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Contents

Report of the 2010 International Symposium on Forest CO_2 Flux

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Terrestrial ecosystems play a crucial role in global carbon cycle. In particular, the forest ecosystem, which has a 43% areal coverage of terrestrial ecosystems, accounts for 72% of the total NPP. The NPP and soil carbon sink have direct influences on the concentration of green house gases. Therefore, a good understanding of the carbon, water and energy budget of the forest ecosystem is essential for ecosystem monitoring. Over the last decade, several regional flux monitoring networks have been established in Asia, including ChinaFlux, JapanFlux, and KoFlux. Since 2005, four flux monitoring stations in Taiwan have been registered in the Asiaflux, and there are also several non-registered stations which may join the Asiaflux in future. In order to integrate resources of CO_2 flux observation in Taiwan and to share and exchange experiences with researchers of other fluxnet communities, The National Taiwan University Experimental Forest (hereinafter referred to as the NTUEF) organized and hosted the 2010 International Symposium on Forest CO_2 Flux on December 6-7, 2010. (The first of such symposium was also hosted by NTUEF in 2008).

2010 International Symposium on Forest CO_2 Flux

Over 80 researchers from four countries participated in the 2010 International Symposium on Forest CO_2 Flux. In the morning of 6 Dec. 2010, Prof. Ya-Nan Wang delivered a welcome and opening address. As the director of the NTUEF, she gave a brief introduction to the progress of CO_2 flux research at NTUEF and addressed the importance of forest ecosystems as a carbon sink in the terrestrial ecosystem.

Figure 1. Professor Ya-Nan Wang delivered a welcome address in the opening ceremony of 2010 International Symposium on Forest CO_2 Flux.

Professor Xu-Hui Lee from the University of Yale and Professor Ji-Quan Chen from the University of Toledo also gave lectures. Their lectures covered a wide range of topics, including net exchanges of carbon, water and energy measured by the Eddy Covariance methods, quantitative assessment of the ecosystem carbon flux, and the multi-scale issue of flux monitoring from tower to regional and global scales. Prior to the commence of regular sessions in the afternoon, a field excursion to the Xitou CO_2 flux tower at NTUEF was arranged. The field excursion provided participants with background information about the natural environment and geography of the Xitou area where the NTUEF flux tower is located. Dr. Saigusa Nobuko from CGER of NIES Japan gave an interesting and informative talk about integrated usage of AsiaFlux data for continental-scale estimation of carbon budget after the field visit.

In the afternoon session, Dr. Yu-De Pan from USDA forest service first gave a lecture on comparing flux tower measurements with the biometric data which provides basis for upscaling from the tower measurements to landscape scale estimates. Prof. Jing-Ming Chen from the University of Toronto also presented the latest development of the Chinese land-atmosphere data assimilation system for regional and global carbon cycle research. Dr. Nai-Shen Liang of NIES Japan gave a lecture on an integrated study on carbon balance of forest ecosystem. Professor Ji-Quan Chen gave his second talk about the methods for quantifying ecosystem carbon fluxes. Lastly, before closing the first day's sessions, staff of LI-COR introduced some of their state-of-the-art instruments. After the dinner, Professor Ya-Nan Wang further discussed with invited speakers and members of the NTUEF CO_2 flux research group about future operation of the NTUEF flux tower and possible international collaboration and exchange with Asiaflux.

The second day's sessions included presentations contributed by researchers from Taiwan. In addition, Prof. Ji-Quan Chen of the University of Toledo and Dr. Nai-Shen Liang of NIES Japan also gave talks about the evolution of tower-based flux measurement and techniques for long-term and large-scale measurement of soil respiration. Professor Yue-Joe Hsia from National Donghuwa University addressed the instrumental problems of flux tower under heavy-mist climate based on his experience at the CLM flux tower site. Professor Shih-Chieh Chang also shared his results of the ecophysiological studies at the CLM site. Professor Ben-Jei Tsuang from National Chung Hsing University gave a lecture on development of a system for continuous measurement of CO_2 and CH_4 fluxes using related relaxed eddy accumulation method in Taiwan. In the afternoon session of second day program, Professor Jehn-Yih Juang from National Taiwan University talked about the data processing and QA/QC which is essential and crucial prior to analysis of the flux data. Lastly, Professor Po-Hsiung Lin of the National Taiwan University presented measurements of the NTUEF flux tower and demonstrated results of boundary layer simulation in the mountainous Xitou area. Professor Ya-Nan Wang and all the invited speakers co-chaired a general discussion session on the role and operation of the NTUEF flux tower site. It was suggested that NTUEF flux tower site should achieve regular

Figure 2. Lecture of Professor Ji-Quan Chen

Figure 3. Professor Yue-Joe Hsia (left) introduced Professor Xu-Hui Lee (right) prior to his lecture.

operation and make continuous CO_2 flux measurements as soon as possible, and strengthen its collaboration with other research communities, especially within the AsiaFlux. With many of its advantages, including easy traffic access from major highways, convenience in lodging and food and power supply, the NTUEF Xitou flux tower site can be expected to be a "SUPERSITE" and be developed into an research center for TaiwanFlux in the near future.

