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Study on the processing method of nighttime CO_2 eddy covariance flux data in ChinaFLUX

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Abstract At present, using Eddy Covariance (EC) method to estimate the "true value" of carbon sequestration in terrestrial ecosystem arrests more attention. However, one issue is how to solve the uncertainty of observations (especially the nighttime CO_2 flux data) appearing in post-processing CO_2 flux data. The ratio of effective and reliable nighttime EC CO_2 flux data to all nighttime data is relatively low (commonly, less than 50%) for all the long-term and continuous observation stations in the world. Thus, the processing method of nighttime CO_2 flux data and its effect analysis on estimating CO_2 flux annual sums are very important. In this paper, the authors analyze and discuss the reasons for underestimating nighttime CO_2 flux using EC method, and introduce the general theory and method for processing nighttime CO_2 flux data. By analyzing the relationship between nighttime CO_2 flux and air fraction velocity u_*, we present an alternate method, Average Values Test (AVT), to determine the thresholds of fraction velocity (u_{*c}) for screening the effective nighttime CO_2 flux data. Meanwhile, taking the data observed in Yucheng and Changbai Mountains stations for an example, we analyze and discuss the effects of different methods or parameters on nighttime CO_2 flux estimations. Finally, based on the data of part ChinaFLUX stations and related literatures, empirical models of nighttime respiration at different sites in ChinaFLUX are summarized.

Keywords: eddy covariance, nighttime CO_2 flux, data correction, ChinaFLUX.

Eddy Covariance (EC) is one of the best methods for measuring energy and mass exchange of terrestrial ecosystem and is applied widely in the world[1−4]. Even so, many errors and uncertainties still exist[5,6]. There are about 270 long-term and continuous observation stations in the world[7], none of which has really continuous observations. In general, the effective and reliable CO_2 flux data measured by eddy covariance (hereafter referred to as CO_2 flux or F_c) are about 65%−75% of all data[8]. Especially, the ratio of the effective and reliable nighttime CO_2 flux to all nighttime data is commonly less than 50%. Therefore, to calculate CO_2 exchange annual or monthly sums using EC method, we must correct error data and fill the missing observations rationally[9].

For a specific natural ecosystem, the efflux of CO_2 depends on the biomass such as microorganism, root, stalk and leaf, etc., and environmental factors, e.g. air and soil temperature and/or humidity[10−12]. Many researches show that the CO_2 flux measured in the daytime is reliable if the instruments work well and other necessary conditions are satisfied. However, during the nighttime, it becomes complicated and uncertain. Because of the relatively stable air stratification in the nighttime, EC sensors cannot measure the real CO_2 exchange on the surface, which induces a lot of questions. For example, during the nighttime, whether can the results observed by EC method at a relatively high place represent the real CO_2 exchange between the surface and atmosphere? How to assess the reliability of nighttime CO_2 flux data? How to correct error CO_2 flux data or how to fill the missing data? The objects of this study are: (i) to present a method for processing nighttime CO_2 flux data in ChinaFLUX; (ii) to determine the criterion of correcting nighttime CO_2 flux data; (iii) to analyze and discuss the effect of different methods or parameters on nighttime CO_2 flux estimations. In addition, by analyzing the relationship between nighttime CO_2 flux and air fraction velocity u_*, we attempt to present an alternate method, Average Values Test (AVT), for filtering the unreliable nighttime CO_2 flux data. Meanwhile, based on the data of part ChinaFLUX stations and related literatures, some empirical models for filling the missing data at different ChinaFLUX stations are summarized.

1 Processing method of nighttime CO_2 flux data

1.1 General course for processing nighttime CO_2 flux data

At present, there is no commonly accepted method to process nighttime CO_2 flux data[13]. However, there are some basic understandings. The basic method and steps can be described as follows: (1) assessing and controlling the quality of nighttime CO_2 flux data; (2) establishing statistical models using reliable nighttime CO_2 flux data and meteorological data, such as air and/or soil temperature and humidity; (3) correcting incorrect data or filling the gap data using the model above.

1.2 Quality controlling criterion of nighttime CO_2 flux data

In general, after necessary corrections were made for CO_2 flux data, e.g. coordinate rotation, WPL conversion[14], etc., there are still many errors in nighttime CO_2 flux data. Although at present there are no commonly accepted criterions for assessing and judging the reliability of the data, some basic understandings on this issue are accepted: (1) Negative nighttime CO_2 flux data must be deleted because of no photosynthesis during the nighttime; (2) even if the nighttime CO_2 flux is positive (respiration), it is still useless if the value exceeds the maximum respiration density of ecosystem; (3) fraction velocity u_* can be used as the main criterion of turbulence intensity, so only those nighttime CO_2 flux data with u_* higher than the threshold (u_{*c}) can be regarded as reliable data. The determination of u_{*c} often depends on the empirical approach. Usually, for short vegetation, such as farmland and grassland surface, u_{*c} is about 0.1−0.2 $m \cdot s^{-1}$, and for high vegetation, e.g. forest, it is about 0.2−0.4 $m \cdot s^{-1}$.

