ASSESSING REMOTELY-SENSED ABOVEGROUND BIOMASS ESTIMATES IN THE SIERRA NATIONAL FOREST

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ABSTRACT

Mapped estimates of forest aboveground biomass (AGB) at regular intervals are important in carbon cycle studies. In the southwestern United States, there have been extensive changes to forests over the last decade, due to wildfire, climate-driven insect outbreaks and disease, increasing forest-human interaction, resource exploitation, and increasing aridity [1]. Earlier estimates of AGB based on MISR geometric-optical model cover and height retrievals were found to be highly compatible with US Forest Service maps constructed using empirical relationships and MODIS vegetation index data [2][3]. However, these maps were not validated against field data. This paper reports on efforts to assess mapped estimates of forest AGB in the Sierra National Forest, California, against field inventory data.

Index Terms— forest, biomass, carbon,

1. INTRODUCTION

The objective of this study was to use per-tree AGB estimates – based on careful application of allometric relationships – from fifteen 200 x 200 m plots in the Teakettle Experimental Forest to compare different biomass mapping methods using field inventory and estimates from high resolution panchromatic imagery and the CANAPI algorithm [4]. If validated the CANAPI outputs could be applied over much larger, contiguous areas, allowing the evaluation and comparison of mapped aboveground biomass estimates from MISR, radar, lidar, and MODIS; otherwise these estimates can be inter-compared.

2. METHODS

Biomass estimates (Mg ha^{-1}) were calculated for 200 x 200 m plots and larger areas based on the following data sets, as appropriate:

- The Teakettle Ecosystem Experiment (TEE) field inventory database [5]
- The Teakettle Ecosystem Experiment Remeasure (TERE) database
- Tree crown radii and heights derived from QuickBird 0.6 m spatial resolution panchromatic imagery using the CANAPI method [4]
- The US Forest Service MODIS-based biomass map [2]
- NASA LVIS RH50 returns (HOME), as described in [6]
- National Biomass and Carbon Dataset v.2 (NBCD, [7] File used: NBCD_MZ06_FIA_ALD_biomass.tif).
- MISR/Geometric-Optical model inversion estimates (MISR/GO), [3])
- MISR/Boosted Regression Tree (MISR/BRT, unpublished).

The TEE database was used to calculate biomass for the fifteen 200 x 200 m plots, on a per tree basis, using species-specific equations, viz.: B = exp(b_0 + b_1 ln(DBH)) where B is total AGB (kg), DBH is stem diameter at breast height (cm), ln is the natural log base "e", and b_0 and b_1 are coefficients [8]. However, the total biomass values obtained per plot were far too high and neither of the allometric approaches used with the CANAPI/QB tree maps – [8] and [9] – resulted in agreement with the TEE-based values; moreover, the TEE estimates had a very weak correlation with the NBCD estimates (based on the original 30 m biomass map).

AGB estimates from all remote sensing data sources were calculated for a 6800 ha region (32 row x 34 column x 250 m mapped MISR cells) a few kilometers northeast of the TEE area. This area was selected as it is covered by September 2008 NASA Land, Vegetation, and Ice Sensor (LVIS) lidar instrument over-flights. The MISR/GO cover and height retrievals were used to predict biomass (Mg ha^{-1}) via least-squares regression; and the MISR-based LiSparse-RossThin (LSRT) BRDF model kernel weights and nadir camera green, red, and near-infrared, BRFs were used to train a Boosted Regression Tree (BRT) model. Least-squares regression was used to predict biomass from LVIS RH50 (height relative to ground at 50% of accumulated waveform energy, also known as HOME: height of median