Field Excursion to the Xitou CO_2 Flux Tower Site

All participants were invited to visit the Xitou CO_2 flux tower site in the morning of December 6, shortly after taking group photos. The new 40-meter high NTUEF Xitou flux tower was built in the December of 2008. The tower is located in the 173rd plantation sector of Cryptomeria japonica with a mean canopy height of about 28 meters. Dr. Tsong-Huei Wey, Dr. Yen-Jen Lai and Dr. Chiang Wei introduced the background information and major CO_2 flux measuring facilities, and led participants to the instrument room and the top of the tower.

Summary

In general, the 2010 International Symposium on Forest CO_2 Flux provided a platform and opportunities for research groups, scientists and participants from different countries to share their results and experiences in CO_2 flux measuring techniques and related topics. The NTUEF flux tower site aims to provide valuable flux measurements in a subtropical region with complex terrain. Researchers at NTUEF are committed to using measurements from the NTUEF flux tower to gain better understanding of the forest ecosystem and to achieve sound management practices of the forest resources.

Figure 4. Briefing by Dr. Tsong-Huei Wey during the field visit to Xitou CO_2 Flux Station

Figure 5. Group photo of the 2010 International Symposium on forest CO_2 Flux

CarboEastAsia Workshop 2011
"Data-Model Synthesis for Quantifying Carbon Budget in East Asia"
February 22-23, 2011 in Tokyo, Japan

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Asakusa is an old town that still maintains an atmosphere of Edo, the ancient name of Tokyo, and is one of the most popular sight-seeing spots in Tokyo. From February 22nd to 23rd, 2011, CarboEastAsia Workshop was held in this attractive venue, just around the corner from Sensoji Temple, Tokyo's oldest temple and a landmark of Asakusa.

36 CarboEastAsia program members from ChinaFlux, JapanFlux, and KoFlux gathered in Asakusa. CarboEastAsia (http://www.carboeastasia.org/) is an international project started in 2007 for the term of three years (1st phase), and extended two more years (2nd phase), with financial supports from Japan Society for the Promotion of Science (JSPS), National Natural Science Foundation of China (NSFC), and National Research Foundation of Korea (NRF). CarboEastAsia aims at capacity building to cope with climate change protocols by synthesizing measurement, theory and modeling in quantifying and understanding of carbon fluxes and storages in East Asia. Main results of the 1st phase of CarboEastAsia have been published in a special issue of Biogeosciences (http://www.biogeosciences.net/special_issue63.html).

The objectives of the Asakusa workshop were:

1) to discuss research proposals submitted by the project members for the 2nd phase
2) to create standardized CarboEastAsia dataset based on the observed data provided by three member networks
3) to conduct uncertainty assessment on the dataset using different gap-filling programs provided by member networks
4) to conduct the model-data inter-comparison and integration to quantify magnitude, uncertainties, and its mechanisms of terrestrial carbon budget in Asia

On the first day morning, participants gave presentations on their research proposals for the 2nd phase of CarboEastAsia. The first-day afternoon and the second day morning were spent for in-depth discussions by two subgroups – group 1: networking flux measurements (inter-site comparison), and group 2: model development, parameterization and validation, up-scaling, and integration.

Group 1 focused their discussions on two issues. First, they evaluated research proposals submitted for the 2nd phase of CarboEastAsia

Figure 1. Memorial Photo of the Symposium

Figure 2. Presentation and discussion in the workshop.

and exchanged ideas on improving their scientific quality. Group members also discussed details of each proposal with respect to its novelty, research focus, appropriateness of the hypothesis, method, and data to be used.

The second issue discussed by group 1 was about the approaches to establishing and sharing gap-filled flux data for the 2nd phase collaborative researches of CarboEastAsia. All member networks (ChinaFlux, JapanFlux, KoFlux) brought to this workshop the same sets of flux data that were gap-filled using their own standard gap-filling procedures. During the group session, the three sets of gap-filled flux data were compared, and the similarities, disparities, and characteristics of different gap-filling methods were discussed. It was found that the differences in the gap-filled data were not very significant and was within the acceptable range. However, some systematic discrepancies which might have stemmed from their differences in data quality control procedures became apparent. Finally, the subgroup agreed to share among members: (1) three different datasets (with option of one more dataset processed by the site PI) for each site, including the information about their uncertainties; and (2) the outline and the method of data processing.

Group 2 discussed the status and future plans of their collaborative project of model-data synthesis study to quantify terrestrial carbon source/sinks in East Asia. Sixteen members who specialize or are interested in modeling joined this group to exchange their ideas. Based on their experiences and results from more than ten terrestrial ecosystem models, a few problems, such as over- or underestimating LAI and terrestrial carbon budget, sensitivities to the water limitation, lack of sufficient modeling experiences in rice paddy, heterogeneity of Asian landscapes that hampers scaling up, and responses to the monsoon climate, in applying widely used terrestrial ecosystem models to Asian ecosystems were pointed out. With the awareness of these problems, the group set the following goals for their model-data synthesis studies: (1) to estimate the magnitude and uncertainties of terrestrial carbon budget in Asia, (2) to characterize each model's behavior in response to environmental changes such as climate anomaly, and (3) to evaluate the model applicabilities to the Asian ecosystems. To achieve these goals, the group also identified the requirements for model-data synthesis analysis at both site and regional scales, and set schedules for such studies.

