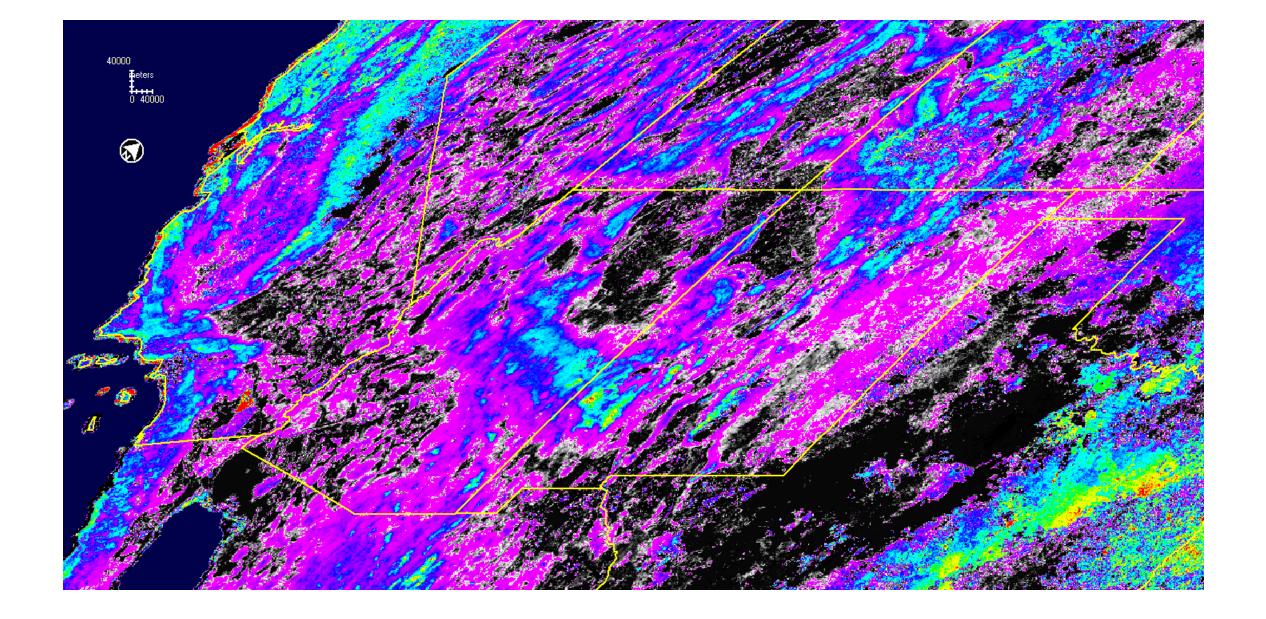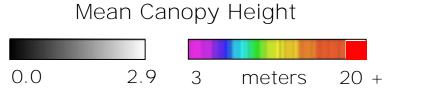# Mapping Forest Crown Cover, Mean Canopy Height, and Aboveground Biomass using a Geometric-Optical Model and MODIS Data

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Red band bidirectional reflectance data from the NASA MODerate resolution Imaging Spectroradiometer (MODIS) acquired over the southwestern United States were interpreted through a simplified geometric-optical canopy reflectance model (SGM) to provide maps of mean canopy height and fractional crown cover at 250 m spatial resolution. Adjustment of the parameters of the model was performed after dynamic injection of a background contribution predicted via the kernel weights of a bidirectional reflectance distribution function (BRDF) model. The resulting maps were assessed with respect to Multiangle Imaging SpectroRadiometer (MISR) retrievals, contemporary US Forest Service (USFS) maps, and lidar-derived height data. Random samples of MODIS (N=895) and MISR (N=576) retrievals of forest height and cover showed good agreement with USFS maps, with MODIS mean absolute errors (MAE) of 0.09 and 8.4 m respectively; and MISR MAE of 0.10 and 2.2 m, respectively. The respective MAE for aboveground woody biomass were both ~10 Mg ha$^{-1}$, although the MODIS $R^2$ was weaker. These results are supported by good MISR height accuracies with respect to lidar-based estimates and have implications for the use of moderate resolution remote sensing data in the assessment of woody biomass loss and recovery from disturbance.

