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Relação entre a turbulência do dossel e distribuição vertical de gases reativos na floresta tropical da Amazônia central

Relationship between canopy turbulence and vertical distribution of reactive gases in the central Amazon rainforest

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Abstract

Ozone plays a crucial role in the chemistry of the tropical atmospheric boundary layer. In the rainforest, ozone sources and sinks are complex due to numerous chemical reactions and surface deposition. Turbulent transport controls the vertical distribution of ozone. A field study in the Amazonia, near Manaus, Brazil during 2014 shows different shapes of ozone profiles as a response to changes in air turbulence during night-to-day and day-to-night transitions. During the night-to-day transition following sunrise ozone levels increase within the canopy due to photochemical production and increased vertical mixing. The vertical transport of ozone to the lower layers of the canopy is enhanced after the thermal inversion in the canopy disappears. At night, the ozone deposition to the ground and the foliage in the lower canopy is strong. After midnight, the lower canopy is devoid of ozone. Relatively high gradients of ozone levels within the forest during the nighttime also result from the decoupling between the in- and above-canopy environment that limits the forest-atmosphere ozone exchange. Processes responsible for the vertical distribution ozone are necessary to estimate the oxidation of the plant-emitted gases whose reaction products are aerosol precursors.

Resumo

O ozônio desempenha um papel fundamental na química da camada-limite atmosférica tropical. Sobre uma floresta tropical, as fontes e sumidouros de ozônio são complexas, devido a numerosas reações químicas e à deposição seca e úmida na superfície. O transporte turbulento controla a distribuição vertical de ozônio. Um estudo de campo na Amazônia, nas proximidades de Manaus, Brasil, durante 2014, revelou diferentes formas para o perfil de ozônio dependendo da turbulência atmosférica durante as transições noite-dia e dia-noite. Após o nascer do sol, os resultados mostram que durante a transição noite-dia os níveis de ozônio aumentam no dossel devido à produção fotoquímica. O transporte vertical de ozônio para os níveis mais baixos do dossel é intensificado depois que a inversão térmica dentro do dossel desaparece. Durante a noite, o sumidouro de ozônio no solo é forte, em comparação com a deposição nas folhas. Após a meia-noite, a parte mais baixa do dossel não contém mais ozônio, e como resultado os perfis de ozônio deixam de se modificar durante várias horas. Gradientes relativamente fortes de ozônio dentro da floresta durante o período noturno também aparecem como resultado do desacoplamento entre o dossel e a atmosfera acima da copa. Isso limita as trocas de ozônio entre a floresta e a atmosfera acima. Dado que o ozônio reage com compostos orgânicos emitidos pela vegetação, e que os produtos dessas reações podem se condensar, o resultado final é a produção de aerossóis: desta forma, a distribuição vertical de ozônio é um indicador importante de quais reações são possíveis, e em particular do potencial de produção de aerossóis.

Keywords: Ozone, turbulence, rainforest, Amazon, forest canopies

1. Introduction

Tall and dense forests experience unique interactions with the overlying atmosphere that result in a complex vertical distribution of reactive gases. Most of the momentum sink takes place within the forest crown and as a consequence air turbulence in the trunk space remains largely quiescent (Finnigan 2000; Wilson and Shaw 1977) Deep within the canopy small-scale wake turbulence dominates whereas above the forest large-scale turbulence controls the motion. This juxtaposition of the flow patterns within and above forests results in coherent and strong sweeps and ejections of air parcels. These turbulence features dominate the transport of energy, mass, and momentum within and above forests (Gao and Shaw 1989; Thomas and Foken 2007). Depending on their turbulent scales and frequency of occurrences, coherent events govern the time air parcels remain within the forest canopy. Due to such turbulent features and their high leaf area indices (>4 m^2 m^{-2}), tall forests experience in-canopy air parcel residence times that often exceed the lifetimes of chemical species such as biogenic hydrocarbons (Fuentes et al. 2007). Therefore, the environment in canopies such as the rainforest promotes different rates of chemical cycles compared to those observed above the forest. The differences are ascribed to the chemical signatures associated with sweeps and ejections. For instance, downdrafts carry ozone enriched and hydrocarbon depleted air to the forest canopy whereas updrafts transport ozone depleted and hydrocarbon enriched parcels out of the forest canopy. In the case of the rainforest, it is of particular importance to quantify in-canopy reaction rates of plant emitted hydrocarbons and generated reaction products, which can subsequently transform into secondary organic aerosols. In this presentation, we focus on the nigh-to-day and day-to-night transition periods to determine the relationship between canopy turbulence and vertical distribution of reactive gases in the central Amazon rainforest.