Gu[13] presented a method and developed a software called Moving Point Test (MPT) recently, which is completely based on the statistics and can automatically determine the fraction velocity thresholds (u_{*c}). The main ideas and methods are like that: In developing the MPT method, they recognized that both ecosystem respiration and u_* exhibit diurnal and seasonal cycles and there are potential correlative changes between them, which must be removed before u_* is used as a filter criterion. MPT applies an iterative approach to simultaneously determine a valid temperature response function, which is used to normalize nighttime flux measurements, and identify u_* thresholds based on the normalized fluxes. After the steps above, two small "windows" (in each "window", consecutive and quantitatively equated observations are selected according to the order of u_* from small to large or the reverse) will be selected simultaneously from the smallest u_* and the largest u_* and respectively moved to the middle if necessary. After that, by respectively comparing the average values of CO_2 flux in two moving "windows" (F_m) with the average of the remaining data among two "windows" (F_r) using statistical t-test, the discrepancy between F_m and F_r is obtained. If the discrepancy is statistically evident, the "window(s)" will be moved continuously to the middle according to the order of u_*, and the test will be done again until it is not statistically evident. And now two u_* thresholds, u_{*cL} (lower limit) and u_{*cH} (upper limit), are determined. The steps above are loops and iterative. In each step, the previously modeled data will replace the useless data, and they are used to establish a new model in the next loop. The MPT has methodological creation and has been recommended to AmeriFLUX now. It makes the determination of u_{*c} more objective and more consistent, and however, other problems on the nighttime CO_2 flux still exist.

Ohtani[15] presented a method for determining u_{*c} to process nighttime CO_2 data in Fuji Mountains flux station in Japan. First, different u_{*c} values are assumed, so different statistical models between the nighttime CO_2 flux and the soil temperature can be calculated. Then, flux estimations with 20℃ soil temperature can be obtained by using the developed models above. Finally, it is found that the nighttime CO_2 flux is the maximum when u_* is 0.2 $m\cdot s^{-1}$, so u_{*c} is set at 0.2 $m\cdot s^{-1}$.

1.3 *The choice of respiration models*

Once the effective data are screened, selecting a suitable statistical model is very important. Ecosystem respiration mainly depends on the biomass of soil and vegetation, and is dominated by environmental factors, such as air and/or soil temperature and humidity. Commonly, the response of ecosystem respiration to the temperature is described as exponential expression[16,17]. Now, the following three models are used widely. They are Van't Hoff model (eq. (1)), Arrhenius model (eq. (2)) and Lloyd & Taylor model (eq. (3)).

$$R_{eco} = R_{eco,ref}\, e^{B(T_K - T_{ref})}, \quad (1)$$

$$R_{eco} = R_{eco,ref}\, e^{\left\{\frac{E_a}{R}\left(\frac{1}{T_{ref}} - \frac{1}{T_k}\right)\right\}}, \quad (2)$$

$$R_{eco} = R_{eco,ref}\, e^{E_0\left(\frac{1}{T_{ref}-T_0} - \frac{1}{T_K - T_0}\right)}, \quad (3)$$

where $R_{eco,ref}$ is the ecosystem respiration at reference temperature (T_{ref}); B is a fitted site-specific parameter; T_K is temperature(K); E_a is the activation energy ($J\cdot mol^{-1}$), which is a fitted site-specific parameter; R is the gas constant (8.134 $J\cdot K^{-1}\cdot mol^{-1}$); E_0 is set at 309 K in practice; T_0 is a fitted temperature parameter (K).

The effect of soil water content on the ecosystem respiration is relatively complex. Here, as a methodological study, it is not taken into consideration.

2 Application of the processing method of nighttime CO_2 flux in ChinaFLUX

To date, there are 10 observation sites located in 8 ChinaFLUX stations. The surface types include farmland, forest and grassland. In this paper, two stations, Yucheng cropland station and Changbai Mountains forest station, are selected to perform the study. Some issues, such as the criterion for screening effective data (u_{*c} determining method), the choice of empirical models and research period determination, etc., will be discussed next.

2.1 *Sites and instrumentations*

Yucheng Comprehensive Experimental Station, the Chinese Academy of Sciences (CAS), is located in Shandong Province, China (36°57′N, 116°36′E, 28 m). The main vegetations are winter wheat and corn. The EC instruments are installed at 2 m height. Changbai Mountains Forest Ecosystem Research Station is located in the Changbai Mountains Nature Reserve in Jilin Province (42°24′9″N, 128°05′45″E, 761 m). The forest is dominated by matured Korea pine (*Pinus koriaensis*), Tuan linden (*Tilia amurensis*), Mono maple (*Acer mimo*), etc. Average canopy height is 26 m. The topography is flat and the EC instruments are mounted at 50 m height.

The instruments in the two stations are the same, including open-path eddy covariance system and other supporting observation instruments, which can measure air temperature and humidity, soil temperature and moist, radiations, and so on. The sampling frequency and averaging period of EC are 10 Hz and 30 min, respectively[18]. The WPL conversions for CO_2 and water fluxes are done online. In post-processing, the data will be corrected by using coordinate rotation[19,20].

