



# Diel variation in isotopic composition of soil respiratory CO<sub>2</sub> fluxes: The role of non-steady state conditions



Hella van Asperen<sup>a,\*</sup>, Thorsten Warneke<sup>a</sup>, Simone Sabbatini<sup>b</sup>, Martin Höpker<sup>c</sup>, Giacomo Nicolini<sup>b,d</sup>, Tommaso Chiti<sup>b,e</sup>, Dario Papale<sup>b</sup>, Michael Böhm<sup>c</sup>, Justus Notholt<sup>a</sup>

<sup>a</sup> Institute of Environmental Physics, University of Bremen, Otto-Hahn-Allee 1, Bremen 28359, Germany

<sup>b</sup> Department for Innovation in Biological, Agro-food and Forest Systems (DIBAF), University of Tuscia, via S. Camillo de Lellis s.n.c., 01100 Viterbo, Italy

<sup>c</sup> Center for Industrial Mathematics, University of Bremen, Bibliothekstrasse 1, 28359 Bremen, Germany

<sup>d</sup> Euro Mediterranean Centre on Climate Change (CMCC) – Impacts on Agriculture, Forests and Ecosystem Services (IAFES), via A. Pacinotti 5, 01100 Viterbo, Italy

<sup>e</sup> Far Eastern Federal University (FEFU), Ajax St., Vladivostok, Russky Island, Russia

## ARTICLE INFO

### Article history:

Received 3 May 2016

Received in revised form

16 December 2016

Accepted 19 December 2016

Available online 30 December 2016

### Keywords:

Soil respiration

Carbon isotope

Keeling plots

Diffusive fractionation

Non-steady state conditions

Arid ecosystems

## ABSTRACT

The measurement of soil CO<sub>2</sub> fluxes and their isotopic composition is increasingly used to study and distinguish respiration sources in the soil profile. The influence of non-steady state processes on soil respiratory  $\delta^{13}\text{CO}_2$  values, such as diffusive fractionation, remains unclear but is suggested to be strong, especially in arid ecosystems. In this study, an in situ Fourier transform infrared spectrometer was coupled to automated soil flux chambers and installed in an arid grassland in Italy. Hourly flux and concentration measurements of CO<sub>2</sub> and its isotopic composition were taken over bare soil and senescent grass material. CO<sub>2</sub> fluxes were stable at night ( $\sim 1 \mu\text{mol m}^{-2} \text{s}^{-1}$ ), and showed peak emissions during the day (up to  $10 \mu\text{mol m}^{-2} \text{s}^{-1}$ ). Respiratory  $\delta^{13}\text{CO}_2$  values showed a diel pattern. Daytime respiratory  $\delta^{13}\text{CO}_2$  values were on average  $-24.8\%$  and nighttime values were on average  $-26.9\%$ , but showed significantly more depleted values during nights with strong increase in atmospheric CO<sub>2</sub>. We hypothesize that the observed diel variation in respiratory  $\delta^{13}\text{CO}_2$  values was a consequence of the non-steady state process “diffusive fractionation” induced by the increasing atmospheric CO<sub>2</sub> concentrations at night.

© 2016 Elsevier B.V. All rights reserved.

## 1. Introduction

Soil respiratory CO<sub>2</sub> fluxes are one of the largest terrestrial carbon fluxes within ecosystems (Houghton, 2003). However, in arid ecosystems, which cover approximately 45% of the land area and 20% of the soil carbon pool (Lal, 2004; Scharlemann et al., 2014), soil respiration processes are still poorly understood and measurements in these areas are few. Expected is that soil respiration processes in arid ecosystems are different than in other ecosystems because of the effects of drought and high temperatures (Lal, 2004; Scharlemann et al., 2014; Schimel, 2010). Studying the isotopic composition of soil respiratory fluxes can help to further assess soil respiration processes and sources in arid ecosystems (Boone et al., 1998; Griffis, 2013; Hanson et al., 2000; Kayler et al., 2010; Wang et al., 2014).

The isotopic composition of C in CO<sub>2</sub> is commonly defined by its  $\delta^{13}\text{C}$  value, a standardized  $^{13}\text{C}:^{12}\text{C}$  ratio expressed in ‰ (Keeling, 1958). In this paper, we will use the notation  $\delta^{13}\text{CO}_2$  instead of  $\delta^{13}\text{C}$  when the ratio of the isotopologues  $^{13}\text{CO}_2/^{12}\text{CO}_2$  is concerned. Carbon stored in terrestrial ecosystems is usually more depleted in the heavy isotope ( $^{13}\text{C}$ ) than atmospheric carbon due to the strong fractionation which takes place during photosynthesis ( $-30$  to  $-22\%$  in C3 crop ecosystems versus  $-8.3\%$  in the atmosphere) (Affek and Yakir, 2014; Farquhar et al., 1989). Because ecosystem carbon is depleted in  $^{13}\text{C}$ , respiratory CO<sub>2</sub> fluxes are depleted as well. The degree of depletion is dependent on many factors, and can vary in spatial and temporal scale (Affek and Yakir, 2014; Bowling et al., 2008, 2002; Farquhar et al., 1989; Lai et al., 2005; Risk et al., 2012; Unger et al., 2010, 2012).

