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Seasonal variations in whole-ecosystem BVOC emissions from a subtropical bamboo plantation in China

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HIGHLIGHTS

- Terpenoid emissions were measured in a Lei bamboo plantation in China.
- Isoprene contributed 99% of terpenoid emissions.
- Terpenoid emissions exhibited strong diurnal and seasonal variations.
- Water vapor and stomatal conductivity may influence BVOC emissions.
- Averaged emission factors were 3.6 (mgm^{-2} h^{-1}) for isoprene and 0.16 for α-pinene.

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ABSTRACT

Isoprene and monoterpene emissions and environmental conditions were measured over a six month period in a Lei bamboo *(Phyllostachys violascens)* forest in a subtropical region in China. Isoprene and monoterpene emissions were measured using a relaxed eddy accumulation (REA) system on an above-canopy tower. From July to November of 2012, isoprene contributed 99.1% of terpenoid emissions. α-pinene, constituting 0.8% of total observed terpenoid emissions, was the only monoterpene for which a significant flux was detected. Emissions of the sesquiterpenes longifolene and α-cedrene were observed at very low rates. Isoprene and α-pinene emissions exhibited strong diurnal variations, with lower emissions in the morning and late evening, and the highest emissions around noon. BVOC peak emissions typically occurred a few hours after the noon PAR peak and coincided with the daily temperature peak. This behavior can be described reasonably well by the MEGANv2.1 biogenic emission model. During the campaign (i.e., from 7 July, 2012 to 19 Jan., 2013), the mean (and maximum) emission fluxes (mg m^{-2} h^{-1}) were 0.95 (10.32) for isoprene, 0.010 (0.176) for α pinene, 0.001 (0.063) for longifolene, and 2.6×10^{-4} (0.009) for α-cedrene, respectively. During the winter season, when the ground was covered by organic mulch to increase soil temperature and to increase the yield of bamboo shoot, there was no evident impact on BVOC emissions. The observed seasonal variation followed the general behavior predicted by the MEGANv2.1 model, with lower emissions associated with cooler conditions, but the magnitude of the emission decrease was greater than expected indicating driving variables are missing from the model. Emission factors, representing the emission expected for a Leaf Area Index of 5 at a temperature of 30 °C and PAR of 1500 μmol m^{-2} s^{-1}, during the peak growing season for this site were 0.008 mg m^{-2} h^{-1} for α-pinene and 3.3 mg m^{-2} h^{-1} for isoprene. The isoprene emission factor is similar to the value (3.6 mg m^{-2} h^{-1}) for this location in the MEGANv2.1 global biogenic emission model. A second bamboo plantation, containing Moso bamboo (*Phyllostachys heterocycla*), was investigated and found to have similar isoprene and monoterpene emission rates as Lei bamboo forest. The emission data obtained in this study are the first canopy-scale flux measurements reported for bamboo plantations and

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demonstrate the potential importance of bamboo isoprene emissions for regional ozone and organic aerosol production.

1. Introduction

Biogenic volatile organic compounds (BVOCs) dominate the global emission of volatile organic compounds (Singh and Zimmerman, 1992). Isoprene (53%) and monoterpenes (15%) are the main components of the global BVOC flux (Guenther et al., 2012). With their high reactivity, BVOCs play important roles in the formation of O_3, secondary organic aerosol (SOA), peroxyacyl nitrates, etc. (e.g. Chameides et al., 1988; Yu et al., 1999; Claeys et al., 2004; Kanakidou et al., 2005) in the troposphere. They can be photooxidized to SOA which can increase cloud condensation nuclei and thus influence radiative transfer in the atmosphere (Spracklen et al., 2011).

