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Can flux tower research neglect geochemical CO_2 exchange?

Andrew S. Kowalski [a,*], Penélope Serrano-Ortiz [a], Ivan A. Janssens [b], Sergio Sánchez-Moral [c], Soledad Cuezva [c], Francisco Domingo [d], Ana Were [d], Lucas Alados-Arboledas [a]

[a] Departamento de Física Aplicada, Universidad de Granada, Calle Fuente Nueva, S/N, 18071 Granada, Spain
[b] Department of Biology, University of Antwerpen, Universiteitsplein 1, B-2610 Wilrijk, Belgium
[c] Departamento de Geologıa, Museo Nacional Ciencias Naturales CSIC, Jose Gutierrez Abascal, 2, E-28006 Madrid, Spain
[d] Estación Experimental de Zonas Áridas, CSIC, 04001 Almería, Spain

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ABSTRACT

This study examines the hypothesis that surface-atmosphere exchange of CO_2 in terrestrial ecosystems always can be interpreted purely in terms of biological processes, neglecting geochemical cycling by karst systems that characterize 22 million km^2 in the world [Yuan Daoxian, G., 1997. The carbon cycle in karst, Zeitschrift für Geomorphologie 108 (Supplementbände), 91–102]. Eddy covariance data of net CO_2 fluxes are examined for two ecosystems over karstic substrates in contrasting climates in the North and South of Spain. A semi-arid matorral is found to behave similarly to previously studied ecosystems when well watered, but sizeable mid-day CO_2 emissions during extended drought and plant senescence are found to be incompatible with ecophysiological interpretations of the flux. For a temperate pasture overlying an accessible cave, afternoon CO_2 emissions in summer are likewise inexplicable in a biological context, but coincide with periods when ventilation is observed inside the subterranean cavity. These results suggest direct linkages at times in CO_2 exchanges among atmosphere, ecosystems, and carbonate substrates which represent more than a tenth of the Earth's land surface.

1. Introduction

In the last quarter century, the accurate characterization of the global carbon cycle has emerged as an outstanding scientific challenge. Since the revelation of rising atmospheric CO_2 concentrations (Keeling, 1960), concerns about terrestrial warming via the greenhouse effect have become global. The Kyoto Protocol, in addition to motivating emissions reductions, highlights the need to identify and quantify sinks (and sources) of atmospheric CO_2 to enable management for sink optimization. Lately, understanding has grown as research assesses exchange of CO_2 at a variety of spatial scales – from leaf to globe – between the atmosphere and Earth's surface, with micrometeorology providing valuable information at the ecosystem scale (Houghton, 2002).

Eddy covariance and other, indirect micrometeorological techniques quantify surface-atmosphere exchange of momentum and energy and mass (Dabberdt et al., 1993) such as CO_2. Direct flux measurement in near-surface turbulence generally requires fast-response (ca. 10 Hz) instruments and provides exchange information on timescales of hours or less. Despite the difficulties of keeping such instruments operating correctly, long-term integrations of CO_2 exchange have been demonstrated feasible (Wofsy et al., 1993) and since then the

* Corresponding author. Tel.: +34 958 24 29 28; fax: +34 958 24 32 14.
E-mail address: andyk@ugr.es (A.S. Kowalski).
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use of ''flux towers'' has proliferated. Networks have been established on continental (Aubinet et al., 2000) and even global scales (Baldocchi et al., 2001), with hundreds of towers/nodes dedicated to the estimation of annual CO_2 exchange by the surface under the point of measurement. In these investigations – and indeed even at larger scales – the terrestrial CO_2 flux is generally interpreted in the context of an unstated hypothesis that biological processes alone determine surface exchange (Bala et al., 2005; Baldocchi, 2003; Houghton, 2002), with very few notable exceptions (Emmerich, 2003; Mielnick et al., 2005).

The mother material in karst systems, carbonate rocks are widespread globally and may play a direct role in the global carbon cycle. Carbonate rocks representing the world's largest carbon reservoir (Liu and Zhao, 2000) outcrop on ca. 12% of the water-free Earth surface (Ford and Williams, 1989). Along with biologically respired CO_2, karstic formations such as limestone and dolomite dissolve in groundwater to participate in chemical reactions. Carbonate rock dissolution represents a sink process with respect to CO_2 and solid stone, consuming both to produce bicarbonate and other aqueous phase ions. Rock weathering can enlarge fissures and form macropores (caves) capable of storing large quantities of carbon in both gaseous and aqueous phases. When geochemistry operates in reverse, carbonate precipitation represents a local source of both rock and CO_2, forming speleothems and tufa deposits. These geochemical processes are highly dependent on groundwater acidity (Cardell-Fernández et al., 2002) and may be important for inclusion in characterizations of the global carbon cycle (Cheng et al., 2005; Yuan Daoxian, 1997), with magnitudes representing a non-negligible fraction of the ''missing sink'' for atmospheric CO_2 (Gombert, 2002; Liu and Zhao, 2000).

