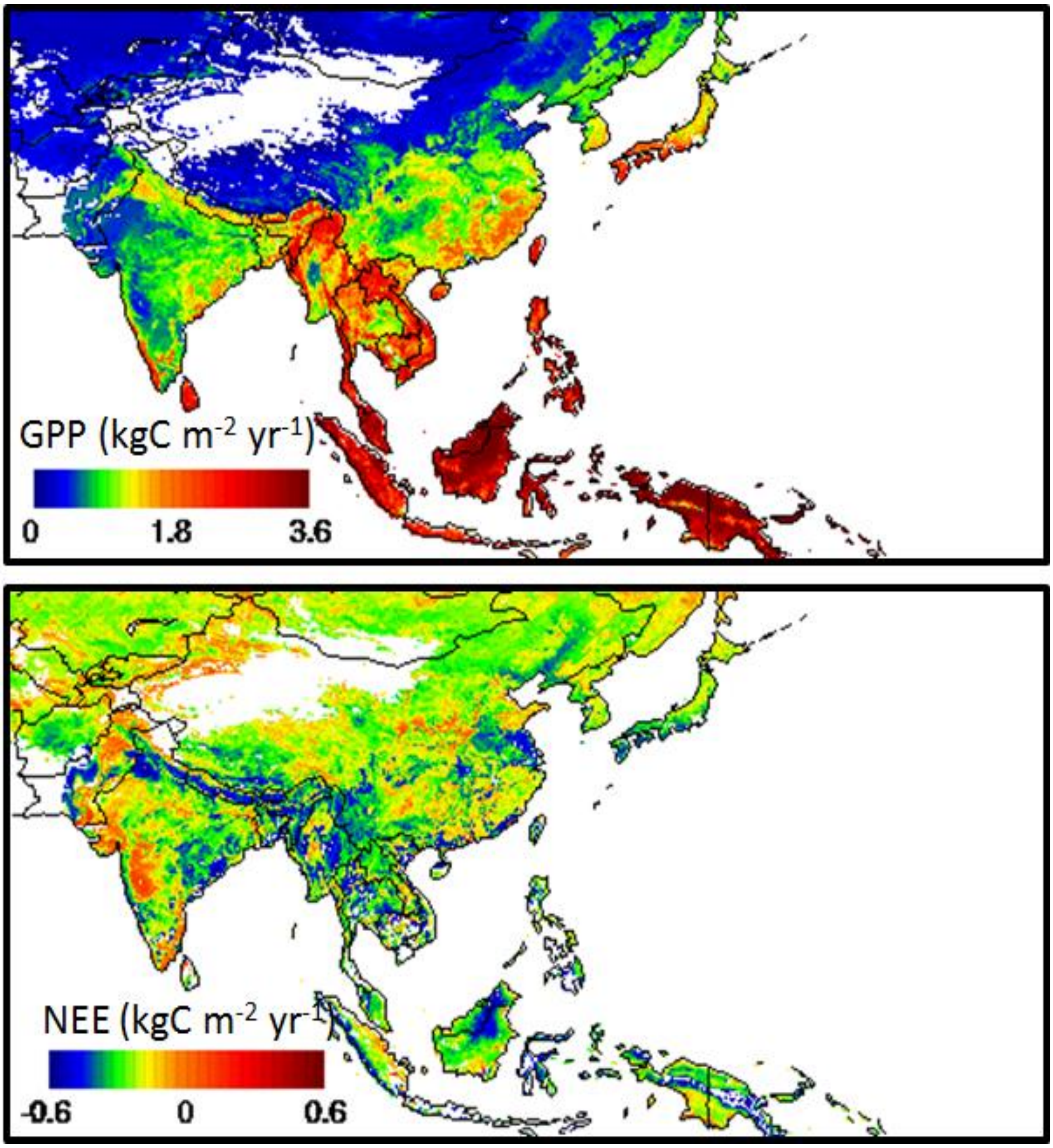


Figure 3.7 Estimated terrestrial CO_2 fluxes (averaged from 2001 to 2014) in monsoon Asia region.

However, the uncertainties associated with these results should be quantified and taken into consideration for proper assessment. The estimated spatial and temporal variations in terrestrial CO_2 fluxes require further evaluation with other independent methodologies. One of the possible candidates is satellite-based products such as sun-induced chlorophyll fluorescence (SIF) from satellites (e.g., GOME-2, GOSAT) (*e.g*. Joiner *et al*., 2013). These datasets provide proxy GPP data, therefore, the spatially upscaled estimates may be compared with those from SIFs. The GOSAT level 4A products (Maksyutov *et al*., 2013) offer net atmosphere-land CO_2 fluxes based on atmospheric inversion model constrained by GOSAT CO_2 column concentration. And these will also help evaluate the empirically upscaled CO_2 flux estimates.

