ESTIMATING LANDSCAPE-LEVEL CARBON FLUXES FROM TOWER CO_2 MIXING RATIO DATA

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ABSTRACT
Variations of the CO_2 mixing ratio in the atmosphere near the surface result from several processes, including photosynthesis and respiration of the underlying ecosystems, vertical mixing near the surface and in the planetary boundary layer (PBL), and entrainment of air above the PBL. We developed a novel approach for isolating ecosystem metabolism signals at the landscape scale (10^2-10^4 km^2) in an hourly CO_2 record using a vertical diffusion scheme coupled with an ecosystem model.

INTRODUCTION

Carbon balance estimates at global and continental scales have been much improved through atmospheric inverse modeling. Many efforts are also made to interpret and predict the role of terrestrial ecosystems in the global carbon balance. Ecosystem functioning and its effects on the carbon cycle have been much better understood through collecting and analyzing energy and CO_2 fluxes made at local sites using eddy covariance (EC) measurement techniques. These progresses are achieved at the extreme ends of the spatial scale spectrum, either large regions/continents or small vegetation stands. Continuous CO_2 mixing ratio data collected at tall towers are influenced by the land surface metabolism and by fast and efficient mixing in the atmosphere at the landscape level, an intermediate scale of great interest to upscaling from stands to regions. The focus of this present study is to extract ecosystem flux components, such as the gross primary productivity (GPP), from the diurnal variation pattern of the CO_2 mixing ratio. Based on our early work on simulating hourly CO_2 mixing ratios through combining an ecosystem model with a vertical diffusion scheme (VDS) [*Chen et al.*, 2004], we developed a methodology that allows the estimation of daily fluxes from hourly concentration measurements near Fraserdale, Canada [*Chen et al.*, 2005]. Concentration-derived flux information represents footprint areas of up to 10^5 km^2, which are several orders of magnitude larger than the direct flux measurements using the EC technique.

METHODOLOGY

As the air CO_2 mixing ratio at a given height is determined by both the surface metabolism and atmospheric mixing processes, it would be possible to isolate the signals for the metabolism if the atmospheric diffusion is accurately modeled. However, to ensure a reasonable accuracy in modeling the diffusion processes, we first need to simulate the variability of the CO_2 mixing ratio to a satisfactory accuracy. This requires that both the ecosystem metabolism and atmospheric diffusion are well simulated. The methodology of retrieving gross primary productivity (GPP) signal from the CO_2 diurnal variation is demonstrated in Fig. 1, where the simulated hourly CO_2 concentration at 30 m was compared with the observation on the Wisconsin tower. It must be realized that to mimic the diurnal variation in the CO_2 mixing ratio, both diffusion and metabolism have to be simulated with reasonable accuracies. The good agreement between modeled and measured results indicates that the diffusion is well simulated day and night. We then, in the model, turn off the gross primary productivity, i.e., setting GPP=0 without changing the ecosystem respiration (ER*)*, and simulate the evolution of the CO_2 mixing ratio with time from sunrise to sunset. The curve with GPP=0 gradually departs from the observed curve, and stays at a certain level during the well mixed hours because of the large capacity of the mixed layer and then increases in the late afternoon when respiration exceeds photosynthesis. The mean difference between the curve with GPP=0 and the observed curve is then entirely due to GPP, or the accumulated hourly difference is proportional to the daily total GPP, if other processes (diffusion and respiration) are simulated accurately. In this way, the signal due to daytime photosynthesis is extracted from the CO_2 record. The main advantage of this methodology over the first order estimation, *i.e.,* tuning GPP to match the CO_2 record, is that it involves no assumption of horizontal homogeneity or directional variability because the GPP signal extracted this way is the true GPP in the footprint area, however spatially variable and wherever may it be.

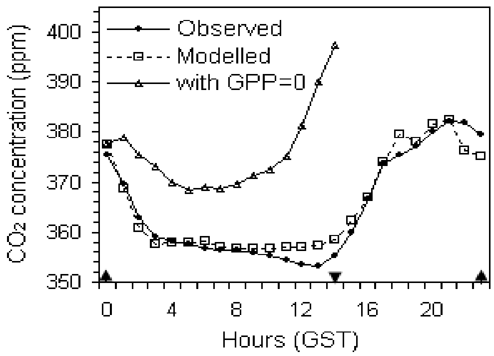

Fig. 1. A demonstration of the methodology for extracting GPP information from the diurnal pattern. Measured and modeled CO_2 mixing ratios at 30 m above the ground at the Wisconsin tall tower, July 26, 2001(GST) are compared. Also shown is the modeled CO_2 mixing ratio with GPP=0 at daytime. Triangles indicate the times of sunrise and sunset; GST is 6 hours ahead of local time.

RESULTS AND DISCUSSION

The methodology shown in Fig. 1 was tested at the Wisconsin tall tower. Concentration-derived daily GPP values are correlated with those derived from the eddy covariance (EC) measurements at the same heights, r^2 being 0.67, 0.51 and 0.51 at 30 m, 122 m, and 396 m, respectively. When averaged for 10-day periods, the corresponding r^2 values are 0.92, 0.85 and 0.84 because the impacts of synoptic variations are greatly reduced. At 30 m, the concentration-derived GPP is larger than EC-derived GPP by about 21%. The typical footprint area of EC measurements is about 1 km^2, while the footprint area for concentration measurements is of the order of 10^4-10^5 km^2. Because the tower is located in the middle of a grassy patch of about 180 m in radius, it is expected that this grassy area had a lower productivity than the surrounding forested areas, making EC-derived GPP smaller than the concentration-derived GPP. Concentration-derived carbon flux information can therefore be useful for upscaling from flux towers to the landscape around the tower, an intermediate scale critical to scaling from site to region.

The methodology has been applied to a 12-year (1990-1996, 1998-2003), hourly CO_2 record measured at 40 m at Fraserdale, Canada. The CO_2 record at Fraserdale was well simulated (r^2 equals 0.70 and 0.87 at hourly and daily time steps, respectively). The annual means of concentration-derived daily GPP were found to be more sensitive to air temperature than total ecosystem respiration, leading to larger sinks in warmer years during the 12-year period [*Chen et al.,* 2005]. Through BEPS simulations, it was found that faster net nutrient mineralization at higher temperatures was likely the reason for GPP being more sensitive to temperature than ecosystem respiration. This sensitivity difference represents the average conditions of boreal ecosystems around the tower consisting of conifer and deciduous forests of various ages, wetlands, grasslands as well as small fractions of recently burned and harvested areas. According to analysis of the mean CO_2 concentration measured at the tower against the CO_2 free troposphere global matrix based on marine boundary measurements, we found that the depletion atmospheric CO_2 was larger in warm years than in cold years, supporting the temperature sensitivity difference between GPP and ER. Unbiased extraction of GPP from the CO_2 record is essential for the finding of this temperature sensitivity difference.

REFERENCES

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