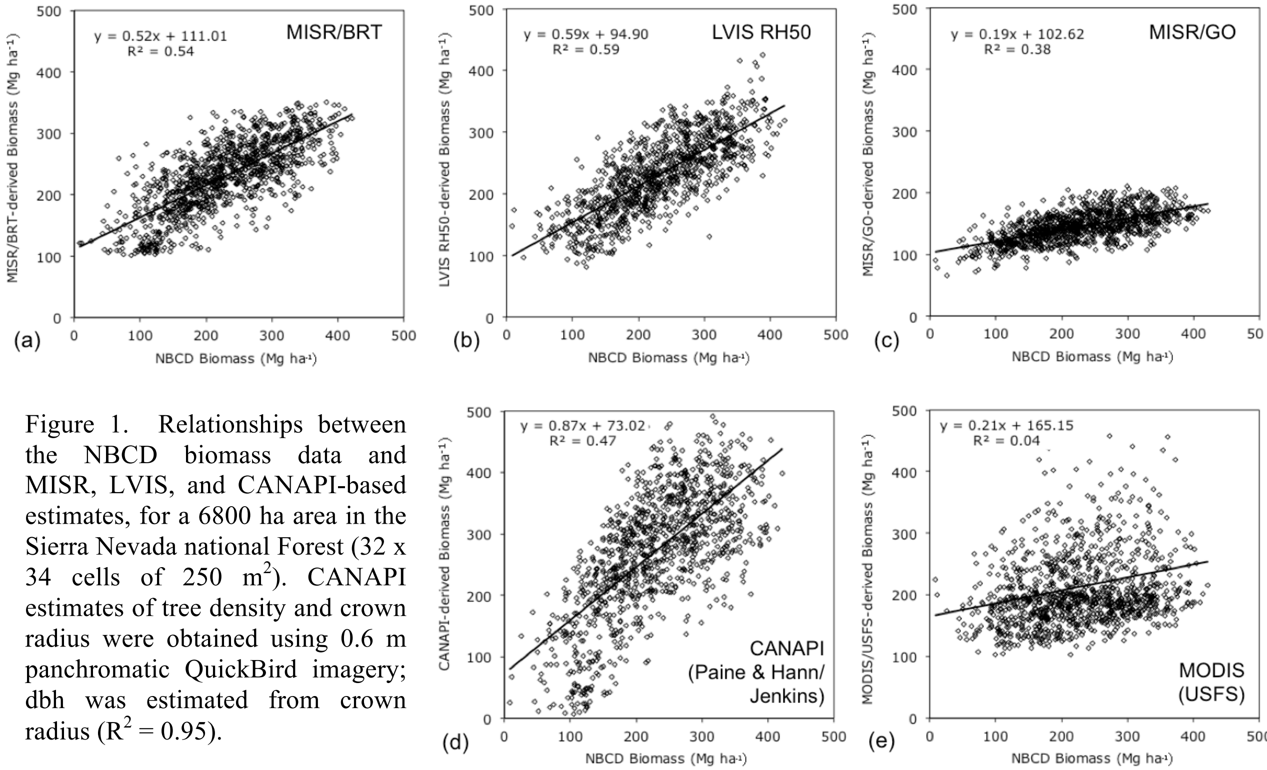

Figure 1. Relationships between the NBCD biomass data and MISR, LVIS, and CANAPI-based estimates, for a 6800 ha area in the Sierra Nevada national Forest (32 x 34 cells of 250 m^2). CANAPI estimates of tree density and crown radius were obtained using 0.6 m panchromatic QuickBird imagery; dbh was estimated from crown radius (R^2 = 0.95).

energy). To obtain biomass from CANAPI, DBH was first estimated from crown radius using relationships given in [10] for white fir (*Abies concolor*) and incense cedar (*Calocedrus decurrens*) that together account for ~86% of all tree species in the TEE plots. Biomass was then calculated using species-weighted coefficients for the Jenkins et al. (2003) equation [8].

Since correlations between both the original TEE and CANAPI estimates were very weak, new biomass estimates were calculated using the Teakettle Remeasure data for 2012 and the CANAPI estimates were re-done; the latter are referred to as CAN14.

Evaluations of AGB estimates over the 1088 cells were made with respect to the NBCD data (since aboveground biomass estimates from the TEE database of field measurements were found to have almost no correlation with NBCD or CANAPI-based estimates), noting that this does not imply that these are validated data.

3. RESULTS

The MISR/BRT and LVIS RH50-based estimates provided the best matches to the NBCD biomass estimates for this area. The MISR/GO-based values were underestimates, though it is worth noting that the model inversions were based on older data with flawed calibration. There was a moderately strong relationship with the CANAPI-derived estimates but a very weak one with the MODIS-derived estimates.

The distribution of MISR, MODIS, LVIS, and CANAPI-based biomass estimates yielded least-squares lines of best fit with respect to the NBCD estimates that have an intercept much greater than zero (~100 Mg ha^{-1}). This may indicate that NBCD underestimates biomass in the low AGB ranges and/or that the other methods underestimate biomass at high ranges.