The carbon isotopic composition of respiratory CO<sub>2</sub> fluxes is usually not stable, and sometimes shows fluctuating values with a diel pattern. Diel variation in soil respiratory  $\delta^{13}\text{CO}_2$  ( $\delta^{13}\text{CO}_{2\text{resp}}$ ) values is described by many studies and is often attributed to a shift in ratio of contributing CO<sub>2</sub> producing sources (Bahn et al., 2009; Klumpp et al., 2005; Kodama et al., 2008; Marron et al.,

\* Corresponding author.

E-mail address: [v.asperen@iup.physik.uni-bremen.de](mailto:v.asperen@iup.physik.uni-bremen.de) (H. van Asperen).

2009; Unger et al., 2010). An example is a diel shift in the ratio of heterotrophic and autotrophic respiration. Heterotrophic and autotrophic respiration originate from different carbon sources, each with their own characteristic  $\delta^{13}\text{C}$  value, and each responding differently on (diel) environmental changes. Also, different heterotrophic microbial communities can have a different response on changing conditions. These types of differences can result in a fluctuating net  $\delta^{13}\text{CO}_{2\text{resp}}$  value, and in a diel  $\delta^{13}\text{CO}_{2\text{resp}}$  pattern (Bahn et al., 2009; Griffis, 2013; Kodama et al., 2008; Unger et al., 2010; Werner and Gessler, 2011). However, the processes and mechanisms of (diel) isotopic variation in autotrophic and heterotrophic respiration are still largely unknown and under current investigation (Bowling et al., 2015; Tcherkez, 2010; Werner and Gessler, 2011; Werner et al., 2011). Also, a shifting ratio in contribution of isotopically different vertical soil layers, caused by temperature–respiration hysteresis effects, can result in a shifting net outgoing  $\delta^{13}\text{CO}_{2\text{resp}}$  value (Ehleringer et al., 2000; Gaumont-Guay et al., 2006; Wynn et al., 2006). Diel variation can also be caused by a shifting relative contribution of biological and non-biological carbon sources, namely the outgassing of  $\text{CO}_2$  with a geological origin (Etiope, 1999; Rey et al., 2012). The study of Rey et al. (2012) shows that  $\text{CO}_2$  fluxes with a geological origin can play a major role in ecosystems situated in geological active areas, and suggests that the outgassing of  $\text{CO}_2$  with a geological origin is related to wind speed and turbulence.

Recent studies suggest that a diel variation in  $\delta^{13}\text{CO}_{2\text{resp}}$  values is not necessarily caused by a shift in contributing carbon sources, but can also be induced by the 4.4‰-difference in relative diffusion rates between the faster (lighter)  $^{12}\text{CO}_2$  molecules and the slower (heavier)  $^{13}\text{CO}_2$  molecules (Cerling et al., 1991; Moyes et al., 2010; Nickerson and Risk, 2009). Under non-steady state conditions (NSS), this can lead to “diffusive fractionation”: the isotopic partitioning due to divergent diffusion rates. For example, Moyes et al. (2010) observed diel variation in the surface  $\delta^{13}\text{CO}_{2\text{resp}}$  values (up to 5‰) in absence of autotrophic respiration, and suggested that the observed diel variation was solely caused by diffusive fractionation induced by changing soil  $\text{CO}_2$  production: e.g. when soil  $\text{CO}_2$  production went up, the newly produced  $^{12}\text{CO}_2$  molecules traveled faster to the soil surface than the slower  $^{13}\text{CO}_2$  molecules. During this time, relatively more  $^{12}\text{CO}_2$  molecules were emitted at the surface, which caused the  $\delta^{13}\text{CO}_{2\text{resp}}$  values to be temporary more depleted. The significance of diffusive fractionation during changing soil  $\text{CO}_2$  production has been considered plausible by several other authors (Bahn et al., 2009; Bowling et al., 2015; Nickerson and Risk, 2009; Moyes et al., 2010; Werner and Gessler, 2011) but also has been questioned (Risk et al., 2012) and is still under discussion. Other effects of non-steady state conditions are described by Fassbinder et al. (2012) who observed that, during periods of high atmospheric turbulence, more isotopically enriched respiratory  $\text{CO}_2$  was emitted. Fassbinder et al. (2012) suggest that, under higher atmospheric turbulence, soil  $\text{CO}_2$  transport is not purely diffusional and soil advective fluxes occur, wherefore the consequences of the different isotopic diffusion rates are less strong. To our knowledge, diffusive fractionation effects caused by other non-steady state conditions have not been reported so far.

