FluxLetter

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Carbon dioxide flux measurements at young post-fire Boreal forest sites in central Canada

by Brian Amiro

Fire in the boreal forest

Fire clearly is one of the most important processes that control vegetation development in the circumboreal forest. Figure 1 graphically demonstrates that the wide band of the North American boreal forest has experienced much fire in recent decades, and this has been typical over the past few thousand years. In Canada alone, an average of 2 to 3 million hectares burn annually, although there is large inter-annual variability (Stocks et al. 2002). About 2/3 of the area burned is caused by lightning, and many large fires are difficult to control because of the huge amount of energy released (often > 10 MW/m of fire line; Amiro et al. 2004) and the remote location.

Fire affects the forest carbon (C) balance through two physical events: first, carbon is released by combustion during the fire event, and second, the post-fire forest carbon dynamics are a combination of carbon net uptake by regenerating vegetation and decomposition of fire-killed vegetation. This is further controlled by the type of regeneration following fire, which is a function of the pre-fire vegetation and the post-fire environment. Much of the area burned is characterized by total tree death, and the young post-fire vegetation is dominated by fast growing successional species, which are eventually succeeded by longer-lived tree species. Direct fire combustion releases in Canada are about 1.5 kg C m^{-2} on average, plus some additional greenhouse gases such as methane and nitrous oxide (Amiro et al. 2009). If a forest is to remain carbon-neutral, it needs to gain

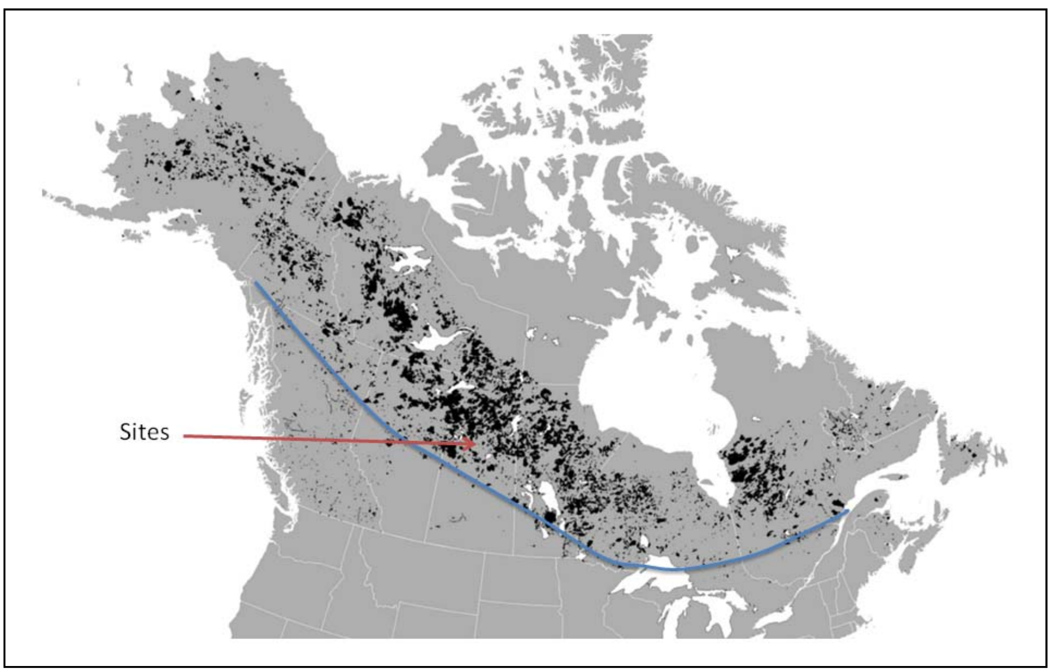

Figure 1: Fires across boreal North America from 1980 to 1999. Each black polygon represents a burned area. The blue line across Canada represents the approximate southern limit of boreal forest. The northern limit corresponds to the area north of the fire polygons. The fire polygons were kindly provided by Canadian fire agencies (provinces, territories, national parks) and the State of Alaska.

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Figure 2: Photographs of the post-fire sites. The upper panels show the 1998 site at 7 years of age, the bottom left panel is the 1989 site and the bottom right is the 1977 site.

this combusted carbon back over the period between sequential fires. Inventory models tell us that fires are an important control determining whether the boreal forest is a net carbon source or sink over any given period (Kurz et al. 2008).

The post-fire sites in central Saskatchewan

In the late 1990s, following the BOREAS experiments in Canada, eddy covariance towers were established along post-fire chronosequences in northern Manitoba and Alaska (led by Mike Goulden and Jim Randerson, respectively, University of California, Irvine). The Canadian Forest Service (led by Brian Amiro) also established a post-fire chronosequence in central Saskatchewan. The Manitoba and Saskatchewan sites took advantage of the long-term mature forest anchor sites that continued since BOREAS. We selected sites that had been burned in 1998, 1989 and 1977 that were within the former southern study area of BOREAS (Figure 2). This area is now the Boreal Ecosystem Research and Monitoring Sites (BERMS), supported by Environment Canada, the Canadian Forest Service, Parks Canada, and funded by various agencies to support university investigators. The post-fire sites had ages that were typical of major fire years in this region. Although we had earlier field campaign measurements (Amiro 2001), the first full year of measurement was in 2001. We gathered full annual data from 2001 to 2006 at the 1998 site, 2003 to 2005 at the 1989 site, and 2004 to 2006 at the 1977 site (Amiro et al. 2006a, Mkhabela et al. 2009). In this area, post-fire vegetation development is often a competition between fast growing trembling aspen and slower growing jack pine and black spruce. We had all three species at the post-fire sites. However, the mature BOREAS sites had been selected to represent large areas of single tree species, which became the Southern Old Aspen, the Southern Old Jack Pine, and Southern Old Black Spruce sites. Much of the surrounding forest tends to be a mixture of these species (often with patches that vary on the order of a few 100 metres), so it is difficult to identify a true mature "control" site for the post-fire chronosequence. We really need to understand the way that these species compete and colonize the landscape to determine the carbon flux dynamics.

The post-fire sites illustrate that fire changes the energy balance,

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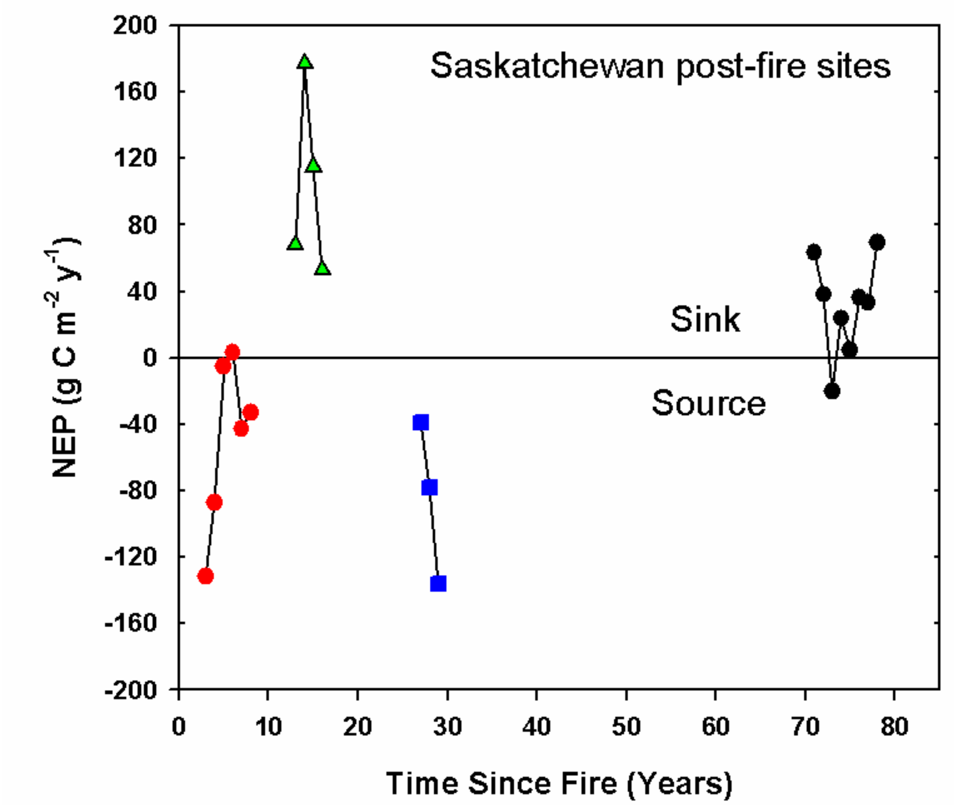

Figure 3. Net ecosystem production at the fire chronosequence sites. Positive NEP is a forest carbon sink. The mature site is the southern old jack pine site as a reference.

with younger sites having higher albedo over about the first 20 years (Amiro et al. 2006b). Peak evapotranspiration is suppressed immediately following the fire, but quickly becomes greater than mature forests because of more broad-leaved species dominating the regenerating forest. Summer-time daily mean Bowen ratios can be as low as 0.5 at about 10 years, compared to mature coniferous forests with values of about 2.

The net ecosystem production (NEP) data tell an interesting story. Figure 3 shows annual NEP for the three post-fire sites plus the southern old jack pine site. The youngest site (burned in 1998) shows clearly increasing NEP, reaching carbon neutrality at five years of age. However, the last two points in the time series for the 1998 site (ages 7 and 8) appear to be a slight carbon source again. This is caused by heterotrophic respiration increasing faster than gross ecosystem production (GEP), possibly because of more fire-generated coarse woody debris becoming in contact with the ground and decomposing. The 1989 site shows strong net carbon uptake. The 1977 site is a consistent carbon source. Although this site has slightly more GEP than the 1989 site, it has greater respiration, probably caused by decomposition of coarse woody debris that is visibly soft and punky. This period of carbon loss at about 30 years could be just a short period when the coarse debris quickly decomposes. This would be consistent with observations when walking through forests of different ages: sites less than 20 years often have perched deadfall, whereas those older than 30 years are often easily traversed because fire-killed trees are lying on the ground and mostly decayed. The mature old jack pine site is a slight carbon sink in most years. As mentioned, this is not the perfect control site for the post-fire chronosequence, which will likely develop into an aspen/pine/spruce mixture of patches.

As a side note, the three post-fire sites used open-path infrared gas analysers. We identified problems with measurements during winter, because we often saw carbon uptake during frozen conditions. The issue has been identified as sensor heating, but there is no easy correction for our data because the tilted configuration makes it difficult to derive heat transfer equations. Our interim solution has been to exclude all carbon flux data when air temperatures are below 0 °C, and gap-fill these by extending regressions from higher temperatures (i.e., only respiration is gap filled). This adds to the uncertainty in the data, although in some years, we have done a sensitivity analysis using various winter respiration rates to see the effect (Amiro et al. 2006a).

Comparisons with nearby harvested sites

The BERMS area also has a harvest chronosequence, which has allowed a comparison of fire and harvest carbon dynamics (Mkhabela et al. 2009). Despite the very close proximity of all sites (less than 100 km), site differences, such as soil moisture, make it difficult to attribute different carbon dynamics caused by fire compared to harvesting. However, the post-fire sites definitely have a greater amplitude in both GEP and ecosystem respiration, which is clearly shown by a greater response of GEP to photosynthetically-active radiation and respiration to temperature. This is caused by more diverse successional vegetation at the post-fire sites, possibly because of heavier soils

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and a more diverse vegetation history.

