IMPROVEMENT OF CO₂ EDDY FLUXES MODELLING IN TOPOGRAPHICALLY COMPLEX TERRAIN

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Abstract

Annual sums of net ecosystem exchange (NEE) estimated by eddy covariance method (EC) are often used for comparisons among sites. But application of EC in topographically complex terrain restrains application of standard methods for their estimation. Analysis of friction air velocity response of night-time CO₂ fluxes and estimation of mean daily ecosystem respiration from daytime NEE showed that night-time data and fluxes measured early after sunrise or late before sunset are not sufficiently reliable for computation of accurate annual sums of NEE. Therefore presented method takes into account auxiliary soil chamber measurements and applies correction factor in ecosystem respiration model calibrated to biomass inventory results. Also automated algorithm for computation of light response curve parameters in constrained range was established. This method produced accurate annual sums of NEE that were only 7.2% ± 5.2 higher than values determined by biomass inventory method.

Keywords: *eddy covariance; u* threshold; gap-filling; flux partitioning; complex terrain.*

Introduction

Eddy covariance method (EC) is one of the most accurate and direct approaches for measurements of fluxes of matter and energy on the level of whole ecosystem. CO₂ fluxes data acquired using the global network of EC flux towers help us to better understand the impacts of natural and anthropogenic phenomena on the global carbon balance.

Comparisons among different sites are usually performed on annual sums of net ecosystem exchange (NEE). However, the average data coverage during a year is only 65% due to system failures or data rejection [1.]. Often used approach for removing fluxes measured during nights with insufficient turbulent conditions (characterised by low friction wind velocity; u^*) is u^*-filtering [2.]. The need of robust and consistent gap filling method for the global network resulted in creation of application (CarboEurope-IP database, http://www.bgc-jena.mpg.de/bgc-mdi/html/eddyproc/) for computing annual sums of NEE based mainly on methodology described in [2.].

Nowadays, the EC is also used in complex terrains on the edge of its applicability (e.g. hills, cities) such as at our experimental site Bílý Kříž (basic information about the complicated air flow in topographically complex terrain can be found e.g. in [3.]). This requires revisiting of generally applied algorithms for computation of annual sums of NEE (CarboEurope-IP application strongly underestimates ecosystem respiration; R_{eco}).

As night-time fluxes are not often reliable, auxiliary measurements are taken into account. Soil chamber measurements can give us information about soil respiration (R_{soil}) component of R_{eco}. However, R_{soil} to R_{eco} ratio strongly differs for different ecosystems and it changes with age of a stand and even during the year [4.]. Soil respiration component is the largest of all R_{eco} components and R_{soil} to R_{eco} ratio can range from 48% [4.] to 71% [5.]. Other method, biomass

inventory method, applies allometric equations to estimate annual carbon sequestration [6.] and allows comparison with annual sum of NEE.

During previous years common approach for estimation of annual sum of NEE was application of one model equation for NEE consisting of two components with parameters set for individual day. First one accounts for soil temperature response of R_{eco} (Arrhenius type function) and second one describes photosynthetically active radiation (PAR) response of gross primary production (GPP) – light response curve (LRC). Parameters of Arrhenius type function were expertly estimated with regards to soil chamber measurements of soil respiration during growing season. LRC parameters were set manually for each day by iterative least-squares fitting using Solver tool of Microsoft Excel application.

This approach suffered from high degree of subjectivity and retrospective comparison of annual sums of NEE with biomass inventory did not show good relationship. The aim of this study was therefore setting standardised algorithm for computation of accurate annual sums of NEE when compared to biomass inventory using soil chamber measurements. Also analysis of reliability of night-time CO_2 fluxes in context to computed u^* threshold was performed.

