**Processing and Quality Control of Flux Data at Gwangneung Forest**

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**ABSTRACT**

In order to ensure a standardized data analysis of the eddy covariance measurements, Hong and Kim's quality control program has been updated and used to process eddy covariance data measured at two levels on the main flux tower at Gwangneung site from January to May in 2005. The updated program was allowed to remove outliers automatically for CO$_2$ and latent heat fluxes. The flag system consists of four quality groups (G, D, B and M). During the study period, the missing data were about 25% of the total records. About 60% of the good quality data were obtained after the quality control. The number of record in G group was larger at 40m than at 20m. It is due that the level of 20m was within the roughness sublayer where the presence of the canopy influences directly on the character of the turbulence. About 60% of the bad data were due to low wind speed. Energy balance closure at this site was about 40% during the study period. Large imbalance is attributed partly to the combined effects of the neglected heat storage terms, inaccuracy of ground heat flux and advection due to local wind system near the surface. The analysis of wind direction indicates that the frequent occurrence of positive momentum flux was closely associated with mountain valley wind system at this site. The negative CO$_2$ flux at night was examined in terms of averaging time. The results show that when averaging time is larger than 10min, the magnitude of calculated CO$_2$ fluxes increases rapidly, suggesting that the 30min CO$_2$ flux is influenced severely by the mesoscale motion or nonstationarity. A proper choice of averaging time needs to be considered to get accurate turbulent fluxes during nighttime.

**Key words**: Quality control, Energy balance, Turbulent flux, Gwangneung forest

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**I. INTRODUCTION**

Terrestrial ecosystem plays an important role in climate and carbon budget through exchange of mass and energy. The need to understand and quantify the exchange of carbon dioxide, water vapor and energy has led to an establishment of global network of micro-meteorological flux measurement sites, FLUXNET. KoFlux (Kim *et al.*, 2002), which is the one of FLUXNET sites, has been established at Gwangneung and Haenam to quantify CO$_2$ exchange over forested and agricultural area, respectively.

The eddy covariance technique is the most widely used method to quantify the net carbon exchange of terrestrial ecosystem at flux measurement sites. To compare the eddy covariance data of different flux
measurement stations, the quality of the flux data has to be assessed. There are various sources of errors in flux measurements such as failure to satisfy theoretical assumptions and failure of the technical set-up. In order to provide a consistent product across measurement networks, some investigators have developed automatic checks for frequently occurring problems in data records. Foken and Wichura (1996) applied criteria to fast-response turbulence data to test nonstationarity and substantial deviations from flux-variance similarity theory. Vickers and Mahrt (1997) developed a framework of test criteria for quality control of fast response turbulence time series which is not framed in terms of similarity theory nor assumes that the fields necessarily follow any particular statistical distribution. Hong and Kim (2002) developed a quality control program to process the eddy covariance data based on Foken and Wichura (1996) and Vickers and Mahrt (1997). The program consists of basic test of raw data, statistical test and coordinate rotation. Although the program has been successfully used to process eddy covariance data, there are still outliers which are not screened by the program.

Energy balance closure has been accepted as an important test of evaluating the reliability of eddy covariance data and a number of individual sites report energy balance closure as a standard procedure. However, a general concern has developed within the micrometeorological community because surface energy fluxes are frequently (but not always) underestimated by about 10-30% relative to estimates of available energy (Wilson et al., 2002). Particularly, large imbalance has been reported at forested sites in complex terrain. Topography plays an important role in developing thermally induced circulation which complicates surface energy budget and carbon budget through horizontal and vertical advection.

The objectives of this study are twofold. The first objective is to update the Hong and Kim's quality control program (hereafter HK program) in order to get more reasonable data based on automated procedures. The second objective is to examine the feature of turbulent fluxes at Gwangneung site located in complex terrain.