CarboEastAsia is the first international joint program among China, Japan, and Korea for carbon flux study. Through numbers of program activities during the past three years, the members have strengthened not only their research collaboration but also rapport and friendship. Despite the language and cultural barriers, such collaborative relationships have led to many productive research works, and outlook for further collaboration even after the program period looks promising. The program is promoting international collaboration based on data sharing with from more than 30 site in East Asia. CarboEastAsia will continue to play an even more important role in AsiaFlux. The heated discussions and significant achievements of this workshop will certainly contribute to further scientific advances.

Long-term ecosystem research sites in Taiwan - the Xitou and Pingdong forest CO_2 flux tower stations

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General site description

The Xitou long-term ecosystem research site (23°39'N, 120°47'E) was established in 1950 for studying the effect of planting space on Cryptomeria japonica growth condition. In 2009, a CO_2 flux tower was built by the Experimental Forest of the National Taiwan University (NTUEF). It is located in an evergreen coniferous forest in central Taiwan with terrain elevation varies from 800 m to 2000 m above the mean sea level (Figure 1). The dominant species, Cryptomeria japonica, was first planted over 60 years ago. Soil (pH value below 5.0) at the site belongs to Inceptisol with over 50% of coarse lithic sandstone. The soil contains low base cations because of high precipitation. The site has an annual mean temperature of 16.6℃, with a higher mean temperature of 20.8 ℃ in July and a lower mean temperature of 12 ℃ in January. Mean annual precipitation at the site is 2635 mm. The area has distinct wet season (May to September) and dry season (October to April of the next year). The topography at the Xitou site is relatively homogeneous, with an average slope of 15°.

The Pingdong long-term ecosystem research site (22°31'N, 120°36'E) was established in 2008 by NTUEF. The site is located in southern Taiwan with tropical and subtropical evergreen broadleaf forests, at an elevation of 60 m above the mean sea level (Figure 1). Fourteen broadleaf species were planted in 2002-2005. The soil (with pH value of 5.5) belongs to Entisol with over 60% of sandstone. The soil contains low base cations because of high sand percentage. Annual mean temperature at the site is 25.1℃, with a higher mean temperature of 28.4℃ in July and a lower mean temperature of 20.1℃ in January. Mean annual precipitation at the site is 2022 mm. The area has distinct wet season (May to September) and dry season (October to April of the next year). The topography at Pingdong site is relatively homogeneous, with an average slope less than 5°.

Several research works focusing on the following goals have been conducted at the Xitou and Pingdong sites:

▪ understanding the energy, water, and nutrient cycles of the Cryptomeria japonica and broadleaf forest ecosystem, and

▪assessing the capacity of carbon sequestration of these two forest ecosystems.

Research programs

The two flux tower sites are maintained by NTUEF. These sites also facilitate research needs of colleagues from NTU and other universities in Taiwan through research collaboration. Since 2010, NTUEF has established international collaborations with the University of Toledo, USA and NIEA of Japan. Some of the research programs at these sites are summarized below.

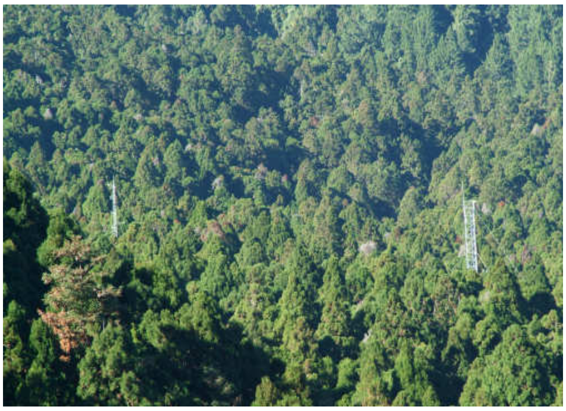

Figure 1. Flux towers of the Xitou (left) and Pingdong (right) sites .

1) Nutrient stocks

Major components of nutrient stocks in the forest that have been investigated include:

▪ Aboveground (leaves, branches, stems) and belowground (fine and coarse root, in different depths) biomass of Cryptomeria japonica and broadleaf plantation,

▪ Organic and mineral layers of the soil in different depths, and

▪ Forest floor vegetation.

Nutrient (C, N, Na, K, Ca, Mg, and P) concentrations of Cryptomeria japonica were analyzed. Although these sites were established in recent years, biometric measurements of Cryptomeria japonica have been taken since 1950. These data are useful for NPP estimation.

2) Nutrient and energy fluxes monitoring

Measurement of meteorological and soil parameters (see Table 1) at the Pingdong and Xitou sites began in 2008 and 2009, respectively. Measurements of these parameters are recorded at a 10-minute interval. Nutrient flux monitoring is expected to start in 2011.

3) CO_2 fluxes

The Xitou flux station has two towers which are equipped with both closed-path and open-path eddy covariance systems. The open-path eddy covariance systems (Campbell CSAT3, LI-COR 7500) were installed at Tower 1 and Tower 2 in 2009 and 2011, respectively. The extremely humid weather condition at Xitou caused frequent malfunction of the open-path systems. As a result, a closed-path system (Campbell CSAT3, EC-155) was installed in January 2011. A new Tower 3 which aims to measure the CO_2 advection is expected to be constructed in 2011.

