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Contents

Workshop Summary: CarboEastAsia Workshop 2009 "Toward Integration of Field Observations, Remote Sensing, and Modeling" February 18-19, 2009 in Tsukuba, Japan

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The workshop was successfully held in Tsukuba, Japan from February 18-19, 2009. Over 30 participants from China, Korea and Japan discussed the current progress and future direction of A3 Foresight Program 'CarboEastAsia.' The main objective of the workshop was to share the progress of the collaborative research works by the two of the sub-project groups (subgroup 2 and 3) under CarboEastAsia. The objective of subgroup 2 is networking flux measurements (inter-site comparison), and that of subgroup 3 is model development and integration efforts with topics of inter-site comparison and quality controls of flux observation, scaling-up from point to area, remote sensing, modeling, and atmospheric inversion.

The CarboEastAsia project started in 2007 aiming at capacity building among ChinaFlux, KoFlux and JapanFlux to cope with climate change protocols by synthesizing measurements, theory and modeling in quantifying and understanding of carbon fluxes and storages in East Asia. The partnership that CarboEastAsia strives to build among the three networks under these themes is expected to serve as a testbed for accomplishing AsiaFlux's long-term vision. The scientific priorities of the project are: (1) Understand important mechanisms driving carbon cycle, (2) Quantify variability and uncertainty of carbon fluxes, (3) Identify temporal and spatial patterns, (4) Develop carbon cycle models suitable to East Asia, (5) Evaluate impact of land use and climate change on carbon cycle, (6) Establish database for regional estimates, (7) Provide scientific insights leading to policy making, and (8) Assess the role of East Asian carbon cycle in a global context.

Oral presentation session started with the special talks by Prof. Joon Kim (Yonsei University, Korea) and Dr. Akihiko Ito (National Institute of Environmental Studies, Japan). They reported the overview of Asilomar Flux and Modeling Workshop held in February 9-11 hosted by FLUXNET from the view points of synthesis of observation and modeling (Prof. Kim) and modeling (Dr. Ito). Their presentations suggested (1) importance of synthesizing flux data and modeling as well as collaboration of the scientists involved, (2) long-term observation and modeling, and (3) disturbance effects on carbon cycles. Their presentations reaffirmed the purpose of this workshop and threw several key questions that the workshop should address through discussions.

Oral presentation from subgroup 2 members mainly focused on the importance of gap-filling and quality controls of observed data, and synthesis of multiple site eddy-covariance measurements and soil respiration measurements. Dr. Jinkyu Hong (Yousei University, Korea) introduced standardized quality and gap-filling method used in KoFlux and suggested applying the common standardized methodology to CarboEastAsia flux data sets. Dr. Hyojung Kwon (Yonsei University, Korea) presented KoFlux multi-year and multi-site observation results with some detected terrestrial carbon cycle anomalies related to climate. Dr. Naishen Liang (National Institute for Environmental Studies, Japan) presented a network of soil respiration measurements across Japan and suggested the importance to understand sensitivity of soil respiration to climate change for modeling. Nobuko Saigusa showed the impacts of meteorological anomalies in 2003 summer on observed gross primary productivities at several sites synthesized with some remote sensing and model outputs, and stated the importance for gap-filling and quality controls.

Oral presentations from subgroup 3 mainly focused on regional and continental ecosystem modeling, remote sensing data analysis, and model optimization. Dr. Weimin Ju (Nanjing University, China) presented a model parameter optimization using flux observation and its spatial application to Asia. Kazuhito Ichii

Figure 1. Group photo of the CarboEastAsia Workshop (Feb. 18, 2009)

introduced a model intercomparison project in Japan, model - remote sensing data comparison in Asia, and application to earth system modeling. Dr. Sinkyu Kang (Kangwon National University, Korea) analyzed a watershed-scale hydro-ecological model to attempt scale it up to a larger space. Dr. Mei Huang (Chinese Academy of Sciences, China) showed a historical ecosystem model simulation in China with the trends in carbon cycle from 1980s and some validation works in 2003 summer drought effects in southern China.

We also had 15 poster presentations. The topics they covered include eddy-covariance measurements, soil respiration observations, flux data processing methodologies, inter-site comparison, remote sensing, regional and continental scales ecosystem modeling, and atmospheric inversion studies. The poster session hours successfully ended with valuable discussions and expectations for future collaborations. The posters were displayed throughout the whole workshop, giving ample time for further discussions.

One unique attempt of this workshop was to allocate large portion of workshop time (50 minutes for the first day, and 3.5 hours for the second day) to discussions. On the first day, we had a discussion after each oral session, identifying current problems and necessary actions in each subgroup. The remaining half-day session on the second day was spent exclusively for discussion by the entire group and by each subgroup to summarize the tasks to be resolved and the steps to accomplish them. As a result of very vigorous discussions, following items were proposed as top-priority tasks for CarboEastAsia: (1) standardize gap-filling and flux partitioning method and quantify the effects of different gap-filling algorithms on carbon budget estimation, (2) share model input/output data as well as flux observation data, (3) quantify disturbance effects on carbon budget.

The other unique attempt of this workshop was the tutorial session on data analysis using free software "Octave" taught by Kazuhito Ichii. These days, researchers have to face numerous types of data such as observation data from multiple sites, satellite data, and model input/output. How to manage these data effectively is one of the keys for conducting interesting analyses and retrieving meaningful results. This tutorial aimed to equip participants with basic skills to process large data of various types efficiently and create multiple graphs to analyze them using 'Octave'. After learning the basics of "Octave", the participants started analyzing global temperature records, Southern Oscillation Index (SOI) records, and atmospheric CO_2 concentration data (as text data) to find global relationships of climate and carbon cycle, and satellite-based vegetation index data (Terra/MODIS Normalized Difference Vegetation Index (NDVI) data for Asia as binary data) to characterize seasonal variations in terrestrial vegetation activities, and pick up specific regions using the materials prepared by the lecturer.

A half-day lecture was closed in a success with warm applause of appreciation to the lecturer. The participants gained skills to use text and binary data effectively and a tutorial CD and text to take home. The hands-on exercise in the tutorial was a refreshing experience for both flux scientists and model scientists, giving them reaffirmation that exchanging data analysis techniques with others is beneficial to improve individual skills.

Finally, the workshop organizing committee appreciates the financial support by National Natural Science Foundation of China (NSFC), Korea Science and Engineering Foundation (KOSEF) and Japan Society of Promotion of Science (JSPS). Details of the meeting including program and abstracts are located at CarboEastAsia web site: http://www.carboeastasia.org/event.html.

Figure 2. A scene from the tutorial session.

CELTICFLUX: Measurement and Modeling of GHG Fluxes from Grasslands and a Peatland in Ireland

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Abstract

Internationally, forests have been studied more extensively than grasslands or peatlands. By comparison with forests, grasslands and peatlands in temperate climates have been reported to be either small sinks or small sources for CO_2. We selected three sites for greenhouse gas (GHG) flux measurements in southern Ireland and installed eddy covariance flux towers at these three sites which have been operating continuously since 2002. For each of the five years (2003-2007), the three sites were sinks for CO_2. The peatland was a small sink for CO_2 (annual average of -0.6 t C ha^{-1} yr^{-1}) while the two grasslands (Dripsey and Wexford) were sinks for CO_2 (of annual average -2.6 t C ha^{-1} yr^{-1} and -4.8 t C ha^{-1} yr^{-1} respectively). The Wexford grassland for 2006 and 2007 had a mixed land cover (part grassland and part winter kale) which resulted in a significant reduction of the size of the CO_2 sink (to - 1.75 t C ha^{-1} yr^{-1}). The wet gley soils at Dripsey are a robust sink for CO_2 even under a wide interannual variability in rainfall. The free draining soils in Wexford are a significant sink for CO_2. Under climate change, wetter winters are unlikely to reduce the CO_2 uptake, but warmer summers and an earlier start to the growing season coupled with a longer growing season may enhance the annual CO_2 sink. The N_2O emissions at the Dripsey grassland ranged from +1.6 to +8.6 kg N-N_2O ha^{-1} yr^{-1} corresponding to 1.4% to 4.2% of the nitrogen in the applied artificial fertiliser. The N_2O emissions in Global Warming Potential (GWP) have the effect of reducing the CO_2 uptake by ~ 20%. The emissions of CH_4 at the peatland were ~0.05 tC-CH_4 ha^{-1} yr^{-1} (or ~10% of the annual C-CO_2 sink). The small annual sink of CO_2 and high interannual variability at the Atlantic blanket peatland suggests that under climate change predictions, blanket peatlands are likely to become sources rather than remain as sinks for CO_2. The huge store of carbon in Irish peatlands is in danger of being lost to the atmosphere.

1. Introduction

1.1 Background

As a signatory to the United Nations Framework Convention on Climate Change (UNFCCC), Ireland is obliged to produce inventories of GHGs (CO_2, N_2O and CH_4) emissions and sinks. Under the Kyoto Protocol, Ireland has committed to limiting the increase in GHGs to 13% above its 1990 levels, a limit set for the period 2008-2012. Agriculture in Ireland is estimated to be the largest contributor to GHG emissions at 26.1% of total. There is a small falling trend in agricultural emissions since 1999, due to decreasing cattle and sheep populations (thereby reducing CH_4 emissions) and falling fertiliser use (reducing N_2O emissions). In view of the significance of grasslands to Irish land cover, the economy, GHG emissions, and ongoing land use changes, the status of grasslands as a source or sink for GHG's needs to be quantified. Grasslands remove CO_2 from the atmosphere via photosynthesis and emit CO_2 to the atmosphere via respiration. When summed over the year, the net effect of photosynthesis and respiration may result in the grassland being either a source or a sink for CO_2. Emissions of N_2O are a significant GHG (~298 times more potent than CO_2) and are released into the atmosphere from grasslands after the application of nitrogen in fertilisers, animal excreta and manures. In grasslands CH_4, is a GHG from ruminant animals. It is generally thought that relatively intact peatlands in Ireland are sinks for carbon. Almost no field measurements of GHG's have been made in Irish peatlands and so their ecosystem status as a sink or source for carbon has not yet quantified. Because of their extent in Ireland, it is important to determine whether peatlands are a sink or source for GHG's.

