Geophysical Research Abstracts,
Vol. 10, EGU2008-A-02259, 2008
SRef-ID: 1607-7962/gra/EGU2008-A-02259
EGU General Assembly 2008
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Attenuation of trace gas fluctuations associated with turbulent flow in tubes: Application to sampling water vapor with closed-path eddy covariance systems

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Eddy covariance (EC) is the standard for measuring trace gas fluxes between the atmosphere and the terrestrial (vegetation/soil) surface. Nevertheless, the quality and reliability of fluxes measured with EC technology depend heavily on the unavoidable filtering effects associated with sensor design and sampling methods. Both open- and closed-path trace gas EC sensors can sample the atmospheric trace gas fluctuations fast enough to make reasonably reliable flux measurements. But closed-path sensors, which usually require long intake tubes, attenuate high frequency fluctuations more strongly than open-path sensors. On the other hand, closed-path sensors are the only available option for some trace gases (e.g., ozone) and often they can be used under conditions that preclude the use of open-path sensors (e.g., carbon dioxide and water vapor flux measurements during rain or snow events). Therefore, studies of tube attenuation effects should aid in the development of EC sensor technology and improve the reliability of and reduce the uncertainty inherent in EC trace gas fluxes.

This study reports on the development of a physically-based model of the attenuation of atmospheric water vapor fluctuations on the inside walls of closed-path EC sampling tubes during turbulent tube flow for application to the measurement of water vapor (or evapotranspiration) fluxes. The specific goal of this study is to derive a mathematically-simple physically-based transfer function that can be used to correct closed-path EC fluxes for tube attenuation effects. We begin by reviewing observational studies of the attenuation of water vapor fluctuations during turbulent tube flow.

We then outline the mathematical statement of this problem and we compare our new model, which we developed for this study, with previous models. Next we develop a physically-based semi-empirical boundary condition to describe sorption/desorption fluxes at the tube wall. This boundary condition is critical because it dictates the strength of the attenuation. But it is difficult to formulate precisely because the physical processes occurring at the tube wall are physiochemical in nature and involve various aspects of the dynamics of turbulent tube flow, the kinetic theory of gases, thin film dynamics, and phase changes (condensation and evaporation) on clean homogeneous surfaces and on internal tube surfaces contaminated with atmospheric aerosols. The model predicts that the attenuation of water vapor fluctuations increases non-linearly as ambient humidity increases (in agreement with observations). Nevertheless, it is not clear how well the model captures the influence that the tube flow Reynolds number can have on the attenuation.