P1.14 Evaluation of Local Turbulent Flux Using a Displaced-beam Small Aperture Scintillometer Above The Forest Canopy

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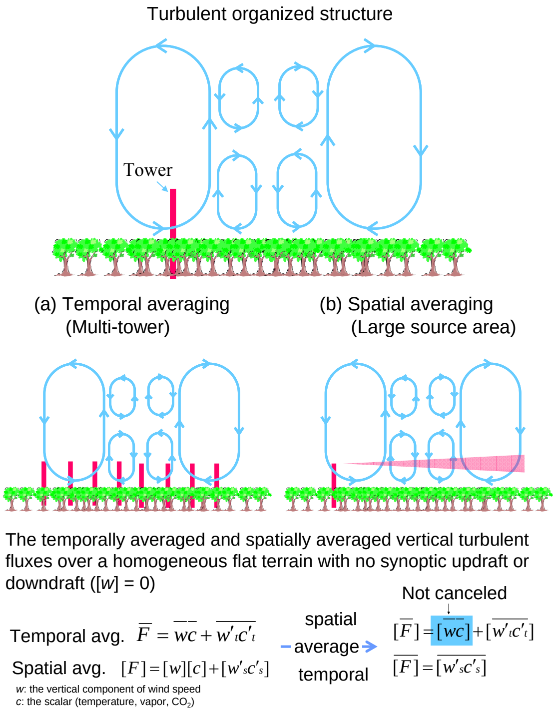
1. Introduction

Observation of turbulent flux in the atmospheric boundary layer provides an effective means to investigate the interaction between the atmosphere and vegetative ecosystems. Such observations can be used to evaluate the vertical exchange of energy and mass. Recently, the eddy-covariance (EC) method has been used widely to estimate turbulent fluxes. In addition, long-term continual observations of CO_2 flux have been performed actively to evaluate carbon cycling in terrestrial ecosystems.

However, many flux sites have been reported for cases in which accuracy problems of flux measurement can occur, even by EC method, which can measure turbulent flux directly. The energy imbalance issue, i.e., a phenomenon by which the turbulent heat flux does not match the measured net radiation, is regarded as a typical problem of accuracy in flux measurements. The energy balance is a valid criterion of turbulent flux measurement; the energy imbalance status implies some bias of the estimated turbulent flux.

A recent study showed the inherent negative bias of the imbalance of fluxes of single-tower measurements. The study used homogeneous ground surface heating conditions resulting from the turbulent organized structure (TOS) using numerical experiments with large-eddy simulation (LES) in a convective boundary layer (Kanda et al., 2003). The necessity of horizontally distributed observation networks, such as multi-tower measurements, was suggested for evaluation of regionally averaged fluxes (Katul et al.,).



The temporally averaged and spatially averaged vertical turbulent fluxes over a homogeneous flat terrain with no synoptic updraft or downdraft ([*w*] = 0)

Temporal avg. $\overline{F} = \bar{w}\bar{c} + \overline{w'_t c'_t}$

Spatial avg. $[F] = [w][c] + [w'_s c'_s]$

$[\overline{F}] = \boxed{[\bar{w}\bar{c}]} + [\overline{w'_t c'_t}]$

$\overline{[F]} = \overline{[w'_s c'_s]}$

w: the vertical component of wind speed
c: the scalar (temperature, vapor, CO_2)

Fig.1 Concept of the Turbulent organized structure (TOS) effects on flux measurements.

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Presuming that the factors described above are the main factors causing this imbalance, measured values obtained using an instrument that senses a signal from a larger source area might approach the correct spatially averaged value (Fig.1).

The objective of this study is to elucidate the structure of turbulent transportation above a forest canopy using a scintillometer. That instrument is expected to have a larger source area of flux measurement than conventional EC sensors. In addition, this paper presents discussion of the improved spatial representativity using the energy imbalance as a criterion for flux measurement validity. The study also proposes a new method for determining the turbulent flux; the method combines both the DBSAS and EC systems.

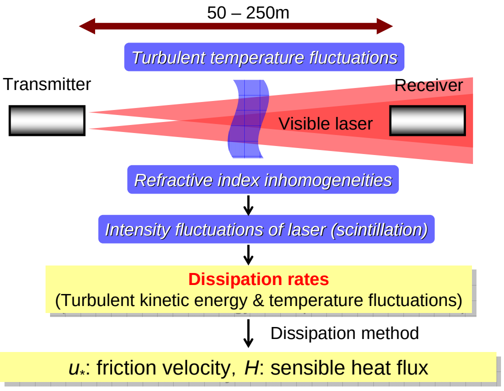
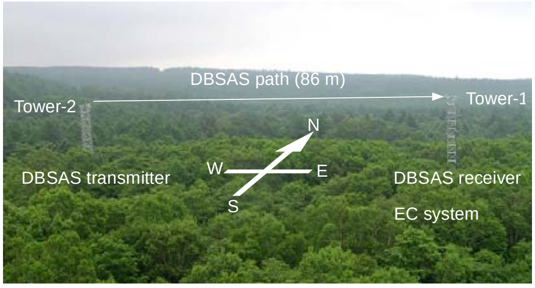


Fig.2 Theory of flux evaluation by displaced-beam small aperture scintillometer (DBSAS).

