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FluxLetter

THE NEWSLETTER OF FLUXNET

A focus on a few of the FLUXNET network's sites where scientists are using eddy covariance methods in conjunction with a broader measurement set to uncover ecological insights.

In This Issue:

In this issue of the FLUXLETTER we profile a few of the sites where extensive ecological investigations are occurring. We also highlight some of the new technologies and data sources that are now, or soon to be available for Fluxnet scientists to access. For those of you who were unable to attend the Fluxnet and Remote Sensing Open Workshop held in Berkeley, California this past June, much of the workshop materials can be found at this website: http://nature.berkeley.edu/biometlab/fluxnet2011/fluxwkshp_post.html

Incorporating Ecological Insights into Fluxnet Investigations: Fluxnet Sites as Research Hubs

An Editorial by Laurie Koteen and Dennis Baldocchi

Fluxnet is a unique and evolving resource that links scientists from across the globe and allows them to share and synthesize information through a curated database. Primarily, they share data about the way that ecosystems store and exchange carbon, water and energy between the land surface and the atmosphere. To date, Fluxnet has greatly advanced our understanding about the magnitude of surface fluxes across ecosystem types and climate zones. It has also provided insights about how fluxes correlate with climate variables seasonally and inter-annually, and about what properties and process rates ecosystems seem to share, and where they differ. More recently, scientists have developed novel and creative uses for the Fluxnet network. Researchers at Fluxnet sites are now documenting how material fluxes track recovery from disturbance, how flux rates differ in forests at different points in stand maturity through chronosequences studies, or at different elevations in sites arrayed along elevation gradients. Methane fluxes are being measured at several Fluxnet sites as well as SOX, NOX and VOCs. Researchers are also using Fluxnet data to serve new scientific goals. Both flux and optical data from Fluxnet field sites have become an important source for bottom-up inputs to models that upscale flux quantities, (see FluxLetter Vol. 3, No. 3). Data from these sites also serve as a validation tool for top-down modeling from satellite, lidar and aircraft optical measurements. These issues, and others, were the subject of a recent meeting in Berkeley California, and much of the topical information from this meeting can be found

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here: http://nature.berkeley.edu/biometlab/fluxnet2011/fluxwkshp_post.html. However, much potential still remains for Fluxnet to expand its scope and use the network of established sites as a platform for scientific innovation. The studies and sites highlighted in this issue of FluxLetter all represent departures from the more traditional set of measurements that occur at Fluxnet sites, or seek to highlight new data streams now coming online which will be available to merge with flux data.

Moving forward, we hope that a greater number of Fluxnet sites will become research hubs where teams of scientists from a variety of ecological disciplines are working in concert to not only measure flux rates, but also to develop a broader understanding of the ecosystem drivers and vulnerabilities unique to each site. We envision teams of scientists (*i.e.* ecologists, soil scientists, atmospheric chemists, eco-hydrologists, geomorphologists…) combining efforts to gain a mechanistic understanding of ecosystem function at the sites that make up Fluxnet and to understand how they may respond to global change. Correlations between ecosystem response to interannual climatic variability as a basis for inferences about ecosystem change, although of great value, can only provide a partial picture. Moreover, at a time when many ecosystems are in a state of transition, a focus on flux measurements and climate variables alone may provide information that is of transient value. More comprehensive mechanistic insights are more likely to come from multidisciplinary teams and approaches. From this perspective, the eddy covariance tower and associated measurements become less of an end point at Fluxnet sites and more of a measurement set within a broader investigation.

In addition, a shift in focus towards greater inclusion of ecological drivers, and diligence in sharing this information through the Fluxnet database, will provide for a much richer dataset for researchers to draw from for synthesis studies. Such efforts would create new categories for investigation, *i.e.* syntheses across sites with deep vs. shallow-rooted vegetation to precipitation anomalies, or a comparison of flux responses in phosphorus vs. nitrogen-limited systems, or the degree of ecosystem buffering to climate anomalies in highly diverse systems vs. systems with low diversity, or changes in flux rates across systems subject to recent species invasion or undergoing community shifts… and many others. We hope the articles highlighted in this issue serve as an inspiration for researchers to go deeper into understanding the ecological dynamics operating at their sites and we look forward to seeing the results.

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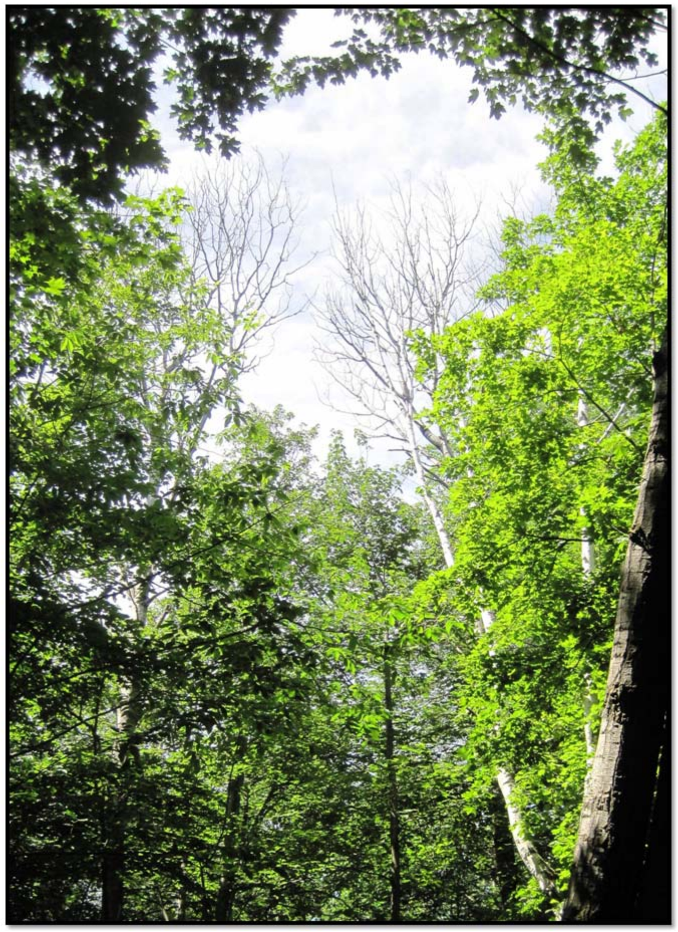
Biogeochemical cycles in future forests: Linking structure and function using multiple research approaches at the University of Michigan Biological Station

Christopher M. Gough and Lucas E. Nave

Recent studies show that many old forests continue to be carbon sinks long past their presumed peak. What are the mechanisms behind recently observed high levels of carbon storage in old forests? How much carbon will forests of the future store? How will nitrogen cycling interact with and constrain carbon storage? U.S. DOE and NSF-supported FLUXNET investigators at the University of Michigan Biological Station (UMBS) are addressing these questions by combining experimental and observational studies that use meteorological and ecological approaches.

Understanding what presently limits carbon storage in old forests and predicting future levels of carbon storage require perspective on forest disturbance regimes –past, present, and future. While global disturbance frequency is on the rise, disturbance intensity is also changing in many forested regions. In the Great Lakes region of North America, forest disturbances are transitioning away from severe events causing complete stand replacement, such as historic clear-cut harvesting and fires, towards more subtle disturbances that cause only partial canopy defoliation or the loss of select species. These more minor, often spatially diffuse disturbances, include partial harvests, pathogenic (frequently invasive) insects, diseases, and age-related senescence. At the same time, forests in the region are getting older. Age-related mortality has become common in older secondary forests of the Great Lakes region, where short-lived, early-successional canopy species that established following clear-cutting and severe fires a century ago are now dying and giving way to longer-lived, later-successional canopy dominants.

As the disturbance ofearly-successional tree mortality ripples through these aging forests, how will ensuing changes in structure alter ecosystem function, including the carbon balance? Long-term observations together with experimental studies from UMBS suggest that subtle disturbances may lead to greater structural and biological complexity, causing increased rates of carbon storage. FLUXNET investigators at UMBS want to know why.



Succession in progress: small-scale age-related mortality at UMBS, with two dead aspens standing over a proliferating maple subcanopy.

Study description

Investigators at UMBS are using two complementary approaches to examine carbon cycling responses to subtle disturbance and ongoing ecological succession to elucidate the underlying mechanisms responsible for such biogeochemical changes. The first is the Forest Accelerated Succession Ex-

Biogeochemical cycles in future forests: Linking structure and function using multiple research approaches at the University of Michigan Biological Station

Christopher M. Gough and Lucas E. Nave

perimenT (FASET), in which all early successional aspen and birch trees (~35 % LAI) within 39 ha of forest were stem girdled in 2008 to accelerate their age-related senescence and the transition of the forest as a whole to a more advanced successional state. This large-scale experimental manipulation is testing the hypothesis that net ecosystem production will increase with forest age due to disturbance-mediated changes in nitrogen availability and the development of a more nitrogen-rich, biologically and structurally complex canopy. The experiment employs a suite of paired on-the-ground carbon and nitrogen cycling measurements, replicated in plots distributed throughout separate treatment and control meteorological flux tower footprints. A second, observational approach makes use of rich meteorological and ecological datasets collected continuously over a dozen years from a non-manipulated area of the forest, and also ecological data from a 180-yr forest chronosequence that permits investigators to examine changes in the carbon cycle over much longer time periods. Together, this complement of meteorological and ecological data from experimental and observational studies allows investigators to examine drivers of change in the carbon cycle at a variety of temporal and spatial scales.