Material and methods

The u^*-threshold was derived specifically for each site using a 95% threshold criterion similar to [2.]: for the u^*-filtering, the data set is split into six temperature classes of sample size (according to quantiles) and for each temperature class, the set is split into 20 u^*-classes. The threshold is defined as the u^*-class where the night-time flux reaches more than 95% of the average flux at the higher u^*-classes. The threshold is only accepted if for the temperature class, temperature and u^* are not or only weakly correlated ($|r| < 0.4$). The final threshold is defined as the median of the thresholds of the (up to) six temperature classes. This procedure is applied to the subsets of four 3-month periods to account for seasonal variation of vegetation structure. For each period, the u^*-threshold is reported, but the whole data set is filtered according to the highest threshold found (conservative approach). In cases where no u^*-threshold could be found, it is set to 0.4 m s^{-1}. A minimum threshold is set to 0.1 m s^{-1}. Night-time data with the best quality (flag 0) were selected according to PAR threshold of 5 μmol m^{-2} s^{-1}, and defined as R_{eco}. The range of number of values in u^* classes for years 2009–2011 was 7–13.

R_{eco} and gross primary production (GPP) are simultaneously modelled as parts of one model equation. This equation can be separated into two parts. Light response curve and Arrhenius type respiration function. Physiological parameters of these functions are set for each day during the year using only fluxes with quality flag 0.

Equation for light response curve [7.] with convexity parameter fixed to 0.00002 (dimensionless) describes response of GPP to PAR:

$$NEE = \frac{\alpha \cdot PAR + GPP_{max} - \sqrt{(\alpha \cdot PAR + GPP_{max})^2 - 4 \cdot \alpha \cdot 0.00002 \cdot GPP_{max} \cdot PAR}}{2 \cdot 0.00002 \cdot (-1)} + R_{eco},$$

where α is apparent quantum yield at low irradiances, GPP_{max} is the asymptotic maximum assimilation rate or optimum gross primary production under high light level. R_{eco} in the equation is used for interconnection with Arrhenius type R_{eco} model [8., 9.]:

$$NEE = R_{10} \cdot Q_{10}^{\frac{T - T_{10}}{10}} + GPP,$$

where R_{10} is the R_{eco} at reference temperature 10 °C (T_{10}), Q_{10} determines change in respiration rate resulting from a 10 °C increase in temperature T.

In addition to these functions other type of light response curve [10.] was used for estimation of mean daytime R_{eco}:

$$NEE = 2 \cdot GPP_{max} \cdot \left(0.5 - \frac{1}{1 + \exp\left(\dfrac{-2 \cdot \alpha \cdot PAR}{GPP_{max}} \right)} \right) + R_{eco}.$$

Different methods for R_{eco} and GPP separation from NEE were used but only the method with the lowest difference of annual sums of NEE and annual carbon sequestration estimated by biomass inventory method for years 2009–2011 is presented. R_{10} and Q_{10} values were computed for each day when soil chamber measurements were available (Dařenová, unpublished results). R_{10} and Q_{10} for each day of the rest of year were computed with R software for 60 to 90 days window. On the base of our data analysis a correction factor (1.6) was determined and applied for all R_{10} values. Iterative least-squares fitting using Solver tool of Microsoft Excel application for setting GPPmax and α values was automated for whole year with constraining conditions GPPmax < 100, α > 0.009 and α < 0.1. GPPmax was set to zero for days with unlikely photosynthesis (little difference between day/night fluxes, lower than zero soil and air temperature, low PAR).

Results and discussion
When using u^*-filtering it is typical to find rather stable night-time CO_2 fluxes at particular temperature class at u^* higher than u^* threshold. In 2011 we observed high value of u^* threshold (1.04 m s^{-1}) caused by unrealistically high CO_2 fluxes at high u^* classes. This overestimation of fluxes could be caused by complicated air flow observed at our site during nights ([11.], personal communication) resulting in summing fluxes from different directions. On the other hand, during years 2009 and 2010 fluxes were almost even in all u^* classes of each temperature class resulting in low value of u^* threshold (0.37 and 0.30 m s^{-1}, respectively). The mean night CO_2 flux was unrealistically low (1.89 and 1.98 µmol(CO_2) m^{-2} s^{-1}, respectively) during these years probably due to missed CO_2-exchange (possible catabatic or drainage flow) but mean night CO_2 flux was even lower in the year 2011 (1.86 µmol(CO_2) m^{-2} s^{-1}). Therefore simple application of u^*-filtering is not acceptable and it can lead to underestimation of night CO_2 fluxes (years 2009 and 2010) or to removing most of the CO_2 flux data and overestimation of night R_{eco} (year 2011).

