Response of high elevation rocky mountain (Wyoming, USA) forest carbon dioxide and water vapor fluxes to a bark beetle epidemic

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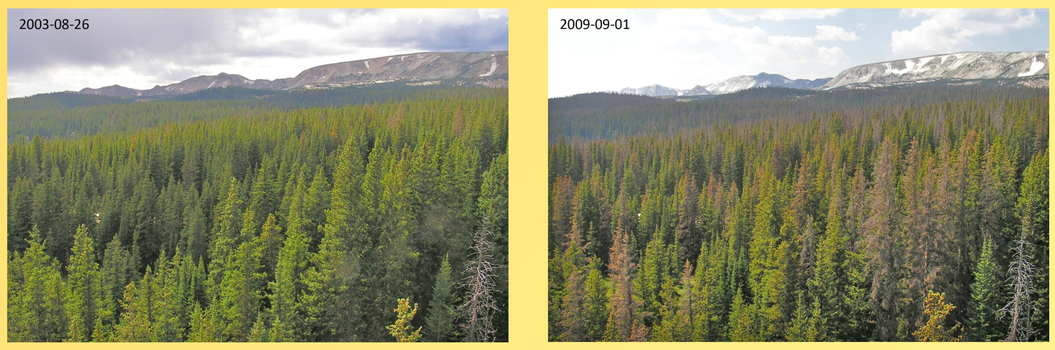
Introduction

In the past decade, considerable forested areas in western North America have been impacted by a variety of bark beetle epidemics. These disturbances result in significant tree mortality and inevitably alter the balances of ecosystem carbon and water exchange. In this study we investigate the impact of this bark beetle epidemic on the net ecosystem exchange of carbon (NEE) and evapotranspiration (ET) at the GLEES AmeriFlux site (southeastern Wyoming, USA). GLEES is a high elevation subalpine forest dominated by Engelmann spruce (*Picea engelmannii*) and subalpine fir (*Abies lasiocarpa*) and is currently experiencing an outbreak of spruce beetle (*Dendroctonus rufipennis*). Given the importance of self heating associated with open-path IRGAs on estimates of NEE, two methods for quantifying the correction are compared.



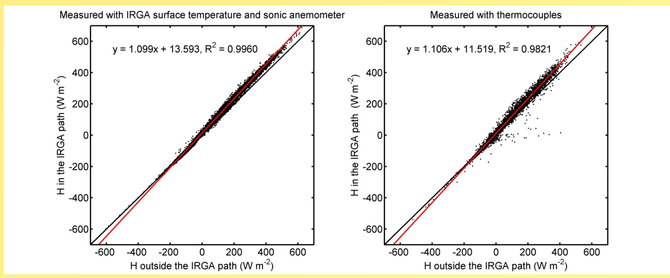
Repeat photography from the GLEES AmeriFlux scaffold showing the forest mortality caused by the spruce beetle epidemic.

Methods

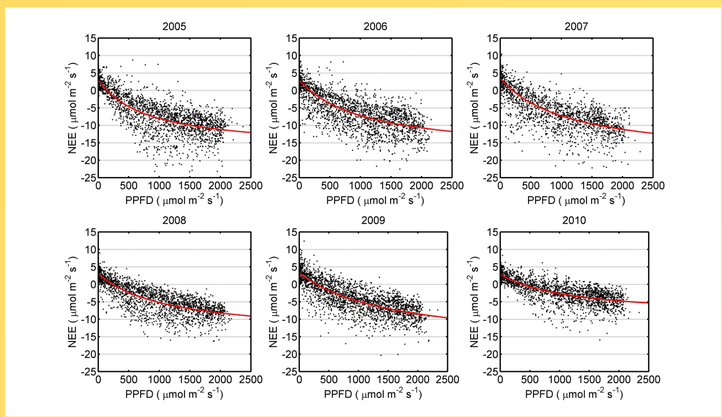
NEE and ET were measured using the eddy-covariance technique at the GLEES AmeriFlux site. Beginning in 2009, IRGA surface temperatures (LI-7500, LiCor, Inc.) were continuously measured and used to drive a thermodynamic heating model to estimate sensible heat flux (H) (Burba et al. 2008). In 2010, H was measured in and out of the path of the IRGA with micro-thermocouples. A site specific empirical model was used to estimate surface temperatures for 2005 through 2008, although this may not have been as valid for the oldest (2005) data.