Investigator, Chris Gough, stem girdles an aspen tree during the implementation of the Forest Accelerated Succession ExperimenT (FASET) in May, 2008. Stem girdling eliminates transport of photosynthate to the roots, eventually causing root, and subsequently, tree death.

Combining meteorological and ecological methods enhances efforts to understand controls on carbon fluxes, and their variation over time and space. On-the-ground ecological measurements are particularly useful in ascribing mechanisms to patterns revealed by meteorological data. For example, meteorological data from the FASET project indicated a modest decrease in net ecosystem exchange in the area disturbed by the experimentally accelerated senescence of early successional tree species, a response that was within the bounds of interannual variability. Although the apparent treatment effects on whole ecosystem carbon cycling were subtle, complementary ecological data revealed an underlying cascade of important, interrelated biogeochemical changes that promoted functional resilience in carbon storage. Plot-scale measurements within the treatment footprint revealed rapid replacement of senescing species' declining leaf area as soil nitrogen availability increased and was reallocated

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Christopher M. Gough and Lucas E. Nave

to newly expanded leaf area of later-successional canopy dominants. Lysimeter measurements, which quantify nutrient losses from leaching, indicated near-complete retention of actively-cycling soil nitrogen, demonstrating that efficient nitrogen redistribution to later-successional trees was a mechanism for resilience of net ecosystem production in this nitrogen-limited forest during the disturbance period (Nave *et al.*, in press).

Long-term observations in non-manipulated areas of the forest and in chronosequences provide complementary understanding of how structural changes that play out over decades alter trajectories of carbon storage. For example, decadal records of tree growth indicate that resilience to age-related declines in net primary production is highest where a diversity of canopy tree species is present, because later successional species rapidly compensate for declining growth of early successional species (Gough *et al.*, 2010). Investigators are also finding that long-term resilience of forest carbon storage to disturbance is dependent upon canopy structural reorganizations that enhance carbon uptake (Hardiman *et al.*, 2011). Canopy structural complexity, which increases with forest age, is positively correlated with decadal net ecosystem production in stands ranging in age from 5 to 200 years. The root cause of high productivity in structurally complex old forests is still under investigation, but preliminary evidence suggests that increased structural complexity of the canopy improves resource use efficiency. These results have important implications for tracking and predicting carbon cycling resilience, suggesting that long-term forest carbon storage trajectories depend not only on replacement of lost leaf area, but also on shifts in forest structure that permit greater efficiency of use of limiting resources to drive carbon storage. In application, remotely sensed metrics of 3-dimensional cano-

Spatial variation in early-successional tree mortality following experimental disturbance. Integrating across this variation with the meteorological approach while also quantifying variation with on-the-ground sampling yields greater insight than using either approach alone.

Biogeochemical cycles in future forests: Linking structure and function using multiple research approaches at the University of Michigan Biological Station

Christopher M. Gough and Lucas E. Nave

py structure may improve accuracy of forest carbon storage estimates, and allow for more robust simulations of regional forest carbon dynamics.

Future directions

As the UMBS Forest Ecosystem Study (FEST) research program moves through its second decade, investigators are adding to existing meteorological and ecological data streams. Our intent is to reveal the mechanisms underlying carbon cycle changes in response to disturbance, ecological succession, and ongoing climate change. Continued tower and ground-based carbon flux measurements in control and treatment footprints will help elucidate how near-term disturbance effects mediate long-term trajectories of carbon storage. For example, the long-term carbon balance following disturbance to the UMBS forest is likely to shift following the transfer of large carbon stocks from senescing aspen biomass to woody debris pools, and as nitrogen redistribution to the developing canopy continues. Ongoing ecological investigations include a ^{15}N tracer study to understand differences in ecosystem nitrogen distribution and cycling in control and treatment flux tower footprints. As paired meteorological and ecological measurements continue, investigators are integrating these mechanistic data with remote sensing and ecosystem modeling approaches to forecast regional shifts in carbon cycling as forests age . Additionally, by participating in research networks like FLUXNET and the National Soil Carbon Network, the UMBS FEST team is ensuring that site data contributes to large-scale collaboration and synthesis among the broader carbon cycle science community . Recent years have seen a significant increase in synthesis products that add huge value to archived data. Continued data streams, especially from places with already long-term records (*e.g.*, Metolius, Morgan-Monroe State Forest, Harvard Forest, UMBS), create even stronger opportunities for synthesis and the advances that our science needs. Finally, a mechanistic understanding of how forests work is enhancing science-based products that will inform land managers and policy makers how to manage forests in the backdrop of local and global environmental change.

2011 UMBS-FEST participants in the field. The researchers above, as well as others not pictured, collaborate on interdisciplinary studies of forest ecology and biogeochemistry at a site near the center of the Great Lakes Region in northern Michigan.

Biogeochemical cycles in future forests: Linking structure and function using multiple research approaches at the University of Michigan Biological Station

Christopher M. Gough and Lucas E. Nave

UMBS Forest Ecosystem Study (FEST) website: http://umbs.lsa.umich.edu/research/fest

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Further reading

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Providing access to subsets of remote sensing data for flux tower sites

Suresh Santhana Vannan, Maria Martinez Gonzalez, Robert Cook

To address questions related to carbon cycle and ecosystems, researchers have to identify, download, understand, and assemble remote sensing data from disparate sources. For scientists working at spatial scale of less than 100 x 100 km, assembling the time-series data is particularly challenging because of the huge amounts of data that have to be downloaded relative to the spatial scale of the analysis. Also, researchers have to understand file formats, data structure, and data access mechanisms across the various types of data. Valuable resources that can be spent on research are spent in assembling the data. To address this issue, ORNL DAAC and FLUXNET are performing a pilot study to provide subsets of remote sensing data for flux tower sites.

We are currently exploring the following data products to be subsetted and delivered for selected tower sites:

- ALOS PALSAR SAR Subsets
- EO-1 Hyperion
- Landsat
- MODIS
- Daymet
- NPP-VIIRS

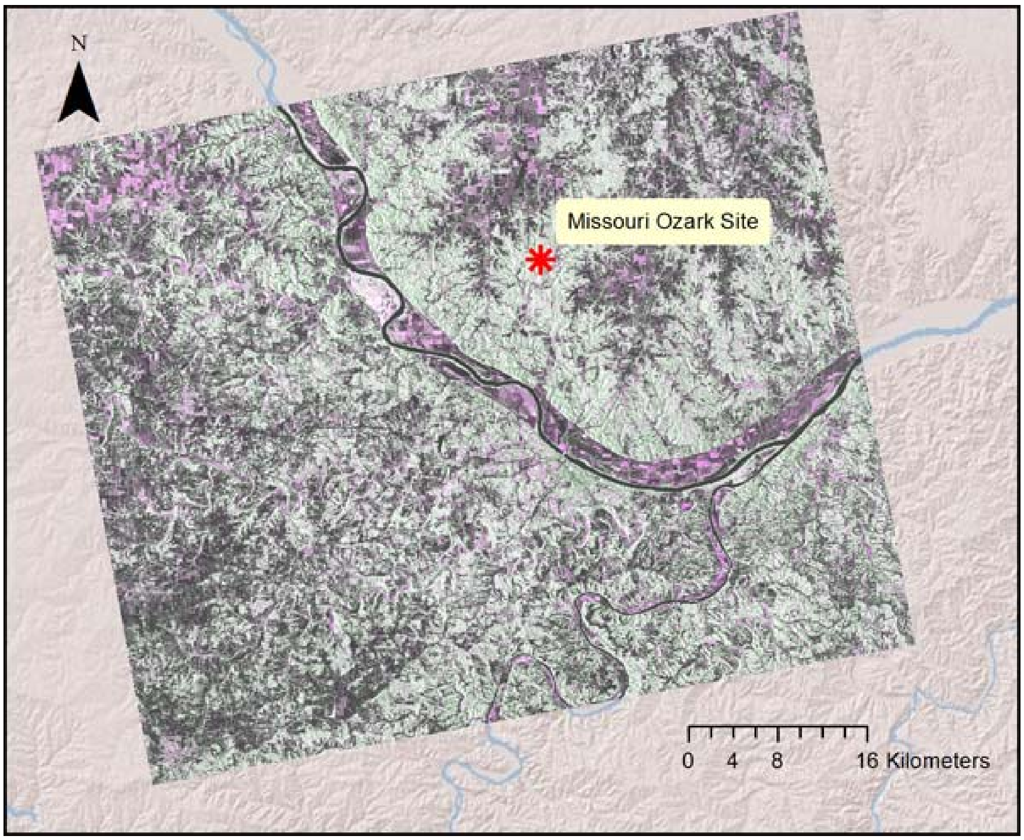

Figure 1. Subset of PALSAR (Phased Array type L-band Synthetic Aperture Radar) sensor data from the Advanced Land Observing Satellite (ALOS) in GeoTIFF format for the Missouri Ozark flux tower site. The resulting image shows vegetation in shades of green and barren land in shades of pink or purple. The subsets are provided in collaboration with Alaska Satellite Facility and National Snow and Ice Data Center. For more information: http://daac.ornl.gov/LAND_VAL/sar.shtml

Subsets of PALSAR (Phased Array type L-band Synthetic Aperture Radar (SAR)) sensor data from the Advanced Land Observing Satellite (ALOS) are currently provided for selected flux tower sites in GeoTIFF format at the ORNL DAAC (Figure 1). SAR data are particularly useful in understanding human impacts on vegetation at a local scale, detecting deforestation and forest degradation and in estimating biomass. The DAAC has provided examples of how SAR data can be used at flux tower sites.