To estimate mean daytime respiration from daytime NEE by modeling CO_2 fluxes was used Antje Mofat equation [10.]. However, produced values of daytime respiration were low or even negative (indicating assimilation). Mean daytime respiration is computed as y-intercept from LRC. As the slope of the linear part of LRC is affected mainly by close to zero irradiance fluxes, correct estimation of mean daytime R_{eco} requires reliable eddy flux measurements during transition from night conditions with low turbulence to daytime conditions with fully developed turbulence. Therefore low or even negative mean daytime values of R_{eco} indicate that CO_2 fluxes measured at our eddy covariance tower early after sunrise or late before sunset are not reliably reflecting physiological processes in the ecosystem.

For simplification of algorithm for GPP and R_{eco} separation the same correction factor of 1.6 was used both for soil chamber and EC based computation of R_{10} values. Multiplicator of 1.6 for R_{10} derived from chamber measurement can be interpreted as R_{soil} component is accounting for only 62.5% of R_{eco}. This result is within the middle of acceptable range [5.]. The estimation of missed CO_2-exchange on days when chamber measurement is not performed is very difficult.

Multiplicator of 1.6 for R_{10} derived from EC data suppose 37.5% of missed CO_2-exchange. Constraining conditions for GPPmax and α were set in physiologically accepted range. This algorithm resulted in very good relationship of annual sums of NEE (years 2009–2011) with biomass inventory method with only slightly higher values in average (107.2% ± 5.2).

Conclusion

The analysis of night-time CO_2 fluxes response to u^* showed that application of u^*-filtering is not appropriate for our site and its simple application does not yield reliable data. Estimation of mean daytime respiration from daytime NEE showed that data measured early after sunrise or late before sunset are not reliably reflecting physiological processes in the ecosystem. Therefore night-time fluxes were replaced by model for soil temperature response of R_{eco}. R_{10} and Q_{10} parameters of this model were derived from chamber measurements during the growing season and from EC data in the rest of year. All R_{10} values were multiplied by correction factor 1.6 accounting for the R_{soil} to R_{eco} ratio and missed CO_2-exchange. Automated algorithm for computation of LRC parameters in constrained range was established. This method produced accurate annual sums of NEE that were only 7.2% ± 5.2 higher than values determined by biomass inventory method. The creation of complex respiration model, assembling of look-up table for gap-filling longer periods of missing data and the correction for storage effects will be needed in the future.

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Abstrakt

Pro porovnání mezi různými stanicemi se často využívá ročních sum čisté ekosystémové výměny (NEE) stanovených eddy kovarianční metodou (EC). Avšak aplikace EC v topograficky složitém terénu zamezuje použití standardních metod pro jejich stanovení. Analýza závislosti nočních toků CO_2 na frikční rychlosti vzduchu a stanovení průměrné denní ekosystémové respirace z denní NEE ukázala, že v noci měřená data a toky měřené brzy po východu slunce nebo před jeho západem nejsou dostatečně spolehlivé pro přesný výpočet ročních sum NEE. Prezentovaná metoda tudíž bere v úvahu doplňková měření půdními komorami a zavádí v modelu ekosystémové respirace korekční faktor kalibrovaný na základě výsledků inventarizace biomasy. Dále byl sestaven automatizovaný algoritmus pro výpočet parametrů světelné křivky fotosyntézy v omezeném rozpětí. Touto metodou byly získány přesnější roční sumy NEE, které dosahovaly pouze o 7,2 % ± 5,2 vyšších hodnot než hodnoty určené metodou inventarizace biomasy.