2. Research methods

Profile measurements took pace during December 2014 at the Cuieiras Biological Reserve. The Reserve is located 60 km northwest of the City of Manaus, Amazonas, Brazil at the K34 tower site (2° 36' 33.31" S, 60° 12' 32.58" W). A 50-m tower was used to deploy the instruments in the middle of a dense tropical rainforest with a 35-m canopy height (h_c) and leaf area index of cirta 6-7 m^2 m^{-2}. A winch was used to move the air intake between50-m to 5-m above the surface. The air take was connected to gas analyzers to determine ozone levels.. Starting from 50 m, ozone mixing ratios were measured every 5 m and aggregated to a single 4 minute average per level. The ozone analyzer, Thermo Scientific 49i (Thermo Fisher Scientific Inc., MA, USA) recorded the ozone levels. Ozone data were recorded with a data logger (model CR1000, Campbell Scientific, Logan, UT) at 1 Hz. Air turbulence was studied within and above the forest using ten sonic anemometers (model CSAT3D, Campbell Scientific Inc. Above the forest, incoming solar radiation, temperature, relative humidity, and wind speed were continuously recorded.

3. Results

With decreasing incoming solar radiation (ISR), the standard deviation of vertical velocity (σ_w) and the ozone mixing ratios begin to decrease in the afternoon (Figure 1). The variations for σ_w and ozone mixing ratio from 15:00 to 18:00 hours are 0.3 m s^{-1} and 16 ppbv, respectively. Since the two main sources of daytime ozone are photochemical production from nitrogen oxides and air entrainment from aloft, the significant decrease of ozone just before sunset can be qualitatively interpreted as the attenuation of both vertical mixing from aloft and solar radiation. During nighttime ozone profiling, σ_w was low (less than 0.1 m s^{-1}) which indicates weak vertical mixing throughout the nighttime. Variations of ozone profiles under stable nocturnal conditions and times of ozone profiles, as designated by the dotted lines, are presented in Figure 1.

Figure 2 shows the evolution of ozone profiles at different times of the evening. As shown in the third panel of Figure 2, the standard deviation of vertical velocity at all levels decreases rapidly after sunset and the vertical mixing is weak throughout the night.

