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Effects of foggy conditions on the measurement of stem respiration in a cloud forest in Taiwan

S. C. Chang, H. K. Wang, Y. C. Lin and Y. J. Hsia
Department of Natural Resources and Environmental Studies, National Dong Hwa University, Hualien, Taiwan
(scchang@mail.ndhu.edu.tw / Fax: +886-3-8633260)

Abstract

Stem CO_2 efflux of a *Chamaecyparis obtusa* var. *formosana* forest ecosystem was measured at the Chi-Lan Mountain site in northern Taiwan. The site is located at an altitude of 1650 m and is subjected to frequent fog coverage around the year. Stem CO_2 efflux was measured continuously at 1 m height by horizontally mounting an automatic soil respiration chamber system (LI-8100 Survey Chamber, LI-COR) on the stem surface. Under clear weather, e. g. on May 16, 2009, the diurnal stem CO_2 efflux rate vs. stem temperature showed a clear hysteresis loop. The daytime stem CO_2 efflux rates were lower than the potential values, which were predicted by the nighttime stem temperature-stem CO_2 efflux relation. The magnitude of the daytime depression of the stem CO_2 efflux was positively correlated with the sapflow velocity. On the contrary, when the site was submerged in fog during the daytime, the hysteresis did not take place and the very low sapflow velocities caused only minor decrease in the daytime stem CO_2 efflux compared to those in nighttime. In May 2009, the daily accumulated daytime depression of stem CO_2 efflux ranged from 0.54 to 7.70 mmol m^{-2}. The daily daytime foggy time had a negative linear correlation with the amount of daily depression. The stem CO_2 efflux measured by the chamber method might significantly underestimate the stem respiration rate. In a clear day the daytime total stem CO_2 efflux may represent only 85% of the stem respiratory CO_2. However, in a foggy day, 99% of the respired CO_2 might diffuse out of the bark and be detected by the chamber system.

1. Introduction

Aboveground woody tissue respiration is a significant component of carbon flux in forested ecosystems because it may return 5-15% of gross primary production to the atmosphere. Worldwide great uncertainties have been shown in quantifying stand-scale stem respiration from the chamber measurements due to the large spatial and temporal variations within an ecosystem. More detailed studies are thus needed also for the modeling purpose.

As part of the carbon project at the Chi-Lan Mountain (CLM) long-term ecosystem research site, we conducted the stem respiration measurements in 2008-2009. Both the spatial and temporal variability of stem CO_2 efflux were evaluated for the upscaling to the stand scale. In this paper we present the part of the continuous measurement in 10-min frequency. The results might offer an opportunity for elucidating the controlling mechanism of stem respiration in the humid subtropical region.

2. Material and methods

2.1 The study site

The study was conducted at the Chi-Lan Mountain site (24°35'N, 121°25'E) located in northern Taiwan. Long-term ecosystem research program including the study of carbon budget has been carried out since 2002. This mountainous forest ecosystem is subjected to frequent foggy condition and the *Chamaecyparis obtusa* var. *formosana* stand adds more than 300 mm yr^{-1} of fog deposition to its 4350 mm yr^{-1} precipitation [2]. Due to the high soil water content and the relatively low annual air temperature (13.8 °C), the soil respiration rate was estimated to be an extremely low value of 1.6 ton C ha^{-1} yr^{-1} [1].

2.2 Setup of the measurements

The stem CO_2 efflux was measured using the LI-8100 Automated Soil CO_2 Flux System (LI-COR Biosciences, USA). PVC collars of 10 cm in diameter were mounted on the stem surface and the LI-8100-102 Survey Chamber was attached horizontally to the collar by measurement. Measurements of spatial variation at 1 m height were

done on 25 *C. obtusa* var. *formosana* trees. Three of which were selected for the investigation of vertical gradient by measuring at 1, 2, 4, and 6 m height. The measurements were performed every 4 weeks. For the rest of time, the chamber was mounted on one of the trees for continuous measurement in a frequency of once per 10 min. Stem temperature beside 7 of the collars was monitored using thermisters installed 0-3 cm into the stem.

The meteorological and ecophysiological parameters used in this study, including the horizontal visibility and the sapflow rate, were part of the monitoring program at the CLM site.

3. Results and discussion

The temporal variation of stem CO_2 efflux followed an obvious diurnal pattern as well as a seasonal pattern. The similar trend of stem temperature and stem CO_2 efflux, as shown in May 2009 (Figure 1), depicts a significant correlation between them. The stem CO_2 efflux (F, in [μmol C m^{-2} s^{-1}]) grows exponentially with the stem temperature (T, in [˚C]):

$$F = -0.523 + e^{-0.506+0.069*T} \qquad (1)$$

with R^2=0.90.

