Preliminary Investigations of the Role of Smoke Aerosols on Carbon Uptake of a Northern Australian Tropical Savanna

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Introduction

The growth and productivity of plants are largely controlled by solar radiation along with CO_2, temperature, water and nutrient availability. The biomass produced by plants is limited primarily by the quantity of radiation captured when water or nutrient supplies do not limit plant growth (Mavi and Tupper 2004). Recent studies have shown that, not only quantity but the quality of radiation is also vital for plant photosynthesis and growth. Many anthropogenic and natural forces such as volcanic eruption (Roderick et al. 2001; Farquhar and Roderick 2003), forest fire (Henson 2000; Kobayashi et al. 2004), and pollution (Chameides et al. 1999; Niyogi et al. 2004; Misson et al. 2005) have reduced the quantity of total incoming solar radiation to the earth's surface through absorption and reflection. Aerosols originating from these sources on the other hand can increase the relative proportion of diffuse solar radiation reaching the forest canopy. Diffuse radiation provides a more even illumination of leaf surfaces and greater penetration of leafy canopies and therefore can lead to a larger photosynthetic efficiency per unit of total global radiation (Gu et al. 2002). It is likely that forest structure and regional differences in aerosols will produce different responses to diffuse radiation. We have tested this hypothesis for a savanna site in Northern Australia.

Research exploring the relationship between atmospheric aerosols and carbon uptake by plants is still new and most studies have been focused on northern hemisphere ecosystems (Cohan et al. 2002; Gu et al. 1999, 2002, 2003; Niyogi et al. 2004; Rocha et al. 2004; Mission et al. 2005; Min 2005). Nevertheless, they produced conflicting results with different species at different environmental settings producing different responses to aerosols. Therefore, it is vital to explore this link across various ecosystems (e.g., savanna woodland). Australia's tropical savanna covers 2 million km^2, 25% of Australia's land surface or 12% of total global savanna woodland. Globally savanna sequester as much as 0.5 PgC per year (Henry et al. 2005). Therefore, they are important ecosystems in terms of carbon storage (Williams et al. 2004). Studies in North Australian tropical savanna indicate that the net exchange of carbon between the atmosphere and savanna in this region is a carbon sink despite the frequent fire (Eamus et al. 2001; Chen et al. 2003; Beringer 2005). In northern Australia, vast areas of savanna are burnt annually and biomass burning emissions result in a range of aerosol loadings. Organic carbon, which is the most abundant carbonaceous aerosol species is an effective scatterer of solar radiation (Christopher and Zhang 2002, Posfai et al. 2003 and Li et al. 2003) and therefore it cools the atmosphere and does not significantly absorb in the visible range of the spectrum which is used for photosynthesis (Posfai et al. 2003). Therefore, aerosols originating from savanna fires may be expected to scatter the incoming solar radiation and provide more diffuse radiation reaching the forest canopy, thereby increasing the carbon uptake by ecosystems. In addition to that, aerosols from dessert dust and sea salt particles are also abundant in this region. Therefore, there may be a link between aerosols from savanna burning and other sources of aerosols and plant productivity through changes in the diffuse radiation fraction. In this study, the impact of aerosols on the carbon uptake by a savanna ecosystem in Northern Australia was analyzed.

Study Area

The study area, Howard Springs (Figure 1a) is located at 12.425ºS and 130.891ºE and approximately 35 km to the southeast of Darwin, the capital city of Northern Territory, Australia. This area is dominated by *Eucalypt* (*tetrodonta and miniata*) woodland open savanna forest (14-16 m in height) with underlying grassland (C_4 annual grass *sorghum spp.*) (Figure 1b). The study area and other parts of the Northern Territory are subject to two pronounced seasons namely dry (May-September) and wet (November-March) seasons. Under-storey LAI varies between 1.2-1.5 during wet and ~0.2 during dry seasons, whereas over-storey LAI ranges between 0.95-0.6 during wet and dry seasons, respectively.