Results

For the first method of estimating the self-heating correction, H estimated by IRGA surface measurements was 9.9% higher than H from the sonic anemometer. For the second method, H measured in the IRGA path with thermocouples was 10.6% higher than H measured out of the path with thermocouples. Inclusion of the self-heating correction increased measured annual NEE by 280 gC m^{-2} yr^{-1}.



Two methods for estimating the self-heating correction. Both methods show a 10% increase in H in the path of the IRGA.



NEE light response curves. Years 2005 to 2007 were similar. A moderate decrease in ecosystem photosynthetic capacity occurred in 2008 and 2009. This became dramatic in 2010.

Table 1. NEE light response curve parameters

Year	R_d (μmol m^{-2} s^{-1})	A_{max} (μmol m^{-2} s^{-1})	Φ_a (mol mol^{-1})
2005	3.1	20.0	0.0251
2006	2.9	21.2	0.0195
2007	3.5	22.7	0.0207
2008	3.0	17.5	0.0157
2009	3.3	20.9	0.0135
2010	2.9	11.9	0.0106

From 2005 to 2007, the light response curves and their derived parameters (R_d = dark respiration, A_{max} = maximum assimilation rate, and Φ_a = quantum yield) were consistent and demonstrated that the gross photosynthetic capacity of the forest at maximum light was 14.2 μmol m^{-2} s^{-1}. In 2008 and 2009 the quantum yield decreased and the capacity reduced to 11.5 μmol m^{-2} s^{-1}. The quantum yield decreased even more in 2010 when the capacity reduced to 7.6 μmol m^{-2} s^{-1}.

Table 2. NEE at GLEES

Year	Summer (Jul – Sep) (gC m^{-2})	Winter (Nov– Apr) (gC m^{-2})	Annual (gC m^{-2})
2005	-229	-54*	-486*
2006	-182	67	-267
2007	-163	172	-171
2008	-102	90	-83
2009	-81	131	-8
2010	9	167	171

* See Methods

Table 3. ET at GLEES

Year	Summer (Jul – Sep) (cm)	Winter (Nov – Apr) (cm)	Annual (cm)
2005	25.0	27.9	72.1
2006	26.8	27.2	75.0
2007	26.9	22.6	70.1
2008	22.5	29.8	66.5
2009	20.6	24.9	61.5
2010	20.7	21.2	57.6

Total summer (July to September) NEE increased steadily each year, to the point that in 2010 the forest became a summer carbon source. Although winter (November to April) respiration increased over the past three years, it was highly variable which was likely due to non-beetle drivers. Total annual NEE increased each year, and in 2010 the forest became a net carbon source.

Total annual ET was more variable over time, but has decreased steadily since 2006. Summer ET was consistent from 2005-2007, but permanently decreased in 2008. Winter sublimation has decreased in the past two years.

Discussion

The effectiveness of the open-path IRGA self-heating correction was confirmed by direct thermocouple measurements of H. This additional WPL correction dramatically increased and improved annual NEE measurements.

The impact of spruce beetle caused mortality on the forest was clearly shown in the light response curves, as gross photosynthetic capacity was reduced to 81% in 2008 and 2009, and 54% in 2010. Changes in annual NEE were attributed to summer increases, which implicates the reduction in forest photosynthesis as the main driver in annual carbon dynamics. The decrease in annual ET was attributed to the 2008 through 2010 reduction in summer ET, presumably due to reduced forest transpiration. The recent decrease in winter sublimation could be attributed to reduced canopy interception of snowfall.

Conclusions

The spruce beetle epidemic at GLEES has dramatically changed the balances of ecosystem carbon and water exchange. It has caused forest photosynthesis to decrease, summer and annual NEE to increase, and changed the ecosystem from a total carbon sink to a source. It has also caused forest transpiration, summer ET, winter sublimation, and annual ET to decrease. In the process the bark beetle epidemic has influenced the ecosystem more than any inter-annual change in drivers.

References - Burba, G. G., D. K. McDermitt, A. Grelle, D. J. Anderson, and L. Xu (2008). Addressing the influence of instrument surface heat exchange on the measurements of CO2 flux from open-path gas analyzers. *Global Change Biology*. *14*:1854-1876.

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