

MN345: Monitoring protocols for REDD in Mahamavo

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Virtually all schemes for land management-related carbon projects, both government level REDD and within voluntary carbon markets, require biomass estimates in the present day, models of biomass in contrasting future scenarios, and some capacity to monitor biomass in the future should a project be approved.

At present, best practice is to estimate biomass in a set of appropriately sampled plots using field methods – basically tape measures - and look-up tables such as the IPCC AFOLU tables and then extrapolation across a classified Landsat-class image to estimate total biomass in a study area by multiplying class mean biomass estimates by area of each class. Monitoring is achieved by periodically making repeat measurements of plots to detect degradation and by periodically classifying more Landsat-class data to detect land cover change effects. LIDAR can potentially aid in the extrapolation process, but having LIDAR data doesn't change the requirement to have at least some plot measurements and Landsat-class data. LIDAR data is also not free as you need an aircraft equipped with the instrument. L-band SAR offers a promising alternative approach, however the restrictive data policies and the recent failure of the PALSAR sensor prohibit operational use of this strategy.

These demanding data requirements present an obstacle to the growth of carbon markets and the enfranchisement of local communities in developing countries in such markets. At present, preparation of a design document for a potential carbon project which will satisfy a carbon standard is a very time-consuming and hence costly task for an experienced RS specialist because of the complexity of the data processing which currently needs to be done.

There is a critical need to develop and validate methods which could make use of the wide range of free data available with global coverage to improve either the estimation and monitoring of biomass or the monitoring of land cover change. Mahamavo offers an excellent case study site to address these issues since you can easily access both tropical dry forest and savanna systems and because the environment has gradients of disturbance and degradation and is very dynamic such that validation sites which have experienced a wide range of historical land cover change trajectories can be found.

In Mahamavo you will have access to a wide range of operationally produced free global-coverage moderate resolution satellite data products from NASA and ESA sensors especially MODIS on Terra+Aqua, MISR on Terra, ASAR+MERIS on Envisat.

In addition, to permit development and validation of new methods, we have forest plot data at Mahamavo, very high-resolution commercial multi-spectral images of Mahamavo, time series of cloud-free atmospherically, terrain and BRDF corrected cloud-free 30m Landsat images of Mahamavo, 30m elevation models, 30m atmospherically corrected hyperspectral data, and of course the capability to collect further field measurements as necessary.

It is important to understand that processing large volumes of raw satellite data to usable products is quite fiddly, especially for more esoteric sensors such as spaceborne LIDAR and Synthetic aperture radar. However you will not need to do any of this as the appropriate products for the Mahamavo study site will be prepared for you in advance. This releases you to concentrate on the more interesting issue of what the information content of each product is and how they might be combined or modeled to produce useful knowledge.

There are two broad questions to consider within this dissertation theme:

Improving methods to monitor land cover change and degradation with remote sensing using free data

Potential data sources for operational use include:

- nadir-view atmospherically, terrain and BRDF corrected cloud-free surface reflectance (MOD09)
- land cover classification products (MOD12, GLOBCOVER)
- land cover change product (MOD44A)
- vegetation continuous fields (MOD44B)
- nadir-view atmospherically, terrain and BRDF corrected cloud-free surface reflectance (MOD09)
- vegetation indices (MOD13)

There are a wide range of possible change detection methods which could be compared and evaluated for the purpose of monitoring forest loss and degradation to assess compliance with a carbon project. Using Landsat-class data as a reference, you might compare the performance of MOD44A, univariate differencing of MOD09 derived indices (especially the TC Disturbance Index), delta classification of MOD12, change vectors of MOD09, change in linear spectral mixture proportions of MOD09 with endmembers from either pure MOD12 pixels or Hyperion (this approach would be particularly suited to detection of degradation). You might also explore to what degree texture information from MOD13 can help at 500m scale.

Developing methods to invert biophysical parameters (especially biomass) directly from remote sensing using free data

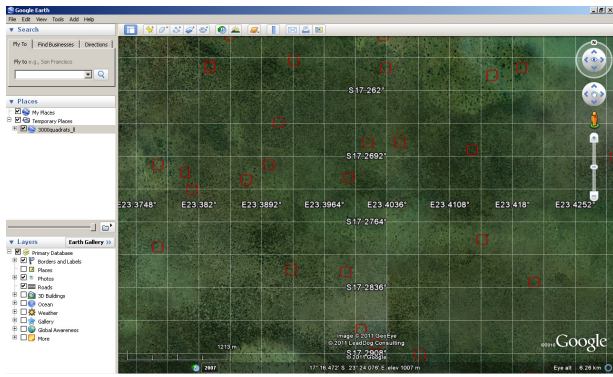
Potential data sources for operational use include:

- nadir-view atmospherically, terrain and BRDF corrected cloud-free surface reflectance (MOD09)
- BRDF parameters iso, vol, geo (MOD43)
- multi-angular reflectance (MISR)
- land surface temperature (MOD11)
- C-band SAR (ASAR)
- ICESat waveforms (GLAS06)