II. SITE DESCRIPTION AND DATA

The study site (37° 45' N, 127° 9' E, 340m a.s.l.) is located in Gwangneung experiment forest at the west-central portion of Korean peninsular which is part of KoFlux sites (hereafter GK site). This topography is rugged and elevations range from about 90m to 600m. Surface flux measurements have been made at 40m and 20m on the main tower which is located in forested inter-mountain basins and surrounded by hilly terrain. The terrain has a valley-like topography with about 10° slope along the east-west direction. The forest is dominated by serrata oak (Quercus serrata, ~58%). The mean canopy height is approximately 19m and maximum foliage area index is ~6. The tree age ranges from 60 to 600 years and some trees were disturbed by severe thunderstorms during summer. The annual mean air temperature is 11.3 °C and the annual mean precipitation is 1,365mm. More detail information on the study site can be found in Lim et al. (2003).

Turbulent fluxes have been measured with eddy covariance system installed at 40m and 20m on the main tower in GK site. The main system consists of a three-dimensional sonic anemometer (CSAT3, Campbell Scientific Inc, Logan, UT, USA) and an open-path H2O/CO2 gas analyzer (LI7500, LICOR, Lincoln NE, USA). Sampling rate was 10Hz and the data were stored in a data-logger (CR5000, Campbell Scientific Inc.) with a real-time processing every half hour.

A radiometer (CNR1, Kipp and Zonnen, The Netherlands) was installed at 40m above the ground to measure downward and upward components of short wave and long wave radiations. Soil heat flux plate was buried at 0.01m under the ground to measure soil heat flux.

III. EDDY COVARIANCE DATA ANALYSIS

In order to ensure a uniform data analysis of the eddy covariance measurements, the comprehensive software package, HK program, has been developed at Yonsei University (Hong and Kim, 2002). The program was originally designed for processing eddy covariance data at one level. For using the program at GK site with two measurement levels, the program has been modified to process eddy covariance data at two levels in this study. We also added more criteria for quality control such as absolute limit, malfunction of instrument and test on normalized standard deviation of CO2 and H2O concentration, which are explained in detail in next section. The major step of this quality control system is shown
in Fig. 1. The first step in data processing is the quality tests of the raw data which exclude the physically not possible values and spikes (Vickers and Mahrt, 1997). Then the coordinate system of the sonic anemometer measurements is transformed into a coordinate system that is parallel to the mean streamlines using the planar fit method (Wilczak et al., 2001). Afterwards the averages, variances and covariances are calculated for 30 min interval and post field quality control is applied to turbulent flux data. Because density fluctuation of constituent can result from fluctuation in water vapor density and temperature, the correction of Webb et al. (1980) (called the WPL correction) is applied to turbulent fluxes of CO$_2$ and H$_2$O. The results of quality corrected are combined to give a quality flag for every 30 min turbulent flux value. The flag system consists of four groups (G, D, B and M). Dubious and bad qualities are represented by D and B, respectively. When passing all quality tests, the record are assigned to G group and if there is no data in a record, we regard such record as missing (M) (see Table 1). After all these steps, finally corrected and quality assured results of turbulent fluxes are obtained. When more than 95% of points remain in each record after basic test on raw data, the record is used in calculation and analysis of turbulent statistics.

**Table 1.** The flag system. $u$ and $v$ are the horizontal wind components and $w$ is vertical wind component. $T$ is air temperature. $\sigma_x$ and $\bar{x}$ indicate the standard deviation and the mean, respectively.

<table>
<thead>
<tr>
<th>Quality information</th>
<th>D</th>
<th>B</th>
<th>G</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absolute limit, spike, $(u, v, w, T)$=0</td>
<td>√</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low wind speed ($u &lt; 0.5 m s^{-1}$)</td>
<td>√</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Integral Turbulence Characteristics</td>
<td>√</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non stationarity of Flux $\sigma_x/\bar{x}$ for CO$_2$ and H$_2$O</td>
<td>√</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3.1. Quality control for raw data

In this section, we present parameters that describe unusual behavior of the time series. Threshold values for these parameters have been specified to identify records that should be removed from future study. These threshold values are determined empirically based on the frequency distribution of each variable at this site.

