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Evaluation of MODIS NPP and GPP products across multiple biomes

David P. Turner [a,*], William D. Ritts [a], Warren B. Cohen [b], Stith T. Gower [c], Steve W. Running [d], Maosheng Zhao [d], Marcos H. Costa [e], Al A. Kirschbaum [a], Jay M. Ham [f], Scott R. Saleska [g], Douglas E. Ahl [c]

[a] *Department of Forest Science, Oregon State University, Corvallis OR 97331, United States*
[b] *USDA Forest Service, 3200 SW Jefferson Way, Corvallis OR 97331, United States*
[c] *Department of Forest Ecology and Management, University of Wisconsin, Madison WN 53706, United States*
[d] *School of Forestry, University of Montana, Missoula MT 59812, United States*
[e] *Department of Agriculture and Environmental Engineering, University Federal Vicosa, Vicosa, MG 36570, Brazil*
[f] *Department of Agronomy, Kansas State University, Manhattan KS 66506, United States*
[g] *Department of Earth and Planetary Sciences, Harvard University, Newton MA 02160, United States*

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Abstract

Estimates of daily gross primary production (GPP) and annual net primary production (NPP) at the 1 km spatial resolution are now produced operationally for the global terrestrial surface using imagery from the MODIS (Moderate Resolution Imaging Spectroradiometer) sensor. Ecosystem-level measurements of GPP at eddy covariance flux towers and plot-level measurements of NPP over the surrounding landscape offer opportunities for validating the MODIS NPP and GPP products, but these flux measurements must be scaled over areas on the order of 25 km^2 to make effective comparisons to the MODIS products. Here, we report results for such comparisons at 9 sites varying widely in biome type and land use. The sites included arctic tundra, boreal forest, temperate hardwood forest, temperate conifer forest, tropical rain forest, tallgrass prairie, desert grassland, and cropland. The ground-based NPP and GPP surfaces were generated by application of the Biome-BGC carbon cycle process model in a spatially-distributed mode. Model inputs of land cover and leaf area index were derived from Landsat data. The MODIS NPP and GPP products showed no overall bias. They tended to be overestimates at low productivity sites — often because of artificially high values of MODIS FPAR (fraction of photosynthetically active radiation absorbed by the canopy), a critical input to the MODIS GPP algorithm. In contrast, the MODIS products tended to be underestimates in high productivity sites — often a function of relatively low values for vegetation light use efficiency in the MODIS GPP algorithm. A global network of sites where both NPP and GPP are measured and scaled over the local landscape is needed to more comprehensively validate the MODIS NPP and GPP products and to potentially calibrate the MODIS NPP/GPP algorithm parameters.

Keywords: MODIS; Landsat; Net primary production; Gross primary production; Biomes; Validation; Global; Monitoring

1. Introduction

A standard suite of global products characterizing vegetation cover, leaf area index, gross primary production (GPP), and net primary production (NPP) at the 1 km spatial resolution is now being produced operationally based on observations from the MODIS (Moderate Resolution Imaging Spectroradiometer) sensor (Justice et al., 2002; Running et al., 2004). The GPP product has an 8-day temporal resolution and is intended for monitoring seasonal and spatial patterns in photosynthetic activity. MODIS NPP is an annual value and provides a means of evaluating spatial patterns in productivity as well as interannual variation and long term trends in biosphere behavior (e.g. driven by climate variation or change, Nemani et al., 2003). Validation of these products is an essential step in establishing their utility; however, validation is challenging because of a variety of scaling issues (Morisette et al., 2002; Turner et al., 2004). These issues include matching the 1-km resolution of the MODIS products with plot-scale measurements on the ground

* Corresponding author. Tel.: +1 541 737 5043; fax: +1 541 737 1393.
E-mail address: david.turner@oregonstate.edu (D.P. Turner).

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(Cohen et al., 2003a; Turner et al., 2003a, 2004, 2005). The BigFoot Project (2005) was designed to address many of these scaling issues, and here we report on comparisons of BigFoot and MODIS-based GPP and NPP at 9 sites representing a range of biome types.