The Future

The Saskatchewan post-fire chronosequence measurements ended in 2006. However, we are recognizing that there is much more to be learned by measurements at such sites, especially related to the dynamics between successional vegetation development and decomposition of the dead biomass created by fire. Projections indicate that it is likely we will have more future fire in the boreal forest as a consequence of a warming climate (Flannigan et al. 2005), highlighting the need to understand how these post-fire forests operate. These sites, grouped with data from other disturbance chronosequences are part of a current synthesis of data for the North American Carbon Program.

Acknowledgments

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References

Amiro, B.D. 2001. Paired-tower measurements of carbon and energy fluxes following disturbance in the boreal forest. Global Change Biol. 7, 253-268.

Amiro, B.D., Logan, K.A., Wotton, B.M., Flannigan, M.D., Todd, J.B., Stocks, B.J., D.L. Martell. 2004. Fire weather index system components of large fires in the Canadian boreal forest. Inter. J. Wildland Fire 13, 391-400.

Amiro, B.D., Barr, A.G., Black, T.A., Iwashita, H., Kljun, N., McCaughey, J.H., Morgenstern, K., Murayama, S., Nesic, Z., Orchansky, A.L., Saigusa, N. 2006a. Carbon, energy and water fluxes at mature and disturbed forest sites, Saskatchewan, Canada. Agric. For. Meteorol. 136, 237-251.

Amiro, B.D., Orchansky, A.L., Barr, A.G., Black, T.A., Chambers, S.D., Chapin III, F.S., Goulden, M.L., Litvak, M., Liu, H.P., McCaughey, J.H., McMillan, A., Randerson, J.T. 2006b. The effect of post-fire stand age on the boreal forest energy balance. Agric. For. Meteorol. 140, 41-50.

Amiro, B.D., Cantin, A., Flannigan, M.D., de Groot, W.J. 2009. Future emissions from Canadian boreal forest fires. Can. J. For. Res. 39, 383-395.

Flannigan, M.D., Logan, K.A., Amiro, B.D., Skinner, W.R., Stocks, B.J. 2005. Future area burned in Canada. Clim. Change 72, 1-16.

Kurz, W.A., Stinson, G., Rampley, G.J., Dymond, C.C., Neilson, E.T. 2008. Risk of natural disturbances makes future contribution of Canada's forest to the global carbon cycle highly uncertain. Proc. Nat. Acad. Sci. 105, 1551-1555.

Mkhabela, M.S., Amiro, B.D., Barr, A.G., Black, T.A., Hawthorne, I., Kidston, J., McCaughey, J.H., Orchansky, A.L., Nesic, Z., Sass, A., Shashkov, A., Zha, T. 2009. Comparison of carbon dynamics and water use efficiency following fire and harvesting in Canadian boreal forests. Agric. For. Meteorol. 149, 783-794.

Stocks, B.J., Mason, J.A., Todd, J.B., Bosch, E.M., Wotton, B.M., Amiro, B.D., Flannigan, M.D., Hirsch, K.G., Logan, K.A., Martell, D.L., Skinner, W.R. 2002. Large forest fires in Canada, 1959-1997. J. Geophys. Res. 107, 8149, doi: 10.1029/2001JD000484.

Editorial

Rodrigo Vargas and Dennis Baldocchi

We are delighted to celebrate with the FLUXNET community the starting of the third year of FluxLetter. Without the contribution of FLUXNET scientists from different regional networks and active participation of Young Scientists the success of FluxLetter would not be the same. FluxLetter is proud to highlight the high quality of observations of the "breathing of the biosphere" that scientists are recording all around the globe. These unprecedented measurements are part of the legacy that FLUXNET is contributing for the broader scientific community. With this incredible wealth of information new discussions are arising about the use of the data set. In this number, Han Dolman (Chairman of the Terrestrial Observation Panel for Climate) discusses about data policy and the implications of data sharing for the broader scientific community. Furthermore, John Gamon discusses the importance of integrating flux measurements with remote sensing measurements. He presents SpecNet as a way to bridge the measurement gap between satellites and flux towers. We encourage the FLUXNET community to use FluxLetter as a way to share ideas and opinions throughout the network.

FluxLetter has tried to present the diversity of opinions, research sites, young members, and research around FLUXNET. This issue highlights the effects of disturbances in ecosystems showing three cases (fire, hurricane, and insects). Thus, this shows that importance of using long term eddy flux measurements to bring new insights on how ecosystem processes are modified by disturbances.

Our excitement about this issue is shadowed by the lost of a colleague and friend: Laurent Misson. With this issue we want to make a small tribute to Laurent and share with the community thoughts from close friends and colleagues. The FLUXNET Office is deeply touched by the lost of Laurent and we invite the community to read and post on the FLUXNET blog at: http://www.fluxdata.org/Blog/default.aspx


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In This Issue:

A plea for a fully open data policy for FLUXNET

Han Dolman

It has been now over more than 10 years since FLUXNET started expanding rapidly. The recent debate about the leaked CRU emails urges us to reconsider once again our data policies. In essence the debate about these emails centers around the use of data and, in particular, whether such data is freely and publicly available. This goes from the processed data that tends to be more publicly available, to the raw data where data quality control and assessment may generate debates between research groups. While the recent initiative to open up part of the la Thuile database is indeed a much needed and fully laudable first step, I would like to argue that we learn more from the CRU debate and that all data we take in FLUXNET is made publicly available.

Progress in science is often best served by applying new analysis techniques and methods to “old” data. The young aspiring climate modeler for instance, who is developing a complicated land surface scheme, would love to have FLUXNET data on surface energy partitioning. For most of us, particularly the more ecologically minded, surface energy partitioning is a nice side product to see if our eddy covariance achieves energy balance closure. In the hands of this climate modeler such data however are at the core of his validation efforts. Still, our current restricted data policy does not allow such exchange easily. There may well be increased understanding lurking around the corner, but we fail to see it, because the next generation of whizz kids from other institutions and next-door departments has no access to our data.

FLUXNET has shown great value because of the number of sites and biomes that are involved, and the common data processing and analysis techniques that were developed within our community. The la Thuile dataset shows this progress and the added value that has been made in harmonized data processing and common analysis tools. The la Thuile set and previous synthesis datasets have also generated numerous co-authorships for most of us, which have significantly helped shaping our careers. Both data takers and modelers have benefited from these common analyses and while the cases where data takers have not been properly acknowledged or data been misused were painful and should have been avoided, they are negligible in number compared to the overwhelmingly large number of successful collaboration.

Our FLUXNET network is however still run by a rather loose group of individual institutions, that follow not always the same protocols, exert not always the same quality control on the data and often suffer from periodic shortfalls in funding leading to the use of old equipment or substantial data loss. The data FLUXNET produces is however increasingly recognized as an extremely rich and essential data source in various fields, from Kyoto type assessments, to weather prediction and climate models. As a response to this, in several continents groups are in the process of moving this research driven network into a more sustainable routine monitoring network. It is vital for achieving this sustainability that our data policy is more open. Such a policy is completely in line with recommendation of the Global Climate Observing System (GCOS) and the Group on Earth Observation’s (GEO) guidelines and data principles (1). For the establishment of, for instance a Global Integrated Carbon Observing System, we need to make the transition from research network to routine monitoring network (2). This cannot be achieved without an open data policy and transparency. It is in our own and societies best interest that the data of our current network is as freely available as possible, since that only increases the chances of making this transition. An open data policy on its own is not sufficient to make this transition. Data quality control and assessment need to be an integral part of an open data policy. Particularly with the la Thuile harmonized data sets we have taken major strides towards such a transparent quality control procedure. Once such routine systems exist, we can use the data reliably and make progress in our understanding of the working of the major biogeochemical cycles on land. This stops us having to bear the full burden of running these sites, often on a shoestring budget. Instead we can then develop and test our novel techniques at these routine sites and do our analysis work on the full set of sites.

I strongly believe that we can be in the driver seat for a number of the processes mentioned in this comment, such as producing exiting new science and develop the routine monitoring networks. There are also major unknowns in the role of the terrestrial vegetation in the carbon cycle or in the climate system that we yet need to address with our techniques. The response of vegetation to drought, the interaction of carbon with water and nitrogen, the role of forest in a changing climate, or how can carbon sequestration offset effects on the hydrological balance of forests or change radiative properties? All of these questions are of vital importance for progress in the broad field of climate or Earth System Science. We can loose this valuable opportunity to play a leading role and develop into a closed, inward looking community. I do not believe we are a closed community, but to be able to lead the field I suggested above, we urgently need to open up our datasets more widely.

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Integrating remote sensing and flux measurements

John A. Gamon

Eddy covariance is widely used to quantify biospheric-atmospheric carbon and water vapor fluxes and to improve our understanding of the controls on these fluxes. However, from a global perspective, flux towers represent "points" on the ground and cannot cover the entire range of climate space (Running et al. 1999). Furthermore, eddy covariance is best applied in flat terrain and uniform vegetation, leaving much of the world's terrestrial surface unsampled. Satellite remote sensing, including the MODIS sensor, now offers more complete and uniform global coverage and calculates carbon fluxes based on the light-use efficiency model (Running et al. 2004). Relative to field sampling, MODIS operates at coarse temporal and spatial scales, creating data incongruities when comparing satellite data to flux tower data. Efforts at direct comparison often reveal discrepancies between remotely sensed and ground measurements. Sources of disagreement include the difference in sampling scales; b) the reliance of satellite algorithms on biome-based lookup tables and interpolated meteorological data fields to calculate final flux products; and c) the inability of current algorithms to adequately capture short-term variability due to disturbance and stress (Cheng et al. 2006, Running 2008). A more direct assessment of surface-atmosphere fluxes from remote sensing could lead to improved carbon flux estimates that better agree with ground-measured fluxes (Rahman et al. 2005, Gamon et al. 2006b, Sims et al. 2006b). A greater agreement among flux estimates from these diverse sampling methods is becoming increasingly crucial as policymakers and carbon markets demand defensible and transparent data on biospheric carbon exchange.

One way to bridge the measurement gap between satellites and flux towers is to apply scale-appropriate optical sampling that more closely matches the temporal and spatial scale of the flux tower footprint. SpecNet (Spectral Network) was formed with this goal in mind. Since 2003, SpecNet has been advocating the integration of optical sampling with flux measurements for the purpose of improving remote estimates of carbon and water vapor exchanges (Gamon et al. 2006b, 2010). Integrated optical and flux sampling has been adopted at a number of flux tower sites, and has been embraced by several projects within the European Union (e.g. COST Action ESO903 – "Spectral Sampling Tools for Vegetation Biophysical Parameters and Flux Measurements in Europe"), but the full advantages of this integration across the FLUXNET and SpecNet communities have yet to be widely realized. In this editorial, the challenges and benefits of this coordinated optical sampling approach are briefly outlined, with the goal of spurring greater adoption of this method at FLUXNET sites, and a wider collaboration between the remote sensing and flux sampling communities.