Spikes are typically characterized as short duration, large amplitude fluctuations that can result from random noise in the electronics. The effect of water collecting on the transducers of some sonic anemometers often appears as spikes. Insufficient electrical power supplies can lead to frequent spiking (Vickers and Mahrt, 1997). In HK program, any point in data record that is more than 20 standard deviation from the data record mean was considered a spike. Because there are still spikes that are not screened by 20 standard deviation, we lowered the threshold value from 20 standard deviation into 5 standard deviation based on visual inspection of raw data.

A number of unrealistic data are detected by simply comparing the minimum and maximum value of all points in the record using some fixed limits considered unphysical (Vickers and Mahrt, 1997). HK program specified the absolute limit for vertical wind component only. We added the absolute limits for the horizontal wind components, air temperature, CO$_2$ concentration and H$_2$O concentration (Table 2).

Table 2. Absolute limits of wind components, CO$_2$ concentration ($c$), H$_2$O concentration ($q$) and temperature, respectively

<table>
<thead>
<tr>
<th>Variable</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>$u$</td>
<td>-20ms$^{-1}$</td>
<td>20ms$^{-1}$</td>
</tr>
<tr>
<td>$v$</td>
<td>-20ms$^{-1}$</td>
<td>20ms$^{-1}$</td>
</tr>
<tr>
<td>$w$</td>
<td>-8ms$^{-1}$</td>
<td>8ms$^{-1}$</td>
</tr>
<tr>
<td>$c$</td>
<td>500mg m$^{-2}$</td>
<td>900mg m$^{-2}$</td>
</tr>
<tr>
<td>$q$</td>
<td>0gm m$^{-2}$</td>
<td>50gm m$^{-2}$</td>
</tr>
<tr>
<td>$T$</td>
<td>-30°C</td>
<td>50°C</td>
</tr>
</tbody>
</table>

There are some cases that all wind components and temperature have a zero value at the same time. This may be due to malfunction of sonic anemometer temporarily. To detect these unphysical behaviors, we added criteria for that.

3.2. Post field quality control

3.2.1. Test for integral turbulence characteristics

Flux-variance similarity is a good measure to test the development of turbulent conditions. This similarity means that the ratio of the standard deviation of a turbulent parameter to turbulent flux is nearly constant or a function of stability. These so-called integral turbulence characteristics are basic similarity characteristics of the atmospheric turbulence (Wyngaard et al., 1971; Foken et al., 2004). Foken and Wichura (1996) applied criteria to fast-response turbulence data (i.e., 10Hz data) to test substantial deviations from flux-variance similarity theory. The used non-dimensional forms for $\phi_\omega$ (vertical velocity) is

$$\phi_\omega = \sigma_\omega / \bar{u},$$

where $\sigma_\omega$ is the standard deviation of $w$ and $\bar{u}$ is friction velocity. The used formulation of in this study is given by (Kaimal and Finnigan, 1994)

$$\phi_\omega = \left\{ \begin{array}{ll}
1.25(1 + 3|z/L|) & -2 \leq z/L \leq 0 \\
1.25(1 + 0.2|z/L|) & 0 \leq z/L \leq 1
\end{array} \right.$$  

(2)

where $L$ is the Obukhov length.

The observed and the calculated parameters according to equation (2) will be compared according to

$$ITC = \left| \frac{\phi_{\text{observed}} - \phi_{\text{calculated}}}{\phi_{\text{calculated}}} \right|$$

(3)

If the test parameter, ITC, is larger than 50%, a well developed turbulence cannot be assumed. Therefore the flag is raised for the record.