Here we examine the hypothesis that such geological exchange processes can be neglected when interpreting surface-atmosphere exchange measured by micrometeorology. We present eddy covariance measurements above two distinct ecosystems growing on karstic formations in Spain, and attempt to model CO_2 exchange at half-hourly timescales in terms of widely-used empirical models for ecophysiological processes (photosynthesis and respiration). Particularities from each of the two field sites assist in the assessment: in one case data from an extended drought and in the other, where access to the underlying cave is possible, gas concentration measurements in this macropore. The objective here is not a quantitative characterization of carbon cycling at either site, but rather a qualitative examination of contributing processes.

2. Measurements and analyses

2.1. Field sites and instrumentation

All measurements were taken at each of two climatologically distinct sites on Spanish karstic formations, by two teams differing in equipment and initial objectives. Here we describe the relevant geological and biological aspects of the two study sites, as well as the measurement systems.

2.1.1. *The Sierra de Gádor*

A flux tower was installed in the spring of 2004 to assess the biological CO_2 source/sink of a *matorral* (scrub) ecosystem at *El Llano de los Juanes*, a 1600 m plateau in the *Sierra de Gádor* in the South-eastern Spanish province of Almería (36°55′41.7″N; 2°45′1.7″W). With its feet at the Mediterranean coast, the *Sierra de Gádor* consists of Triassic carbonate rocks – mainly dolomitic limestones (Vallejos et al., 1997). The measurement site is 18 km distant from the coast in a semi-arid climate with annual mean precipitation of 465 mm and mean annual temperature of 12 °C. Dominant ground cover types (as percent of total) are bare soil and rock (53.3%), *Festuca scariosa* (Lag.) Hackel (19%; this is the dominant non-woody plant), and a mix of woody plants including *Genista pumila* (Vierch) ssp pumila (11.5%) not exceeding 50 cm in height. The extent of homogeneous surface (i.e., ''fetch'') is several hundreds of meters from the tower in every direction. More details about vegetation and soil characteristics can be found in Serrano-Ortiz et al. (2007).

The measurement system centers on a datalogger (CR23X, Campbell Scientific, Logan, UT, USA; hereafter CSI) that records semi-processed data from ''fast'' turbulent sensors and ''slow'' instruments measuring atmospheric and soil states. The datalogger calculates and stores means, variances, and covariances every 15 min. Two ''fast'' instruments sample 10 Hz eddy fluctuations at 2.5 m above ground level (AGL). A three-axis sonic anemometer (CSAT-3, CSI) measures wind speed and temperature, and an open-path infrared gas analyser (Li-Cor 7500, Lincoln, NE, USA) measures CO_2 and H_2O densities. ''Slow'' instruments are queried by the datalogger once every 10 s. At 1.5 m AGL two quantum sensors (LI-190, Li-Cor) detect incident and reflected photon fluxes. In the soil, a water content reflectometer (CS615, CSI) measures volumetric soil water content at 15 cm depth and temperature is determined as the mean of four thermocouples (TCAV, CSI) at 1, 2, 4, and 8 cm.

An automated soil CO_2 flux system (LI-8100, Li-Cor) with 10-cm survey chamber made continuous measurement campaigns. The chamber was installed over a single PVC collar (10 cm inner diameter; 5.25 cm height) adjacent to the flux tower, and programmed to make a 2 min measurement every half-hour, allowing thorough aeration between measurements. Soil CO_2 effluxes were estimated using the initial slope of a fitted exponential curve (according to the instrument manual), adjusted for the total (chamber and collar) volume.

2.1.2. *The Altamira cave*

In the Northern Spanish province of Cantabria (43°22′40″N; 4°7′6″W), carbonate rock dissolution processes are studied in the Altamira cave with a goal of conserving its famous Palaeolithic artwork (http://museodealtamira.mcu.es/). The cave, one of many cavities in the upper vadose area of the karstic system, is situated at a depth of 3–22 m (averaging 8 m) below the surface, and is covered by a pasture. The rock consists of Cenomanian (Upper Cretaceous) carbonate rocks—mainly limestone, with very little porosity (<5%). Directly over the rock lies a porous (25–40%) artificial soil of little development (3–60 cm). The climate is more temperate than at the *Sierra de Gádor*, with annual precipitation of 1352 mm and a mean annual temperature of 14 °C.