Hyperion data will be useful for its high spectral resolution. Landsat and MODIS have been used in numerous ecosystem studies (Figure 2)

Daymet is a model that generates daily 1 x 1-km surfaces of temperature, precipitation, humidity, and radiation over large regions of complex terrain for North America (Mexico, USA, and Cana-

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da, south of 52N). No other weather/climate data at this temporal and spatial resolution exists. Daymet data will be useful in understanding vegetation parameters in relation to climate/weather.

The ORNL DAAC will also be offering NPOESS Preparatory Project (NPP)-Visible/Infrared Imager Radiometer Suite (VIIRS) as they become available. Launch for NPP is now scheduled for October 2011.

ORNL DAAC will be using Open Geospatial Consortium (OGC) standards to visualize and distribute these data bundles. Users can also download the csv or GeoTIFF data directly from an FTP/Web server.

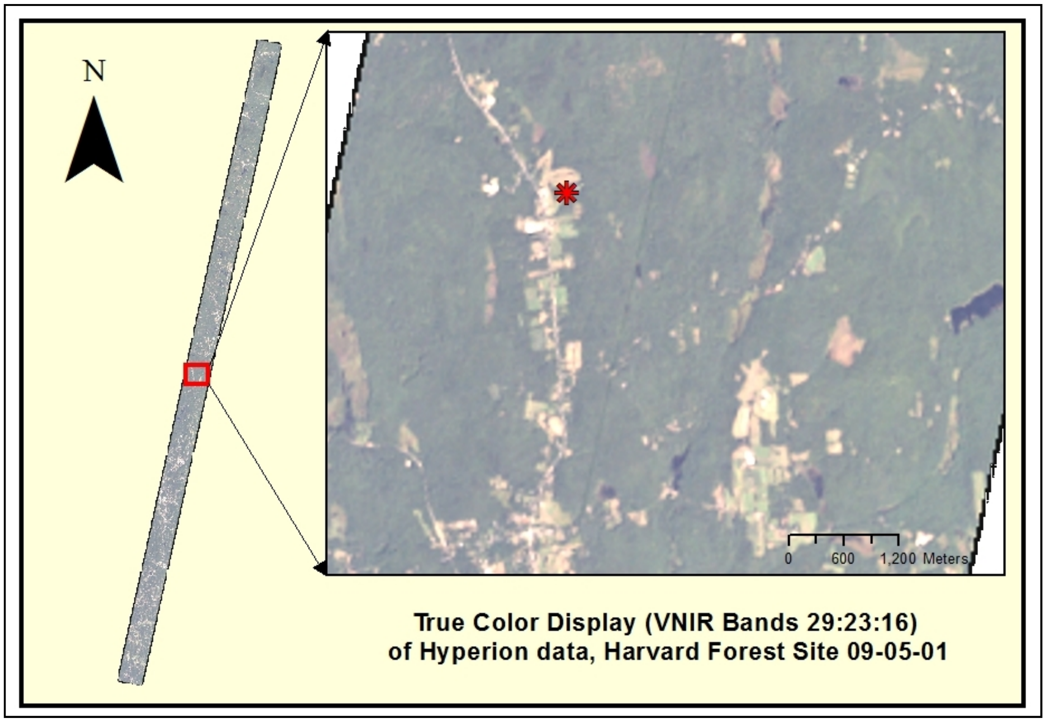

Figure 2. E0-1 HyperIon data for Harvard Forest. True color image of the Hyperion image using Visible Near Infrared data is shown for a 7.5 km swath.. The HyperIon instrument is designed to provide Earth images using 220 spectral bands.

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Are flux towers becoming advanced weather stations?

Jiquan Chen

In early 1990, the scientific communities of ecology and micrometeorology were excited and stimulated by the first permanent eddy-covariance (EC) tower that was installed at the Harvard Forest. Not only was it because we had direct, continuous measurements of carbon, water, and energy fluxes at the ecosystem level (versus fluxes at leaf or individual plant levels) that allowed us to examine ecosystem responses and functions continuously. But, more importantly, we were excited because the new technology brought scientists from several fields together to understand the changes in CO_2, H_2O, and energy from physical, biological, and ecological perspectives and the underlying mechanisms and biophysical regulations. The establishment of several networks, officially sponsored (EuroFlux, AmeriFlux) or constructed as consortiums (e.g., US-China Carbon Consortium, USCCC), promoted rapid, cross-lab collaborations through data sharing. Some great examples include the deposition of AmeriFlux data at the U.S. Oak Ridge National Laboratory and the development of the LaThuile database and synthesis (http://www.fluxdata.org/default.aspx).

Regardless of various critiques related to the technical pitfalls, such as issues involved with complex terrains and sensors, EC flux towers have been favored by the broader scientific community, agencies, and foundations across the globe. Over two hundred flux towers, for example, were installed in China over the past ten years. In the United States, EC towers are now considered a central piece of any NEON site. Publications based on this flux data have flooded the mainstream journals (e.g., Agric For Meteorol, JGR-B, Tree Physiol, etc.) Meanwhile, murmurs against the above development began, including the popular comment of "flux towers are advanced weather stations".

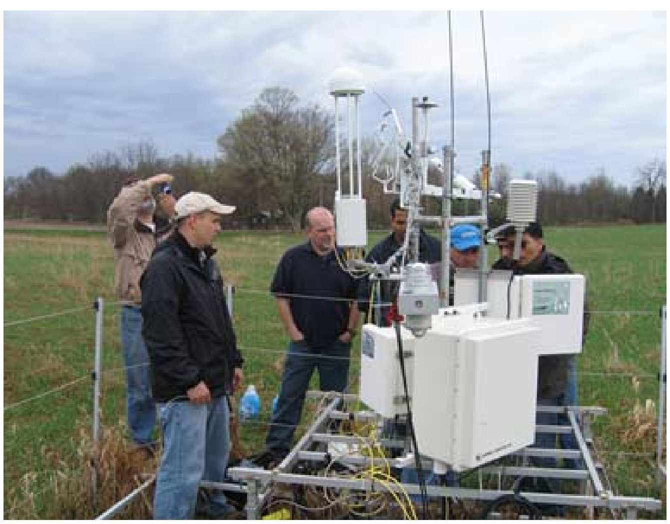

Photo 1: The J-Rover developed for the bioenergy study at the GLBTRC/KBS site in Michigan was enhanced to include a CH_4 sensor (LICOR 7700) in May 2010.

Facing the above challenge to the FLUXNET community, our members need to be stimulated to explore new grounds with our growing measurement facility and maturing collaborations. Obviously, we can continue our endeavors in maintaining these towers to gain a better understanding of the long-term ecosystem changes, waiting for low-frequency events to happen (e.g., fires and insect outbreaks, extreme climate; Amiro *et al*. 2010), starting manipulations at our EC flux site such as the girdling experiment at the University of Michigan Biological Station (UMBS; Nave *et al*. in press), adding new sensors to the towers so that fluxes of other trace gases (e.g., CH_4 and N_2O) will be measured (Photo 1), installing more towers at less-studied ecosystems, or continuing our scaling up efforts. Here, I offer two other research directions for the FLUXNET community to discuss: 1) applying mobile flux towers to address the changes in flux properties across space, and 2) incorporating flux measurements into manipulative experiments for hypothesis testing.

At the 1st and 2nd AmeriFlux annual meetings, I attempted to sell the concept of mobile flux towers using our study at the Wind River Canopy Crane Site as an example (Chen *et al*. 2002). The primary rationale is that we will never have enough towers to cover every ecosystem on the earth at all times. One alternative is to have the flux towers moved across the landscape. Unlike the vessel-based flux system, the mobile flux tower can be left at an ecosystem for a varia-

Are flux towers becoming advanced weather stations?