3.2.2. Test for non-stationarity of flux

Almost all atmospheric motions are non-stationary or inhomogeneous to some degree. Non-stationary meso-scale motions modulate the turbulent flux and sometimes lead to computed flux on scales larger than turbulent motions (Mahrt, 1998). Averaged over many records, this larger-scale flux might be near zero but can still significantly alter the total flux for a given data record (Sun et al., 1996; Mahrt, 1998). To reduce the influence of the larger-scale motion on the computed flux, many investigators filter by linear detrending, quadratic detrending, or applying higher-order filters to the variables needed to compute the flux. However, the calculated flux is usually sensitive to the type of filter, cutoff wavelength, and the record length itself. And there is no physical reason why the larger-scale motions must be linear (Mahrt, 1998). In this program, the non-stationarity of fluxes are measured using the NR developed by Mahrt (1998) and defined as

$$NR = \frac{\sigma_{\text{obs}}}{RE}$$

where the random error estimate $RE$ is the standard
error based on the within-record variability, and $\sigma_{btw}$ is the between-record standard deviation of the record averaged flux. Most of the calculating steps are well described in Mahrt (1998). To avoid that the discarding nonstationary records leads to a bias that is important to the goal of the investigation, we selected more lenient cutoff value of NR than Mahrt (1998). We considered records to be nonstationarity when NR exceeds 3 and raised flag for the turbulent fluxes.

3.2.3. Test for the normalized standard deviation of CO$_2$ and H$_2$O

Trends in time series can arise from instrumental drift and atmospheric changes. The latter include the advection of eddies of significant size over the measurement site, tropospheric processes like the passage of clouds that affect the surface energy balance, large scale changes of air mass and the evening and morning transitions in stability. The data records with trend or abrupt change show relatively large standard deviation. Therefore, we used the normalized standard deviation to detect the data record with unreasonably large flux due to trend or abrupt change. We specified threshold value for the normalized standard deviation of CO$_2$ and H$_2$O based on their frequency distribution and occurrence ratio of outlier. We defined outlier as data record which fluxes are more than 5 standard deviations from the monthly mean for CO$_2$ and H$_2$O fluxes.

IV. Results

The updated Q.C. program was run to process eddy covariance data measured at two levels on the main tower for 5 months from January to May in 2005. The total number of record is 7,248 (30min averaged). And the number of missing data record is 1,826, about 25% of the total record.

4.1. Threshold value for normalized standard deviation of CO$_2$ and H$_2$O

Fig. 2 shows relative frequency distribution of normalized standard deviation ($\sigma_i/\bar{x}$) for CO$_2$ concentration and water vapor concentration. The number of record decreases rapidly with increasing normalized standard deviation.

To specify threshold value of $\sigma_i/\bar{x}$ for outliers, we analyzed the distribution of occurrence ratio of outlier in terms of $\sigma_i/\bar{x}$. The occurrence ratio is calculated as the ratio of number of outlier to total number of record for each bin of $\sigma_i/\bar{x}$. Fig. 3 shows the occurrence ratio of outlier in terms of $\sigma_i/\bar{x}$ for CO$_2$ and H$_2$O fluxes. Large occurrence ratio is shown at large value of $\sigma_i/\bar{x}$. Based on Fig. 2 and Fig. 3, we determined the threshold value at which occurrence ratio of outlier is about 50%. The specified threshold values of the ratio $\sigma_i/\bar{x}$ are 0.015 and 0.15 for CO$_2$ and H$_2$O, respectively. If the ratio is larger than the threshold value, flag is raised for the turbulent fluxes.

4.2. The effect of updated Q.C. program

In order to examine the effect of updated Q.C. program on data quality, we investigated the number of outlier in turbulent fluxes. In this study the outlier is defined as record which flux value exceeds more than 5
standard deviation from monthly mean. Fig. 4 shows the comparison of the number of outlier before and after update of Q.C. program at 40m. Updated program shows larger improvement for CO\textsubscript{2} and latent heat fluxes than momentum flux, which is due that the test for the normalized standard deviation effectively screened outliers for CO\textsubscript{2} and latent heat fluxes. The test for the normalized standard deviation reduced the number of outlier for CO\textsubscript{2} and latent heat flux by 40% and 41% at 40m and 49% and 44% at 20m, respectively. Added criteria for raw data also eliminated outlier more effectively for CO\textsubscript{2} and latent heat fluxes than momentum.

