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A numerical and experimental study of a new design of closed dynamic respiration chamber

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ABSTRACT

Carbon dioxide soil efflux modelling in closed dynamic respiration chambers is a challenging task. This is attributed on many occasions to the very small concentrations of carbon dioxide being transported between soil and the atmosphere. This paper describes a portable device which was made exclusively to accurately measure carbon dioxide efflux from soil locations. The blowing fan creates a forced convective flow to occur in the chamber making the K-Epsilon turbulence model a necessity to model the occurring flow in the respiration chamber gas domain. Furthermore the Darcy model is applied on the porous domain to model the flow pattern within the soil. The measurement process was achieved through measuring carbon dioxide concentration, temperature and relative humidity inside the chamber in relation to time. Simulation and experimental data is obtained using ANSYS and MATLAB. A significant agreement between the experimental and numerical results was achieved.

1. Introduction

Soil can be defined as a complex system, consisting of a mixture of organic and mineral particles, soil solution and air, resulting from the interaction between biotic and abiotic factors; it is the medium in which plants acquire water and nutrients through their roots system. It is known by scientists that one of the physical properties of carbon dioxide contained in the atmosphere is that it reflects heat back to the earth's surface. Consequently gradually the earth's atmosphere traps more heat. Respiration chambers can be used to quantify the soil efflux whereby they come in different shapes and sizes this depends on their application of use. They are composed of two main parts; namely the chamber shell and the gas sensor. To quantify the amount of produced carbon dioxide at one location, an enclosed cavity or space like a chamber is used. An efflux is flowing out or forth from a porous medium (Soil) which for our case of concern is carbon dioxide. Carbon dioxide gas in the soil is produced due to the biological activity in the soil domain. This method was first proposed by Henrik Lundegardh in the form of the respiration bell (Larkum, 2005). In the general context, studying respiration chambers can give scientists some insight to how fertile the studied site is. That is by measuring the rate of carbon dioxide produced for a certain site of concern in order to predict its impact on global warming issues (Raich and Potter, 1995). Consequently with the increase of carbon dioxide concentrations in the atmosphere, earth responds to it (Bazzaz, 1990). Climate change is one of the most critical challenges that are facing the mankind, and it is well related to the greenhouse emissions which help trapping heat and making the earth warmer that affect directly weather patterns, people, plants and animals. Greenhouse fluxes measurement between the soil and the atmosphere is of a great importance to help to understand the biochemical parameters effects on the global warming issue. This has lead scientists to use numerical nonlinear models to predict future concentrations of carbon dioxide in the atmosphere (Joos et al., 1999). Subsequently others used more sophisticated models such as the dynamic global vegetation model (Cramer et al., 2001) as shown in Fig. 1.

The used chamber methods have been surveyed in Parkinson (1981) where by it showed that new methods were proposed since the early 80s with growing interest in the global warming issue, Kyoto protocol. Scientists using these chambers can quantify the soil site carbon budget (Schlesinger and Andrews, 2000).

The rational for this study is to interpret and quantify for a specific location how soil produced carbon dioxide contributes to the greenhouse effect. This is done by using a designed respiration chamber by our research group. The main focus of this study is to use CFD

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Nomenclature

Roman symbols

A	sample area cross section
A′	infinitesimal planar control surface
A_n	area of a single pore
B	body force vector
C	carbon dioxide constants in Sutherland equation
C(t)	carbon dioxide concentration as a function of time
$\widetilde{C(t)}$	carbon dioxide filtered concentration as a function of time
D_n	total Integrated area for permeability function
D_{total}	total area of pores
d_{av}	the average pore diameter for a segment of pore sizes
H(z)	concentration Filter function
K	soil permeability
K^{ij}	area porosity tensor
K_{perm}	permeability
K_{loss}	empirical loss coefficient
P_k	turbulence production
$\grave{p}$	modified pressure
R^{ij}	resistance to flow in the porous medium
r_{sand}	sand grain diameter
r_{silt}	silt grain diameter
r_{clay}	clay grain diameter
T	instance of time
U	velocity vector field
V	studied volume of soil
V′	the volume available to flow in an infinitesimal control cell surrounding the point

Greek symbols

Γ_e	effective thermal diffusivity
Γ	volume porosity
Θ	volumetric water content
M	air dynamic viscosity
μ_e	effective viscosity
P	air density