Jiquan Chen

ble amount of time before it is moved to another system through scheduling. A major disadvantage of this approach is that one will have major data gaps along the time series, preventing us from understanding the temporal variability across continuous scales. Our major gains are from significant increases in spatial coverage. This concept has been generally supported by the community as it has been applied in several ongoing projects and used as a way of calibrating field sites for landscape or regional scaling up (i.e., carbon and water fluxes at broader spatial scales, Xiao *et al*. 2011). In Northern Wisconsin, the LEES members designed and installed two permanent EC towers and three mobile ones. Over the five-year study period (2001-2005), we collected data at 14 forest types within the 18x20 km landscape. This data provided us great information to understand the carbon and water fluxes of a managed landscape (Noormets *et al*. 2007). This concept was later modified to have the flux sensors mounted on a mobile cart, known as the J-Rover (Photo 1) so that the flux system can be moved easily to match the needs (e.g., frequency of MODIS satellite) of a landscape. On the Mongolia Plateau, a region lacking *flux* measurements (Jung *et al*. 2010), we deployed two J-Rovers to fill the data gaps of permanent tower networks (Photo 2). Within a three-year study period, we anticipate quality data for ~15 land cover types across the 2.5 million km^2. The data will be necessary for regional estimations (Xiao *et al*. 2011). Clearly, in locations where there's almost no data, this technique is particularly useful to provide baseline estimates for fluxes.

Photo 2: The mobile J-Rovers deployed on the Mongolia Plateau in 2009. These towers are moved across the plateau annually to gain information of as many ecosystems as possible for regional estimates of carbon and water fluxes through scaling up exercises.

Flux towers are not just advanced weather stations. They can be used to record both processes and functional responses of an ecosystem within a manipulated environment. In New Mexico, paired flux towers (disturbed vs. undisturbed) were installed at three locations along an elevation gradient (a.k.a., NMEG) to separate the effects of climate, disturbances, and ecosystem type using six flux towers (Anderson-Teixeira *et al*. 2011); a similar design was employed by the Institute of Botany-CAS along the precipitation and grazing gradients in Inner Mongolia (Miao *et al*. 2009). Recently, we used this concept of cluster towers in a two-way factorial design of a bioenergy study at the Kellogg Biological Station (KBS) to understand the productivity and resource use of biofuel fields of Switchgrass, corn, and mixed prairies (three types) that were developed from two land use types. Data collected from these direct measurements provides us with convincing evidence of fuel production during the land conversion process at each of the bioenergy systems (Zenone *et al*. 2011), and/or of answering bigger questions (calculating global warming potentials through life cycle analysis; Gelfand *et al*. 2011). The most recent application of the tower cluster is in the "Environmental Sensor Network (ESN)", which is installed at a small watershed in the western basin of Lake Erie (Fig. 1), where two permanent EC towers were installed to the existing tower network on land. A mobile EC system is being built to fit vessel- or land vehicle-based measurements. Data from the ESN is linked with the NOAA monitoring stations in

Are flux towers becoming advanced weather stations?

Jiquan Chen

the basin for both basic scientific investigations (e.g., modeling greenhouse gases) and policy making (lake water quality, land use, adaptation plans, etc.)

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Photo 3. The environmental sensor network (ESN) at the western Lake Erie Basin. The tower cluster is the foundation for basic scientific investigations, education, and policy making through the Lake Erie Center, University of Toledo.

Highlight Young Scientist

Monica Garcia

Monica Garcia

How I could have guessed when I started my bachelor's degree in Agricultural Engineering in Madrid that I would end up doing cool research in Africa on surface fluxes? Well, I have to say that it was not a quite direct path. Nonetheless, looking back two topics were always present: water-limited ecosystems and remote sensing.

Since September 2010 I have been a postdoc in the groups of Prof. Inge Sandholt (Copenhagen University) and Dr. Pietro Ceccato at IRI (Columbia University). My work aims to estimate evapotranspiration and soil moisture in West Africa within the CaLM project: Earth Observation of long term changes in land surface moisture conditions. My research group has been working in Africa since the 1980's, and they run an instrumented site in the semi-arid savanna of Dahra, in Senegal (Picture 2). The site is instrumented with a set of spectral and thermal sensors that allow up-scaling for comparison with satellite data. Last year, hyperspectral measurements in continuous and rotating mode using ASD spectroradiometers were set up in the site by Prof. Fensholt of Copenhagen University. A flux tower was set up as well in collaboration with Prof. Ardö of Lund University, Sweden.

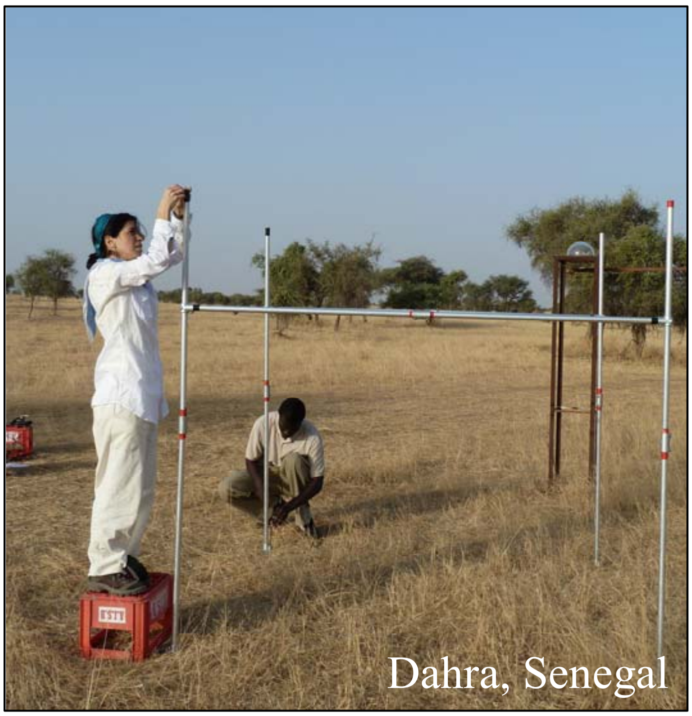
With such a nice framework, I hope to answer some of the questions that intrigue me most now. One pertains to how to integrate more spectral information into existing land surface models. Currently thermal information and vegetation indices are widely incorporated into such models, yet additional spectral information is under-used. Regarding other spectral information, it is clear that indices such as the PRI (Photochemical Reflectance Index), or water band indices, correlate with physiological activity and other canopy properties. However, we have still to investigate how to incorporate them into models in a robust and physically sound way across different environmental conditions. We need to link changes in optical and thermal properties of plant canopies and soils to shifts in ecosystem functions, e.g. changes in transpiration or carbon assimilation. At present, I am reviewing some of the assumptions of operative evapotranspiration (ET) models, and trying to improve them by incorporating additional spectral or thermal information. To do so I use "real" data to evaluate models at the field level with eddy covariance ET from sites differing in their water and energy limitations (Garcia et al., 2011; submitted). I also work with simulated data using a detailed hydrological model coupled to a two source surface energy balance model (MIKE-SHE) capable of simulating heat fluxes, soil moisture and surface temperature (Ridler et al., submitted). Once I have developed reliable models, I will map surface fluxes in West Africa to determine how they might change as a result of land use changes or drought.

But how did I start working with remote sensing? It was at the University of California, Davis, during my M.Sci. (2000) and later during my PhD at the Technique University of Madrid (2003) under the supervision of Prof. Susan Ustin. I tried to understand the role of rainfall and ENSO (El Niño Southern Oscillation) in driving primary productivity in Mediterranean ecosystems. I evaluated the spatial and temporal patterns of photosynthetic and non-photosythetic vegetation fractions using hyperspectral AVIRIS images. I found that significant temporal and

Highlight Young Scientist

Monica Garcia

spatial changes in vegetation fractions associated with ENSO events in central California would be overlooked unless sufficient spectral and spatial resolution were used to monitor them as revealed from change detection, semivariogram analyses and comparison with results from broadband sensors (García et al., 2001; 2003). At a broader regional scale I evaluated how different plant functional types cope with increased rainfall variability in a global change scenario. To do so, I selected a 5-year period within the 30-year NDVI-AVHRR time-series resembling GCM rainfall projections for the region. I found that all the plant functional types I evaluated were capable of buffering the effect of rainfall anomalies within the first year but effects of rainfall anomalies on vegetation greenness were more persistent in the case of chaparral and evergreen forests (8 months). Lagged NDVI-rainfall correlations provided forecasting tools for pasture production based on ENSO SST (Sea Surface Temperature) indices as El Niño events were associated with higher than normal winter precipitation while opposite but more predictable effects were found for La Niña events. (Garcia et al., 2010)



It was only after my PhD that I started doing research related to the surface energy balance and evapotranspiration in Spain. I was a postdoc at the Spanish National Research Council (CSIC) Institute Experimental Station for Arid lands (EEZA) in Almeria. I refer to this region *familiarly* as the “Far East” as several Spaghetti westerns such as the Good, the Bad and the Ugly were filmed here. One can imagine the challenge of estimating evapotranspiration in a place where rainfall can be as low as 200 mm, and falls mostly during the cold season. The bad news is that the daily evapotranspiration values are about the same order of typical errors of models using remote sensing information during several dates (~0.8 mm day^{-1}) . The good news is that if a model is able to perform well under these extreme conditions, it is highly probable that it would also do so in humid sites. As the only remote sensing person in the team during that time, I learned very actively from micrometeorologists (Garcia et al., 2007; 2008a; Villagarcía et al., 2007; 2011).