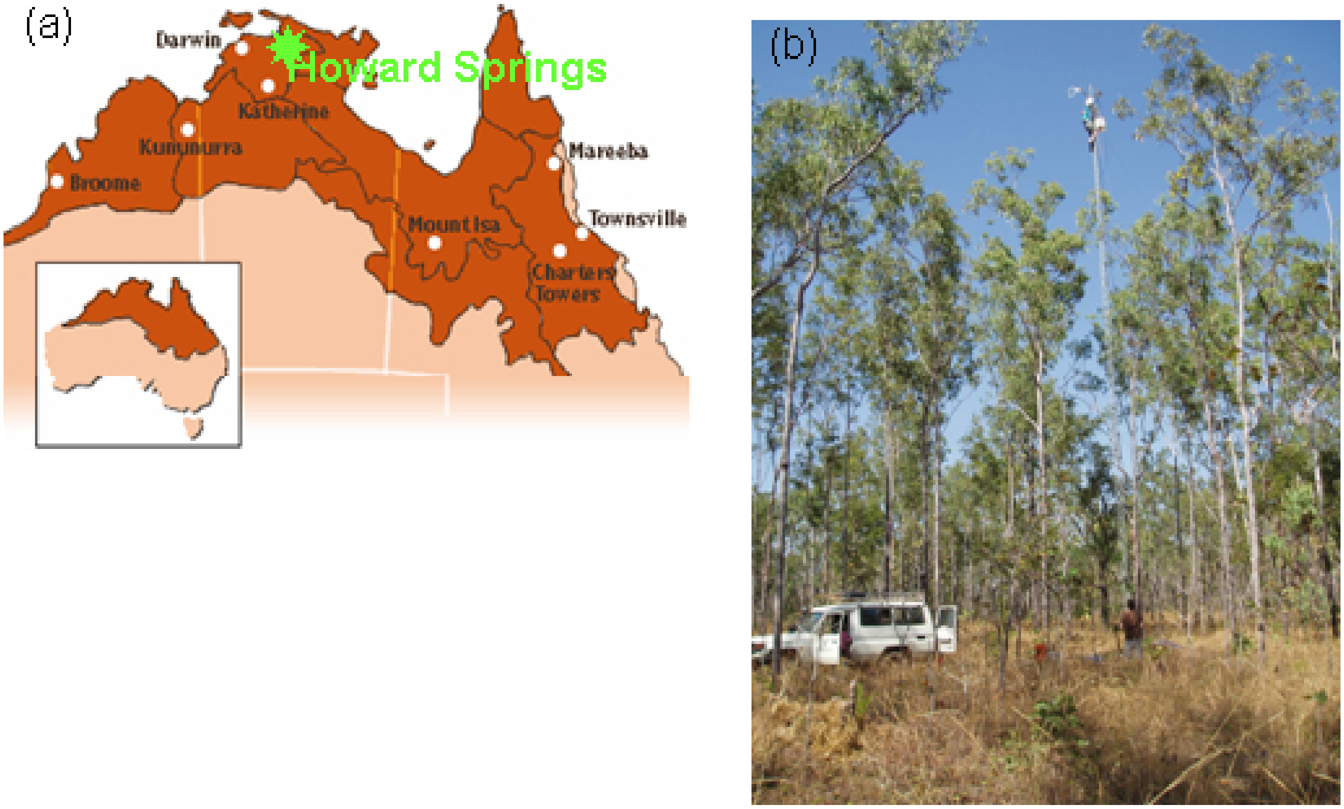

Figure 1. Location of the study area: Howard Springs, Northern Australia.

Data

Data used in this study cover two seasons namely dry (June and July) and wet (December-March) from 2002-2005. All the data were obtained from two sources:

(i) CO_2 flux data were measured using the Eddy Covariance technique using flux tower instrumented at Howard Springs (Figure 1) since August 2001 (Beringer 2005). CO_2 flux data were constructed for every 30 minutes.

