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A new model of gross primary productivity for North American ecosystems based solely on the enhanced vegetation index and land surface temperature from MODIS

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Abstract

Many current models of ecosystem carbon exchange based on remote sensing, such as the MODIS product termed MOD17, still require considerable input from ground based meteorological measurements and look up tables based on vegetation type. Since these data are often not available at the same spatial scale as the remote sensing imagery, they can introduce substantial errors into the carbon exchange estimates. Here we present further development of a gross primary production (GPP) model based entirely on remote sensing data. In contrast to an earlier model

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based only on the enhanced vegetation index (EVI), this model, termed the *T*emperature and *G*reenness (TG) model, also includes the land surface temperature (LST) product from MODIS. In addition to its obvious relationship to vegetation temperature, LST was correlated with vapor pressure deficit and photosynthetically active radiation. Combination of EVI and LST in the model substantially improved the correlation between predicted and measured GPP at 11 eddy correlation flux towers in a wide range of vegetation types across North America. In many cases, the TG model provided substantially better predictions of GPP than did the MODIS GPP product. However, both models resulted in poor predictions for sparse shrub habitats where solar angle effects on remote sensing indices were large. Although it may be possible to improve the MODIS GPP product through improved parameterization, our results suggest that simpler models based entirely on remote sensing can provide equally good predictions of GPP.

Keywords: Gross photosynthesis; GPP; Carbon modeling; Eddy covariance; Flux tower; Surface temperature

1. Introduction

The MODIS product termed MOD17 (Running et al., 2004) is one of the primary sources of remote sensing based gross primary productivity (GPP) estimates at the global scale. It provides an 8-day mean GPP at 1 km spatial resolution for the entire vegetated land surface. However, several recent studies have highlighted limitations of this model (Heinsch et al., 2006; Turner et al., 2003, 2005; Yuan et al., 2007; Zhao et al., 2006). The most serious limitation arises from the uncertainties of coarse resolution DAO meteorological reanalysis data used in MOD17 (Heinsch et al., 2006; Zhao et al., 2006). MOD17 also depends on estimates of light use efficiency (LUE) obtained from lookup tables based on vegetation type, which may contain errors either in the original estimate of LUE for a particular vegetation type or in the assignment of vegetation type to a pixel.

Although it may be possible to correct problems with the current version of MOD17 by improving the accuracy of the meteorological and other data inputs, it is also worthwhile to explore alternative methods for estimation of global GPP that may not require so many inputs. The simplest possible model would be a direct correlation between GPP and greenness indices such as the normalized difference vegetation index (NDVI) or the enhanced vegetation index (EVI). Sims et al. (2006b) demonstrated that this simpler model, using EVI alone, could provide estimates of GPP that were as good as or better than MOD17 for many sites during the period of active photosynthesis. This result was possible because of correlations between LUE and EVI that made an independent estimate of LUE unnecessary, as well as the elimination of short-term fluctuations in solar radiation and other environmental parameters by the 16-day averaging period. Changes in vegetation greenness would not be expected to be rapid enough to allow this simple relationship to hold over short time periods of hours to days, but EVI did show significant variation from one 16-day period to the next.

However, this simplest model, based entirely on EVI, does have its limitations. It provided no means for estimating the timing of the photosynthetic inactive period for sites with strongly evergreen vegetation. It also resulted in poor active season GPP estimates for sites subject to summer drought or with strongly evergreen vegetation. Since the inactive periods were mostly the result of low temperatures, and summer drought periods are characterized by high temperatures and vapor pressure deficits (VPD), it is clear that incorporating some measure of temperature and drought stress might improve the model. This is consistent with the MOD17 model, where temperature and VPD were chosen as the two scalars directly modifying LUE (Running et al., 2004).

Consequently, our objective in this study was to add temperature and drought stress information to the simple model, while keeping the model based entirely on remotely sensed variables without any ground based meteorological inputs. The land surface temperature (LST, Wan et al., 2004) product from MODIS can potentially be used both as a measure of temperature and VPD (Hashimoto et al., in press). Combined data from the Terra and Aqua satellites provide LST values 4 times a day; in late morning and early afternoon and twice during the night as well. LST is, strictly speaking, a measure of surface or “skin” temperature, rather than air temperature, which is more commonly used in physiological studies. However, since physiological activities of leaves are likely to be more closely related to their actual temperature, rather than air temperature, LST should be a useful measure of physiological activity of the top canopy leaves, provided that leaf cover is great enough that LST is not significantly affected by soil surface temperature. LST has also been shown to be closely related to VPD (Granger, 2000; Hashimoto et al., in press) and thus may provide a measure of drought stress. We explored the relationship between LST and various meteorological variables that are important determinates of carbon flux and developed a simple model (the *T*emperature and *G*reenness model or “TG model”) for estimation of GPP. By including LST in addition to EVI, the TG model avoids many of the limitations present in the simpler model using EVI alone.

2. Methods

2.1. Study sites

The eddy covariance tower flux data came from the same 9 AmeriFlux tower sites used previously (Sims et al., 2006b) plus two additional deciduous forest sites (Michigan and Willow Creek) (Table 1). These sites represent a wide diversity of natural vegetation across North America (see