BVOC Emissions at the Canopy Scale:
Micrometeorological Flux Measurements

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Introduction

The emission inventories of biogenic VOCs (BVOCs) are generally based on emission models. In these models the emissions are calculated using emission rates obtained by the cuvette technique together with ecosystem data. Canopy-scale BVOC emissions, measured by micrometeorological methods, can serve as an intermediate step when upscaling branch level measurements to regional-scale emission inventories. The effect of various meteorological factors can also be studied using the micrometeorological flux measurements.

Experimental

As a part of the BIPHOREP project, two micrometeorological campaigns were conducted during the summers of 1996 and 1997 to measure BVOC emissions at the canopy scale in boreal forests. Other fluxes, such as those of O_3, CO_2 and H_2O, were also measured, and various meteorological parameters were recorded.

Methods

The vertical fluxes of the BVOCs were obtained by the gradient method. The turbulent exchange coefficients were, however, calculated using eddy covariance measurements of the momentum and sensible heat fluxes. Using the universal flux-gradient relationships, the flux F_c was calculated using equation (1):

$$F_c = \frac{-ku_*\left[\bar{c}(z_2) - \bar{c}(z_1)\right]}{\ln\frac{z_2 - d}{z_1 - d} + \Psi_H\left(\frac{z_1 - d}{L}\right) - \Psi_H\left(\frac{z_2 - d}{L}\right)}, \tag{1}$$
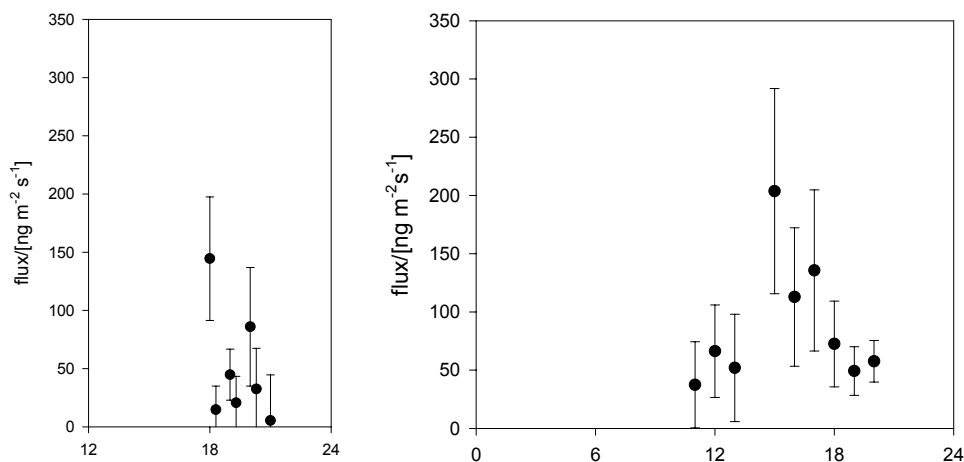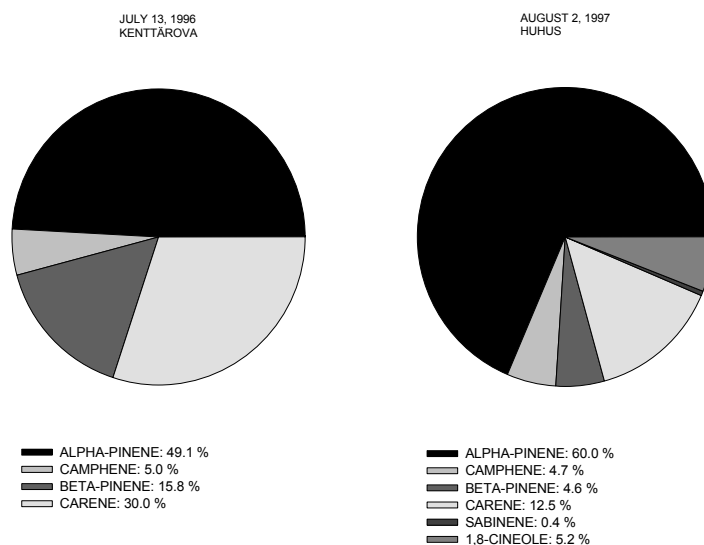
Figure 1. *Measured vertical fluxes of the sum of four monoterpenes (α- and β-pinene, Δ^3-carene and camphene) at the Kenttärova site on July 13, 1996 (left panel) and the sum of six monoterpenes (α- and β-pinene, Δ^3-carene, camphene, sabinene and 1,8-cineole) at the Huhus site on August 2, 1997 (right panel).*

(e.g. Fuentes et al. 1996) where k is the von Kármán constant, u_* is the friction velocity, $c(z)$ is the concentration of the species c at a height z, d is the zero plane displacement height, L is the Obukhov length and Ψ_H is the Monin-Obukhov stability function for heat.