(ii) Solar radiation, Aerosol Optical Depth (AOD) (from multi-filter rotating shadowband radiometer) and sky cover (total sky imager) data were downloaded and processed from the Atmospheric Radiation Measurement (ARM) http://www.arm.gov/site. All the data were averaged at 30 minutes interval to match the CO_2 flux data.

Both CO_2 flux and ARM site data were quality assured. Periods with either CO_2 flux, AOD or radiation measurements missing were eliminated. Only daytime observations (from 10 am to 4 pm) were used because early morning and late evening periods correspond to low sun angles and therefore can cause high diffuse radiation. In addition to that, these periods were selected because they correspond to high carbon uptake by plants.

Analysis

Diffuse radiation and CO_2 flux values were both normalized by global irradiance to investigate the effect of diffuse radiation on CO_2 flux regardless of cloud cover or aerosol loadings. Data were analyzed according to the AOD values for clear sky both in the dry and wet seasons. Then data were grouped into aerosol and thin cloud in the dry season and into thin and thick clouds and aerosols in the wet season based on cloud cover and AOD values. The following criteria were used to group the data:

(a) thick cloud= cloud cover (% opaque) 100% or complete obstruction of direct solar radiation
(b) thin cloud 10-99% (% opaque)
(c) aerosol = AOD (500 nm) more than 0.05 and cloud cover less than 10% (both % opaque and thin).

Results and Summary

Based on the 4 years of data, high AOD was found in the late dry season (July-December), suggesting strong contribution from seasonal biomass burning (Figure 2).

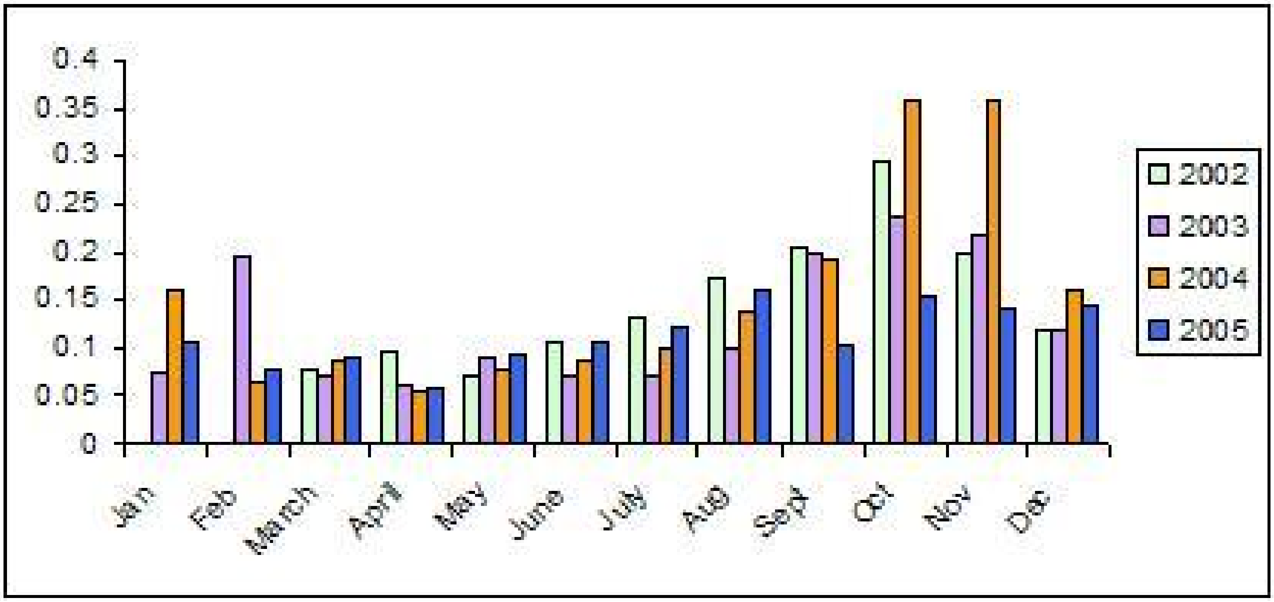

Figure 2. Monthly average values of AOD (500 nm) in Darwin, Australia, from 2002-2005.