3.3. Activation of national/regional networks in southeast and south Asia

3.3.1. A network of flux sites in Thailand (ThaiFlux)

Since the launch of ThaiFlux at the AsiaFlux Workshop in Cheng Mai in 2006, ThaiFlux had generally been dormant and disconnected from AsiaFlux until recently despite striving efforts of key scientists/laboratories. Our activities supported by APN project, as well as IMPAC-T (Integrated study on Hydro-Meteorological Prediction and Adaptation to Climate Change in Thailand) supported by Japan International Cooperation Agency (JICA), stimulated and revitalized ThaiFlux.

The initial numbers of ThaiFlux were 11 (Fig. 3.8a), and in 2013, four sites under the IMPAC-T have been added (Fig. 3.8b). Although some of the ThaiFlux sites have already terminated observation, 8 sites are currently registered as AsiaFlux sites. During the APN project, ThaiFlux has sent young scientists to most of the APN project activities (the workshops and the training courses & seminars). Further, ThaiFlux sent ten members to a manufacturer of eddy covariance instruments for training by using their own funding. Recently, a new soil respiration dataset from dry diptercarp forest (Hanpattanakit *et al*., 2015) is uploaded on the AsiaFlux Database. ThailFlux is also contributing to research network collaborations, education and agencies. For example, Phayao site was visited by several agencies including officers from National Park, Wildlife and Conservation Department, Department of Environmental Quality Promotion, Mae Fah Luang Foundation under Royal Patronage, and from Institute de recherché pour le développement.

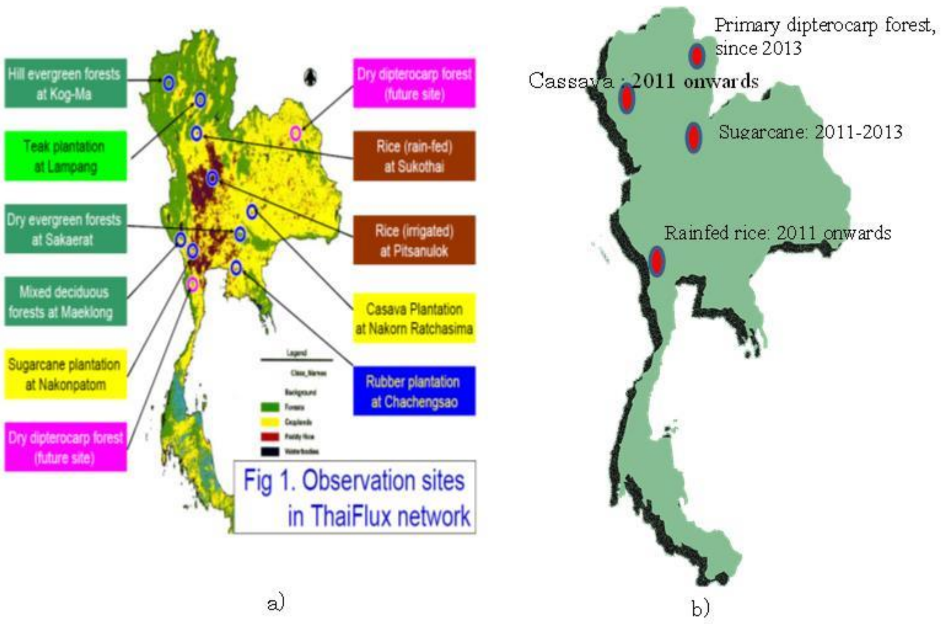
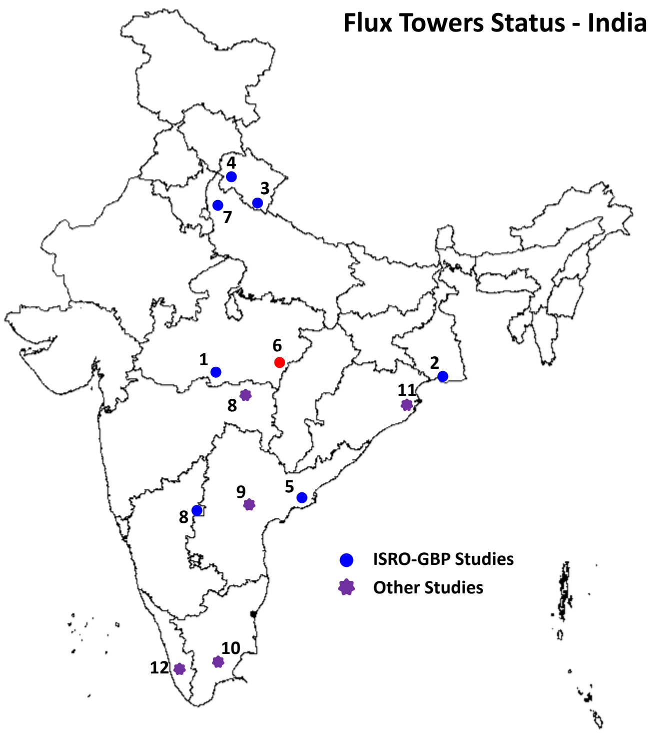


