4.24 TRACEFLUX - A SMALL SCALE TRACER EXPERIMENT AT A FORESTED SITE

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INTRODUCTION

At Tharandt (SW of Dresden, Germany) continuous eddy covariance fluxes and concentration profiles of trace gases (H_2O and CO_2) are measured since 1996 within EUROFLUX and CARBOEURO-FLUX. In order to interpret flux and concentration measurements made in forested, complex and not perfectly homogeneous terrain, it is of fundamental importance to allocate the source area (footprint) of the species considered. For understanding the spatial context of trace gas measurements additional information on the area of influence is needed. Size and location of this area are can basically be modelled with three different methods: by calculating analytical solutions of the diffusion equation, applying Lagrangian or Eulerian stochastic dispersion models, or large eddy simulation (Schmid, 2002). But whatever model is applied for calculating the area of influence, validation data is needed. So far models calculating the complex flow in and above plant canopies were mainly compared against each other using the more sophisticated modelling type as reference (e.g.: Baldochi, 1997, Rannik et al. 2000). There exist only few data sets that allow a verification of model performance above vegetation (e.g.: Leclerc et al. 2003). To the authors knowledge essentially no validation data exists for in-canopy dispersion. Still it is known that the size and probability distribution of footprints emanating from inside or below the forest canopy may differ significantly from those observed above forests (Baldocchi, 1997). It was therefore our intention to collect a dataset of trace gas concentrations inside the canopy in the area of Tharandt forest. This data set will be used to check model performances on calculating the tracer concentrations. This abstract provides a description of the tracer experiments, illustrates measured concentration fields and provides some background information on the meteorological conditions during the experiments.

EXPERIMENTAL DESIGN

Tharandt Anchor station (AS) is located in a coniferous forest (mainly Picea abies) which has a mean height of 29 m, a tree density of 440 per ha and a LAI of 8. The 40 m high tower is situated 380 m a.s.l in a relatively flat area with moderate southeast exposition. In some distance towards north-east and south-east however the terrain is declining with slopes up to 10°. In the west it is rising up to 422 m a.s.l..

Meteorological measurements

Since 2001 concentrations of CO_2 and H_2O are continuously monitored at 8 levels (0.2, 1, 2, 8, 26, 33, 37, 40 m a.g.). Turbulence is measured in 42 and 33 m a.g. with ultrasonic anemometers (sonics). During the experimental period (08/09 2003) additional turbulence measurements were carried out in the canopy and in trunk space. During an intensive measuring period, connected with VERTIKO-MORE II, three additional towers were erected (P1, 2, 3) each with -amongst others- two sonics, one in trunk space and one just above the canopy (Fig. 1). Information about near field turbulence conditions was provided by a sonic that was operated at the tracer release point. For estimations of the mixed layer height (temperature) profiles were measured with a tethered balloon (DigiCora Tethersonde System, RS90-Sonde). Furthermore a SODAR was operated for information on the wind field at up to

500 m. An overview on the turbulence measurements is given in table 1, the spatial distribution of towers and instruments is shown in figure 1.

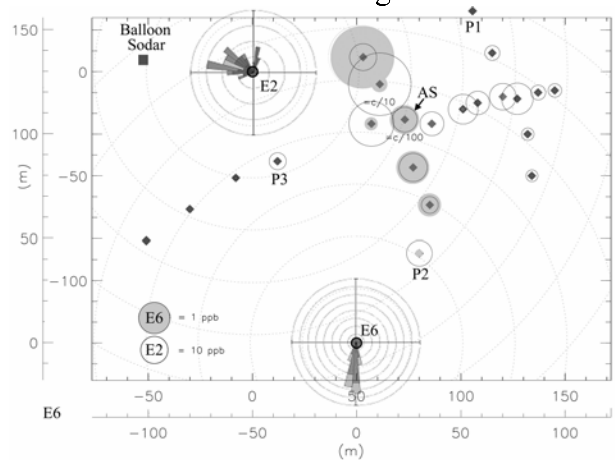

Figure 1. Schematic of setup and measured concentration fields of experiments E2 (white dots) and E6 (grey filled dots). Fractional concentrations refer to E6. Diamonds refer to tracer sampling stations. Axis are given with the point of origin being located at the release point. Additionally wind conditions at the release points are shown.

Table 1. Overview of instrument types and measurements. z stands for height above ground and h for canopy height.

Station	Instrument	Instrument type	*z/h* ( )	Output sampling rate (s)
AS	Sonic	Metek	0.68, 1.14, 1.45	0.05, 0.10, 0.10
AS	Sonic	CSAT	0.07	0.05
P1	Sonic	Metek	0.09, 1.10	0.05
P2	Sonic	Metek	0.09, 1.07	0.05
P3	Sonic	Metek	0.09, 1.08	0.05
Release	Sonic	CSAT	0.07	0.05

Tracer release and measurements

The gas release started about 15 minutes prior to sampler activation. The tracer (SF_6) was released from a point source 2 m a.g.. The gas was released through a nylon tube that was connected to a mass flow controller. For each experiment a release point was chosen, depending on the meteorological conditions (i.e. wind speed and direction).

