Validating MODIS Terrestrial Ecology Products: Linking *In Situ* and Satellite Measurements

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MODIS (the Moderate Resolution Imaging Spectrometer) is the principal high temporal frequency global mapping sensor on-board NASA's Earth Observation System (EOS) (http://modarch.gsfc.nasa.gov/MODIS/). The MODIS instrument views the entire Earth's surface every 1–2 days, acquiring data in 36 spectral bands at spatial resolutions from 250 m to 1 km (Running et al., 1994). The specifications for the MODIS instrument push the limits of engineering (Barnes et al., 1998), and MODIS data volumes will be several times that of the NOAA-AVHRR (Masuoka et al., 1998). MODIS data are processed to provide well-quantified and calibrated data sets of the Earth's surface, corrected for instrument radiometry, geometric distortions, atmospheric attenuation, and cloud effects (Justice et al., 1998a). As these data are used, they will improve our understanding of global dynamics and processes occurring on the land surface and in the oceans and atmosphere.

This unprecedented data volume has led the MODIS instrument team to develop a number of derived data products, with the intent of reducing the burden of data processing on the user. A series of land product algorithms were selected by open competition and have been peer-reviewed twice during their development. The MODIS Land Discipline Group (MODLAND) has been charged with development of the MODIS-based algorithms, the generation of the associated geophysical products, and their validation. These MODLAND data products include surface reflectance, spectral albedo, land surface temperature, spectral vegetation indices, leaf area index and the absorbed fraction of photosynthetically active radiation (LAI/fAPAR), fire, snow, ice, and land cover, and net primary productivity (NPP). These and other, higher-order products derived from MODIS data will play an important role in measuring and monitoring surface variables and in the development of global, interactive Earth–system models that are able to predict global change accurately enough to assist policy makers in making sound decisions concerning the management of our environment. MODIS data will be used to parametrize and/or validate models of land–atmosphere interactions, ecosystem processes, biogeochemical cycles, surface hydrology, land cover, and land use.

Validation of these global data products is crucial, both to establish the accuracy of the products for the science-user community and to provide feedback so that the data processing algorithms and product-oriented models can be improved. The MODLAND validation approach developed around the hierarchical test-site concept of the Terrestrial Observation Panel for Climate (GCOS, 1997). The intensive study sites which form a major component of the MODLAND validation plan have evolved into a number of Core Land Validation Sites for the EOS program (Justice et al., 1998b) (http://modarch.gsfc.nasa.gov/MODIS/LAND/VAL/). The MODLAND group has coordinated a number of EOS land validation prototyping experiments at the site level using ground measurement, aircraft, and satellite data.

Recognizing the new challenge of validating global products, NASA formed an EOS Validation Program to assist the instrument teams with product validation

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(http://eospso.gsfc.nasa.gov/validation/). As a precursor to this validation initiative, the NASA Terrestrial Ecology Program (under the direction of Dr. Diane Wickland) funded a small group of scientists, consisting primarily of ecologists from the Long-Term Ecological Research (LTER) network, to focus on validation of some principal ecologically oriented MODLAND products. The primary aim of this group (referred to as "MODLERS") was to develop validation protocols and explore scaling issues that would lead to an improved understanding of selected MODIS land products. At a workshop held in May 1996 the decision was made to develop the articles for this special issue, summarizing the results of this exploratory research. In 1998, the LTER validation scientists reorganized their validation scaling activities around four sites containing eddy-covariance flux towers, strengthened their linkages to the MODIS instrument team, and developed a follow-on proposal to the NASA Terrestrial Ecology Program. This follow-on project, named "BigFoot," is now funded and focused on scaling up from *in situ* ground measurements to the moderate spatial resolution of the MODIS data products (http://www.fsl.orst.edu/larse/bigfoot).

Flux towers have a variable-sized "footprint" over which gas flux data are collected. The size, shape, and orientation of the footprint varies with height of the gas sensors above the local vegetation, the wind speed and direction, and associated factors, but is generally about 1 km or less (Baldocchi et al., 1996). The BigFoot project sites are centered around flux towers; however, because of a need to define a site containing multiple MODIS pixels, the extent of BigFoot sites is 25 km^2. Hence the derivation of the project's name.