4.3. Frequency of occurrence of quality control flags

Table 3 shows the number of record classified by flag system. $u'w'$ is kinematic momentum flux, $w'c'$, $w'q'$, and $w'T'$ are turbulent flux of CO\textsubscript{2}, water vapor and temperature.

<table>
<thead>
<tr>
<th>Level</th>
<th>$u'w'$</th>
<th>$w'c'$</th>
<th>$w'q'$</th>
<th>$w'T'$</th>
</tr>
</thead>
<tbody>
<tr>
<td>40 m</td>
<td>G  4,301</td>
<td>4,246(4,130)</td>
<td>4,301(4,130)</td>
<td>4,337</td>
</tr>
<tr>
<td></td>
<td>D  119</td>
<td>69</td>
<td>61</td>
<td>83</td>
</tr>
<tr>
<td></td>
<td>B  938</td>
<td>1043</td>
<td>996</td>
<td>938</td>
</tr>
<tr>
<td></td>
<td>M  1,826</td>
<td>1,826</td>
<td>1,826</td>
<td>1,826</td>
</tr>
<tr>
<td>20 m</td>
<td>G  3,942</td>
<td>3,924(3,792)</td>
<td>3,960(3,792)</td>
<td>3,990</td>
</tr>
<tr>
<td></td>
<td>D  156</td>
<td>156</td>
<td>156</td>
<td>156</td>
</tr>
<tr>
<td></td>
<td>B  1,226</td>
<td>1,332</td>
<td>1,283</td>
<td>1,226</td>
</tr>
<tr>
<td></td>
<td>M  1,826</td>
<td>1,826</td>
<td>1,826</td>
<td>1,826</td>
</tr>
</tbody>
</table>

The number in parenthesis indicates the number of good data after WPL correction.
Nonstationarity of turbulent fluxes is larger for momentum and sensible heat flux than \( \text{CO}_2 \) and \( \text{H}_2\text{O} \) fluxes.

The number in parenthesis in Table 3 indicates the number of good data after WPL correction. For application of WPL correction to \( \text{CO}_2 \) and latent heat fluxes, all of \( \text{CO}_2 \) fluxes, latent heat fluxes and sensible heat fluxes are used. Therefore, we applied WPL correction to record which has good quality for all three fluxes. As a result, after WPL application, the number of \( \text{CO}_2 \) fluxes and latent heat fluxes was reduced.

The number of record in B group is larger at 20m than at 40m. To examine the cause, we investigated the number of record flagged by each quality control criteria for bad data (Table 4). Large difference is shown in the number of record flagged by low wind speed. The criteria of low wind speed have been used in HK project for bad data (Table 4). Large difference is shown in the number of record flagged by each quality control criteria for bad data. As a result, after WPL application, the number of \( \text{CO}_2 \) fluxes and latent heat fluxes was reduced.

More records at 20m are screened by ITC quality control than those at 40m. It is due that the level of 20 m is within the roughness sublayer that is dynamically influenced by length scales associated with the vegetation elements. The turbulent statistics in the roughness sublayer are known to deviate from surface layer similarity relationship (Nakamura and Mahrt, 1999). Several observation and model studies have suggested some roughness sublayer similarity which holds under special assumption and circumstances (Katul et al., 1999; Mölder et al., 1999; Nakamura and Mahrt, 1999; Graefe, 2004). But no similarity did get the general agreement in the roughness sublayer as Monin-Obukhov similarity does in surface layer. Therefore, we applied current ITC test to the roughness sublayer data. However, to process data in roughness sublayer, appropriate ITC coefficient for the roughness sublayer should be developed and considered.

