IPCC Expert Meeting: Role of Remote Sensing in Forest and National Greenhouse Gas Inventories

Hayama, Japan

23 – 25 October 2012

Task Force on National Greenhouse Gas Inventories

INTERGOVERNMENTAL PANEL ON climate change

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Foreword

The IPCC's Task Force on National Greenhouse Gas Inventories has, as part of its mandate, the objective of encouraging users to adopt the IPCC methodological guidelines for estimating national inventories of greenhouse gases. This report is one of a series, developed through expert meetings, which aims to assist users of the IPCC guidelines by addressing specific problem areas. Application of IPCC guidelines to estimation of emissions and removals from forests poses a significant challenge to inventory compilers particularly with regard to the difficulties with data collection, both current and time series, and with appropriate parameters for use in GHG inventory compilation. Remote sensing technologies have the potential to address some of these issues especially in light of considerable improvement in quality, coverage, availability and cost of remote sensing products in recent years as well as much wider experience in their use by inventory compilers. *IPCC meeting on National Forest GHG Inventories - A Stocktaking,* held in Yokohama Japan in February 2010[1], sought to address some of the challenges in the application of IPCC Guidelines to forest GHG inventories. Amongst other recommendations, it identified the need for another more focused expert meeting on technical issues in Forest GHG Inventories that would, among other issues, address the use of remotely sensed data in forest GHG inventories including on stratification, change assessment and methods for biomass estimation. *IPCC Expert Meeting: Role of Remote Sensing in Forest and National Greenhouse Gas Inventories,* held in Hayama, Japan on 23-25 October 2012, built on the work done earlier in the Forest GHG Inventory Meeting by providing extremely relevant and useful information on the application of remote sensing technologies in forest GHG inventories and issues in their use besides identifying areas for future work. We, the Co-chairs of the Task Force Bureau, would like to thank all those involved in this meeting, and would like to express our sincere thanks and appreciation to Institute for Global Environmental Strategies (IGES) and the Government of the Japan for their support in hosting this meeting.

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[1] IPCC (2010). *National Forest GHG Inventories – A Stock Taking*. Eds: Eggleston, H. S., Srivastava, N., Tanabe, K., and Baasansuren, J. IPCC Expert Meeting Report, Pub. IGES, Japan.

Executive Summary

The *IPCC Expert Meeting: Role of Remote Sensing in Forest and National Greenhouse Gas Inventories* reviewed the use of remote sensing (RS) in forest greenhouse gas (GHG) inventories.

The meeting discussed three topics relating to the use of RS in forest GHG inventories: a) combination of remote sensing and ground-based observations; b) use of RS for biomass measurement; c) use of RS in assessing and monitoring forest degradation. On each of these topics, the meeting discussed the information required to apply the IPCC guidelines methods to forest GHG inventories; current RS capabilities and their anticipated development; and steps that could be taken by the RS community and GHG inventory experts to facilitate forest GHG inventories.

The meeting concluded the following:

a. While using RS to monitor forest areas can be a routine activity, given sufficient resources and capacity, widespread monitoring of forest carbon stocks in many countries is still not widely applicable. For those countries where RS methods can be applied, they will require access to remotely-sensed data, resources and capacity development to provide these capabilities to countries that need them.

b. Currently the only widely accepted remote sensing-based method available to estimate biomass stocks in forests is to use the remotely sensed data to estimate areas of each forest stratum and multiply this area by a biomass density obtained from ground based surveys and other ancillary data, if available. Although methods for estimating biomass by using RS data jointly with field data for model calibration and validation have been demonstrated in specific cases, they are not yet ready to be operationalized in routine national forest monitoring in most countries.

c. Detection of forest degradation using RS is a particular challenge due to different drivers of degradation that may impose distinct challenges in identification and assessment of changes. Of particular relevance is the difficulty to assess the impact on carbon stocks from forest degradation activities, including fire, logging and pest attacks, among others, and the extensive resources, both financial and human, required for validating results of degradation.

d. There are a number of techniques under development and new satellites to be launched in the next few years that will lead to increased capabilities of RS of forests. However, to speed up the development of operational techniques, closer collaboration of RS experts, terrestrial biosphere modellers and emission inventory experts is needed.

Abbreviations

AD	Activity Data
AFOLU	Agriculture, Forestry and Other Land Use
ALOS PALSAR	Advanced Land Observing Satellite Phased Array L-band Synthetic Aperture Radar
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
CBERS	China Brazil Earth Resources Satellite
CO_2	Carbon Dioxide
DBH	Diameter at Breast Height
DMC	Disaster Monitoring Constellation
EF	Emission Factor
ENVISAT	Environmental Satellite
ERS	European Remote Sensing Satellite
ESA	European Space Agency
ETM	Enhanced Thematic Mapper
GHG	Greenhouse Gas
GPG-LULUCF	Good Practice Guidance for Land Use, Land-Use Change and Forestry
HWP	Harvested Wood Products
ICESat	Ice, Cloud, and land Elevation Satellite
ILOVE	ISS-JEM LiDAR Observation of Vegetation Environment
IPCC	Intergovernmental Panel on Climate Change
IRS	Indian Remote Sensing Satellite
ISS-JEM	International Space Station Japanese Experiment Module
JERS	Japanese Earth Resources Satellite
LiDAR	Light Detection And Ranging

LULUCF	Land Use, Land-Use Change and Forestry
MERIS	Medium Resolution Imaging Spectrometer
MODIS	Moderate Resolution Imaging Spectroradiometer
NASA	National Aeronautics and Space Administration
NFI	National Forest Inventory
REDD+	Reducing Emissions from Deforestation and forest Degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries
RS	Remote Sensing
RSE	Relative Standard Error
SAR	Synthetic Aperture Radar
SPOT	Satellite Pour l'Observation de la Terre (Satellite for observation of Earth)
UNFCCC	United Nations Framework Convention on Climate Change
VIIRS	Visible Infrared Imaging Radiometer Suite

1 Introduction

This report summarises the conclusions of the *IPCC Expert Meeting: Role of Remote Sensing in Forest and National GHG Inventories* ("Forest RS Meeting") which took place in Hayama, Japan, on 23-25 October 2012. The meeting aimed to review the current state-of-play on the use of Remote Sensing (RS) and *in-situ* observations in estimating greenhouse gas (GHG) emissions and removals from forests.

Many countries use remotely sensed data in conjunction with ground data to compile their GHG inventories for the Land Use, Land-Use Change and Forestry (LULUCF) or Agriculture, Forestry and Other Land Use (AFOLU)[2]. Since the *2006 IPCC Guidelines* were produced, RS technologies have further continued to develop and there is now considerably more experience in their use. In addition, the need for reliable estimates of GHG emissions and removals from forests in developing countries has increased because of proposed GHG mitigation measures such as the REDD+ process under the UNFCCC.

The *2006 IPCC Guidelines for National GHG Inventories* (*2006 IPCC Guidelines; IPCC (2006)*) explicitly refer to the use of RS data to obtain, amongst other things, maps of land-use at regular intervals, estimates of changes in carbon stocks in above-ground biomass, and to assess areas and types of disturbances. However, there is no detailed discussion of using remotely sensed data, its advantages and limitations in this field of application.

The Forest RS Meeting was held in two parts, with a series of presentations being followed by group discussions (see Agenda in Annex 1). Annex 2 gives the list of participants. The presentations are given in Annex 3.

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[2] LULUCF and Agriculture in the *Good Practice Guidance on Land Use, Land-Use Change and Forestry (GPG-LULUCF; IPCC (2003b))* were integrated into AFOLU Sector in the *2006 IPCC Guidelines*.

2 Use of RS in estimating GHG emissions and removals from forests

2.1 Introduction

The general approach to estimate GHG emissions and removals in the IPCC Guidelines is to multiply Activity Data (AD) by an Emission factor (EF)[3] . For forests, the AD means typically the forest area.

The IPCC Guidelines consider the following carbon pools in any land-use category[4] (Chapter 2, Volume 4, *2006 IPCC Guidelines*), i.e., :

- Above-ground biomass
- Below-ground biomass
- Dead wood
- Litter
- Soil organic carbon

The CO_2 emission factor reflects the change in the total carbon stocks in each one of these five pools associated with the activity in question. Changes in each pool are estimated by either the difference in carbon stock at two points in time (*Stock-Difference Method*) or as carbon gains (e.g., through annual growth) minus carbon losses (e.g., through harvest, disturbances) (*Gain-Loss Method*)[5]. The total forest area should be sub-divided (stratified) into areas of similar characteristics in order to apply a constant EF.

In summary, the annual net emissions (emissions/removals) from forests can be generally estimated using Equation 1:

Equation 1 Estimation of CO_2 fluxes from forests

$$Annual\ National\ Flux\ (CO_2\ eq) = \sum_{All\ strata,\ \ All\ Pools} AD\ (Area) \times EF\ (CO_2\ eq/Area)$$

Both RS and ground data can be used to provide AD and, to some extent, EFs, depending on which techniques are applied. Historically, RS has contributed mostly to the estimation of AD, while the EFs are estimated

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[3] Conventionally an *emission factor* can be associated to an emission or to removal of a GHG from the atmosphere.

[4] The *2006 IPCC Guidelines* also provide guidance on Harvested Wood Products (HWP) pool. However, the annual change in carbon stocks in the HWP pool can be reported as zero, if these are considered to be *insignificant* by the inventory compiler (Section 12.2.1, Chapter 12, Volume 4(2) of the *2006 IPCC Guidelines*). This is sometimes referred to as the default assumption of *instantaneous oxidation* of HWP.

[5] Chapter 2, Volume 4 of *2006 Guidelines* provides description and equations for the two methods.

predominantly from ground observations. Indeed, the IPCC Guidelines provide methodological guidance for estimating EFs based on field data.

IPCC provides three Approaches to represent land, which is the basis for estimating forest-related AD (Box 1).

Box 1
Approaches to consistent representation of land in the *2006 IPCC Guidelines*

The *2006 IPCC Guidelines* describe three Approaches that may be used to consistently represent areas of land-use categories across time. These are presented in the order of increasing information content but are not hierarchical in the sense that moving to a different Approach does not imply an increase or decrease in accuracy.

Approach 1 only identifies the net areas and net area changes of individual land-use categories in a country without providing any information on areas of specific conversions between land-use categories (e.g., Forest Land Converted to Cropland) through time. Consequently, the exact location or pattern of land-use conversions in a country is not known.

Approach 2 provides information on specific land-use conversions between land-use categories but not on a spatially explicit basis. In Approach 2, information on the exact pattern of land-use conversions involving specific land-use categories is known but not their geographical location.

Approach 3 allows for tracking of land-use conversions on a spatially explicit basis so that both the exact geographical location and pattern of land-use conversions between land-use categories are known.

IPCC methods are applied by land-use category at the pool level then summed to give the emissions or removals. IPCC methods do not necessarily require that countries have a national forest inventory in place, although the *Stock-Difference Method* does so. IPCC methods all require a forest classification/stratification and the area of each stratum. IPCC EFs are described[6] at three levels or Tiers of detail and complexity. The simplest Tier 1 methods use global or regional default values for the required parameters and the users simply have to provide AD (in the absence of national AD Tier 1methods can use AD from international datasets). Tier 2 methods, suitable for sources that contribute significantly to countries' total emissions or removals or their trends, generally use the same equations as Tier 1, but call for country-specific values for the EFs and any other parameter required, as well as the national AD at finer resolution. Tier 3 methods are generally more complex modelling or measurement approaches.

While default data and assumptions are available for the simplest Tier 1 methods, more accurate higher tier methods (Tiers 2 & 3) require more detailed and accurate local information. For example, locally applicable allometric equations can be used to go from typical forest inventory[7] measurements to above-ground biomass; below-ground biomass can then be estimated from above-ground biomass. AD on areas of land-use and land-use change may be obtained from RS or from ground-based data, e.g., rates of forest establishment or conversion to other land uses. Some AD is not area-related, e.g., firewood collection, or harvesting rates.

There is normally a need for some ancillary data. Ancillary data is supporting information used to link AD to the appropriate EF and help interpret GHG estimates, and may include forest maps, soil surveys, climatic data, topography etc.

It is difficult to separate natural and anthropogenic fluxes in a globally consistent way and so the IPCC Guidelines consider only fluxes from managed lands as a proxy for anthropogenic emissions and removals (IPCC, 2010). Therefore complete RS coverage (either by sampling or wall-to wall approaches) may not be needed. However, the unmanaged land needs to be monitored since areas affected by disturbances, for example, if followed by a land-use change, are then considered to be managed and therefore, emissions and removals need to be estimated.

National GHG Inventories clearly need information at the national scale, stratified as necessary. Reporting at finer spatial scales may also be needed for assessing the effects of drivers, or identifying projects (demonstration /projects). While deforestation is normally clear (conversion of forest land to other land-use category), forest degradation is more difficult to define (IPCC, 2003a). However, for the purposes of GHG inventories, any change in carbon stock in forest land in managed land is included as part of the inventory, regardless of the nature of the change (e.g., degradation process, enhancement of stocks). The basic data needed to estimate emissions and removals from forests following the approach adopted by the IPCC are:

- *Total area and AD*. Total forest area, measured at the hectare or sub-hectare[8] level is needed. Total forest area should be appropriately stratified, e.g. by forest type, climate zone, soil type etc., to reflect variation in EFs within the forest. Net changes in forest area due to deforestation and reforestation (AD) need to be estimated. This ideally should be done annually, but in the absence of yearly estimates of total forest area, net annual changes can be estimated based on monitoring over longer time intervals. Table 1 shows the current potential for RS technology to provide AD for different types of forest activity.
- *Forest Composition*. At the national level, there is little operational RS capacity at present. National Forest Inventories (NFI) and forest maps based on ground information provide this information.

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[7] A Forest Inventory is a statistically designed inventory of national forests, usually undertaken for resource management. It is not the same as a GHG inventory, though the former may provide information useful for the latter, especially on emission factors.

[8] National forest definitions may use minimum forest areas down to 0.05 ha.

- *Biomass*. Ideally, the carbon stock of each of the five IPCC carbon pools is needed. Usually inventory compilers use allometric equations to estimate above-ground biomass from measurements. Below-ground biomass is generally estimated by multiplying above-ground biomass with root-to-shoot ratio although sometimes allometric equations are also used. For estimating C stocks of other pools, generally IPCC default methods and assumptions are used.
- *Growth and Harvest*. Typical growth rates are used to estimate CO_2 uptake while data on the amounts harvested provide estimate of emissions. Knowledge of the distinct harvesting practices allows to estimate transfers of carbon between pools. While clear-cutting and large scale harvesting may be detectable, detecting and quantifying selective logging is more challenging using coarse and mid-resolution RS imagery.

Table 1 RS capabilities and forest monitoring needs for AD[9]

Activity	Issues	RS Capability
Deforestation	• Defined as transition from forest land to non-forest land use. • Cost and availability of data. • Need to continue to monitor land-use after transition to estimate subsequent emissions and removals.	• Operational[10] but continuity of wall-to-wall RS may be a problem due to limited human and financial resources. Historical data is needed to monitor trends.
Degradation	• Need operational definition which may differ between countries, but needs to be consistently applied. The sustained reduction of carbon stocks is the key criteria in GHG inventories. • Need to have ground-truth data at fine scales to calibrate results.	• Globally potential methods include the use of surrogates (e.g., roading) for secondary forests, and the use of intensive feature extraction techniques. • Optimum resolution needs to be determined. • Optical very high spatial resolution imagery has demonstrated potential; however operational capacity is not available for national level monitoring.
Conversion of natural forest to plantation	• Need ability to distinguish plantation from natural regrowth. • Some planted forests may resemble natural forest regrowth.	• Potentially operational with need for ancillary data.
Conservation, sustainable management of forests and enhancement of forest carbon stocks	• A clear definition is needed to guide what needs to be monitored. • Emphasis on carbon stock change. • Needs land tenure maps. • Examples such as "Mata Atlântica Project" in Brazil.	• Good operational capacity not available at present. • Need to use proxies.

[9] De Sy *et al.* (2012)

[10] "Operational" is defined here as capable of being used for national reporting. This implies that appropriate sensors are available, at appropriate resolutions, with orbital/revisit characteristics to allow sufficient coverage at most latitudes to meet national or regional reporting obligations in the time-frames required. It does not necessarily imply that this data is currently available, or free-of-charge.

2.2 RS information

RS data can come from a variety of sources and techniques. Aircraft or satellites are normally used and techniques can be grouped into the following methods:

2.2.1 Passive RS approaches including the use of spectral indices

Passive optical sensors on earth orbiting satellites have provided regular observations of earth's forests since the 1980s. Several passive optical sensors currently provide up to daily global coverage in multiple bands adequate for identifying changes in land cover. These include the Landsat, ASTER, SPOT, IRS, DMC, and CBERS missions which image Earth's surface at a spatial resolution of 10-80 m. Other instruments, most notably MODIS, VIIRS, and MERIS provide more frequent (near-daily) observations at a more coarse resolution. Other satellites (e.g., IKONOS, RapidEye, and Quickbird) provide much higher spatial resolution (1-5 m), but more limited spectral resolution, spatial extent, and revisit periods, making them less suitable for regular wall-to-wall mapping in most countries. Observations of all these sensors are obstructed by the presence of clouds. This restricts their use for land cover monitoring through repeat-observations in tropical regions, particularly during the wetter seasons, unless diverse sources of remotely sensed data are available to fill in gaps in observation.

2.2.2 Active optical techniques such as Light Detection And Ranging (LiDAR)

Light Detection And Ranging (LiDAR) measures how light emitted from the sensor itself is echoed off the Earth's surface. Control of the illuminating beam and the relatively constant speed of light allow LiDAR instruments to estimate the distance between the sensor and the Earth's surface from the time recorded between the emission of a light pulse and its return to the sensor. LiDAR observations over forests can represent the top of the canopy and the soil surface when only the first and last returns signals over an area are measured, or a vertical profile of the vegetation when the waveform of the return signal is measured. From these metrics, biophysical characteristics of the canopy can be estimated, such as canopy height and density. These, in turn, may be used to estimate timber volume or above-ground biomass. In forest applications LiDAR instruments most often emit near-infrared radiation, which vegetation is highly reflective of. This implies that the LiDAR measurements, like passive optical observations, are compromised by clouds. In contrast to the latter, LiDAR observations can be made at night. Since the end of the ICESat mission (2003-2009), which was designed primarily for cryosphere observations but proved also to be valuable for forest monitoring, LiDAR instruments are no longer active on space-based systems (although new missions are planned for the coming years). Instead, LiDAR instruments are commonly carried on aircraft, generating observations over a wide range of spatial resolutions ('footprints'), in specific sampled areas tailored to the specific mission.

2.2.3 Radar techniques such as Synthetic Aperture Radar (SAR)

Synthetic Aperture Radar (SAR) measurements have the advantage of not being compromised by the presence of cloud, hazardous weather or night-time. Similar to LiDAR, radar observations measure the return of a signal emitted by the sensor itself (i.e., they are 'active' sensors). Currently or recently operational SAR sensors on earth-orbiting platforms (e.g., ERS1/2 SAR, JERS-1, ENVISAT-SAR, ALOS PALSAR, and Cosmo Skymed SAR) operate at wavelengths of 3 to 23 cm that exhibit signal saturation under high biomass conditions (> 150 Mg/ha), that are typical of tropical forests. As part of the BIOMASS mission, the European Space Agency (ESA) is designing a P-band sensor, i.e., operating at a 70 cm wavelength (Le Toan 2011; RSE 115, 2850-2860), to overcome this limitation. However, its launching is not anticipated before 2020.

Table 2 EF information from RS and ground data

	EF	Ancillary Data
RS	• Not currently operational but: o Potential for model-based estimate of biomass (Section 3.1) o Potential for peat combustion and subsidence from LiDAR o LiDAR in combination with ground data can help estimate biomass and growth factors.	• Supporting information to help link AD and appropriate EF and to help interpret the GHG estimates (e.g., forest type maps, soil surveys, climatic data etc.) • Land-use after transition • Local data to guide interpretation (land surveys e.g., to interpret forests conversion) • Agriculture management practices • Stratification to help link AD to EFs • Allometric equations and root-to-shoot ratios to estimate biomass (above- and/or below-ground)
Ground data	• National Forest Inventories can give EF and removal factors. Need to ensure the coverage meets reporting requirements. • Research studies can be used to derive EFs. • Non-CO_2 EFs are obtained mainly from research studies. Soil C change data is mainly from research although modelling is sometimes used. For dead wood and litter either default approach or modelling may be more cost-effective than measurement.	

2.3 Ground data[11]

Typically these are repeated surveys that provide information on forest type, resources, and management practices. They may generate forest maps that may be useful when stratifying forest lands, and may be a valuable source of information on EFs.

2.3.1 National Forest Inventories (NFI)

Traditional NFIs use sample plots where trees are measured following nationally established sampling strategies and design. For example, plot design is standardised and measurements may include tree diameter at breast height (DBH, typically 1.3 m) and tree height. They often focus on national commercial tree stocks rather than changes in forest carbon. Trees below a pre-determined diameter and non-commercial plants may not be included. The sampling design may not always be suitable to detect deforestation, even if it occurs at high rates

[11] Kissinger *et al.* (2012)

due to the length of inventory cycle (normally every 10 years) and deforestation being a relatively rare event in the forest landscape as a whole. Supplementary sampling would therefore be necessary to increase the accuracy of the annual estimates.

Thus there are challenges in adapting traditional NFI to carbon stock change estimation. New NFI approaches that incorporate RS to assist with forest stratification and sampling design can improve the results. One important consideration relates to the temporal and spatial coverage required to match the forest monitoring needs for annual or biannual reporting.

NFIs can in general provide EFs. *In-situ* tree measurements can be used to estimate biomass and changes in biomass and hence, carbon stock changes and CO_2 emissions. However, it is important to ensure that the coverage meets reporting requirements. Various research studies can be used to derive EFs (non-CO_2 EFs come mainly from research studies). Where sub-national estimates are needed, the use of Tier 2 may likely be needed to improve the accuracy of the estimates. However, the use of a Tier 2 method may be challenging to some countries.

While the below-ground biomass pool can be estimated from the above-ground biomass, through a root-to-shoot ratio, typical NFI measurements do not always provide information on the other carbon pools. Soils present a particular challenge: soil carbon change data is normally derived from research programmes, although modelling approaches have also been used in some cases. Where forests occur on organic soils, emissions from the soil may dominate if the water table is lowered. For dead wood and litter either the default approach in the IPCC Guidelines or modelling may be more cost-effective than measurements.

Currently only about 16% of Annex I Parties to the UNFCCC use RS in GHG inventory compilation[12]. This is possibly due to the fact that most countries have reliable and well established NFI in place, based on field sample plots.

2.3.2 Use of ground data to validate RS

Remotely sensed data normally needs ground data for calibration and validation. A key factor is the need for good georeferencing of the ground plots to ensure they are matched to the correct RS pixel. Otherwise, large co-registration errors may occur. Consideration also needs to be given to linking the plot dimensions to RS datasets. Multiscale/multistage approaches can be used.

Issues in the use of ground data combined with RS include:

- How to upscale from plot scale information to global-scale estimation
- Use of allometric equations

[12] http://unfccc.int/2860.php

- Spatial coverage: wall-to-wall and sampling approaches:
    - Sampling can be applied to both RS and ground-based measurements.
    - In the case of detecting biomass changes due to deforestation or intense degradation, sampling can be intensified in “hot-spots”, i.e., areas with high deforestation rates or anthropogenic pressure on forests. The initial identification of hotspots can be done using coarse resolution RS imagery and then refined further using multi-temporal imagery.
- Temporal coverage (can it be done annually or more frequently?):
    - Depends on the spatial scale, level of automation, weather and availability of verification information.
- Relationship between NFI and RS in estimating biomass:
    - NFIs have traditionally been used for forest resource information collection, conducted on longer temporal cycles and therefore need interpolation for the purposes of national GHG inventories.
    - RS can supplement traditional NFIs by providing area information at a higher frequency.
    - The role of ground-based data will tend to shift from traditional NFIs to providing EFs or calibration information for RS.
- Practicality and availability for the present and potential for the future

2.4 Drivers

In order to understand changes in forest cover/use and monitor the implementation of measures and policies, it is important to also monitor drivers of degradation. For REDD+, the identification of drivers is an important part of the process. Examples of such drivers include:

- Selective logging
- Conversion of forests to plantations or crops for food and energy production
- Charcoal production
- Agricultural practices (e.g., crop- or grazing land expansion)
- Socio-economic pressure (e.g., road networks, settlement expansion)
- Fires and natural disturbances
- Pollution (e.g., smoke, acid rain)

3 Biomass estimation using RS

There have been some demonstrations of biomass estimates from RS, normally coupled with ground information (Baccini *et al.,* 2012; Saatchi *et al.,* 2011). These have focussed on above-ground biomass, leaving out below-ground biomass, dead organic matter (dead wood and litter) and soil organic carbon. These methods have several limitations for use in routine inventories including high uncertainty and limited time-series availability. This is a developing field with new capabilities developing rapidly.

3.1 Methods for estimating biomass, their relative advantages and disadvantages

There are different basic techniques proposed to estimate biomass using RS:

- Methods that use optical images to support the stratification of the forest area while using average biomass density from ground-based methods ("Stratify and Multiply"; e.g., Gibbs *et al.,* 2007)
- Methods that use spectral information from passive sensors to estimate biomass, with or without other ancillary or ground-data (e.g., Baccini *et al.*, 2012: Saatchi *et al.* 2011; Foody *et al.*, 2003)
- Methods relying on the ability of LiDAR or SAR to capture forest structure information (e.g., Asner *et al.*, 2012; Le Toan *et al.*, 2004)

Currently, only the first method is operational in the sense that it can be routinely employed to produce annual estimates in most countries. The others have only been demonstrated as research projects in particular circumstances. It should be noted that the methods above can be combined. Biomass estimates from airborne or satellite-based LiDAR measurements can be upscaled using a "Stratify and Multiply" approach (e.g., Asner *et al.*, 2012) or through use of regression models driven with spectral data (e.g., Baccini *et al.*, 2012). Data derived from passive and optical sensors can also be combined to directly estimate above-ground biomass without stratifying the landscape (Cartus *et al.*, 2012).

3.1.1 Methods using optical images to determine forest strata

These methods use RS to estimate the area of each forest stratum after stratification. The RS data can be used in conjunction with other geographic data, such as soil maps, altitude and climatic factors. The area can then be multiplied by EFs determined from ground-based data, including from NFI (a "Stratify-and-Multiply" approach). Traditional optical sensors for land cover mapping are normally used (mid-resolution or better, global scale imagery with annual coverage). The current workhorses are Landsat ETM7, SPOT4 and SPOT5. It is anticipated that these will be supplemented by Landsat 8, Sentinel 1, 2, 3, CBERS, SPOT6 and SPOT7.

Traditional passive optical RS has some limitations that include:

- Potentially limited ability to discriminate different land cover classes unless high spatial resolution remotely sensed data is used. However, this may be constrained by cost and processing capacity.
- Cloud cover and illumination effects.

3.1.2 Methods using RS indices

These methods need calibration using ground-based observations. Some countries are beginning to use these methods on a national scale for biomass estimation. However it is more suitable for some ecosystems than others and the interpretation of passive optical radiometric data is confounded by issues such as:

- Saturation[13]
- Layering
- Non-biomass components, such as the dead organic and soil organic carbon pool

3.1.3 LiDAR and SAR

LiDAR

LiDAR has the potential to overcome some of these issues but some practical difficulties remain:

- Difficulty to obtain permission to fly over forested areas with a LiDAR sensor in some countries (sovereignty issues)
- Expensive to employ sufficient sampling intensity
- Limited experience with time-series data for change estimation
- Limited technical resources and capacity
- No operational satellites (NASA may launch a satellite after 2016 but it is currently scoped as a single mission so will not support long-term time series.)

SAR

SAR's most compelling feature is its ability to obtain images even under cloud-cover conditions. The broad use of SAR data for biomass estimation is still under investigation. While different wavelengths are sensitive to different biomass features, there are saturation issues at high biomass levels typical of tropical forest ecosystems.

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[13] Passive short wave infra-red imagery has demonstrated potential to overcome saturation issues because of its sensitivity to structural attributes of vegetation such as stem density, crown size, and canopy shadowing, which correlate in some degree with biomass (Baccini *et al.*, 2012; Puhr *et al.*, 2000; Tangki *et al.*, 2008) . However, short wave infra-red imagery is less widely available than visible RS imagery.

3.2 Monitoring changes in biomass

"Stratify-and-Multiply" is the only currently available technique for change detection at national scales.

Biomass change detection should be feasible in the future using remotely-sensed data in conjunction with a model appropriately calibrated with field observations, rather than assigning carbon density values to a land cover map based on RS. Outstanding issues for further consideration before this approach can be widely used include: validation of changes detected; time-series consistency issues; and lack of appropriate ground data for validation of historical change.

RS is useful to identify areas that need more intensive investigation ("hot spot areas"). This will enhance efficiency by focusing on the use of higher resolution, more resource intensive methods, or ground-based investigations on areas where they are most needed.

There is a need for continuous reliable satellite systems as time series data is required to detect degradation. Matching data from different satellites at different times is an additional source of uncertainty. In planning RS, it is important to consider the scale of temporal dynamics.

4 Future capabilities

Future techniques used will need to be at appropriate scales to monitor changes and both the spatial resolution and the timing and frequency for RS need to be considered.

4.1 Technical developments which could be helpful

1. Use of hyperspectral data to detect species composition change. Hyperspectral sensors provide images from a much larger set of spectral bands than the more common multispectral sensors (e.g., Landsat, SPOT).
2. A constellation of matched satellites with Landsat type bands and moderate resolution could provide adequate coverage for national annual reporting particularly for areas with persistent cloud cover especially for developing countries.
3. Drones/UAVs could be used to produce very high resolution data, but this may lead to coverage issues (e.g., for broad territorial coverage) and may need permission to fly. Operational L-band SAR observations are expected from 2014 with the launch of ALOS-2 that is carrying a PALSAR instrument with higher temporal and spatial resolution than the one carried on the original ALOS satellite launched in 2006 and operational until 2011.
4. ISS-JEM LIDAR Observation of Vegetation Environment (ILOVE) to estimate forest height is under study and expected to be installed on-board ISS in late 2010s.
5. Missions to measure CO_2 concentrations. Such space borne observations will not be operational in 5 years and for country-scale measurements users will need to wait for future satellites. There are also issues related to discrimination of anthropogenic and natural CO_2 sources and forest fluxes from fluxes from other economic sectors.

4.2 New data possibilities and needs

1. It is possible to produce global forest cover maps and some have already been generated. Such maps could be produced to address specific needs of a range of users. In 2013, ESA will deliver global land cover maps (for years 2000, 2005, 2010) under the Climate Change Initiative. These maps will allow to estimate the global extent of forests by forest types. It may be possible to generate several different maps using different forest definitions. The use of the Land Cover Classification System (LCCS) should be fostered in the land monitoring community[14].

[14] http://www.esa-cci.org/; Di Gregorio (2005)

2. Some countries have developed country-specific observation systems but these are still not broadly available. Expansion of these systems requires resources, access to data and capacity building.

3. The ability to reliably estimate biomass from remotely sensed data would significantly improve forest-related GHG estimation and reporting and may become available in the near future (refer to Section 3.1).

4.3 Emission and removal factors

1. There is a potential for using atmospheric concentration measurements to directly estimate emissions or emission rates from fires.

2. LiDAR and RADAR may be used to estimate regrowth (accuracy of maximum canopy height in LiDAR footprint is 3m.). There needs to be a rigorous evaluation of the potential of RS observations for estimation of removals of CO_2 from the atmosphere.

Table 3 Quantifying carbon stock change: expected capabilities in 5 years' time

Variable	Resolution	Current status	Resource Requirement
Density	Medium	Operational	Low
Fragmentation	Medium	Operational	Low
Species detection	Fine	Case Specific	High
Crown cover	Medium	Operational	Low
Height of trees	Fine	Operational	High
Canopy structure	Fine	Case Specific	High
Stand structure	Medium	Case Specific	High
Forest type detection	Medium	Operational	Low
Photosynthetic capacity – biochemical concentration	Medium	Operational	Low

Table 4 Detection of degradation: expected capabilities in 5 years' time

Variable	Resolution	Current status	Resource Requirement
Canopy gap fraction	Medium	Operational	Low
Health/Stress – water stress, etc.	Fine	Case Specific	High
Fire	Medium	Operational	Low
Species diversity	Fine	Case Specific	High
Change in height of trees	Fine	Operational	High
Soil erosion/Suspended sediment	Fine	Case Specific	High
Note: Also includes all items in Table 3			

There remain a number of important variables that cannot be assessed and/or monitored from RS and this is likely to remain the case in the foreseeable future. Further development activities may address some of these. Issues. This could be facilitated by better communication between the RS community and terrestrial biosphere modellers. These variables include those associated with:

- Soil carbon, dead organic matter, litter and the below-ground biomass carbon pools;
- Forest structure once the point of saturation is passed.

5 Conclusions

The meeting concluded that:

a. Currently the only widely accepted remote-sensing based method to estimate changes in carbon stocks in biomass is to use remotely sensed data to estimate the area of distinct forest strata in forest land and develop emission factors for each stratum based on ground based surveys and/or NFI. The product of the area and associated emission factor provides the emissions/removals associated with the observed changes in carbon stocks. The following may be helpful:

    I. Combining medium resolution data with more detailed spatial data on “hot spots” (areas of high rate of change) can reduce costs while providing quality results.

    II. The temporal resolution of forest monitoring is important. Constructing a consistent time series for annual or biennial change estimation requires routine, repeated, RS data over many years. This has been difficult to achieve without complementing with different data sources.

b. Using RS to monitor forest areas can be a routine activity, given sufficient resources and capacity.

c. Methods for estimating biomass by using RS data jointly with field data for model calibration and validation have been demonstrated in specific cases but are not yet ready to be operationalized in routine national forest monitoring. These methods show promise for the future, but they need to be verified and validated on a wide scale.

d. Detection of forest degradation from remotely sensed data may pose a particular challenge, and is highly definition dependent. Different drivers of degradation have different impacts on the forest structure which adds to the complexity of identification and change detection. Validating results of degradation requires extensive resources, both financial and human, to implement.

e. There are a number of techniques under development and new satellites to be launched in the next few years that will lead to increased capabilities for the use of RS in forests.

f. Widespread forest monitoring of carbon stocks and CO_2 emissions and removals in many countries will require access to remotely-sensed data, resources and capacity development.

g. To speed up the development of operational techniques, closer collaboration of RS experts, terrestrial biosphere modellers and emission inventory experts is needed.

References

Asner, G.P., Clark, J. K., Mascaro, J., Galindo García, G. A., Chadwick, K. D., Navarrete Encinales, D. A., Paez-Acosta, G., Cabrera Montenegro, E., Kennedy-Bowdoin, T. Duque, Á., Balaji, A., von Hildebrand, P., Maatoug, L., Phillips Bernal, J. F., Yepes Quintero, A. P., Knapp, D. E., García Dávila, M. C., Jacobson, J., and Ordóñez, M. F. (2012). High-resolution mapping of forest carbon stocks in the Colombian Amazon, *Biogeosciences*, 9: 2683-2696. doi:10.5194/bg-9-2683-2012.

Baccini, A., Goetz, S. J., Walker, W. S., Laporte, N. T., Sun, M. et al. (2012). Estimated carbon dioxide emissions from tropical deforestation improved by carbon-density maps. *Nature Climate Change*, 2: 182-185. doi:10.1038/nclimate1354.

Cartus, O., Santoro, M., and Kellndorfer, J. (2012). Mapping of Forest Aboveground Biomass in the Northeastern United States with ALOS PALSAR Dual-Polarization L-Band. *Remote Sensing of Environment,* 124:466-478.

De Sy, V., Herold, M., Achard, F., Asner, G. P., Held, A., Kellndorfer, J., and Verbesselt, J. (2012). Synergies of multiple RS data sources for REDD + monitoring. *Current Opinion in Environmental Sustainability*, 4, 1–11.

Di Gregorio, A. (2005). Land *cover classification system: classification concepts and user manual*: LCCS. Food and Agriculture Organization of the United Nations.

Foody, G M, Boyd, D. S. and Cutler, M. E. J. (2003). Predictive relations of tropical forest biomass from Landset TM data and their transferability between regions. *Remote Sensing of Environment,* 85: 463–74.

Gibbs, H.K., Brown, S., Niles, J.O, and Foley, J.A. (2007). Monitoring and estimating forest carbon stocks: making REDD a reality. *Environmental Resource Letters* 2. IOP Publishing Ltd., UK. Available online at: http://www.iop.org/EJ/article/1748-9326/2/4/045023/ erl7_4_045023.html

IPCC (2003a). *Definitions and Methodological Options to Inventory Emissions from Direct Human-induced Degradation of Forests and Devegetation of Other Vegetation Types,* eds: Jim Penman, Michael Gytarsky, Taka Hiraishi, Thelma Krug, Dina Kruger, Riitta Pipatti, Leandro Buendia, Kyoko Miwa, Todd Ngara, Kiyoto Tanabe, and Fabian Wagner IPCC, Pub IGES, Japan 2003.

IPCC (2003b). *Good Practice Guidance for Land Use, Land-Use Change and Forestry.* Eds. Penman J., Gytarsky M., Hiraishi T., Krug T., Kruger D., Pipatti R., Buendia L., Miwa K., Ngara T., Tanabe K. & Wagner F. Intergovernmental Panel of Climate Change (IPCC), IPCC/IGES, Hayama, Japan.

IPCC (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Prepared by the National Greenhouse Gas Inventories Programme. Eds. Eggleston H.S., Buendia L., Miwa K., Ngara T. & Tanabe K. Published: IGES, Japan.

IPCC (2010). *Revisiting the Use of Managed Land as a Proxy for Estimating National Anthropogenic Emissions and Removals*, eds: Eggleston H.S., Srivastava N., Tanabe K. and Baasansuren J. IPCC Expert Meeting Report, Pub. IGES, Japan.

Kissinger, G., Herold, M. and De Sy, V. (2012). Drivers of Deforestation and Forest Degradation: A Synthesis *Report for REDD+ Policymakers* (p. 26). Vancouver, BC, Canada.

Le Toan, T., Quegan, S., Woodward, I., Lomas, M., Delbart, N. and Picard C. (2004). Relating radar remote sensing of biomass to modeling of forest carbon budgets. *Climate Change,* 76: 379–402.

Le Toan T., Quegan, S., Davidson, M., Balzter, H., Paillou, P., Papathanassiou, K., Plummer, S., Saatchi, S., Shugart, H. and Ulander, L. (2011). The BIOMASS Mission: Mapping global forest biomass to better understand the terrestrial carbon cycle. *Remote Sensing of Environment*, 115(2011)2850-2860.

Puhr, C. and Donoghue, D. (2000). RS of upland conifer plantations using Landsat TM data: a case study from Galloway, South-West Scotland*. International Journal of Remote Sensing,* 21: 633–646.

Saatchi, S.S., Harris, N L, Brown, S., Lefsky, M., Mitchard, E. T. A, Salas, W., Zutta, B. R., Buermann, W., Lewis, S. L., Hagen, S., Petrova, S., White, L., Silman M., and Morel., A. (2011). A Benchmark map of forest carbon stocks in tropical regions across three continents. *Proceedings of the National Academy of Sciences*, 2011: DOI: 10.1073/pnas.1019576108.

Tangki, H. and Chappell, N. (2008). Biomass variation across selectively logged forest within a 225-km^2 region of Borneo and its prediction by Landsat TM. *Forest Ecology and Management,* 256: 1960t Eco.

Annex 1 Agenda

IPCC Expert Meeting: Role of RS in Forest and National GHG Inventories

Hayama, Japan

23 – 25 October 2012

AGENDA

Tuesday 23rd October		
09:00	Registration	
09:30	Open Meeting	*Taka Hiraishi* (IPCC TFI) *Thelma Krug* (IPCC TFI)
	Welcome to Participants	*Hideyuki Mori* (Institute for Global Environmental Strategies) *Hiroshi Tsujihara* (Ministry of the Environment, Japan)
	Presentations	
10:00		GFOI Methods and Guidance in the Use of RS and Ground Observations for Estimates of GHG Emissions and Removals - *Miriam Baltuck (Australia)*
		GFOI Methods and Guidance Document Overview - *Jim Penman (UK)*
10:50	COFFEE	
11:10		Role of RS for GEOSS and IPCC - *Yukio Haruyama (Japan)*
		JAXA's Earth Observation Satellites and Forest Mapping - *Masanobu Tsuji (Japan)*
		The Role of RS/GIS Applications for National Forest Monitoring Systems in the Context of REDD+ - *Inge Jonckheere (FAO)*
12:50	LUNCH	
14:00		Indonesia's National Forest Monitoring System as Main System for REDD+ MRV- *Ruandha Agung Sugardiman (Indonesia)*
		RS Data-based Forest Inventories and Carbon Stock Reporting - *Brice Mora (Netherlands)*
		GHG Inventories: The Case of Land Use, Land Use Change and Forestry (LULUCF) Mapping in Eastern and Southern Africa - *Erick Khamala (Kenya)*
15:40	COFFEE	
16:00		Integration of Optical and SAR Data for Land Cover Classification - *Hasi Bagan (Japan)*
		Amazon Biomass Estimation Using X and P Band SAR Data - *Carlos Alberto Pires de Castro Filho (Brazil)*
18:00	CLOSE	
Wednesday 24th October		
09:15		Analysis of the Normalized Differential Vegetation Index (NDVI) for the Detection of Forest Degradation Coverage in México - *Meneses Tovar Carmen Lourdes (Mexico)*
		Using SPOT 5 Satellite Multispectral Imagery and LiDAR Data to Monitor Forest Carbon Stocks and Stock Change in New Zealand - *Deborah Burgess (New Zealand)*
		Forest Degradation : the DEGRAD Project at INPE - *Thelma Krug (Brazil)*
		Use of Airborne and Satellite LiDAR for Estimating Forest Carbon Stock and its Changes - *Yasumasa*

		Hirata (Japan)
11:00	COFFEE	
11:20		Detecting Forest Degradation by Using Gramm-Schmidt Transformation - *Carlos Humberto Bahamondez (Chile)*
		Using RS Measurements Constrain Terrestrial Biosphere Model Predictions - *Paul Moorcroft (US)*
13:00	LUNCH	
14:00		Obtaining Reliable Fine-Scale Estimates of Biomass Using Ground-Based Methods - *John Raison (Australia)*
		Estimating Tropical Forest Biomass With Multisource RS Data: Predictions Between Regions - *Mark Cutler (UK)*
		Satellite-Based Carbon Stock Measurements in the Tropics - *Pieter S. A. Beck (USA)*
16:00	COFFEE	
16:15		Global and Regional CO_2 Flux Estimation Using Atmospheric CO_2 Data Obtained by GOSAT, GOSAT-2, and Other Future Satellites - *Tsuneo Matsunaga (Japan)*
		High Spatial Resolution RS Improves Forest Carbon Stock Estimation in Dry Forests - *Amon Murwira (Zimbabwe)*
		Biomass Dynamics in Mozambican Woodland - *Casey Ryan (UK)*
18:00	CLOSE	

Thursday 25th October

09:15	Break-Out Groups - BOG 1: Use of RS for Biomass Measurements - BOG 2: Combination of RS and Ground Data to Improve National GHG Inventories - BOG 3: Use of RS for Degradation Measurements
11:15	COFFEE
11:30	Break-Out Groups Continue
13:00	LUNCH
14:00	Closing Plenary (Brief Report by BOGs). Summary of Conclusions

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Annex 3 Presentations[15]

1) *GFOI Methods and Guidance in the Use of RS and Ground Observations for Estimates of GHG Emissions and Removals* - Miriam Baltuck (Australia)
2) *GFOI Methods and Guidance Document Overview* - Jim Penman (UK)
3) *Role of RS for GEOSS and IPCC* - Yukio Haruyama (Japan)
4) *JAXA's Earth Observation Satellites and Forest Mapping* - Masanobu Tsuji (Japan)
5) *The Role of RS/GIS Applications for National Forest Monitoring Systems in the Context of REDD+* - Inge G.C. Jonckheere (FAO)
6) *Indonesia's National Forest Monitoring System as Main System for REDD+ MRV* - Ruandha Agung Sugardiman (Indonesia)
7) *RS Data-based Forest Inventories and Carbon Stock Reporting* - Brice Mora (GOFC-GOLD)
8) *GHG Inventories: The Case of Land Use, Land Use Change and Forestry (LULUCF) Mapping in Eastern and Southern Africa* - Erick Khamala (Kenya)
9) *Integration of Optical and SAR Data for Land Cover Classification* - Hasi Bagan (Japan)
10) *Amazon Biomass Estimation Using X and P Band SAR Data* - Carlos Alberto Pires de Castro Filho (Brazil)
11) *Analysis of the Normalized Differential Vegetation Index (NDVI) for the Detection of Forest Degradation Coverage in México* - Meneses Tovar Carmen Lourdes (Mexico)
12) *Using SPOT 5 Satellite Multispectral Imagery and LiDAR Data to Monitor Forest Carbon Stocks and Stock Change in New Zealand* - Deborah Burgess (New Zealand)
13) *Forest Degradation : the DEGRAD Project at INPE* - Thelma Krug (Brazil)
14) *Use of Airborne and Satellite LiDAR for Estimating Forest Carbon Stock and its Changes* - Yasumasa Hirata (Japan)
15) *Detecting Forest Degradation by Using Gramm-Schmidt Transformation* - Carlos Humberto Bahamondez (Chile)
16) Using *RS Measurements Constrain Terrestrial Biosphere Model Predictions* - Paul Moorcroft (US)
17) *Obtaining Reliable Fine-Scale Estimates of Biomass Using Ground-Based Methods* - John Raison (Australia)
18) *Estimating Tropical Forest Biomass With Multisource RS Data: Predictions Between Regions* - Mark Cutler (UK)
19) *Satellite-Based Carbon Stock Measurements in the Tropics* - Pieter S. A. Beck (USA)
20) *Global and Regional CO_2 Flux Estimation Using Atmospheric CO_2 Data Obtained by GOSAT, GOSAT-2, and Other Future Satellites* - Tsuneo Matsunaga (Japan)

[15] All presentations are available on: http://www.ipcc-nggip.iges.or.jp/meeting/meeting.html

21) *High Spatial Resolution RS Improves Forest Carbon Stock Estimation in Dry Forests* - Amon Murwira (Zimbabwe)
22) *Biomass Dynamics in Mozambican Woodland* - Casey Ryan (UK)

GFOI Methods and Guidance in the use of Remote Sensing and Ground Observations for Estimates of GHG Emissions and Removals

Miriam Baltuck
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Hayama, Japan 23-25 October

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Global Forest Observations Initiative

GFOI Methods and Guidance Documentation Timeline to Completion

Completed Steps-2012

February-GFOI country co-leads agree that Australia will lead pursuit of this area.

May- First AG meeting one day session hosted by World Bank to assess ad hocdraft documents for end-to-end completeness, identify gaps, redundancies, etc in the context of a single compiled document. . Authors invited to participate in MGD writing.

June 26-28- the authors and AG met to discuss AG recommendations and develop document outline and content and agree to writing assignments and nominal timeline to completion.

Current activity (as of October 2012)

June/July to October- electronic correspondence during rewrite.

Oct-- 1st cut draft to review by MGD Advisory Group

Oct/Nov/Dec –review by AG, revise in response to AG review

Future Steps-2012 to 2013

Dec/Jan-commence GEO and external review of documents; aim for completion by Jan 2013

February- MGD AG and Writing Team meet to revise in response to reviews and COP outcome

April/May-Completion of Methods and Guidance Book-beta version

May-August-"Field test" of Methods and Guidance Book (rigorous review by user *community)*

September--adjustments as appropriate. (Additional Writing Team meeting may be required)

October-submission to GEO Plenary X

November-Final report approved by GEO Plenary X

GROUP ON EARTH OBSERVATIONS

GFOI Global Forest Observations Initiative

GFOI Methods and Guidance Documentation

Chapter 1- Introduction (see previous presentation)

Chapter 2- Generic guidance for estimation of GHG emissions and removals for forests

- **2.1 Introduction**
- **2.2. Description of REDD+ activities and their effects on GHG emissions and removals.**
- **2.3 Generic description and guidance for each IPCC Tier.**
- **2.4 Generic Methods for Estimating Activity Data**
- **2.5 Generic Methods for Estimating Emissions and Removals Factors**
- **2.6 Estimation of GHG emissions and removals**

Chapter 3- Using remote sensing and ground observations to estimate GHG emissions and removals caused by specific forest activities

- **3.1 Introduction**
- **3.2 Activity data**
- **3.3 Estimation of emissions and removals of carbon**
- **3.4 Non-CO2 emissions (fire and soil)**
- **3.5 Guidance on uncertainties**
- **3.6 Advice on Reporting**

GROUP ON EARTH OBSERVATIONS

GFOI Global Forest Observations Initiative

GFOI Methods and Guidance Documentation

Chapter 2- Generic guidance for estimation of GHG emissions and removals for forests

Provides generic guidance on using remotely sensed and ground based data in combination to estimate GHG emissions and removals for forests. The guidance in chapter 2 is intended for use in chapter 3, which sets out how to apply these methods to the REDD+ activities being discussed under the UNFCCC.

2.1 Introduction

Previews the topics covered in this chapter and outlines the gain-loss and stock difference methods for estimating emissions or removals as annual rates of change in carbon stocks and circumstances which might lead to use of one or the other approach.

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Global Forest Observations Initiative

GFOI Methods and Guidance Documentation

Chapter 2- Generic guidance for estimation of GHG emissions and removals for forests

2.2. Description of REDD+ activities and their effects on GHG emissions and removals.

This section briefly describes each of the six forest activities relevant to REDD+ and the effects of these on GHG emissions and removals.

Deforestation

Forest degradation

Establishment of forest on non-forest land

Conservation, sustainable management of forests, and enhancement of forest stocks

Conversion of native forests to plantations

Rehabilitation of degraded peat forests

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Global Forest Observations Initiative

GFOI Methods and Guidance Documentation

Chapter 2- Generic guidance for estimation of GHG emissions and removals for forests

2.3 Generic description and guidance for each IPCC Tier.

This Section provides an accessible introduction to the IPCC Good Practice Guidelines including a description of the five principles underlying the IPCC , then builds on this to outline the three Tiers of reporting and the circumstances under which they might be selected.

While the IPCC guidelines provide methodologies relevant to all source and sink categories likely to be encountered in the monitoring and reporting of GHG emissions and removals form forests, they do not refer to terms such as deforestation and degredation. This section suggests how such activities being discussed by the UNFCCC can be addressed by the IPCC Guidelines.

The section also provides useful detail on performing Quality Control/Quality Assurance and obtaining appropriate reviews to assure validation and verification of reporting material.

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Global Forest Observations Initiative

GFOI Methods and Guidance Documentation

Chapter 2- Generic guidance for estimation of GHG emissions and removals for forests

2.4 Generic Methods for Estimating Activity Data

Data sets associated with land-use and land-use change are often very large. This applies to remote sensing (RS), but can also be the case with ground observations such as forest inventories and soil surveys which will may contain observations from many thousands of plots.

Using and combining such data sets to make greenhouse gas inventory estimates meeting good practice requirements including those of consistency and comparability poses particular challenges for data processing. These challenges are addressed in this section which includes description of RS techniques including basic preparation (e.g. selection of imaging technology(ies) image registration/ orthorectification, radiometric and geometric corrections, mosaicking of multiple images) and ground observations and their use in combination.

This section will also cover related uncertainties, as well as issues associated with Tier 3 methods

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Global Forest Observations Initiative

GFOI Methods and Guidance Documentation

Chapter 2- Generic guidance for estimation of GHG emissions and removals for forests

2.5 Generic Methods for Estimating Emissions and Removals Factors

Although RS is usually associated with activity data there have been advances in its use for direct estimation of biomass, and some techniques can be used to estimate forest structure.

This section will discuss how such techniques can be used to best effect in combination with ground based data.

The section offers guidance on selection of reporting tiers, selection of emission factors, model choice, parameters etc and overall uncertainty estimate**.**

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Global Forest Observations Initiative

GFOI Methods and Guidance Documentation

Chapter 2- Generic guidance for estimation of GHG emissions and removals for forests

2.6 Estimation of GHG emissions and removals

This section will show how to bring together activity data and emissions and removal factors in a consistent fashion.

The section also addresses cross-cutting issues such as uncertainty estimation, ensuring time series consistency, data gap filling, interoperability issues between different sources of RS data.

It is possible that the final document may deal with these issues adequately in the previous section and in Ch 3, in which case this section might be unnecessary.

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Global Forest Observations Initiative

GFOI Methods and Guidance Documentation

Chapter 3- Using remote sensing and ground observations to estimate GHG emissions and removals caused by specific forest activities

Chapter 3 sets out how to apply the generic methods of Chapter 2 to the REDD+ activities being discussed under the UNFCCC.

Chapter 3 provides specific guidance for using remote sensing and ground observations to construct or improve estimates of GHG emissions and removals.

For each of the six forest activities guidance is provided for each component (carbon pools and non-CO2 emissions) of the GHG estimates reported using IPCC methodology.

-Above and below ground biomass

-Deadwood and litter (dead organic matter)

-Soil carbon

-Non-CO_2 from soils and fire

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Global Forest Observations Initiative

GFOI Methods and Guidance Documentation

Chapter 3- Using remote sensing and ground observations to estimate GHG emissions and removals caused by specific forest activities, continued

For each combination of forest activity and GHG category guidance is provided on:

- Choice of method for estimating GHG emissions & removals as outlined in the 2006 IPCC Guidelines
- Activity data (usually area, but also other factors affecting GHG emissions such as disturbance history) consistent with the method chosen
- Choice of emission and removal factors and other parameters
- Other supporting data such as forest type, soil type, or climate that is useful or necessary to implement the chosen methodology.
- Quantification of uncertainties and combining them in estimating GHG emissions

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GFOI Methods and Guidance Documentation

Chapter 3- Using remote sensing and ground observations to estimate GHG emissions and removals caused by specific forest activities

Non-CO2 emissions (fire and soil)

This section will reference internationally available data sets (e.g. on fire extent) as resources for analysis and estimation.

This section will include advice on establishing the relationship between soil/soil management data and soil emissions.

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GFOI Global Forest Observations Initiative

GFOI Methods and Guidance Documentation

Chapter 3- Using remote sensing and ground observations to estimate GHG emissions and removals caused by specific forest activities

Guidance on uncertainties

The MGD adopts an approach to uncertainty analysis consistent with that taken by IPCC. This recognises that uncertainty estimates are an essential element of a complete GHG inventory of emissions and removals.

The MGD will provide:

•advice on a simple approach based on the activity data x emission factor equation plus error propagation

• generic advice on a more complex approach using monte-carlo analysis or equivalent.

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GFOI Global Forest Observations Initiative

GFOI Methods and Guidance Documentation

Chapter 3- Using remote sensing and ground observations to estimate GHG emissions and removals caused by specific forest activities

Advice on Reporting

This section provides a preview of likely reporting requirements. Including likely COP 18 outcomes. It will be updated accordingly.

MRV reporting requirements will probably conform to the general requirements of *good practice* set out in MGD Chapter 1, consistent with a phased approach building on existing systems, the availability of financial support, and with the flexibility to allow for improvement.

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Global Forest Observations Initiative

GFOI Methods and Guidance Documentation

Next Steps

Advice welcome!
Constructive Reviewers welcome!

MGD will be revised as new methodologies are adopted and new requirements are defined.

MGD will have an online wiki presence with hyperlinks to references, documents, illustrations and Youtube demonstrations.

The intent is to make this document useful across the UNFCCC community and beyond: The MGD will be available to any organisation wishing to develop forest reporting capacity consistent with IPCC GPG.

GROUP ON EARTH OBSERVATIONS

Global Forest Observations Initiative

GFOI Methods and Guidance Document Overview

Jim Penman

Environment Institute

University College London

Hayama 23 to 25 October 2012

Global Forest Observations Initiative

Established in 2010 by Group on Earth Observations (GEO). Five work areas:

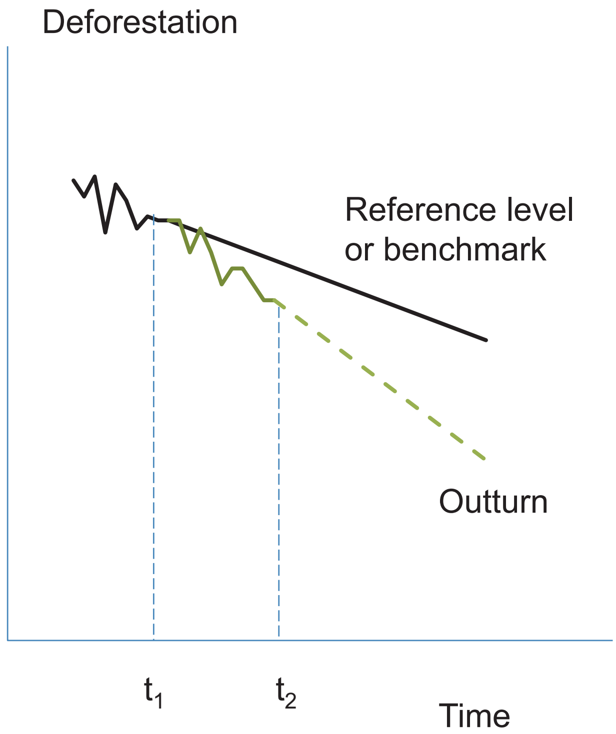
1) Coordination of satellite data supply
2) Capacity Building
3) Methods and Guidance Documentation
4) R&D
5) Administration and coordination

Conceptual Model

Results-based finance based on the difference between actual emissions in future periods and a reference level requires:

- Methodologies to estimate of actual emissions and removals
- Establishment of a reference level with the same coverage of emissions and removals.

Implies need to consider historical as well as current and future data, on a consistent basis



Coverage of REDD+

- National (sub-national interim)
- 5 plus activities: reduced emissions from deforestation, forest degradation, and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries; possible extension to other activities that drive REDD+
- 5 pools: above and below ground biomass, deadwood, litter, soil organic matter
- Related non-CO_2 GHG emissions

Probable elements of a REDD+ MRV decision in Doha

- Use of IPCC methods, further work by IPCC
- Transparency, consistency, completeness, accuracy, comparability and QA/QC
- Stepped approach building on existing forest monitoring systems and with sub-national approaches as an interim
- Identification of changes in natural forest
- Identification of uncertainties
- Stepwise approach to incorporate better data for pools and/or gases and to improve methodologies
- Possible use of conservativeness
- Request that availability of RS data be facilitated – *most powerful in combination with ground based data*
- Envisages technical assessment of reported data and reference levels

IPCC Guidance and Guidelines

- IPCC first produced GHG inventory guidelines in 1995 and 1996, building on previous work by OECD
- KP implied the need for greater specificity, and hence the IPCC Good Practice Guidance.
- IPCC methods are tiered to accommodate all national circumstances. Higher tiers are called for key categories, unless the resources called for are disproportionate.
- Definition is that Good Practice inventories *are those which contain neither over-nor underestimates so far as can be judged, and in which uncertainties are reduced so far as is practicable*

IPCC estimation methods

- Gain-loss: emission factor x activity data; most widely applicable (basis for IPCC default method)
- Stock-difference: needs national forest inventory (NFI - not necessarily cost effective to establish, and supplementary sampling may be needed to detect deforestation efficiently)
- Some overlap – e.g. non-CO_2 gases always require EF x AD calculations; existing NFI can be used to establish EF even if sampling not optimal for deforestation; sampling to establish EF in the absence of an NFI may be similar to supplementary sampling
- MGR will consider different cases

IPCC GPG General Principles

IPCC good practice guidance entails adherence to principles of:

- Transparency
- Completeness
- Consistency
- Comparability
- Accuracy

GPG and land area identification

- Three approaches:

1. Tracks land area by land use (no LUC matrix)
2. Adds LUC matrix, but not necessarily spatially explicit
3. Spatially explicit matrix (sampling or complete tally)

- Guidance on sampling, use of RS and ground-based data and uncertainties
- See http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_03_Ch3_Representation.pdf

Relationship between GFOI, IPCC and GOFC-GOLD

- IPCC: operational guidance for greenhouse gas inventories
- GFOI: operational guidance for users and suppliers of RS data for use in greenhouse gas inventories consistent with IPCC guidance
- GOFC-GOLD: continuously updated review of applicable science and technologies relevant to IPCC and GFOI.

The MGD will…

- Be consistent with IPCC methods, and cross-reference them throughout
- Identify the steps that countries need to go through in making use of RS and ground based data in combination
- Communicate to RS data providers what the needs of countries are in this context
- Be practical, operational, and understandable by non-specialists
- Use decision trees, appropriately cross-referenced to IPCC methods
- Draw on other relevant work, notably GOFC-Gold

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Role of Remote Sensing for GEOSS and IPCC

Yukio Haruyama
Remote Sensing Technology Center of Japan
(RESTEC)

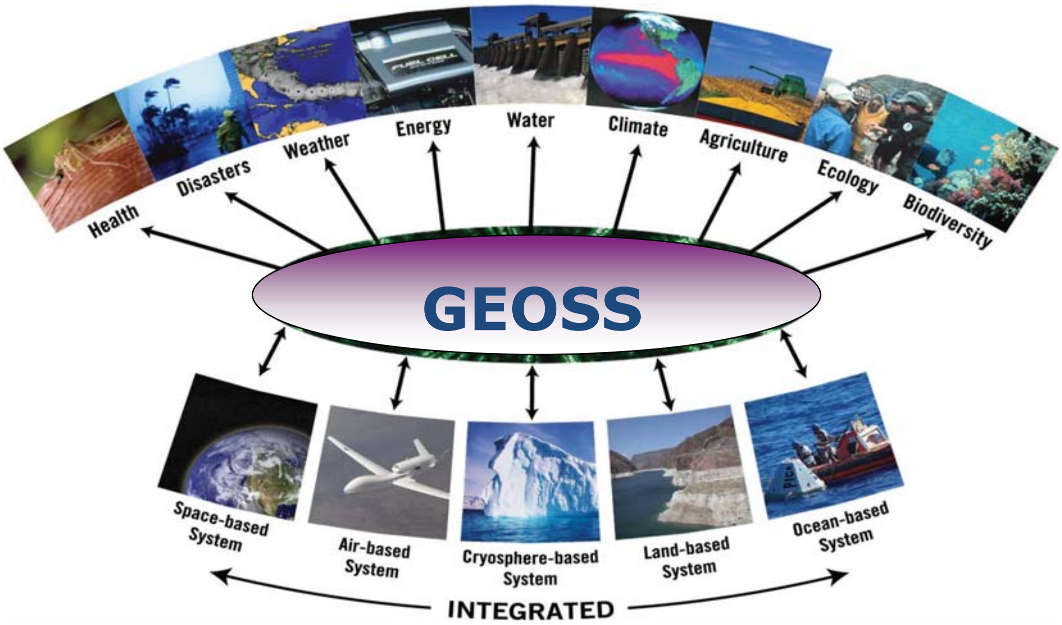
IPCC Expert Meeting: Role of Remote Sensing in Forest and National GHG Inventories
23-25 October 2012
IGES, Hayama, Japan

Introduction

- The Intergovermental Panel on Climate Change Forth Assessment Report (IPCC-AR4,2007) suggests that deforestation ,forest degradation and land use change contribute almost 20% of global GHG emissions.
- The Parties to the United Nations Convention on Climate Change (UNFCCC) are committed to providing national inventories of greenhouse gas emissions from human activities, including land use, land use change and forestry(LULUCF) .
- The UNFCCC is also considering policy approaches and positive incentives specific to the forest sector (REDD+ activities) as a way to reduce global GHG emissions.
- The Group on Earth Observations(GEO) Forest Carbon Tracking (FCT) task, which has been underway since 2008, focuses on a series of national demonstrators, and on developing methods and protocols for the use of observations in national forest monitoring systems.
- Based on GEO-FCT activities, the Global Forest Observation Initiative (GFOI) has been developed and the Implementation Plan was accepted at GEO-VIII in November 2011.

Global Earth Observation System of Systems (GEOSS)

- GEOSS is a comprehensive, coordinated, and sustained observations of the Earth system.
- GEOSS will enhance the development and use of Earth observations in 9 societal benefit areas.



GEOSS has been building-up on 3 Pillars

1. Coordinated Data Access
2. Open Data Policy
3. Political Visibility

The GEO Forest Carbon Tracking Task

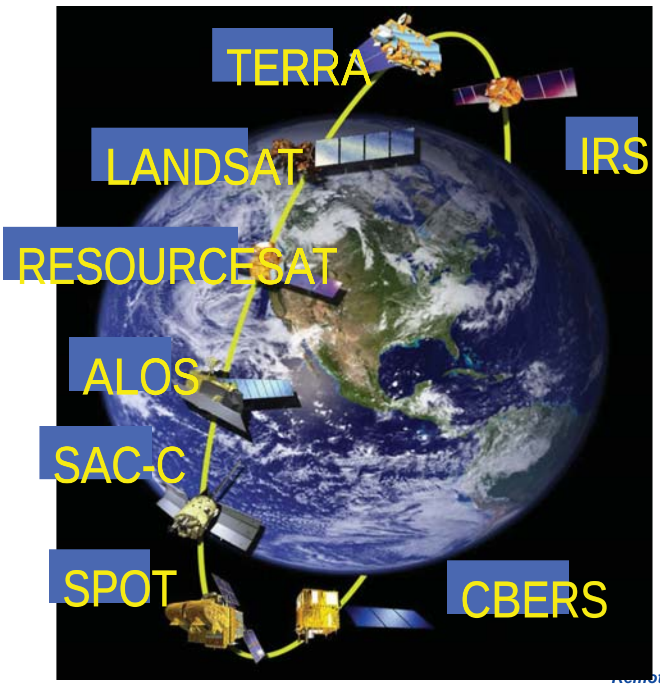
GEO established in 2008 the Forest Carbon Tracking (FCT) task demonstrate that **coordinated Observations from satellites**, validated by in situ measurements and properly linked to carbon modeling can provide reliable, accurate, consistent and continuous information to address the monitoring component of national MRVs.

The FCT overall goals are

1. to show the feasibility of performing coordinated, large scale satellite observations and
2. to test and compare the use of various observations, models, tools and methodologies in order to provide options, advice and guidelines to Countries willing to implement national systems.

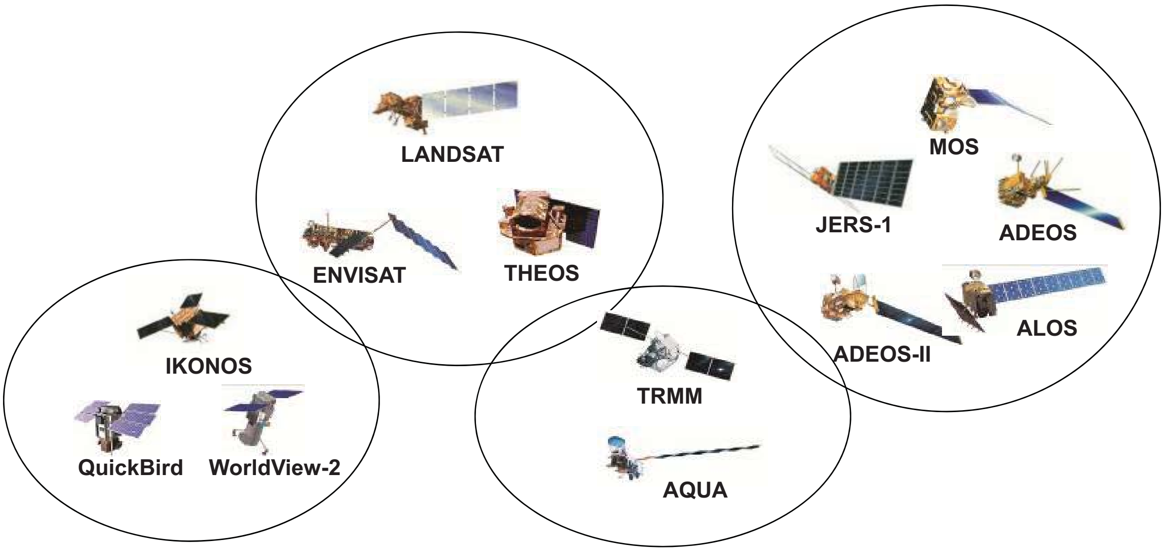
Remote Sensing from Space

GEOSS Coordinate Access to Satellite Data (with CEOS)

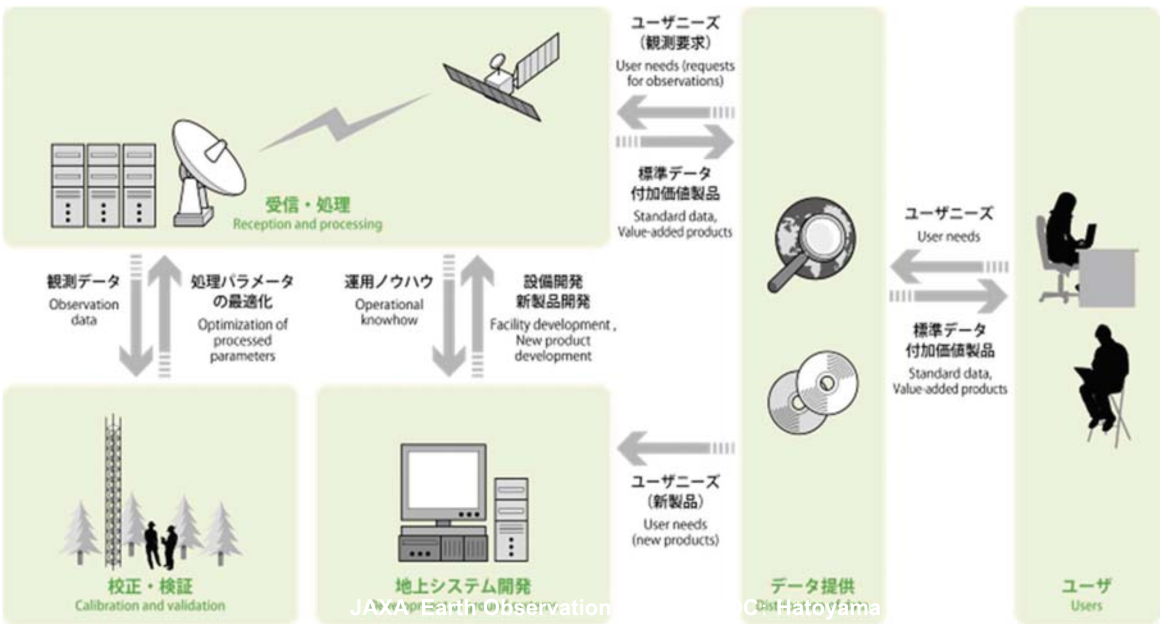


Access to EO satellites

- Various kind of satellite data available so far
- Continuously develop appropriate applications.



Earth Observation Satellite Operation



EOS Data Applications

Forest Coast Agriculture Disaster

Others

Remote Sensing Technology Center of Japan

FCT Network of “National Demonstrators”

11 ND Countries

- Australia (Tasmania)
- Brazil
- Cameroon
- Colombia
- DR Congo
- Guyana
- Indonesia (Sumatra, Kalimantan)
- Mexico
- Nepal
- Peru
- Tanzania.

From 2009
- Brazil
- Guyana
- Mexico
- Indonesia (Kalimantan)
- Australia (Tasmania)
- Cameroon
- Tanzania

From June 2010
- Colombia
- DR Congo
- Peru, and
- adding Sumatra to Indonesia

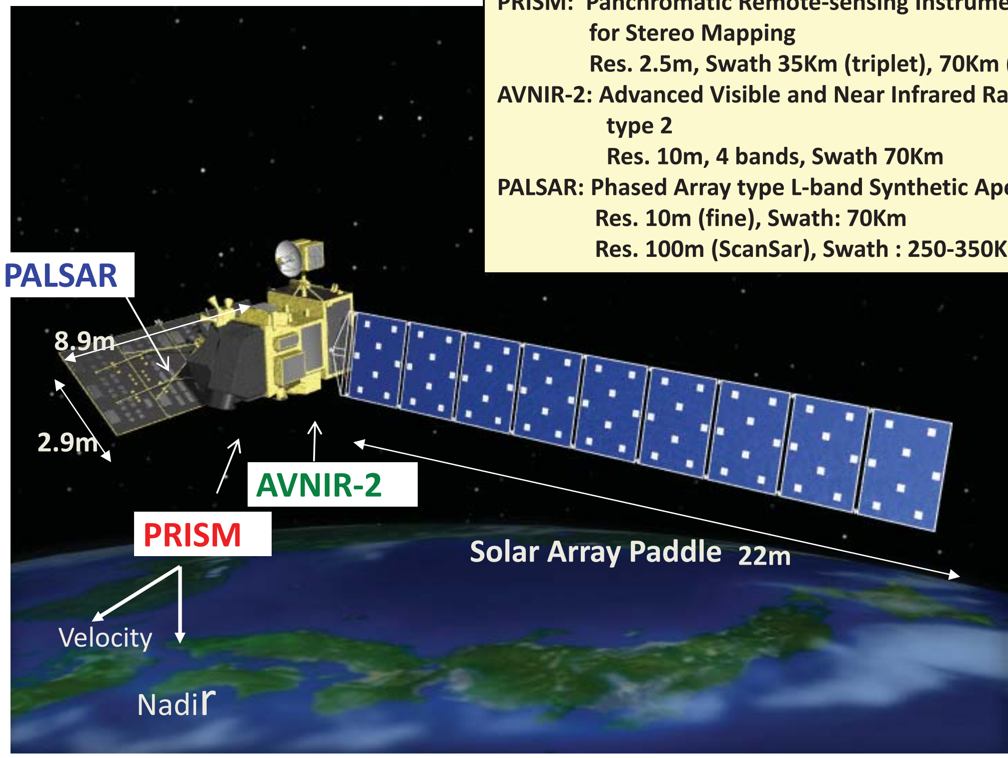
From June 2011
- Nepal

ALOS Launched: Jan. 2006

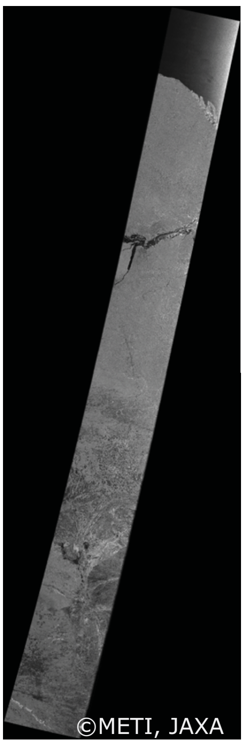
PRISM: Panchromatic Remote-sensing Instrument for Stereo Mapping
Res. 2.5m, Swath 35Km (triplet), 70Km (Nadir)

AVNIR-2: Advanced Visible and Near Infrared Radiometer type 2
Res. 10m, 4 bands, Swath 70Km

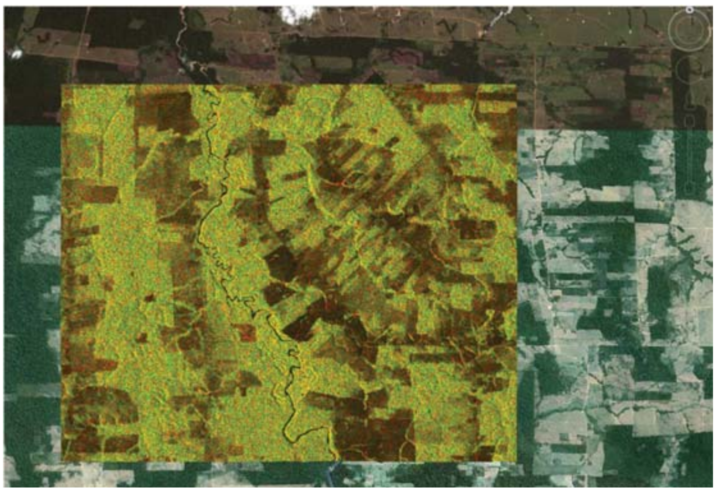
PALSAR: Phased Array type L-band Synthetic Aperture Radar
Res. 10m (fine), Swath: 70Km
Res. 100m (ScanSar), Swath : 250-350Km



(Forest) Illegal logging Monitoring,Brazil



- The Brazilian Institute of Environment (IBAMA) and the Federal Police Department (DPF) had a strong interest in PALSAR data to protect forest from illegal logging.
- JICA launched 3 year project called "Utilization of ALOS images to support protection of the Brazilian Amazon forest and combat against illegal deforestation".



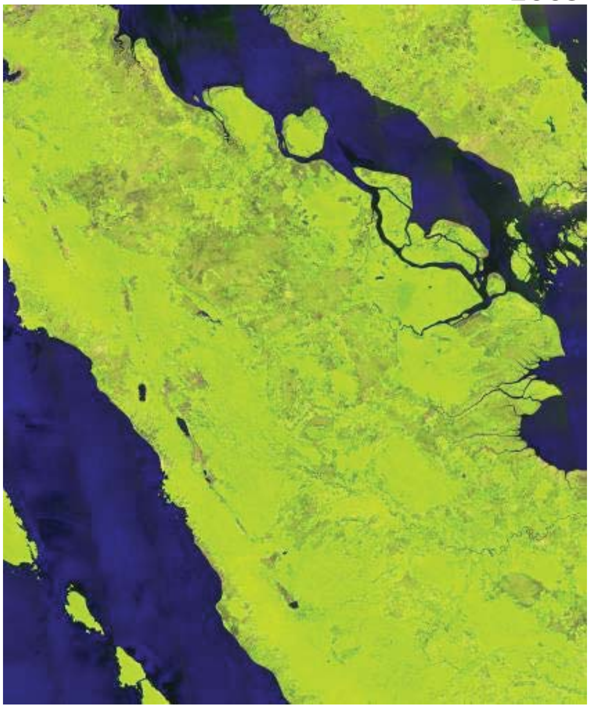
©RESTEC included ©JAXA, METI
Background ©Cnes/Spot Image, ©2011 GeoEye and ©2010 Google

- RESTEC transfers techniques of PALSAR as well as RS and GIS software.
- IBAMA makes color composite images from PALSAR ScanSAR strip data and overlay on Google Earth.

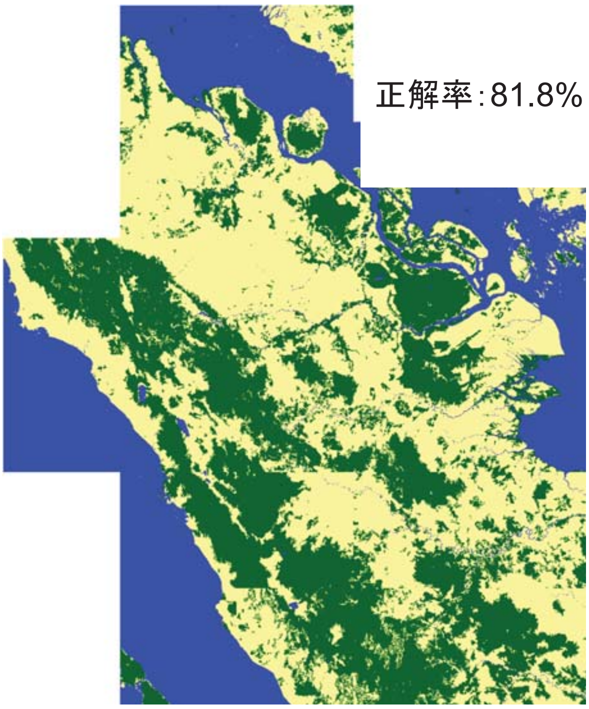
Forest/Non-Forest (FNF)

Indonesia, Sumatra, Liau

PALSAR RGB
2009



PALSAR Forest/Non-Forest
2009



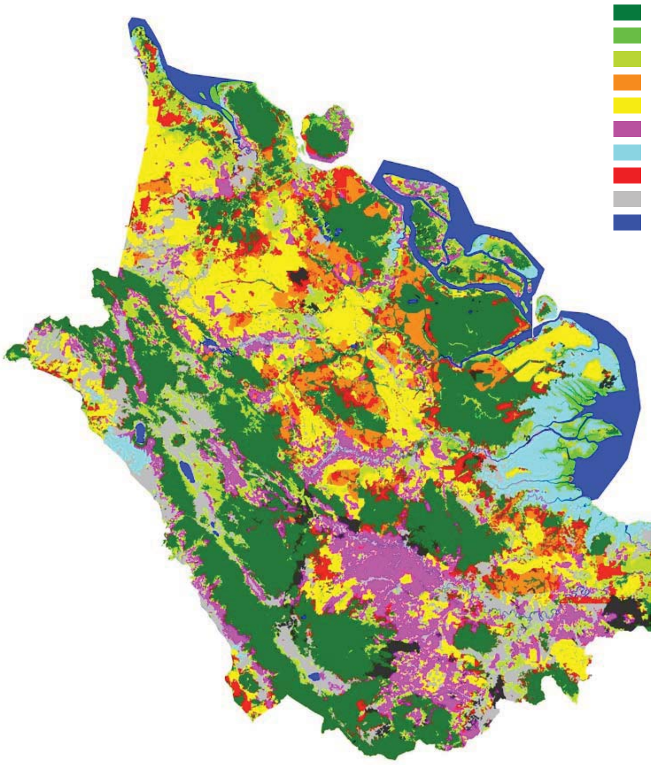
●: HH, ●: HV, ●: HH/HV

●: Forest, ●: Non-Forest, ●: Water

Land Cover (LC)

RESTEC

Indonesia, Sumatra, Liau



- Natural forest
- Natural mangrove forest
- Natural re-growth
- Acacia
- Oil Palm
- Rubber
- Coconut
- Open area
- Other
- Water

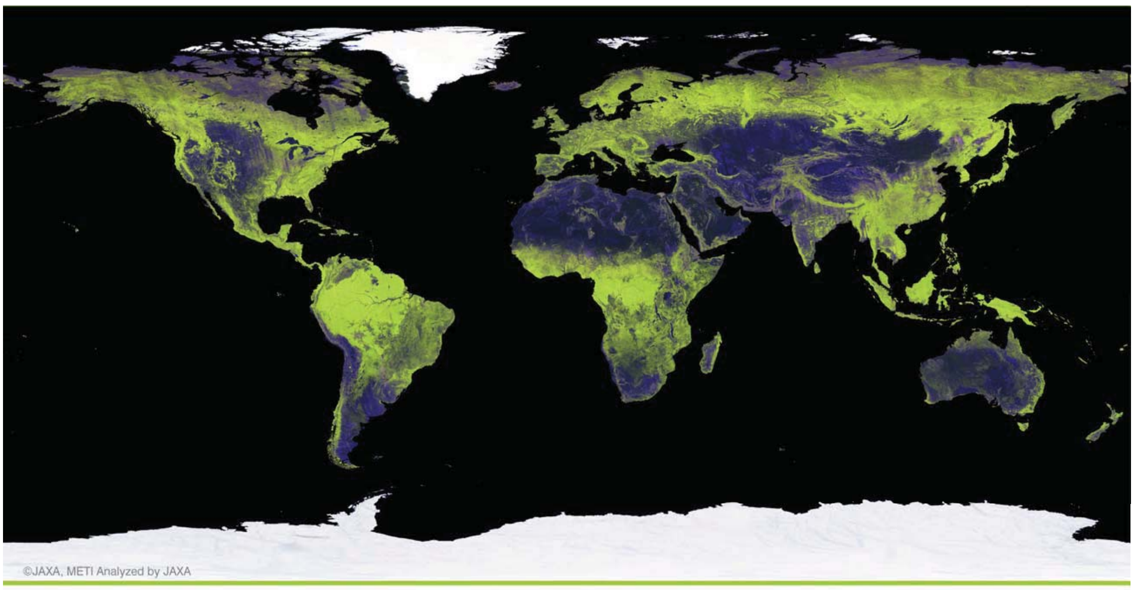
Sumatra, Indonesia (GEO-FCT ND)

FCT products in Sumatra, Indonesia

1) Slope-Corrected Mosaic (HH)

2) Slope-Corrected Mosaic (HV)

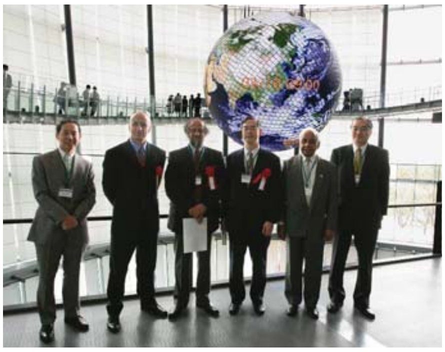
PALSAR Global Mosaic (PGM)

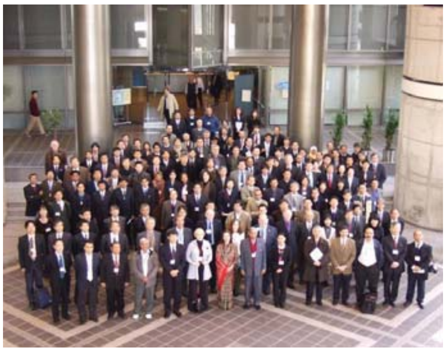


1. PALSAR Global Mosaic (PGM) are 10/25m resolution seamless ortho-rectified PALSAR mosaic data sets covering whole global land area.
2. PGM is composed by the 'Tile of Images' by each lat/long degree and polarization (HH/HV).
3. Processed by RESTEC under the contract of JAXA

GEOSS-AP Symposium

1st, 2nd, 3rd and 5th GEOSS Asia-Pacific Symposiums (including FCT session) were held in Japan.




The 5th GEOSS Asia – Pacific Symposium

GEO Initiatives towards Green Growth in the Asia-Pacific Region

Date : 2nd - 4th April 2012
Venue : National Museum of Emerging Science and Innovation (Miraikan)

The 5th GEOSS Asia-Pacific Symposium will promote societal benefits from the Global Earth Observation System of Systems (GEOSS) and discuss how GEOSS can contribute to the upcoming United Nations Conference on Sustainable Development (Rio+20).

The Symposium will further strengthen international networking within the region and share the Asia-Pacific's experiences with the world. Each country will report on the progress it has made in implementing GEOSS since the last Asia-Pacific Symposium in Indonesia.

PROGRAM

Day 1 : 2nd Apr. (Mon) - Plenary
- Keynote Speech
- GEOSS Activity Report
- Country and Regional Reports on GEOSS-related Activities

Day 2 : 3rd Apr. (Tue) - Parallel Sessions
- Asian Water Cycle Initiative (AWCI)
- Asia-Pacific Biodiversity Observation Network (AP-BON)
- Forest Carbon Tracking (FCT)
- Ocean Observation and Society
- Agriculture and Food Security

Day 3 : 4th Apr. (Wed) - Plenary
- Reports from each Parallel Session and Discussion
- Summary of Symposium

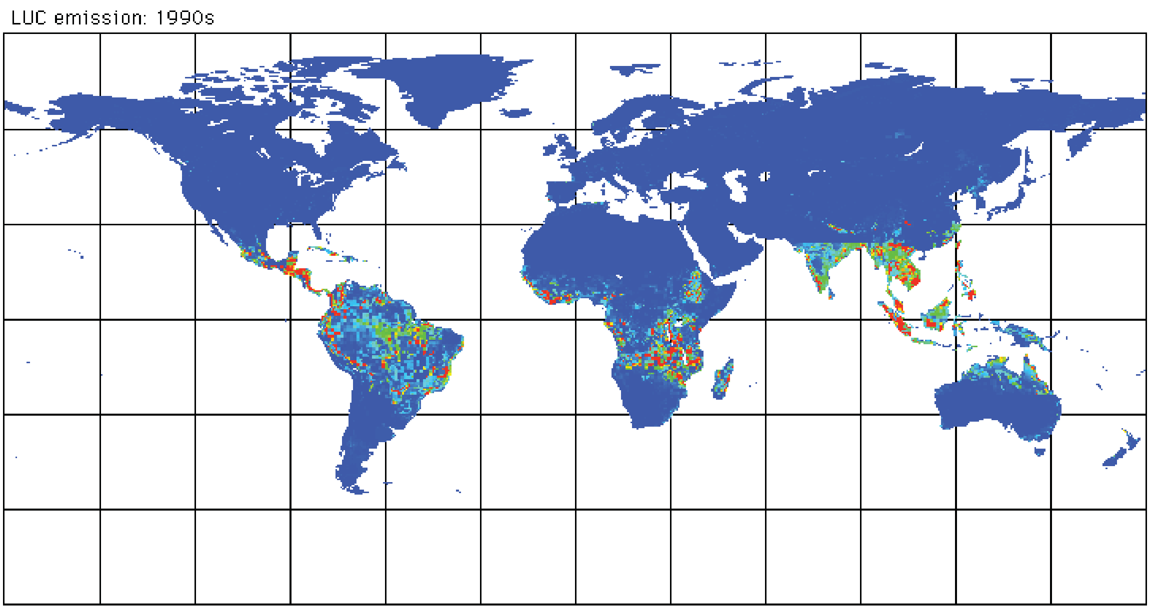
SIDE EVENT
2nd - 3rd Apr. Exhibition
2nd Apr. Short Lectures - Recovery from Earth Quake & Tsunami -

5th GEOSS AP WG 3
Forest Carbon Tracking

- Co – Chair Yoshiki Yamagata, National Institute for Environmental Studies, **Japan**
- Co – Chair Miriam Baltuck, Commonwealth Scientific and Industrial Research Organisation, **Australia**
- Ake Rosenquist, soloEO, **Japan**
- Hamdan Omar, Forest Research Institute of Malaysia, **Malaysia**
- Orbita Roswintiarti, Indonesian National Institute of Aeronautics and Space, **Indonesia**
- Nguyen Phy Hung, Forest Inventory and Planning Institute, **Vietnam**
- Chandra Shekhar Jha, Indian Space Research Organisation, **India**
- Masanobu Shimada, Japan Aerospace Exploration Agendy, **Japan**
- Kenlo Nasahara, University of Tsukuba, **Japan**
- Tamotsu Sato, Forestry and Forest Products Research Institute, **Japan**
- Mitsuru Osaki, Hokkaido University, **Japan**
- Nobuko Saigusa, National Institute for Environmental Studies, **Japan**

Remote Sensing Technology Center of Japan

CO_2 emission from deforestation, 1990s



Huge emissions from tropics

NIES (Ito et.al)

FCT Network of “National Demonstrators”

11 ND Countries

•Australia (Tasmania)
•Brazil
•Cameroon
•Colombia
•DR Congo
•Guyana
•Indonesia (Sumatra, Kalimantan)
•Mexico
•Nepal
•Peru
•Tanzania.

From 2009
- Brazil
- Guyana
- Mexico
- Indonesia (Kalimantan)
- Australia (Tasmania)
- Cameroon
- Tanzania

From June 2010
- Colombia
- DR Congo
- Peru, and
- adding Sumatra to Indonesia

From June 2011
- Nepal

GEO-FCT and GEO-CFP

GEO&APN: Capacity Building of ALOS satellite data to support Mapping and Monitoring Deforestation and Degradation in Indonesia (2011-2012)

➢ GEO’s Call For Proposal (CFP) was released by GEO secretariat in February 2009.
➢ First face-to-face meeting in Bali as a side meeting of the 4th GEOSS-AP Symposium in March 2010.
➢ Second fact-to-face meeting in Japan in March 2010.
➢ RESTEC, BPPT and Ministry of Forestry submitted the Full Proposal to GEO secretariat in April 2010.
➢ The project was accepted by GEO secretariat in October 2010.