Analysis of carbon flux shows that Howard Springs acts as a sink of carbon most of the time except for being a small source for carbon several months following fire in the dry season (Figure 3). Analysis of the carbon flux and radiation data (Figure 4) show that as the fraction of diffuse radiation increases the ratio of CO_2 flux; global irradiance also increases. The increase is higher in the wet season than in the dry season. This is mainly due to the contribution from under-storey grass biomass in the wet season.

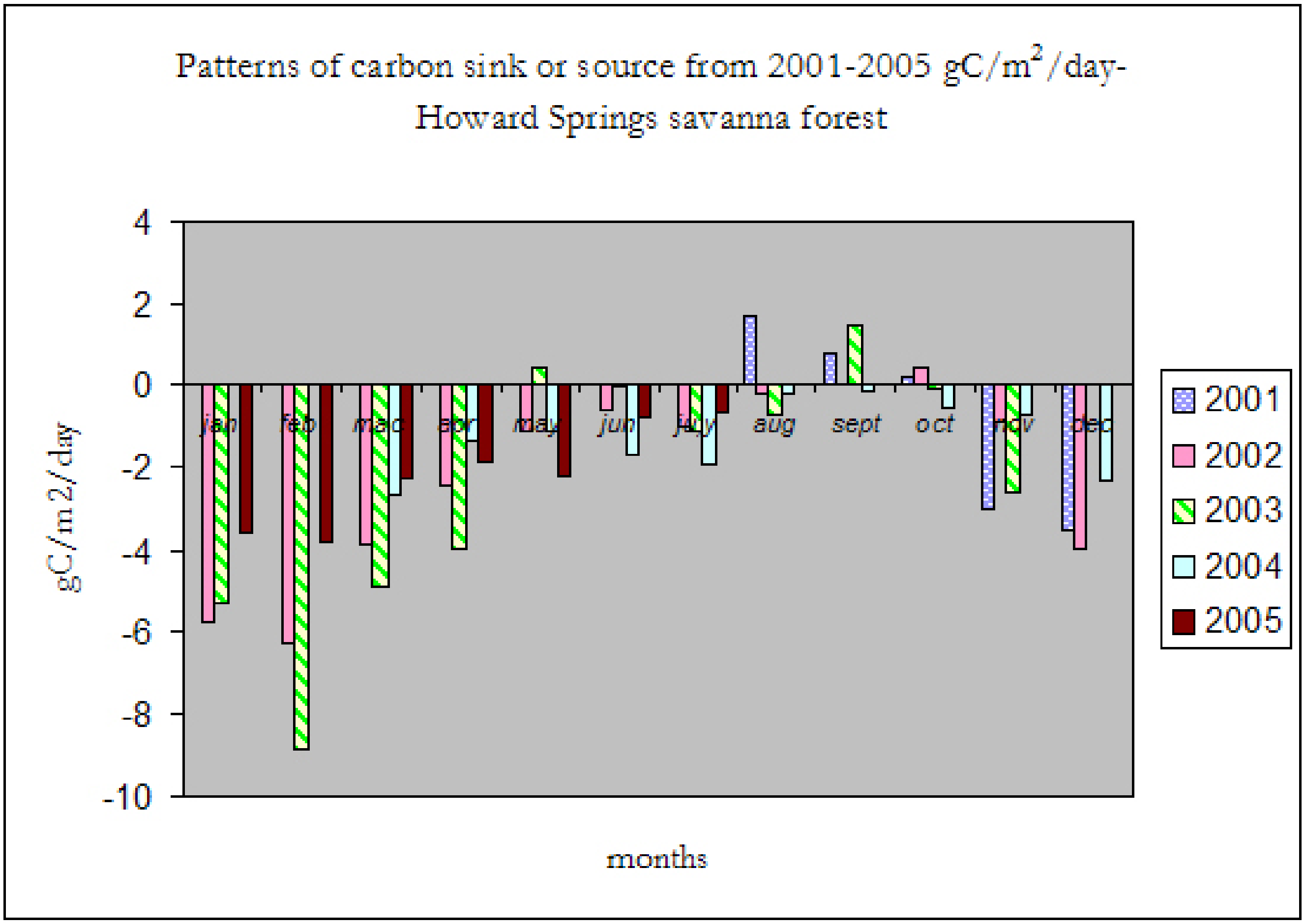

