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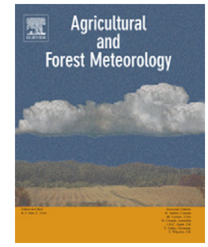

Cross-site evaluation of eddy covariance GPP and RE decomposition techniques

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ARTICLE INFO

Article history:
Received 27 July 2007
Received in revised form
14 November 2007
Accepted 23 November 2007

Keywords:
Eddy correlation
Carbon balance
Net ecosystem exchange
GPP
RE

ABSTRACT

Eddy covariance flux towers measure net exchange of land–atmosphere flux. For the flux of carbon dioxide, this net ecosystem exchange (NEE) is governed by two processes, gross primary production (GPP) and a sum of autotrophic and heterotrophic respiration components known as ecosystem respiration (RE). A number of statistical flux-partitioning methods, often developed to fill missing NEE data, can also be used to estimate GPP and RE from NEE time series. Here we present results of the first comprehensive, multi-site comparison of these partitioning methods. An initial test was performed with a subset of methods in retrieving GPP and RE from NEE generated by an ecosystem model, which was also degraded with realistic noise. All methods produced GPP and RE estimates that were highly correlated with the synthetic data at the daily and annual timescales, but most were biased low, including a parameter inversion of the original model. We then applied 23 different methods to 10 site years of temperate forest flux data, including 10 different artificial gap scenarios (10% removal of observations), in order to investigate the effects of partitioning method choice, data gaps, and intersite variability on estimated GPP and RE. Most methods differed by less than 10% in estimates of both GPP and RE. Gaps added an additional 6–7% variability, but did not result in additional bias. ANOVA showed that most methods were consistent in identifying differences in GPP and RE across sites, leading to increased confidence in previously published multi-site comparisons and syntheses. Several methods produced outliers at some sites, and some methods were systematically biased against the ensemble

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doi:10.1016/j.agrformet.2007.11.012

mean. Larger model spread was found for Mediterranean sites compared to temperate or boreal sites. For both real and synthetic data, high variability was found in modeling of the diurnal RE cycle, suggesting that additional study of diurnal RE mechanisms could help to improve partitioning algorithms.

1. Introduction

The terrestrial component of the global carbon cycle can be divided in two large and opposing terms, both of which represent aggregated ecosystem processes: gross primary production (GPP) and total ecosystem respiration (RE). The order of magnitude smaller imbalance between these two fluxes, termed net ecosystem exchange (NEE), is considered to be the primary source of observed interannual variability in atmospheric accumulation of carbon dioxide (CO_2) (Peylin et al., 2005). Furthermore, understanding how plant and soil processes impact this interannual variability requires quantifying GPP and RE. However, it is currently not possible to obtain direct, integrated observations of either GPP or RE, because these processes represent a multitude of responses by a combination of autotrophic and heterotrophic organisms. Scaling from chamber level measurements to canopy level is labor intensive and fraught with high sampling uncertainty.

The eddy covariance (EC) technique is the well-established method to directly measure flux and NEE over a fetch larger than typical plot level measurements (Baldocchi, 2003). Gaps in NEE time series are inevitable due to operational and micrometeorological constraints. Numerous methods have been developed to fill the gaps due to observational and micrometeorological constraints, and many of these also decompose NEE into GPP and RE (Falge et al., 2001). In most of the methods, errors in estimation of RE offset errors in GPP, so gap filling of NEE by modeling GPP and RE has been largely successful (Moffat et al., 2007).

Methods to partition NEE to its component fluxes, GPP and RE, have also been developed independent of gap-filling techniques as a way to assess carbon pathways in ecosystems. At present, there is no standard method commonly in use (Reichstein et al., 2005; Stoy et al., 2006). While many partitioning methods typically rely on the concept of zero GPP at night and strong correlation of GPP and RE to environmental driving variables, such as temperature, water availability and solar radiation (Law et al., 2002), newer techniques, such as neural networks, which have few underlying assumptions regarding these relationships, have been developed and are evaluated here. We also investigated process-based ecosystem model inversion and advanced data assimilation techniques which have only recently been developed.

Despite advances in NEE partitioning, direct evaluation of GPP and RE estimates has been scant. Previous studies have tested multiple methods at a few sites (Stoy et al., 2006) or a few methods at many sites (Falge et al., 2001; Law et al., 2002; Richardson et al., 2006a; Reichstein et al., 2005). Analyzing NEE time series from a boreal transition forest, Hagen et al. (2006) reported that GPP estimates for a given year could vary by over 100 g C m^{-2} depending on the partitioning algorithm (neural network vs. physiologically based) and fitting method (maximum likelihood vs. ordinary least squares) used. Evaluation of GPP and RE at multiple sites with multiple methods has not been performed. There is great interest in performing cross-site comparison of GPP and RE. Without an evaluation of GPP and RE methods across a range of sites, investigator-reported values of GPP and RE for individual sites cannot be reasonably used to compare values across multiple sites because it is not known how the partitioning method employed may affect the result.

The goal of this article is not to discuss mechanistic evaluation of GPP and RE. To do this requires independent flux observations from chambers, biometry, and models or inversions, each of which is subject to its own set of errors and uncertainties. Instead, our focus is on assessing the role of model selection and data gaps on variability in GPP and RE estimates derived from NEE time series. To accomplish this assessment, we evaluated 23 different partitioning methods, using 10 site years of CO_2 flux data. These data, originally compiled for a gap-filling intercomparison (Moffat et al., 2007), come primarily from temperate forests sites in Europe. Though not all kinds of ecosystems are tested, the sites chosen span a reasonable range of variability seen in flux tower time series.

Questions motivating this research are

1. What is the inherent variability in estimated GPP and RE for any single site as a function of method, and what does this imply for giving uncertainty bounds on GPP and RE values from any one method?
2. Is within site variability of derived GPP and RE as a function of partitioning method smaller than typical interannual variability in GPP and RE (~10% of 100 gC m^{-2} $year^{-1}$, Richardson et al., 2007)?
3. Are some methods more sensitive to data gaps than others in terms of mean variability? Do gaps induce any systematic biases?
4. Does choice of partitioning method alter understanding of differences in seasonal and diurnal variability of GPP and RE, or cross-site rankings of annual sums of these component fluxes? Are certain methods systematically biased across the sites with respect to the ensemble mean of GPP or RE?

Though independent evaluation of GPP and RE is not performed here, a preliminary test of method fidelity can be done by testing against synthetic data (Stauch and Jarvis, 2006). Prior to comparison of methods against observed data, we investigated whether methods could accurately estimate GPP and RE from NEE generated by a reasonably complex, complete and well-tested ecosystem model, BETHY (Knorr and Kattge, 2005). To further simulate observation conditions,