2.2 *General flow for processing nighttime CO_2 flux data*

Fig. 1 is a flowchart for processing nighttime data of ChinaFLUX. The process is as follows: Firstly, based on the knowledge of some basic conditions of data to determine an appropriate research period, which is commonly about 3—6 mon; secondly, to determine the upper and lower limits of effective CO_2 flux data according to experiences or other methods,

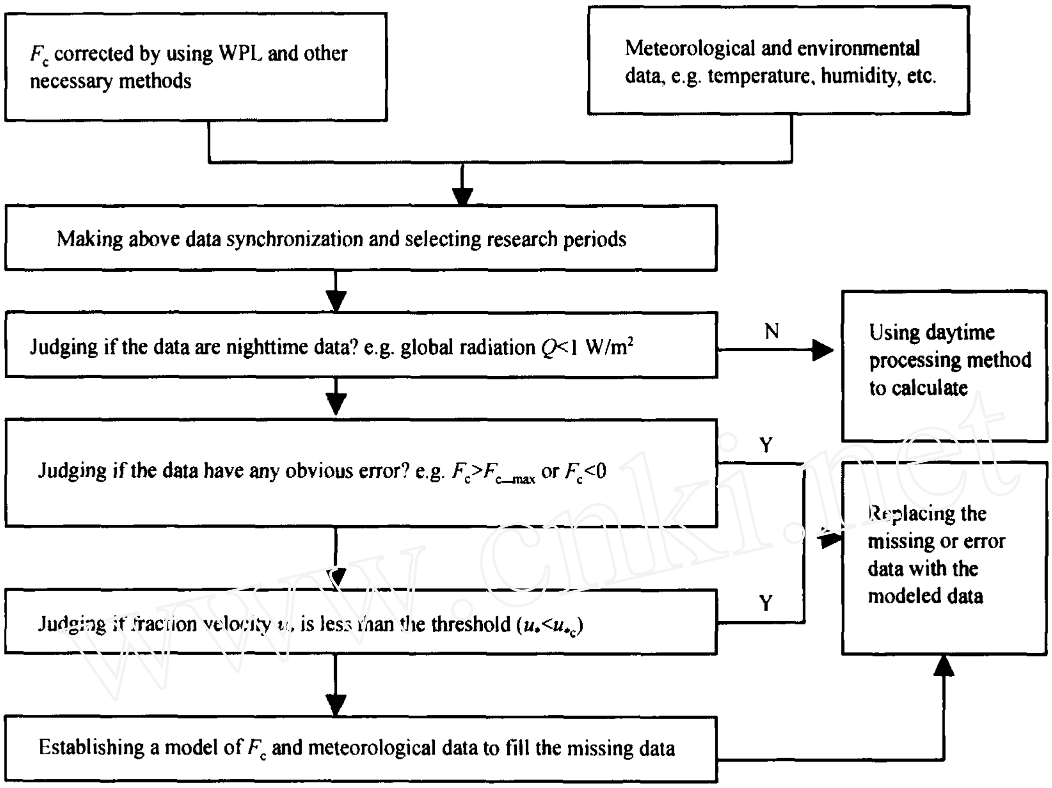

Fig. 1. Flowchart for processing nighttime CO_2 flux data in ChinaFLUX.

for example, the lower limit and upper limit of nighttime CO_2 flux can be defined as 0 and 0.6 $mg \cdot m^{-2} \cdot s^{-1}$, respectively; thirdly, to establish models using those effective CO_2 flux data and meteorological data; finally, to replace those incorrect and missing data with the modeled estimations above. Global radiation or local sunrise/sunset time can be used to divide all data into the daytime or nighttime data. The determination of u_{*c}, research periods and empirical models will be discussed in the following in detail.

2.3 The determination of u_{*c}

As far as the correction and filling of nighttime CO_2 flux are concerned, the most important issue is how to determine an appropriate fraction velocity threshold u_{*c}. The principle of determination is that the quality and quantity of effective data must be taken into account simultaneously. If u_{*c} is too small, though the quantity of sample is enough, many incorrect data will be regarded as effective data. In reverse, if u_{*c} is too large, the quantity of sample is too small to represent the real exchanges.

Although MPT is a very good method for determining u_{*c} because of the relative complexity, it is difficult for a general researcher to use. To simplify the determining method, we present an alternate method to determine u_{*c}, Average Values Test (AVT), which can also reduce the subjective effect of different researchers.

Lots of researches have shown that there is a positive statistical relationship between nighttime CO_2 flux and u_*, however, it is difficult to determine u_{*c} by only using the scatter plots of them. To solve this problem, the averages of CO_2 flux within different u_* ranges are calculated first. Fig. 2 demonstrates the change of nighttime CO_2 flux within different u_* ranges (F_{c1}, solid line with dots). It is obvious that in both of Yucheng and Changbai Mountains station, when u_* is in a relatively small zone, the change rates of F_{c1} with u_* are relatively large; while in a large zone, the relationship of them becomes weaker, even disappears.