Figure 3.8 Flux monitoring sites in Thailand. (a) The initial members of ThaiFlux, and (b) new ThaiFlux sites established in 2013.

3.3.2. A network of flux sites in India (IndoFlux)

India has been attracting our interest from the early stage of AsiaFlux because it has the second largest land area and population in Monsoon Asia next to China. However, collaboration between AsiaFlux and India had been dormant until recently. The situation was changed by proactive involvement of Indian Space Research Organization (ISRO) to the APN-funded AsiaFlux activities. The number of participants in AsiaFlux activities from other research institutes and universities in India has also been increasing.

After an Indo-US bilateral workshop (Sundareshwar *et al*., 2007), ISRO, in collaboration with several Indian universities and research institutions, has initiated the National Carbon Project (NCP) to establish an observational network to assess the carbon pools, fluxes and net carbon balance for terrestrial biomes in India. A nationwide network of flux towers in major forests, croplands and grasslands has been installed for the long-term measurement of fluxes of CO_2 and water vapor using the eddy covariance technique to monitor net carbon exchange and up-scaling of carbon assimilation fluxes to regional scale using satellite remote sensing (Fig. 3.9). Five-year data at Betul (teak mixed forest) and four-year data at Sundarbans (Mangrove forest) demonstrate strong seasonal variations in net ecosystem CO_2 exchange influenced by monsoon climate. At Sundarbans, methane flux has also been monitored by the eddy covariance measurement.



1. Betul, teak forests, Madhya Pradesh
2. Mangroves, Sundarbans, West Bengal
3. Mixed plantation, Haldwani, Uttarakhand
4. Sal forests, Barkot, Uttarakhand
5. Rice crop, Maruteru, Andhra Pradesh
6. Sal Forests, Kanha, Madhya Pradesh
7. Rice Crop, Sahranpur
8. Cotton Crop, Raichur, Karnataka
9. Gumngaon (NEERI)
10. Mahabubnagar (By IITM)
11. Grasslands, Madurai
12. Rice crop, CRRI, Cuttack
13. Rubber Plantation, RRI, Kottayam

Figure 3.9 Flux monitoring sites in India. Photos on the right bottom show flux towers at Betul (1) and Sundarbans (2).

3.3.3. Flux sites in other countries in Southeast and South Asia

Monitoring of carbon and methane fluxes in tropical/subtropical as well as temperate regions in Asia is expanding, and data from those study sites will enable us to capture comprehensive insight into carbon cycle of those ecosystems. For instance, at Nam Cat Tien, Vietnam, Vietnam and Russia Tropical Center has been monitoring carbon and water exchange in tropical monsoon forest since 2011 (Kurbatova *et al*., 2013), while at Cermat Ceria, Betong, Sarawak, Malaysia, monitoring of carbon and methane fluxes in a tropical swamp forest has been operating since 2011. In the International Rice Research Institute (IRRI), Philippines, CO_2 and methane fluxes has been monitored at rice fields with different water crop residue management (Alberto *et al.*, 2012; 2014), while at Mymensingh, Bangladesh, Bangladesh Agricultural University has been monitoring carbon and water fluxes in double-cropping rice fields since 2006 (Hossen *et al.*, 2012), and recently methane flux was added to the monitoring. Methane flux measurements in temperate regions also continue to expand and make contributions to mitigation of greenhouse gas emission (*e.g*. Kim *et al.*, 2016). The workshops and training & seminars held by the APN-funded project (Appendix A1) encouraged scientists who are engaged in monitoring in those study sites, which promote not only consolidating AsiaFlux Network but integrating data from those study sites.

4. Conclusions

The threefold aims of CarboAsia were to achieve 1) filling the critical data gaps in tropical/subtropical forests and croplands in Asia into the AsiaFlux database by facilitating the tower-based flux observation networks in Southeast and South Asia; 2) scrutinizing these data to elucidate inter-annual and site-to-site variabilities in ecosystem carbon budgets in Asia through the integrated analyses of tower flux data, ecosystem modelling and satellite remote sensing, and 3) providing pertinent workshops and training courses to cultivate next generation of leaders and stewards who will continue pursuing the vision of AsiaFlux.