1.2. Grassland CO_2 Fluxes

Studies of carbon fluxes in temperate grasslands have been overlooked due to the perception that this ecosystem is carbon neutral. Representing approximately 32% of the earth's natural vegetation, temperate grasslands are now revisited for carbon flux studies. Temperate grasslands are the dominant ecosystem in Ireland, representing ~ 90% of agricultural land (or 54% of the total land area). Finding economical GHG mitigation strategies is a strong motivation for studying the effects of grassland management on GHG fluxes. Several short-term studies have shown that grassland ecosystems can sequester atmospheric CO_2 but few multi-annual data sets are available. Long-term measurements are essential for examining the seasonal and interannual variability of C fluxes. Grassland ecosystems may act as either sources or sinks of CO_2. Whether grasslands are a source or sink for CO_2 is dependent on the climate, soil type, land use and management practices, such as rates of nitrogen fertiliser application. The literature shows that the net ecosystem exchange of grasslands varies from an uptake of - 800 g C m^{-2} y^{-1} to an emission of + 521 g C m^{-2} y^{-1} with most grassland ecosystems in the range ± 200 g C m^{-2} y^{-1} (± 2 t C ha^{-1} y^{-1})

1.3 Peatland CO_2 fluxes

Although northern peatlands are generally of low productivity, they are important ecosystems because they contain up to one third (455 Gt) of the world's estimated soil carbon (C) pool. The future of this C reservoir is of key interest as many regions (e.g. the arctic tundra) have already undergone a C status change from sink to source due to global warming. Climate warming is expected in peatlands to affect the hydrolog, the vegetation zones and plant composition, all factors influencing the C dynamics. Some peatlands have been found to be net sources of CO_2, others were found to be net CO_2 sinks, while others were found to be a sink in one year or a source in another year. Blanket bogs are ombrotrophic mires receiving water and nutrients only from atmospheric depositions. In the global context, blanket mires are rare ecosystems, accounting only for ca. 3 % of the world peatland surface. However, locally they are important, not only for biodiversity but for their role in the C balance of regions. In Ireland, out of 1.34 million of hectares covered by peatlands (~17% of the national landscape), about 240,000 ha are blanket bogs. The role of this regionally large ecosystem in C dynamics has not been quantified. Peatlands have a key role in controlling the terrestrial carbon cycle, with a dual effect on atmospheric C gas concentrations

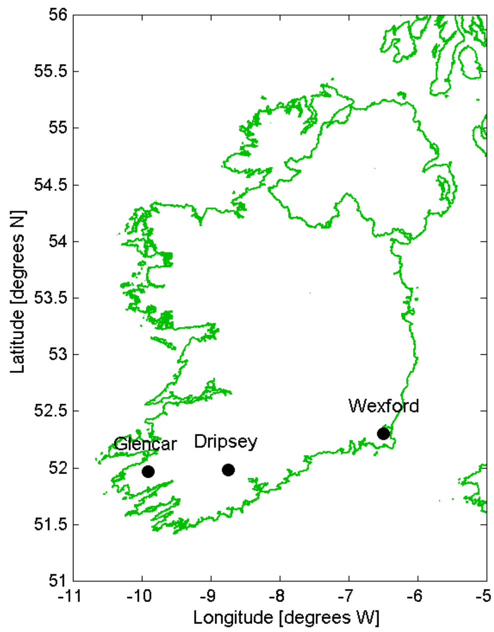

Figure 1. The three EC Flux Towers in Southern Ireland. Dripsey in County Cork is an intensively managed grassland (impeded drainage soil type) at an elevation of 190 m asl. Wexford is an intensively managed grassland (free draining soils) with some arable fractions at an elevation of 58 m asl. Glencar is a pristine Atlantic blanket peatland in County Kerry at an elevation of 150 m asl.

(CO_2 and CH_4). Peatlands act as a long-term sink of C, owing to the CO_2 uptake in photosynthesis and incomplete decomposition of the organic matter in water logged, cold and acidic conditions. The residual organic matter, peat, has a high soil organic carbon content of ca 45%. The long term average annual C accumulation rate in different boreal peatlands has ranged from 17 to 29 g m^{-2}.

1.4 Aims and Objectives

The objectives of the project were to quantify the carbon (CO_2) source/sink status of the three Irish sites along with the emission N_2O and CH_4 emissions.

2. Materials and methods

2.1 Experimental Sites

We selected three sites for GHG flux measurements in southern Ireland and installed eddy covariance flux towers at these three sites in 2002. These are: the Dripsey grassland site in County Cork; the Wexford grassland at Johnstown Castle in Wexford and the Glencar Atlantic blanket peatland in County Kerry. The locations within Ireland are shown in Fig. 1.

2.2 Meteorological methods

Meteorological variables were continuously measured at the three eddy covariance (EC) tower sites in the South of Ireland. The meteorological data supported the GHG flux measurements as they were used to model missing flux data and in the process-based models, PaSim and DNDC. Moreover, meteorological variables were used to establish continuous time series of gas fluxes from intermittent point measurements from trace gas chamber measurements. Signals from all sensors were averaged (or, in the case of precipitation, summed) over a 30-minute period.

2.3 Eddy Covariance Methods

The EC method is a micrometeorological technique that measures the turbulent flux across the vegetation canopy-atmosphere layer to determine the net difference of material moving across this interface. Two fast response instruments are necessary for EC measurements: a 3-D sonic anemometer and a gas analyser, both operating at high frequency, to cover the full range of the turbulent motion. CO_2 concentrations were measured with an open-path infrared gas analyser (IRGA), installed beside the sonic anemometer. The N_2O

Figure 2. The EC tower (10 m high) at the Dripsey grassland in County Cork. The ecosystem is grassland and the soils are impeded drainage. The EC instruments were set at 10 m for 2002, 2003 and 2004 with an associated average footprint extent of 1000 m in the southwest direction. For 2005, 2006 and 2007 the EC instruments were at 6 m with a footprint extent of 600 m.

Figure 3. The EC tower at the Wexford grassland. The ecosystem is predominantly grassland with some arable fraction (from 2006 onwards). In the foreground we note grassland and in the background a winter kale forage crop over a fraction of the footprint. The EC instruments (sonic anemometer and Li-cor CO_2/H_2O gas analyser) are located at a height of 1.5 m above the ground with footprint extent of ~ 150 m in the southwest direction. The grassland is laid out in paddocks.

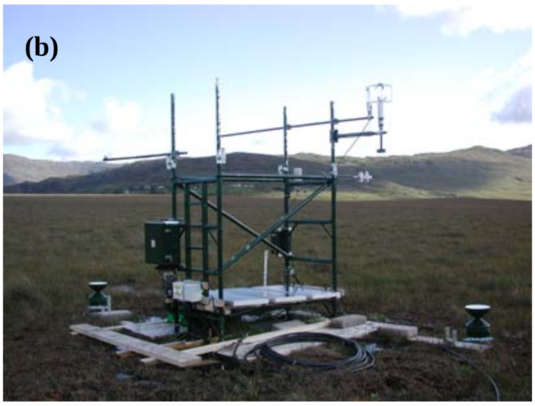

Figure 4. The EC tower arrangement at the blanket peatland at Glencar, County Kerry: (a) view of the Glencar Atlantic blanket bog with a hummock and hollow in the foreground; and (b) EC 3m high scaffold tower with ~ 1 km of bog in the background. The EC instruments (sonic anemometer and Li-cor CO_2/H_2O gas analyser) are located at a height of 3 m above the ground.

concentrations were measured with a closed-path trace gas analyser (TGA). This system consisted of a sensor intake, positioned beside the sonic anemometer, a tube that carries the sample air to the gas analyser which is a tunable diode laser absorption spectrometer tuned for N_2O. An averaging time of 30 minutes was chosen, as is generally applied in EC studies. The eddy-covariance CO_2 sensors were mounted: at 10 m above ground level in Dripsey (for years 2002 to 2004) and at 6 m thereafter; at 1.5 m in Wexford and at 3 m in Glencar. The N_2O gas analyser at the Cork grassland site had its air intake at 6 m above ground level while the N_2O gas analyser itself was positioned at ground level. The measured CO_2 fluxes were considered to correspond to the net ecosystem exchange (NEE), because the stored flux in the canopy was considered negligible in these treeless ecosystems. The micrometeorological convention treats fluxes from the atmosphere as negative and fluxes from the ecosystem as positive. The source area of the EC measured gas flux, called the footprint, roughly estimated on a footprint length to sensor height ratio of 100:1. Pictures of the three instrument set up are shown in Figs. 2 to 4.