Capacity Building of ALOS satellite data to support Mapping and Monitoring Deforestation and Degradation in Indonesia

Proposal Overview (Objectives)

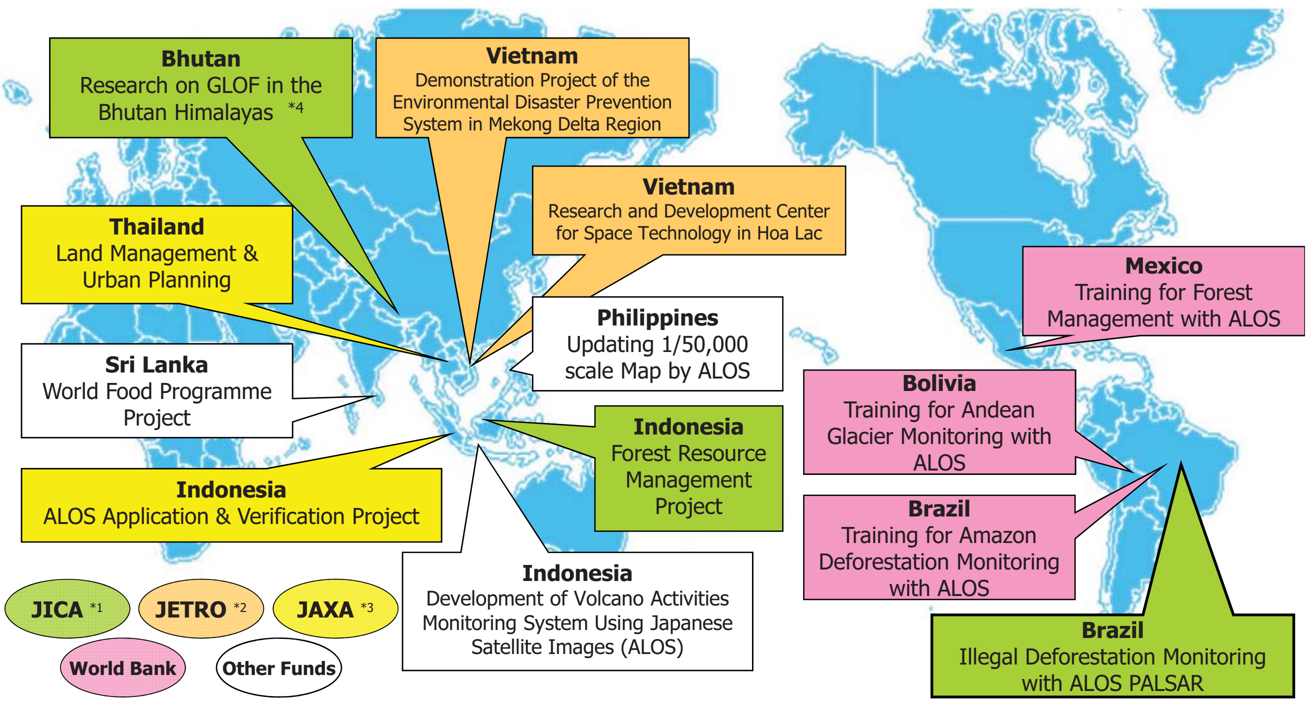
- To develop new change detection mapping and monitoring methods for forest and peat land in Indonesia using ALOS/PALSAR satellite data
- To assess the applicability of the new methods, in terms of reliability, credibility, and consistency to improve capacity, capability, and quality of mapping and monitoring system for deforestation and degradation on forest and peat land.
- To incorporate the newly developed methodology start to operate within both National and Local level of decision making process

GEO-CFP Capacity Building

A capacity building project proposed by Indonesia BPPT and Ministry of Forestry with RESTEC was accepted by GEO-CFP (Call For Proposals) and APN (Asia-Pacific Network for Global Change Research). 2 weeks training was held in Tokyo in May 2012.

Capacity Building

- **Carrying out various programs from fundamental to advanced based on both Japanese and International programs**



*1 JICA (Japan International Cooperation Agency)

*2 JETRO (Japan External Trade Organization)

*3 JAXA (Japan Aerospace Exploration Agency)

*4 Project of JICA and JST (Japan Science and Technology Agency)

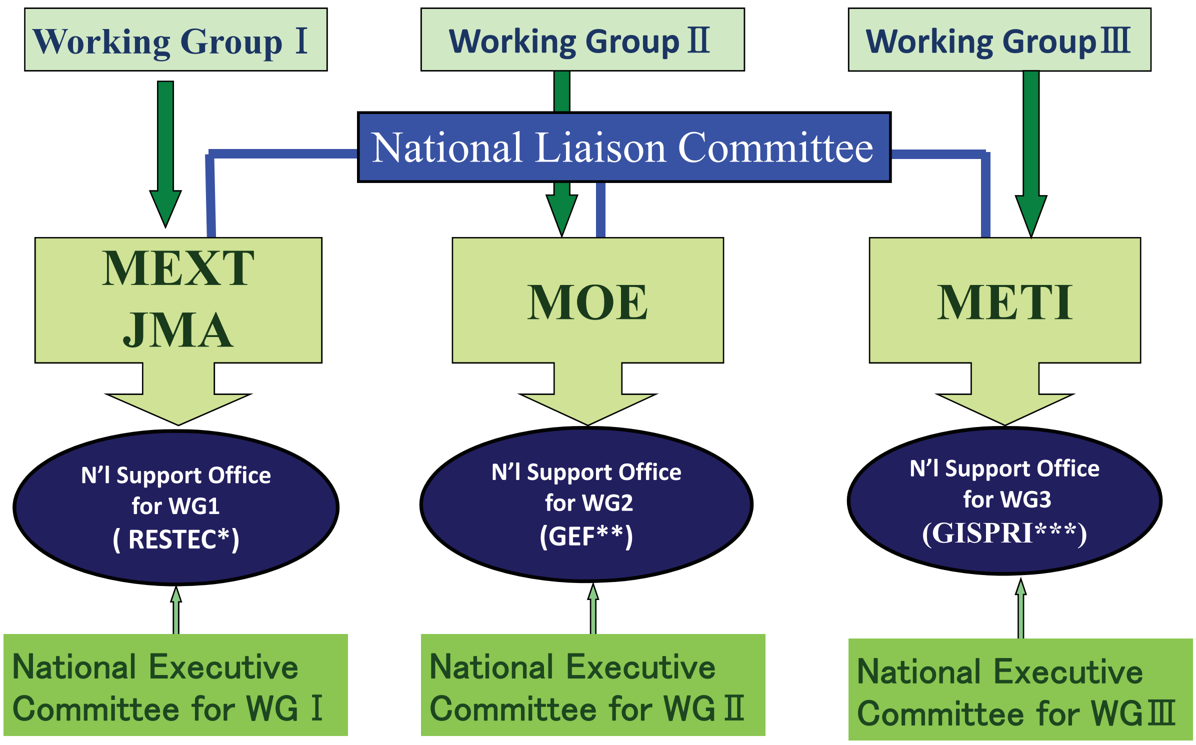
Contribution to five core areas of GFOI (GFOI Work Plan for 2012-2013)

1. Coordination of Satellite Data Supply
2. Capacity Building and the National Demonstrators (FCT and GFOI)
3. Method and Guidelines Documentation
4. Research and Development Plan
5. GFOI Governance,Administration and Coordination

Contribution to Intergovernmental Panel on Climate Change (IPCC)

- In order to contribute to the preparation of the IPCC 5th Assessment Report (AR5), which will be submitted to the IPCC Plenary in 2014, the Ministry of Education, Culture, Sports, Science and Technology (MEXT) has streamlined a supporting and cooperating framework for the IPCC Working Group 1 (WG1).
- Its purpose is to promote coordination and cooperation among research institutions and researchers in Japan conducting researches on physical science aspects of climate change related to the IPCC WG1.
- For its implementation, the RESTEC launched a national support office of IPCC WG1 and has been promoting activities of support and cooperation described.

National Support Offices for IPCC-AR5



*: Remote Sensing Technology Center

**: Global environmental Forum

***: Global Industrial and Social Progress Research Institute

JAXA's Earth Observation Satellites and Forest Mapping

23-25 October 2012

Masanobu Tsuji

Earth Observation Research Center (EORC)
Japan Aerospace Exploration Agency (JAXA)

IPCC Expert Meeting: Role of Remote Sensing in Forest and National GHG Inventories

Japanese Main Activities of Earth Observation

GEOSS 10 years implementation plan

① **Disasters**
- Disaster prevention and mitigation
- Monitoring flood, earthquake, crustal deformation, forest, biomass, etc.

② Health

③ Energy

④ **Climate**
- Greenhouse gas and carbon flux

⑤ **Water**
- Climate change and water cycle
- Precipitation, cloud, aerosol, SST, snow, ice, etc.

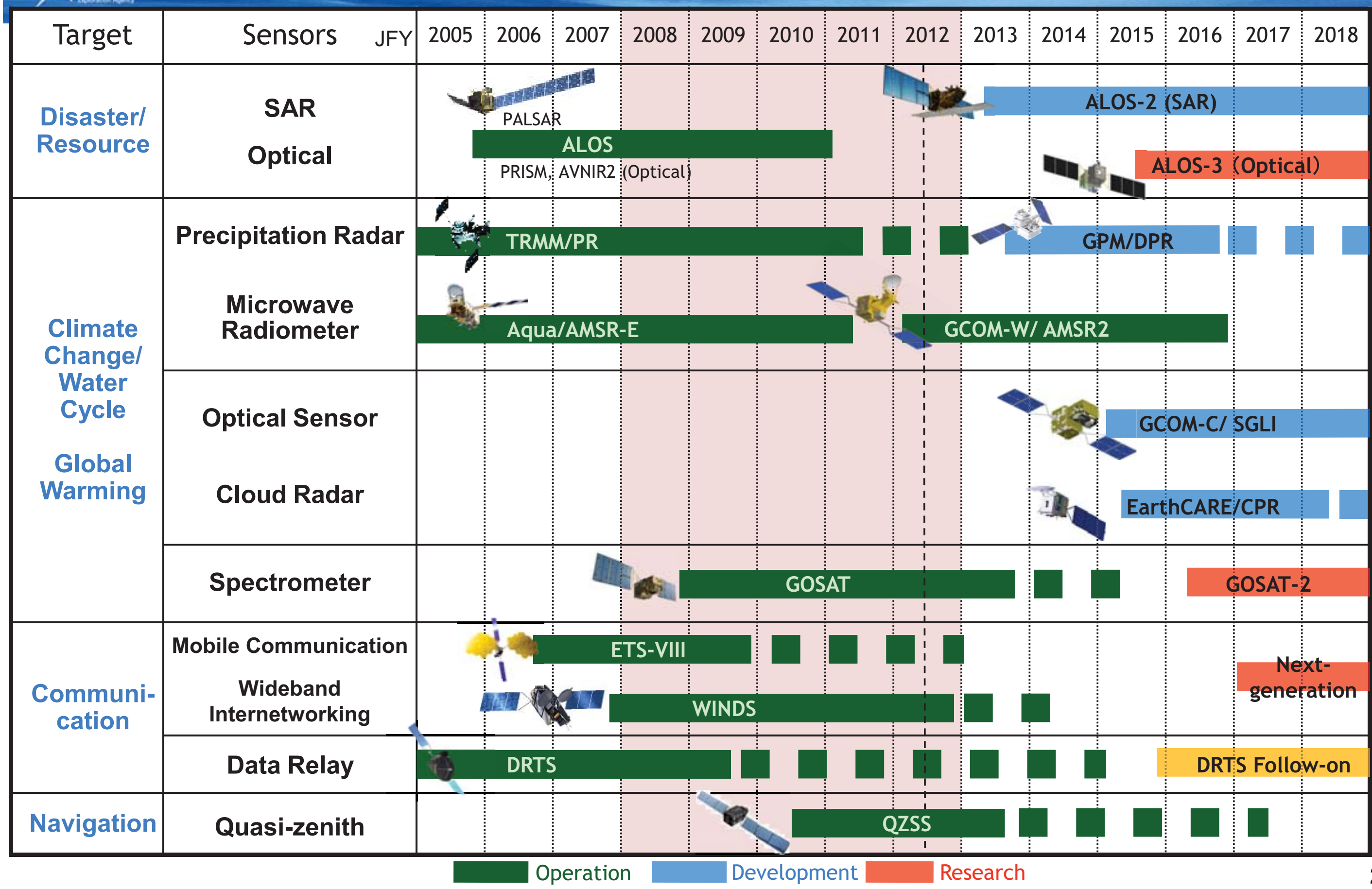
⑥ **Weather**
MTSAT (JMA)

⑦ Eco-systems

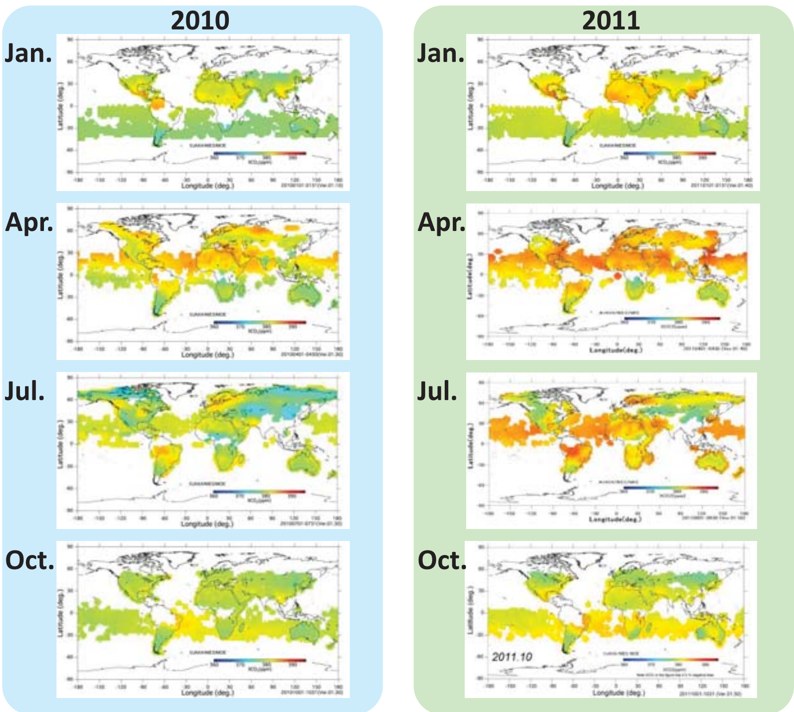
⑧ Agriculture

⑨ Bio-diversity

Mid-Term Plan



GOSAT (Greenhouse Gases Observing Satellite)



Global Distribution Map of CO_2
slight annual increase in any seasons

TANSO-FTS
(Fourier Transform Spectrometer)
the highest spectrometer resolution in the world

TANSO-CAI
(Cloud and Aerosol Imager)

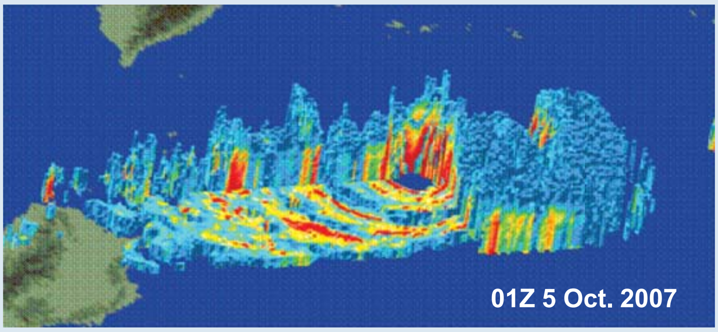
- **Measure global distribution of GHGs, and understand how their emission is reduced**
- **The world's only satellite for monitoring CO_2 and methane**

TRMM/PR, Aqua/AMSR-E: Japan-US joint project

TRMM/PR (launch: 1997)

- Japan provides PR (Precipitation Radar) and launch vehicle, and US provides four observation instruments.
- Understanding tropical rainfall structure using radar instruments

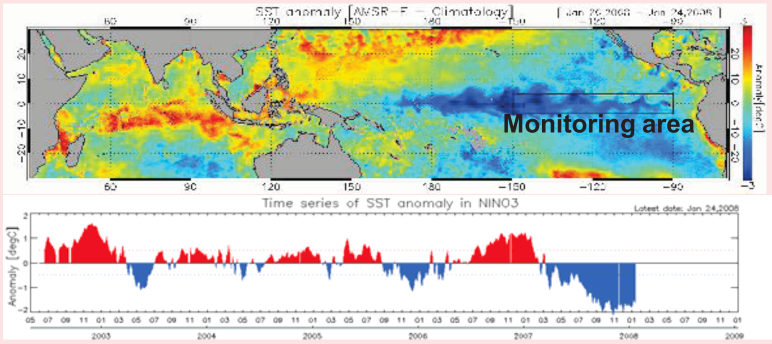
3-D structure of rainfall of Super Typhoon KROSA observed by PR



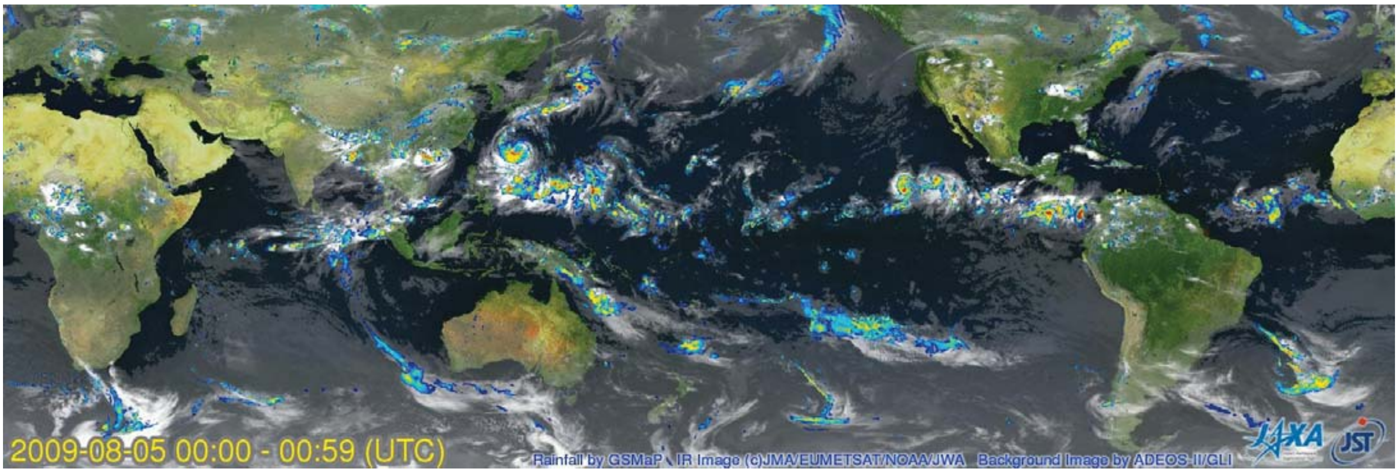
Aqua/AMSR-E (launch: 2002)

- Japan provides AMSR-E, and US provides four observation instruments.
- Understanding water circulation mechanism

El Niño Watch



Global Rainfall Map in Near Real Time

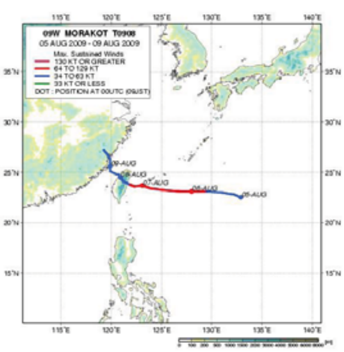


Typhoon MORAKOT (09W): Aug. 5 – 10, 2009 (Big impact in Chinese Taipei)

Rain 0.1 0.5 1.0 2.0 3.0 5.0 10.0 15.0 20.0 25.0 30.0 [mm/hr]

- Global rainfall map merging TRMM, AMSR-E and other satellite information
- Available 4-hour after observation, hourly update
- 0.1-degree latitude/longitude grid

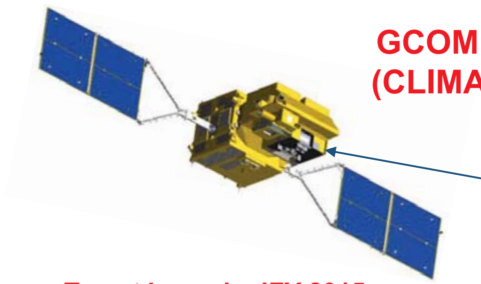
http://sharaku.eorc.jaxa.jp/GSMaP/



Global Change Observation Mission (GCOM)

- Long-term observation (over 10 years) for global climate change and water cycle.
- Two satellite series;
  - ✓ **GCOM-W :** Microwave observation using AMSR2 (AMSR-E follow on) for observing water circulation
    (water vapor, precipitation, soil moisture, sea surface temp., wind speed, etc)
  - ✓ **GCOM-C :** Optical multi-channel observation using SGLI (GLI follow on) for radiation budget and carbon cycle
    (aerosol, clouds, ocean color, vegetation, snow ice, etc)

Launched: 18 May 2012
(Regular observation operation from 10 August 2012)



Target Launch: JFY 2015

Sensor	Advanced Microwave Scanning Radiometer 2 (AMSR2)
Design Life	5 years

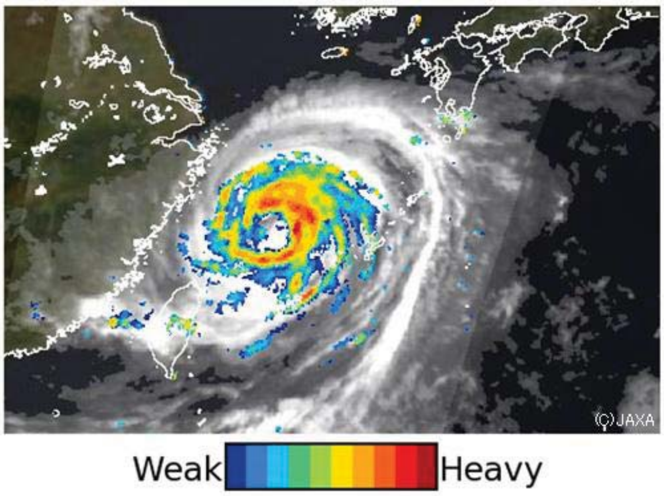
Sensor	Second generation GLobal Imager (SGLI)
Design Life	5 years

The current status of GCOM-W1 "SHIZUKU"

- Initial CAL/VAL has started in August, after satellite commissioning
- L1 Products: released in Jan 2013, L2 Products: released in May 2013 at "GCOM-W1 Data Providing Service" https://gcom-w1.jaxa.jp

Sea ice extent in the Arctic Ocean

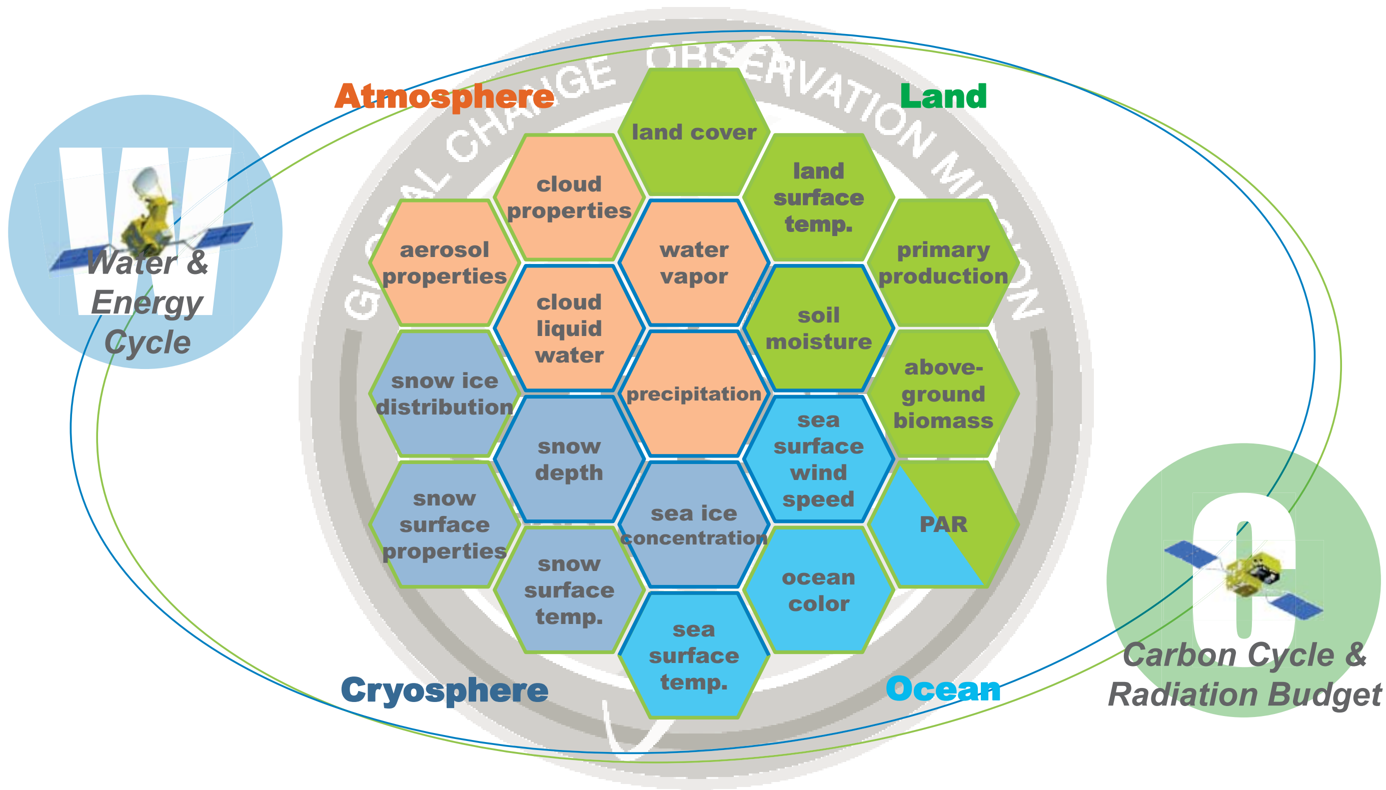
Sea ice extent in the Arctic Ocean has become the smallest (3.49 million square kilometers) on this September in observation history, comparing with the past record marked in 2007.



Typhoon No.11 "HAIKUI" on 7 August

"SHIZUKU" image identified the eye of the typhoon more clearly than "HIMAWARI".

GCOM Geophysical Parameters



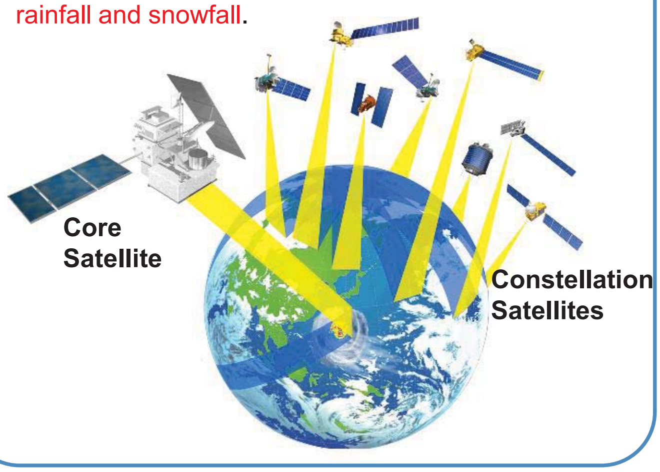
International Cooperation Projects

Global Precipitation Measurement (GPM)/ Dual-frequency Precipitation Radar (DPR)

■ Global Precipitation Observation with high accuracy and frequency at three-hour intervals with the GPM Core Satellite and eight Constellation Satellites.

■ JAXA provided NASA with the Dual-frequency Precipitation Radar (DPR) for Core Satellite on March.

■ DPR is the world's only precipitation radar which can observe 3D structure of rainfall. The simultaneous dual-frequency observation can detect even weak rainfall and snowfall.

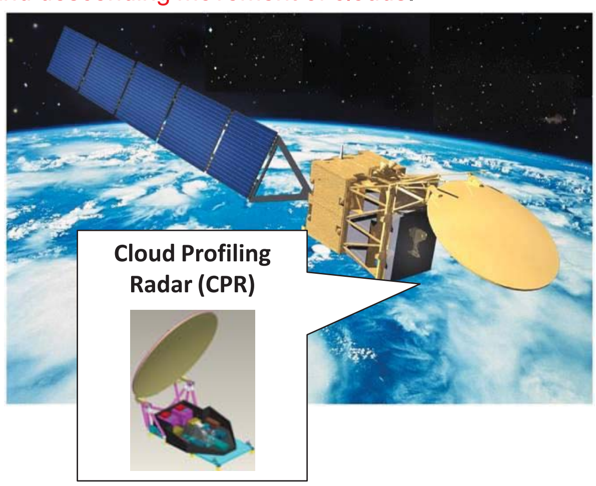


EarthCARE/Cloud Profiling Radar (CPR)

■ EarthCARE will observe 3D structure of clouds and aerosols, and reduce errors in climate change and weather forecast , by Japan-Europe cooperation.

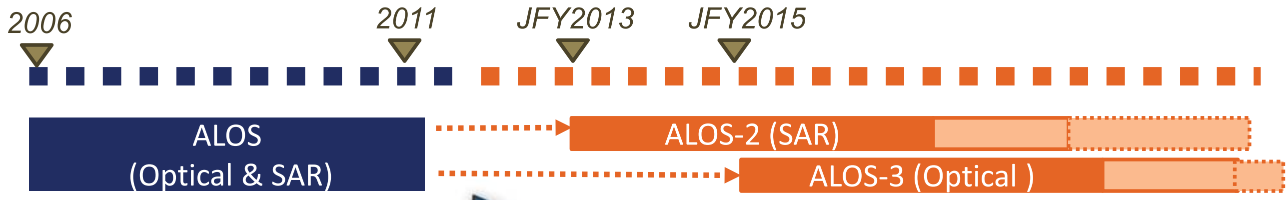
■ JAXA provides Cloud Profiling Radar (CPR) to ESA.

■ CPR is the world's first W-band Doppler radar (94GHz) aboard a satellite. We can understand the vertical structure of clouds, as well as the ascending and descending movement of clouds.



ALOS series

- Wide-swath and high-resolution data of ALOS series will contribute to public safety, land management, assurance of food/resource/energy, solution of global environment issues
- Promoting public-private partnership, since its data has commercial value

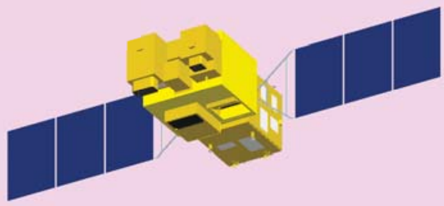


ALOS
(Optical & SAR)
(2006～2011)

- Wide-swath (Max 490km), High-resolution (1-3m)
- L-band SAR (PALSAR-2)

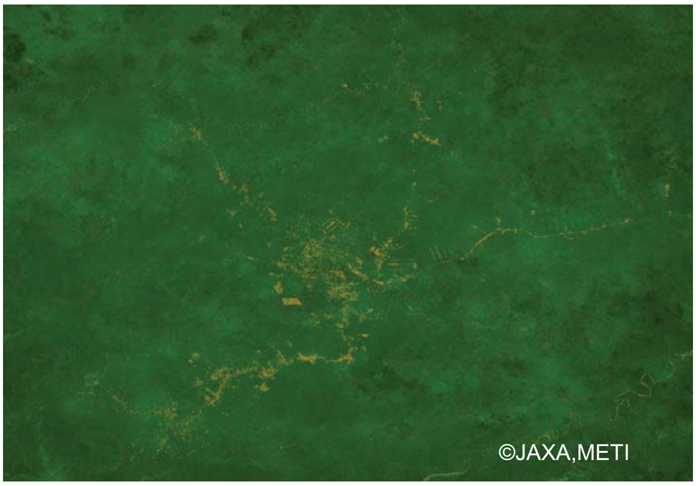
ALOS-2 (SAR) (Launch: JFY2013)

- Panchromatic imager with wide-swath (50km) and high-resolution (0.8m)
- obtain global 3D geospatial information

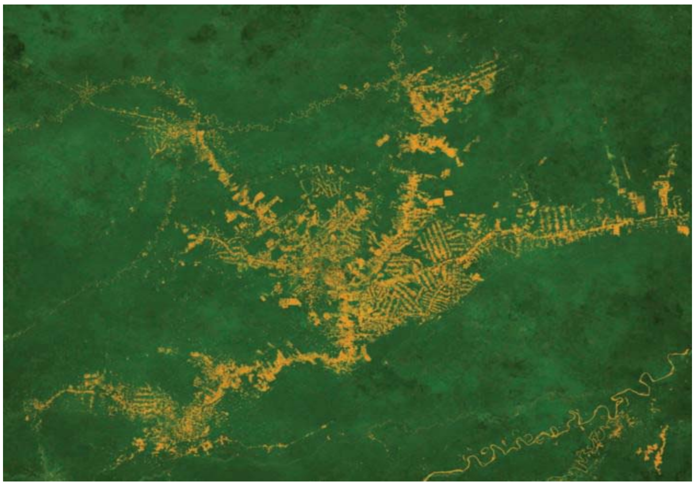


ALOS-3 (Optical) (Launch: JFY2015)

Monitor the Forest in Amazon (illegal logging)



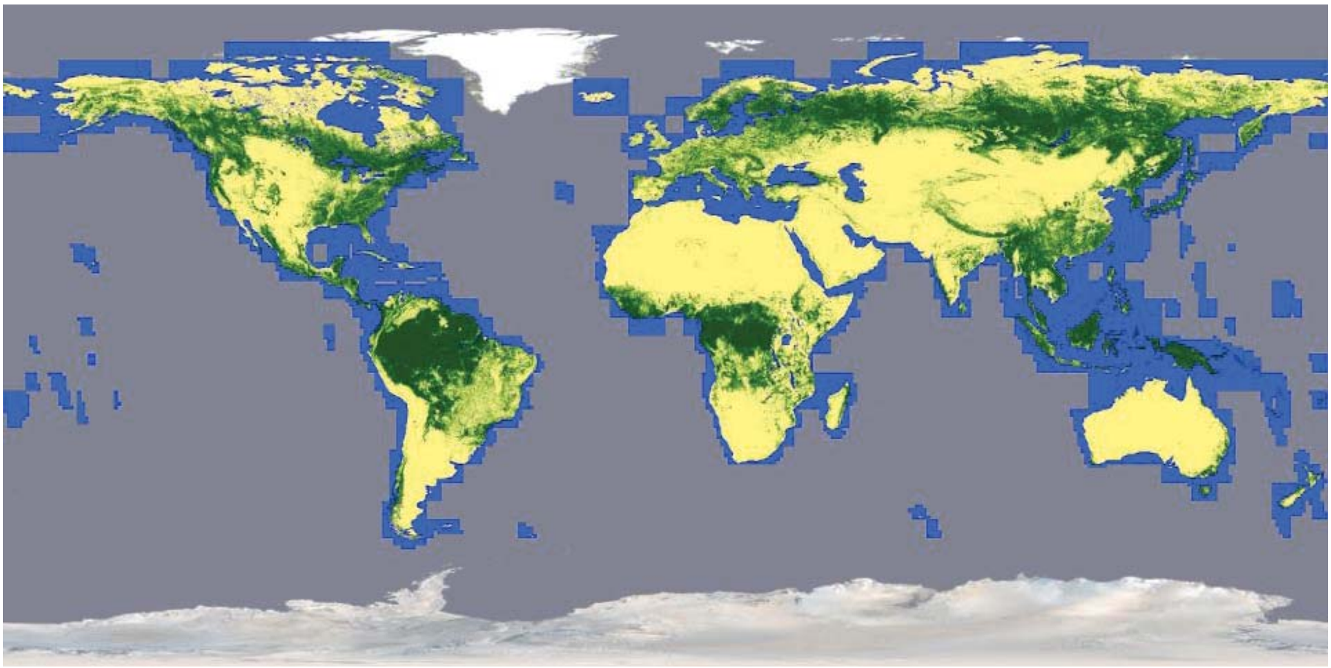
1995 (JERS-1)



2007 (ALOS)

- **Within seven days after the data acquisitions, JAXA provides the quickly processed SAR images to IBAMA.**
- **The data are being utilized for the illegal deforestation monitoring.**

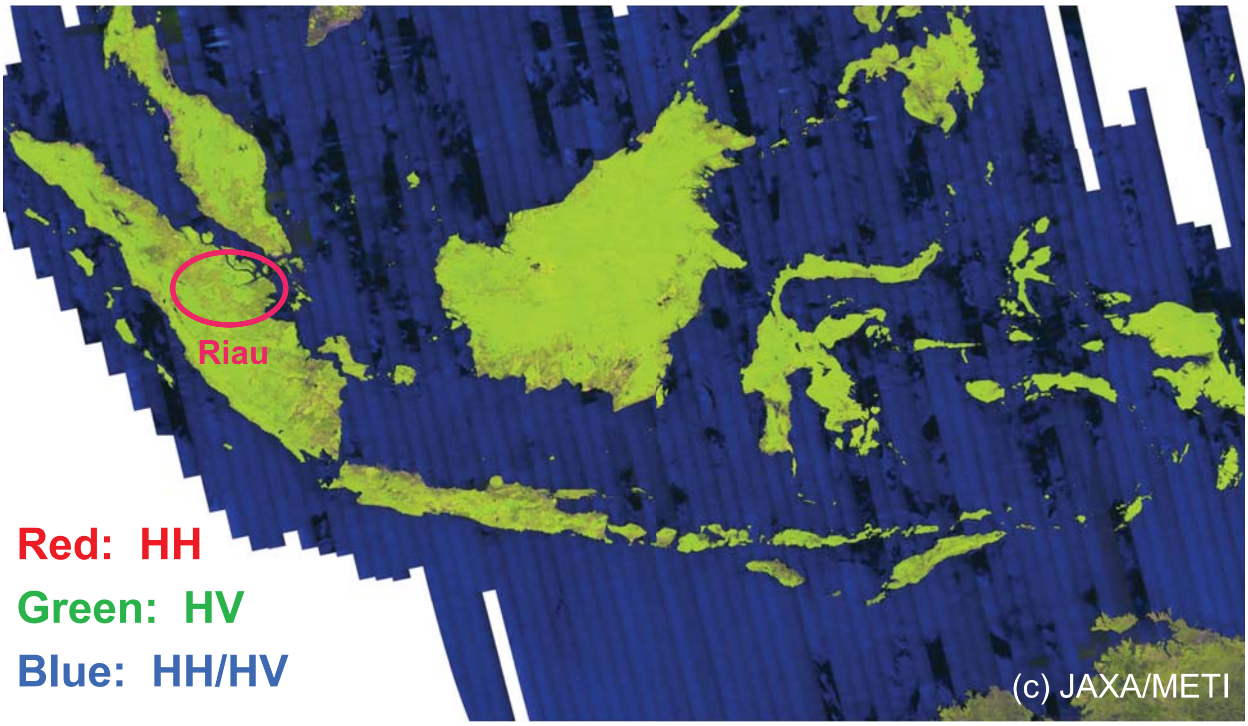
PALSAR 10m Global Forest/Non-Forest Map 2009



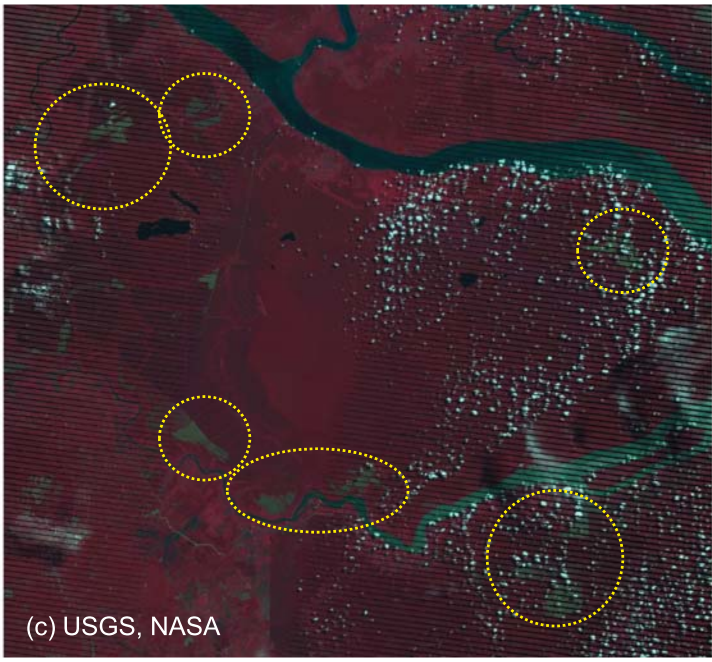
©JAXA,METI analyzed by JAXA

PALSAR 25-m yearly global mosaic

Year 2010

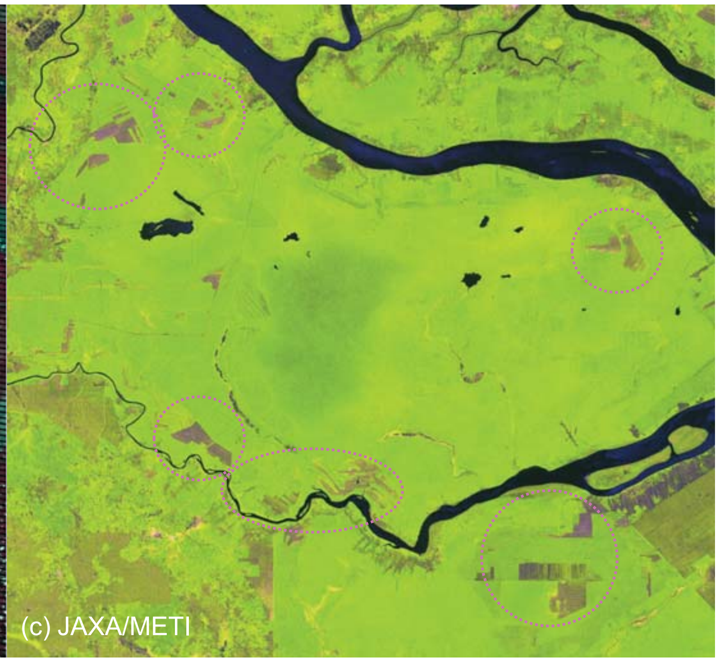


Landsat-7 ETM+ (2010/06/18)



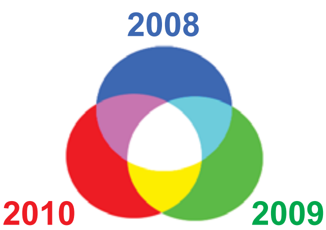
R: band-4, G: band-3, B: band-2
(false-color)

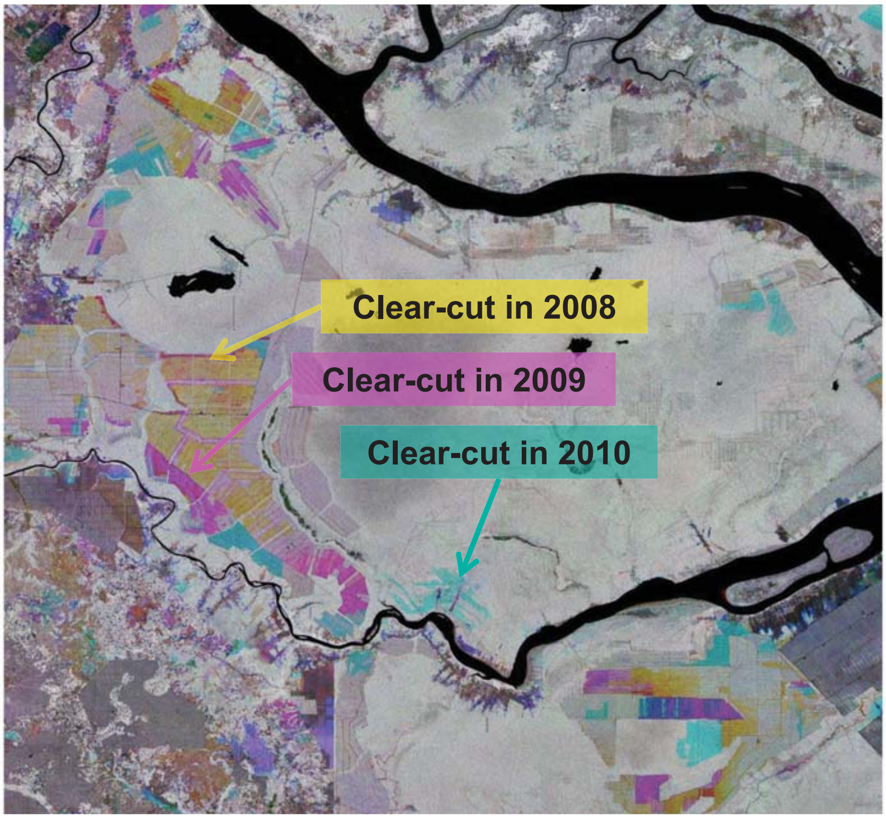
PALSAR mosaic (2010)



R: HH, G: HV, B: HH/HV

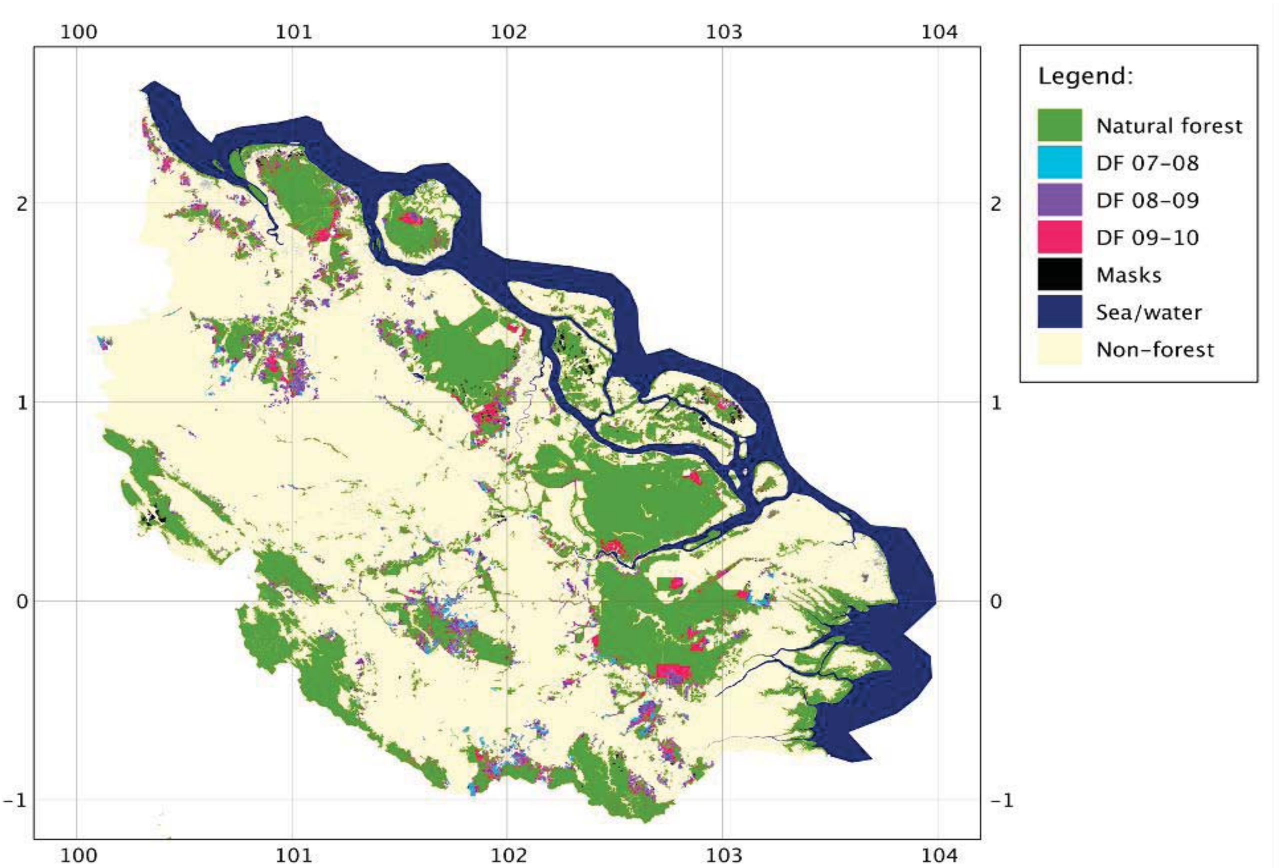
RGB composite of multi-year PALSAR mosaic HV polarization





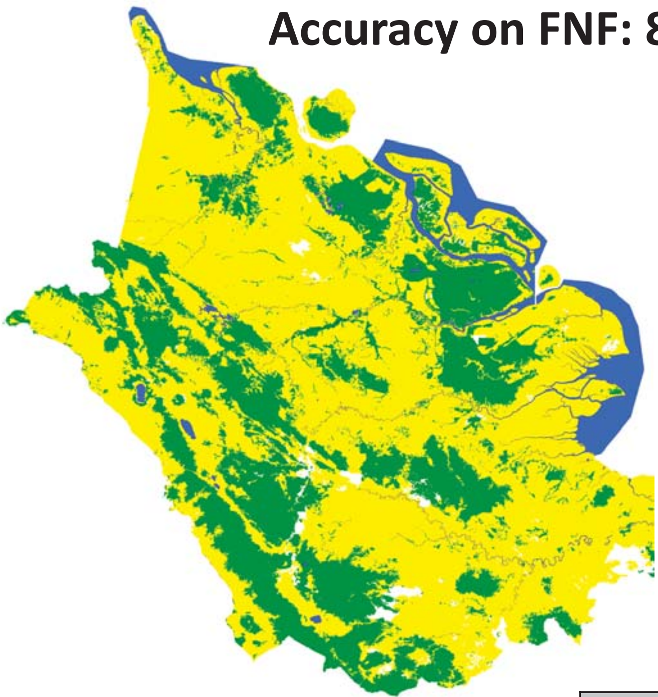
(c) JAXA/METI

PALSAR-based forest loss map in Riau, Indonesia



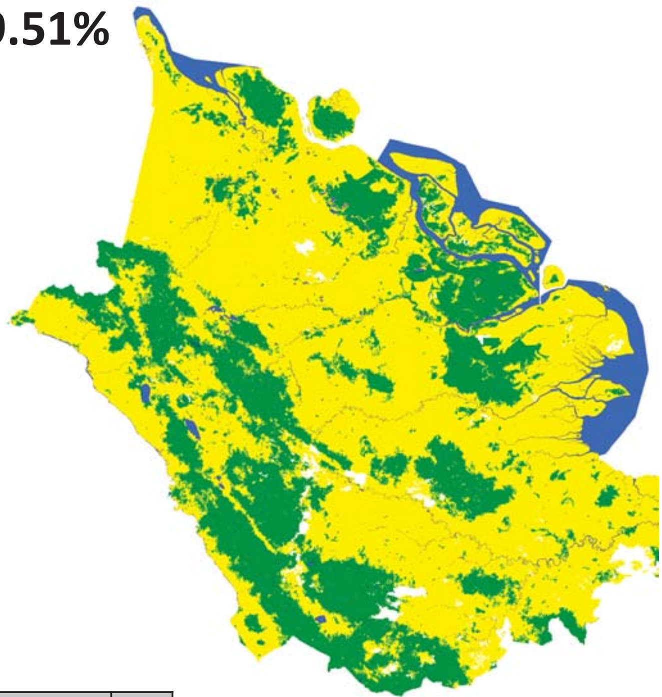
Forest/Non-Forest classification by Random Tree method

Accuracy on FNF: 89.51%



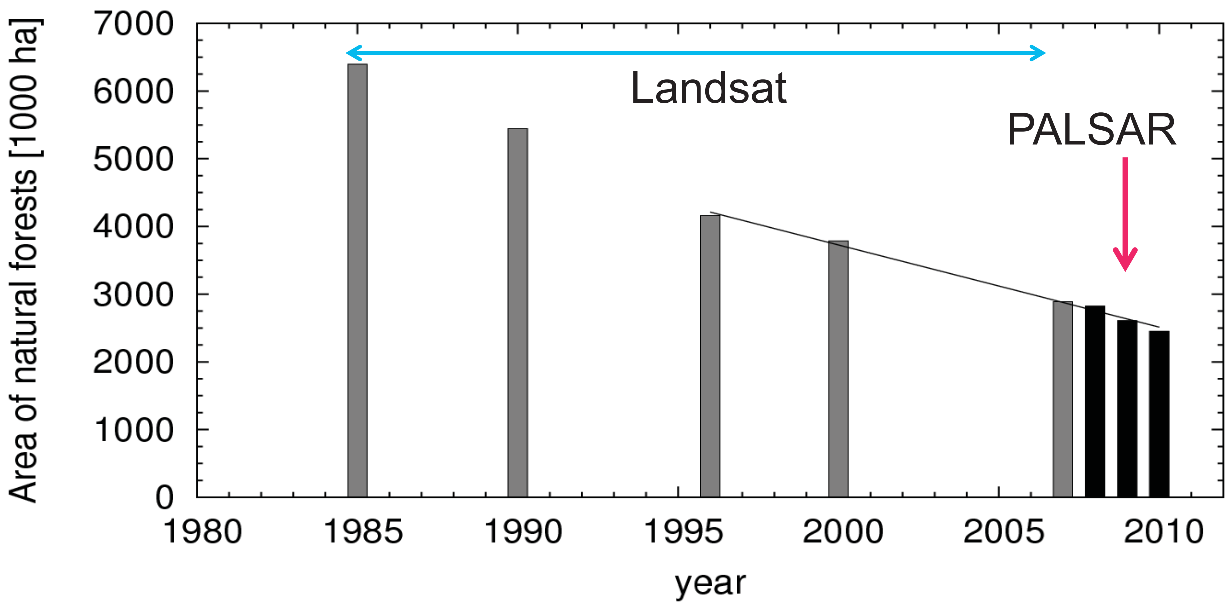
Reference map(WWF)

Class	Col
Unclassified	
Forest	
Non-Forest	
Non-Forest(Water)	



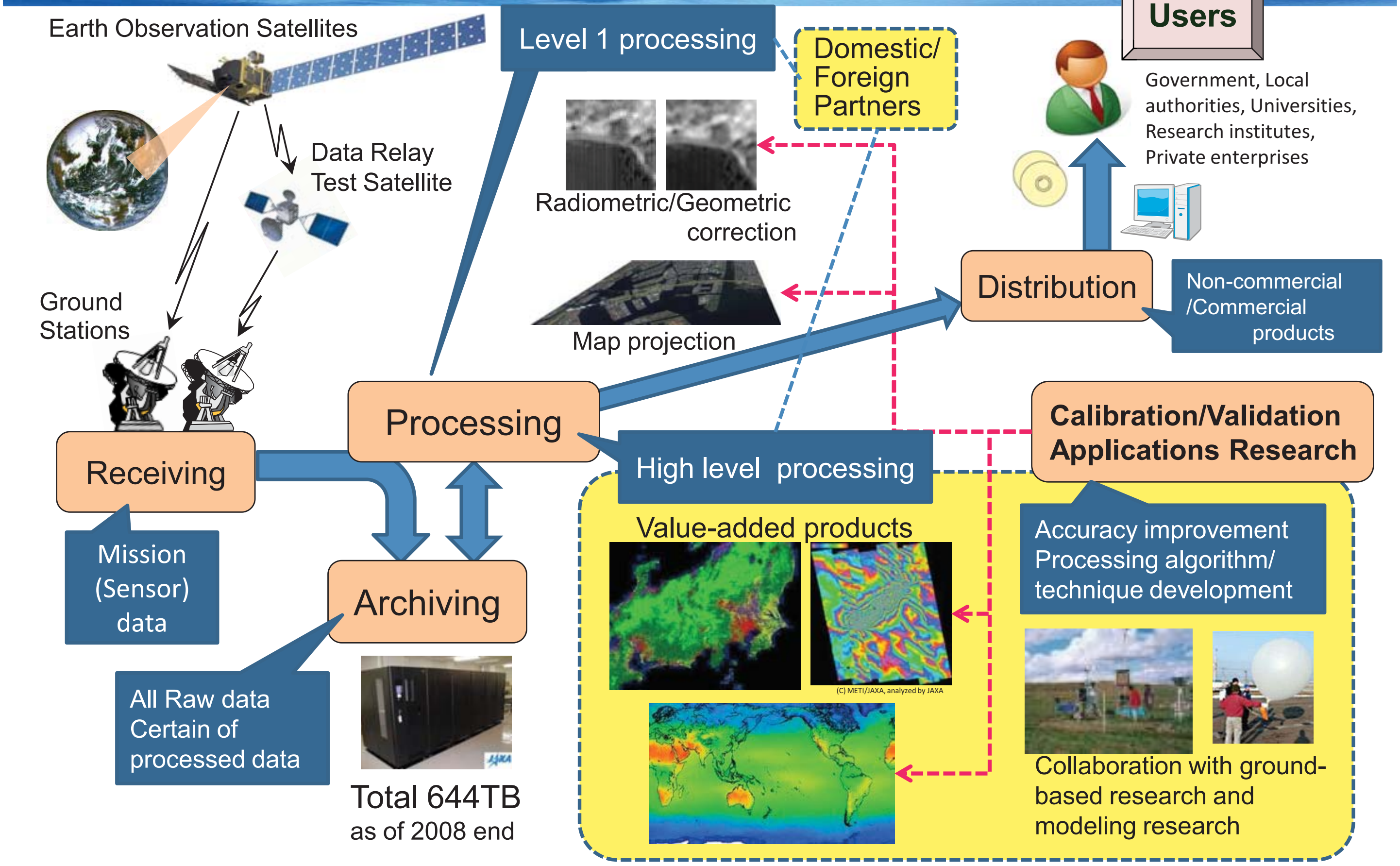
Result of classification (Random Tree method)

Trends of forest area in Riau, Indonesia



• Data of 1985, 1990, 2000, and 2007 are obtained from the WWF Indonesia land cover data (Uryu et al., 2008; Uryu et al., 2010).
• Data of 1996 are obtained from the report by Forest watch Indonesia/Global forest watch (2002).

Activities of JAXA / EORC



This photo is taken by KAGUYA, JAXA's Lunar Explorer

Thank you for your attention!

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UN-REDD PROGRAMME

The role of RS/GIS applications for National Forest Monitoring Systems in the context of REDD+

Dr. Inge JONCKHEERE

UN-REDD Team (FAO HQ Rome, Italy)
INPE/FUNCATE Team (Sao Jose dos Campos, Brasil)

IPCC Expert Meeting, Hayama, JAPAN
23 October 2012

UN-REDD Programme

- Supports countries benefit from REDD+ (UNFCCC)
  - National REDD+ Strategies and Readiness
- Established in 2008 by FAO, UNDP & UNEP
  - Response to UN Framework Convention Climate Change (UNFCCC) Bali Action Plan 2007
- Offers UN Joint Program: Delivering as One UN
- Agreed delivery platform with Forest Carbon Partnership (FCPF) and Forest Investment Programme (FIP)
- Current contributions: US$ about 70 million (without pledges) from donors Norway, Denmark, Spain and Japan

UN-REDD PROGRAMME

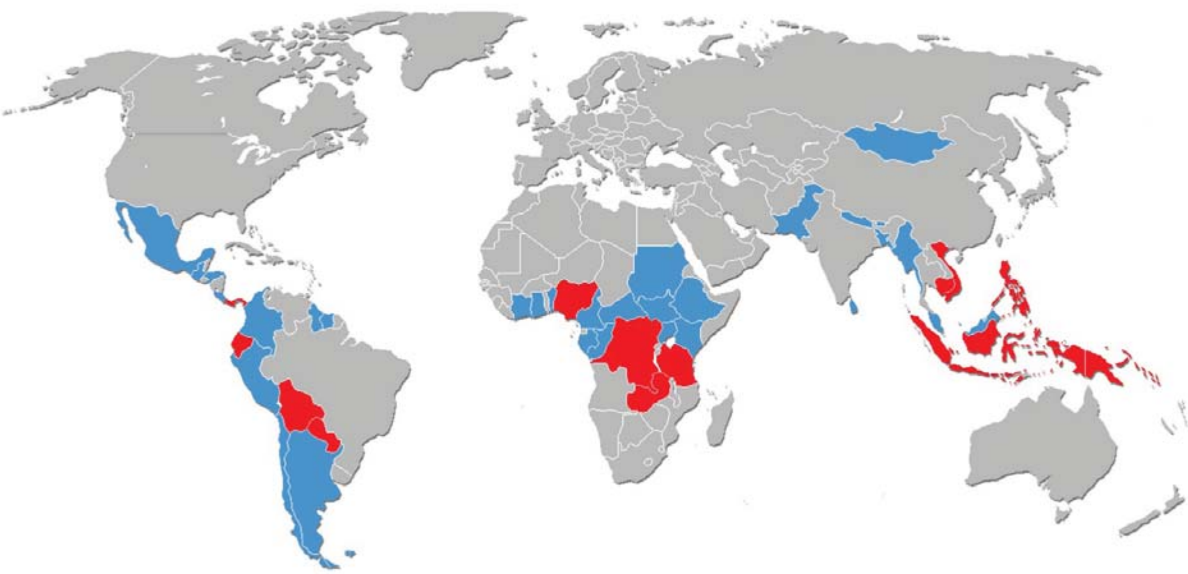
6 UN-REDD Work Areas

REDD+ Strategies

- MRV and Monitoring
- REDD+ Governance
- Stakeholder Engagement
- Multiple Benefits of forests/REDD+
- Transparent Equitable Accountable Management of REDD+ Payments
- REDD+ as Catalyst of Green Economy

UN-REDD
PROGRAMME

National Programmes (NP)



Countries receiving support to National Programmes: Bolivia, Cambodia, Democratic Republic of the Congo (DRC), Ecuador, Indonesia, Nigeria, Panama, Papua New Guinea, Paraguay, the Philippines, Republic of Congo, Solomon Islands, Sri Lanka, Tanzania, Viet Nam and Zambia.

Other partner countries: Argentina, Bangladesh, Benin, Bhutan, Cameroon, Central African Republic, Chile, Colombia, Costa Rica, Ethiopia, Gabon, Ghana, Guatemala, Guyana, Honduras, Ivory Coast, Kenya, Malaysia, Mexico, Mongolia, Myanmar, Nepal, Pakistan, Peru, South Sudan, Sudan, Suriname and Uganda.

www.un-redd.org

UN-REDD
PROGRAMME

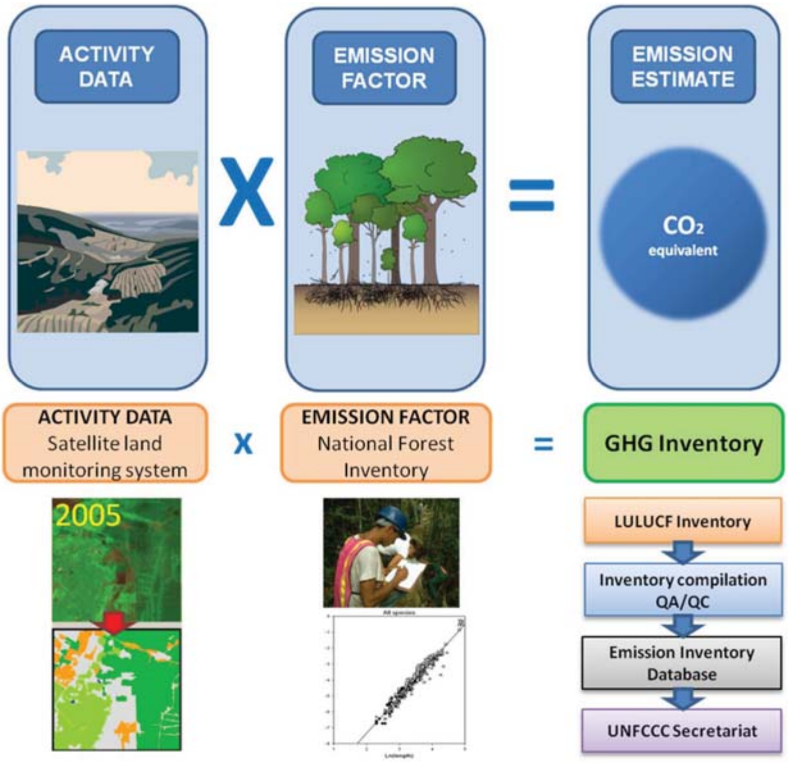
Lead Implementation Role MRV in the NP: FAO

Measurement (M), reporting (R), verification (V) (MRV)

- Cornerstone for carbon monitoring
  - national communications to UNFCCC
  - starting point for R(E)L establishment
  - supports national / sub-national implementation of incentive systems
- Support to policy formulation and feedback
  - knowledge of drivers of change
  - information on multiple benefits

UN-REDD
PROGRAMME

MRV: Measurement



The IPCC's methodological approach to calculate anthropogenic GHG emissions by sources and removals by sinks related to forest land.

MRV: Measurement of area change (AD) and forest carbon stock changes (EF)

This information provides the basis to compile a GHG inventory

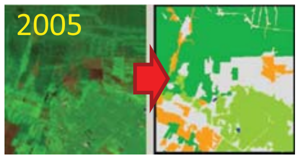
1) **Activity data (AD)**
- – Area / forest cover change data (hectares per year)
- – Achieved using a satellite land representation system (SLRS)
- – So far mainly based on Landsat, MODIS, upcoming RapidEye, DMCii in some cases as well as other commercial (VHR) data

2) **Emission factors (EF)**
- – Forest carbon change
- – Assessment of biomass, carbon stocks and emission factors
- – Data are obtained from national forest inventory (NFI)

! Upcoming: database and software based on allometric relationships gathered worldwide to calculate EFs and biomass, Initiative of FAO, University of Tuscia and CIRAD (to be launched in Doha)(L. Picard, L. Saint-André, R. Valentini and M. Henry)

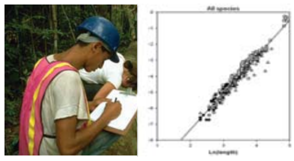
3) **GHG Inventory (GHGI)**
- – GHG assessment to determine national mitigation performance
- – Based on the data collected from the NFI and SLRS
- – UNFCCC templates available

ACTIVITY DATA
Satellite Land
Representation System



X

EMISSION FACTORS
National Forest
Inventory



=

GHG Inventory

REDD+ under the UNFCCC: The Cancun Agreements (COP 16)

- ***Decides*** that Parties should follow a **phased** approach to REDD+:
  1. Readiness
  2. Results-based demonstration activities
  3. Positive incentive for verified performance

- Developing country Parties are *requested* to develop:
  - – Robust and transparent **national forest monitoring systems** for the monitoring and reporting of REDD+ activities (***Monitoring & MRV***)
  - – A system for providing information on REDD+ safeguards

United Nations FCCC/CP/2010/7/Add.1

Framework Convention on Climate Change

Distr.: General
15 March 2011
Original: English

Conference of the Parties

Report of the Conference of the Parties on its sixteenth session, held in Cancun from 29 November to 10 December 2010

Addendum

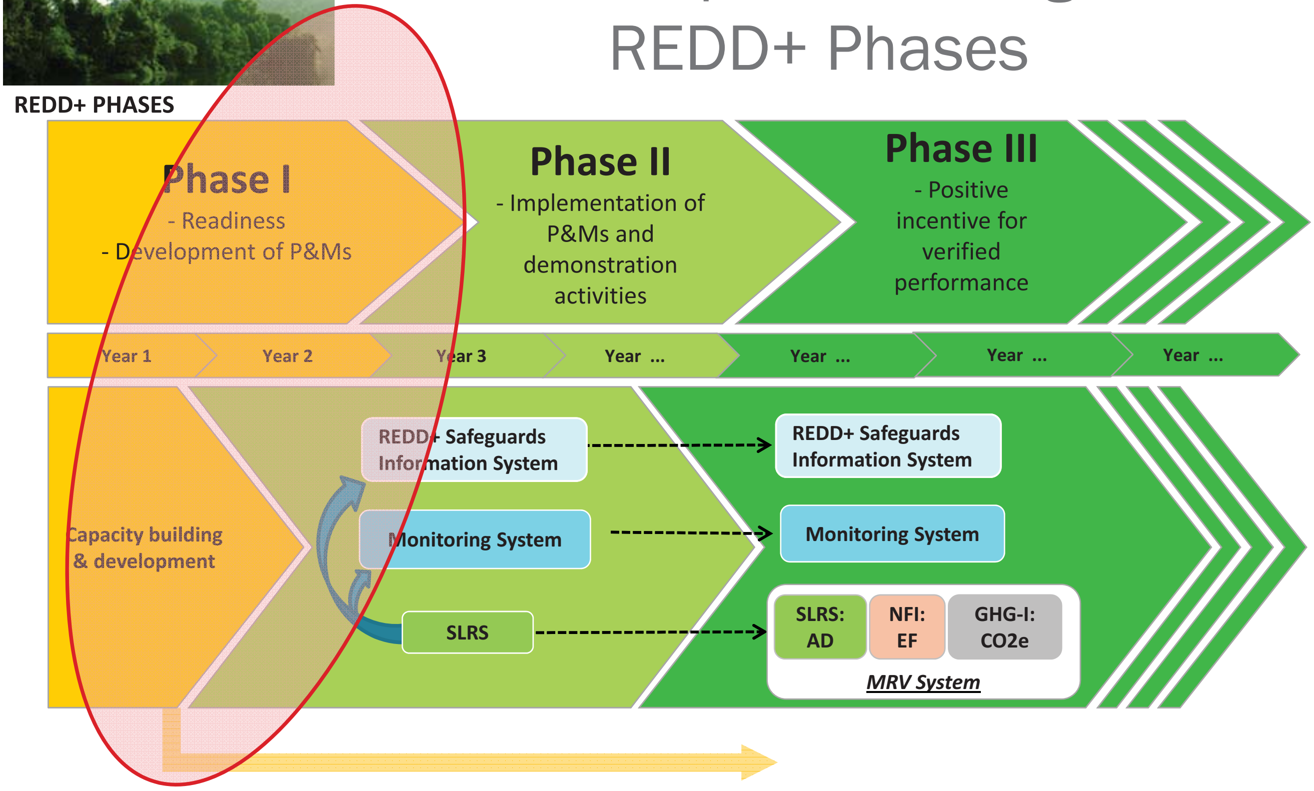
Part Two: Action taken by the Conference of the Parties at its sixteenth session

Contents

Decisions adopted by the Conference of the Parties

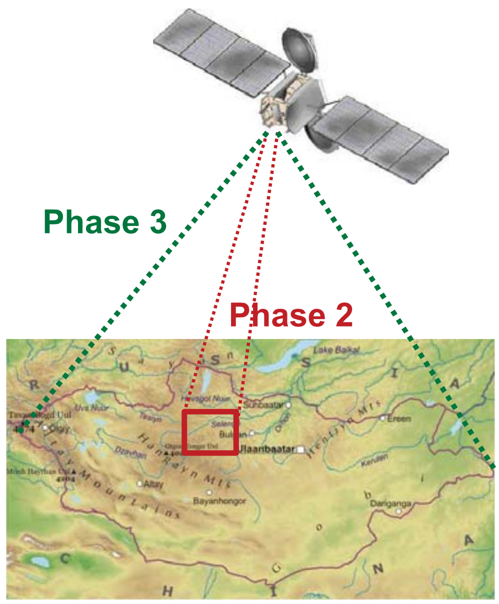
Decision		*Page*
1/CP.16	The Cancun Agreements: Outcome of the work of the Ad Hoc Working Group on Long-term Cooperative Action under the Convention	2

Information, Monitoring and MRV Development through the 3 REDD+ Phases



Monitoring Systems

- To assess whether REDD+ is resulting in net positive outcomes, i.e. results-based
- In Phase 2 of REDD+
  - To monitor the outcomes of demonstration activities
- In Phase 3 of REDD+
  - To monitor the outcomes of national policies and measures on all the national territory
- Technical requirements
  - Satellite Land Monitoring System (operational remote sensing)
  - Web-GIS interface (for transparency, open access)

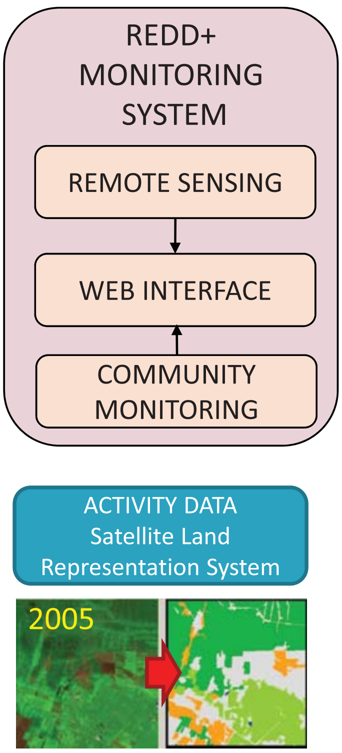


Monitoring systems : the end

- To sustainably manage forest at national level
- To fulfill the requirement of the REDD+ Decision (1/CP.16)
  (establish an operational NFMS and move towards the phase 2, phased approach)
- To demonstrate to the international community that the country is monitoring its REDD+ activities in a transparent and verifiable way
- To secure funds for the implementation of national REDD+ and forest policies
- To monitor the national forest resources and the impacts of national forest policies

UN-REDD
PROGRAMME

National forest monitoring systems



- Satellite data to monitor REDD+ activities at sub-national (demonstration) and national level
- Disseminated over internet through a web-GIS interface
- Measurements of area change (Activity Data)

UN-REDD
PROGRAMME

Forest monitoring system : Brazil

- **PRODES – Amazon Deforestation Monitoring Project**
  (Annual Deforestation Assessment)
- **DETER – Near real-time Deforestation Detection with MODIS**
  (Support for Law Enforcement for Deforestation Control)
- **DEGRAD – Amazon Degradation Monitoring Project**
- **DETEX - Selective logging activities**
- **TerraClass - Land use monitoring of deforested area (2008)**

http://www.dpi.inpe.br/prodesdigital/prodes.php

UN-REDD PROGRAMME

FAO-INPE collaboration

- Development of prototypes of national forest monitoring systems for/with developing countries : DRC, PNG, Paraguay
  Upcoming in 2012-2013: Tanzania, Zambia, Mongolia and Viet Nam
- Build on existing national forest monitoring experiences and algorithms
- Two components: TerraX platform
  National forest monitoring portal
- Combination of open-source database, user interface, tools and algorithms adapted according to country needs
- Free-of-charge and supported by analysis and programming teams in Brazil (INPE) and FAO HQ
- Linkage of information from other technical partners and contributors for analysis and verification.
- New outcomes to be presented at the 18th COP in Doha, Qatar (2012).

Objectives

1. Enable the developing countries countries to follow all the actions related to the implementation of its national REDD+ policies and measures using RS data;
2. Build a platform to obtain regular information on their REDD+ results;
3. Actions should be related, directly or indirectly, to the national REDD+ strategies and may also include actions unrelated to carbon assessment, e.g. forest law enforcement;
4. Support the REDD+ phased approach under Paragraph 73 1/CP.16;

UN-REDD PROGRAMME

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UN-REDD PROGRAMME

Start-up Phase

Democratic Republic of Congo (DRC)

JUSTICE PAIX TRAVAIL

République Démocratique du Congo

FAO UNDP UNEP

How

- Development of a DRC REDD+ wall-to-wall National Forest Monitoring System based on (freely) available satellite data;

→ Without reinventing the wheel!
  - Capacity building and knowledge and technology transfer → training;
  - Draw on (freely) available satellite data and existing mapping and change detection technologies;
  - Include tools developed and applied by FAO and INPE;
  - Linked to the REDD+ national registry
  - Build on concrete and existing collaborations in-country (DIAF, OSFAC, OFAC, etc.) and actions to strengthen DRC's technical capacities to monitor their forest land.

Mission impossible ?

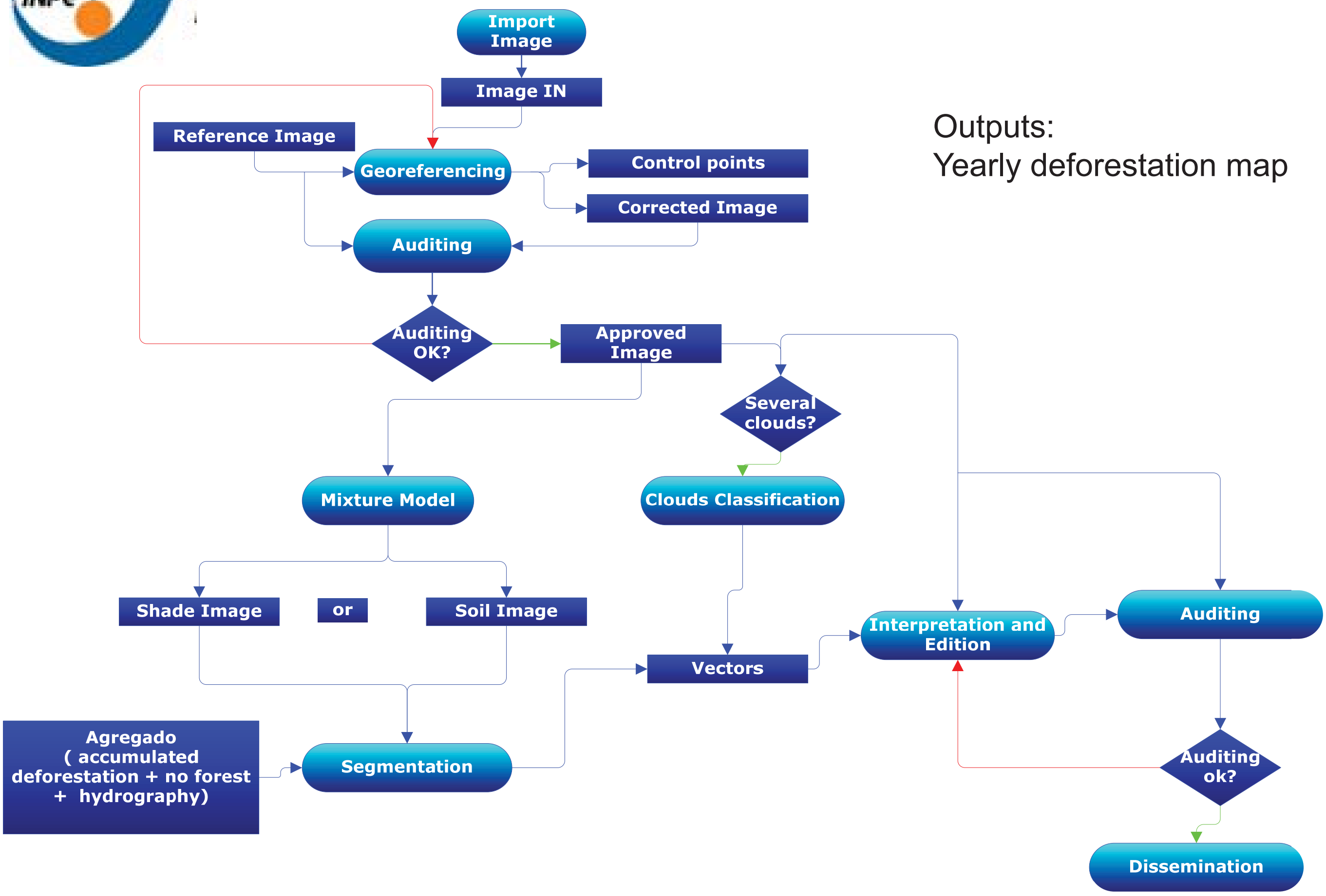
- Cost: $ 100 k for beta in 2011, $ 450 k in 2012
- Time: 6 months for beta, 18 months to be operational;
- Laboratory: 8 computers;
- (Wo)Man power: 5 technicians;
- Data: mostly freely available satellite data;
- Operational: self-sustaining system;
- Phased process.

TerraCongo

- Start-up Phase: development carried out at the premises of FAO UN-REDD;
- Guided by the DRC Government, FAO and INPE/FUNCATE is guiding the DRC System development and operationalisation of the system at a national level, ensuring that necessary adaptations are made to reflect national circumstances;
- The DRC National Forest Monitoring system is linked with the INPE platform TerraAmazon (renamed TerraCongo for the DRC), which combines GIS, image processing, database management and data access functionalities;
- In a second phase (2012), the system will be put in place in the DRC.

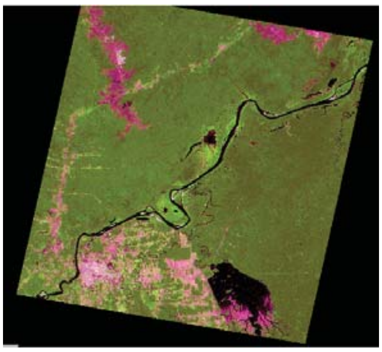
UN-REDD PROGRAMME

PRODES methodology

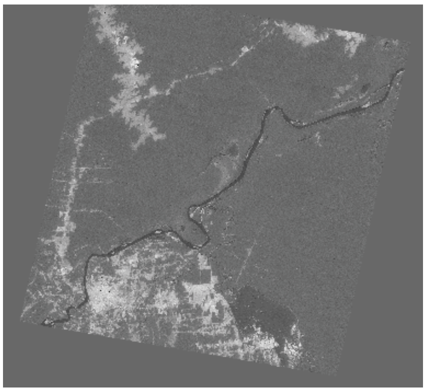


Outputs:
Yearly deforestation map

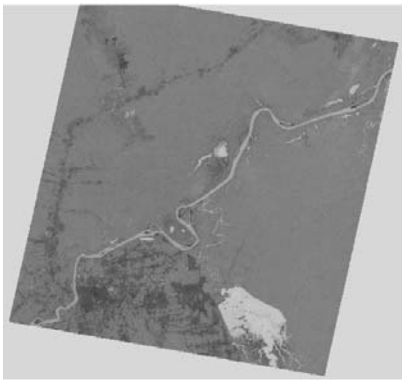
Application of linear mixing model



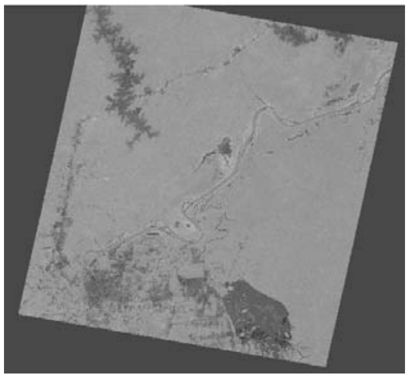
SOIL

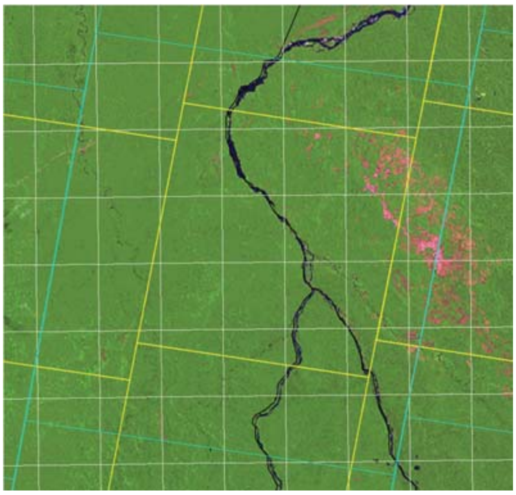


SHADOW

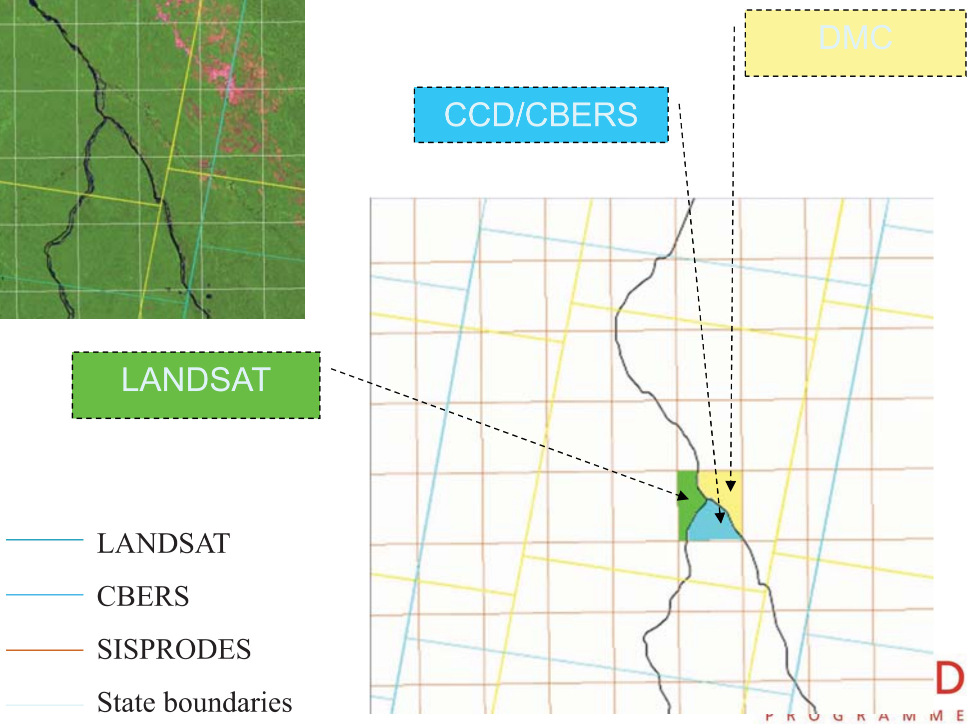


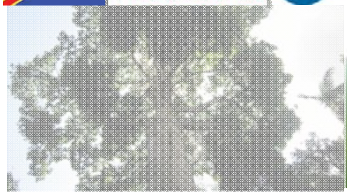
GREEN VEGETATION



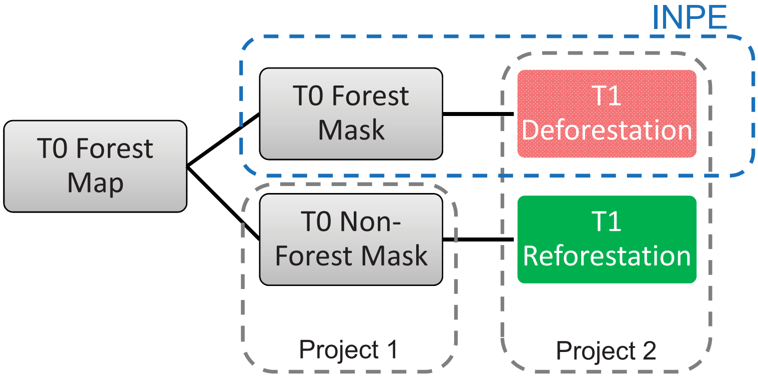


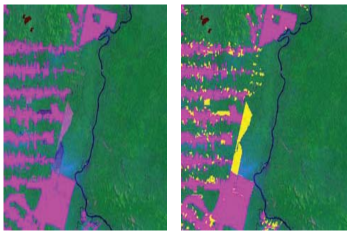
Multidata approach

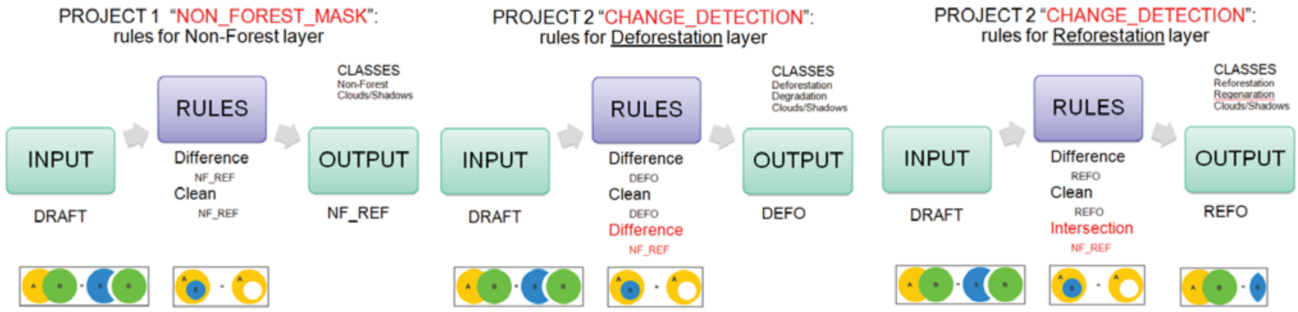




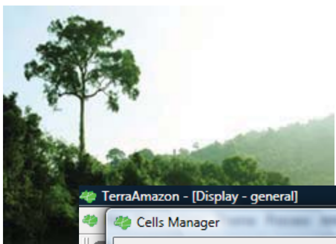
DRC Conceptual Model

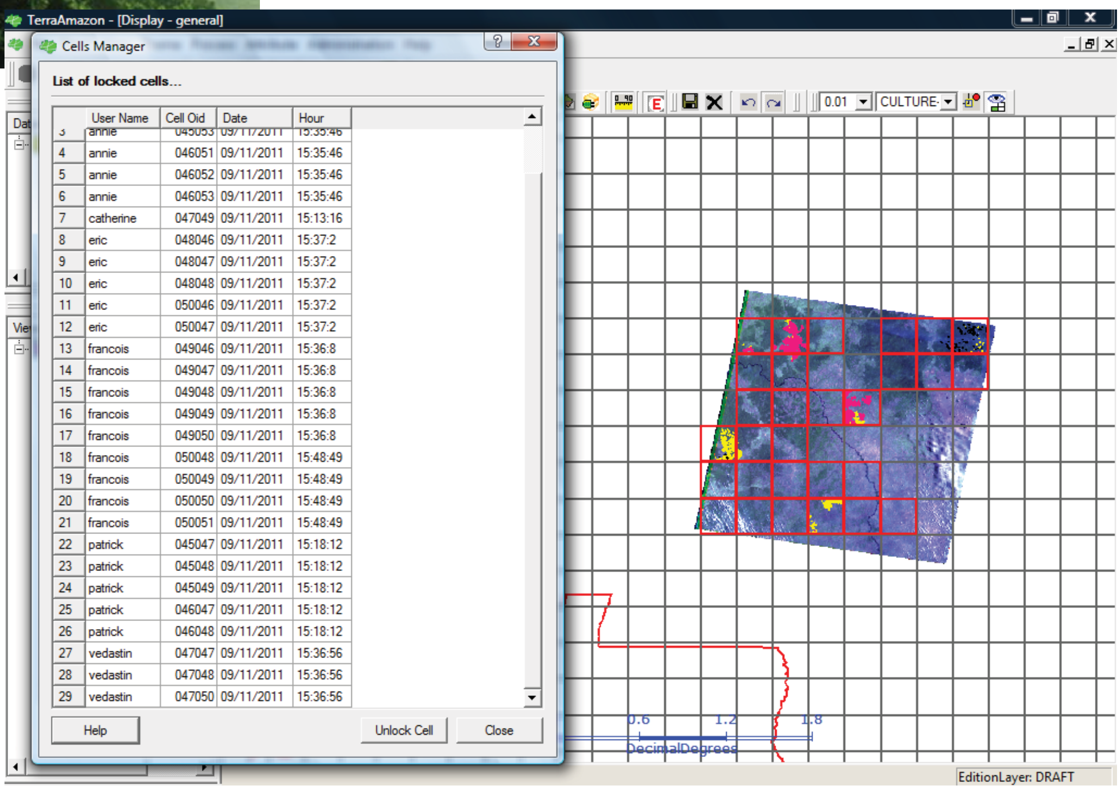




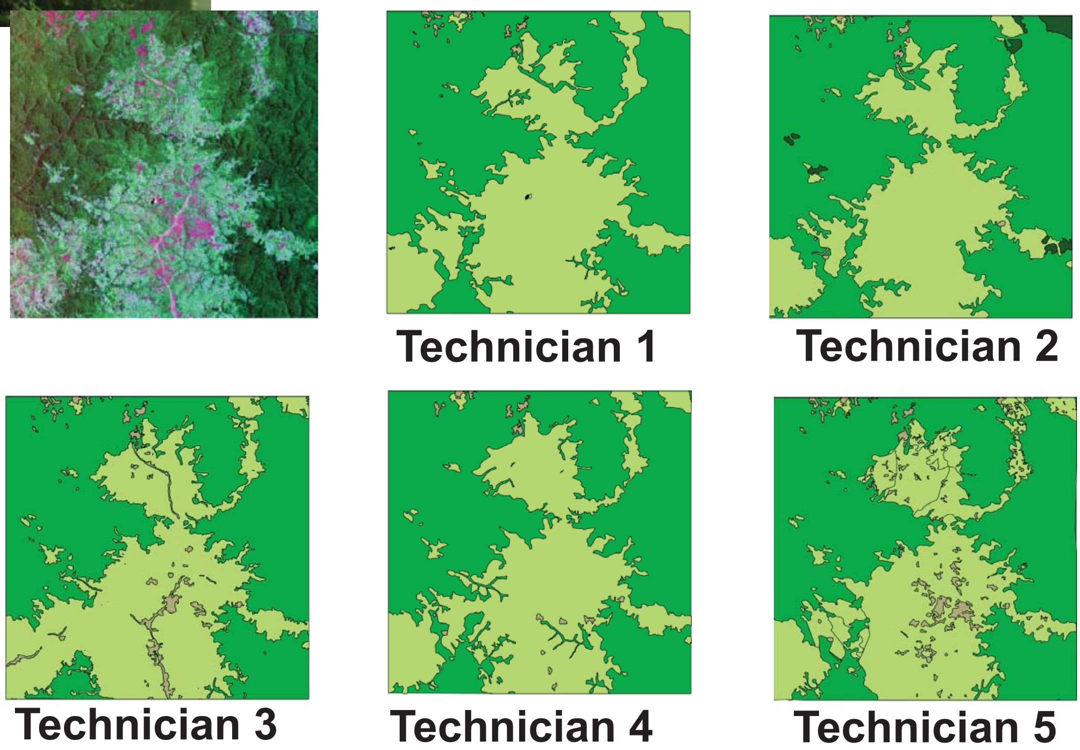


TerraCongo workshop
Multi-user edition

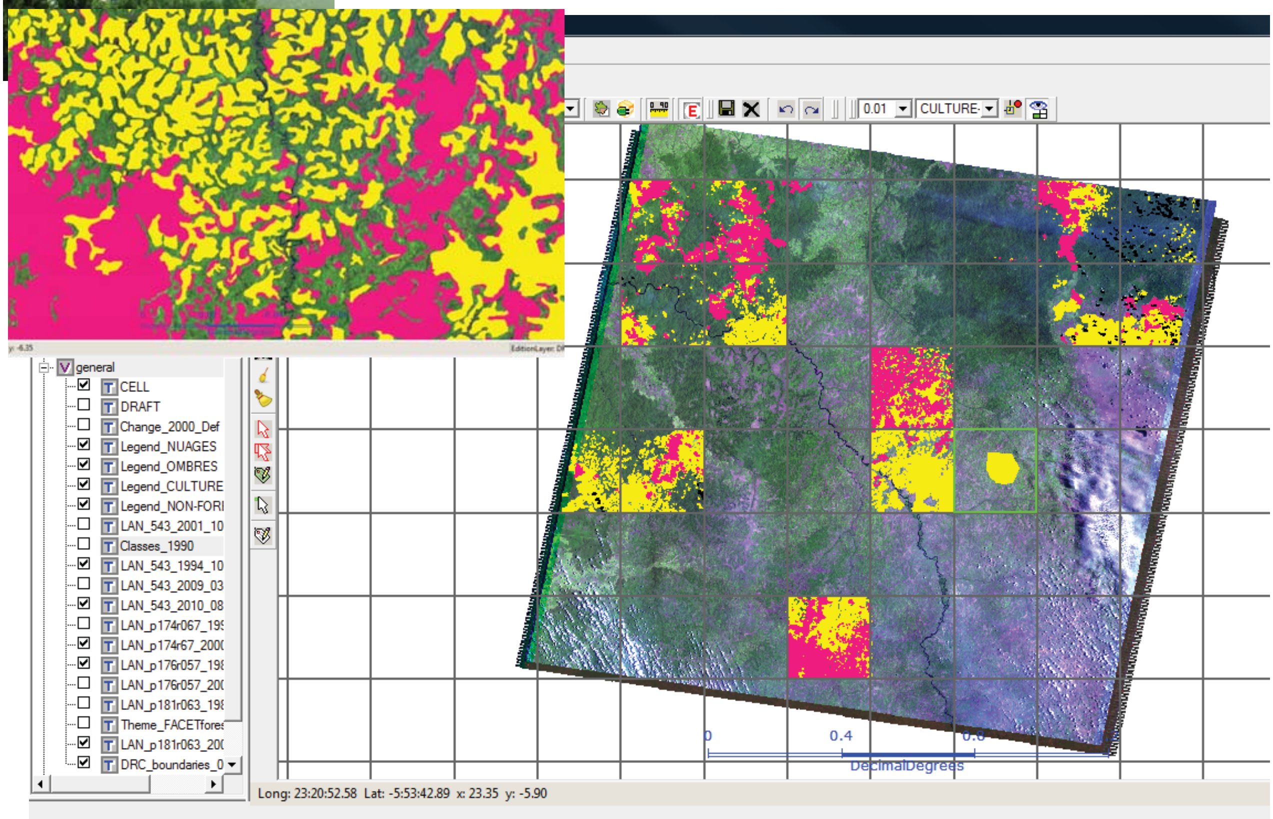




TerraCongo Workshop
Calibration of interpretation



TerraCongo Workshop Results



Processing chain:

FRA RSS,FAO-FIN,UN-REDD

FAO FRA RSS

LC/LU sample sites checked by regional experts

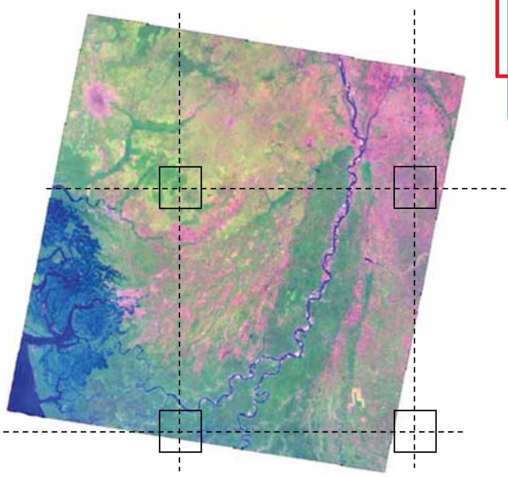
FAO-FIN

Open Foris tool kit

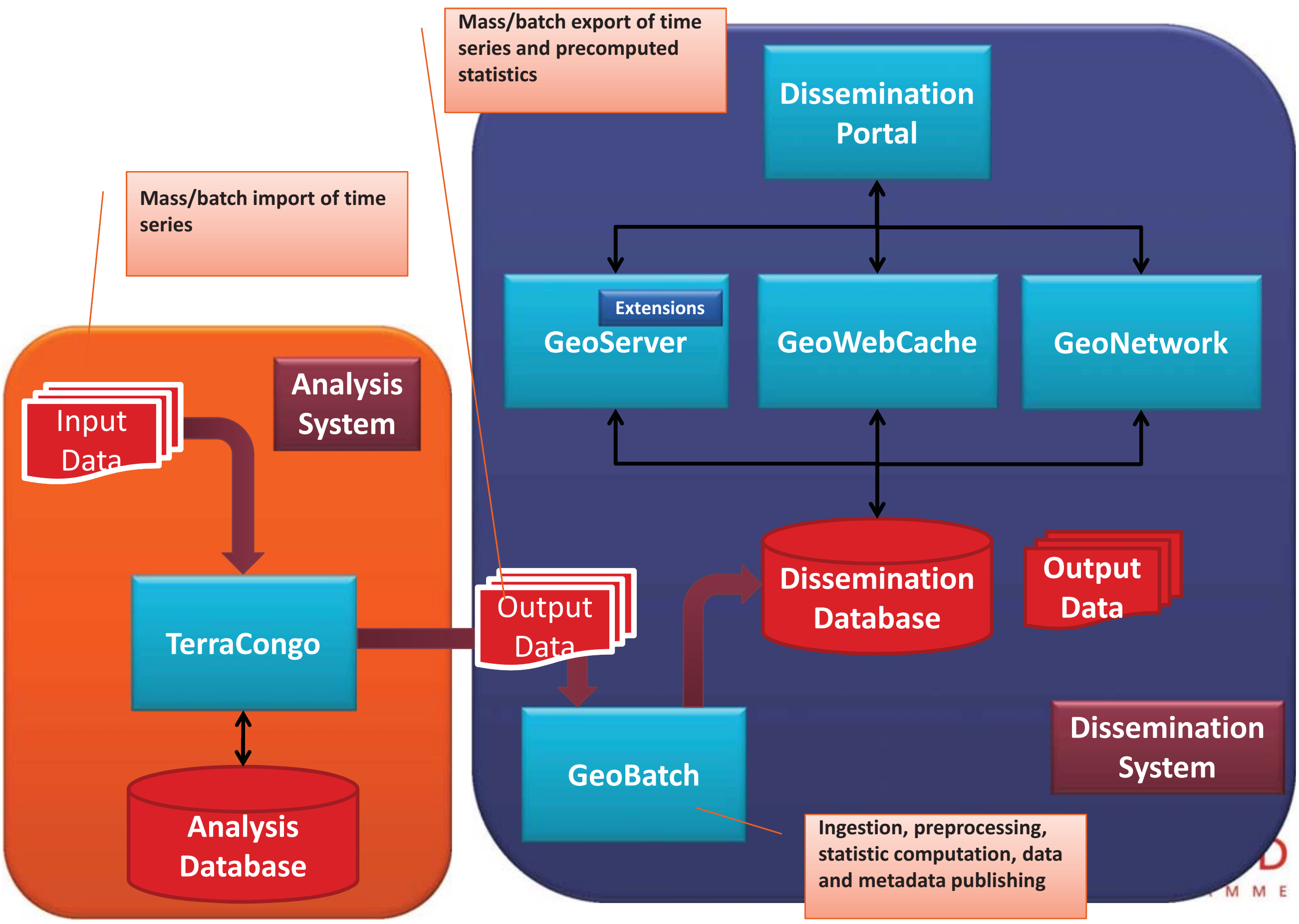
Pre-processing
Segmentation
Supervised classification

UN-REDD

Edition in TA



TerraCongo linked to dissemination portal

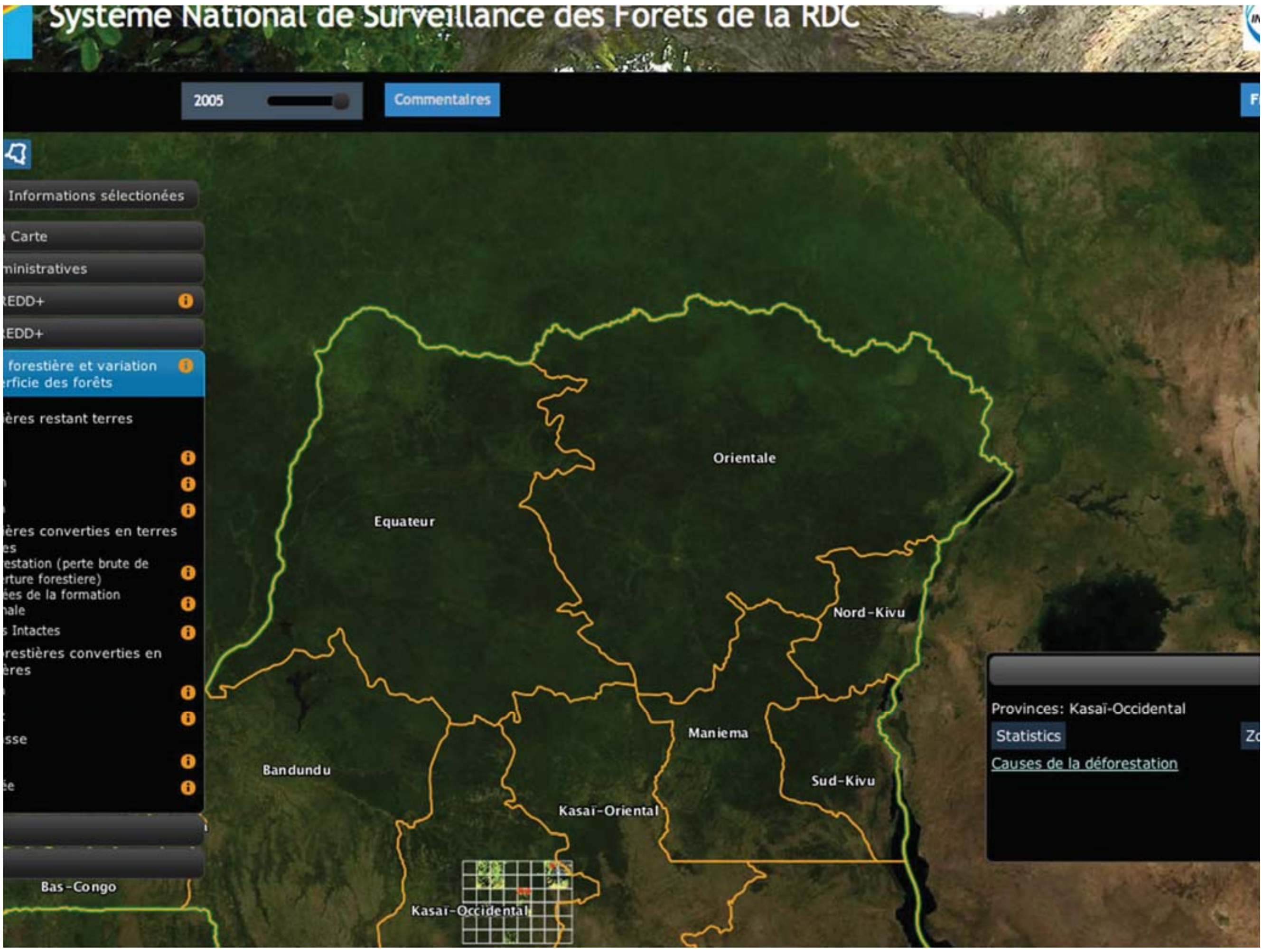


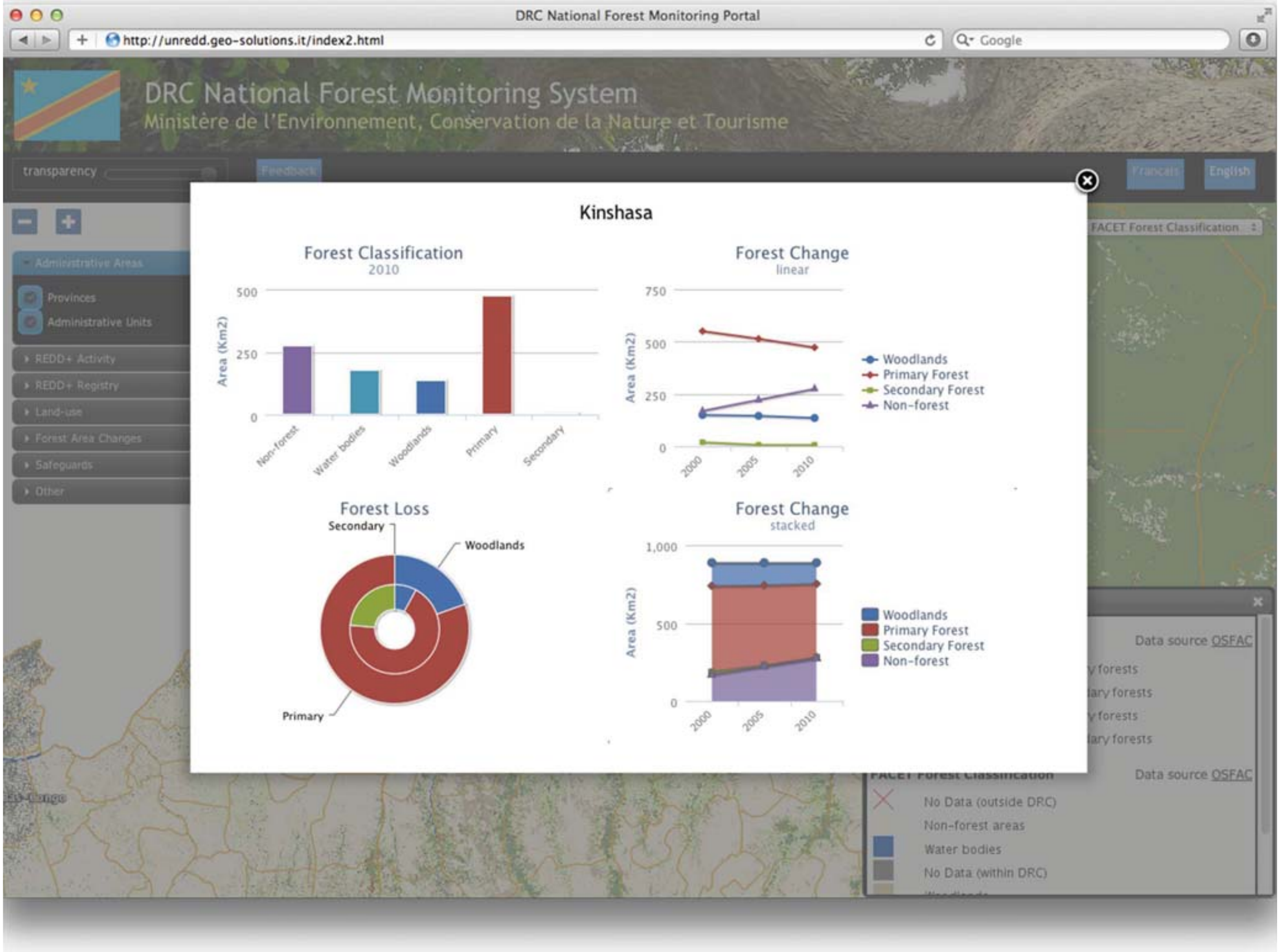
DRC National Forest monitoring portal

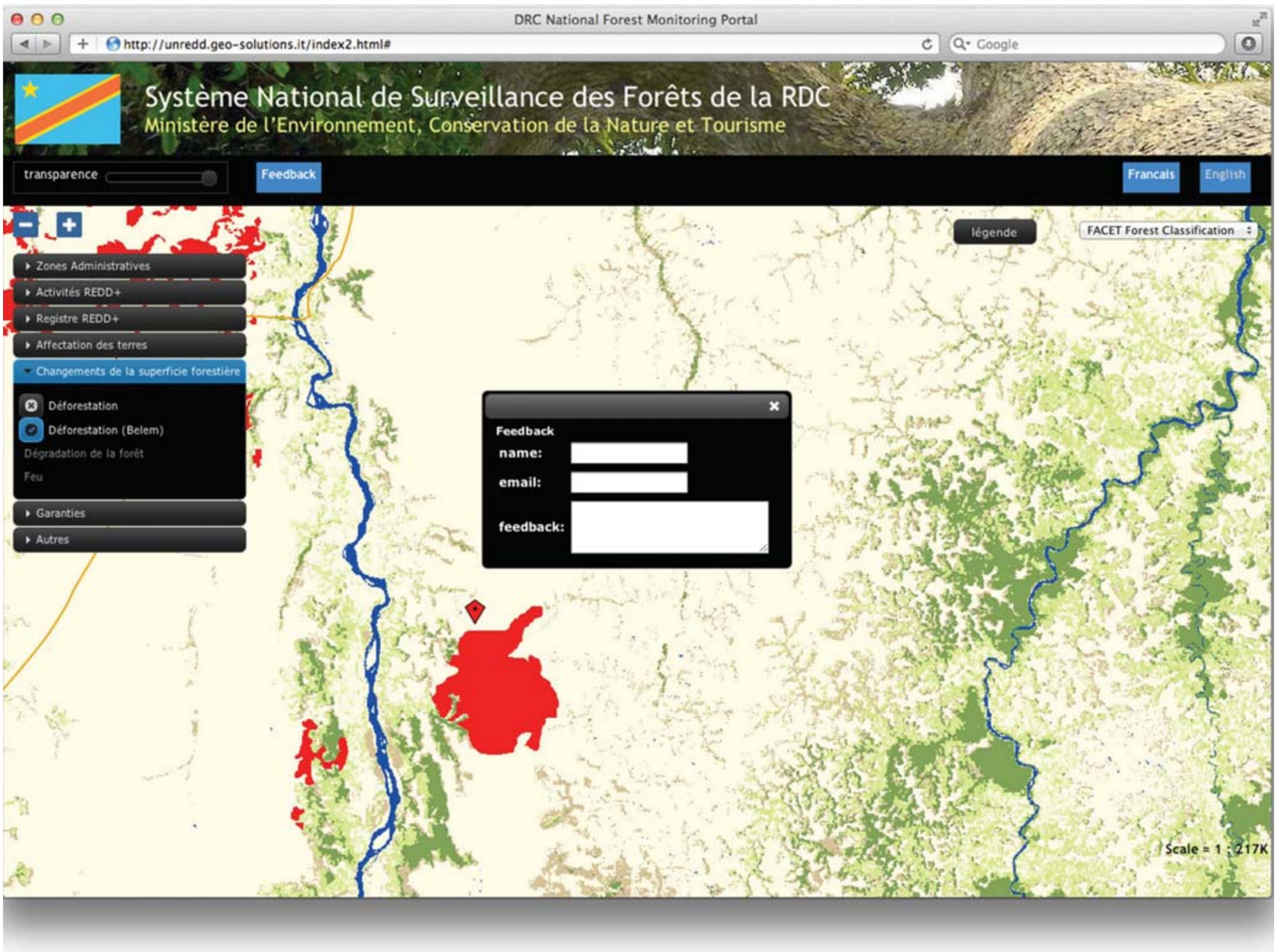
http://rdc-snsf.com

- Allows any user to interact with the system through a web-interface;
- Visualise country data;
- Download statistics on deforestation and the other 4 REDD+ activities;
- Visualise information on logging concessions, protected areas etc;
- Look at existing REDD+ projects;
- Allow users (aim is to involve local communities as much as possible) to provide feedback on areas of deforestation, etc.

INPE UN-REDD PROGRAMME




DRC National Forest Monitoring Portal
http://unredd.geo-solutions.it/index2.html
DRC National Forest Monitoring System
Ministère de l'Environnement, Conservation de la Nature et Tourisme
transparency
Feedback
Francais
English
Administrative Areas
Provinces
Administrative Units
REDD+ Activity
REDD+ Registry
Land-use
Forest Area Changes
Safeguards
Other
Kinshasa
Forest Classification
2010
Area (Km2)
Non-forest
Water bodies
Woodlands
Primary
Secondary
Forest Change
linear
Area (Km2)
Woodlands
Primary Forest
Secondary Forest
Non-forest
Forest Loss
Secondary
Woodlands
Primary
Forest Change
stacked
Area (Km2)
Woodlands
Primary Forest
Secondary Forest
Non-forest
FACET Forest Classification
Data source OSFAC
No Data (outside DRC)
Non-forest areas
Water bodies
No Data (within DRC)


DRC National Forest Monitoring Portal
http://unredd.geo-solutions.it/index2.html#
Système National de Surveillance des Forêts de la RDC
Ministère de l'Environnement, Conservation de la Nature et Tourisme
transparence
Feedback
Francais
English
légende
FACET Forest Classification
Zones Administratives
Activités REDD+
Registre REDD+
Affectation des terres
Changements de la superficie forestière
Déforestation
Déforestation (Belem)
Dégradation de la forêt
Feu
Garanties
Autres
Feedback
name:
email:
feedback:
Scale = 1 : 217K

Milestones and way forward

- FAO HQ Team in place, all partners on board: INPE/FUNCATE, GeoSolutions, link with EC-JRC
- First prototype of the portal (15/9/2011)
- Training of in-country people in Belem & Rome (sept 2011)
- Final release of the software (1/12/2011)
- Beta version presentation COP 17, Durban (dec 2011)
- *Algorithm adaptation and country tailoring* (2012)
- *Presentation of first in-country results in COP 18, Doha*

Way forward

- Integration of existing data pre-processing and change detection algorithms for different ecosystems
- Approach of 'modules' which allows the countries to pick and chose dependent on the country needs (data bulk downloading ,preprocessing (geometric/radiometric), cloud masking, change detection, statistics, mapping)
- All open-source applications are more than welcome!
- Safeguards'system

Other Web-GIS dissemination portals

- Web portal developed at FAO – HQ (GeoSolutions support)
- Allow all end-users to follow and have open access to available forest data, updated frequently to represent national forest conditions
- Launched in DRC, PNG and Paraguay

rdc-snsf.org

png-nfms.org

paraguay-smf.org

UN-REDD PROGRAMME

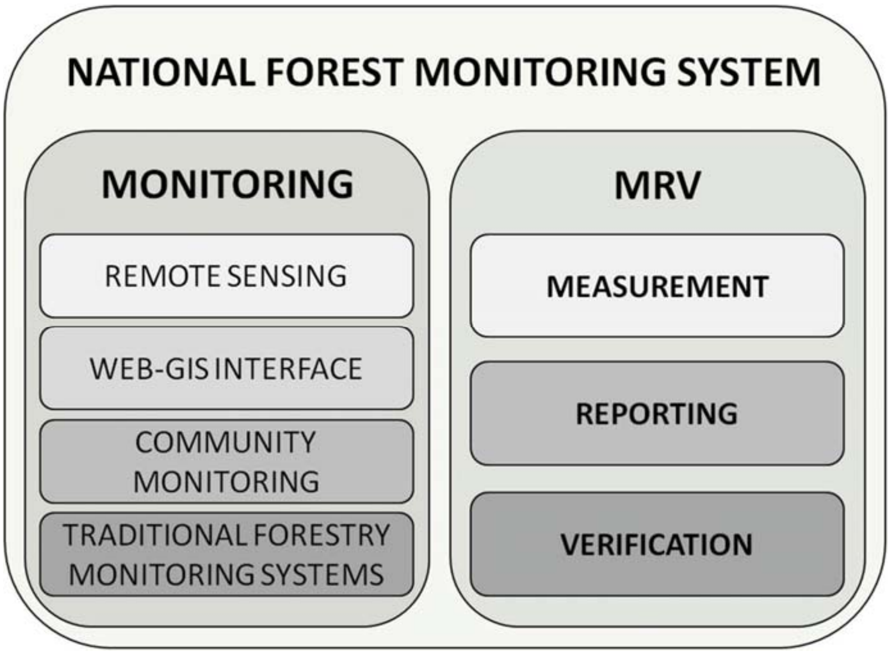
Information on REDD+ Safeguards

- Parties must develop a system for **providing information** on how **REDD+ safeguards** are being addressed and respected throughout the implementation of REDD+ activities

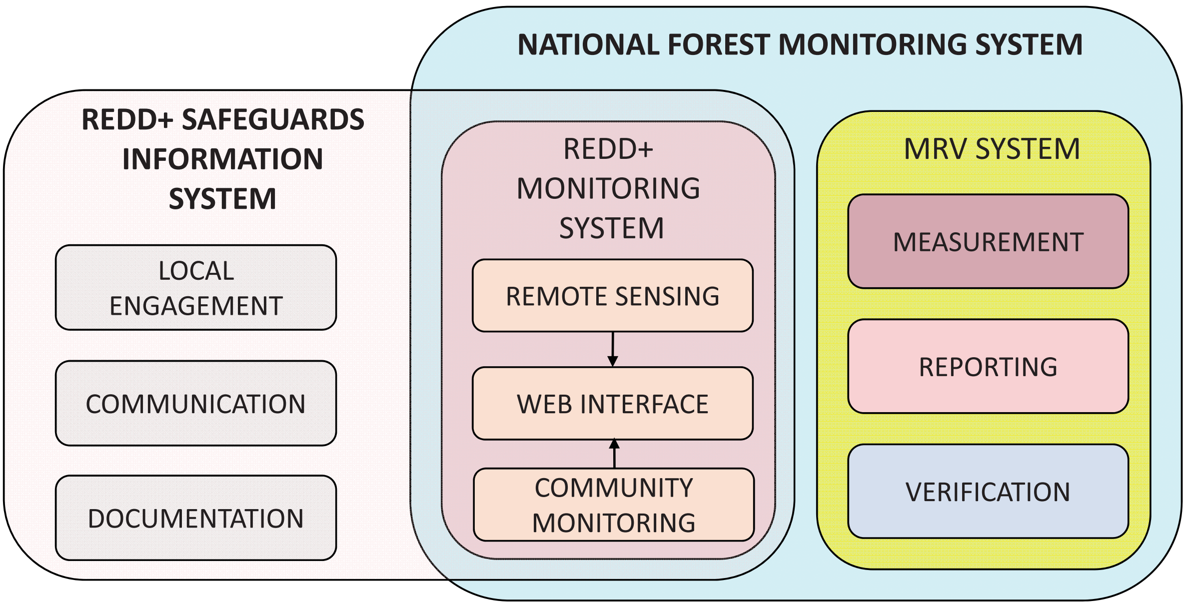
- Some of the REDD+ safeguards (Appendix 1 of Decision 1/CP.16) will require spatial and monitoring information

  a) Consistent with the objectives of NFPs and international agreements
  b) Transparent and effective national **forest governance structures**
  c) Respect for the knowledge and **rights of indigenous peoples and local communities**;
  d) The full and effective participation of relevant stakeholders
  e) Consistent with the **conservation** of natural forests and **biological diversity**
  f) Actions to address the risks of reversals (**permanence**)
  g) Actions to reduce displacement of emissions (**leakage**)

Dual functions of the national forest monitoring system for REDD+



Fitting the Systems Together






Important data considerations

- For **sustainable** autonomous national systems: capacity building and technology transfer is needed in-country, especially in the field of radar/lidar, so far mainly efforts in optical domain
- **Data availability/access** is a limiting factor for work done in-country
- Important is to build links with **National Forest Inventories** (NFIs)
- Important to distinguish R&D from **operational applications** ready to be implemented in Non-Annex-I countries





What if…
…countries have **no** system?

- The country will be unable to ***nationally monitor*** the implementation of its REDD+ policies and measures and results based demonstration activities and actions;
- Failing to implement specific Paragraphs of Decisions 4/CP.15 and 1/CP.16, means that the country will not be in a position to ***demonstrate internationally*** that it is effectively implementing REDD+ activities and thus unable to receive funding for REDD+ under the UNFCCC in Phases 2 and 3.

Thank you for your attention!

inge.jonckheere@fao.org

rdc-snsf.org
png-nfms.org
paraguay-smf.org

UN-REDD PROGRAMME

MINSITRY OF FORESTRY

IPCC INTERGOVERNMENTAL PANEL ON climate change WMO UNEP

Indonesia's National Forest Monitoring System as main system for REDD+ MRV

Ruandha Agung Sugardiman
DG of Forestry Planning

"IPCC Expert Meeting:
Role of Remote Sensing in Forest and National GHG Inventories"

23 - 25 October 2012, Hayama, Japan

The Cancun Agreements

FCCC/CP/2010/7/Add.1, paragraph 71

Decision 1/CP.16
The Cancun Agreements: Outcome of the work of the Ad Hoc Working Group on Long-term Cooperative Action under the Convention

- A **national strategy** or action plan;
- A **national forest reference emission level and/ or forest reference level**;
- A robust and transparent **national forest monitoring system** for the monitoring and reporting of REDD+ activities;
- A system for providing **information on REDD+ safeguards**.

Report of the Conference of the Parties on its sixteenth session, held in Cancun from 29 November to 10 December 2010
Addendum Part Two: Action taken by the Conference of the Parties at its sixteenth session

MRV and Monitoring System

Measurable, reportable and verifiable

SBSTA decision:

- To establish robust and transparent national forest monitoring systems [..] using a **combination of remote sensing** and **ground-based forest carbon inventory** approaches.
- Monitoring systems should provide estimates [..] suitable for review as agreed by the COP.

NATIONAL FOREST INVENTORY

NFI PROJECT
FAO - GOI

NFI COMPONENTS

1. FOREST RESOURCES ASSESSMENT (FRA)
2. FOREST RESOURCES MONITORING (FRM)
3. GEOGRPHIC INFORMATION SYSTEM (GIS)
4. USER'S INVOLVEMENT (USER)

1986 - 1990

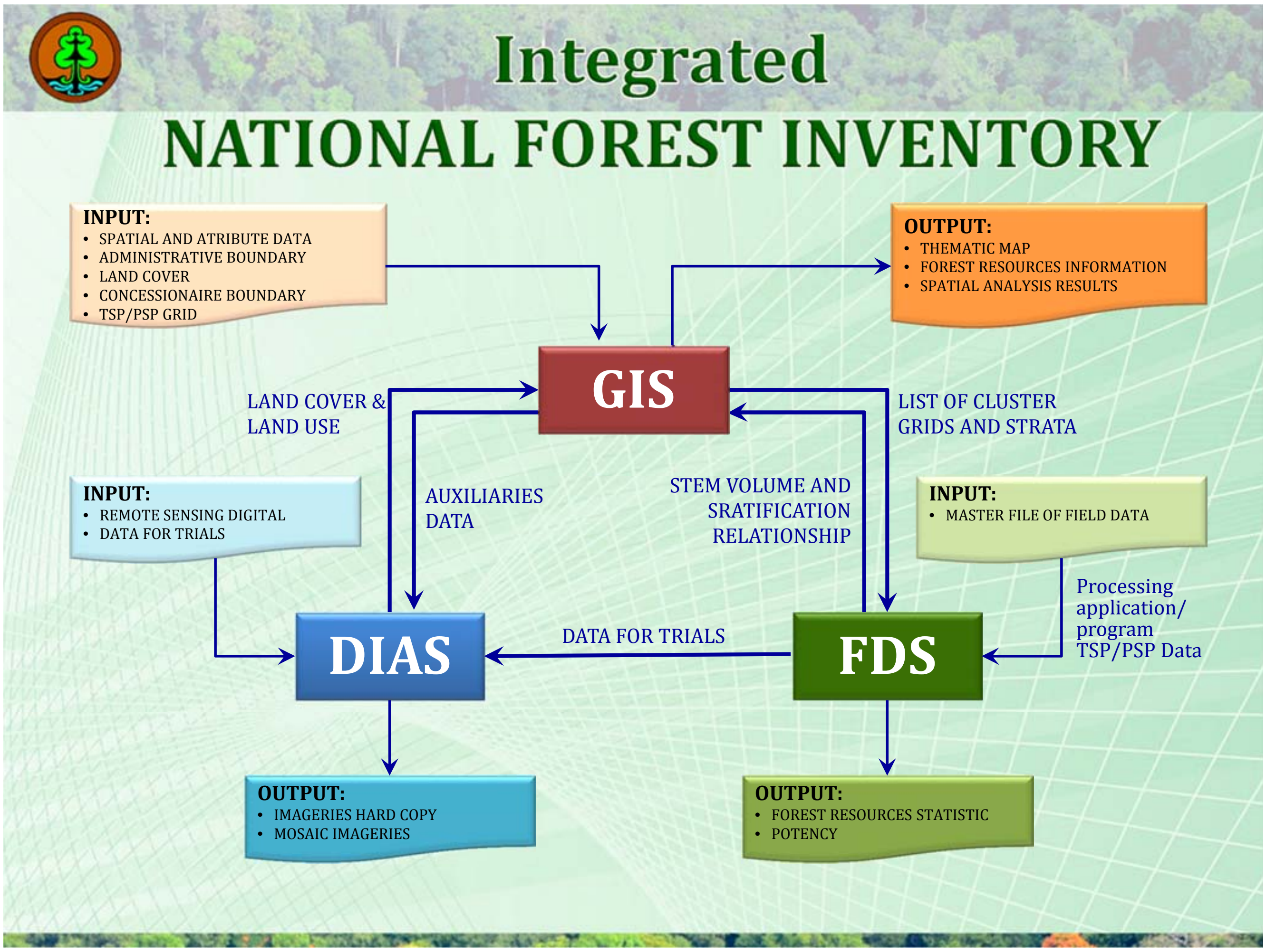
Objectives:

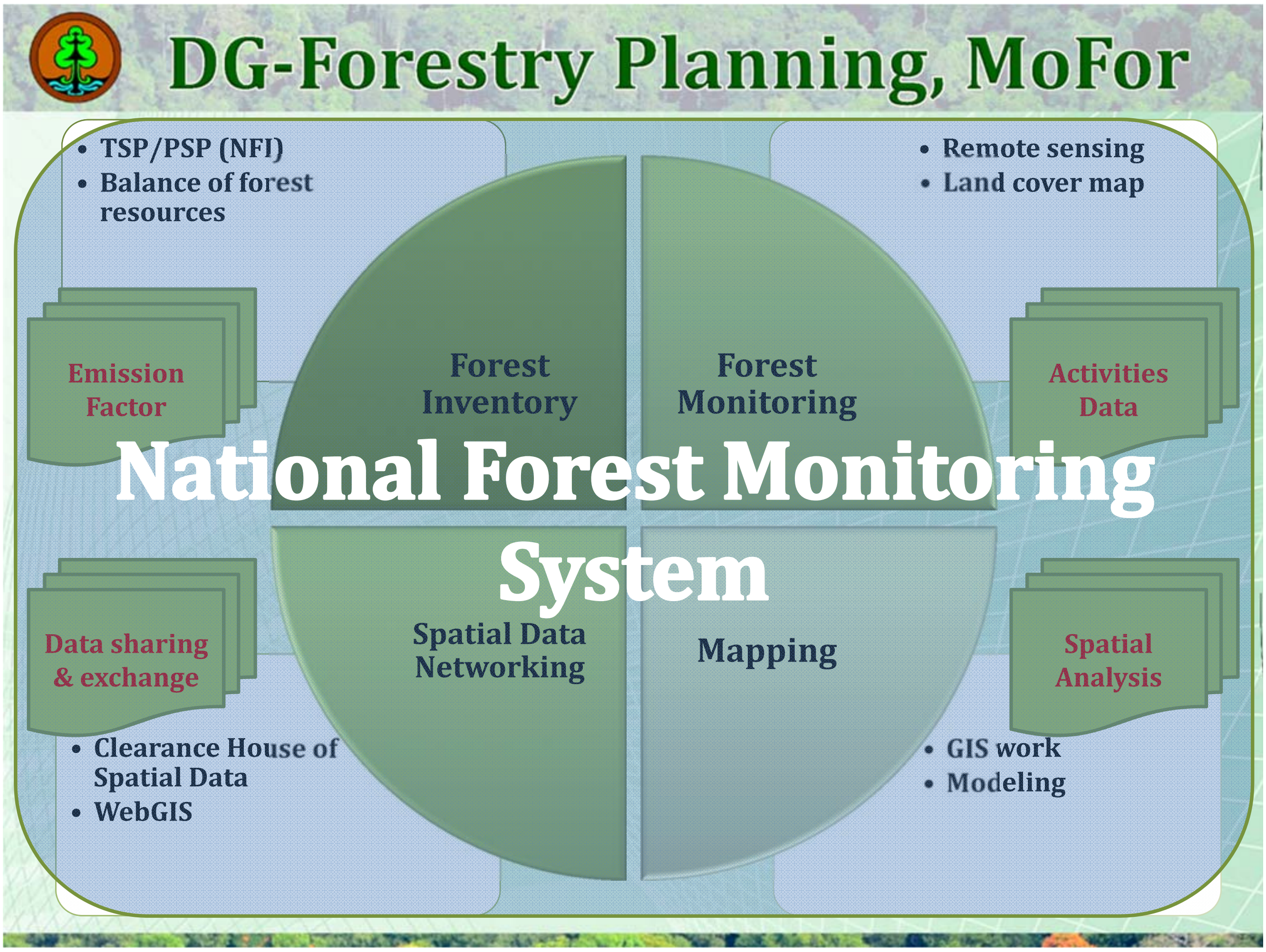
1. To provide information on location and area of forest type and land covers.
2. To build and develop national forest inventory and monitoring system.
3. To predict stem (timber) volume, growth and yield of forest stand based on forest type, species and group of species.

1996

1. **FDS** (Field Data System)
2. **DIAS** (Digital Images Analysis System)
3. [illegible] Resources Monitoring)
4. [illegible]hic Information System)
5. [illegible] Services of NFI

Provide information for decision making process to support policy formulation, planning, management and controlling on forestry sector in national, regional and province level.


Integrated
NATIONAL FOREST INVENTORY
INPUT:
• SPATIAL AND ATRIBUTE DATA
• ADMINISTRATIVE BOUNDARY
• LAND COVER
• CONCESSIONAIRE BOUNDARY
• TSP/PSP GRID
OUTPUT:
• THEMATIC MAP
• FOREST RESOURCES INFORMATION
• SPATIAL ANALYSIS RESULTS
GIS
LAND COVER &
LAND USE
LIST OF CLUSTER
GRIDS AND STRATA
INPUT:
• REMOTE SENSING DIGITAL
• DATA FOR TRIALS
AUXILIARIES
DATA
STEM VOLUME AND
SRATIFICATION
RELATIONSHIP
INPUT:
• MASTER FILE OF FIELD DATA
Processing
application/
program
TSP/PSP Data
DIAS
DATA FOR TRIALS
FDS
OUTPUT:
• IMAGERIES HARD COPY
• MOSAIC IMAGERIES
OUTPUT:
• FOREST RESOURCES STATISTIC
• POTENCY


DG-Forestry Planning, MoFor
• TSP/PSP (NFI)
• Balance of forest
resources
• Remote sensing
• Land cover map
Emission
Factor
Forest
Inventory
Forest
Monitoring
Activities
Data
National Forest Monitoring
System
Data sharing
& exchange
Spatial Data
Networking
Mapping
Spatial
Analysis
• Clearance House of
Spatial Data
• WebGIS
• GIS work
• Modeling

Measurement, Reporting & Verification

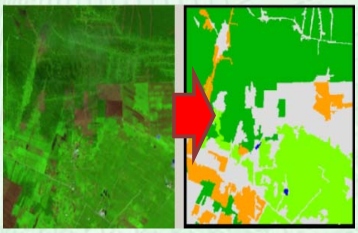
National Forest Monitoring System as main system for REDD+ MRV

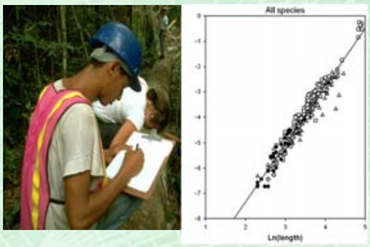
M

ACTIVITY DATA
Satellite Land Representation System

x

EMISSION FACTOR
National Forest Inventory





R

=

REDD+ GHG Inventory

LULUCF Inventory

UNFCCC

Inventory compilation QA/QC

Emission Inventory Database

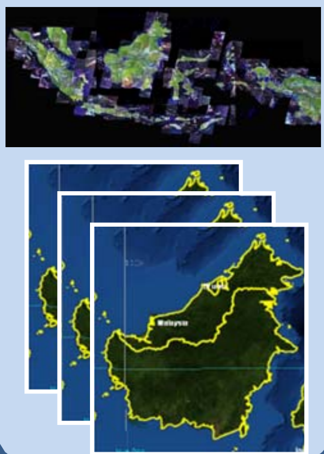
V

UNFCCC Secretariat
Roster of Experts

GHG inventory for the LULUCF

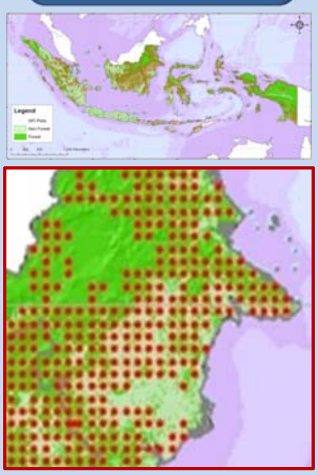
Following Good practices and Guidelines of the Intergovernmental Panel on Climate Change (IPCC)

ACTIVITY DATA



X

EMISSION FACTOR



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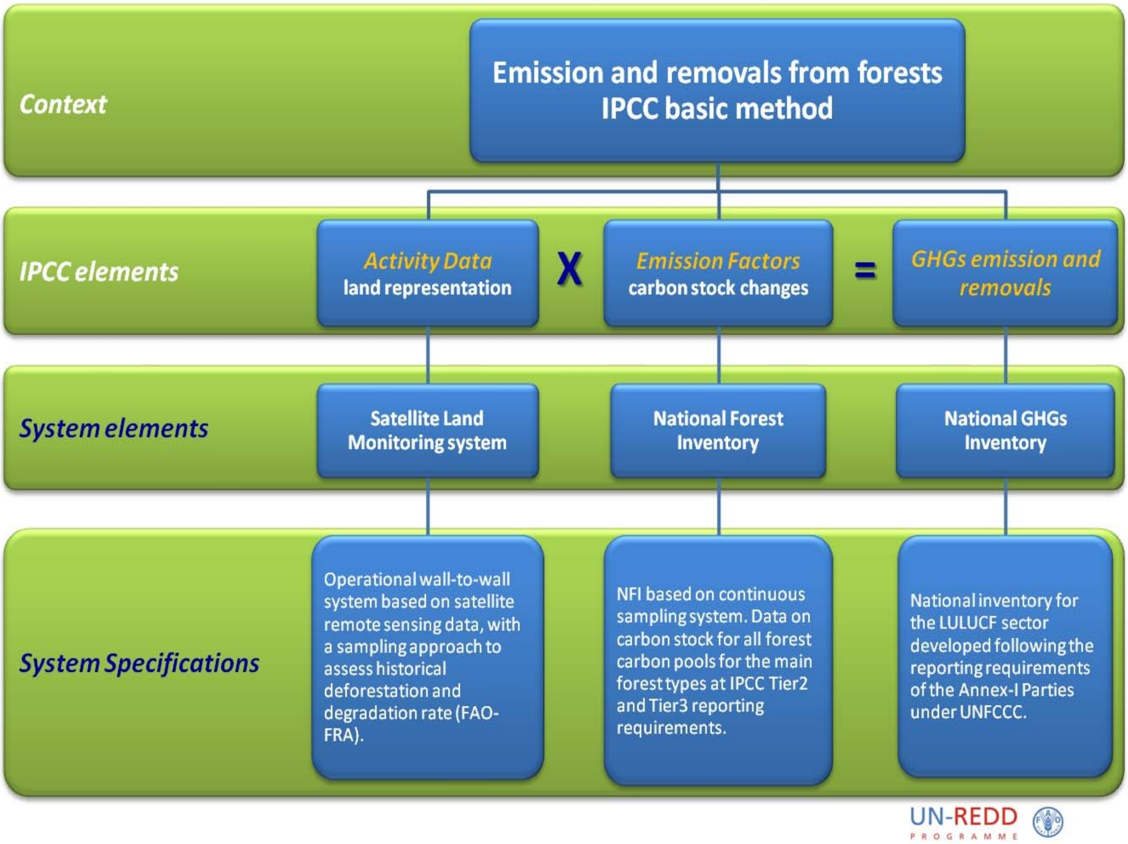
EMISSION ESTIMATE

CO_2
equivalent

Modified from: **Alberto Sandoval, Rosa Ramon –UNREDD general and MRV framework COP, 2010**

MRV basic elements under IPCC



EMISSION ESTIMATION

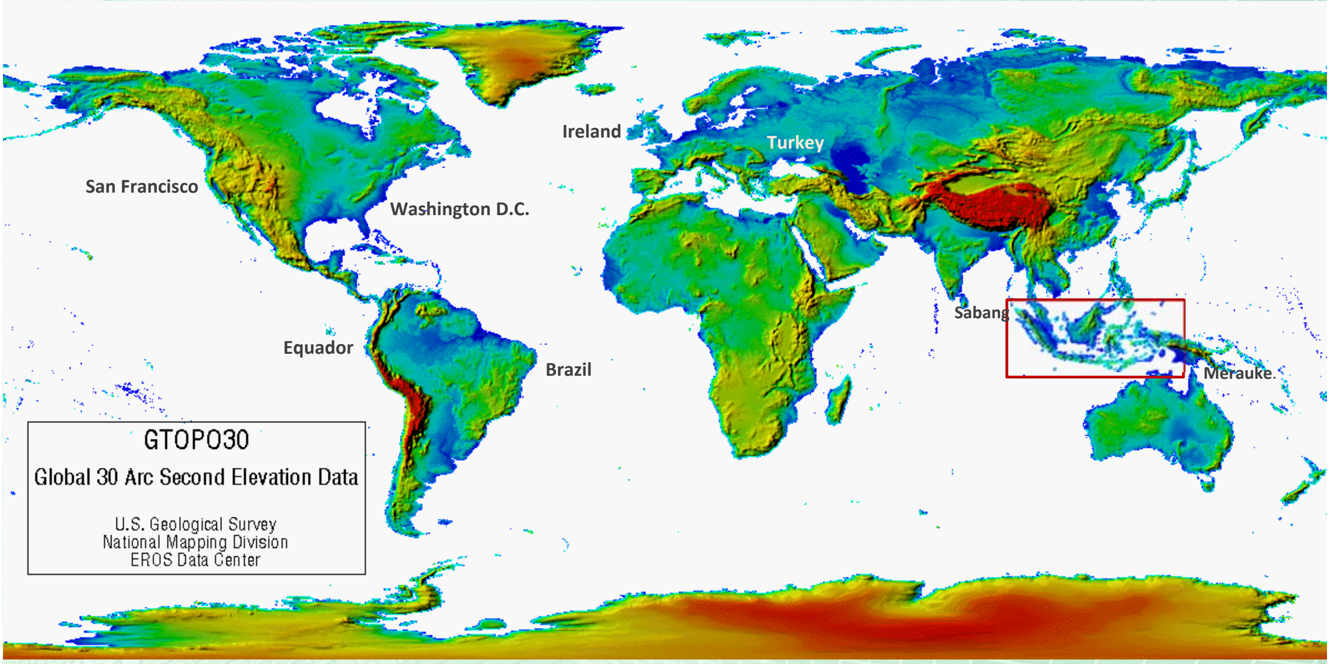
- **Activity data:**

  Land cover change: Landsat 5, Landsat 7 ETM+ (1990, 1996, 2000, 2003, 2006, 2009, 2011)

- **Emission/Removal Factor:**

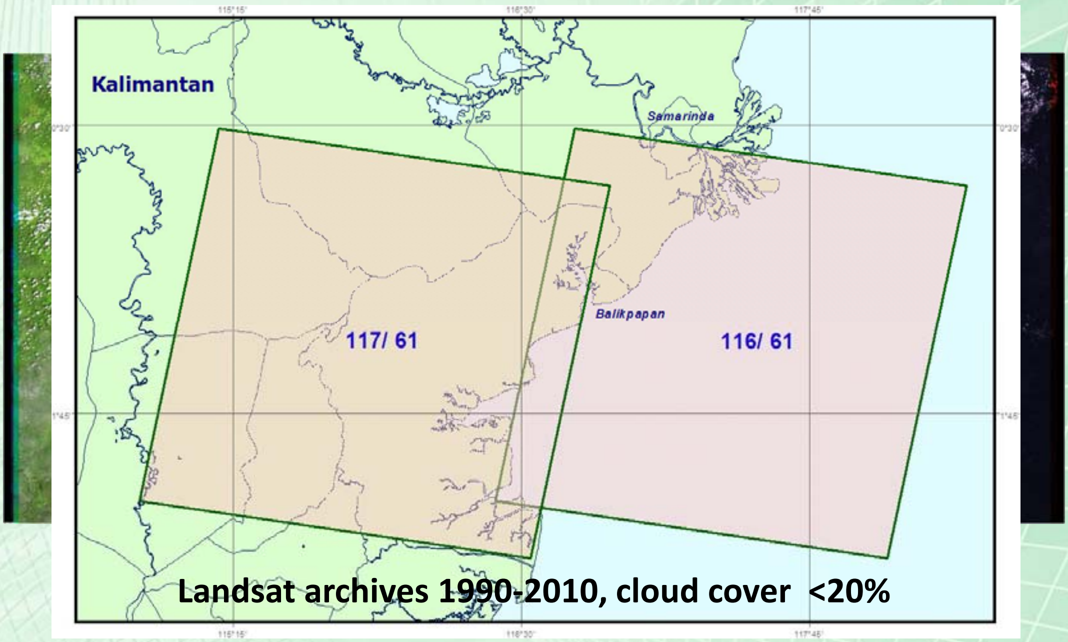
  National Forest Inventory (NFI) Sample Plots
  - 1990-1996 (2.735 cluster plots)
  - 1996-2000 (1.145 cluster plots)
  - 2000-2006 (485 cluster plots)
  - 2006-2014 (>3.000 cluster plots) → **Redesign NFI**

How Indonesia? Challenges

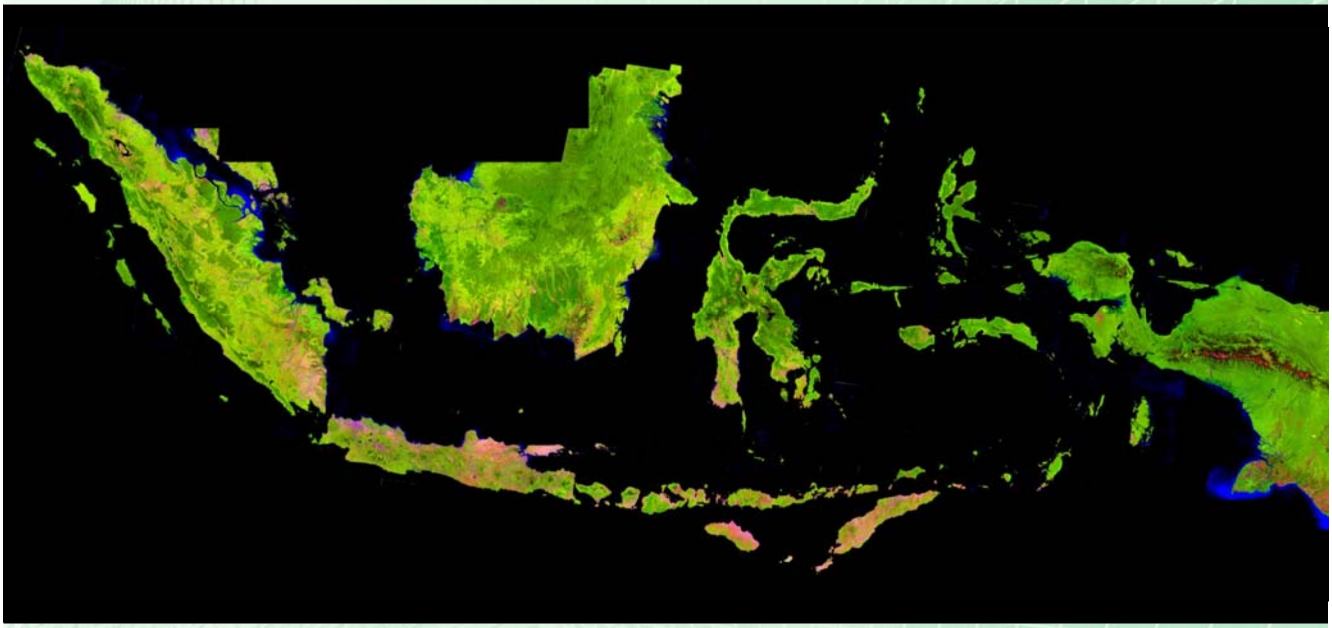


Challenges

- Archipelago → Intensity of Cloud Cover is very high (~10-30%)

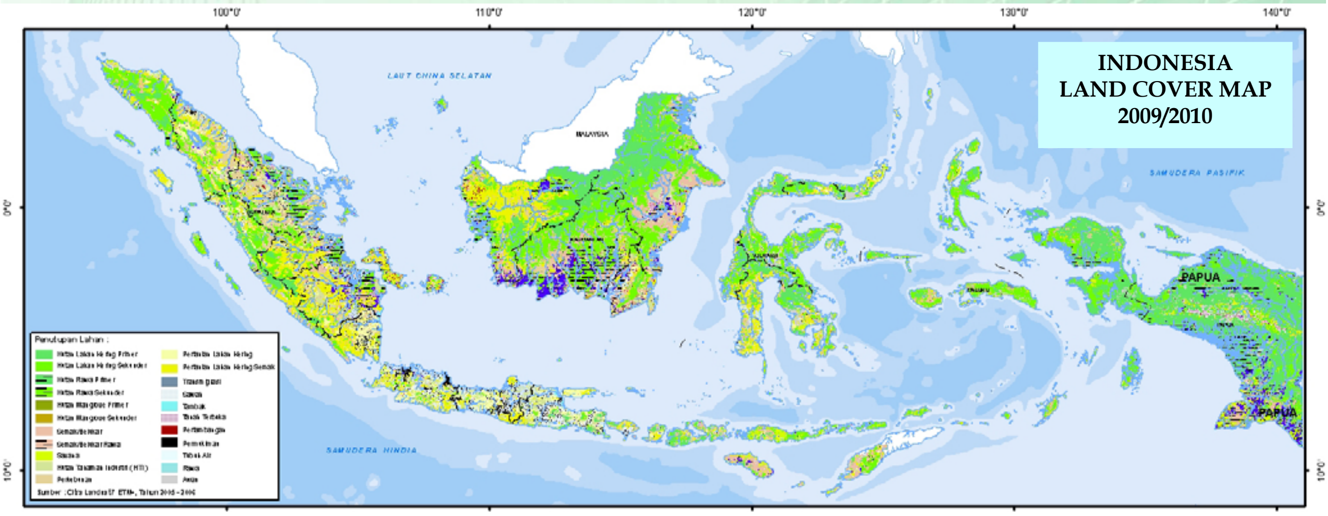


Land Cover Mapping for the whole Indonesia



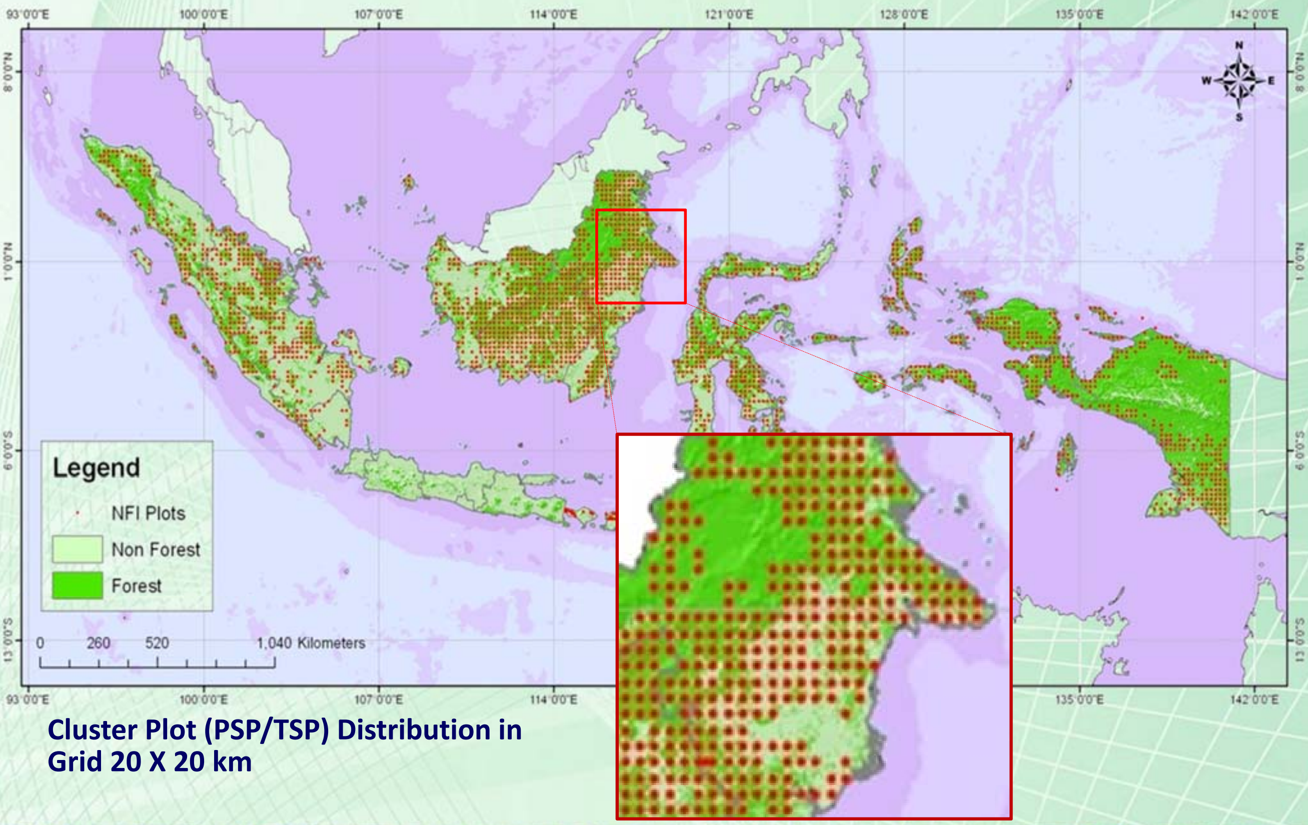
Remark: Landsat 7 ETM+ coverage for the whole Indonesia (217 scene)

Land Cover Mapping Recalculation using image of Landsat (2009/2010)



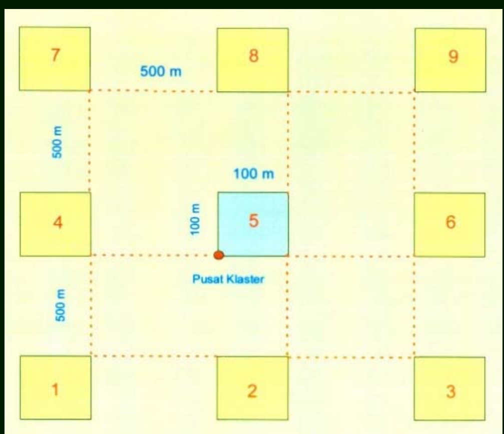
Remark: Landsat images of 2009/2010 were orthorectified, using SRTM and ground checked.

NFI-Cluster Plot Distribution

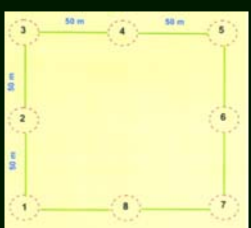


Cluster Plot (PSP/TSP) Distribution in Grid 20 X 20 km

CLUSTER PLOT LAYOUT



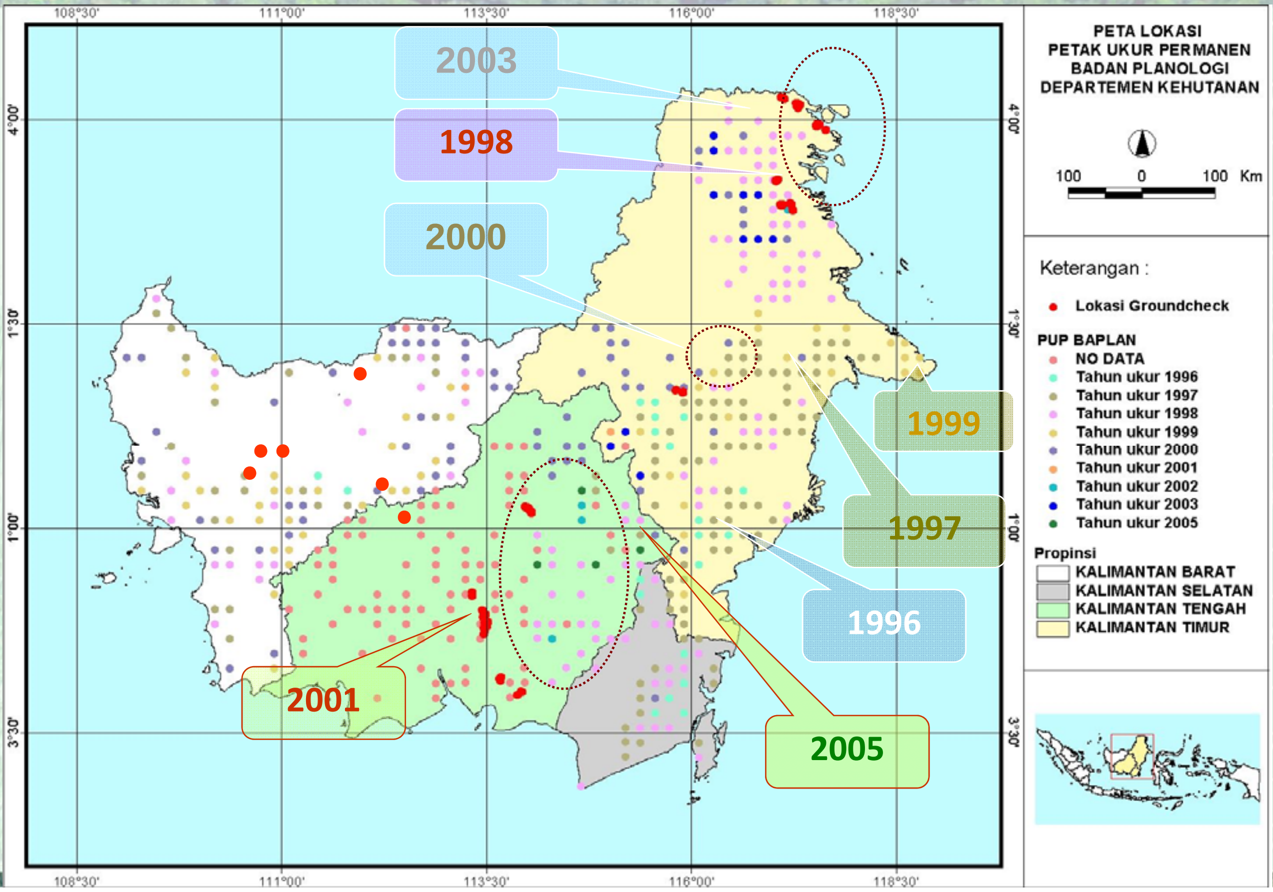
A Cluster contents
9 Tract



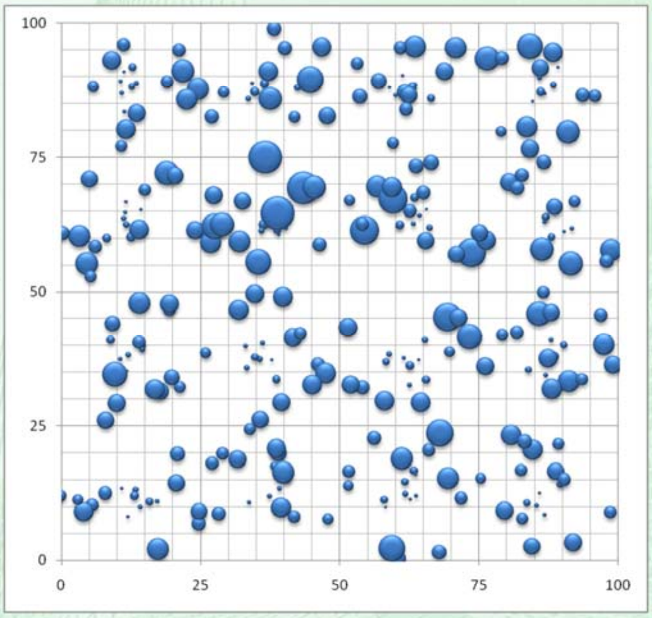
A tract Temporary Sample Plot (TSP) contents 8 Sub Plot. Measurement using sampling point (BAF 4)

Permanent Sample Plot (PSP)
Only on tract 5
size 100 m x 100 m
with 16 sub-plot.

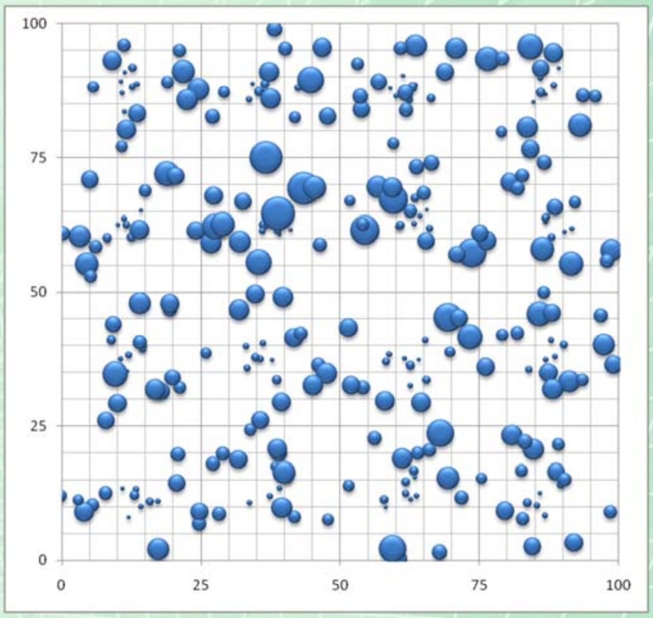
TSP/PSP DISTRIBUTION IN KALIMANTAN



Tree Plot Increment



1992
123 Ton C

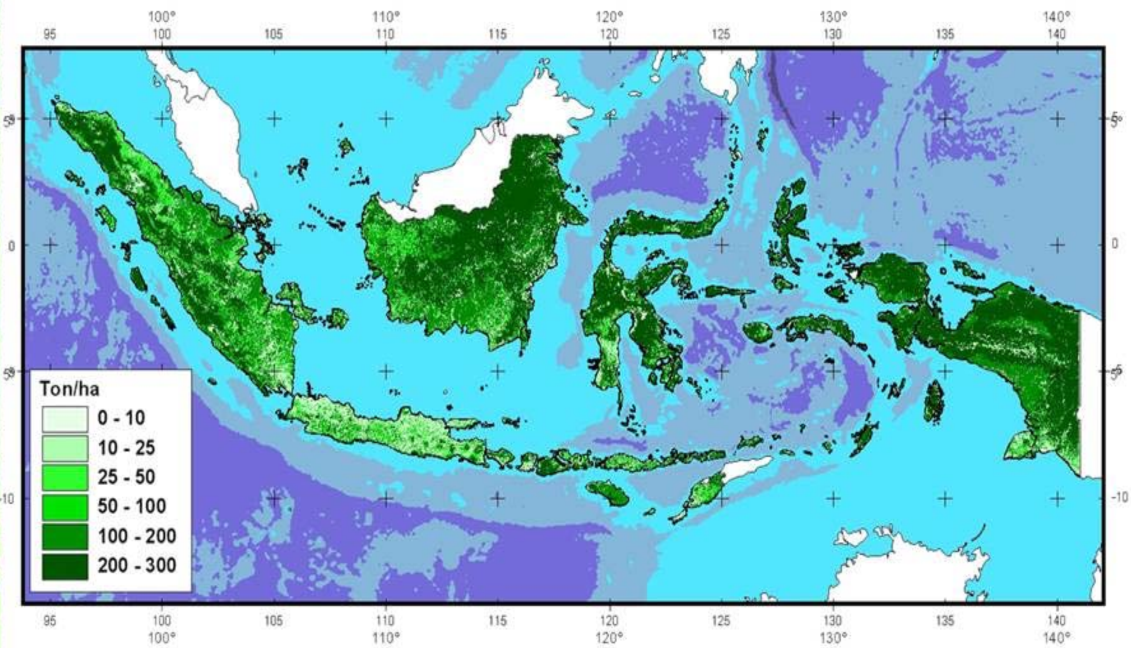


1998
133 Ton C

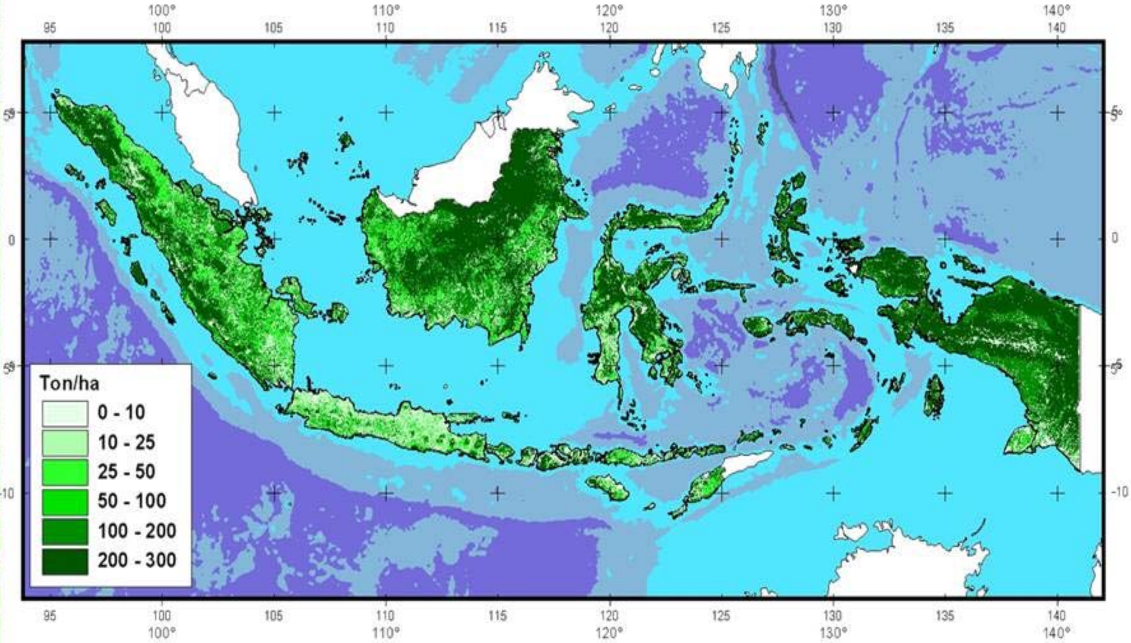
Land Cover → Forest Carbon

- Land Cover Mapping
- Ground based measurement → TSP/PSP - NFI
- Forest Biomass Mapping
- Forest Carbon Mapping
- Forest Carbon Monitoring

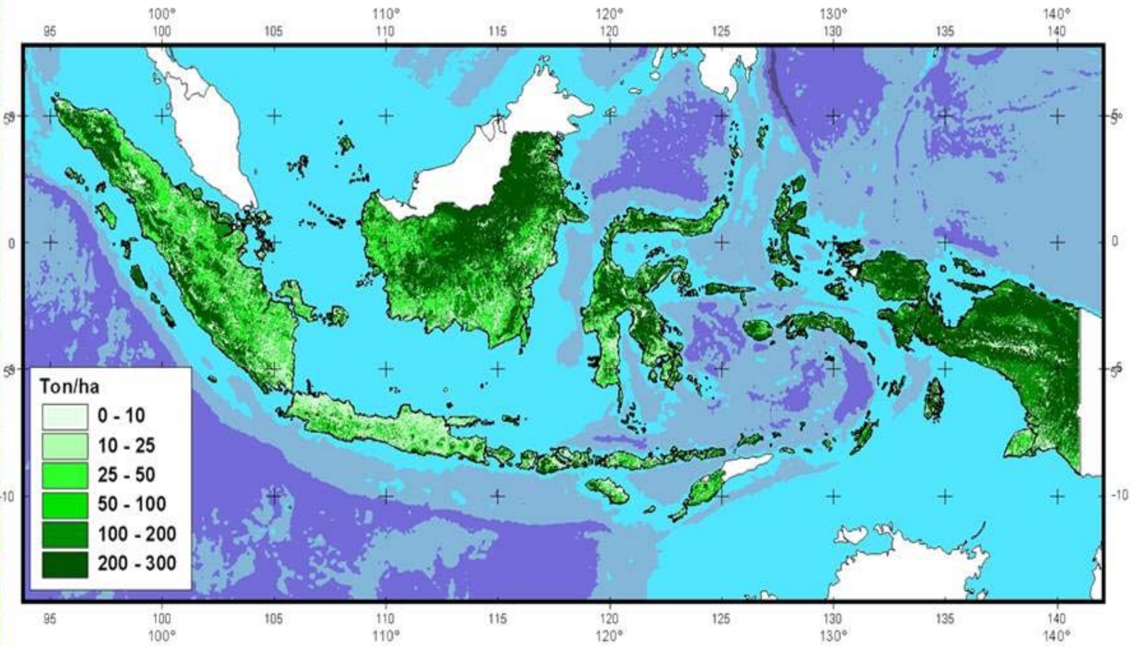
Above Ground Biomass Map of Indonesia 1990



Above Ground Biomass Map of Indonesia 2000

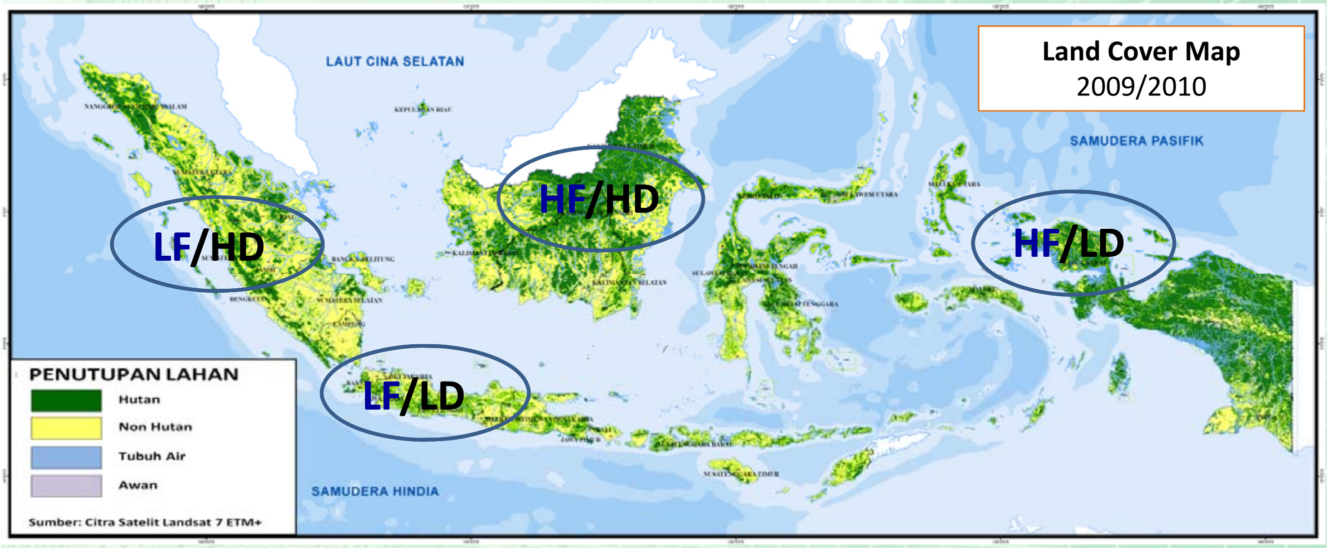


Above Ground Biomass Map of Indonesia 2005



Above Ground Biomass Map of Indonesia 2011

CLUSTER OF FOREST COVER and DEFORESTATION RATE



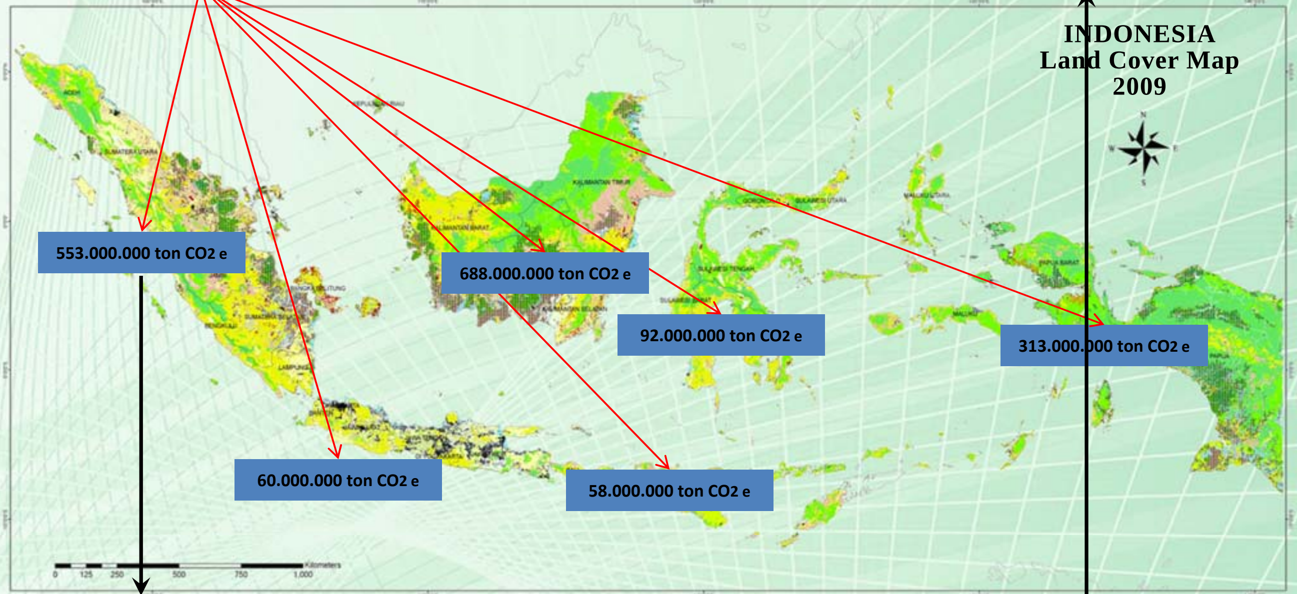
Note:

Low - High

Forest - Deforestation

NATIONAL CONSULTATION

1.760.000.000 ton $CO_{2\,e}$ → **REDD+ NATIONAL STRATEGY** ← Accumulation of all provinces/ regional (sub-national) Action Plan to reduce GHG emissions



Regional Sumatera:

- **REL** is defined by central government
- **Regional Action Plan to reduce GHG emissions** must be taken into account Regional **Development Plan** and Province **Spatial Planning**

Result:
1.Source carbon
2.Sink carbon

THANK YOU

Indonesia's National Forest Monitoring System as main system for REDD+ MRV

Ruandha Agung Sugardiman
DG of Forestry Planning, MoF

"IPCC Expert Meeting:
Role of Remote Sensing in Forest and National GHG Inventories"
23 - 25 October 2012, Hayama, Japan

Remote sensing data-based forest inventories and carbon stock reporting

IPCC Expert meeting on Role of Remote Sensing in Forest and National GHG Inventories

October 23-25, 2012

Hayama, Japan

Brice Mora

GOFC-GOLD
Global Observation of Forest Cover and Land Dynamics
Land Cover Project Office

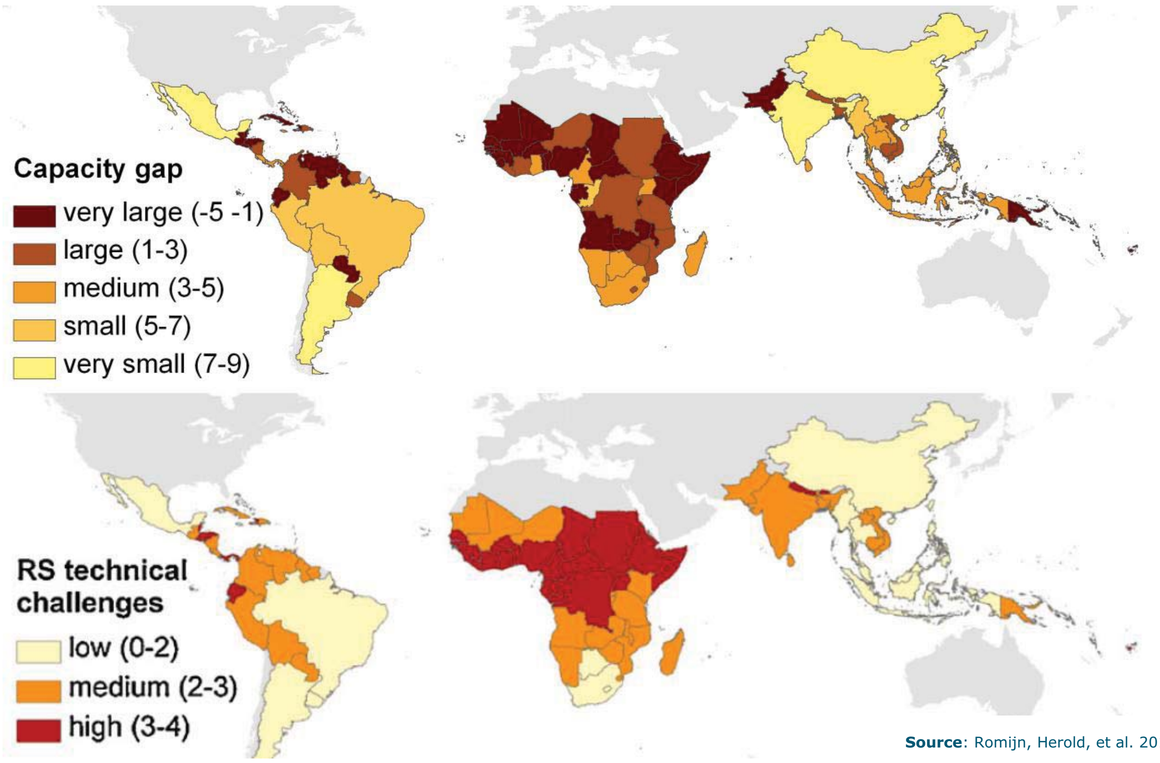
WAGENINGEN UR
For quality of life

Outline

- Technical capabilities of remote sensing sensors for the generation of (national) REDD+ information products
- Operational level of forest information products in REDD+ context
- Key synergy potentials for generating improved forest information products
  - a Canadian example
- Monitoring of changes in forest area
  - forest degradation
- Biomass map comparison (Uganda case)
- GOFC-GOLD REDD Sourcebook (update)

Source: Romijn, Herold, et al. 2012

Country national forest monitoring capacity gaps



Source: Romijn, Herold, et al. 2012

Technical capabilities of remote sensing sensors for the generation of (national) REDD+ information products

Source: De Sy et al., Herold, Achard, Asner, ..., 2012.
Synergies of multiple remote sensing data sources for REDD+ monitoring.
In:
Current Opinion in Environmental Sustainability

Forest information product	Sensor type						
	Optical/thermal			Radar/SAR		LiDAR	
	Coarse	Medium	Fine	Medium	Fine	Satellite (Large footprint*)	Airborne (Small footprint*)
Forest area change monitoring	light grey	black	black	dark grey	dark grey	white	light grey
Near real-time deforestation detection	dark grey	dark grey	white	light grey	white	white	white
Land use change patterns and tracking of human activities	light grey	black	black	dark grey	light grey	white	white
Forest degradation monitoring	white	dark grey	black	light grey	dark grey	white	dark grey
Monitoring of wildfires and burnt areas	dark grey	dark grey	light grey	light grey	light grey	white	light grey
Biomass mapping	light grey	light grey	dark grey	dark grey	dark grey	dark grey	black
Sub-national hotspot monitoring	light grey	dark grey	black	white	dark grey	white	dark grey
Forest type mapping	white	light grey	black	white	dark grey	white	black

* Footprint is the ground instantaneous field-of-view, which is a measure of the ground area viewed by a single detector element in a given instant in time.