The AGB estimates based on LVIS RH50 data were correlated reasonably well with NBCD, with R^2 = 0.59 and RMSE = 51 Mg ha^{-1}, compared with the next best result, MISR/BRT, with R^2 = 0.54 and RMSE = 55 Mg ha^{-1} (Figure 1). The CANAPI-based estimates had a somewhat lower correlation coefficient (0.47) and higher RMSE (87 Mg ha^{-1}) but this was far better than the MISR/GO or MODIS-based estimates (0.38, 108.2 Mg ha^{-1} and 0.04, 103.9 Mg ha^{-1}, respectively).

In terms of the spatial distribution of biomass at large scales (Figure 3), MISR-based maps are more closely related to the NBCD map than the MODIS-based one. The MISR/GO outputs were smoother than the MISR/BRT estimates that have a somewhat more quantized and less nuanced distribution.

Since it is important that all AGB estimates are evaluated against accurate reference data, the new Teakettle Remeasure version of the TEE database was examined, since it could allow more robust evaluations of all the remote-sensing-based AGB data sets examined here, using the TEE-to-CANAPI scaling protocol outlined above (and assuming the CANAPI estimates are also robust).

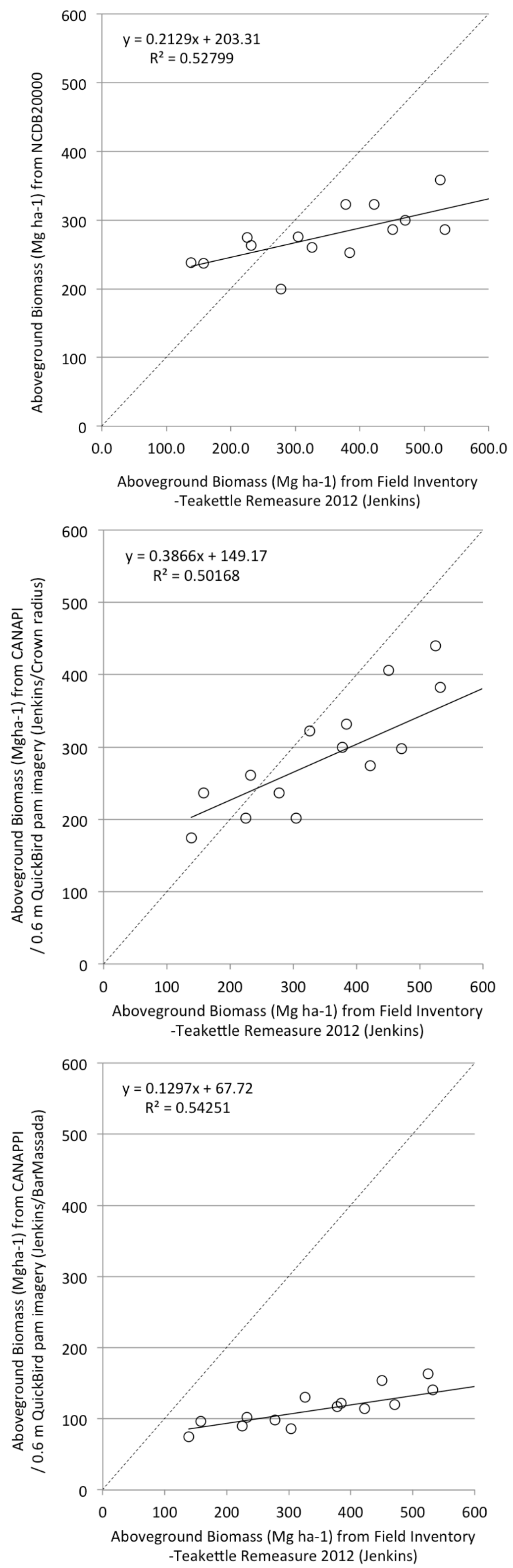

Figure 2 Aboveground biomass vs Teakettle Remeasure 2012 (“TERE”) (a) NBCD (b) CANAPI/QuickBird/Jenkins (dbh estimated from crown radii) (c) CANAPI/ QuickBird /Bar Massada (based on crown radii and heights).

Furthermore, if it can be shown that the NBCD data are robust, the MISR and MISR/MODIS-based estimates for 2000 can be assessed against these data; similarly, if the CANAPI-derived biomass estimates are found to be accurate, then AGB can be obtained wherever suitable high resolution imagery are available.

