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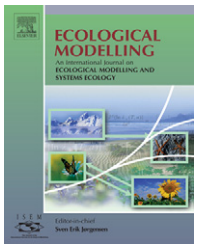

# Modification of an ecosystem model for filling medium-sized gaps in tower-based estimates of net ecosystem productivity

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ABSTRACT

Gap filling of flux data is necessary to assist with periodic interruptions in the measurement data stream. The gap-filling model (GFM), first described in Xing et al. [Xing, Z., Bourque, C.P.-A., Meng, F.-R., Zha, T.-S., Cox, R.M., Swift, E., 2007. A simple net ecosystem productivity model for gap filling of tower-based fluxes: an extension of Landsberg's equation with modifications to the light interception term. Ecol. Model. 206, 250–262], was modified to account for the day-to-day control of net ecosystem productivity (NEP) by incorporating air and soil temperature as new controlling variables in the calculation of NEP. To account for the multiple-phase influences of air and soil temperature on plant growth we model ecosystem respiration as a function of soil and canopy respiration. The paper presents model development in an incremental fashion in order to quantify the contribution of individual model enhancements to the prediction of NEP during periods when air and soil temperature variations are important.

Model efficiency (ME) was used to compare the performance of the various forms of the GFM under several combinations of weather conditions during a 34-day period. Results from model comparisons illustrated that the models displayed reasonable performance (ME = 0.75–0.95), with the final GFM displaying the best overall performance. Further evaluation of the final GFM was conducted by comparing the NEP-model results with results generated with an alternative gap-filling approach espoused by Fluxnet-Canada Research Network (FCRN). These evaluations are based on the same 34-day dataset as used in the initial model comparison. Both gap-filling methodologies performed well, but some level of disagreement was present.

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## 1. Introduction

Gaps (due to data missing or rejected for quality reasons) in eddy covariance-based measurements are common. These gaps potentially bias calculations of NEP, as in other flux-based variables such as sensible and latent heat. Data gaps need to be filled in order to derive annual sums or to simply analyze temporal trends in the data. In previous work, Xing et al. (2007) developed a gap-filling model (GFM) that takes into account the non-uniform influence of available photosynthetically active radiation (typically with a response time of a few minutes to hours) within stratified plant canopies to improve the quality of gap filling. However, air and soil temperature, which tend to vary at a lower frequency also have their influence on NEP (with a response time of a few hours to a day). To properly model gaps in NEP data lasting more than a few hours to a day, temperature influences on NEP need addressing.

Controversy exists as to the degree temperature controls net ecosystem productivity (NEP). Chen et al. (2002) found that air temperature had no significant influence on NEP in old-growth forests, but demonstrated greater influence in younger forests. Bassow and Bazzaz (1998) suggested that air temperature explained approximately 12% of the photosynthetic variation in red oak (*Quercus rubra* L.), 16% in yellow birch (*Betula alleghaniensis* Britt), and to a lower degree in white birch (*Betula papyrifera*). They also found that air temperature was only weakly correlated with photosynthesis during the summer, but had a higher correlation in September for many tree species. After a thorough review of 27 scientific articles on this subject, Saxe et al. (2001) concluded that high temperatures increased the rate of carbon dioxide ($CO_2$) absorption to an optimum, but the extent of this increase depended on ambient temperatures. Air temperatures higher than optimum tend to cause a reduction in $CO_2$ uptake.

As Bassow and Bazzaz's (1998) path analysis[1] indicated, air temperature may impact photosynthesis in both direct and indirect ways. Temperature has been shown to directly affect photosynthesis by affecting (i) photosynthetic chemical reactions, (ii) photochemical efficiency of PSII,[2] and (iii) photo-inhibition. Temperature may indirectly affect photosynthesis by altering (i) pigment content in leaves, (ii) apparent quantum yields, and (iii) respiration rates, by modifying secondary environmental-growth controls, such as water vapor pressure deficit (VPD), nutrient availability, and associated bio-geochemical interactions in soils. This dependence on temperature is well documented (e.g., McMurtrie and Wang, 1993; Hollinger et al., 1999; Cai and Dang, 2002; Leuning, 2002), although mechanisms for this dependence may vary from time to time depending on prevailing meteorological and site conditions.