- **black** = very suitable
- **dark grey** = suitable
- **light grey** = contributing
- **white** = limited to no technical capabilities

Operational level of forest information products in REDD+ context

Forest information product	Operational level		
	Local pilot and research studies	Large area research demonstrations	Operational use at national level
Forest area change monitoring			i.e. Brazil, India
Near real-time deforestation detection			only Brazil
Land use change patterns and tracking of human activities			i.e. Indonesia
Forest degradation monitoring			
Monitoring of wildfires and burnt areas			
Biomass mapping			
Sub-national hotspot monitoring			
Forest type mapping			

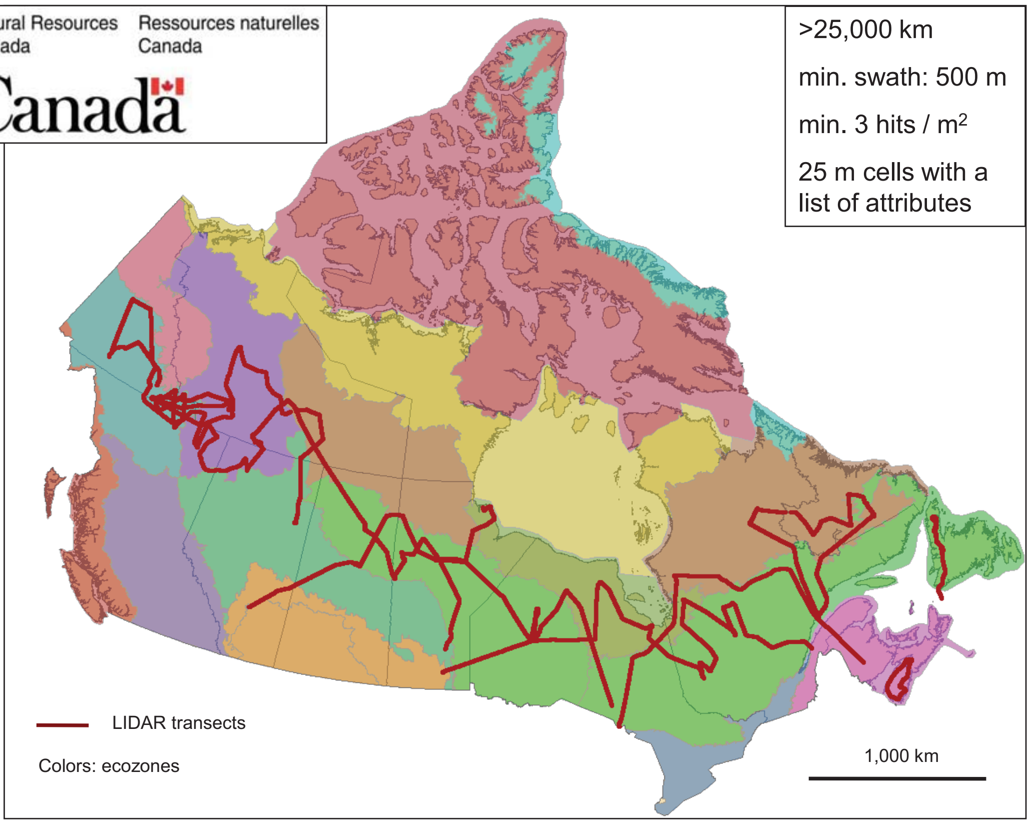
Source: De Sy et al., 2012

WAGENINGEN UR
For quality of life

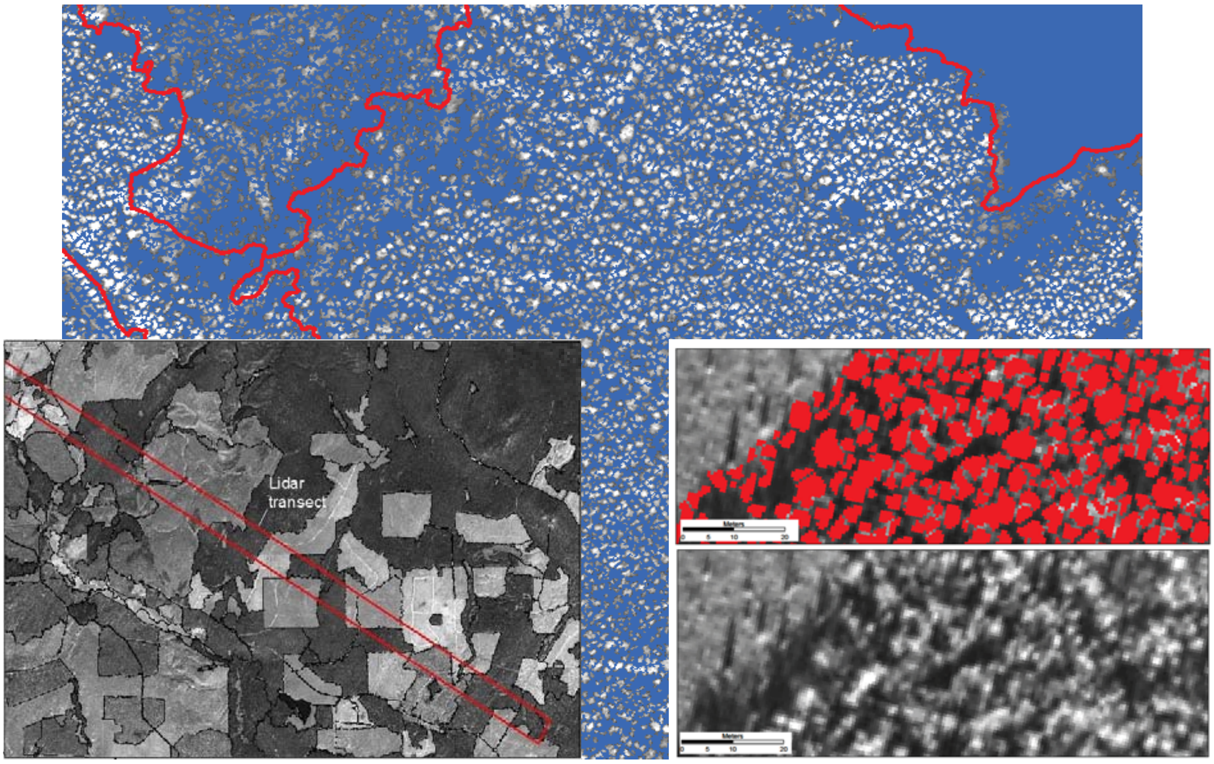
Synergies of RS data: the Canadian example

Natural Resources Canada | Ressources naturelles Canada

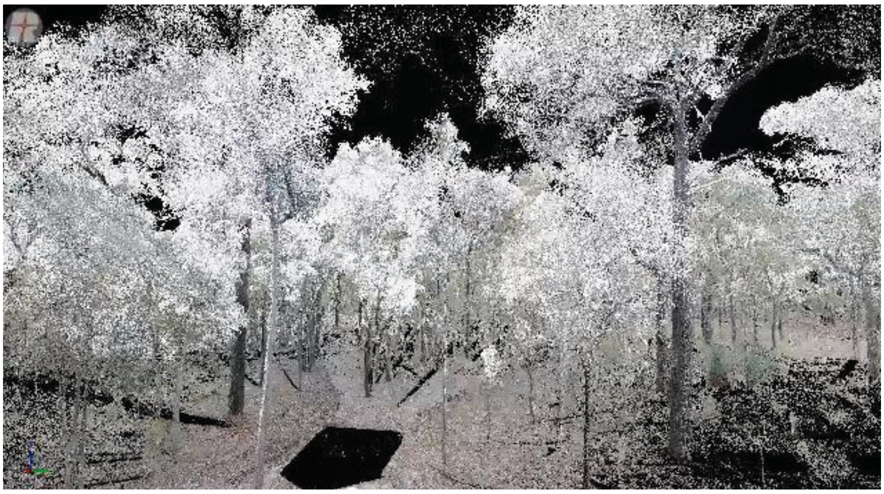
Canada



Synergies of RS data: the Canadian example



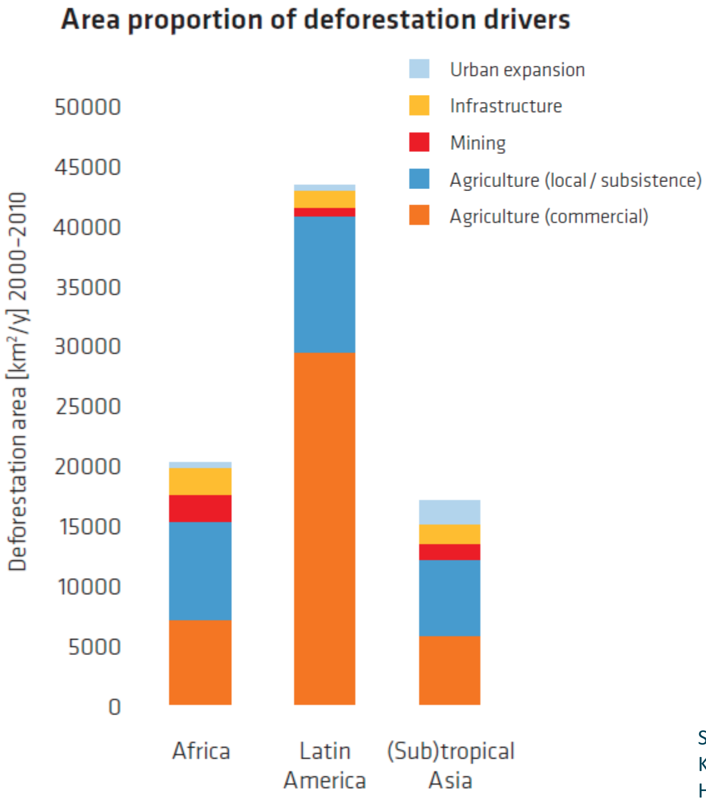
Synergies of RS data: terrestrial Lidar



Animation available online:
http://www.youtube.com/watch?v=1y43jjt5wN0&feature=plcp

WU terrestrial Laser Scanning Research
http://www.grs.wur.nl/UK/Research/Remote+sensing+science/LiDAR/

Monitoring of changes in forest area

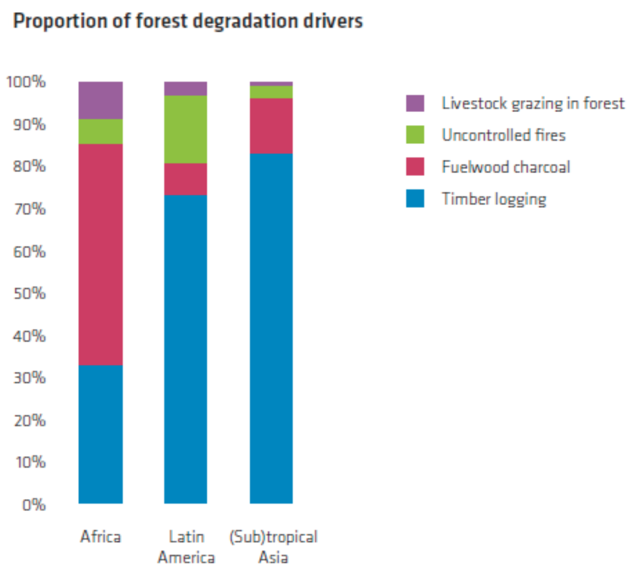


http://www.decc.gov.uk/assets/decc/11/tackling-climate-change/international-climate-change/6316-drivers-deforestation-report.pdf

Sources:
Kissinger et al., 2012
Hosonuma et al., 2012

GOFC-GOLD
Global Observation of Forest Cover and Land Dynamics
Land Cover Project Office

Monitoring of changes in forest area



http://www.decc.gov.uk/assets/decc/11/tackling-climate-change/international-climate-change/6316-drivers-deforestation-report.pdf

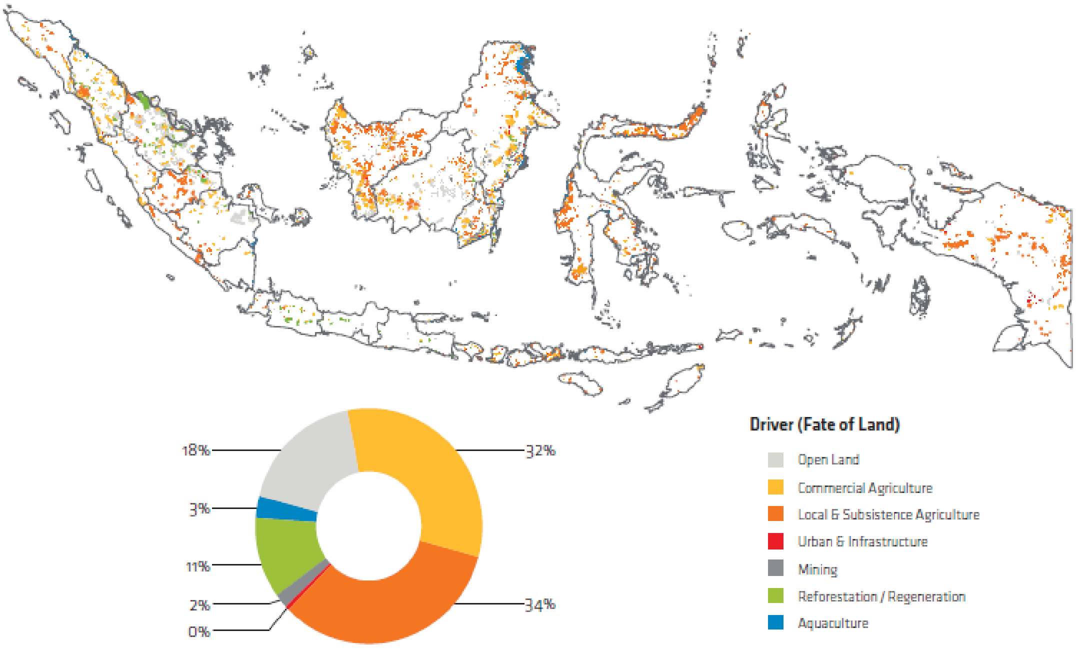
WAGENINGEN UR
For quality of life

Source: Kissinger et al., 2012

GOFC-GOLD
Global Observation of Forest Cover and Land Dynamics
Land Cover Project Office

Monitoring of changes in forest area

Spatial distribution of deforestation areas and its follow-up land use in Indonesia (Landsat data 2000-2009 period)



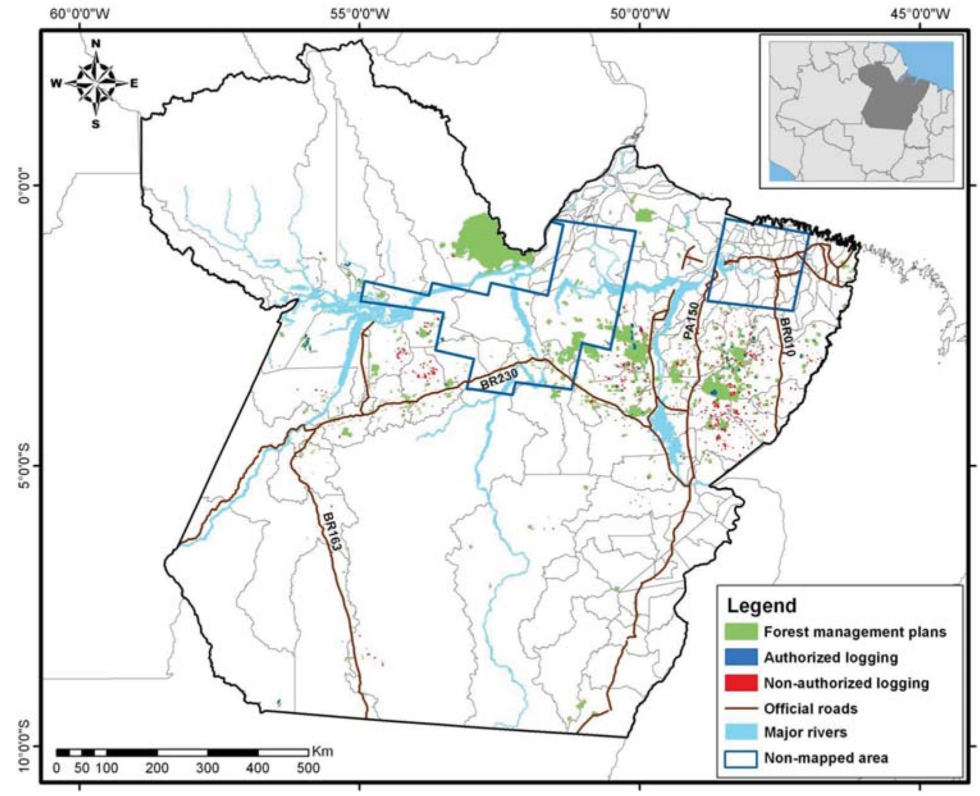
Direct approaches to detect forest degradation

Highly Detectable	Detection limited & increasing data/effort	Detection very limited
• Deforestation • Forest fragmentation • Recent slash-and-burn agriculture • Major canopy fires • Major roads • Conversion to tree monocultures • Hydroelectric dams and other forms of flood disturbances • Large-scale mining	• Selective logging • Forest surface fires • A range of edge-effects • Old-slash-and-burn agriculture • Small scale mining • Unpaved secondary roads (6-20-m wide) • Selective thinning of canopy trees	• Harvesting of most non-timber plants products • Old-mechanized selective logging • Narrow sub-canopy roads (<6-m wide) • Understory thinning and clear cutting • Invasion of exotic species

WAGENINGEN UR For quality of life

(using Landsat-type observations) Peres et al., (2006) TREE

Monitoring of changes in forest area

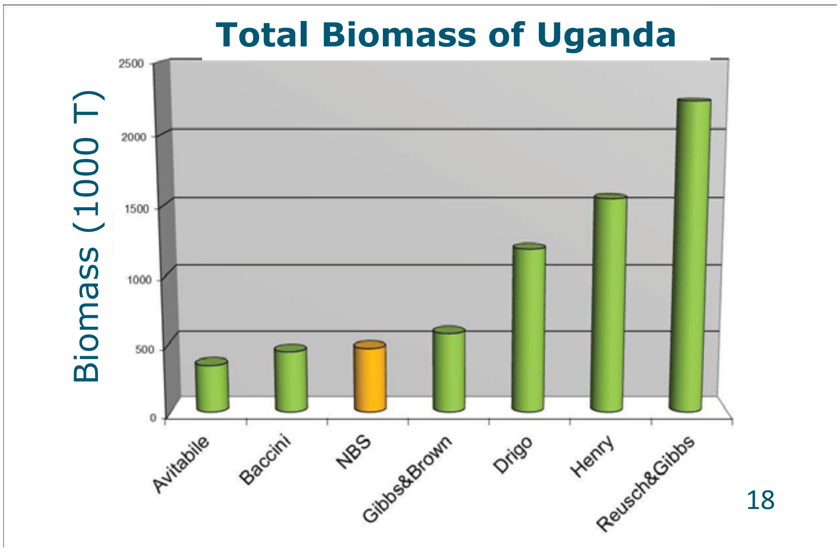


Monteiro, A., Cardoso, D., Conrado, D., Veríssimo, A., & Souza Jr., C. (2011). Boletim Transparência Manejo Florestal Estado do Pará (2009 e 2010) (p. 16). Belém: Imazon.

Biomass maps comparison in Uganda

	Spatial Data	Biomass data	Reference
1.	Landsat	+ Field data *	Avitabile et al., 2012
2.	MODIS	+ Field data *	Baccini et al., 2008
3.	National LC	+ Field data	NBS, 2003 *(Reference map)*
4.	Global LC	+ Biome Av.	Gibbs & Brown, 2007
5.	National LC	+ Biome Av.	Drigo, 2006
6.	Global LC	+ Field data	Henry et al., 2010
7.	Global LC	+ IPCC Tier 1	Reusch & Gibbs, 2008

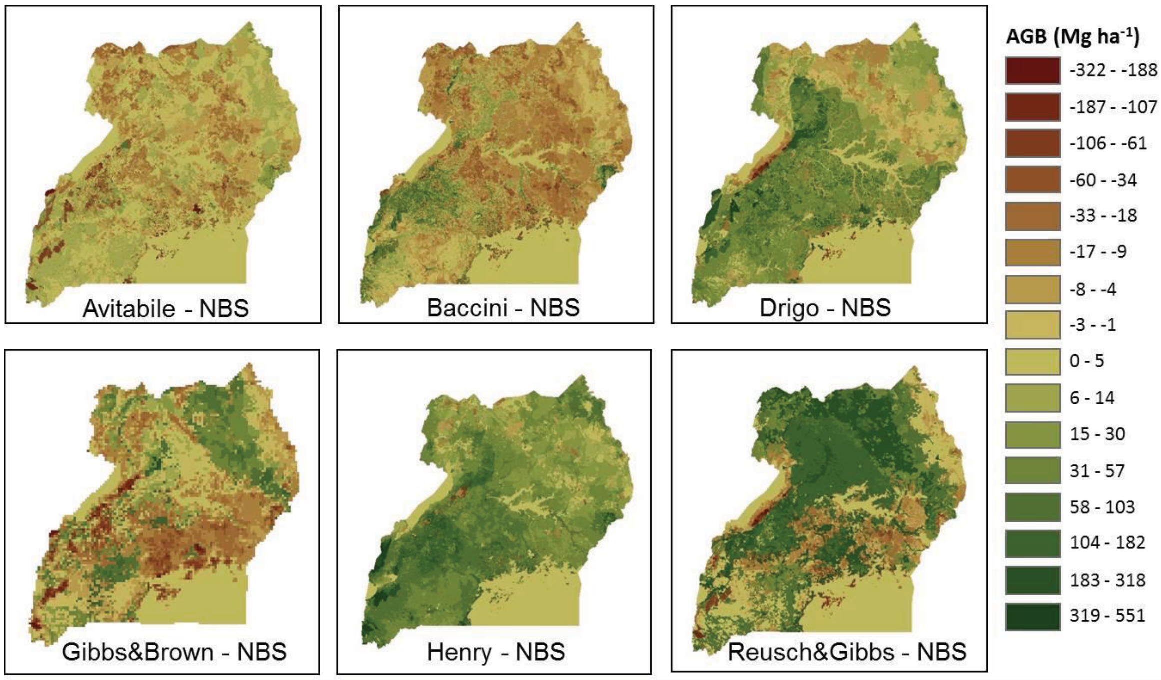
(* = subset of NBS field data)



Avitabile et al., 2011 (CBM)

Biomass maps comparison in Uganda

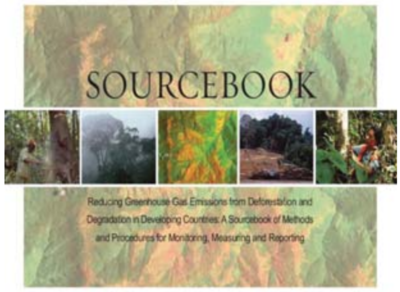
Difference maps (!)



Avitabile et al., 2011 (CBM)

GOFC-GOLD REDD+ Sourcebook updates

Notable sourcebook updates:



- UNFCCC/REDD+ progress
  - negotiation / policy topics
  - new country experiences
- Revise technical sections based on user survey
- Usefulness and presentation
  - training materials (lectures etc.)
  - develop interactivity (web-page, wiki, links)

Sponsors of the Global Terrestrial Observing System

FAO ICSU UNEP UNESCO WMO

Sourcebook authors:

Olivier Arino, Gregory P. Asner, Luigi Boschetti, Barbara Braatz, Emilio Chiuvieco, Ivan Csiszar, Bernardus de Jong, Michael Falkowski, Sandro Federici, Scott Goetz, Nancy Harris, Yasumasa Hirata, Anja A. Hoffman, Hans Joosten, Chris Justice, Josef Kellndorfer, Stephen Kull, Werner Kurz, Eric Lambin, Mike McCall, Suvi Monni, Rebecca Moore, Brice Mora, Erik Næsset, Ross Nelson, Marc Paganini, Tim Pearson, Gary Richards, David Roy, Jeremy Russell-Smith, David Shoch, Florian Siegert, Margaret Skutsch, Allan Spessa, Patrick Van Laake, Michael Wulder

Support for GOFC-GOLD REDD working group :

esa START Canada The Nature Conservancy NASA CSA ASC

Conclusions (1/2)

- Remote sensing is an essential component of monitoring forests for REDD+.
- Many suitable remote sensing sensors available but operational usefulness for REDD+ is often constrained.
  - Coordinated international efforts of the remote sensing community and data providers needed Landsat Data Continuity Mission / Sentinel-2.
  - Countries have confidence investments in building capacity for use of remote sensing forest monitoring will provide long-term benefits under REDD+.
- Transition from remote sensing research to more operational generation of information products on the national level requires additional efforts.
- Research efforts needed to further develop and consolidate appropriate approaches for different national circumstances.
- Remote sensing capacities do exist in developing countries. Further development of technological transfer and capacity development as part of South-South and regional cooperation needed.

Conclusions (2/2)

- Degradation monitoring:
  - less efficient than for deforestation: lower C-emissions per ha versus higher costs & lower accuracies
  - significance of different degradation processes
- Biomass/carbon stock (change) data are essential:
  - a few products suitable for national use
  - largely uncertain in many developing countries
- Need for efficient, effective and equitable solutions integrating different data sources for REDD+ MRV
- GOFC-GOLD REDD+ Sourcebook as a hub
- Next GOFC-GOLD Sourcebook version released for COP18

References

- Asner, G. P., Knapp, D. E., Broadbent, E. N., Oliveira, P. J. C., Keller, M., & Silva, J. N. (2005). Selective logging in the Brazilian Amazon. *Science*, *310*, 480–482.
  http://www.sciencemag.org/content/310/5747/480.full.pdf
- Avitabile, V., Herold, M., Henry, M., & Schmullius, C. (2011). Mapping biomass with remote sensing: a comparison of methods for the case study of Uganda. *Carbon balance and management*, *6*(1), 1–14.
  http://www.cbmjournal.com/content/6/1/7
- De Sy, V., Herold, M., Achard, F., Asner, G. P., Held, A., Kellndorfer, J., & Verbesselt, J. (2012). Synergies of multiple remote sensing data sources for REDD + monitoring. *Current Opinion in Environmental Sustainability*, *4*, 1–11.
  http://dx.doi.org/10.1016/j.cosust.2012.09.013
- GOFC-GOLD. (2011). *A sourcebook of methods and procedures for monitoring and reporting anthropogenic greenhouse gas emissions and removals caused by deforestation, gains and losses of carbon stocks in forests remaining forests, and forestation - Version COP17-1*. *Carbon* (p. 209). Alberta, Canada.
  http://www.gofcgold.wur.nl/redd
- Herold, M., Román-Cuesta, R. M., Mollicone, D., Hirata, Y., Van Laake, P., Asner, G. P., Souza, C., et al. (2011). Options for monitoring and estimating historical carbon emissions from forest degradation in the context of REDD+. *Carbon balance and management*, *6*(13), 1–7. doi:10.1186/1750-0680-6-13
  http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=3233497&tool=pmcentrez&rendertype=abstract
- Kissinger, G., Herold, M., & De Sy, V. (2012). *Drivers of Deforestation and Forest Degradation: A Synthesis Report for REDD+ Policymakers* (p. 26). Vancouver, BC, Canada.
  http://www.decc.gov.uk/assets/decc/11/tackling-climate-change/international-climate-change/6316-drivers-deforestation-report.pdf
- Romijn, E., Herold, M., Kooistra, L., Murdiyarso, D., & Verchot, L. (2012). Assessing capacities of non-Annex I countries for national forest monitoring in the context of REDD+. *Environmental Science & Policy*, *19-20*, 33–48.
  http://www.sciencedirect.com/science/article/pii/S1462901112000202

Thank you

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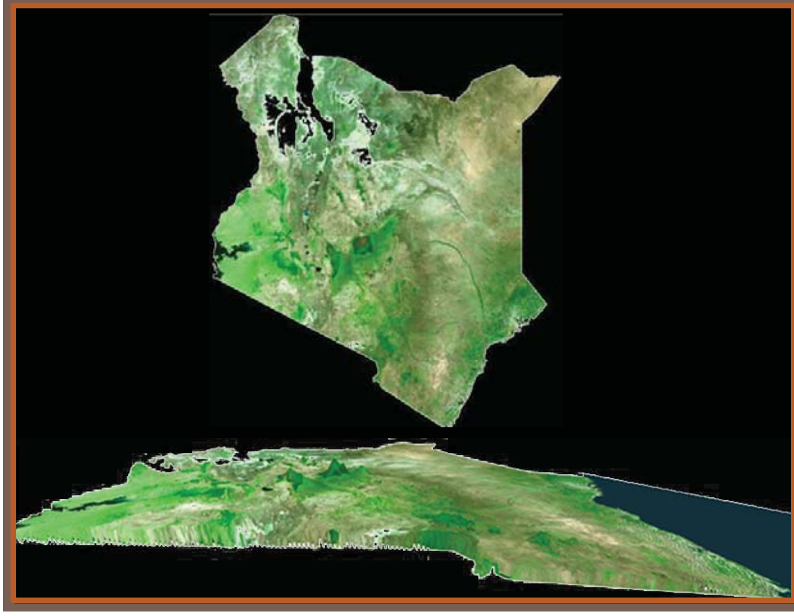
Twitter: @GOFCGOLD_LC

Greenhouse Gas Inventories:

The Case of Land Use, Land Use Change and Forestry (LULUCF) Mapping in Eastern and Southern Africa



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Hayama, Japan
23 – 25 October 2012

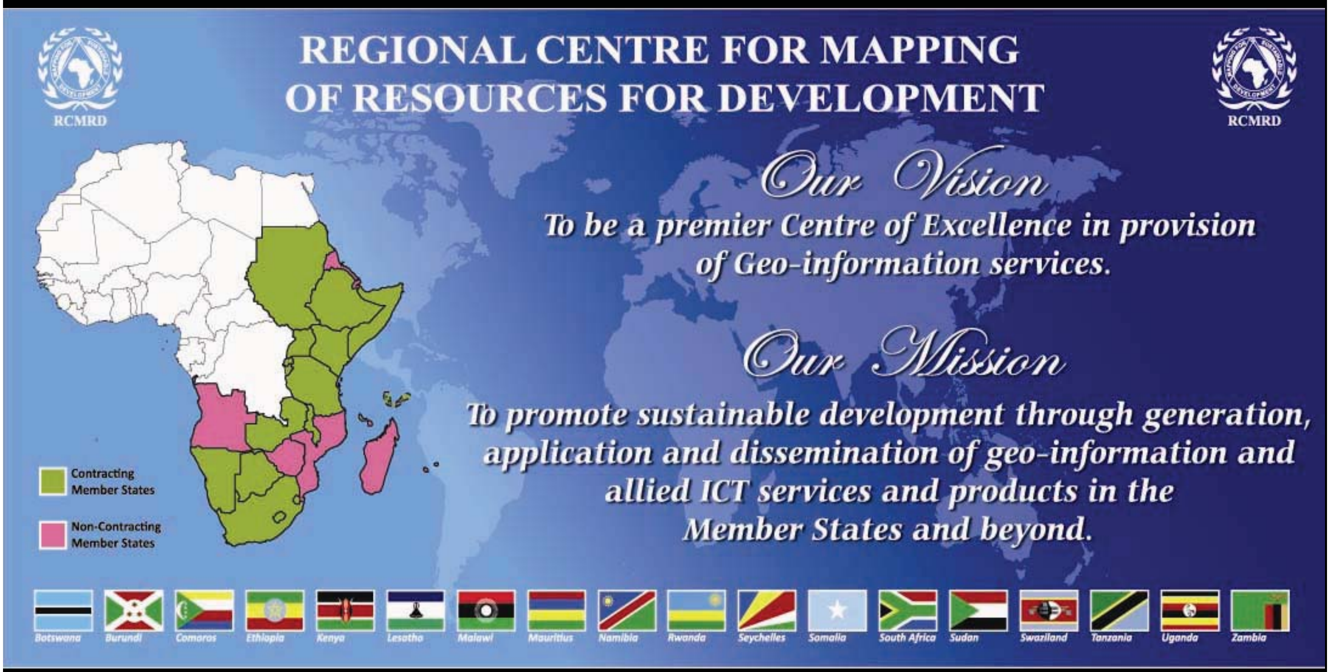
IPCC Expert Meeting:
Role of Remote Sensing in Forest and National GHG Inventories

Presentation Outline

- ❖ **RCMRD:** Who we are
- ❖ **Land Use / Land Cover Mapping:** Sampling the RCMRD Menu
- ❖ **GHG Inventories:** LULUCF Mapping in Eastern and Southern Africa Region
- ❖ **Looking Ahead:** Challenges and Opportunities

1. RCMRD: Who we are

- Based in Nairobi, Kenya
- An inter-governmental organization established in 1975 under the auspices of the Organization of African Unity (OAU), now African Union (AU) and the United Nations Economic Commission of Africa (UNECA)



Key Services

- ❖ Resource Mapping using Geo-Information technologies (GIS, Remote Sensing, GPS)
- ❖ Training in modern Geo-information technologies and applications and in Information and Communication Technologies (ICTs)
- ❖ Advisory and consultancy services in our areas of specialization
- ❖ Servicing and maintenance of surveying and mapping equipment

Management Structure

Conference of Ministers
Ministers responsible for Lands / Environment

↓

Governing Council
Permanent / Principle Secretaries responsible for Lands / Environment

↓

Technical Committee
Surveyor Generals

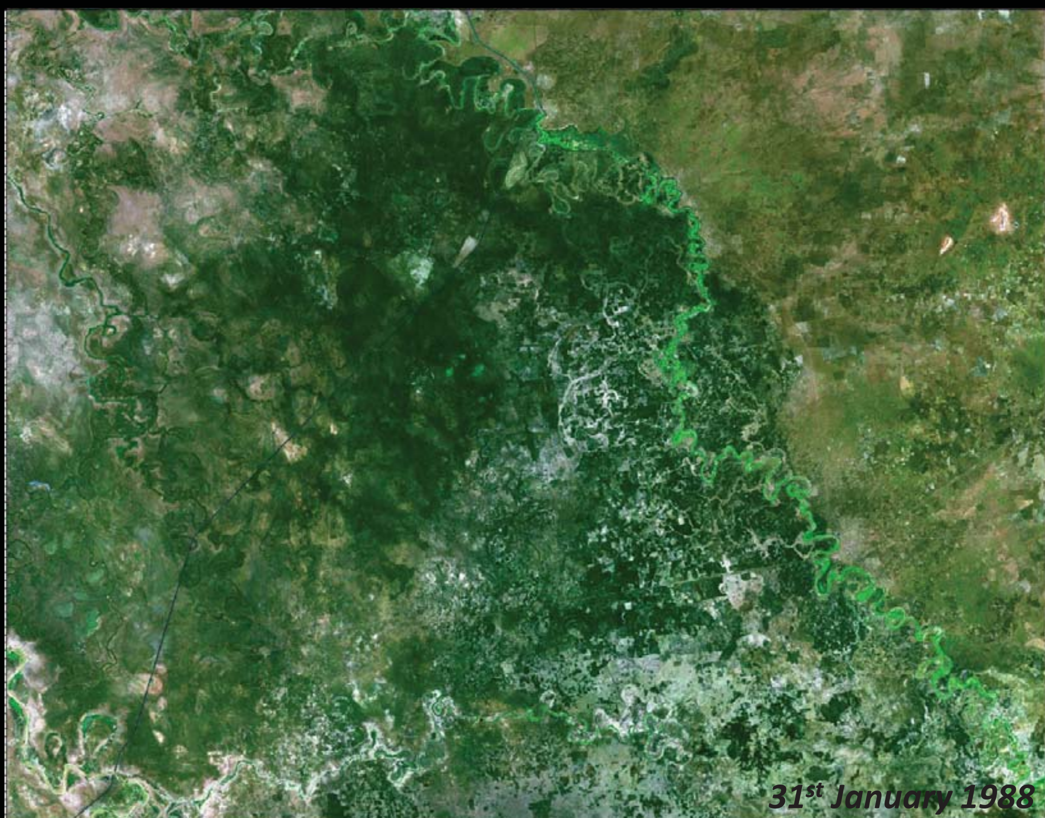
↓

Director General

2. Land Use / Land Cover Mapping: Sampling the RCMRD Menu

- **FAO Africover Project:** LC mapped for10 countries; Burundi, DR Congo, Egypt, Eritrea, Kenya, Rwanda, Somalia, Sudan, Tanzania and Uganda
- **Land use / Land Cover Mapping and Change Detection of South Kordofan, Sudan;** undertaken under the Range Management Strategy Study and Khor Abu Habil Catchments Basins Planning and Water Development Study
- **Mapping Gums and Allied Dryland Resources in Karamoja, Uganda:** A Presidential Initiative that helped alleviate poverty and conflict in Karamoja
- **Rehad River and Barrage Pond Mapping, Sudan:** A project that showed the increasing pressure on water resources due to agricultural expansion
- **Resource and Pastoral Mobility Mapping, Northern Kenya:** A project that supported Drought Risk Reduction
- **Land Degradation and Natural Habitat Conservation, GHA:** Implemented under the AMESD program
- **Forest Restoration Strategy, Mau Forest, Kenya:** A project that mapped Forest Cover Change and provided a strategic approach for Forest Cover Restoration
- **Climate Change Implications on Agriculture:** The case of Baringo, Kenya

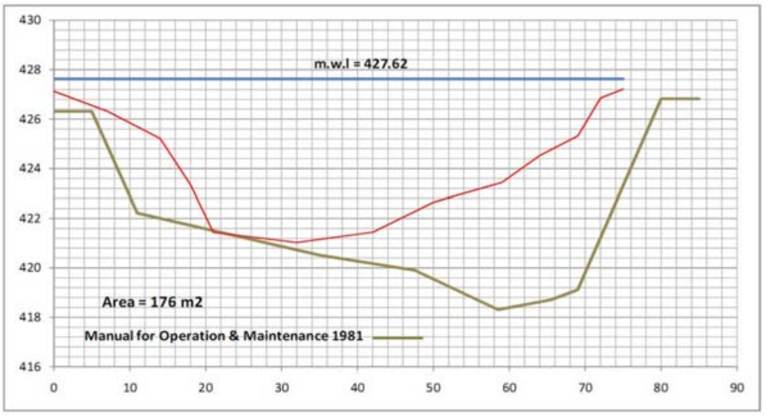
Rehad Driver and Barrage Pond Mapping, Sudan



Cross Section Of Pond kilo 3+500

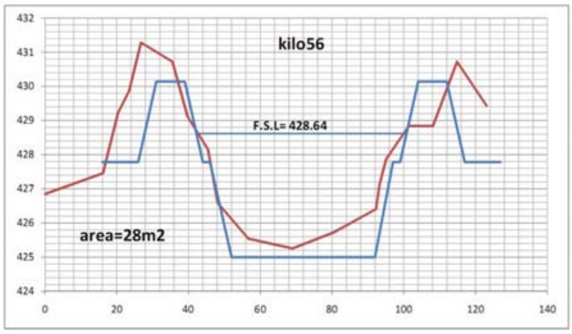
distance	reduced level
0	427.12
7	426.32
14	425.21
18	423.33
21	421.43
32	421.03
42	421.45
50	422.65
59	423.43
64	424.52
69	425.32
72	426.85
75	427.21

EASTING	NORTHING
656535	1511506



Cross-Section of the Canal at Kilo56

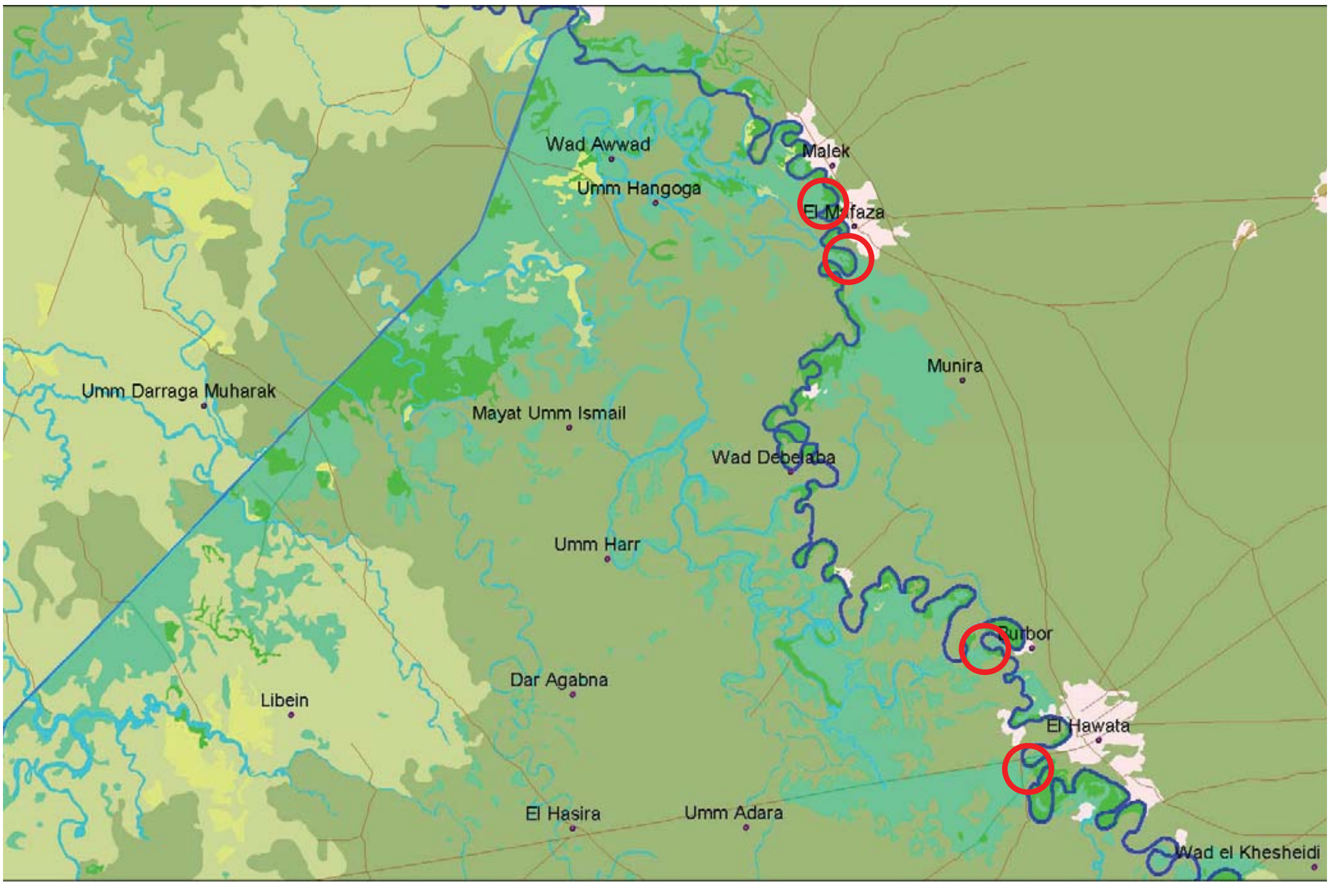
dist	Elev	Km56
0	426.845	0
16.17	427.457	1
20.27	429.193	2
23.43	429.848	3
26.79	431.278	4
35.51	430.717	5
39.73	429.116	6
45.42	428.155	7
48.11	426.593	8
56.63	425.548	9
69.01	425.257	10
80.52	425.725	11
92.27	426.41	12
93.28	427.136	13
95.09	427.873	14
101.43	428.837	15
108.13	428.839	16
114.82	430.72	17
123.06	429.429	18



killo56

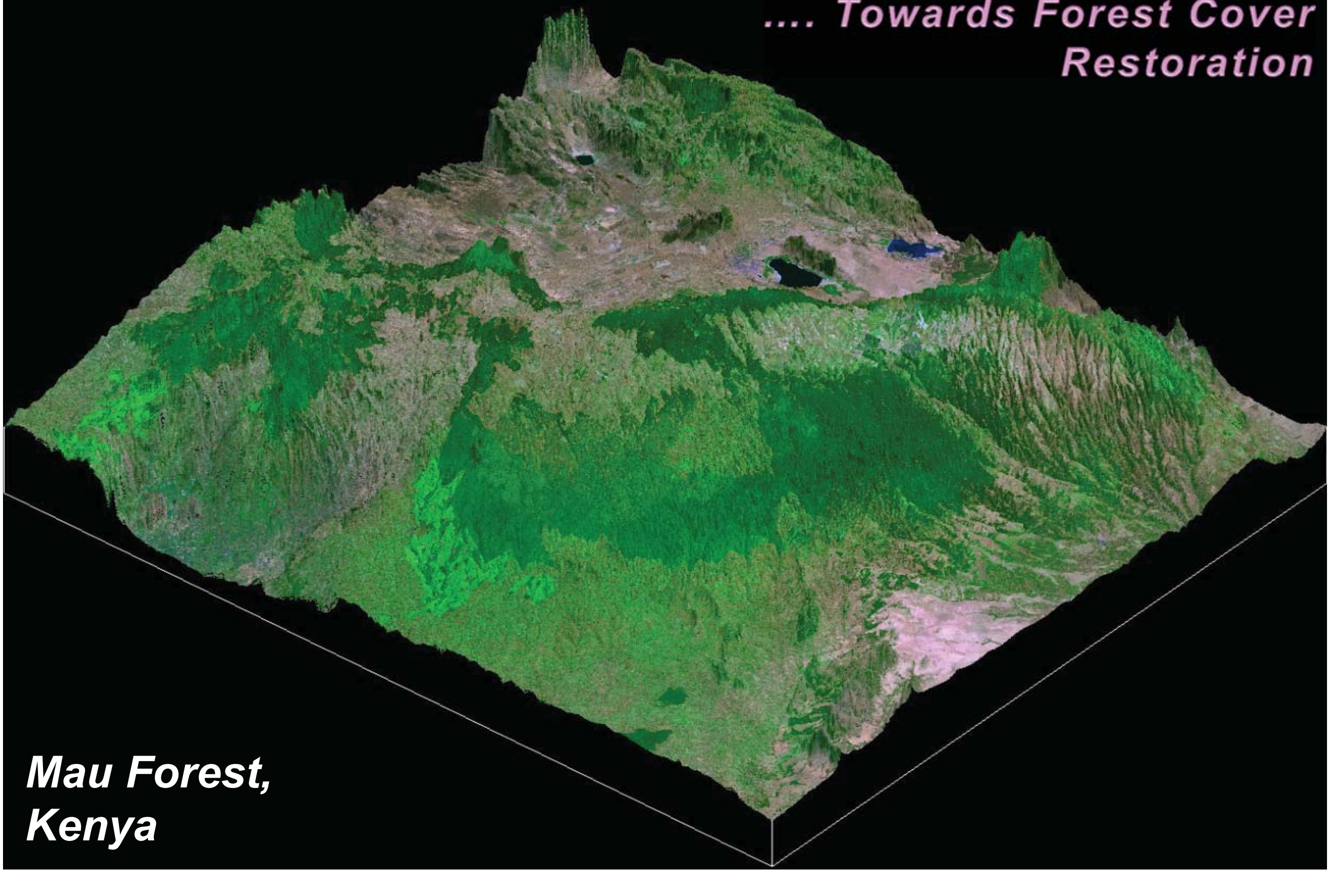
distance	reduse level
0	427.79
10	427.79
15	430.14
23	430.14
28	427.79
30	427.79
36	425
76	425
81	427.79
83	427.79
88	430.14
96	430.14
101	427.79
111	427.79

Illegal Breakage Points By Upstream Farmers

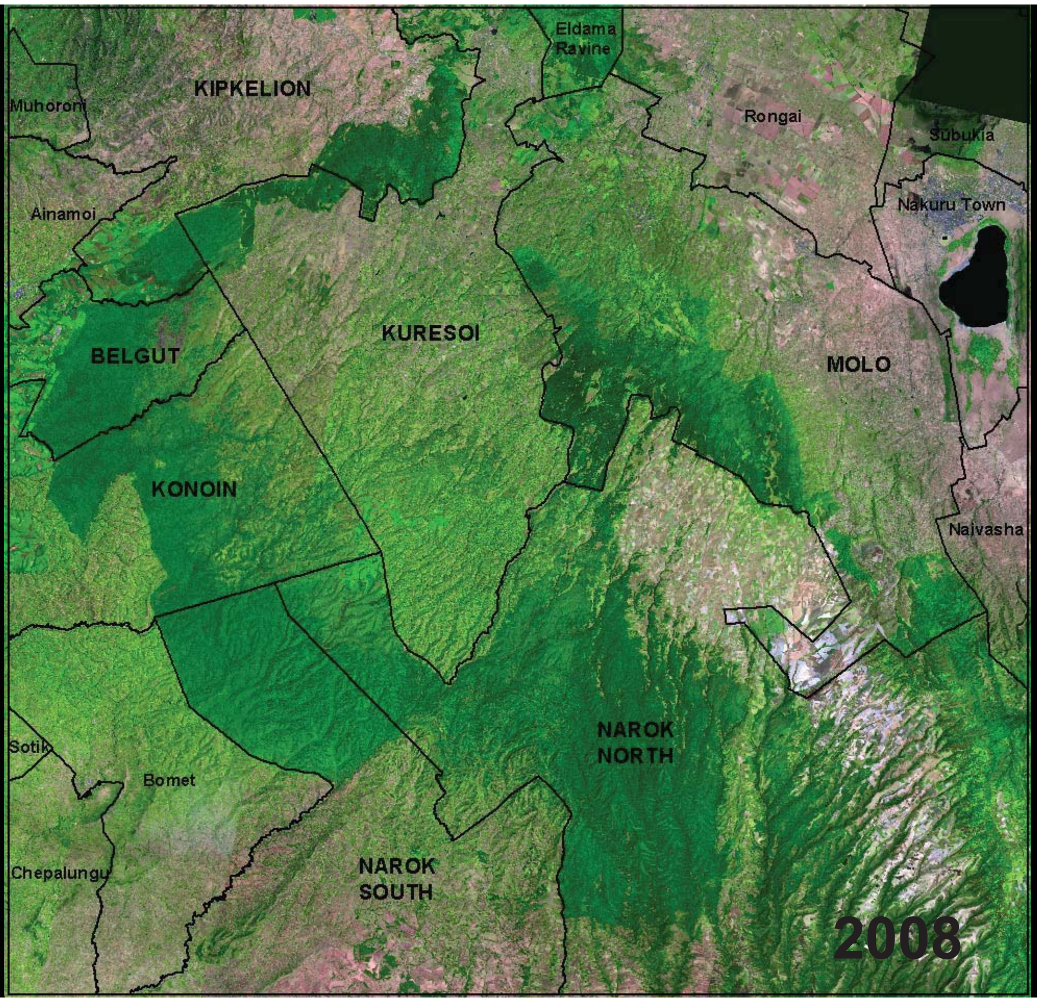


Land use / Land Cover Change

.... Towards Forest Cover Restoration

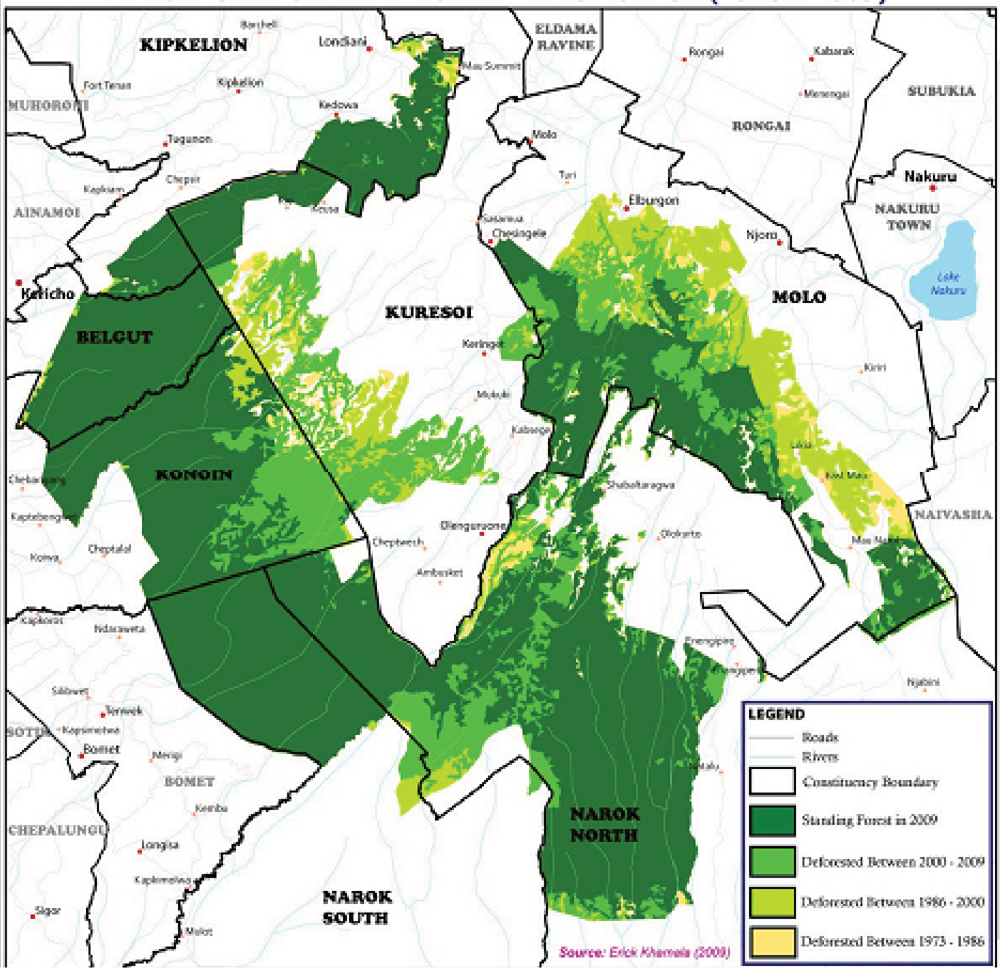


Historical Assessment of Deforestation



The path the Mau has come!

DEFORESTATION TREND OF THE MAU FOREST (1973 - 2009)



Strategic Approach Towards Restoration

Total land to be reforested will be as follows:

Phase 1: 53,376

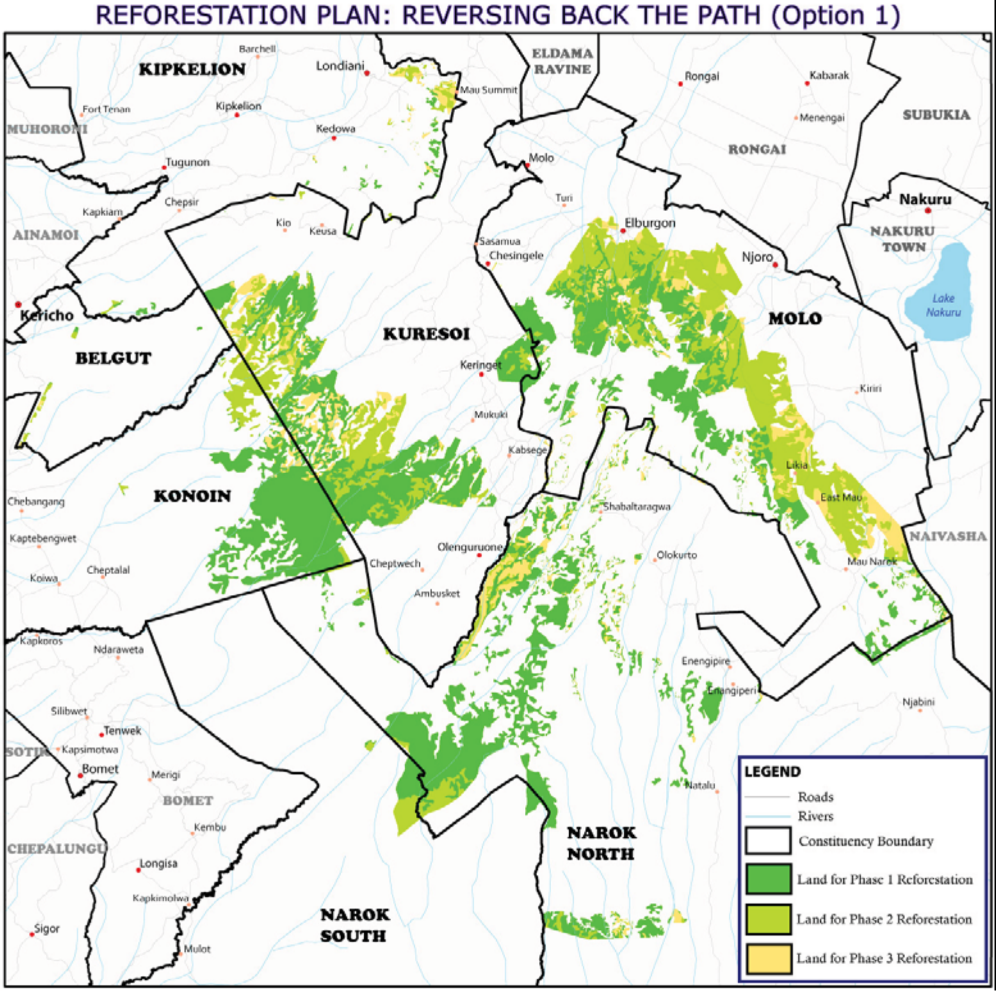
Phase 2: 28,828

Phase 3: 10,635

TOTAL: 92,839

(Area in Hectares)

REFORESTATION PLAN: REVERSING BACK THE PATH (Option 1)



Strategic Approach Towards Restoration

Total land to be reforested will be as follows:

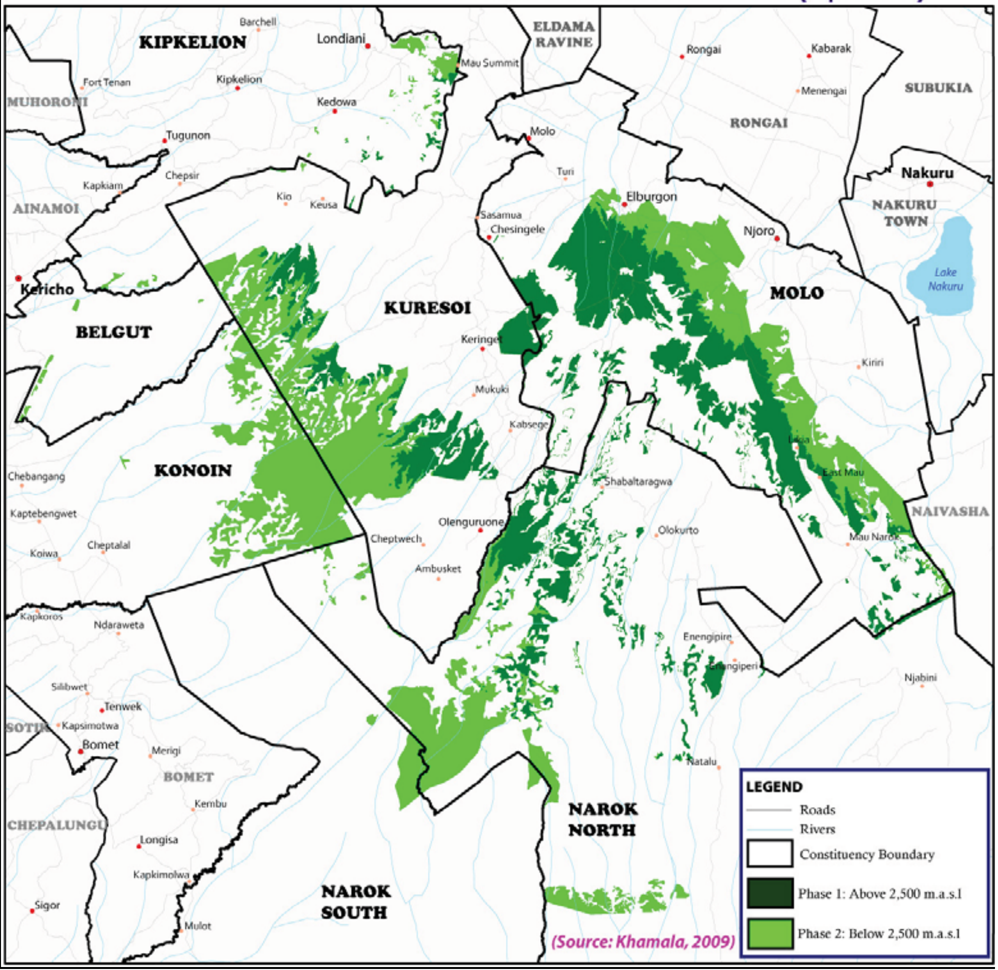
Phase 1: 39,571

Phase 2: 53,269

TOTAL: 92,840

(Area in Hectares)

REFORESTATION PLAN: USING ELEVATION AS CRITERIA (Option 2)



Strategic Approach Towards Restoration

Total land to be reforested will be as follows:

Phase 1: 62,688

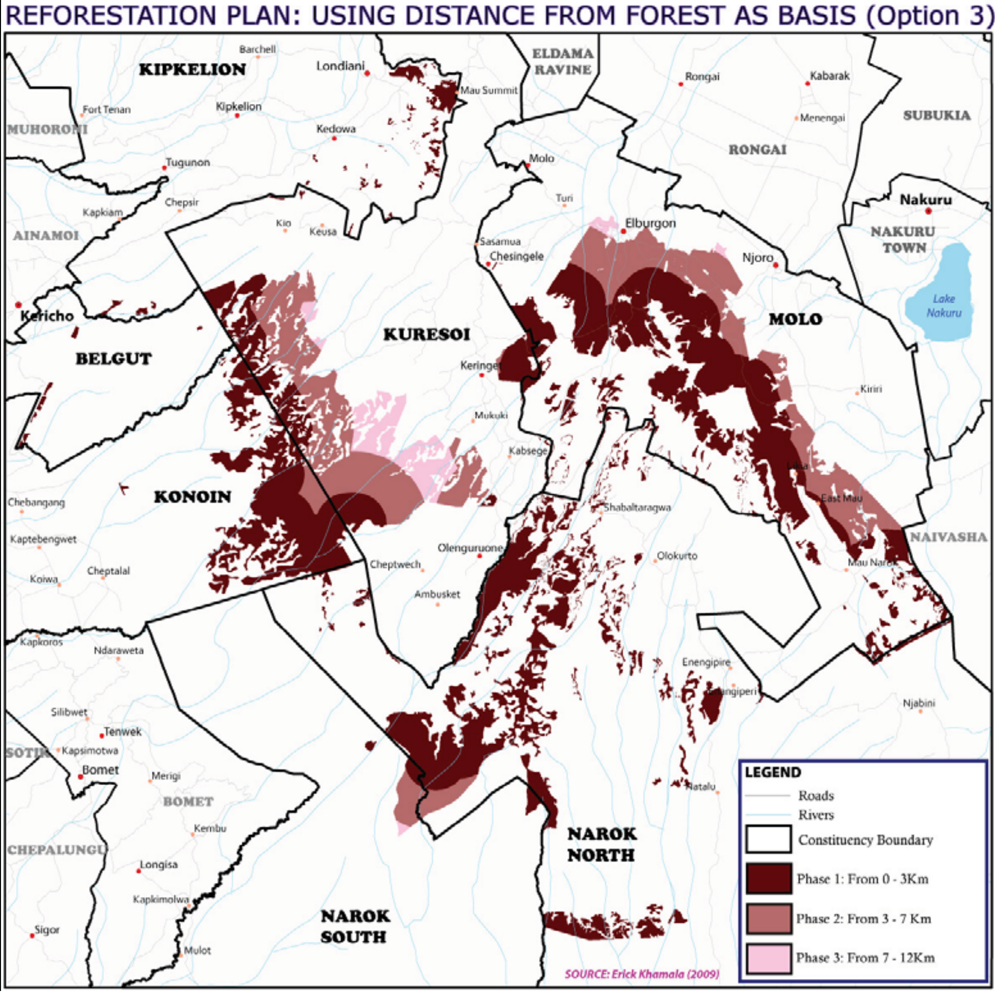
Phase 2: 25,711

Phase 3: 4,441

TOTAL: 92,840

(Area in Hectares)

REFORESTATION PLAN: USING DISTANCE FROM FOREST AS BASIS (Option 3)



Budget Options for Each Option

Option 1: Reversing back the Path:

- Phase 1: Ksh. 7,472,640,000
- Phase 2: Ksh. 4,035,920,000
- Phase 3: Ksh. 1,488,900,000

Option 2: Using Elevation as Criteria:

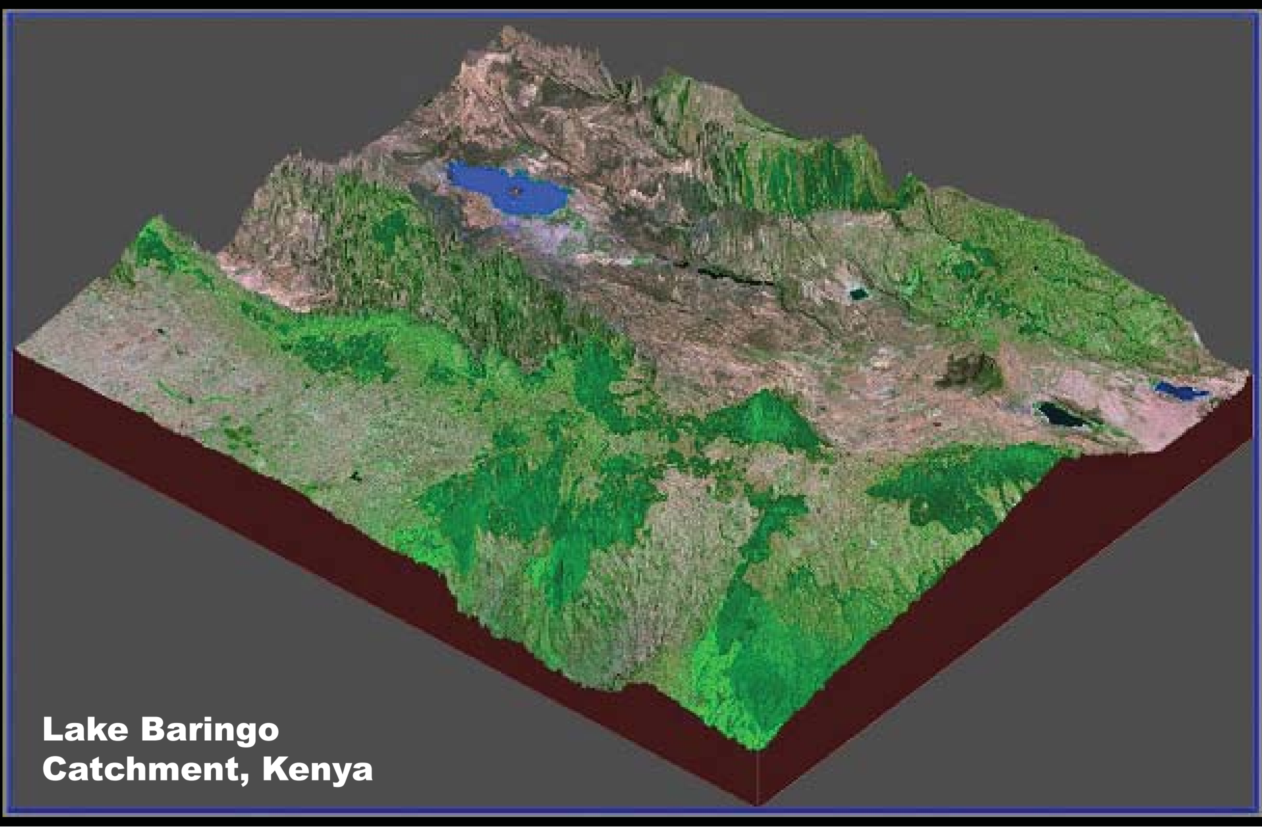
- Phase 1: Ksh. 5,539,940,000
- Phase 2: Ksh. 7,457,660,000

Option 3: Using Proximity to Current Forest as Criteria:

- Phase 1: Ksh. 8,776,320,000
- Phase 2: Ksh. 3,599,540,000
- Phase 3: Ksh. 621,740,000

Climate Change

..... implications to agriculture



Lake Baringo Catchment, Kenya

Past, Current and Future Deforestation

1973

1986

2009

(Kenya's Vision 2030) 2030

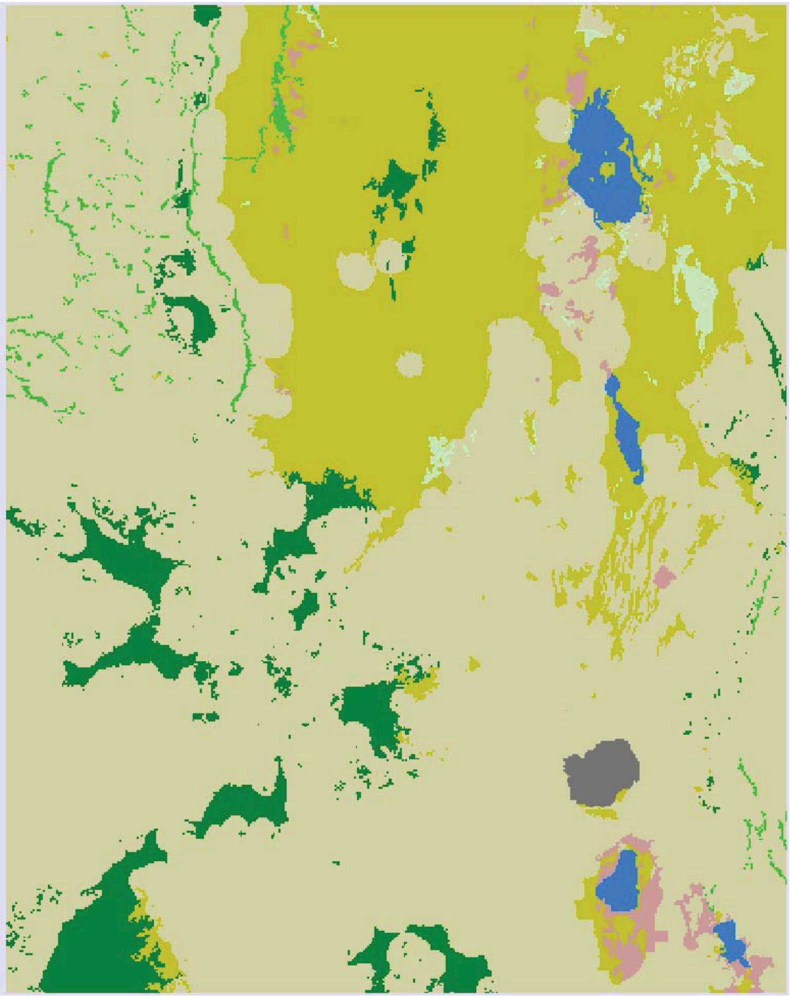
2050

2080

LEGEND

- Bare
- Anthropogenic Disturbances
- Crater
- Forest
- Grassland
- Lake
- Open to Closed Shrubs
- Riverine Vegetation

**If factors were to remain constant*



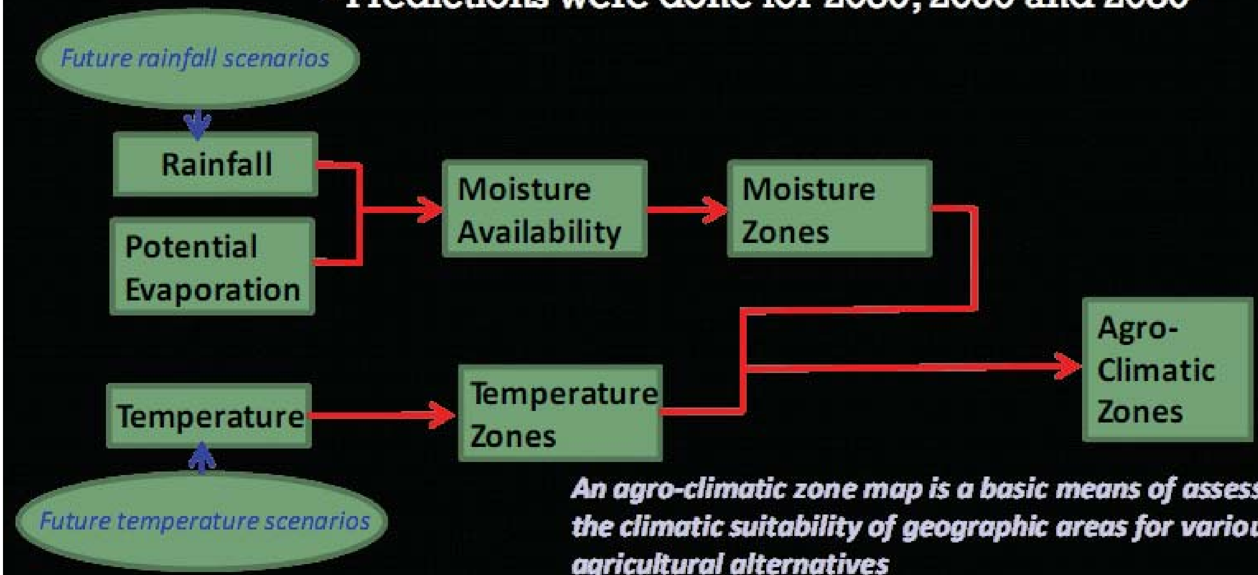
Historical and Future Land Use / Land Cover Change Analysis

LULC Class	1973	1986	2009	2030	2050	2080
Bare	513.2611112	317.0562656	224.4623801	224.4623801	224.4623801	223.6213821
Anthropogenic Disturbances	7114.759421	7675.957421	8794.73713	9747.756123	10486.74111	11073.92595
Crater	81.9973101	84.2680048	84.2680048	84.2680048	84.2680048	84.2680048
Forest	3124.644163	2782.442055	2206.44249	1699.236564	1343.578488	1221.633771
Grassland	535.6316594	374.748732	289.2192301	208.2311177	180.3940822	168.9565087
Lake	251.9630164	231.863163	235.2271552	235.2271552	235.2271552	235.2271552
Open to Closed Shrubs	5869.745905	6045.934997	5669.924768	5305.099813	4949.862235	4498.75088
Riverine Vegetation	135.6529858	115.4690326	123.4585141	123.4585141	123.2062146	121.3560189

Area in Km^2

Understanding Future Climate Change Trends and their implications to Agriculture

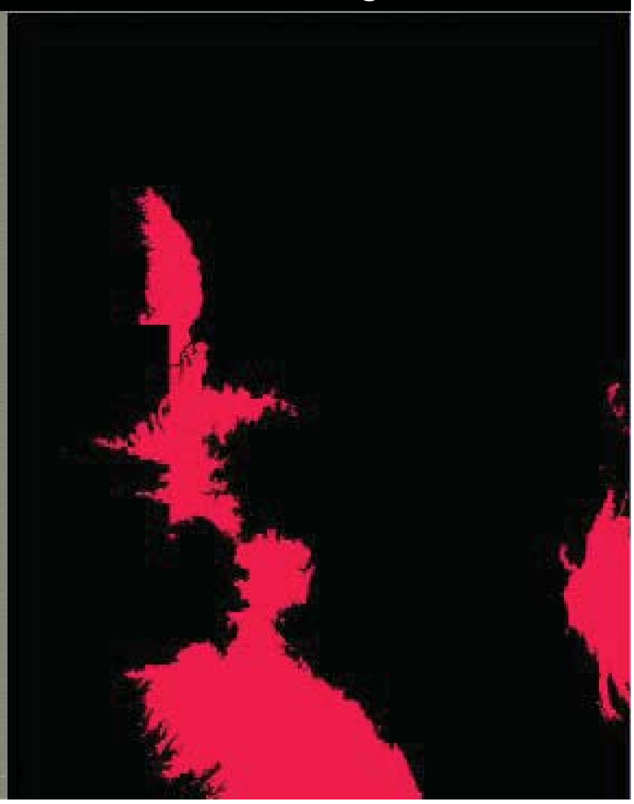
- Climate change scenarios were modeled as follows:
  - Current agricultural suitability analysis
  - Future agricultural suitability analysis based on precipitation and temperature trends
  - Predictions were done for 2030, 2050 and 2080



An agro-climatic zone map is a basic means of assessing the climatic suitability of geographic areas for various agricultural alternatives

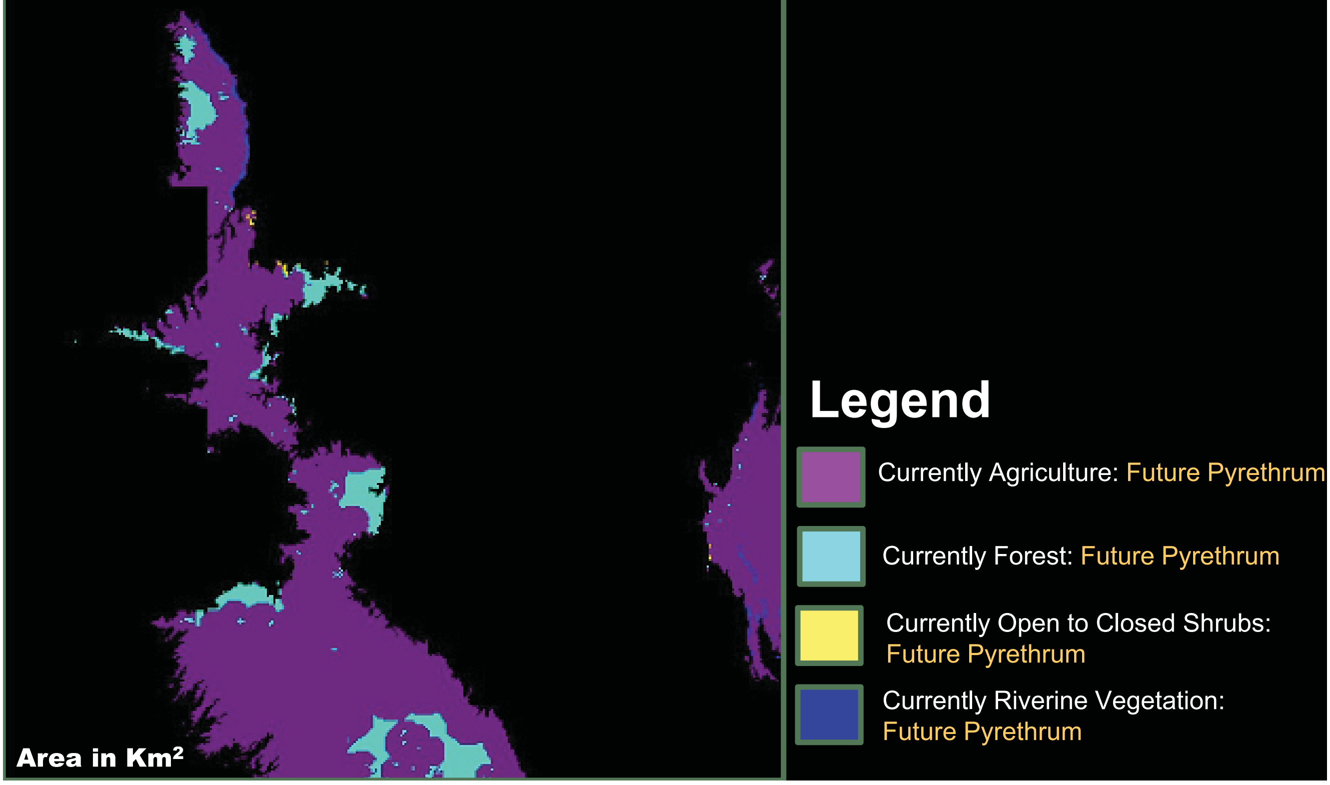
Current Potential Pyrethrum Growing Areas

Future Potential Pyrethrum Growing Area



Area in Square Kilometers in 2080

2053.5538000 Agriculture and Pyrethrum
230.1817000 Forest and Pyrethrum
2.5230000 Open to Closed Shrubs and Pyrethrum
20.2681000 Riverine Vegetation and Pyrethrum



HARNESSING NATURAL RESOURCES TO ALLEVIATE POVERTY AND CIVIL CONFLICT:

Developing the Gum Arabic and Allied Dryland Resources Sub-Sector in Karamoja Region of Uganda

Alternative Resources in Karamoja Region

Gum arabic

❖ is used primarily in the food industry as a stabilizer such as in the soft drinks industry (Coca Cola, etc)

Aloe

❖ Health products help rebuild human skin, hair and digestive health

Other dryland resources

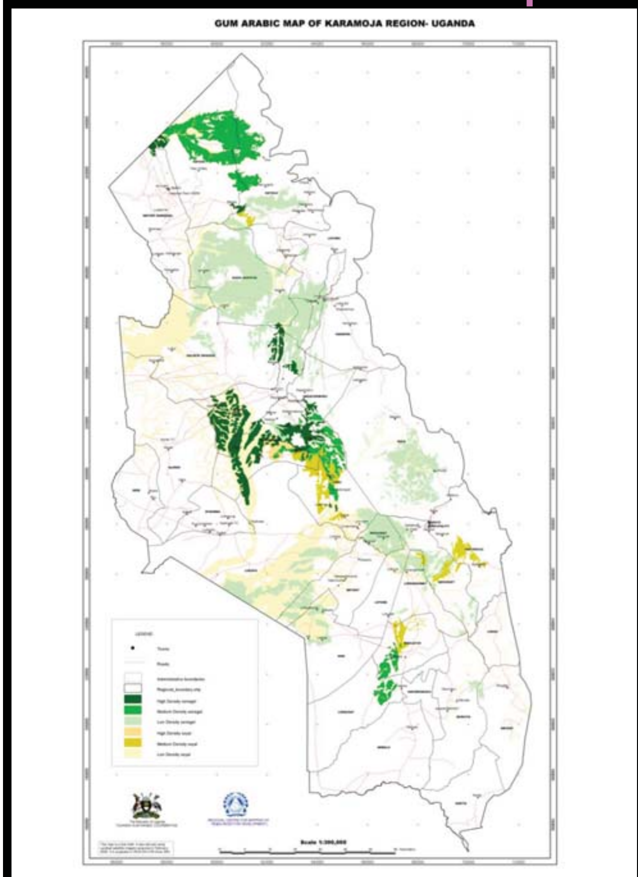
❖ Saddlewood – cosmetic industry

❖ Shea tree – shea nut butter

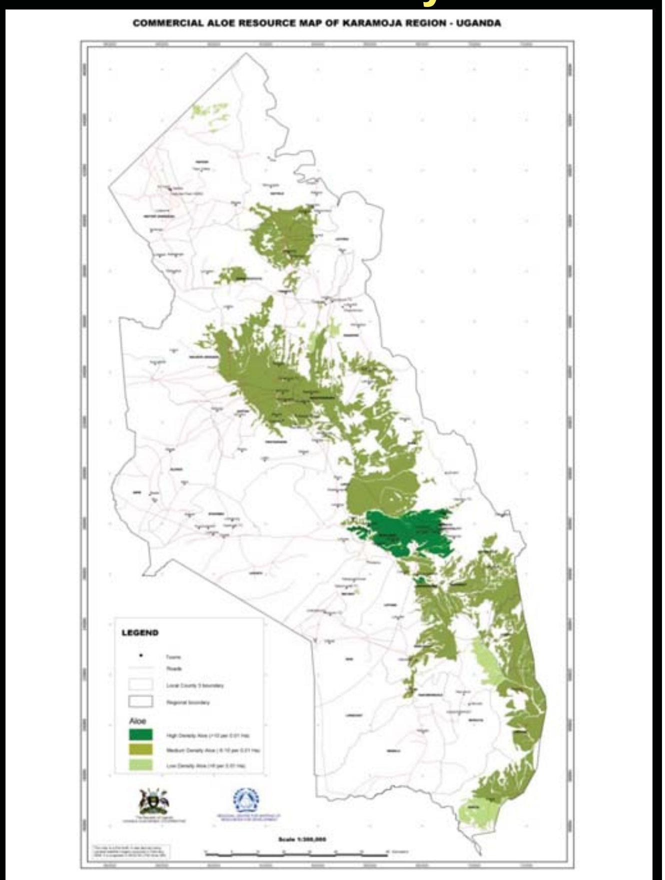
❖ Amarula – Amarula wine

Natural "plantation" of Aloe

Resource Maps: Distribution and Density



Gum Arabic



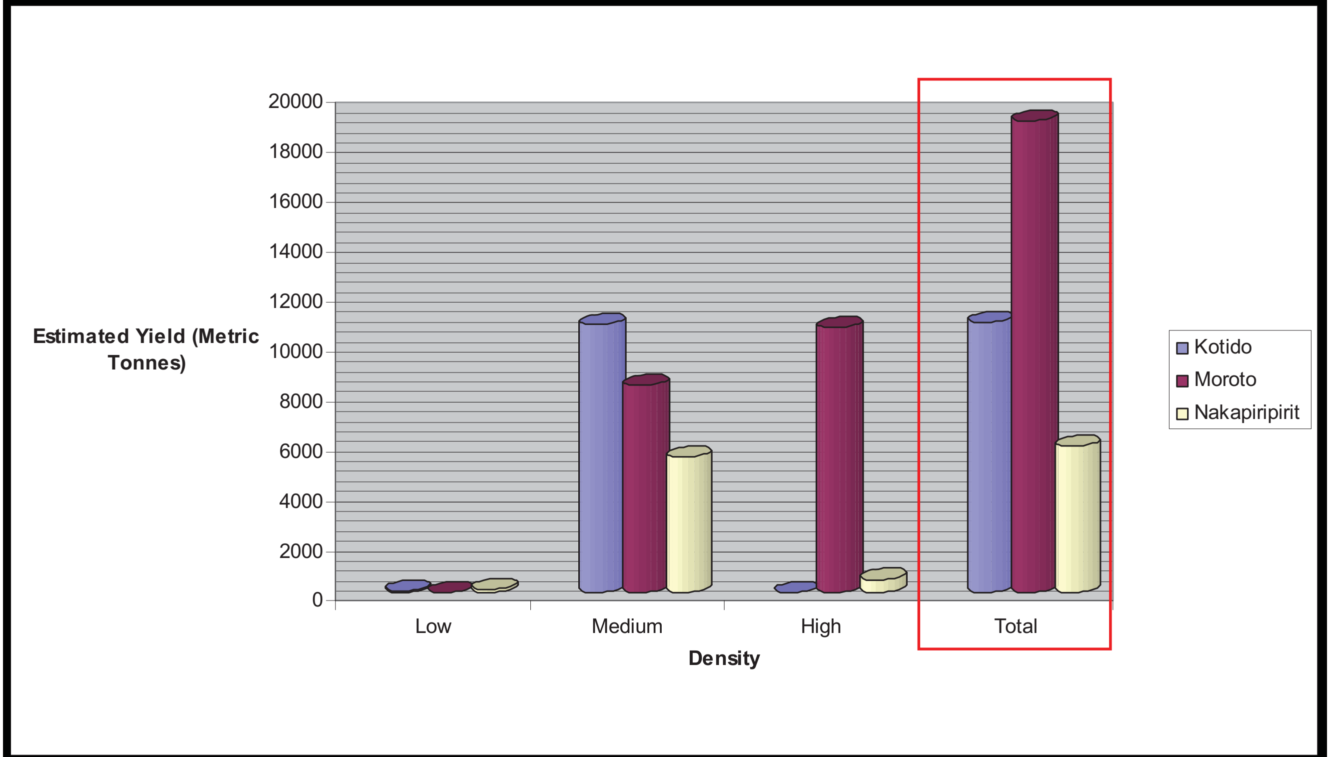
Aloe

Measuring Production

Aloe Yield Estimation

DISTRICT	Density Class	Mean Density (ha)	Area (ha)	Population (stems)	Estimated Yield (MT)
Kotido	Low	700.00	8,295.98	1,451,797	72.59
	Medium	2,363.00	182,529.69	215,658,829	10,782.94
	High	4,600.00	35.00	120,750	6.04
Subtotal			190,825.67	217,231,376	10,861.57
Moroto	Low	700.00	324.52	56,791	2.84
	Medium	2,367.00	140,622.87	166,427,167	8,321.36
	High	6,300.00	45,009.33	212,669,084	10,633.65
Subtotal			185,956.71	379,153,042	18,957.65
Nakapiripirit	Low	700.00	14715.08	2,575,140	128.76
	Medium	1,863.00	116690.95	108,697,620	5,434.88
	High	6,033.00	2352.80	10,645,832	532.29
Subtotal			133,758.83	121,918,592	5,868.45
TOTAL			**510,541.21**	**718,303,010**	**35,915.15**

Estimated Yield for Aloe



Total yield of Aloe in Karamoja Region = **35,915.15 metric tonnes**

3. GHG Inventories:

LULUCF Mapping in Eastern & Southern Africa Region

❖ RCMRD is implementing TWO MAJOR PROGRAMS:

- **LULUCF Mapping for Kenya:** Under the Forest Preservation Program being implemented via the Japanese Grant Aid to the Republic of Kenya.
  Implementers: Pasco Corporation (Japan), RCMRD, Government of Kenya (Kenya Forest Service and the Department of Resource Surveys and Remote Sensing)

- **Eastern and Southern Africa Land Cover Mapping for GHG Inventories:** Funded by USAID
  Implementers: RCMRD, EPA (USA)

❖ Both programs commenced on 1st March 2012

Approach

❖ **Multi-institutional:**
- North – South partnership
- Partnership with Government Agencies

❖ **Use of Earth Observation Data:**
- Three epochs high resolution EO data (1990, 2000, 2010)
- Incorporates use of existing ancillary data and field data

❖ **Capacity development:**
- On-the-job training of nationals in the mapping methodology

❖ **Consultative process:**
- National stakeholder engagement

Methodology

❖ Satellite image processing:

- Image quality assessment
- Re-projection
- Ortho-rectification

❖ National consultations

- To agree on classification scheme and definition of classes
- Collect existing ancillary data
- Establish networks with countries

❖ Image classification:

- Using 6 IPCC classes (Forest land, Cropland, Grassland, Wetland, Settlement, Other land) at details agreed with each country
- Preliminary image interpretation for each epoch (on-screen digitization / segmentation / supervised classification)
- Ground truthing fieldwork
- Final image interpretation
- Accuracy assessment
- Change detection
- Statistics derivation
- Cartographic design and draft final map compilation
- Internal quality check at all stages of image classification

❖ Draft final products preparation:

- Three-epoch land use maps (1990, 2000, 2010)
- Change maps (1990 – 2000, 2000 – 2010, 1990 – 2010)
- Land use and land use change statistics
- Procedure manual
- Project Report

❖ Stakeholder engagement:

- National mapping agencies (quality control throughout the mapping process)
- National stakeholders engagement on final products

❖ Final products preparation and submission:

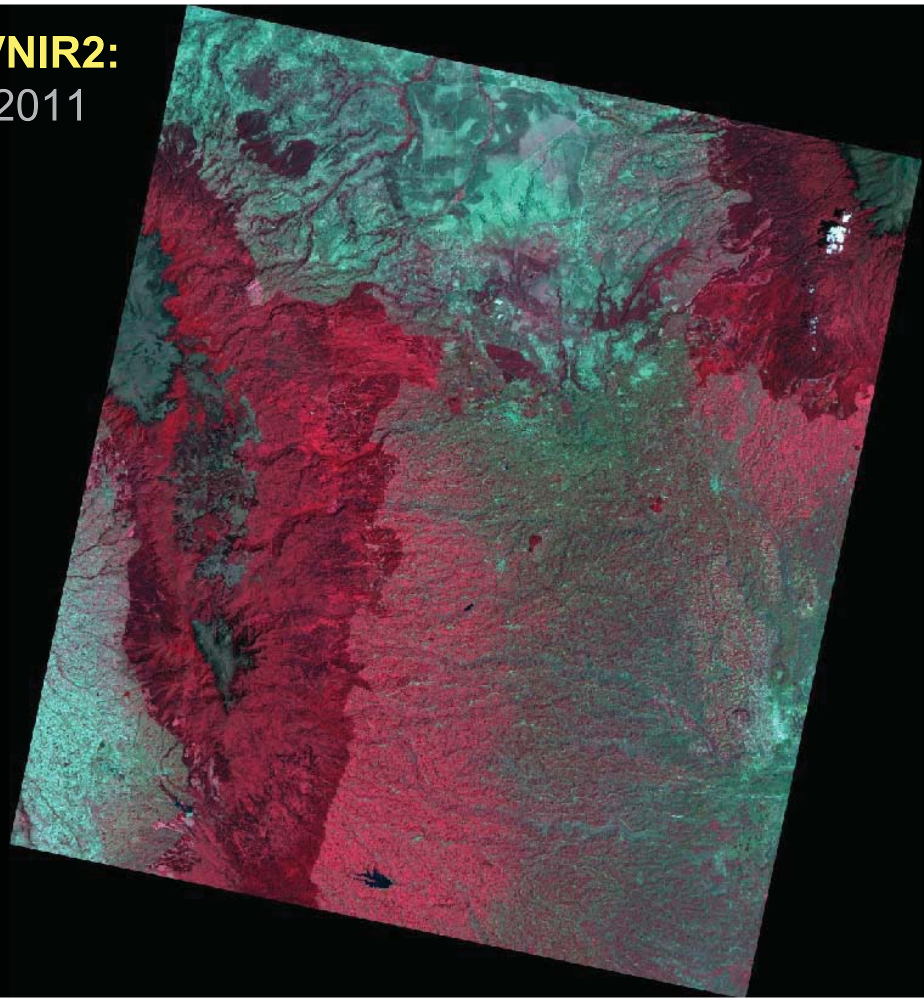
- Three-epoch land use maps (1990, 2000, 2010)
- Change maps (1990 – 2000, 2000 – 2010, 1990 – 2010)
- Land use and land use change statistics
- Procedure manual
- Project data and metadata
- Project Report

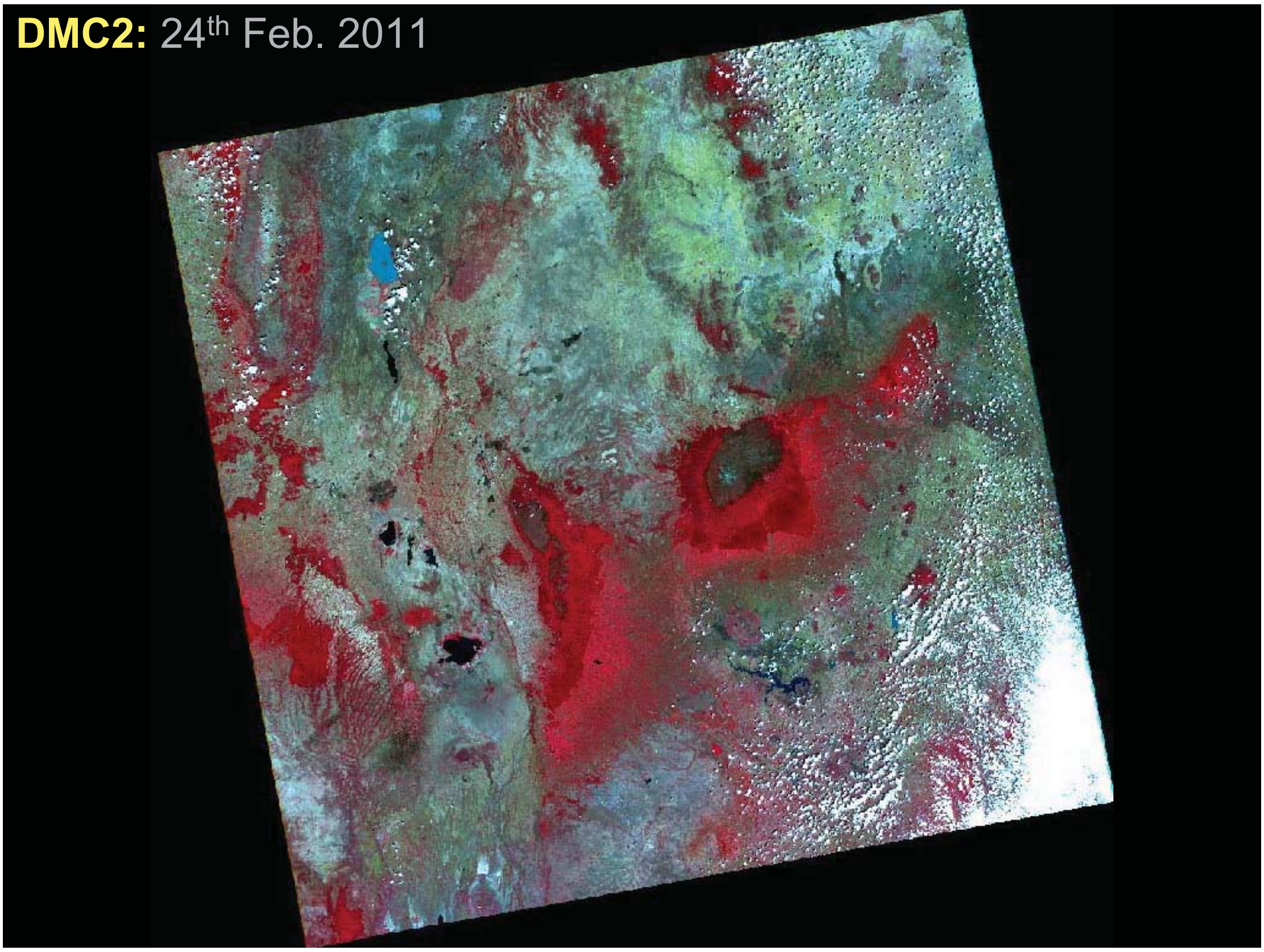
The Case of Kenya: using ALOS AVNIR2, DMC, Landsat

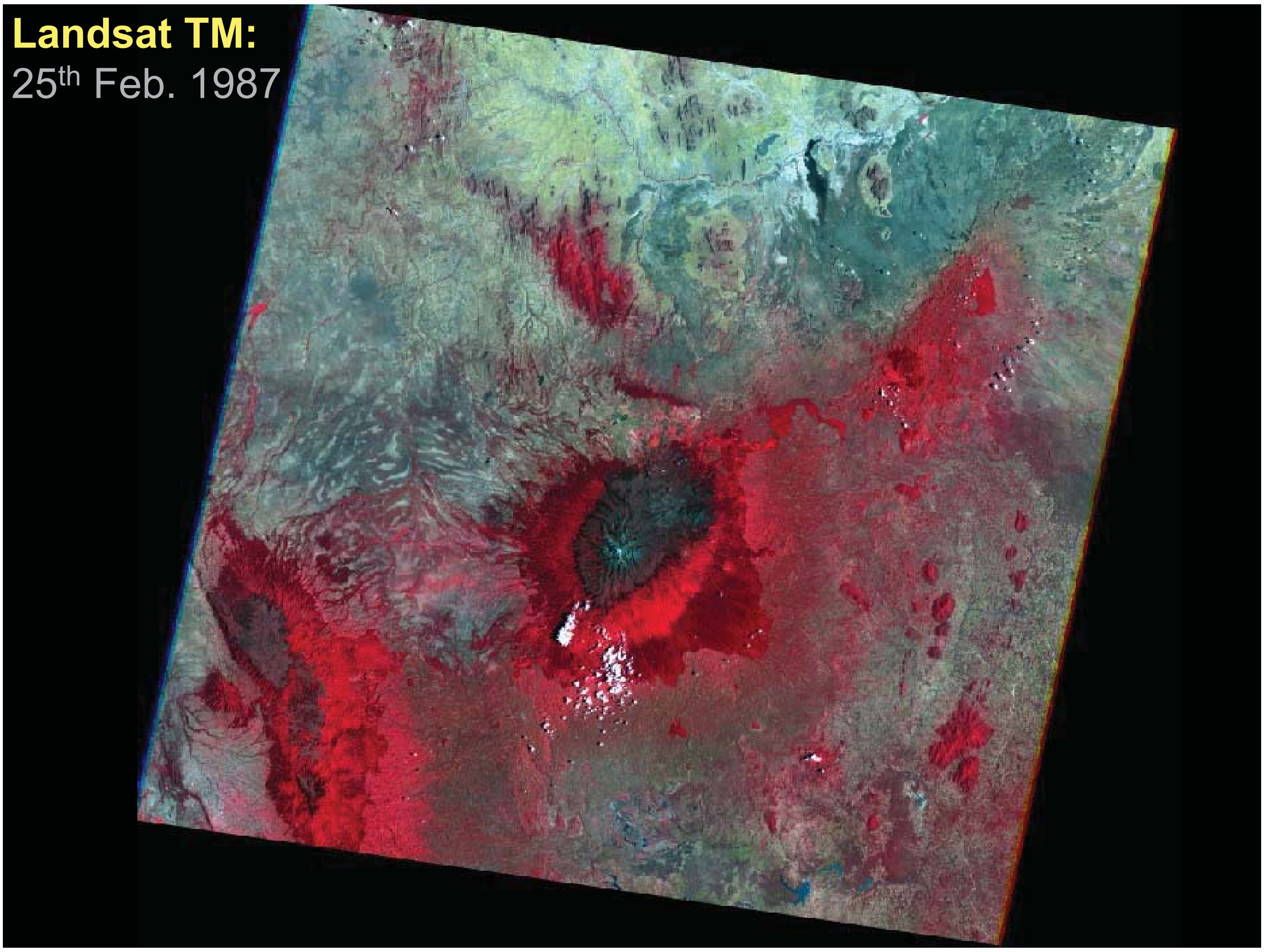
- **Primary satellite images for 2010 LU interpretation: ALOS AVNIR2**
  - ALOS – Advanced Land Observing Satellite
  - AVNIR2 – Advanced Visible and Near Infrared Radiometer Type 2
  - Key characteristics of ALOS AVNIR2:
    - 10m Spatial Resolution (at Nadir)
    - Multispectral (4 bands)
    - 70 Km Swath Width (at Nadir)
- **Secondary satellite images for 2010 LU interpretation: DMC2 and Landsat TM**
  - DMC – Drought Monitoring Constellation
  - Key characteristics of DMC2:
    - 22m spatial resolution
    - Multispectral (3 bands)
    - 650Km Swath Width
- **Primary and secondary satellite images for 1990 and 2000 LU interpretation: Landsat TM and ETM**
  - Key characteristics of Landsat:
    - 28.5m spatial resolution
    - Multispectral (7 bands for TM and 8 bands for ETM)
    - 185Km Swath Width

