FLUXNET A Global Network

FluxLetter

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Highlight FLUXNET sites
SE Asian Tropical Forest Network

Highlighting Sites in tropical southeast Asia
by Takashi Hirano and Ryuichi Hirata

In Southeast (SE) Asia, tropical forests occupy a terrestrial area of about 2 million km^2, which accounts for 10% of the total tropical forest area in the world. The monsoon governs the climate of SE Asia and makes large geographical differences in precipitation, such as seasonal variation and the annual sum. According to precipitation regimes, two types of forests are distributed in SE Asia: tropical seasonal forest and tropical rainforest. The former dominates in the Indochina Peninsula, including Thailand and Cambodia, where a strong dry season exists causing defoliation in the dry season. The tropical rain forest is mainly distributed in Malaysia and Indonesia, where seasonal variations in precipitation are relatively small. In lowlands of Sumatra, Borneo and the Malay Peninsula, swamp forests extensively coexist with tropical peat. However, the tropical forests have been rapidly deforested at a rate of more than 1% yr^{-1} in SE Asia (FAO FRA 2005-global tables, http://fao.org/forestry/32033/en/) for logging and land-use change into farmland. In addition, El Niño events change precipitation regimes and bring drought especially to the southern part of SE Asia at intervals of several years, and consequently enlarge field fires, which are usually ignited at first for farmland management. As a result, a huge amount of smoke is emitted from large-scale biomass burning and shades the ground as haze. Sumatra and Borneo become hot islands in El Niño years, because flammable peat is widely distributed there.

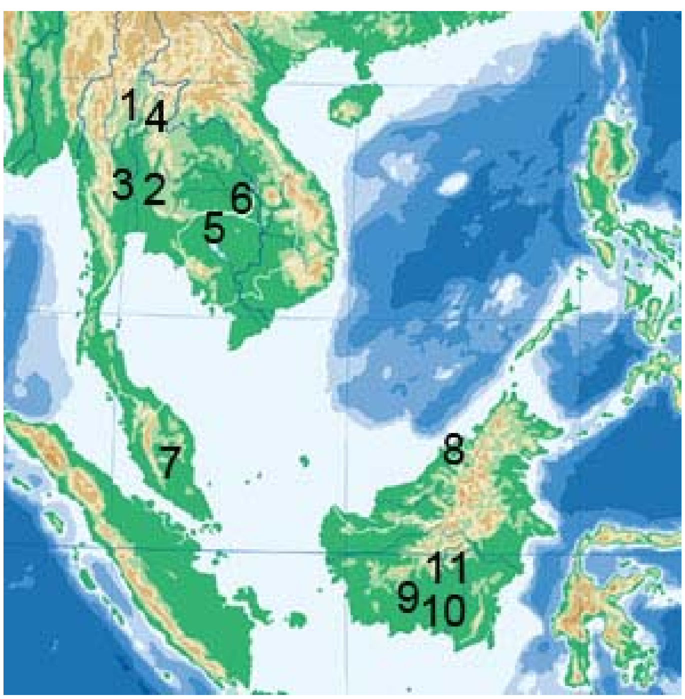

Figure 1: Map of sites (1. KWM, 2. SKR, 3. MKL, 4. MMP, 5. Kampong Chhnang, 6. Kampong Thom, 7. PSO, 8. Lambir, 9. Undrained swamp forest in Palangkaraya, 10. PDF, 11. drained cutover in Palangkaraya)

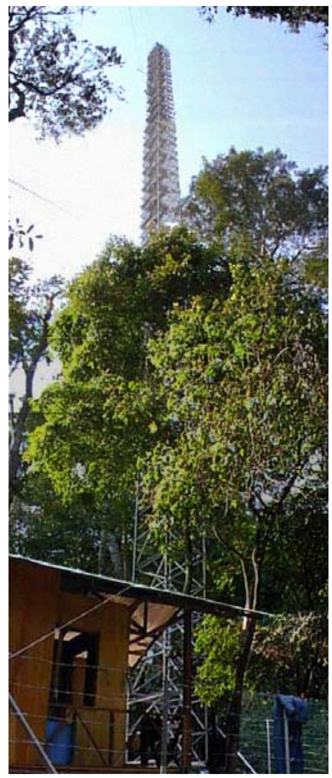

Figure 2: The tower in KWM.

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Figure 3: The tower in SKR.

Figure 4: The tower in MKL.

Haze diffuses leeward to the Malay Peninsula with the trade winds and can cover a wide area of SE Asia.

Canopy-scale gas exchanges of SE Asian tropical forests have been studied since International Biological Program (IBP) in the 1970s mainly by Japanese researchers. However, the geographical distribution of the gas exchanges and their controls are not yet well described, because the studies were so far site-specific. Also, the effects of disturbances, such as El Niño drought and haze, on CO_2 balances and evapotranspiration are still under investigation. In order to advance such studies, we established a tower network of flux measurement in SE Asia under the support of Grant-in-Aid for Scientific Research (No. 21255001) from JSPS. The network consists of 11 flux towers of JapanFlux, which were built in tropical forests by Japanese researchers (Figure 1). Four tower sites are located in tropical seasonal forests in Thailand, including two evergreen forests: Kog-Ma (KMW, 18°48´N, 98°54´E, Figure 2) and Sakaerat (SKR, 14°30´N, 101°55´E, Figure 3), a deciduous forest: Mae Klong (MKL, 14°35´N, 98°51´E, Figure 4), and a teak plantation: Mae Moh (MMP, 18°25´N, 99°43´E, Figure 5), which is deciduous. Two towers were recently built in tropical seasonal forests in Cambodia, which are a deciduous forest (Kampong Chhnang) (11°59´N, 104°44´E) and an evergreen forest (Kampong Thom) (12°44´N, 105°28´E). There are two towers in Malaysian rainforests; one is Pasoh (PSO, 2°58´N, 102°18´E, Figure 6) in the Malay Peninsula and another is Lambir (4°12´N, 114°02´E, Figure 7) in northern Borneo. Three sites join the network from Indonesian swamp forests. All the sites are located in tropical peatlands in Palangkaraya, Central Kalimantan (southern Borneo) within 15 km, whereas their disturbance levels are different. They are an undrained swamp forest (02°19´S, 113°54´E, Figure 8), a drained swamp forest (PDF, 02°21´S, 114°02´E) and a drained cutover (02°20´S, 114°02´E). An abbreviation with three letters in each parenthesis is a site code registered into AsiaFlux. More information is available for such sites through the AsiaFlux web site (http://asiaflux.yonsei.kr/sf_southeast.html). Annual mean air temperature and annual precipitation range from 20

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Figure 5: The tower in MMP.

Figure 6: The tower in PSO.

Figure 7: The tower in Lambir.

to 27°C and from 1400 to 2800 mm yr^{-1}, respectively, within the sites, thus the sites can cover typical climate divisions in SE Asia.

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Figure 8: The tower in an undrained swamp forest in Palangkaraya.

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Opinion

Flux towers in the Amazon forests

Bart Kruijt

'Tropical rain forests are climax ecosystems, in equilibrium with their environment and thus they cannot be a source or a sink of CO_2'. This was the dominant view on the role of rain forests in the global carbon balance and its 'missing sink', until the mid-nineties. Then John Grace, Antonio Miranda, Carlos Nobre, Antonio Nobre and John Gash, and their teams from the UK and Brazil started to measure CO_2 fluxes with tall flux towers in the Amazon, within the ABRACOS project (abraços is Brazilian for 'hugs'). First in the Southwestern Amazon state of Rondonia, later in central Amazonia north of Manaus. Getting to these towers was not a simple trip: whole-day canoe trips and slippery unpaved road journeys made maintenance quite an adventure. We needed to keep laptops and pumps going in the middle of wet and hot forests, and carry in batteries for power all the time. To the surprise of many, these measurements appeared to show substantial carbon uptake, questioning the climax hypothesis! Looking back at work by early pioneers, Steve Wofsy and David Fitzjarrald (the ABLE project, but here we have only a few hours to days of data!), this uptake even seemed to be rising over time. Because the maintenance of these remote towers was very demanding only a few months of data could be collected at these sites, so the conclusion that Amazonian forests were a net carbon sink was, though new and exciting, pretty premature.

After these first results it lasted a few years before finally long term measurements were started. Within the scope of the Large-Scale Biosphere-Atmosphere Experiment in Amazonia (LBA), a large cooperation between Brazilian, South - American, North-American and European scientists, six tower sites were planned and installed between 1999 and 2001, in seasonal, non-seasonal, central and eastern forest as well as in a savanna ('Cerrrado') region. Apart from that measurements were also started in two (deforested) pastures. Over years, and across various supporting projects, most of these towers have survived until now and data sets are now around ten years long! Meanwhile, more towers have joined the Amazon network. There are towers in transitional forest (Mato Grosso state), in seasonally inundated savanna (Ilha do Bananal, Tocantins), and even in the more remote and extremely wet north-western Amazon (Sao Gabriel da Cachoeira).

So, what are they telling us? All in all, the final word on Amazon forest carbon uptake has not fallen yet. First of all, most flux towers have shown a sustained carbon uptake. This uptake is still controversial, however, because calm nights are dominant and traditional u*-based corrections lead to large corrections. Depending on where the threshold for acceptable u* values lies, most apparent sinks turn into a zero balance or even source of carbon. This realization triggered several research projects that looked into the night-time carbon budget in more detail. For example, Jon Lloyd, during the CLAIRE-II atmospheric sampling project, made vertical airplane CBL profiles above the forests north of Manaus, and concluded that the boundary-layer budgets imply that there is no net sink or source of carbon. Studies with Radon profiles in the area south of Santarem (Tapajos national forest) showed that at least in

Figure 1: Amazon plateau-valley landscape shrouded in mist.