Pingdong flux tower which is equipped with an open-path eddy covariance system (Campbell CSAT3, LI-COR 7500) was constructed in 2008 and has in operation since then.

Measurements of CO_2 fluxes taken at these sites are used for the following studies:

▪ Quantitative analysis of ecosystem-scale fluxes,

▪ Evaluating the effects of fog on ecosystem productivity, and

▪ Assessing the topographic effects on flux measurements.

CO_2 fluxes within the ecosystem are analyzed using chamber methods. An automatic multi-chamber system (LI-COR 8100) is used for measurement of soil respiration with a high temporal resolution. The trench method is exploited to separate autotrophic and heterotrophic contributions to soil respiration. Since June 2008, a portable photosynthesis measurement system (LI-COR 6400) has been used to measure the photosynthesis of 14 canopy species at different locations in the Pingdong site.

4) **Upscaling to regional scale**

Measurements of the flux tower system using the eddy-covariance methods can provide long-term and continuous flux data of CO_2, heat and water vapor. The footprint of the flux tower observation is about 200-1500m at Xitou, which roughly matches the spatial resolutions of satellite images, such as MTSAT, MODIS, ASTER and Landsat. Integrated usage of the tower-based observations and the remote sensing images has the potential of upscaling from the stand scale to region scale. Thus, one of the objectives of the Xitou flux tower is to develop remote sensing techniques for estimation of regional-scale evapotranspiration.

Further information

For further information please contact Professor Ya-Nan Wang (m627@.ntu.edu.tw) or Professor Ming-Jer Tsai (tmj@ntu.edu.tw), Experimental Forets, National Taiwan University, Taiwan.

Meteorological and soil parameters	Air temperature, relative humidity, visibility, wind speed, wind direction, wind profile, PAR, soil water content, soil temperature, soil heat flux, CO_2 concentration profile, soil CO_2 flux
Nutrient fluxes	forest floor, leachate, mineral soil seepage, aboveground litterfall, de-composition

Table 1. Parameters monitored at the Xitou and Pingdong sites.

Linking flux measurements and remote sensing with field optical sampling

John A. Gamon
University of Alberta, Canada

While we understand the basic processes controlling biosphere-atmosphere fluxes, the exact budget remains unclear due to the enormity of the sampling challenge. Perturbations of fluxes due to natural and anthropogenic disturbance have been poorly quantified (Running 2008). To resolve the global carbon budget, we need to understand how carbon flux varies in space and time, across contrasting functional types, ecosystems and biomes, and across varying disturbance regimes. This knowledge is needed for sound carbon policy, and can help put a value on biospheric carbon as carbon markets emerge (Gamon et al. 2011). Given these multiple needs, it is essential that carbon monitoring be cost-effective, readily validated and transparent.

The global flux network (FLUXNET) and the regional networks (including AsiaFlux) provide an essential foundation for reaching these goals. However, flux towers are costly to purchase and maintain, and are limited to specific regions of suitable terrain, so must be supplemented by other methods. To attain a truly global understanding of biosphere-atmosphere fluxes, we must link these efforts to remote sensing, with its unique capability of uniform, synoptic sampling. Existing satellite sensors now provide continuous estimates of regional and global carbon flux, yet these do not always agree with ground measurements, demonstrating an ongoing need for calibration and validation. Scale-appropriate optical sampling, the core focus of SpecNet (Spectral Network, http://specnet.info), provides an ideal way to bridge the sampling gulf between flux and satellite measurements, providing a key foundation for workable scaling protocols that enable validated global flux estimates.

Brief history of SpecNet

SpecNet (Spectral Network, http://specnet.info) began in 2003 as a "working group" with support from the National Center for Ecological Analysis and Synthesis (NCEAS, Santa Barbara, CA, USA). A key technical focus remains scale-appropriate field optical sampling (close-up remote sensing) that can match the temporal and spatial scales of flux tower footprint, yet provide explicit links to aircraft and satellite monitoring. Additional objectives include the development, propagation, and standardization of optical measurements at spatial and temporal scales that can be linked to carbon fluxes, and the validation of satellite products with independent ground measurements. Since its inception, SpecNet has evolved into a voluntary collaboration of scientists working at approximately fifty sites around the world sharing a common interest in linking flux measurements, remote sensing, and optical sampling.

Full standardization of sampling methods has been difficult, because the original SpecNet funding did not support purchases of sampling equipment, and the current voluntary nature of SpecNet does not provide equipment funding. Without a central funding source, it has been difficult to impose a single set of standards. In several SpecNet meetings, it became clear that excessive enforcement of standards might restrict innovation, which has been a SpecNet strength from the beginning. Instead, SpecNet investigators have pursued a variety of novel solutions to field optical sampling, with method including simple radiometers, manual or automated field spectrometers, imaging spectrometers, and airborne sensors (figure 1). Participants at the several SpecNet meetings to date focused on defining several "recommended" options, and encouraging databases with rich metadata that would facilitate synthetic activities, including data comparisons, modeling and cross-site analyses (Gamon et al. 2010).