While the dependence of stem CO_2 efflux on stem temperature seems apparent at the monthly time scale, the diurnal course of the efflux rate showed a clear hysteresis with stem temperature. Figure 2 gives a typical example of the hysteresis for clear days at the CLM site. The nighttime stem CO_2 efflux rates were higher than the daytime ones giving the same stem temperature. This phenomenon is well recognized in the literature [3] and the deviation of daytime efflux rates from the nighttime values results mainly from the upward transport of dissolved CO_2 in the xylem sap when transpiration takes place. The bubble size in Figure 2, an indication of the strength of sapflow rate, clearly suggests its relation with the amount of deviation of daytime to nighttime stem CO_2 efflux rate.

To quantify the effect of transpiration on the measurement of stem CO_2 efflux, the "daytime depression (DD)" of the stem CO_2 efflux was calculated as follows: (1) a daily potential CO_2 efflux function was derived by fitting the nighttime efflux rate and the respective stem temperature to a linear equation; (2) for each daytime measurement, the potential daytime CO_2 efflux was calculated using the respective stem temperature and the function derived above; (3) the DD was calculated by subtracting the potential efflux rate with the actual efflux rate.

Taking the data in May 16, 2009 as an example again, the DDs calculated for the daytime measurement points (from 06:00 to 18:00) showed a significant

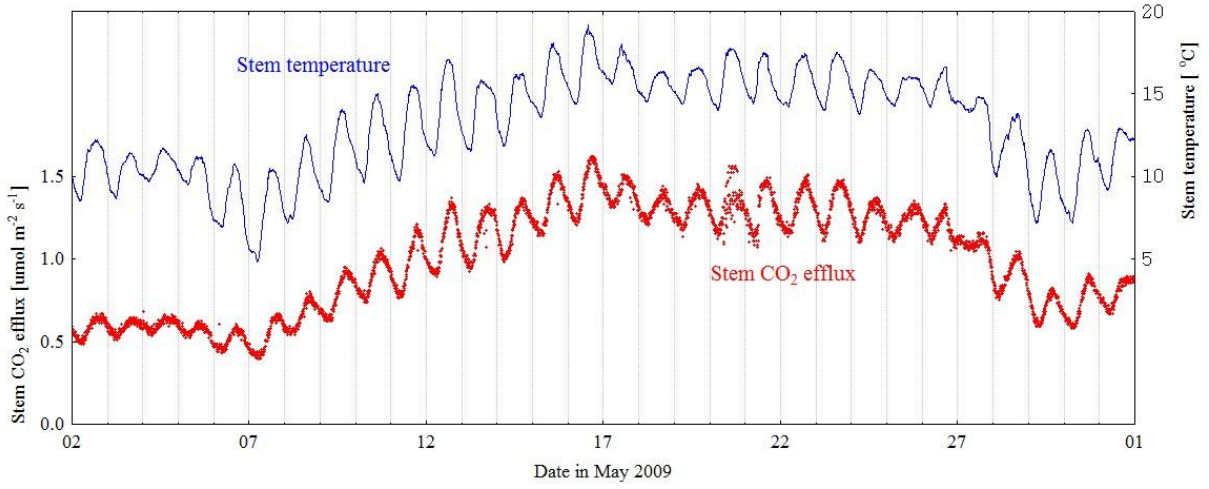

Figure 1: Stem CO_2 efflux and stem temperature of a *Chamaecyparis obtusa* var. *formosana* tree in May 2009 at the CLM site.

positive linear correlation with the sapflow rates (R^2=0.92) (Figure 3).

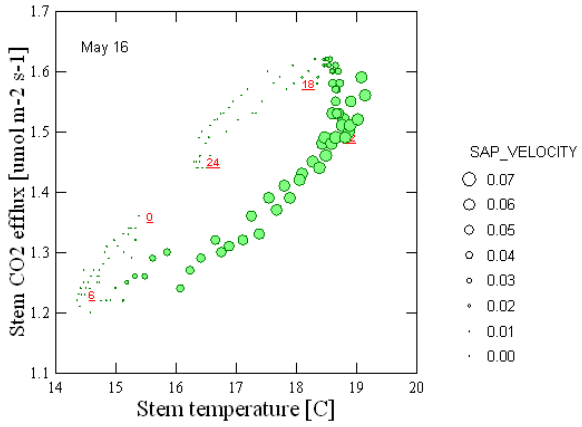

Figure 2: Dependence of stem CO_2 efflux on stem temperature in a clear day (May 19, 2009). The underlined numbers indicate the time of the day. The size of the circles represents the rate of sapflow [cm min^{-1}].

