ADVECTIVE TRANSPORT OF CO_2 IN PERMEABLE MEDIA INDUCED BY ATMOSPHERIC PRESSURE FLUCTUATIONS

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ABSTRACT

Pressure fluctuations at the earth's surface are caused by a variety of atmospheric phenomena. Examples include low frequency barometric pressure variations, high frequency atmospheric turbulence, atmospheric gravity waves, and quasi-static pressure fields created as wind blows over or around topographic features, like buildings, hills, wind breaks, etc. These naturally occurring pressure fields cause air to move in and out of soils, snowpacks, and other permeable media. Consequently, the uptake or release of trace gases from soils and snowpacks is a combination of molecular diffusion and advective flows caused by surface pressure fluctuations. Such pressure forcing has been found to influence the exchange rate of many trace gases from the underlying substrate to the atmosphere. Given the importance of these trace gases to understanding biogeochemical cycling and global change, it is crucial to quantify (as much as possible) any impact these advective flows can have on gas transport within soils and snowpacks.

First, this paper develops a physically-based analytical model that describes the effects of natural pressure pumping on CO_2 profiles and fluxes within a layered medium. The model is a two-layered model, which assumes that each layer has uniform, but different, physical properties with a CO_2 source term located in either the upper or lower layer. The pressure forcing, modeled as plane wave in time and the horizontal direction, has an amplitude that varies in the vertical direction as described by an analytical solution to the diffusion equation. The CO_2 response is decomposed into a steady-state diffusion solution and a plane wave solution of the advective-diffusive equation, which also has an amplitude that varies in the vertical direction. The model is formulated for both dispersive and non-dispersive media. In the case of a dispersive medium, the dispersion coefficient [m^2/s] is expressed in terms of the horizontal wave number, the amplitude of the pressure forcing at the upper surface, and the vertical structure and dispersivity [m] of the medium.

Second, the model is applied to the case of a snowpack with an underlying [snow-covered] soil. Meadow and forest CO_2 amounts, sampled beneath an approximately meter deep (steady state) snowpack at a subalpine site in southern Rocky Mountains of Wyoming (USA) between December 19, 2000, and February 8, 2001, are observed to vary by nearly 200 ppmV over periods ranging from 4 - 15 days. With the aid of the physically-based model inferences are made about the nature of the physical properties of both the forcing mechanism and the snowpack that contribute to these periodic variations in undersnow CO_2. Results are consistent with the hypothesis that the undersnow CO_2 is being driven by advective flows induced by pressure fields created when the wind interacts with the local aerodynamic roughness elements (nearby mountain peaks, forest edges, snowdrifts). Non-harmonic spectral and cospectral techniques indicate that the wind modulates the low frequency temporal dynamics of the undersnow CO_2. Whereas, comparisons of the modeled and observed time lag between the surface forcing and the response of the undersnow CO_2 suggest that site topography determines the horizontal structure of the wind (surface pressure) forcing. Results also suggest that the snowpack is at best a weakly dispersive medium. Finally, because the model includes a CO_2 source term in the soil underlying the snowpack, other findings suggest that both the wintertime CO_2 fluxes emanating from the snowpack and the soil

respiration rates may vary significantly between a meadow soil and a forest soil at this site. During the period covered by this study the meadow soil displayed higher respiration fluxes in the wintertime than the forest soil.