Current methods

A common conceptual theme within SpecNet has been the light-use efficiency (LUE) model, which states that carbon gain by vegetation or terrestrial ecosystems is a function of absorbed radiation (*APAR*), and the efficiency (ε) with which absorbed radiation is converted to fixed carbon:

$$\text{Carbon gain} = f(APAR \times \varepsilon) \quad (1)$$

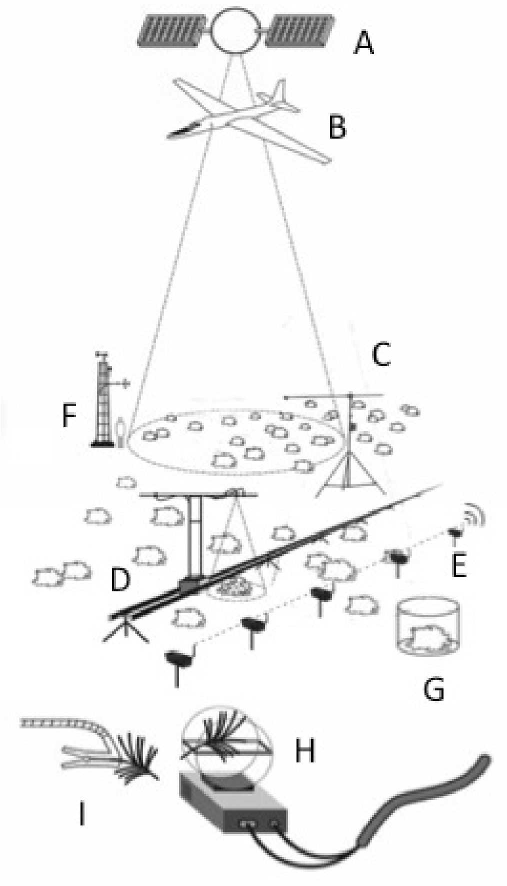

Figure 1. Multi-scale sampling scheme integrating flux with optical measurements. Satellites (A) and aircraft (B) are coupled with automated ground optical sampling, including phenology station (C), robotic tram system (D), wireless networks (E) or sensors mounted on flux tower (F). These measurements can be related to direct flux measurements, including eddy covariance (F) and chamber gas exchange (G,H) using a LUE or similar model (see text). A wide range of wireless sensor options (E) can be added in flexible configurations to sample spatial fields of irradiance, temperature, moisture, and other variables. Field spectrometers can also be configured for leaf-level sampling (I) to explore physiological controls on optical signals. In this way, optical and flux measurements can be integrated in a multi-scale sampling scheme. Figure adapted from Gamon et al. (2006a).

Depending on how the model is formulated, "carbon gain" can represent gross or net photosynthetic uptake, gross or net primary production, or net ecosystem exchange, and the literature contains examples of all applications. In its original formulation derived for crops (Monteith 1977), this model used dry matter yield (crop yield) as the metric of carbon gain. Since that time, the model has also been used for leaf- or canopy-level photosynthesis (Gamon et al. 2001), for gross ecosystem production (Huemmrich et al. 2010a&b) or for net primary production (e.g. Running et al. 2004). When estimating net carbon uptake, production, or exchange, respiration is included, either implicitly or explicitly, within the modeling framework. For example, for global NPP estimates from satellite, GPP is first estimated, then respiration is added as a separate submodel (Running et al. 2004). Alternatively, respiration can be incorporated within the "efficiency" term of the model (Gamon and Qiu 1999).

Regardless of how it is formulated, the strength of this model from a remote sensing perspective lies in its ability to use simple, widely available optical measurements to define the APAR term. APAR is calculated as the product of irradiance in the "photosynthetically active radiation" (PAR) region (i.e. irradiance measured by a PAR sensor or quantum sensor), and fraction of that irradiance absorbed by green vegetation (F_{PAR}, sometime called "green F_{PAR}" to indicate that only light absorbed by green canopy materials is used for photosynthesis). For example the "normalized difference vegetation index" (NDVI, figure 2), a widely used metric of vegetation "greenness," combined with PAR irradiance measurements, provides a direct measure of *APAR*. Until recently, the efficiency term (ε) has been more difficult to derive. While many versions of this model utilize meteorological data (primarily temperature and moisture) to drive the efficiency term, recent research has demonstrated that efficiency can also be determined optical measurements. For example, the photochemical reflectance index (PRI, figure 2) or the water band index (WBI, figure 2) provide measures of xanthophyll cycle pigment activity and plant water status respectively, both of which serve as indicators of physiological state and photosynthetic light use efficiency (Gamon and Qiu 1999). Consequently, it is possible that this model can be driven *entirely* from remote sensing. One of the primary goals of SpecNet

