Biomass Estimation and Mapping
From Carbon Policy to Technical Training

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Workshop Manual
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Introduction

Tropical forest biomass and deforestation play a central role in the global carbon cycle which in turn affects our climate. As part of the UNFCC negotiations, a new carbon finance mechanism known as REDD has been adopted to reduce emissions from deforestation in the tropics. At various levels of REDD “readiness,” however, most tropical countries are not well prepared and, in order to set up their REDD strategies, they are in need of information to identify the best techniques and tools to accurately map and monitor aboveground biomass loss and gain. To assist tropical countries with their REDD carbon mapping goals, we have been developing methods and teaching materials to facilitate carbon mapping in order to implement REDD projects.

This manual was written as a reference for a remote sensing workshop held in Tanzania during November 2012 organized by the Woods Hole Research Center (WHRC) and the JGI. It is intended as a supplement to presentations and exercises that will be provided during the workshop. Most of the initial teaching material was developed as part of the WHRC pantropical scholars program with AMNH.

The manual’s various sections provide a general overview of biomass, why forest biomass mapping is important, and how to map forest biomass and emissions from deforestation from field surveys to processing remotely sensed data to estimate biomass and emissions. Each section will be covered in detail during the workshop and is accompanied by practical exercises.

A method developed by WHRC which uses aircraft and satellite-based lidar sensors to complement forest inventories will be described in detail using various imagery. But all the methods described in the manual rely on field surveys to measure the biomass of individual trees; those measurements are then used to derive estimates of biomass for a specific area (plots) or combined with remote sensing to provide biomass maps. Lidar information is being used increasingly for biomass studies, and during the workshop we will show how lidar measurements from satellites can be used to compliment field survey data.

The manual also provides information on where to find different types of satellite-based imagery to create maps of biomass at local through global scales and also a simple GIS method to estimates carbon emissions. Practical work will provide information and experience necessary to download and use freely available data and free software to process the imagery.

Finally, this manual and all of the workshop presentations, exercises and data will be available on the WHRC FTP server through the URL: http://chronos.whrc.org. The user name is: Workshop. The password is: User2012.

When any of this material is used, please acknowledge “WHRC Pantropical Program” and let us know by email if the information provided for your work was useful. The email address is: pantropical-network@whrc.org

Why is above-ground forest biomass important?

Forests cover roughly one-third of the Earth's land area and store more carbon than any other terrestrial ecosystem. Trees store Carbon (C) in their biomass by removing carbon dioxide CO₂ from the atmosphere, a process called carbon sequestration, through photosynthesis. When a tree dies, the
carbon stored in its tissue is released to the atmosphere, slowly through decomposition or more rapidly through biomass burning.

With the use of fossil fuels for transport, heating, cooling, or the clearing of forests for agriculture (deforestation), or the thinning of forests for fuel wood or timber products (degradation), the concentration of carbon-based greenhouse gases (GHGs) such as carbon dioxide CO$_2$ and methane CH$_4$ is increased globally. As the word greenhouse gas indicates, these GHGs change the properties of the atmosphere, trapping heat and leading to the increase in temperatures worldwide that is affecting our climate. The role of forests as a carbon reservoir is very important in the carbon cycle. Carbon is an element that humans can manage to some extent by controlling how much is stored through carbon sequestration or emitted through deforestation and the burning of fossil fuels. When trees are removed from an ecosystem through cutting or burning, much of the carbon that was stored is released into the atmosphere where it accumulates as a greenhouse gas. Researchers have determined that emissions due to deforestation and forest degradation account for roughly 15% of the global carbon emissions that are released on an annual basis. In some years, emissions from forest clearing and degradation can be higher than emissions from the global transportation sector.

It is therefore very important to measure above-ground biomass to better estimate carbon emissions and better understand the carbon cycle, especially in relation to forests dynamics. Above-Ground Living Biomass (AGLB) from trees usually holds the greatest weight of terrestrial carbon and is what most readily contributes to carbon emissions when a tree is cut or burned. From a practical standpoint, Below-Ground Biomass (BGB) is generally estimated as a percentage of AGLB. To address the difficulty in measuring below-ground biomass, researchers have developed conversion factors that can be used to estimate below-ground biomass from above-ground biomass figures.

