Measurement of Scalar Flux from a Forest Using the Bandpass Covariance Method

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Abstract

The bandpass covariance method is proposed by Horst and Oncley (1995) for long term measurements of scalar flux. This method is similar to the direct measurement in principle, but can be achieved by an instrument with slow response and little maintenance on the assumption that there is spectral similarity among scalar fluxes.

We measured the energy budget of a deciduous forest on July 25-27 in 1995, including an experiment for measuring turbulence. Instruments used for this experiment were a sonic anemometer, open-path infrared gas analyzer (fast response sensor) for eddy correlation, and an aspirated humidity sensor (slow response) for bandpass covariance. Using these results, we checked the applicability of the bandpass covariance method for latent heat flux by comparing it with the ordinary eddy correlation method. The spectral similarity in our experimental site was confirmed by the measurements taken by the fast response sensors which showed that normalized cospectra were almost identical between the latent heat and the sensible heat. Diurnal variation of the latent heat flux by the bandpass covariance method agreed well with that of the eddy correlation method. The daily mean value of the latent heat flux by bandpass covariance (July 27) was 108.9 Wm⁻² and that by eddy correlation was 107.0 Wm⁻². From these results, it can be concluded that the bandpass covariance method is applicable to a long term monitoring of the latent heat flux from a forest.

Keywords: Bandpass covariance method, Latent heat flux, Spectral similarity

1. Introduction

For direct measurements of water vapor and CO₂ fluxes, we need to use a sonic anemometer and an open-path gas analyzer (a fast response sensor) for fast data sampling. However, because an open-path gas analyzer requires extensive maintenance, it is unsuitable for long term measurements.

The bandpass covariance method is proposed by Horst and Oncley (1995) for the long term measurement of scalar flux. The bandpass covariance method is similar to the direct measurement in principle. This method can be achieved by a slow response sensor, and it requires little maintenance. The only assumption in this method is that there is spectral similarity among scalar fluxes.

This paper introduces the bandpass covariance method and shows its application to flux measurement above a forest.

2. The bandpass covariance method

Fluctuations in vertical wind velocity and air temperature are measured using a sonic anemometer and the sensible heat flux is calculated in the same manner as the ordinary
eddy correlation method. The frequency region of the sensible heat flux resolved by this method is \( f > f_1 \), where \( f \) is frequency and \( f_1 \) is the lower limit of the frequency's region and \( f_1 \) is determined by measuring time.

Concentration of the scalar entity is measured by a slow response sensor which has an upper limit of the frequency \( f_2 \). For example, we can use a capacitive relative humidity sensor for measuring water vapor and a closed-path sensor for measuring CO\(_2\).

Assuming that co-spectra of each scalar flux are similar in all frequency regions, the ratio of the scalar flux to the sensible heat flux is the same at higher frequencies as it is at lower frequencies, i.e.,

\[
\frac{(w's')_{hp}}{(w'T')_{hp}} = \frac{(w's')_{bp}}{(w'T')_{bp}} = 1
\]

where \( w' \), \( T' \) and \( s' \) are the fluctuation in the vertical wind velocity (ms\(^{-1}\)), air temperature (K), and scalar entity (kgm\(^{-3}\)) respectively. (\( \cdot \))\(_{bp} \) is the bandpass region that the slow response sensor can measure real fluctuations (\( f_1 < f < f_2 \)), and (\( \cdot \))\(_{hp} \) is the higher frequency region (\( f > f_2 \)). The scalar flux (\( F_s \)) can then be written as

\[
\frac{F_s}{\rho} = \frac{w'T'}{\beta_{hp}}
\]

For the water vapor flux (\( E \)), this equation is

\[
\frac{E}{\rho} = \frac{(w'q')_{bp}}{(w'T')_{bp}} \frac{w'T'}{w'q'}
\]

where \( \rho \) is air density (kgm\(^{-3}\)), \( q \) is specific humidity (kgkg\(^{-1}\)).

3. Measurement

The experiment was carried out at a deciduous forest in Kawagoe city, Saitama Prefecture, Japan on July 25 - 27 in 1995. The mean tree height was about 15m. The turbulence instruments used were a three dimensional sonic anemo - thermometer (DAT-310, Kaijo) with a 20 cm sound path and an open-path infrared H\(_2\)O•CO\(_2\) fluctuation meter (E009A, Advanet) with a 20 cm path length as a fast response sensor. These instruments were used for the ordinary eddy correlation method. For the bandpass covariance method, we used a relative humidity sensor (HMP35D, Vaisala) as a slow response sensor. These instruments were installed at 20.0 m on a 25 m tower.

Signals from the sensors were recorded on magneto optical disk at 10 Hz using a digital data recorder (DRM2a, TEAC). The duration of each run was 14 minutes. The linear trends
were removed from the data. By three dimensional coordinate rotation, the mean wind direction \( \bar{u} \) was fixed parallel to the local mean stream line (McMillen, 1988). Velocity components were then calculated on the new coordinate system, resulting in \( \bar{w} = 0 \). We applied a correction of the flux measurement for density effects due to heat and water vapor transfer as shown by Webb et al. (1980) to the calculation of the latent heat flux.

4. Results

Fig. 1 shows co-spectra of \( w'T' \) and \( w'q' \) calculated from the ordinary eddy correlation measurements, normalized by the vertical fluxes of \( w'T' \) and \( w'q' \) respectively. It is apparent that the normalized \( wt'- \) and \( wq'- \) co-spectral shapes were almost identical. Therefore, it is confirmed that spectral similarity is satisfied in our experimental site.

Fig. 2 shows a comparison of the \( wq'- \)cospectrum obtained by the slow response sensor with that by the fast response sensor. They agreed well at low frequency regions (below about 0.03 Hz). The response of the slow response sensor was attenuated for frequencies above approximately 0.03 Hz. From this figure, the bandpass limits for this experiment were selected at \( 0.0012 \text{ Hz} \leq f \leq 0.0293 \text{ Hz} \). This bandpass region could be dynamic because the sensor response may change depending on temperature and humidity, but was fixed tentatively for the present series of experiments.

The \( wq'- \)cospectra calculated by the bandpass covariance method \( (wT/\beta_{bp}) \) and by the ordinary eddy correlation method using the fast response sensor \( (wq,(fast)) \) are shown in Fig. 3. The two co-spectral shapes were almost the same at all frequency regions.

Diurnal variations of the latent heat flux by the bandpass covariance method and that by the eddy correlation method are presented in Fig. 4. The latent heat flux of the bandpass
covariance agreed well with that of the eddy correlation. The daily mean value of the latent heat flux by the bandpass covariance was 108.9 Wm\(^{-2}\) and that by the eddy correlation was 107.0 Wm\(^{-2}\).

From these results, it can be concluded that the bandpass covariance method is applicable to measurements of the latent heat flux from a forest, and is expected as the technique for a long term monitoring of flux.

![Fig.3 Comparison between the two cospectra of \(w'q'\) calculated from the bandpass covariance (\(wT/\beta_{bp}\)) and the eddy correlation (\(wq(\text{fast})\)).]

5. Conclusion

The bandpass covariance method was adopted to measure the latent heat flux above a forest. The only assumption in the bandpass covariance method, the spectral similarity among scalar fluxes, was found to be valid in the present site. The latent heat flux determined by the bandpass covariance method agreed well with that of the eddy correlation method. This indicates that the bandpass covariance method can be applied to observation of the latent heat flux from a forest.

References