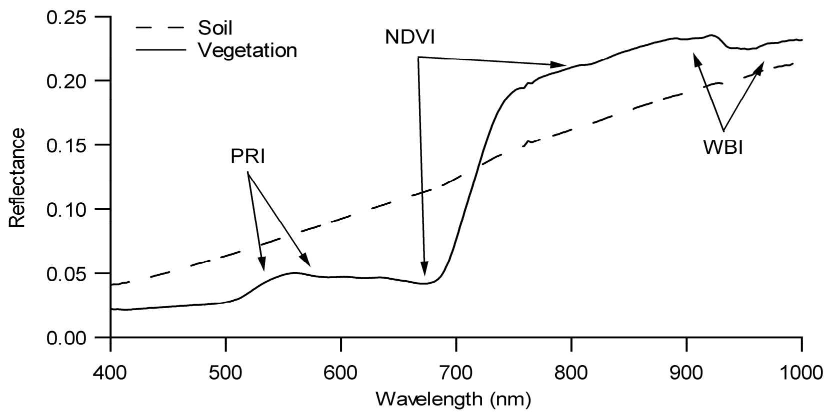

Figure 2. Reflectance spectra of soil and green vegetation, showing wavebands used for key "vegetation indices," including the Normalized Difference Vegetation Index (NDVI a measure of vegetation greenness), the Photochemical Reflectance Index (PRI, a measure of xanthophyll cycle activity and photosynthetic light-use efficiency) and the Water Band Index (WBI, a measure of water content).

has been to test this hypothesis, and a variety of sampling approaches are being used to do this.

Within the SpecNet community, a diversity of sampling methods are being used (Figure 1), and common methods tend to fall within one of several categories: 1) simple radiometers, 2) field spectrometers, 3) automated field spectrometers, 4) cameras, and 5) imaging spectrometers. These options span a wide range of cost and technological complexity, providing many sampling options for scientists wishing to add optical sampling to flux campaigns. Most of these methods can be used to obtain the two terms of the LUE model (APAR and ε), and are briefly discussed below:

1) Simple radiometers — This simple and inexpensive technology is based on the observation by Huemmrich et al (1999) that combinations of PAR (quantum) and pyranometer sensors can provide a continuous measure of vegetation greenness, within the flux tower footprint. Many eddy covariance stations already have PAR and pyranometer sensors for monitoring irradiance; by simply adding downward-looking sensors, it is possible to calculate the albedo in the PAR and pyranometer regions, allowing the calculation of a simple approximation of NDVI. Because these observations closely match the seasonal flux phenology observed by eddy covariance (Huemmrich et al. 1999), these simple radiometers are sometimes called "phenology stations." Because these sensors provide a low-cost method of monitoring carbon flux, these phenology stations are now being successfully used at many sites around the world, providing a simple, cost-effective field-based NDVI.

Examples of the application of phenology station to flux estimation is shown in figures 3 and 4 for an alfalfa (*Medicago sativa*) field in Edmonton, Alberta, Canada. In this case, the PAR and pyranometer sensors are mounted on a tripod and boom (figure 3) in the footprint of an eddy covariance system (figure 1). Calculation of net ecosystem exchange (NEE) from the optical sensors using the LUE model closely match the seasonal course of NEE measured by eddy covariance (figure 4). Note the several gaps in the flux measurements during periods of snow and rain. In this case, the continuous sampling provided by the phenology station provides a possible way to "gap fill" the missing flux data, which illustrates one application of paired optical and flux measurements.

2) Field spectrometers — represent the next level of cost for field optical measurements. Many brands of field-portable spectrometers now exist that can sample everything from a single leaf to entire canopies or stands (figure 1). To sample stands within a flux tower footprint, it is often necessary to design a sampling scheme (e.g. transect or grid design) that provides a reasonable representation of the flux tower footprint, and this is easily possible with most field-portable spectrometers (figure 5). A particular benefit of field spectrometers is that

Figure 3. “Phenology station” sampling NDVI using simple, 2-band radiometers in an alfalfa field (Edmonton, Alberta, Canada). Shown here is a system sold by Onset Computer Corporation (Bourne MA, USA), but many brands of these sensors now exist. These stations can be operated alone, or linked into an expandable global network using satellite links. When properly calibrated against eddy covariance, phenology station sensors can provide reliable estimates of biospheric carbon uptake, and can be used to fill gaps in flux measurements (figure 4). The stations can also be compared to aircraft and satellite sensors (figure 8) to validate remotely sensed products, and enable wider regional extrapolation of carbon flux measurements.

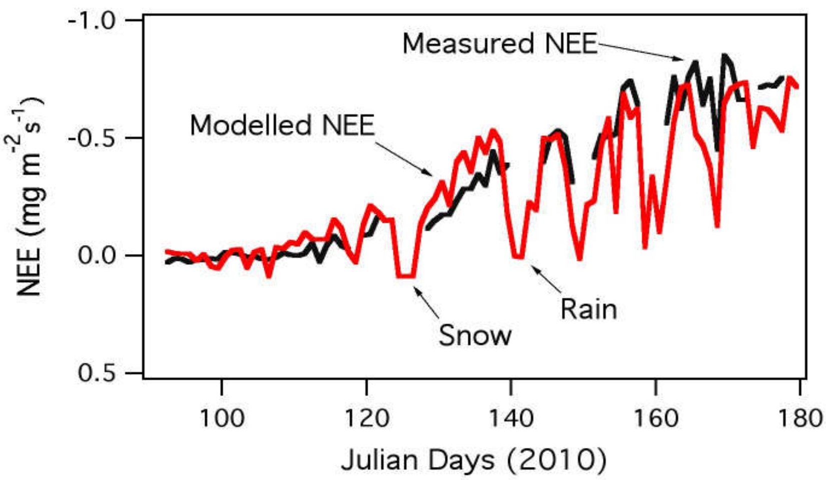

Figure 4. (above) Temporal trajectory of measured (black) and modelled (red) net ecosystem exchange (NEE) for a growing alfalfa field in summer, 2010. Negative NEE values indicate carbon dioxide uptake by the ecosystem. Measured NEE derived from eddy covariance using a commercial eddy covariance system (Campbell Scientific, Logan Utah, USA), with an open-path IRGA (LI-COR, Lincoln, NE, USA). Modeled NEE derived from a phenology station (figure 1 & 3, Onset Computing Corporation, Bourne, MA, USA) using the LUE model. Castro & Gamon, in preparation.