A wide range of optical sampling methods have been developed to assess biosphere-atmosphere fluxes. Optical measurements can serve as useful proxies for variables in flux models. The light-use efficiency model states that GEP can be derived as the product of absorbed PAR (APAR) and the efficiency (ε, also called light-use efficiency or LUE) with which absorbed PAR is converted to fixed carbon

Figure 1 - "Phenology station" sampling NDVI in a fen site, Churchill, Manitoba, Canada. Note the flux tower in the background (operated by M. Tenuta, University of Manitoba).

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Figure 2 - PRI Sensors mounted in a Douglas-fir forest canopy, Campbell River, British Columbia, Canada. Sensors based on a design by Garrity et al. 2010. Photo courtesy Martin van Leeuwen.

(Monteith 1977). Good methods exist for measuring *both* terms of this model using optical sensors: APAR can be measured with PAR or NDVI sensors, and light-use efficiency can be measured with PRI (the Photochemical Reflectance Index, Gamon et al. 1997, 2001, Garrity et al. 2010). Similarly, optical sensors can estimate vegetation water content which provides an indicator of stress for drought-prone ecosystems. Water content can be used to estimate evapotranspiration (Claudio et al. 2006, Fuentes et al. 2006), and can provide further indications of light-use efficiency.

Optical sampling methods exist at several levels of technology and cost (figures 1-5). At the most basic level, 2-band "radiometers" can be assembled from paired upward- and downward-looking PAR sensors and pyranometers, and these sensors are already present at many flux tower sites. When properly applied, these instruments can provide a surrogate normalized difference vegetation index (NDVI), a useful metric of both absorbed PAR and phenology that often scales closely with whole-ecosystem carbon fluxes (Huemmrich et al. 1999) or biomass gain (Gamon et al. 2010). Similarly, many sites are now employing webcams for surrogate NDVI measurements (Richardson et al. 2007, see also figure 5). Two-band radiometers are also being used for other wavebands and indices, including the photochemical reflectance index (PRI), offering year-round estimates of photosynthetic light-use efficiency (Garrity et al. 2010, figure 2).

An intermediate level of technology and cost is provided by field spectrometers, including "hyperspectral" (narrowband) sensors that can provide any number of proxy measures, including absorbed radiation (APAR), photosynthetic light-use efficiency, and vegetation water or pigment content. Due to their broad and detailed spectral coverage, these sensors provide more options for modeling carbon or water vapor fluxes than simple radiometers. Recent advances in sensor design and application, including robotic and multi-angle sampling methods (figures 3-5), now allow automated field sampling of flux tower footprints (Gamon et al. 2006a, Leuning et al. 2006, Hilker et al. 2007). These automated instruments provide novel methods for relating whole-ecosystem optical properties to flux measurements and enable year-round observation of light-use efficiency from optical sensors (Sims et al. 2006a, Hall et al. 2008, Hilker et al. 2008, Middleton et al. 2009). Recent studies have demonstrated these stand-level signals can be related to MODIS signals when directional and atmospheric scattering effects are considered (Drolet et al. 2008, Hilker et al. 2009).

Finally, a new variety of imaging spectrometers (Ustin et al. 2004, Bannon 2009), combining the power of imagery with spectral information, are becoming a cost-effective solution to the problem of mapping within a satellite pixel. These spectrometers can be mounted on towers, trams, or airborne platforms to provide a range of coverage in the region of a flux tower, and are particularly useful in footprint analyses (Sims et al. 2006a). When mounted on airborne platforms, these spectrometers provide a bridge between field sensors and satellite sensors (Cheng et al. 2006).

In combination, automated field optical sensors, aircraft imaging spectrometers, and satellite measurements provide a powerful array of data sources for modeling surface-atmosphere

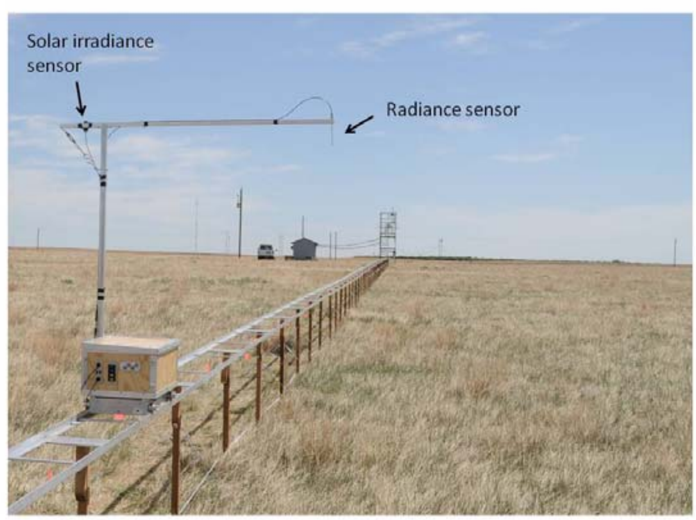

Figure 3 – Tram system (Gamon et al. 2006a) sampling spectral reflectance of the flux tower footprint in a prairie grassland, Lethbridge, Alberta, Canada. Note the flux tower (operated by L. Flanagan, U. Lethbridge) at the end of tramline.

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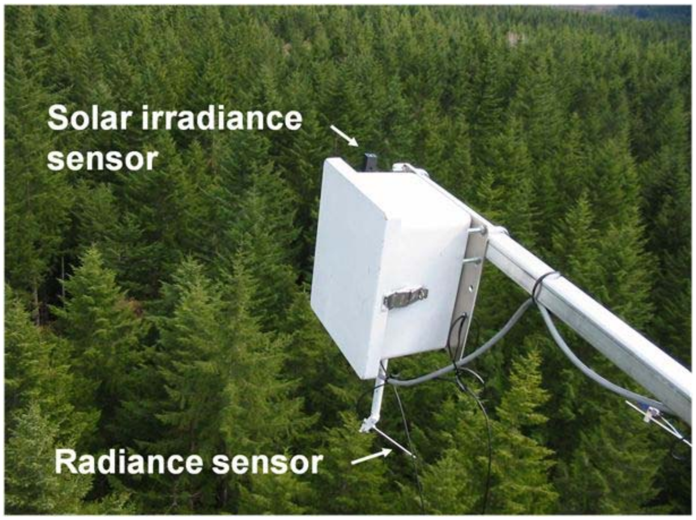

Figure 4 - AMSPEC system (Hilker et al. 2007) for automated, multi-angle hyperspectral measurements of a Douglas-fir forest, Campbell River, British Columbia, Canada.

fluxes across multiple spatial and temporal scales. Flux models driven from optical sensors provide independent estimates of biosphere-atmosphere fluxes that can be validated against direct flux measurements. By calibrating optically-based flux models against direct eddy covariance measurements, it is possible to extrapolate flux measurements to larger regions (Rahman et al. 2001, Fuentes et al. 2006). This approach provides a "bottom-up" method of modeling fluxes that complements "top-down" methods of satellite remote sensing (Running et al. 2004, Rahman et al. 2005, Sims et al. 2006b). This integrated, multi-scale analysis of optical and flux sensors can help identify areas where satellite algorithms need further improvement, provide a powerful tool for footprint analyses, or lead to additional methods of gap-filling missing flux data.

A number of challenges currently prevent effective integration of optical and flux measurements. Primary among them is the current lack of standardization among optical sensors and sampling methods. Different sensor brands have different spectral, radiometric and angular responses, and the different temporal and spatial scales of optical sampling often make it difficult to directly compare measurements across sites. While standardization can be beneficial, enforcement of standards is difficult and sometimes stifles innovation. One solution lies in creating better informatics and cyberinfrastructure tools (i.e. more effective databases and metadata) that enable the flux and optical sampling communities to better define and report the particular sampling methods used. To this end, members of the SpecNet community have begun exploring informatics solutions to data and metadata challenges (Gamon 2006b, 2010), analogous to some of the data standardization and sharing efforts initiated within the flux community (Agarwal et al. 2008, 2010).

To fully benefit from the power of remote sensing, optical sampling and flux measurements, a greater level of coordination between the flux, optical sampling, and remote sensing communities will be needed, with a concerted focus on informatics, including issues of data provenance and transparency. Full realization of the synergistic opportunities provided by linking flux and optical sampling will require that a larger percentage of flux tower sites gather and report optical sampling data along with suitable metadata. Better cyberinfrastructural approaches to storing and accessing data and metadata are needed. The SpecNet web site (http://specnet.info) provides a site registration tool that gathers and makes available basic information on sites and optical sampling methods, and we invite members of the flux sampling community employing optical sampling to register online. Members of the FLUXNET and SpecNet communities are beginning to explore more effective methods for sharing and integrating data. Better integration of flux and optical sampling can ultimately yield an improved understanding of the spatial and temporal patterns of fluxes, the controls of these fluxes, and the opportunities for biospheric carbon sequestration.

Acknowledgements: Thanks to D. Agarwal, N. Coops, T. Hilker, S. Running, and D. Thayer and to members of the SpecNet and FLUXNET communities for helpful comments and contributions to this editorial.

Figure 5 - AMSPEC II system combining a webcam with multi-angle spectral reflectance measurements of the Southern Old Aspen site, Saskatchewan, Canada. Photo: Thomas Hilker.

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References

Agarwal, D.A. 2008. Fluxnet Synthesis Dataset Collaboration Infrastructure . FluxLetter, Vol 1, Issue 1, 2008, pp. 5-7. LBNL Paper LBNL 1273E. http://escholarship.org/uc/item/3dn028qn

Agarwal, D.A. 2010. A data-centered collaboration portal to support global carbon-flux analysis. Lawrence Berkeley National Laboratory: Lawrence Berkeley National Laboratory. LBNL Paper LBNL-1827E. http://www.escholarship.org/uc/item/5rm4c0n2

Bannon, D. 2009. Cubes and Slices. Nature Photonics 3, 627-629.

Cheng, Y., Gamon J.A., Fuentes, D.A., Mao, Z.., Sims, D.A., Qiu H-L., Claudio, H.C., Yang, W., and Huete, A. 2006. A multi-scale analysis of dynamic optical signals in a Southern California chaparral ecosystem: a comparison of field, AVIRIS and MODIS data. Remote Sensing of Environment. 103, 369-378.

Claudio, H.C., Gamon, J.A., Cheng, Y., Fuentes, D., Rahman, A.F., Qiu, H.-L., Sims, D.A., Luo, H., Oechel, W.C. 2006. Monitoring drought effects on vegetation water content and fluxes in chaparral with the 970nm water band index. Remote Sensing of Environment. 103, 304-311.

Drolet, G.G., Middleton, E.M., Huemmrich, K.F., Hall, F.G., Amiro, B.D., Barr, A.G., Black, T.A., McCaughey, J.H., & Margolis, H.A. (2008). Regional mapping of gross light-use efficiency using MODIS spectral indices. Remote Sensing of Environment, 112, 3064-3078

Fuentes, D., Gamon, J.A., Cheng, Y., Qiu, H.-L., Mao, Z., Sims, D.A., Rahman, A.F., Oechel, W.C., Luo, H. 2006. Mapping carbon and water flux in a chaparral ecosystem using vegetation indices derived from AVIRIS. Remote Sensing of Environment. 103, 312-323.