Flux towers in the Amazon forests

that area, there are indeed large night-time drainage losses of CO_2, confirming the u* correction. In the area north of Manaus, however the tower is situated in moderately complex terrain, on top of a plateau incised by valleys of around 40 m deep. The tower fluxes are suggesting that strong underestimations of fluxes during most nights are partly compensated by flushes of CO_2 during the morning hours. By measuring the CO_2 concentrations along the slope from plateaus to valley bottoms, Alessandro Araújo indeed showed that that CO_2 drains downhill and pools in valleys during nights, but we also show that these stores of CO_2 contribute significantly to the fluxes measured on the tower during the morning. Julio Tota performed a series of detailed in-canopy advection measurements. These suggest that what we consider drainage flow or uphill flow, in fact is part of a complex along-valley flow pattern transporting the CO_2 across the landscape, sometimes uphill, sometimes downhill. This does not make things easier: we need to find a way to correct for only part of the drainage! To assess the carbon budgets, we cannot do without also considering results of biometric plot studies, as for example are being assembled in the RAINFOR network, initiated by Yadvinder Malhi, Oliver Phillips and colleagues. All information taken together, we might reach a consensus estimate for average NEE of Amazon forests around 1 (+/- 1) tonne per hectare per year.

Apart from the 'grand' question about the Amazon carbon budget, the accumulating eddy correlation data are of course providing a wealth of other information. One important aspect, on which we have focused for the past few years, is whether we can use these data to assess the effects of climatic drought. There are a few active experiments in the Amazon, employing rainfall exclusion (run by Daniel Nepstad and colleagues and by The University of Para and Patrick Meir of Edinburgh University) but the multi-year flux data could also give us some clues, through the analysis of dry seasons and dry years. Now the somewhat surprising conclusion of this analysis was that some of the forests appear more productive (in NEE) in the dry seasons, even in the very dry year 2005, than in the wet seasons, peaking towards the end of the dry season. This especially applied to the Central-Eastern forests of Tapajos and to a lesser extent also to the forests north of Manaus, as was shown by Scott Saleska and colleagues. Many vegetation models have difficulty in representing this. The more strongly seasonal forests in SW Amazonia are, on the contrary, clearly more productive in the wet season, and the RAINFOR plot data did show net carbon losses during the dry year 2005. The hunt is now on to elucidate the reasons for the apparent 'reverse seasonality'. Cleary, soil water availability is less important than previously assumed. Most likely this is because rooting is deep. But that is not enough to explain the seasonal dynamics, as productivity does not simply peak with peaking radiation instead. Currently the various researchers are looking into the prediction of leaf area phenology as a clue.

Figure 2: Tower photo of K34 with Antonio Nobre on top

Where is the Amazon tower network going in the future? The existing towers are still kept going actively by the Brazilian research institutes INPA (Antonio Manzi), INPE (Celso von Randow), MPEG (Leonardo Sá), USP (Humberto Rocha) and others. At the same time, the network is being expanded, mainly with Brazilian national and private funding, to better cover the enormous variability in forest types and eco-climatic zones. Priorities for this are southern Amazonas state, with distinct clay soils, the western Amazon (Peru, UK-AMAZONICA project) and secondary forests. With recently even the inclusion of methane flux measurements, and possibly in the near future a really tall tower (300 m) we are now looking at a mature, still very vibrant network of greenhouse-gas flux research sites, worth to work with and to invest in!

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Data Resources

MODIS Data Complements Flux Tower Information

by Robert Cook, Suresh K. Santhana Vannan, and Tammy Beaty

The MODIS (Moderate Resolution Imaging Spectroradiometer) sensor aboard NASA's Terra and Aqua satellites provides information about Earth's ecosystem characteristics and dynamics on a near-daily basis for a resolution of 250 to 1000 m. The MODIS sensor acquires data in 36 spectral bands which are used to produce standardized products including phenology, land cover, primary production, vegetation characteristics (leaf area index and vegetation indices), reflectance, and albedo. The MODIS products provide information about ecosystem dynamics at a space and time scale appropriate for the flux tower community. MODIS data can be used to scale point measurements to areas comparable to a tower's footprint and they can be used to drive models to understand dynamics of carbon, water, and energy.

However, the MODIS products require specialized software and considerable time to process. These products are distributed as data files covering a 1200 km square area of the earth in a data format intended for regional analysis and modeling. These large data files are not optimal for use in field investigations at individual sites (100- x 100-km or smaller).

In order to provide MODIS data for field investigations, the Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center (DAAC) has developed a tool that prepares and distributes subsets of selected MODIS Land Products in a scale and format useful for field researchers. The subsets are offered in both tabular ASCII format and in GIS compatible GeoTIFF formats. Time series plots and grid visualizations, along with quality assurance indicators are also provided. An example of this is shown in Figures 1 and 2 for the Collelongo-Selva Piana, Itlay flux tower site. These MODIS subsets are produced

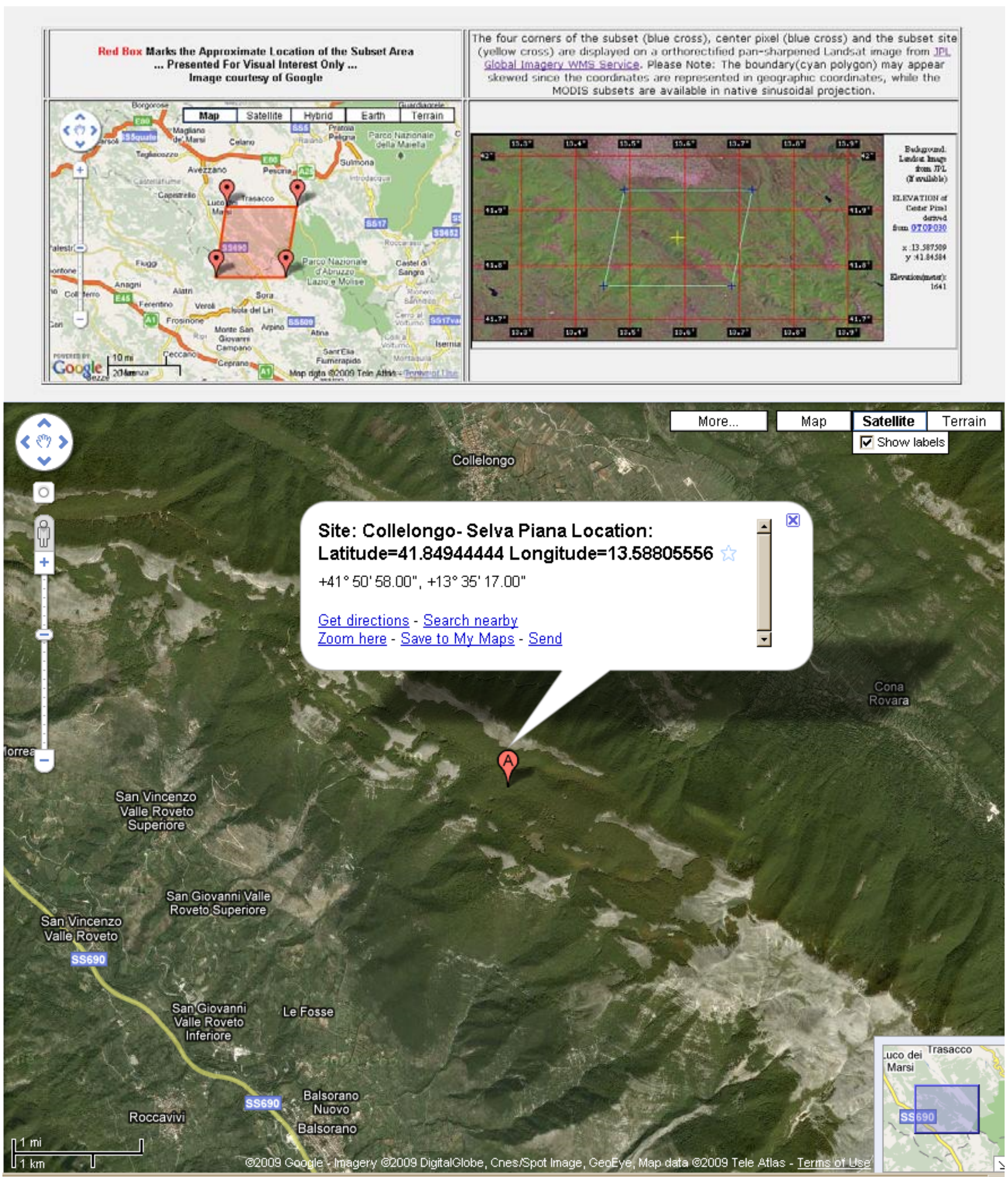

Figure 1: Location information for Collelongo-Selva Piana, Italy flux tower available from the MODIS Subsetting Tool. Top left-hand panel is a Google Map showing the areal extent of the MODIS subset. Top right-hand panel is a LandSat image served from NASA's Jet Propulsion Lab to the ORNL DAAC's Web Site. Bottom panel is a Google Map of the flux tower location.