The flux monitoring tower sites established in tropical/subtropical regions and the associated institutes have been augmented into the existing infrastructure of AsiaFlux. Furthermore, these sites already have begun to make important contributions to AsiaFlux database. These data are currently being used to fill in the critical gaps in data-model integration and synthetic analysis. Despite the complexity and heterogeneity in terrestrial ecosystems in Asia, the updated datasets (re-processed through standardized protocols) have been used successfully for spatial upscaling along with remote sensing data. We now can provide independent estimations of spatio-temporal variations in terrestrial CO_2 fluxes in Asian regions. However, the resultant estimates of spatial and temporal variations are subject to further scrutiny with other independent methodologies and longer time series of field data as well as the quantification of uncertainties.

5. Future Directions

The newly established tower sites, especially in tropical/subtropical and cropland regions, should continue monitoring, processing, and providing datasets under the capacity building framework of AsiaFlux. The ‘CarboAsia’ project supported by APN has successfully initiated the capacity development not only in human resources (by intensive training and focused workshops) but also in infrastructural, institutional and procedural dimensions (by augmenting several national networks, activities, data production and information sharing into the AsiaFlux framework). These dimensions in capacity building are not the final product but an ongoing process, and therefore deserve further efforts and persistent supports.

There is still one particular concern which requires special attention and priority support, that is the mismatch between ‘the rapid advances in data collection/sharing’ and ‘appropriate applications of modern statistical and modelling tools.’ Future efforts must address inherent challenges of making useful translations and predictions from complex data such as deciding the usefulness and robustness of data and models, selecting a best model or combination of models, avoiding overfitting, and incorporating uncertainties (*e.g.*, Nearing and Gupta, 2016).

References

Alberto, M. C. R., Hirano, T., Miyata, A., Wassmann, R., Kumar, A., Padre, A., Amante, M., 2012. Influence of climate variability on seasonal and interannual variations of ecosystem CO2 exchange in flooded and non-flooded rice fields in the Philippines. *Field Crops Research*, **134**, 80-94.

Alberto, M. C. R., Wassmann, R., Buresh, R. J., Quilty, J. R., Correa, Jr., T. Q., Sandro, J. M., Centeno, C.A.R., 2014. Measuring methane flux from irrigated rice fields by eddy covariance method using open-path gas analyzer. *Field Crops Research*, **160**, 12-21.

Ciais, P., *et al*., 2010. GEO Carbon Strategy, GEO Secretariat Geneva, FAO, Rome.

Cox, P., Betts, R., Jones, C., Spall, S., and Totterdell, I., 2001. Meteorology at the Millennium, volume 83 of International Geophysics Series, chapter 21: Modelling Vegetation and the Carbon Cycle as Interactive Elements of the Climate system. Academic Press, UK. pp 259-279.

Field, C.B., Randerson, J.T. and Malmström, C.M., 1995. Global net primary production: Combining ecology and remote sensing. *Remote Sensing of Environment*, **51**(1), 74-88.

Hanpattanakit, P., Leclerc, M. Y., Mcmillan, A. M. S., Limtong, P., Maeght, J.-L., Panuthai, S., Inubushi, K. and Chidthaisong, A., 2015. Multiple timescale variations and controls of soil respiration in a tropical dry dipterocarp forest, western Thailand. *Plant and Soil*, **390**, 167-181

Hossen, S., Mano, M., Miyata, A., Baten, M.A and Hiyama, T., 2012. Surface energy partitioning and evapotranspiration over a double-cropping paddy field in Bangladesh. *Hydrological Processes*, **26**, 1311-1320.

Ichii, K. *et al*., 2013. Site-level model–data synthesis of terrestrial carbon fluxes in the CarboEastAsia eddy-covariance observation network: toward future modeling efforts. *Journal of Forest Research*, **18**(1), 13-20.

Ito, A., 2008. The regional carbon budget of East Asia simulated with a terrestrial ecosystem model and validated using AsiaFlux data. *Agricultural and Forest Meteorology*, **148**(5), 738-747.

Ito, A., Nishina, K. and Noda, H. M., 2016. Evaluation of global warming impacts on the carbon budget of terrestrial ecosystems in monsoon Asia: a multi-model analysis. *Ecological Research*, DOI 10.1007/s11284-016-1354-y.

Joiner, J. *et al*., 2013. Global monitoring of terrestrial chlorophyll fluorescence from moderate-spectral-resolution near-infrared satellite measurements: methodology, simulations, and application to GOME-2. *Atmos. Meas. Tech.*, **6**(10), 2803-2823.

