Remote Sensing of Mangrove Structure and Biomass

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Introduction

Mangrove and Wetland forests are one of the most important ecosystems from biodiversity, carbon sequestration and economical standpoints. By quantifying the amount of above and belowground biomass and consequently carbon stored in forest ecosystems, we are able to derive estimates of carbon sequestration, emission and storage. Quantifying mangrove extent, structure and biomass is also of great importance for addressing climate change adaptation and mitigation. Mangrove forests, in addition to providing habitat and nursery grounds for over 1300 animal species, are also an important sink of carbon. Although they only constitute about 3% of the total forested area globally, their carbon storage capacity-in forested biomass and soil carbon- is greater than that of tropical forests (Alongi, 2002; Lucas et al, 2007). In addition, the amount of mangrove carbon- in the form of litter and leaves- exported into offshore areas is immense, resulting in over 10% of the ocean’s dissolved organic carbon originating from mangroves (Dittmar et al, 2006).

Because of the difficult environmental conditions of constant or near constant inundation by water, the monitoring of these ecosystems from field data alone is very difficult. Remote Sensing has been extensively employed to measure wetland biomass. In this presentation, we review the most up-to-date methodologies for estimating mangrove structure (height and density) and biomass.

Methods

There are two distinct methodologies for estimating mangrove biomass from remote sensing data: 1) by using passive optical data and average biomass values and 2) through height or volume measurements from active LiDAR and radar instruments. We concentrate on measurements from active instruments from airborne and spaceborne platforms. In particular, we will concentrate on mangrove forest height and biomass measurements from:

1) Polarimetric SAR data from the Japanese ALOS/PALSAR and the NASA UAVSAR
2) Interferometric Synthetic Aperture Radar data (InSAR) from the Shuttle Radar Topography Mission (SRTM)
3) Lidar data from the GLAS instrument and airborne platforms

Optical (or passive) remote sensing uses visible and near-infrared reflectance from the earth to form images. This type of remote sensing data forms the basis for much of current global scale vegetation mapping due to the large number of sensors such as Landsat, MODIS, ASTER, IKONOS, etc., the greater ease of image interpretation and
increasing numbers of freely available data archives such as Google Earth™ software. Optical measurements have been widely used in studies that link above ground biomass measurements from the field to satellite observations. The main challenge with optical data is the presence of persistent cloud cover, particularly in tropical regions, which make the use of optical data difficult. The simplest approach to derive biomass from this type of data is to derive landcover or forest type using optical data, then assign a value to each landcover type. In the case of mangroves these types could be determined by zonation, canopy shape, and average density per pixel. To calculate biomass, the total area of each landcover type is then multiplied by the value. While this is the simplest method to estimate AGB, it does not take into account variations of structure and the error is great when looking at very large or very heterogeneous forests (Goetz et al, 2009).

**Polarimetric SAR**

Synthetic Aperture Radar images are not affected by cloud cover, which gives SAR data a distinct advantage over optical images in tropical regions. Recent advances in SAR technology and the development of multiple polarimetric SAR instruments such as the JAXA ALOS/PALSAR and NASA UAVSAR are greatly increasing the mapping capability in mangrove areas.

SAR uses microwaves emitted by an instrument and reflected by the earth surface to form an image. SAR imaging, because of its penetration capability and sensitivity to water content in vegetation, is sensitive to the forest spatial structure and standing biomass in ways not possible with other active sensing methods. Polarized microwave signals can be horizontally (H) or vertically (V) transmitted and received, resulting in co (HH and VV) and cross (HV or VH) polarized data. The backscatter coefficient of a forest canopy depends upon the interaction of microwaves with leaves, branches and trunks. Longer wavelengths (L- and P-band) are able to penetrate the canopy and are scattered by larger components, such as the trunk and the ground and thereby increase the returned signal. In forests, there is a positive relationship between measured backscatter and aboveground biomass. However this relationship only exists up to a threshold biomass value after which the backscattering coefficient saturates. The threshold is dependent on the polarization and wavelength of the radar signal. In mangroves, P-band frequency and HV polarization has been found to have the highest sensitivity to biomass, with a saturation level of 160 Mg/ha, followed by L-HV (140 Mg/ha) and C-HV (70 Mg/ha) (Mougin, 1999; Proisy, 2002, Lucas, 2007). Preliminary studies have shown the use of L-band data from to estimate forest biomass and structure (Lucas, 2007). In addition to forest structure and biomass measurements, SAR data can also be used for land cover classification and land cover change measurements.

**InSAR and LiDAR**

Forest structure (in terms of height and density) is a direct measurement that can be used to derive biomass, especially in high biomass systems, such as mangroves. To measure tree height using radar data, a technique known as Interferometric Synthetic Aperture
Radar (InSAR) is used. InSAR estimates the tree height by using interference patterns between two radar signals in order to derive terrain height. To derive biomass, the tree height is directly correlated to DBH and biomass through allometric equations. To quantify forest structure and make estimations of biomass in mangroves, the Digital Elevation Model (DEM) derived from the Shuttle Radar Topography Mission (SRTM) has proven most successful. We have used the SRTM DEM in combination with field validation data and Lidar to estimate mangrove forest 3-D structure and aboveground biomass in the Americas and Africa (Fatoyinbo et al, 2008; Fatoyinbo and Armstrong 2010).

The height measurement that can be derived from InSAR data is the sum of the tree canopy height and the height of the ground. In forests where there is significant topography, the height of the ground has to be subtracted before calculating the height of the canopy. In mangroves however, the topography is negligible and the ground is considered flat.

To calibrate the InSAR data, “real” canopy height measurements, from field measurements or LiDAR data have to be used. LiDAR (Light Detection and Ranging) measures vegetation height at very high accuracy (up to millimeters) and is considered the most accurate and consistent measurement of vegetation structure because of its systematic measurements and because field-based measurements are often limited in amount and spatial distribution. The ICESat/GLAS (Geoscience Laser Altimeter System) sensor is a spaceborne waveform LiDAR system, which continuously records the amplitude of the lidar pulse returned through the different layers of the forest canopy. This provides a measurement of the vertical structure of the forest. LiDAR is only able to measure a small sample of the total forest area, and therefore it is generally used to calibrate other datasets. The GLAS data provides the best alternative for global canopy height calibration and is freely available from the National Snow and Ice Data Center (http://nsidc.org/data/icesat). An example of GLAS shots over the mangroves of the Niger Delta in is presented in Figure 1. Figure 2 shows the mangrove height map of Nigeria and Cameroon derived from SRTM and GLAS.

Results and Discussion:

We have developed mangrove height and biomass estimates for Indonesia using SRTM and ICESAT/GLAS data. A similar map of mangrove height for Nigeria is shown in the figure below. This map will be available for distribution, discussion and validation. We will also discuss the availability of remotely sensed data for the monitoring, reporting and verification processes. In addition, we will also discuss field measurements that are necessary for the calibration of the remotely sensed data. Mangrove height and biomass maps for Africa and South America are available online at www-radar.jpl.nasa.gov/coastal/.
Figure 1 Example of the available GLAS footprints available over the mangrove forests in the Niger Delta. The GLAS footprints are shown in red, mangrove forests in bright green, the ocean in blue and other landcover in black.

Figure 2 Height map of mangrove forest in Nigeria and Cameroon derived from SRTM and GLAS.
References:


Lucas, R.M., et al., 2007. The potential of L-band SAR for quantifying mangrove characteristics and change: case studies from the tropics. Aquatic Conservation: Marine and Freshwater Ecosystems, 17, 245,