MODIS Data Complements Flux Tower Information

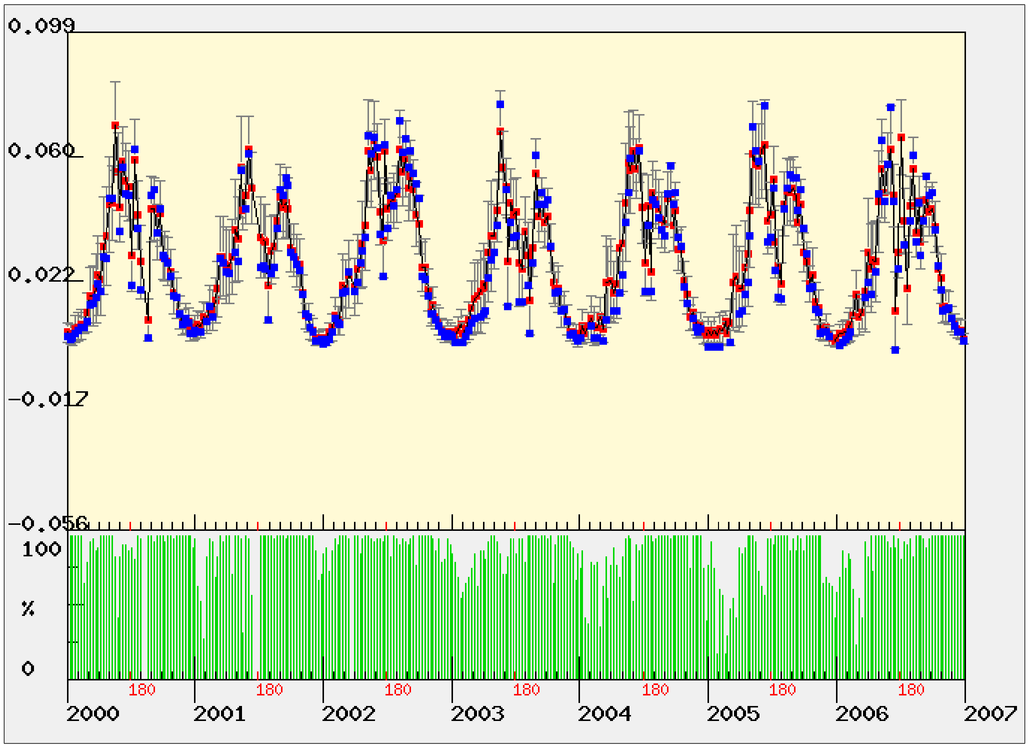

Figure 2: An example MODIS data subset visualization from 2000 to 2006 of Gross Primary Productivity (cumulative 8-day values in kg C m^{-2}) for the Collelongo- Selva Piana, Italy flux tower site.

automatically for more than 1,200 sites around the world, including the FLUXNET tower sites. The locations of FLUXNET research sites were registered with the ORNL DAAC so that these data are now available to researchers from the beginning of MODIS data acquisition in the year 2000 to the present.

In addition to offering subsets for fixed locations, the ORNL DAAC also offers the capability to create user-defined subsets for any location worldwide. The DAAC's MODIS Global subsetting tool provides data subsets from a single pixel up to a 201- x 201-km area for any user-defined time range. Data statistics, time series plots, and GIS compatible data files for the customized subsets are also distributed through this tool. Users place an order for a MODIS data subset with the subsetting tool online and the subset is typically produced within 60 minutes. An email is sent to the user with the necessary information to access the custom data product.

Researchers can also use Web Services to access subsets of these MODIS data products. Web Services facilitate data processing directly on the user's local computer by providing access functions: to retrieve subsets through command line operations; to import subsets directly into software such as Kepler or Matlab; to integrate the data into workflows on their desktop computer; and to write custom code to use the subsets for visualization or data reformatting. For example, researchers are using the MODIS Web Service as part of their data assimilation / data fusion methods to improve predictions from ecosystem dynamics models as well as to improve process representation within the models.

A number of professors are using the MODIS Subsetting tools in graduate and undergraduate courses, to demonstrate use of remote sensing data to understand ecosystem dynamics, phenology, and carbon dioxide fluxes (Beitler, 2009)..

The tool enables students to use the data including quality flags, without having to know image processing. Kirsten de Beurs' Remote Sensing and Phenology class at Virginia Tech compared MODIS vegetation data to observations of phenological events on campus, such as the bloom of dogwood trees, to obtain a broader interpretation of these start-of-season signals (Beitler, in press). Tristan Quaife used the MODIS Web Service as part of the Summer Course in Flux Measurements and Advanced Modeling, (University of Colorado) to examine the relationship between remote sensing and flux tower observations.

More information about the MODIS subsets and tools to access them can be found at the link for "MODIS Subsets" on the NASA ORNL DAAC site at http://daac.ornl.gov/MODIS/

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Editorial

FLUXNET Young Scientists Network

by Rodrigo Vargas, Sebastian Wolf, Matthias Zeeman

Everyone has been a young scientist at one point in their academic carrier. The FLUXNET Young Scientists Network (YSN) was established in 2004 with the objective to connect young scientist within the FLUXNET community and the regional flux networks. The forum was initiated by Alexander Knohl and a group of ex-"young" scientists. Thanks to their commitment many of the former FLUXNET young scientists are now well integrated in the scientific community.

The YSN serves as a platform for young scientists within the FLUXNET community. This network goes beyond "biological age" and is focused rather on "academic age", Thus, FLUXNET young scientists are students (from undergraduate to PhD) and post docs who do not lead their own research groups.

The YSN provides an informal exchange platform for questions regarding research, career and funding opportunities for young scientists. Young scientist can present themselves and meet others in the YSN with interactive discussions and personal websites. Furthermore, established researchers [without being "young" in age or spirit] can search for potential candidates to join their research groups.

The YSN has grown and evolved along with the FLUXNET community as new young scientists incorporate to the network. After the first 5 years of the YSN the accomplishments were assessed and ideas were discussed on how to continue and improve these networking activities. The YSN is now comprised of two main tools: a new mailing list and a new interactive webpage.

To participate in the YSN , a registration for the mailing list

Is needed at https://acs.lbl.gov/mailman/listinfo/young-scientist. Afterwards, the subscriber will receive details to register for access to the interactive website (password protected). This new website consists of forums for questions and ideas, blogs, wiki, calendar of events, and a file repository maintained by an active community of young scientists.

With the establishment of a new interactive and password protected website it seems appropriate to start a new mailing list to keep track of members and updates. Thus, the old FLUXNET young scientist mailing list [fluxnet-young@lists.ornl.gov] will be closed in January 2010 and fully replaced by the new mailing list:

Young-Scientist@fluxdata.org .

We invite all young scientists to join or continue with this networking opportunity. The success of the YSN will depend on the feedback, interaction, participation, and energy of young scientists. The interactive website contains multiple tools for networking, but only with active participation it can be a useful networking and scientific resource.

The YSN is open for new ideas and feedback and we hope they can be expressed in the mailing list and the interactive website. We look forward to see the YSN grow and evolve with the active participation of young and not so young scientists.

Further information on the YSN can be found at:

FLUXNET Website – Program Information – Young Scientists Forum (http://www.fluxnet.ornl.gov/fluxnet/youngscientists.cfm)

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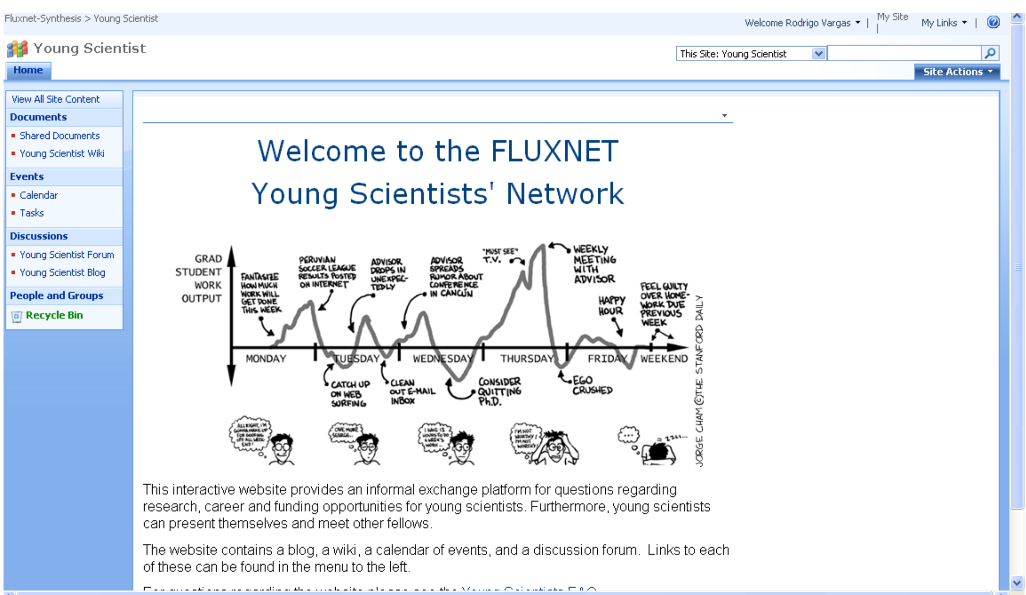

Figure 1: Screen shot of home page of the interactive Young Scientist Forum website

Highlight Young Scientist

Natsuko Yoshifuji

I belong to Kyushu University, Japan, and work on ecohydrology of tropical forests in Southeast Asia with Dr. Tomo'omi Kumagai and many other researchers. Looking back over the past, the first chance that lead me to become an environmental scientist goes back to my first trip abroad when I was 12 years old. I flew over Siberia at that time, and I was surprised to see boundless forest, which I had never seen in Japan as a small island nation. I had already learned at school that there was a big forest called Tiga in Siberia

Figure 1: Natsuko Yoshifuji

By looking at the Tiga I understood that empirical experience is quite different from book learning. I was shocked and excited to realize that there was a vast land filled with the unknowns for me in the world, and I wanted to know more about Nature and the Earth. After that experience I became interest in geography, ecology, and geophysics. Environmental problems such as deforestation and global warming were among the hottest topics on mass media in those days, and that also influenced my interest. Thus, I decided to study environmental science and enrolled at the University of Tokyo. I joined the laboratory of forest hydrology at the University because I thought that I could conduct a study about interaction of biotic and abiotic elements at ecosystem scale. The style of research activities based on the field observations was also attractive for me. I studied in this lab until I was awarded my Ph.D.

