Forest Cover and Height in Topographically Complex Landscapes from MISR Assessed with High Quality Reference Data

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Introduction: Previous research has shown that inverting the simple geometric-optical model (SGM) with bidirectional reflectance factor (BRF) data from the NASA Multiangle Imaging SpectroRadiometer (MISR) can provide spatially contiguous 250 m retrievals of forest canopy height and fractional crown cover, important primary forest parameters that are useful in estimating aboveground woody biomass and in other applications. However it remained unclear whether this approach could provide reliable estimates for topographically complex landscapes with marked relief; when the approach was applied over the entire southwestern US, anomalous results were sometimes obtained for such areas, with cover overestimated and height underestimated. These may be owing to model inadequacies, poor estimates of the soil-understory background bidirectional reflectance distribution function (BRDF), and/or problems with the inversion protocol. This study attempts to address these questions using high quality reference data sets for an extensive study area in the Sierra Nevada National Forest, an area of considerable topographic complexity. The study area is centered on the area surveyed by the NASA Laser Vegetation Imaging Sensor (LVIS, an advanced full waveform lidar), in September 2008 in the Sierra National Forest in southern California, USA. It encompasses an area of 65,625 ha (37° 10' 46''N, 119° 17' 40''W by 35 ° 31' 26''N, 118° 18' 21''W) with elevation ranging from ~850 to 2,700 m (Figure 1).

Method: Tree number density (number per m²), mean crown radius (m), and fractional cover reference data were obtained via analysis of QuickBird 0.6 m spatial resolution panchromatic imagery using the Canopy Analysis with Panchromatic Imagery (CANAPI) algorithm (Figures 2 and 3), while canopy height data were obtained from LVIS (Figure 4). The mean incidence angle of the LVIS data set was 2.8°with a standard deviation 1.4° - none of the data were acquired at an incidence angle greater than 10° The LVIS RH50, RH75, and RH100 values within each mapped MISR 250 x 250 m cell were averaged (separately) to obtain canopy height reference data sets, thus these data are not original LVIS data but derived quantities. These canopy parameters were used together with an empirically-calibrated background BRDF to drive a modified version of the SGM to predict BRF for typical MISR viewing and illumination angles. The new model assigns signatures to shaded components and crowns rather than leaves, as in the original Li-Strahler model. The background model kernel weight regression coefficients were based on a set of highly contrasting surface types (Figures 5 - 7; Table 1). Fractional cover and mean canopy height maps were obtained through adjustment of the SGM against MISR 672 nm BRFs on a 250 m grid. The free model parameters were tree number density and mean crown radius; other parameters were fixed (crown reflectance = 0.03, shadow signature = 0.02, and crown aspect ratio = 4.0). Inversion results were evaluated with respect to the LVIS and CANAPI data (N = 1048).

Results: The model accurately reproduced patterns of MISR surface 672 nm band reflectance (mean Root Mean Square Error (RMSE) = 0.011,

TABLE 1. BACKGROUND MODEL KERNEL WEIGHT COEFFICIENTS

Kernel Weight Regression Coefficients
(bold = not significant @ p=0.05)

	Background model (RTLSR)		
Observed (RNLSR)	Isotropic	Volume	Geometric
Intercept	**0.008**	0.133	-0.013
Isotropic kernel weight	0.955	-0.960	0.112
Volume scattering kernel weight	-1.096	**2.879**	-0.489
Geometric kernel weight	**0.334**	3.485	0.641

TABLE 2. SGM MODEL INVERSION STATISTICS

	Model-Fitting RMSE	Model-Fitting R²
Minimum	0.001	0.000
Maximum	0.283	0.999
Mean	0.009	0.775
Mode	0.008	0.925
Standard Deviation	0.009	0.199

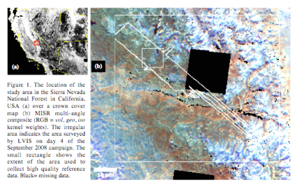

Figure 1. The location of the study area in the Sierra Nevada National Forest in California, USA (a) over a crown cover map (b) MISR multi-angle composite (RGB = soil, geo, iso kernel weights). The irregular area indicates the area surveyed by LVIS on day 4 of the September 2008 campaign. The small rectangle shows the extent of the area used to collect high quality reference data. Black=missing data.

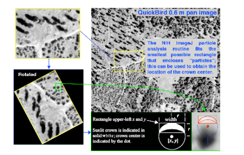

Figure 2. Schematic showing the principles on which the CANAPI algorithm isolates tree or shrub crowns, finds crown radii, and estimates heights from shadow lengths. The algorithm is implemented in U.S. National Institutes of Health ImageJ image processing package. See Chopping 2010 for details.

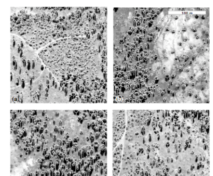

Figure 3 Typical CANAPI crown (circle) and tree shadow (line) detections over QuickBird 0.6 m panchromatic images in the Teakettle Experimental Forest, Sierra National Forest, California. Shadows that are truncated by tree crowns or the edge of the image are not used in tree height calculation. The imagery was acquired June 25, 2003.

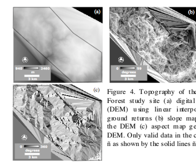

Figure 4. Topography of the Sierra National Forest study site (a) digital elevation model (DEM) using linear interpolation on LVIS ground returns (b) slope map generated from the DEM (c) aspect map generated from the DEM. Only valid data in the center of the maps – as shown by the solid lines – were used.

