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Effect of smoke and clouds on the transmissivity of photosynthetically active radiation inside the canopy

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Abstract. Biomass burning activities emit high concentrations of aerosol particles to the atmosphere. Such particles can interact with solar radiation, decreasing the amount of light reaching the surface and increasing the fraction of diffuse radiation through scattering processes, and thus has implications for photosynthesis within plant canopies. This work reports results from photosynthetically active radiation (PAR) and aerosol optical depth (AOD) measurements conducted simultaneously at Reserva Biológica do Jaru (Rondonia State, Brazil) during LBA/SMOCC (Large-Scale Biosphere-Atmosphere Experiment in Amazonia/ Smoke, Aerosols, Clouds, Rainfall, and Climate) and RaCCI (Radiation, Cloud, and Climate Interactions in the Amazon during the Dry-to-Wet Transition Season) field experiments from 15 September to 15 November 2002. AOD values were retrieved from an AERONET (Aerosol Robotic Network) radiometer, MODIS (Moderate Resolution Spectroradiometer) and a portable sunphotometer from the United States Department of Agriculture – Forest Service. Significant reduction of PAR irradiance at the top of the canopy was observed due to the smoke aerosol particles layer. This radiation reduction affected turbulent fluxes of sensible and latent heats. The increase of AOD also enhanced the transmission of PAR inside the canopy. As a consequence, the availability of diffuse radiation was enhanced due to light scattering by the aerosol particles. A complex relationship was identified between light availability inside the canopy and net ecosystem exchange (NEE). The results showed that the increase of aerosol optical depth corresponded to an increase of CO_2 uptake by the vegetation. However, for even higher AOD values, the corresponding NEE was lower than for intermediate values. As expected, water vapor pressure deficit (VPD), retrieved at 28 m height inside the canopy, can also affect photosynthesis. A decrease in NEE was observed as VPD increased. Further studies are needed to better understand these findings, which were reported for the first time for the Amazon region under smoky conditions.

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1 Introduction

Aerosol particles are well known to affect the climate system by interacting with solar radiation through direct and indirect processes. The direct process involves absorption and scattering of solar radiation. While scattering affects climate by reflecting part of the available radiation back to space and thus cooling the surface, absorption of solar radiation can cool the surface and heat the atmosphere. Both effects of cooling the surface and heating the atmosphere can stabilize the atmosphere by changing its thermodynamic profile. If less energy is available at surface level, turbulent fluxes are inhibited with less evaporation of water from vegetation and water bodies, resulting in a drier lower atmosphere. If the atmosphere is more stable and drier, fewer clouds can be formed, termed a semi-direct aerosol effect (Hansen et al., 1997; Koren et al., 2004). The indirect process is coupled to the cloud condensation nuclei property of aerosol particles, whose excess can change cloud properties and lifetime in the atmosphere (Twomey, 1977; Kaufman and Nakajima, 1993; Kaufman and Fraser, 1997; Andreae et al., 2004). Recently another consequence of the aerosol direct effect on solar radiation has been brought under investigation, namely, the effect on vegetation carbon gain due to a reduction in total photosynthetically active radiation (PAR, 400 to 700 nm) reaching the Earth's surface and the increase of the diffuse fraction of PAR (Chameides et al., 1999; Cohan et al., 2002; Gu et al., 2002; Gu et al., 2003). The first studies considering diffuse radiation due to cloud cover on photosynthetic activities date from the 1980's. Young and Smith (1983) reported an increase in carbon uptake and a reduction in transpiration on cloudy days compared to clear days for *Arnica latifolia* Bong, an understory species common throughout the Rocky Mountains. The increase in carbon uptake was related to the increase of diffuse light in the presence of clouds. Spitters et al. (1986) proposed a more realistic partitioning between diffuse and direct solar radiation based on daily total radiation reaching the surface from measurements. Spitters (1986) incorporated that relationship on a model for daily canopy assimilation of CO_2 and obtained a better agreement between model calculation and measurement of CO_2 assimilation rates for sugar beet crop.

