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Atmospheric Environment 39 (2005) 2061–2070
ATMOSPHERIC ENVIRONMENT
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The flux of isoprene from a willow coppice plantation and the effect on local air quality

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Received 6 July 2004; received in revised form 22 November 2004; accepted 9 December 2004

Abstract

Isoprene fluxes from a *Salix viminalis* (willow) plantation in western Sweden were measured using the relaxed eddy accumulation (REA) technique. Fluxes of up to 0.23 $\mu g\,m^{-2}\,s^{-1}$ could be observed. A standard emission factor at 303 K and a PAR flux of 1000 $\mu mol\,m^{-2}\,s^{-1}$ was estimated to 0.98 $\mu g\,m^{-2}\,s^{-1}$ by using the G93 algorithm. The chemistry of an air parcel passing over a willow coppice plantation was investigated utilising a Lagrangian box model in which the measured isoprene fluxes were used as input data. Dispersion after the field was accounted for by a procedure based on the Gaussian plume model. The calculations indicate that, in most cases, the isoprene emissions have a small effect on the local air quality.

Keywords: *Salix viminalis*; REA; Micrometeorology; Modelling; Isoprene emission

1. Introduction

The Swedish government decided in 1996 to have, as an objective, the closing down of two nuclear power plants (Barsebäck I and II). The first plant was closed in November 1999 and the second is scheduled to be shut in December 2005. This is a step towards the change-over to energy production based on renewable sources in accordance with the Swedish law governing the phasing-out of nuclear power. However, the condition for closing down nuclear units is that the need for energy should be kept satisfied. Therefore, large scale use of fast-growing biomass, e.g. willow, for energy production appears to be necessary if Sweden is to succeed in phasing out nuclear power. Moreover, willow species are also utilised for purification of waste water and sludge, primarily for removal of nitrogen and phosphorus (Perttu and Kowalik, 1997; Rosenqvist et al., 1997; Dimitriou and Aronsson, 2004), indicting the potential for multipurpose use.

Willows are already grown in coppice plantations in Sweden for biofuel production, but the acreage would have to be increased greatly to give a significant contribution to the energy supply. However, willows are strong emitters of isoprene (2-methyl-1,3-butadiene), which is the predominantly emitted volatile organic compound (VOC) from deciduous species. The emission rate is dependent on the intensity of solar radiation and leaf temperature, and shows considerable variation between species. Isoprene is chemically a very active compound, and its oxidation in the atmosphere may be initiated by ozone or photochemically produced radicals. The oxidation passes through a number of steps and several comparatively stable intermediate products appear, which may affect the air quality. VOC and NO_x, in combination with solar radiation may produce ozone

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1352-2310/$ - see front matter
doi:10.1016/j.atmosenv.2004.12.015

(Atkinson and Arey, 2003) and peroxyacetyl nitrate (PAN) (Wang and Shallcross, 2000; Grosjean, 2003) in the planetary boundary layer. Even at low concentrations, ozone affects humans (Goodman and Gilman, 1996; von Mühlendahl, 1997) and vegetation (Bastrup-Birk et al., 1997). Other species, which may significantly influence the air quality, are aldehydes, ketones, alcohols and carboxylic acids. Photochemically produced OH-radicals are the most important initiators of oxidation reactions in the atmosphere. These reactions are of the greatest importance for cleansing of the atmosphere. Since isoprene is very reactive, it will, if released in quantity, consume much of the available OH-radicals, impairing the removal of other pollutants. Ozone formation in rural areas is expected to be NO_x limited. Thus, elevated concentrations of ozone and PAN may be expected if plantations are located close to sources of NO_x, such as urban areas with intense traffic. Since transport costs contribute to the price of biofuel-derived energy, it is reasonable to assume that many coppice plantations will be located close to urban areas.

The aim of this study was to investigate the impact on local air quality of isoprene emitted from large-scale willow plantations near urban areas. The common belief has been that such emissions are of no consequence for air quality. Little support for this position can however be found in the literature. To bring the subject forward, it is important to determine typical emission rates of isoprene from willow plantations located in Scandinavia. Subsequently, by using the emission rates as input in a mathematical model, concentrations of compounds affecting air quality can be estimated.

Flux measurements of isoprene have been made above canopies of different biotopes, using micrometeorological methods (e.g. Geron et al., 1997; Greenberg et al., 1999; Westberg et al., 2001; Rinne et al., 2002). However, no flux measurements have been made above the canopy of short rotation monocultures in Scandinavia. In this study, the relaxed eddy accumulation (REA) technique (Businger and Oncley, 1990; Olofsson et al., 2003) was used to measure isoprene fluxes from a willow coppice plantation. Furthermore, a model based on the master chemical mechanism (MCMv3) (Derwent et al., 2001) was used to describe the effects of the measured isoprene emissions.

2. Experimental

2.1. Sampling site

The sampling site is located near Grästorp in the province of Västergötland, Sweden (58°20.85′N; 12°34.17′E). The field measures $5.82 \times 10^4\,m^2$ (Fig. 1). The willow coppice plantation is surrounded by several

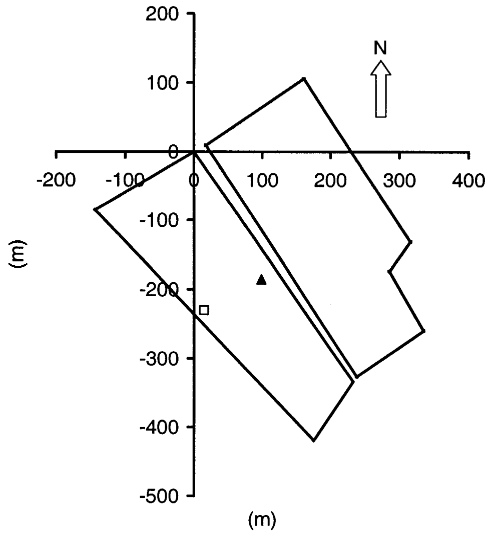

Fig. 1. The willow coppice plantation located in Salstad, western Sweden, with the origin at 58°20.852′N 12°34.173′E. Measurements were made on the western field, which measured about $58\,200\,m^2$. Depending on wind direction, air sampling was made either at the triangle (▲) or the square (□).

square kilometres of flat agricultural fields. Air sampling was carried out above the canopy at the downwind side of the plantation. The plantation consisted of clones of three varieties of *Salix viminalis*: number 07, 112 and 183 in the Swedish inventory, distributed: 1:1:1. The canopy typically measured 3.8 m, the plant density was 1.2 plants m^{-2} (average of 4 randomly selected areas of $120\,m^2$), the foliar mass-density (D) was estimated to 298 g dry weight m^{-2} (gdw m^{-2}) and the leaf area index (LAI) was 5.8 (31/8, 2002). The neighbouring fields, carrying cultivated wheat, were located beyond the REA fetch area. The fetch requirements were investigated by using the method proposed by Olofsson et al. (2003). Measurements were carried out in the middle of June, at the end of July and in the middle of September 2002 in order to cover most of the growing season.

2.2. The REA system

The principle behind REA flux measurements is that the turbulent vertical flux of a compound is proportional to the difference in its concentration between air parcels transported up- and downwards by turbulence. The vertical net flux is calculated by

$$F_{REA} = \sigma_w \beta (C_{up} - C_{down}), \tag{1}$$

where β is an empirical constant and $\sigma_w (m\,s^{-1})$ the standard deviation of the vertical wind velocity. C_{up} and C_{down} are the average concentrations of a substance transported upwards and downwards, respectively, by