If u_{*c} is determined only by using the change trend of F_{c1} with u_*, the result will still have uncertainties because of the difference of different data-analyzers' subjective judgment. To get more objective and appropriate u_{*c} and decrease the uncertainties resulting from subjective difference, we borrow the basic idea and method of MPT, and present a simplified and improved alternate method for determining u_{*c}. As shown in Fig. 2, the solid line with triangles (F_{c2}) is the accumulative re-average of those F_{c1} in which u_* is larger than the u_* at this point. This average line (F_{c2}) can demonstrate the total average of CO_2 flux in the station. There are two methods for determining u_{*c}: (1) Visual judgment. By looking into the change of two curves (F_{c1} and F_{c2}), when F_{c1} is close to F_{c2}, i.e. there are no evident differences between F_{c1} and F_{c2}, the u_* at this point can be regarded as u_{*c}. (2) Statistical t-test determination. First we can calculate the statistical variable T as the following equation:

$$T = \frac{|F_{c1} - F_{c2}|}{\sigma / \sqrt{n}}, \tag{4}$$

where σ and n are the standard error and the number of samples of F_{c1}, respectively. By looking up the statistical t-test table, t_α, related to n and the confidence level α, can be acquired. If $T< t_\alpha$, it means that there is no evident statistical difference between F_{c1} and F_{c2}. And then the u_* can be regarded as u_{*c}. As shown in Fig. 2, in Yucheng, when u_* changes in the range of 0 to 0.1 m·s^{-1}, F_c fast increases with the increase of u_*, which implies that u_* affects F_{c1} obviously. When u_* is in the range of 0.1—0.4 m·s^{-1}, the change of F_{c1} with u_* is not as obvious as the above. In Changbai Mountains, when u_* is less than 0.24 m·s^{-1}, F_c increases obviously with u_*, and when u_* is in 0.24—0.4 m·s^{-1}, the relation of them is weak. According to the principle of u_{*c} determination and referring to the changes of two curves in Fig. 2, it is appropriate that u_{*c} is determined at 0.15 m·s^{-1} in Yucheng and 0.25 m·s^{-1} in Changbai Mountains, respectively.

2.4 Determination of research periods

The main factors influencing ecosystem respiration are different in different seasons or locations. During the growing season, the respiration is dominated by vegetations in general. And in the non-growing season, it results from the microorganism and litter. Fig. 3 plots the relationship between the screened nighttime CO_2 flux (0< F_c <0.5 mg·m^{-2}·s^{-1}, u_*>0.15 m·s^{-1}) and the soil temperature at 5 cm depth (T_{s5}) as well as the regression model in Yucheng. Fig. 3(a) presents the relations for all year of 2003, and Fig. 3(b) shows it just in the wheat growing season (March—May, 2003). Obviously, the relationship between them in the growing season, as shown in Fig. 3(b), is better than that in all year of 2003. During the maize growing season (in summer), the temperature is high, which maybe is not the main limiting factor, so the relationship of them is not clear. It means that the temperature is not the unique factor to influence the ecosystem respiration. Having analyzed the relationship between nighttime respiration and soil temperature, Guan[21] calculated the regression models based on the data

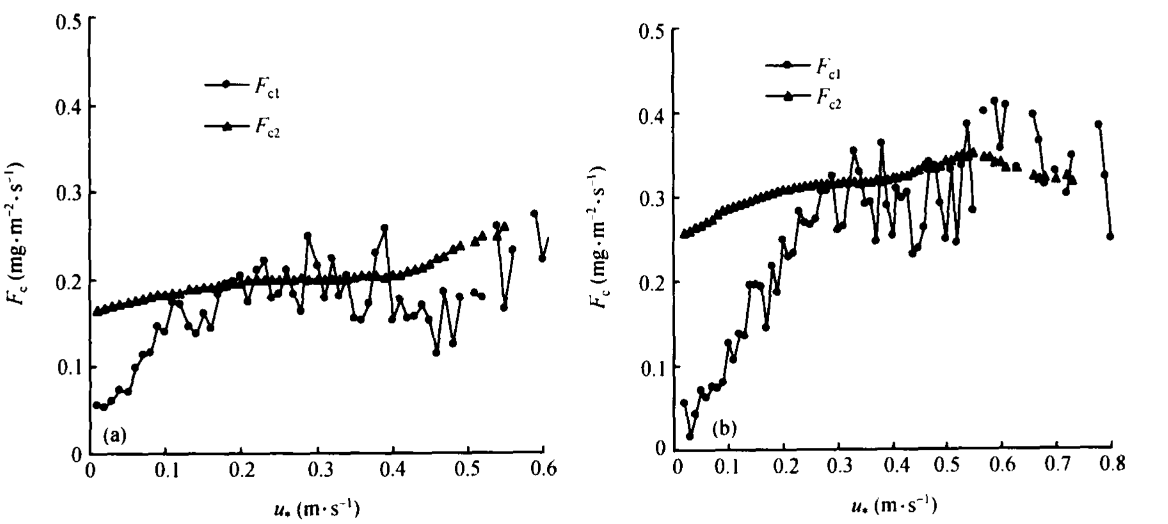

Fig. 2. The relationship between the average of nighttime CO_2 flux (F_c) and fraction velocity (u_*). (a) Yucheng; (b) Changbai Mountains.