While I was pursuing my Master studies, I was given an opportunity to take part in an ecohydrological study at a tropical forest in Southeast Asia. My first work in the project was to measure sap flow at a hill evergreen forest in northern Thailand to understand the seasonal variation in transpiration. Hill evergreen forest is one of the typical types of forests in Thailand distributed on the mountainous area over 1000 m above sea level (Tanaka et al., 2008). The climate of this area is influenced by Asian monsoons, where there is a clear dry season lasting as long as 6 months when the mean monthly rainfall is below 100 mm. At first, we expected that tree transpiration of a hill evergreen forest decreases in the dry season because of the soil drought based on a few previous reports at different types of forest in Thailand. Contrary to our expectation, I found that transpiration peak appeared in the late dry season when atmosphere and surface soil were the driest (Tanaka et al., 2003). Through this experience, I learned that it is a fun to find an unexpected result from my own data.

I also started ecohydrological research at teak plantation in northern Thailand with many other researchers at the end of my Master studies. Teak (*Tectona grandis* Linn. f.) is a deciduous species occurring naturally in Thailand, and these plantations are now prevalent in northern Thailand. The main goal of the research there was also to understand the impact of seasonal and inter-annual variation in precipitation on energy, water, and carbon exchange, but in the beginning there was not a tower for eddy covariance measurements. Therefore, I began with preliminary measurement of sap flow and monitoring leaf phenology to understand the seasonal pattern of transpiration and its relationship to leaf phenology and rainfall. After three years, I found that year-to-year variation in the length of the canopy duration and transpiration period spanned about 40 and 60 days at most, respectively, as a result of the changes in the timings of leaf-out, leaf-fall, and the beginning and the end of transpiration corresponding to the year-to-year changes in the timings of rainfall occurrence (Yoshifuji et al., 2006). Before the start of the measurement, I had thought that it was possible that the length of transpiration period and canopy duration would vary with climate condition, but I was surprised because the extent of the change was large considering that the mean length of canopy duration and transpiration period was about 310 and 260 days, respectively. This surprise gave me new questions. How much is the impact of such a large inter-annual variation in phenology on annual gas exchange? Is the year-to-year variation in phenology large in other deciduous forests in Southeast Asia? It is exciting that one result produces new questions, thus I still continue my research because my questions are not ending.

Research at the hill evergreen forest and the teak plantation is being continued with many re-

Highlight Young Scientist

Figure 2: Natsuko Yoshifuji in Thailand.

searchers and students from Japan and Thailand, and continuous measurement of water and carbon fluxes by eddy covariance method have already been started. Both sites are included in the network of flux measurement in Southeast Asia, which was established to encourage comprehensive understanding of gas exchange in Southeast Asia (see previous article in this issue). I am very lucky that I am given a chance to continue my studies in Thailand and other forest sites in this network. Flux data will enables me to solve the first question above. I am analyzing satellite remote sensing data to answer the second question. I also started a study about the response of transpiration to environmental variation at tropical rain forests in Borneo Island based on sap flow measurement. I hope that I can continue my ecohydrological studies mainly based on the field measurement by myself and make novel analysis using remote sensing data and modeling. I hope new data and expected or unexpected results in the future will keep giving me further questions and passion for science.

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Highlight Young Scientist

Rodrigo da Silva

My name is Rodrigo da Silva, and I will tell you how I made the Amazon Region my place. I was born in Brazil (07-Oct-1971) in a place called Rio Grande do Sul, so I am Gaucho (people from the south). The gauchos are land man, farmers, and cowboys. Thus I grew up living many adventures riding horses, playing soccer, swimming in rivers and lakes, but I always find time to stop and listen to the wind. Everyone thought I will be a biologist or a veterinary or some like that, even a soccer player. But not!... I graduated in Physics, so I am a physicist. I made my studies in the Federal University of Santa Maria (UFSM) where I made my Master degree studying turbulence and the boundary layer. In that time (1998) I started to develop my skills with flux tower instrumentations working in the Micrometeorology Laboratory coordinate by Dr. Osvaldo Moraes. Together we installed a flux tower in the middle of a valley near a hydroelectric to study turbulence over complex terrain. This first experience was amazing because I discovered that my researcher was going to be outdoors to seek information about the climate and the environment. After this first year of learning, we made several intensive campaigns of measurements of nocturnal boundary layer using tethered balloon in different regions of the Rio Grande do Sul, always associated with measurements of flux towers. In January 2001, at the beginning of my doctorate I was invited by David R. Fitzjarrald from S.U.N.Y at Albany, to participate in the Amazon region of the research carried out within the LBA project (Large Scale Biosphere Atmospheric experiment in Amazon). I fell extremely privileged to have the opportunity to study that incredible region and work in that large project. I went to Santarem in January 2001 where I met Dr. Ricardo Sakai who showed me all sites into the jungle and the network of weather stations installed in the region. Near Santarém, the LBA Project have four flux towers, three in the National Forest of Tapajos (FLONA Tapajos) and one in the open farming field. The forest towers have 68 meters tall and they are measuring and monitoring the exchange processes of mass and energy between surface and atmosphere, one in an old growth spot, one in a selective logging and other in a gap. The tower in the pasture site has 20 meters tall. One day at my return from working at the sites, Dr. Sakai took me to a paradisiacal place called Alter do Chão. I still remember my thoughts when I saw that place… "That's the place to live and see the kids grow up". The forest is powerful and the Tapajos River is unforgettable. During this year I went four times to Santarém to work in different projects with the flux towers. However, in this first year of my doctoral studies I wasn't sure what question I will try to answer, because I had so many options and all were challenging. Osvaldo Moraes and David Fitzjarrald, my advisors, decided that I had to go to US for one or two years. That was scary but decisive to define what I would like to do. Both years 2002 and 2003 in Albany, NY were very important to my live. I actually couldn't believe that I was getting paid for having so wonderful experiences. Late in 2003 after participated to HVANS Experiment (Hudson Valley Experiment) I come back to Brazil to work in Santarém to finish my thesis. In my studies, we showed the results from three campaigns on which the nocturnal vertical profiles of carbon dioxide, temperature, water vapor, and winds were measured at two sites at the Amazonian region, one above the forest, the other at a deforested region. The purpose of the observations was twofold: identifying the surface accumulation layer and comparing the fluxes obtained from the boundary layer budget to those determined from the eddy covariance at the nearby micrometeorological towers. More than merely

Figure 1: Rodrigo da Silva

Highlight Young Scientist

providing a means of comparing the fluxes, this study clarifies the physical processes driving the exchange at such environments. This is because vertical gradients are available at a much larger scale than provided by the tower. Furthermore, we used the same technique used by Mahrt and Vickers (2006) and by Acevedo et al. (2007) to decompose the exchange in its temporal scales, allowing the proper identification of the turbulent exchange and how it is interacts with the entire accumulation layer. In July 2005, Dr. Antonio Manzi invited me to coordinate the flux towers in Santarém, working in the LBA Office at Santarém. In August 2006, I got a position in the Federal University of Pará at Santarém where I teach an undergraduate course in environmental physics. In 2008 I and other partner (Dra. Rosa Mourão) made a project to create the first Masters Course in Natural Resource of Amazon in Santarém. This project was approved by the Ministry of Education and the first class started in 2009. In March I was convened by Dr. Antonio Manzi to take care of all LBA Project in Santarém. Today I have so many responsibilities teaching, training, coordinating and make researches in Santarém. I'm very excited about the future here and would like to encourage future collaborations as well as keep strong the established.

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Further Reading

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Figure 2: Rodrigo da Silva and Prince Charles

CO_2 fluxes of tropical ecosystems with different land-use in Panama

Sebastian Wolf, Werner Eugster and Nina Buchmann

Land-use change has significant impacts on the carbon cycling of terrestrial ecosystems. In particular tropical ecosystems are affected by ongoing land-use change, primarily driven by the demand for timber and arable land. Since biophysical and biogeochemical feedbacks influence the global climate, an improved understanding how different land-use types affect carbon cycling in tropical ecosystems is needed. However, continuous measurements of ecosystem scale CO_2 fluxes are still scarce in tropical regions, with only few localities in Central America. Although carbon accounting within the Clean Development Mechanism (Kyoto Protocol) might also be an option for Panama, no information on carbon sinks and sources of Panamanian ecosystems is available up to now. Within our project, we thus aim to quantify the CO_2 and water vapour fluxes of two tropical ecosystems with different land-use in Panama (afforestation and pasture), to assess potential differences in the driving factors of net ecosystem fluxes, and to estimate the carbon sequestration potentials for both land-use types.

Based on collaborations with Catherine Potvin (McGill University) and the Smithsonian Tropical Research Institute (STRI), we have been running two flux towers in Sardinilla, Central Panama (Fig. 1) since February 2007. Sardinilla is located about 40 km north of Panama City, at 9.3° N, 79.6° W at 70 m a.s.l.. The site has a mean temperature of 26.5 °C and receives 2350 mm precipitation annually, with a pronounced dry season from January to April (less than 50 mm rain per month). One tower has been installed in an improved afforestation (i.e., a plantation using native tree species only), and the second one in an adjacent, traditionally grazed pasture (Fig. 2). Like other countries in Central America, Panama experienced considerable land-use change in the last 60 years (Wright & Samaniego 2008). The site, part of the "Sardinilla Project" (www.gl.ipw.agrl.ethz.ch/infrastructure/research_sites/international/panama), was logged in 1952/1953 and used for agriculture for two years, before being converted into pasture (Wilsey et al. 2002). In 2001, parts of the site were turned into an improved afforestation (as a tree diversity experiment; Potvin et al. 2004) while grazing continued on the adjacent pasture.