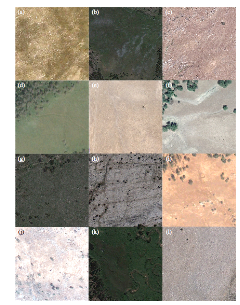

Figure 5. A selection of image chips from Google Earth showing the wide range of non-tree-backgrounds for which the GO modeling framework must attempt to predict BRDF (a) rocky/stony scrub (b) meadow with lichens (c) senescent sparse grasses with rocks (d) lush meadow (e) senescent grasses (f) senescent grasses with exposed soil (g) low shrubs, rocks/stones, exposed soil, grasses (h) highly stratified uplifted and tilted rock face (i) senescent grasses with exposed bright mineral soil (j) bright exposed caliche with rock outcrops and stones (k) wet meadow grasses and low shrubs (l) talus slope.

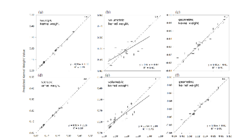

Figure 6. (a)-(c) Predicted vs optimal background BRDF model red band isotropic, volume, and geometric scattering kernel weights for the 28 background calibration sites (d)-(f) for backgrounds predicted using kernel weights plus the green and near-infrared BRFs from the MISR nadir camera.

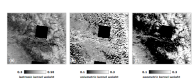

Figure 7. Maps of the predicted background BRDF model kernel weights (a) isotropic (diffuse) (b) volume scattering (c) geometric scattering.

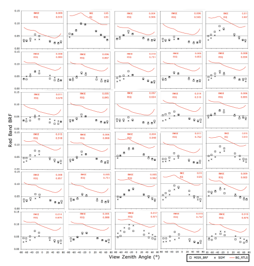

Figure 8. SGM predicted BRF, driven by CANAPI tree number density and mean crown radius, LVIS RH100 canopy heights, and using the RTLS BRDF model to represent the background contribution.

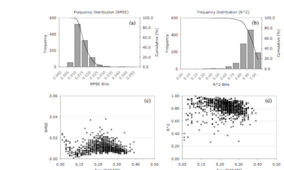

Figure 9. Results of the GO model predictions when driven by CANAPI tree number density and mean crown radius, LVIS RH100, and the RTLS BRDF model representing the background, for 1048 contiguous locations (a) histogram of modeled *vs*. MISR RMSE values (b) histogram of modeled *vs*. MISR coefficient of determination (R^2) values (c) distribution of RMSE values with respect to CANAPI/QuickBird fractional cover estimates (fcov) (d) distribution of R^2 values with respect to CANAPI/QuickBird fractional cover estimates.

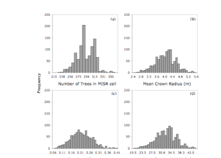

Figure 10. Histograms for tree number, mean crown radius, fractional cover, and mean canopy height obtained by inversion of the GO model against MISR red band BRFs in all nine cameras.

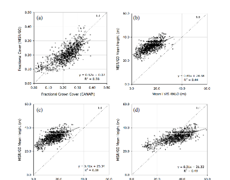

Figure 11. (a) MISR fractional crown cover from inversion of the GO model vs. CANAPI/QuickBird-derived fractional crown cover (b) MISR mean canopy heights with no rescaling vs. mean LVIS RH50 canopy heights (average over the 250 x 250 m MISR cell) (c) vs. RH75 (d) vs. RH100. See Table 2 for inversion statistics.

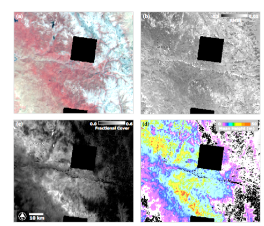

Figure 12. (a) MISR An (nadir) camera 250 m false color composite with RGB=NIR, Red, Green BRFs (b) 250 m map of RMSE on GO model fitting (c) 250 m map of retrieved fractional crown cover, assuming crown overlap (d) 250 m map of retrieved mean canopy height. The dotted line indicates the validation area for which CANAPI and LVIS data were both available. Black rectangular areas indicate missing data owing to cloud.

Results… mean $R^2 = 0.82$, N=1048), with little bias with cover (Figures 8 and 9). The ranges of the adjusted model parameters were very reasonable (Figure 10). Model adjustment against the MISR red band BRFs resulted in mean (standard deviation) model-fitting RMSE and coefficient of determination values of 0.009 (0.009) and 0.78 (0.199) respectively, with modes of 0.008 and 0.925 (Table 2). RMSE values for the MISR/GO cover and height retrievals with respect to the CANAPI and LVIS RH100 reference data were 0.05 and 6.65 m, respectively, with R^2 of 0.54 and 0.49, significant at the 99% level (Figure 11). The mapped inversion results and RMSE are quite reasonable (Figure 12).

Conclusions: The results show that GO model inversion for simultaneous retrieval of crown cover and mean canopy height can provide useful maps of canopy structural parameters even in areas of considerable topographic variation. Refinements to the model and its inversion protocol are required to improve the precision of retrievals. This study adds to the recent literature showing that it is possible to leverage multiangle imaging for forest structure mapping, with the possibility of realizing important synergies with active instruments for forest mapping at regional scales.

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http://csam.montclair.edu/~chopping/woody http://csam.montclair.edu/~chopping/CANAPI/