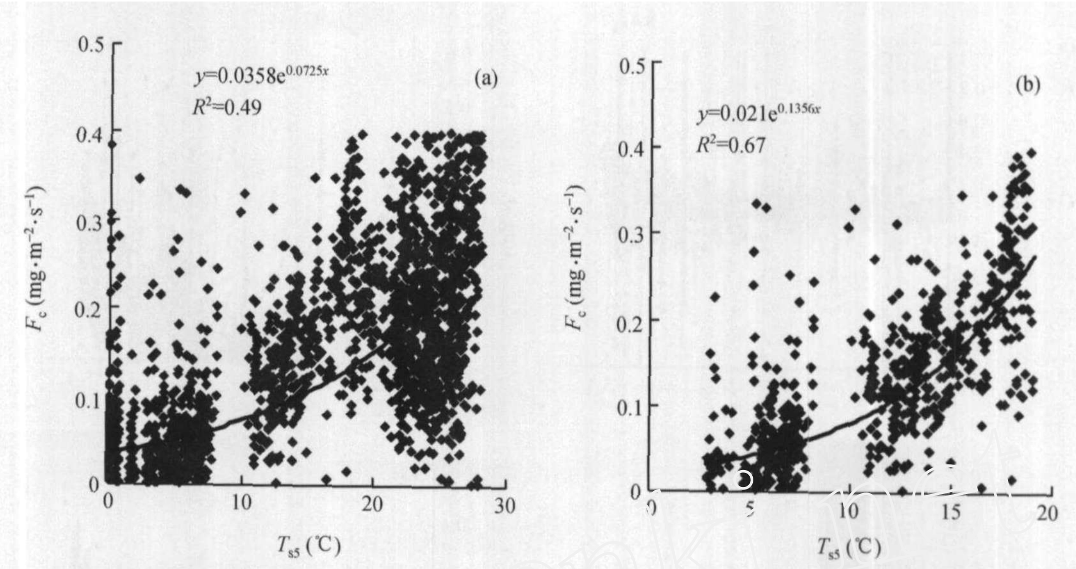

Fig. 3. The relationship between nighttime CO_2 flux and 5-cm soil temperature in Yucheng. (a) All year in 2003; (b) wheat growing season (March—May in 2003).

before or after July, 2003 in Changbai Mountains, respectively. So in order to upgrade the accuracy of estimations, it is necessary to establish different models during different seasons.

2.5 *Choice of empirical models*

Although different models' expressions are different, there are no differences in nature. The relationship between respiration and temperature is expressed as exponential, but the selected temperature parameters are different in different models. For example, some models use air temperature[22,23] and some use soil temperature[24,25]. The best criterion for judging their applicabilities is the correlation coefficient. Having analyzed the relation of nighttime respiration with different soil temperatures and air temperatures, Yu[10] educed that the regression models of respiration with air temperature in Qianyanzhou station, and with soil temperature in Changbai Mountains station, are the best. Using the method and observed data in Yucheng, we calculated different kinds of models (Table 1). As a whole, in Yucheng, the relationship of respiration with soil temperature is better than that with air temperature, and the Lloyd & Taylor model is the most suitable. In Table 1, the models acquired in other ChinaFLUX stations were collected. Some models were calculated by using Chamber method data[26−28], and some were gotten by using EC method.

2.6 *Case study of nighttime CO_2 flux correction*

Fig. 4 shows the nighttime CO_2 flux results after different correcting steps in Jan. — Apr., 2003 in Yucheng. Fig. 4(a) shows the uncorrected nighttime CO_2 flux changes with different dates. It can be seen that there are a lot of spikes and obviously incorrect nighttime CO_2 flux data. For example, some F_c data are negative, and some are too big and exceed the rational range even though they are positive. All these data must be corrected. Fig. 4(b) shows the data processed by using the empirical lower and upper limits filter of F_c (in Yucheng, the lower limit and upper limit of F_c are 0.0 and 0.6 $mg \cdot m^{-2} \cdot s^{-1}$, respectively), namely, those F_c are maintained within the range of the lower limit and upper limit of F_c. Fig. 4(c) demonstrates the data after the u_* filter. The u_{*c} of Yucheng is 0.15 $m \cdot s^{-1}$ here, which implies that those data when $u_* < 0.15$ $m \cdot s^{-1}$ are omitted. Although most data are rational, there are still lots of incorrect data. Fig. 4(d) presents the data changes with date after all correcting and filling steps. Those data passing the above filters are regarded as effective data, and they will be used for establishing the model. The remaining data, which do not pass the filters, will be replaced with modeled estimations. The empirical model calculated by using the above effective data is

