



Distributed Modified Bowen Ratio method for surface layer fluxes of reactive and non-reactive trace gases

J.-C. Mayer^{a,*}, A. Bargsten^a, U. Rummel^b, F.X. Meixner^{a,c}, T. Foken^d

^a Biogeochemistry Department, Max Planck Institute for Chemistry, Joh.-J.-Becherweg 27, 55128 Mainz, Germany

^b Richard Aßmann Observatory Lindenberg, German Meteorological Service, Germany

^c Department of Physics, University of Zimbabwe, Harare, Zimbabwe

^d Department of Micrometeorology, University of Bayreuth, Bayreuth, Germany

ARTICLE INFO

Article history:

Received 31 March 2010

Received in revised form

24 September 2010

Accepted 4 October 2010

Keywords:

Flux

Trace gas

Exchange

Timescale

Turbulence

ABSTRACT

Modified Bowen ratio technique was used in a horizontally distributed form to determine turbulent fluxes of CO₂, H₂O, O₃, NO and NO₂ over a semi-natural grassland site in North-Eastern Germany. The applicability of the distributed variation of the Modified Bowen Ratio technique was proven prior to the calculation of trace gas fluxes. Turbulent NO fluxes were compared to fluxes up-scaled from laboratory measurements of biogenic NO emission from soil samples, which have been taken at the field site. The NO fluxes up-scaled from laboratory measurements were slightly larger than the fluxes observed in the field. However, both NO fluxes agreed within a factor of two. Under suitable night time conditions, we performed a detailed comparison of turbulent fluxes of CO₂ and O₃ with fluxes derived by the boundary layer budget technique. While there was agreement between these fluxes in a general sense, specific deviations were observed. They could be attributed to different footprint sizes of both methods and to *in situ* chemistry within the nocturnal boundary layer.

© 2010 Elsevier B.V. All rights reserved.

1. Introduction

Temporal and spatial variations of trace gas fluxes from and to the surface are crucial for understanding exchange processes between the atmosphere and terrestrial surfaces. A lot of effort in this respect has been done for the species carbon dioxide (CO₂), mostly using eddy covariance (EC) techniques (see e.g. Aubinet et al., 2000; Baldocchi et al., 2001, 1988; Suni et al., 2003). Turbulent fluxes of reactive trace gases, e.g. ozone (O₃), nitrogen oxide (NO) and nitrogen dioxide (NO₂), are currently measured more on campaign than on a continuous basis (see e.g. Keronen et al., 2003; Rummel et al., 2002; Wesely et al., 1982). If fast enough sensors for EC measurements for these trace gases are available at all, they often need permanent maintenance, making them less suitable for permanent measuring networks.

An alternative technique to measure turbulent fluxes of trace gases is the so-called Modified Bowen Ratio (MBR) method (Businger, 1986; Leuning et al., 1979; Sinclair et al., 1975; Verma and Rosenberg, 1975). Originally, fluxes of trace gases have been derived from sensible heat flux (H) and vertical differences of air temperature (ΔT) and mixing ratio (Δc), where H has been typically determined by the Bowen Ratio method (Bowen, 1926; Lewis,

1995). With the development of sonic anemometers, a direct measurement of H became feasible, reducing the instrumental effort because radiation and soil heat flux measurements were no longer needed (Liu and Foken, 2001). The application of this method however is only feasible if the vertical source/sink distribution of the surrogate scalar (here: heat/temperature) is similar to that of the tracer.

The traditional setup of a MBR station includes EC measurements of H and the determination of ΔT and Δc at the same location. Furthermore, ΔT and Δc have to be measured at the same heights. However, if several trace gases have to be measured and analyzer or inlet constructions are somewhat bulky, measurement errors due to flow distortion could be substantial. But this error source can be tackled (if a sufficiently large, homogeneous site is available) using distributed locations for the individual measurements of Δc , ΔT and H . Moreover, for intercomparison studies, this reduces potential deviations between different measuring systems to the trace gas part of the measurements, as all flux calculations will relate on the same data set of H and ΔT . This approach will be presented in this paper and will be referred to as the Distributed Modified Bowen Ratio (DMBR) method.

The methods for measuring the fluxes of reactive trace gases are in principle the same as for non-reactive trace gases. The concept, whether the reactivity of a trace gas has to be taken into account was firstly described by Damköhler (1940). Therefore, the ratio of the characteristic time scale for chemical reactions to the

* Corresponding author. Tel.: +49 6131 305 582; fax: +49 6131 305 584.

E-mail address: jens.mayer@mpic.de (J.-C. Mayer).

Table 1
Setup of the field site during the LIBRETTO campaign. Only instruments being relevant for this work are listed.