Instrumentation & Experiences at the site

Our flux measurement systems consist of open path infrared gas analyzers (Licor-7500) and CSAT3 sonic anemometers (Campbell), both hooked up to an industrial PC running a LINUX system (Fig. 3). Additional measurements include soil climate profiles, soil respiration fluxes, leaf area index (LAI), biomass production as well as grazing intensity. After solving some problems in the beginning

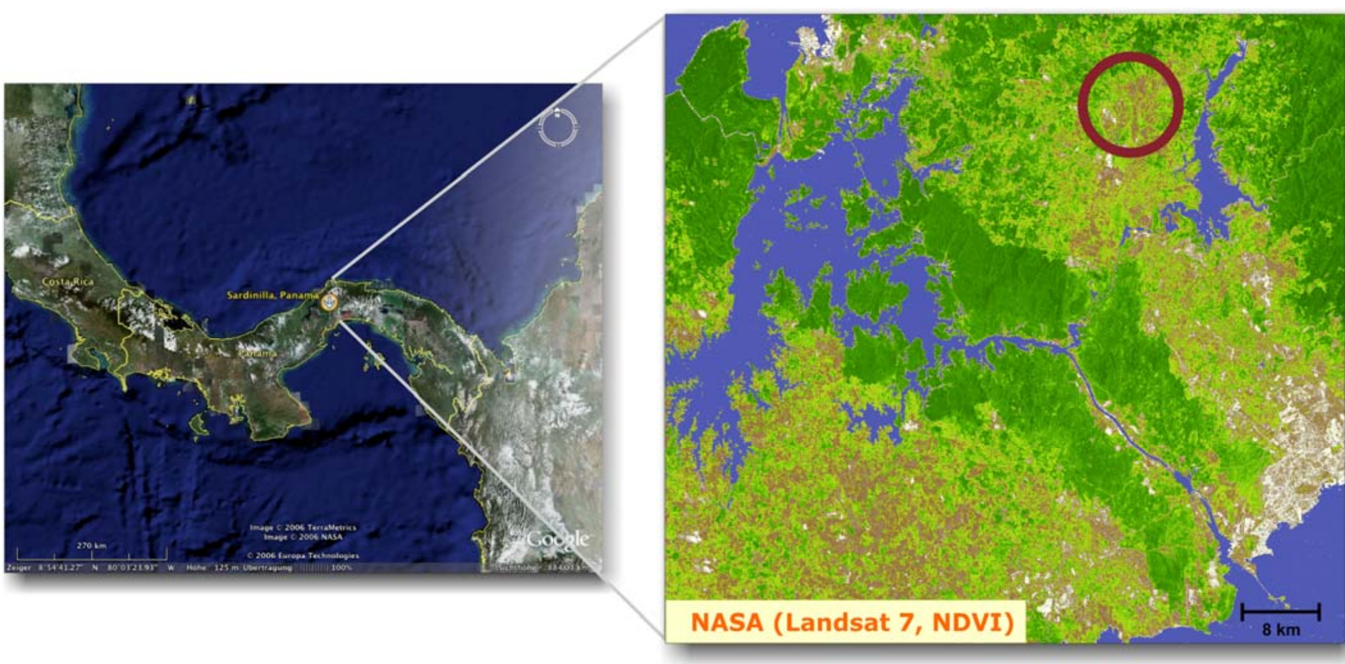

Figure 1: Location of Sardinilla, Panama

CO_2 fluxes of tropical ecosystems in Panama

Figure 2: Seasonal changes in phenology at the two Sardinilla flux tower sites. Dry season pictures were taken in March 2007, wet season pictures in June 2007 (360° panoramas).

due to heavy rainfall during the rainy season, we have been acquiring continuous flux data since June 2007. Particularly with the help of our local technician in Panama, we were able to cope with further challenges we experienced at our site, including insects in and around our installations (e.g., ants and spiders) as well as some security issues (e.g. equipment theft).

First results

Analyzing Net Ecosystem Exchange (NEE) of both ecosystems from June 2007 to March 2009, we observed considerable differences in diurnal and seasonal NEE between both land-use types (Fig. 4). High midday assimilation rates of the pasture ecosystem were likely related to the high productivity of dominating C_4 grasses. However, respiration losses in the pasture exceeded photosynthetic inputs at daily and longer time scales, resulting in a carbon source on an annual time scale. In contrast, the afforestation system was a carbon sink on an annual time scale, although mean midday assimilation was lower than that of the pasture during the rainy season. An interesting period was the prolonged dry season in 2008, when both ecosystems became carbon sources in April and May. The pasture ecosystem seemed to be more susceptible than the afforestation system (due to soil water limitations), as seen in the pasture assimilation flux being reduced gradually to zero during this drought period until the onset of the rainy season (Fig. 5). In addition, carbon loss of the 9 ha pasture seemed also to be related to grazing intensity. During most of the year, grazing intensity was relatively low (8-12 cattle per 9 ha), but increased up to 70 cattle for short periods. Such high stocking rates reduced standing biomass

Figure 3: Fieldwork in Sardinilla. (a) Sebastian Wolf and José Monteza (technician; right). (b) José Monteza cleaning sonic anemometer. (c) Curious visitor on pasture site. (d) Spider webs on sonic anemometer. (e) Sebastian Wolf taking soil respiration measurements. (f) José Monteza working at bottom of afforestation tower.

CO_2 fluxes of tropical ecosystems in Panama

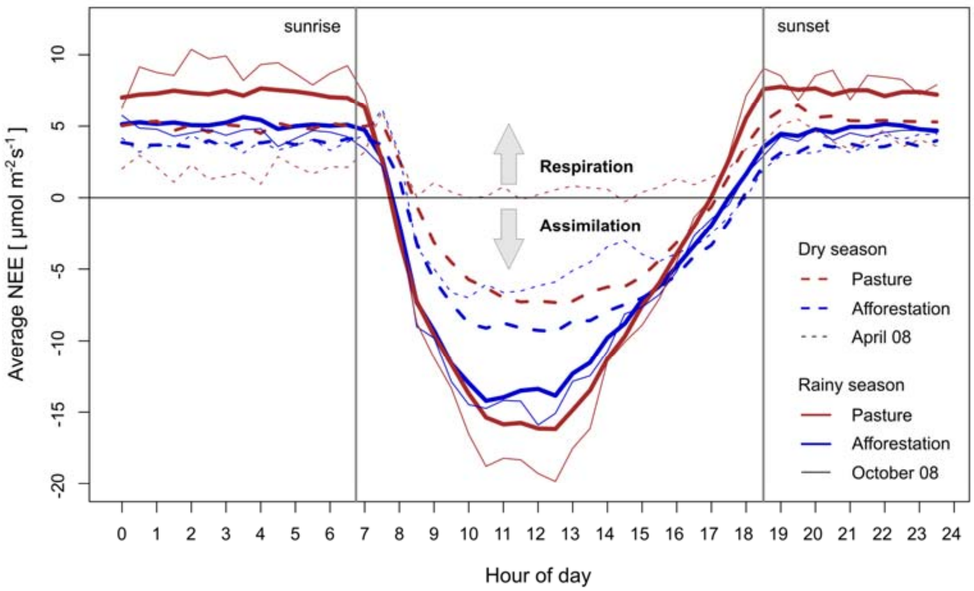

Figure 4: Seasonal mean diurnal NEE from June 2007 to March 2009. April and October 2008 show selected months with low and high ecosystem productivity.

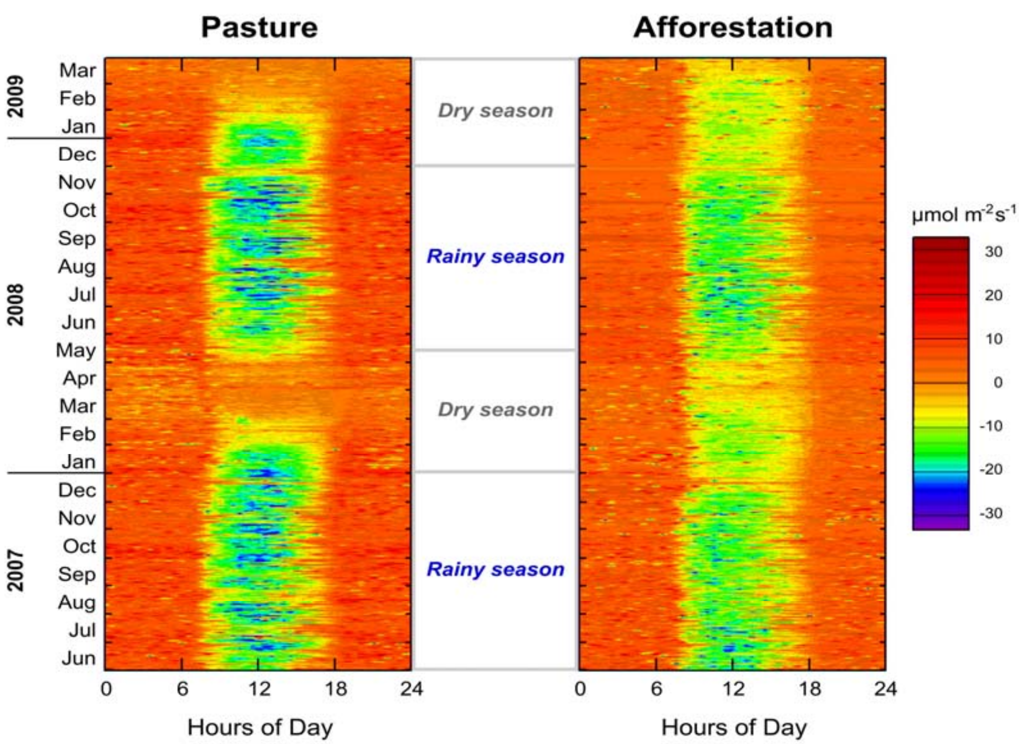

Figure 5: Fingerprints of gap-filled NEE from June 2007 to March 2009

and thus also assimilation fluxes, leading to carbon losses from the pasture system. Consequently, the pasture ecosystem lost about 230g C/m² from June 2007 to March 2009 (2008: 114g C/m²), while the 8-yr-old afforestation system gained about 315g C/m² (2008: 181g C/m²).