3. Results - Cork Grassland

3.1 Meteorological Observations

One of the key drivers of ecosystem CO_2 fluxes is precipitation. Most rain falls in the wintertime from October to February, with the maximum monthly rainfall recorded being 260 mm in November 2002. The average annual rainfall at this location is ~1500 mm. Another key driver of the ecosystem CO_2 fluxes is the solar radiation or the measure that is used, photosynthetically active radiation (QPAR). Typically the daytime radiation (QPAR) ranges from ~ 200 µmol m^{-2} s^{-1} in the winter to ~ 550 µmol m^{-2} s^{-1} in the summer. The monthly lows in air temperature were ~ 5 ºC in winter and up to 15 ºC in summer.

3.2 Eddy Covariance CO_2 Fluxes

The monthly time series of CO_2 in g C-CO_2 m^{-2} are shown in Figs. 5 and 6. The months of October to January are net emissions months, while February and September are closer to neutral. The six months of March to August are net uptake months. The net uptake in the peak month May or June is ~ -100 g C-CO_2 m^{-2} while the emission months are typically less than +20 g C-CO_2 m^{-2}. In Fig. 5 we note a clear seasonal trend with typical uptake in the summer months and lower emission in the winter months. In Fig. 6 the cumulative CO_2 fluxes in g C-CO_2 m^{-2} y^{-1} is shown. The four years 2002, 2003, 2005 and 2006 had a range of NEE of ~ -220 to -260 g C-CO_2 m^{-2} y^{-1} (~ -2.4 tC-CO_2 ha^{-1} y^{-1}) while the year 2004 was almost twice that at -390 g C-CO_2 m^{-2} y^{-1} (~ -3.9 tC-CO_2 ha^{-1} y^{-1}).

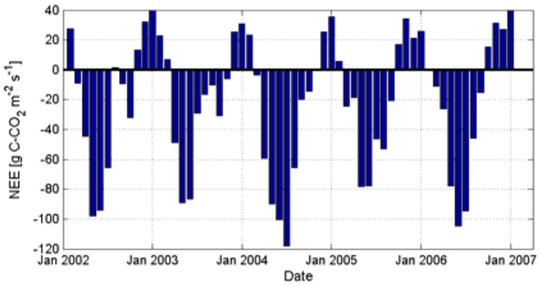

Figure 5. The five-year time series of monthly CO_2 fluxes given in units of g C-CO_2 m^{-2}.

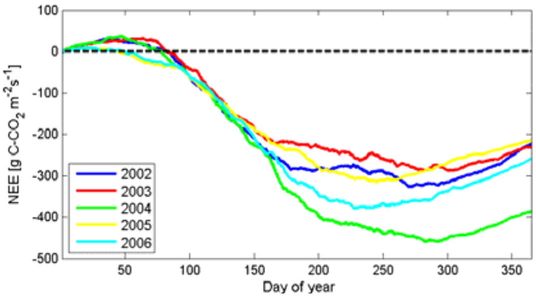

Figure 6. Cumulative sums of the CO_2 fluxes given in units of g C-CO_2 m^{-2} y^{-1}.

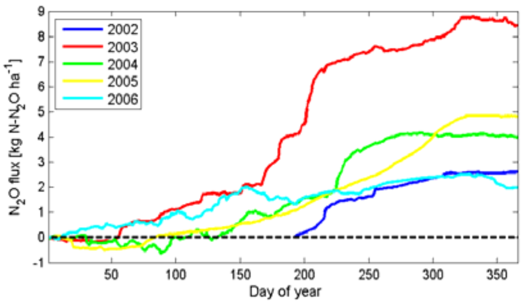

Figure 7. Cumulative fluxes of N_2O in units of kg N-N_2O ha^{-1}. Over the five years (2002 to 2006) the annual emission of N_2O ranged from 1.6 to 8.6 kg N-N_2O ha^{-1} y^{-1}.

3.3 Eddy Covariance N_2O Fluxes

Emissions of N_2O from soils are variable in both space and time. The cumulative emission for the years 2002 to 2006 ranged from 1.99 to 8.43 kg N-N_2O ha^{-1} y^{-1} (Fig. 7). This includes background or non-anthropogenic N_2O emissions which are estimated at 0.5 kg N m^{-2} $year^{-1}$. The emission factor we observed is higher than the IPCC guideline emission factor for national GHG inventories of 1.25 % but the wet, mild conditions at this site favour high rates of denitrification.

3.4 Discussion

The EC CO_2 fluxes at this grassland site show both seasonal and interannual variability. In the spring-summer season there is a net uptake of CO_2. In the autumn-winter there is a net emission of CO_2. Integrated over the year the flux of CO_2 has an interannual variation of -210 to -390 g C-CO_2 m^{-2} y^{-1} (-2.1 to -3.9 tC-CO_2 ha^{-1} y^{-1}). The annual N_2O fluxes ranged from 2.0 to 8.4 kg N-N_2O ha^{-1}. With an estimated background flux (due to soil processes in the absence of N fertilisation) of ~0.5 kg N-N_2O ha^{-1}, we note that since 2003, there has been a reduction in N_2O emissions. This is due in part to the EU Nitrate Directive and in part to a reduction in animal numbers. (e.g. conversion of a fraction of grassland to forestry and to barley). This model study of the Dripsey grassland site using PaSim showed that the process oriented model (PaSim) for carbon cycling in this grassland simulates well the EC measured NEE over the five-year study period.

4. Results – Wexford Grassland

4.1 Eddy Covariance CO_2 Fluxes

The Net ecosystem exchange (NEE) was continuously measured with an EC system from October 2002 to December 2007. In Fig. 8 we present the monthly CO_2 fluxes in units of g C-CO_2 m^{-2}. A net uptake was present for most months of the year except January and December. It is relevant to note that winter Kale made up > half the EC footprint from June 2006 onwards. The effect of the kale is significant. For the years when grassland occupied 100% of the footprint (2003, 2004 and 2005), the monthly CO_2 magnitudes are similar year on year. However, once the kale was growing there was a significant reduction in the CO_2 uptake in the Summer of 2006 and 2007 and a corresponding increase in the winter emissions of CO_2 for the winter of late 2006 and 2007. Kale is a short cabbage like crop, when mature, the cattle are allowed to graze it during the latter end of the year. Fig. 8 shows the impact of kale on the CO_2 response after June 2006. In Fig. 9 we present the cumulative

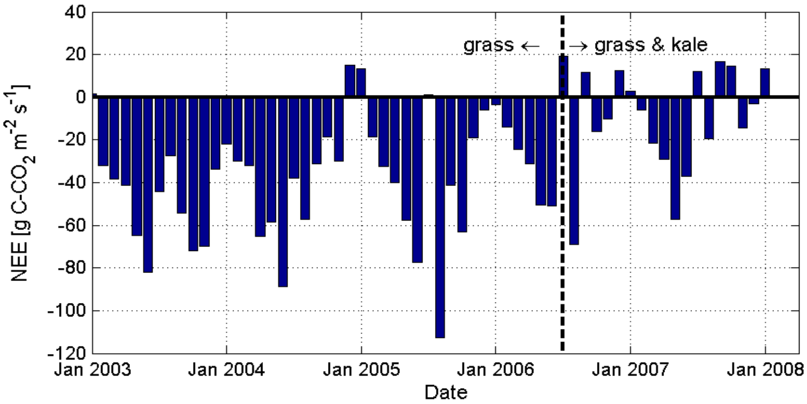

Figure 8. The five-year time series of monthly sums of the CO_2 fluxes given in units of g C-CO_2 m^{-2}. It is important to note that winter Kale was planted in June 2006 and due to ploughing and cattle grazing the Kale in the following winters, this had a significant impact in reducing the CO_2 uptake by comparison with the grassland of earlier years.

CO_2 flux for each of the five years in g C-CO_2 m^{-2} y^{-1}. The calendar year 2003 had the highest CO_2 uptake at -582 g C-CO_2 m^{-2} y^{-1} (or -5.82 t C-CO_2 ha^{-1} y^{-1}) in a year when the ecosystem footprint was 100% grassland. The other two grassland years (2004 and 2005) were a little less productive at -410 and -460 g C-CO_2 m^{-2} y^{-1}. In the subsequent two kale years the NEE uptake drops significantly to -220 and -130 g C-CO_2 m^{-2} y^{-1} in 2006 and 2007 respectively. A net uptake of CO_2 by the ecosystem was observed in all years of the study.

4.2 Discussion

The April CO_2 fluxes from the Wexford site in 2007 were within 20% of those observed in the Aprils of 2002-2005 despite much lower precipitation. Soil moisture content remained close to the levels of previous years during April of both 2006 and 2007. The soil remained wet throughout summer 2007 due to heavy rainfall in June, July and early August. The June CO_2 fluxes varied during 2002-2005, due to variation in harvesting dates. There was a net emission of CO_2 flux at Wexford during the extremely wet June of 2007; however, this is likely to be at least partially due to the reseeding of part of the measurement area with winter Kale. QPAR was also below average in June of 2007. June 2005 and 2006 also saw net emissions of CO_2 under different climatic conditions (higher QPAR and drier soils) to 2007 but similar management conditions. CO_2 uptake for July 2007 was less than previous years; for the remainder of 2007 small monthly uptakes or emissions were observed. This may be due to the extremely wet conditions following the 2007 harvest. The Autumn and winter monthly fluxes in 2006 and 2007 show markedly lower uptakes than other years or net CO_2 emission in some months. This may be attributable to the effect of planting the winter Kale crop in June 2006 and June 2007 in part of the EC footprint area. Under a grassland management system for three years, 2003, 2004 and 2005, the Wexford site had CO_2 uptakes that were -582, -410 and -460 g C-CO_2 m^{-2} y^{-1} respectively. Under the winter Kale crop for the two years, 2006 and 2007, the uptakes were significantly lower at -220 and -130 g C-CO_2 m^{-2} y^{-1} respectively.