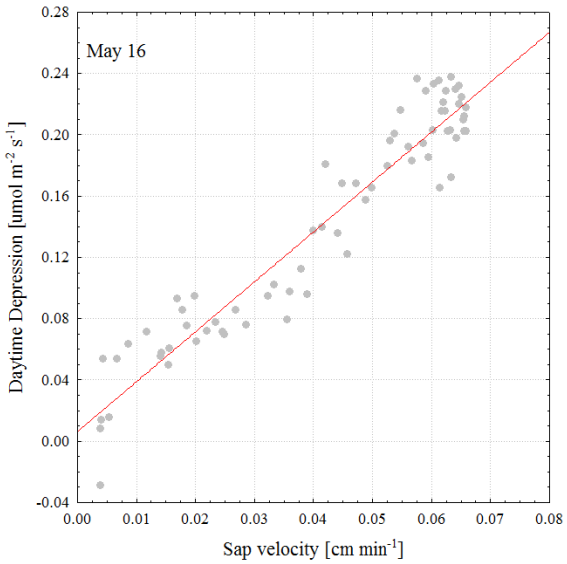

Figure 3: The dependence of the daytime depression on the sapflow rate for a clear day of May 16, 2009 at the CLM site. The points represents the daytime (06:00 to 18:00) 10-min measurements. The solid line is the linear regression curve.

In contrast with the clear days, the diurnal course of stem CO_2 efflux for the foggy days did not present any clear hysteresis pattern. Figure 4 shows an example of foggy day on May 24, 2009, with total fog duration amounted to 310 min. On this day, the daytime efflux-temperature relation did not depart much from that in the nighttime. It seems that only minor part of the respired CO_2 was transported upwards under the very low daytime average sapflow velocity of 0.026 cm min^{-1}. On the contrary, the average sapflow velocity on May 16, 2009 was 0.046 cm min^{-1}. The 77% higher sapflow velocity on that clear day has caused the daytime depression of the stem CO_2 efflux.

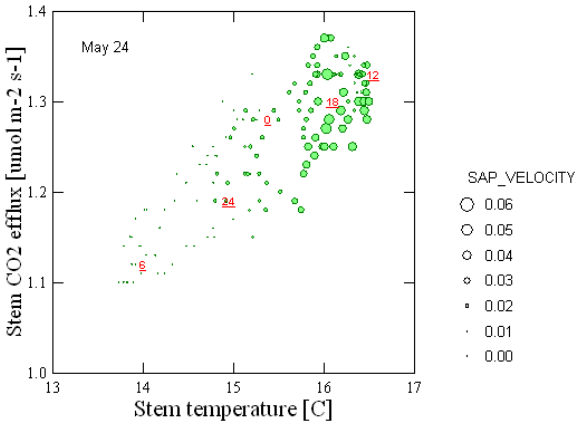

Figure 4: Dependence of stem CO_2 efflux on stem temperature in a foggy day (May 24, 2009). The underlined numbers indicate the time of the day. The size of the circles represents the rate of sapflow [cm min^{-1}].

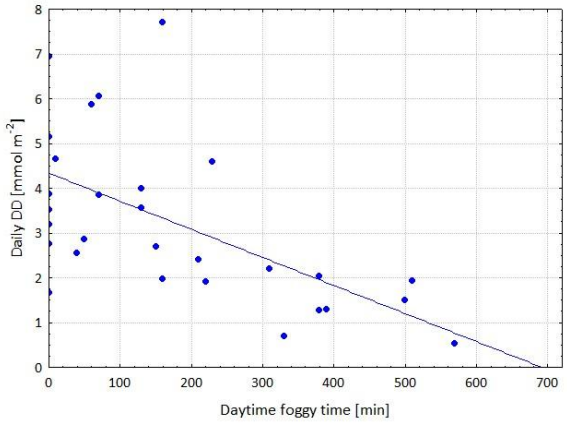

Figure 5: Relation between daily daytime depression (DD) and daily daytime foggy time in May 2009 at the CLM site. The solid line represents the linear regression curve.

To get more insight into the effect of foggy condition on the stem CO_2 efflux, the daily accumulated daytime depression was calculated for each day of May 2009. The daily DD ranged from 0.54 to 7.70 mmol C m^{-2} d^{-1}, with the low values being from the heavy foggy days (Figure 5). When the daily foggy time was longer than 300 min, the depression was up to 2 mmol C m^{-2} d^{-1}. However, in clearer days, the depression as well as the variation of depression got higher, indicating a more complicated control over the distribution of respired CO_2 in the stem.

The effects of foggy conditions on the stem CO_2 efflux measurement might have some ecological implications. The frequent occurrence of fog in the cloud forests, where the transpiration rates are low, might guarantee a less biased estimation of stem respiration by the chamber method. The measured stem CO_2 efflux might significantly underestimate the stem respiration rate of the living cells in the stem. As the case at the CLM site showed, in a clear condition the daytime total stem CO_2 efflux may represent only 85% of the stem respiratory CO_2. However, in a foggy day 99% of the CO_2 evolved from the respiration might diffuse out of the bark and be detected by the chamber system.

4. Conclusions

At the CLM site, the climatic condition might strongly influence the stem CO_2 efflux rate measured by chamber method. Under clear weather, the transpiratory water movement in the xylem reduced the amount of CO_2 efflux rate. Daily export of dissolved CO_2 might amount to 7.7 mmol C m^{-2} d^{-1}., or 15% of the total respired CO_2. On the contrary, in the foggy days the CO_2 efflux rate represented a significant part of the respired CO_2 in the stem.

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