In summary, our results indicate a carbon storage potential for the native tree species plantation in Panama, at least during the establishment phase. Besides the seasonally constrained availability of water, grazing intensity seems to play a major role in the pasture ecosystem, leading to unsustained carbon losses.

Outlook

Measurements at the afforestation tower were discontinued in July 2009 while flux measurements over the pasture ecosystem are continued until at least January 2010. With more than two consecutive years of continuous data, we now have a small but unique dataset of two common land-use types in Panama. Because of the sparse flux coverage in Central America, these two datasets might also be of interest for the growing FLUXNET modelling community.

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Between deforestation and climate impact: the Bariri Flux tower site in the primary montane rainforest of Central Sulawesi, Indonesia

Panferov, O., Ibrom, I., Kreilein, H., Oltchev, A., Rauf, A., June, T., Gravenhorst G. and A. Knohl

Tropical rain forests in Indonesia are challenged by land use and climate changes

Tropical forest ecosystems play an important role in the interaction between climate and biosphere. They are vulnerable to external forcing, especially along their boundaries (in transient zones between land use types) and, when affected, may exercise important controls on the global Earth system. Recent reports showed alarming data on net loss in tropical forest areas (FAO, 2000). A particular rapid decrease of tropical forests is observed in South-East Asian countries, where areas covered by forest decreased from 53.9% in 1990 to 48.6% in 2000 (UN, 2005). In many regions including Indonesia such changes are connected with a rapidly growing human population and non-sustainable land-use practices for food and timber production. Weber et al, 2007 estimated the average rate of anthropogenic deforestation on Sulawesi of about 0.6% yr^{-1} for the period of 1971-2001. Additionally to anthropogenic deforestation some losses of forests can be also caused by natural factors, e.g. climate change, extreme weather events including El Niño Southern Oscillation (ENSO) caused droughts. Deforestation of tropical rain forest areas results in changes of energy, H_2O- and CO_2-budgets of the land surface, and as a consequence, in changes of local and regional climate (Lawton et al., 2001). The Lore Lindu National Park (LLNP) in Sulawesi plays an essential role in conservation of endemic flora and fauna. Therefore, deforestation, either natural or anthropogenic, results in serious threats for remaining rainforest ecosystems and in loss of biodiversity.

Indonesia, the so called Maritime Continent, is on the one hand particularly exposed to the irregularities of global circulation patterns (Walker Circulation, Hadley Cell) like ENSO due to its location in Western Equatorial Pacific. On the other hand it is characterized by a highly heterogeneous mixture of mountainous islands and ocean surface which in some parts amplify and in some parts inhibit the impact of global circulation. Our analysis of remote sensing data has shown (Erasmi et al., 2009) that the montane rainforests of Sulawesi are particularly resilient to the drought anomalies caused even by strongest ENSO-warm events (El Niño), but its future sensitivity to the changing frequency and extent of climatic variability is unknown. The current trends in land use change indicate that these mountainous rain forests might soon become the only remaining tropical rain forest relicts in the area. These facts make the forests a unique object for medium- to long-term studies of rainforest ecosystem functioning and responses to climate variability and climate anomalies. Therefore, over the last nine years a large multi- and trans-disciplinary research program Stability of Rainforest Margins (STORMA) funded by the German Science Foundation (DFG) was carried out in Central Sulawesi in order to assess the natural and socio-economic factors leading to deforestation (www.storma.de).

The Bariri Flux Site (BFS)

The investigation area is located on Central Sulawesi, Indonesia (Fig. 1). The study site near the village Bariri (1°39.476'S, 120° 10.409'E) is a part of the LLNP and lies on a small plane that is surrounded by mountain chains surmounting the plane by 300 to

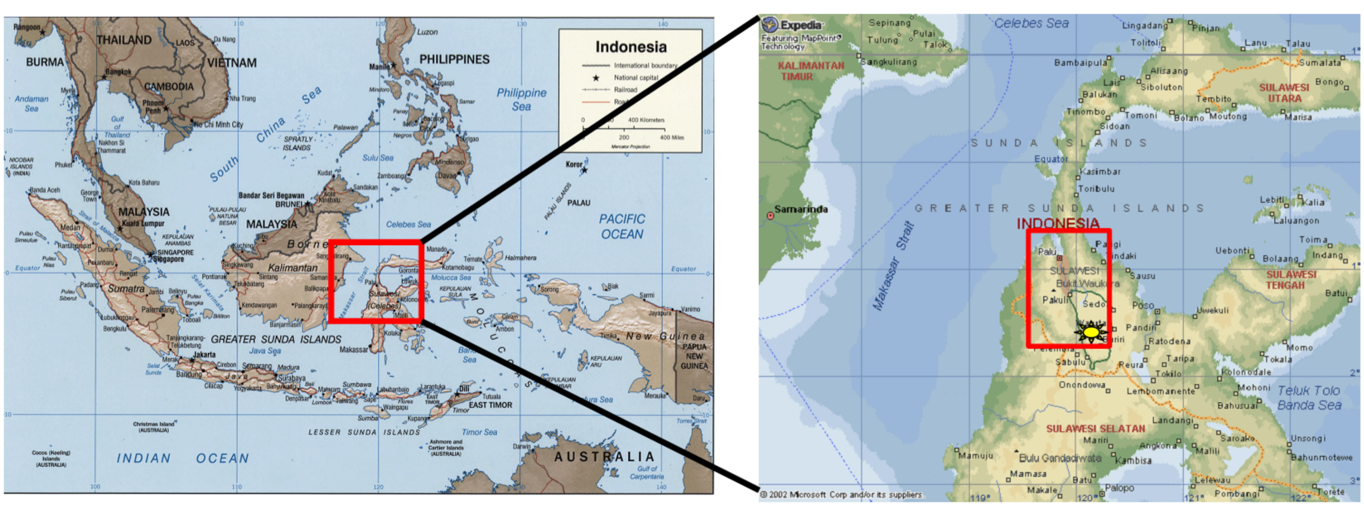

Figure 1. Map of Indonesia (left) and a geographical location of Lore Lindu National Park in the island of Sulawesi (right). Yellow star at the right panel shows a position of the flux tower.

Between deforestation and climate impact

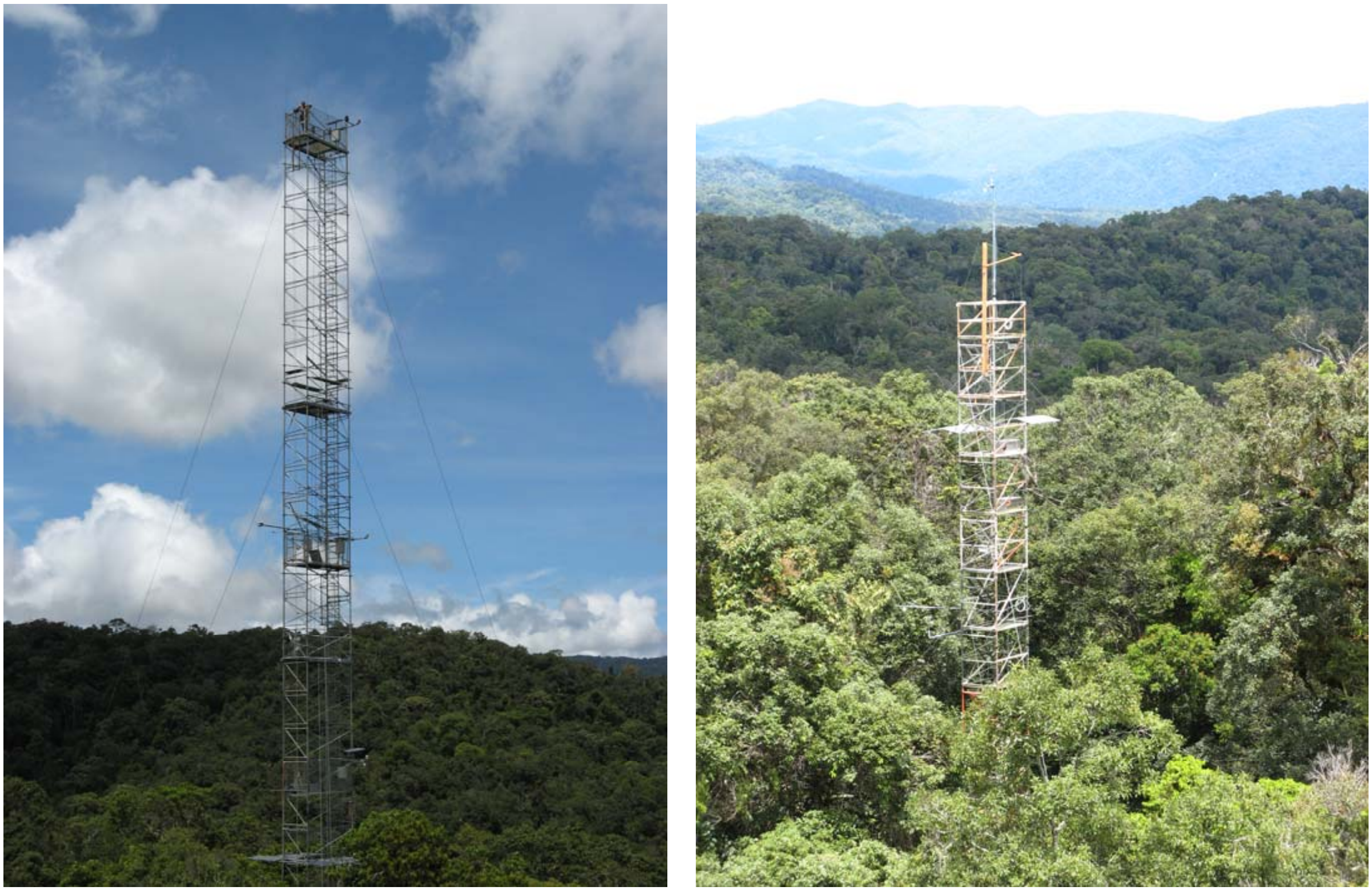

Figure 2: A view on the main 70 m tall flux tower at BFS (left) and one of the two additional towers for measuring horizontal advection (right) Photos H. Kreilein.