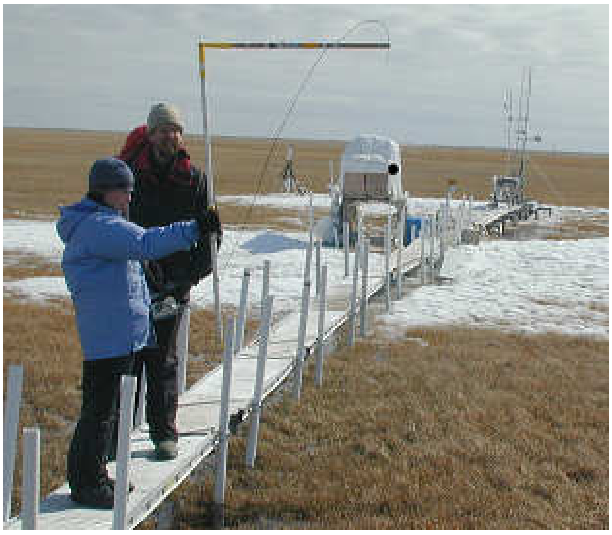

Figure 5. (right above) Sampling surface reflectance in a flux tower footprint near Barrow, Alaska, using a portable field spectrometer (UniSpec, PP Systems, Amesbury MA, USA).

they can also be matched to the scale of field plots (e.g. chamber gas exchange), providing a direct link between ecosystem respiration, photosynthesis and optical indices (e.g. NDVI). In many studies, such plot-level measurement of NDVI provide a good correlation with carbon fluxes (Gamon et al. 2006b) and can be used in a simple, optically-driven model to estimate whole -ecosystem production (Street et al. 2007, Huemmrich et al. 2010a&b).

3) Automated field spectrometers — Some brands of spectrometers can be readily automated for continuous, use in the field. Applications of automated spectrometers include mobile sampling units (e.g. "trams" – Gamon et al. 2006a, Goswami et al 2011) and tower-mounted units (Leuning et al. 2006, Hilker et al. 2007). Innovative applications of automated sensors now allow for sampling at multiple sun angles and view angles (figure 6, see also Hilker et al. 2007). These experiments demonstrate that angular considerations are important in optimal extraction of LUE model terms from remote sensing. Angular considerations have been explored in the remote sensing community for years, particularly in the context of defining vegetation "bidirectional reflectance distribution functions" (BRDF, Deering and Leone 1986, Sandmeier & Itten 1999).

4) Cameras — The advent of inexpensive webcams is now allowing the exploration of image-based approaches to monitoring vegetation phenology at flux tower sites. The global PHENOCAM network (http://phenocam.sr.unh.edu/) has demonstrated this potential. However, angular sampling effects (see above) and calibration challenges make it difficult to derive quantitative data from webcams, so are more typically used for qualitative assessments of seasonal change. For example, cameras are being used at many sites to monitor leaf flush, leaf drop, and weather events.

5) Imaging spectrometers — At the higher end of the cost scale, imaging spectrometers can be used to explore explicit spatial patterns in the vicinity of the flux tower footprint. New imaging spectrometers are now allowing relatively low-cost methods of exploring spectral patterns in the spatial domain. Many of these sensors can provide high spectral and spatial detail (figure 7). These instruments enable many novel applications that have only begun to be explored by the flux sampling community. For example, imaging spectrometers can be used to help define the landscape surrounding a flux tower, can help interpret the flux tower footprint, and provide ideal "scaling tools" for extrapolating from points on the ground to satellite images.

Future directions

Given the range of methods now being employed at SpecNet sites, a continued emphasis needs to be placed on designing data systems (informatics and cyberinfrastructure) that can accommodate the diverse data structures emerging and facilitate data sharing. Greater data transparency and accessibility of data, including automated methods of tracking provenance and acknowledging data sources, are needed. To assist in this, members of the SpecNet community are working on web-based tools for uploading, processing, visualizing, and sharing data. To facilitate cross-site comparison, and to enable data sharing across methods, sites, and investigators, metadata-rich approaches are needed. Current cyberinfrastructure efforts within SpecNet are focused on applying these capabilities within the framework of a scaleable LUE model. In this way, data from different methods, investigators and sites can be readily compared to each other, and to flux data. By focusing on the model terms also derived from satellite (e.g. MODIS), this approach provides a clear path to validating and calibrating satellite data products. An example of such a comparison is shown in figure 8, comparing a MODIS NDVI product to a phenology station on the ground. In this comparison, it becomes clear that both sensors depict similar seasonal courses of vegetation activity (phenology), but the MODIS NDVI reads higher than the ground values, providing a basis for "calibrating" satellite sensors against ground sensors for individual sites. Understanding these offsets, which have also been reported for other sites (e.g. Cheng et al. 2006), is an important step if we are to develop validated global flux measurements from satellites, and may help explain why previous comparisons of satellite estimates to flux towers do not always agree for all sites (Turner et al. 2005).

