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Quantifying nighttime ecosystem respiration of a meadow using eddy covariance, chambers and modelling

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Abstract

Aim of the present paper is to quantify the ecosystem respiration of a mountain meadow in the Austrian Alps during the vegetation period 2002 by constraining nighttime eddy covariance measurements with ecosystem respiration derived from (i) daytime eddy covariance, (ii) ecosystem chamber and (iii) scaled up leaf and soil chamber measurements. The study showed that the discrimination of valid nighttime eddy covariance measurements based on friction velocity (u^*), the so-called u^*-correction, is very sensitive to the imposed quality control criteria. Excluding half-hourly nighttime data, which deviate more than 30% from the stationarity and integral turbulence tests caused the magnitude of the u^*-correction to be significantly reduced. Based solely on nighttime eddy covariance data, we are currently unable to decide whether the observed high CO_2 fluxes during intermittent turbulence represent artefacts and should be screened out, or whether these reflect a genuine transport of CO_2 not accounted for by the storage term and must be retained. Evidence against the inclusion of these data is derived from soil respiration rates measured in situ and calculated inversely from the other approaches, which were significantly lower as compared to soil respiration calculated from inversion of the half-hourly nighttime data inclusive of the observations which failed to meet the specified quality control criteria. Seasonal (8 March–8 November 2002) nighttime carbon balances simulated based on the parameters derived from the remaining approaches agreed with each other to within 35%, which is of the order of the uncertainty of each individual approach.

Keywords: Carbon dioxide emission; Friction velocity; Parameter inversion; Stationarity

1. Introduction

The steady rise in atmospheric carbon dioxide (CO_2) concentrations since the industrial revolution

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(30% increase over the last 150 years) and the anticipated adverse consequences on the global climate system, have triggered a strong scientific and public interest in the global carbon cycle (Steffen et al., 1998; Lloyd, 1999). A key variable in this context is the net ecosystem CO_2 exchange (NEE), which is the (small) difference between daytime photosynthetic CO_2 uptake and respiratory losses of CO_2 during nighttime. If photosynthetic uptake prevails over respiratory losses, NEE, according to meteorological notation, is negative and the ecosystem is said to be a net sink for CO_2. Conversely, NEE is positive and the ecosystem is said to be a net source of CO_2 if losses exceed uptake of CO_2.

Measurements of NEE usually require the quantification of the net flux of CO_2 across the boundaries of a notional or real control volume erected above the ecosystem using micrometeorological or ecophysiological (chamber) methods, respectively. Among the micrometeorological methods, the eddy covariance technique is the currently most widely used (Aubinet et al., 2000; Baldocchi et al., 2001), and in principle, allows derivation of daily to decadal estimates of NEE by integrating quasi-continuous short-term (usually 0.25–2 h) measurements of NEE (e.g. Barford et al., 2001). Employing a single set of instruments the eddy covariance method relies upon the assumption of horizontal homogeneity of fluxes, when NEE reduces to the sum of the vertical net exchange and the storage flux, the latter accounting for the net storage of CO_2 in the control volume (Finnigan et al., 2003; Massman and Lee, 2002). This assumption is often violated under calm and stable nighttime conditions, when CO_2 is suspected to leave the control volume other than in the vertical (advection, drainage flows) and thus undetected by the eddy covariance sensors, leading to an underestimation of nighttime respiration and consequently to an overestimation of NEE (Aubinet et al., 2003; Staebler and Fitzjarrald, 2004). The widely adopted engineering-type approach to deal with what is often referred to as the ‘nighttime-problem’, is to discard NEE measurements during calm conditions and replace the missing values with NEE modelled as a function of temperature parameterised with measurements during windy conditions, when the eddy covariance system is supposed to capture the ‘true’ biological flux (Massman and Lee, 2002). Discrimination between calm and windy

Nomenclature

a, b, c	parameters of Eq. (A.2a) and (A.2b)
E_x	activation energy of plant (x = p) and soil (x = s) respiration (J mol^{-1})
f	normalised frequency
F_{NEE}	net ecosystem CO_2 exchange (μmol m^{-2} s^{-1})
$F_{GPP,sat}$	gross primary production at high irradiance (μmol m^{-2} s^{-1})
f_x	normalised peak frequency of cospectral reference model
L	plant area index (m^{-2} m^{-2})
N	normalisation constant of cospectral reference model
Q_{PPFD}	photosynthetically active radiation (μmol m^{-2} s^{-1})
R	universal gas constant (8.314 J mol^{-1} K^{-1})
R_{eco}	ecosystem respiration (μmol m^{-2} s^{-1})
R^*_{eco}	ecosystem respiration normalised to 10 °C and unit leaf area (μmol m^{-2} s^{-1})
R_x	plant (x = p) and soil (x = s) respiration (μmol m^{-2} s^{-1})
$R_{x,Tref}$	plant (x = p) and soil (x = s) respiration at reference temperature (μmol m^{-2} s^{-1})
T_{ref}	reference temperature (283.16 K)
T_x	plant (x = p), air (x = a) and soil (x = s) temperature (°C)
u^*	friction velocity (m s^{-1})
$\overline{w'c'}$	covariance of vertical velocity and CO_2 mixing ratio (μmol m^{-2} s^{-1})

Greek letters

α	apparent quantum yield (μmol CO_2 μmol photon s^{-1})
β	slope parameter of cospectral reference model
Δ_{ITT}	deviation from integral turbulence test (%)
Δ_{ST}	deviation from stationarity test (%)
ζ	Monin–Obukhov stability parameter
μ	broadness parameter of cospectral reference model
σ_w	vertical velocity standard deviation (m s^{-1})
ϕ_w	stability function for vertical velocity