$$F_c = 0.0133e^{0.1765T_s}, \tag{5}$$

where T_s is soil temperature at 5 cm depth (℃). After

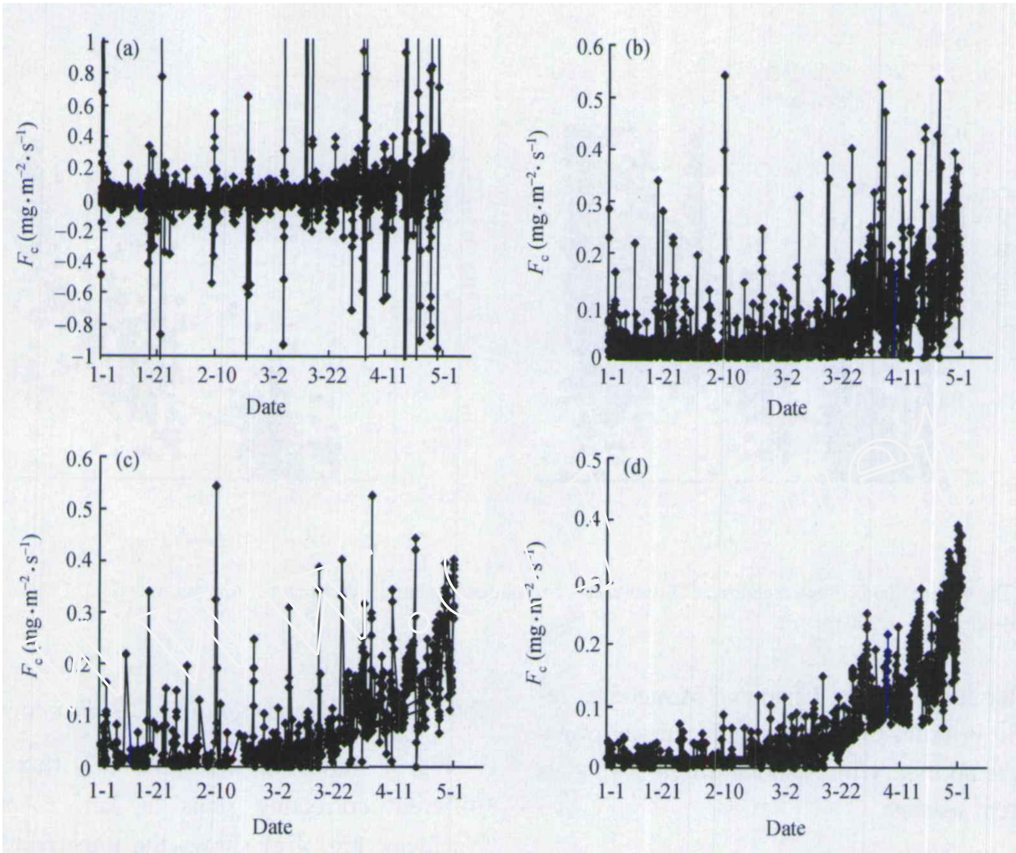

Fig. 4. The comparisons of nighttime CO_2 flux data after different correcting steps (data from Jan.—Apr., 2003, Yucheng). (a) Uncorrected data; (b) data passing F_c filter ($0.0 < F_c < 0.6$ mg·m^{-2}·s^{-1}); (c) data passing u_* filter (u_{*c} = 0.15 m·s^{-1}); (d) data after all correcting and filling steps.

these correcting and filling steps, several spikes still exist. Finally, the running-average method is used for deleting the spikes, and the corrected data are rational obviously.

3 Discussion

Nighttime CO_2 flux plays an important role in estimating regional carbon balance. Massman and Lee[5] analyzed the theoretical and practical causes for underestimating nighttime CO_2 flux using EC method. One results from the instruments and another is caused by the surrounding environment and meteorological conditions. Here, taking the data in two stations for an example, we will analyze the percentage of effective nighttime CO_2 flux and the effect of different u_{*c} on nighttime CO_2 flux estimations.

3.1 The percentage of effective nighttime CO_2 flux

By analyzing the frequency distribution of nighttime u_*, the ratio of effective nighttime CO_2 flux data to all nighttime data at different u_{*c} can be determined. Fig. 5 presents the frequency distribution of nighttime u_* at different ranges (bar) and the ratio of effective data (line) in Yucheng and Changbai Mountains stations. With the increase of u_{*c}, the ratio decreases. For example, in Yucheng, if u_{*c}=0.15 m·s^{-1}, about 50% of nighttime CO_2 flux data are unreliable. Meanwhile, even if $u_* > 0.15$ m·s^{-1}, some F_c data are still incorrect. So less than half nighttime CO_2 flux data must be replaced with the modeled estimations. In Changbai Mountains station, if u_{*c} = 0.25 m·s^{-1}, about 60% of nighttime CO_2 flux data must be corrected or filled.

3.2 Effect analysis of different u_{*c} on the estimations of nighttime CO_2 flux

Nighttime CO_2 flux will be separated into effective and ineffective data by using u_{*c}. Different u_{*c} will result in different nighttime CO_2 flux estimations. Fig. 6 shows the changes of nighttime CO_2 flux average F_c (Fig. 6(a)), and the correction coefficient of Van't Hoff model (Fig. 6(b)) with different u_{*c}. In Yucheng, when u_{*c} changes from 0 to 0.1 m·s^{-1}, the average of night-