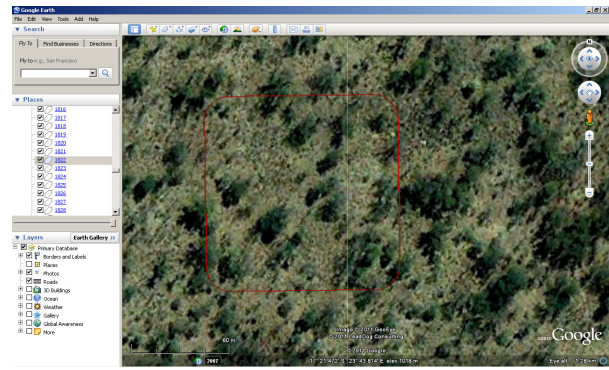
In Mahamavo, you could use parameters (such as biomass, proportion of tree cover etc) derived from field data or visual interpretation of commercial multispectral data as response variables in a regression model using explanatory variables from any of MOD09, MOD43, MISR, MOD11, and ASAR.

Although multi-angular reflectance probably won't work well in tropical moist forests with a closed canopy, in tropical dry forest and savannahs where light can penetrate within the canopy, models based on MISR (or MODIS swath) data have great potential. Similarly ASAR has polarimetric diversity and operates in C-band which penetrates at least 6m through vegetation canopies which makes this data particularly promising for use in dry forests, even though again it might not be ideal for moist forests. The unique ICESat full laser pulse waveform parameters GLAS06 dataset might also be very useful, especially if it can be cross-calibrated with MISR or ASAR signatures. A neglected, but potentially very valuable dataset is the MOD11 day and night land surface temperatures from both Terra and Aqua which give four daily measurements of temperature and permit rates of temperature change (related to specific heat capacity and hence biomass). Although this is confounded (as is SAR) by water from precipitation, in dry forests, in the dry season it has a lot of potential.

In practice what you will do is to look in the commercial multispectral archives (and on Google Earth) to see on which dates Quickbird, Ikonos, Worldview etc images have been acquired. You can then generate a large number, say 3000, randomly positioned virtual quadrats appropriate in size and shape to the GIFOV of the moderate resolution sensor given its known geolocation accuracy and save it as a kml file. You then visit each of the quadrats in Google Earth and record in a table one or more response variables such as proportion of different vegetation covers (trees, water, bare soil, shrubs, grass), or number of trees (which can be converted to tree density since the quadrat area is known) or tree shadow length in savannah (which can be converted to tree height with simple trigonometry with knowledge of the sun-sensor geometry).



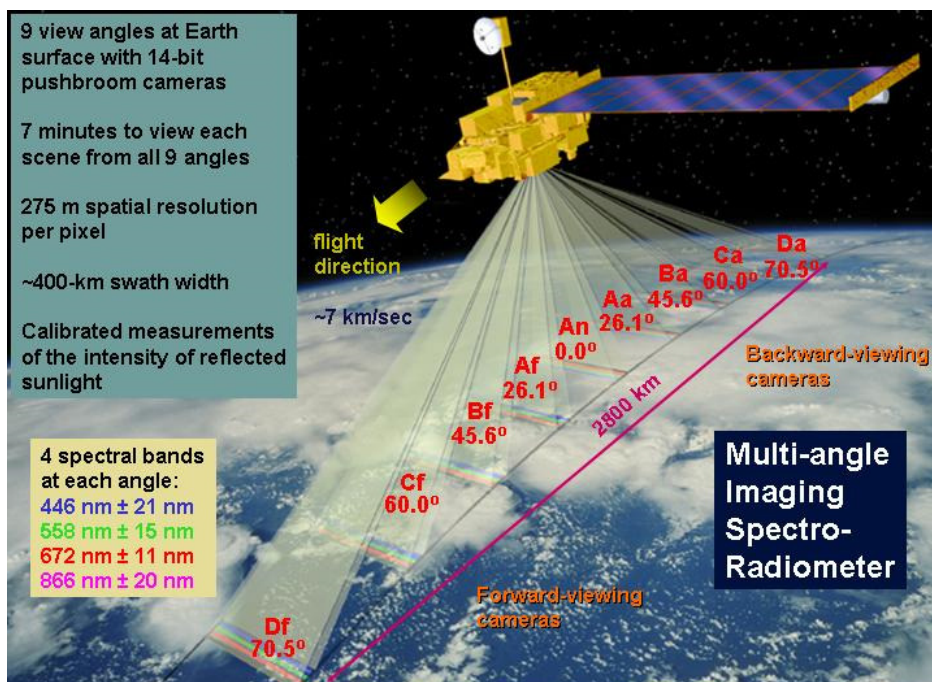
Example of use of virtual quadrats approach in Zambia



Zoomed in on a single quadrat on an Ikonos scene

You then get the moderate resolution data products of interest (MODIS, MERIS, ASAR etc) on the corresponding date to the commercial multispectral image that you have interpreted and spatially query the value of the moderate resolution data product at the centroid of each virtual quadrat.