The sampling was based on the collection of air in Saran bags. Details on the equipment are given in Gryning (1981) and are only briefly described here. The air was aspirated by diaphragm pumps from 20 m above ground to the sampling units. The air was led through one of three magnetic valves, the units thus inflated one of 3 bags in sequence each having a sampling time of 30 min. The units were simultaneously started by a radiosignal. For each experiment 19 samplers were installed. Additionally two profile samplers were used which measured in 2, 8, 20 or 33 and 26 m a.g.. These units were based on the same sampling principle. They were, however, started by a preset clock timer and the valves where triggered such, that all heights were sampled synchronously. The profile samplers were installed at locations AS and P1 (Fig. 1).

Immediately after the experiments the air samples were brought to the laboratory for chemical analysis. A detailed description of the SF_6-analysis is given in Goanta et al. (2004) and again only the most important points are outlined here. The analysis was carried out with a gaschromatograph (GC) equipped with an electron capture detector (ECD), where the chromatogramm and therefore the SF6 peak area was given by an integrator. The main problem with GC/ECD measurements is the often observed small linear response range. By using a special column which is very sensitive to halogen compounds and by injecting different air volumes the measuring range could be extended to as much as 25 ppt to 1 ppm. As background concentrations are less than the lower limit of the linear measurement range (5.7-8.2 ppt) air samples collected previous to each experiment were sent to the Umweltbundesamt for analysis.

METEOROLOGICAL CONDITION

A total of six tracer experiments was carried out. Wind velocities during all experiments were fairly small. As can be seen from the distributions of wind direction and wind speed (Fig. 2) only 4 of the 6 experiments can be considered quasi stationary and will therefore be considered here.

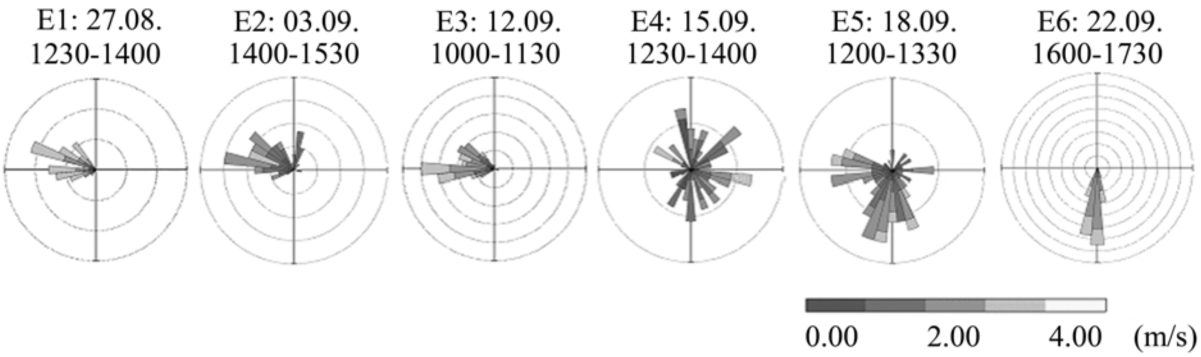

Figure 2. Frequency distribution of wind direction and speed basing on 1 min mean data measured in trunk space. Times indicated are given in CET (=GMT+1).

The integral statistics of the wind field for the first experiment are exemplarily shown in figure 3. Above the forest a logarithmic mean wind profile is observed. In the forest canopy wind speed decays exponentially and can be parameterised with

$$\bar{u}(z) = \bar{u}(h)\exp\left(\alpha_{u1}\left(z/h-1\right)\right) \tag{1a}$$

where z is the height above ground and h stands for canopy height (e.g.: Kaimal and Finnigan, 1994). The extinction coefficient α_{u1} depends on the canopy density and a value of 4.0 has been used for the present data. For taking into account the secondary maximum of wind velocity in trunk space, we introduce

$$\bar{u}(z) = u(z_t)/\exp(\alpha_{u2}(z/z_t-1)) \tag{1b}$$

where α_{u2} =0.4 and $z \le z_t$ z_t being the trunk space height. This secondary maximum is a typical feature of wind profiles in dense forests and is regularly observed in Tharandt forest. Please mind that the tethered balloon was released in a nearby clearing and therefore observed wind velocities continuously decrease with height. The dense canopy is a strong sink for momentum and there is a rapid decrease of (kinematic) momentum flux with decreasing height. The momentum flux is fairly well represented by the parameterisation. This holds for the exponentially decaying standard deviations of velocity components ($\sigma_{u,v,w}$) too, if a trunk space parameterisation analogous to the one shown for the wind profile is introduced. A secondary maximum in $\sigma_{u,v}$ is less frequently reported than for the mean wind velocity. It may be caused by at least two different mechanisms: on the one hand it may result from pressure disturbances (connected with Kelvin-Helmholtz type instabilities) which lead to an increase of turbulent kinetic energy in trunk space. On the other hand it could be an effect caused by the nearby clearing. However, against the latter argues that the increase in horizontal velocity fluctuations is independent from wind direction. 'Measured' values of the dissipation rate , are derived by relating , to the spectral power in the inertial subrange. Considering the uncertainty and/or inaccuracy of even assuming an inertial subrange in a forest canopy, the parameterisation fits data surprisingly well if no roughness sublayer parameterisation is introduced. The Lagrangian time scales are then calculated as $T_{Lv,w} = 2\sigma^2_{v,w}/C_0$, and are considered constant with height from *h* downwards.