What is forest biomass?

Carbon/biomass is a key element in all living organisms, and it is this element that is cycled in and around the Earth. In simple terms, biomass is the weight, or mass, of the collection of all living material of an organism. Above-Ground Living Biomass (AGLB) includes living material on or above the Earth's surface, and Below-Ground Biomass (BGB) includes all living material below the Earth's surface (e.g., roots, micro-organisms). Ecologists also categorize biomass by specific types of organisms that are being considered, such as animal biomass or phyto biomass.

Climate scientists as well as foresters are interested in the quantity of carbon in forests (the sum of all the biomass of trees above a certain diameter and height). To determine the weight of carbon in vegetation, it is common to divide the dry biomass by two. For example, a forest with a dry biomass of 100 tons per hectare would have 50 tons or carbon per hectare.

$$\text{Biomass (t/ha)} = 2 \times \text{Carbon (t/ha)}$$

The remainder of this document will focus on above-ground forest biomass. Our definition of “forest” includes woody vegetation with a diameter at breast height (1.3 meters above the ground) of 5 centimeters or greater.

How biomass is estimated?

There are many methods that have been developed to estimate forest AGLB. The most accurate is to cut down all the trees in an area, dry them, and then measure the weight of the leaves, branches, and
trunks of all the trees and convert it to carbon. This is impractical to do for more than a few trees because it is both extremely time consuming and destructive. Instead, researchers have used this destructive approach to create relationships between forest tree metrics such as Diameter at Breast Height (DBH) and tree height and their biomass content. These relationships are used to create allometric equations that calculate biomass by using one or more specific tree characteristics that are easy to measure in the field (e.g., DBH, tree height) or by using remote sensing derived metrics such as tree crown diameter and tree height.

**Sampling framework**

Before collecting data to calculate ABLB, it is necessary to determine which method will be used to determine the actual biomass. In most cases, the forest metrics used in a particular method will need to be measured in the field. The two most common metrics measured in the field are DBH and tree height. Most forest services have developed their own approach to balance time, cost, and accuracy, but the estimation of forest biomass always starts by developing a sound statistical sampling framework. Traditionally, tropical countries have been estimating forests’ standing biomass using a representative number of forest inventory plots to reach a required level of accuracy. Once the sampling framework has been established, trees must be measured in a given plot for their DBH, height or both. The measurements are then converted to biomass using allometric equations. A specific protocol will be developed indicating which tree metric(s) will be measured, how those metrics will be measured, and the sampling framework for collecting appropriate data to build and test a forest biomass model. The tree metric(s) for use will largely be determined by the allometric equations that are available for a specific study region.

**Allometric equations**

Allometric equations are based on destructive methods that involve cutting the tree and weighing all parts of the tree that are above the soil surface (e.g., trunk, branches, leaves). These measurements are very time consuming and rarely done. Fortunately, over the years in many regions of the world these have been done in the past to develop allometric equations for different forest types, species and tree types and metrics (DBH or height, etc.). Allometric equations have been developed for specific regions of the world (wet, humid, dry tropics) and also for specific types of forests. Some equations are quite specific and others are very general, for example, by biome. The most reliable equations are developed for specific sites and species, but often these specific equations are not available and more general equations are needed. A good place to start for identifying the best allometric equations for a specific study area is to inquire with the local forest department and/or university forest departments. Even if the equations are not available through the forestry department, these offices will likely know which equations are available. If regional or global equations are necessary, it may be necessary to get them from reports or peer-reviewed literature.
Figure 1: Compilations of existing allometric equations to convert DBH measurements to dry biomass from 2,410 measured trees across the tropics- WHRC

Figure 2: Illustration of the distribution of biomass derived from field measurements
**Lidar information**