ALOS AVNIR2:

27th Jan. 2011

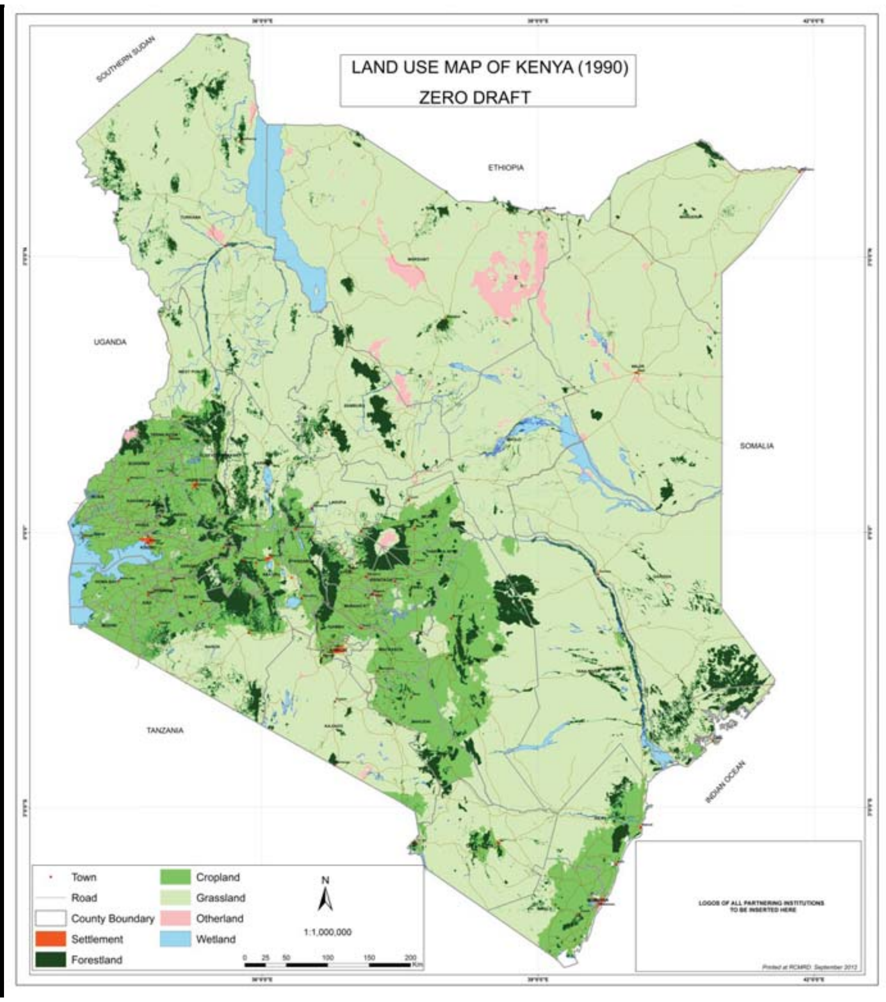



DMC2: 24th Feb. 2011

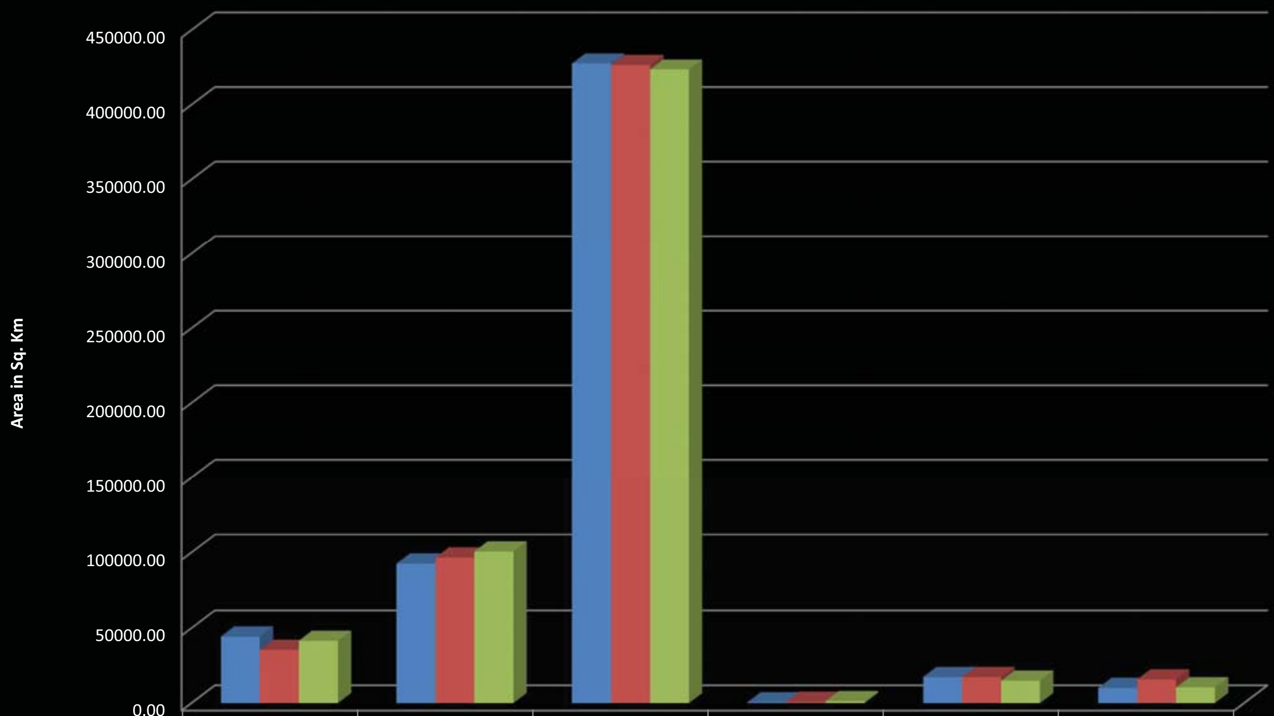

Landsat TM:
25th Feb. 1987

Mapping Procedure

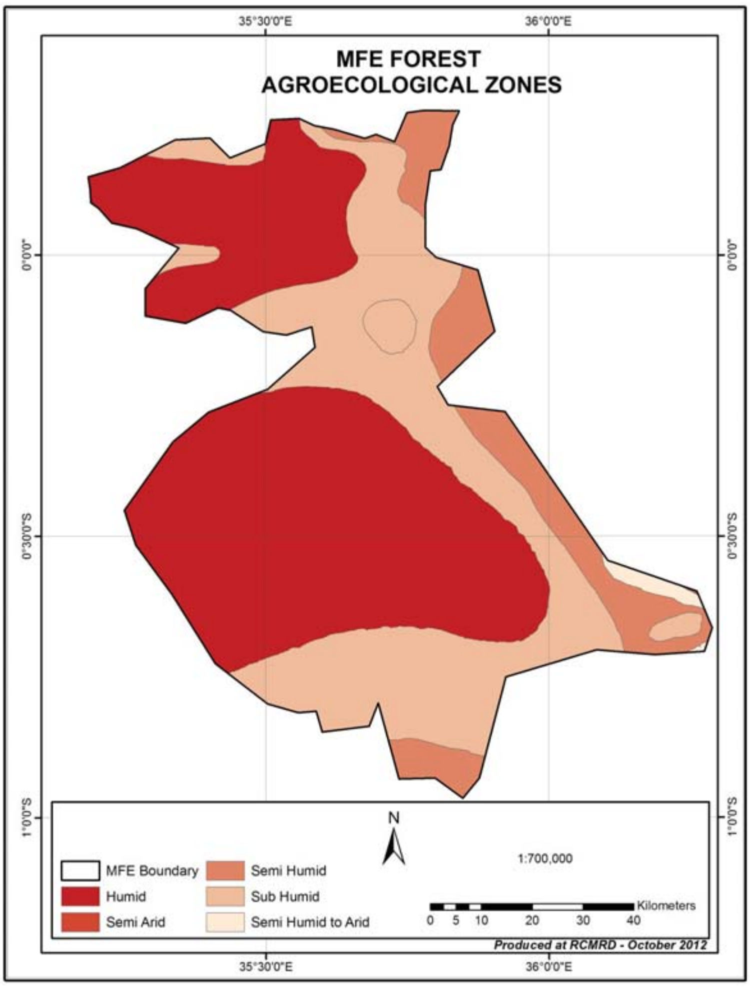
- **Ortho-rectification of images done by PASCO Corporation, Japan**
- **RCMRD began with 2010 LU interpretation:**
  - Forest land was the first to be mapped via on-screen digitization using MADCAT software
  - Reason for using on-screen digitization was due to national definition of Forest Land: **Minimum land area be at least 0.5 Ha; Minimum tree crown cover (cc) be at least 15%;** Minimum tree height be at least 2m
  - Settlements were also mapped via on-screen digitization using MADCAT software
  - Cropland, Grassland, Wetland, Other land were mapped via segmentation using MADCAT software
  - All 6 IPCC class layers were then merged into one shapefile for LU 2010 using ARCGIS 10 software
- **1990 and 2000 LU interpretation:**
  - The LU 1990 and LU 2000 were mapped by editing the LU 2010 shapefile using MADCAT software
- **Change detection mapping:**
  - Change detection was done in a vector environment using ArcGIS 10 software:
  - Change maps produced were: 1990 – 2000, 2000 – 2010, and 1990 - 2010
  - Potentially, a total of 36 LU change classes were to be derived for each change map
- **Cartographic design and map compilation:**
  - Was done using ArcGIS 10 at national scale and further split to 1:100,000 scale topos index grids
  - Image maps in false color were also produces based on the 1:100,000 scale topos index grids
- **Detailed Mapping of Mau Forest Ecosystem (MFE)**
  - Done on pilot basis.
  - ALOS PRISM used for GCP collection
  - Maps for Forest CC, Forest Type, Forest Legal Status and Agro-ecological Zones derived
  - Detailed forest inventory undertaken with support of derived MFE maps



Trend of Kenya Land Use Categories – 1990, 2000 and 2010 (Area in Sq. Km)



	Forestland	Cropland	Grassland	Setlements	Wetland	Other Land
1990_Area_Sq_Km	44296.00	92433.00	427577.00	548.00	17319.00	10045.00
2000_Area_Sq_Km	35399.00	96516.00	426458.00	887.00	17225.00	15758.00
2010_Area_Sq_Km	41557.00	100661.00	423554.00	1237.00	14817.00	10435.00

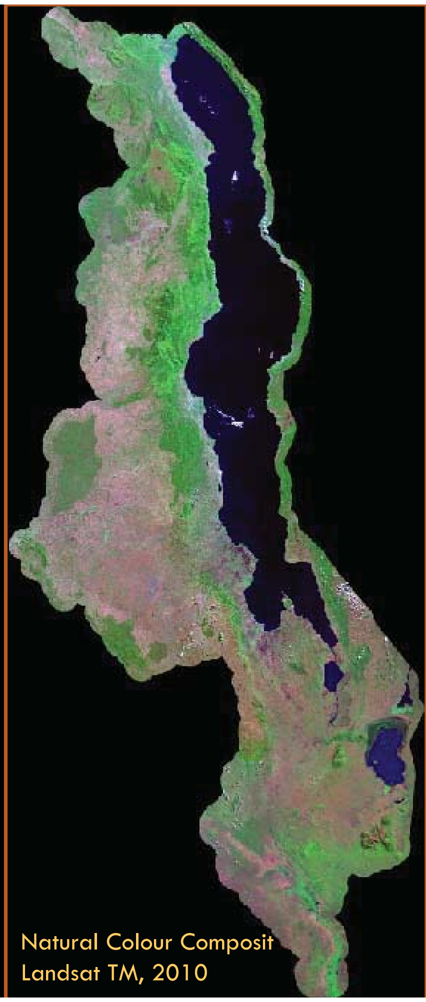


Eastern and Southern Africa: using Landsat

The Case of Malawi

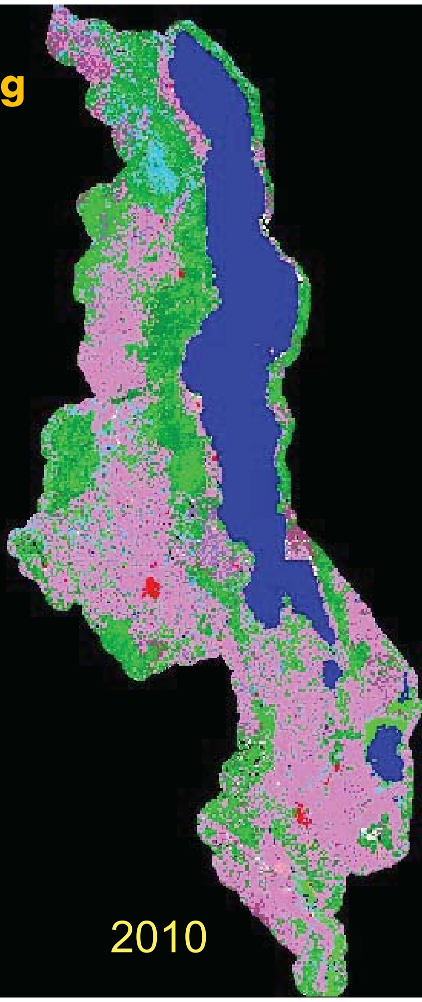
- Initially targeted to carry out mapping for 2000, 2005 and 2010
- 2005 Landsat data could not be used due to stripping problems occasioned by the Scan Line Corrector (SLC) failure in Landsat 7
- Mapping now being done for 1990, 2000 and 2010
- Supervised classification being used to carry out the land use mapping for the three epochs
- Change detection mapping not being done but relevant LU statistics for each year (1990, 2000, 2010) to be submitted to the ALU tool for GHG computations

False Colour Composit
Landsat TM, 2010



Natural Colour Composit
Landsat TM, 2010

Malawi LU Mapping



Classes Mapped

1. Dense Forest
2. Moderate Forest
3. Sparse Forest
4. Closed Grassland
5. Open Grassland
6. Closed Shrubland
7. Open Shrubland
8. Perennial Crops
9. Annual Crops
10. Wetlands
11. Water Bodies
12. Settlements
13. Other Lands

4. Looking Ahead: Challenges and Opportunities

A. Challenges:

- Images dates did not exactly match the intended years
- Data gaps especially cloud cover - for Kenya it was easer to circumvent the cloud problem using alternative images
- Mapping forest category was a challenge by virtue of the agreed definitions (using both methods used for Kenya and Malawi)
- Expanded classes beyond the six IPCC classes (in the case of Malawi's 13 classes) possed an added challenge to the mapping
- Data availability (consistency of dates, data gaps – 2005, etc)

B. Opportunities:

- ❖ Synergy and capacity at national level developed
- ❖ Mapping methodology (documented in manual) developed
- ❖ Developed LU base maps will facilitate cheaper and faster future LU mapping
- ❖ New satellites (Sentinel 2, Landsat 8, etc) should provide data continuity
- ❖ Lessons learnt from the different methodological approaches
- ❖ Growing awareness/interest on the important of GHG inventorying

THANK YOU

Integration of optical and SAR data for land cover classification

Hasi Bagan, Yoshiki Yamagata

CGER

National Institute for Environmental Studies, Japan

IPCC Expert Meeting: Role of Remote Sensing in Forest and National GHG Inventories

Hayama, *Japan*, *23-25 October 2012*

Content

1. Integration of optical and SAR data for classification
   - Subspace classification methods
   - Evaluate the classification accuracy

2. Land cover classification and change analysis
   - Combination of remote sensing, GIS, and population census data for urban growth analysis in Tokyo between 1972-2011
   - Land cover in Inner Mongolia and change analysis in the Horqin sandy land from 1975 to 2007

1. Integration of optical and SAR data for classification

- Subspace classification methods
- Evaluate the classification accuracy

2. Land cover classification and change analysis

- Combination of remote sensing, GIS, and population census data for urban growth analysis in Tokyo between 1972-2011
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Subspace classification methods

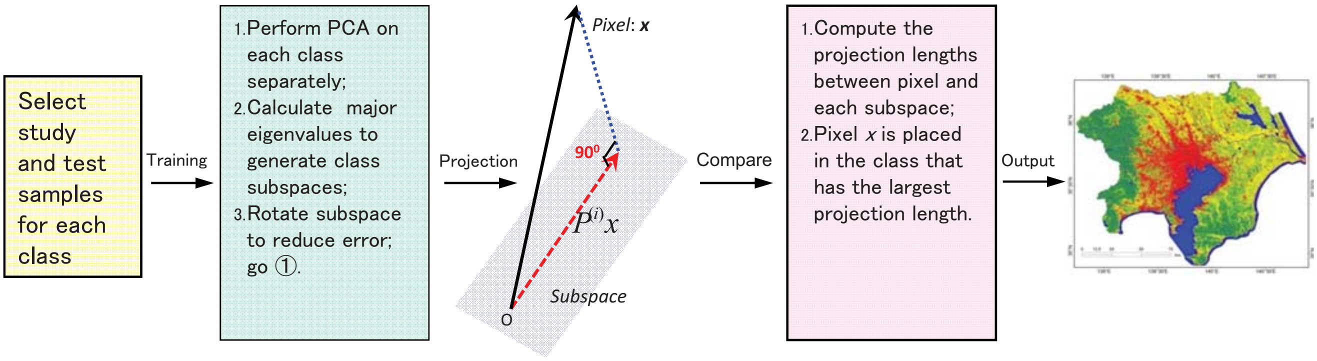
We have developed Subspace classification methods for multispectral, hyperspectral, and SAR data classification, which written in C++.

Subspace method:

1) can achieve dimension reduction and classification concurrently;

2) possesses high speed convergence.

Subspace classification method



A) Only 3 parameters are required to be set, and these can easily be determined by an automatic procedure.

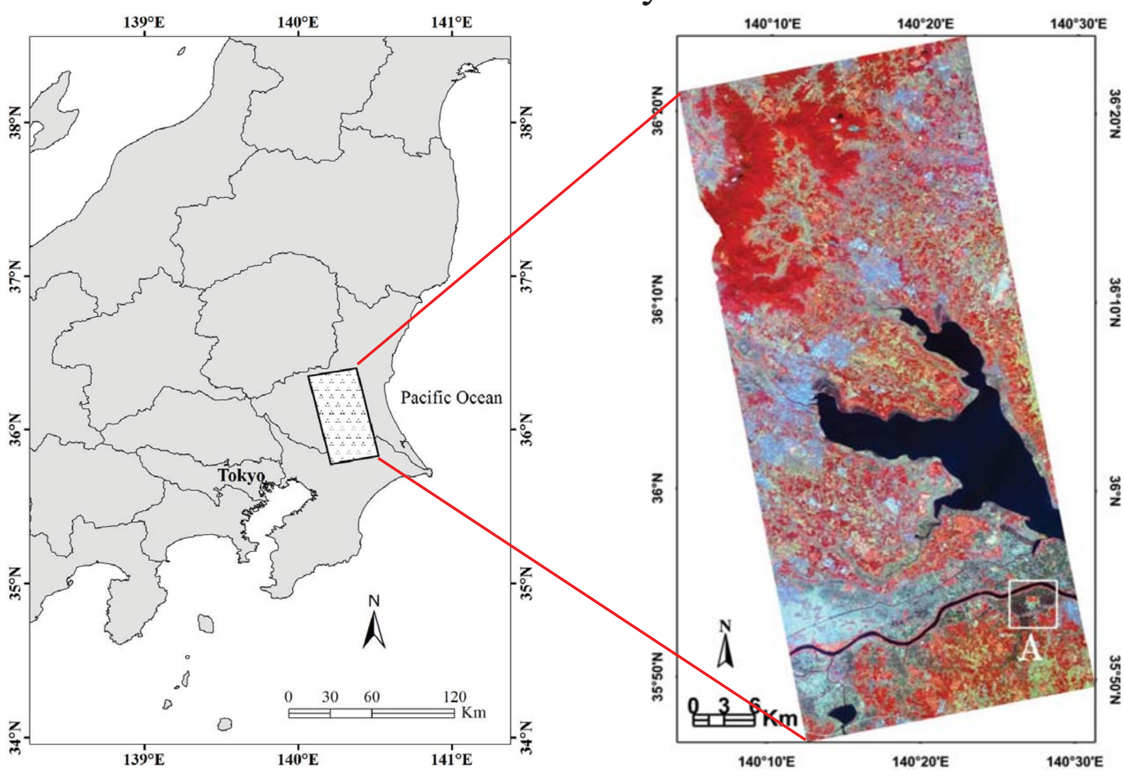
B) The computational speed is faster than SVM and similar to the MLC.

C) Could be a promising tool for this and future land cover classifications.

(Bagan. H.& Yamagata.Y., *PE&RS*, 76,(11), 2010)

1. Study area

Location of the study area



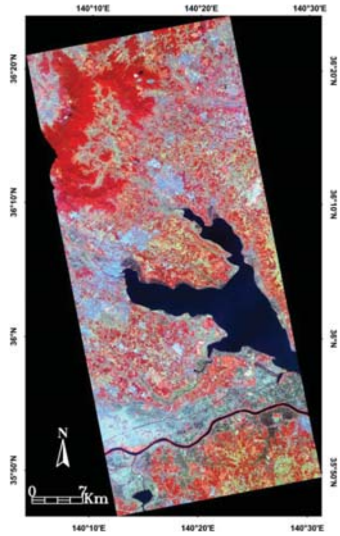
AVNIR-2(4, 3,1), 2009/04/13

2. Data sets

AVNIR-2 image acquired in 13 April 2009 with a 15-m spatial resolution

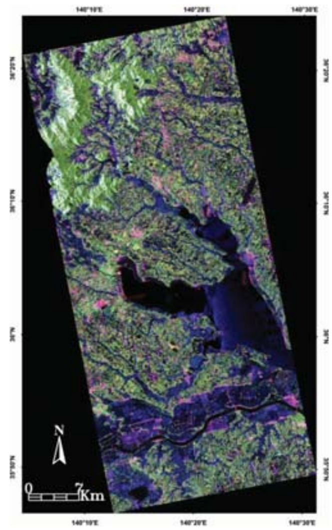
PALSAR level 1.1 at L-band in quad-polarization mode acquired in 7 April 2009

AVNIR-2



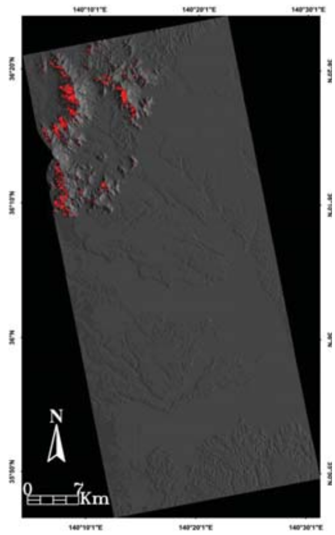
Spectral information

PALSAR



Scattering information

Layover



2. Data sets

1. AVNIR-2: 4 visible and near-infrared bands

2. PALSAR: 4 channels HH/HV/VH/VV Level 1.1 product

Convert to a normalized radar cross section (dB), as follows:

$$\sigma^0_{1.1\,product} = 10.\log_{10}\left\langle I^2 + Q^2 \right\rangle + 80$$

3. Coherency matrix T_3: 9 independent elements from T_3

$$T_3 = \left\langle \underline{k} \cdot \underline{k}^{*T} \right\rangle = \frac{1}{2} \begin{bmatrix} \left\langle |S_{HH}+S_{VV}|^2 \right\rangle & \left\langle (S_{HH}+S_{VV})(S_{HH}-S_{VV})^* \right\rangle & 2\left\langle (S_{HH}+S_{VV}) S_{HV}^* \right\rangle \\ \left\langle (S_{HH}-S_{VV})(S_{HH}+S_{VV})^* \right\rangle & \left\langle |S_{HH}-S_{VV}|^2 \right\rangle & 2\left\langle (S_{HH}-S_{VV}) S_{HV}^* \right\rangle \\ 2\left\langle S_{HV}(S_{HH}+S_{VV})^* \right\rangle & 2\left\langle S_{HV}(S_{HH}-S_{VV})^* \right\rangle & 4\left\langle |S_{HV}|^2 \right\rangle \end{bmatrix}$$

3 real diagonal elements and the real and imaginary parts of the 3 off-diagonal elements

3. Land cover classification

We designated 11 land-cover types in this experiment, based on field survey, IKNOS, GeoEye-1, and Digital Map 2500 GIS data.

Land Cover Class	Class Description	Training Pixel Count	Test Pixel Count
1. Urban/Built-up	Buildings, concrete, and other human-made structures	1463	861
2. Forest	Forests (canopy cover more than 50%)	1609	1079
3. Water	Rivers and lakes	1307	829
4. Paddy	Plowed paddy fields before flooding	1814	867
5. Wheat	Winter wheat	1079	781
6. Flooded paddy	Plowed paddy fields flooded by shallow water	1107	571
7. Lotus	Lotus fields	773	452
8. Cropland	Dry croplands	1111	573
9. Grassland	Dominated by dense grass or shrubs	1040	624
10.Sparse	Sparse vegetation areas: e.g., parks, golf courses, playing fields	1012	585
11. Road	Asphalt paved road	947	551
Total		13262	7773

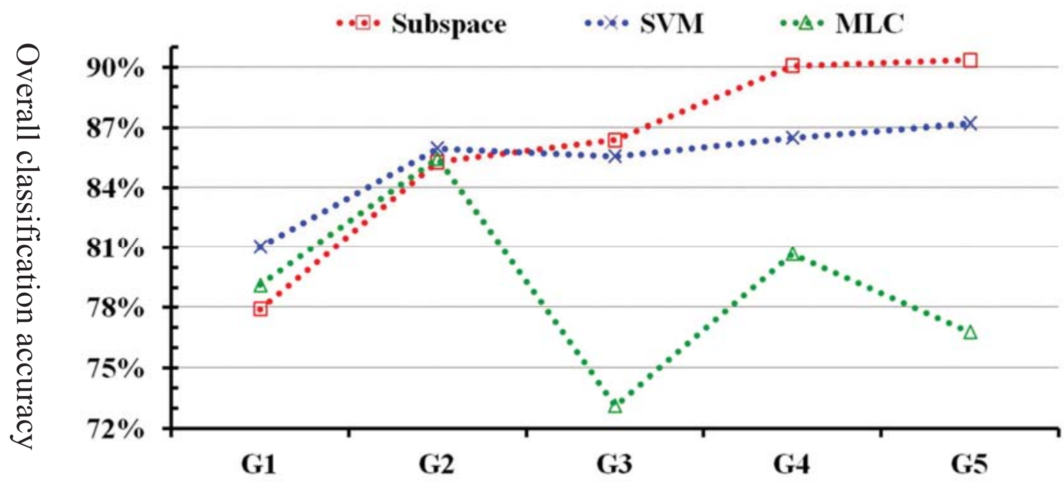
3. Land cover classification

we set up five data set groups designated G1–G5 to evaluate how different source data sets contributed to classification accuracy.

Group	Data	Designation	Total no. of bands	Pixel size
G1	AVNIR-2	Bands 1–4	4	15 m
G2	AVNIR-2, PALSAR	Bands 1–4, *HH*, *HV*, *VH*, *VV*	8	15 m
G3	AVNIR-2, T3	Bands 1–4, T_{11}, T_{22}, T_{33}, Re(T_{12}), Im(T_{12}), Re(T_{13}), Im(T_{13}), Re(T_{23}), Im(T_{23})	13	15 m
G4	AVNIR-2, PALSAR, six elements of T3	Bands 1–4, *HH*, *HV*, *VH*, *VV*, Re(T_{12}), Im(T_{12}), Re(T_{13}), Im(T_{13}), Re(T_{23}), Im(T_{23})	14	15 m
G5	AVNIR-2, PALSAR, T3	Bands 1–4, *HH*, *HV*, *VH*, *VV*, T_{11}, T_{22}, T_{33}, Re(T_{12}), Im(T_{12}), Re(T_{13}), Im(T_{13}), Re(T_{23}), Im(T_{23})	17	15 m

Subspace, Support vector machine (SVM) , and Maximum likelihood classifier (MLC) methods were each applied to the five data set groups.

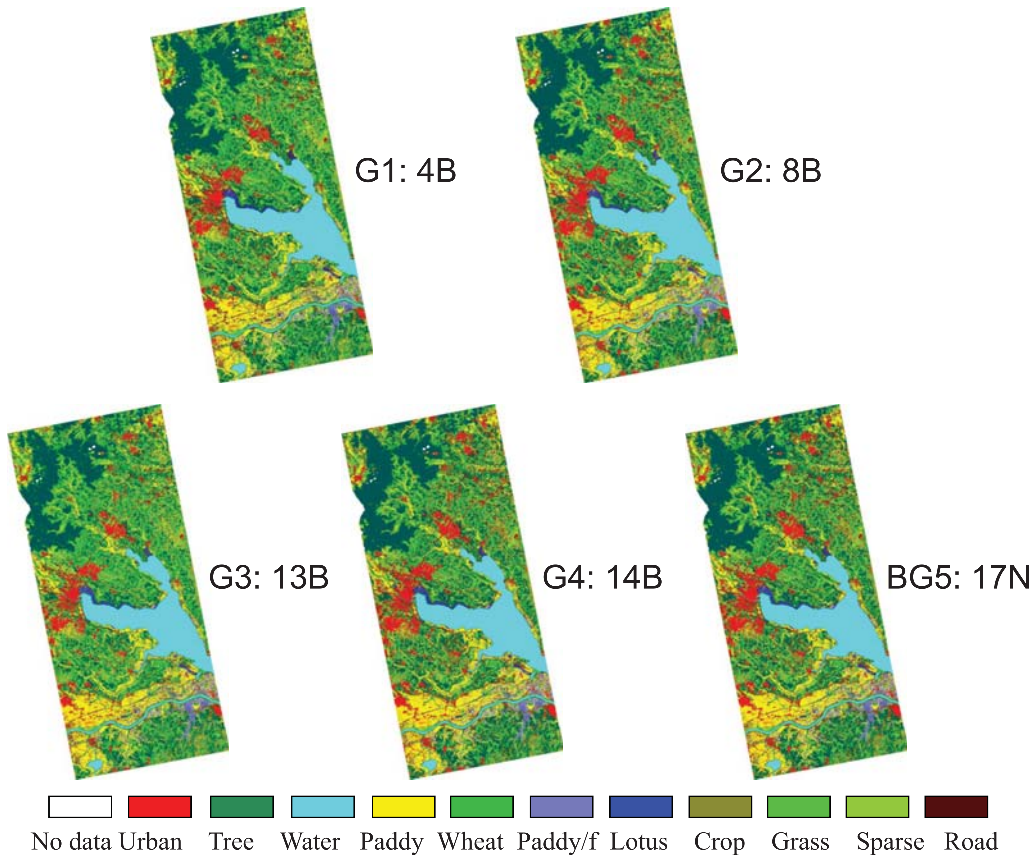
3. Land cover classification



Combining optical AVNIR-2 and PALSAR, achieved better classification results than the optical-only G1 data set.

Subspace method performed better than the SVM or MLC method in high-dimensional data set classification.

3. Land cover classification



Conclusions and future work

Conclusions

SAR data and optical data provide complementary information, and their combination leads to increased classification accuracy.

Fully polarimetric PALSAR data improve the accuracy of the land cover classifications.

Subspace method is promising as a tool for classification using optical+SAR images.

Future work

Add other polarimetric indicators to assess the classification accuracy.

(Bagan. H., Kinoshita.T, & Yamagata.Y., *IEEE TGRS*, 50(4), 2012)

1. Integration of optical and SAR data for classification
   - Subspace classification methods
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2. Land cover classification and change analysis
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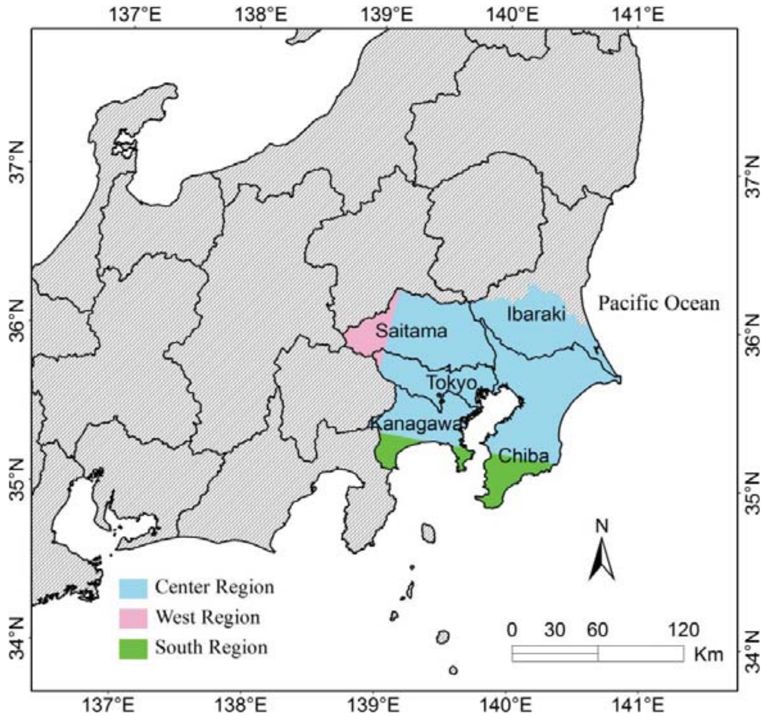
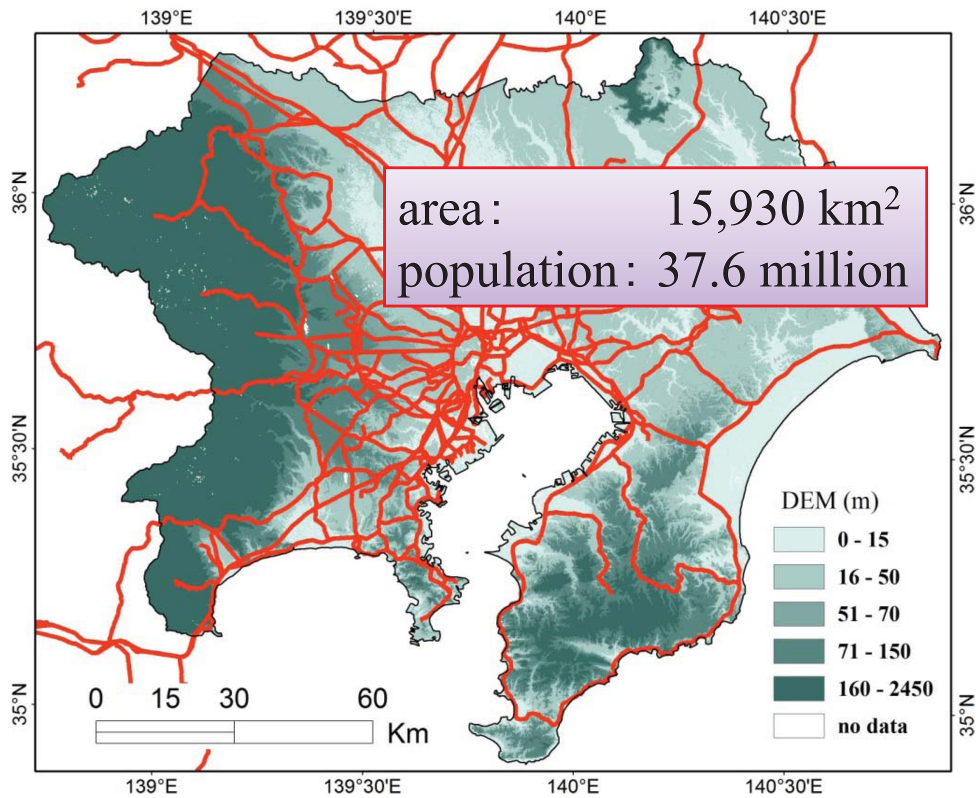
Study area



Study area is composed of Tokyo, Chiba, Kanagawa, Saitama, and the part of Ibaraki. Three Landsat scenes, namely the center, west, and east, cover the study area.



The gray image is a DEM generated from SRTM.
Right lines refer to the major railway and metro lines.

Landsat MSS/TM/ETM+

We acquired Landsat images to interpret land-cover changes from 4 separate dates (nominally 1972, 1987, 2001, and 2011).

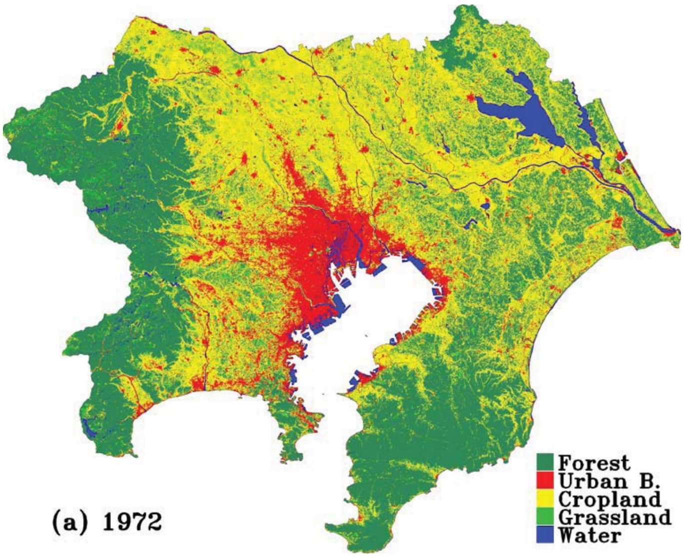
Table. Summary of Landsat images used in this study.

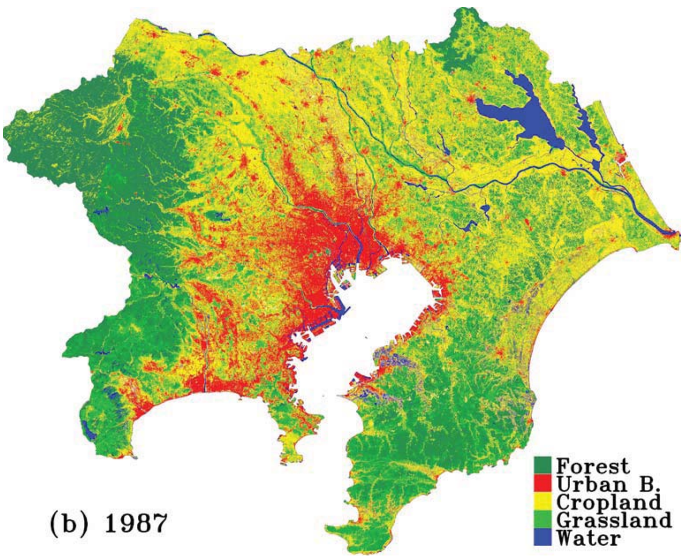
Year	Sensor	Date (yyyy-mm-dd)	Path/row	Location	Spatial resolution (m)
1972	Landsat-1 MSS	1972-11-26	115/35	Center	60
	Landsat-1 MSS	1972-11-26	115/36	South	
	Landsat-1 MSS	1972-11-09	116/35	West	
1987	Landsat-5 TM	1987-05-21	107/35	Center	30
	Landsat-5 TM	1993-05-21	107/36	South	
	Landsat-5 TM	1990-12-06	108/35	West	
2001	Landsat-7 ETM	2001-09-24	107/35	Center	30
	Landsat-7 ETM	2001-09-24	107/36	South	
	Landsat-7 ETM	2001-11-02	108/35	West	
2011	Landsat-5 TM	2011-04-05	107/35	Center	30
	Landsat-5 TM	2011-04-05	107/36	South	
	Landsat-5 TM	2010-04-25	108/35	West	

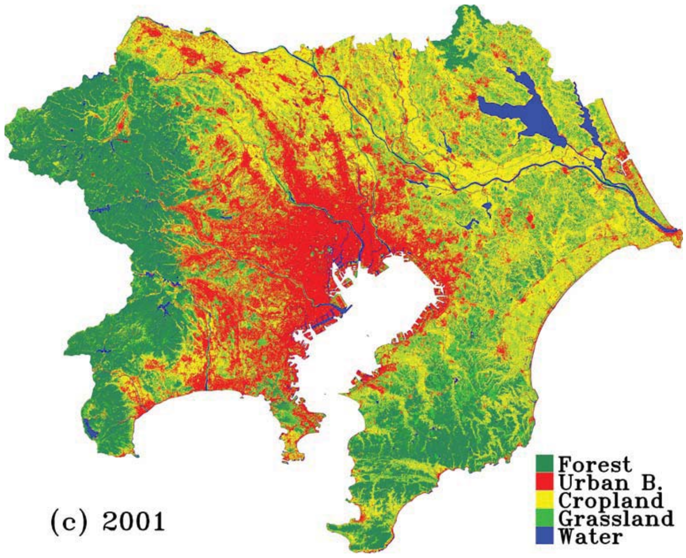
First, we designated 5 to 9 land-cover types in 1972, 1987, 2001 and 2011 Landsat imagery;

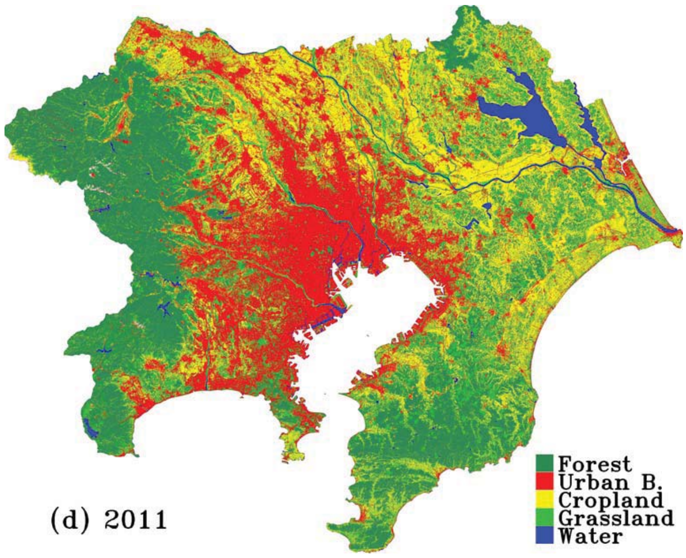
Then, we aggregated land-cover categories into 5 categories to ensure uniform labeling and therefore facilitate comparisons.

Land-cover class	Class description
C1. Forest	Forests (more than 50% canopy coverage)
C2. Urban/built-up	All residential, commercial, and industrial areas; villages; settlements; transportation infrastructure
C3. Cropland	Crop and paddy fields
C4. Grassland	Areas dominated by dense grass or shrubs
C5. Water	Permanent water bodies: rivers, lakes, ponds, canals

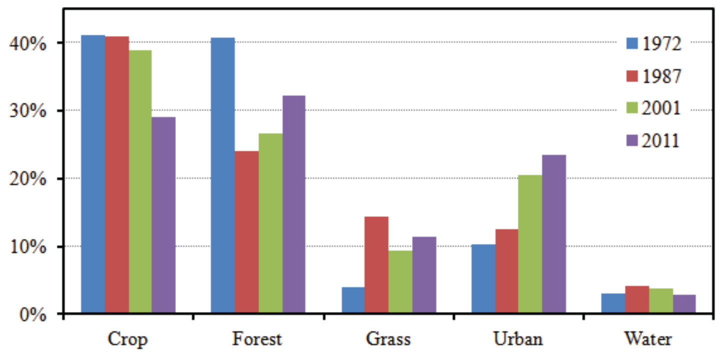

Forest
Urban B.
Cropland
Grassland
Water
(a) 1972


Forest
Urban B.
Cropland
Grassland
Water
(b) 1987


Forest
Urban B.
Cropland
Grassland
Water
(c) 2001


Forest
Urban B.
Cropland
Grassland
Water
(d) 2011

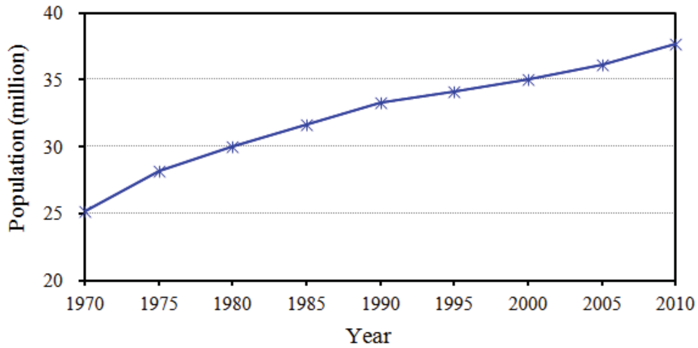
Land cover change vs. population growth



Total area of each of the land-cover categories from 1972 to 2011.

Urban area increased rapidly, and there was a marked decrease in cropland.

Forest decreased between 1972 and 1987, after 1987 there was a steady increase of forest growth.



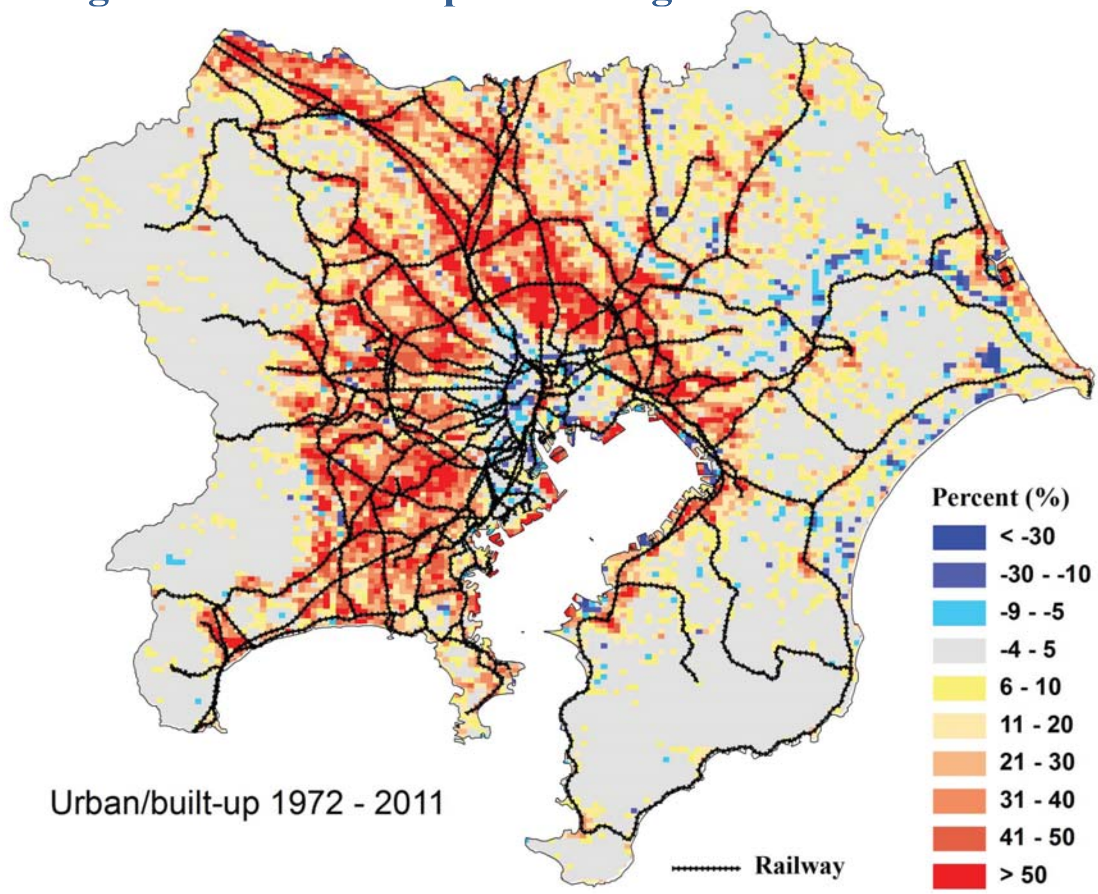
Population growth during 1970–2010 in 5-year increments.

Population increased from 25.2 million in 1970 to 37.6 million in 2010.

Rate of urban growth exceeded the population growth rate by a factor of 2.6

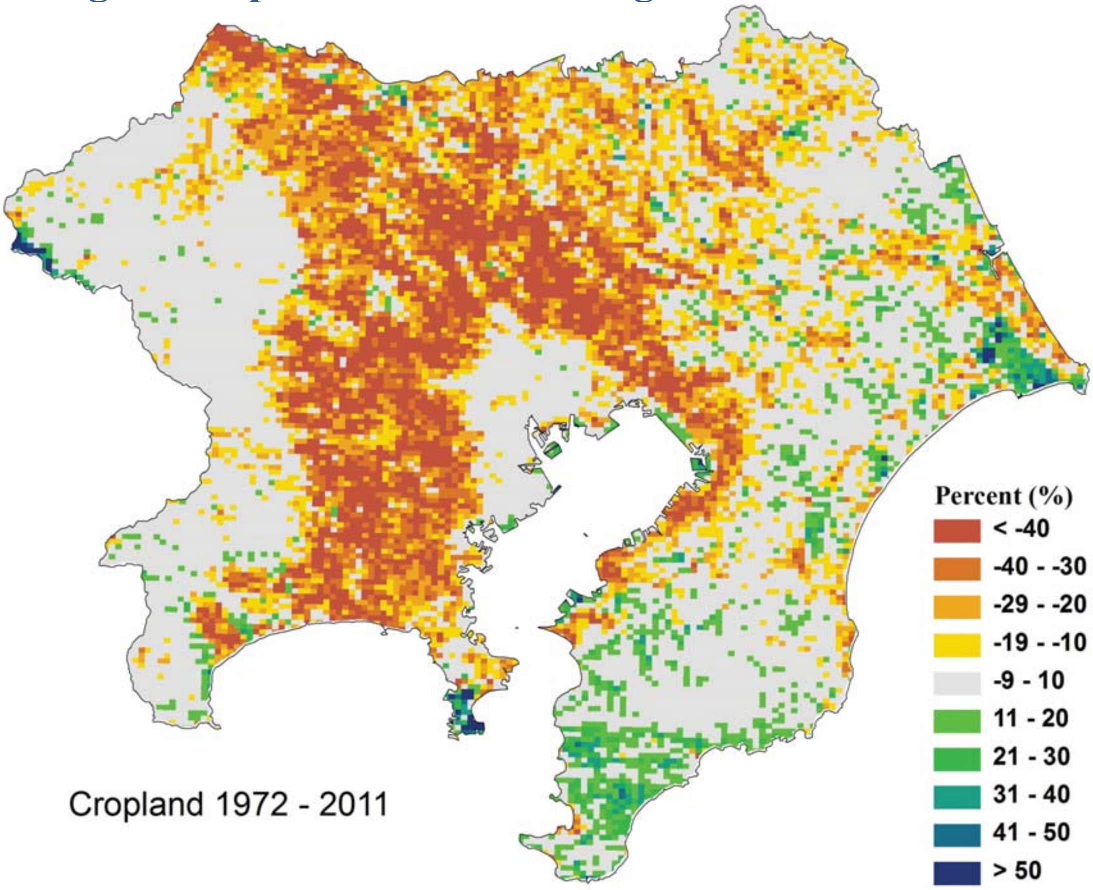
(Bagan. H.& Yamagata.Y., *Remote Sensing of Environment*, 2012)

Change of urban/built-up in 1-km^2 grid cells from 1972 to 2011



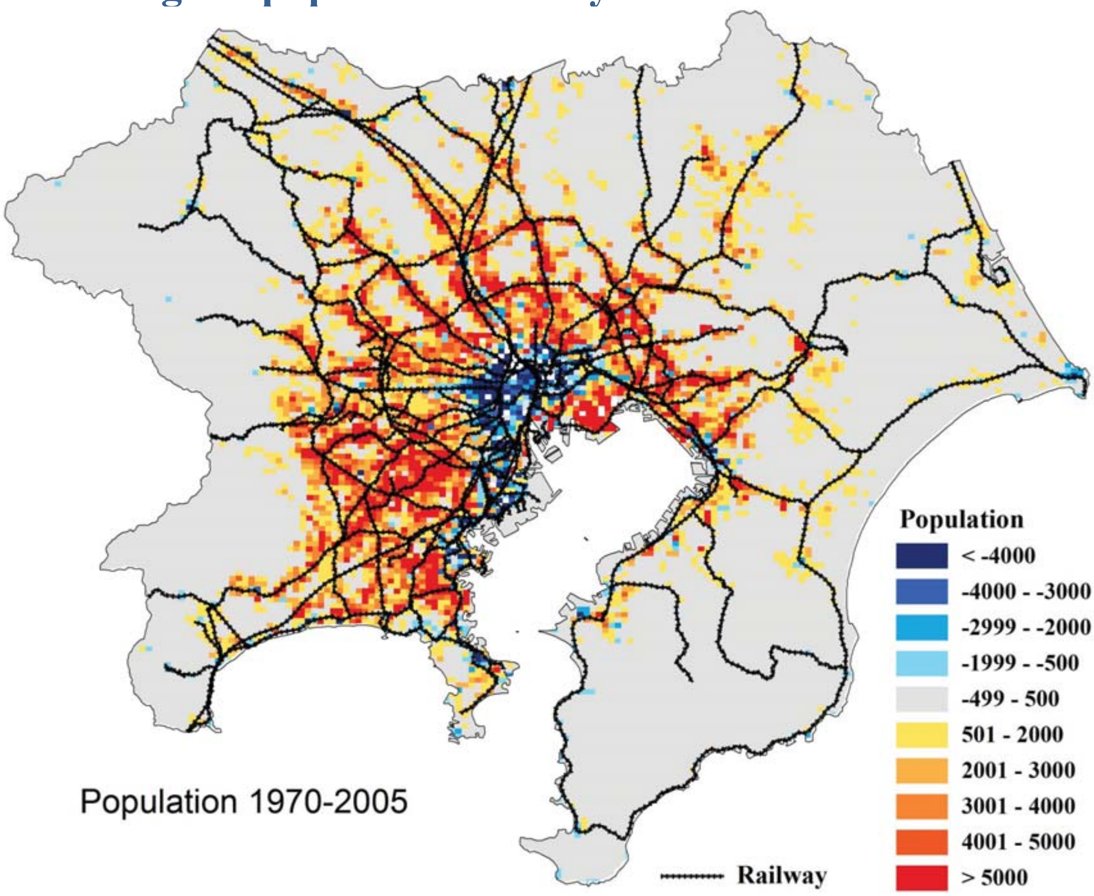
Urban expanded to the suburban, and decreased in the center of the city.

Change of cropland area in 1-km^2 grid cells from 1972 to 2011



Decreases in cropland took place in either large and flat areas or in proximity to urban regions.

Change in population density between 1970 and 2005



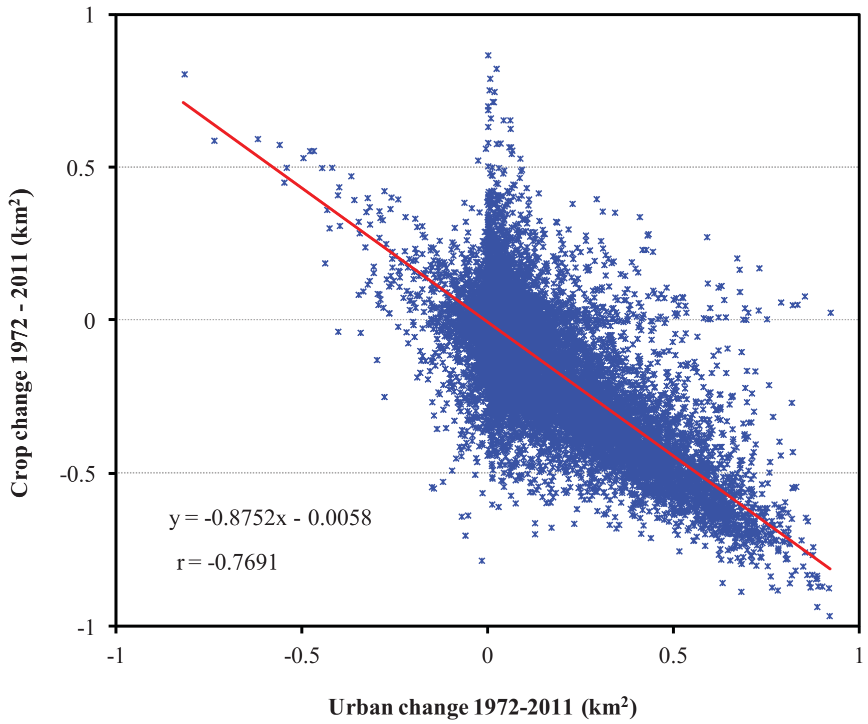
Spatial distribution of population increase trends is similar to the urban expansion trends.

Correlations between the changes of land-cover categories (1972–2011) and population density change (1970–2005)

	Urban	Crop	Forest	Grass	Water	Population
Urban	1					
Crop	**-0.7691**	1				
Forest	0.0213	**-0.3915**	1			
Grass	-0.1904	-0.0445	**-0.4515**	1		
Water	-0.1025	-0.1306	-0.1153	0.0431	1	
Population	**0.5902**	**-0.4778**	-0.0066	-0.0890	0.0213	1

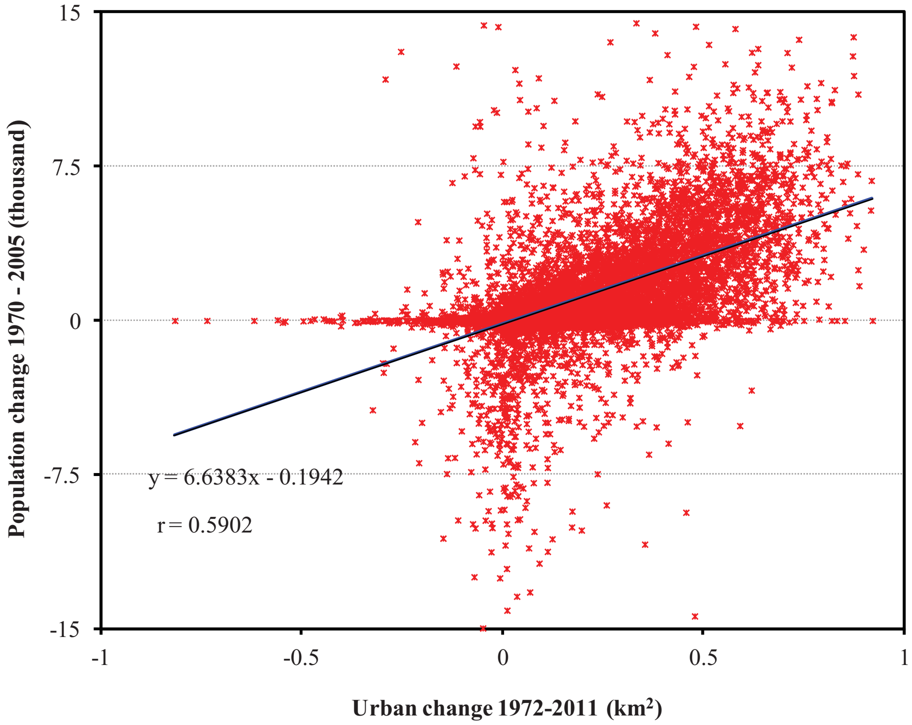
(Bagan. H.& Yamagata.Y., *Remote Sensing of Environment*, 2012)

Scatter plot of urban changes versus cropland changes



Strong, negative linear relationship between urban/built-up change and cropland change.

The correlation between the urban/built-up changes for 1972–2011 and population density changes for 1970–2005

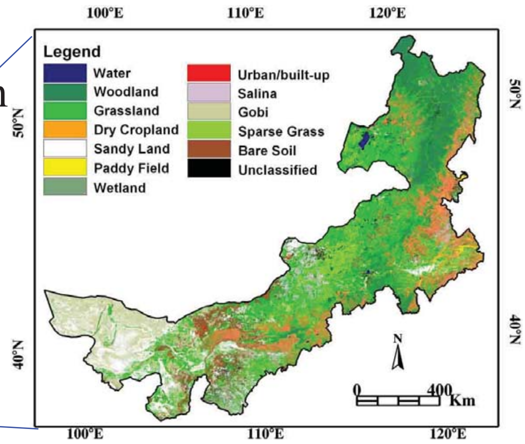


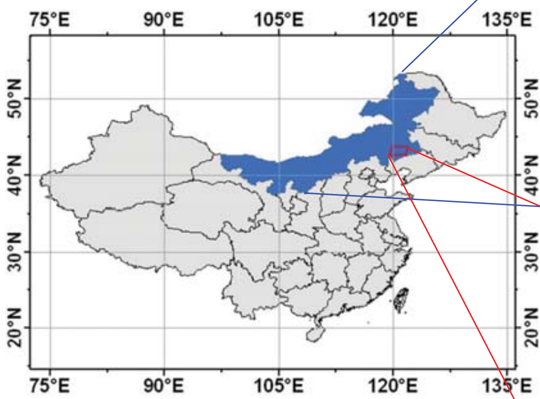
Urban/built-up change has a significant positive correlation with the population density change.

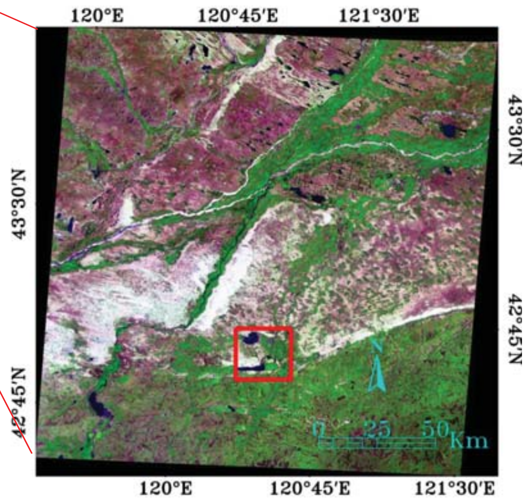
1. Integration of optical and SAR data for classification
   - Subspace classification methods
   - Evaluate the classification accuracy

2. Land cover classification and change analysis
   - Combination of remote sensing, GIS, and population census data for urban growth analysis in Tokyo between 1972-2011
   - Land cover in Inner Mongolia and change analysis in the Horqin sandy land from 1975 to 2007

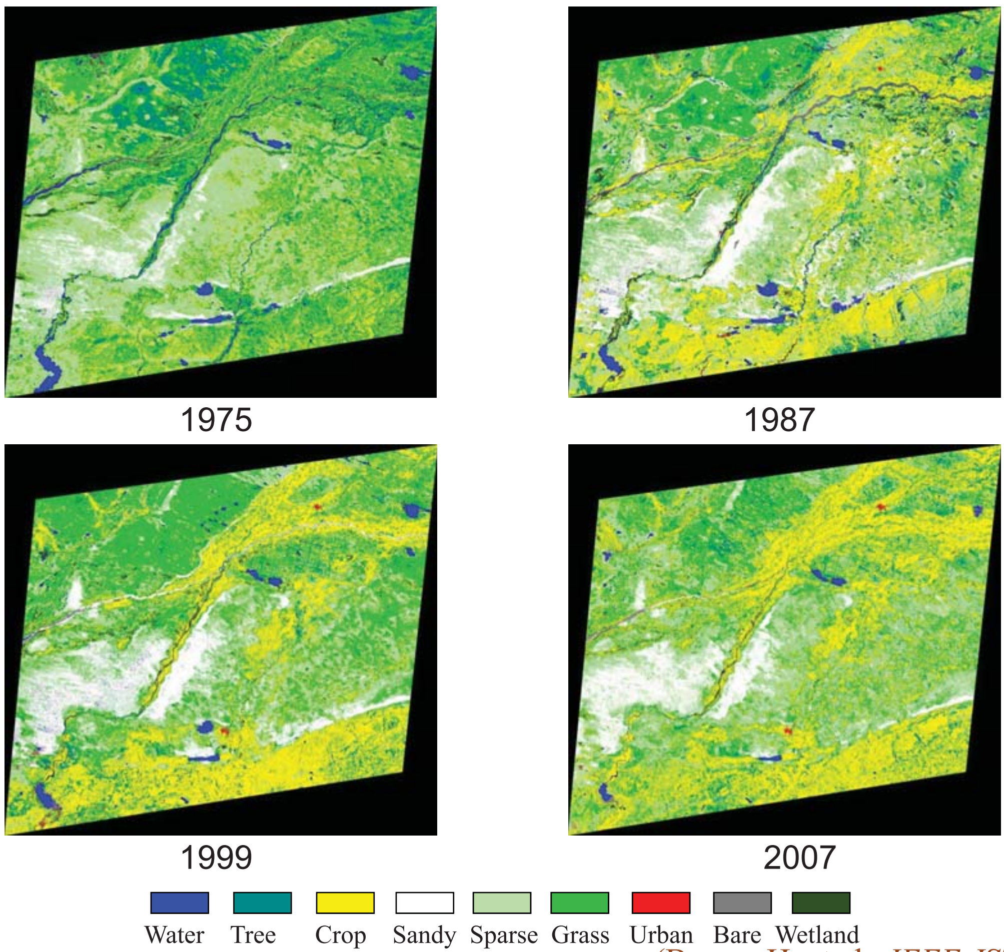
Inner Mongolia Autonomous Region





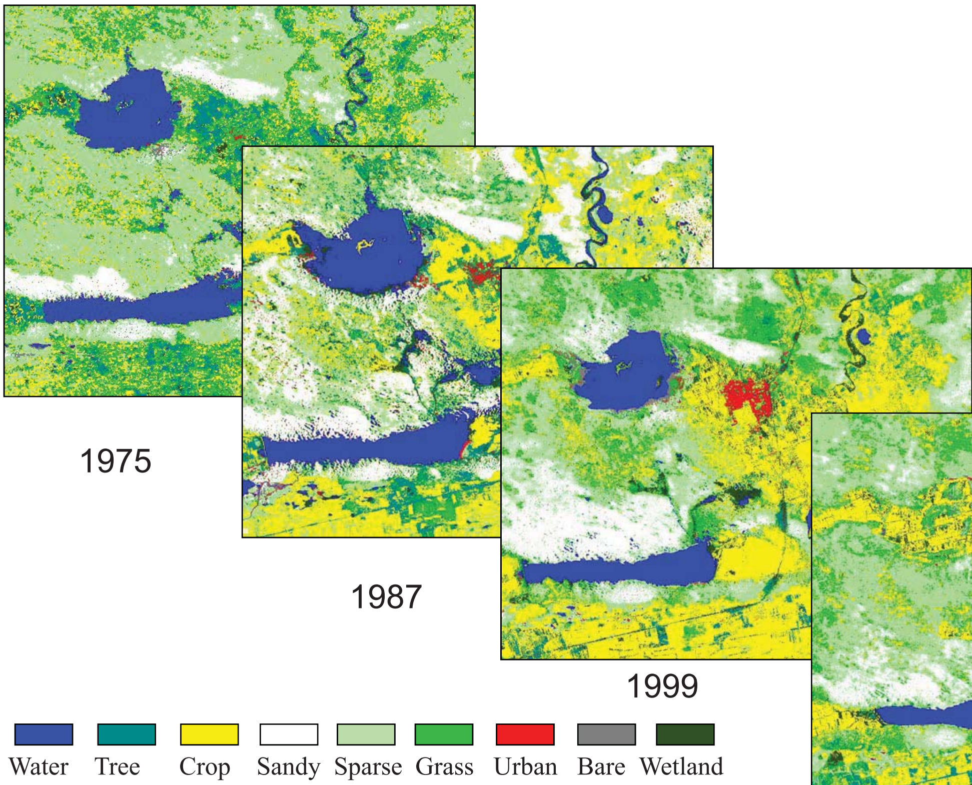


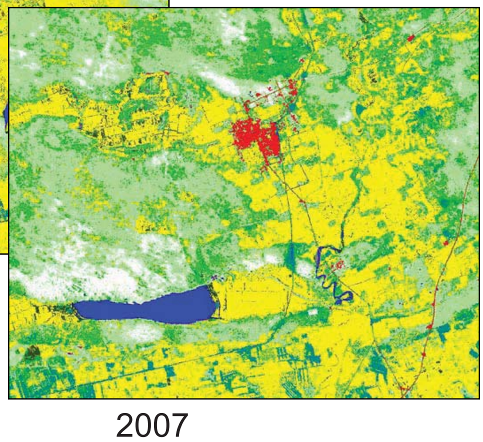
The Horqin Sandy Land is in the arid and semi-arid southeastern part of the Inner Mongolian Autonomous Region in China.



(Bagan, H. et al., *IEEE JSTARS*., 2010)

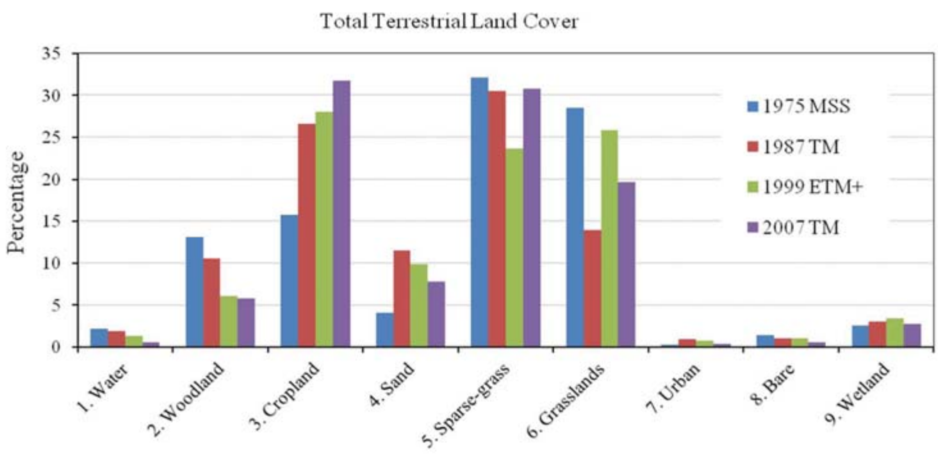
Land cover changes in Inner Mongolia from 1975 to 2007 using Landsat

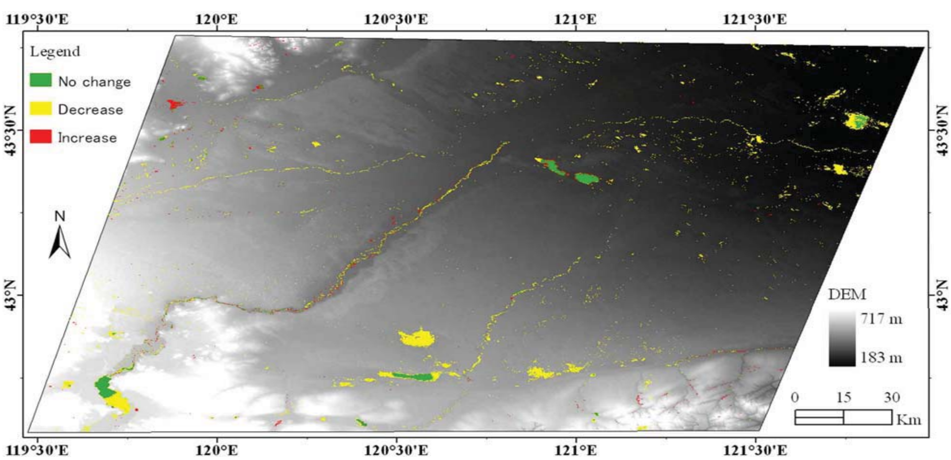




Major changes are conversion of grass and forest to cropland fields, rapid urban growth, and water area decreased heavily over the last three decades.

Bagan, H. et al., IEEE JSTARS., 2010





In reaction to land degradation events, the central government initiated the Sloping Land Conversion Program (also known as Grain for Green) in 1999.

Inner Mongolia is implementation of the ecological migration policy:

the families of local herders and farmers were moved from desertified steppe and settled in new villages which mainly located along river courses.

Minato Mirai, Yokohama. *Height*: *Lidar*; *RGB*: *airborne image*

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NATIONAL INSTITUTE FOR SPACE RESEARCH

Amazon forest biomass estimation using X and P band SAR data

CARLOS ALBERTO **PIRES** DE CASTRO FILHO – MSc

CORINA DA COSTA FREITAS - PhD

SIDNEI JOÃO SIQUEIRA SANT´ANNA - PhD

Motivation

- ✓ Carbon accounting is needed to support the objectives of international agreement to mitigate global climate change. Need for forest biomass estimation for carbon policy development;
- ✓ Traditional forest inventories that rely on fieldwork require high costs, specially in the tropics, where forest extends over large geographic areas with difficult terrain;
- ✓ Remote sensing is an important tool for tropical forest measurements;
- ✓ ... "Brazil has 53% of the world´s REDDs (*Reduce Emissions for Deforestation and Degradation*) potential" (FUJIHARA, 2010, apud BONATELLI, 2010).

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Objective

Present the preliminary results using CADAF forest inventories together with X and P band SAR data to model the biomass stock in different regions of the Amazon Forest.

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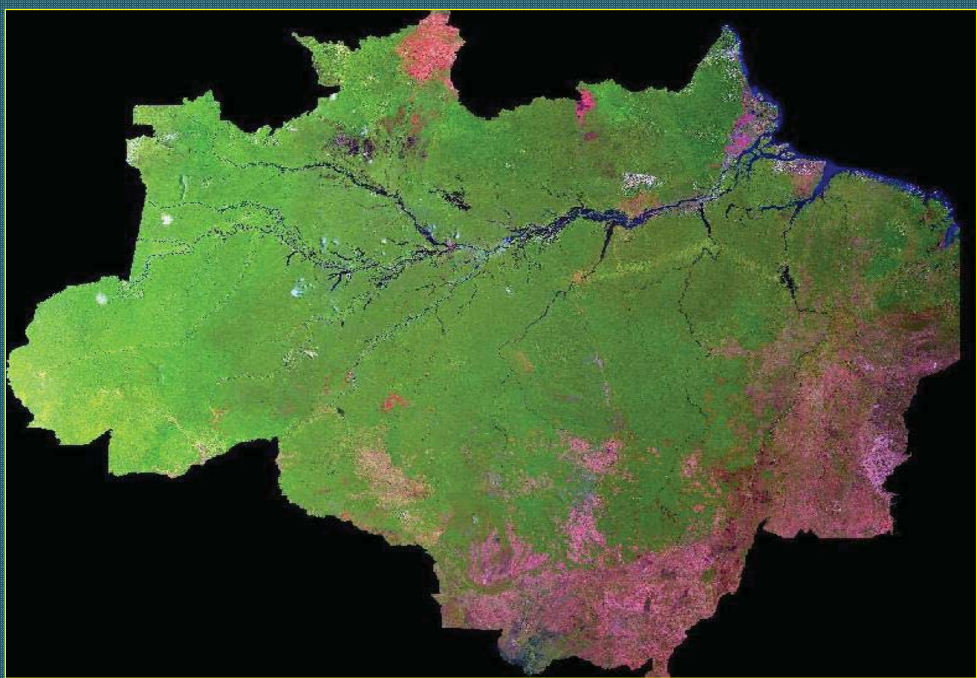
Amazon Region



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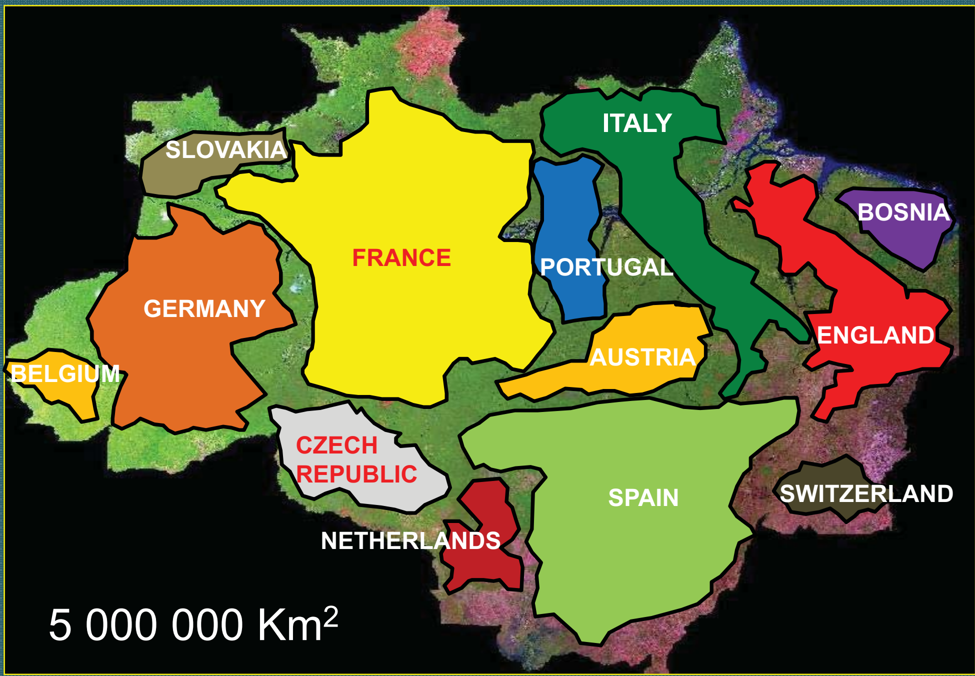
Amazon Region



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Amazon Region

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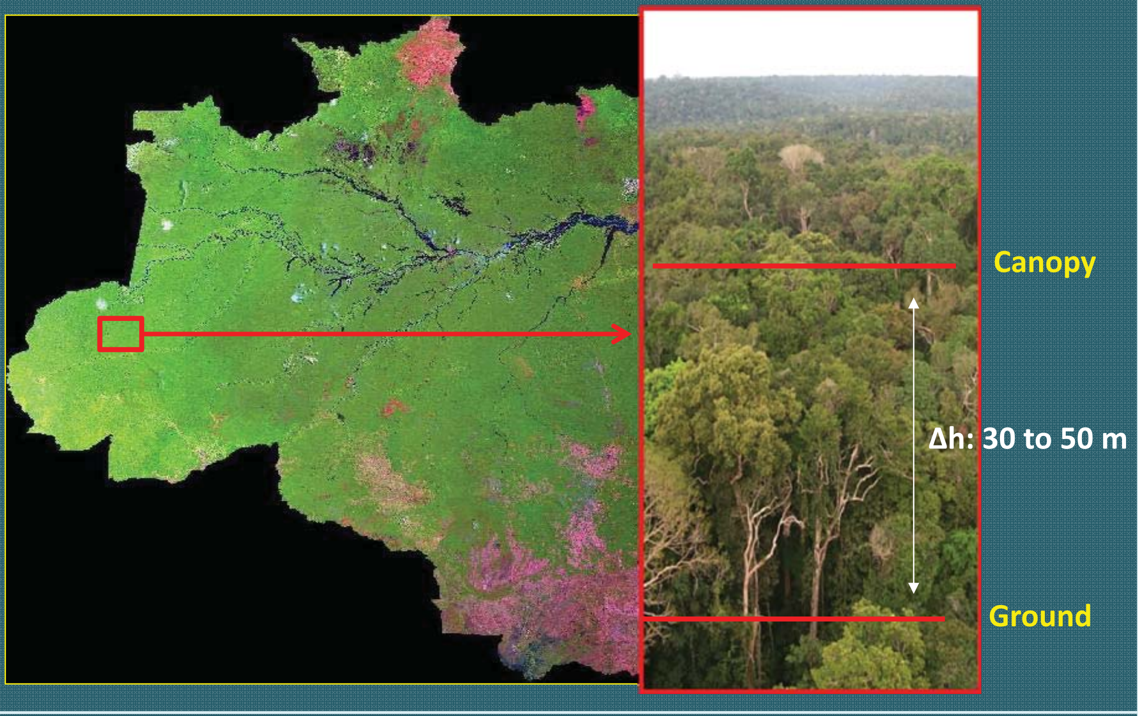
Amazon Region



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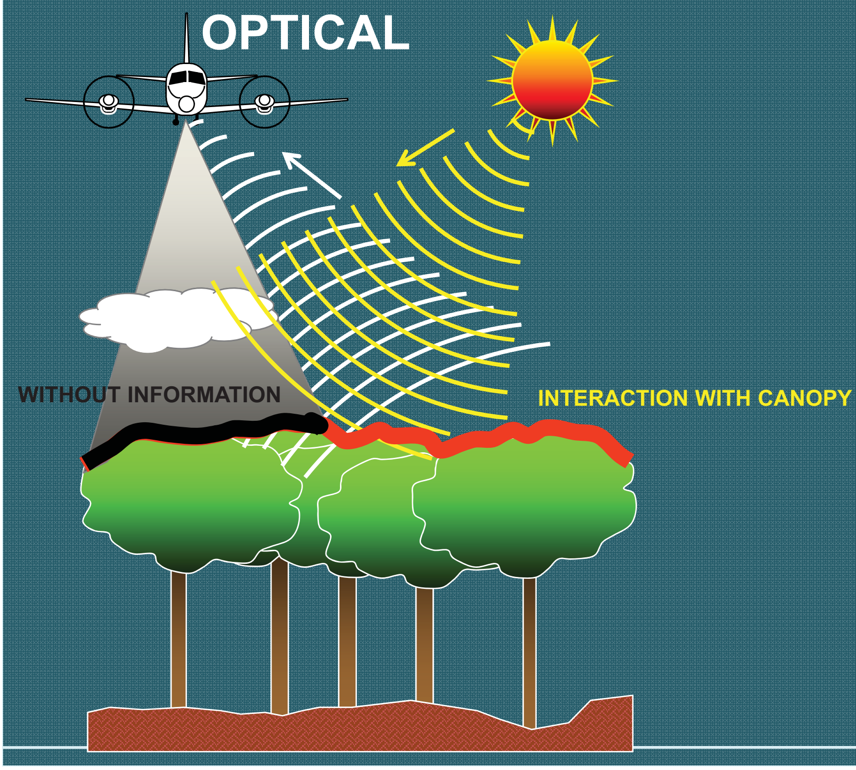
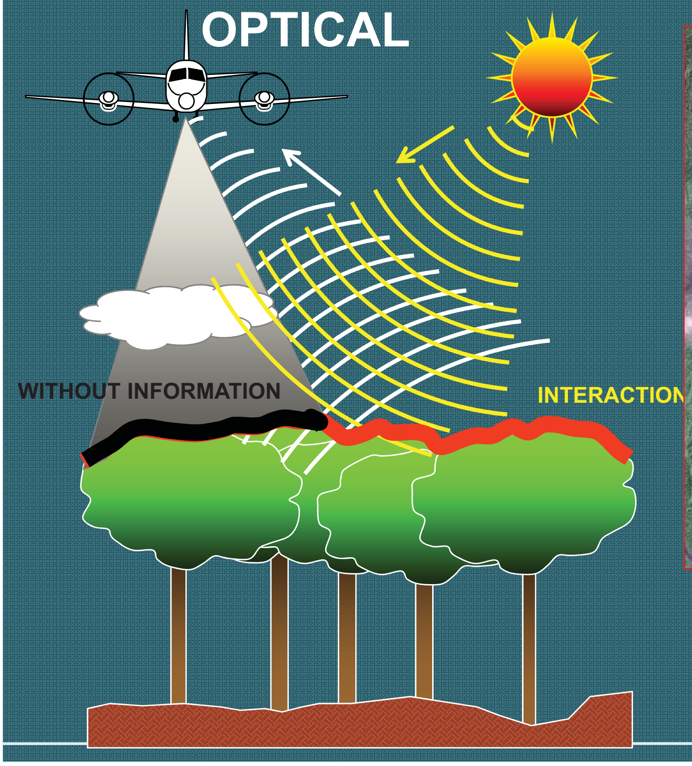
Technical Problem



Technical Problem



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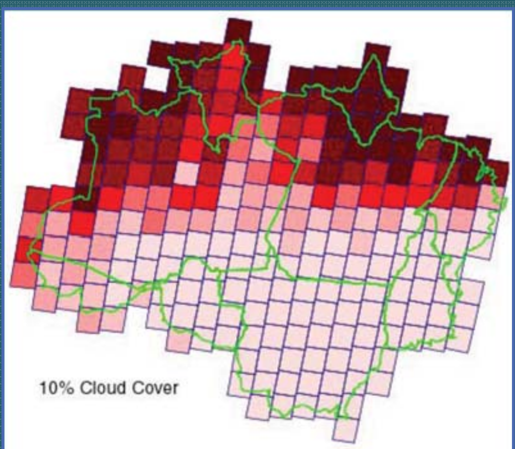
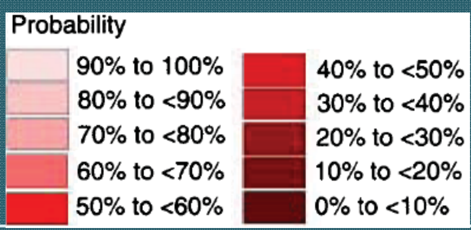
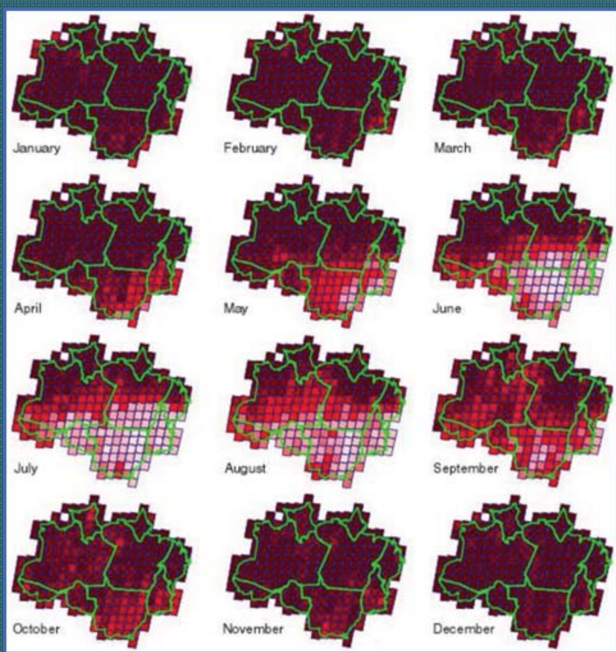
Cloud Cover in Brazilian Amazon



Annual probability of obtaining a Landsat TM scene with 10% or less cloud cover.





Monthly probabilities of obtaining a Landsat TM scene with 30% or less cloud cover. Asner (2001).

