Scaling Forest Biometric Properties Derived from High Resolution Imagery to the Amazon Basin using Moderate Resolution Spectral Reflectance Data

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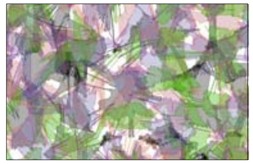

Abstract

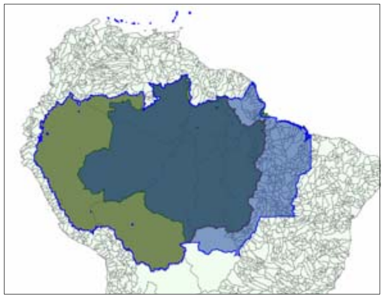

Figure 1. The Brazilian legal Amazon (darker blue) and the Amazon basin (green) outline shown against South American watersheds in the background (grey).

We are integrating field-measured tropical forest biometric variables with multi-scale remote sensing data from numerous sensors, for the purpose of characterizing and understanding patterns of forest structure across Amazonia. The Amazon basin contains the largest continuous tropical forest on the Earth (6 million km^2) and constitutes 40% of the remaining area for this ecotype. The dynamic processes of growth and disturbance are reflected in the structural components of forests. Because Amazonia contains a large stock of biomass and because unmanaged Amazon forests currently may be a significant sink for carbon, understanding Amazonian forest dynamics reflected in forest structure is important for understanding regional and global carbon and biogeochemical cycles. A lack of comprehensive estimates of forest structural properties across the Amazon basin currently limits our ability to map carbon balances in this region. Recent observations from plots and eddy flux towers of carbon sink activity in Amazonian forests could be caused by recovery from disturbance, Because many or most of the currently studied forest plots were not randomly selected, and because their geographic distribution leaves vast areas unstudied, regional remote sensing data is required to understand the rate and frequency of forest disturbance in Amazonia and the linkage of disturbance to ecosystem carbon flux. We are using high resolution optical data to quantify forest structural properties including stem frequency, crown dimensions, and canopy gap fraction. Next, we will extrapolate these estimates of forest structure from the local and regional scale to the basin scale by linking them statistically with synoptic reflectance data from moderate resolution sensors (MODIS/MISR). This will be done annually for seven years (2002-2008) using linear and non-linear statistical methods. The resulting temporal and spatial distributions of forest structural properties will provide insight into changes in carbon cycling at regional scales.

Background

Forests play important roles in the ecosystem functioning and biological diversity throughout the world (Spies 1998). Forest complexity and structure is the result of the autecological properties of species and responses of these species to patterns in space and time (Watts 1947). Components of forest structure include canopy geometry and tree architecture, size distributions of trees, and species diversity (Spies 1998). The history, function, and prediction of future states of forested ecosystems are understood by examination and understanding the forest structure (Spies 1998). Tropical forests are among the most structurally complex of all forested ecosystems (Whitmore 1982). Spatial and temporal variation in disturbances and growth influence forest types and are reflected in the spatial variation in forest structure (Tansley 1935, Whitmore 1982, Spies 1998).

Remote sensing aids ecological studies by allowing examination of vegetation over wide areas with repeated temporal sequences (Roughgarden et al. 1991).Remote sensing of tropical forest structure has been greatly advanced owing to new satellite platforms and sensors, as well as a current research activities (many from LBA) conducted in conjunction with field based measurements for comparison (Chambers et al. 2007). To understand forest structure and disturbance in Amazonia, as well as other tropical forests, a unique set of strategies tuned to observations of ecosystems dynamics, such as gap formation and blow-downs, is vital. In order to extract information related to changes in forest structure over a large region, we must devise ways to combine data from multiple sensors at multiple spatial and temporal scales.

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Our challenge is to plumb the information in the MODIS and MISR signals that relate to disturbances such as changes in gap frequency and structure. These structural properties are clearly evident in high resolution imagery (Palace et al. 2008). The process of relating high resolution satellite or ground data to moderate resolution reflectance data is mostly one of statistical or mechanistic relationship building. Moderate resolution data contain potentially rich information about sub-pixel characteristics via multiple bands and/or multiple angles. The unmixing of structural properties is enhanced with information from multiple angles, such as the data provided by MISR (multi-angle imaging spectral radiometer), also aboard the Terra satellite (Asner et al. 1998, Braswell et al. 2003a). These additional data channels, although not completely uncorrelated, provide additional quantitative perspectives on the observed target, which can be, for example, translated into distributions of mixtures of land-cover type (e.g. Braswell et al. 2003). In addition, the multivariate data can represent more subtle biometric characteristics such as mean crown width, which can be derived from analysis of high resolution data (Braswell et al. 2002). We propose a synergistic approach of moving from biometric field collected data and crown recognition high resolution passive optical data to regional estimates of forest structure using moderate resolution imagery

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Overview and Methods

We propose to synthesize, compare, and update existing measurements of Amazon region forest structural properties associated with natural forest dynamics. We will combine data from a large number of high resolution data sets (IKONOS/Quickbird/OV3) to produce and validate scaling relationships with satellite data that are available for the entire region at regular intervals, although with far less spatial resolution (MODIS and MISR). In particular, we will work toward mapping the spatial distribution of observable canopy structural properties (e.g. gap fraction, mean crown diameter, and stem density), as well as modeled biometric (e.g. DBH distribution, basal area, biomass, and tree height). Comparisons and interpretations based on LBA-related field assessments will play a central role. We will also examine forest dynamics across Amazonia using our estimates of forest structure, with respect to other data including soils and climate.

