10.9 IMPACTS OF CLOUDS ON GPP AND ECOSYSTEM RESPIRATION OF CONTRASTING TERRESTRIAL ECOSYSTEMS

Lianhong Gu* and Dennis D. Baldocchi, University of California, Berkeley
Shashi B. Verma, University of Nebraska, Lincoln
T. A. Black, University of British Columbia, Vancouver
Timo Vesala, University of Helsinki, Helsinki

1. INTRODUCTION

The presence or absence of clouds in a region is a consequence of complex interactions among many atmospheric, oceanic and terrestrial processes. It is a physical expression of changes in a number of environmental factors, such as radiation, heat, temperature, moisture, precipitation, etc. All these factors are vital for the functioning of terrestrial ecosystems, and influence the exchange of energy and mass of terrestrial ecosystems with the overlying atmosphere. In particular, it has been observed that for many forest ecosystems, the maximal net uptake of carbon dioxide (CO_2) often occurs on cloudy rather than on sunny day. In a previous study, we showed that a boreal deciduous forest and a temperate deciduous forest had maximal carbon uptake under sky conditions with a solar radiation level equivalent to about 70-80% of the corresponding clear-sky solar irradiance. We also demonstrated that the two forests could tolerate a cloud-induced sunlight reduction of as much as 50% without lowering the capacity to sequester carbon as compared with sunny days (Gu et al. 1999). However, uncertainties remain in regard to the mechanism of this phenomenon. Since variations in net carbon uptake can be achieved through changes in photosynthesis, or respiration or both, an interesting question is: does moderate cloudiness increase net carbon uptake by enhancing canopy photosynthesis or by reducing ecosystem respiration or both? Canopy photosynthesis can be enhanced by increased diffuse radiation (Gu et al. 2002) or reduced water stress (Freedman et al. 2001). Ecosystem respiration can be reduced by decreased temperature under cloudy conditions. In this study, we have investigated the responses of contrasting terrestrial ecosystems to cloudiness by analyzing tower flux measurements. We have found that moderate cloudiness tends to enhance canopy photosynthesis. For the influences of clouds on ecosystem respiration, the responses are more complex. Some ecosystems show reduction in ecosystem respiration in the presence of clouds, but for others the response is weak. Possible explanations for this difference include temperature - moisture interactions on soil respiration.

2. MATERIAL AND METHODS

This study utilizes tower flux data collected and archived through the Fluxnet project (http://public.ornl.gov/FLUXNET/). Here we report results of analyses conducted for three tower sites: a Scots pine forest in Finland, an aspen forest in Canada, and a native tallgrass prairie in Oklahoma. For information about these sites, readers are referred to Gu et al. (2002). Gross primary production (GPP) and ecosystem respiration are inferred from net ecosystem exchange (NEE) measurements through a multiple response model which uses diffuse photosynthetically active radiation (PAR), direct beam PAR, soil and air temperatures as variables (Gu et al. 2002). Sky conditions are measured by relative irradiance, which is the ratio of global solar radiation to clear-sky global solar radiation at the surface (Gu et al. 1999). The details about the method of analysis can be found in Gu et al. (1999) and Gu et al. (2002).

3. RESULTS

Typical patterns of the changes of GPP with relative irradiance are featured by a concave shape (Figure 1), indicating that GPP peaks under cloudy conditions. Note that under cloudy conditions, relative irradiance may exceed 1. This is caused by sunlight reflections from cloud walls, a phenomenon termed the 'cloud-gap effect' in Gu et al. (1999) and analyzed in detail in Gu et al. (2001). In general, the cloud-gap effect leads to enhanced canopy photosynthesis.

