529 Characteristics of Relative Sampling Errors in Eddy Covariance Measurements and Their Application to Flux Aggregations

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INTRODUCTION

- The eddy covariance (EC) measurements are based on hypotheses of the stationarity and ergodicity of time series which is fixed sample number N measured by the same interval during time length L.
- These hypotheses are mainly disturbed by spatial heterogeneities such as variations in the roughness length, temperature, water content, photosynthesis, and respiration or by combinations thereof under neutral and unstable atmospheric conditions as well as gravity waves and synoptic changes under stable atmospheric condition.
- Under disturbed conditions, L that satisfies average convergence is longer than those estimated under the hypotheses. In other words, the relative sampling error ε can rise under a shorter L of EC measurements.
- The aims of this study are to 1) evaluate the minimum value of ε for understanding the range of EC measurement uncertainties, 2) investigate the relationship between ε and the similarity parameter φ for presenting ε as one of the EC quality parameters, and 3) suggest an aggregation method considering ε for estimating more reliable EC measurements.

MATERIALS & METHODS

- **Key governing equations**

1. Relative sampling error (Kim *et al.* 2011)

$$\varepsilon = \frac{\sigma}{|F|}$$

2. Sampling error (Finkelstein and Sims 2001)

$$\sigma = \left[\frac{1}{N}\left(\sum_{p=-m}^{m}\gamma_{ww}(p)\gamma_{\xi\xi}(p) + \sum_{p=-m}^{m}\gamma_{w\xi}(p)\gamma_{\xi w}(p)\right)\right]^{\frac{1}{2}}$$

3. Weighted average (Kim *et al.* 2015)

$$\overline{F} = \frac{\sum_{i=1}^{n}\frac{F_i}{\varepsilon_i^2}}{\sum_{i=1}^{n}\frac{1}{\varepsilon_i^2}}$$

- **Measurement site**
  Tangerine orchard (33.507883N 126.680908E 81m a.s.l.) in Jeju, Korea

