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Turbulent fluxes by "Conditional Eddy Sampling"

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Turbulent flux measurements are key to understanding ecosystem scale energy and matter exchange, including atmospheric trace gases. While the eddy covariance approach has evolved as an invaluable tool to quantify fluxes of e.g. CO_2 and H_2O continuously, it is limited to very few atmospheric constituents for which sufficiently fast analyzers exist. High instrument cost, lack of field-readiness or high power consumption (e.g. many recent laser-based systems requiring strong vacuum) further impair application to other tracers.

Alternative micrometeorological approaches such as conditional sampling might overcome major limitations. Although the idea of eddy accumulation has already been proposed by Desjardin in 1972 (Desjardin, 1977), at the time it could not be realized for trace gases. Major simplifications by Businger and Oncley (1990) lead to it's widespread application as "Relaxed Eddy Accumulation" (REA). However, those simplifications (flux gradient similarity with constant flow rate sampling irrespective of vertical wind velocity and introduction of a deadband around zero vertical wind velocity) have degraded eddy accumulation to an *indirect* method, introducing issues of scalar similarity and often lack of suitable scalar flux proxies.

Here we present a real implementation of a true eddy accumulation system according to the original concept. Key to our approach, which we call "Conditional Eddy Sampling" (CES), is the mathematical formulation of conditional sampling in it's true form of a *direct* eddy flux measurement paired with a performant real implementation. Dedicated hardware controlled by near-real-time software allows full signal recovery at 10 or 20 Hz, very fast valve switching, instant vertical wind velocity proportional flow rate control, virtually no deadband and adaptive power management. Demonstrated system performance often exceeds requirements for flux measurements by orders of magnitude. The system's exceptionally low power consumption is ideal for the field (one to two orders of magnitude lower compared to current closed-path laser based eddy covariance systems). Potential applications include fluxes of CO_2, CH_4, N_2O, VOCs and other tracers.

Finally we assess the flux accuracy of the Conditional Eddy Sampling (CES) approach as in our real implementation relative to alternative techniques including eddy covariance (EC) and relaxed eddy accumulation (REA). We further quantify various sources of instrument and method specific measurement errors. This comparison uses real measurements of 20 Hz turbulent time series of 3D wind velocity, sonic temperature and CO_2 mixing ratio over a mixed decidious forest at the "ICOS" flux tower site "Hainich", Germany.

Results from a simulation using real wind and CO_2 timeseries from the Hainich site from 30 April to 3 November 2014 and real instrument performance suggest that the maximum flux estimates error (50% and 75% error quantiles) from Conditional Eddy Sampling (CES) relative to the true flux is 1.3% and 10%, respectively for monthly net fluxes, 1.6% and 7%, respectively for daily net fluxes and 8% and 35%, respectively for 30-minute CO_2 flux estimates. Those results from CES are promising and outperform our REA estimates by about a factor of 50 assuming REA with constant b value. Results include flux time series from the EC, CES and REA approaches from 30-min to annual resolution.