Figure 1. MODIS (a) GO-retrieved mean canopy height (b) GO-retrieved fractional canopy cover (c) aboveground biomass (regression estimate on Forest Service data) (d) model-fitting RMSE
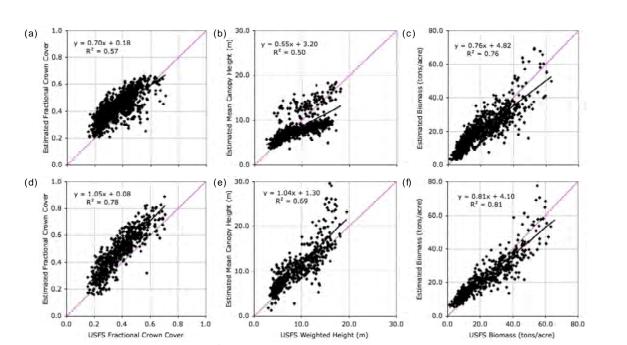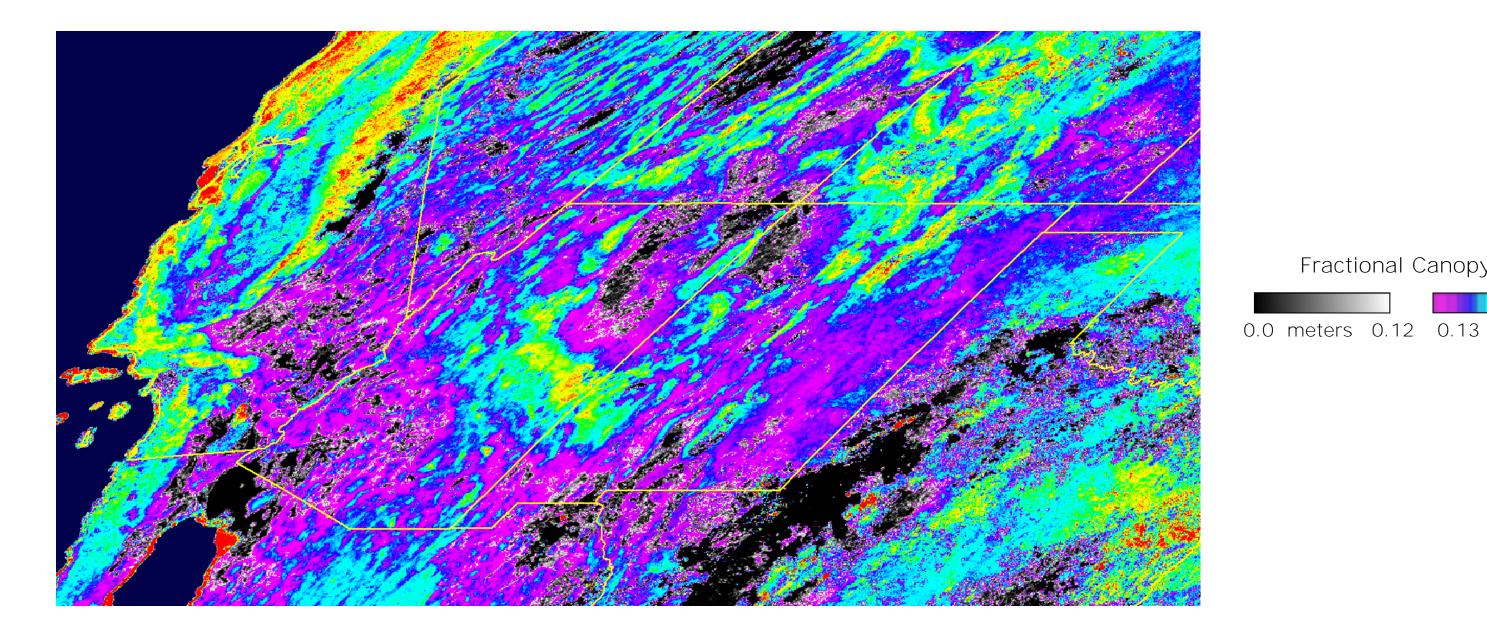
Table 1. MODIS (N= 895) and MISR (N= 576) Error Statistics vs Forest Service Interior West Map Data.