We propose that a different non-steady state process can have a major influence on respiratory  $\delta^{13}\text{CO}_2$  values. Non-steady state conditions in the soil profile may also occur at night, during a nocturnal boundary layer (NBL) buildup. The NBL is characterized by a stable and layered structure that causes the  $\text{CO}_2$  molecules, emitted by the respiring ecosystem, to be retained close to the soil surface (Stull, 2000). This results in a gradual increase of local atmospheric  $\text{CO}_2$  concentrations, and in a gradual decrease of atmospheric  $\delta^{13}\text{CO}_2$  values (due to addition of isotopically depleted  $\text{CO}_2$  molecules). Due to atmospheric invasion, a natural part of diffusion, this nighttime atmospheric air is diffusing into the soil and

affecting (reducing) the existing soil–atmosphere  $\text{CO}_2$  concentration gradient. Assuming an ongoing  $\text{CO}_2$  production, this reduced gradient leads to an accumulation in subsurface soil  $\text{CO}_2$  concentrations until the equilibrium has been restored. However, faster  $^{12}\text{CO}_2$  molecules will quicker re-equilibrate the soil–atmosphere  $^{12}\text{CO}_2$  concentration gradient, which will temporary lead to higher  $^{12}\text{CO}_2$  fluxes in comparison to  $^{13}\text{CO}_2$  fluxes. During these moments, the respiratory surface flux will show more depleted  $\delta^{13}\text{CO}_2$  values, and these values will continue to decrease as long as atmospheric  $\text{CO}_2$  concentrations increase. When atmospheric  $\text{CO}_2$  concentrations start to decrease, subsurface soil  $^{12}\text{CO}_2$  molecules are quicker equilibrated to the less steep soil–atmosphere  $\text{CO}_2$  gradient, causing the surface flux to be temporary more isotopically enriched. The existence of the described non-steady state process was suggested before by Nickerson and Risk (2009), but was expected to be dampened by the simultaneous decrease in atmospheric  $\delta^{13}\text{CO}_2$  values.

The influence of non-steady state conditions on (varying) respiratory  $\delta^{13}\text{CO}_2$  values is still under discussion. However, understanding these mechanisms is of high importance: the measurement of respiratory  $\delta^{13}\text{CO}_2$  values is increasingly used to study and distinguish respiration sources, and possible effects of non-steady state conditions can lead to biased conclusions when overlooked. Expected is that non-steady state processes play a larger role in arid ecosystems in comparison to other ecosystems: due to the dry conditions, soil profiles often have high air-filled porosities and low soil  $\text{CO}_2$  production, which makes them more sensitive to non-steady state processes such as diffusive fractionation (Fassbinder et al., 2012; Moyes et al., 2010). Furthermore, under arid conditions, (heterotrophic) soil respiration often becomes the most dominant source of respiration in an ecosystem because other parts of the ecosystem are dead or in dormant state, which makes the possible effects of non-steady state conditions on soil respiration fluxes more visible on ecosystem scale.

In situ continuous and simultaneous observations of  $\text{CO}_2$  fluxes and its isotopic composition are still relatively rare, especially for arid ecosystems, but are needed to study soil respiratory processes, and are essential for understanding the influence of non-steady state conditions on respiratory  $\delta^{13}\text{CO}_2$  values. We present continuous measurements of atmospheric  $\text{CO}_2$  concentrations, respiratory soil  $\text{CO}_2$  fluxes and the respective isotopic compositions over an arid grassland, with the aim of understanding the driving factors behind diel variation in  $\delta^{13}\text{CO}_{2\text{resp}}$  values. In this paper we hypothesize that diel variation in soil respiratory  $\delta^{13}\text{CO}_2$  values can be caused by non-steady state conditions in the soil profile, induced by increasing atmospheric  $\text{CO}_2$  concentrations at night.

## 2. Material and methods

### 2.1. Study site

We performed a field experiment in a grassland (Fluxnet site: IT-Ro4, harvested cropland, approximately 250 m by 450 m, lat 42.37° N, long 11.92° E, 147 m a.s.l.), in the province of Viterbo, Italy. The study site is located in a seismic active region (Section 2.6). The climate is Mediterranean, with a typical drought period covering approximately 2 months during summer (July–August). Mean annual temperature is 14 °C and annual rainfall is 755 mm. The underlying material is Tuff, soil texture is clay loam and soils are classified as Eutric Cambisol (IUSS, 2014). Yearly, the fieldsite is ploughed to a depth of 20 or 50 cm, depending on the cultivation type which changes from one year to the next. Since 2008, rapeseed, sunflower, clover, and oat-vetch (C3 crops) were cultivated. During the experiment, vegetation was not managed and was a mix of invasive species such as *Amaranthus retroflexus* (L.),

Download English Version:

<https://daneshyari.com/en/article/6457974>

Download Persian Version:

<https://daneshyari.com/article/6457974>

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