Until recently, lidar sensors for biomass estimation have been limited to aerial platforms for forestry applications. Remote sensing such as lidar can measure tree height or canopy structure and can provide estimation of biomass from a specific tree to a larger plot. More recently the **Geoscience Laser Altimeter System** (GLAS) has collected global lidar data sets. (The GLAS instrument failed in October of 2009, but a new sensor is being planned for launch.) Airborne lidar systems range from profile systems that are capable of recording tree heights along a transect directly beneath an aircraft to scanning lidar systems that are capable of recording a number of points (samples) sufficient to create an image. From each point, information can be used to characterize sub-canopy vegetation and vertical structure. The collection of airborne lidar data is prohibitively expensive for many projects, but the cost of lidar surveys is decreasing as companies compete and new systems are developed.

Lidar is an active sensor that fires a laser (beam of Infrared light) to the Earth's surface and measures the time it takes for the laser beam to return and its strength. The simplest lidar systems measure only the first part of the laser beam that is reflected back to the system's sensor; more complex lidar systems measure multiple returns to the sensor (e.g., first and last return) or even the entire wave (full waveform) of returning light. For example, using a first return system over a forest would provide data about the top of the canopy. Because some beams also hit the ground, it is possible to estimate tree height by the difference between the ground and the top of the forest canopy. Using a first and last return system, data is provided for the top of the canopy (first return) and the ground (last return), giving a more direct measurement of tree height. Full waveform lidar provides data from the ground, from inside the canopy (based on understory structure), and from the top of the canopy.

**GLAS overview and metric descriptions**

The GLAS lidar system is mounted on the ICESAT satellite and collects full waveform data. These data can be processed to generate several dozen lidar metrics that can be used to characterize biome, forest type, and structure (tree height / forest canopy). GLAS was active between 2003 and 2009. A new sensor is planned to be launched soon.

**Figure 3** illustrates a waveform collected from a full-waveform lidar such as GLAS. The right side of the figure shows a few of the metrics that are calculated based on the shape (peaks and valleys height/depth and width) of the waveform.

In addition to the GLAS metrics labeled on figure 3, several other metrics are calculated by WHRC researchers for use in modeling forest characteristics such as structure and biomass. Below is a list of some of the variables that they calculate:

- Roughness
- Slope of the ground-based
- Energy of the transmitted and returned pulse
• Energy of the last peak of the return pulse
• Length of the leading and trailing edge of the waveform
• Number of peaks
• Height in meters where 10% - 100% (in 10% increments) of the total energy has been reached
• Area under the waveform
• Ground and canopy energy
• Canopy depth

Calibrating GLAS data using field data

Designing and implementing an efficient and effective sampling strategy is a prerequisite for both traditional biomass estimates and those using remotely sensed datasets. Since GLAS metrics do not directly measure biomass, we need to develop a model to estimate biomass by determining the relationship between GLAS metrics and actual above-ground forest biomass. To accomplish this, we need to collect forest inventory data from plots that correspond to the location of a GLAS laser beam, a GLAS shot, and hit measurements on the ground. Next, the inventory data is converted to biomass using allometric equations. The size of the footprint of a GLAS laser beam on the ground is roughly 70 m in diameter. Many plots are measured to train a model to calculate the GLAS-biomass relationship. The number of plots, sampling framework for representation, is crucial.

The WHRC uses regression or the random forests algorithm models to predict biomass from GLAS metrics. The input to the algorithm is biomass measured in the field (the response variable) and several metrics from the GLAS shot (the predictor variables) that correspond with plots where the biomass data were collected. The output from the model is the relationship between the GLAS metrics and above-ground forest biomass. This relationship is then used to predict biomass for all of the GLAS shots covering the area of interest. This creates a data set of several thousands or even millions of biomass estimates distributed throughout a study area that would be impractical or impossible to collect solely using field methods. This large data set of biomass samples can then be used to create a biomass map using image data.