Gamon, J.A., Cheng, Y., Claudio, H., MacKinney, L., Sims, D. 2006a. A mobile tram system for systematic sampling ecosystem optical properties. Remote Sensing of Environment. 103, 246-254

Gamon, J.A., Coburn, C., Flanagan, L., Huemmrich, K.F., Kiddle, C., Sanchez-Azofeifa, G.A., Thayer, D., Vescovo, L., Gianelle, D., Sims, D., Rahman, A.F., Pastorello, G.Z. 2010. SpecNet revisited: bridging flux and remote sensing communities. Canadian Journal of Remote Sensing. Accepted.

Gamon, J.A., Field, C.B., Fredeen, A.L., Thayer, S. 2001. Assessing photosynthetic downregulation in sunflower stands with an optically-based model. Photosynthesis Research. 67, 113-125.

Gamon, J.A., Rahman, A.F., Dungan, J.L., Schildhauer, M., Huemmrich, K.F. 2006b. Spectral Network (SpecNet): what is it and why do we need it? Remote Sensing of Environment. 103, 227-235.

Gamon, J.A., Serrano, L., Surfus, J.S. 1997. The photochemical reflectance index: an optical indicator of photosynthetic radiation-use efficiency across species, functional types, and nutrient levels. Oecologia. 112, 492-501.

Garrity, S.R., Vierling, L.A., Bickford. K. 2010. A simple filtered photodiode instrument for continuous measurement of narrowband NDVI and PRI over vegetated canopies. Agriculture and Forest Meteorology. 150(3), 489-496. doi:10.1016/j.agrformet.2010.01.004.

Hall, F.G., Hilker, T., Coops, N.C., Lyapustin, A., Huemmrich, K.F., Middleton, E.M., Margolis, H.A., and Drolet, G.G. 2008. Multi-angle remote sensing of forest light use efficiency by observing PRI variation with canopy shadow fraction. *Remote Sensing of Environment*, 112(7), 3201-3211.

Hilker, T., Coops, N.C., Hall, F.G., Black, T.A., Wulder, M.A., Nesic, Z., & Krishnan, P. (2008). Separating physiologically and directionally induced changes in PRI using BRDF models. Remote Sensing of Environment, 112, 2777-2788

Hilker, T., Coops, N.C., Nesic, Z., Wulder, M.A., Black, A.T. 2007. Instrumentation and approach for unattended year round tower based measurements of spectral reflectance. Computers and Electronics in Agriculture. 56, 72–84.

Hilker, T., Lyapustin, A., Hall, F.G., Wang, Y., Coops, N.C., Drolet, G., & Black, T.A. (2009). An assessment of photosynthetic light use efficiency from space: Modeling the atmospheric and directional impacts on PRI reflectance. Remote Sensing of Environment, 113, 2463-2475

Huemmrich, K. F., Black, T. A., Jarvis, P. G., McCaughy, J. H., Hall, F. G. 1999. High temporal resolution NDVI phenology from micrometeorological radiation sensors. Journal of Geophysical Research. 104 No. D22, 27,935-27,944.

Leuning, R., Hughes D., Daniel, P., Coops, N.C., Newnham, G. 2006. A multi-angle spectrometer for automatic measurement of plant canopy reflectance spectra. Remote Sensing of Environment. 103, 236–245.

Middleton, E.M., Cheng, Y.B., Hilker, T., Black, T.A., Krishnan, P., Coops, N.C., and Huemmrich, K.F. 2009. Linking foliage spectral responses to canopy-level ecosystem photosynthetic light-use efficiency at a Douglas-fir forest in Canada. Can. J. Remote Sensing. 35(22), 166-188.

Monteith, J.L. 1977. Climate and the efficiency of crop production in Britain. Philosophical Transactions of the Royal Society of London. B281, 277-294.

Rahman, A.F., Gamon, J.A., Fuentes, D.A., Roberts, D.A., Prentiss, D. 2001. Modeling spatially distributed ecosystem flux of boreal forests using hyperspectral indices from AVIRIS imagery. Journal of Geophysical Research. 106, No. D24, 33579-33591.

Rahman, A.F., Sims,D.A., Cordova,V.D. El-Masri, B.Z. 2005. Potential of MODIS EVI and surface temperature for directly estimating per-pixel ecosystem C fluxes. Geophysical Research Letters. 32, L19404, doi:10.1029/2005GL024127.

Richardson, A.D., Jenkins, J.P., Braswell, B.H., Hollinger, D.Y., Ollinger, S.V., Smith, M.L. 2007. Use of digital webcam images to track spring green-up in a deciduous broadleaf forest. Oecologia. 152, 323–334.

Running, S.W. 2008. Ecosystem disturbance, carbon and climate. Science. 321, 652-653.

Running, S.W., Nemani, R.R., Heinsch, F.A., Zhao, M., Reeves, M., Hashimoto, H. 2004. A continuous satellite-derived measure of global primary production. BioScience. 54(6), 547-560.

Running, S.W., Baldocchi, D.D., Turner, D.P., Gower, S.T., Bakwin, P.S., Hibbard, K.A. 1999. A global terrestrial monitoring network integrating tower fluxes, flask sampling, ecosystem modeling and EOS satellite Data. Remote Sensing of Environment. 70, 108-127.

Sims, D.A., Luo, H., Hastings, S., Oechel, W.C., Rahman, A.F., Gamon, J.A. 2006a. Parallel adjustments in vegetation greenness and ecosystem CO_2 exchange in response to drought in a Southern California chaparral ecosystem. Remote Sensing of Environment. 103, 289-303.

Sims, D.A., Rahman, A.F., Cordova, V.D., El-Masri, B.Z., Baldocchi, D.D., Flanagan, L.B., Goldstein, A.H., Hollinger, D.Y., Misson, L., Monson, R.K., Oechel, W.C., Schmid, H.P., Wofsy, S.C., Xu, L. 2006b. On the use of MODIS EVI to assess gross primary productivity of North American ecosystems, Journal of Geophysical Research. 111, G04015, doi:10.1029/2006JG000162.

Ustin, S.L., Roberts, D.A., Gamon, J.A., Asner, G.P., Green, R.O. 2004. Using imaging spectroscopy to study ecosystem processes and properties. BioScience. 54(6), 523-533

Highlight Young Scientist

Lutz Merbold

My name is Lutz Merbold and I am currently working on total greenhouse gas balances of managed grasslands in Switzerland. The dynamic team I am part of is the Grassland Science Group at the Swiss Federal Institute of Technology (ETH), Zurich, headed by Prof. Nina Buchman.

Looking back in the past I tried to remember how I ended up here: an exciting job which is often challenging and at the same time satisfying, while being able to do ecological research around the globe and interact with different cultures and people. After finishing my undergraduate studies in biology I wanted to focus primarily on ecology and therefore moved to Jena, a small town in the east of Germany where Ernst Haeckel historically defined the subtopic of "ecology" in biology in 1866. Today that same institute of ecology continues to do research on a wide spectrum of ecological subjects. During my undergraduate studies I started working as a research technician for the Max- Planck Institute for Biogeochemistry (MPI-BGC) in Siberia and returned one year later to an outstanding place (Figure 2) to do my MSc thesis research.

In Siberia I tried to explore how the ecosystem carbon exchange of a typical tundra ecosystem may change after drainage as one possible outcome of ongoing global climate change in the region (Merbold et al. 2009a). In particular, the Arctic regions are supposedly severely struck by increasing global surface temperatures. Detailed understanding of ecosystem responses to changing abiotic factors is of crucial importance in this region as this may affect the vast reservoir of carbon stored in permafrost soils which were accumulated during the Pleistocene (Dutta et al. 2006; Zimov et al. 2006). The study showed strong decreases in the global warming potential of the tundra ecosystem after drainage, while simultaneously functioning as a small source of greenhouse gases to the atmosphere. The data collected can be used a baseline for long-term ecological research at this experimental site.

Doing research in Siberia influenced my further decision on strengthening my scientific comprehension of nutrient cycling (primarily carbon) in terrestrial ecosystems through the application of a whole range of different technologies, such as eddy covariance and chamber measurement. I was offered a PhD position supervised by Dr. Werner L. Kutsch at the MPI-BGC and was able to spend three years working in Zambia and South Africa. During this time, I specialised in developing a detailed understanding of the two major processes, respiration and photosynthesis, in the still poorly understood *miombo* woodlands (see also Fluxletter Vol.2 No. 1, 2009).

One part of the thesis was to study the variation of ecosystem carbon fluxes across a rainfall gradient in a variety of ecosystems across Africa (Merbold et al. 2009b). The study showed that mean annual precipitation is the major driver of carbon fixation in savanna ecosystems, while ecosystem type showed less influence. Temperature had an effect on ecosystem respira-

Figure 1: Lutz Merbold

Figure 2: Aerial image of a large scale drainage experiment in a common tussock-tundra ecosystem, Far-East Federal District, Russia. Photo credit S.A. Zimov

Highlight Young Scientist

Figure 3: Crew during the installation of the lightning protection at the Mongu Fluxtower in Kataba Forest, Western Zambia. photocredit W. Ziegler

tion in regions receiving more than 1000 mm of rainfall per year. Respiration at sites receiving less precipitation per year was driven by water availability in the soil. Additional to specifying primary drivers influencing carbon exchange, the study linked information found at the ecosystem level using eddy covariance data to remote sensing products. This is important since the network of long-term carbon observation in Africa is still very limited. Eco-physiological interpretation of flux-tower data was achieved in connection to satellite products as f_{APAR}. We could clearly differentiate between C_4- and C_3-plant dominated ecosystems from the obtained remote sensing data in relation to the flux measurements.

During this time I realized that carbon cycle research tends to focus on natural "intact" ecosystem primarily, while disturbances and the accompanying changes in ecosystem structure and therefore also in carbon exchanges are less understood for most ecosystems. Therefore I finalized my thesis on the aspect of carbon exchange of highly seasonal environments (Africa and Siberia) under the aspect of anthropogenic disturbance. Anthropogenic disturbances were defined on two different timescales, long-term such as climate change in Siberia and short-term such as deforestation and continuous land degradation due to charcoal production in the *miombo* woodland in Zambia.

Understanding the responses of ecosystems to disturbances such as forest degradation by logging, charcoal production and global climate change in the future will be one of the big challenges not only in terms of carbon storage but also in the context of conserving biodiversity. In trying to comprehend such responses, I combined carbon flux measurements at the ecosystem and process level scale in Zambia, including the site specific disturbance regime. Some important findings were that we observed no changes in soil respiration between the undisturbed and the degraded (logging, grazing and charcoal production) site in Zambia. When analyzing data spatially, another key result was that there exists a close correlation between respiratory efflux and soil carbon content, but not with meteorological variables nor total above- or belowground biomass. The gained knowledge can either be applied for further protection scenarios and/or be applied for sustainable use of the natural woodlands in Zambia (Merbold et al. submitted and Kutsch et al. in prep).

What's next? I'll continue working on flux data; particularly data collected during the three years of CarboAfrica and widen my horizon to more complex structures in nutrient cycling. This will include the linkage of other nutrient cycles (e.g. Nitrogen and Phosphorous) and determining total greenhouse gas balances of ecosystems as well as associated new techniques to study the various pathways of C and N in the terrestrial biosphere. One of my additional interests is to learn more about large scale ecological models.