400 m. Within a 500 m radius around the tower, elevation is 1416 m a. s. l. with a standard deviation < 20 m. The plane is slightly inclined (< 5%) towards West. The mean annual temperature is 19.1°C, relative humidity 83.3% and precipitation is 2700 mm yr^{-1} (Rauf, 2009).

Measuring fluxes in a tall montane tropical forest

Measurements at BFS began in October 2003 and still continue. The eddy covariance system consists of a three-dimensional sonic anemometer (USA-1, Metek, Elmshorn, Germany) and an open-path CO_2–H_2O sensor (LI-7500, Li-Cor, Lincoln, Nebraska, USA) which are installed on the 70 m tall steel tower (Fig 2). Additionally short and long wave radiation, air temperature and humidity, horizontal wind speed and precipitation rate are measured at various heights. The sets measuring the incoming and outgoing short and long wave radiation are mounted above and below the tree canopy. Due to the complex topography of the site (Fig. 3) we expected vertical and horizontal advection to play a relevant role and installed two additional towers with 6 sonic anemometers to quantify these effects (Fig 2).

A strong carbon sink?

The long-term eddy covariance data starting in 2003 indicate that the forest at BFS is an unexpectedly strong sink for atmospheric CO_2 (Fig. 4). The data show considerable seasonal variation both of the net flux and its components, partly reflecting wetter and drier periods. Using these data, Ibrom et al. (2008) suggested a novel approach describing the dependence of GPP on absorbed photosynthetically active radiation. The method allows overcoming the problem of saturation of canopy photosynthesis under the high irradiance which complicates the implementation of the common light use efficiency approach in tropical forests. The analysis showed that the irradiance level, at which photosynthesis saturated, decreased with increasing vapour saturation deficit, thereby explaining the effect of dryer seasons on carbon uptake.

The overall annual CO_2 budget estimate based on the single tower eddy covariance measurements amounts to a high net-uptake of 970 g m^{-2} yr^{-1}. Like in other tropical sites the carbon budget is relatively uncertain, because of the high proportion of calm nights. The complex terrain complicates the correct

Between deforestation and climate impact

Figure 3: A view on the 70 m tall flux tower at BFS within the landscape.

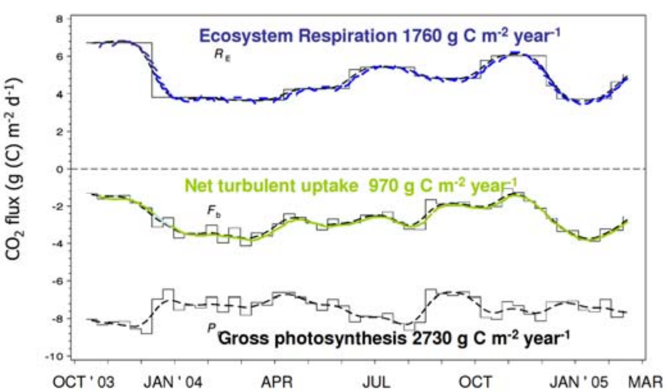

Figure 4: Annual variation of measured net ecosystem exchange flux Fc, of extrapolated respiration flux RE, and the sum of both fluxes gross photosynthesis (Pg) at the Bariri Tower site (g (C) m^{-2} 10 $days^{-1}$). Values are not corrected for advection.

interpretation of the measured signal and the contribution of the surrounding forest especially during night time. Therefore we used the 3D atmospheric boundary layer model SCADIS based on E-ω closure (Sogachev and Panferov, 2006) to evaluate the influence of heterogeneous terrain on CO_2 and H_2O fluxes between rainforest and the atmosphere. The estimated correction coefficient varied (depending on wind direction) from 0.6 – east wind to 1.5 west wind. To apply the correction factors, the measured data were classified according to the condition of atmospheric stratification (stable, neutral, unstable) and the separate corrections was applied for each situation. The correction reduced the net uptake by 152 g (C) m^{-2} yr^{-1} under conditions of neutral stratification and by 204 g (C) m^{-2} yr^{-1} at stable atmospheric stratification resulting in an about 20% lower estimation of annual CO_2 uptake (Ross, 2007). As an independent measure, we try to estimate the carbon uptake of the system with biometric assessment of the carbon pools and their changes and with biophysical modelling using field measurements of photosynthesis at leaf level and canopy structure parameters (Rakkibu, 2008).

Current analyses showed that measuring carbon fluxes at this unique site provide excellent means to observe ecosystem responses to climatic variability and to investigate carbon fluxes in tall vegetation and complex terrain. It is essential that flux investigations at the Bariri Flux Site continue, because (i) it is one of only two sites worldwide where primary mountainous rain forest can be studied in situ and (ii) it is located in South East Asia with its unique tropical climate, a region of tight land-atmosphere-ocean interaction, but where coverage with flux sites is extremely low.

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Looking back and looking forward at eddy flux studies in forests

David R. Fitzjarrald

[“Do not confuse the star you steer by for your destination.” John Barth, Lecture, Univ. of Illinois, 1968.]

When eddy covariance fluxes were finally accepted by the ecological community, the need to account for ecosystem respiration reinvigorated meteorological interest in nocturnal turbulent fluxes. When water vapor and heat fluxes were paramount, micrometeorologists concentrated on the more tractable daytime convective cases. It takes some audacity to apply the eddy flux approach to get long-term flux averages in forests. After years of seeking places with no obstacles to measure fluxes, researchers feared the subcanopy (Fig. 1). Many other difficulties flowed directly from the nature of Reynolds averaging. In stable conditions, effects of temporal or spatial inhomogeneities are exaggerated, as turbulent intermittency, breaking waves, and drainage flows all confound the situation.

In the end, the clear advantages of using the eddy covariance approach finally won over the ecological community. However, early eddy CO_2 flux results indicated that nocturnal that made little ‘ecological sense’—too much carbon was accumulating given growth rates estimated using other approaches. The Goulden et al. ‘u_* correction’, the solved this issue for many—simply replace measured fluxes on calm nights with ‘reliable’ ones measured on well-mixed nights. Also, discard rainy periods, and finesse the lack of energy balance closure with artful adjustments. Overlook transient events (e.g., nocturnal CO_2 venting). Now many labor to produce regular flux time series, happily supplanting observations with corrected numbers, filling gaps by inserting fictional output from a site-specific model. The resulting continuous record then ‘validates’ (such a self-serving term!) another model or remotely sensed data. It is considered acceptable to discard 60-90% of nocturnal data at some sites with surrogates and still refer to the product as data. These efforts feed interesting data-model fusion activities. Do we risk introducing a bias with our well-behaved data? What information is discarded?

Horizontal subcanopy motions and scalar budgets

[“It's one of those things a person has to do; sometimes a person has to go a very long distance out of his way to come back a short distance correctly.” Edward Albee, The Zoo Story.]

Consider the issue of the calm night eddy CO_2 fluxes. If we do not measure CO_2 emerging vertically from a forest on calm nights, does it go out the sides of the box? What observational arrays are needed to estimate subcanopy trace gas divergence in forest canopies? The answers have been trickling in over the last few years, but they might have come much earlier. In 1978, a mixed crew of ecology and meteorology graduate students sat with Prof. Garstang in Charlottesville to design a project to measure heat, moisture and CO_2 budgets through the forest canopy. In the room were veterans of BOMEX and GATE, large-scale tropical meteorological campaigns (e.g., Esbensen 1975). It seemed natural to apply the same techniques to estimate water and energy budgets on the microscale in forests.