I also used this dryland region as a prototype to evaluate the effect of disturbance related to desertification (land degradation in drylands). There is a pressing need for operational, objective desertification indicators for large regions. Currently, most of the global indicators derived from remote sensing, such as the Rainfall Use Efficiency (RUE), rely on Net Primary Productivity (NPP) estimates (Garcia et al., 2008). However, NPP in desertification studies has generally been estimated from NDVI, and has been based on a light use efficiency approach that fails to account for changes in light use efficiency (Prince et al., 2007). In addition, using NDVI in drylands is problematic as the mosaics of vegetation, dry matter and bright soils cause nonlinear effects in pixel reflectance that can mask vegetation signals (Asner et al., 2003). We focused on developing a new type of land degradation indicator that corresponds with changes in the surface water deficit. As it has been stated that degraded ecosystems are less efficient in resource use, we tested the hypothesis that disturbed sites in drylands would dissipate less energy as latent heat (evapotranspiration). And, we did find lower evaporative fractions on a set of disturbed sites (fire, land use changes, topsoil losses)

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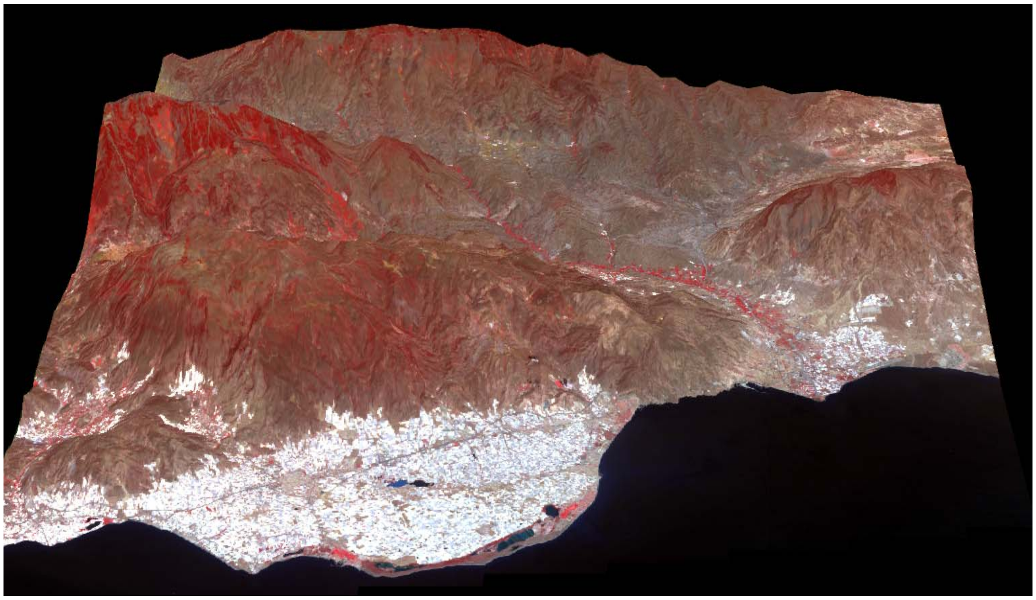

Picture3: 3D false color composite of ASTER 18-07-2004 over Almeria region (Spain)

with respect to control sites. Then, we proposed a new indicator of land degradation risk: the *Non-Evaporative Fraction Standardized (NEFS)*. *NEFS* can be used across different climatic regions, and has a value range between 0-1. For instance, *NEFS* of 0.4 at sites with topsoil losses indicates that 40% less water is being used with respect to a hypothetical non-degraded situation (García et al., 2008b).

We also identified a feedback effect to the atmosphere from the largest greenhouse area in the world (26,000 ha) (picture 3) due to increases in surface albedo. Using MODIS data, we found that annual radiative forcing (RF) due to the expansion of greenhouse horticulture is twelve times stronger, and contrary in sign to CO_2 radiative forcing. This may have masked local warming signals due to greenhouse gases and may in part explain a significant decadal trend in local surface air temperature of −0.3°C (Campra et al., 2008, Nature Geoscience News).

At the CSIC I also had the opportunity to work at Estacion Biologica de Doñana (EBD) in the Dept. of Conservation Biology in one of the most emblematic Spanish Natural parks. I evaluated how modeled evapotranspiration fluxes of ecosystems with different water-use strategies were affected by drought. During 2004, annual rainfall was 75% lower than the previous year, which was reflected in almost proportional reductions on ET from marshes and xerophytic shrublands. By contrast, an almost negligible effect was found on pines and dense shrublands as they accessed groundwater sources, resulting in annual ET values that were three times higher than annual rainfall that year (Garcia et al., 2009). In order to expand the results to 2000-2009 a monitoring system was proposed. As an indicator of ecosystem resilience, duration of effects after a rainfall disturbance, the period (lagged time) during which precipitation anomalies and ET anomalies are significantly correlated was used. The maximum value of the lagged correlation (Pearson coefficient) was interpreted as an indicator of ecosystem resistance (intensity of effects) (Garcia et al. 2010). In 2010 we started to instrument the shrublands site with sap flow, soil moisture and radiation sensors. Unfortunately, eddy covariance data is still in the process of being set up, and hopefully model validation will come soon.

Only recently have I started exploring the interrelationship between carbon and water fluxes, as much can be gained from modeling them in a coupled approach (Houborg et al., 2009). As a start, we compared information from field spectroradiometer and thermal sensors with physiological variables (Licor-6400) in a tussock grassland. We found that the PRI and thermal stress indices correlated best with leaf conductance and transpiration. For net CO_2 flux (Fc) and Light Use Efficiency (LUE) thermal indices provided again some of the best correlations. But in this case chlorophyll, carotenoids and canopy water content indices provided better correlations than the PRI (Domingo et al., 2011).

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These results emphasize the importance of using different spectral regions and thermal information to characterize vegetation functioning (Domingo et al., 2011). It remains to be seen what insights will be revealed through the addition of ecosystem-scale measurements using the eddy covariance method and airborne or satellite imagery, and through the inclusion of other research sites. This is why it is so exciting to be involved in an initiative such as Specnet.

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TRY – a global database of plant traits – meets FLUXNET

Jens Kattge, Markus Reichstein, Michael Bahn, Sandra Díaz, Sandra Lavorel, Gerhard Bönisch, Colin Prentice, Paul Leadley, Christian Wirth and the TRY network

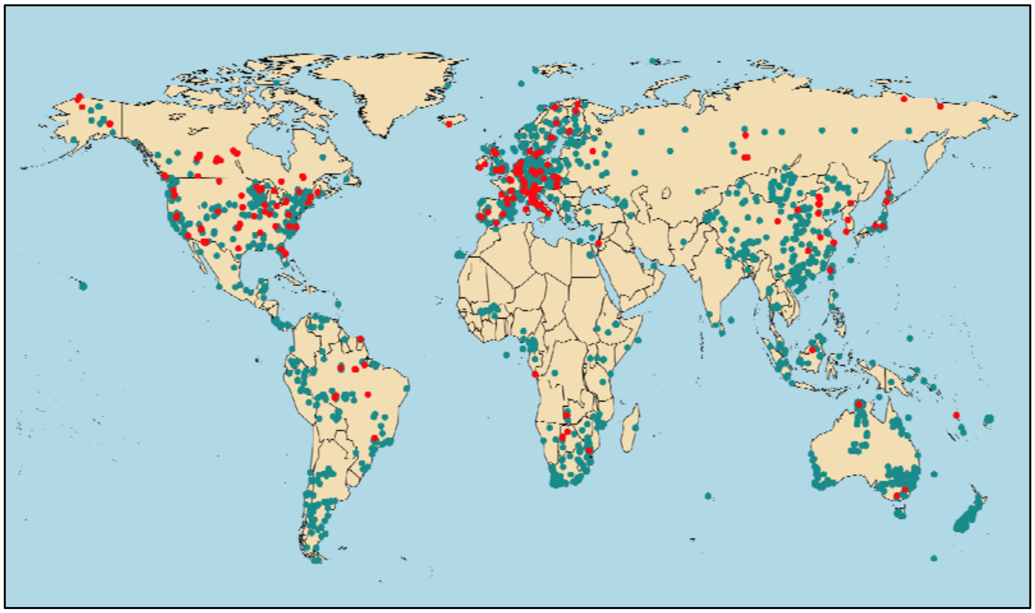
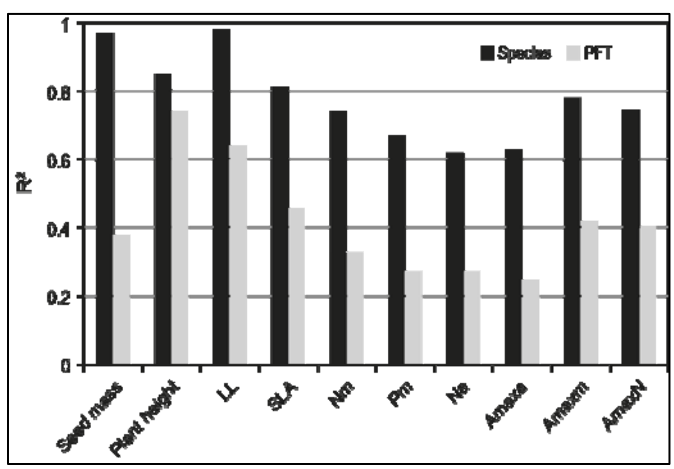


Figure 1: Locations of the measurement sites in TRY (green) and in FLUXNET (red).