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Further Reading

Merbold L, Ardö J, Arneth A, Scholes RJ, Nouvellon Y, de Grandcourt A, Archibald A, Bonnefond J M, Boulain N, Brueggemann N, Bruemmer C, Cappelaere B, Ceschia E, El-Khidir H A M, El-Tahir B A, Falk U, Lloyd J, Kergoat L, Le Dantec V, Mougin E, Muchinda M, Mukelabai M M, Ramier D, Roupsard O, Timouk F, Veenendaal E M and Kutsch W L 2009a Precipitation as driver of carbon fluxes in 11 African ecosystems. Biogeosciences 6, 1027-1041.

Merbold L, Kutsch W L, Corradi C, Kolle O, Rebmann C, Stoy P C, Zimov S A and Schulze E D 2009b Artificial drainage and associated carbon fluxes (CO_2/CH_4) in a tundra ecosystem. Glob. Change Biol. 15, 2599-2614.

Zimov S A, Davydov S P, Zimova G M, Davydova A I, Schuur E A G, Dutta K and Chapin F S 2006 Permafrost carbon: Stock and decomposability of a globally significant carbon pool. Geophys. Res. Lett. 33.

Merbold L, Mukelabai M M, Ziegler W and Kutsch W L (xxxx) Spatial and temporal variation of CO_2 efflux along a disturbance gradient in a *miombo* woodland in Western Zambia. submitted to Biogeosciences

Kutsch W L, Merbold L, Ziegler W, Muchinda M, Mukelabai M M and Scholes R J (xxxx) *Miombo* forests and the energy needs of people: The Charcoal Trap. in preparation

Investigating disturbance and recovery following a hurricane along the Everglades mangrove coast

Victor Engel, Jose Fuentes, Jordan Barr

Since 2003, we have investigated net ecosystem exchange (NEE) of CO_2 using eddy covariance (EC) above the largest contiguous mangrove forest in North America, found along the Gulf of Mexico coast in Everglades National Park. This coast is subject to periodic hurricane disturbance, and this forest was impacted by the Labor Day storm of 1935, Donna in 1960, and Andrew in 1992. The most recent storm to hit this region was Hurricane Wilma in October 2005 with sustained winds of 176 kilometer per hour. The center of landfall was close to our EC site. During the storm the tower, instrumentation, and data acquisition system were destroyed by winds and ~2. 5 m storm surge. We rebuilt the site and measurements resumed in November 2006. The storm provided a natural experiment, and before and after Wilma observations document hurricane impacts on carbon cycling in mangroves.

Site location and description

The site (25.3646°N, 81.0779°W) is located within a riverine and fringing mangrove forest close to the mouth of Shark River in western Everglades National Park (Figure 1). Dominant tree species reach heights of 15-20 m. The region experiences semi-diurnal tides, and tides reach up to 0.5 m above the surface. Peat thickness above the karst bedrock reaches 5 to 6 m. Annual minimum salinity ranges from 2 to 18 parts per trillion (ppt) during peak river discharge, and maximum salinity (30-35 ppt) occurs in May and June.

Construction of a 30-m flux tower (Figure 2) and a 250-m boardwalk from the banks of Shark River started in June 2003. The tower base is 1.5 m above the surface, and is supported by a square grid of central tiers driven ~3 m into the sediment. Crossbeams to peripheral tiers provide additional stability and prevent the structure from sinking into the peat.

Impacts of and recovery from Wilma

Prior to Wilma, annual net ecosystem productivity (NEP) estimates for 2004-05 (1170 ± 145 g

Figure 1: The mangrove forest occupying the Gulf of Mexico coast in Everglades National Park is the largest of its kind in North America.

Figure 2. The eddy covariance tower, seen here before Hurricane Wilma, extends ~10 m above the 20 m tree tops and is supported by a wooden platform built on a peat substrate 5 to 6 m thick.

Investigating disturbance and recovery following a hurricane

Figure 3. In October 2005, Hurricane Wilma inflicted heavy damage to the mangrove forest along the Gulf of Mexico coast in Everglades National Park (top panels, courtesy of Thomas J. Smith III, USGS) as depicted in these before and after comparisons. The storm resulted in near complete defoliation and 30% mortality of trees at the study site (bottom panels). EC measurements resumed in November 2006.

C m^{-2} yr^{-1}) were greater than those reported for terrestrial ecosystems (e.g., Baldocchi et al., 2001; Hirata et al., 2008). In Barr et al. (2010), we describe how tidal export of dissolved carbon is largely responsible for high NEP estimates derived from EC. However, in general the annual NEP of tropical ecosystems is greater than that of temperate ecosystems due to year-round productivity (Luyssaert et al., 2007). Relatively low ecosystem respiration rates (R_E) as a result of anaerobic conditions were also responsible for high NEP estimates. Nighttime R_E values varied from 1.71 ± 1.44 to 2.84 ± 2.38 μmol (CO_2) m^{-2} s^{-1} at soil temperature of 15 ± 2 °C and 20 ± 2 °C, respectively. These R_E values are lower by a factor of 2 compared to terrestrial AmeriFlux and EuroFlux sites (Falge et al., 2001).

The storm defoliated much of the forest and resulted in ~30% mortality of mature trees at the EC site (Figure 3). Following Wilma, we observed decreases in daytime NEE. For example, monthly composite diurnal NEE trends showed that in April 2007, mid-day NEE was reduced by 3 to 8 μmol (CO_2) m^{-2} s^{-1} compared to April 2004 (Figure 4). Differences in pre- and post-storm NEE values were not attributed to inter-annual differences in the local climate. Environmental drivers such as solar irradiance, net radiation, air temperature, and vapor pressure deficit were not substantially different during these two periods. A similar decrease in total annual NEP was observed when post-storm values were compared to pre-storm quantities (Figure 5). The largest decreases occurred during 2007 and 2008, and by 2009, the differences between pre- and post-storm annual NEP values had declined. Such results indicate the state of

Investigating disturbance and recovery following a hurricane

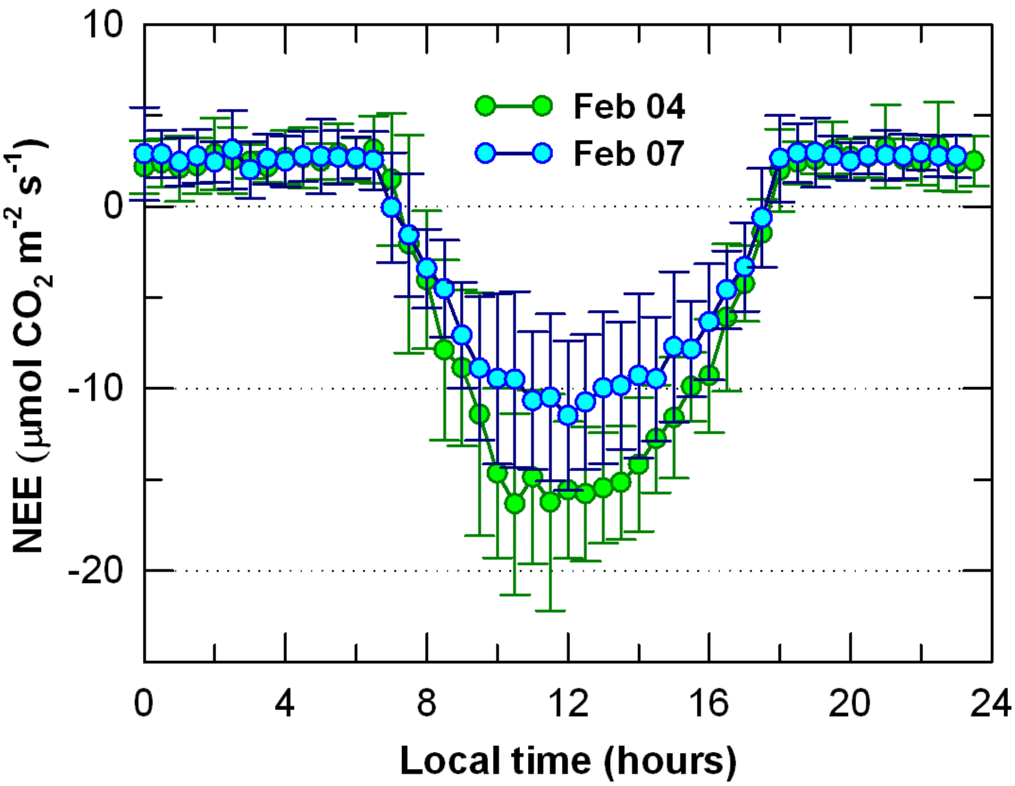

Figure 4 Higher nighttime respiration and reduced daytime uptake rates are apparent in net ecosystem CO_2 exchange after Wilma.

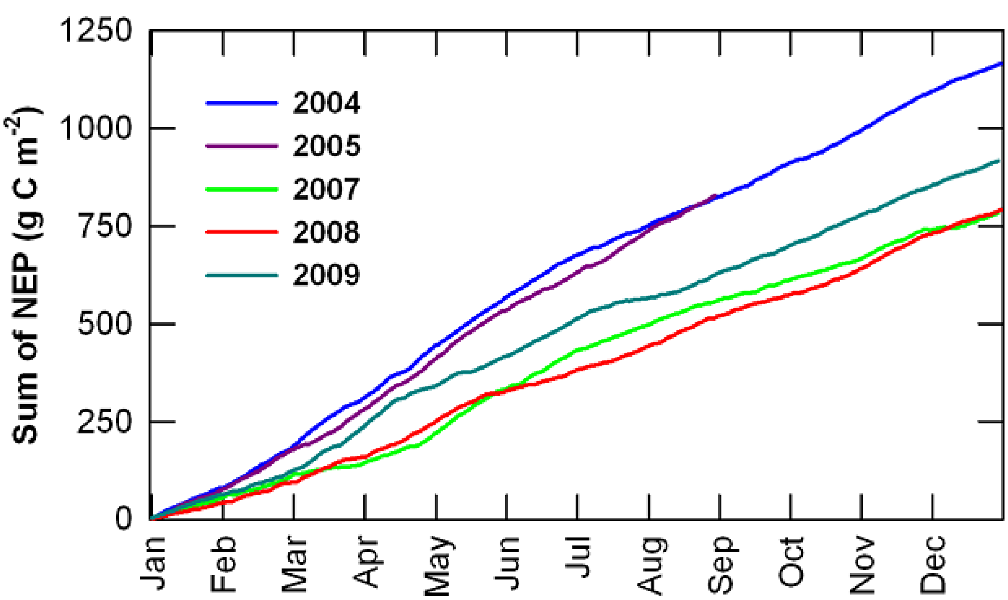

Figure 5 A running summation of daily NEP shows large differences in the magnitude of annual carbon uptake by the forest before and after Wilma. Recovery is apparent in the partial return in 2009 towards pre-storm NEP values.

ecosystem recovery.

Reductions in NEP were mediated via several intrinsically related processes. First, following defoliation and tree mortality, there was an immediate reduction in physiologically active biomass. Second, litter and woody debris from downed limbs and stems were generated by the hurricane. Decomposition of this material contributed to forest respiratory fluxes. In response to loss of foliage in the upper canopy layers, increased penetration of solar irradiance resulted in a 1.8 to 3.6 °C increase in soil temperature, and a more aerated canopy further augmented respiratory processes. The lower net productivity values in the first few years after the storm were likely a result of both decreased foliage and enhanced respiratory processes.

