APPLYING A LINEAR DETREND TO EDDY CORRELATION DATA IN REAL TIME

(Research Note)

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Abstract. It is shown that by accumulating an appropriate combination of the sums of fluctuating variables and their cross products it is possible to apply a linear detrend to eddy correlation data, and calculate variances and fluxes in a single pass operation. When applied to real time systems this method should give improved measurements of variances and fluxes.

1. Introduction

The eddy correlation method of calculating fluxes requires that the fluctuating components of the measured signals are derived by subtracting them from the mean signals. In steady-state conditions simple linear means would be adequate, but steady state conditions rarely exist in the atmosphere and it is necessary to remove the long term trends in the data which do not contribute to the flux. Sensor drift may contribute additional unwanted contamination of the signals. This detrending is normally done retrospectively using a two-pass method. The data are first divided into blocks each long enough to contain all the eddies transferring the flux — normally 20–30 minutes in the atmospheric surface layer — and a linear regression of the measured signal on time is then calculated. The fluctuations with respect to the regression line are then calculated during a second pass through the data.

An alternative approach is to calculate the fluxes with respect to a filtered "mean", which is derived by feeding the measured signal through a low-pass filter. Since this is a single pass method it can be used in real-time to calculate the fluxes as the data are collected. This avoids the need to store large amounts of turbulence data and is useful where long runs of flux measurements are needed, or where the lack of power in remote locations would prevent the use of complicated recording equipment. The approach was originally pioneered in the Fluxatron (Dyer et al., 1967), which used analogue filters, and was later successfully applied in the Hydra device by Lloyd et al. (1984) and Shuttleworth et al. (1988) using a low power microprocessor to calculate an autoregressive moving average (ARMA) — a digital filter. The time constant for the filter defines the effective cutoff for short period eddies, and was originally determined empirically by finding the time constant which gave the closest result to a linear detrend on a set of twenty minute blocks.
of data. Recent systems such as that developed by Moncrieff et al. (1996) use an ARMA to give a real time calculation of flux, but have the option of storing the data so that a linear detrend may be performed retrospectively. In general, because the ARMA can only respond to the past, it is regarded as an inferior method to a linear detrend, which considers the whole trend over any particular averaging period. Shuttleworth (1988) derived a first-order correction procedure to account for the effect of background concentration change and sensor drift in systems which use the ARMA approach. He also evaluated the errors in a case study using data collected with a Hydra device. The corrections calculated for the standard deviation of temperature were found to be large, with the uncorrected deviation being twice the corrected value in rapidly changing conditions. Corrections to the sensible heat flux varied between zero and some 20 per cent. Doubts over the appropriate time constant to use in the ARMA are also a cause of concern.

The Hydra device programmed by Lloyd et al. (1984) used a microprocessor which was stretched to the limit of its speed and precision, and which had to be programmed in machine code. Modern computers have far higher speeds, larger memory stores, and can be programmed in high level languages, while still having sufficiently low power consumption to allow them to be used in the field for long periods. It is therefore timely to ask whether it is now feasible to replace an ARMA analysis with a linear detrend for real time applications in the field. The most efficient way to do this would be to derive a method which could perform a linear detrend in a single (real time) pass through the data. In this paper it is demonstrated that this can in fact be achieved by accumulating a combination of linear sums, and the sums of auto and cross products of the measured signals.*

2. Theory

Consider the flux $F_s$ of a quantity $s$ in the direction of the wind component $w$. For a run of $n$ samples $F_s$ is given by

$$F_s = \frac{1}{n} \sum_{i=1}^{n} (w_i - \langle w \rangle_i) (s_i - \langle s \rangle_i),$$

(Shuttleworth et al., 1988). In the present case however the angle brackets are assumed to represent a regression line instead of the more usual running mean, such that for the $i$th sample

$$\langle w \rangle_i = A + B i,$$

* During the review process for this paper a similar method to that proposed here has been given by Pattey et al., 1995. (Pattey, E., Cessna, A. J., Desjardins, R. L., Kerr, L. A., Rochette, P., St-Amour, G., Zhu, T. and Headrick, K., 1995: Herbicides volatization measured by the relaxed eddy-accumulation technique using a two trapping media. Agric. Forest Meteorol. 76, 201–220).