The VOCs were sampled at heights of 31 and 18 metres. Samples of the light hydrocarbons (C_2-C_5) were drawn into steel canisters via Teflon tubing. Heavier hydrocarbons were absorbed into 250 mg of Tenax TA using two automated samplers. The chemical analysis was conducted by GC/FID (canister samples) and GC/MS (Tenax samples) as described by Hakola et al. (1998).

The momentum and sensible heat fluxes were measured by the eddy covariance technique at heights of 31 and 18 metres by acoustic anemometers. The measurement system and data processing procedures are described in detail by Aurela et al. (1996, 1998) and Tuovinen et al. (1998). The fluxes of water vapour and carbon dioxide were also measured by the eddy covariance method, and several meteorological parameters were recorded.

JULY 13, 1996
KENTTÄROVA

AUGUST 2, 1997
HUHUS

ALPHA-PINENE: 49.1 %
CAMPHENE: 5.0 %
BETA-PINENE: 15.8 %
CARENE: 30.0 %

ALPHA-PINENE: 60.0 %
CAMPHENE: 4.7 %
BETA-PINENE: 4.6 %
CARENE: 12.5 %
SABINENE: 0.4 %
1,8-CINEOLE: 5.2 %

Figure 2. Relative abundancies of the monoterpene species in the total fluxes presented in Figure 1.

To maintain the quality of the measured VOC fluxes, data associated with too weak turbulence ($u_* < 0.1$) or wind directions with inadequate fetch were removed. The turbulence data was also compared with other meteorological data and inconsistent data points were removed.

Measurement sites

During the BIPHOREP project two micrometeorological measurement campaigns were conducted in boreal forest sites in Finland. The first campaign was conducted in July 1996 at Kenttärova (67º58'N, 24º14'E) near the Pallas-Ounastunturi national park in northern Finland; the second one was carried out in July-August 1997 at Huhus (62º52'N, 30º49'E) near the Mekrijärvi research station in eastern Finland.

The Kenttärova site is situated near to the northern border of the boreal vegetation zone. The forest at the site is composed mainly of Siberian spruce (*Picea abies* subsp. *obovata*) and mountain birch (*Betula pubescens* subsp. *czerepanovii*). The Huhus site lies on the border of the south and middle boreal subzones. The forest at the Huhus site is Scots pine (*Pinus sylvestris*) with some common juniper (*Juniperus communis*).
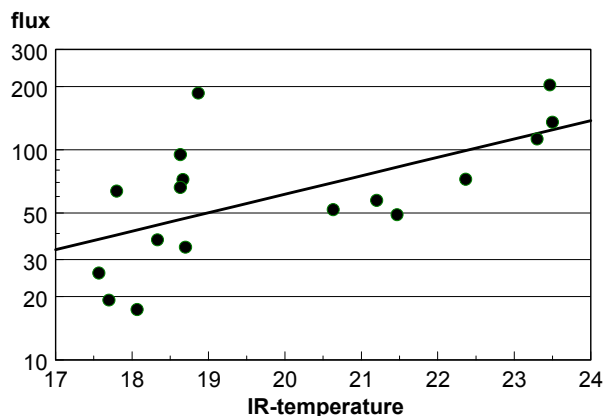
Figure 3. Temperature dependency of monoterpene fluxes measured at Huhus on July 31st and August 2nd, 1997. Fluxes are in ng m^{-2} s^{-1} and temperature in °C. The coefficients in equation (2) are β=0.202 and α=1.07.

Results

At both sites the concentrations of BVOCs were dominated by monoterpenes. The most abundant monoterpene was α-pinene. The vertical fluxes of monoterpenes on two measurement days are presented in Figure 1, and their relative abundancies in Figure 2. The air temperatures during the monoterpene flux measurements at Kenttärova on July 13, 1996, were 14-17°C, and 16-21°C at Huhus on August 2, 1997. The mean emission rates during these two days, normalized to 30°C using the temperature coefficient β=0.09, were 190 ng m^{-2} s^{-1} and 180 ng m^{-2} s^{-1} at Kenttärova and Huhus, respectively.