2. Spatial variety of turbulent flux

The scintillation method estimates the momentum flux (u_*) and the sensible heat flux (H) from the fluctuations of refractive index in atmosphere caused by the turbulent temperature variations (Fig.2). The scintillation method is expected to measure spatial averaged turbulence signals better than EC because its optical measurement path can be set from 50 m to 250 m. No precedent exists for application of scintillometry to a forest. Characteristics above a forest canopy are not well known. In this study, simultaneous measurements using a commercially available displaced-beam small aperture scintillometer (DBSAS) and two sets of EC systems were used during 2002-2005 to investigate the applicability of DBSAS above a forest canopy. Experimental site is in about 50-year-old secondary deciduous forest near Karuizawa, central Japan (36º24'N, 138º35'E, 1380 m a.s.l.) (Fig.3).



Flux Measurement

- Site: 50-year-old secondary mixed deciduous forest (18m)
  central Japan (elevation 1380 m a.s.l.)
- Period: Jan. 2002 -- Dec. 2005
- Tower: Two 28 m-tall scaffolding towers, 86 m apart East-West
- Eddy-covariance (EC): USA-1 (Metek), LI-7500 (Licor)
- Displaced-beam small aperture scintillometer (DBSAS) : SLS40A(Scintec)

Data processing

- DBSAS: dissipation rates of turbulent kinetic energy (TKE) and temperature fluctuations (ε_{SAS} ε_{TSAS})
- EC system: dissipation rates (ε_{EC}, ε_{TEC}) and fluxes (H, lE, F_c)
- Block averaging time: 30min

Fig.3 Overview of the observation.

The terrain is flat with a gentle slope of -3º from the southwest to the northeast. Two 28-m-tall scaffolding towers were erected 86 m apart through an 18-m-high deciduous mixed forest canopy.

The sensible heat fluxes observed at two towers showed remarkable differences (Fig.4).

Meanwhile, heat fluxes were biased toward the other tower when the averaged energy budgets between the two towers were not similar. These results imply that the TOS causes an energy imbalance of flux measurement.

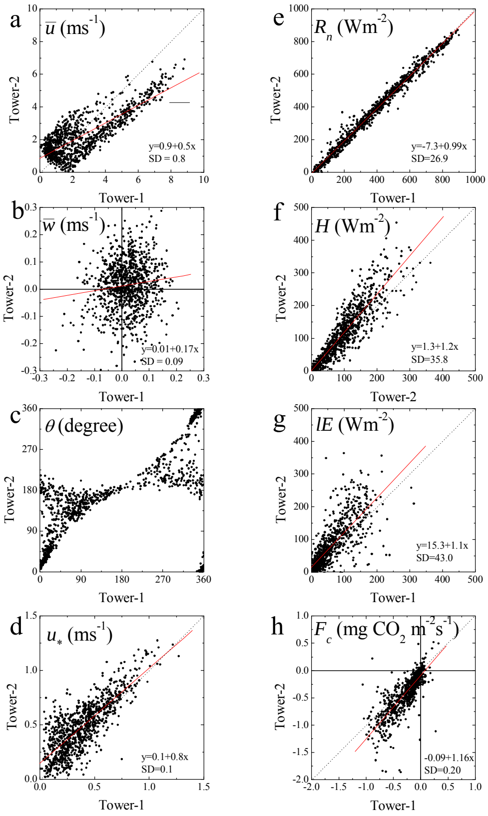


Fig.4 Comparison of wind characteristics and fluxes between towers: (a) mean wind velocity; (b) mean vertical flow; (c) wind direction; (d) friction velocity; (e) net radiation; (f) sensible heat flux; (g) latent heat flux; (h) CO_2 flux.

The DBSAS uses some assumptions in derivation of u_* and H from the dissipation rates of turbulent kinetic energy (TKE) and temperature fluctuations (Fig. 2). Therefore, the dissipation rates were calculated from the EC sensors for comparison. Results showed that the difference in dissipation rates using the different sensors changed asymptotically with the relative turbulent intensity (σ_w /u) (Fig. 5). The DBSAS dissipation rates are sometimes larger than EC under the conditions of smaller σ_w /u. The DBSAS results tended to be larger than EC for both the dissipation rate and the sensible heat flux. This bias functions to reduce the energy imbalance of flux measurements. These results indicate that the dissipation rate increases by spatial averaging according to the source area of flux measurement; this effect is remarkable for the smaller σ_w /u (Nakaya et al. 2006).