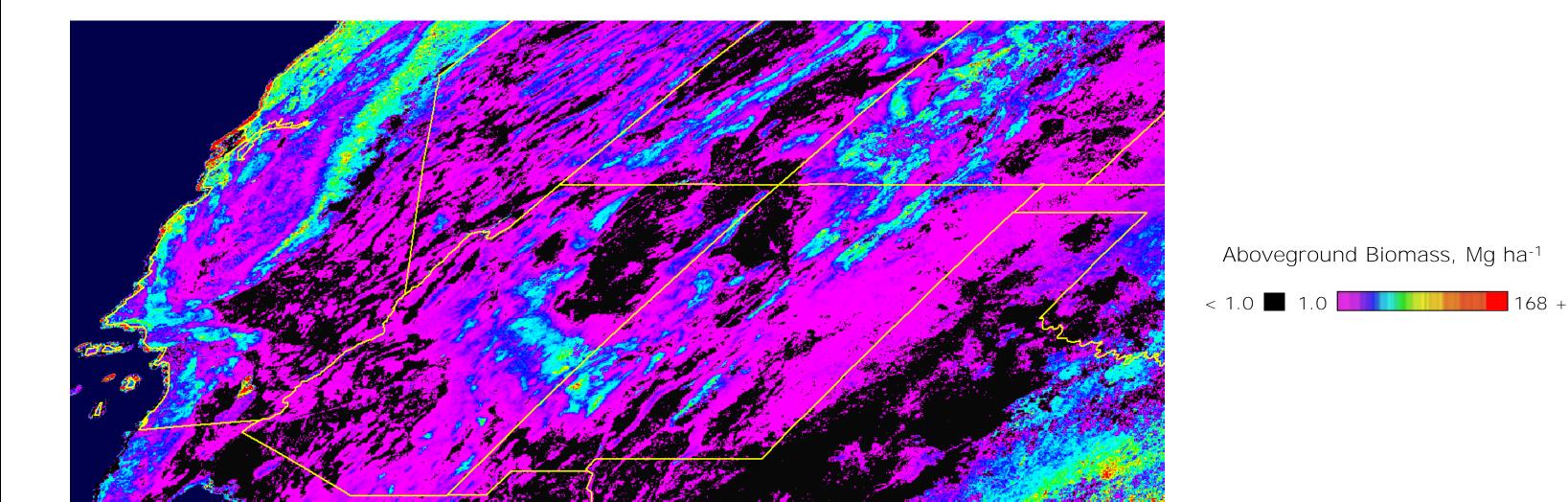| | Fractional cover (dimensionless) | | Mean height (meters) | | Aboveground Woody Biomass | | | |
| | | | | | tons/acre | | Mg ha$^{-1}$ | |
|---|---|---|---|---|---|---|---|---|
| | MODIS | MISR | MODIS | MISR | MODIS | MISR | MODIS | MISR |
| Mean relative error (%) | 26 | 30 | 20 | 28 | 25 | 28 | n/a | n/a |
| Mean absolute error | 0.09 | 0.10 | 8.4 | 2.2 | 4.5 | 4.5 | 10.1 | 10.1 |
| 2 Standard Deviations | 0.19 | 0.30 | 5.4 | 10.1 | 20.8 | 26.0 | 46.6 | 58.2 |
| Means | 0.44 | 0.48 | 7.8 | 10.3 | 20.5 | 21.8 | 46.0 | 49.0 |
| $R^2$ | 0.55 | 0.78 | 0.50 | 0.70 | 0.75 | 0.81 | n/a | n/a |
| RMSE | 0.10 | 0.12 | 2.6 | 3.3 | 6.0 | 6.2 | 13.4 | 14.0 |

The GO maps were assessed against from US Forest Service raster maps with a spatial resolution of 250 m for the Interior West (IW) produced a modeling framework that relies mainly on Forest Inventory Analysis survey data, soils, topographic, MODIS vegetation index, MODIS Vegetation Continuous Fields, and climate variables. Both MODIS and MISR fractional cover and mean canopy height retrievals show strong linear relationships with the USFS map data for random sites in Arizona and New Mexico, with some unexplained scatter and bias in the MODIS height retrievals (Figure 2). This is likely to be owing to inadequate prediction of the background contribution, stemming from the inconsistent angular sampling of the MODIS data (Figure 3) that affects background extraction, the Li-Ross kernel weights used in background prediction, and eventual model adjustment. Nevertheless, the correspondence between the MODIS, MISR, and USFS estimates is striking (Figure 4).