The isoprene gradients at both sites were very low and their uncertainty exceeded the gradients themselves. The mean of all daytime flux measurements at the Kenttärova site was 3±17 ng m^{-2} s^{-1}; the uncertainty is an order of magnitude higher than the flux. The situation was similar at the Huhus site.

At Huhus, α-pinene was the dominant monoterpene emitted, whereas at the Kenttärova site Δ^3-carene emission comprised more than half of the α-pinene emission. Other species contributing to the total monoterpene emission at Kenttärova were β- pinene and camphene, and at Huhus β-pinene, camphene and 1,8-cineole, with sabinene having minor importance. Limonene

Table 1. *Correlation matrix of the meteorological parameters and the total monoterpene fluxes measured at Huhus on July 31st and August 2nd, 1997. One asterisk indicates correlations exceeding the critical value for the 5 % risk level and two asterisks that for the 1 % risk level. Tair: air temperature; Tir: Canopy temperature measured by infra-red thermometer; PAR: photosynthetically active radiation; Rglob: global radiation; VPD: vapour pressure deficit.*

	Tair	Tir	PAR	Rglob	VPD
Tir	0.96**	1			
PAR	0.56*	0.76**	1		
Rglob	0.56*	0.76**	1.00**	1	
VPD	0.91**	0.96**	0.72**	0.72**	1
F	0.48	0.56*	0.55*	0.56*	0.44
ln F	0.54*	0.61**	0.57*	0.58*	0.53*

was excluded from the flux calculations due to problems with its chemical analysis. The concentrations of limonene were about 20 % of the total monoterpene concentration at the Kenttärova site and about 5 % at the Huhus site. The concentration profiles at both sites were similar to the emission profiles.

Monoterpene fluxes correlated significantly with several meteorological parameters which, however, also correlated with each other (Table 1). The best correlation was found with the IR-temperature of the canopy. The temperature dependencies of the monoterpene fluxes followed the exponential equation (2):

$$F_{mt} = e^{\beta T + \alpha}, \qquad\qquad\qquad (2)$$

where α and β are empirical coefficients (Figure 3). The temperature coefficient at the Scots pine stand at the Huhus site was close to that for Scots pine published by Janson (1993). At Kenttärova the temperature coefficients were higher than the published ones.

Conclusions

The vertical fluxes of monoterpenes and isoprene were measured at two sites in the boreal forest zone in Finland. The uncertainty of the isoprene gradient exceeded the magnitude of the gradient at both sites and the monoterpene flux was at least an order of magnitude higher than the isoprene flux. The abundance of α-pinene was typical for the monoterpene emissions of

the forest at both sites. Significant correlations were obtained between the measured monoterpene fluxes and several meteorological parameters but these parameters were also very strongly correlated with each other.

Acknowledgments

References

Aurela, M., Laurila, T. and Tuovinen, J.-P., 1996: Measurements of O_3, CO_2 and H_2O fluxes over a Scots pine stand in eastern Finland by the micrometeorological eddy covariance method. Silva Fennica, 30, 97-108.

Aurela, M., Tuovinen, J.-P. and Laurila, T., 1998: Carbon dioxide exchange in a subarctic peatland ecosystem in northern Europe measured by the eddy covariance technique. Journal of Geophysical Research 103, 11289-11301.

Fuentes, J. D., Wang, D., Neuman, H. H., Gillespie, T. J., Den Hartog, G. and Dann, T. F., 1996: Ambient biogenic hydrocarbons and isoprene emissions fron a mixed deciduous forest. Journal of Atmospheric Chemistry 25, 67-95.

Hakola, H., Rinne, J. and Laurila, T., 1998: The hydrocarbon emission rates of tea-leafed willow *(Salix phylicifolia)*, Silver birch (*Betula pendula*) and European aspen (*Populus tremula*). Atmospheric Environment 32, 1825-1833.

Janson, R., 1993: Monoterpene emission of Scots pine and Norwegian spruce. Journal of Geophysical Research 98, 2839-2850.

Tuovinen, J.-P., Aurela, M. and Laurila, T., 1998: Resistances to ozone deposition to a flark fen in the northern aapa mire zone. Journal of Geophysical Research 103, 16953-16966.