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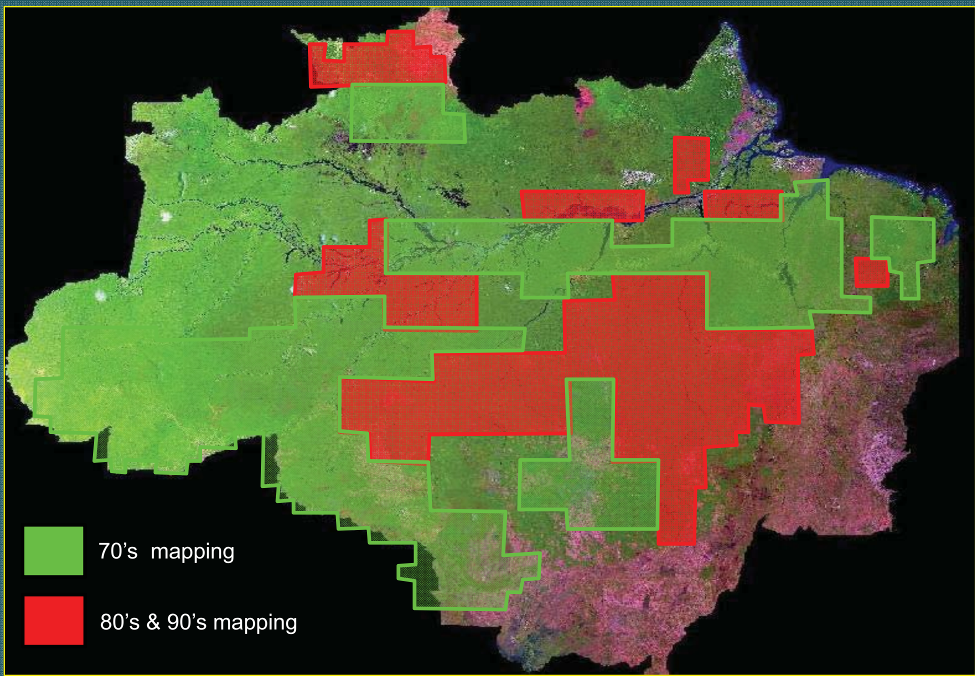
Amazon Region



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AMAZON CARTOGRAPHY PROJECT

✓ "Amazon Radiography": SAR (Synthetic Aperture Radar) data

✓ CENSIPAM (Operations and Management Center of the Amazonian Protection System)

✓ Use of PolInSAR X and P bands

✓ 2.9 x 0.9m spatial mapping resolution → 5.0 x 5.0m spatial product resolution

✓ 1st stage: Map approximately 1,150,000 km^2

✓ Process over 10 PB of data

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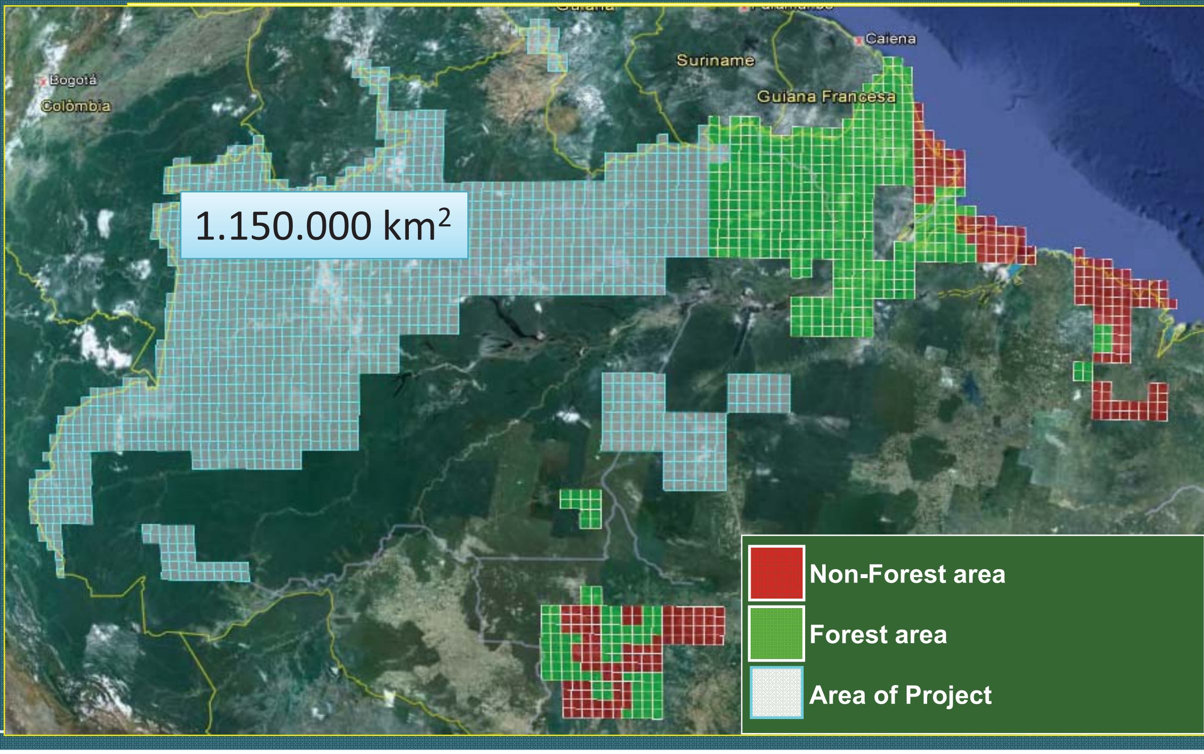
Cartographic Blank



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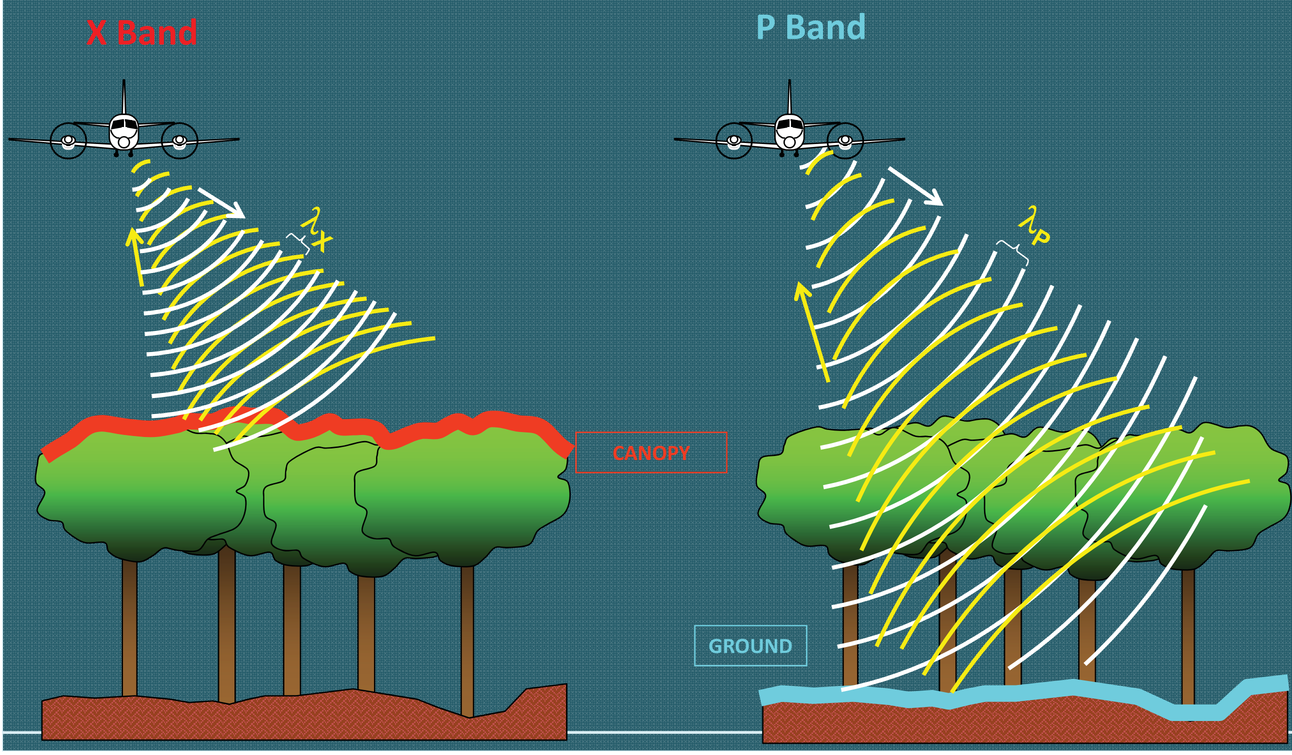
Technical Solution



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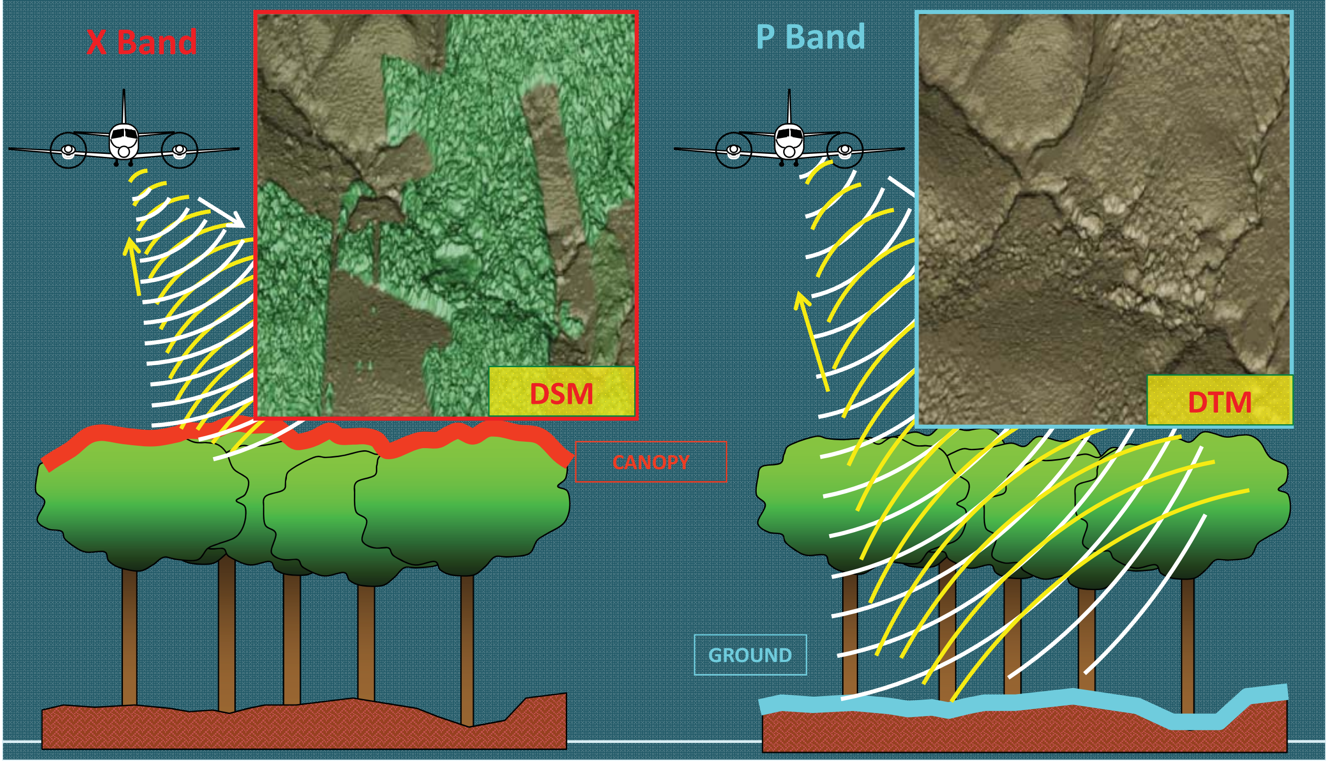
Technical Solution



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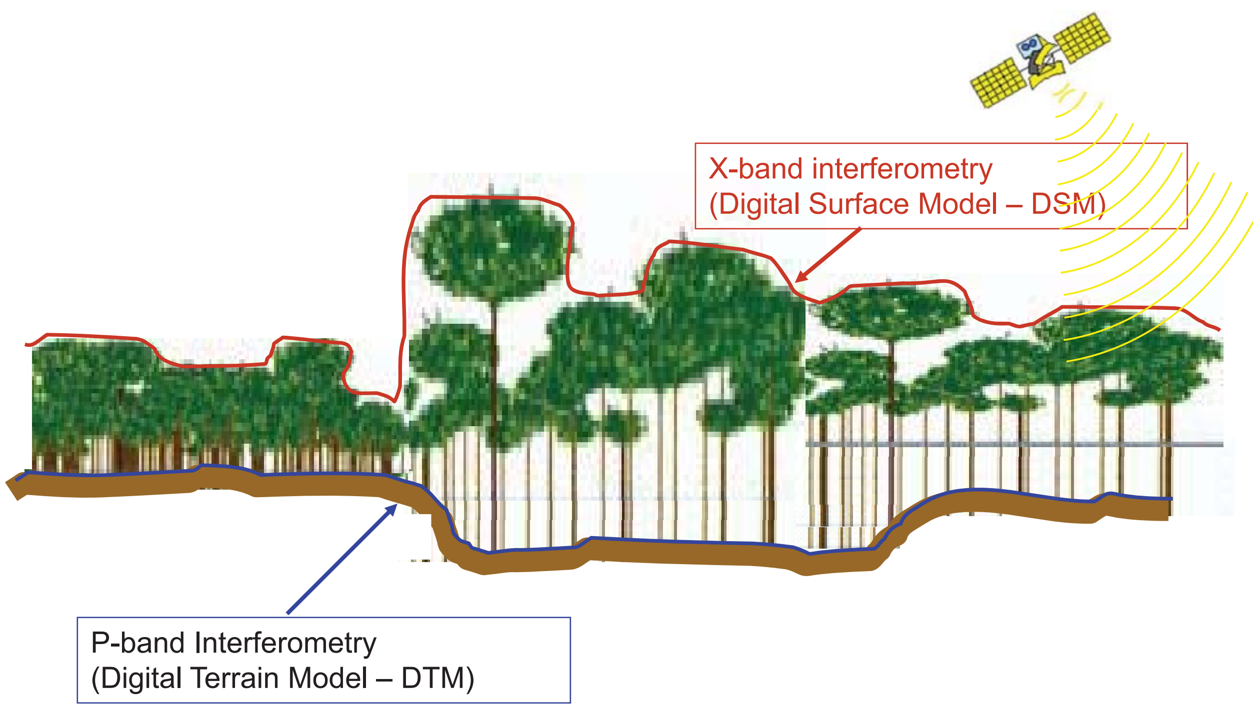

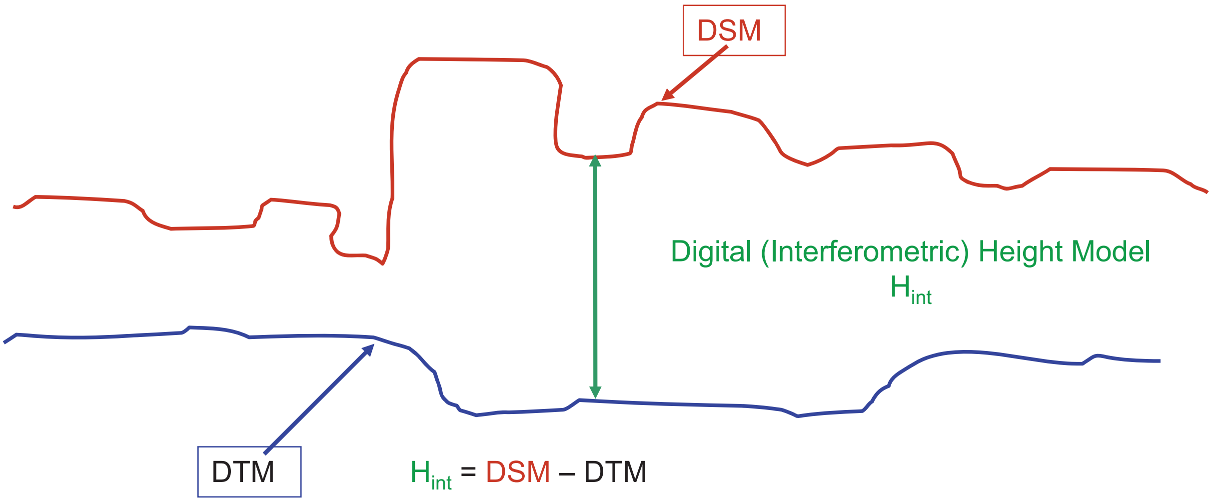

H_{int} = DSM – DTM

H_{int} is related to trees height

→ related to Biomass

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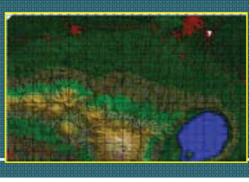
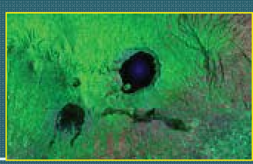
PHASES OF "AMAZON RADIOGRAPHY" PROJECT

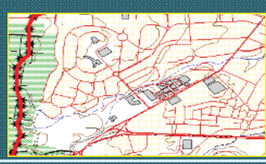
- Field Survey Data

- Processing of SAR data

- Extraction of Cartographic Features







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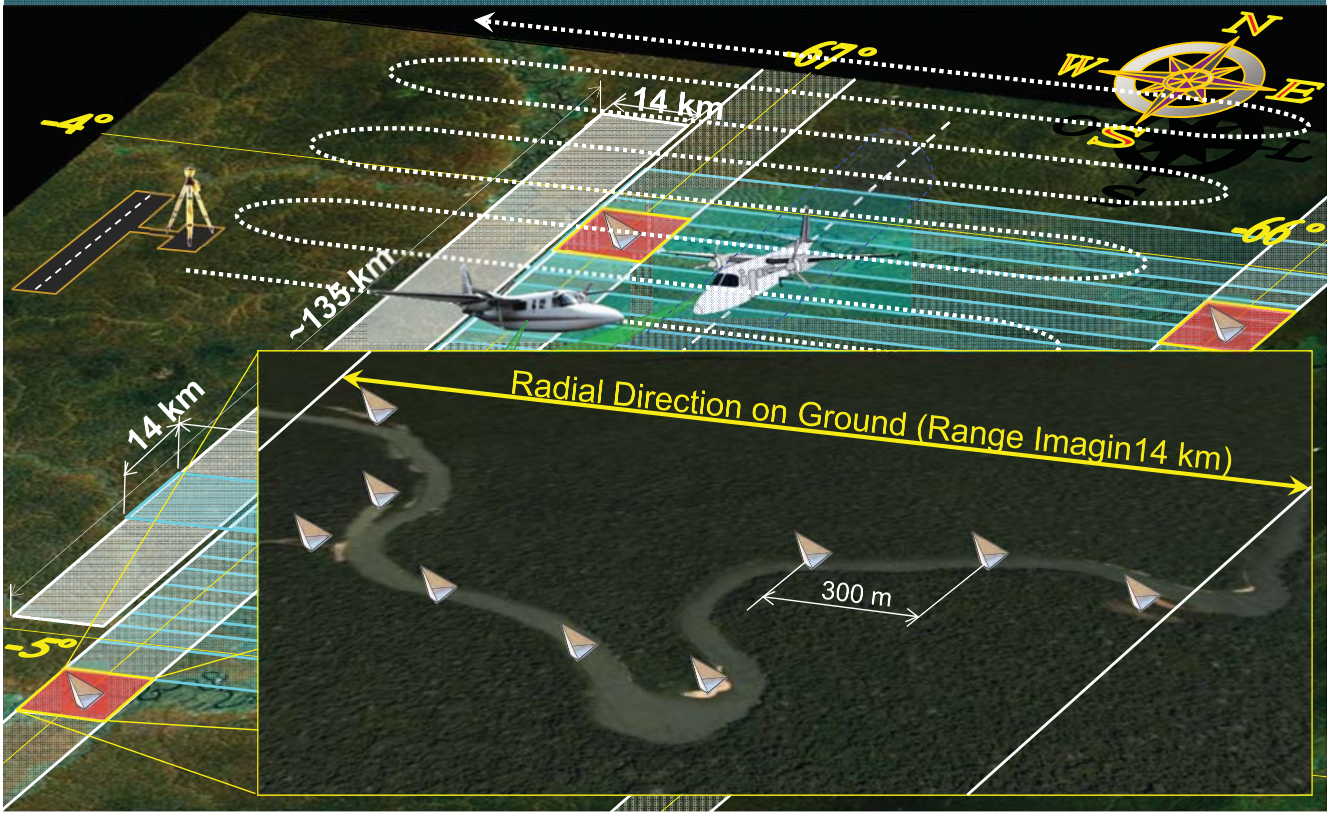

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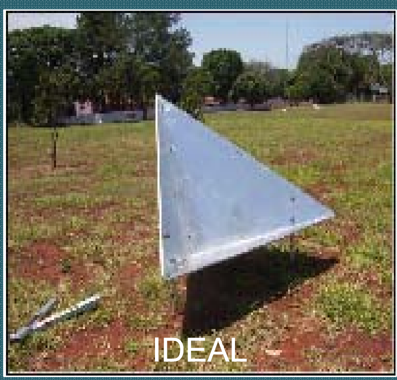
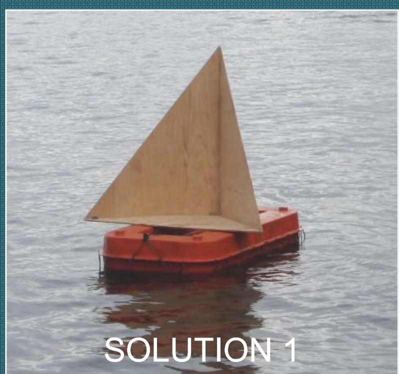
RADAR PRE-SIGN SOLUTIONS





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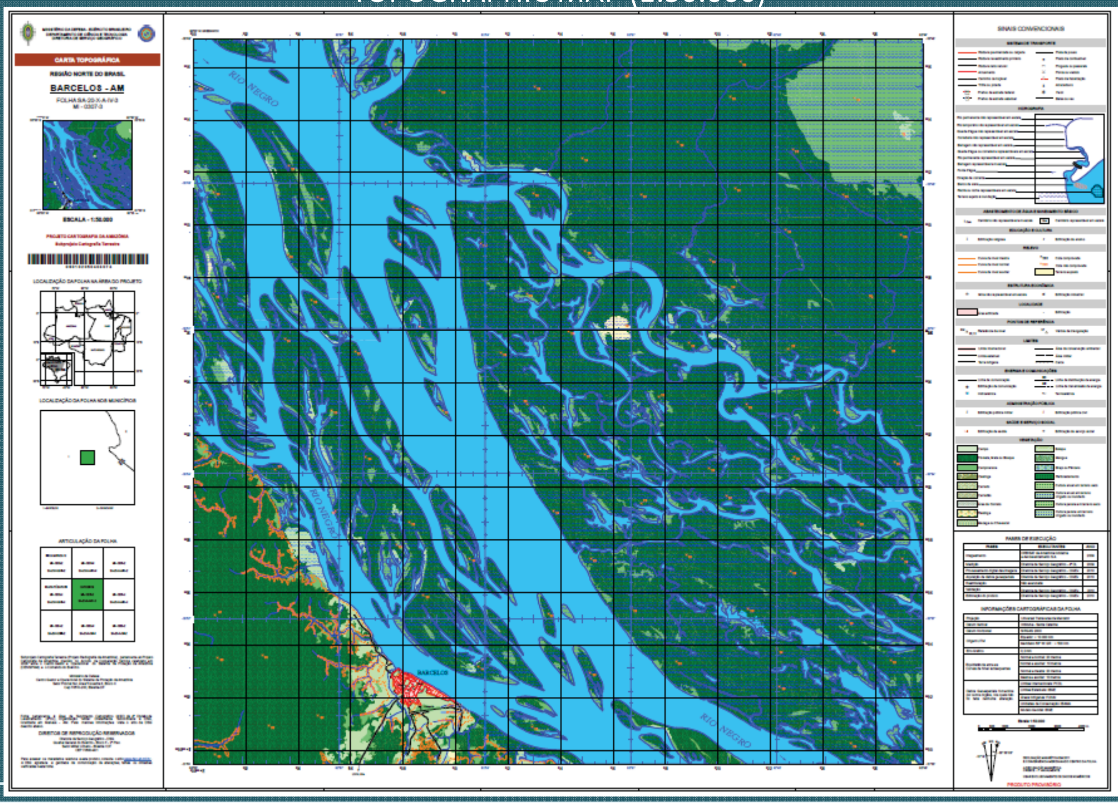
TOPOGRAPHIC MAP (1:50.000)



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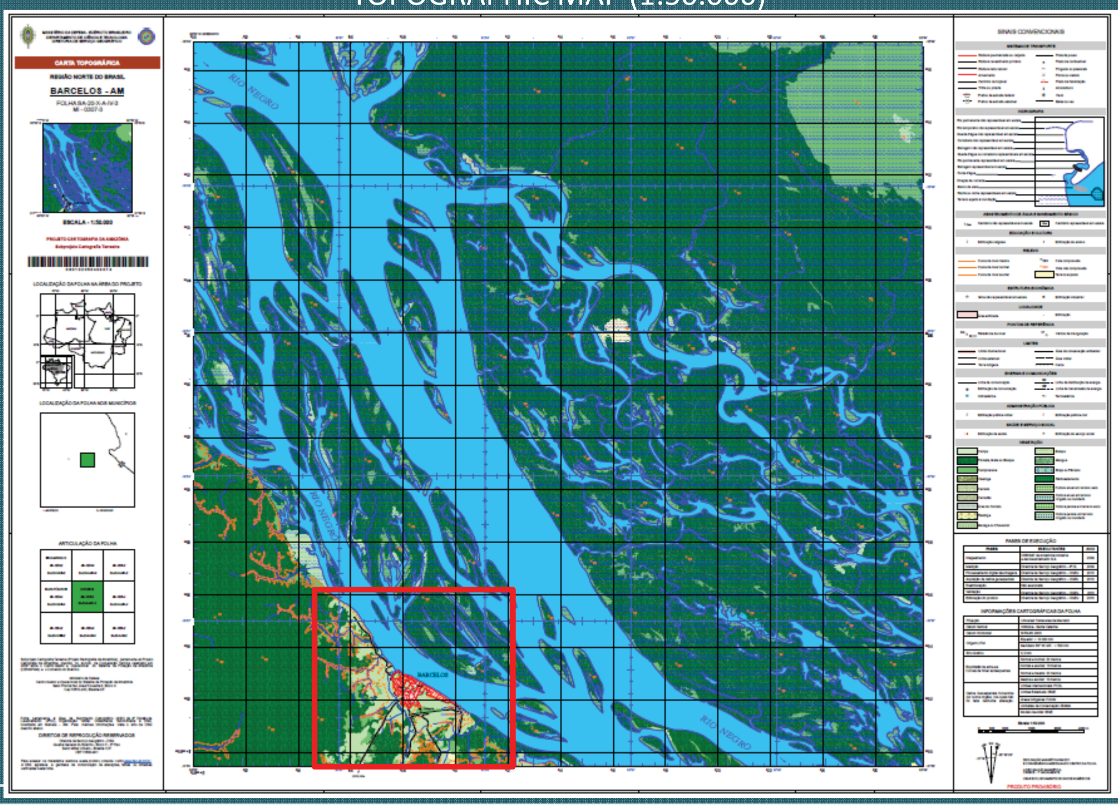
TOPOGRAPHIC MAP (1:50.000)



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TOPOGRAPHIC MAP (1:50.000)

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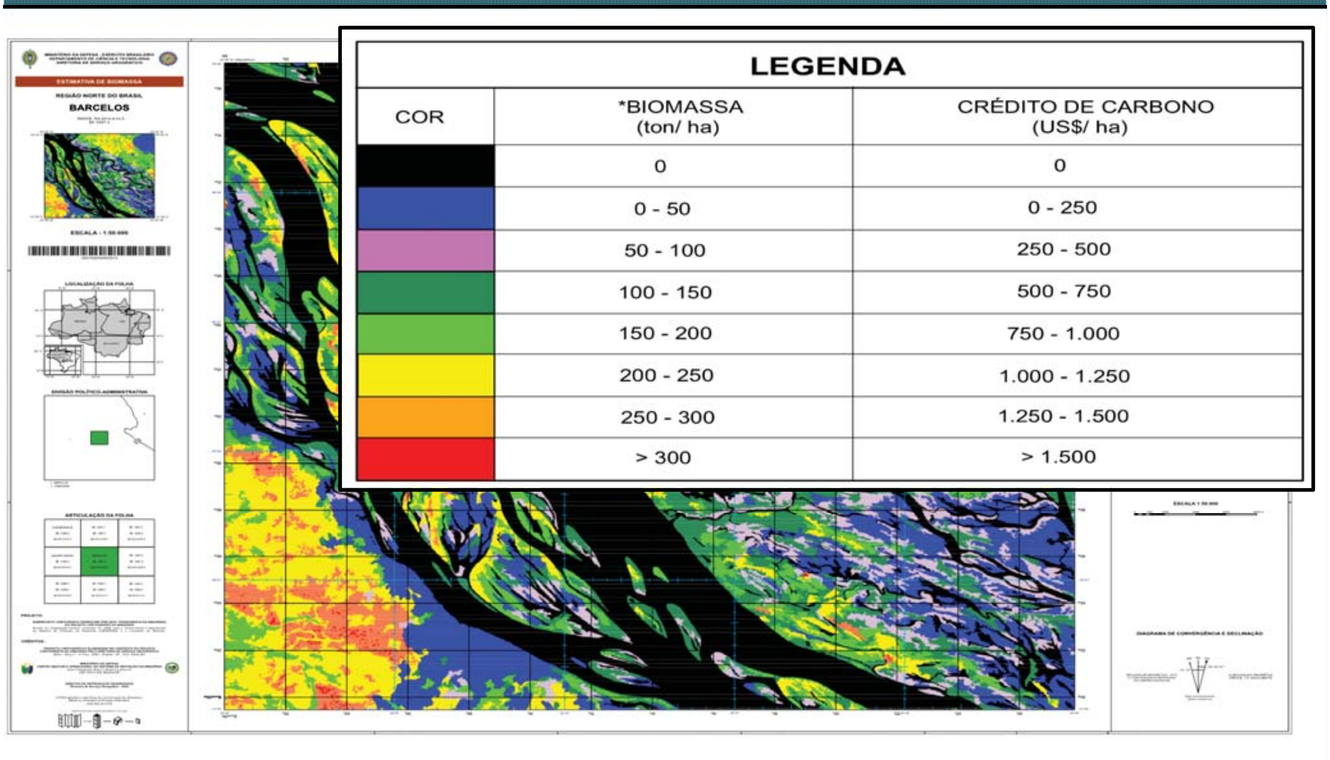
Carbon Stock



LEGENDA

COR	*BIOMASSA (ton/ ha)	CRÉDITO DE CARBONO (US$/ ha)
(preto)	0	0
(azul)	0 - 50	0 - 250
(rosa)	50 - 100	250 - 500
(verde escuro)	100 - 150	500 - 750
(verde claro)	150 - 200	750 - 1.000
(amarelo)	200 - 250	1.000 - 1.250
(laranja)	250 - 300	1.250 - 1.500
(vermelho)	> 300	> 1.500

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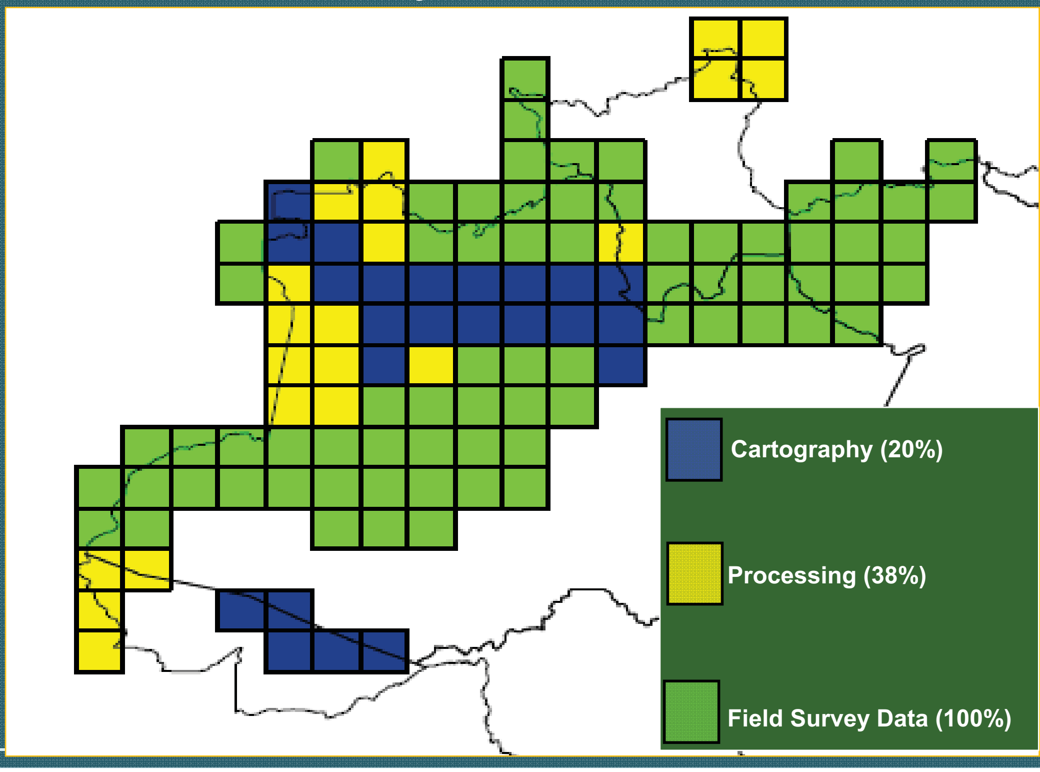
Project Status



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Carbon Dynamics of Amazonian Forest Project

✓ proposed by the Government of Brazil and the Forestry and Forest Product Research Institute in Japan: agreement with JICA in 2009

✓ Aims at building a foundation on conserving Amazonian forest to contribute to the countermeasures against deforestation and global climate change, including REDD activities

✓ INPA (Brazilian National Institute for Amazon Research): 205 new continuous forest inventories (CFI) in accordance with IPCC guideline of 2006

✓ plots of 125 x 20 m in São Gabriel da Cachoeira and Unini: DBH (> 10cm)

✓ LIMA et al. Allometric models for estimating above- and below-ground biomass in Amazonian forest at São Gabriel da Cachoeira in the upper Rio Negro, Brazil. Forest Ecology and Management, 227 (2012)163 -172.

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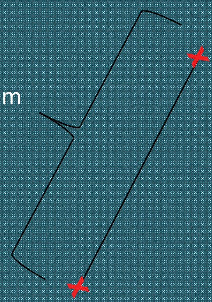
Data Received

Cam 1 A Fi,-0.126509321853519,-67.0155487954617,29-ago-10 9:05:07
Cam 1 A In,-0.127532836049795,-67.0159766077996,29-ago-10 8:11:25
Cam 1 B Fi,-0.12435257434845,-67.0145147200674,29-ago-10 9:53:56
Cam 1 B In,-0.125418165698648,-67.0149656664581,29-ago-10 9:32:50
……

Plot area:



- Coordinate transformation from Lat/Lon to UTM from center points

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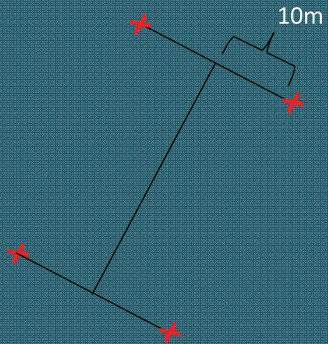
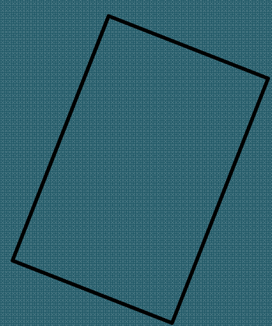
Data Received

Cam 1 A Fi,-0.126509321853519,-67.0155487954617,29-ago-10 9:05:07
Cam 1 A In,-0.127532836049795,-67.0159766077996,29-ago-10 8:11:25
Cam 1 B Fi,-0.12435257434845,-67.0145147200674,29-ago-10 9:53:56
Cam 1 B In,-0.125418165698648,-67.0149656664581,29-ago-10 9:32:50
……

Plot area:



- Acquisition of the four coordinates of the polygon.



- Construction of the plot´s polygon

Biomass Prediction Models Using RADAR Data

✓ PolSAR high frequency C and X bands saturate at 40t/ha

✓ PolSAR low frequency L and P bands saturate at rates above 100t/ha

(BEAUDOIN et al., 1994; POPE et al., 1994; IMHOFF, 1995; KASISCHKE et al., 1997; SAATCHI e MOGHADDAM, 2000; ASKNE et al., 2003; SANTOS et al., 2003; e SAATCHI et al., 2007)

✓ PolInSAR data can achieve rates over 300t/ha

(NEEFF et al., 2005; GAMA, 2007; TREUHAFT et al., 2009; WILLIAMS et al., 2009; NI et al., 2010)

State-of-Art RADAR Biomass Prediction Models for Brazilian Amazon Forest

✓ NEEFF et al. (2005)
✓Tapajós region: Center of the Amazon forest
✓ 44 plots ranging from 5.0 (SS) to 350.0 (PF) t/ha
✓ $r^2 = 0.84$

$$AGBiomass = 44{,}965 + 13{,}87 H_{int} + 10{,}566 \sigma^{0}_{pHH}$$

✓ SAMBATTI et al. (2012)
✓Paragominas region: East of Amazon forest
✓ 42 plots ranging from 0.042 (SS) to 385.077 (PF) t/ha
✓ $r^2 = 0.83$

$$log_{10}\ AGBiomass = -6.68 + 6.94\, log_{10}\ H_{int} - 0.03(\ pHV - pVV\ )$$

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Study Area

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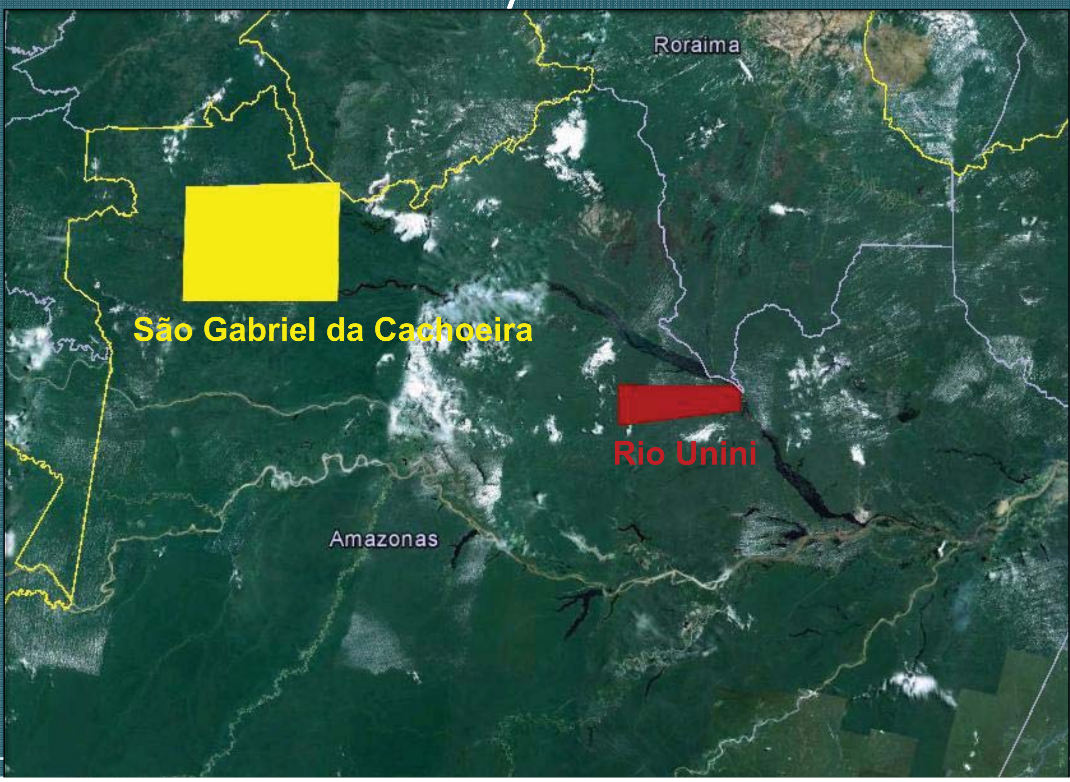
Study Area



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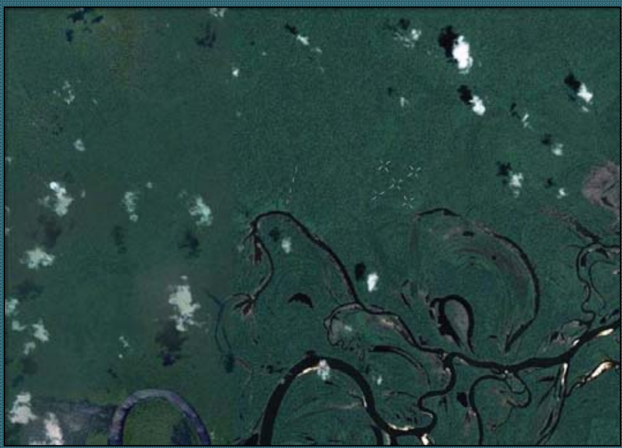
Study Area



- ✓ Rio Unini watershed
- ✓ Isolated site
- ✓ dense tropical forest
  X
  areas of contact between campinarana (grassland) and evergreen forest
- ✓ 60 plots on the radar processing block of 6263w0102s

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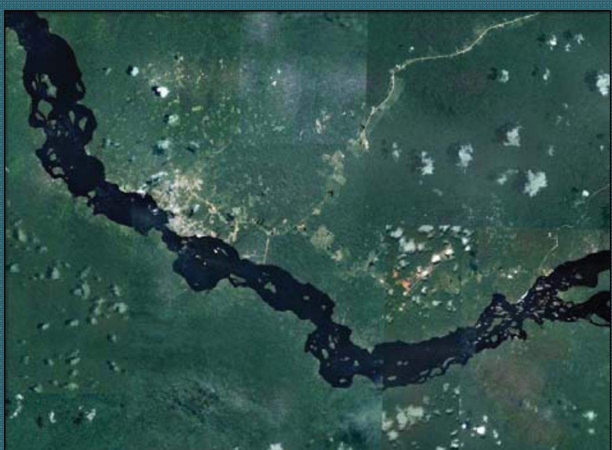
Study Area



- ✓ São Gabriel da Cachoeira city surroundings
- ✓ original homogeneous primary forest intercepted with campinarana
- ✓ 29 plots on the radar processing block of 6768w0001s

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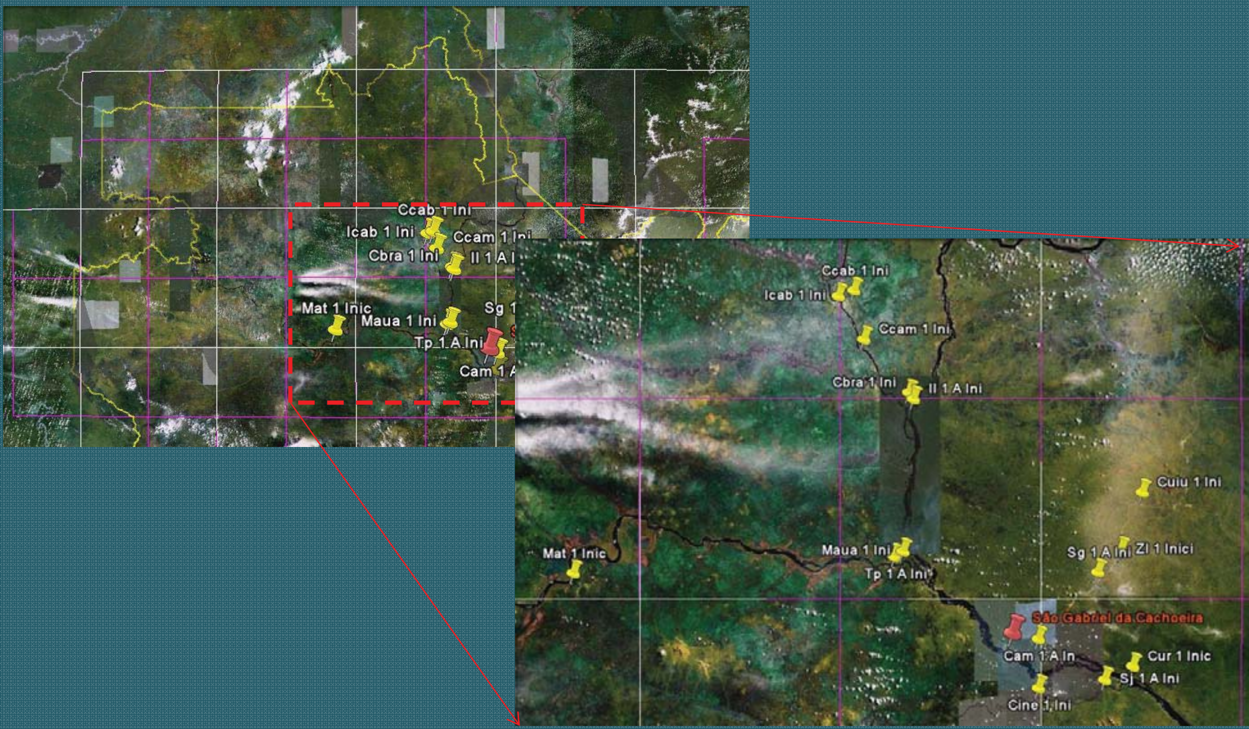

Google Earth (2010)

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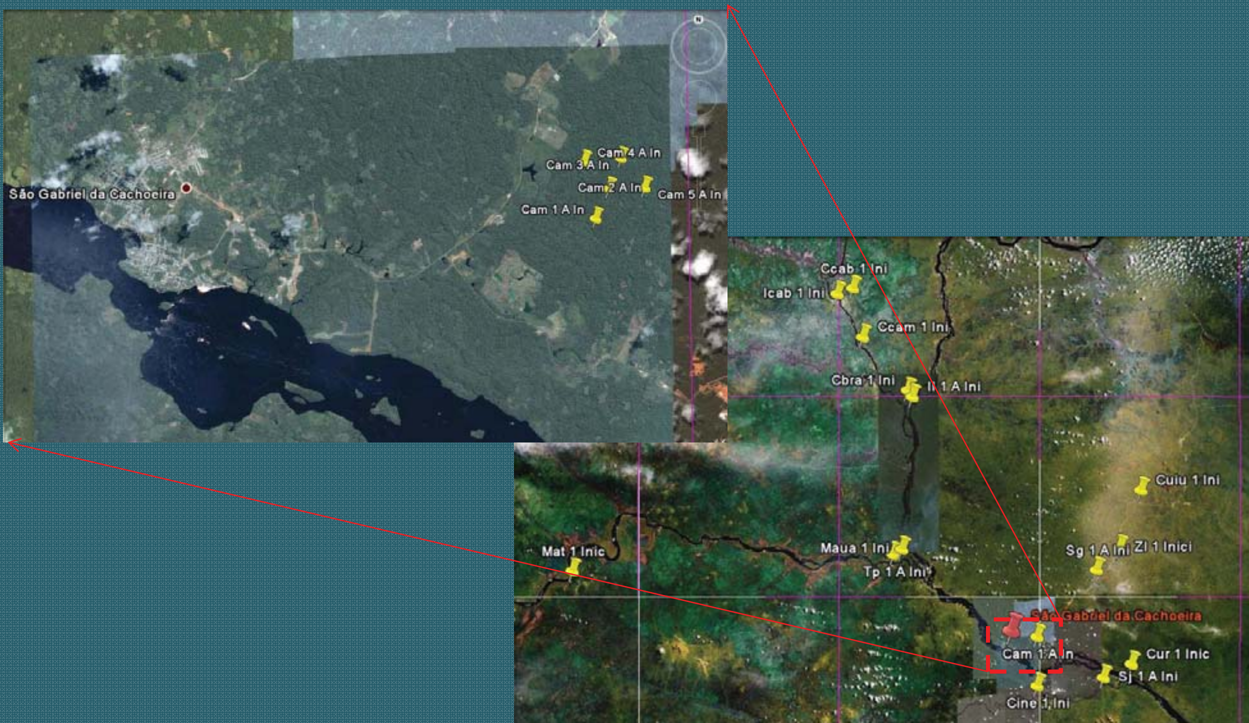
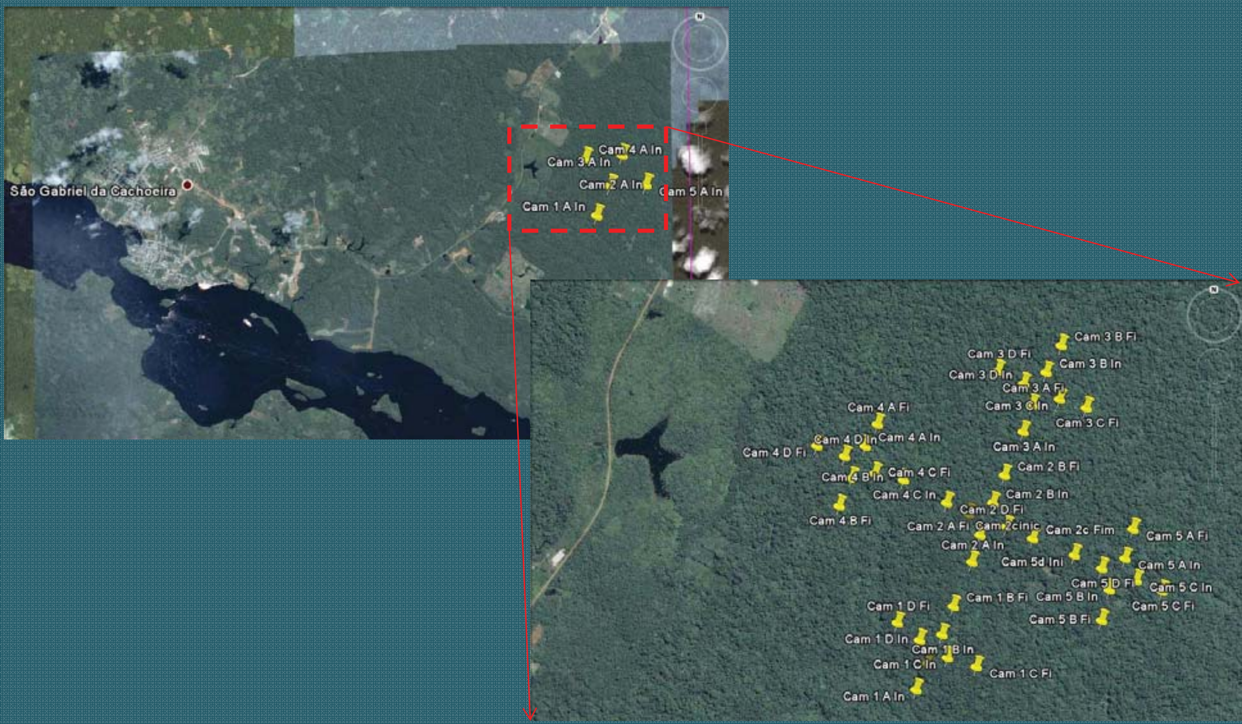


Google Earth (2010)

BRAZILIAN NATIONAL INSTITUTE FOR SPACE RESEARCH



Google Earth (2010)

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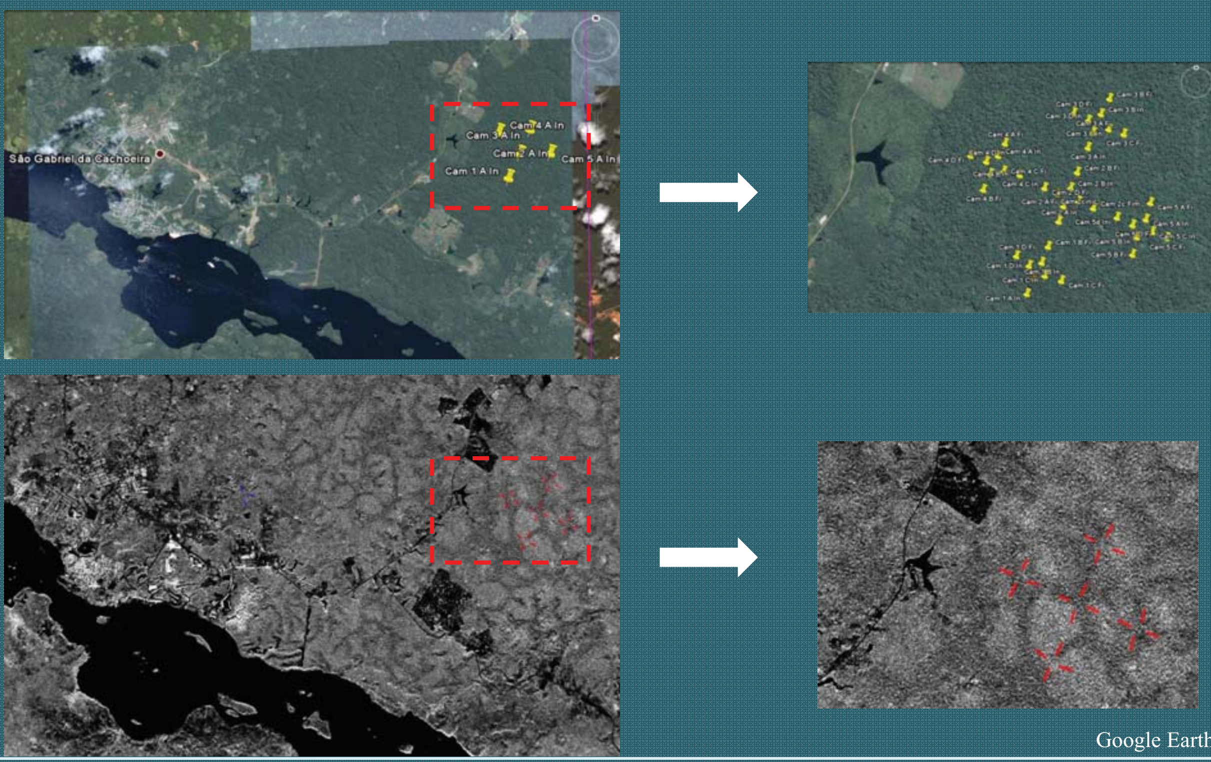
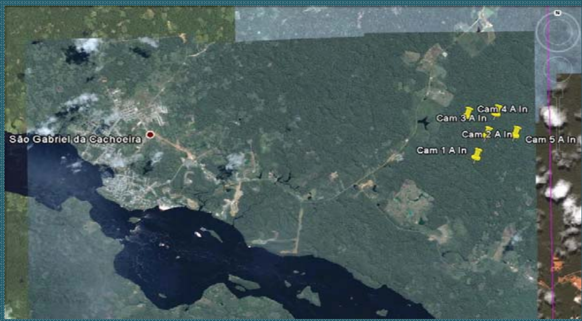
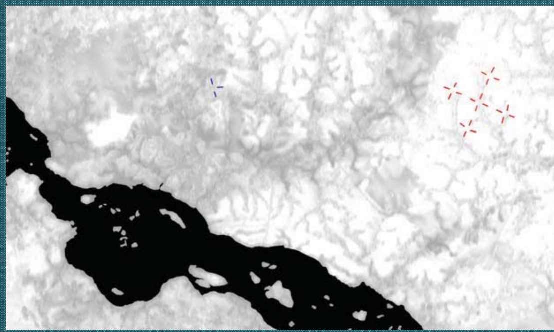


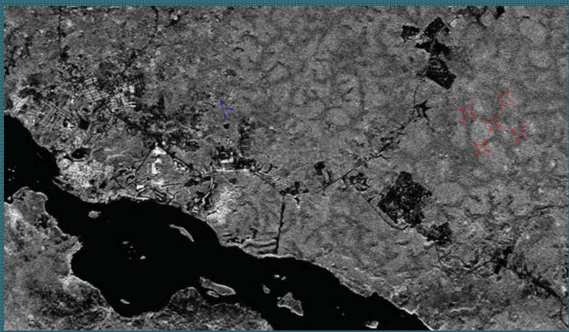
Google Earth (2010)



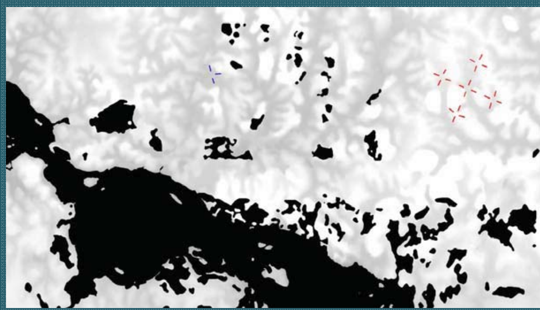
Google Earth (2010)



DSM (InSAR X)



Amplitude image Phh



DTM (InSAR P)

Method for the Preliminary Results

- ✓ feature extraction using texture and topography: 118 independent variables
- ✓ Pearson correlation method and forward stepwise multiple regression method to select up to 20 features
- ✓ best subset search method to analyze the multiple regression models using the previously selected features
- ✓ the higher determination coefficient was chosen after analyzing the correlation between the variables: no statistical significant correlation was accepted
- ✓ graphs were built to analyze each variable
- ✓ detailed residual and outlier analyzes are still to be done

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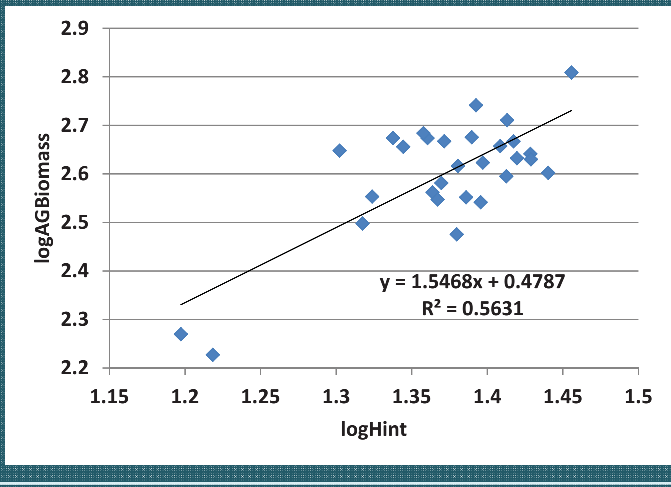
Preliminary Results and Analysis – São Gabriel da Cachoeira

- ✓ 29 plots ranging from 169t/ha to 643t/ha
- ✓ $log_{10}AGBiomass = -18.48 + 1.33(log_{10}H_{int}) + 0.003(X_{hh}Mean) + 8.62(P_{hv}Entropy)$
- ✓ $r^2=0.69$
- ✓ larger range of *AGBiomass* values
- ✓ significant correlation between *AGBiomass* and H_{int}



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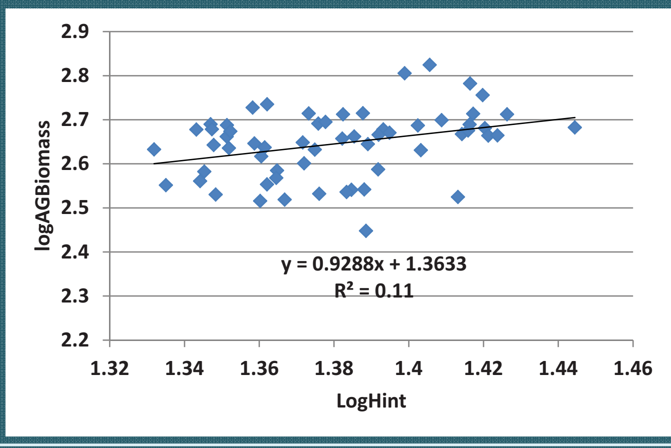
Preliminary Results and Analysis – Unini

- ✓ 60 plots ranging from 280t/ha to 668t/ha
- ✓ $log_{10}AGBiomass = -1.86 + 0.64(log_{10}H_{int}) + 0.02(P_{vv}Correlation) – 0.21(P_{hv}-P_{vv})$
- ✓ $r^2=0.41$
- ✓ shorter range of *AGBiomass* values
- ✓ poor correlation between *AGBiomass* and H_{int}



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Conclusion

✓ The mapping of the Amazon Forest has a strategic dimension and it will provide a deeper understanding of the region, including geospatial data of biomass and carbon stocks.

✓Different regions of the Amazon forest must be first analyzed separately, creating different models.

✓The interferometric height has been proven as a significant variable on the estimation of biomass.

✓ Possibility for LIDAR data to calibrate the interferometric height

✓ Further analyzes will be held.

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Thank you!

pires@dpi.inpe.br

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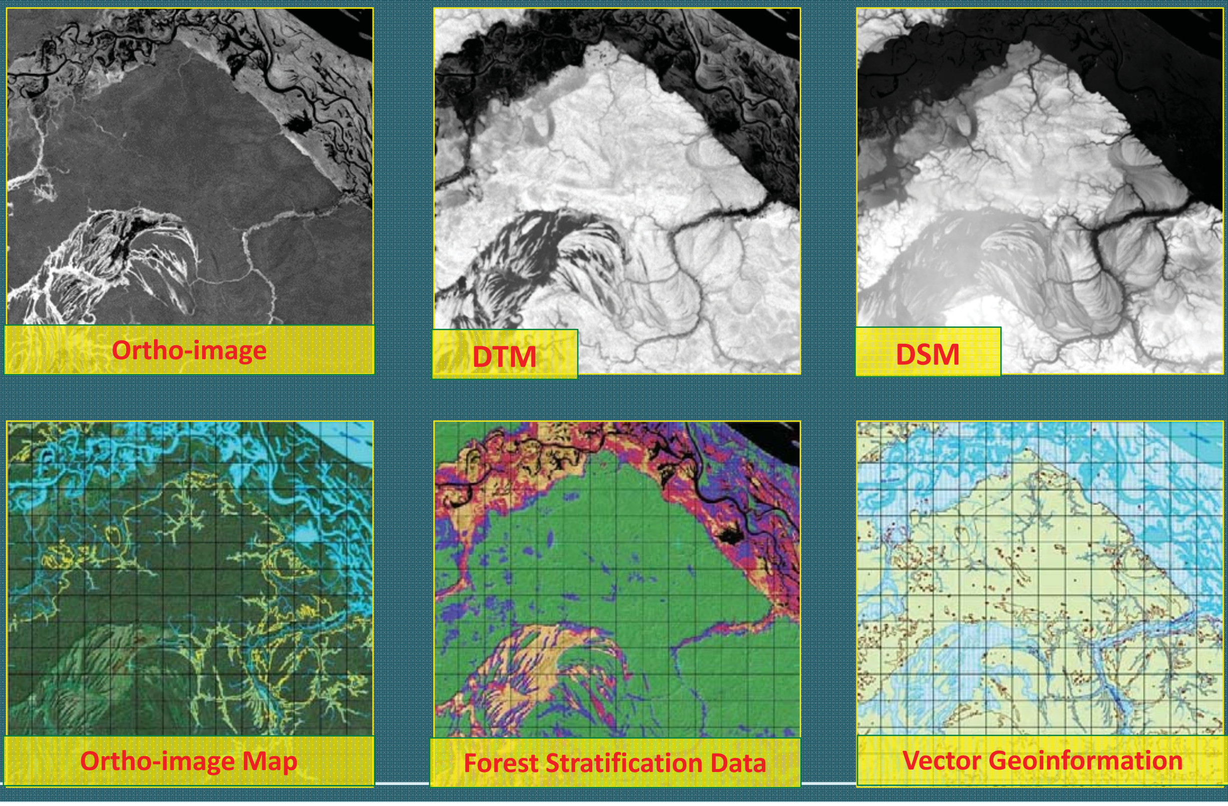

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Doctoral Thesis – Main Stages

Feature extraction
↓
Feature Selection
↓
Prediction Models - KDD
↓
Models Evaluation
↓
Feature-class Discretization
↓
Map Construction

Field Work:
CFI and Biomass Measure by INPA in CADAF PROJECT

Data features needed:
- Idt and x/y of individual tree inside the plot;
- Idt and Lat/Lon of the plot;
- Accuracy of plot positioning;
- date of inventory;
- DBH;
- height ;
- family, genus and specie;
- other notes (condition of the individual, type of forest).

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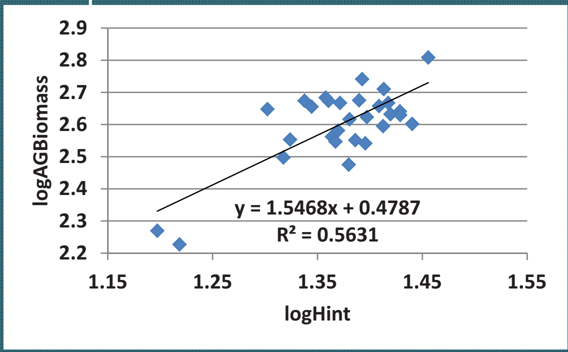
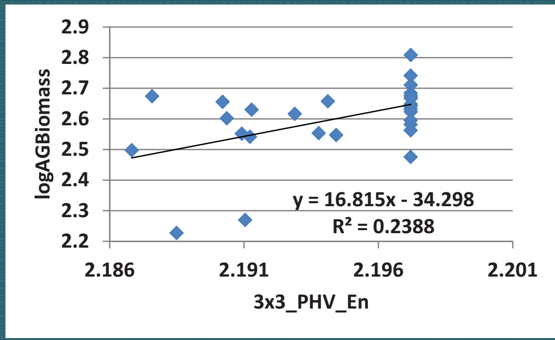
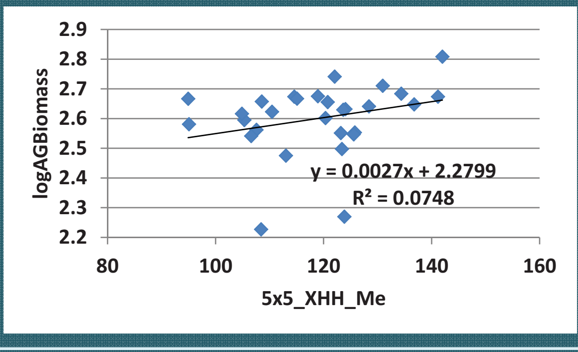
Preliminary Results – São Gabriel da Cachoeira

✓ Graphs







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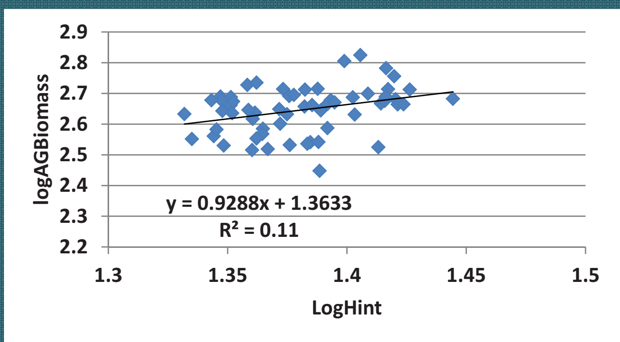
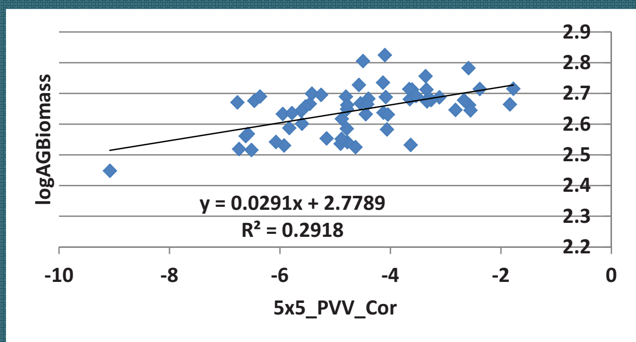
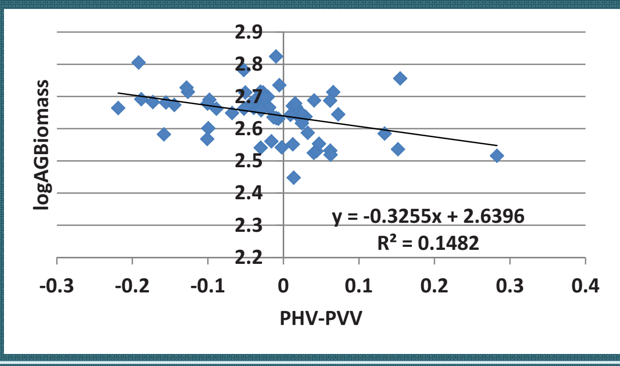
Preliminary Results – Unini

✓ Graphs







IPCC Expert Meeting
Role of Remote Sensing in Forest and National GHG Inventories
Hayama, Japan
23 – 25 October 2012

Analysis of the Normalized Differential Vegetation Index (NDVI) for the Detection of Forest Degradation Coverage in México

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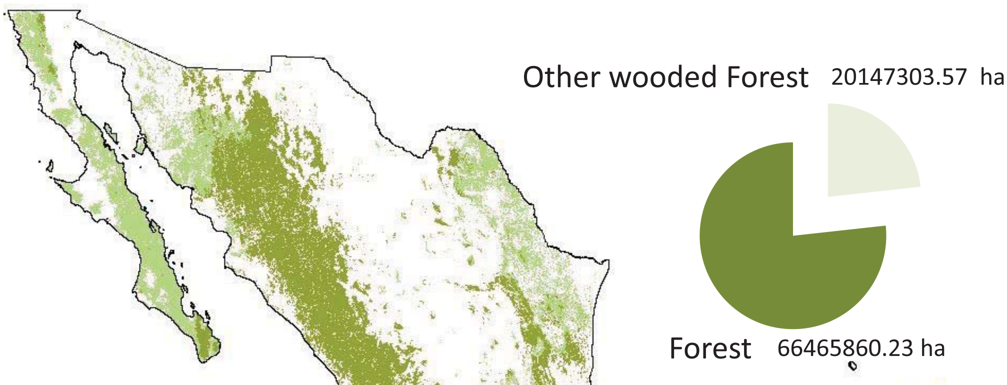
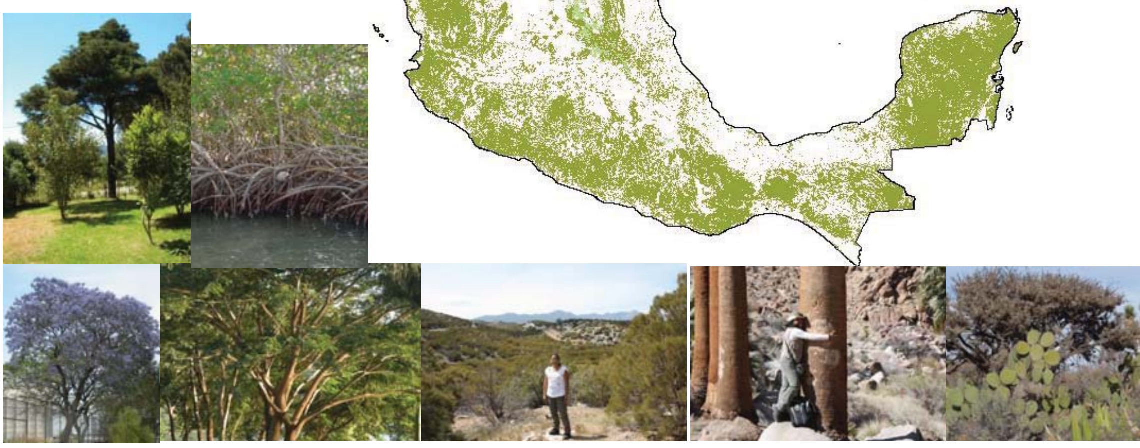
Sub manager of Remote Sensing
National Forest Inventory and Geomatic Department
National Forest Commission - Mexico
cmeneses@conafor.gob.mx / meneses_carmen@hotmail.com

Forest Cover in Mexico





Objetive

- Show the yearly trend of the forest coverage changes in the country
- Find relations between forest coverage features and the Normalized Differential Vegetation Index (NDVI) estimated from satellite imagery
- Detect forest degradation throw NDVI changes.

2006

2012

Study area:
México 1.956.612 km^2

Sensor: MODIS 250 m

Definitions: Understanding the Mexican Vegetation condition

<u>"Primary vegetation"</u> is defined as vegetation that preserves, in large part, its condition of density, coverage, and number of species, from its original, primary, ecosystem and from that represented in the cartography of Use of the Ground and Vegetation from INEGI at a scale of 1:250,000. (INEGI, 2004)

TEMPERATE FOREST
- ✓ Conifers (Pino)
- ✓ Oak (Quercus)
- ✓ Sacred fir (Abies u Oyamel)
- ✓ Cupressus (Cedro)
- ✓ Douglas fir (Ayarin)
- ✓ Mixed: Pine-oak and Oak-pine
- ✓ Mesophilus

TROPICAL FOREST
- ✓ High (perennial - deciduous)
- ✓ Medium (perennial - deciduous)
- ✓ Low (perennial - deciduous)

ARID AND SEMIARID AND OTHER
- ✓ Chaparral
- ✓ Mesquite
- ✓ Shrubs
- ✓ Wetland, mangroves, palm

<u>"Secondary vegetation"</u> is defined as the vegetation present where it has substituted totally or partially for the original (primary) vegetation as a result of some changes in the use of the ground or because of natural causes or where there is evidence of recovery of the vegetation community in some of the sucesional stages of vegetation ("trees", "bushes or shrubs" and "herbaceous)". (INEGI, 2004)

Definition

Deforestation or Loss of forest: permanent change in the forest coverage to land use.

- The loss of primary vegetation (e.g. Conifers forest→ Urban)
- The loss of primary vegetation with secondary trees vegetation (Conifers forest /VSA → Crop)

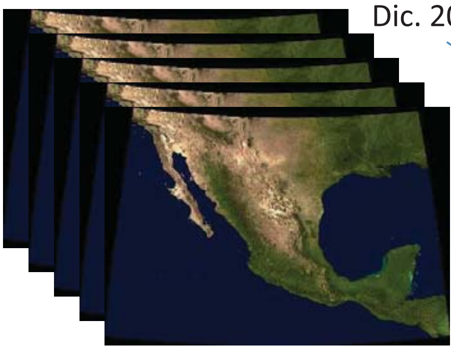
Degradation or alteration of the forest condition: indicates a change or degradation in the coverage without necessarily a loss from its original condition, but a negative change to a structure that diminishes its capacity to generate service and products and can be considered a loss of biodiversity or a decrease in biomass.

- primary vegetation that changes to secondary vegetation
- secondary vegetation that converts to inferior states for example from trees to bushes or tress to herbals

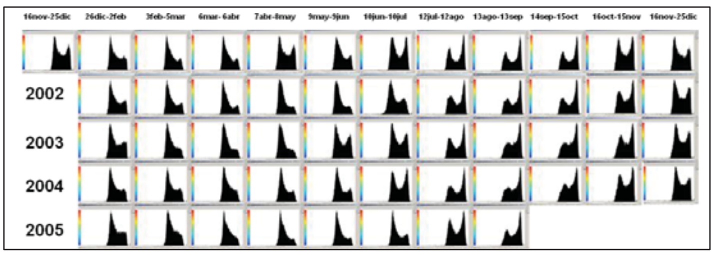
Recovery process: is the natural expansion of forest into areas where the land had been in use.




Input Data: MODIS satelite imagery



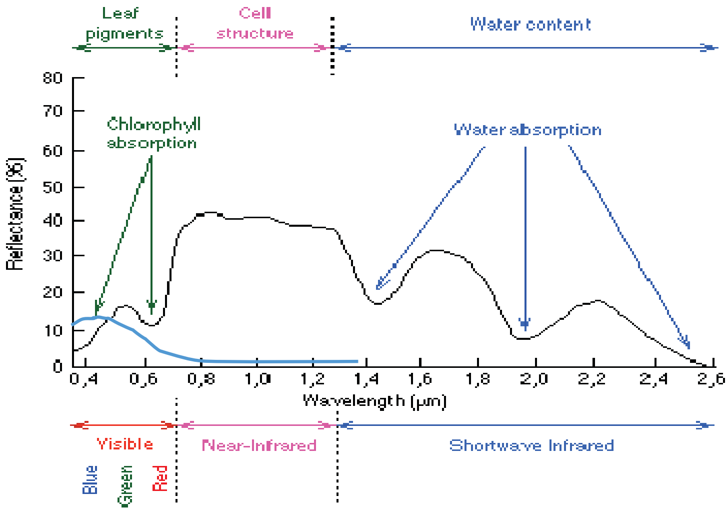
NDVI 53 monthly composites (32 days)

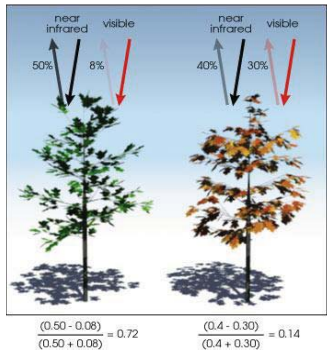


← Dry Period → | Transition | ← Wet Period → |Transition

Fuente: imágenes del sensor MODIS procesadas por el "Institute for Advanced Computer Studies" de la Universidad de Maryland, USA

Plant cell components and their reflectance behavior

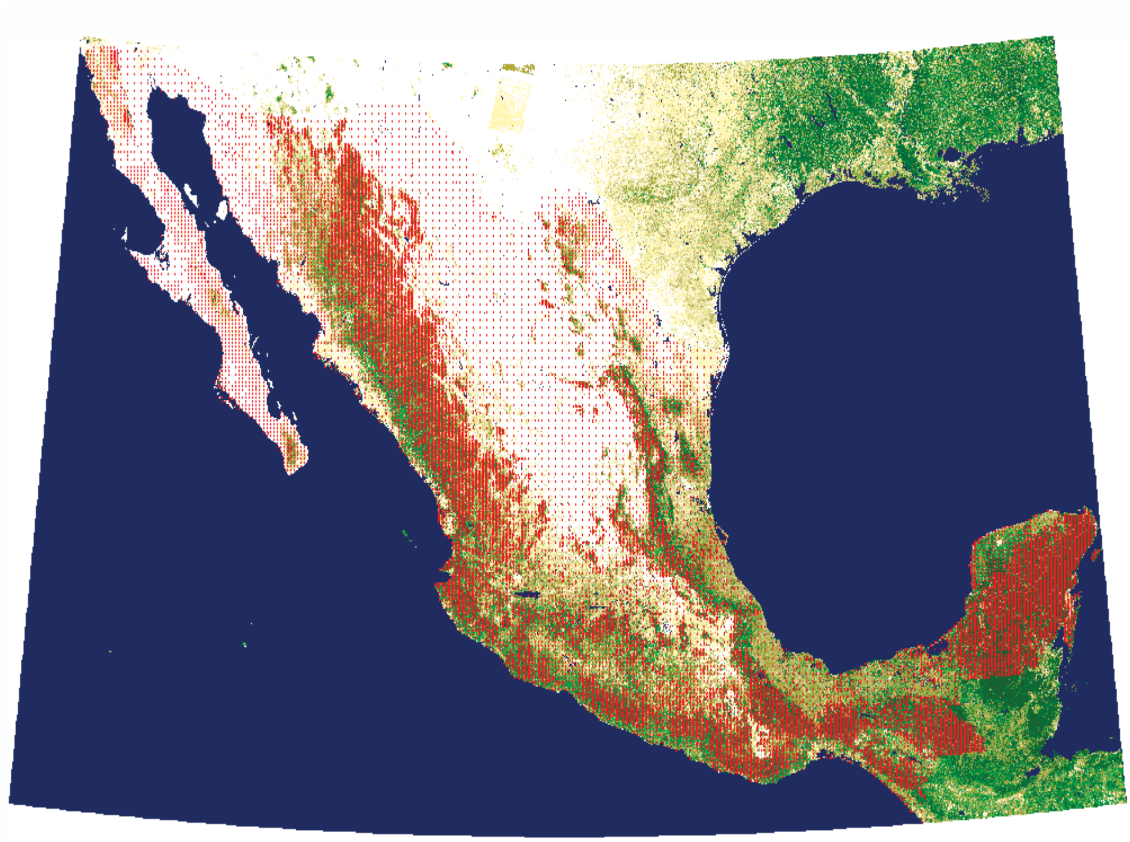




$$NDVI = \frac{B2 - B1}{B2 + B1}$$

[1] Servilla, M. S., Multispectral Remote Sensing and Agriculture, Photon Research Associates Inc. Albuquerque N.M. 1-4, 1998

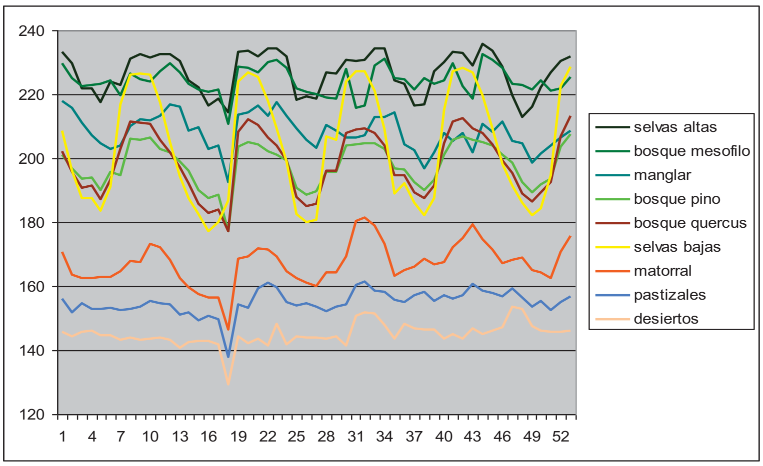
Fields subplots of National Forest and soils Inventories (NF&SI)



Classification of field observation of NFI between 2004 and 2007 by Vegetation community.

Vegetation community	National Statistics and Geography Institute key	Number of sites
Holm oak forest	Holm oak and holm oak-pine	20 139
Pine forest	Pine, fir, juniper, cypress Juniper and pine-holm oak with predominance of pine	6 276
Desert and dune	Microphyllous desert scrub land	199
Mangrove	*Rhizophora* spp.	980
Shrub land	Various types of scrub land	10 945
Mesophile forest	Very moist montane forest	1 526
Rangeland	Natural rangeland and through presence of sodium and chalk	235
High- and medium-altitude rain forest	High- and medium-altitude rain forest (deciduous or evergreen)	16 976
Lowland rain forest	Lowland rain forest (deciduous or evergreen)	6 470
Tule vegetation	*Thyphus* spp.	190
Without plant cover	Without plant cover	1 229

Yearly NDVI behavior by vegetation type



We applied statistic control of process methodology in every vegetated community taking in a count a level of 3 σ.
We found in forest and tropical forest that points below of the range have more standing dead or stumps than trees.

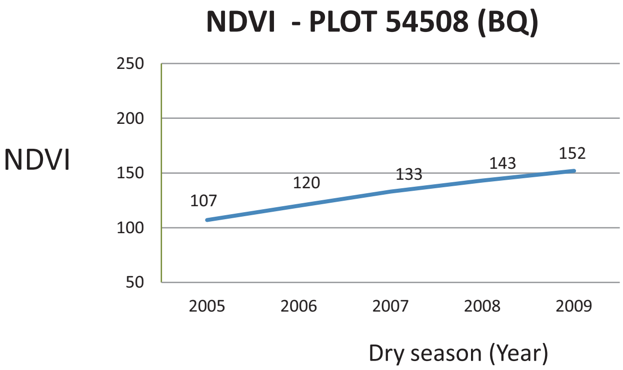






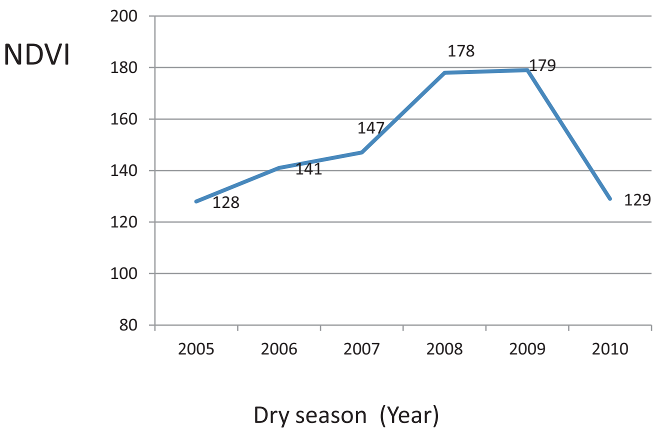
NDVI - Undisturbed plot

		cm	m	%	m	
Date	N° Trees	DN	DIAM crown	Cover	hight	Stumps
10/12/2005	160	13.25	3.47	89.5	11.37	5
08/06/2009	139	13.13	2.77	51	9.54	1

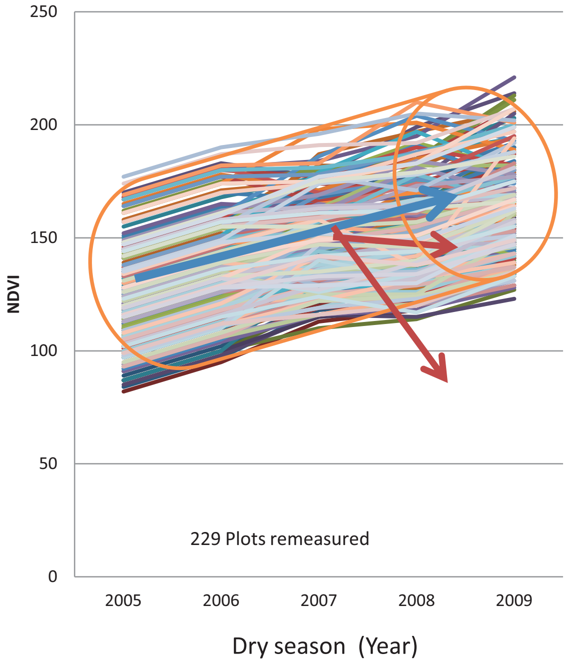


NDVI - Disturbed plot

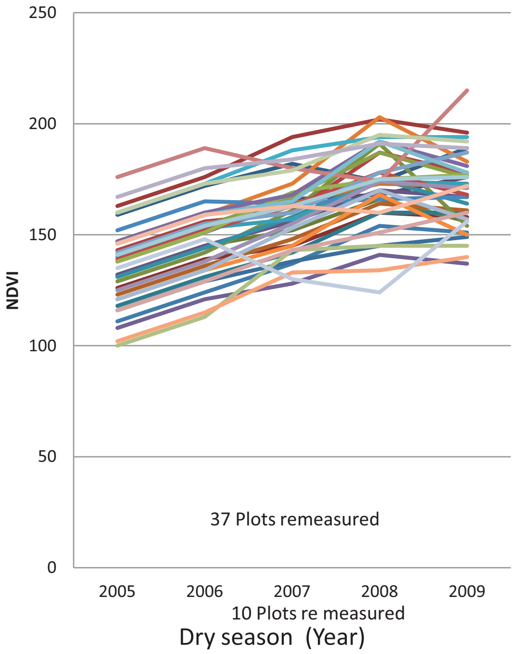
		cm	m	%	m	
date	N° Trees	DN	DIAM Crown	Cover	Hight	Stump
09/08/2005	192	11.82	2.51	60.1	8.98	0
17/04/2009	0	0	0	0	0	0



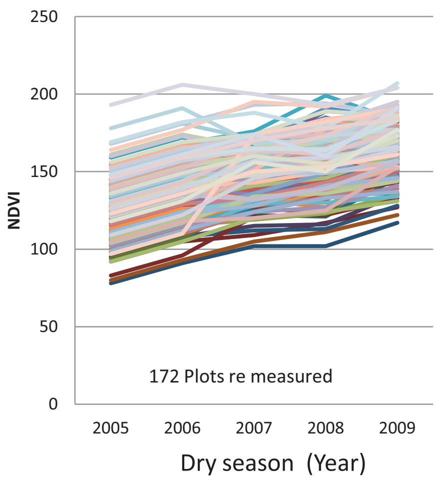
Oak Forest con VSA



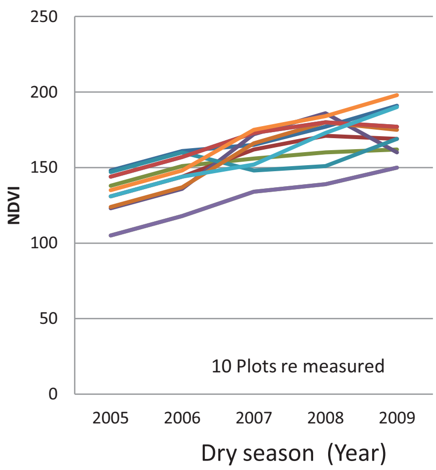
Deciduous Tropical Forest



Conniferus



Sacred Fir Forest



Resultado del Comparativo entre el NDVI de la época seca de los años 2011 y 2010

Some plot of the remeasured cycle with degradation indicate:

5 Re measured plot inside degradated areas

2 plot Damage by pest or insect 36 of 44 trees

2 plot Damage by fire 100 %

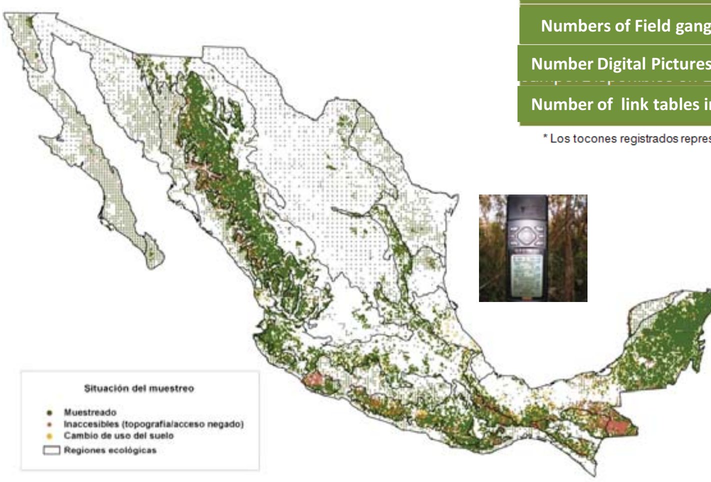
Damage by deforestation 1 subplot

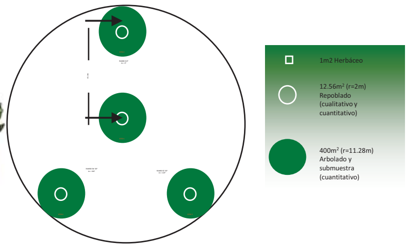
Input Data: National Forest Inventory (NFI) 2004 – 2007 and updating INF 2009 - 2014

Variables:
Trees: 39
Seedling and bushes strata: 23
Herbaceous strata: 20
Soil: 10
General and ecological information: 80

Inventario Nacional Forestal y de Suelos, muestreo de campo 2004 –2007	
Plot	24,659
SubPlot	81,665
Trees (DN ≥7.5 cm) and stump	1,305,130*
Trees (DN ≤ 7.5 cm) and shrubs	254,470
Numbers of Field gang	700
Number Digital Pictures of Field validation	150,000
Number of link tables in Data Base	76

* Los tocones registrados representan el 1.8% del total.

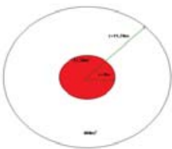




Other Variables: Seedling Data (Sub Plot 12.56 m^2) Sub Sample trees and Lichen and moss

COVERT (SUBPLOT 12.56 m^2)

Vegetation	Covert %
Tress	
Shrubs	
Herbaceous	
Total (0 - 300%)	



Genus	Frequency and age of seedling (Subplot 12.56 m2)						Vigor	Damage	Damage %	Use
	Height (m)									
	0.25 - 1.50		1.51 - 2.75		> 2.75					
	Frequency	Age	Frequency	Age	Frequency	Age				

1 No. árbol	2 Diámetro basal (cm)	3 Azimut *	4 Distancia * (m)	5 Edad (años)	6 No de anillos en 2.5cm	7 Longitud 10 anillos (mm)	8 Grosor de corteza (mm)	9 Distribución de productos (Número de trozas**)							
								1	2	3	4	5	6	7	8

Diversity of Epiphyte						
	Trunk			Branches		
Class	Scare < 15%	Abundant 15 - 40%	Plentiful > 40%	Scare < 15%	Abundant 15 - 40%	Plentiful > 40%
1. Bracken						
2. Orquids						
3. Moss						
4. Liquen						
5. Cactus						
6. Bromelias						
7. Others						

Estimation of Wood Volume m3 /ha from dasometric values.

The first approximation of the woody volume is calculate assuming a cone equation.

woody volume {m^3} $V = \frac{\pi \cdot r^2 \cdot h}{3}$

h= Total height (1.3 ≥ h ≤ 35 m)
r = DN/ 2 {m^2}
DN=diameter at breast height (7.5 ≥ h ≤ 100 cm)

In this equation do not taking in account: standing dead, stump, branches or specie

Estimation of Aerial Biomass Ton/ha

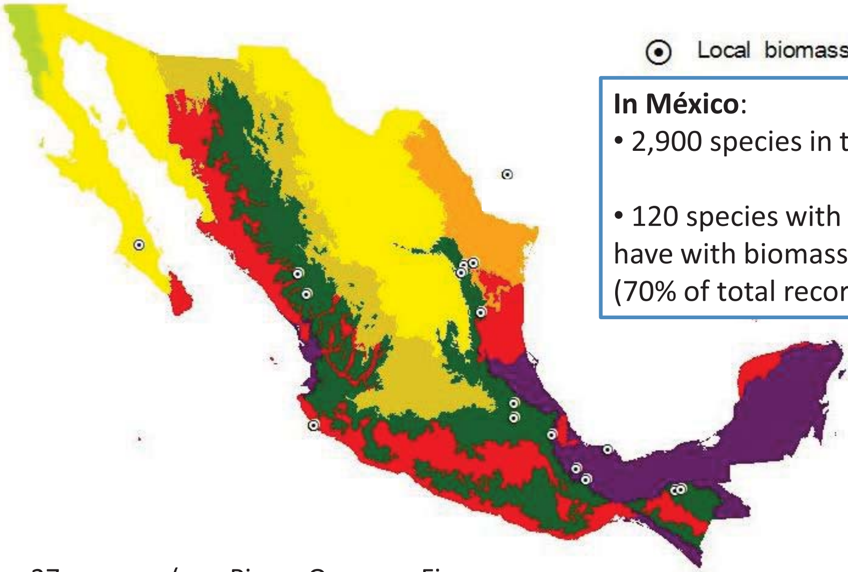
Quality control of NFI data:

- 1,267,446 records in the original database
- 37,334 records excluded from the biomass analysis

Causa de la exclusión del individuo		Condición del arbolado				
Criterio	Descripción	Árbol vivo	Árbol muerto en pie	Tocón con marca	Tocón sin marca	Total general
1	Cociente entre altura total y DN mayor a 2	464	41		2	507
2	Sin información de DN	2804	140	4063	18905	25912
3	Sin información de altura	69	198	59	198	524
4	AB del árbol muy grande	9	2			11
5	ΣAB árboles del conglomerado muy grande	2703	8			2711
6	Sin nombre científico de especie, nombre común o género		7612			7612
7	Condición de tocón (con o sin marca)			11	46	57
	Total general	6049	8001	4133	19151	37334

Fuente Ben de John et al.

Biomass data: Local allometric equation



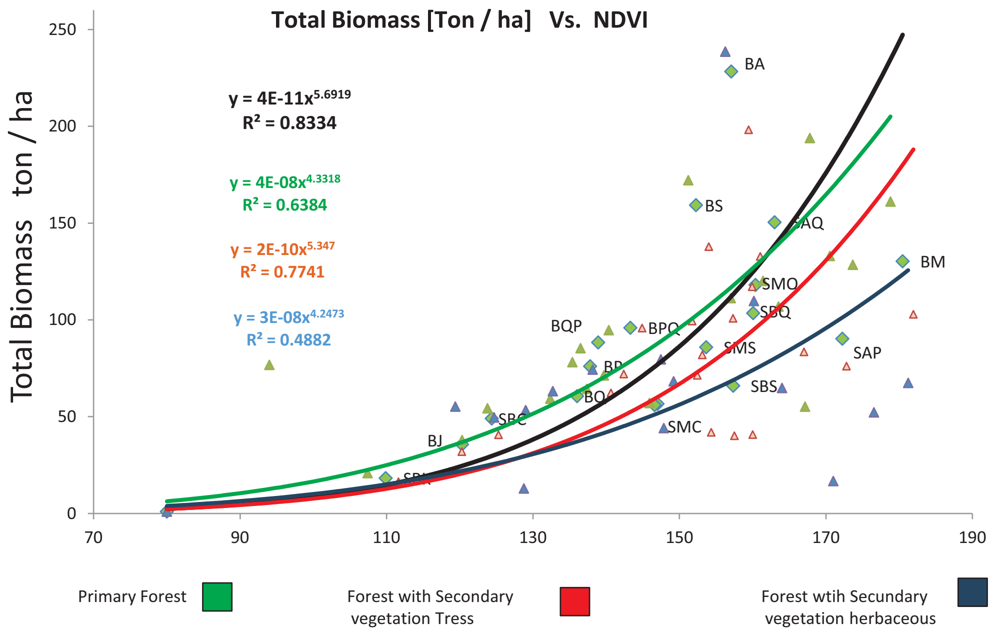
In México:

- 2,900 species in the NFI
- 120 species with >2000 records that have with biomass-volume equations (70% of total records)

27 genuses (e.g. Pinus, Quercus, Ficus, Piper)
176 species have eq. (some species with more than one eq. E.g. *Pinus pseudostrobus*)

Fuente Ben de John et al.

Relation between NDVI and Biomass



Discussion

Limitation about images:

- ✓ *Anisotropic illumination considerations*
- ✓ *Atmospheric effect considerations*
- ✓ *Presence of clouds and cloud shadows.*
- ✓ *Noise from the reflectance of vegetated ground*
- ✓ *Effect of treatment of the data or of saturation on NDVI*
- ✓ *Phenological aspects of the vegetation.*

Limitation by Biomass estimation

- ✓ seedling
- ✓ Fallen leaves
- ✓ Fuel
- ✓ Stumps
- ✓ Standing dead
- ✓ Branches
- ✓ Trees bellow 7.5 cm DHB
- ✓ There is not equation for arid and semiarid areas, wetland or jungles.

Oportunity areas in degradation indicators

Plot level volume increment based on re-measured sites

- ✓ In 2008 about 2,000 plots re-measured (e.g. DBH, Height)
- ✓ In 2009 there will be 4,500 plots re-measured

We can explore others data base information.