Following Gu et al. (1999), we use optimal relative irradiance and critical relative irradiance to characterize the influence of clouds on GPP. Optimal relative irradiance is the relative irradiance that has the highest GPP for a given solar elevation angle. Critical relative irradiance is the relative irradiance that has a GPP equal to the clear-sky GPP for a given solar elevation angle. Both optimal relative irradiance and critical relative irradiance tend to decrease with solar elevation angle (Figure 2). For the aspen forest, however, both indices reached the minimum around a solar elevation angle of 47^o. The optimal relative irradiance and critical relative irradiance of the tallgrass prairie, which is dominated by C4 species, converge towards unity at low solar elevation angle. Also they are higher than corresponding values for the aspen and Scots pine forests. This difference reflects that the photosynthesis of C4 species respond more linearly to variations in sunlight than C3 species does. For comparison, Figure 2 includes the optimal and critical relative irradiance determined for NEE. They closely match those for GPP.

The influence of clouds on ecosystem respiration is more complicated (Figure 3). It ranges from a strong dependence (tallgrass prairie) to weak dependence (aspen forest) to no response (Scots pine forest). This may be due to the compounding effects of soil moisture on ecosystem respiration. Further studies are needed.

* *Corresponding author address*: Lianhong Gu, 151 Hilgard Hall, Department of Environmental Science, Policy and Management, University of California, Berkeley, CA 94720;
email:lianhong@nature.berkeley.edu

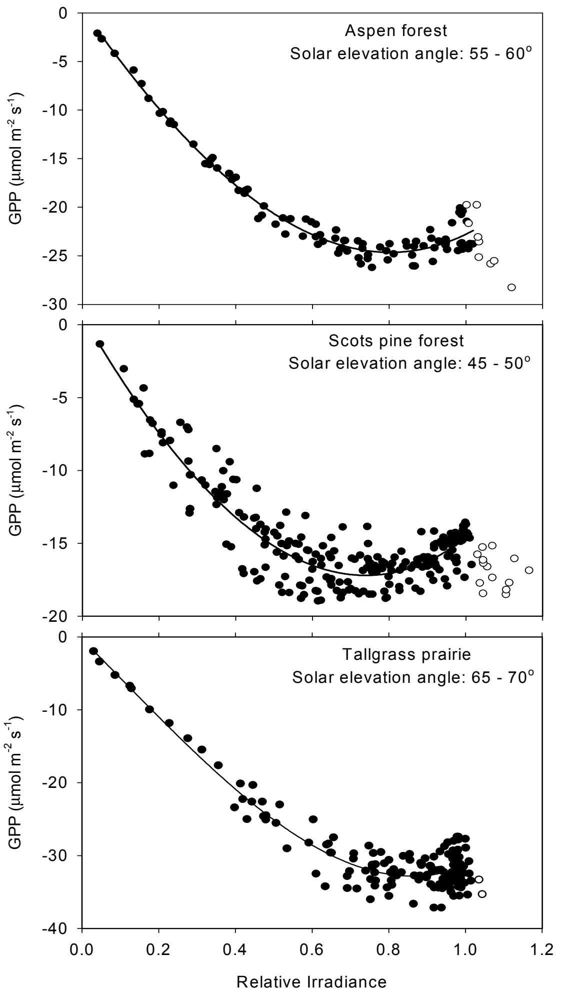

Figure 1. Typical patterns of GPP as a function of relative irradiance. Occassionally, surface irradiance under cloudy conditions exceeds the corresponding level under clear sky due to reflection from cloud walls (Gu et al. 2001). These points are denoted by open circles in the plots.