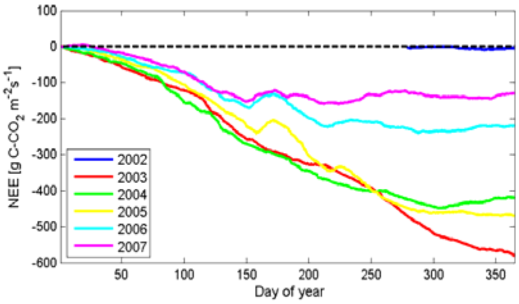

Figure 9. Cumulative sums of the CO_2 fluxes given in units of g C-CO_2 m^{-2} y^{-1}.

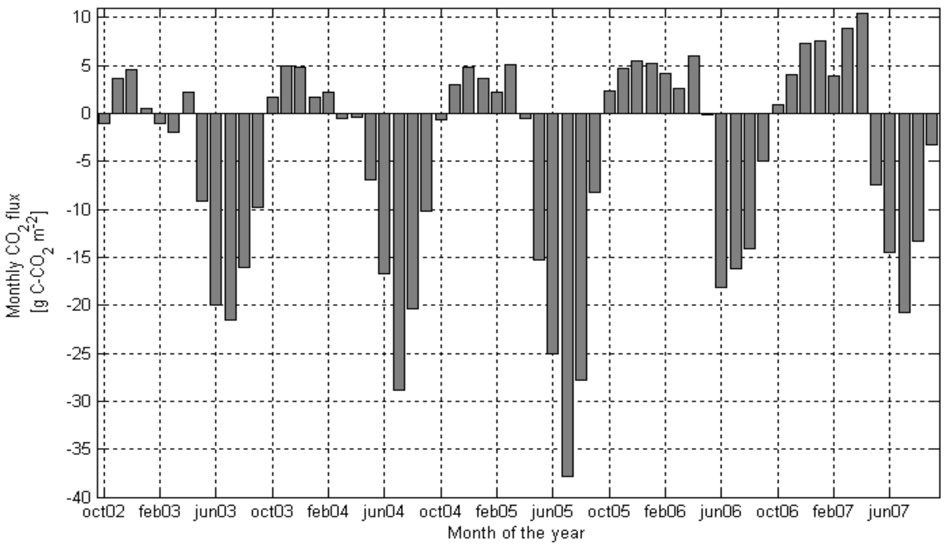

Figure 10: The 5 year time series of the EC measured monthly CO_2 fluxes in g C-CO_2 m^{-2}. The seasonal (summer/winter) differences are clear. The interannual variability is clearly visible.

5. Results – Kerry Blanket Peatland

5.1 Meteorological Observations

All analysis was based on the hydrological year (Oct. 1 to Sept. 30).

Precipitation was abundant throughout the year, (~2500 mm per year) with typically very high rainfall in the winter and autumn. The water table follows the precipitation pattern with a range of level of only about 20 cm. The coldest month of the year was February, with monthly temperatures ranging between 5.6 and 6.9 ºC over the five years, while the warmest months were July and August, with a monthly maximum of 16.4 ºC. The monthly averaged soil temperature at a depth of 20 cm is similar to the air temperature but the diurnal fluctuations are not as high.

5.2 CO_2 and CH_4 Fluxes

The monthly NEE for the peatland is shown in Fig. 10. Five of the twelve months (May to September) are CO_2 uptake months in all five years. The largest uptake month was July 2005 (~38 g C-CO_2 m^{-2}). For 2007, we note a stronger emission in the winter and spring months, while 2003 showed the lowest winter CO_2 loss. This different pattern was likely due to the high temperature and deep water table (meaning drier conditions) in 2007, which increased the decomposition processes. The lower temperature and higher water table level, was likely to have slowed decomposition in the winter of 2003. The highest CO_2 uptake in the summer was recorded in 2005 from May to August. In Fig. 10 we present the five year time series of monthly CO_2 fluxes and note the strong seasonal and interannual variability. Fig. 11 shows the cumulative NEE for the five hydrological years. The cumulative NEE uptake ranged from a low of -17 g C-CO_2 m^{-2} (-0.17 t C ha^{-1}) for the year 2006/2007 to a high of -97 g C-CO_2 m^{-2} (-0.97 t C ha^{-1}) for the 2004/2005 year. Although small when compared to grassland NEEs in absolute terms, this is a large relative range that indicates considerable CO_2 interannual variability. This indicates that the peatland is subject to significant interannual variability of CO_2 even though there was only mild environmental interannual variability between 2002 and 2007. This suggests that if there were significant environmental variability (i.e. climate change) then the peatland NEE fluxes might either become a source for carbon or a strong sink (as it did in 2004/05). The NEE fluxes suggest that the peatland is a sensitive environment and may suffer rapid change in the event of climate change. The carbon balance of the peatland includes: the carbon uptake of the CO_2 flux from atmosphere to the biosphere; the carbon in the CH_4 flux from the biosphere to the

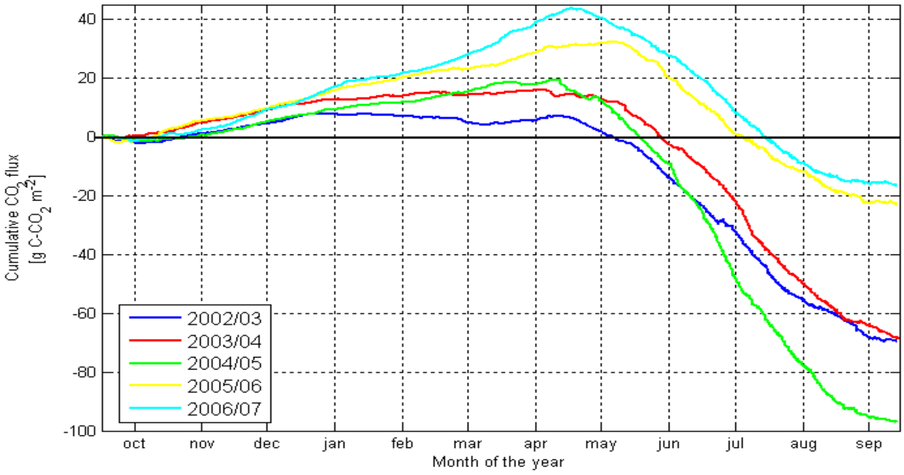

Figure 11: Cumulative uptake of CO_2 in g C-CO_2 m^{-2} for five hydrological years. The cumulative NEE uptake ranges from -17 to -97 g C-CO_2 m^{-2} (-0.17 to -0.97 t C ha^{-1}).

atmosphere; and the carbon lost as dissolved organic carbon (DOC) in the peatland stream. The inclusion of components (CH_4 and DOC) could turn the bog ecosystem from a net sink to a net source of carbon.

5.3 Discussion

The CO_2 fluxes in the Glencar Atlantic blanket bog measured over a 5 year period showed a large seasonal and interannual variation. The interannual variation ranged between an uptake of -17 to -97 g C-CO_2 m^{-2} y^{-1} (-0.17 to - 0.97 t C-CO_2 ha^{-1}) with an average of -55 g C-CO_2 m^{-2} y^{-1} (-0.55 t C-CO_2 ha^{-1}). As the water table is persistently high, decomposition was expected to be low and therefore CO_2 uptake high. Although Glencar has a mild maritime climate, the blanket bog is a net sink for CO_2 for only five months of each year. The CO_2 uptake by the peatland is five to ten times less than the CO_2 uptake at the grassland sites of Wexford and Dripsey. The monthly uptake is about ½ to ⅓ of the uptake values in mid summer at the grassland sites. A key difference between the grassland sites and the Glencar peatland is that the grasslands are fertilised, grazed and harvested; none of which occurs in the peatland. The grasslands productive season is from about March to September (about 7 months) while in the peatland the productive season is from May to September (5 months). The NEE measured during the hydrological year 2003/2004 with the EC system (-0.69 t C-CO_2 ha^{-1}) was very close to that measured and scaled up to the ecosystem level with the chambers in the same time period (-0.65 t C-CO_2 ha^{-1}).

Acknowledgments

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A new lidar for water vapor and temperature measurements in the Atmospheric Boundary Layer

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Introduction

Processes governing weather and climate at the large scale are affected by turbulent interactions at the land-atmosphere interface. To understand and better predict the exchange of water and heat at the earth's surface, the distribution of temperature and water vapor in the lower atmosphere must be accurately measure both in space and in time, and at a range of scales. To investigate these land-atmosphere interactions at small scales, a new lidar (Light Detection and Ranging) was designed and constructed. This new generation lidar is based on the Raman scattering effect and is capable of providing simultaneous high resolution measurements of temperature and water vapor, from distances of 15 to 500 meters, measuring every meter and every second, day and night. It provides an unprecedented view of the spatial and temporal variability of these scalars. The operating principle and design of the EPFL Raman lidar and some profiles of water vapor taken above the EPFL campus is presented here, as well as the results from the first real outdoor test experiment, which took place over a vineyard, close to Geneva, Switzerland, from September 6th to 12th, 2007.