- **Instrumentation**

1. Sonic anemometer: CSAT3, Campbell Scientific, Utah, USA
2. Open-path gas analyzer: LI7500, LI-COR, Nebraska, USA

RESULTS

Minimum Relative Sampling Error

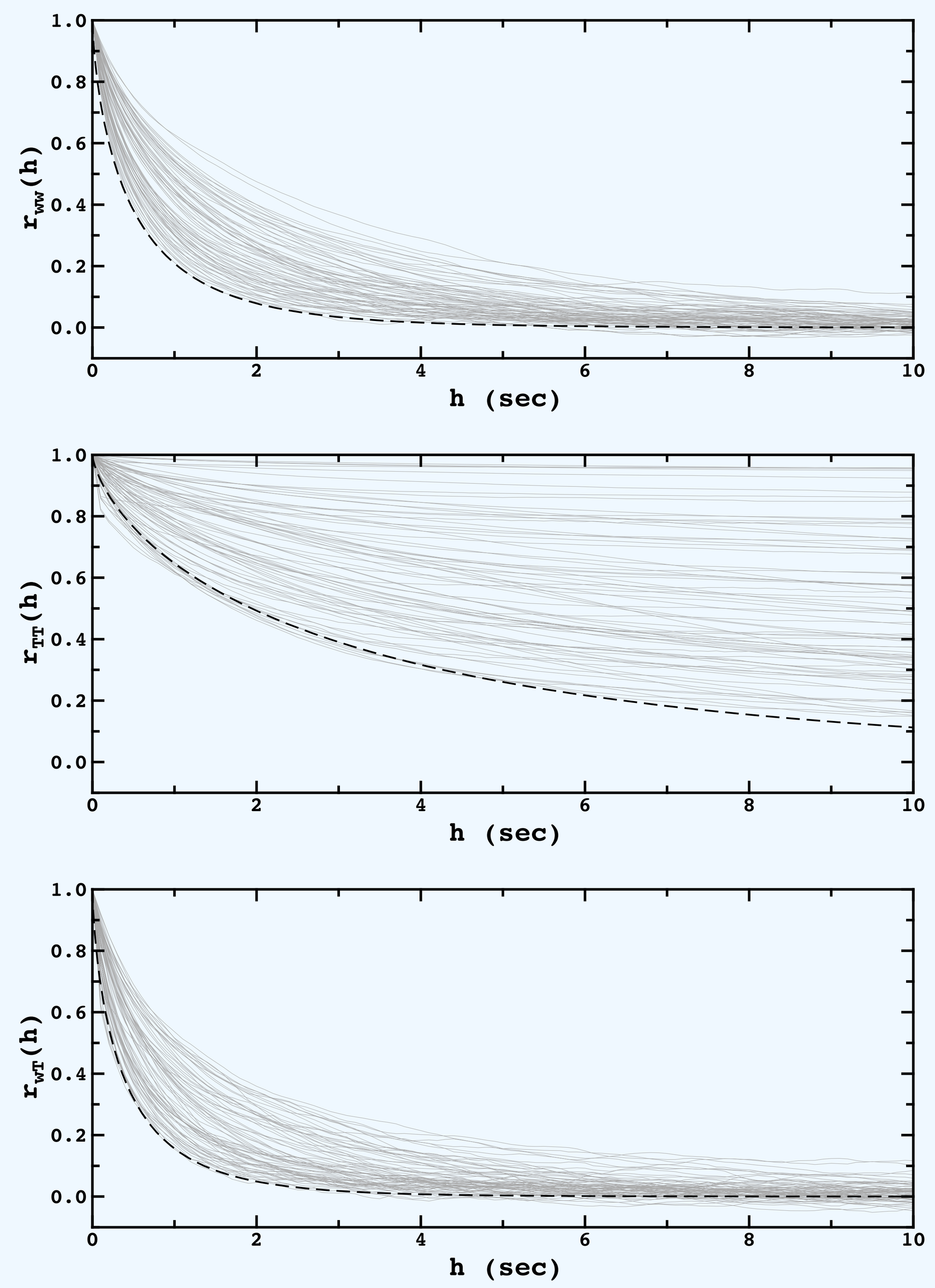

Figure 1. The autocorrelation function estimated by each fluctuation of vertical velocity w', temperature T', and those product $w'T'$ measured at tangerine orchard in Jeju, Korea, for 11-13 January, 2015. Every solid line is estimated by 10Hz measurement for 1 hr, and the dashed line is fitted for a minimum autocorrelation function. The model for the autocorrelation function is defined at Discussion, and its a is 0.7, and b is 0.32, 1.15 and 0.27 sec for $r_{ww}(h)$, $r_{TT}(h)$, and $r_{wT}(h)$ respectively. Where r denotes the correlation coefficient, and h the lag time.

Relative Sampling Error as Similarity Parameter

Table 1. The percentage interval of the relative sampling error ε according to the classification of the integral turbulence characteristics (ITC) based on Foken et al. (2004).

Class	ITC	ε
1	0–15	5–10
2	16–30	6–12
3	31–50	7–14
4	51–75	8–16
5	76–100	9–18
6	101–250	10–32
7	251–500	18–54
8	501–1000	30–99
9	1000–	55–