### Table 4. The number of records flagged by each quality control criteria for bad data

<table>
<thead>
<tr>
<th>Level</th>
<th>Quality information</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>40m</td>
<td>Absolute limit, spike, (u, v, w, T) = 0</td>
<td>219</td>
</tr>
<tr>
<td></td>
<td>Low wind speed (&lt; 0.5ms(^{-1}))</td>
<td>578</td>
</tr>
<tr>
<td></td>
<td>Integral Turbulence Characteristics</td>
<td>152</td>
</tr>
<tr>
<td></td>
<td>( \sigma_{\text{CO}_2} )</td>
<td>201</td>
</tr>
<tr>
<td></td>
<td>( \sigma_{\text{H}_2\text{O}} )</td>
<td>124</td>
</tr>
<tr>
<td>20m</td>
<td>Absolute limit, spike, (u, v, w, T) = 0</td>
<td>175</td>
</tr>
<tr>
<td></td>
<td>Low wind speed (&lt; 0.5ms(^{-1}))</td>
<td>889</td>
</tr>
<tr>
<td></td>
<td>Integral Turbulence Characteristics</td>
<td>188</td>
</tr>
<tr>
<td></td>
<td>( \sigma_{\text{CO}_2} )</td>
<td>247</td>
</tr>
<tr>
<td></td>
<td>( \sigma_{\text{H}_2\text{O}} )</td>
<td>163</td>
</tr>
</tbody>
</table>

### 4.4. Energy balance closure

The energy budget is defined as

\[
R_n - R_g - S_f = H + L E
\]

where \( R_n \) is the available energy, typically defined as the net radiation \( (R_n) \) minus the soil heat flux \( (G) \) and heat storage terms \( (S_f) \). At this site, the storage term was not measured and therefore, was not considered in the energy budget.

To examine how well the surface energy balance was closed at each level, we evaluated the energy balance closure at each level using two different methods. The first method is to derive linear regression coefficients (slope and intercept) from the ordinary least squares (OLSs) relationship between the half-hourly estimates of the dependent flux variables \( (H+LF) \) against the independently derived available energy \( (R_n-G) \). Ideal closure is represented by an intercept of zero and slope of 1. Regression coefficients of \( H+LF \) against \( R_n-G \) using OLSs on all of the good quality half-hour data for each level are shown in Table 5. At 40m, the regression between the sum of the turbulent fluxes and the available energy yielded a slope of 0.43 and an intercept of 19.23Wm\(^{-2}\). Similarly, the regression between \( H+LF \) and \( R_n-G \) at 20m, resulted in a slope of 0.43 and an intercept of 22.24Wm\(^{-2}\). The variance in available energy is explained by sum of turbulent fluxes by 91% and 93% at 40m and 20m, respectively.

A second method to evaluate closure is to cumulatively sum \( R_n-G \) and \( H+LF \) over whole study period and calculate the energy balance ratio (EBR) (Mahrt, 1998; Gu et al., 1999).

\[
\text{EBR} = \frac{\sum (H+LF)}{\sum (R_n-G)}
\]

### Table 5. The linear regression coefficients for energy balance closure for two levels at GK site.

<table>
<thead>
<tr>
<th>Level</th>
<th>N</th>
<th>Intercept</th>
<th>Slope</th>
<th>( r^2 )</th>
<th>EBR</th>
</tr>
</thead>
<tbody>
<tr>
<td>40m</td>
<td>3,084</td>
<td>19.23</td>
<td>0.43</td>
<td>0.91</td>
<td>0.40</td>
</tr>
<tr>
<td>20m</td>
<td>2,828</td>
<td>22.24</td>
<td>0.43</td>
<td>0.93</td>
<td>0.39</td>
</tr>
</tbody>
</table>
Both levels show similar value of 0.4 for EBR (Table 5). These results indicate that the surface turbulent fluxes at GK site amounts to, on average, 40% of the measured available energy at both levels during the study period. Note that, since our study period did not include the summer growing season, this imbalance does not represent the annual or long term energy balance at GK site. Wilson et al. (2002) and many other studies reported the energy imbalance of 10~30% at forested sites. Compared to other forested sites, energy imbalance is very high at GK site.