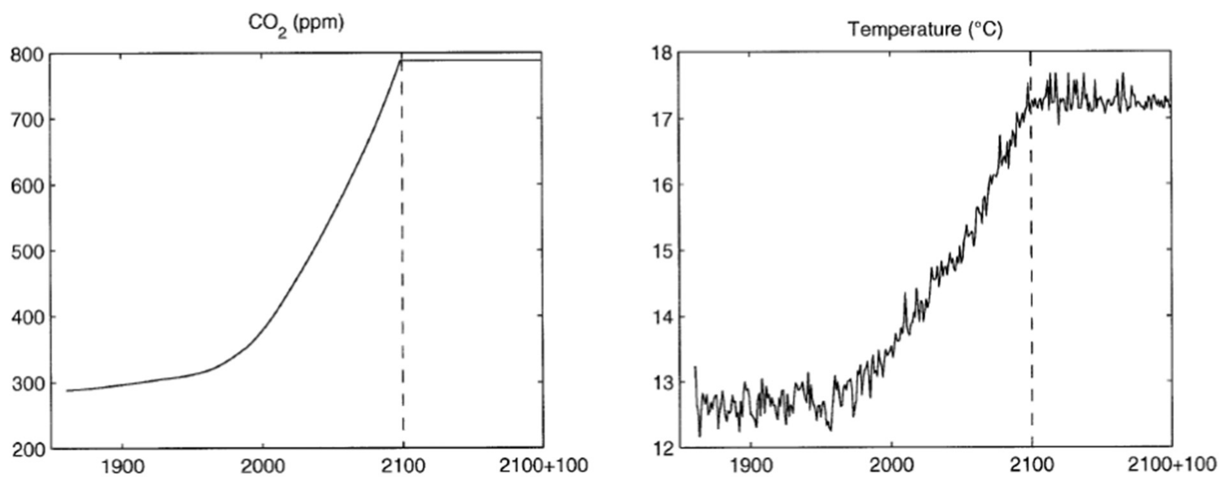

Fig. 1. IPCC IS92a projections of atmospheric CO2 concentration and the HadCM2 SUL climate model simulations of temperature over land (excluding Antarctica).

numerical models to show how they can assist in making the right dynamic chamber designs to get the right measured fluxes representing the biological activity of location. This helps in finding the right locations to install the gas sensors within the chamber and also to ensure through mixing for the gas mixture. The process is firstly conducted using CAD and secondly using CFD design optimization. The chamber uses a sampling tube connected with the sensor hence it takes samples at all the inner chamber elevations furthermore it relies on the convective flow produced by the fan to get the correct measurements instead of using a gas sensor that sucks the gas sample and takes several seconds to analyse it. The selection of the blowing fan location is also selected to draw out the carbon dioxide within the soil layer and at the same time not to cause any disturbance to the biological activity in the soil as for cooling or increasing water evaporation rates. A significant agreement between the experimental and numerical results was achieved.

2. Respiration chambers

Scientists know that no ideal experimental chamber exists (Widén and Lindroth, 2003), therefore the aim is always to reduce measured errors. That is due to the great spatial variability in soil emissions, and to the fact that the quantification of these emissions is complicated by the high spatial variability exhibited by many microbial processes (Roelle et al., 1999). Respiration chambers are produced either privately for research groups or by commercial companies. The transparent chamber is intended to be used to measure total flux from a specific location, it is automated to ventilate the chamber, while the none-transparent one is the total flux excluding the flux resulting from photosynthesis process. The top hat type chamber is used for a quick site deployment where ventilation is conducted manually, mostly intended for soil flux measurements. Different types of chambers are available depending on the intended efflux quantity to be measured as shown in Fig. 2. The figure presents an example of chambers produced by the Li-Cor Inc Company with the named different parts. There are four types of chambers characterized according to their operational mode these are closed dynamic, open dynamic, closed static and open static chambers.

2.1. Methods of efflux measurements

Scientists have an option to choose from several methods for measuring soil carbon dioxide efflux. These methods can be summarised into four ones, starting with the chamber soda lime (Keith and Wong, 2006) or what is called sometimes by alkali solution method which absorbs the respired carbon dioxide from the soil, it is an easy and cheap method to apply. The second method is by using the soil carbon dioxide gradient system method (Maier and Schack-Kirchner, 2014),