Grant et al. (2005) found that high air temperatures adversely affected NEP in temperate and boreal coniferous forests by increasing respiration. Model results generated by Grant et al. (2001) predicted that black spruce forests in the boreal region of Canada would change from a $CO_2$ sink to a $CO_2$ source with an increase in daily minimum and maximum temperatures above 15 and 25 °C, respectively. Above-average temperatures in British Columbia in 1998 were found to increase annual respiration in temperate coastal Douglas fir forests, which caused a reduction in annual NEP (Morgenstern et al., 2004). Temperature influences on regional estimates of NEP also depend on in situ conditions, such as forest species composition, stand age, and interannual climate variation.

Currently, there are two ways to incorporate air temperature effects in NEP models. One way is to use temperature as a modifier of stomatal conductance either at the canopy or the leaf level (Jarvis and McNaughton, 1986; Leuning, 1995). The second way is to use air temperature as a modifier of maximum quantum efficiencies and related parameters (Farquhar, 1980; Harley and Baldocchi, 1995; Leuning et al., 1998; Chen et al., 1999; Caemmerer, 2000). Traditionally, the modifier is treated as an Arrhenius function—a polynomial function of air temperature. This function has been broadly used in ecosystem models such as *ecosys* (Grant, 2004), CLASS (Verseghy, 1991, 2000; Verseghy et al., 1991), and ecological assimilation of climate and land observation (EALCO). However, as Grant et al. (2005) point out, the Arrhenius function performs "too gradually" in some cases, or "too abruptly" in others, because the function cannot be easily adjusted to account for the effects of other key environmental controls.

In relation to assessing NEP, ecosystem respiration is often problematic because of the difficulty and uncertainty associated with its determination. Soil respiration, a significant component of ecosystem respiration, is critical to nighttime NEP (Zha et al., 2007). Although soil respiration is highly regulated by soil temperature (Lloyd and Taylor, 1994; Gu et al., 1999; Coleman et al., 2002; Lavigne, 2003), recent modelling and experimental investigations by Liu and Edwards (2006) have identified several non-soil temperature controls on soil respiration (e.g., soil water content and soil texture). Lavigne (2003) demonstrated that the $Q_{10}$[3] parameter may vary with year, soil temperature category, and weather zonation; most likely as an outcome of variations in these non-soil temperature controls.

Soil temperature is considered as an important variable in soil bio-geochemical processes (Kimmins, 1987) as temperature controls (i) the activity of roots and soil organisms, (ii) rates of decomposition, and (iii) nutrient uptake and release and subsequently controls the amount of $CO_2$ produced in soils by autotrophic and heterotrophic processes. However, the transportation of $CO_2$ gas in soils is very much regulated by the surface condition of the soil complex and prevailing weather conditions. For example, heavy rain may cause pooling of water over the soil complex effectively blocking the release

[1] Path analysis is a method of "decomposing and interpreting linear relationships among a set of variables by assuming that (1) a weak causal order among these variables is known and (2) the relationships among these variables are causally closed". Path analysis may be viewed as "a method of working out the logical consequences" of these two assumptions.

[2] PSII = photosystem II, which absorbs a shorter wavelength of light (680 nm).

[3] $Q_{10} = e^{10B(1/T/T_{opt})}$, defines the respiration rate for a 10 °C increase in temperature and serves as a parameter in the soil respiration function, $SR = R_{10}Q_{10}^{(T-T_{opt})/T_{opt}}$, where $R_{10}$ is an equation parameter, $T$ is soil temperature, and $T_{opt}$ is a reference temperature.

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