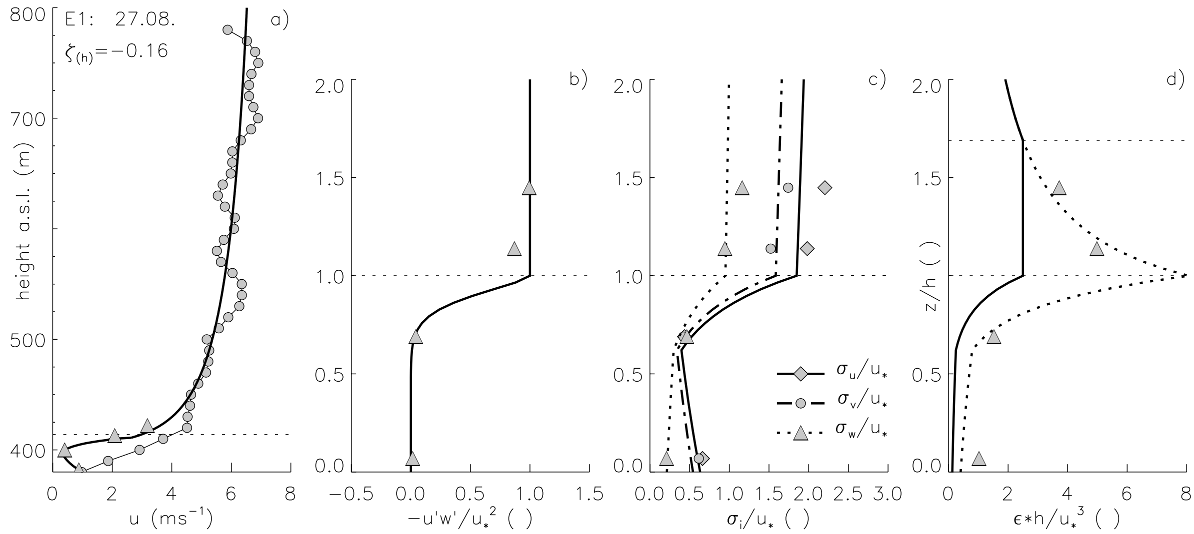

Figure 3. Integral statistics (30 min means) of the wind field. a) Mean wind profile: line stands for parameterisation, grey dots for tethered balloon and grey triangles for sonic measurements. Normalised profiles of b) (kinematic) momentum flux c) standard deviations and d) dissipation rate. Lines stand for parameterisations, symbols for sonic measurements. In d) the solid line stands for a parameterisation considering a roughness sublayer.

MEASURED AND MODELLED CONCENTRATION FIELDS

In a first approach we used the model of Horst and Weil (1994). Their analytical solution of the advection-diffusion equation (based on the van Ulden (1978)) takes the logarithmic wind profile and atmospheric stability into account. Model parameters and lateral dispersion are calculated as in Gryning et al. (1987).

Given the fact that the wind profile in the canopy differs substantially from logarithmic the model performs surprisingly well for experiments E1 to E3. Even though only 35 to 44% of the measured values lie within a factor of 2 of the modelled ones, essentially all values lie within a factor of 10. The modelled concentrations are generally lower than the measured ones (fbias). Only close to the source the opposite is true. If we consider that close to the source, where the mean plume height is low, the wind velocities are higher than further downwind, where the mean plume height is more elevated, this is exactly what we would expect as a model result error. For E6 however the model fails completely. One possible reasons which can explain this failure are fairly high wind velocities in trunk space combined with very low TKE-levels inhibiting both, lateral and vertical mixing. This leads to a very narrow plume in downwind direction (figure 1).

Table 2. Statistics as proposed by Hanna et al. (1993) to evaluate the model performance

	E1	E2	E3	E6
corr	0.48	0.62	0.50	-0.06
f2	0.35	0.42	0.44	0.05
f10	0.94	1.00	0.94	0.21
fbias	0.81	0.78	0.69	0.10
nmse	1.45	1.18	1.05	17.38

CONCLUSIONS AND OUTLOOK

During 08/09 2003 SF_6 tracer experiments were carried out in Tharandt forest. First modelling attempts with the analytical model of Horst and Weil (1994) show fairly promising results even though the underlying assumption (e.g. shape of the wind profile) are violated. We therefore intend to apply a Lagrangian stochastic model with implemented canopy wind and turbulence profile, which is also capable of resolving horizontal inhomogeneities.

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