The WHRC field survey approach

WHRC has developed a manual describing in detail how to collect forest inventories for the GLAS shot and has also developed a field protocol. This field guide and the protocols are available in different languages and can be downloaded at no charge from the WHRC website:
http://www.whrc.org/resources/fieldguides/carbon/

Satellite-based biomass mapping

As computers and remote sensing information have become more available, mapping forests and their associated carbon stocks are becoming affordable to most countries. Most biomass maps are created using a combination of field surveys and remote sensing information. Those methods can involve the use of aerial photography, satellite imagery, radar data, or lidar data or a combination of these. One of the earliest methods used for mapping biomass was to first create a land cover map and then assign an
average biomass value to each land cover type. This indirect approach is still quite popular, but it has some fundamental problems. First of all, it works on the assumption that there is little variation in biomass throughout an individual land cover class. This is rarely the case since most land cover classes do not take density or maturity of tree stands into consideration; thus there can be a great deal of variation in biomass within individual land cover classes. Another problem is that it can be very time consuming to collect data for individual land cover classes. To develop a robust average biomass value for each land cover class, it is necessary to sample a sufficient number of plots within each land cover class in a given study area to calculate an accurate average biomass figure for each class. This could require hundreds of sample plots for each class.

It would be ideal to use remote sensing methods to directly measure biomass. While it is currently not possible to do this, there are some remotely sensed direct measurements than can be correlated to biomass. This more direct approach is likely to be the most robust method for mapping and monitoring above-ground forest biomass. The specific methods that are used depend largely on the size of the region being mapped and the type of data available. A huge advantage of using a direct remote sensing approach is that differences across similar land cover types are mapped as biomass is predicted at the pixel level.

**Sampling strategies and data for measuring above-ground forest biomass**

The sample framework required to collect data to calibrate and validate a biomass model must be carefully designed in order to create a biomass map of sufficient and known accuracy. The goal of a sampling design is to minimize bias and reach a predetermined level of accuracy, and it is composed of the following four qualities: number of samples, distribution of samples, sample plot size and shape, and a measurement protocol. There are a number of publications and documents that provide a tremendous amount of information about how to develop an optimum sampling design, but compromises must often be made due to practical considerations, such as limited time, money, or access. It is always recommended to consult with a statistician who is knowledgeable with sampling frameworks to discuss the suitability of any sample design before it is implemented.

**Model calibration**

Two primary reasons for measuring above-ground forest biomass are to collect data sets for the calibration of the satellite or airborne measurements “model calibration” and to use field data sets to evaluate the results of “model validation” for accuracy. Model calibration involves developing a relationship between actual measurements and a set of predictor variables from a remote sensing sensor. For biomass mapping, the predictor variables might include satellite imagery, lidar data, terrain and other environmental variables such as elevation, slope, aspect, soil characteristics, and climate.
GLAS waveforms illustrations are different according to levels of biomass, respectively 205, 78 and 30 t / ha. The first step toward mapping biomass is to explore the relation between GLAS metrics with biomass estimates from co-located field measurements.

**Figure 4**: GLAS waveforms illustrations are different according to levels of biomass, respectively 205, 78 and 30 t / ha. The first step toward mapping biomass is to explore the relation between GLAS metrics with biomass estimates from co-located field measurements.

**Model validation for biomass maps**

After a model is developed and a forest biomass map has been created, the map must be tested to **determine the accuracy of the biomass estimates**. This validation step involves comparing a sufficient number of predicted biomass values with corresponding field-measured values that represent actual or true biomass. Accuracy estimates can be a simple percentage, such as 75% accurate, if categorical data are mapped, or if the predicted values are continuous data (i.e., biomass value for each pixel), the error information can indicate the average difference between the actual and predicted values (mean square error) or other measures of how well model predictions match observed (actual) values.
It is important that data used to assess the accuracy of model predictions (data for validation) are independent from the data used to calibrate the model (data for calibration). One would expect that predictions made from data that were used to calibrate a model would be quite accurate even if the model didn't perform well when used for predictions outside of the training data set. Using independent data provides a true test of the model's predictive power.