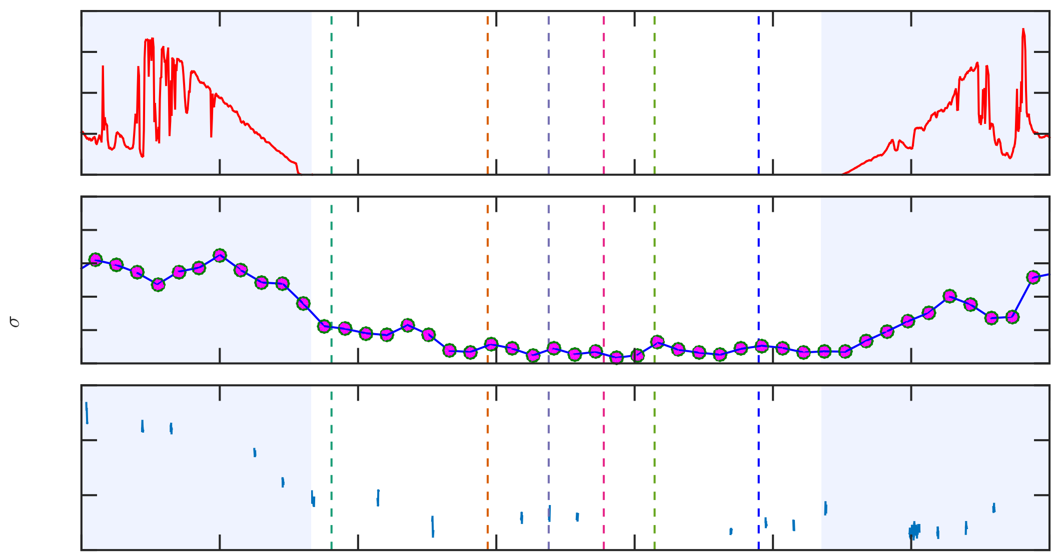

Figure 1. Time series for incoming solar radiation (ISR), standard deviation of vertical velocity (σ_w) and ozone mixing ratio above the canopy for the period of profiling.

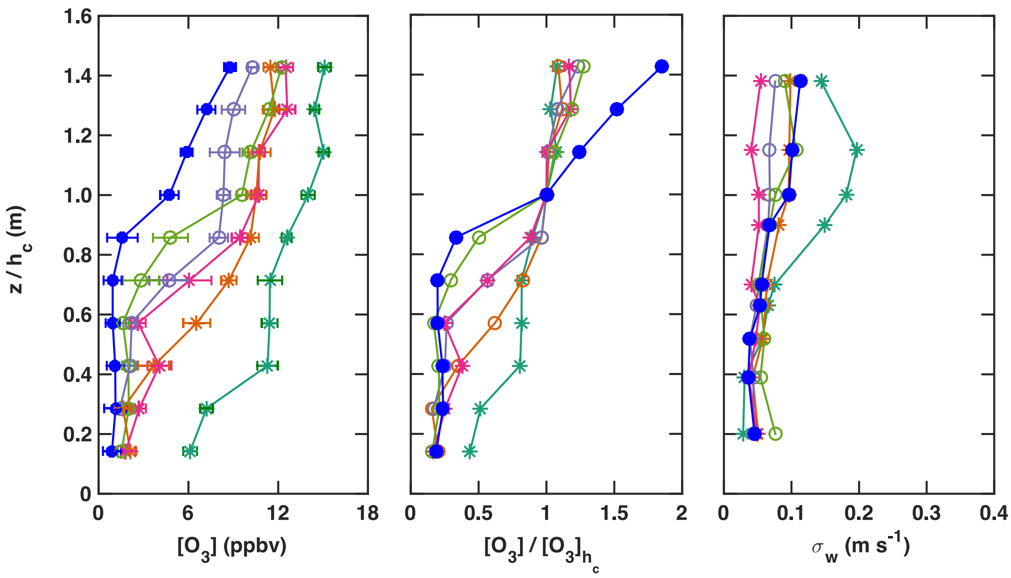

Figure 2. Vertical profiles for ozone mixing ratio, ozone-to-ozone at the canopy ratio and standard deviation of vertical velocity (σ_w) and ozone mixing ratio.

Photochemical production of ozone ceases immediately after sunset, which leads to decreases of ozone levels in and above the canopy (Figure 1). In the lower part of the canopy (0.2 <z/h_c< 0.6), there is a positive gradient of ozone concentration during the first half of the night and this gradient become close to zero after midnight due to the dry deposition to the ground and vegetation. After mid-night the ozone mixing ratios in the lower canopy are close to zero and no apparent evolution of ozone profiles were observed. Unlike the lower canopy, the upper part (0.8 <z/h_c< 1) has relatively higher levels of ozone mixing ratios, about 5 ppbv even around 4:30 am, which suggests that the upper canopy is not as strong a sink as the ground. Additionally, the strengthening gradient between in-canopy and above canopy ozone mixing ratios (Figure 2), could indicate the decoupling between the in-canopy and the above canopy environment.

4. Conclusions

Ozone mixing ratio decrease significantly in the late afternoon shortly after the solar radiation begins to go down. The upper canopy acts to decouple the exchanges between air above the canopy and air in the canopy during the nighttime. The ground and the vegetation in the lower canopy are sinks of ozone at night. The low ozone levels during the nighttime in the lower canopy slow down the deposition to the ground and the evolution of ozone profiles.

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