Figure 3. Patterns of carbon sink or source from 2001-2005 at Howard Springs savanna forest.

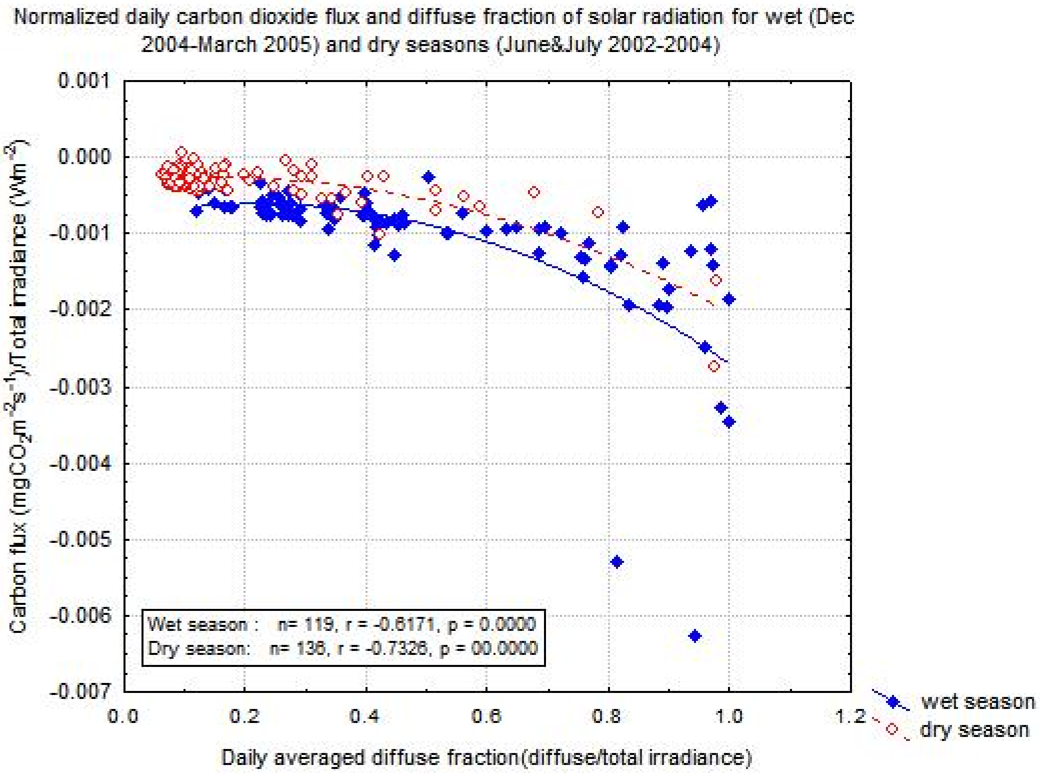

Figure 4. Normalized daily CO_2 flux versus diffuse radiation for wet (Dec-March 2004-2005) and dry (June-July 2002-2004) seasons.

Both in the dry and wet seasons little difference was found in the CO_2 flux:total irradiance ratio under thin clouds and aerosol loadings. However, in the wet season thick clouds scatter more radiation and cause higher CO_2 flux:total irradiance ratios compared to thin clouds or aerosols (Figure 5).