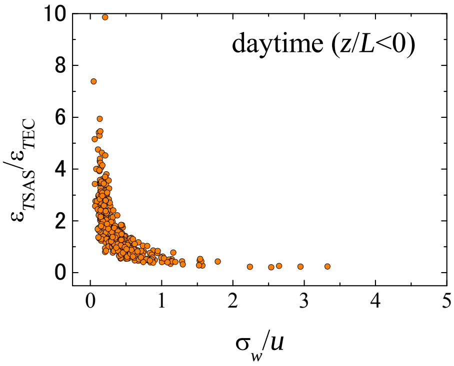


Fig.5 Difference in dissipation rates using the different sensors changed asymptotically with the relative turbulent intensity (σ_w /u).

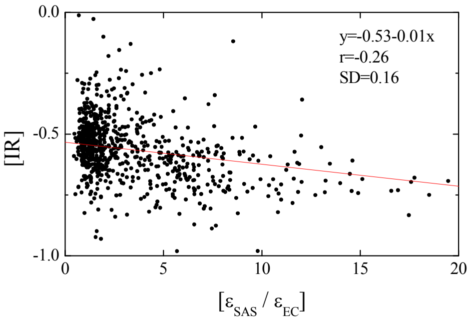


Fig.6 Averaged imbalance ratios between towers increase along with the difference of measured values between EC and DBSAS. IR= (H + lE –R_n) / R_n .

3. Spatial averaging effect by DBSAS

By spatial averaging, the contribution of local advection caused by TOS, which is regarded as the residue of the energy balance equation (Fig. 6), is canceled out because the spatial scale of measurement covers up the heterogeneity provided by TOS (Fig. 1). Assuming that DBSAS applied to a mixed forest can better measure spatial averaged turbulence signals then EC, the relative turbulent intensity (σ_w /u) measured using a single tower is considered to be one criterion of TOS existence. A new method was developed that corrects u_* and H measured using EC system into the DBSAS corresponding value (Nakaya et al., 2007). This method is based on the proportional relationship between the ratio of H and the ratio of the dissipation rate and both rates are obtained using DBSAS and EC measurements. The ratio of dissipation rates, which corresponds to a correction coefficient, is described as an empirical function of the σ_w /u and the ratio of source area of DBSAS and EC. Furthermore, presuming that the inevitable underestimation by EC is caused by the TOS over forest canopy, this relationship is extended to water vapor flux E. The energy balance closure was improved; furthermore, the greater spatially averaged flux was evaluated using the revised heat fluxes.

4. Comparison of flux data with biometric measurement

The effect of DBSAS correction was examined according to the carbon balance in the forest using CO_2 flux revised analogously to water vapor flux revision.

Although the maximum photosynthetic rate of the ecosystem derived from the EC result was less than the photosynthetic rate derived from the individual leaf photosynthesis rates, the revised value reached the calculated value (Fig. 7).

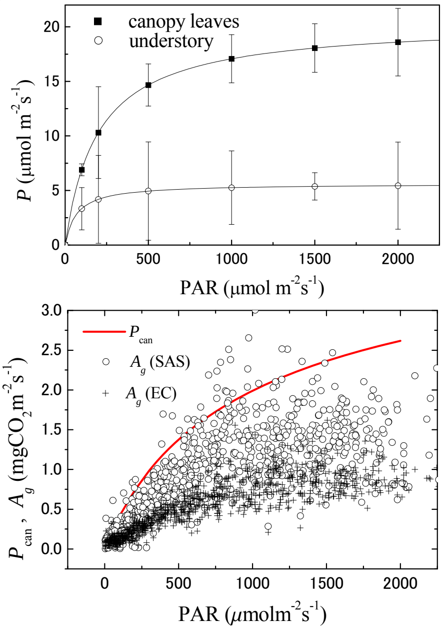


Fig.7 DBSAS correction effect on maximum photosynthetic rates. Photosynthetic rate potential (P_{can}) was given by a simple light-transmittance model and photosynthetic rates of leaves.

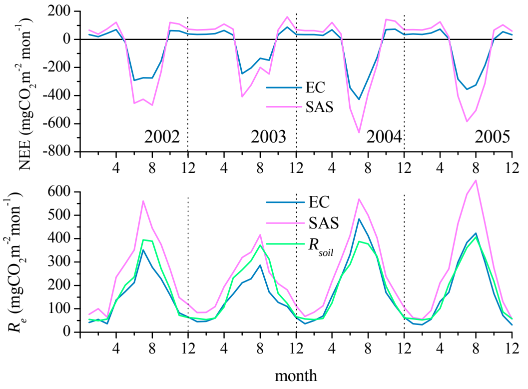


Fig.8 DBSAS correction effect on long-term flux evaluation. R_{soil} values were obtained by soil-chamber measurements.

The flux-based ecosystem respiration was sometimes less than the soil respiration estimated by soil chambers. Considering the respiration calculated using the above-ground plant body, this result was inconsistent. The ecosystem respiration derived from the revised CO_2 flux was reasonably larger than the soil respiration (Fig. 8). Consequently, the net ecosystem exchange (NEE) increased because of the change of CO_2 balance caused by the flux CO_2 correction for emission and absorption.

5. Conclusion

The new method, which combines both DBSAS and EC method, approaches the spatially averaged value and can be used to verify and correct turbulent flux measurements.

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