EPFL Raman lidar principle

The EPFL Raman lidar is based on the same basic principle as other active remote sensing techniques (radar, sonar, sodar), in which the instrument transmits a short electromagnetic or acoustic pulse and then detects and analyzes the response from the fluid. The light pulse is emitted from a quadrupled nd:YAG laser at 266 nm. This wavelength is in the UV range known as the "solar-blind" region (wavelengths shorter than 300 nm) because practically all radiation at these wavelengths is absorbed by the ozone layer in the stratosphere. It gives the advantage that there is no daytime solar background radiation in the system (Renaut, Pourny et al. 1980; Grant 1991). During its propagation through the atmosphere, the pulse of light is scattered and spreads out or backscatters, as it encounters various molecules in the air. Because the laser pulse is very short, only a certain volume gives a backscatter response at a given time. The measurements thus have a spatial resolution that is defined by the laser pulse duration. The radiation that is scattered back towards the receiver contains information on atmospheric properties and the spectrum of the scattered radiation has several important features. The spectrum of the Raman lines used by the lidar is presented in Fig. 1. The "elastic line" has the same wavelength as that of the laser. "Raman lines" are wavelengths shifted from the elastic line. Each wavelength shift is specific for a particular scattering molecule, and the scattering intensity is a function of molecule concentration and temperature. The pure rotational Raman lines surrounding the elastic line are temperature sensitive, and are used for temperature

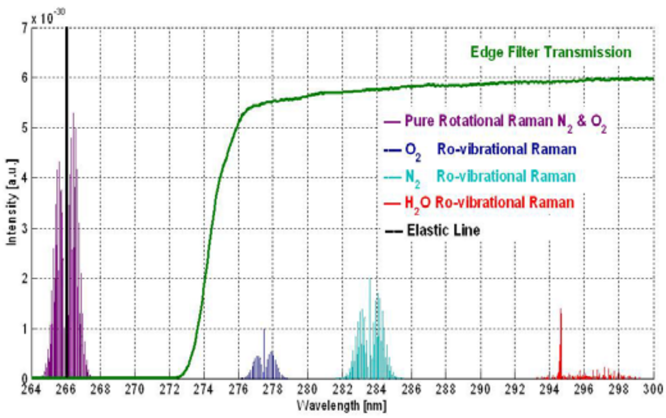

Figure 1. spectroscopic principle

measurements (Arshinov, Bobrovnikov et al. 1983; Mattis, Ansmann et al. 2002). The water vapor concentration is derived from the ratio of water vapor to nitrogen ro-vibrational Raman lines (Whiteman, Melfi et al. 1992). The oxygen ro-vibrational Raman lines are used for alignment purposes and tropospheric ozone correction. The initial spectral separation between "temperature" and "water vapor" signals is done with an edge filter; its transmission is also shown in green on Fig. 1. Two different optical analyzers called polychromators are used for the final spectral analysis of these two parts of the spectrum.

Lidars usually collect the backscattered light with a single mirror telescope. A major issue is that the amount of collected light is proportional to the mirror's area and inversely proportional to the square of the distance to the scattering volume. Thus, the accuracy decreases

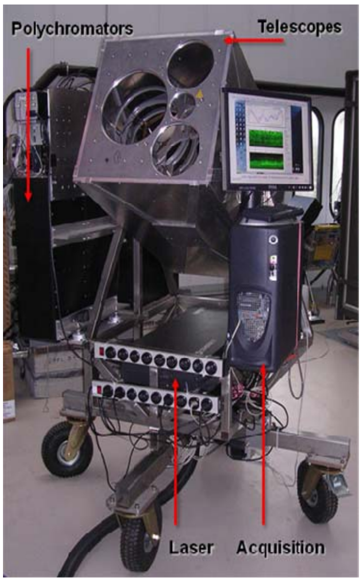

Figure 2. EPFL Raman lidar

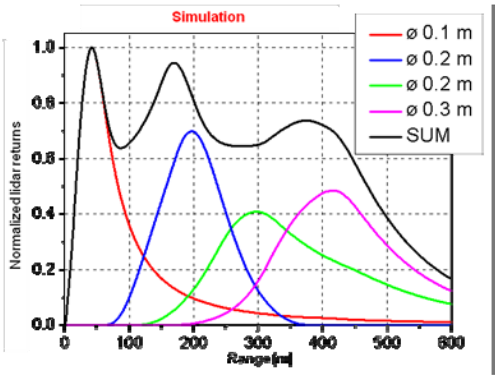

Figure 3. telescopes overlap

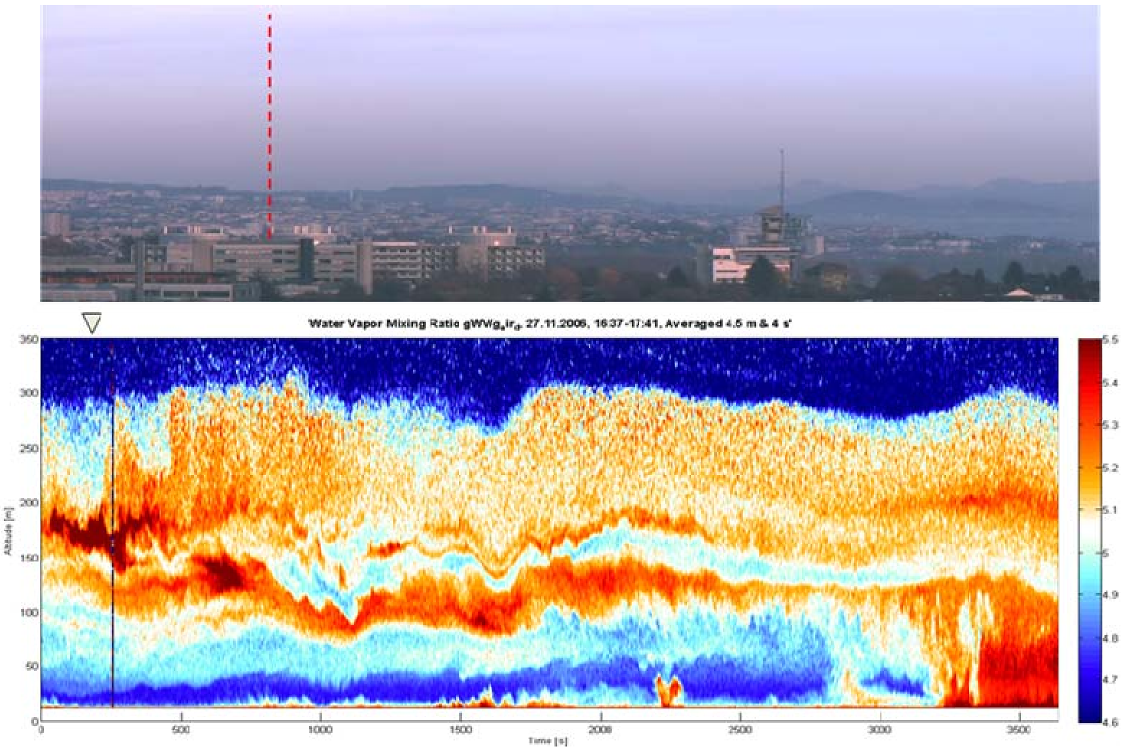

Figure 4. site view and vertical evolution of the water vapor mixing ratio

rapidly as distance from the receiver increases. By introducing a design (Fig. 2) that uses four receiving telescopes instead of one, an almost range-independent signal over its entire operational range (15-500 m) is obtained (Fig. 3) giving us measurements with almost constant spatial and temporal resolution and accuracy.

Vertical profiles

One of the first test measurements of water vapor was done on November 27th 2006, between 16:37 and 17:41 local time, on the EPFL campus, during calm weather conditions with light fog. This high resolution image (fig. 4) gives us an idea of the variability of water vapor, even in calm weather conditions. A clear double layer of water vapor, which collapsed to the ground after sunset at the end of the measurements period can be observed.

Vineyard test experiment

The first real outdoor test experiment carried out with the EPFL Raman lidar was made above a vineyard parcel (100x150m), equipped with two eddy covariance towers. Four temperature and humidity point sensors mounted on a Sensorscope wireless local network was also used, set in a line right below the principal line of sight of the lidar. A top view of the site and the instrumental configuration is shown in Fig. 5. The purpose of the vineyard experiment was first to compare lidar data with simultaneous point-sensor measurements at different horizontal distances. This showed that the multi-faced design telescope is reliable. We also could estimate the accuracy of the measurements; 0.15 g/kg for water vapor and 0.3°K for temperature, with 60 seconds averaging. One hour and a half time series comparison of lidar data and sensor is shown in Fig. 6. The first sensor has a small shift because this sensor was too much below the lidar beam, due to a small terrain depression. The usual estimation of lidar precision with Poisson statistics overestimates the real noise present in our profiles. The