In the first year of measurements following the storm, annual NEP was reduced by 33% compared to 2004, with an 8% reduction in GPP and a 21% increase in R_E (Figure 6). To differentiate the direct effects of the storm from those induced by inter-annual climate variability we employed multivariate ridge-regression models relating monthly NEP, GPP, and R_E to environmental variables. The model was conditioned on pre-storm data and then used to generate post-storm estimates of monthly NEP, GPP, and R_E based on environmental conditions recorded in 2007-09. The disturbance caused a reduction of at least 1100 g m^{-2} in NEP during these three years. R_E remained significantly higher

Investigating disturbance and recovery following a hurricane

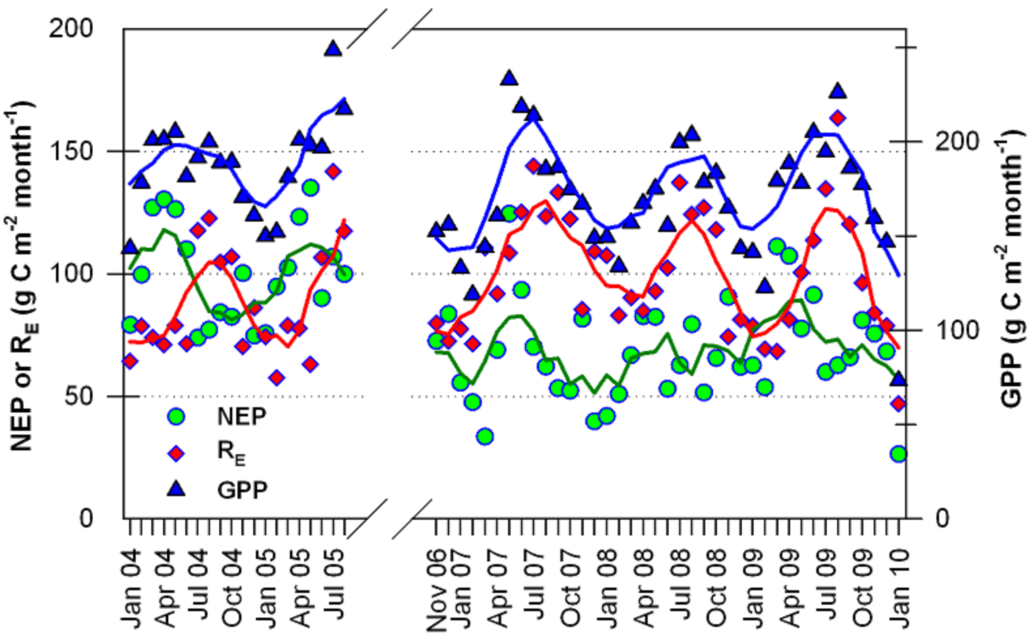

Figure 6. Monthly total NEP was lower and R_E was higher in the years following Hurricane Wilma. The storm's effects on GPP were less obvious due to rapid leaf regeneration and accelerated growth in the understory.

than pre-storm values through 2009. GPP recovered more quickly than NEP or R_E, probably due to widespread epicormic leaf regeneration and accelerated growth in the understory. The quick recovery of GPP to pre-storm values reflects the adaptation of mangroves to frequent disturbances. This recovery is consistent with the 4-year recovery to the universal "self-thinning" line of mangroves shown by surveys along the Everglades coast following Hurricane Andrew (Ward and Smith, 2007).

Implications and future directions

Prior to the storm, our data showed canopy light use efficiency decreases with increasing salinity (Barr et al. 2010). In the era of sea level rise, salinity at this site is expected to increase. Our findings suggest increased salinity can cause a decrease in productivity, and therefore, in peat accretion. If peat accretion is lower than rate of sea level rise, the survival of mangroves may be in question. The before and after Wilma data indicate that hurricane impacts on carbon cycling must also be considered in any long-term projections of mangrove ecosystem function. A recent grant from the Department of Energy's National Institute of Climate Change Research with collaborators from the Florida Coastal Everglades LTER (FCE-LTER), Thomas J. Smith III (USGS) and Victor Monroy-Rivera and Robert R. Twilley (Louisiana State University) will help us address this issue.

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References

Baldocchi, D.D., et al., 2001. FLUXNET: a new tool to study the temporal and spatial variability of ecosystem-scale carbon dioxide, water vapor, and energy flux densities, Bull. Amer. Meteorol. Soc., 82, 2415-2434.

Barr J.G., Engel, V.C., Fuentes, J.D., Zieman, J.C., O'Halloran, T.L., Smith III, T.J., and Anderson ,G.H., 2010. Controls on mangrove forest-atmosphere carbon dioxide exchanges in western Everglades National Park. In revision, J. Geophys. Res. [Biogeo.]

Hirata, R., et al., 2008. Spatial distribution of carbon balance in forest ecosystems across East Asia. Agric. For. Meteor., 148, 761-775.

Luyssaert, S., et al., 2007. CO_2 balance of boreal, temperate, and tropical forests derived from a global database, Global Change Biology, 13, 2509-2537.

Falge, E., et al. 2001. Gap filling strategies for defensible annual sums of net ecosystem exchange, Agric. For. Meteor., 107, 43-69.

Ward, G. A., and Smith, T.J. III. 2007. Predicting mangrove forest recovery on the southwest coast of Florida, in *Science and the storms: the USGS response to the hurricanes of 2005*, edited G.S. Farris et al., pp. 175-182, U.S. Geological Survey Circular 1306.
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Impacts of beetle-induced forest mortality on carbon, water and nutrient cycling in the Rocky Mountains

Elise Pendall, Brent Ewers, Urszula Norton, Paul Brooks, W.J. Massman, Holly Barnard, David Reed, Tim Aston, John Frank

Conifer forests across western North America are undergoing a widespread mortality event mediated by an epidemic outbreak of bark beetles of the genus *Dendroctonus* and their associated bluestain fungi (*Ophiostoma* spp.). As of late 2009, beetles have impacted over 600,000 hectares in northern Colorado and southern Wyoming (US Forest Service aerial survey estimates), with the majority of mature lodgepole pine (*Pinus contorta*) and Englemann spruce (*Picea englemanii*) expected to be dead by 2012 (Figure 1; Figure 2). While bark beetles are native to North American forests, the importance of insect outbreaks on water, C and N cycling has increased in recent years as a result of past timber management, fire exclusion, recent warming trends and drought (Allen et al. 2010). A recent modeling study suggests that CO_2 emissions from beetle-induced lodgepole pine mortality in British Columbia, Canada may be similar in magnitude as stand-replacing fires (Kurz et al 2008).

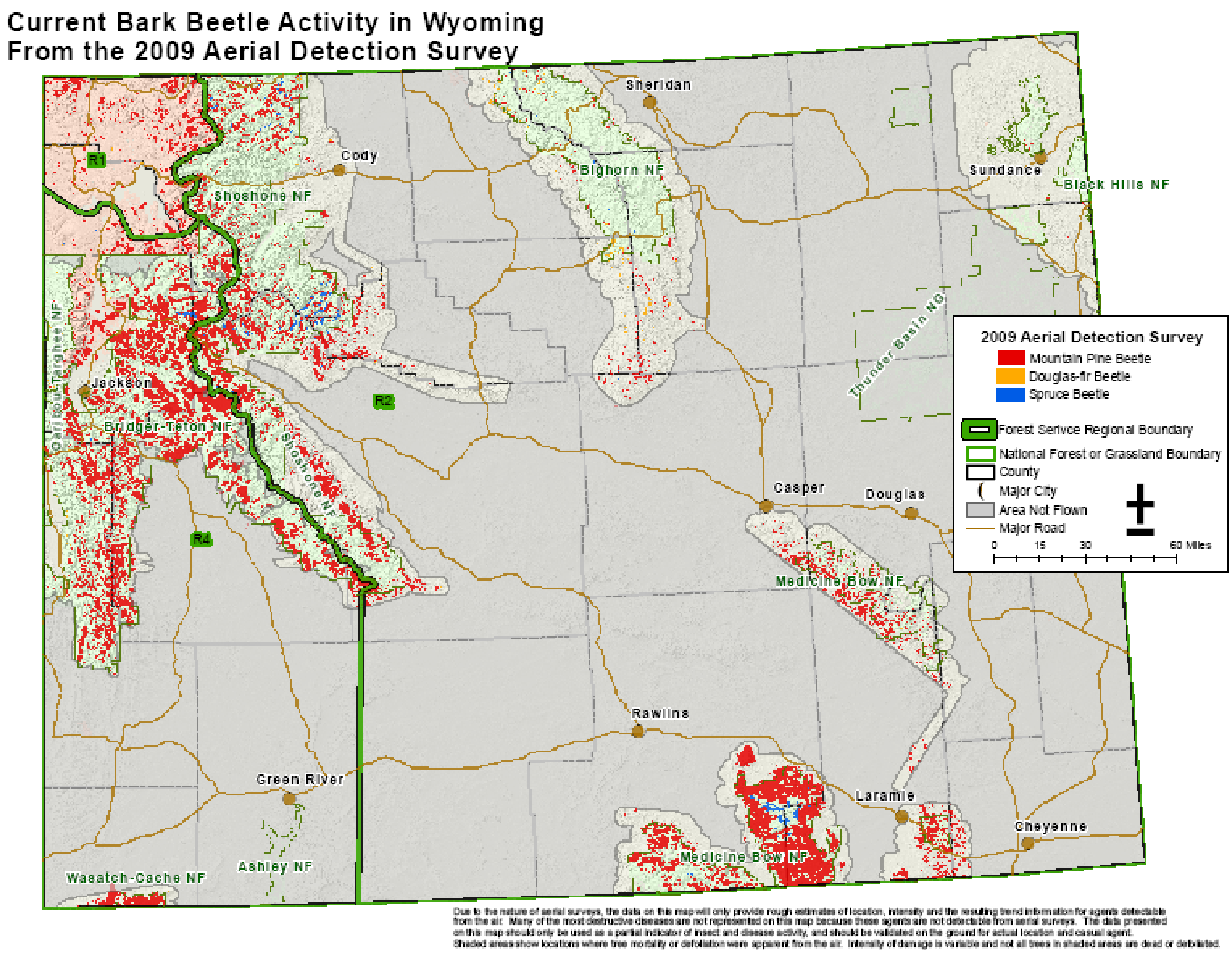

Figure 1: Current bark beetle activity in Wyoming

Impacts of beetle-induced forest mortality

Figure 2. View of middle-elevation lodgepole pine forest in foreground, Medicine Bow range in background. Photography by Josh King.

Experimental girdling of lodgepole pines led to a 92% increase in water outflow, compared to a 277% increase resulting from clearcutting (Knight et al. 1991). Despite the enormity of the currently spreading bark beetle epidemic, little is known of its impact on carbon, water and nitrogen cycles.