In some cases the sampling framework involves two stages. The first involves using field measurements to create a relationship between actual biomass and a set of remotely measured variables such as point data derived from full waveform lidar (e.g., data from the GLAS sensor on-board the IceSat satellite). In the second stage, biomass estimates derived from the remotely measured point variables are used as training data to calculate the relationship between above-ground forest biomass and the variables (satellite image bands and environmental variables) used to create a biomass map.

**Primary types of imagery to derive biomass maps**

Two broad categories for remotely sensed data that can be used for biomass mapping are passive and active sensors. A sensor is passive if it relies on energy from the sun to illuminate a target (such as a forest) and the reflected energy is then measured and recorded by the detector in the form of an image, much the same way a digital camera records an image. An optical sensor is limited to recording light energy that ranges from the ultra-violet wavelength to the middle-infrared wavelengths (show EM spectrum). A limitation to using passive optical systems for mapping forest biomass is that the light measured by the sensor is limited to light reflected from the forest canopy, recording little if any direct information from the understory.

An active sensor on the other hand provides its own source of energy to illuminate a target. The two most common active sensors are radar and lidar. Radar emits microwave energy and lidar systems use a laser to emit visible or near-infrared light. Both radar and lidar systems record the time it takes for the signal to travel from the instrument reflect off of a target and then be recorded by a detector. The intensity of the return is also recorded, and in the case of radar the polarity of the emitted energy can be controlled and the detected signal can also be recorded using specific polarizations.

An advantage of using active systems is that they can measure properties of trees below the canopy. Some radar systems operate at a frequency (wavelength) that is able to penetrate a tree canopy and in some cases travel through a forest canopy to or even beneath the soil surface (Figure 5). Lidar on the other hand uses optical wavelengths of light that cannot pass through leaves or branches, although some of the laser pulses are able to pass through small gaps in the canopy and reflect off of the soil surface, branches, leaves and sub-canopy shrubs.
Figure 5: The longer the wavelength (λ) of a radar system, the deeper it can penetrate into a forest canopy

In addition to the selection of sensors, there are different options available for platforms to hold the sensors. Sensor platforms can be ground-based, such as hand-held devices and devices mounted on tripods or poles. Aerial platforms traditionally included manned fixed wing aircraft and helicopters also include unmanned platforms, such as kite, blimps, and radio controlled aircraft. For large areas or global mapping, satellite platforms are usually used. Methods for using different sensors have been developed for a range of biomass mapping applications, and this is an area of active research with new methods and instruments being developed. It is beyond the scope of this document to discuss all the options in detail, but an overview of some of the possibilities is presented. The selection of the platforms and sensors used for a specific project depends on budgets, study area location, and characteristics (accessibility, terrain, cloud cover, size of the area), available image processing expertise, and the goal of the project (mapping deforestation or biomass or mapping changes in biomass).

Passive optical sensors are used with all of the platforms listed above. These sensors range from simple hand-held cameras to sophisticated satellite-based sensors capable of acquiring high-resolution (1 meter or finer resolution) data on a daily basis using several or even hundreds of different bands (hyperspectral imagery). The indirect approach mentioned above that assigns biomass values to land cover categories is quite popular, but increasingly, projects are producing maps by correlating actual biomass values to the spectral information contained in the satellite images. The data used to train the models to correlate actual biomass measurements with the image data can be collected from field plots or from data collected using other remotely sensed data such as tree heights and vegetation structure acquired from lidar or radar, or crown diameter data collected from high resolution satellite imagery or aerial photos.

Radar sensors can be carried on aircraft, but satellite-based radar systems are more common, and in recent years a number of high-resolution radar from the C band to P band have become available. Systems that combine different sensors are being developed for both aerial and space-based platforms.
It is likely that these combined sensor systems will provide the best capability for mapping and monitoring biomass. This research is going on in the commercial and governmental sectors.

**Overview of image options**

Mapping above-ground forest biomass usually requires the use of remotely sensed data suited to the study area and within the human and financial resources available for the project. A range of remotely sensed data collected from hand-held digital cameras to scanners on-board satellites can be used for biomass mapping and monitoring. Historically, remotely sensed imagery has been used to create a series of map products such as biomass, land cover, and productivity, and it is also used to monitor changes over time. There are several archives of imagery that are available free of charge or for relatively little cost, and these are increasingly being used to map above-ground biomass around the world. Information on how to access different types of freely available satellite image data is noted at the end of this section.