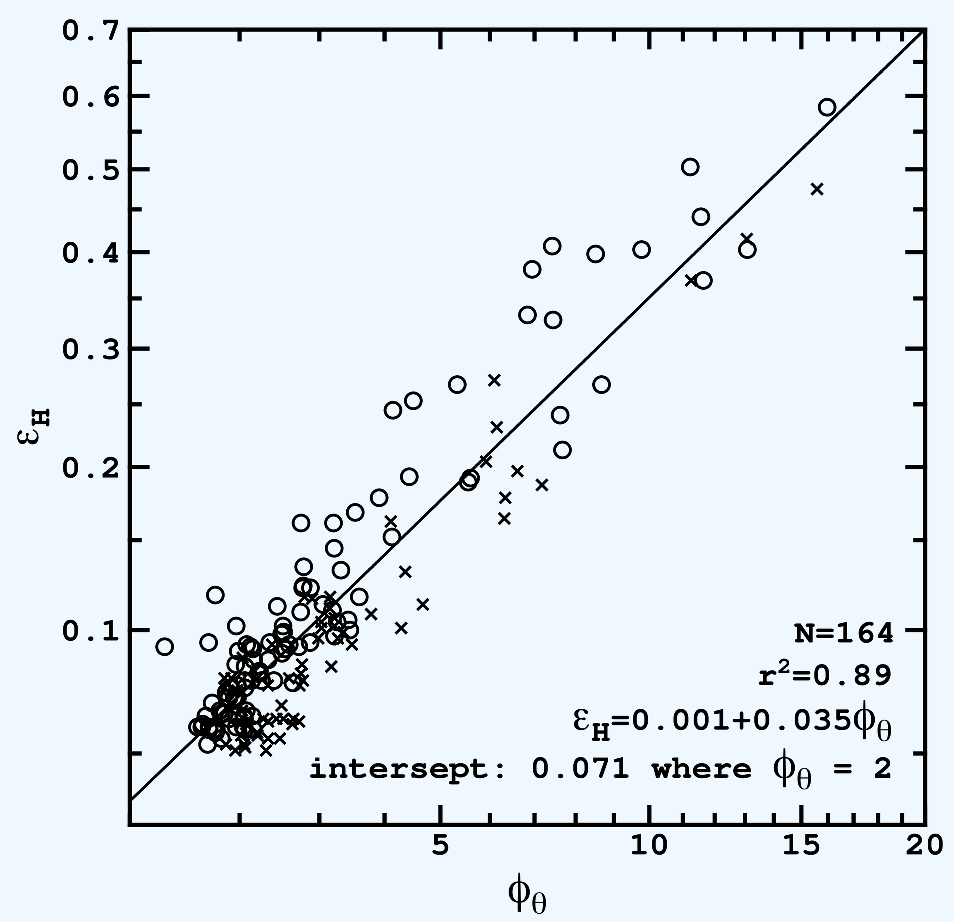

Figure 2. Relationship between the similarity parameter of the temperature φ_θ and the relative sampling error of the sensible heat flux ε_H estimated by the measurements of a tangerine orchard in Jeju Island, Korea, during 9–15 April 2014 (◯) and 11–13 January 2015 (╳). The text within the panel describes the statistical information of a regression line between φ_θ and ε_H. N denotes the sampling number, and r^2 denotes the coefficient of determination.