Figure 2. Retrieved fractional canopy cover and height and estimated aboveground woody biomass vs reference data from a 2005 Forest Service map series for the Interior West (random samples). (a)-(c) MODIS cover, height, and biomass, respectively (N = 895); (d)-(f) MISR cover, height, and biomass, respectively (N = 576).
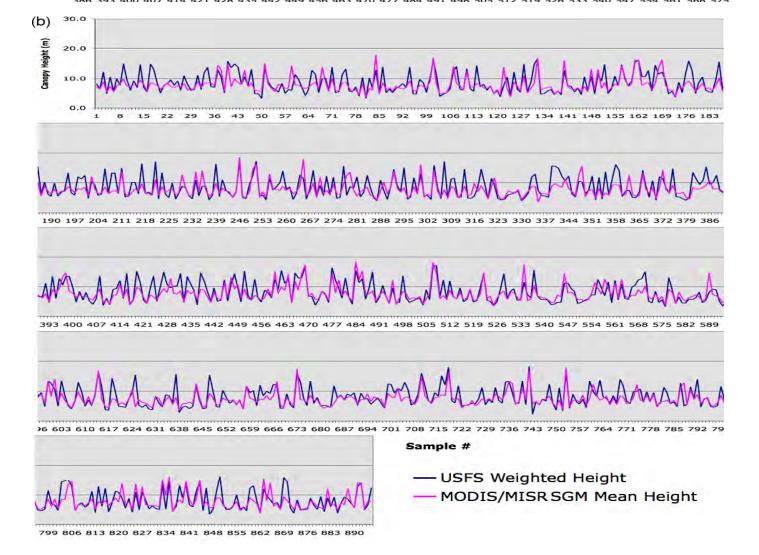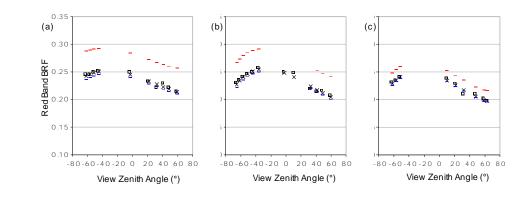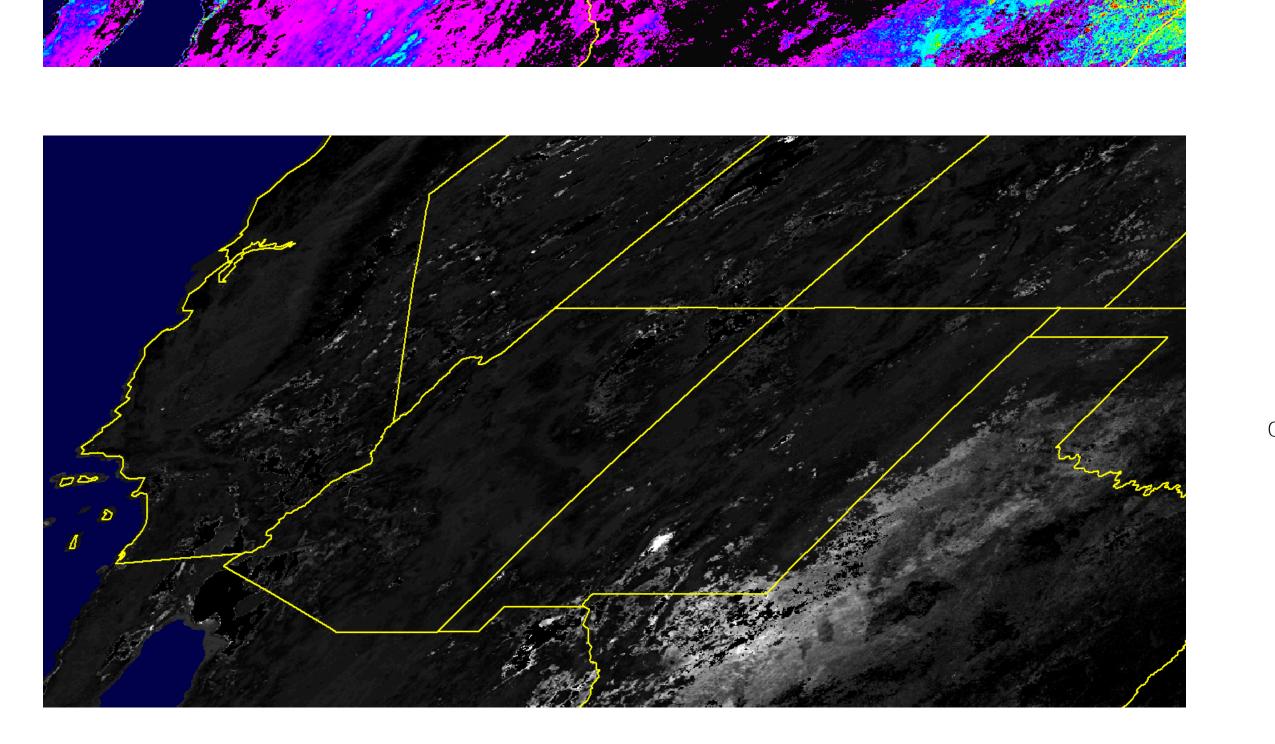


Figure 4. (a) MISR (N=576) and (b) MODIS (N=895) forest canopy height retrievals, filtered for high model fitting error and topographic shading for random samples and in random order and estimates extracted from the 2005 US Forest Service Interior West map.