**Passive optical**

Common passive sensors include Landsat TM & ETM+, MODIS, ASTER, SPOT and many others. Most of the passive sensors used for mapping above-ground forest biomass are optical sensors that are sensitive to visible and infrared wavelengths of light. Optical sensors have been used from the early days of remote sensing and are still used today since they are easy to process and interpret, and they are effective at providing different metrics related to vegetation type, productivity and extent. Working in the optical range of wavelengths also poses some problems related to clouds and haze, especially in the humid tropics, that tend to degrade the energy as it passes through the atmosphere toward the ground and back to the sensor.

**Radar**

Radar imagery is available from several different satellites and some aircraft sensors, and these data are increasingly used for classifying land cover. A team of researchers at the WHRC has processed complete coverage of RADAR imagery for the tropics from recent imagery provided by the Japanese Space Agency (JAXA).

**Satellite image preprocessing overview**

When we receive remotely sensed image data, it may be necessary to do some preprocessing before the imagery can used in a model, and some preprocessing may be done before receiving the imagery. The extent of preprocessing that has been done to an image that one receives should be documented in the image's metadata. Some products, such as most MODIS products, have undergone extensive processing before they are made available to the public in standard formats and georeferencing. Imagery such as Landsat TM and ETM+ are now precision orthorectified, so they should overlay nicely with other georeferenced data; however, radiometric processing is usually limited to recording radiance at the sensor. Corrections to reduce radiometric distortions related to terrain and atmospheric conditions such as haze and clouds often need to be done by the end user.

**Finding and downloading MODIS NBAR imagery**

Using remotely sensed imagery to map large areas is facilitated through the use of data that covers a large area and has been processed to provide calibrated data with a frequent repeat cycle. NASA's MODe rate-resolution Imaging Spectroradiometer (MODIS) Reflectance sensor records an image with a
swath width of 2330km and it is able to view the entire surface of the earth every one or two days. For mapping land cover or above-ground forest biomass it is helpful to work with surface reflectance data. The MODIS Nadir BRDF-Adjusted Reflectance (NBAR) Product was created to address this need. One of the NBAR products is produced with a 500m resolution using 16-day composites (MCD43A4). A 16-day composite image is created by using the best data for each pixel over a 16-day period, so that haze and clouds are largely removed from the images. Only persistently cloudy (i.e., cloudy for all 16 days) areas will have clouds in the NBAR product. Each pixel in an NBAR image provides the estimated surface reflectance for that 500m² area as if it were acquired from a nadir (directly under the satellite-based sensor) view.

The MODIS NBAR data are distributed using the Hierarchical Data Format (HDF-EOS) and the standard projection is Sinusoidal. Not all geospatial processing software can read and process these data, so NASA provides some utilities to convert the imagery into a format that is suitable for most software. The tools that we will use are available from the USGS Land Processes Distributed Active Archive Center (LP DAAC) website: https://lpdaac.usgs.gov/get_data/. If you are interested in downloading NASA or USGS data, it is a good idea to become familiar with the tools on this website.

Sites that offer access to a wide variety of satellite imagery including MODIS data include the following:

- Reverb (formerly WIST): a web-based client to search and order earth science data from various NASA and affiliated centers.
- USGS Global Visualization Viewer (GloVis): An online search and order tool for a wide variety of satellite data.
- LP DAAC Data Pool: the publicly available portion of the LP DAAC freely available online holdings.

These web sites allow you to create accounts that will save your searches. Each of these sites also has help information and user guides to help you learn to select, order and download data. Spending a few minutes to learn how to use the site will save you time and frustration.