Kang, M., Kim, J , Kim, H-S., Thakuri, B. M., and Chun, J-H. 2014. On the nighttime correction of CO_2 flux measured by eddy covariance over temperate forests in complex terrain. *Korean J. of Agricultural and Forest Meteorology*, **16**(3), 231-243.

Kim, W., *et al.*, 2015. FluxPro as a realtime monitoring and surveilling system for eddy covariance flux measurement. Journal of Agricultural Meteorology, 71, 32-50.

Kim, Y., Talucder, M. S. A., Kang, M., Shim, K-M., Kang, N., and Kim, J. 2016. Interannual variations in methane emission from an irrigated rice paddy caused by rainfalls during the aeration period. Agriculture, *Ecosystems and Environment*, **223**, 67-75.

Kurbatova, J. A., Deshcherevskaya, O. A., Avilov, V. K., Novichonok, A. O., Dinh, B. D., Kuznetsov, A. N., 2013. Establishment of eddy-flux site in Vietnam: first results. *AsiaFlux Newsletter*, **36**, 16-20. (http://asiaflux.net/?page_id=24, accessed 2016-03-31)

Maksyutov, S. *et al*., 2013. Regional CO_2 flux estimates for 2009–2010 based on GOSAT and ground-based CO_2 observations. *Atmos. Chem. Phys.*, **13**(18), 9351-9373.

Nearing G. S. and Gupta, H. V., 2016. The quantity and quality of information in hydrologic models. *Water Resources Research*, **51**, 524-538.

Oleson, K.W. *et al*., 2008. Improvements to the Community Land Model and their impact on the hydrological cycle. *Journal of Geophysical Research*, **113**(G1), .

Piao, S.L. *et al*., 2012. The carbon budget of terrestrial ecosystems in East Asia over the last two decades. *Biogeosciences*, **9**(9), 3571-3586.

Platt, T. and Denman, K., 1975. Spectral analysis in ecology. *Annual Review of Ecology and Systematics*, **6**, 189-210.

Sasai, T., Ichii, K., Yamaguchi, Y. and Nemani, R., 2005. Simulating terrestrial carbon fluxes using the new biosphere model “biosphere model integrating eco-physiological and mechanistic approaches using satellite data” (BEAMS). *Journal of Geophysical Research*, **110**(G2), G02014.

Sato, H., Itoh, A. and Kohyama, T., 2007. SEIB–DGVM: A new Dynamic Global Vegetation Model using a spatially explicit individual-based approach. *Ecological Modelling*, **200**(3-4), 279-307.

Sitch, S. *et al*., 2003. Evaluation of ecosystem dynamics, plant geography and terrestrial carbon cycling in the LPJ dynamic global vegetation model. *Global Change Biology*, **9**(2), 161-185.

Suzuki, T. and Ichii, K., 2010. Evaluation of a terrestrial carbon cycle submodel in an Earth system model using networks of eddy covariance observations. *Tellus B*, **62**(5), 729-742.

Thornton, P.E. *et al*., 2002. Modeling and measuring the effects of disturbance history and climate on carbon and water budgets in evergreen needleleaf forests. *Agricultural and Forest Meteorology*, **113**(1–4), 185-222.

Sundareshwar *et al*. 2007. Environmental monitoring network for India. *Science*, **316**, 205-206.

Thornton, P. E., Law, B. E., Gholz, H. L., Clark, K. L., Falge, E., *et al*., 2002. Modeling and measuring the effects of disturbance history and climate on carbon and water budgets in evergreen needle leaf forests. *Agricultural and Forest Meteorology*, **113**, 185–222.

Ueyama, M. *et al*., 2013. Upscaling terrestrial carbon dioxide fluxes in Alaska with satellite remote sensing and support vector regression. *Journal of Geophysical Research Biogeosciences*, **118**(3), 1266-1281.

Yang, F. *et al*., 2007. Developing a continental-scale measure of gross primary production by combining MODIS and AmeriFlux data through Support Vector Machine approach. *Remote Sensing of Environment*, **110**(1), 109-122.

Appendices

Appendix A1. Workshops/Seminars

In this project we held three workshops and three seminars including a mini-workshop (Table A1.1). Agenda/Programme and the participants list with e-mail address are included in the following proceedings/abstracts (Fig. A1.1). Reports on respective workshops and seminars are also listed below.

Table A1.1 Workshops and seminars held in the project.