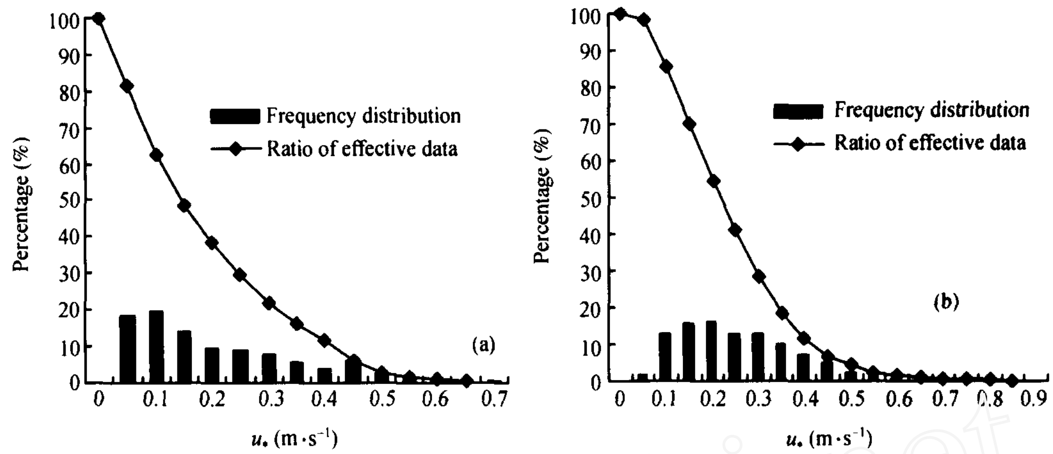

Fig. 5. The frequency distribution of nighttime u_* (bar) and the ratio of effective data (line). (a) Yucheng; (b) Changbai Mountains.

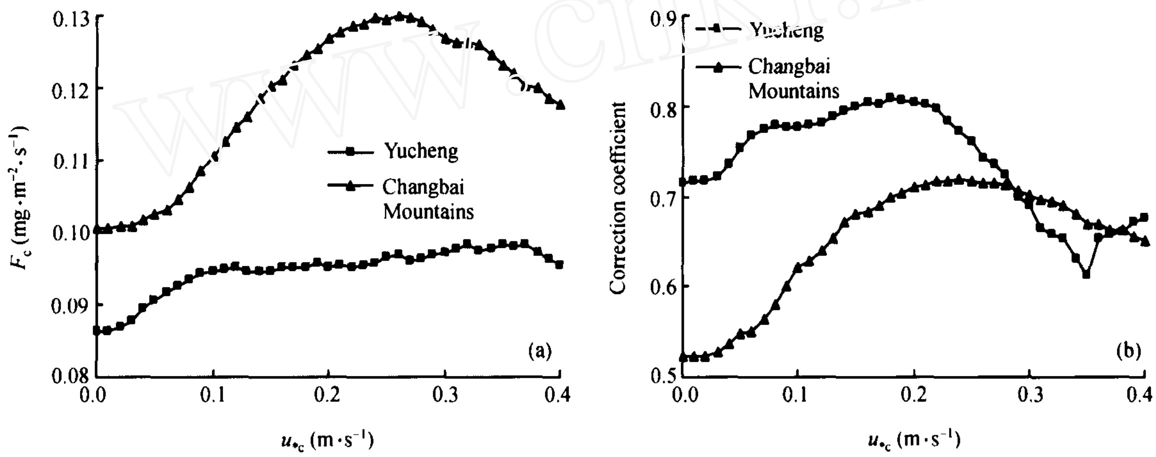

Fig. 6. The changes of nighttime CO_2 flux F_c average (a) and the correction coefficient of Van't Hoff model (b) with u_{*c}.

time F_c changes obviously, and then, it changes gently. When u_{*c} is more than 0.35 m·s^{-1}, the nighttime F_c presents a descent trend and most of F_c estimations are the modeled data, which is because that the observation is too small to represent the real ecosystem respiration. In Changbai Mountains, when u_{*c} changes from 0 to 0.25 m·s^{-1}, the average of nighttime F_c increases quickly, and reaches the maximum at u_{*c} = 0.26 m·s^{-1}, and then it also presents a descent trend. In addition, the changes of correction coefficient of model with u_{*c}, as shown in Fig. 6(b), can be also used to demonstrate the effect of different u_{*c} on nighttime CO_2 flux estimations. For example, in Yucheng, with the changes of u_{*c} from 0 to 0.1 m·s^{-1}, the ineffective data will decrease gradually, and so the correction coefficient of model increases gradually. When u_{*c} changes from 0.1 to 0.2 m·s^{-1}, the coefficient varies gently. It means that there are no obvious differences if u_{*c} changes in this range. In Changbai Mountains, the correction coefficient is less than that in Yucheng, but the changes trend and pattern are similar with that in Yucheng. When u_{*c} is given at about 0.25 m·s^{-1}, the coefficient reaches the maximum. Summarizing all analysis above, we conclude that u_{*c} is determined at 0.15 m·s^{-1} in Yucheng and 0.25 m·s^{-1} in Changbai Mountains, and meanwhile, the minimum of u_{*c} should not be less than 0.1 m·s^{-1} in Yucheng and 0.2 m·s^{-1} in Changbai Mountains.

