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Why We Nneed to Estimate Sampling Error in Eddy Covariance Measurement?

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INTRODUCTION

- Eddy covariance (EC) measurement operates fundamentally over the hypotheses of stationarity, so that averaging problem is an inherent issue in the EC measurement. Therefore, it is valuable to estimate a relative sampling error ε in a classical time averaging length in terms of the performance estimation of EC measurement.

- In classic quality control and quality assurance (QCQA), 1) it is the arbitrary values that the rank of qualities with an integral turbulence characteristic (ITC) and a stationarity, 2) measurement gaps are inevitably increased in accordance with QCQA filtering, and 3) no error information coming from the averaging problem is regarded. If ε represents ITC, it will be a convenient and comfortable parameter for scaling both error and quality of EC measurements.

- The ε will contribute to the investigations to compare vegetations responses in climate change, and to integrate regional or global values of the exchange, as well as to validate model performance or satellite analysis, and to synthesis the spatiotemporal values by data assimilation. Therefore, in consideration of turbulent characteristics the averaging method of EC measurement is to be meditated

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

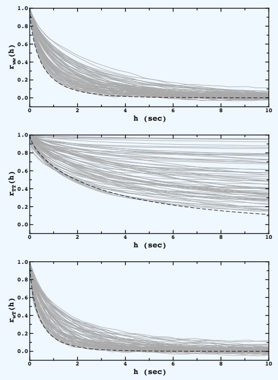

Figure 1. The autocorrelation function estimated by each fluctuation of vertical velocity w', temperature T', and those product $w'T'$ measured at tangerine orchard in Jeju, Korea, for 11-13 January, 2015. Every solid line is estimated by 10Hz measurement for 1 hr, and the dashed line is fitted for a 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	5-6
2	16-30	6-7
3	31-50	7-8
4	51-75	8-9
5	76-100	9-10
6	101-250	10-18
7	251-500	18-30
8	501-1000	30-55
9	1000-	55-

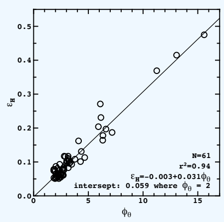

Figure 2. The relationship between the similarity parameter of temperature φ_θ and the relative sampling error of sensible heat flux ε_H estimated by the same experimental data of Fig. 1. The text within a panel describes the statistical information of a regression line between φ_θ and ε_H. N denotes the sampling number, and r^2 the coefficient of determination.

Relative Sampling Error as Weighting Factor

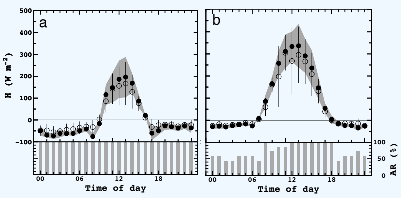

Figure 3. The mean diurnal variation of sensible heat flux H estimated by the same experimental data of (a) Fig. 1 in this study, and (b) Fig. 16 in Kim *et al*. (2015). The closed circle and the shadow denote the weighted mean trend and its standard deviation σ on the base Discussion. The opened circle and the whisker is the arithmetic mean and its σ respectively. The vertical bar at the bottom panel designates the acquisition ratio (AR) during experimental days.

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) because of considering uncertainty according to approximation of a and b.

- Fig. 2 shows the relationship between ε_H (= $\sigma_{w'T'}/\ w'T'$) and φ_θ (= $\sigma_T u_*/\ w'T'$) with r^2 = 0.94, 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 sacaling parameter becomes the universal function of the atmospheric stability. Therefore, integral turbulence characteristics (ITC) could be described as ITC=$|(\varepsilon_{min}-\varepsilon)/\varepsilon_{min}|$ based on Foken *et al*. (2004). 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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