The exchanges of carbon dioxide, water vapour and energy measured by the eddy covariance method are emergent properties of the ecosystem that, driven by climate, arise from the interplay of soil and vegetation (and in some cases also macro-fauna). The characteristics of plants, called plant traits, should therefore be an obvious set of data to complement eddy covariance measurements. Plant traits are the morphological, anatomical, biochemical, physiological and phenological features that are measurable at the individual leaf level, like specific leaf area, leaf nitrogen content, leaf photosynthesis and respiration rates and, stomatal conductance, but also include whole plant characteristics, such as plant height, rooting depth and root architecture and more general characterizations such as plant growth form type and nitrogen fixation capacity (Violle et al., 2007). They reflect the outcome of evolutionary and community assembly processes in response to abiotic and biotic environmental constraints (Valladares et al., 2007), and they determine how primary producers respond to environmental factors. Plant traits should therefore, in combination with soil, climate and other site-level data, help us to better understand ecosystem functional properties, like GPP, ecosystem respiration or fluxes of latent and sensible energy.

We here want to advertise a new global initia-

Figure 2: Trait variance explained by species or by plant functional type (as commonly used in global vegetation models). R^2: fraction of variation explained by species or by PFT, respectively. LL: leaf longevity, SLA: specific leaf area, Nm: leaf nitrogen content per leaf dry matter; Pm: leaf phosphorus content per leaf dry matter, Na: leaf nitrogen content per leaf area, Amaxa: maximum photosynthesis rate per leaf area, Amaxm: maximum photosynthesis rate per leaf dry matter content, AmaxN: maximum photosynthesis rate per leaf nitrogen content (from Kattge et al. 2011).



TRY – a global database of plant traits – meets FLUXNET

Jens Kattge, Markus Reichstein, Michael Bahn, Sandra Díaz, Sandra Lavorel, Gerhard Bönisch, Colin Prentice, Paul Leadley, Christian Wirth and the TRY network

tive on plant traits, called TRY (http://www.try-db.org/), which has managed to combine many of the existing efforts - about 110 separate plant trait databases from 98 different institutions - to produce a global database that contains 3 million trait records for about 69 000 plant species of the world's ≈300 000 plant species (Figure 1). The database covers about 1000 different plant traits for all relevant plant functional properties. The TRY initiative is an ongoing project supported by IGBP (the International Geosphere-Biosphere Program) and DIVERSITAS (International Program of Biodiversity Science), with the aim of making plant trait data available for ecological analyses and ecosystem modeling.

A first analysis of the TRY dataset shows that most trait variation is between species (Figure 2; Kattge et al., 2011). However, for some traits, a significant fraction of the variation is observed within species and can account for up to 40% of the overall variation. Plant functional types (PFTs), as commonly used in vegetation models, also capture a substantial fraction of the observed variation for some traits, while for other traits up to 75% of the variation is observed within individual PFTs. Some of the traits most closely related to ecosystem functional properties, like photosynthetic capacity or leaf nitrogen content, seem to fall into the latter group. This highlights the variability of plant characteristics within PFTs and as well between eddy covariance sites of the same PFT and probably even within eddy covariance sites. But note that within a PFT, and between and within sites there may also be considerable variation in species composition, i.e. interspecific variability should play a significant role. Hence, the TRY database – with trait information at species and even individual level together with environmental co-

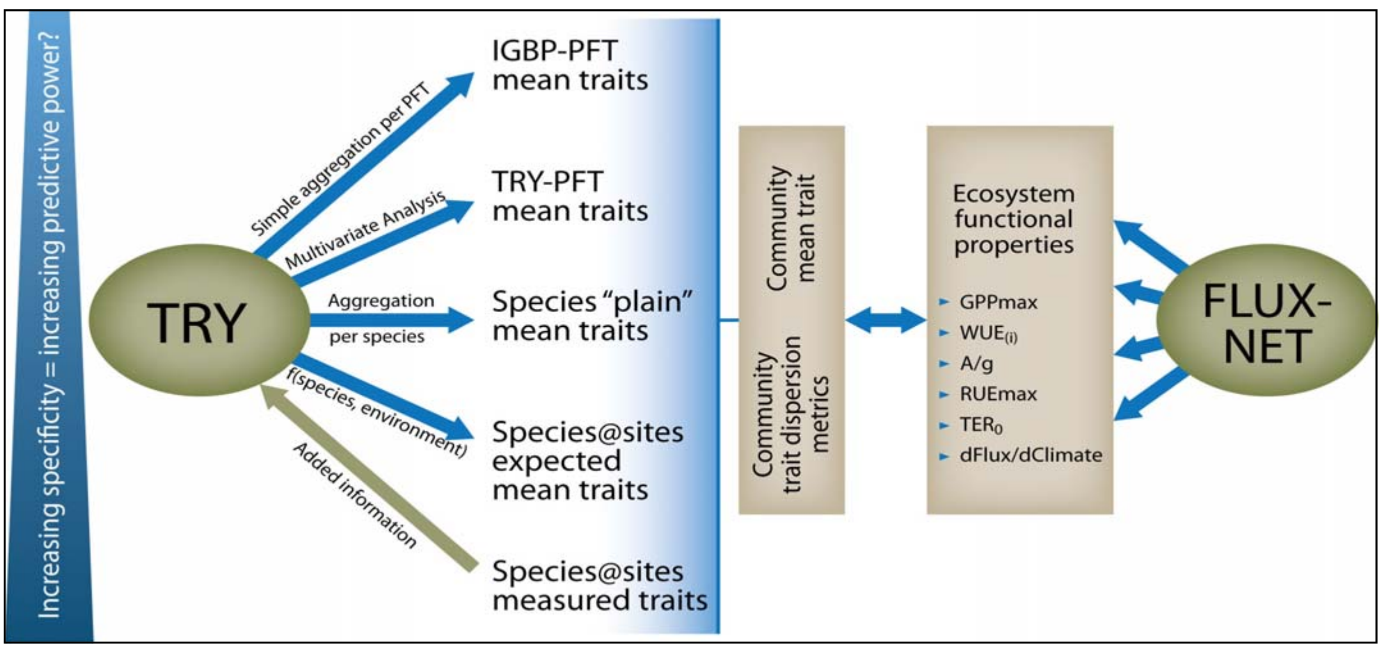


Figure 3: Schematic approach to disentangle the impact of plant traits on ecosystem functional properties by a stepwise adding of specific trait information. Developed at the TRY workshop 2011 (M. Reichstein/M. Bahn).

TRY – a global database of plant traits – meets FLUXNET

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variates – offers great potential for interpretation of ecosystem-level properties derived from FLUXNET observations (Figure 3). In particular, an effect of plant traits and climate on ecosystem fluxes may be disentangled by co-analyzing the TRY and FLUXNET databases. A first joint project of FLUXNET and TRY has recently started to systematically explore the applicability of the global plant trait database in the context of eddy covariance measurements. The project still welcomes additional partners. In case of interest to join the project, or use or contribute plant trait data to the global database, please contact the author.

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TRY Logo.

Versatile investigations to reveal ecosystem- atmosphere interactions at a boreal flux station SMEAR II in Hyytiälä, Finland

Eero Nikinmaa, Liisa Kulmala, Jaana Bäck, Eija Juurola, Pasi Kolari, Janne Korhonen, Mari Pihlatie, Albert Porcar-Castell, Jukka Pumpanen, Janne Rinne and Timo Vesala

Introduction

After about a three hours drive north from Helsinki through a forested landscape that is interrupted by occasional fields and lakes, one suddenly notices a tall mast sticking out of a conifer dominated forest. This is the first sign that we will soon arrive at one of the global hot spots of studies on how terrestrial ecosystems, including lakes and wetlands, interact with the atmosphere. Some kilometres more and one arrives at the University of Helsinki forestry field station called Hyytiälä where the SMEAR II (Station for Measuring Ecosystem Atmosphere Relations) is situated. Hyytiälä has been a focal point of university level forestry education in Finland for more than 100 years, but in the last 20 years, the station has also become a centre for studies of ecosystem- atmosphere interactions. The station offers year-round accommodation for app. 100 people, kitchen services and lectures, office and basic laboratory premises to the visitor. Particular attractions of Hyytiälä are the two lakeside saunas and the famous boreal dinner that many scientists around the world have experienced in the dark boreal winter forest. The SMEAR station is reached after a small hike from the station yard and one arrives in a forest instrumented like a patient in intensive care.