For example you might decide to use multiangular blue, green, red and near-infrared reflectance from MISR as an explanatory variable in building a model of savannah biomass.



MISR schematic diagram

This spatial joining process will generate a massive table, which will look roughly like this:

Virtual quadrat	High resolution data	Date	Response variable(s) interpreted from Google Earth virtual quadrats			Many explanatory variable(s) from moderate resolution sensor(s) at virtual quadrat centroid.		
			eg number of trees	Eg sum of tree heights	Eg tree biomass per unit area	Eg MISR red at 70 forward	eg MISR red at 60 forward	eg MISR red at 45 forward
1	Quickbird	10 July 2011	6			0.14	0.17	0.21
2	Quickbird	10 July 2011	19					
3	Quickbird	10 July 2011	4					
n	Quickbird	10 July 2011	0					

Note that you can augment this kind of table by using more than one date of high-resolution data from anytime in the period 2000-present from the Mahamavo field site, and you can augment the table by collecting field records of any parameter of interest in an appropriate spatial sampling scheme (basically with replication within the moderate resolution GIFOV) during the summer 2012 season.

Next, you would need to partition the cases in this table, use some of the cases to make a predictive model of a response variable of interest as a function of the moderate resolution explanatory variables, probably using a multiple regression approach, perhaps with multi-model inference, and validate it using other cases from the partitioning, probably using major axis regression as both the model prediction and reference data will be continuous and as both are subject to an error process. Once you have produced and validated a satisfactory model which inverts the RS data to a biophysical parameter of interest you can apply the model to a time-series of the relevant moderate resolution data to produce a series of maps to demonstrate how your model might be applied operationally and see how your biophysical parameter varies over space and time.

Summary of properties of data sources for land cover change and inversion methods

Data source	L5 TM L7 ETM E0-1 ALI	MOD09 sur refl MOD43 BRDF	Envisat ASAR C-band HH, VV	MODIS derived products				MISR	Commercial multispectral
				MOD 12 class	MOD 44A change	MOD 44B VCF	MOD 11 temp		
Spatial resolution	30m	250m, 500m	~30m ~150m	500m	500m	500m	1km	275m	<10m
Temporal grain	~ annual	8-day	~6 mon	6 mon annual	6 mon annual	6mon annual	8 day	8 day	>annual
# reflective bands	6	7	NA	NA				4	~3
# angles	1	1	1	1				9	1
Atmospheric	Yes	No	No	No				No	Yes

correction needed?									
Archive since	1984 (TM)	2000	2000	2000				2000	~2000
Radiometric resolution	8 bit	10 bit	10bit	NA				14 bit	8 bit
Successors?	L8, S2A,B	NPP	S1	NPP				No	lots
Data policy	free	free	free	free				free	costly
Ease of data preparation	Moderate	Easy	Moderate	Easy				Moderate	Easy
Visual interpretation	yes	yes	yes	yes	yes	yes	yes	yes	yes
Heads-up digitising	yes	No	No	NA				No	yes
Counting/measuring things	No	No	No	No	No	No	No	No	Yes
Differencing:									
- raw	Yes	Yes	Yes	NA	Yes	Yes	Yes	Yes	Yes
- TC DI	Yes	Yes	NA	NA	No	No	No	No	No
- NDVI	Yes	Yes	NA	NA	No	No	No	No	Yes
- EVI	yes	Yes	NA	NA	No	No	No	No	Yes
Delta classification	Yes	Yes	Yes	Yes	NA	NA	NA	No	No
CVA	Yes	Yes	Yes	No				NA	No
Unmixing	Yes	Yes	No	NA				No	No
Inversion to biophysical	Yes	Yes	Yes	No				Yes	No

Further reading

Because this project is quite complicated I would strongly advise starting with books which offer detailed overviews before going to the primary literature. Some of this literature is quite hard to find, so contact me if you want me to send you scans of the book chapters relevant to your proposed project.

Congalton, Green (2009) Assessing the accuracy of remotely sensed data: principles and practices 2nd edition. CRC Press

Jones S, Reinke K (2008) Innovations in remote sensing and photogrammetry. Springer

Jones HG, Vaughan RA (2010) Remote sensing of vegetation: principles, techniques and applications. Oxford

Liang S (2004) Quantitative remote sensing of land surface properties. Wiley

Liang S (2008) *Advances in land remote sensing: system modelling, inversion and application*. Springer.

Lillesand TM, Kiefer RW, Chipman JW (2008) *Remote sensing and image interpretation*. 6th edition. Wiley

Schowengerdt RA (2007) *Remote sensing: models and methods for image processing*. 3rd edition. Academic Press

Algorithm theoretical basis documents (ATBDs) for all the sensors and moderate resolution products of interest.
Available from the MODIS, MERIS, MISR, ASAR and ICESat websites