In addition to these online archives that allow you to download imagery, there is the MODIS Reprojection Tool (MRT) to prepare MODIS images for use with most remote sensing and GIS software. The web-based version of MRT is available at: https://mrtweb.cr.usgs.gov/. You will need to create an account to use this tool. The MRTWeb tool is designed to have a user interface similar to the GloVis web site and it allows you to select MODIS images, process them to your specifications and download the processed image for use.

If you prefer to download the unprocessed MODIS products you can use the desktop MRT software that can be downloaded from the LP DAAC website: https://lpdaac.usgs.gov/tools/modis_reprojection_tool. After installing the software you can process your MODIS data on your desktop. The desktop version of MRT provides the capability of batch processing many images through the use of scripts. This can be a huge time-saver when many images need to be processed. There are user guides available to learn the steps required for using the MRT tools:

MRTWeb: https://lpdaac.usgs.gov/get_data/mrtweb


**Finding and downloading Landsat imagery**

The entire Landsat archive and many other types of imagery stored at the United States Geological
Survey are available for free download using the Global Visualization (GloVis) web site: http://glovis.usgs.gov/. Click on the “Collection” menu label to see a list of what's available. If you look at Collection => Landsat Archive you will see the different Landsat image archives that are available. You can select the archives you want to search by clicking in the check box next to the archive name.

To select the location you want to search you can enter the WRS path/row values if you know them or the latitude longitude coordinates. You can also enter a month and year to limit your search to a specific time period.

In the large image display window on the right, you will see samples (quicklooks) of the imagery you selected. You can change the resolution by clicking on “Resolution” menu label. There are two resolution options. If you select “1000m”, a 3 x 3 matrix of sample images will be displayed. If you select “240m”, a single image will be displayed. You can add or remove map layers by clicking on “Map Layers” and using the “Read Shapefile...” option you can input your own vector file to help locate your area of interest. Shapefiles must use latitude and longitude coordinates.

When you click on an image in the viewer, information about the image is displayed in the “Scene Information” box under the location map. The image ID, cloud cover (CC), Date, Quality (0-9), and type of image (L1T = level 1 terrain corrected). You will also sometimes see a “Downloadable” label in the upper left corner of the image display window. This means the image is available for immediate download. If that label does not appear then the image needs to be ordered and you will be notified when it is ready to be downloaded – usually after a few days. When you find an image you like, click on the “Add” button at the lower left corner of the GloVis window. You can add several images to a list.

When all of your images are in the list, you can click on “Send to Cart” to download and/or order the images.

**Finding and downloading PALSAR mosaic data**

Two radar products have been created to support the ALOS Kyoto and Carbon Initiative Project; a 50m and 500m radar mosaic created using PALSAR imagery. Information related to downloading the 50m or 500m PALSAR mosaics can be found on the JAXA website: http://www.eorc.jaxa.jp/ALOS/en/kc_mosaic/kc_mosaic.htm.

To determine which tile you need for the PALSAR 50m mosaic, go to the product page (http://www.eorc.jaxa.jp/ALOS/en/kc_mosaic/kc_map_50.htm) and click on your area of interest. If you click on Africa, a new page will open with an index map that informs you which tiles are available. Clicking on the “FTP” label to the right of each image tile takes you directly to the download area for that tile. Once on the FTP server, you will need to go to the directory you want. Clicking on the “FBD” directory takes you to a directory with a “PNG” and “RAW” directory. The “PNG” directory contains images that are suitable for publication but should not be used for analysis. The images in the “RAW” directory are the ones that can be used for mapping.

**Introduction to R (with tutorial)**

Some of the exercises during the workshop use R software for processing image and vector data. This
section provides an overview of the R software with a focus on geospatial processing.

**Overview of R**

R is a state of the art language and environment for statistical computing and graphics. It is an open source software project and is compatible with Windows, Apple, and Linux computers. The R project started in the early 1990s as a tool for teaching statistics but quickly grew into a powerful program suitable for many disciplines that use statistical processing. R is used to manipulate data, perform calculations, visualize data, and it is able to work with several different types of data, including images and vectors. It can take a while to learn to use R, but the effort is worthwhile, since it opens data processing possibilities not available from other software.