The main idea of SMEAR infrastructures is continuous, comprehensive measurements of fluxes, storage and concentrations of material and energy in the land ecosystem–atmosphere continuum. The aim is to clarify how different ecosystem processes influence and interact with atmospheric processes. Simultaneous measurements of several phenomena in a forest ecosystem and atmosphere at different temporal and spatial scales enables not only the analysis of carbon, nitrogen and water circulation, but also of how ecosystem emitted substances contribute to atmospheric chemistry. Both these sets of processes are important controls of climate change. Due to the complexity of the system, high demands are placed on the instrumentation which works continuously year–round, including through the duration of the northern harsh winter -. An impression of a forest in intensive care is not far-fetched: A number of log cabins are filled with instruments, with pipes and wires spreading like a spider web into the forest. A number of aluminium measuring towers and the 127m tall steel mast give access to the tree canopy and the atmospheric surface layer.

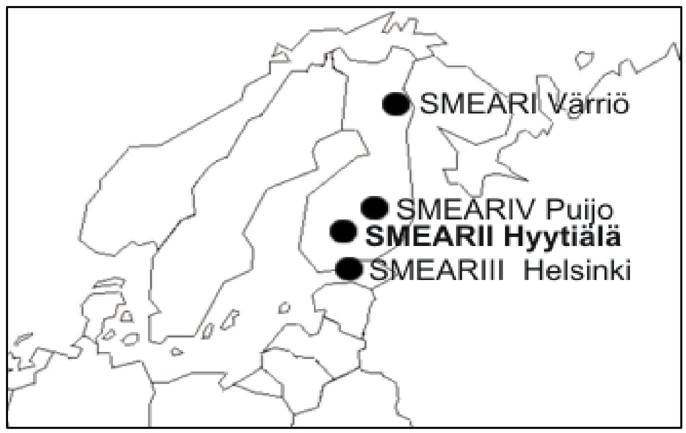

Figure 1: The SMEAR I measuring station was set up in 1991 to measure the pollution fall-out to Eastern Lapland from the mining industry in the Kola-peninsula in Russia. The SMEARII in the Scots pine forest is the most intensively equipped SMEAR-station in Finland. The urban SMEAR III station started in Helsinki in autumn 2004. The Puijo measurement station in Kuopio joined the SMEAR network in 2009.

Site description

At the core of the SMEAR II station (61° 51'N, 24°17'E, 181 m above sea level) is a Scots pine (Pinus sylvestris L.) dominated stand that was established in 1962 by sowing after the area had first been treated with prescribed burning and light soil preparation. Norway spruce (Picea abies Karst.) and some broadleaved trees, mainly birches, as-

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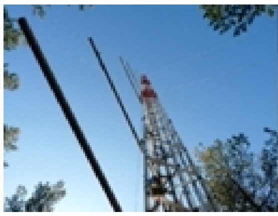

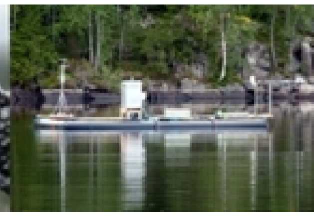

pen and mountain ash have naturally established at the site since then. At close proximity there are also older spruce and younger pine dominated stands making the area as a whole very representative of a typical mosaic of managed forests in South Finland. The forest floor vegetation is dominated by lingonberry, blueberry and mosses. The annual mean temperature is 3°C and precipitation 700 mm (1960–2000). The station represents boreal coniferous forests, which cover 8% of the earth's surface and store about 10% of the total carbon in terrestrial ecosystems.

The main components of SMEAR II are: the 127 m tall instrumented mast (extended from 73 m for ICOS (Integrated Carbon Observation System) GHG-measurements in 2010) with basic meteorological measurements and gas profiles (7 levels), systems for monitoring aerosols and air chemistry, instrumentation

for monitoring tree and soil functioning and radiation, two instrumented mini water catchments, two above-canopy and one sub-canopy eddy covariance (EC) measurement set-ups, EC measurements also for O_3, BVOCS and aerosol number fluxes, automatic chamber measurements for CO_2, H_2O, NO_X, O_3, N_2O, CH_4, BVOC fluxes and additional flux measurements at a nearby wetland, Siikaneva fen and Lake Kuivajärvi.

Multipurpose gas-exchange measurements

The backbone of SMEAR II biosphere-atmosphere exchange studies are the gas exchange measurements done with both eddy-covariance and chamber based methods that have been running for more than 15 years. The particular feature of our site is the continuous automatic chamber measurements. The instrumentation consists of soil, shoot and trunk chambers, tubing systems, gas analysers and a control unit operating the system automatically. The chambers are dynamic, that is, they are open most of the time exposing the chamber interior to ambient conditions. For measuring fluxes, the chambers are closed intermittently for one or a few minutes 70–100 times a day. During a closure, measurements of gas concentrations (CO_2, H_2O, O_3, NO_x, BVOCs), air temperature inside the chambers and

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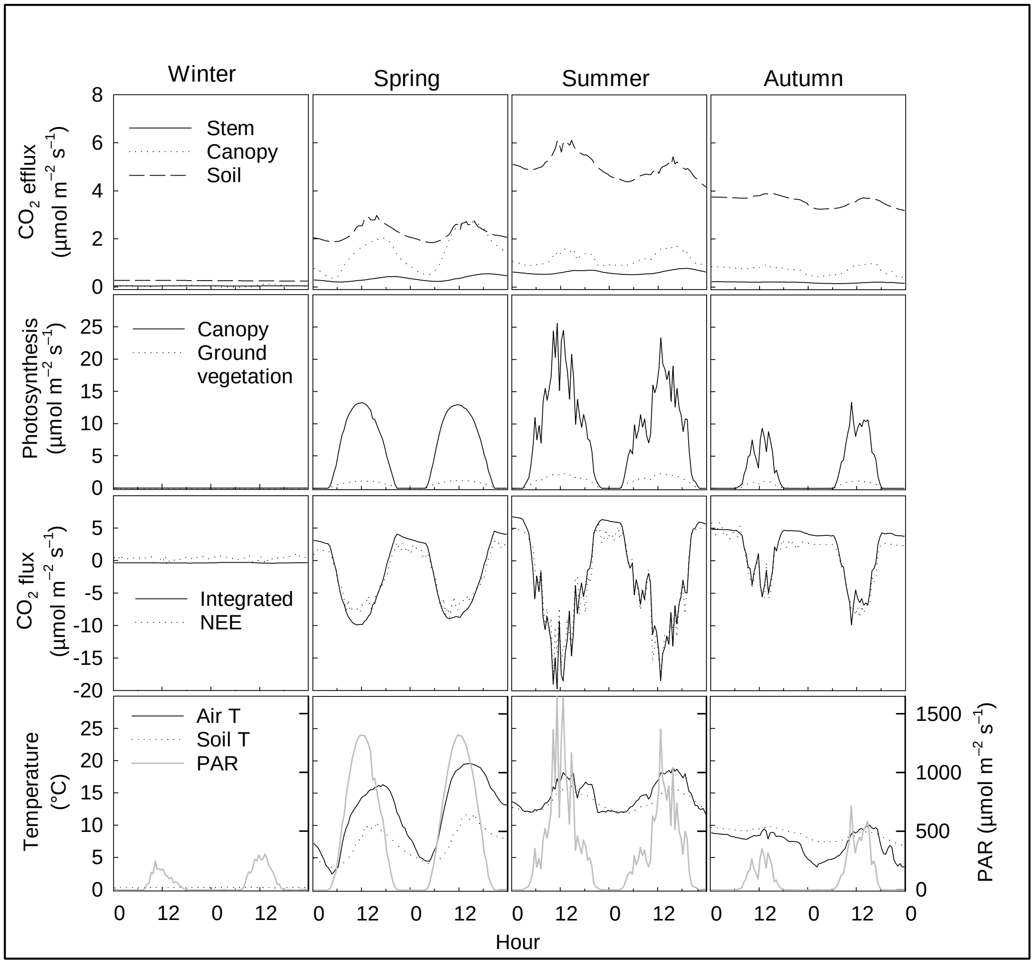

Figure 2: Diurnal patterns of component CO_2 fluxes and integrated component fluxes upscaled from chamber measurements and NEE on selected two-day periods in winter (26–27 February), spring (2–3 May), summer (12–13 July) and autumn (29–30 September) of 2004. Contemporary measurements of soil and air temperatures and PAR are shown in the lowest panels. Negative CO_2 flux values denote uptake of CO_2 by the ecosystem. Redrawn from Hari and Kulmala (2008).

photosynthetically active radiation (PAR) outside the chambers are performed.