Relative Sampling Error as Weighting Factor

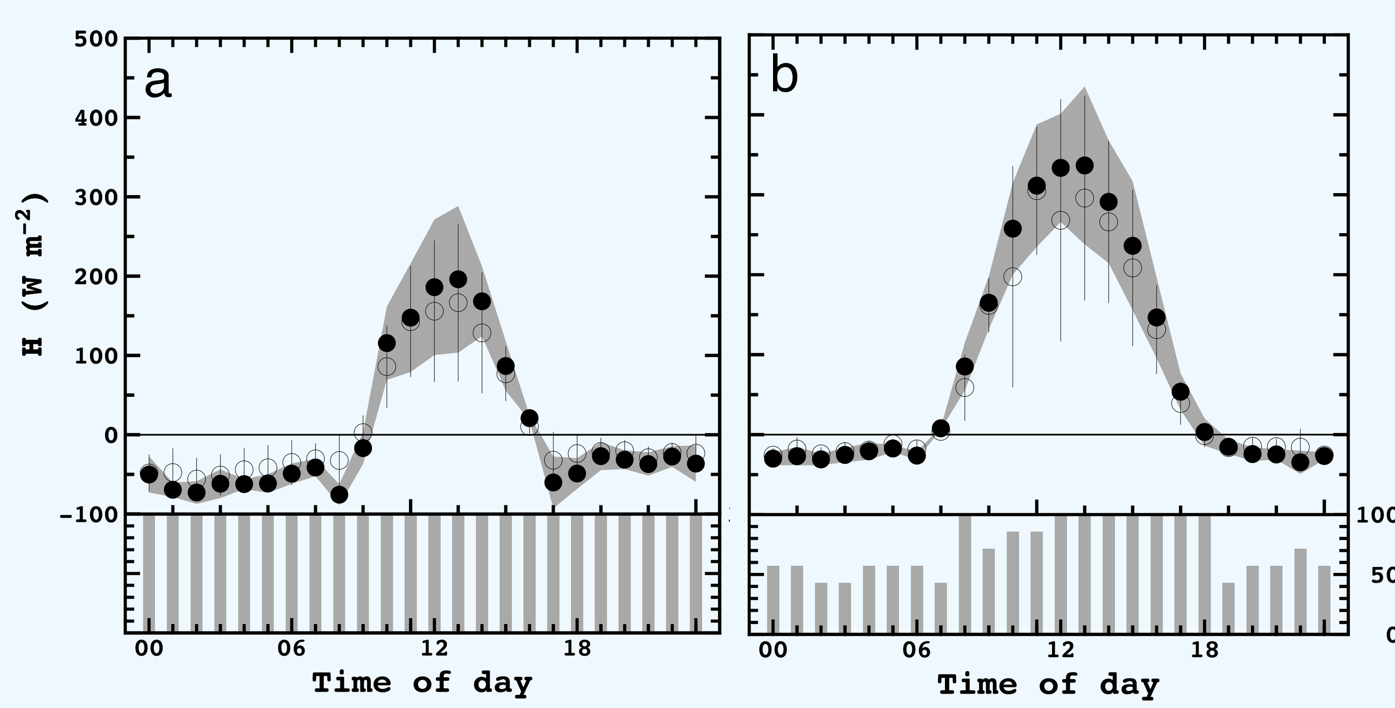

Figure 3. The mean diurnal variation of the sensible heat flux H estimated by the same EC measurements shown in Fig. 2. in this study and in (b) Fig. 16 in Kim *et al.* (2015). The closed circle and the shadow region denote the weighted mean H trend and its standard deviation σ on the basis of Eq. (18) and Eq. (19), and the open circle and the whisker are the arithmetic mean H trend and its standard deviation σ, respectively. The vertical bar at the bottom panel designates the acquisition ratio (AR) of hourly EC measurements in each time of day; e.g., the 57% AR at 00 in the left panel means that 4 days EC measurements observed at 00:00 are available for a week.

DISCUSSION

- Fig. 1 presents an autocorrelation function $r(h)$ to estimate the integral time scale $\mathscr{T}$ with its minimum line in our measurements with the equation proposed by Finkelstein and Sims (2001) as $r(h)=\exp(-h^a/b)$. If $r(h)$ is independent between vertical velocity w and temperature T, the relative sampling error ε could be minimized to about 3% by $N^{-1/2}(\mathscr{T}_a+\mathscr{T}_c)^{1/2}/|r|$. Nevertheless the estimated ε by Eq. 1 using the same time series of previous analysis do not approach less than 5%, and ε_{min} records 5.1%. Hereafter, we assign 5% to ε_{min} for the 1.0 hr (N = 36000).
- Fig. 2 shows the relationship between ε_H (= $\sigma_{w'T'}/|w'T'|$) and φ_θ (= $\sigma_T u*/|w'T'|$) with r^2 = 0.89, where $u*$ is the friction velocity. These results are not surprising because, according to Monin-Obukhov Similarity Theory, the atmospheric statistic normalized by an appropriate power of the scaling parameter becomes the universal function of the atmospheric stability. Therefore, the test values of the developed turbulent conditions could be described as ${}_\varepsilon\mathrm{ITC}_\sigma=|[\varphi_\varepsilon-\varepsilon(1+0.4|\zeta|)]/\varphi_\varepsilon|$ based on Foken *et al.* (2004), and then $\varepsilon=\varepsilon_{min}(1+\mathrm{ITC}_\sigma)$. Therefore, the ε interval is summarized as Table 1 in accordance with the classification of ITC.
- It is clarified that σ_H is fluctuated according to various atmospheric conditions and has a liner relationship to H when ε is identical. These two evidences provide that a weighted mean is required instead of an arithmetic mean, and $1/\varepsilon^2$ for a weighting factor and σ_H instead of $1/\sigma_H^2$, because every H has have a uniform quality to estimate the mean of H by the arithmetic mean, and every σ against H has been an independent quantity to be used as a weighting factor of the weighted mean. Therefore, we suggests Eq. 3 for the mean of H.
- Fig. 3 shows comparison results between the weighted and the arithmetic of the mean diurnal variation of EC measurements for two periods. While the results do not have a statistical significance, it is considerable in terms of dealing a role of land surface because the weighted H of 0.33±0.63 MJ m^{-2} day^{-1} means not only source of heat but also sink of heat, rather the arithmetic 0.76±0.75 MJ m^{-2} day^{-1} is just source. In addition, the difference between the weight and the arithmetic is fully systematic, and it might be that a large ε appeared at a small H because the atmospheric conditions to measure H is inappropriate for EC measurement in lots of cases. This point details that the classical method has a passibility of an underestimation of daytime H, and an overestimation of nighttime H .

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