CANOPY HEIGHT, CROWN COVER, AND ABOVEGROUND BIOMASS MAPS FOR THE SOUTHWESTERN UNITED STATES FROM MISR, 2000 AND 2009

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Many science questions in large-scale terrestrial ecology are concerned with changes in the Earth's carbon cycle and ecosystems and the consequences for the Earth's carbon budget, ecosystem sustainability, and biodiversity [1]. To address these questions, we must know the distribution of aboveground woody carbon stocks; how much, where, and why woody carbon stocks are changing; and what proportion of the annual net flux to/from land is the result of disturbance and recovery [2]. These questions can be addressed using measures of forest canopy physical structure (horizontal and vertical distributions) through the synergistic use of data from lidar and radar remote sensing instruments [3]. However satellite systems with global observing capability are at least eight years away [4]. In the meantime it is possible to make use of existing NASA multiangle remote sensing resources and specifically the Multiangle Imaging SpectroRadiometer (MISR) [5] to obtain first-order estimates of primary canopy parameters (fractional crown cover, mean canopy height), at moderate resolution, and from 2000 onwards, and to estimate aboveground standing live woody biomass from these parameters. This capability has been demonstrated for arid and semi-arid regions in published studies ([6]-[8]). There is thus the potential to perform a decadal survey of crown cover, canopy height, and aboveground standing live biomass for extensive areas in which soils are bright, understories are generally sparse and/or often senescent, and woody canopies are not prohibitively dense.

We present here the use of MISR to provide maps of these parameters for the entire southwestern United States, for 2000 and 2009, to coincide with the 10th anniversary of both MISR and the NASA Earth Observing System Terra satellite on which it is flown. The goal was to make wall-to-wall maps of forest and shrub canopy parameters over large areas and at annual intervals on a 250 m grid. The approach exploits the structural effects of canopies reflected in observed anisotropy patterns in the MISR red (672 nm) band to retrieve physical parameters. Other attempts have relied on scattering indices [9] or on empirical methods that require a large number of input variables and are less robust [10]. Red band terrain radiance data in nine viewing angles from MISR on the Terra satellite, were obtained for one month at the end of the dry season (May 15 – June 15) for 2000 and 2009. The calibrated spectral radiances were converted to surface bidirectional reflectance factor (BRF) estimates via regression on atmosphericallycorrected 1 km BRF values in the MISR land product, obtained using MISR aerosol optical depth retrievals, and resampled onto a 250 m Albers Equal Area projection grid. These data were used to obtain maps of woody plant fractional crown cover, mean canopy height, and aboveground standing live biomass for the southwestern United States, via inversion of the Simple Geometric-optical Model (SGM) that is based on the principles of Boolean geometry first exploited in Li-Strahler models [11]. The contribution of the background in the MISR geometry is provided by the empirical four-parameter Walthall BRDF model [12]; this is estimated before numerical methods are used to adjust the SGM. The mean crown radius (*r*) and crown shape parameters (*b*/*r*, where *b* is crown vertical radius) were adjusted using the Praxis optimization algorithm (an adaptation of the Powell algorithm), allowing retrieval of fractional crown cover, mean canopy height (*h*+*b*, where *h* is mean crown center height and *b* is mean crown vertical radius). Fractional cover and mean canopy height are obtained by adjusting *r* and *b*/*r* parameters with fixed number density and *h*/*b* via $h = h/b \times b$; $b = b/r \times r$. It is possible to extract both parameters simultaneously because their respective effects differ: the bell shape of the reflectance curve with respect to view zenith angle becomes more marked with increasingly prolate crowns, while increasing cover results in an even reduction in red band BRF across all viewing angles. Relationships between retrieved fractional crown cover and mean canopy height and aboveground standing live biomass were obtained via regression on USDA Forest Service (USFS) maps based on Forest Inventory Analysis plot data, MODIS vegetation index and continuous fields maps, and several other geospatial layers [13].

In arid and semi-arid environments, GO model inversion for upper canopy parameters is greatly hindered if the soil-understory background contribution at the instrument illumination-viewing geometry is not accounted for [6-8]. For each MISR observation the background contribution was predicted *a priori* by developing relationships between the isotropic, geometric, and volume scattering kernel weights of the semi-empirical LiSparse-RossThin kernel-driven bidirectional reflectance distribution function (BRDF) model (adjusted against the same MISR red band data) and the four Walthall model parameters. Earlier attempts used a background BRDF regression that was based on coefficients developed using 19 grass- and shrub-dominated sites in the US Department of Agriculture (USDA), Agricultural Research Service Jornada Experimental Range and MISR nadir (An) camera BRFs as well as the red band kernel weights [6]. This provided distributions for forested areas showing good matches with maps from the USFS, with r^2 of 0.81, 0.78 and 0.74 for biomass, forest cover, and mean canopy height, respectively, after filtering for high root mean square error (RMSE) on model fitting that indicates cloud/cloud-shadow contamination, inversions affected by uneven illumination owing to topographic variation (identified using Shuttle Radar Topography Mission elevation data) and a very small number of physically infeasible values (e.g., negative heights) [6]. In subsequent SGM inversion work in the Colorado Rocky Mountains that showed good matches with canopy heights derived from high resolution discrete return lidar elevation data [8], we found that including the nadir camera blue, green, and near-infrared reflectance bidirectional reflectance data led to over-fitting and less accurate results, while kernel weight-predicted regressions were able to predict physically reasonable (if unverifiable) BRFs at +/-45 degrees viewing zenith angle with the overhead sun, in the solar principal plane (SPP), even though MISR does not view in this plane at these latitudes. We therefore used only red band isotropic, volume scattering, and geometric kernel weights in this study.

To map the entire southwestern US we used the LiSparse-RossThin linear, kernel-driven bidirectional reflectance distribution function (BRDF) model as this combination is most appropriate for arid and semi-arid environments, with ~400 million model inversions. The kernel weights were used to find the regression coefficients needed to predict the background contribution for the subsequent ~400 million SGM inversions. Only the r and b/r parameters were adjustable; plant number density, crown leaf area, leaf reflectance, and h/b ratio were fixed at 0.012 (750 plants per 62,500m^2), 2.018, 0.09, and 2.0, respectively. The MISR terrain data sets used were for paths 29 – 47 and included MISR blocks in the range 56 – 70. One orbit was selected for each path, from the 69 available, on the basis of the number of clear blocks and proportion of ocean. Fractional crown cover and mean canopy height were retrieved with no scaling, not through fitting or training. The maps were composited to fill gaps and take advantage of path overlap by selecting the inversion results with the lowest model-fitting Root Mean Square Error (RMSE), since clouds and other contamination result in RMSE > 0.05, while valid retrievals are usually < 0.02. Preliminary assessments vs. the USFS biomass map [10], Landsat-based fire severity maps for the 2002 Rodeo-Chediski fire area in Arizona, September 2008 NASA Laser Vegetation Imaging Sensor (LVIS) RH100 canopy heights over the Sierra Nevada, and losses from mountain pine beetle in Colorado and Wyoming show that the results are very reasonable. In the latter case, the GO model responds to the lack of live green leaves and does not report the standing dead tree trunks. Prediction of the USFS biomass values was assessed using 290 random points for forest cover > zero: the intercept, fractional cover, and mean crown center height were all significant with p=0.01, with an adjusted r^2 of 0.50. Further quantitative assessment will be performed using heights from discrete return laser elevation data over Colorado and LVIS RH100 heights over desert grassland with shrubs in the USDA, ARS Jornada Experimental Range in southern New Mexico.

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