One possible reason for the high imbalance is neglected storage term. Differently from bare soil or small vegetated canopy areas, the heat storage term is known to be an important component in energy balance in forested area. Turnipseed et al. (2002) showed that heat storage accounted for about 8% of $R_n$ where mean canopy height is 11.5m. Therefore neglected storage term contributes partly to energy imbalance. Another reason is inaccuracy of ground heat flux. The used ground heat flux was only measured at one point. Therefore, the ground heat flux at the forested site may not represent footprint area of turbulent fluxes and radiation. The third possible reason is the effect of complex terrain. Due to complex terrain, local circulation develops well at this site, so horizontal and vertical advection of heat may play a role in the energy budget. Lee and Hu (2002) showed that vertical advection explains a small but statistically significant variation of energy imbalance for daytime period over non-flat terrain. Other general reasons have been suggested by Wilson et al. (2002) to account for the lack of energy balance closure, including (1) sampling errors associated with different measurement source areas for the terms in Eq. (9), (2) a systematic bias in instrumentation, (3) stationary eddy, and (4) the loss of low and/or high frequency contributions to the turbulent flux.

Fig. 5 shows a plot of EBR versus stability parameter $\zeta$ at two measurement levels. EBR was calculated for each stability bin ($-2 < \zeta < 2$). Compared to unstable condition, low EBR is shown in stable condition when turbulence activity is weak. The low EBR in stable condition is consistent with other studies. EBR at two levels shows similar value in unstable condition, which is due to well mixed condition in unstable condition. But in stable condition, the level of 40m shows higher EBR than the level of 20m indicating more turbulent condition at 40m than at 20m.

4.5. Positive momentum flux

The momentum is usually transported downward, resulting in negative momentum flux. Based on this, HK program raised the flag when positive momentum flux occurs. At GK site, however, a number of positive momentum fluxes occur. The number of record with positive momentum flux is 1,430 at 40m and 399 at 20m. One possible reason for this is the development of drainage and valley flow and existence of wind maximum between 20m and 40m which causes upward transport of momentum at 40m. To examine this, we first analyzed the distribution of wind direction when positive momentum flux occurred.

Fig. 6 shows the schematics of GK site terrain which has a valley-like topography with slope of 10° along the east-west direction. Figs. 7a and 7b show the frequency distribution of wind direction during the daytime and nighttime, respectively. Daytime is defined as
hours from 0700 LST to 1800 LST and nighttime from 1800 LST to 0700 LST. Although prevailing wind is westerly, some valley wind (easterly) develops during the daytime and drainage flow develops during night. Fig. 8a and 8b show the frequency distribution of wind direction when positive momentum flux occurred. Large occurrence of positive momentum flux is shown when mountain valley wind system develops, indicating that the occurrence of positive momentum flux is closely associated with mountain valley wind system.

The existence of wind maximum between 20m and 40m can be inferred indirectly through smaller wind shear between two levels. We selected cases with westerly during the nighttime and easterly during the daytime and analyzed normalized wind shear between 20m and 40m for positive and negative momentum flux cases. Fig 9 shows the comparison of normalized mean wind shear between positive and negative momentum fluxes. The normalized mean wind shear is lower for the cases with positive momentum flux than those for negative ones both during the daytime and the night, supporting the possibility for existence of wind maximum between two levels when positive momentum flux occurs.