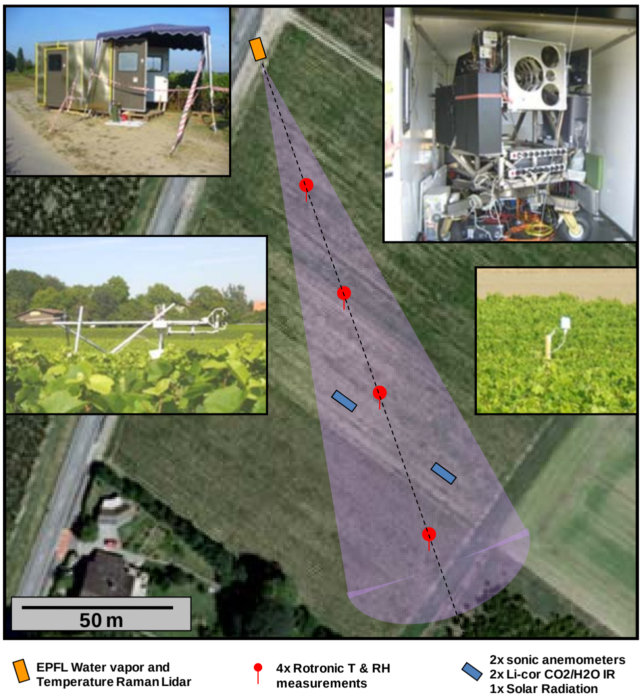

Figure 5. Top view of the experimental site

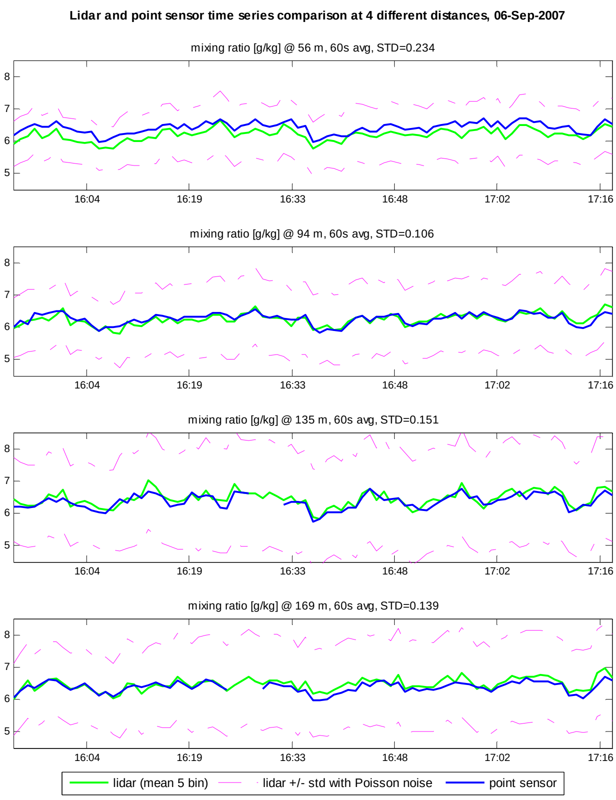

Figure 6. lidar and point sensor mixing ratio comparison

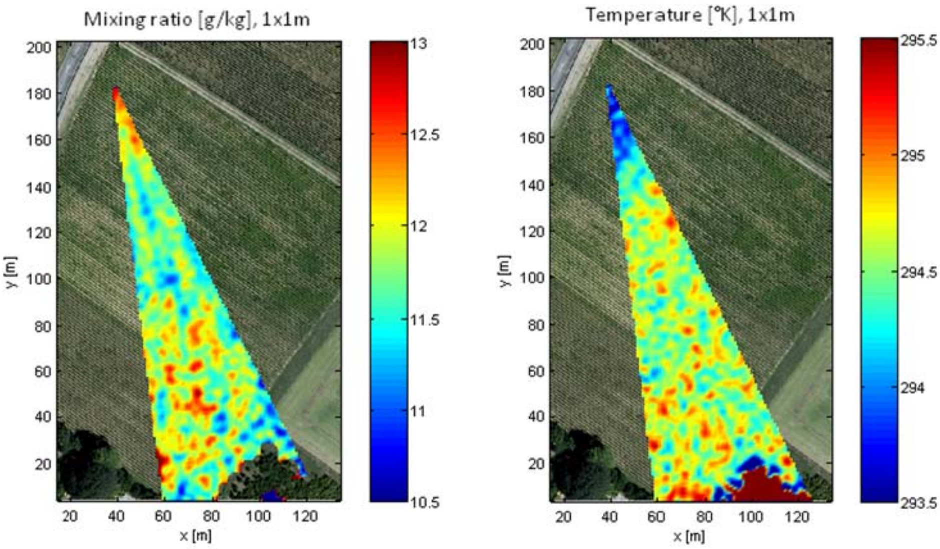

Figure 7. Mixing ratio (left) and Temperature scan (right)

second objective was to observe spatial structures of water vapor and temperature right above a plant canopy by scanning the air horizontally and vertically. The horizontal water vapor scans have complex footprints and source regions are not easy to determine, even if the sounding beam was within one meter of the vegetation. An example of one horizontal scan is shown in Fig. 7, with a pixel resolution of 1x1m and smoothed with a moving average of 4x4 m.

The horizontal temperature field is more variable than water vapor, which contains larger structures. This observation can be explained by the fact that temperature variations are quite large between the shaded and the exposed side of a vineyard line to the sun and could enhance the small-scales buoyancy effects.

The vertical scans were the most informative. A vertical resolution of 0.2 m was obtained by scanning at ~1°/min. The mean of 17 consecutive scans is presented in Fig. 8. During these measurements, the wind was between 0.5 and 1.5 m/s and mainly blowing from right to left on the figure.

We clearly observe the decrease of humidity with height. The air above the middle part of the field has much more water vapor than the surrounding areas.

Smaller scans were acquired during the same sunny afternoon. One of them is shown in Fig. 9. A faster scan allows us to catch almost instantaneous behavior of water vapor.

It clearly shows the internal boundary layer shape due to the wind and the roughness

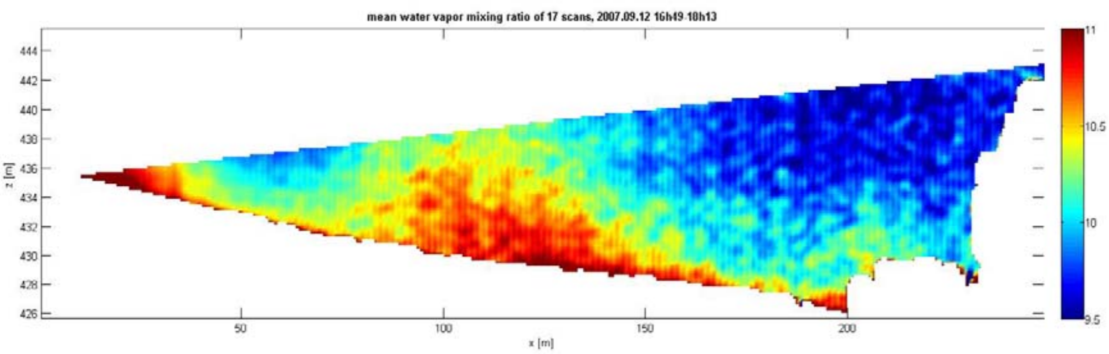

Figure 8. Mixing ratio vertical scan

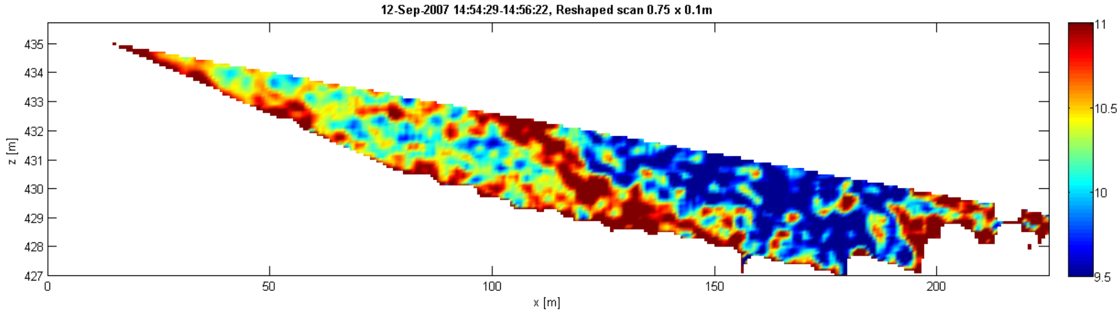

Figure 9. Mixing ratio small vertical scan

change at the end of the vineyard, at 180 m from the lidar. The difference between dry air coming on the site and the more humid air above the field is evident and is about 1 g/kg.

Conclusion

The EPFL water vapor and temperature Raman lidar design has been proven to be valid. The accuracy of the measurements that we obtained during the vineyard test field campaign is promising. The lidar can mesure turbulent structures of meter in size (or less during scans) and over time periods of seconds. Although it was not possible to observe one structure clearly associated with the surface in the horizontal scans, internal boundary shape at the vineyard edge was observed in the vertical scans. Ongoing research investigates methods to derive fluxes of water and heat directly from vertical scans. With such tools, we have now the capacity to measure surface-atmosphere exchanges of water vapor and heat at small scales, which is crucial for the characterization of evaporation and heat fluxes variability and dynamics (Parlange, Eichinger et al. 1995). The question of the spatial footprint of point sensors can be also addressed.

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Forest tree development, phenology, and climate change: an under-explored research intersection

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How environmental change impacts forests, and how forests may feedback on environment, is a key question of global change biology. It is also of large interest to the AsiaFlux community. Yet, as simple as it is to pose, this question is as challenging to answer. For example, forest ecosystems comprise tree life forms and age classes that can vary enormously. Young forests function differently than aged forests, and may respond differently to global warming – not to mention to elevated carbon dioxide, hydrologic regime shifts, and nitrogen deposition (Phillips *et al*., 2008a). Moreover, young/mature foliage on old trees may emerge and function differently than young/mature foliage on young trees, and may respond differentially to climate. While these challenges are daunting, they present excellent research opportunities. Here we describe our recent and current research on the ontogeny ("individual development") and foliar phenology of forest trees, and point to the intersection of ontogeny, foliar phenology, and environmental change as a virtually unexplored research intersection that is ripe for investigation.