3.3 The relationship between EC and other methods

Because there are large uncertainties on the nighttime CO_2 eddy flux, especially, when the errors of some data are very big and difficult to correct, it is necessary to correct further using other methods, if possible. For example, the chamber method is a good choice, which has advantage for measuring ecosystem

Table 1 The relationship between ecosystem respiration and temperature in ChinaFLUX

Station	Equation types	Temperature kind	$R_{eco,ref}$ (283.16 K)	$B/E_a/T_0$	R^2	Main author	Mark
Yucheng	Van't Hoff model	2-m air temp.	0.0635	0.095	0.73	Zhu, this paper	Yucheng, 2003
		5-cm soil temp.	0.0521	0.108	0.74		
	Arrhenius model	2-m air temp.	0.0657	63700	0.70		
		5-cm soil temp.	0.0531	73869	0.74		
	Lloyd & Taylor model	2-m air temp.	0.0737	224.5	0.72		
		5-cm soil temp.	0.0593	231.8	0.75		
Changbai Mountains	Van't Hoff model	2.5-m air temp.	0.163	0.091	0.69	Yu[10]	Changbai Mt. EC data, 2003
		5-cm soil temp.	0.153	0.123	0.84		
	Arrhenius model	2.5-m air temp.	0.165	61490	0.70		
		5-cm soil temp.	0.155	82610	0.84		
	Lloyd & Taylor model	2.5-m air temp.	0.170	226.4	0.71		
		5-cm soil temp.	0.164	233.8	0.85		
Qianyanzhou	Van't Hoff model	1.6-m air temp.	0.08[illegible]	0.055	0.69	Yu[10]	Qianyanzhou EC and meteo. data
		5-cm soil temp.	0.089	0.055	0.60		
	Arrhenius model	1.6-m air temp.	0.084	39670	0.70		
		5-cm soil temp.	0.088	39570	0.61		
	Lloyd & Taylor model	1.6-m air temp.	0.079	219.2	0.71		
		5-cm soil temp.	0.083	219.0	0.62		
Dinghu Mountains[a)]	Van't Hoff model	5-cm soil temp.	16.647	0.1176	0.90	Zhou[26]	needle-broad leaved mixed forest
		5-cm soil temp.	19.912	0.0906	0.77		
Xishuangbanna[a)]	Van't Hoff model	5-cm soil tem.	94.355	0.0171	0.77	Sha[27]	tropical seasonal rain forest
		5-cm soil temp.	93.3	0.0859	0.80		
Tibetan Plateau[a)]	Van't Hoff model	soil surface temp.	17.759	0.0475	0.70	Zhang[28]	alpine grassland
		5-cm soil temp.	15.132	0.0819	0.61		

a) Data were measured by chamber method (unit: $mg \cdot m^{-2} \cdot h^{-1}$).

respiration of some special surfaces, such as cropland, grassland and soil in forest floor. Using the chamber observations, the relationship model between ecosystem respiration and meteorological factors can be obtained. The chamber results can be used to validate or correct the CO_2 eddy flux. In Table 1, a number of models obtained by using chamber data in part ChinaFLUX stations are summarized.

To calculate the forest ecosystem CO_2 flux during a short period (less than 24 h), the store within forest canopy must be taken into account[8,29,30]. Because of weak air exchange between upper and lower level within dense and high forest, the CO_2 flux released by soil respiration on the floor is difficult to conduct into the EC sensors. Thus, CO_2 flux of forest ecosystem will be underestimated if the store change within forest is not taken into account. Because of the limitations of data and methodological research, the store change of forest in Changbai Mountains is not counted in this paper temporarily, but it must be considered in real calculation.

4 Summaries

Based on the analysis and discussion above, some preliminary conclusions can be summarized as follows.

(1) As a whole, the nighttime CO_2 flux is underestimated by eddy covariance method. Strictly assessing and controlling the quality of nighttime CO_2 flux data are necessary.

(2) The general correcting method can be simply illustrated as follows: first, to filter those incorrect data by using the thresholds of nighttime respiration and

friction velocity; then to establish a empirical model using screened CO_2 flux data and meteorological data; finally, to replace the incorrect data or to fill the missing data (gap) with the modeled estimations above.

(3) Friction velocity u_* is the main criterion for judging the quality of nighttime CO_2 flux data. In this paper, we presented an alternate method, Average Values test (AVT), to determine u_{*c} for screening the effective nighttime CO_2 flux data. In Yucheng, u_{*c} = 0.15 m·s^{-1} is appropriate, and in Changbai Mountains, u_{*c} = 0.25 m·s^{-1} is suitable. Meanwhile, the minimum of u_{*c} should not be less than 0.1 m·s^{-1} in Yucheng and 0.2 m·s^{-1} in Changbai Mountains.

(4) In practice, to upgrade the accuracy of nighttime CO_2 estimations, rational research periods and suitable model types are important too. For example, different crops or different growing seasons should use different models. The correction coefficient of model can be used to judge the model's applicability.

(5) If possible, the respiration of cropland, grassland and soil in forest floor can be measured by Chamber method. The result should be used to compare, validate and correct the observations of EC method. For a short period (less than 24 h) study of forest respiration, the changes of CO_2 store with forest canopy must be taken into account.

In a word, the processing method of nighttime CO_2 flux is still in exploring, and up to date, there is no widely accepted method. The method presented in this study can be used as reference to processing nighttime CO_2 eddy covariance flux data in ChinaFLUX station.

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