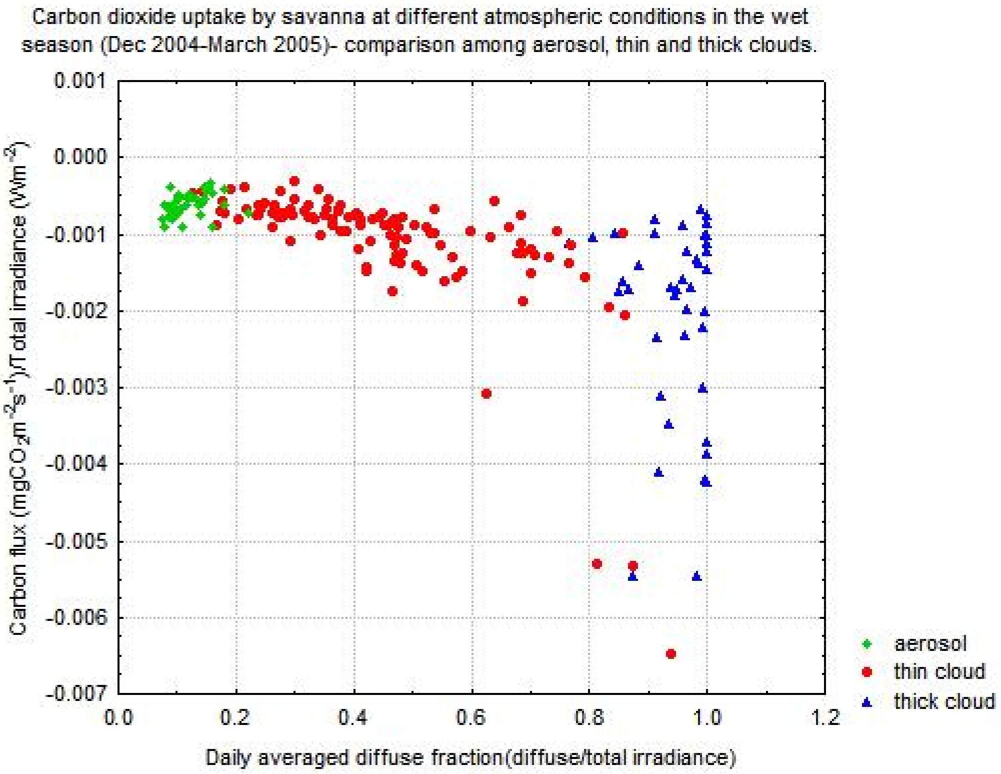

Figure 5. Carbon dioxide uptake by savanna at different atmospheric conditions in the wet season (Dec 2004-March 2005) - comparison among aerosol, thin and thick clouds.

Under an aerosol laden atmosphere more direct radiation is received on the canopy surface compared to the diffuse fraction of solar radiation (Figure 6). Nevertheless, diffuse radiation is enhanced slightly as the AOD increases (Figure 6) but the increase is not sufficient under a small range of AOD to produce any changes in carbon uptake by savanna open forest (Figure 7).