The BigFoot project will focus on validation of the MODIS land cover, LAI/fAPAR, and NPP products. These interrelated MODIS products represent critical variables for monitoring the impact of humans and climate change on the Earth system. BigFoot will develop gridded data layers based on field data, Landsat ETM+, and geostatistical and ecological models at each of the project's four sites using standardized procedures. The sites include a boreal forest in northern Manitoba (the Northern Study Area of the BOREAS project), a mixed deciduous–coniferous forest in Massachusetts (Harvard Forest LTER site), a tallgrass prairie in Kansas (Konza LTER site, where the FIFE project was staged), and an agroecosystem consisting of a mix of corn and soybeans in west-central Illinois. The main goal in developing the biophysical data layers at each site is to produce grids that have ecological significance and a high degree of accuracy at the local site level. Errors in each data layer will be characterized using an independent set of ground reference data.

The research presented in this special issue was instrumental in the development of the BigFoot concept. Explicit examination of scaling from field measurements to MODIS grids is a central theme of BigFoot. Because MODIS grids are being developed to capture global trends, the data, models, and algorithms used are highly generalized. BigFoot grids which are developed at the site level, using extensive field data, higher spatial resolution satellite data, and less generalized models and algorithms, should be more accurate at the site level. The juxtaposition of MODLAND and BigFoot grids will permit a series of exercises that are designed not simply to test the accuracy of MODLAND products, but also to gain an understanding of the causes of errors in MODLAND products and thus provide feedback for potential improvement in second-generation MODIS products. An important criterion for success of MODLAND products is whether they reveal the proper trends across biomes. A simple cross-site comparison of MODLAND and BigFoot data layers permits this, but also facilitates an examination of product accuracy at the biome (or site) level. Given the generalized nature of MODLAND products, we expect site-level errors in estimates for each variable, and BigFoot will isolate and test several factors that might contribute to errors in MODLAND products.

The articles contained in this special issue provide the foundation for the research questions that will be addressed by BigFoot. BigFoot will focus on the NPP product and the contribution of using a global land cover classification scheme versus a site-specific scheme (Thomlinson et al.) to model NPP. We will also turn our attention to the examination of relationships between spectral vegetation indices (SVIs) and LAI (Turner et al.). Of great importance is our examination of observational grain size (Milne and Cohen). As the scale of observation (i.e., spatial resolution) increases, especially in a heterogeneous landscape, functionally-important vegetation patches become unresolvable. We hypothesize that there is a fundamental grain size of each landscape (or biome) above which error rates accelerate when modeling NPP, and we will test this hypothesis explicitly using field data, Landsat ETM+, and geostatistical models.

To the extent possible, BigFoot will use standardized procedures for field data collection, analyses, and modeling, as the following brief summary of the articles contained in this special issue indicates. The article by Ouaidrari and Vermote describes the approach we will use to atmospherically correct the Landsat data which will provide the high resolution site-specific spatial characterizations. Thomlinson et al. discuss issues related to land cover mapping across multiple sites for the purpose of validating MODLAND and related global land cover products. Gower et al. discuss the measurement and quantification of LAI, fAPAR, and NPP of terrestrial ecosystems. The importance of this article is that it synthesizes the relevant literature, bringing us up to date on the assumptions and inconsistencies among various methods, as well as suggesting both indirect (optical) and direct measurement and analysis standards for these ecosystem attributes. The article by Turner et al. evaluates relationships between common SVIs and LAI across three distinct vegetation regions in North America. Reich et al. provide a biological framework linking ecosystem attributes and carbon flux at several scales and summarize the state of knowledge and models in these areas. Milne and Cohen discuss options for scaling continuous and class data from plots to MODIS-sized cells, aimed at preserving both the mean and the multifractal properties of a landscape. Olson et al. describe a data and information system model that facilitates assembling, managing, and sharing diverse data from multiple disciplines, scales, and sites to support integrated ecological studies. Running et al. describe the overall framework for validating MODLAND NPP products within which BigFoot will operate. The truly visionary package of field data, flux tower measurements, remote sensing, and ecological models presented in this article launches remote sensing and related modeling activities into the 21st century.

We hope you enjoy this special issue, and through the articles contained herein, can more fully appreciate the tremendous leap forward that NASA's EOS Program affords the Earth science community, and that MODIS provides the ecological modeling segment of that community.

Three special notes of thanks are in order. Were it not for the solid, unwavering support of Dr. Diane E. Wickland, Manager of NASA's Terrestrial Ecology Program, the research presented in this special issue and the BigFoot project would not have been possible. Dr. Wickland's encouragement for the involvement of LTER scientists in NASA programs is much appreciated, providing an important link between field ecologists, *in situ* measurements, and remote sensing. To the reviewers of this special issue we owe tremendous thanks for excellent feedback that greatly improved individual articles and the special issue as a whole. Finally, we want to thank Dr. Bauer for working with us over the past few years to help us get this special issue in order.

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