Figure 3. (a)-(c) MODIS BRFs, Walthall background contributions, and SGM BRFs for three shrub-dominated sites in the USDA, ARS Jornada Experimental Range near Las Cruces, New Mexico, at various relative azimuths USA (d)-(f) 1 m panchromatic Ikonos image subsets corresponding to these sites (g)-(i) shrub maps derived from the Ikonos imagery, green = shrub, beige = background. Note the variation in background brightness within the site depicted in (f).

Since the concept or retrieving canopy height from mono-spectral moderate resolution Earth observation data may seem implausible in view of the prevailing multi-spectral remote sensing paradigm; since the GO model is conceptually simple; and since the comparisons presented thus far show only assessments against USFS maps made using empirical methods (leading to the charge that these results might be merely spurious), a summary of recent assessments of MISR/SGM height retrievals against lidar data is included below (Figure 5, Table 2).

Table 2. MISR/GO height retrieval root mean square error and correlation vs lidar-derived estimates.

| | RMSE (m) | | | $R^2$ | | |
|---|---|---|---|---|---|---|
| | Mean | Min | Max | Mean | Min | Max |
| April | 2.6 | 1.4 | 5.5 | 0.38 | 0.10 | 0.48 |
| April (abs†) | 2.0 | 1.4 | 3.8 | 0.44 | 0.22 | 0.52 |
| September | 3.8 | 2.8 | 5.6 | 0.59 | 0.24 | 0.73 |
| September (abs†) | 3.6 | 2.8 | 5.6 | 0.66 | 0.38 | 0.73 |

Recent tests of MISR height retrievals against discrete return lidar data over 57 sites in Colorado show good matches. Model inversions were completed for 140 combinations of backgrounds (7, including two intentionally inaccurate backgrounds), r (3.0-6.0 in increments of 1.0) and b/r (0.5-2.5 in increments of 0.5). For all model inversion runs with reasonable backgrounds and an initial b/r value of < 2.0, RMSE distributions vs lidar were centered around 2.5 m and 3.7 m with maxima of 5.5 m and 5.6 m, respectively, while $R^2$ distributions were centered around 0.4 and 0.7 with minima of 0.10 and 0.24. With some care taken in background extraction and selection of initial values, it is possible to achieve a typical RMSE of ~3.0 m and $R^2$ of ~0.7.



Figure 5. Canopy height comparisons for sites in north-central Colorado (1-37: grassland, 38-107: forest). Top: MISR vs lidar. Bottom: Forest Service Interior West (IW) estimates vs. lidar, noting that the FS-IW maps include only forest. The MISR/GO anomaly for sites 95-107 is reflected in cover retrievals >= 1.0.

As far as we know, this is the first time that the structural signal in a synthetic (accumulated) MODIS multi-angle data set has been exploited to map canopy height over large areas. The results show that in spite of many assumptions and approximations, a simplified GO model can be inverted against MODIS or MISR red band multi-angle reflectance data to retrieve reasonable distributions of forest canopy cover and mean canopy height over large areas. Retrievals using MISR data are more accurate than those from MODIS to date but the latter were achieved using data sets with part of the angular domain obscured (missing observations in the 5–40 degree backscattering region; Figure 3)) and a set of background regression coefficients that are known to be far from optimal. It was shown that height retrievals are unlikely to be spurious because MISR height retrievals match lidar-derived heights well and maps of mean crown shape and mean crown radius in southern New Mexico have been shown to match vegetation maps that include dominant shrub species and known distributions. The main limitation of this approach is that it is unsuitable for closed or dense canopies but it is appropriate for mapping vast areas of boreal, montane, and temperate forest as well woodlands, savannas, and shrub-dominated regions worldwide. Further research is required to determine whether it is feasible to use data from MISR and MODIS in combination to obtain a wider angular sampling that might provide more accurate retrievals.

**Related papers:**
Chopping, M., Nolin, A. W, Moisen, G. G., Martonchik, J. V., and Bull, M., (2009) Forest canopy height from the NASA Earth Observing System Multiangle Imaging SpectroRadiometer (MISR) assessed with lidar, submitted.
Chopping, M., Moisen, G. Su, L., Laliberte, A., Rango, A., Martonchik, J.V., and Peters, D.P.C. (2008). Large area mapping of southwestern forest crown cover, canopy height, and biomass using MISR, *Remote Sens. Environ.*, 112: 2051-2063.
Chopping, M., Su, L., Rango, A., Martonchik, J.V., Peters, D.P.C., and Laliberte, A. (2008), Remote sensing of woody shrub cover in desert grasslands using MISR with a geometric-optical canopy reflectance model. 112: 19-34.

http://csam.montclair.edu/~chopping/wood