Ontogeny

"Ontogeny" can be defined as the developmental history of an organism from birth to death. In the context of our research (Phillips et al. 2008a; Cermak *et al*., 2007; Ryan *et al*., 2006; Moore *et al*., 2004; Unsworth *et al*., 2004; Winner *et al*., 2004; Phillips *et al*., 2003a; Phillips *et al*., 2003b; Phillips *et al*., 2002; McDowell *et al*., 2002a; McDowell *et al*., 2002b; Chen *et al*., 2002; Phillips *et al*., 2001) we loosely use this term to refer to the increase in age and size of trees, and the attendant changes in tree form and function. Research over the past two decades has made it clear that large, old trees and forests may function differently than young forests (Ryan *et al*., 2006). Moreover, we are beginning to separate tree age from tree size as factors influencing the difference in physiological function (Vanderklein *et al*., 2007). In many, but not all tree species, individuals approaching their maximum species-specific heights show evidence of reduced leaf gas exchange, and this is consistent with the hypothesis of hydraulic limitations to tree height (Ryan and Yoder, 1997; Ryan *et al*., 2006).

Yet, one of the main challenges to making progress in this research area is our inability to capture the integrated physiological function in the massive tree crowns of tall, old trees (Phillips *et al*., 2008). The ancient Indian parable of the Blind Men and the Elephant comes to mind, as an analogy to ecophysiologists' attempts to characterize crown physiology by, for example, measuring gas exchange in a few leaves, or sap flow in a few branches (Phillips *et al*., 2008b). To overcome this barrier, recently we have turned our focus to a more tractable study organism: palm trees. Tall, solitary, columnar palms, like Mexican Fan Palms (*Washingtonia robusta)* growing at our research site at the Los Angeles County Arboretum (Fig. 1), may have 20-30 leaves instead of the innumerable leaves of a giant fir or oak tree. Thus, a handful of petiole sap flow sensors can characterize a large proportion of crown gas exchange. Their crowns are often compact and exposed equally to sky conditions, independent of size. Yet the biophysics of water transport and carbon metabolism are the same in palms as in other tall trees. In *Washingtonia* individuals, we are finding that leaf gas exchange is not curtailed in some of the tallest known individuals, even as evidence of reduced vertical growth is apparent

Figure 1. *Washingtonia robusta* palms at the Los Angeles County Arboretum, in which sap flow and leaf gas exchange measurements were made. (a) Crown view, showing the open grown aspect of palms of variable height. (b) A row of four exposed palms from 12 to 32 meters tall. The tallest palm is leaning and its crown is obscured from the angle of the photograph. Other nearby open grown palms (not shown) ranged from 1 to 8 m in height.

in these individuals (data not shown; Renninger *et al*., in review). Data emerging from our study of this model organism supports the idea that growth decline in very tall palms is likely *not* due to a limitation of carbon supply to crowns (Ryan *et al*., 2006). Among the other explanations we are currently investigating for the observed growth decline in tall palms are respiratory costs, and internally-mediated (e.g., hormonally) growth decline, including slowing the production and increasing the lifetime of palm fronds. Here we have arrived at one link between ontogeny and foliar phenology.

Ontogeny and Phenology

Foliar phenology can be considered the ontogeny of individual leaves or crowns. Only a few researchers (e.g., Augspurger, 2004; Augspurger and Bartlett, 2003; *Osada et al*., 2002; Seiwa, 1999a, 199b, Lugo and Batlle, 1987) have considered how and why foliar phenology may differ with the size or age of the individual. No one to our knowledge has linked ontogenetic change in foliar phenology to whole crown function generally, or to mechanisms for growth decline in large, old trees, specifically.

Work in our lab is beginning to address this linkage, in palms. Previous work on one palm species has shown that as individuals age, they slow down production and turnover of fronds (Lugo and Batlle, 1987). Because in monocot palms each new frond must be perched vertically above pre-existing fronds, slowing down frond production could translate into slowing down an unavoidable 'ratchet' of height growth. In a palm species we are studying in the Ecuadorian Amazon region (*Iriartea deltoides*) lower annual frond turnover rate helps to explain a vertical growth decline in palms approaching their maximum species-documented height (Fig. 2). While we have only begun to track frond turnover in *Washingtonia*, since frond photosynthesis does not differ by palm height, lower frond turnover alone could not account for reduced height growth, but would need to be coupled to respiratory 'burn-off' of carbon or allocation to pools other than to height growth of the main stem in tall palms to account for vertical growth decline.

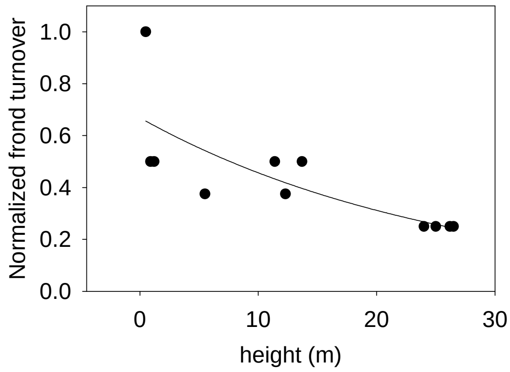

Figure 2. Number of fronds dropped per year (normalized by the maximum observed) in *Iriartea deltoides* palms in the Ecuadorian Amazon.

It has been difficult to separate micro-environment from intrinsic biology as drivers of observed differences in foliar phenology of saplings versus mature trees (Seiwa, 1999a). Small, young trees in a forest understory may produce leaves earlier in the spring than canopy-dominant conspecifics because the understory environment is warmer, and/or due to intrinsic, evolved biological differences in phenology of saplings versus mature individuals. To make progress in this area, we are initiating research at several locations in Massachusetts, where we can deconstruct these confounding factors. The types of studies we plan include (a) placing potted seedlings throughout the vertical crown profiles of mature trees, to track phenological differences by age and size of tree while controlling for micro-environmental variation (Augspurger 2004); (b) planting seedlings of a species next to old, Bonsai individuals of the same species, to track phenological differences in 'trees' of the same size but different age, while maintaining a similar micro-environment. Isolating age from size from micro-environment as controls on phenology will thus allow us to better model tree physiology, including water and carbon exchange, as a function of some or all of those factors.

Ontogeny, phenology, and climate change

Research at the intersection of phenology and climate change has matured beyond the initial documentation that climate change or elevated carbon dioxide drives a change in foliar phenology (e.g. Myneni *et al.*, 1997, Jachs and Cuelemans, 1999). Increasing emphasis is being placed on understanding how such altered phenology feeds back to alter water, carbon, and energy exchanges, and ultimately climate. We may refer to this trend as one towards "functional phenology".

At the Hawkesbury Forest Experiment at the University of Western Sydney, we are piecing together aspects of tree phenology, ontogeny, and response to climate change, in a linked set of experiments and observational studies on *Eucalyptus* species. We have found that Eucalypt seedling growth and development is highly responsive to growing temperature and carbon dioxide level (Ghannoum *et al.*, in review), and separately, that young foliage in young *Eucalypt* trees functions very differently, especially at night, than mature foliage (Fig. 3), in trees growing in field conditions. Because of the indeterminate nature of *Eucalypt* foliage production, young and mature leaves are found side-by-side, and their physiological differences, perhaps not as easily contrasted in trees of a determinate growth habit, stand out in bold relief. Does the difference in leaf "functional phenology" observed in the field persist, or is it modified, under scenarios of global warming or elevated carbon dioxide? We are currently actively investigating this 'intersection' question.

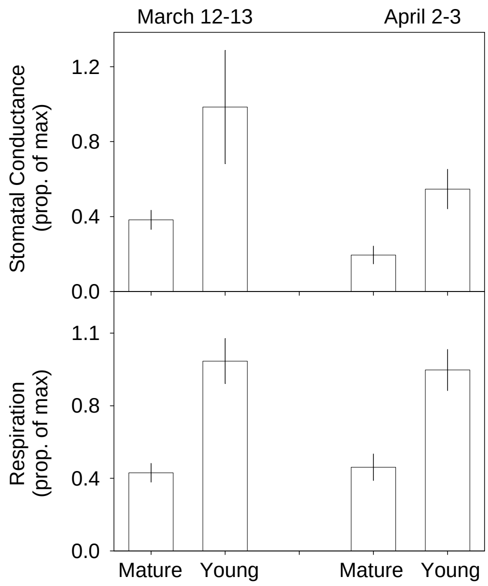

Figure 3. (a) Nocturnal stomatal conductance and (b) nocturnal leaf respiration (both normalized by maximum observed values) in young trees of *Eucalyptus saligna* at the University of Western Sydney.

Our research on *Eucalypts* in Australia has provided an unexpected stimulation of more general research questions, including those closer to home in New England, USA. Were our previous findings at Harvard Forest that some tree species, but not others, showed large nocturnal stomatal conductance (Daley and Phillips, 2006) related to a difference in foliar growth habit (determinate versus indeterminate, like in Eucalpyts)? Will deciduous trees show greater nocturnal gas exchange per unit leaf area in the spring period of leaf emergence, than when the crown matures? What role do these processes play in overall water and carbon balance as diurnal and nocturnal climate changes?

As indicated by our posing more questions than answers here, there are key unknowns remaining in this research intersection. All our research on the physiology of tall trees has occurred during a period of rapid environmental change (Phillips *et al.*, 2008), and we have no data to indicate whether an old growth tree today behaves differently from the same old growth tree would if growing before the Industrial Revolution. The intersection of phenology, tree development, and environmental change is currently small (Fig. 4), but has increasing relevance as land use

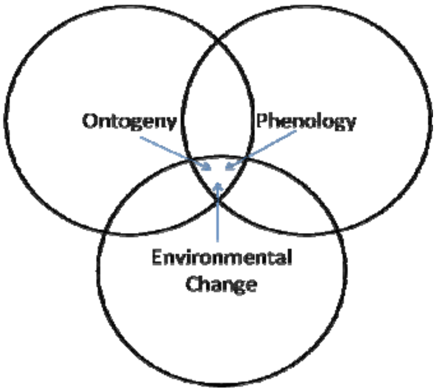

Figure 4. The small intersection of existing research on vegetation ontogeny, phenology, and environmental change.

change and climate change alter forest age/size distributions, seasonal foliar dynamics, and ecophysiological control of carbon and water exchange.