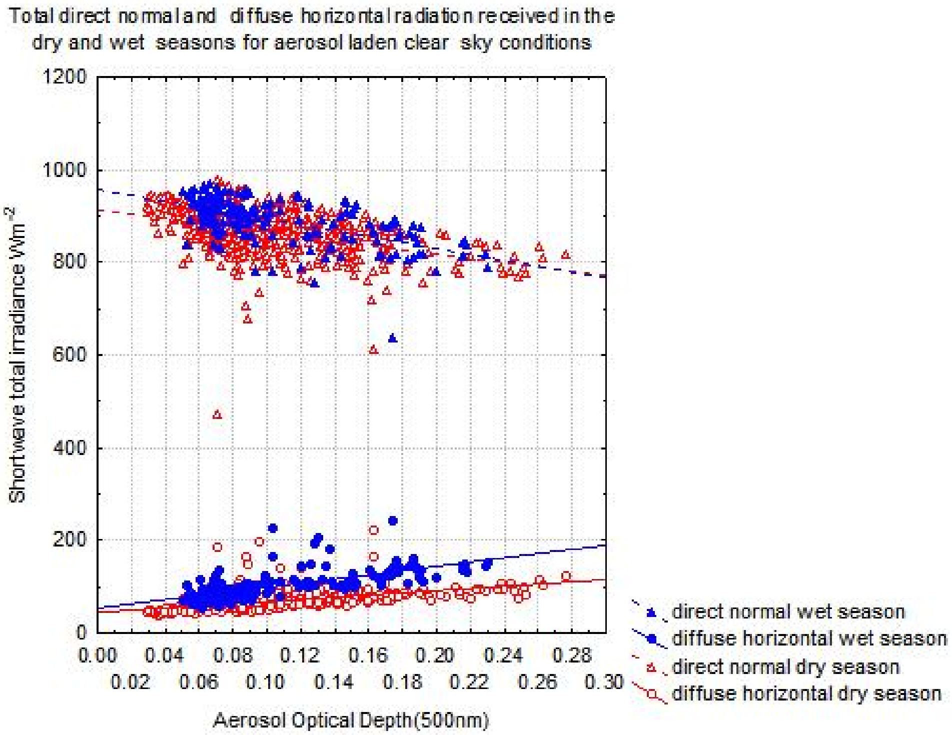

Figure 6. Total direct normal and diffuse horizontal radiation received in the dry and wet seasons for aerosol laden clear-sky conditions.

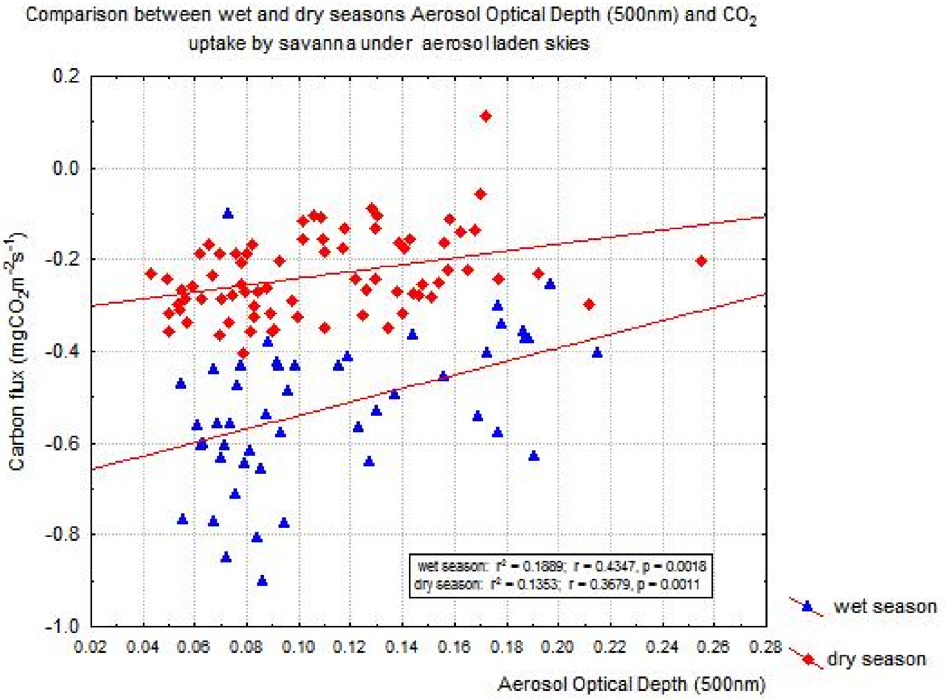

Figure 7. Comparison between wet and dry seasons AOD (500 nm) and CO$_2$ uptake by savanna under aerosol laden skies.

The reasons for the observed patterns of carbon flux could be due to the canopy architecture (open canopy with less than 50% cover), photosynthesis pathway and other environmental and plant physiological factors such as temperature, soil moisture, and leaf area index. These factors are yet to be studied. The findings of this study are in agreement with that of Min (2005) but in contrast to Niyogi et al. (2004). This is because we are dealing with quite different ecosystems.

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