Bark beetles spend much of their life as larvae under the bark of host trees, feeding on phloem. Although healthy host trees can repel beetles through enhanced resin production, the trees' defenses are overwhelmed by mass attacks synchronized by pheromones. Tree death occurs through occlusion of xylem by blue-stain fungus carried by the beetles, resulting in death of trees within months of attack (Figure 3; Knight et al. 1991). While the beetle has several hosts, lodgepole pine is especially important due to its large spatial extent, its timber, recreational and wildlife habitat values, and its controls over carbon, water and nutrient cycles in mid-elevation forests of the central Rockies (Knight et al. 1991) including southern Wyoming. Beetle mortality of Englemann spruce is a concern in subalpine forests, where snowpack accumulates in the headwaters of rivers that supply Western cities with most of their water.

While predictive understanding of the bark beetle epidemic is improving, much less is known about its subsequent impact on plant succession and carbon, water and nutrient cycling. Much of the current understanding has been hypothesized from comparisons to fire research or simulated with models (Kurz et al. 2008). Forest managers believe that lodgepole pine is likely to become re-established following bark beetle mortality (Jenkins et al 2008), but the rate of recovery and resulting stand density and productivity are impossible to predict with current knowledge. Furthermore, successional trajectories at upper and lower forest boundaries may not be predictable from stand dynamics of the recent past. On annual to decadal timescales, the responses of C, water and nutrient cycling to the beetle epidemic are linked to forest stand dynamics, particularly leaf area index (LAI), as suggested by our hypotheses, presented in Figure 4.

Near our study area in the Medicine Bow Mountains (Figure 1), beetle attacks were simulated by girdling trees on small experimental patches with the main objective of studying effects on water and N cycling. The girdling treatment increased discharge below the rooting zone (Knight et al. 1991). Extensive spruce beetle mortality was associated with increased streamflow in Colorado (Bethlahmy 1974) and Montana (Potts, 1984). However, other key components of the water cycle, such as

Figure 3. Center, beetle close-up (~2-mm length) and sapwood in the cross-section stained with bluestain fungus. Tree on left is covered with the typical "popcorn" where the tree has "pitched out" the beetles by exuding resin. In mass attacks, enough beetles survive in the trees to lay eggs and the subsequent generation kills the tree as the bluestain fungus residing in the larval gut occludes the xylem. Brent Ewers photos.

Impacts of beetle-induced forest mortality

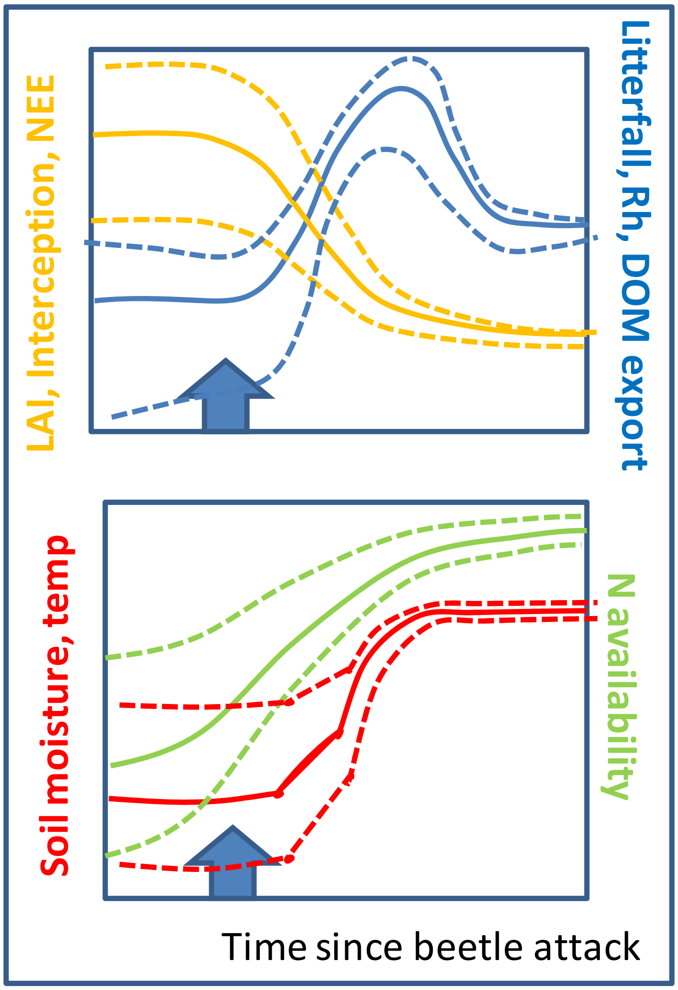

Figure 4. Postulated time course of ecosystem characteristics and biogeochemical responses to MPB attack over 3 year study period in our catchment ecosystems. MPB preferentially kills larger diameter host trees in open stands, leading to spatial variability in mortality patterns and impacts (indicated by dashes). TOP: Tree mortality is associated with rapid loss of LAI, decreased Transpiration, NPP and canopy interception (yellow). A pulse of needle litterfall begins during the second year after attack, and is associated with peaks of decomposition (Rh) and DOM export to streams (blue). BOTTOM: Decreased LAI and transpiration lead to increases in soil moisture and temperature (red). Reduced N uptake by trees enhances N availability (green), which may be inhibited by terpenes the first year after attack.

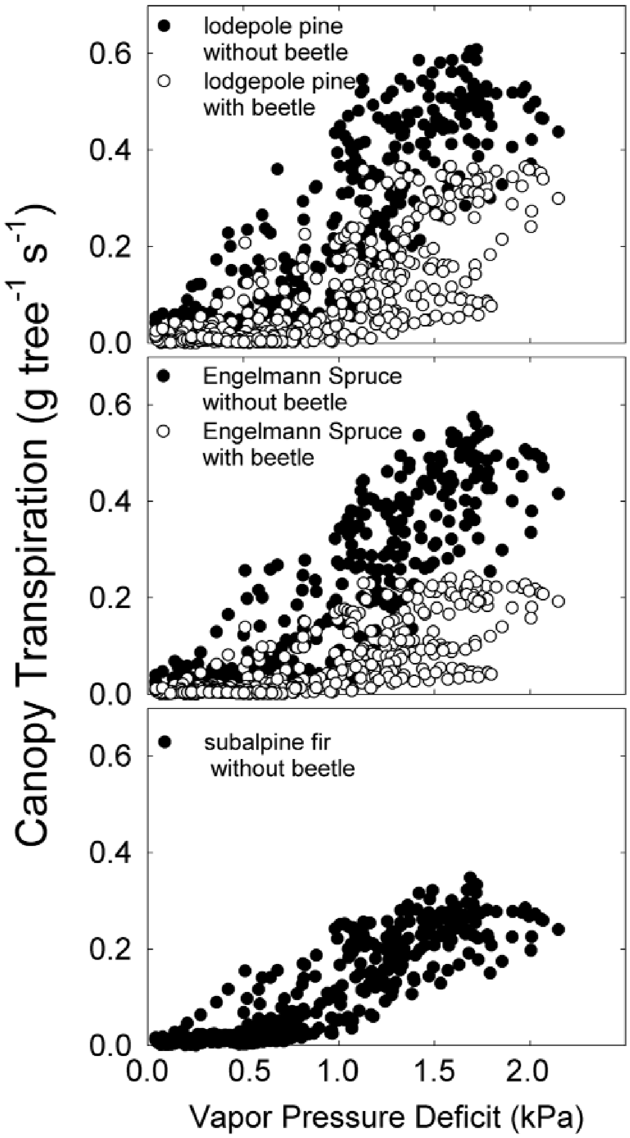

Figure 5. Canopy transpiration with and without beetle/fungus attack from GLEES.

evapotranspiration, have not previously been studied. Our initial sap flux data suggests that within a month of beetle attack and introduction of bluestain fungus, transpiration per tree is reduced to less than half (Figure 5). Water availability following beetle attack is likely to determine in large part the immediate responses of subsequent C and N cycling. Parsons et al. (1994) found that girdling patches with at least 15 trees resulted in significantly greater concentrations of inorganic N while dissolved organic N decreased. Indeed, surviving trees are crucial to retaining N in stands (Knight et al. 1991). How much of this extra available N will be taken up by the next generation of trees, potentially enhancing growth and C sequestration, or lost to streams or denitrifying processes is still unknown.

We are studying ecosystem responses to beetle-induced lodgepole and spruce mortality at middle and upper elevation forests using eddy covariance at Chimney Park (CP) and the Glacier Lakes Ecosystem Experiments Site (GLEES), Wyoming (Figure 6a, b). The GLEES Ameriflux site (41.36642° N ; 106.23995° W; 3126 m) has been in operation since 1999, and is dominated by Englemann spruce and subalpine fir (*Abies lasiocarpa*). Recent data from GLEES suggest a decline in forest C uptake and water loss (Figure 7). The CP site (41.068° N, 106.1195° W 2740 m elevation) has been operating since spring,

Impacts of beetle-induced forest mortality

Figure 6. A. GLEES AmeriFlux scaffold; B. CP tower.

2009, and is dominated by lodgepole pine that has been subjected to varying management regimes in the past several decades. Preliminary data suggest that during the 2009 growing season, mortality had not yet impacted water or CO_2 fluxes. A unique aspect of our study is that we are attempting to close the carbon and water budgets at the tower scale as well as in zero - and first-order drainages via intensive studies of snow hydrology (Figure 8), soil water, respiration and trace gas fluxes within stands varying in time since beetle attack.

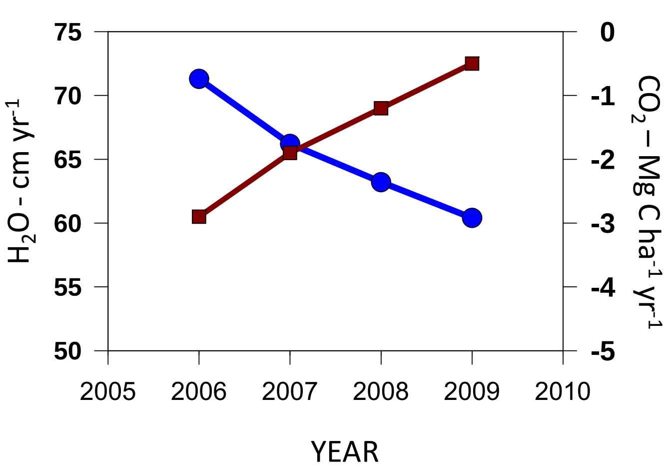

Figure 7. Annual CO_2 and H_2O fluxes from the GLEES AmeriFlux site (negative means uptake by the forest ecosystem).

Clearly, many unknowns exist regarding forest regeneration and C, N and water cycling following beetle attack. Regeneration, or succession, will define the trajectory of forest stand dynamics for the coming century, and the plant communities that are established in the wake of the epidemic will regulate biogeochemical and water cycles over the decadal time frame of succession. Past timber management appears to have affected the rate of infestation and extent of mortality, and will thus also impact regeneration. Our present focus is on short-term (3-year) responses to the current bark beetle outbreak and will set the stage for continued longer-term monitoring (5-10 years and beyond). Our study areas are valuable because of their proximity accessibility in all seasons, and extensive ecological research that has been previously conducted there (e.g., Knight et al. 1991; Parsons et al. 1994; Musselman 1994). Thus, we expect that this initial study should generate mechanistic understanding of immediate

Impacts of beetle-induced forest mortality

Figure 8. Approaching Chimney Park tower in April, 2010, shows high lodgepole mortality especially along the edges of the trail. Ongoing work is documenting the progression of red trees, needlefall, and seedling re-establishment within stands surrounding the tower as drivers of ecosystem fluxes. Paul Brooks photo.

ecosystem responses and also provide a platform for future studies.