4.6. Negative CO$_2$ flux at night

Fig. 10 shows the distribution of CO$_2$ flux classified as good quality data during the night at 40m. Night time is defined as the hours from 1900 LST to 0600 LST. Despite no photosynthetic activities during night, many negative CO$_2$ fluxes occurred. Negative CO$_2$ flux may be due to the use of inappropriate averaging time and transport by other mechanism such as drainage flow and vertical advection.
The use of too large averaging time can lead to serious contamination of the computed turbulent flux by inadvertently captured mesoscale motions (Howell and Sun, 1999; Vickers and Mahrt, 2006). Traditionally, to reveal the contribution to the flux of eddies of different period, empirical cospectral forms have been used. However, the best known of these 'standard spectra', those of Kaimal et al. (1972) were obtained over short vegetation surfaces and are not necessarily appropriate to use over tall forest. An alternative is to use ogive plots that integrate under the cospectral curve and show the cumulative contribution of eddies of increasing period to the total transport. If the ogive curve reaches an asymptote at some period it indicates that there is no more flux beyond that period (Moncrieff et al., 2004).

To examine the contamination of the computed turbulent flux by inadvertently captured mesoscale motion, we used the ogive plots with the selected data record which absolute magnitude of CO$_2$ flux ranges from 1 to 4 μmol m$^{-2}$ s$^{-1}$. The number of selected record is 352 and 276 for negative and positive CO$_2$ flux, respectively. Fig. 11 shows the composite mean CO$_2$ flux with different averaging time. When averaging time is less than 10 min, the magnitude of CO$_2$ flux reaches asymptote with increasing averaging time, which is typical feature of turbulent flux. However, when averaging time is larger than 10 min, magnitude of negative CO$_2$ flux increases rapidly with increasing averaging time. This result indicates that large magnitude of negative CO$_2$ flux is due to use of inappropriate averaging time. Similar behavior is also shown for positive CO$_2$ flux during the night. This result suggests that proper
averaging time needs to be considered to get reasonable turbulent fluxes during night at GK site. Although the use of short averaging time reduces the magnitude of negative CO\textsubscript{2} flux, it does not change the sign of CO\textsubscript{2} flux, indicating that other mechanisms are responsible for the negative CO\textsubscript{2} flux at this site.

V. CONCLUSION

HK program has been updated and tested with eddy covariance data measured at two levels on the main tower in Gwangneung experiment forest for 5 months from January to May in 2005. The updated program has included added criteria for raw data such as absolute limit for all variables and two post field quality controls related to nonstationarity. Flux data are classified into four groups of Good, Dubious, Bad and Missing. The total number of record is 7,248 and the number of missing record is about 25\% of the total. About 60\% and 55\% of records are assigned to Good group at 40m and 20m, respectively. The smaller number of Good record at 20m is due that the measurement level is in the roughness sublayer and hence wind speed is low and turbulent variables deviate from surface layer similarity. The updated program effectively removed outliers particularly for CO\textsubscript{2} and latent heat flux by automatic way.

An evaluation of energy balance closure was performed. The results show that energy balance ratio is about 40\% during the study period. Large imbalance seems to be due to neglected heat storage term, inaccuracy of ground heat flux and advection due to local wind system near the surface. Large occurrence of positive momentum flux is shown at GK site. The analysis of wind direction for the occurrence of positive momentum flux shows that occurrence of positive momentum flux are closely associated with mountain valley wind system at this site. The negative CO\textsubscript{2} flux at night was examined in terms of averaging time. The calculated CO\textsubscript{2} flux with different averaging time shows rapid increases of its magnitude when averaging time is larger than 10min, suggesting that the turbulent flux is contaminated by the mesoscale motion or nonstationarity due to use of inappropriate averaging time. Proper choice of averaging time needs to be considered to get reasonable turbulent fluxes during night. Although the use of short averaging time reduces the magnitude of negative CO\textsubscript{2} flux, it does not change the sign of CO\textsubscript{2} flux. Further analysis is required to examine the cause of negative CO\textsubscript{2} flux at this site.

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