Chamber measurements have allowed us to differentiate the ecosystem flux into component fluxes and quantify the driving influence of light, vapour pressure, temperature and soil moisture (see Figure 2). When compared with estimation from the eddy-covariance measurements over the year, the upscaled photosynthesis from chamber measurements can explain 90–95% of the variation in the momentary photosynthetic rate of the forest stand and also accurately predict the annual cumulative photosynthetic production. During the years 1997–2006 the annual net ecosystem exchange measured by the eddy covariance method varied between -140 and -260 g (C) m^{-2} . The forest floor vegetation accounted for 10–15% of the photosynthetic production. About 60–70% of the stand's respiratory fluxes originated from below ground. Annually this means an efflux of 500–600 g (C) m^{-2} out of which about 50% is estimated to come from consumption of recently synthesized carbon in the rhizosphere. In comparison, the annual respiration of Scots pine shoots totals about 250 g (C) m^{-2} and that of woody tissues of trees is about 100 g (C) m^{-2}.

Quite uniquely, we have measured the temporal dynamics of the pine stand BVOC emissions with a dynamic shoot

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chamber system and eddy covariance flux measurements for several years. BVOCs, together with NO_x and O_3 that are also measured with shoot chambers, contribute to the formation of secondary aerosols which is very intensively studied at SMEARII. We find that the fast time-response on-line measurements (PTR-MS) of monoterpene emissions and fluxes and the conventional adsorbent sampling of emissions and atmospheric concentrations agree well, and indicate that Scots pine monoterpene emissions follow ambient temperature at annual scale. However, the analysis has also shown interesting, high emission periods during spring and autumn when the Scots pines are switching between the summer and winter activity stages. We have also found that the growing needles have a large contribution to canopy scale BVOC flux in early summer. Emissions of methanol and acetone from pine needles are also significant during this period. However, the seemingly homogeneous pine stand shows huge variability in the compound spectrum that is emitted from tree to tree. This has a tremendous influence on air chemistry within and above the canopy.

The temporal variability of fluxes of the long-lived greenhouse gases CH_4 and N_2O are also measured at the SMEAR II station by an automatic closed chamber system. These automatic measurements are further linked to the soil CH_4, N_2O and CO_2 concentrations measured in the soil profile underneath the chamber.

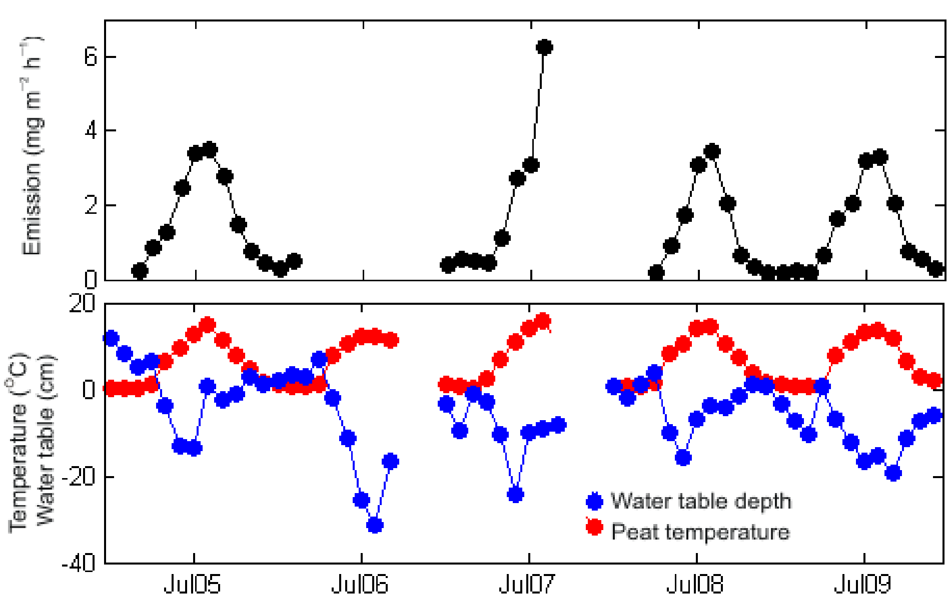

Figure 3: Monthly averages of methane emissions (upper picture), soil temperature and water table depth (lower picture) at Siikaneva wetland during 2005–2009. (Rinne, et al. 2010).

From stand to landscape

Even though terrestrial and aquatic parts of ecosystems are often studied separately, they are closely connected. For studying the functioning of the carbon cycle, it is necessary to understand how carbon enters and leaves the soil. Although, globally it is estimated that the loss of terrestrial organic carbon to rivers is equivalent to 10 % of the net ecosystem production, there are only a few streams and rivers where CO_2 fluxes have actually been analyzed. At SMEAR II, we have started to study how carbon moves through the **terrestrial-aquatic continuum** at the landscape scale by combining the eddy covariance method and direct CO_2

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concentration measurements in Lake Kuivajärvi and stream waters and in the littoral zone. In addition to these measurements, water samples for oxygen gradients and pH are taken, and, water temperature and meteorological variables are measured. The fluxes are monitored also by chambers on a campaign basis.

To complete the picture at the landscape scale, we also study fluxes at the large pristine **wetland,** Siikaneva, close to Hyytiälä (10 minutes drive). One EC set-up has been in use for measuring CO_2, H_2O and CH_4 since 2005 at the fen-type place and another set-up started its operation in the summer in 2011 at a site with bog characteristics, so results for this site are pending. The auxiliary measurements include meteorological variables, peat temperature, water table depth and oxygen concentration. The fluxes are also monitored by chambers on a campaign basis and peat columns have been sampled. The methane emissions show strong seasonal dependence; they are low in the wintertime although not zero. Rinne et al. (2007) found strong dependence of flux size on the peat temperature, which is strongly correlated with water table depth, and can vary several tens of centimetres over short time periods, (Figure 3). CO_2 contributes much more (annually about four times) than methane to the carbon balance and the fen site is annually a carbon sink. The annual carbon sink of the fen is only about 1/5 of that for the nearby Hyytiälä pine forest.

Water and nitrogen flows

The ecosystem- atmosphere interaction and material transport at watershed level cannot be understood without knowing the local water cycle. At SMEAR II we measure the stand water balance. Two adjacent micro-catchments (900 and 300 m^2) enclosed by two dams continuously measure precipitation, throughfall, snow depth, evaporation, transpiration, run off and changes in soil water storage. For transpiration and evaporation, the same measuring setup as for carbon is used but also a number of sap-flow and stem water status measurements are made to highlight the role of trees. These measurements allow continuous and accurate measurement of the drainage flux and quantify the stand water balance. This information is used at watershed level to estimate drainage fluxes to Lake Kuivajärvi down-stream, and for comparison with water flow measurement of main streams flowing into Lake Kuivajärvi.

Along with gaseous components of the nitrogen cycle we have followed other N- input-output processes at the mini watershed scale as well. Our measurements show that currently, the N entering the forest by N deposition or N fixation satisfies a significant part (about a quarter) of the seasonal nitrogen demand of plants, and is cycled tightly within the forest. Only a minor nitrogen fraction is lost from the system in the form of emissions of N_2O from the soil, or through the loss of organic or mineral N with drainage flow. A large part of the N deposited from the atmosphere is in the organic form (DON), a group of compounds that are often neglected in the N deposition measurements.

Optical measurements

The interpretation of the optical data and its use in

Siikaneva Wetland Site

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up-scaling is a topic of intensive research at our site. At SMEAR-II, leaf-level chlorophyll fluorescence has been measured at a high temporal resolution since 2007, and this measurement characterises the annual dynamics of leaf acclimation to the light reactions of photosynthesis. Simultaneously, PRI, NDVI and passive fluorescence have been monitored at the tower level through our network of collaborators (C. Nichol. University of Edinburgh, and L. Eklundh, Lund University). The development by the trees from wintertime dormancy to summer activity has proven to be a particularly interesting period. It marks a time when we observe very strong changes in the optical properties of the evergreens that correspond with strong changes in their photosynthetic capacity. Furthermore, during this period of rapid phenological development, we also register peaks in the Scots pine VOC emissions and consequently, the annual peak of aerosol forming events in early spring.

Final remarks

Climate change is one of the biggest challenges of our time, but the role of ecosystem- atmosphere feedbacks in modifying climate change impacts is still incompletely understood. The SMEARII station has shown that significant new understanding can be gained with simultaneous measurements of a wide range of atmospheric and ecosystem processes. One reason for this is that plant behaviour is simultaneously influenced by various atmospheric, meteorological and soil drivers and following only e.g. carbon cycle would give an incomplete picture of the interaction. The research conducted in SMEARII is a result of a very close co-operation between physicists and forest ecologists. Over the years, the measurements at SMEAR II station have contributed to over 20 Nature and Science papers. Another important part in advancing our understanding is to make the data available to the international scientific community through open data policies and short delays on data release. SMEAR II station only tells the story of one particular site. However, when the data is combined with similar stations in different parts of the world, insights at the global scale start to emerge. SMEAR II has been an active partner in Fluxnet since its beginning. Through various network projects such as ICOS and IMECC our data becomes available in near-real-time to data users. Finally, it is needless to say that provision of continuous good quality data from different instruments places a high demand on the technical design and maintenance of the instruments. At SMEAR II, we have been blessed with skillful and committed technical staff who actively develop the measuring setup and guarante its functioning. The importance of their contribution should not be forgotten when the new findings from the measurement network emerge.

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