To the students, the nocturnal canopy air density profile resembled the tropical convective boundary layer (CBL), so Woodwell & Dykeman (1966) estimating the forest canopy respiration rate by monitoring subcanopy CO_2 accumulation seemed straightforward. We admired Odum & Jordan's (1970) quixotic effort to enclose the rain forest in a large plastic cylinder at the Luquillo Forest. We saw no mystery in ‘countergradient transport’ in the canopy—buoyant advection accomplishes the same in the CBL, where the scale of mixing eddies is larger than that of the local gradient. How small a budget box would be viable? In the end the project was scuttled: Somehow we had overlooked Desjardin’s work

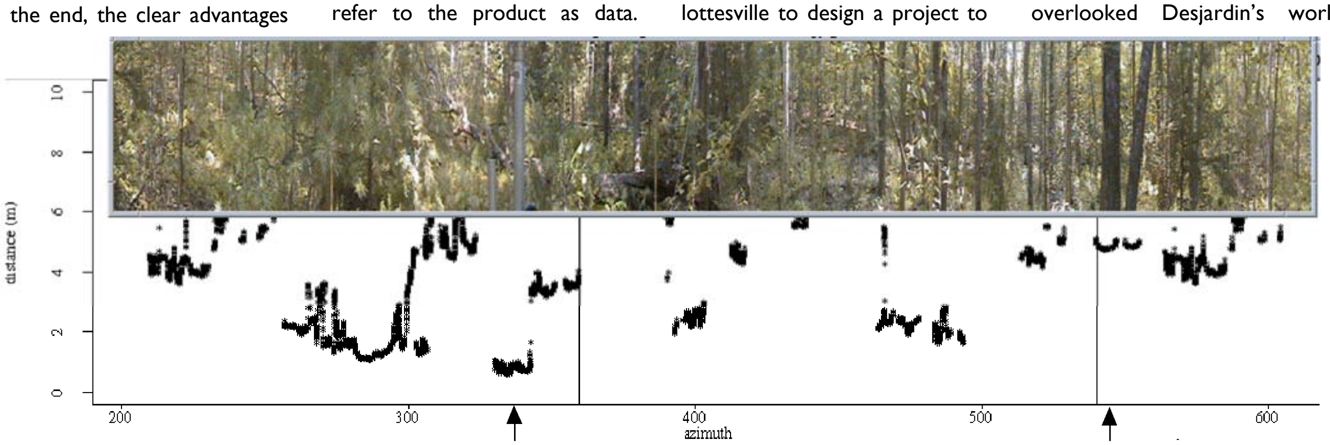

*Figure 1.:*Harvard Forest, Sept. 12, 2002. Rangefinder scan with panoramic photo. A 2D sonic anemometer is visible at 340° (sonic anemometer, arrow). A clearly resolved twin tree at 540° is also marked. (from Staebler 2003).

Looking back and looking forward...

with eddy CO_2 fluxes over crops, our topic fell between disciplines, professors squabbled, and no funding ensued (related events). We could have been contenders! These ideas were left to incubate for years. It was eight years before my seminar on Amazon forest eddy fluxes with the immortal title (no one recalls anything else): "Intermittent nocturnal coupling in the Amazon jungle."

When the 'u_* filter' issue bubbled up, we looked at subcanopy CO_2 advection at Harvard Forest (Staebler and Fitzjarrald 2004, 2005), the 'DRAINO' projects. These started in the growing season of 1999 and, as resources became available and we understood instrumentation issues better, an observation strategy emerged over the following three summers. In moderately complex terrain, we learned to measure the direction that the drainage flow follows (not necessarily down the local terrain gradient), using a 'slope flow rose'. We learned that stations 50 m apart could give reasonable results, but that 20-40 cases were needed to tease out the small signal. Several issues were identified but not understood: What is the source of the cold air that motivates the drainage flow, and how does it get to the forest floor?

We hoped that others would notice our methodology for quantifying horizontal subcanopy advection: 1) Show that systematic subcanopy flows are measurable; 2) Such flows are related to a physical driving mechanism; 3) Observed CO_2 gradients and transport processes in the subcanopy produce mean net transport of CO_2 into or out of the control volume; and 4) A subcanopy network had to include 20-30 cases of light winds and clear skies to capture the relevant gradients and transport processes. Few did. We considered it unfeasible to make advection corrections on the 1-hour time scale, arguing for clear night composites. We retained a general uneasiness about how to deal with quantitative estimates of canopy structure. The elusive goal continues to be to estimate the likely effect of horizontal advection at a given site knowing local topography, estimates of the respiration rates, the mean vertical vegetation profile (e.g., Fig. 2), and the wind aloft.

Our team made similar observations at the LBA-ECO tower site in the Tapajós National Forest, Brazil (Tóta et al. 2009). This site was ideally 'flat' except that it was close to a cliff. We found that the forest floor was so decoupled from the flow aloft that drainage flow toward a local microbasin was observed day and night, casting doubt on the relevance of the nocturnal u_* correction alone. We found that the horizontal advection could indeed be measured, and it could account for most of the 'missing flux'.

Tóta is now documenting a second series of observations at the ZF-2 tower site near Manaus, an area of dissected terrain that forms an airshed that promotes complex subcanopy motions. At this site the original DRAINO approach could not work given our limited equipment. Subcanopy instruments were placed to monitor slopes on either side of one airshed gully adjacent to the flux tower. Tóta found that colder air could move CO_2 laden air uphill at intervals, suggesting the presence of atmospheric seiches in the microbasin.

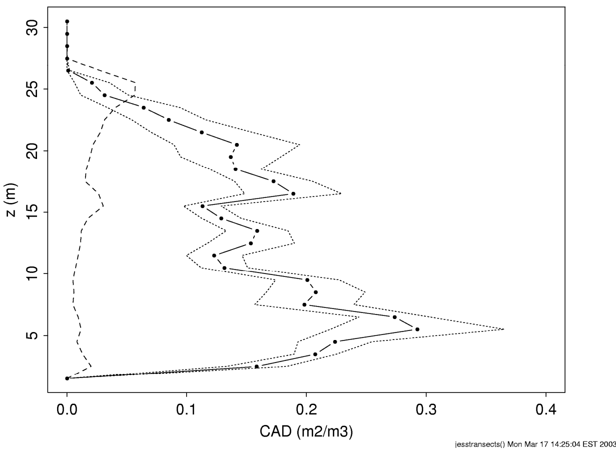

Figure2: Harvard Forest. The average canopy area density (CAD) distribution, its standard error (dotted) and the winter profile of a similar nearby mixed deciduous stand (dashed; Staebler and Fitzjarrald, 2004)

In these studies, we always postulated a similar vertical CO_2 profile shape, forced on us by financial circumstance (e.g., Fig. 3). In 2008, we returned to Harvard Forest to look at subcanopy flows around another flux tower, one in simpler topography with regular subcanopy anabatic and katabatic flows. Case studies of canopy in-canopy scalars are planned to refine our profile shape factors. Linking new sodar observations upwind and in the lee of local topography with the earlier work at Harvard Forest will help us evaluate whether the above-canopy flow can significantly alter subcanopy motions on calm nights.

Ruminations & future directions.

["A good teacher teaches well, regardless of the theory he suffers from." John Barth, Lecture, Univ. of Illinois, 1968.]

What is our goal? Modelers and field observationalists alike seek generalizations. As we rush so confidently to make those lovely global maps of NEE, ET, apparently 'solved' problems should perhaps be revisited at intervals. Data storage is no longer an issue, but finding the resources for mining existing *raw* data remains a major challenge. Recently a conference speaker confidently announced, "The era of curiosity-based science is over…" Will committees be adequate to map out the future for us all?

Observers regularly come upon unexpected and puzzling phenomena. This inclines me to consider observational evidence in 'eco-micrometeorology' as primary to theory regardless of

Looking back and looking forward...

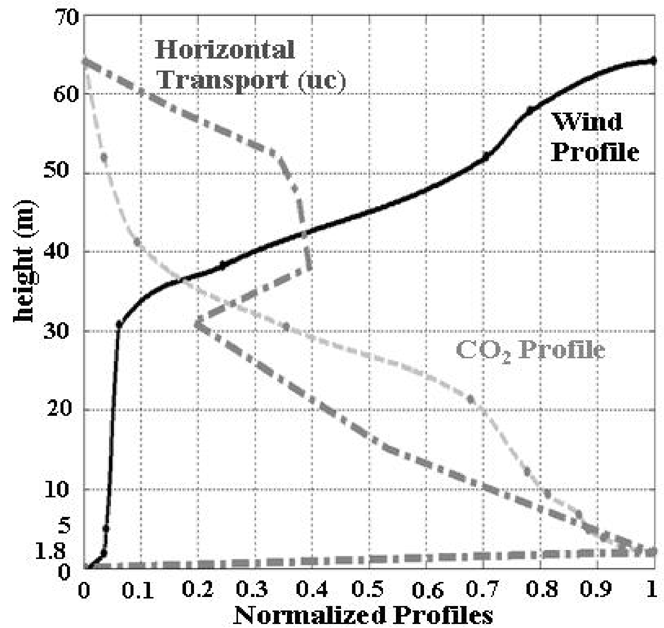

Figure 3: Tapajós National Forest, Brazil.Typical nighttime normalized median profiles of CO_2, wind speed and their product (uc) horizontal transport (from Tóta et al., 2008).

theoretical elegance. Our understanding of turbulence—e.g., the characteristic time and length scales in canopies—is incomplete. Since we often report fluxes without commensurately detailed description of canopy structure, rules to generalize momentum transport in canopies are drawn from intuition in models or from a small number of intensive field observations.

Another way to extract more information from the accumulating Ameriflux records is to consider alternate definitions of the ensemble mean in the Reynolds average to form event-based composites. We recently used this approach to estimate rainfall interception at the Tapajós site reanalyzing existing eddy flux data (Czikowsky & Fitzjarrald 2009).

Answers to some questions that vex me may come from this approach:

- To what extent are parameterizations that link current atmospheric 'forcings' to plant response compromised by circadian rhythms, shown in some studies to march along regardless of local conditions?
- Is the observed enhanced carbon uptake on cloudy days only the result of the diffuse radiation fraction, or does it matter what light-dark cycles the clouds impose on the canopy?

["How more satisfying when the voyage, not the port, was our destination. If life's a journey and the grave its goal, getting there is all the fun. – John Barth, Sabbatical"]

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We plan to make the FLUXNET newsletter a powerful information, networking, and communication resource for the community. If you want to contribute to any section or propose a new one please contact the FLUXNET Office. THANKS!!