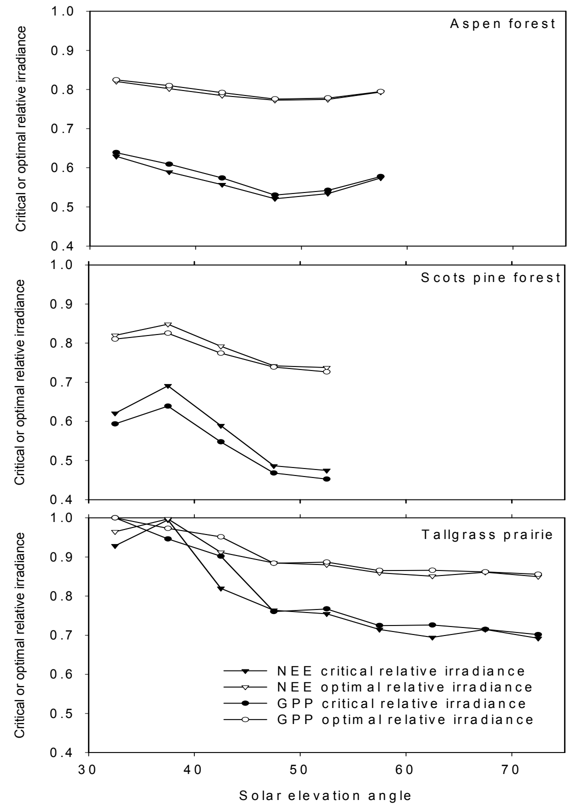

Figure 2. Changes of optimal and critical relative irradiance with solar elevation angle

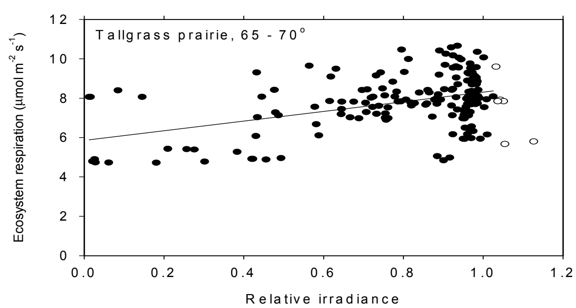

Figure 3, continue.

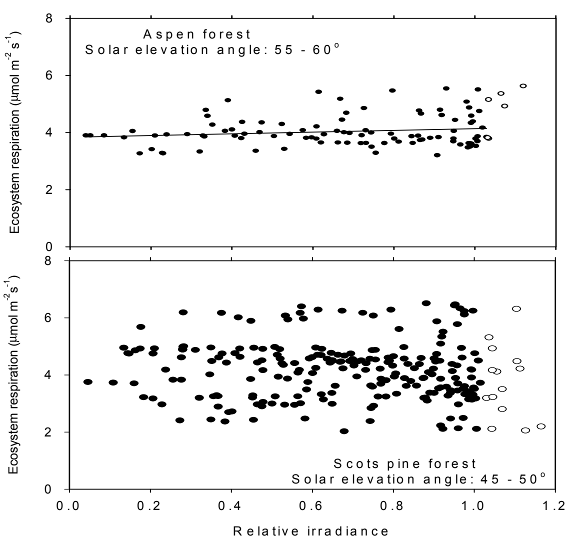

Figure 3. Changes of ecosystem respiration with relative irradiance.

REFERENCES

Freedman, J.M., D.R. Fitzjarrald, K.E. Moore, and R.K. Sakai, 2001. Boundary-layer clouds and vegetation-atmosphere feedbacks. *J. Climate*, **14**, 180-197.

Gu, L., J. D. Fuentes, H. H. Shugart, R. M. Staebler, and T. A. Black, T.A., 1999. Responses of net ecosystem exchanges of carbon dioxide to changes in cloudiness: results from two North American deciduous forests. *J. Geophys. Res.*, **104**, 31421-31434.

Gu, L., J. D. Fuentes, M. Garstang, J.T. da Silva, R. Heitz, J. Sigler, and H. H. Shugart, 2001. Cloud modulation of surface solar irradiance at a pasture site in southern Brazil. *Agric. For. Meteor.*, **106**, 117-129.

Gu, L., D.D. Baldocchi, S. B. Verma, T. A. Black, T. Vesala, E. M. Falge, P.R. Dowty. 2002. Advantages of diffuse radiation for terrestrial ecosystem productivity, *J. Geophys. Res.* (in press).