Parameter	Symbol	Unit	Temporal resolution (min)	Sampling height (m) a.g.l.	Instrument (Model)
Permanent setup					
Sensible heat flux	H	Wm ⁻²	10	2.4	METEK USA1
Air temperature, EC station West/East	T	°C	10	0.55/0.5, 2.8/2.4	Pt-100
Friction velocity	<i>u</i> *	ms ⁻¹	10	2.4	METEK USA1
Global radiation	R _g	Wm ⁻²	10	2.4	Kipp&Zonen CM22
Air temperature, 10 m profile	T	°C	10	0.5, 4	Pt-100
Wind speed	U	ms ⁻¹	10	0.5, 4	Climatronics F460
Rain	R	mm	10	1	Ott, Pluvio
Additional LIBRETTO setup					
Ground based					
Air temperature	T	°C	10	0.25, 0.5, 1.0, 2.0	Aspirated Thermocouple
Carbon dioxide	CO ₂	ppm	10	0.15, 2.0	LiCor LI 7000
Water vapour	H ₂ O	‰	10	0.15, 2.0	LiCor LI 7000
Nitrogen monoxide	NO	ppb	10	0.15, 2.0	EcoPhysics CLD 780
Nitrogen dioxide	NO ₂	ppb	10	0.15, 2.0	EcoPhysics CLD 780
Ozone	O ₃	ppb	10	0.15, 2.0	Thermo Electron 49C
Additional LIBRETTO setup					
Elevator					
Air temperature	T	°C	10	2–99	Thermocouple
Carbon dioxide	CO ₂	ppm	10	2–99	LiCor LI 840
Water vapour	H ₂ O	‰	10	2–99	LiCor LI 840
Air pressure	P	hPa	10	2–99	Vaisala PTB 101B
Ozone	O ₃	ppb	10	2–99	GFAS OS-G-2

time scale of turbulence is referred to as the Damköhler number (DA). As long as DA is much smaller than one, the reactivity can be neglected. Otherwise, chemical alteration during the transport must be considered. A determination of individual fluxes of reactive trace gases independent from the risk of chemical alteration would be a great advantage. In the case of NO, soil emission fluxes, derived from laboratory measurements on soil samples, would be a suitable approach. However, laboratory measurements can provide a sound parameterization of soil NO fluxes only under varying soil moisture and soil temperature conditions; hence, NO fluxes up-scaled from laboratory measurements will never have the status of actual field measurements, which are made under variable ambient conditions. The comparison of laboratory derived fluxes with actual field fluxes will always be challenged by this principal difference between laboratory and field methods.

A similar statement holds, if flux measuring methods differ in the characteristic transport time relevant to the measurements which are being used to compute the fluxes. In case, the trace gas flux is derived from the vertical mixing ratio difference, the characteristic transport time increases, if the vertical spacing between two levels is increased. This, in turn, increases the potential influence of chemical reactions to change the mixing ratios of reactive trace gases (during turbulent transport). This has to be taken into account, when comparing fluxes obtained by methods with large spatial extent to those with only small ones.

If vertical profile data of a quantity, whose flux has to be determined, are available up to the equilibrium height (i.e. where temporal changes of mixing ratios are not observable anymore), the so-called boundary layer budget method can be used (Pattey et al., 2002). This method integrates vertical profiles of the desired quantity and assigns its temporal change to a vertical flux into the corresponding volume (Denmead et al., 1996; Levy et al., 1999). If horizontal advection can be excluded, and the top end of the profile is capped by a “lid”, the temporal change should equal the vertical flux at the bottom end of the profile, i.e. the flux determined by DMBR or EC methods. The “lid” can either be a strong inversion, or the presence of strong wind shear due to a low-level jet (Mathieu et al., 2005). As a case study, we compare fluxes of sensible heat, CO₂ and O₃ obtained from the DMBR method to the respective fluxes obtained from the boundary layer budget method. This comparison should show (a) the similarity of both methods for conservative quantities and (b) the increasing influence of chemical reactions

(on O₃ flux) for the method with the larger spatial extension (the boundary layer budget method).

2. Materials and methods

2.1. Site and setup

The LIBRETTO (LindenBerg REActive Trace gas prOfiles) campaign took place in late summer 2006, from 01 August 2006 until 31 August 2006 at the Falkenberg Boundary Layer Field Site of the Meteorological Observatory Lindenberg (Richard-Aßmann Observatory) (Beyrich and Adam, 2007). The field site is located at 52° 10' 01" N, 14° 07' 27" E, 73 m a.s.l. The main vegetation species are perennial ryegrass (*Loliumperenne*), red fescue (*Festucarubra*), dandelion (*Leontodonautumnalis*, *Taraxacumofficinale*), bromegrass (*Bromushordeaceus*), and clover (*Trifoliumpratense*, *Trifoliumrepens*). The meadow is mowed regularly in order to keep the mean vegetation height below 20 cm (Beyrich and Adam, 2007). However, during the LIBRETTO campaign, the vegetation height was between 5 cm and 8 cm. The measuring site comprises one 99 m and one 10 m high profile mast (air temperature (*T*), relative humidity (*rH*), wind speed (*u*) and wind direction), two identical setups for the measurement of the net radiation flux, two stations for the measurement of turbulent fluxes of momentum, sensible and latent heat (further on referred to as the EC stations), and a sub-site to monitor physical soil quantities (soil temperatures, soil heat flux and soil moisture). A SODAR-RASS system completes the permanent setup of the Falkenberg site. Details about the instrumentation relevant for this work are summarized in Table 1, the spatial situation is shown in Fig. 1. All heights given in this study are heights above ground level, unless otherwise stated.

The 99 m profile mast is equipped with an elevator, usually used for service and maintenance. On this elevator, additional sensors for *T* and *rH* as well as for ozone (O₃), carbon dioxide (CO₂) and water vapour (H₂O) have been installed (see Table 1). However, we limit our evaluation from this system to *T*, CO₂ and O₃, because the H₂O channel of the deployed instrument has unfortunately not worked properly. The elevator was automatically run up and down once every 10 min, interrupted only for data retrieving and service. At bottom and top position, the elevator had approx. 6.5 min idle time for equilibration and intercomparison with stationary sensors and analyzers, thus one profile needed approx. 3.5 min to be measured.

Download English Version:

<https://daneshyari.com/en/article/82150>

Download Persian Version:

<https://daneshyari.com/article/82150>

[Daneshyari.com](https://daneshyari.com)