No.	Workshop/Seminar	Date/ Place	Collabo-ration	Participants /Presentations	Activities	Reports
1	The 11th AsiaFlux Workshop: Communicating Science to Society coping with climate extremes for resilient ecological-societal systems	22-24 Aug. 2013; Seoul National Univ., Seoul, Korea	HESSS[1)] KSAFM[2)]	More than 200 (24 countries); 120 oral and 60 poster	Technical training course; Young scientist meeting; Field trip	Kang *et al*. (2013)
2	AsiaFlux training and seminar on methane flux and carbon cycle	23-27 Feb. 2014; Bangladesh Agricultural Univ., Mymensingh, Bangladesh		About 40 (11 countries); 18 oral	Technical training course On-site training	Talucder *et al*. (2014)
3	AsiaFlux Workshop 2014: Bridging atmospheric flux monitoring to national and international climate initiatives	18-23 Aug. 2014; International Rice Research Institute, Los Baños, Philippines	GRA[3)] MIRSA-2[4)]	More than 110 (19 countries); 44 oral and 31 poster	Technical training course; Young scientist meeting; Field trip	Alberto *et al*. (2015)
4	AsiaFlux training & seminar on tropical ecosystem monitoring	1-5 Dec. 2014; Cat Tien National Park, Vietnam	iLEAPS[5)]	About 50 (9 countries); 17 oral	Technical training course; Field trip	Vitaly *et al*. (2015)
5	AsiaFlux Workshop 2015: Challenges and significance of ecosystem research in Asia to better understand climate change	22-29 Nov. 2015; Indian Institute of Tropical Meteorology, Pune, India	ISPRS[6)]	About 150 (24 countries); 34 oral and 52 poster	Technical training course; Young scientist meeting	Chakraborty *et al*. (2016)
6	AsiaFlux mini-workshop on remote sensing and ecological/environmental monitoring	2-4 March 2016, National Taiwan University, Taiwan		45 (10 countries) 24 oral	Field trip	Cheng (2016)

1) Hydrology delivers Earth System Science to Society
2) Korean Society of Agricultural and Forest Meteorology
3) Global Research Alliance for Agricultural Greenhouse Gases (http://globalresearchalliance.org/)
4) Greenhouse Gas Mitigation in Irrigated Rice Paddies in Southeast Asia, Phase 2 (https://www.s.affrc.go.jp/docs/research_international/english/mirsa2.htm)
5) Integrated Land Ecosystem-Atmosphere Processes Study (https://www.atm.helsinki.fi/ileaps/)
6) International Society for Photogrammetry and Remote Sensing (http://www.isprs.org/)

Figure A1.1 Proceedings of the workshops and abstracts of the seminars.

1) Proceedings of the international joint conference of 11th AsiaFlux international workshop, 3rd HESSS, and 14th annual meeting of KSAFM, 21-24 August 2013, Seoul National University, Seoul, Korea, 172p. [Attached in a separated electric file; also available from http://asiaflux.net/?page_id=19, accessed 2016-04-01]

Kang, M. and Conference Organizing Committee, 2013. Report on the Joint Conference of 11th AsiaFlux International Workshop, 3rd Hydrology delivers Earth System Science to Society (HESSS), and 14th Annual Meeting of Korean Society of Agricultural and Forest Meteorology-19-24 August 2013, Seoul, Korea-. *AsiaFlux Newsletter*, **36**, 1-5. [Attached in a separated electric file; also available from http://asiaflux.net/?page_id=24, accessed 2016-04-01]

2) Abstracts of AsiaFlux training & seminar on methane flux and carbon cycle, 23-27 February, 2014, Bangladesh Agricultural University, Mymensingh, Bangladesh, 25p. [Attached in a separated electric file]

Talucder, M. S. A., M. S. Rumi, M. A. Miah, M. A. Baten, K. Ono, 2014. Report on AsiaFlux Training & Seminar on Methane Flux and Carbon Cycle – 23~27 February 2014, BAU, Mymensingh, Bangladesh. *AsiaFlux Newsletter*, **37**, 3-5. [Attached in a separated electric file; also available from http://asiaflux.net/?page_id=24, accessed 2016-04-01]

3) Proceedings of AsiaFlux Workshop 2014: Bridging atmospheric flux monitoring to national and international climate initiatives, 18-23 August 2014, International Rice Research Institute, Los Baños, Philippines, 77p. [Attached in a separated electric file; also available from http://asiaflux.net/?page_id=19, accessed 2016-04-01]

Alberto, N. C. and Workshop Local Organizing Committee, 2015. 12th AsiaFlux Workshop 2015-Bridging Atmospheric Flux Monitoring to National and International Climate Change Initiatives-. *AsiaFlux Newslette*r, **38**, 1-8. [Attached in a separated electric file; also available from http://asiaflux.net/?page_id=24, accessed 2016-04-01]

4) Abstracts of AsiaFlux training & seminar on tropical ecosystem monitoring, 1-5 December 2014, Cat Tien National Park, Vietnam, 24p. [Attached in a separated electric file]