Validation of the MODIS GPP product has generally taken the form of time series comparisons between GPP estimated from eddy covariance flux tower data and GPP from MODIS for one or more 1-km^2 cells surrounding the tower (Heinsch et al., in press; Turner et al., 2003a, 2005; Xiao et al., 2004). These studies have found a wide range of site-specific agreement or disagreement between the ground-based and MODIS-based GPP estimates. Specific causes of over- or underprediction of GPP in the MODIS product have been traced to MODIS GPP algorithm inputs, including the climate input data, the FPAR (fraction of incoming photosynthetically active radiation that is absorbed by the canopy), and the base rate for light use efficiency. Site-level validation of MODIS NPP has been more limited because of the logistical constraints of measuring NPP and scaling it to the size of a MODIS grid cell (Turner et al., 2004, 2005). These efforts have likewise found site-specific differences in the degree of agreement between ground-based and MODIS-based NPP estimates. The MODIS NPP algorithm requires the computation of autotrophic respiration (R_a) based on inputs of leaf area index (LAI) and temperature, along with look-up table values for allometric constants and the base rate of respiration (Running et al. 2000). Specific problems with the R_a component of NPP have been identified in some cases (Turner et al., 2005).

This paper will present NPP/GPP validation results from the complete set of BigFoot sites. Biome types include boreal forest, temperate coniferous forest, temperate hardwood forest, and tropical moist forest, as well as arctic tundra, temperate grassland, desert grassland, and agricultural fields. A virtue of the BigFoot approach is that a common NPP/GPP scaling protocol based on Landsat data was employed across these widely divergent sites, thus increasing the possibilities for analysis of cross-site patterns. One value of taking a synoptic view of MODIS product performance is that it may reveal possible biases that could be addressed in future releases of the MODIS products or in the design of planned follow-up projects associated with Earth System monitoring.

2. Methods

2.1. Overview

At each of the nine BigFoot sites, digital maps (25 km^2) of land cover, LAI, daily GPP, and annual NPP were developed for one or more years using a combination of imagery from the Landsat Enhanced Thematic Mapper+ (ETM+) sensor and ground measurements (LAI, NPP, GPP). The scaling approach for NPP and GPP was based on spatially-distributed application of a carbon cycle process model (Biome-BGC) over a 25 m grid covering the study area. An eddy covariance flux tower was maintained at each site and it provided meteorological data for input to Biome-BGC and estimates of GPP for comparison with BigFoot GPP. The BigFoot NPP and GPP products were aggregated spatially (i.e. averaging across 25 m cells) to match the 1-km resolution of the MODIS products. GPP was also aggregated temporally to 8-day averages to match the temporal resolution of the MODIS GPP products. Earlier BigFoot papers covered the BigFoot NPP/GPP protocols and site-specific BigFoot/MODIS comparisons (Turner et al., 2003a, 2005, in press). Results at the individual sites (Table 1) are available from the Oak Ridge National Laboratory Distributed Data Archive Center (ORNL, 2005). A file for each site contains the information and comparisons in Table 2.

2.2. MODIS NPP/GPP products

The MODIS NPP/GPP algorithm is described in Running et al. (2004) and Heinsch et al. (2003). A simple light use efficiency model (MOD17) is at the core of the GPP component of the algorithm and it requires daily inputs of incoming

Table 1
Location, vegetation type, climate descriptors, and related publication for the 9 BigFoot sites

Code	Vegetation	Location	Precipitation[a] (cm)	MAT[b] (°C)	Related publication
NOBS	Boreal forest	Lat: 55.885260 Lon: −98.477268	52	−3.2	Goulden et al., 1997
HARV	Hardwood forest	Lat: 42.528513 Lon: −72.172907	11	8.3	Wofsy et al., 1993
CHEQ	Mixed forest	Lat: 45.945404 Lon: −90.272475	75	5.3	Davis et al., 2003
METL	Conifer forest	Lat: 44.450722 Lon: −121.572812	4	7.7	Anthoni et al., 2002
TAPA	Tropical moist forest	Lat: −2.869745 Lon: −54.949355	159	26.4	Saleska et al., 2003
TUND	Arctic tundra	Lat: 71.271908 Lon: −156.613307	5	−10.9	Kwon et al., in press
SEVI	Desert grassland	Lat: 34.350858 Lon: −106.689897	3	13.6	Kurc and Small, 2004
KONZ	Tallgrass prairie	Lat: 39.089073 Lon: −96.571398	87	12.8	Ham and Knapp, 1998
AGRO	Corn/ soybean	Lat: 40.006658 Lon: −88.291535	99	11.2	Meyers and Hollinger, 2004

[a] Annual precipitation (multiple year average).
[b] Mean annual temperature (multiple year average).