**Geospatial packages in R**

Much of the power in R comes from packages that are developed for specific applications. There are hundreds of different packages, as well as the core R software, that can be easily downloaded and installed using the Comprehensive R Archive Network (CRAN - http://cran.r-project.org/) that is available from over 75 servers around the world. Packages in R are organized by “Task Views” and there is a Task View dedicated to the analysis of spatial data with almost 100 packages. To see the different spatial packages visit the R website (http://cran.r-project.org/), click on the “Task Views” link, then click on the “Spatial” link. A good way to get help using the spatial packages is to subscribe to the R-sig-geo email list (https://stat.ethz.ch/mailman/listinfo/r-sig-geo).

Using R packages you can gain access to sophisticated algorithms for geo-processing that are not available from other proprietary or open source software. One nice feature of R packages is that the help information is thorough, and information about each function is organized using the same template, which makes it easy to find what you are looking for. With each function you will also find examples that illustrate how a particular function works, and some packages include sample data to help understand the examples.

**R programming**

One of the strengths of R is that it is possible to write scripts to automate processing. We will use R scripts for some of the exercises during the workshop and each of them uses geospatial packages to read vector and raster data (maptools and rgdal packages) and to process raster imagery (raster package) and vector layers (sp package). To use the scripts in the exercises, it is not necessary to understand R programming (you'll only be editing a few lines), but learning the basics will give you a better idea about the processing steps in each script.

Learning to write scripts in R is not difficult, but it helps if you have some programming experience to better understand how to structure your commands. There is a guide for how to program in R in the Exercises section of this manual.

**Creating an emissions map using a GIS approach**

One of the simplest method to create carbon emissions maps, is to combine deforestation and carbon stocks maps. While it exists some guidelines on how emissions should be calculated for National GHG emissions, there is no agreement on a single methods for reporting emission under REDD.
“... a developing country Party should update a forest reference emission level and/or forest reference level periodically as appropriate, taking into account new knowledge, new trends and any modification of scope and methodologies”

Here we will demonstrate how we can sum the carbon emissions from deforestation in a specific area using a simple GIS approach. This exercise focuses on estimating carbon emissions resulting from deforestation and does not include degradation, unless shifting agriculture is considered as a form of “degradation”.

**Steps to create an emissions map**

The two map data sets we will work with are above-ground forest biomass and forest change. The biomass map can be created using techniques covered in the exercises during the workshop. Forest change mapping is not covered in this manual, but methods for mapping changes in forest cover are well described elsewhere.

If the resolution of the biomass and forest change maps is different, it will be necessary to re-sample the biomass map to match the resolution of the forest change map. This can be done using image processing or GIS software.

Next we need to calculate the total biomass for each pixel in the biomass map by converting the pixel values, which have units of tons of dry biomass/ha. To change pixel values to tons of dry biomass / pixel, we need to divide 1 ha by the area of a pixel. If the pixel of the biomass map is 28.5m x 28.5m then we need to divide the biomass value by 10000/28.5 * 28.5 = 12.31 to calculate tons of biomass / pixel. For example, if a pixel in the biomass image was 200 tons/ha, the output pixel value would be 200/12.31 = 16.25 tons of dry biomass /pixel.

Now that we have dry biomass weight / pixel, we can use a GIS function called zonal statistics to calculate the biomass for the area in the forest change map that was deforested. Zonal statistics will output the total dry biomass for the area that was deforested by summing all of the pixels in the biomass map that correspond with deforested pixels in the forest change map.

The last step is to convert the total dry biomass, in tons, output from zonal statistics to tons of CO₂. We can calculate tons of carbon by multiplying tons of dry biomass by 0.5 since roughly half the dry forest biomass is composed of carbon. To convert to CO₂, we multiply the weight of carbon by 3.66 since a CO₂ molecule weighs 3.66 times the weight of a carbon atom. Therefore, the weight of CO₂ emitted is: tons of dry biomass * 0.5 * 3.66.

All of this processing can be accomplished with a single R script, but it is also easy to do one step at a time using GIS or image processing software.

Reference:

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