Vitaly, A., D. B. Duy, J. Kurbatova, 2015. Report on the AsiaFlux Training & seminar on tropical ecosystem monitoring 1-5 December 2014, National Park Cat Tien, Vietnam. *AsiaFlux Newslette*r, **38**, 9-11. [Attached in a separated electric file; also available from http://asiaflux.net/?page_id=24, accessed 2016-04-01]

5) Proceedings of the joint conference of the AsiaFlux Workshop 2015 and ISPRS (International society for photogrammetry and remote sensing) TC WG VIII/3: Weather, atmosphere and climate studies: Challenges and significance of ecosystem research in Asia to better understand climate change, 22-29 November 2015, Indian Institute of Tropical Meteorology, Pune, India, 107p. [Attached in a separated electric file; also available from http://asiaflux.net/?page_id=19, accessed 2016-04-01]

Chakraborty, S., P. Kumar, D. Burman, 2016. Overview of Asiaflux-2015. *AsiaFlux Newslette*r, **39**, 1-3. [Attached in a separated electric file; also available from http://asiaflux.net/?page_id=24, accessed 2016-04-01]

6) Abstracts of AsiaFlux mini-workshop on remote sensing and ecological/environmental monitoring, 2-4 March 2016, National Taiwan University, Taiwan, 32p. [Attached in a separated electric file; also available from http://asiaflux.net/?page_id=20, accessed 2016-04-01]

Cheng, K. S., 2016. Summary report of AsiaFlux mini-workshop on remote sensing and ecological/environmental monitoring, 2-4 March, 2016, National Taiwan University, Taiwan. *AsiaFlux Newslette*r, **39**, 4-6. [Attached in a separated electric file; also available from http://asiaflux.net/?page_id=24, accessed 2016-04-01]

Appendix A2. Funding sources outside the APN

1) National Institute for Agro-Environmental Sciences, Japan
   Administration support, US$ 25,000 (2013-2015).
2) National Institute of Environmental Studies, Japan
   Personnel support (secretary), US$131,250 (2013-2015). Capacity development, US$ 25,000 (2013-2014).
3) Seoul National University, Korea
   Capacity development and networking, US$25,000 (CarbonTracker-Asia from Korea Meteorological Administration, 2013-12016).
4) Bangladesh Agricultural University, Bangladesh
   In-kind support for the Training and Seminar in Mymmensingh, Bangladesh (2014).
5) Indian Space Research Organization, India
   In-kind support for the AsiaFlux Workshop in Pune, India (2015).
6) Indian Institute for Tropical Meteorology, India
   In-kind support for the AsiaFlux Workshop in Pune, India (2015).
7) National Taiwan University, Taiwan
   In-kind support for the mini-Workshop in Taipei, Taiwan (2016).

Appendix A3. List of Young Scientists

By the support of APN and institutions of the project collaborators, we tried to invite as many young scientists as possible to our activities such as workshops, seminars and training courses. Applicants to the travel support were requested to submit abstract for presentation, curriculum vitae, and a brief description on how these activities are useful for him/her study. The successful candidates listed below were selected from the applicants by Short Course Workgroup of AsiaFlux. Some of them were requested to submit a brief report on the activities to AsiaFlux Newsletter. References on those reports are also included in the list.

1) AsiaFlux training and seminar on methane flux and carbon cycle, 23-27 February 2014, Bangladesh Agricultural University, Mymensingh, Bangladesh

- Mr. Caesar Arloo R. Centeno, International Rice Research Institute, Philippine, c.centeno@irri.org
- Dr. Yuk Fo Lai, The Chinese University of Hong Kong, dyflai@cuhk.edu.hk
- Mr. Md. Badiuzzaman Khan, Bangladesh Agricultural University, Bangladesh, bkhan_envsc@yahoo.com
- Mr. Joseph Wenceslaus Waili, Malaysia, joe_kekan@yahoo.com
- Dr. Chandrashekhar Deshmukh, Vientiane, Lao, chandrashekhar@namtheun2.com
- Dr. Kazunori Minamikawa, National Institute for Agro-Environmental Sciences, Japan, minakazu@affrc.go.jp
- Mr. Samiul Ahsan Talucder, Seoul National University, Korea, samiulsau@gmail.com
  [Talucder, M. S. A., M. S. Rumi, M. A. Miah, M. A. Baten, K. Ono, 2014. Report on AsiaFlux Training & Seminar on Methane Flux and Carbon Cycle – 23~27 February 2014, BAU, Mymensingh, Bangladesh. *AsiaFlux Newsletter*, **37**, 3-5.]