Forests can be considered ecosystems composed of a set of nested life cycles – from the cycle of leaf emergence and drop, to the lifetimes of trees, to forest succession. There are indications that these cycles do not operate independently of one another, making for rich and fertile grounds for research. Moreover, global environmental change may alter the nature of interactions among phenology and ontogeny, adding practical and timely impetus to work at this under-explored intersection.

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Dynamics of Vertical Energy Flux Under Different Land Use In Tropical Region

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ABSTRACT

A research was conducted during May 2005 - June 2006 in the tropical rainforest, Lore Lindu National Park (under STORMA research project), Indonesia to find out the dynamics of energy flux using Bowen ratio energy balance method. The dynamics of energy flux in the forest and grass land were similar to the net radiation pattern. At day time vertical energy flux is generally upward and change to downward at night time. Until noon, latent heat, sensible heat and soil heat fluxes increase and reach their maximums between 12.00 – 13.00 local time. In the forest, a large portion (~ 81.8%) of net radiation was contributed to latent heat flux; besides, the dominant turbulent transport of energy in the grass land was sensible heat (~ 58.8% of the net radiation). This phenomenon indicated that forest conversion to other land use has the potential of heating the atmosphere and may have strong effect on local climate change.

INTRODUCTION

During the past few years, more researchers and experts made study to recognize

Figure 1. STORMA Climate Towers in the forest and the grassland

environmental changes, for example, Twine *et al*., 2004, Pielke, 2001, Berbet and Costa, 2003, Seller *et al.,* 1997, Murdiyarso and Satjapraja, 1991. One of the important results is that land surface type has strong effect on energy and radiation balance. Now environmental change is seriously progressive with increase of carbon in the atmosphere and loss of carbon absorption as an effect from deforestation.

Investigation of energy flux between the land surface and the atmosphere was conducted under research collaboration between Indonesia and German "Stability of Rainforest Margin" (STORMA) in Lore Lindu National Park Central Sulawesi, Indonesia. The main objective of this study is to understand the dynamics of vertical energy flux under different land use. Data collection was performed during 2005-2006.

Observations of weather components were done on STORMA climate towers (Fig. 1) in the forest (height 70 m above forest floor) and the grass land (height 2 m above ground surface). The maximum, minimum, and mean values of all variables were measured and stored every ten minutes. The vegetation characters near the climate tower in the forest areas (radius around 400 m) were inventoried

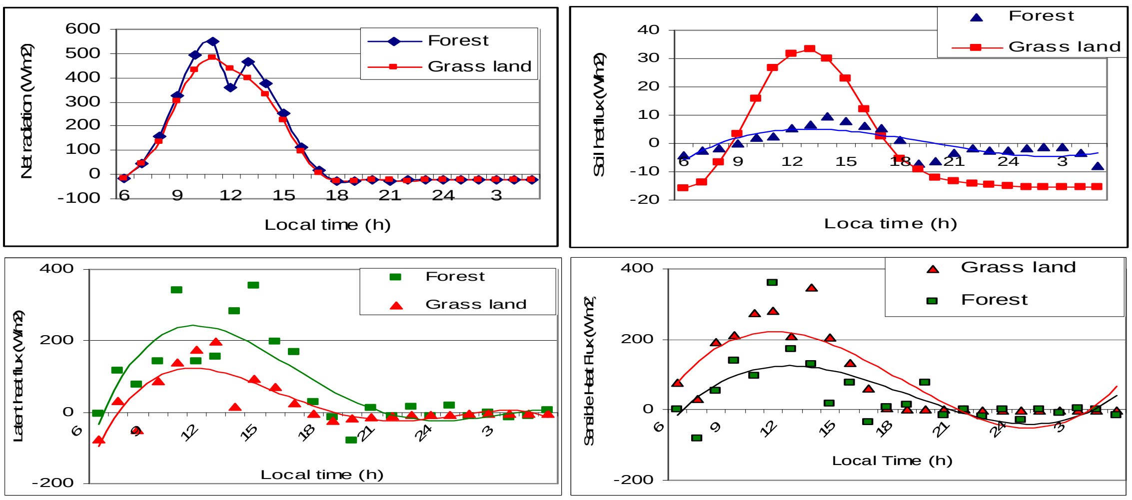

Figure 2. Dynamics of energy flux under different land use on dry-day

Table 1. Vertical energy flux under different land use

Comp.	Unit	Rainy day		Dry day	
		Forest	Grassland	Forest	Grassland
Events	Days	102		111	
Bowen Ratio	-	0.11	1.40	0.34	1.43
daily Rn	$MJ/m^2/day$	10.66	9.50	11.28	10.21
Daily LE	$MJ/m^2/day$	9.53	3.98	8.41	4.21
Daily H	$MJ/m^2/day$	1.06	5.58	2.85	6.00
Daily G	$MJ/m^2/day$	0.06	-0.05	0.02	-0.01

and showed that mean ground cover was 68.5 -92.5 %, canopy wide was 12.1 – 99.8 m^2, tree (DBH > 20 cm) and small tree (DBH 10 -20 cm) densities were 246 tree/ha and 450 tree/ha, respectively, and the leaf area index (LAI) was 4.8 – 6.4. To recognize the energy dynamics, turbulent energy fluxes were analyzed with Bowen ratio energy balance (BREB). This method has been adopted by a lot of researchers to recognize energy flux on the vegetation, for example (Todd *et al.*, 2000).

DYNAMICS OF ENERGY FLUX

The dynamics of vertical energy flux at daytime was upward, while at nighttime changing to downward. The pattern of energy flux was similar to the pattern of net radiation (Fig. 2). Rate of latent heat flux in the forest was higher than that in the grassland and their maximums were reached between 1200 – 1300. On the other hand, sensible heat and soil heat fluxes in the grassland were higher than those in the forest especially at day time. In the afternoon, net radiation decreased. Therefore, latent heat, sensible heat and soils heat fluxes also decreased. Notice that in the forest, latent heat flux was positive during nighttime. This phenomenon indicated that mass transfer from the forest to the atmosphere happened not only at daytime but also nighttime.

TURBULENT FLUX OF ENERGY

Vertical latent heat flux (LE) in the forest in rainy days was 9.53 $MJ/m^2/day$ or 89.40% of the net radiation (Rn) and in dry days this value was 8.41 $MJ/m^2/dayday$ or 74.59% of Rn, both of them were higher than those in the grassland (Table 1).

In the contrary, vertical sensible heat (5.58 $MJ/m^2/day$ or 58.77% of Rn on rainy days) from the grassland to the atmosphere was higher than that in the forest. These values were similar to those in dry days.

Both of the two land use types showed strong

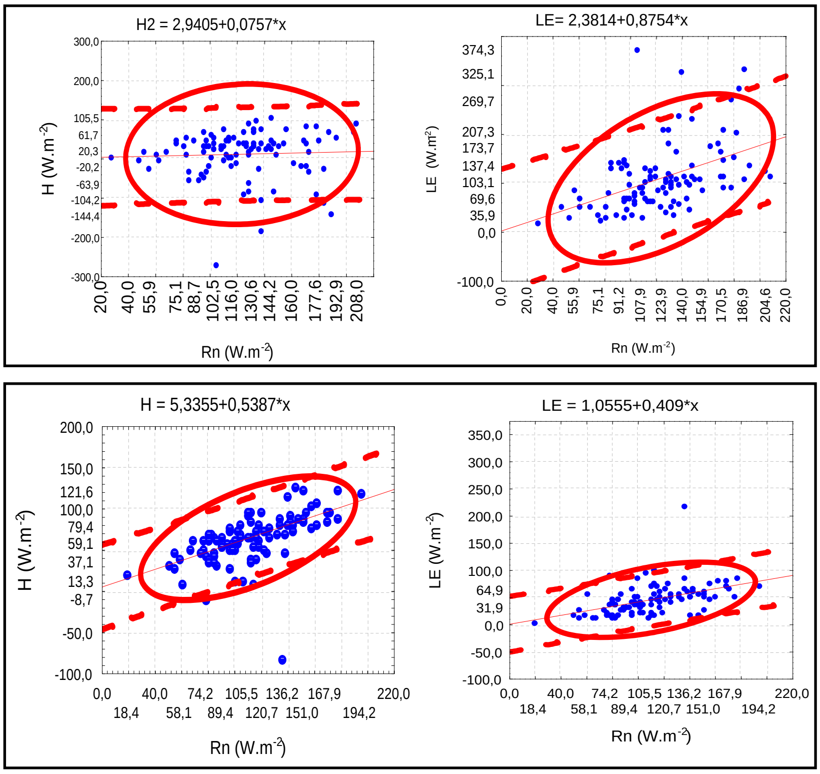

Figure 3. Relationship between Net Radiation (Rn) and Turbulent Transport of Energy (H and LE)

effect to the properties of energy flux. Influence of this process of land use change is important to energy and mass exchange between the surface and atmosphere. The relationship between turbulent flux and net radiation showed that the increase in Rn in the forest induces latent heat flux but in the grass land this increase induces sensible heat flux (Fig. 3)

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