A properly integrated approach to optical, flux and remote sensing measurements, can help the carbon science community address a number of critical questions that are now hard to resolve from any one method alone For example, cross-ecosystem or cross-biome comparisons can help us understand which factors affect carbon flux for different parts of the world. Improving our flux models for different ecosystems can help us understand how to more effectively use remote sensing to estimate global flux patterns.

Figure 6. Sampling surface reflectance in a flux tower footprint using a tram system (Gamon et al. 2006b) in a barley (*Hordeum vulgare*) field (Edmonton, Alberta, Canada). Note that the spectrometer foreoptic can be pointed at different directions, allowing multi-angle sampling. Similarly, by sampling at different times of day, reflectance can be sampled at different sun angles.

Figure 7. False color infrared image (red stripe overlaid on top of Google Earth) from a helicopter flight over the boreal forest near Hinton, Alberta, in May 2010. Note the clear resolution of individual tree crowns (in red), illustrating the high spatial resolution (approx. 20 cm) possible with airborne imaging spectrometry. Carbon flux can be derived from spectral reflectance (invisible Z dimension of the image) using the LUE model. Image centre location approximately 53°55'14.44"N, 116°13'31.36"W, elev. 1209m. Unpublished data, J. Gamon (University of Alberta) and D. Stonehouse (VeriMap Plus, Calgary, Alberta), using an imaging spectrometer (MicroHyperspec, Headwall Photonics, Fitchburg, Massachusetts).

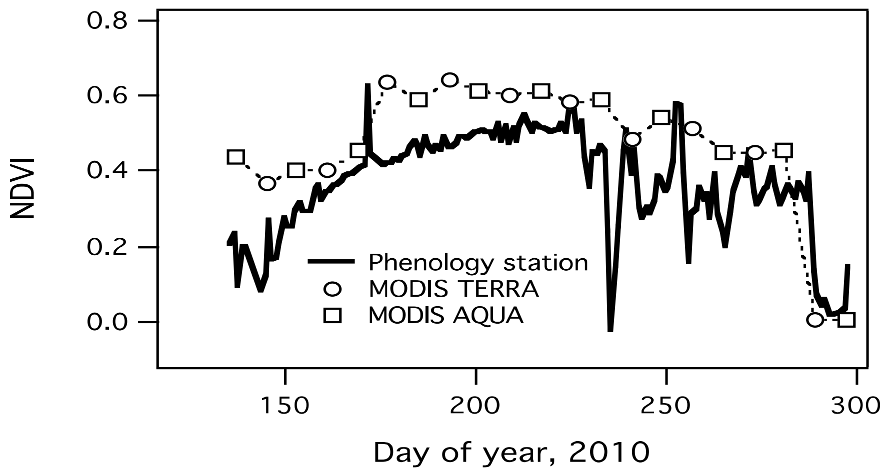

Figure 8. Seasonal trend of NDVI from a phenology station (solid line) and from NASA's MODIS TERRA (circles) or AQUA (squares) satellite sensor. NASA MODIS NDVI represents maximum value composites for 16-day periods, and was obtained from http://daac.ornl.gov/MODIS/. The phenology station NDVI was derived from PAR and pyranometer sensors (Onset Computing Corporation, Bourne, MA, USA). These data have not been "cleaned" for bad data, and illustrate daily excursions due to changing vegetation greenness and weather events (notably rain and snow, which cause sudden peaks and dips in the data). Data collected at an arctic tundra fen site in summer 2010 at Churchill, Manitoba, Canada. G. Zonta-Pastorello and S. Williamson assisted in data preparation.

Impacts of disturbance events, climate change, and biological feedbacks to the atmosphere can be effectively revealed through combined flux, optical, and remote sensing measurements. By helping us quantify biosphere-atmosphere fluxes, a concerted global effort to integrate flux, optical and remote sensing measurements could enable us to better quantify biosequestration, a fundamental step towards valuing biospheric carbon and improving terrestrial resource management (Gamon et al. 2011).

Currently, many geographic regions are not represented within SpecNet. For example, there are currently few SpecNet sites in Asia. New sites and SpecNet members are welcome (please see the SpecNet website at http://specnet.info), and we invite new members of the AsiaFlux community to join, both by registering new sites and by subscribing to the SpecNet mailing list. We also welcome new members to participate in the upcoming FLUXNET-SpecNet meeting scheduled for 7-9 June in Berkeley, California

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Editor's Note

In this issue we have reports of symposium/workshop activities and establishment of new flux tower sites which summarize and signify the vibrant research activities in Asiaflux. I am indebted to all authors of this issue, giving very little time for completing their contributing articles. I am particularly grateful to Dr. Gamon for his contribution on introduction of SpecNet activities and methods for linking flux measurements and remote sensing data. I am sure it will provide insightful information for researchers who are interested in carbon monitoring beyond tower measurements.

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