- ✓ Liquen and moss
- ✓ Number of species
- ✓ Damage condition
- ✓ Soil information
- ✓ Fuel.
- ✓ Covert
- ✓ Stump
- ✓ Standing dead

Forest stand dynamics

- ✓ Growth rate
- ✓ Mortality rate
- ✓ Harvesting rate

Published

www.fao.org/forestry/fra

www.fao.org/forestry/unasylva





http://infoteca.semarnat.gob.mx/website/geointegrador/mviewer/viewer.htm

http://148.223.105.188:2222/gif/snif_portal/index.php?option=com_content&task=view&id=61&Itemid=98

www.fao.org/forestry/unasylva

Thanks for your attention

Using SPOT-5 satellite multispectral imagery and LiDAR data to monitor forest carbon stocks and stock change in New Zealand

Deborah Burgess, NZ Ministry for the Environment

Ministry for the Environment
Manatū Mō Te Taiao

LUCAS
LAND USE AND CARBON ANALYSIS SYSTEM

Outline

- New Zealand's national circumstances
- Mapping forest land and land-use change using satellite remote sensing
- Quantifying carbon stock using ground-based forest plot measurements and LiDAR metrics

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LUCAS
LAND USE AND CARBON ANALYSIS SYSTEM

New Zealand's National Circumstances

- All forest lands are managed
  - 8 million hectares of natural forest
  - 2 million hectares of planted forest
- No pre-existing national spatial forest inventory
- Signatory to UNFCCC and Kyoto Protocol
- Historical difficulties obtaining access to forests

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Forest definition

- New Zealand has chosen the following parameters:
  - Tree height at maturity of 5 metres
  - Minimum crown cover of 30%
  - Minimum area of 1 hectare
  - Minimum width of 30 metres

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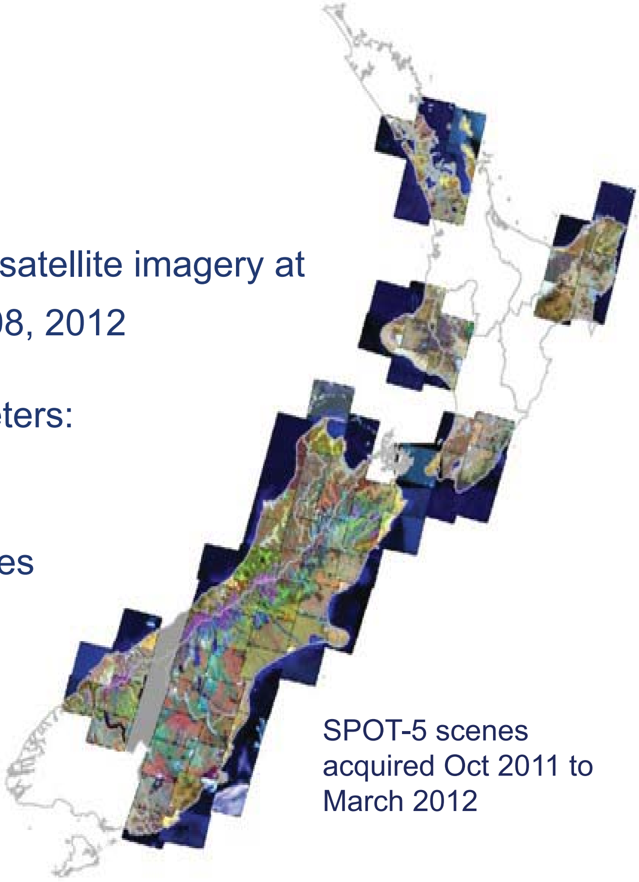
Mapping approach

- Wall-to-wall mapping based on satellite imagery at three mapping dates: 1990, 2008, 2012
- Constrained acquisition parameters:
  - Sun angle > 45 degrees
  - Incidence angle < 20 degrees
  - < 10 % cloud cover
- Imagery converted to standardised reflectance



SPOT-5 scenes acquired Oct 2011 to March 2012

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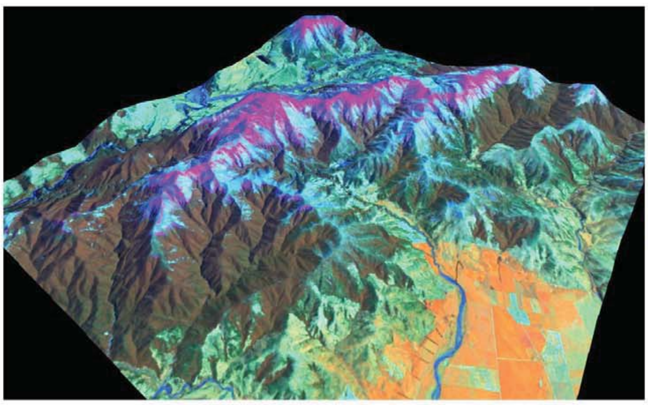
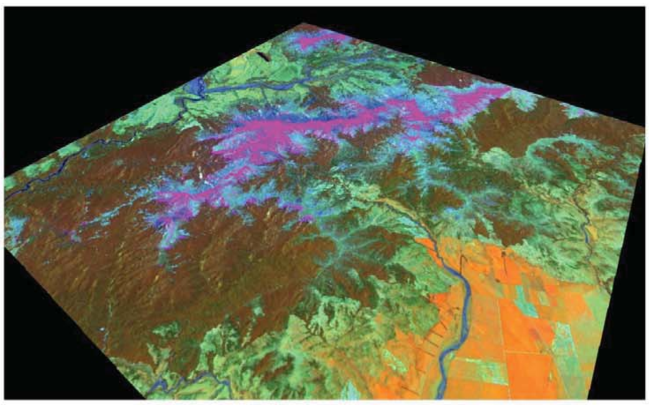
Standardising spectral reflectance



Perspective view of regular image mosaic



Standardised reflectance mosaic

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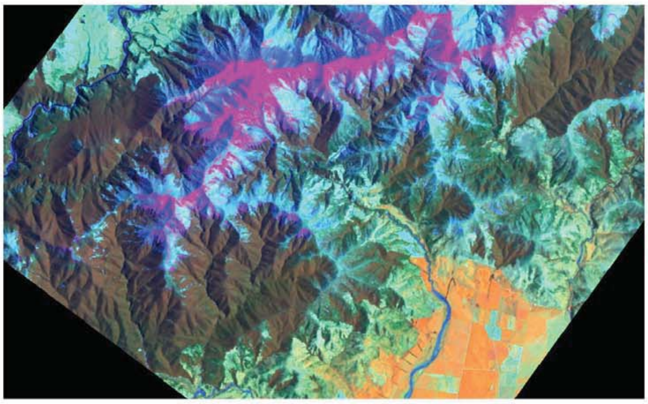
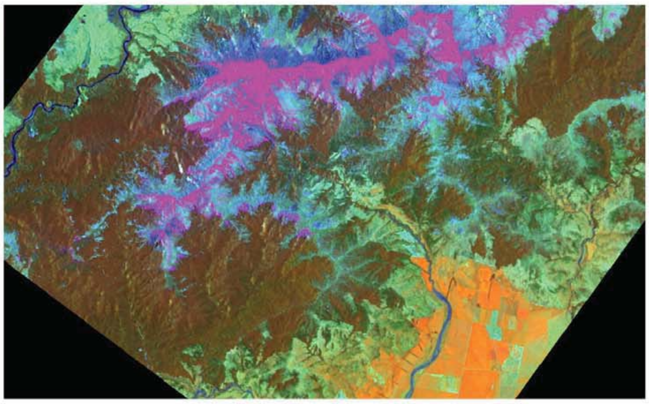
Standardising spectral reflectance



Vertical view of regular image mosaic



Standardised reflectance mosaic

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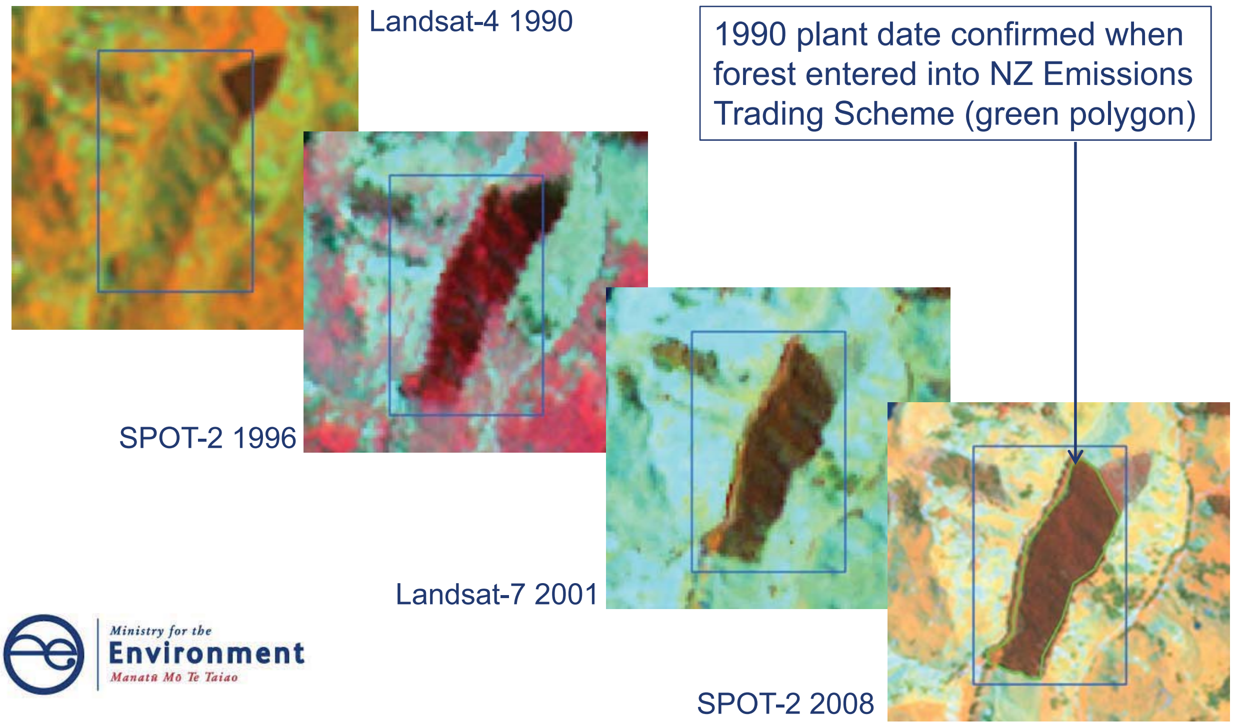
Mapping Pre-1990 and Post-1989 forest areas



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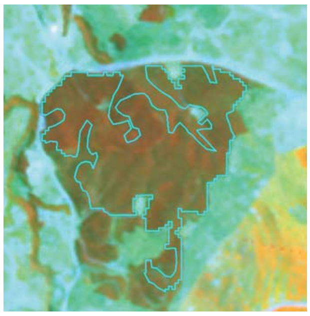
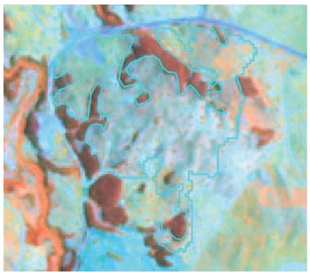
Identifying deforestation

Oblique aerial photography is used to obtain evidence of land-use change

Bay of Plenty 1,857,506 5,730,852 NZTM



SPOT 5 21/11/2007



SPOT 5 19/1/2011

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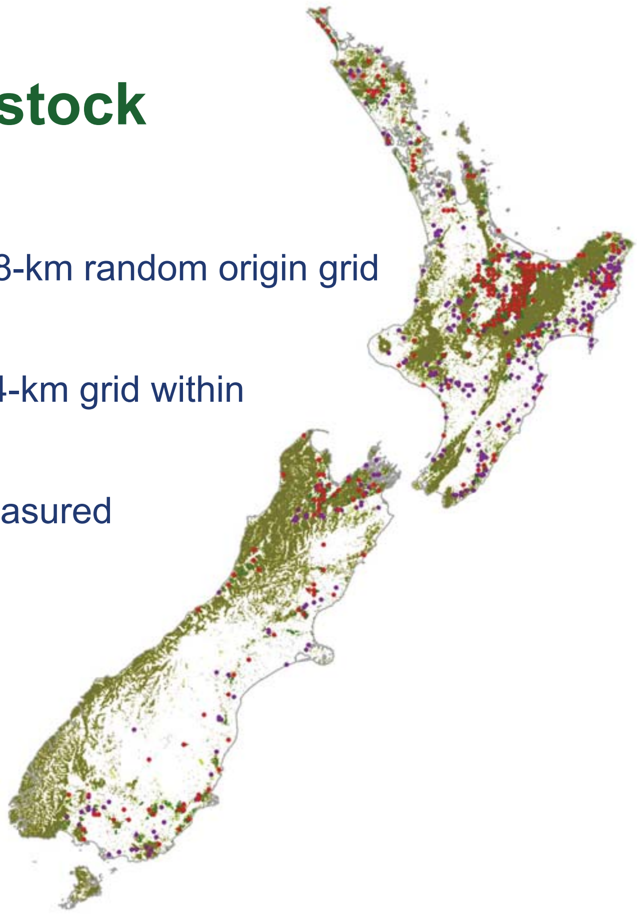
Quantifying carbon stock - ground plots

- Pre-1990 forest sampled on an 8-km random origin grid – 191 plots
- Post-1989 forest sampled on a 4-km grid within 8-km grid – 246 plots
- Circular plots 0.06 ha in size measured to estimate:
  - above-ground biomass
  - below-ground biomass
  - dead wood
  - litter



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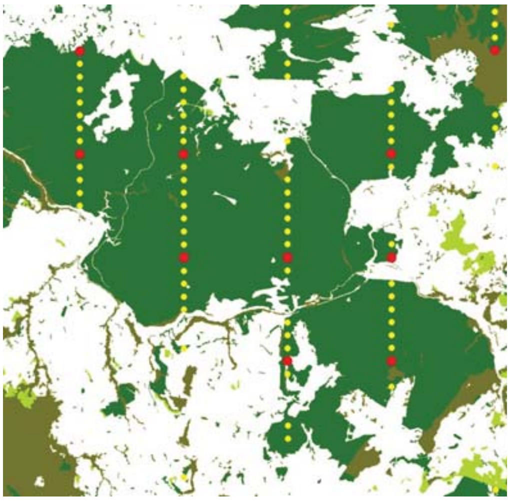
Double sampling approach using LiDAR

- Based on an 8 km x 1 km grid for pre-1990 planted forest
- Incomplete transects only through forests containing an 8-km grid ground plot
- 191 ground plots and 686 LiDAR only plots
- LiDAR data acquired in early 2010


Pre-1990 planted forest sampling in the Central North Island of New Zealand

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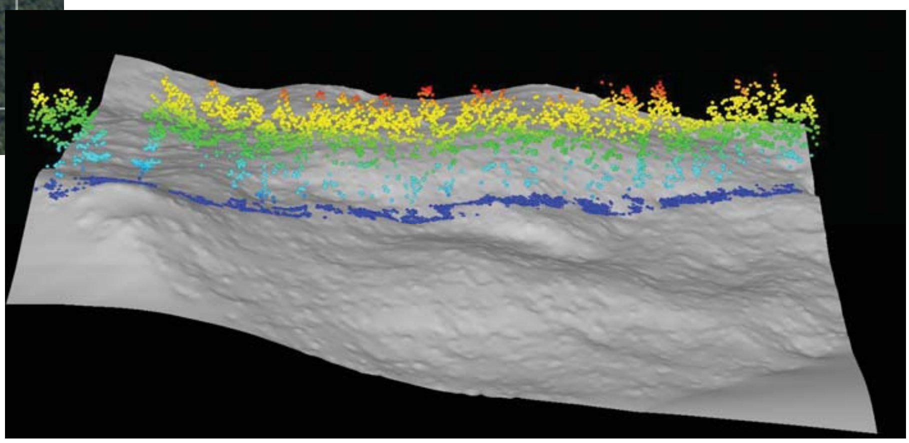
Airborne scanning LiDAR LiDAR

Image left:
- LiDAR transect between points in white rectangle

Image below:
- Ground surface model and 5 m wide point cloud
- First return density 3.46 points per m^2



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Percentage variance explained by various Total C versus LiDAR metric multiple regression models

Number of Independent Variables	LiDAR Metrics in Model	R^2
1	P40ht	80.2
	Meanht	80.0
	P50ht	79.0
	P60ht	77.8
	P70ht	77.8
	P80ht	76.4
	P30ht	75.9
2	P40ht, %Zero	80.5
	P40ht, %Cover	80.5
3	P40ht, %Zero, CV	80.8

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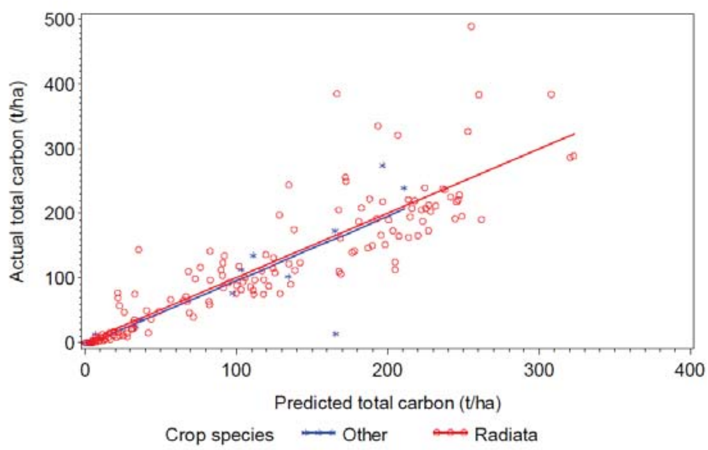
Regression model for predicting total carbon in pre-1990 planted forest using LiDAR metrics

Coefficient	Estimate	s.e.
Intercept	0.4	6.0
P40ht	11.48**	1.40
$P40ht^2$	-0.0214	0.0517
P40ht × %Zero	-0.0630**	0.0232
R^2	80.9	
RMSE	43.52	

** p<0.01



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Reduced uncertainty in total carbon estimate

Estimates of total carbon (t/ha) and 95% confidence interval in Pre-1990 planted forests at 2010	
Ground-based estimate	Regression estimate
100.52 ± 14.17	99.07 ± 11.03

- 95% confidence interval reduced from 14.1% to 11%
- Would require a further 122 ground plots to achieve a similar improvement without LiDAR plots
- Similar approach adopted for Post-1989 forest inventory where key LiDAR metric was P30ht

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Lessons learnt

- LiDAR is a cost effective way to reduce uncertainty in carbon stock estimates
- LIDAR must be used in conjunction with ground sampling due to variations caused by season and silviculture
- Ideally phase 1 LiDAR sample should sample all forests regardless of whether they contain a ground plot
- Image reflectance standardisation in important in steep terrain to ensure accurate classification of forest extent
- Deforestation cannot be reliably distinguished from harvesting in 10m resolution multispectral satellite imagery

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References

Mapping:

Ministry for the Environment, 2012. *Land-Use and Carbon Analysis System: Satellite imagery interpretation guide for land-use classes (2nd edition).* Wellington: Ministry for the Environment. http://www.mfe.govt.nz/publications/climate/satellite-imagery-interpretation-guide/index.html

Shepherd, JD and Dymond, JR, 2003. Correcting satellite imagery for the variance of reflectance and illumination with topography, *Int. J. Remote Sensing*, 2003, vol. 24, No. 17, pp. 3503-3514.

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References (continued)

LiDAR:

Beets, PN, Brandon, AM, Goulding, CJ, Kimberley, MO, Paul, TSH and Searles, N, 2011. The inventory of carbon stock in New Zealand's post-1989 planted forest for reporting under the Kyoto protocol, *Forest Ecology and Management*, vol. 262, pp. 1119-1130.

Beets, PN, Brandon, AM, Goulding, CJ, Kimberley, MO, Paul, TSH and Searles, N, 2012. The national inventory of carbon stock in New Zealand's pre-1990 planted forest using a LiDAR incomplete-transect approach, *Forest Ecology and Management*, vol. 280, pp. 187-197.

Stephens, PR, Kimberley, MO, Beets, PN, Paul, TSH, Searles, N, Bell, A, Brack, C and Broadley, J, 2012. Airborne scanning LiDAR in a double sampling forest carbon inventory, *Remote Sensing of Environment*, vol. 117, pp. 348-357.

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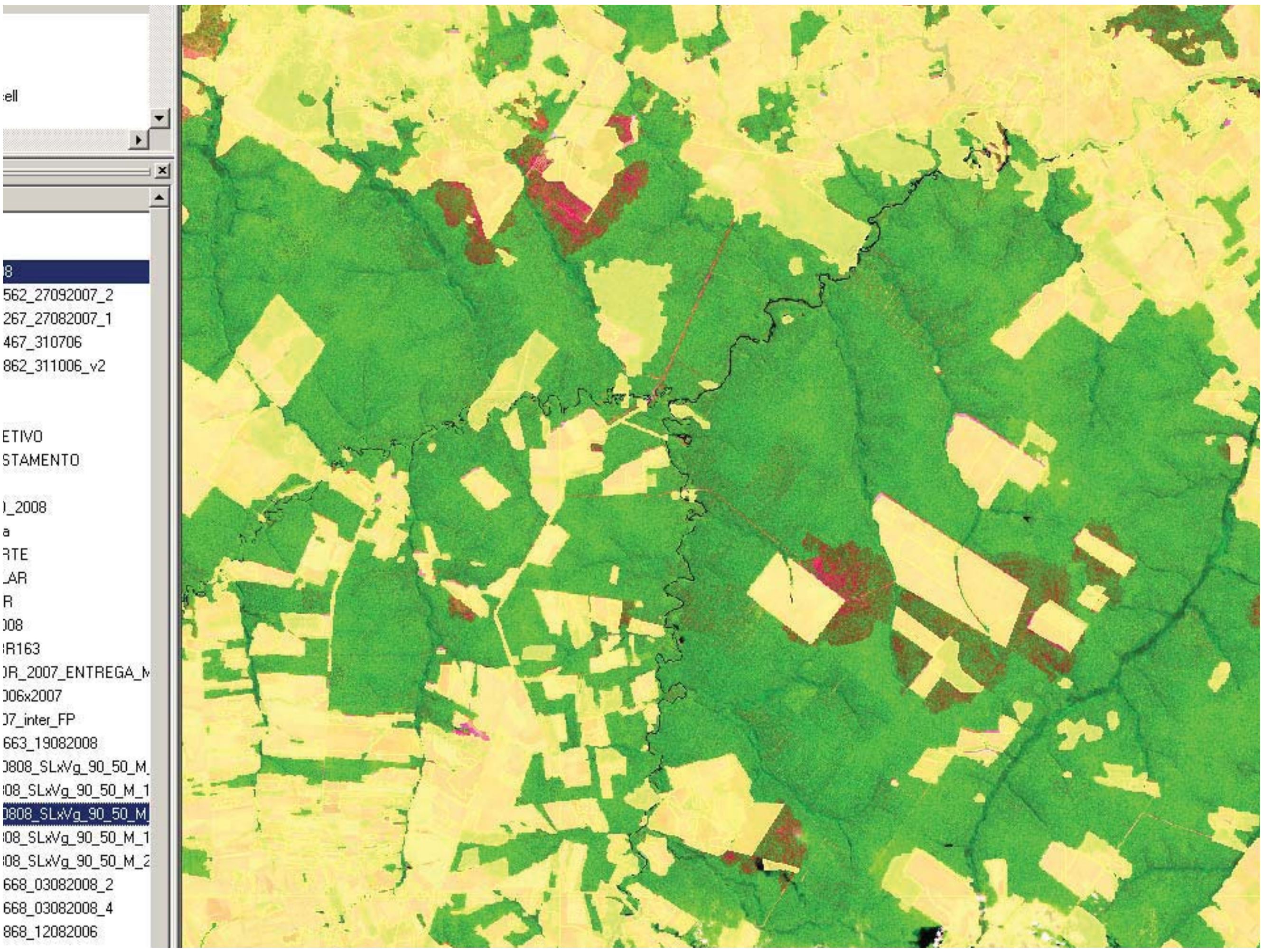
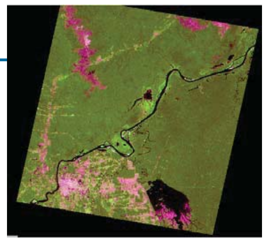
Forest Degradation : the DEGRAD project at INPE

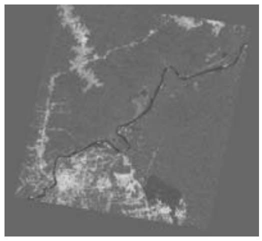
Presented by : Thelma Krug
Slides by : Dalton Valeriano (INPE)

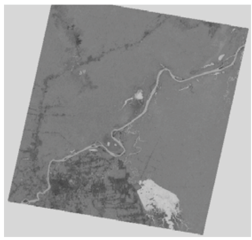


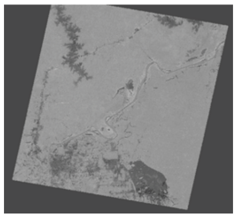
•**Linear Mixing Model**

- soil image
- shadow image
- green vegetation image









Linear Mixture Model – (Shimabukuro & Smith, 1991)

r_i = spectral reflectance for each spectral band *i* for a pixel that contains one or more components

a_{ij} = spectral reflectance of component *j* in each spectral band *i*

x_j = proportion of each component *j* within the pixel

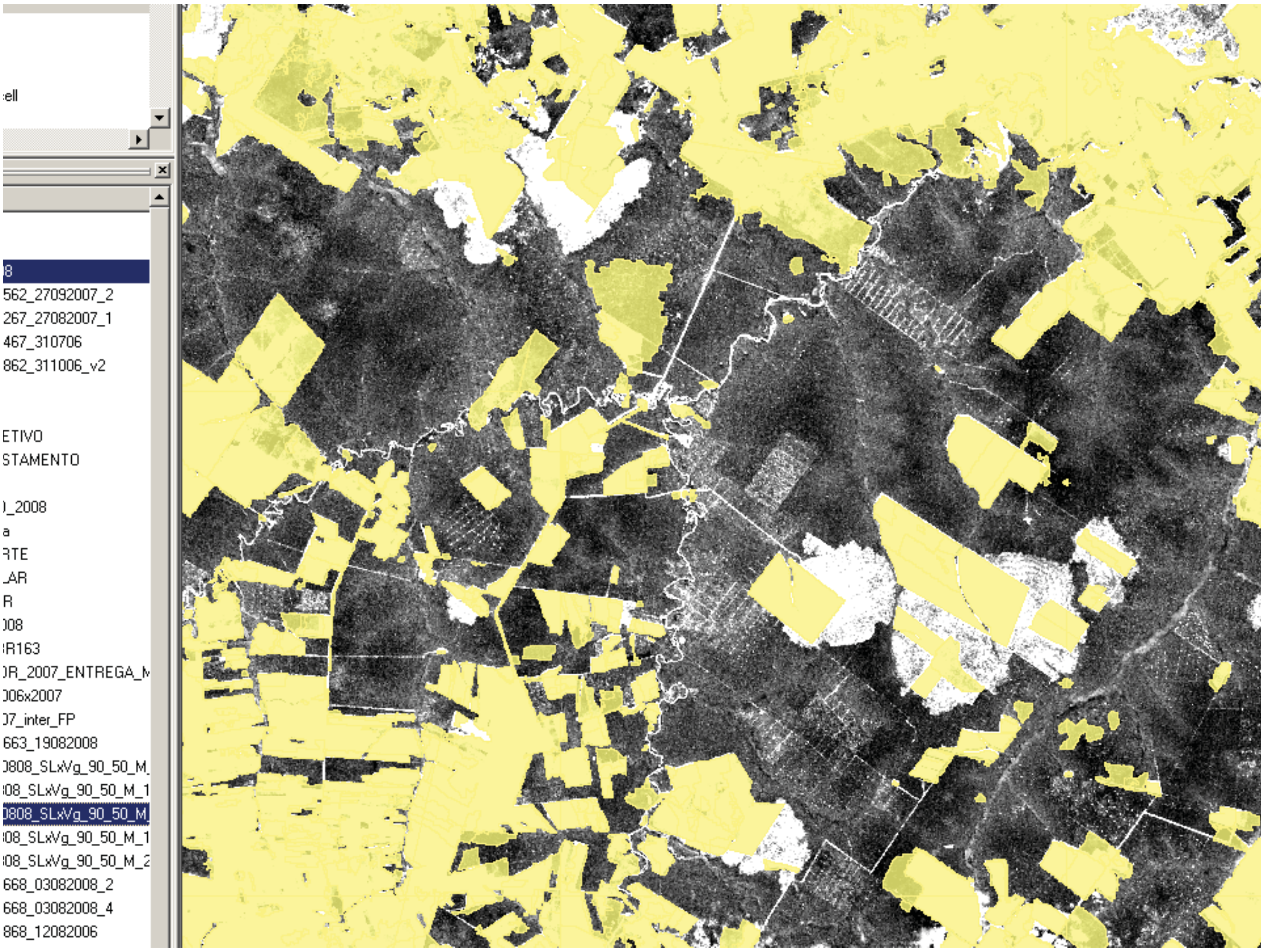
e_i = error for each pixel in band *i*

j = 1, 2, ... , *n* where *n* = number of components

i = 1, 2, ..., *m* where *m* = number of bands

with $\sum x_j = 1$ and $x_j \geq 0$ for all components

$$r_i = \sum_{j=1}^{n} (a_{ij} x_j) + e_i$$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R163
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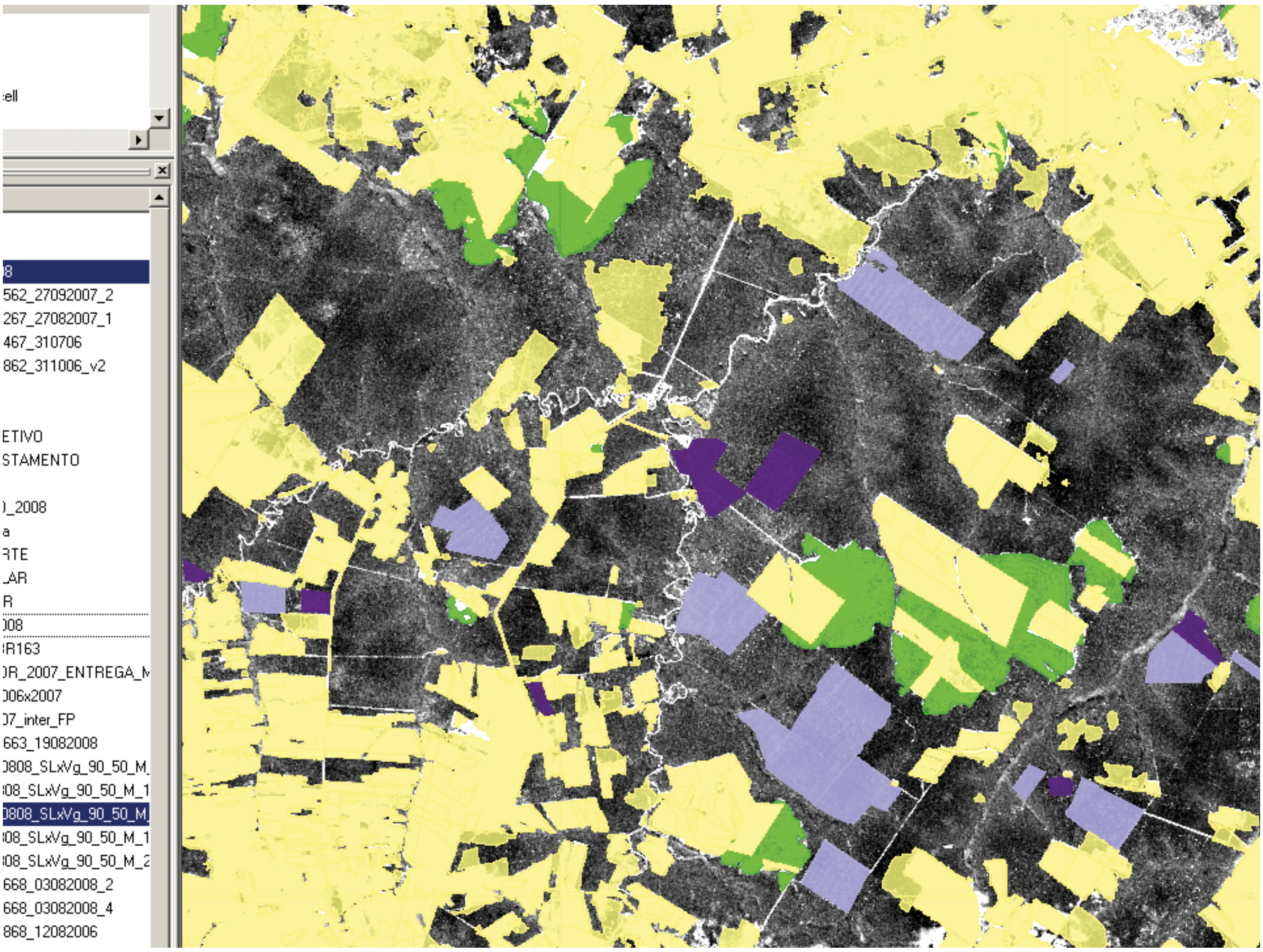
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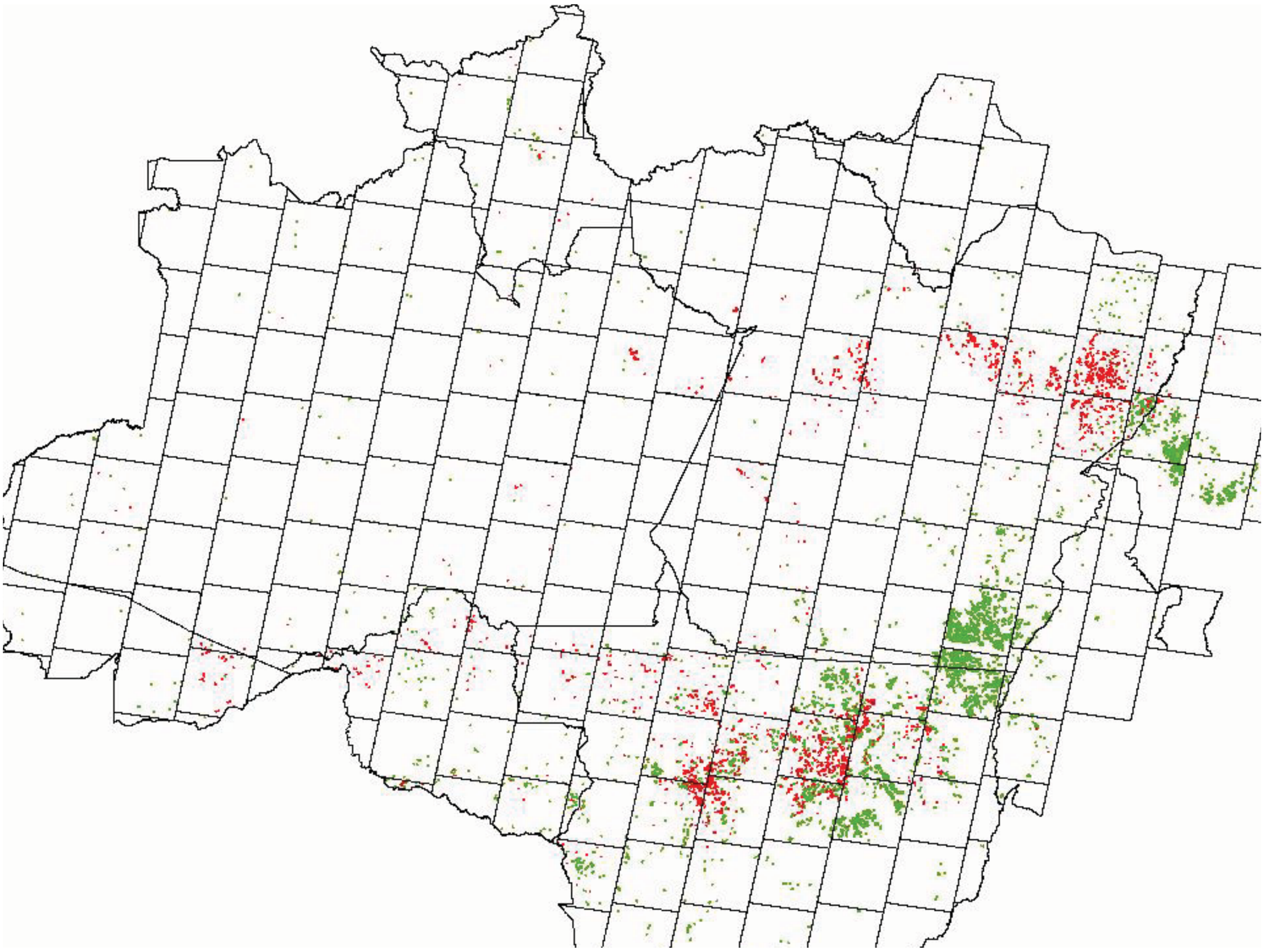


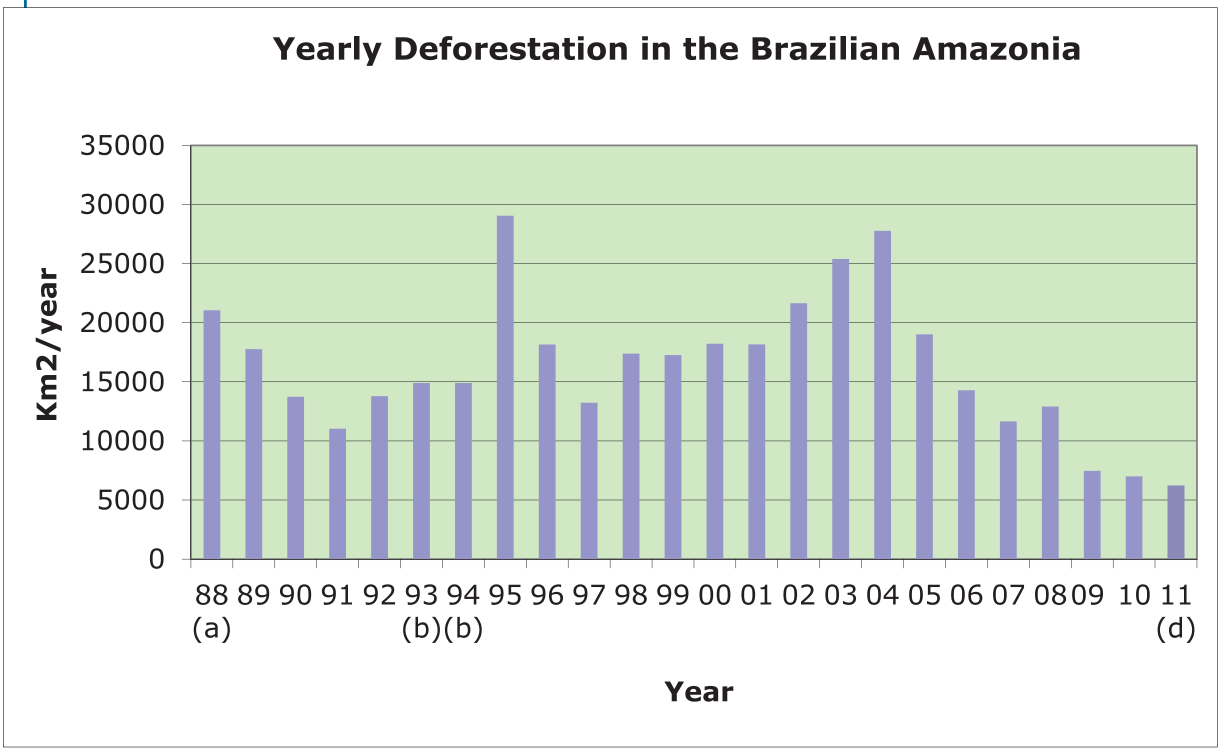
Final Results: 85 scenes

UF	2007(KM2)	2008(KM2)
Acre	122.80	121.34
Amazonas	257.46	412.42
Amapá	50.42	63.18
Maranhão	1976.75	4230.70
Mato Grosso	8951.14	12987.74
Pará	3899.23	8264.82
Rondônia	412.32	643.32
Roraima	137.28	171.39
Tocantins	179.71	522.18
TOTAL	**15987.10**	**27417.10**

Final Results 2007 and 2008

Degradation in 2007 converted to clear cut in 2008:

UF	KM2
Acre	12.41
Amazonas	15.33
Amapá	4.49
Maranhão	169.99
Mato Grosso	932.93
Pará	681.19
Rondônia	107.24
Roraima	40.03
Tocantins	18.87
TOTAL	**1982.48**

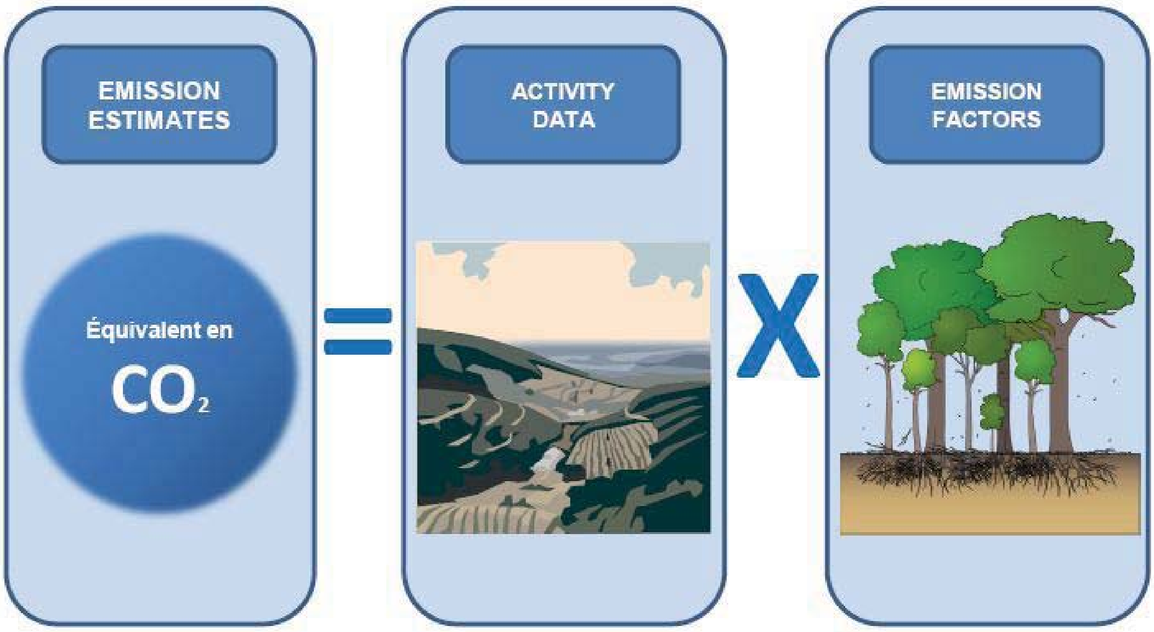


Use of airborne and satellite LiDAR for estimating forest carbon stock and its changes

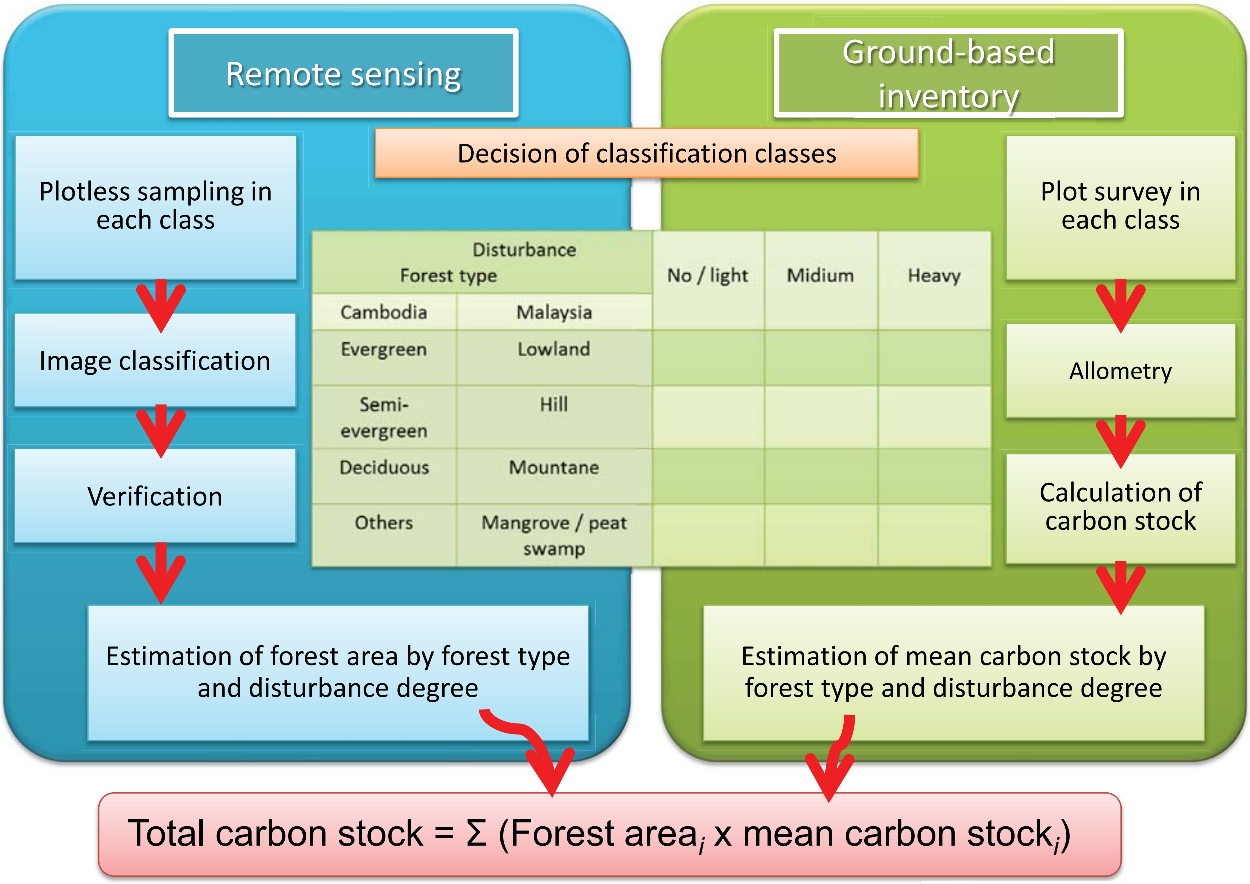
Yasumasa Hirata

Forestry and Forest Products Research Institute, Japan

Calculation of GHG emission from LULUCF sector

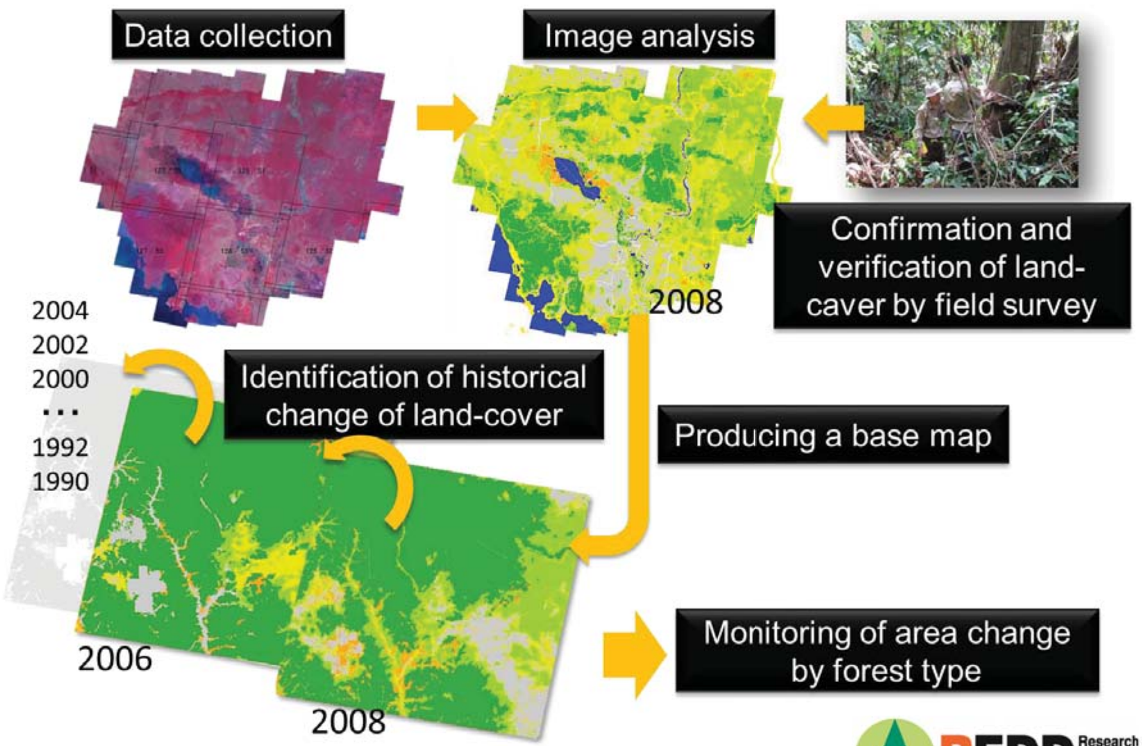


Danilo Mollicone, FAO



Disturbance / Forest type		No / light	Midium	Heavy
Cambodia	Malaysia			
Evergreen	Lowland			
Semi-evergreen	Hill			
Deciduous	Mountane			
Others	Mangrove / peat swamp			

Monitoring of carbon stock changes by deforestation and forest degradation using remote sensing



Field survey for estimating carbon stock




Two types of data from field survey

- For area estimation
  - Training data for image classification
  - Verification data for the result of classification
- For estimation of carbon stock per unit area as emission factor
  - Tree census data

Problems in field survey

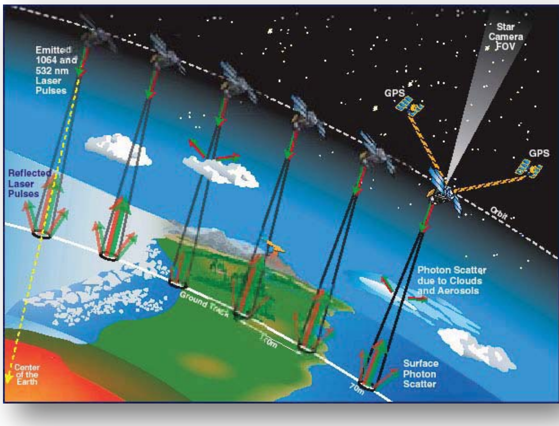
- Ownership
- Accessibility and road condition
- Weather
- Topography (steep slope, stream, etc)
- Dangerous animals, insects, and plants
- Mining
- Illegal logger

Possibility of LiDAR measurement

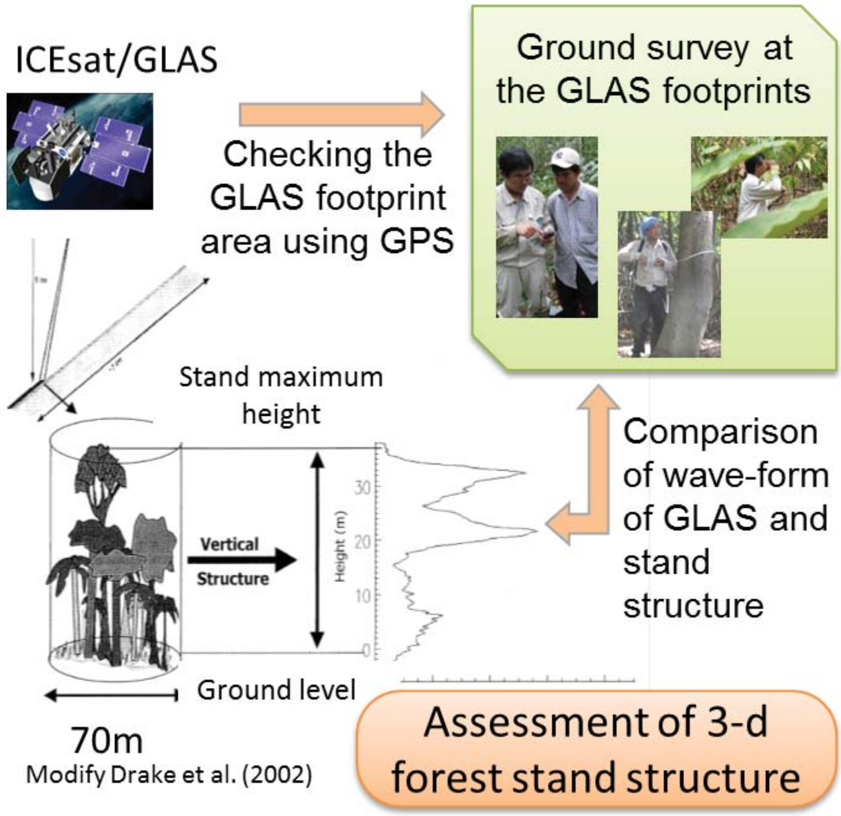
- Satellite LiDAR
  →Training data and verification data acquisition
- Airborne LiDAR
  – Estimation of carbon stock by forest type and degradation degree
- It is difficult to estimate area and its changes from LiDAR measurement.

About ICESat/GLAS

- Launched on 12 Jan 2003
- Mission period from 2003 to 2009
- Footprint size is 65 m
- Interval of footprint is 170 m
- Emitted 1064 qnd 532 nm laser pulses



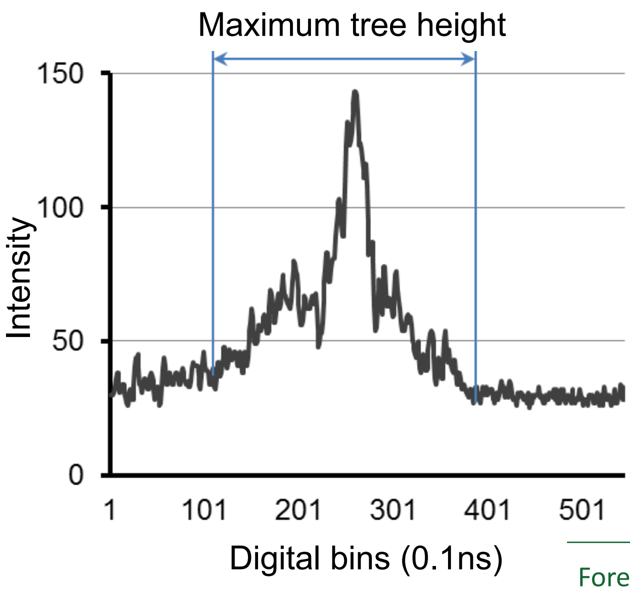
Satellite LiDAR measurement of 3-D structure of forest



Footprints of ICESat/GLAS in Cambodia

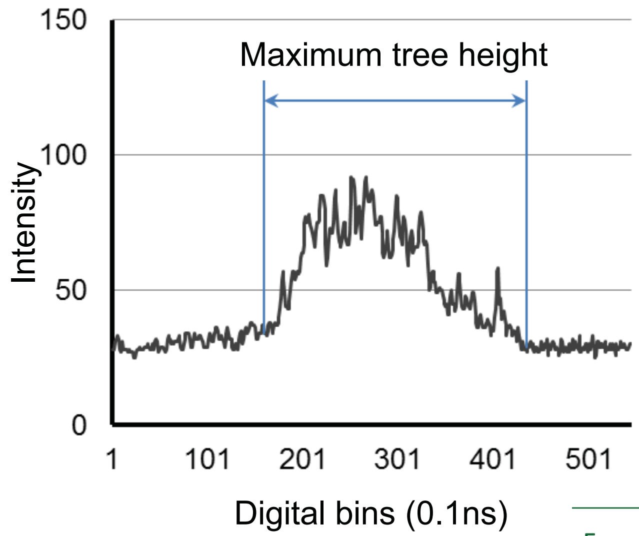
Waveform of LiDAR data in a mature forest

- Maximum tree height derived from LiDAR data was about 43 m.
- Intensity has a peak around 23m height and it means canopy layer.

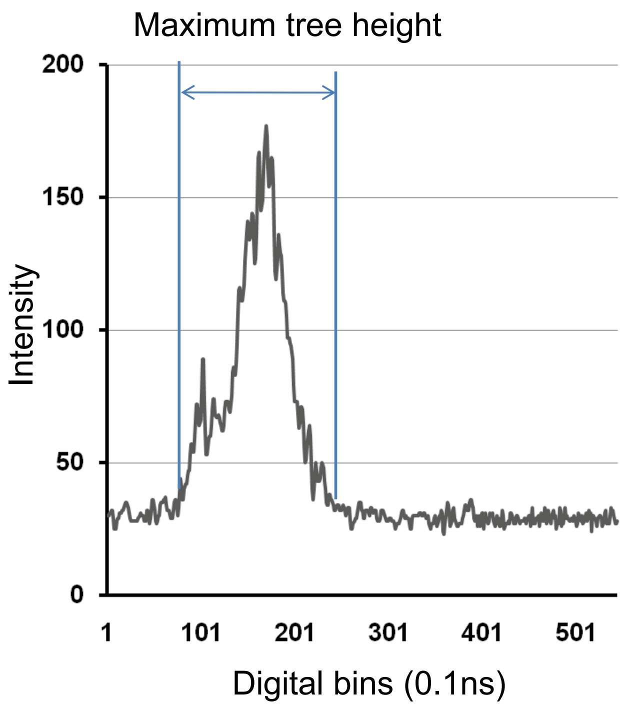


Waveform of LiDAR data in a degraded forest

- Maximum tree height derived from LiDAR data was about 42 m.
- Intensity was relayively weak through all layers.



Waveform of LiDAR data in a rubber plantation

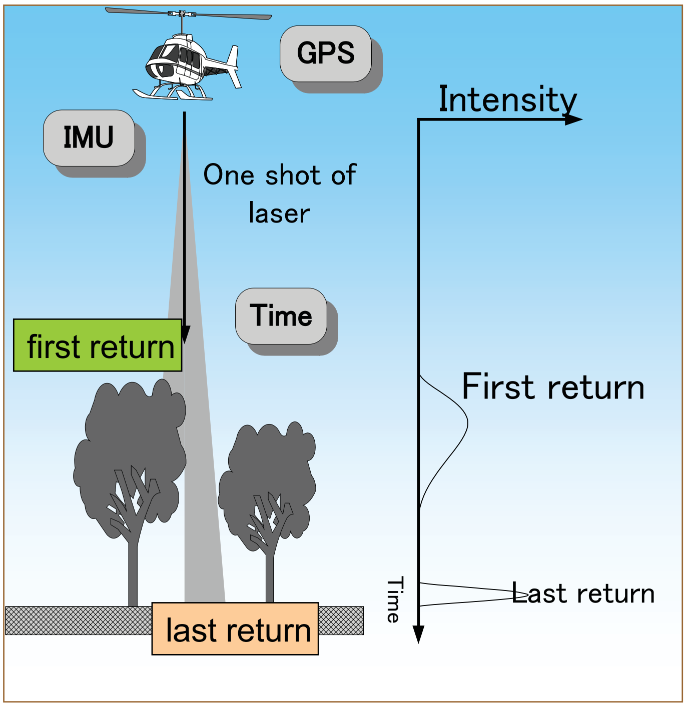


- Maximum tree height derived from LiDAR data was about 23 m.
- Intensity has a peak around 15m height and it means canopy layer.

Concluding remarks for satellite LiDAR

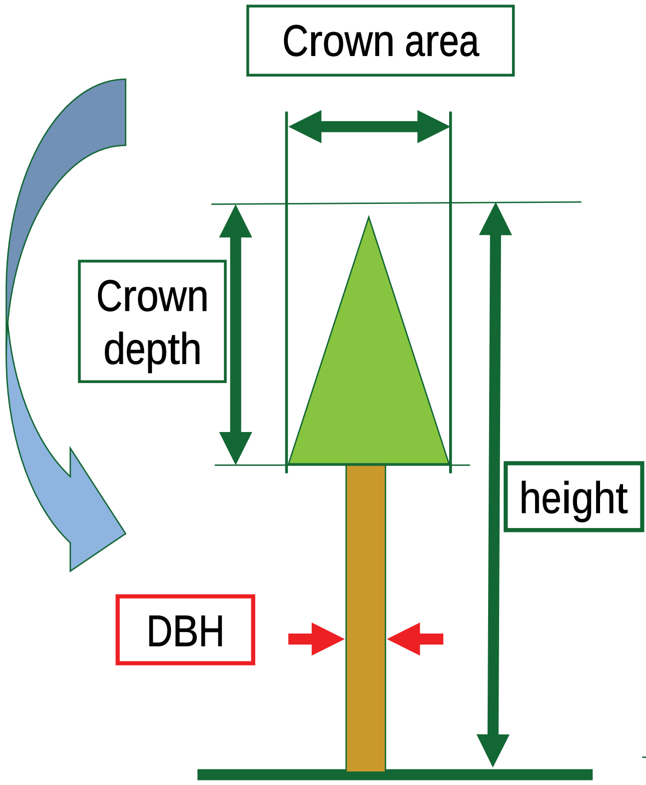
- Stand structure can be estimated from waveform of satellite LiDAR data .
- Leangth of waveform almost indicated maximum tree height.
- Peak position of waveform indicated the height of canopy layer.
- The height and position of peak of waveform indicated the degree of forest degradation.
- Next satellite LiDAR…?
  - Spec of ICESat-2……
  - i-LOVE on ISS in 1918?

Forest measurement by ALS



- Digital surface model (DSM) is created from first return.
- Digital elevation model (DEM) is created from last return.
- Digital canopy height model (DCHM) =DSM –DEM
- Other information (waveform, penetration rate, etc.) is also used to estimate stand condition.

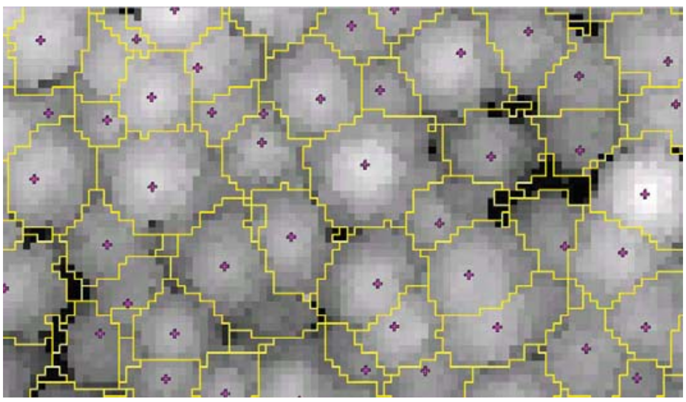
What can be measured using ALS?



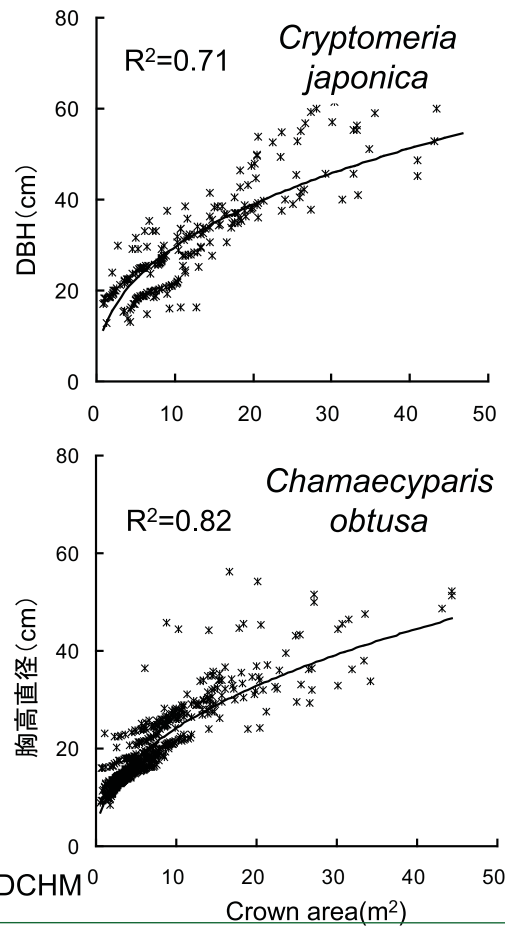
- Direct measurement
  - Tree height
  - Crown area
  - Crown depth
- Estimated parameter
  - DBH
  - Volume
  - (Carbon stock)

Extraction and estimation

- Local maximum filter is applied to DCHM to extract individual tree-tops.
- Watershed method or valley-following method is applied to DCHM to extract individual crowns.



Extraction of tree height, crown area and tree number from DCHM

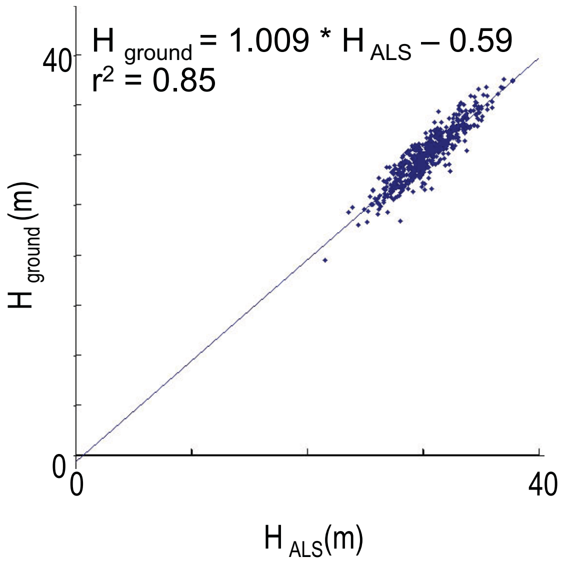


Hirata et al. (2009)

Tree number and height from DCHM

Extraction of individual trees

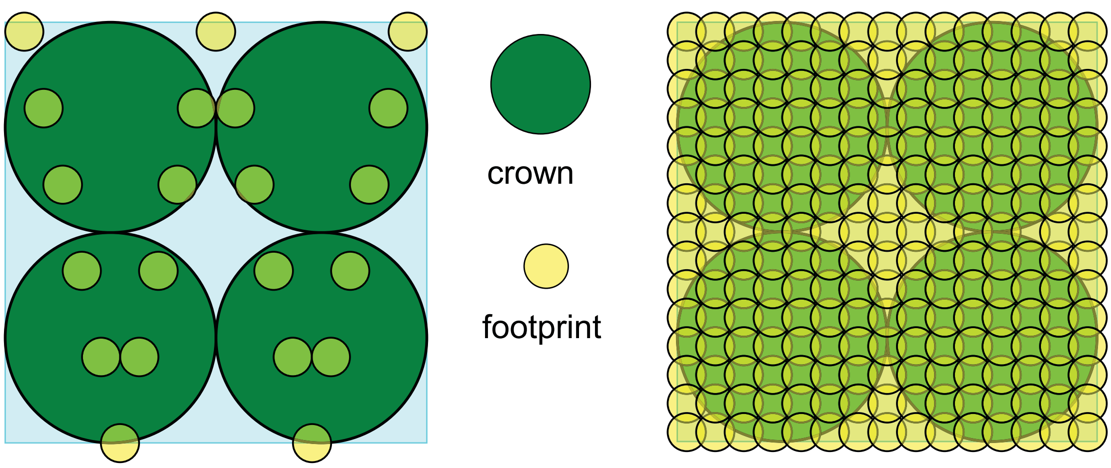
thinning operation	number of standing trees	number of extractive trees	extractive rate (%)
heavy (0.3 ha)	142	136	95.8
light (0.4 ha)	245	212	86.5
no (0.3 ha)	270	203	75.2
Total (1.0 ha)	**657**	**551**	**83.9**



Tree height from DCHM

Hirata (2005)

Sampling density



2 – 3 points/m²

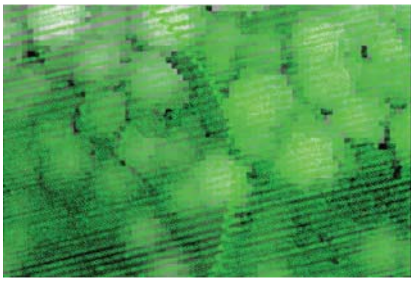
In the case of low sampling density, some tree-tops are not involved by any footprints.

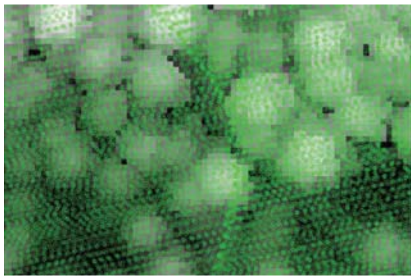
25 points/m²

In the case of high sampling density, each tree-top is involved by one of footprints.

Hirata (2005)

Sampling density


sampling density = 22.53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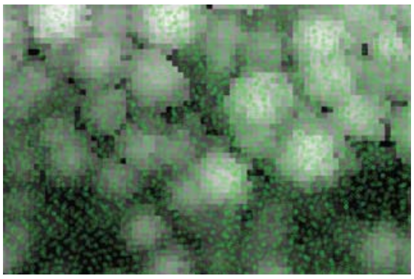
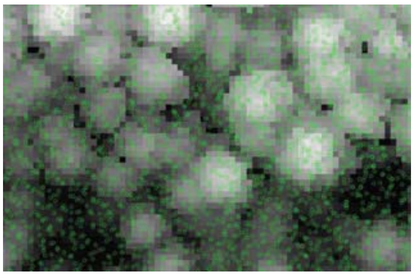
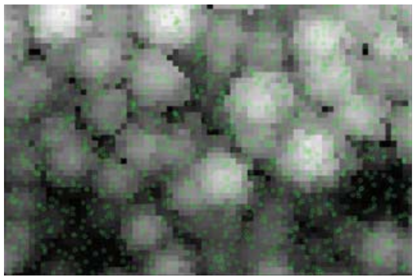
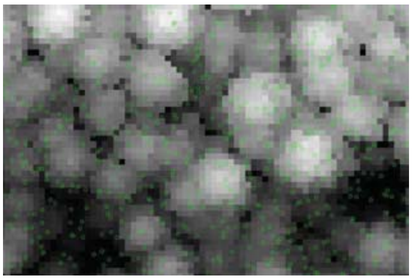
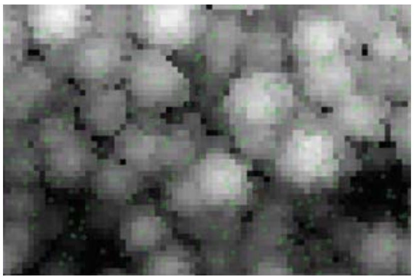

sampling density = 5.64

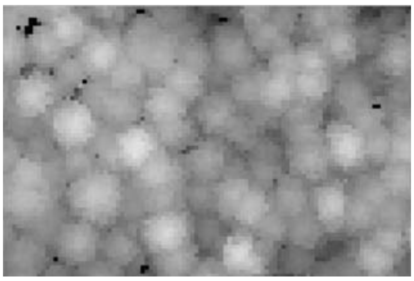

sampling density = 2.82


sampling density = 1.41


sampling density = 0.71


sampling density = 0.35

DCM derived from different sampling density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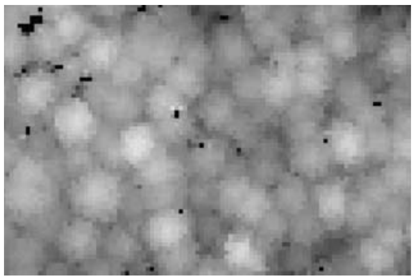
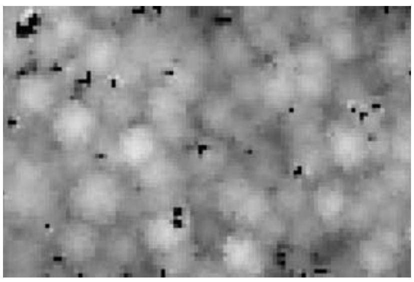
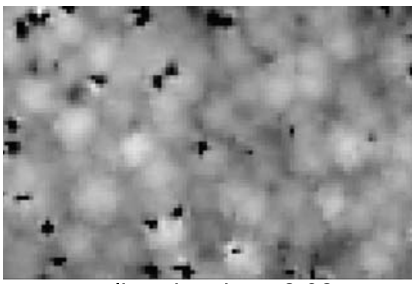
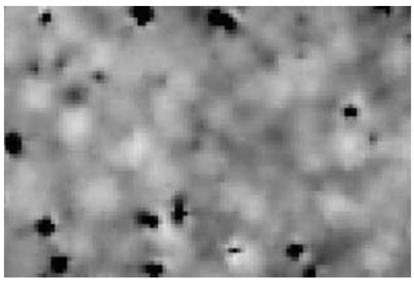
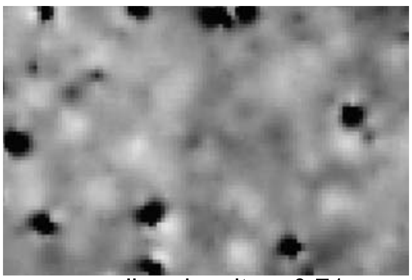
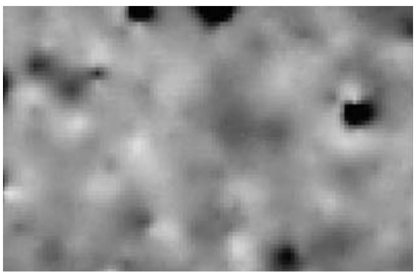

sampling density = 11.28


sampling density = 5.64


sampling density = 2.82

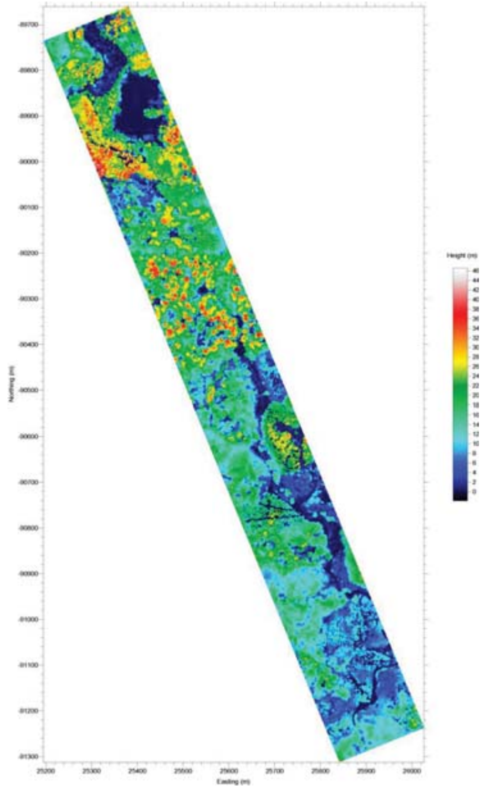

sampling density = 1.41


sampling density = 0.71


sampling density = 0.35

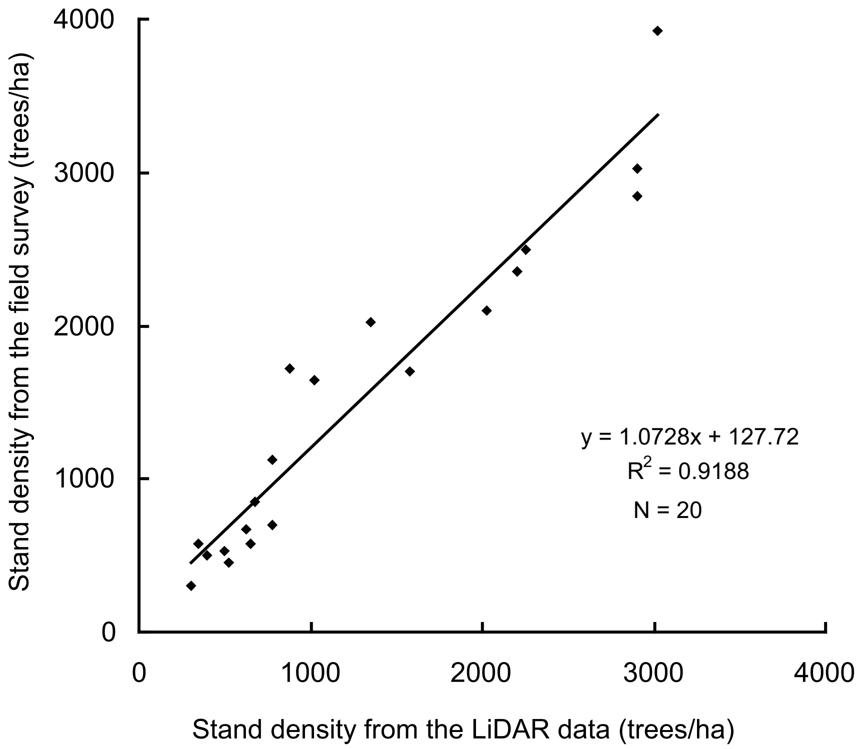
As sampling density runs lower, extractive tree-tops decrease.

Stnand parameter by ALS



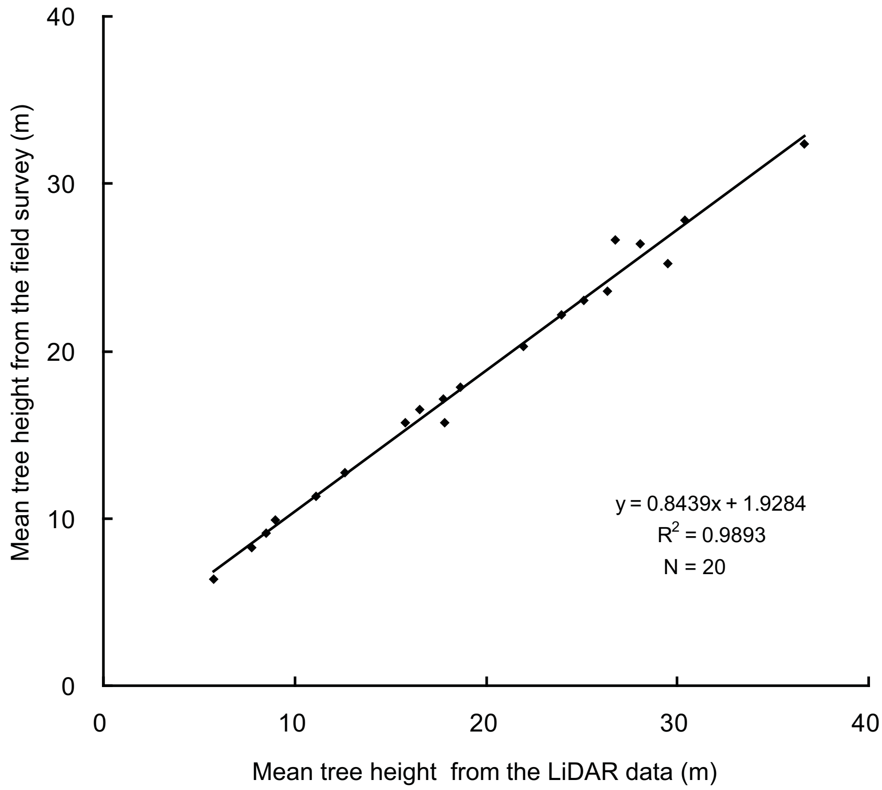
Hirata et al. (2008)

Stand density from DCHM



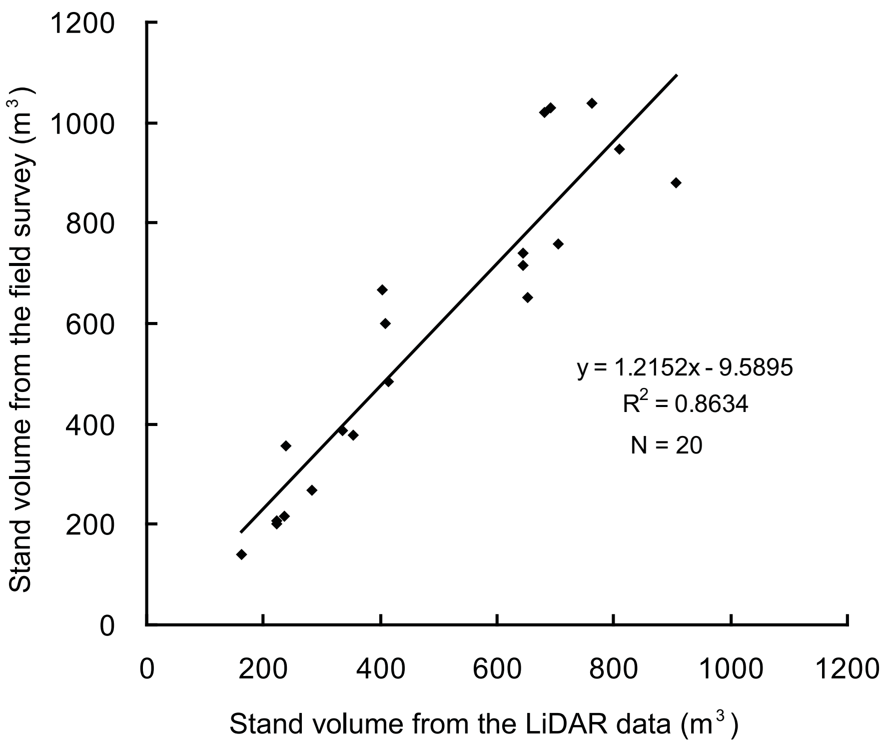
Hirata et al. (2008)

Mean tree height from DCHM



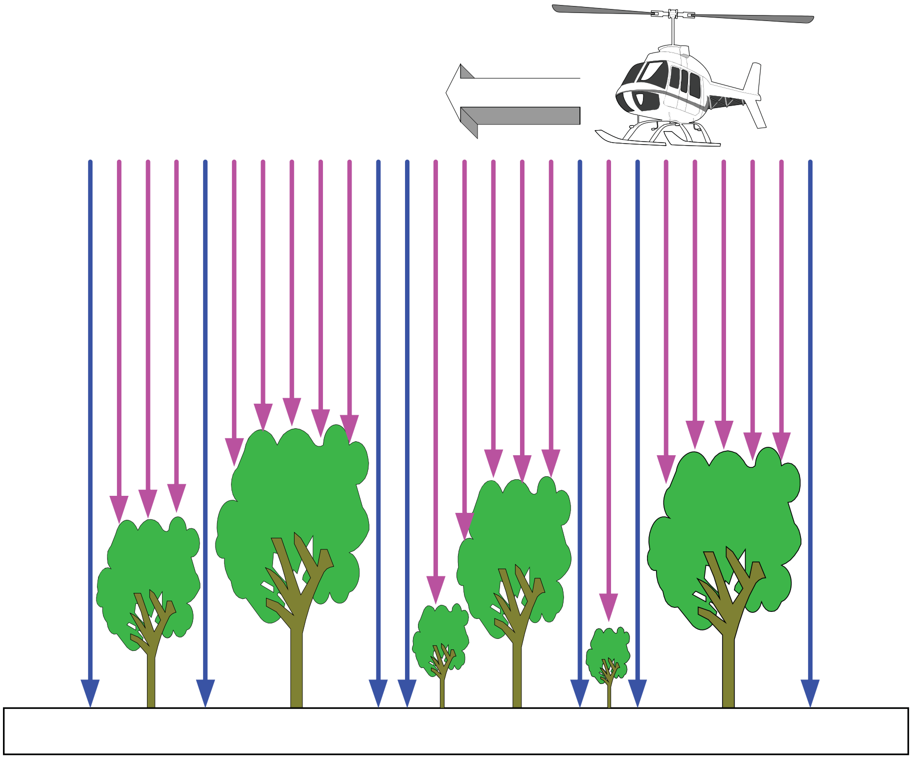
Hirata et al. (2008)

Stand volume by ALS

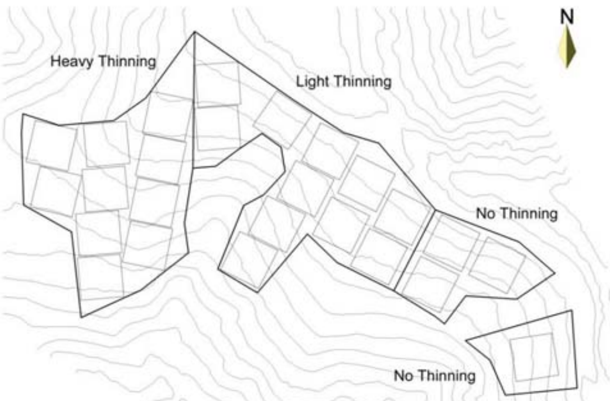


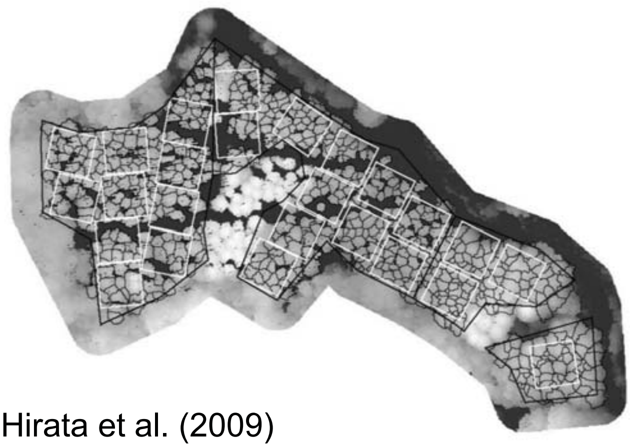
Hirata et al. (2008)

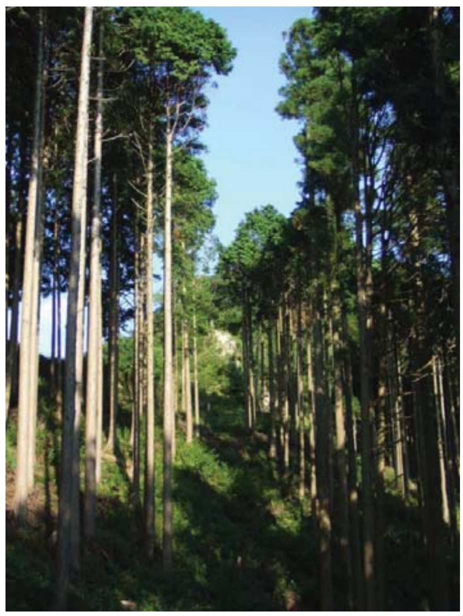
Penetration of laser through canopy



Evaluation of different levels of thinning

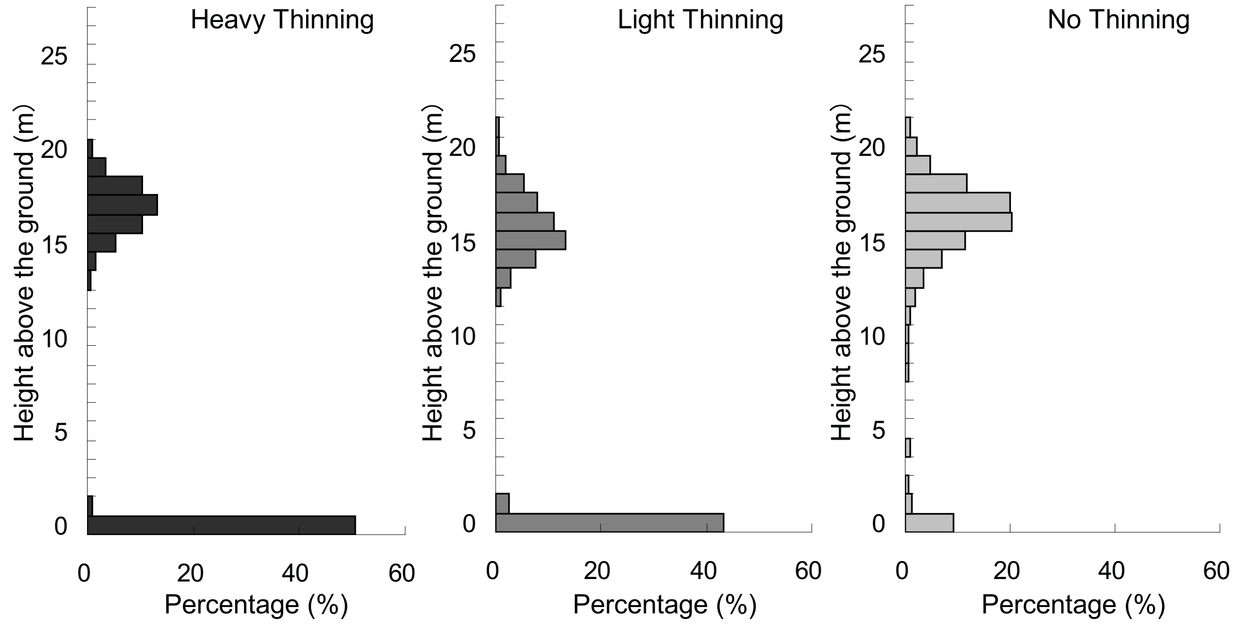






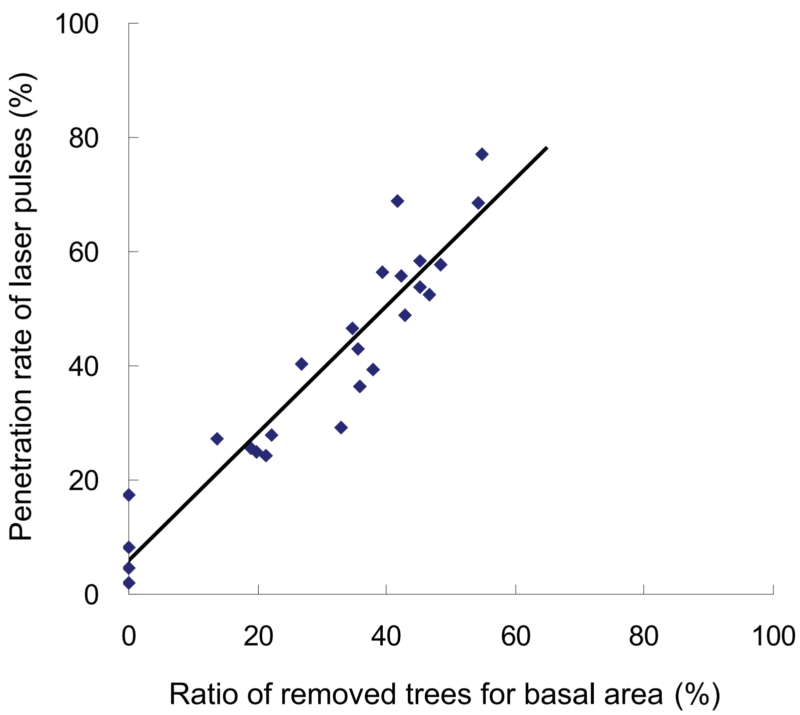
Hirata et al. (2009)

Relative frequency distributions of the heights above the ground where laser pulses reached



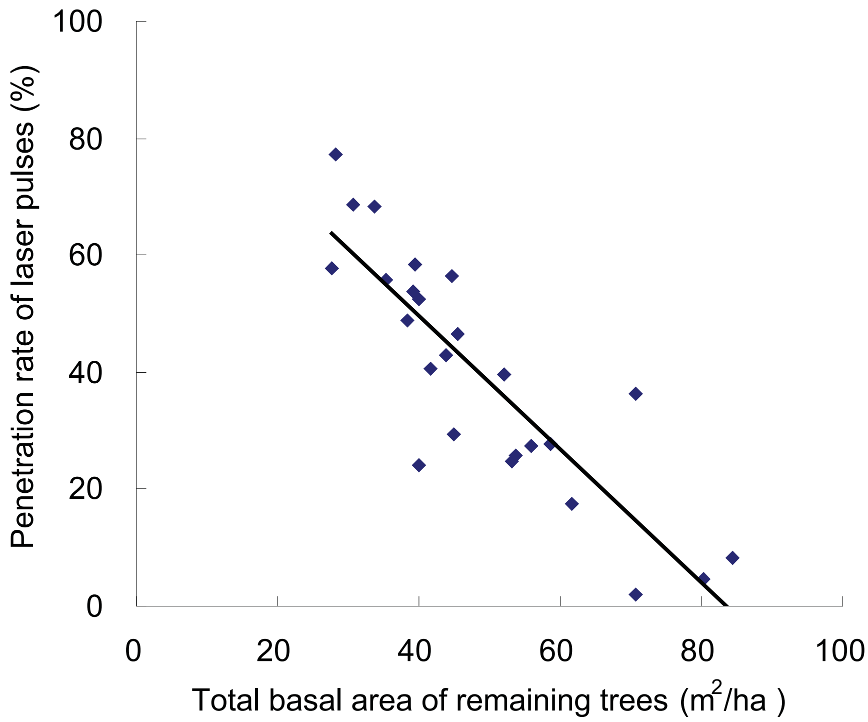
Hirata et al. (2009)

Thinning and penetration rate



Hirata et al. (2009)

Total basal area of remaining trees and penetration rate



Hirata et al. (2009)