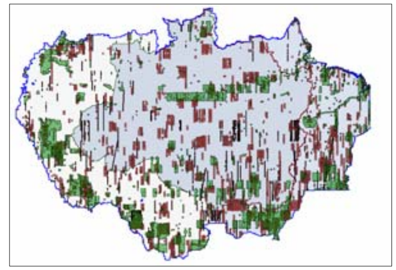


Figure 2. Archival images (<20 % cloud cover) available from three high resolution satellite sensors for Amazonia from 2000 through 2007. (Data provided by GeoEye and DigitalGlobe). The number of archived images with less than 20% cloud cover during this period is 11,058 for IKONOS (green), 4768 for Orb View 3 (brown), and 6,800 for Quickbird (red). More than 33% of Amazonia (combining the river basin and the Brazilian legal Amazon) has been imaged (<20% cloud cover).

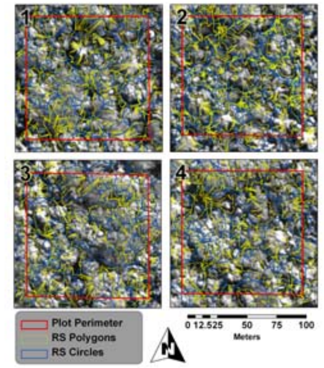


Figure 3. Application of our automated crown characterization program (uncalibrated) in a Bolivian Forest. Automated circle and polygon crown delineations in study plots 1-4 (top left corner) overlaid on the panchromatic Quickbird satellite image (from Broadbent et al. (in press)).

Work Plan
- ***Task 1. Satellite Data and Pre-Processing***
  - ***High Resolution Sensors***
  - ***LANDSAT/ASTER***
  - ***MODIS***
  - ***MISR***
- ***Task 2 – Compilation of Biometric Data of Forest Structure in Amazonia***
- ***Task 3 – High Resolution Image Analysis***
- ***Task 4 – Scaling Approaches Using Moderate Resolution Data***
- ***Task 5- Regional Analysis using Landsat Reflectance Data***
- ***Task 6 – Pan Amazon Basin Synthesis***

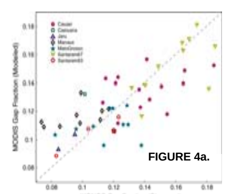
Questions

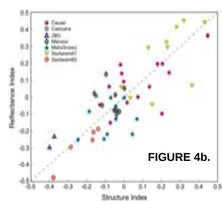
A. How well can multi-resolution optical reflectance data capture tropical forest structure across Amazonia?

B. How do crown width, forest height, and gap fraction vary across Amazonia?

C. Are estimates of forest structure from a multi-scale remote sensing analysis comparable with field based estimates of forest turnover and disturbance?

Preliminary Results





Preliminary results using data analyzed in Palace et al. (2008) from 51 one km^2 tiles from seven sites located across Amazonia. Both the linear regression for gap fraction (Model A) and the canonical covariates analysis for "structural index" (Model B) establish a significant fit between the MODIS reflectances and the IKONOS-derived canopy properties. From the coefficients on the left-hand side of Model B, we interpret the significance of the structural index. A high value of structural index indicates a low gap fraction, low crown area, and a high crown overlap. Based on the model coefficients, RED and MIR1 contribute the most to gap fraction and MIR1 and NIR contribute the most to the Structural Index. The models successfully capture the within scene variance for some scenes (Figure 4; e.g. Santarem 67 and Cauaxi) but not for others (e.g. Manaus). When extrapolated to the forested area within the Amazon Basin, the gap fraction model predicts high values along rivers and in the southern part of Para, and low values in the northwest section of Amazonas (Figure 5a). The structural index is high in the state of Acre and low along the river and in the south of Para (Figure 5b). In the spatial extrapolation, gap fraction and structural index are correlated (R^2=0.8). For comparison, we have included EVI, a commonly-used vegetation index, for the basin (Figure 5c). EVI is weakly correlated ($R^2 < 0.3$) with canopy measures estimated and extrapolated using IKONOS.

Model A: Multiple linear regression using stepwise removal (note that R_{GRN} and R_{MIR2} are not included),

$$GapFraction = 0.22 + 1.29R_{BLU} - 4.81R_{RED} + 2.32R_{NIR} - 3.02R_{MIR1} + 2.80R_{MIR3}$$

where GapFraction training data are derived from IKONOS and R_i values are MODIS reflectances. R^2=0.56 and $P<0.05$

Model B: Canonical Covariate Analysis for Structural Index, *StructIndex=ReflectanceIndex*,

$$-0.59C_{Gap} + 0.37C_{Overlap} - 0.71C_{CrownArea} - 0.12C_{\#ofTrees} =$$
$$-0.09R_{BLU} - 0.03R_{GRN} + 0.15R_{RED} - 0.64R_{NIR} + 0.74R_{MIR1} - 0.08R_{MIR2} - 0.08R_{MIR3}$$

where C_i values are structural information from IKONOS data and R_i values are MODIS reflectances. R^2=0.80 and $P < 0.001$

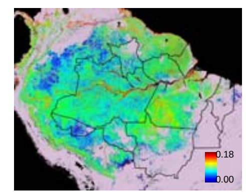


FIGURE 5a. Estimated gap fraction based on MODIS and IKONOS

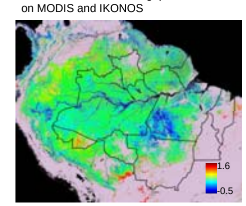


FIGURE 5b. Structural Index based on MODIS and IKONOS

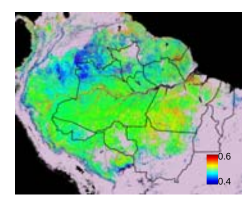


FIGURE 5c. Enhanced Vegetation Index (EVI) for comparison with **b** and **c**