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References

Allen, C.D. et al. 2010. A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests. Forest Ecology and Management, 259(4): 660-684.

Bethlahmy, N. 1974. More streamflow after a bark beetle epidemic. Journal of Hydrology. 23:185-189.

Jenkins MJ, Hebertson E, W Page, CA Jorgensen. 2008. Bark beetles, fuels, fires and implications in the Intermountain West. Forest Ecology and Management 254:16-34.

Knight DH, JB Yavitt and GD Joyce. 1991. Water and nitrogen outflow from lodgepole pine forest after two years of tree mortality. Forest Ecology and Management 46:215-225.

Kurz WA, CC Dymond, G Stinson, GJ Rampley, ET Neilson, AL Carroll, T Ebata, L Safranyik. 2008. Mountain pine beetle and forest carbon feedback to climate change. Nature 452:987-990.

Musselman, R. C., technical coordinator. 1994. **The Glacier Lakes Ecosystem Experiments Site**. Gen. Tech. Rep. RM-249. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 94 p.

Parsons WFJ, SL Miller and DH Knight. 1994. Root-gap dynamics in a lodgepole pine forests: ectomycorrhal and nonmycorrhizal fine root activity after experimental gap formation. Canadian Journal of Forest Research 24:1531-1538.

Potts DF. 1984. Hydrologic impacts of a large-scale mountain pine beetle (*Dendrotonus ponderosae* Hopkins) epidemic. Water Resources Bulletin 20:373-377.

USDA 2010 (http://www.fs.fed.us/r2/mbr/resources/BarkBeetles/index.shtml, 4/12/10)

Correspondence
A tribute to Laurent Misson

A letter to "Speedy" Laurent.

I don't remember precisely when and where we first met. Perhaps you were preparing your research project for CNRS? Or perhaps you were doing a post doc at Marseille modeling the radial growth of Mediterranean trees? Convincing the CNRS of your enormous potential as a researcher was not easy. Your initial project seemed to them to be too ambitious. My role was to help you reduce its scope. Your arrival from UC Berkeley to the DREAM team in Montpellier profoundly influenced our normal habits. The graft worked marvelously. The construction of a rainout shelter – your rainout shelter – demonstrated once again your desire to push the boundaries. Between my modest initial project design and your final realization of it rests the incredible amount of energy you deployed. When I think of you, I can't help think of the Nicolas Ray film "Rebel Without a Cause," in French, "La Fureur de Vivre." The film leaves a sentiment of disillusionment. This sentiment hasn't left me since your departure. I will miss you very much. I miss you already.

Serge Rambal

The minute I got introduced to Laurent, I felt I just met a new friend...and I was right. Back then; I wanted to learn more about plants in arid conditions, since that is where most of the good vineyards are growing. However, with my winemaker background, it was really hard to be taken seriously by the scientific community, and even harder to get enrolled into a PhD program. Laurent was the first person who carefully listened to me. He made me feel that everything I wanted was possible. He helped me refining my ideas and he explained to me how sap flow could be used to quantify the severity of water deficit. Laurent shared his office with me, taught me how to perform field measurement and was the main person helping me throughout my thesis writing. I was amazed by so much generosity. All his actions were a true gift for me, without any expectation in return. He simply cared for others. He thought he could help me and that was enough of a reason for him.

Because I live in Montpellier part of the year, I took care of him when he got appointed to the CNRS and moved back from Berkeley to France. Within a few weeks Laurent had become the friend of all my long time friends; he was organizing documentary sessions to discuss politics and improve social awareness in the community. People from every social layers gravitated around him; with Laurent I met politicians, artists, professional climbers and salsa dancers as well as famous scientists. Life was fun around Laurent. I wish to be able to live my life according to the standards he inspired in me. Laurent Misson was a real mentor.

Thibaut Scholasch

A tribute to Laurent Misson

Laurent passed away already a month ago, and some of us had the opportunity to say goodbye to him in Normandy, together with his family and friends. When our common friend Jeff told me the terrible news, that Friday 5 March, I could hardly believe him. The sudden and absurd disappearance of a dear, irreplaceable, friend, the most enthusiastic and energetic person I've ever met and one of the most involved, bright and hard-worker ecologist of his generation, has changed somehow my conception of life. Life seems a bit more absurd now.

Laurent, was a singular guy, full of contrasts, half Belgian, half French, world citizen, noble inheritance but a bit of a gypsy, an adventurer, funny guy, strong temperament, good friend, smart ass…we actually did not have too many things in common, probably our common interest in understanding things and the pursuit for knowledge. He was interested in whatever kind of knowledge, from science to politics or economics; navigation….I was always interested on listening to his ideas and thoughts.

Laurent and I met the first time in Berkeley; he was actually responsible of my arrival in the biometlab together with Dennis Baldocchi. He used to remind me that the reason he actually choose my CV was because the other's were very bad, no because mine was good, probably trying to keep my ego at the right level. Even if the guy meant to keep the ego of a young scientist under control, he was always, or almost always, able to face challenges with his good sense of humor, very particular, very Laurent. Laurent has a big presence in all the memories I have from this period of my life. I could hardly imagine California without remembering him. We worked together, we laugh, we had party, we fight….but even if we had our personal problems at some point, we were actually able to get over them and continue our friendship and scientific collaboration.

I spent a couple of days with Laurent and Leyla in Montpellier a month before this terrible thing happened. Laurent and I had some articles to discuss and some ideas for future articles. He showed me the huge rain-exclusion roof he and the team built in the experimental site of Puechabon. He was really proud of his rain exclusion experiment and spend sometime to explain me in detail, also how much energy he and the people of the team invested on the design and construction of this, the largest rain-exclusion roofs I've ever seen. He told me his idea of the roof begun to take shape in some conversations we had in an Ameriflux meeting in Boulder together with the two Alex, a couple of years ago. I don't know at which extent I really contributed to this idea, but nonetheless I felt proud that he, such a bright guy, would take my opinions and thoughts into account. At the moment he was actually working on writing papers with the data obtained from the last year water exclusions. He shared with me some of the results obtained so far, how these holm-oaks were able to avoid the water stress. Hopefully his students or colleagues will at some point be able to take over his ideas and ecological vision so we all will benefit from his effort. I am sure he would be happy of that..

We spent some good scientific conversations. He was continuously, almost obsessively, updating his knowledge with new literature in his field. He read a lot before he started writing a paper. At the moment he did a lot of his reading also on ecology and ecological theories and informed me about this "hierarchical theory" he was really interested in, thinking on further developing a theory that at the moment was only this, theoretical. Actually he sounded to me a bit cryptic at that point. I remember I thought I would read a bit about this theory

A tribute to Laurent Misson

before I try and get some more info of what was in his mind. If I have to describe our scientific relation with an ecological term I would say it was a "facultative mutualism".

One thing that struck me from Laurent was that even if he had the position to delegate field work, he was still doing lot of it on his own. I think he just liked a lot to go to the field, spend time in the woods, taking a lot of pleasure of his job. He really loved what he was doing. He was a hard-worker, he always complained I was a lacy guy....probably true, but actually he sometimes made me kind of nervous with his energy and his willingness to work.

His memory is still very present in the day to day life, not only because his name is on some of the articles I am working on right now, but also because my way to think and my vision of life has been somehow influenced by his spirit.

Jorge Curiel Yuste

Truly, I have been avoiding writing this note. On some level, I suppose, I am still in denial of the fact that a person whom I consider my mentor, colleague, and friend, is gone. I met Laurent in 2002, when I was just starting my PhD research. To say that he was instrumental in my work is to say very little indeed; Laurent was my unofficial advisor, and the main force behind my research. After Rodrigo Vargas contacted me with the news, I sat there and thought of the thousands of emails that we've exchanged back and forth, of the dozens of meals that we shared in Berkeley and in the cabins at the Blodgett station, of the tons of soil that we dug preparing the experiments, and of the hundreds of laughs we shared along the way. Laurent always brought 100% of himself to any endeavor, be it a climbing trip, a dinner, or a hard day in the field. It's difficult to think that a person that is such an embodiment of the concept of *Joie de vivre* is not going to pop up on the phone or through Skype and start his usual "What's up, dude! So, listen, I was thinking…." I talked to him a couple of months before the accident through Skype, we discussed a revision of our main paper on Blodgett, and my upcoming trip to Europe, and we were planning to see each other this summer. It's odd that it will always be the last time I saw him.

Laurent's contribution to the field of climate change science is significant and wide-ranging, but that is no secret and not a big surprise, given the amount of talent and energy that he brought to his work. What is amazing is the sheer number of people that he has affected, whom he has worked with, and whose lives he enriched along the way. He has always played down his role in the project we worked on together, but he was instrumental in running an amazing team, and helping the people on that team deal with both scientific and personal troubles. He helped me through some of the most challenging times of my life, and did it completely selflessly. I could go on and describe all the little moments, but there would be far too many to fit here. Suffice it to say that I would have never become the person that I am today, to a large extent, if it was not for Laurent's friendship and support. He will be missed more than words can describe.

Alexander Gershenson

A tribute to Laurent Misson

My memories are full of wonderful moments I shared with Laurent, particularly during our common years in Berkeley. When I came to Berkeley, Laurent was already there, in a different group, though, but at the same building and with similar research interests. His never-ending energy pulled me into new exciting fields of thinking, both scientifically as well as personally. I remember very well, when more than five years ago Laurent – fascinated by his research findings in California – pulled together a group of young scientists to think about new experimental ways on how to investigate the impact of extreme events such as droughts on plant-soil interactions and carbon cycling. He was driven – occasionally even like crazy - and I have to admit, sometime it was hard for me to keep up with his pace. Later then, I saw the impressive facility on whole-ecosystem rain exclusion he built in Montpellier and realized how his vision and thoughts come true. Well, it was not only his vision, but also his strong personal involvement, getting up early in the morning, doing field work, working hard and always with an enthusiastic smile on his face, enjoying what he was doing.

He was not only an inspiring scientist driven by an outstanding amount of curiosity and determination, but also a very close friend. He made my years in Berkeley very special, a memory I will carry with me for the rest of my life. We worked on science, analyzed data and wrote papers, but we also experienced life in California, went to the mountains and deserts, sailed, and explored San Francisco. I am now looking through many, many pictures and see how Laurent laughed and smiled and how he brought smiles to me, to others. Laurent once told me that he wanted to live every moment of his life and didn't want to let invisible boundaries restrict him to a shallow life. Berkeley was an inspiring environment and Laurent was always driving us to challenge our perception in science and beyond science. I remember the moment when he tried to talk a group of us, his friends, into building with him a startup company on environmental consulting at international level. We even went for a little workshop on Berkeley campus on how to build start ups. At the end, the idea did not realize and we continued to be pure scientists, but it taught me how inspiring unrestricted thinking can be, a gift that Laurent had and happily shared.

My thoughts are with Leyla, his wonderful fiancée he met during our shared years in Berkeley, and his family in France and Belgium. Laurent, I miss you.

Alexander Knohl

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