The NBCD estimates provided a much better correlation with the 2012 TERE estimates than the estimates based on the original TEE database (R^2 = 0.53, RMSE = 139 Mg ha^{-1}); as did the recalculated CANAPI estimates using Jenkins allometry [8] (R^2 = 0.50, RMSE = 123 Mg ha^{-1}). The CANAPI-based estimates using Bar Massada allometry [9] yielded a positive relationship (R^2 = 0.54) but were underestimates with RMSE = 275 Mg ha^{-1}, Figure 2).

4. CONCLUSIONS

AGB estimates based on the 2012 Teakettle Remeasure data showed a good relationship to the NBCD estimates, in spite of the ten year interval between them. The recalculated CANAPI estimates also agree with the TERE estimates, giving confidence that the NBCD data are reasonably robust in this area, even though the estimates for the Teakettle plots are off the 1:1 line (and further from it than the CANAPI-based estimates). The high RMSE of the CANAPI/Bar Massada-based estimates is probably owing to the lack of consistent height data from CANAPI (shadows often run into adjacent crowns).

If the NBCD NBCD data are taken as a baseline, then empirically-derived estimates from LVIS RH50 and MISR BRDF model kernel weights appear reasonably robust, while MODIS-based estimates were less so. The MISR /BRT AGB map is more closely related to the NBCD map than the MISR/GO or MODIS–based maps (Figure 3).

Further work is required to fully exploit the revised Teakettle database and understand the reasons for the relatively low correlation between CANAPI and TERE estimates. The new data may also be used to recalibrate relationships used to account for the background BRDF in geometric-optical model inversion against MISR or MODIS data sets.

5. ACKNOWLEDGMENTS

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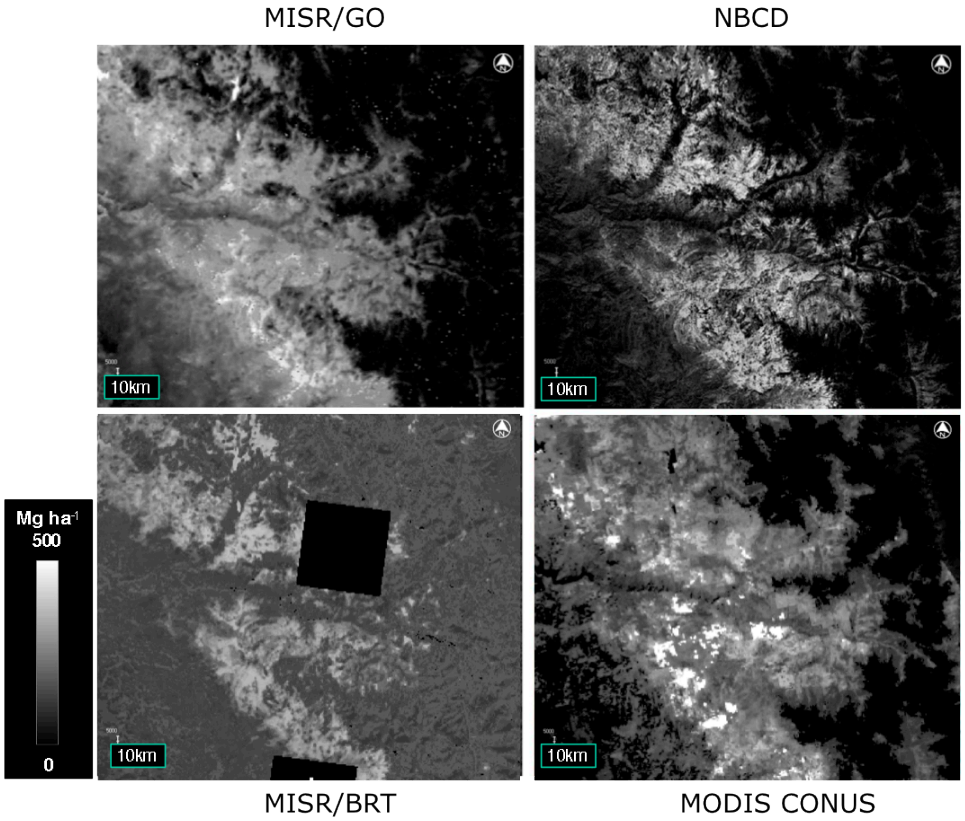

Figure 3. Aboveground biomass maps in the Sierra National Forest from MISR, NBCD, and MODIS. The missing data in the MISR/BRT map is owing to the use of MISR observations from a single Terra overpass.

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