In China, leaf- and branch-level enclosure measurements have been made at some representative sites, e.g., an Inner Mongolia grassland, Xishuangbanna tropical forest, Dinghushan subtropical forest, and urban landscapes in Shenzhen, Beijing, Hong Kong, Pearl River Delta (Shao et al., 1994; Li et al., 1994; Zhang et al., 1994; Mou et al., 1999; Bai et al., 1998, 2003a, 2003b, 2006a, Bai and Baker, 2004; Yang et al., 2001; Klinger et al., 2002; Wang et al., 2002, 2003; He et al., 2004; Geron et al., 2006; Tsui et al., 2009; Situ et al., 2009, 2013; Huang et al., 2011; Wang et al., 2011) and are used as the primary basis for the emission factors used in biogenic emission models (Tie et al., 2006; Guenther et al., 2012). A few above-canopy flux measurements have also been made (Baker et al., 2005; Bai et al., 2012; Situ et al., 2013). BVOC emission rates and fluxes measured in China and other sites have been used to parameterize BVOC emissions in regional and global models but there are few measurements available for evaluating these model emission estimates and their uncertainties (Guenther et al., 2006). China's forests cover 195 million hectares over many climatic zones with a forest stocking volume of 13.7×10^9 m^3 (Mark and Zhang, 2009). Field measurements of BVOC emissions are needed to develop more accurate models of BVOC emissions to improve prediction of their atmospheric impacts (O_3, SOA, etc.) with air quality models and enable China to better control hazardous air pollutants. Bamboo has been identified as having significant BVOC emissions, although there are considerable differences among species (Geron et al., 2006). Bamboo plantations cover about 2×10^{11} m^2 worldwide and 5.38×10^{10} m^2 in China. Since bamboo has a very different canopy structure than other plants, the lack of above-canopy flux measurements has limited our ability to assess the extrapolation of leaf level measurements to the canopy scale. Seasonal canopy-level BVOC emissions from a subtropical bamboo plantation, Zhejiang province, China are reported in this study. These observations are the first reported canopy-scale BVOC fluxes from a bamboo plantation.

2. Site description and methods

BVOC emission measurements, solar radiation and meteorological parameters were carried out at Taihuyuan, LinAn city, Zhejiang province (30°18′N, 119°34′E, 185 m) from 7 July, 2012 to 23 January, 2013. The site is a managed Lei bamboo *(Phyllostachys violascens)* plantation in a subtropical region of China. Lei bamboo, the dominant plant at the site, covers 80% of this landscape. Most of the plants are 2 or 3 years old. The Lei bamboo density is 1.2–1.5 individuals per m^2. There are a few understory shrubs that make a small contribution to the total biomass. The mean Lei bamboo canopy height is 4.5 m with a diameter at breast height (DBH) of 4 cm, the soil type of this area is red earth, and the average slope of this study site is about 2–3°. A 20-m tower was erected for CO_2 flux and meteorological measurements surrounded by the bamboo plantation, which covers 3.3×10^8 m^2, 9 km in north-south direction and 7 km in east-west direction. Average annual precipitation is about 1600 mm, annual temperature is 16 °C (Chen et al., 2013).

A Relaxed Eddy Accumulation (REA) system was used to collect air samples in stainless steel cartridges that were 10 cm in length and 1/4 inch in diameter and filled with Tenax GR and Carbograph 5TD (Markes International Inc., USA). In order to minimize wall losses, the air was pulled directly through a filter and into a cartridge with no sample tubing or valves upstream of the cartridge. Tests conducted on the compounds reported in this study showed that there was no substantial loss of these compounds over the typical storage period. During each 100 ms period, the vertical wind speed measured with a sonic anemometer was used to determine whether to sample into the updraft or downdraft cartridge (or neither if the vertical wind speed was below a threshold value). REA fluxes were estimated for 30 min periods which have been shown to be a suitable sampling period for eddy flux measurements (Guenther and Hills, 1998; Baker et al., 1999; Greenberg et al., 2003; Bai et al., 2015a). The REA system, including a three-dimensional sonic anemometer (RM Young, Traverse City, Michigan, USA, Model 81000) measuring at 10 Hz, was located at the end of a 2-m boom positioned on a platform at a height of 16 m above ground level (AGL) and approximately 8 m above the top of the canopy. The anemometer signal was sent to a data logger (Campbell Scientific, Logan Utah, USA, Model CR1000), which controlled fast solenoid valves that directed samples to either updraft or downdraft cartridges. When vertical wind speeds were below a threshold value (± 0.6 m s^{-1} σ_w, where σ_w is the standard deviation of the vertical wind speed from the previous 30 min period), sample air was collected on a third (neutral) cartridge. O_3 was removed from the sample flow by an ozone filter, which consisted of a glass fiber filter (Pall Corporation, USA) that was impregnated with potassium iodide. We conducted lab experiments that indicated these filters can sufficiently remove ozone (<5 ppbv) from at least 40 L of ozone-rich (100 ppbv) air. Filters were changed in the field after 30 samples were taken to ensure that the filters were not saturated by exposure to more than 40 L of air. The ozone filters also remove highly reactive terpenoid compounds (e.g. beta-caryophyllene) and so we were not able to measure fluxes of these compounds using this approach.

The basic equation to derive fluxes of a given BVOCs species (F_i) from the REA system is:

$$F_i = b\sigma_w (C_{up} - C_{down}) \quad (1)$$

where σ_w is the standard deviation of the vertical wind velocity, b is an empirical coefficient, and C_{up} and C_{down} are the concentrations of the BVOCs species of interest in the up and down cartridges, respectively. The empirical coefficient, b, was determined from the sensible heat flux measured with the sonic anemometer by virtual