2) AsiaFlux Workshop 2014: Bridging atmospheric flux monitoring to national and international climate initiatives, 18-23 August 2014, International Rice Research Institute, Los Baños, Philippines

- Amit Kumar, Indian Agricultural Research Institute, India, amit_bio80@yahoo.com
- Watcharapong Boonruang, University of Phayao, Thailand, watcharapong.atom@gmail.com
  [Boonruang, W., P. Suwannapat, M. Sanwangsri, J. Sathornkich, 2014. Monitoring net ecosystem-scale fluxes with eddy covariance and profile measurements on 18-23 August 2014 at International Rice Research Institute (IRRI), Los Baños, Philippines. *AsiaFlux Neesletter* **38**, 12-13.]

3) AsiaFlux training & seminar on tropical ecosystem monitoring, 1-5 December 2014, Cat Tien National Park, Vietnam

- Dr. Robert Sandlerskiy, A.N. Severtsov Institute of Ecology and Evolution, srobert_landy@mail.ru
- Mr. Cheng-Yu Lan, National Central University, Hong Kong, bluetaipei@msn.com
- Dr. Tassanee Jiaphasuanan, Ubon Ratchathani University, Tas_j2002@yahoo.com

[Jiaphasuanan, T. 2014. Tropical Forest Ecosystem Monitoring , 1-5 December 2014, National Park Cat Tien, Vietnam, *AsiaFlux Newsletter* **38**, 13.]

4) Joint conference of the AsiaFlux Workshop 2015 and ISPRS (International Society for Photogrammetry and Remote Sensing) TC WG VIII/3: Weather, Atmosphere and Climate Studies: Challenges and significance of ecosystem research in Asia to better understand climate change, 22-29 November 2015, Indian Institute of Tropical Meteorology, Pune, India

- Mr. San Win, King Mongkut's University of Technology Thonburi, sanwin.fd@gmail.com

5) AsiaFlux mini-workshop on remote sensing and ecological/environmental monitoring, 2-4 March 2016, National Taiwan University, Taiwan

- Abhishek Chakraborty, Indian Space Research Organization, jeet.abhishek@gmail.com [Chakraborty, A., 2016. Feedback of Asiaflux mini workshop on remote Sensing and Ecological / Environmental monitoring held during 2-4 March, 2016, *AsiaFlux Newsletter* **39**, 7]
- Md. Golam Mahboob, Bangladesh Agricultural Research Institute, Bangladesh, golam.mahboob@gmail.com
- Ms Jinghua Chen, Institute of Geographic Sciences and Natural Resources Research, CAS, China, chenjh.14b@igsnrr.ac.cn
- Nazarin Ezzaty binti Mohd Najib, Universiti Teknologi Malaysia, Malaysia, nazarinnajib@gmail.com
- Swaid Abbas, The Hong Kong Polytechnic University, Hong Kong, sawaid.abbas@gmail.com
- Mr. Taibanganba Watham, Indian Space Research Organization, India, taibang01@gmail.com
- Ms Yanmu Li, Institute of Geographic Sciences and Natural Resources Research CAS, China, liym.14s@igsnrr.ac.cn

Appendix A4. Glossary of Terms

(in alphabetical order)

AsiaFlux: the flux monitoring tower network for carbon and water cycles in terrestrial ecosystems in Asia

CarboAsia: the carbon budget assessment covering the whole Asian terrestrial ecosystems

CarboEastAsia: the China-Japan-Korea collaborative project to cope with climate change protocols by synthesizing measurement, theory and modeling in quantifying and understanding of carbon fluxes and storages in East Asia

CarboEastAsia-MIP: a model intercomparison conducted as a major activities of CarboEastAsia

NEE: Net Ecosystem CO_2 Exchange

FLUXNET: the global flux monitoring tower network for carbon and water cycles in terrestrial ecosystems

GOSAT: Greenhouse gases Observing SATellite

GPP: Gross Primary Productivity

MODIS: Moderate Resolution Imaging Spectrometer

RE: Ecosystem Respiration

SIF: Sun-Induced chlorophyll Fluorescence

SVR: Support Vector Regression

Appendix A5. Project homepage URLs

1) Project website (AsiaFlux Web site): http://asiaflux.net/

2) Project activities:

Workshops: http://asiaflux.net/?page_id=19

Training & seminar/Mini-workshops: http://asiaflux.net/?page_id=20

3) Information of the study sites: http://asiaflux.net/?page_id=22

4) Project Database (AsiaFlux Database): https://db.cger.nies.go.jp/asiafluxdb/

Appendix A6. Contents of the first AsiaFlux Report on the Asian Carbon Budget

Asian Carbon Budget and Implications for the Global Carbon Cycle (draft)