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Eddy-covariance data with low signal-to-noise: time-lag determination, uncertainties and limits of detection

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In addition to systematic errors, eddy-covariance flux measurements are subject to two main random errors. These are associated (a) with the geostatistical representation of turbulence through a single measurement and (b) the instrument noise. While the former error is usually the main component for flux measurements of CO_2 and water vapour, trace gases and aerosols are often measured with sensors providing limit signal-to-noise ratios (SNR). Examples include particle counters, mass spectrometry methods (Proton Transfer Reaction Mass Spectrometry for VOCs, PTR-MS; Aerosol Mass Spectrometry, AMS), optical spectrometers for CH_4 and N_2O, as well as some fast ozone sensors.

The analysis of flux data from noisy instruments that deploy inlet lines is further complicated by the fact that preferably the time-lag is determined by maximisation of the cross correlation between vertical wind component and concentration. If this approach is applied to noisy data, random errors nevertheless induce a systematic bias towards larger values of emission or deposition. This results in a poorly shaped frequency distribution in the derived fluxes, with hardly any fluxes near zero, and an average that differs significantly from the true average. While this problem has been noted regularly in the literature, a systematic assessment of the effect does not appear to have been made.

We here examine the consequences using example data from a range of instruments and by performing numerical experiments on temperature data, that is degraded to mimic the behaviour if different instruments. This study explores the effect using three different methods to determine the time-lag. It provides a novel approach to assessing the random error due to random instrument noise separately and recommends an optimised strategy for data processing and the calculation and reporting of errors when using instrumentation with low SNR.

Finally we demonstrate how flux data, even if associated with a large relative error, is nevertheless useful, if each flux value is reported together with its uncertainty. When averaging the fluxes for the calculation of long-term budgets, average diurnal cycles or according to a driving force, long time-series still provide statistically significant results.