Particles with diameters of 0.1 to 1.0 μm scatter light most efficiently in the wavelengths used for photosynthesis. During the dry season in the Amazon region, large amounts of such particles are emitted from biomass burning activities to the atmosphere (Andreae et al., 1991; Kaufman et al., 1998; Yamasoe et al., 2000). Measurements performed in the region showed significant reduction of downward solar total and photosynthetically active irradiance at the surface (Schafer et al., 2002; Procopio et al., 2004; Eck et al., 1998). On the other hand, diffuse fraction of PAR can increase from 19% with a clear atmosphere up to 80% under heavy smoke conditions (Yamasoe et al., 2006[1]). The purpose of the present work is to assess the effect of the smoke layer on the transmission of PAR inside the canopy in a tropical rainforest in the Amazon region and investigate the possible consequences of this effect to the vegetation.

2 Experimental setup and methodology

The measurements were performed as part of LBA/SMOCC (Large-Scale Biosphere-Atmosphere Experiment in Amazonia/Smoke, Aerosols, Clouds, Rainfall, and Climate) and RaCCI (Radiation, Cloud, and Climate Interactions in the Amazon during the Dry-to-Wet Transition Season) field experiments at a 60-m high micrometeorological tower located at Reserva Biológica do Jaru, hereafter called Rebio Jaru (10°04.7′ S, 61°56.0′ W). The tower is surrounded by tropical rainforest vegetation with mean canopy height of 30–35 m, with some trees as high as 45m. Although the tower is located in a governmental protected area, landless people have recently developed small-scale slash and burn activities in the area (Andreae et al., 2002). In fact, during the first weeks of the field experiment, conducted from 15 September to 15 November 2002, it was possible to see fires and smoke nearby from the top of the tower. Additional information about the site can be obtained from Andreae et al. (2002) and Von Randow et al. (2002).

PAR irradiance measurements were carried out at seven different heights above surface: from the top of the canopy at 39 m, 30, 25, 19, 15, 10 and 5 m. Energy sensors SKE 510 from Skye Instruments were used. The sensors were mounted at the faces to the north, east and west of the tower on 4 m-long-aluminum poles. Six other sensors measured upwelling PAR irradiances at 39 and 30 m at the same three faces. Four other sensors were setup at about 1 m from the surface, also measuring downward PAR irradiance. Measurements were performed every minute.

4 Conclusions

The present work showed that high concentrations of aerosol particles in the atmosphere due to biomass burning decrease the amount of global photosynthetically radiation at varying canopy levels, affecting sensible and latent heat fluxes at the surface. On the other hand, the smoke layer increases the diffuse fraction of PAR, enhancing transmission of radiation inside the canopy. This seems to enhance photosynthetic activity observed as a more negative CO_2 flux, thus indicating a higher CO_2 uptake by the surrounding vegetation. However, for even higher AOD values (>2.0), CO_2 flux and consequently NEE decreased. This could be due to the less availability of PAR or a consequence of the deleterious effects of some chemical compounds in the aerosol particles or gases such as ozone, a secondary product from biomass burning which could be formed from emissions from the surrounding fires. Cloud effect on CO_2 exchange is also difficult to quantify, since cloudiness can vary significantly during the course of a day introducing other complexities in the system. Higher values of water vapor pressure deficit at 28 m height were observed in the afternoon and were related to higher air temperature and lower relative humidity when compared to morning measurements. Those higher values also affected NEE of CO_2, resulting in less negative values in the afternoon indicating a reduction on photosynthetic activity.

During the dry season, large areas are affected by aerosol particles from biomass burning activities due to long-range transport. Thus, the observed effect of the smoke layer on carbon flux and NEE, discussed in this manuscript for the first time for the Amazon region, can have significant implications on the carbon budget of ecosystems. Laboratory studies using photosynthesis chambers, other field campaigns and additional modeling efforts are planned to improve our understanding of the effect of aerosol particles from biomass burning on the carbon budget.

[1] Yamasoe, M. A., Plana-Fattori, A., Corrêa, M. P., Garcia, M. P., Dubuisson, P., Holben, B. N., Schafer, J., Eck, T., and Artaxo, P.: Measurement of global and direct-normal incidence PAR irradiance under smoky conditions in the Amazon Basin, Atmos. Chem. Phys. Discuss, to be submitted, 2006.