Aerial survey in tropical forest

- High spec survey by aircraft

LIDAR/Camera Pod

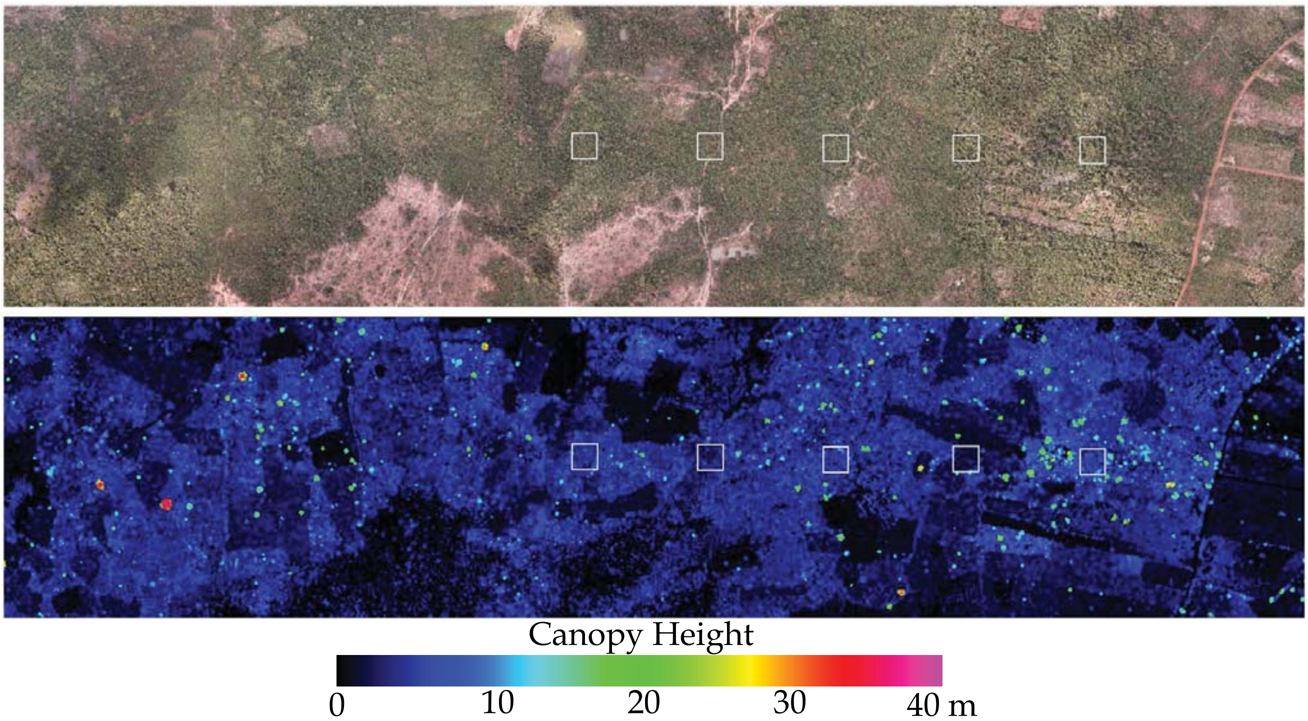
GPS Antenna

Implementation of LiDAR measurement

- Survey implementation in January, 2012 in Cambodia and in October, 2012 in Malaysia (Sabah)
  - 10cm resolution aerial photos
  - 25-50 cm LiDAR height models

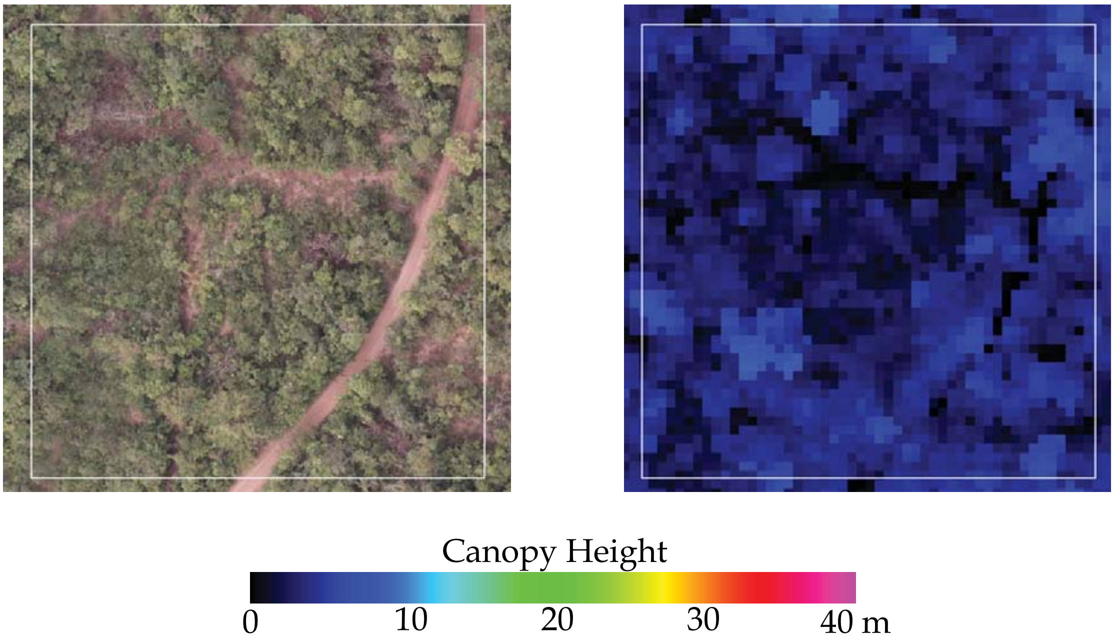
FFPRI 九州大学 東京大学 THE UNIVERSITY OF TOKYO PASCO Measure the Earth, Here and Beyond

Aerial photo & canopy height degraded forest

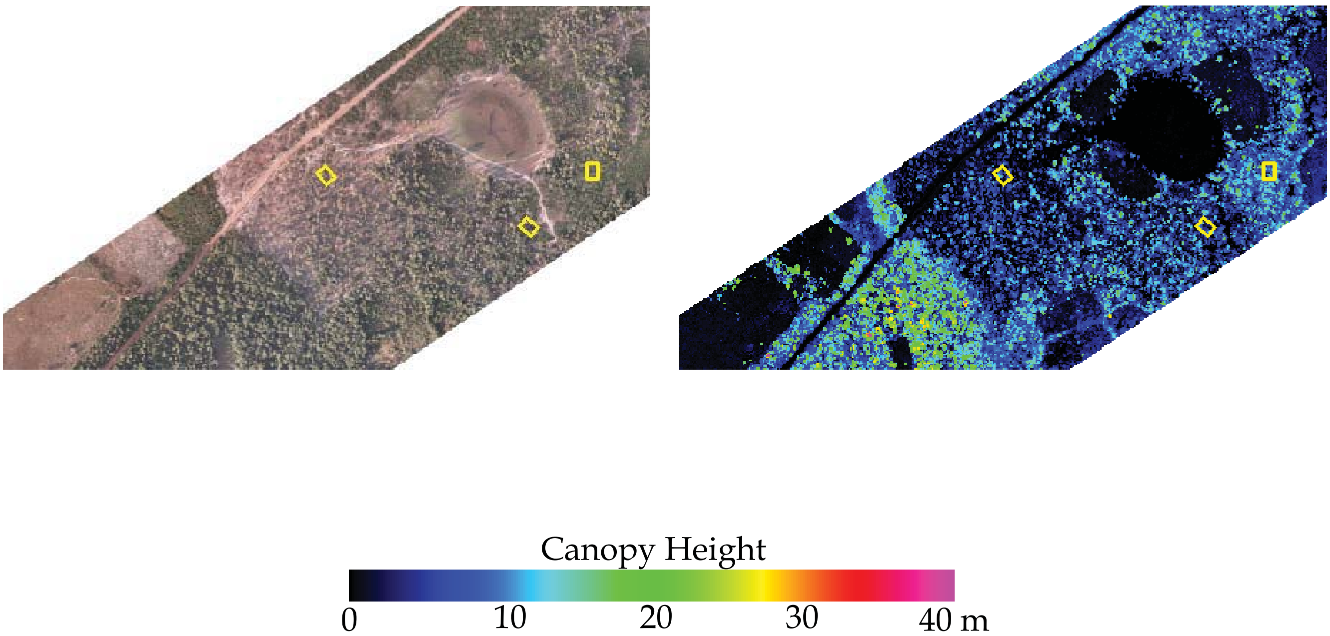


FFPRI 九州大学 東京大学 THE UNIVERSITY OF TOKYO PASCO Measure the Earth, Here and Beyond

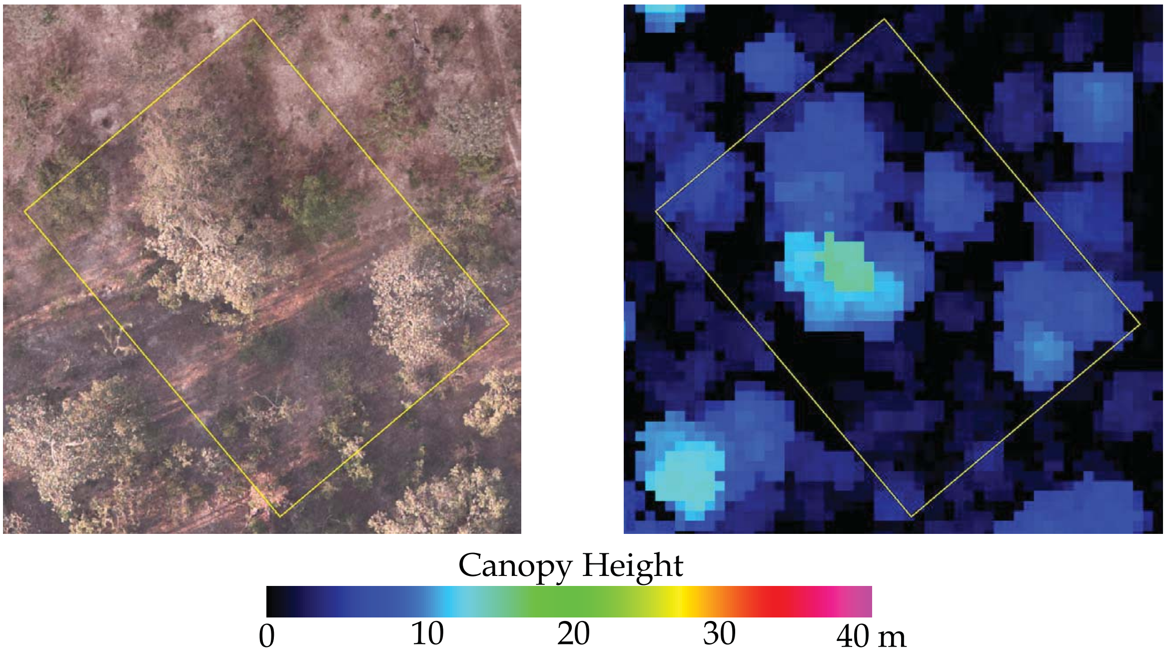
Aerial photo & canopy height degraded forest



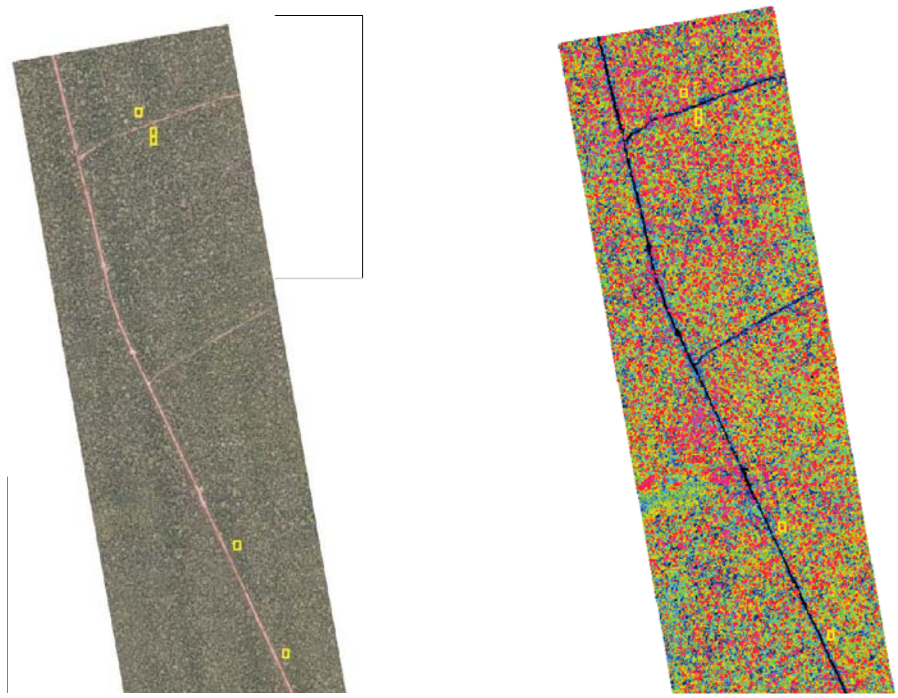
Aerial photo & canopy height DEF & DDF patches

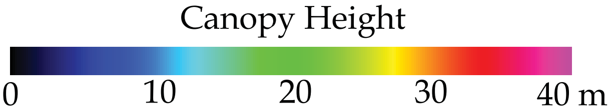


Aerial photo & canopy height
Deciduous forest

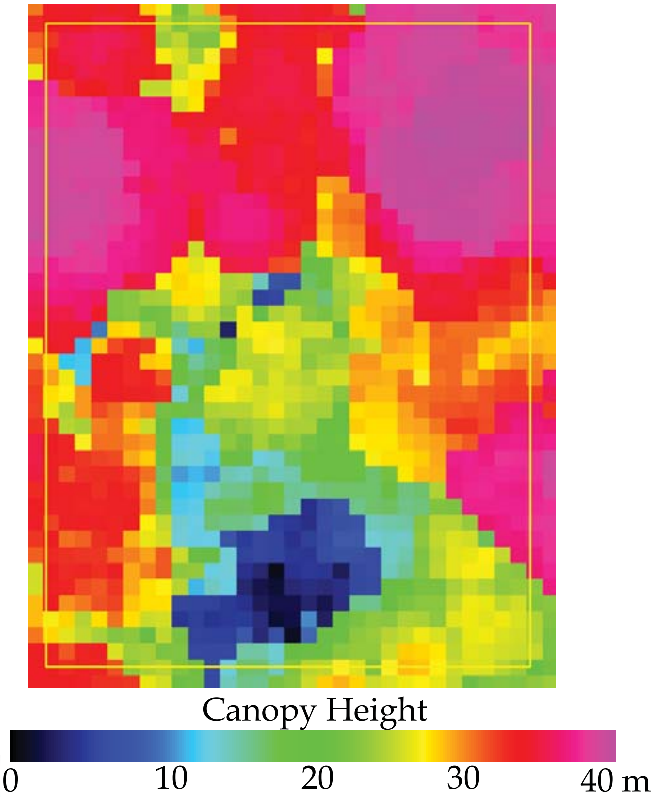


Aerial photo & canopy height
Conserved forest





Aerial photo & canopy height
Conserved forest



Concluding remarks for airborne LiDAR

- Airborne LiDAR is applicable to estimate forest stand parameters accurately, therefore it can estimate forest carbon stock by forest type.
- Cost should be investigated. Ground-based inventory is not also cheap.
  - 500-1000 US$ per 30m*30m plot
  - Car, specialists (species identification, instrument handling), villagers
  - Up to access, road condition, weather, forest condition, distance from accommodation ….
- LiDAR measurement is strongly influenced by weather and regulation of a country (permission).


Thank you for your attention!
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Detecting Forest Degradation by using Gram-Schmidt transformation

IPCC Expert Meeting:Role of Remote Sensing in Forest and National GHG Inventories.

October 23-25. 2012 Jokosuka, Hayama, Japan

Carlos Bahamondez
Forest researcher
Instituto Forestal
Sede Valdivia
Chile

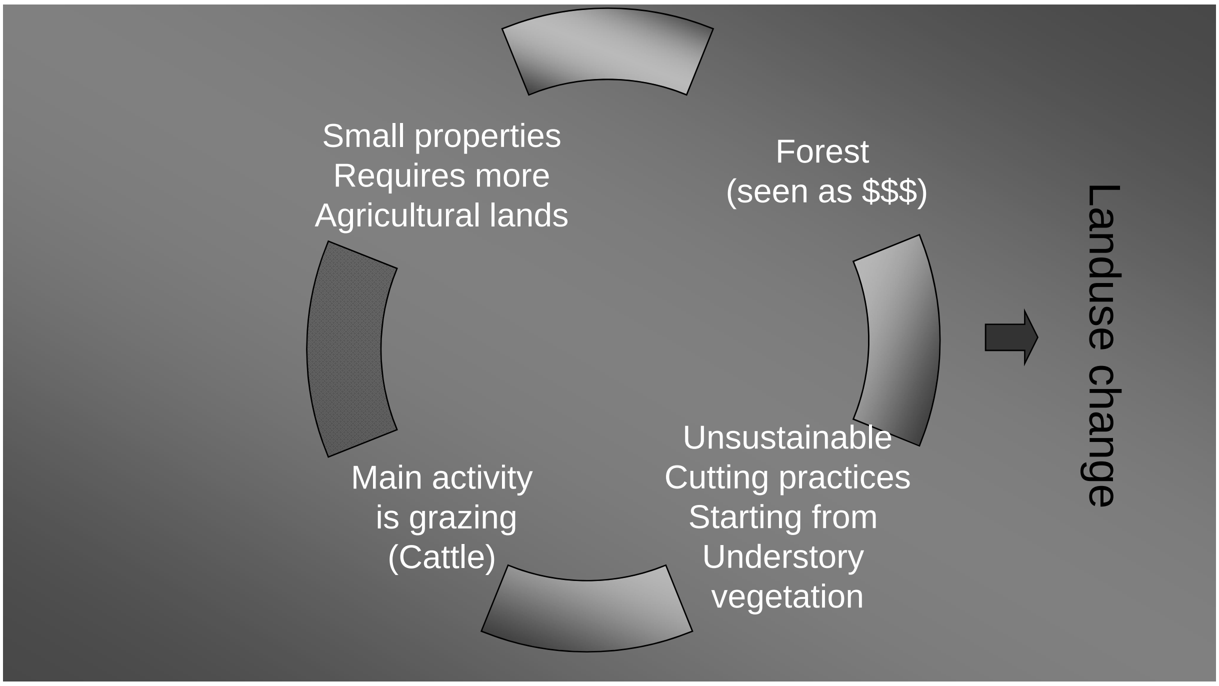
Methodology degradation

- Three main issues are needed:
  - An operational model to forest degradation
  - A remote sensing based algorithm for detecting forest degradation.
  - A model for the degradation -drivers relationship

Degradation in Chile

- Drivers for Degradation in Chile comes from rural population poverty condition.
- Basically, the main driven forces are represented as:
  - The presence of a large and illegal informal fuelwood market. (demand 8 million m3/year)
  - An important group of small landowners with few chances to get liquidity from their small properties.

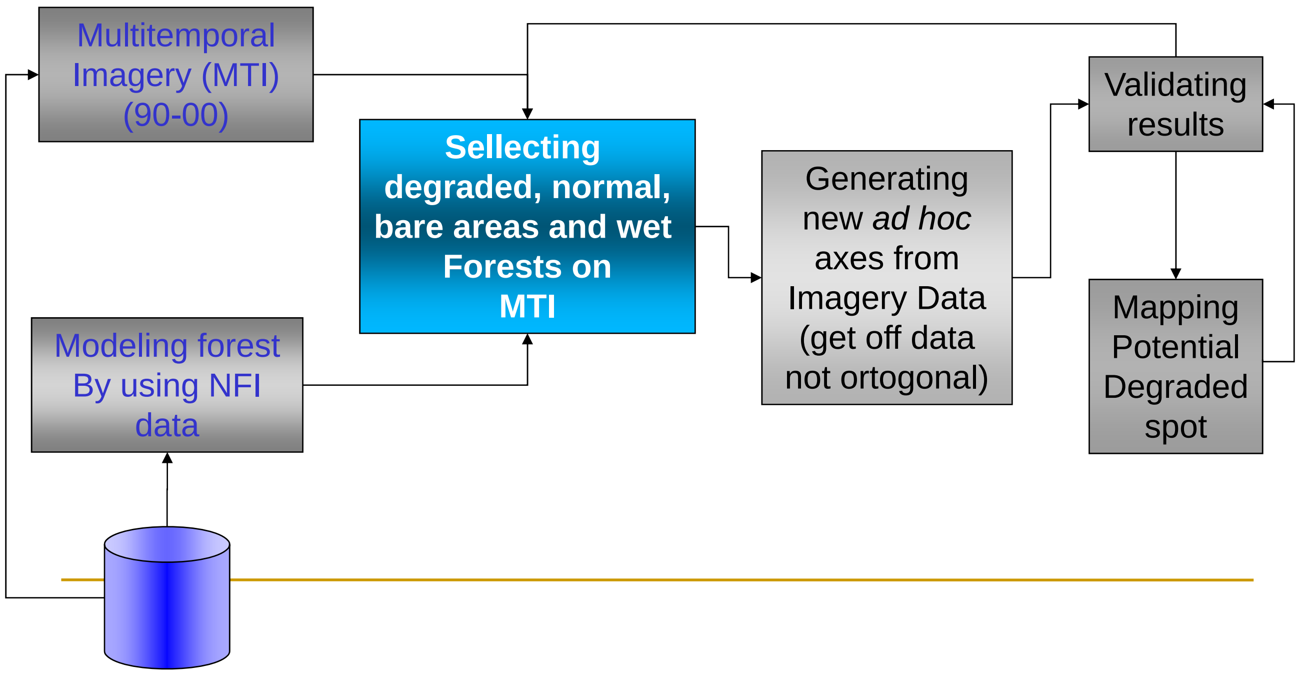
How does forest degradation works?



Degradation unsolved issues

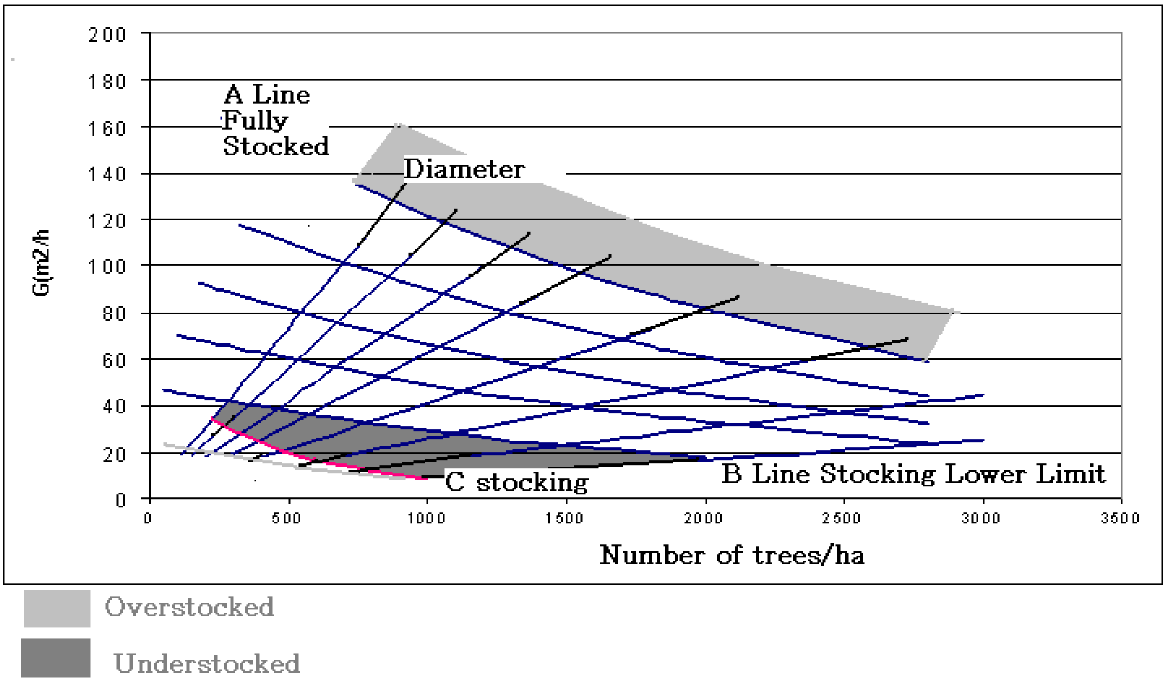
- Lack of country definition or a clear global one (FAO 2005) provoking
  - Problem in disseminating
  - Make the problem invisible
  - No problem No action
- Degradation in forest involves several scales and scopes:
  - Biodiversity
  - Carbon
  - Other emergent properties from Forests
- Spatially involves at least:
  - A stand level
  - A landscape level

The Methodology: integrating forest stand level knowledge and landscape monitoring by using RS techniques



I. Stand level modeling forest using an operational approach to degradation (FAO WP N°158, 2010)

- Using the Stock chart to discriminate degraded –non degraded

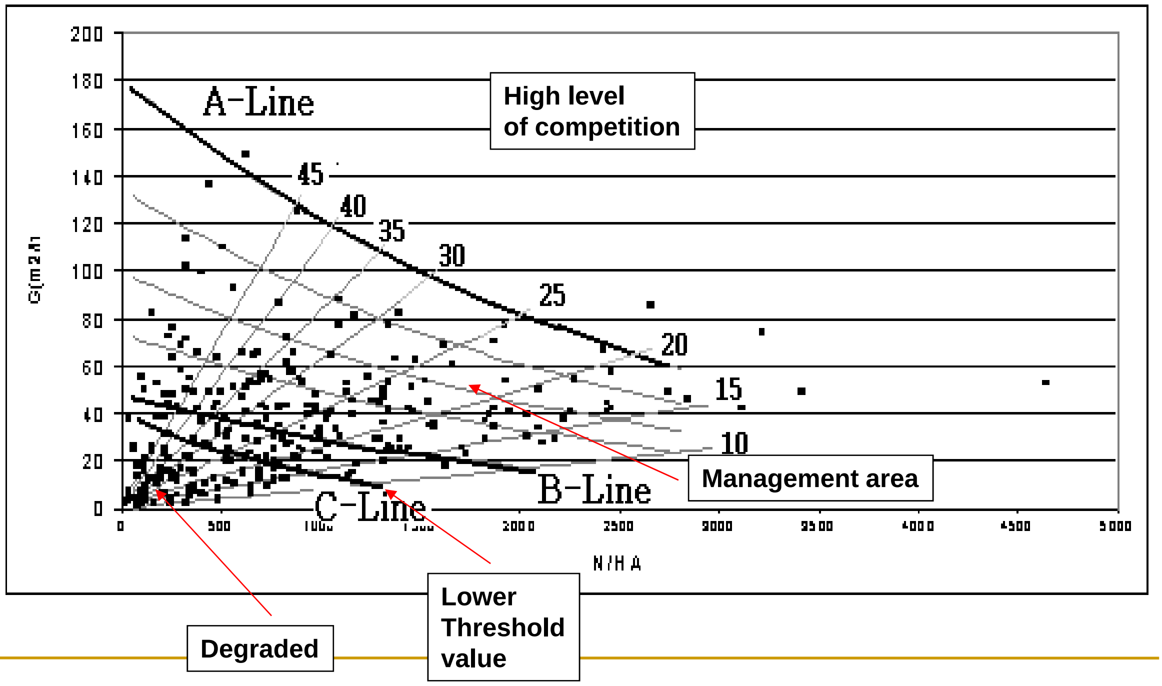


Stock Chart

Forest type

Roble-Rauli-Coihue

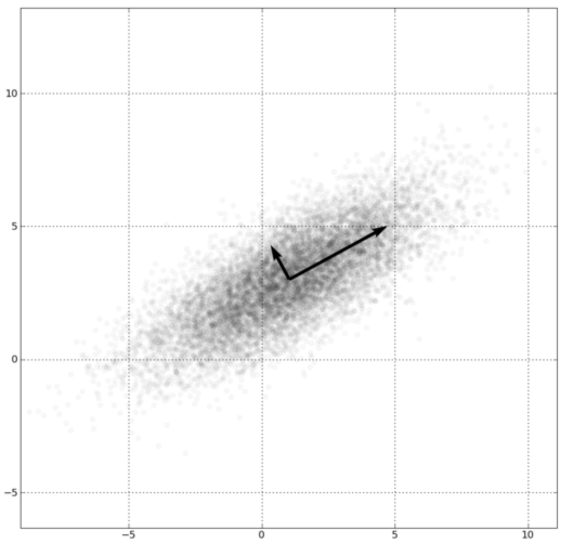
Subtype: *Roble-Rauli-Coihue y Roble*

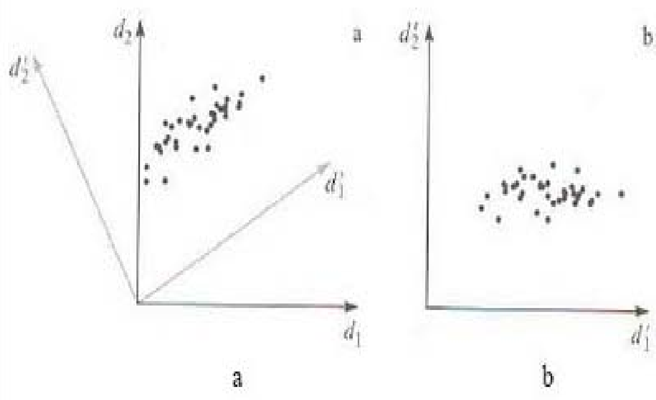


II. At landscape level

- **Method** : Collecting samples from MTI
- **Technique** :Linear transformation (Gram-Schmidt)
- **Material**: Landsat 1990 (TM) -2001 (ETM+)
- **AOI** Región de la Araucania ~0,9 MM ha Roble-Rauli-Coihue

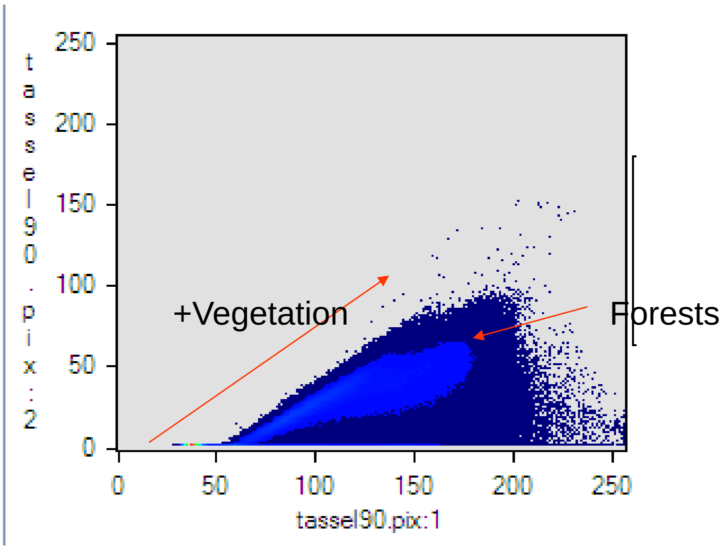
Ex. Principal Components





Ex.Tasseled Cap

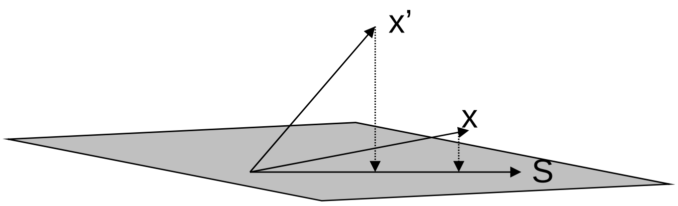
Brightness vs Greeness

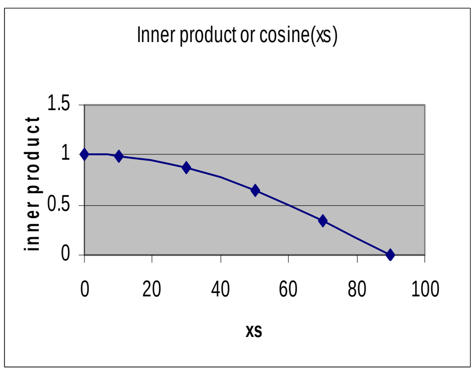


(0.30*C1+0.28*C2+0.47*C3+0.56*C4+0.51*C5+0...
(-0.28*C1-0.24*C2-0.54*C3+0.72*C4+0.08*C5-0..
(0.15*C1+0.20*C2+0.33*C3+0.34*C4-0.71*C5-0...

Projections and Gram-Schmidt ortonormalizing

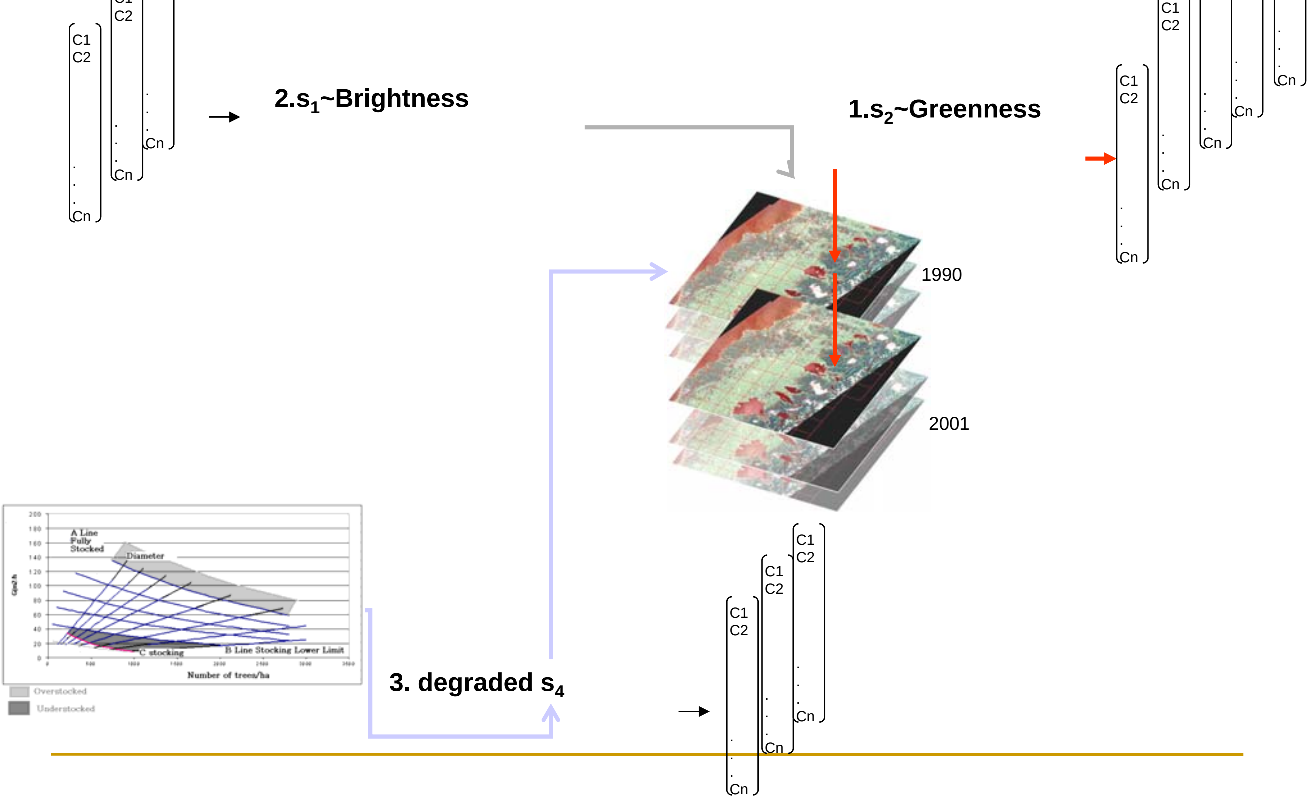
Projecting onto an space explain the proportion of one vector over the subspace. The larger the angle ***xs*** the less influence in the subspace.





$$s_n = x_n - \frac{\langle x_n, s_{n-1} \rangle}{\| s_{n-1} \|^2} s_{n-1} - \dots\dots\dots - \frac{\langle x_n, s_2 \rangle}{\| s_2 \|^2} s_2 - \frac{\langle x_n, s_1 \rangle}{\| s_1 \|^2} s_1$$

Trainning data patterns:



Generating Brightness, Greeness, Wetness and Degradation axes

- Centering vector the darkest one in the AOI
- Brightness Forests <20% canopy cover.

From MTI, collecting the ten most representative vectors for this category and then calculate the mean value vector.

- Greenness dense plain forests >60% canopy cover

From MTI, collecting the ten most representative vectors for this category but also these must be the most distant vector from Brightness and then calculate the mean value vector.

- Wet Forests >60% canopy cover high humidity environment

Very difficult for collecting, no heuristics for selecting, at the end the five most distant vector to Brightness, and Greeness was applied.

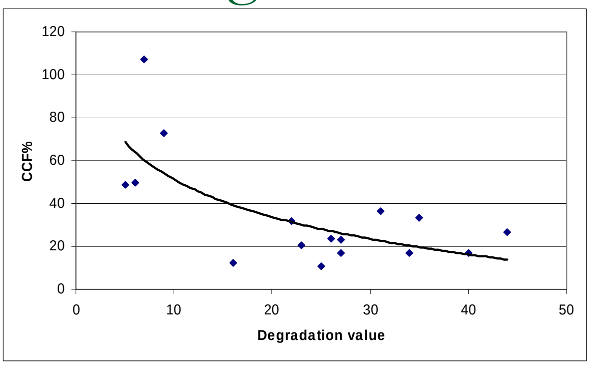
- Degraded forests according to definition

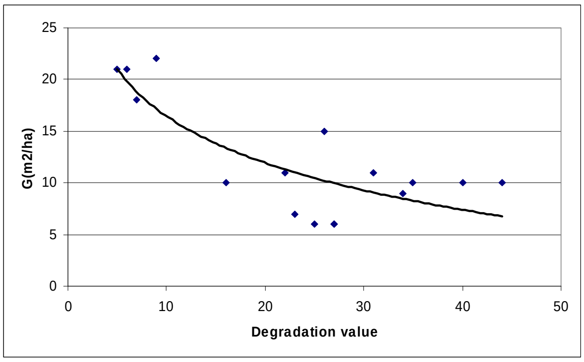
Collecting at most vectors as possible from MTI given the NFI information available, a number of 14 was averaged. No distant requirement was applied.

Results: Covariance Matrix Inspection

	Brightness open forest	Greeness plain forest	Wetness forest	Degraded	Proportion of variation
Brightness open forest	**1.419,48**	940,65	23,95	187,23	**30,129**
Greeness plain forest	940,65	**2.611,56**	156,35	25,53	**55,431**
Wetness forest	23,95	156,35	**78,36**	14,41	**1,663**
Degraded	187,23	25,53	14,41	**147,60**	**3,133**
				Total	**90,356**

Results: Coming back from space, checking correlations

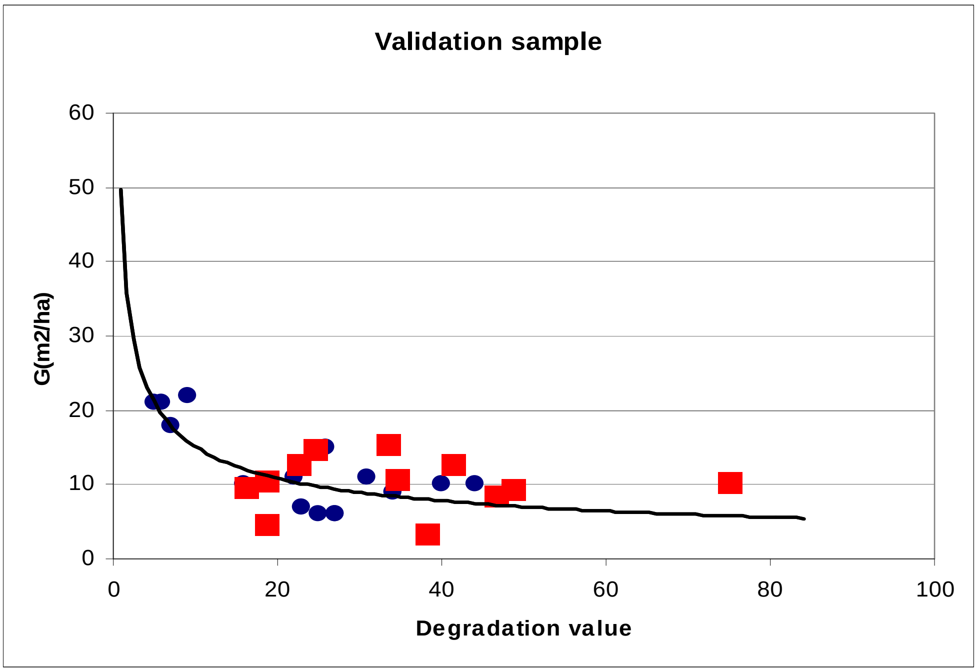




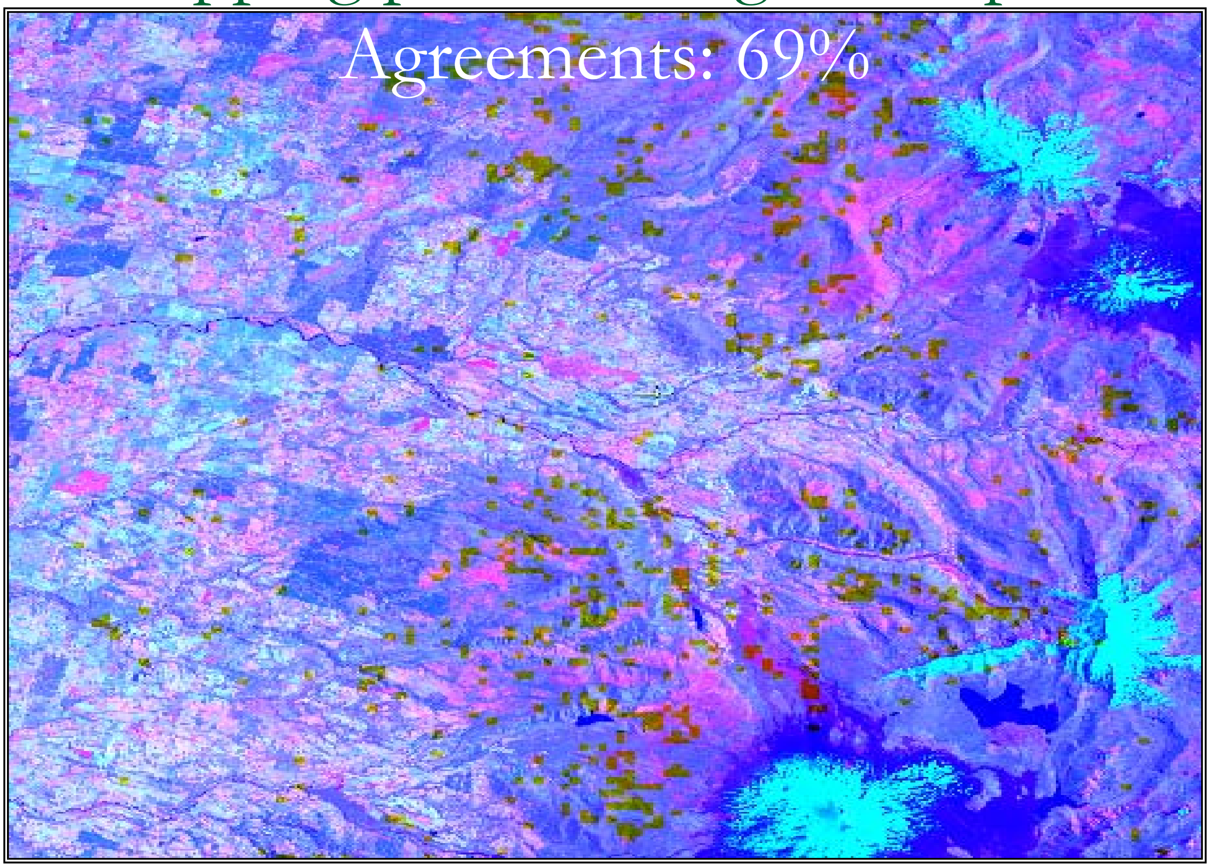
	Basal Área (m2/ha)	Crown Competition Fraction %
Degradation	-0,72	-0,63

Validation

(only 12 independents samples (red dots))



Mapping potential degraded spots



Conclusions ….this study….

- The applied methods showed an acceptable performance in detecting degraded forests.
- The method are far for being automate
- Given that is time consuming and highly interactive and demanding
- The axis Wetness is not easy to determine.
- The amount of suitable samples are difficult to find for both training and validation (its weakness and strength).
- The method is intuitive which it is good.
- It is compulsory to check the potential degraded maps in field.

Ongoing tests…..

$$\underbrace{P(d / m, I)}_{posteriori} \propto \underbrace{P(m / d)}_{Evidence} \underbrace{P(d)}_{Prior}$$

- Modeling the degradations drivers could be an important input to improve degraded maps originated by this method.
- A Bayesian model is being tested, where potential degraded map is the evidence coming from field truth records.
- The drivers model (ANN or Logistic) become the prior

Thanks for your attention!!

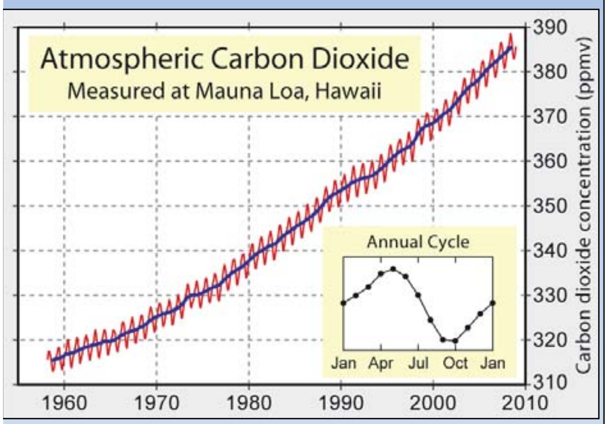
cbahamon@infor.cl

Using Remote Sensing Measurements Constrain Terrestrial Biosphere Model Predictions

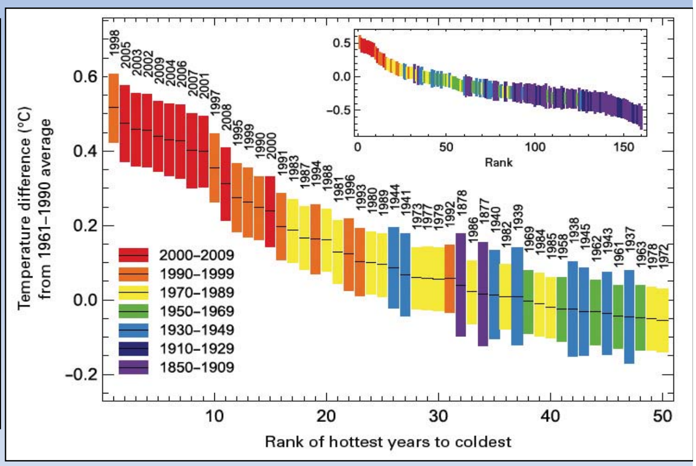
Paul R. Moorcroft
Alex Antonarakis

Harvard University

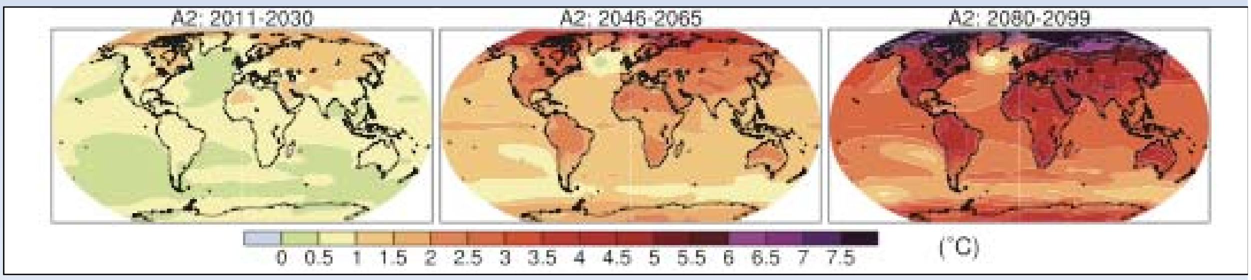

Trend in atmospheric CO_2 concentrations



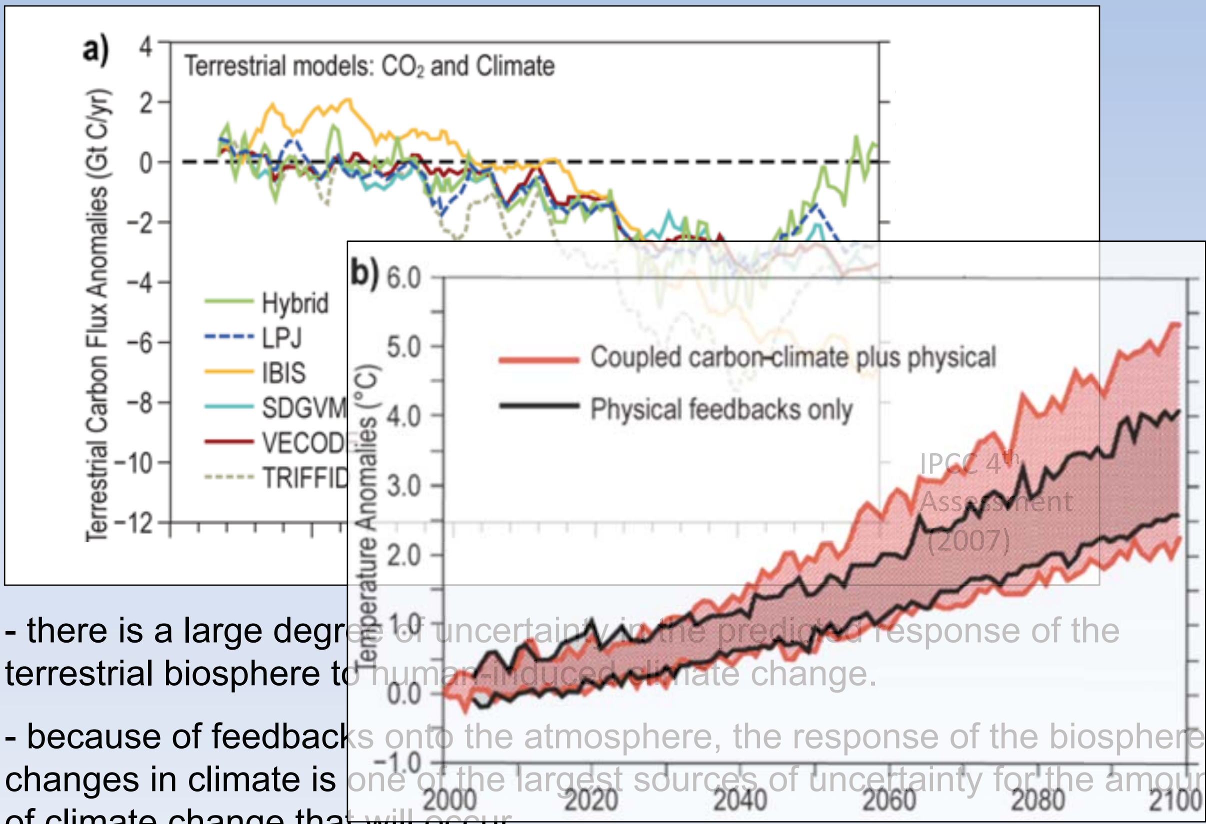
Trends in global temperatures over the past 160 years (WMO 2010)



Predicted temperature changes over the coming century (AR4 2007)



Terrestrial biosphere model (DVGM) predictions for the long-term response of terrestrial ecosystems to climate change



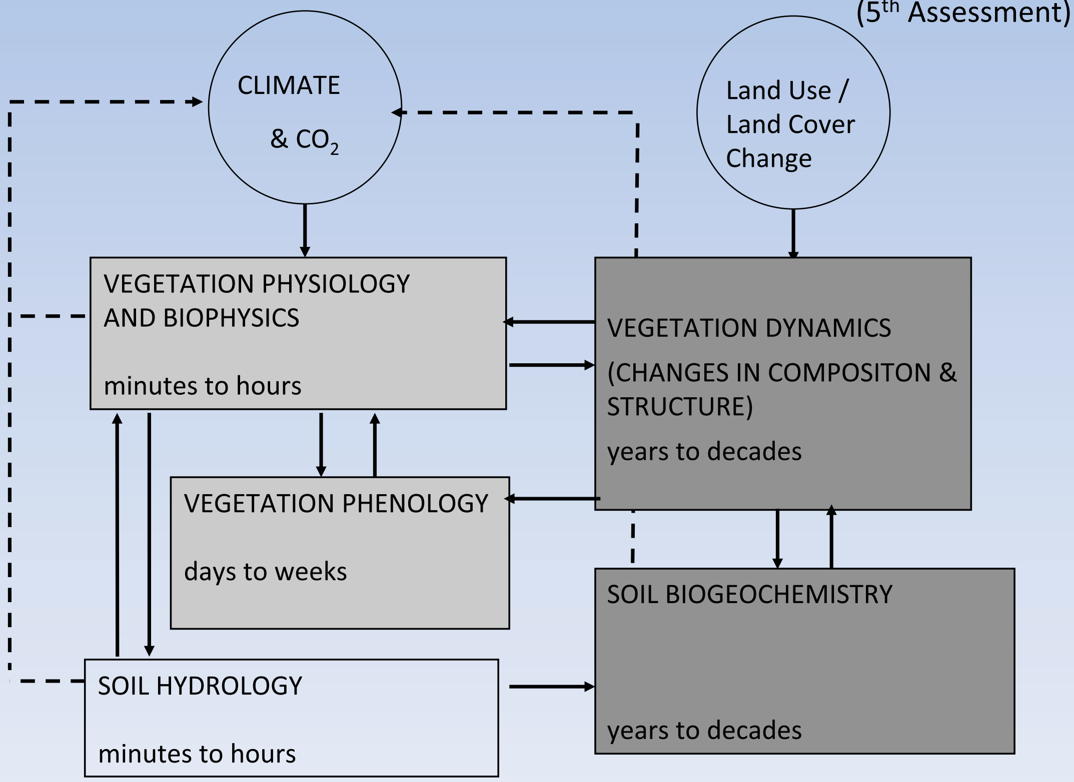
- there is a large degree of uncertainty in the predicted response of the terrestrial biosphere to human-induced climate change.

- because of feedbacks onto the atmosphere, the response of the biosphere to changes in climate is one of the largest sources of uncertainty for the amount of climate change that will occur.

Terrestrial biosphere models

(Dynamic Global Vegetation Models (DGVMs))

(5th Assessment)



Sources of error in terrestrial biosphere model simulations

Process Error: inaccuracies the in model's equations and parameter values: minimize by constrain model's predictions against key observables:

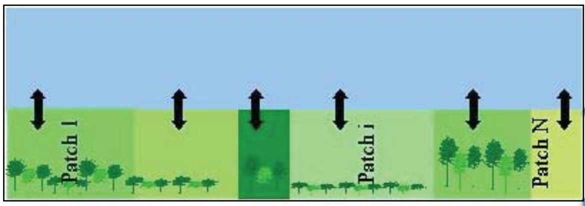
- hourly, monthly & yearly carbon fluxes
- hourly water fluxes (ET)
- above-ground vegetation dynamics (growth & mortality)

Forcing Error: - inaccuracies in meteorological data used in the simulation: minimize by forcing model with observed climate data.

Initialization Error - errors in the model's state variables at the beginning of the simulation: minimize by initializing with observed ecosystem structure and composition.

(Moorcroft et al. 2001, Moorcroft 2006, Medvigy et al. 2009)

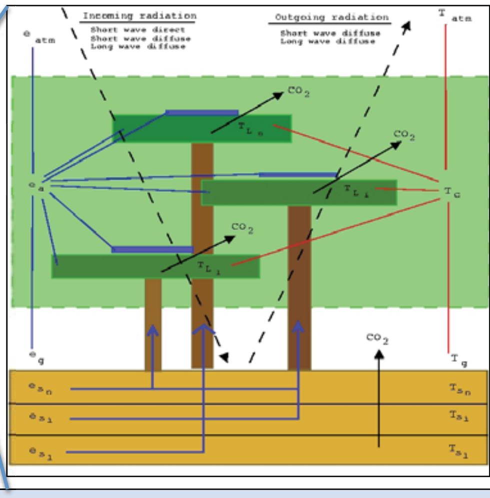
e.g. Calibration and Testing of the ED2 terrestrial biosphere model at Harvard Forest (42^{o}N, -72^{o}W)



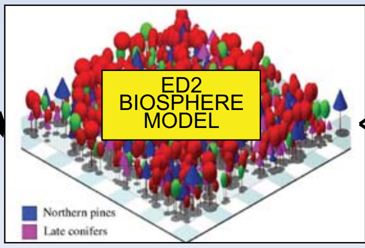
ED2 structured biosphere model

$$\frac{\partial n^{(i)}(z,a,t)}{\partial t} = -\frac{\partial}{\partial z}\left[g(z,a,t)n^{(i)}(z,a,t)\right] - \frac{\partial}{\partial a}n^{(i)}(z,a,t) - \mu(z,a,t)n^{(i)}(z,a,t)$$

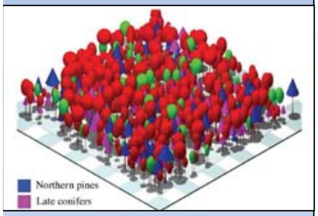
$$\frac{\partial p(a,t)}{\partial t} = -\frac{\partial}{\partial a}p(a,t) - \lambda(a,t)p(a,t)$$

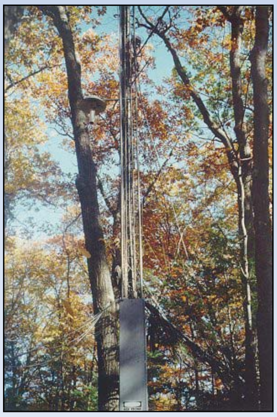


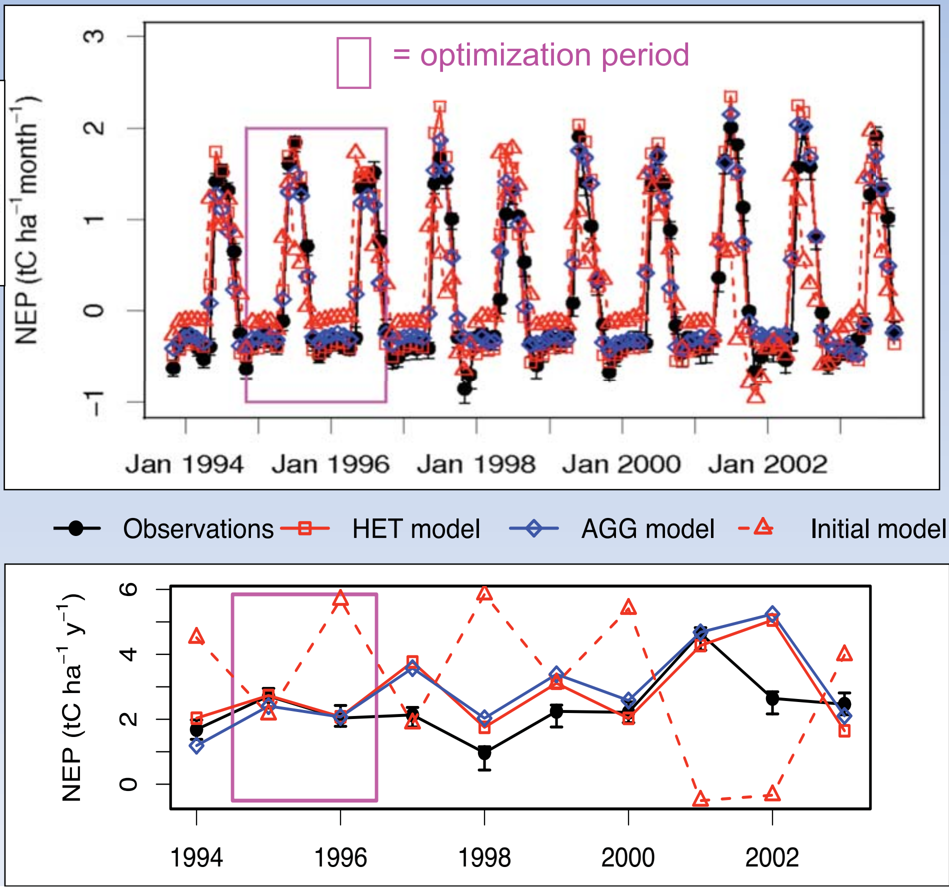
Ground-Based Inventory Measurements → Canopy Composition (abundance of different plant functional types); Canopy Structure (tree size class distribution) → ED2 BIOSPHERE MODEL → Ecosystem Carbon Fluxes; Long-term Vegetation Dynamics



ED2 Biosphere Model Predictions for Harvard Forest: 10-yr simulations (1992-2001)

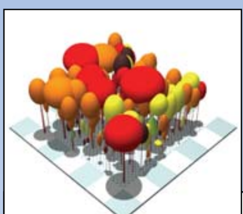




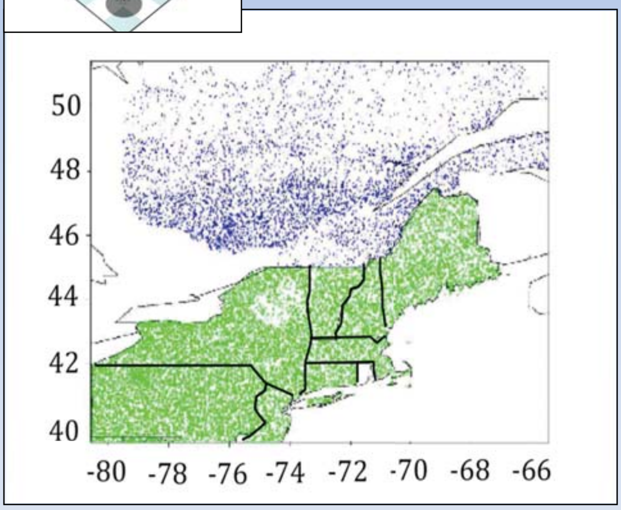


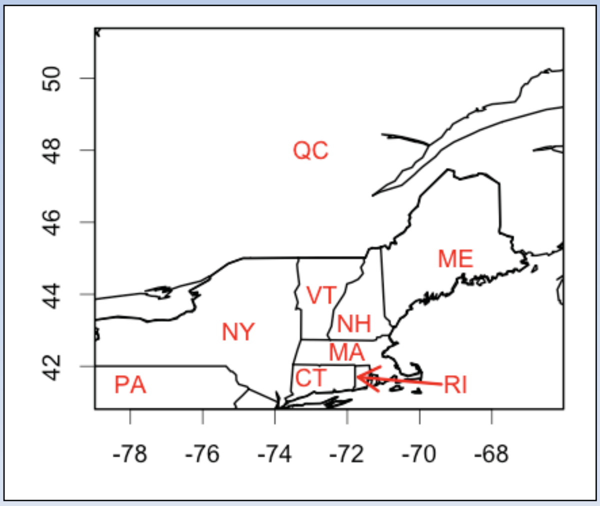
Medvigy & Moorcroft (2012)

Regional decadal-scale evaluation



- stand composition & harvesting rates: US Forest Service & Quebec forest inventory 1985 - 1995

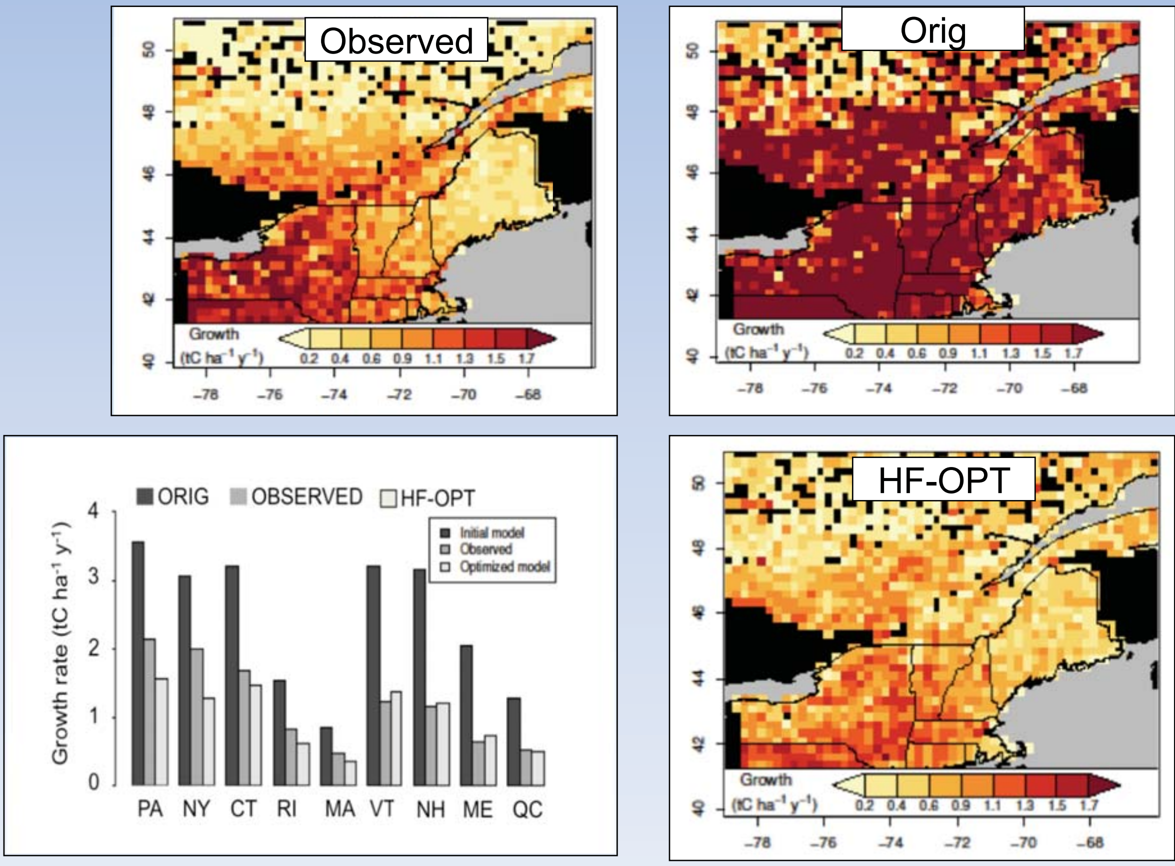




- climate drivers : ECMWF 6-hour reanalysis dataset

- <u>no change in any of the model parameters</u>

Spatial patterns of above-ground biomass growth:



Predictions by plant functional type:

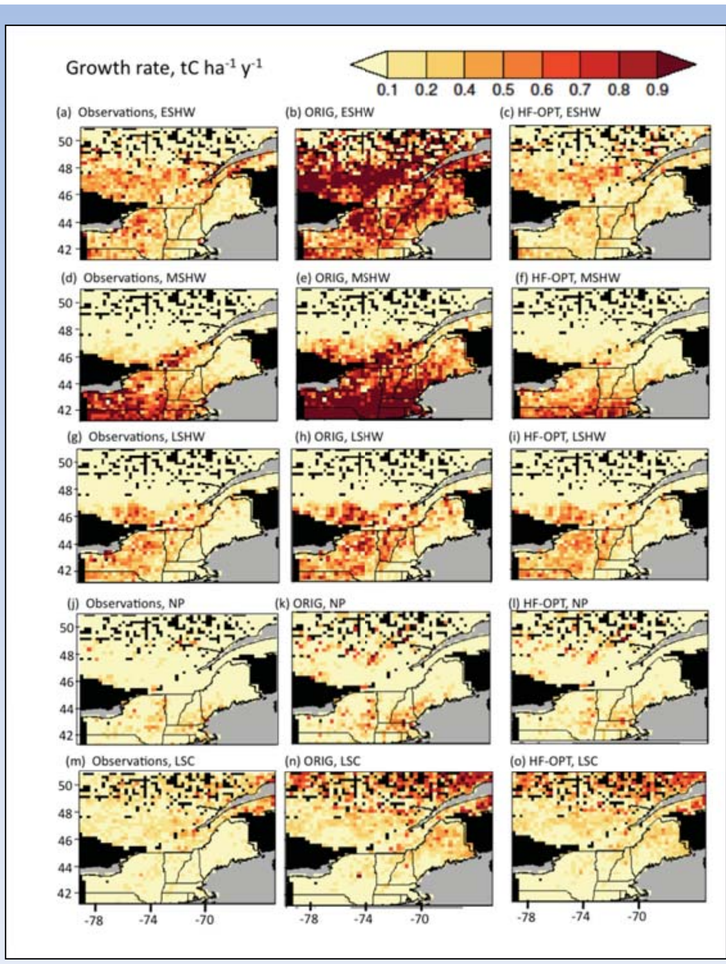
Early-successional hardwoods

Mid-successional hardwoods:

Late-successional hardwoods:

Northern pines:

Late-successional conifers:

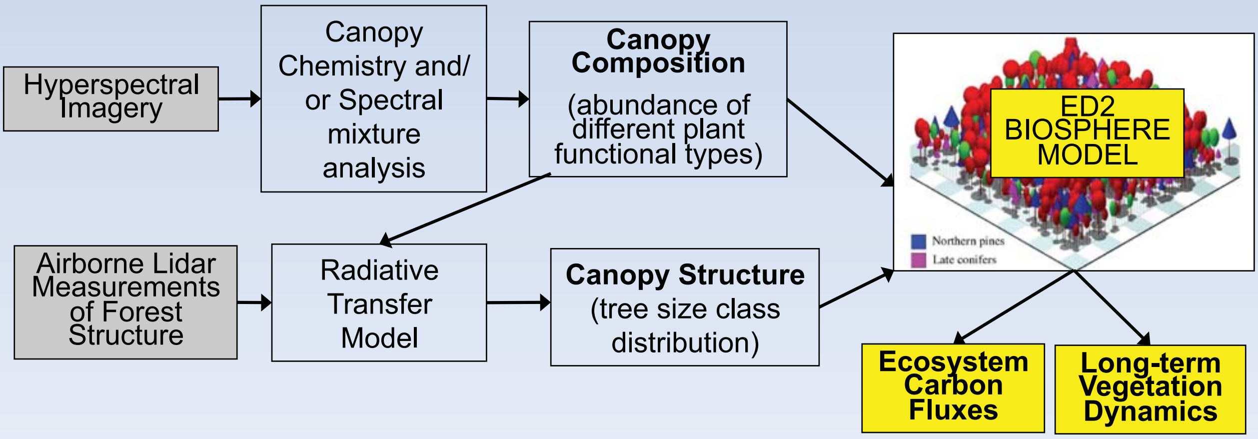


Antonarakis et al. in prep.

Using Remote Sensing Observations of Forest Structure & Composition to Constrain Terrestrial Biosphere Model Simulations

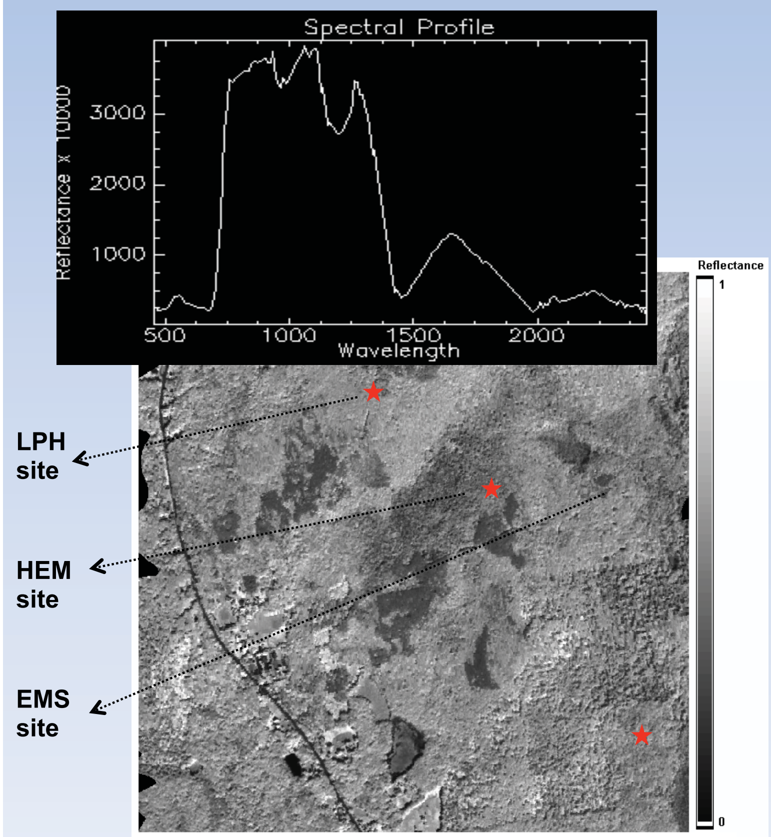
In many areas of the world there are limited ground-based measurements that can be used to constrain terrestrial biosphere models.

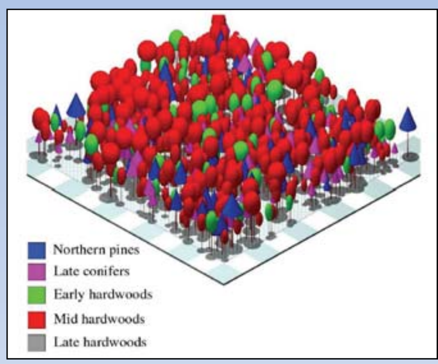
→ can we use remote sensing measurements to provide information on above-ground ecosystem state? [Initialization Error]



Antonarakis et al. in prep.

Plant Functional Type Composition from Hyperspectral Remote Sensing Data



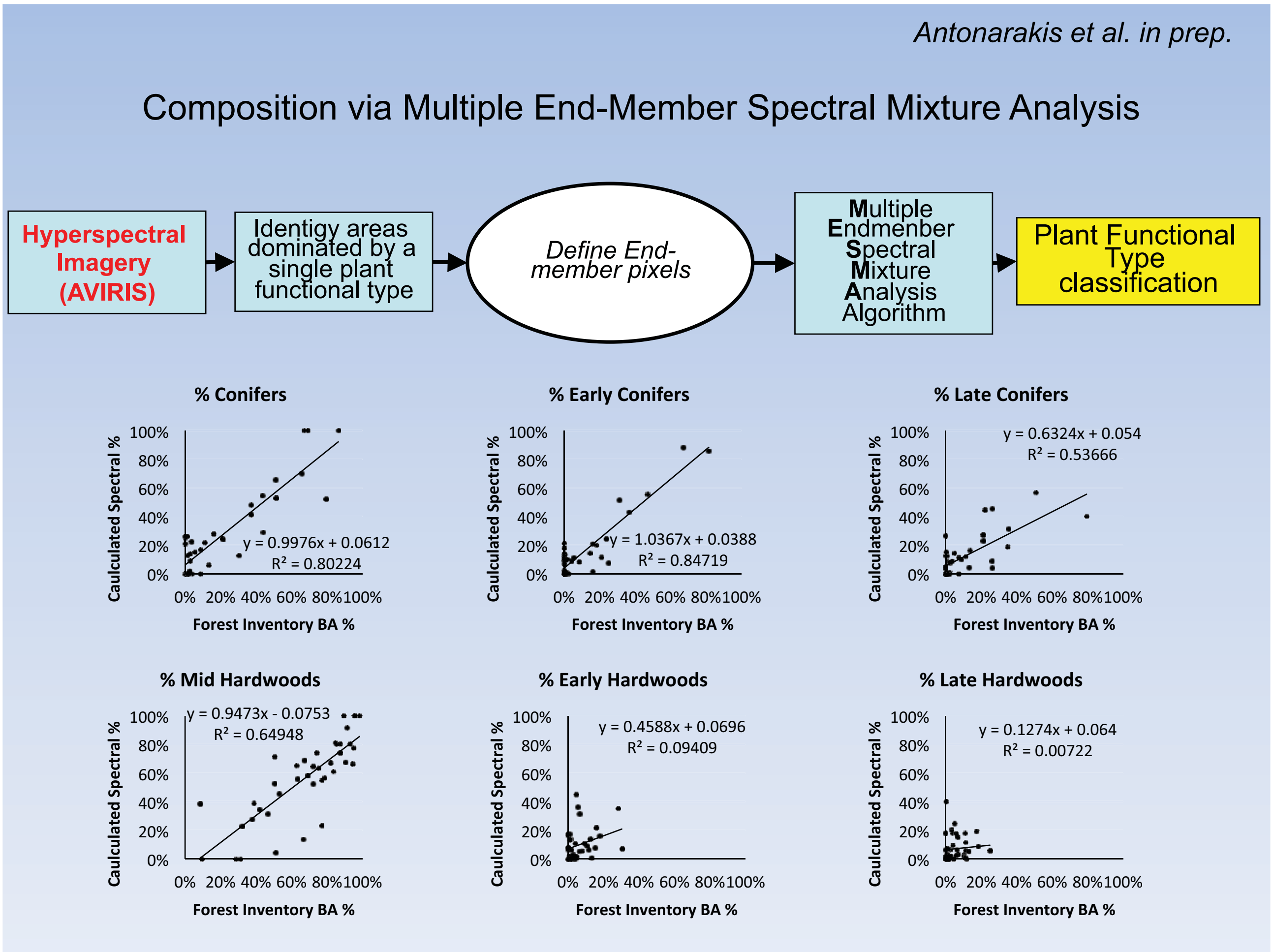


ED2 PFTs

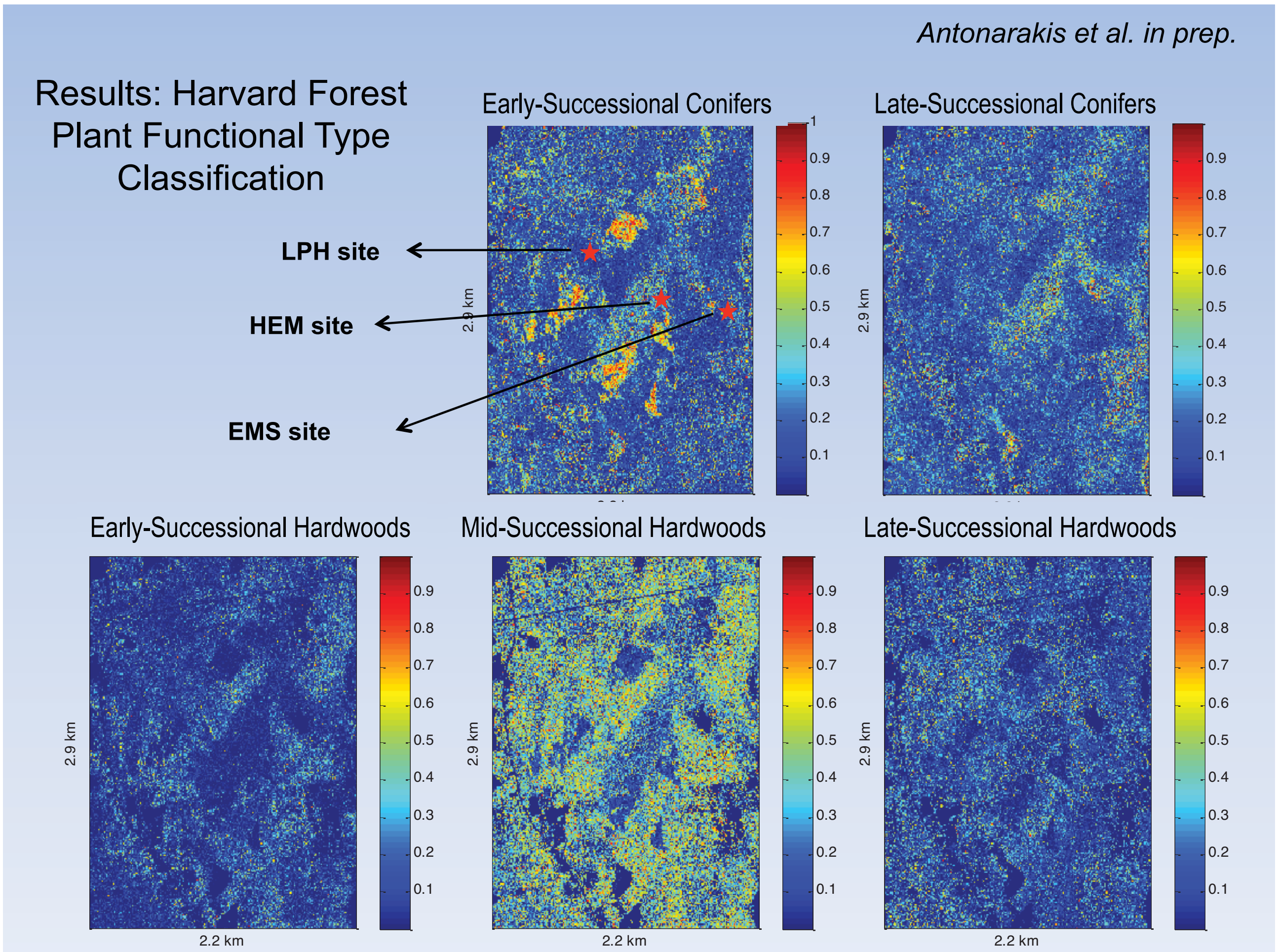
Hardwoods:
- early-successional (birch)
- mid-successional: (red oak & red maple)
- late-successional: (beech, sugar maple)

Conifers:

- northern pines (white & red pine)
- late-successional conifer (hemlock)



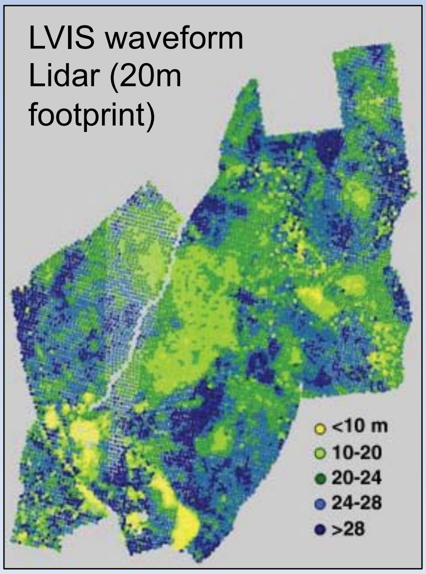
Antonarakis et al. in prep.
Composition via Multiple End-Member Spectral Mixture Analysis
Hyperspectral Imagery (AVIRIS)
Identigy areas dominated by a single plant functional type
Define End-member pixels
Multiple Endmenber Spectral Mixture Analysis Algorithm
Plant Functional Type classification
% Conifers
y = 0.9976x + 0.0612
R² = 0.80224
% Early Conifers
y = 1.0367x + 0.0388
R² = 0.84719
% Late Conifers
y = 0.6324x + 0.054
R² = 0.53666
% Mid Hardwoods
y = 0.9473x - 0.0753
R² = 0.64948
% Early Hardwoods
y = 0.4588x + 0.0696
R² = 0.09409
% Late Hardwoods
y = 0.1274x + 0.064
R² = 0.00722
Caulculated Spectral %
Forest Inventory BA %
0% 20% 40% 60% 80% 100%

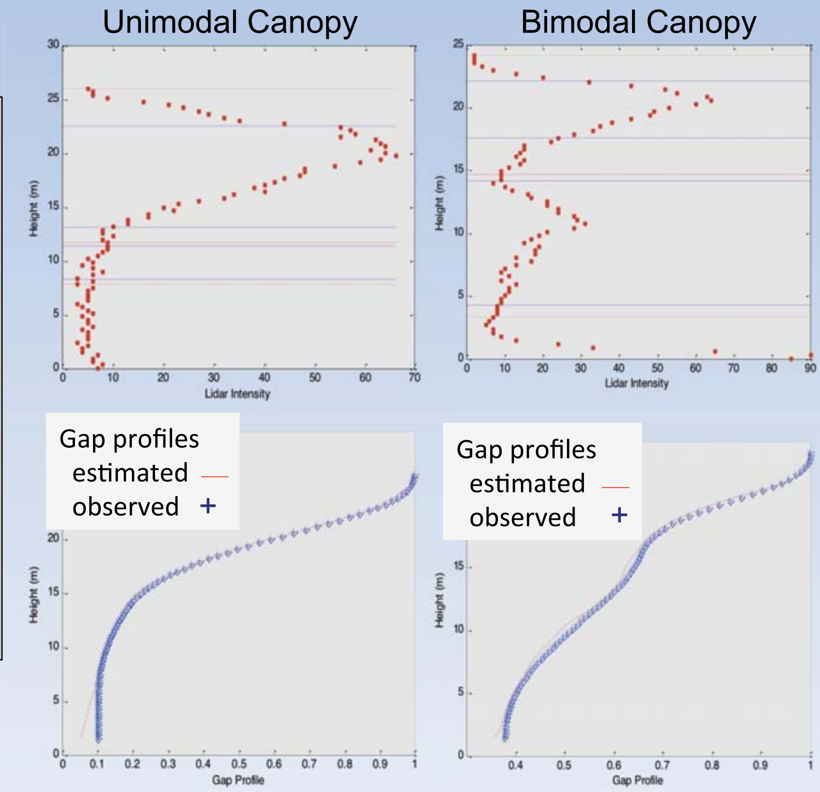


Antonarakis et al. in prep.
Results: Harvard Forest Plant Functional Type Classification
LPH site
HEM site
EMS site
Early-Successional Conifers
Late-Successional Conifers
Early-Successional Hardwoods
Mid-Successional Hardwoods
Late-Successional Hardwoods
2.9 km
2.2 km
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9

Antonarakis et al. in prep.

Lidar-derived estimates of canopy structure





Results: Composition and Structure at 3 Harvard Forest sites

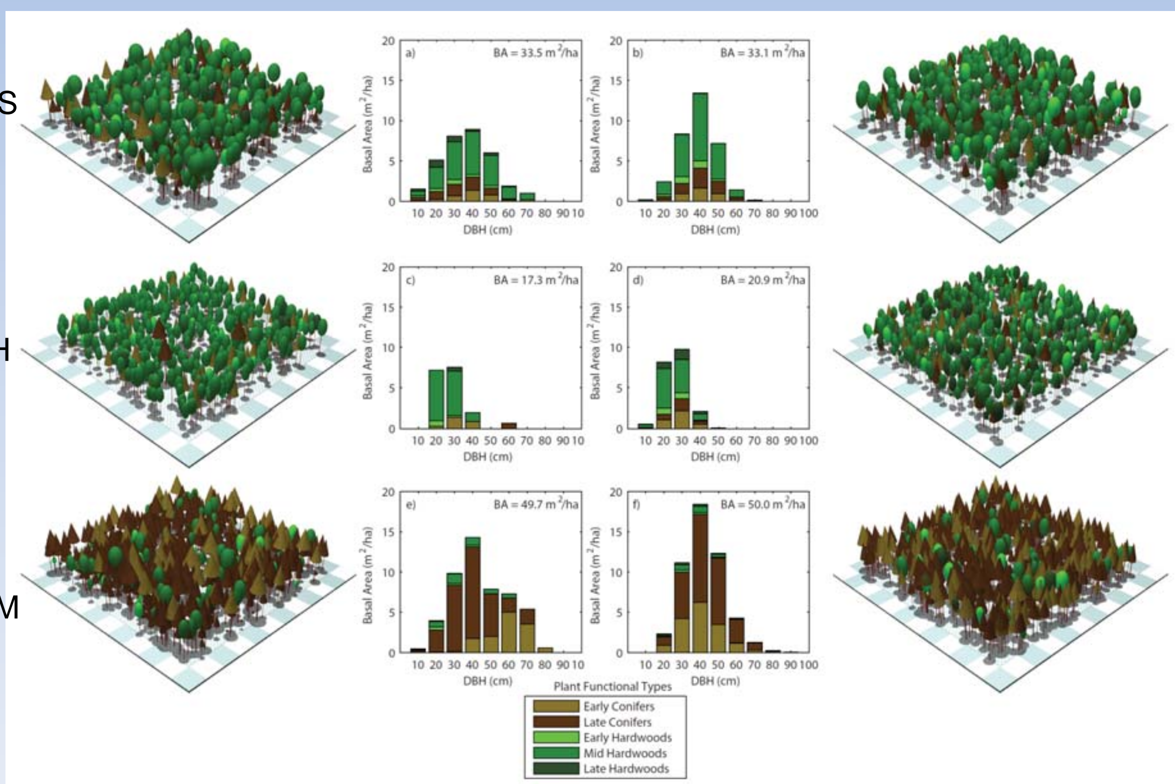
OBSERVED

REMOTE SENSING ESTIMATE

EMS

LPH

HEM



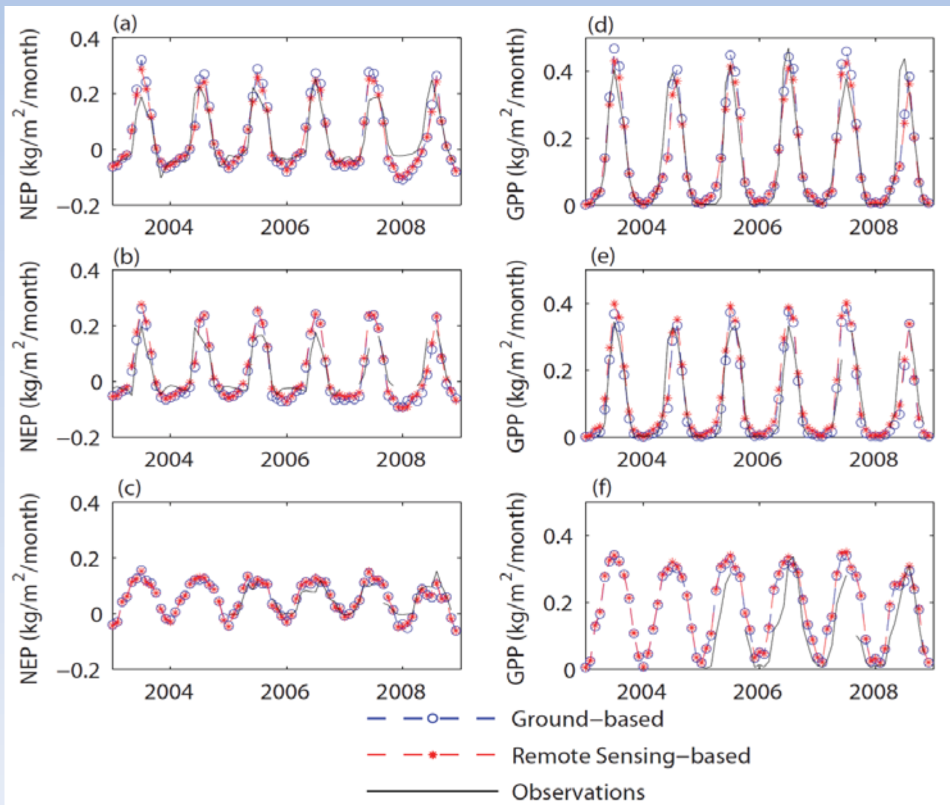
Seasonal Patterns of Carbon Fluxes (2003-2009)

Net Ecosystem Productivity (NEP)   Gross Primary Productivity (GPP)

EMS

LPH

HEM



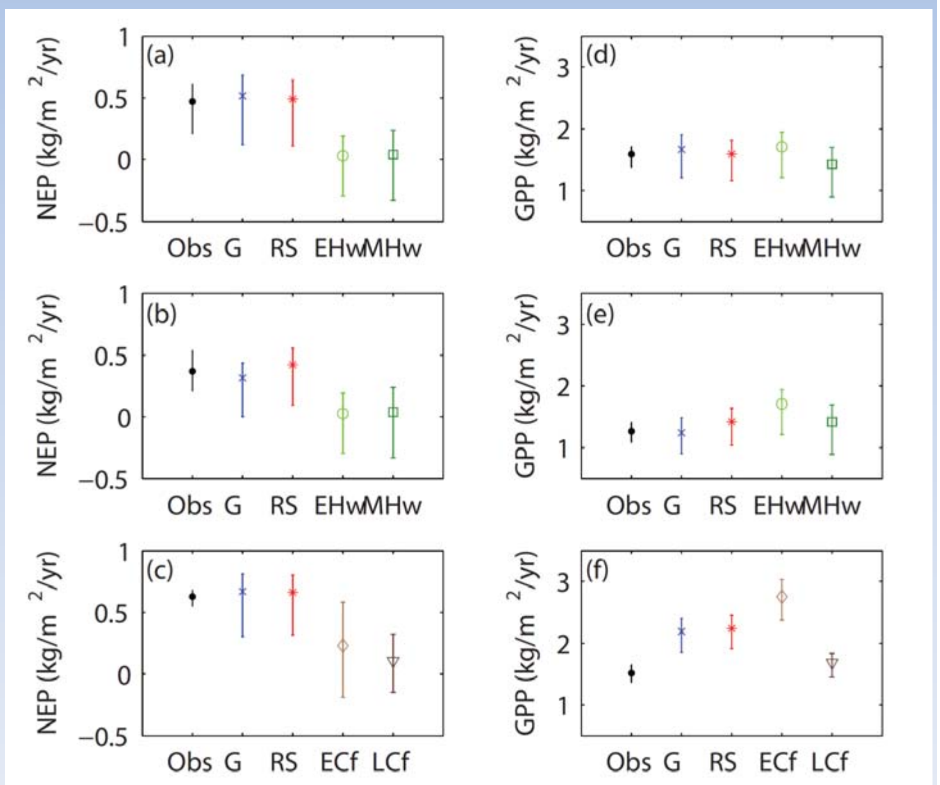
Yearly Carbon Fluxes (2003-2009)

Net Ecosystem Productivity (NEP)   Gross Primary Productivity (GPP)

EMS

LPH

HEM



Conclusions

- Lidar in conjunction with hyperspectral remote sensing measurements can be used to provide consistent spatially-extensive measurements of fine-scale above-ground ecosystem composition and structure.

- These measurements pave the way for far more accurate regional- and global-scale terrestrial biosphere model simulations that are critical for predicting current ecosystem function and how ecosystems will change in the future.

- There is an ongoing convergence between the needs of the terrestrial monitoring and modeling communities.

Key underlying questions:

What is the current state of the land-surface?

And how is it changing as a result of human activities?

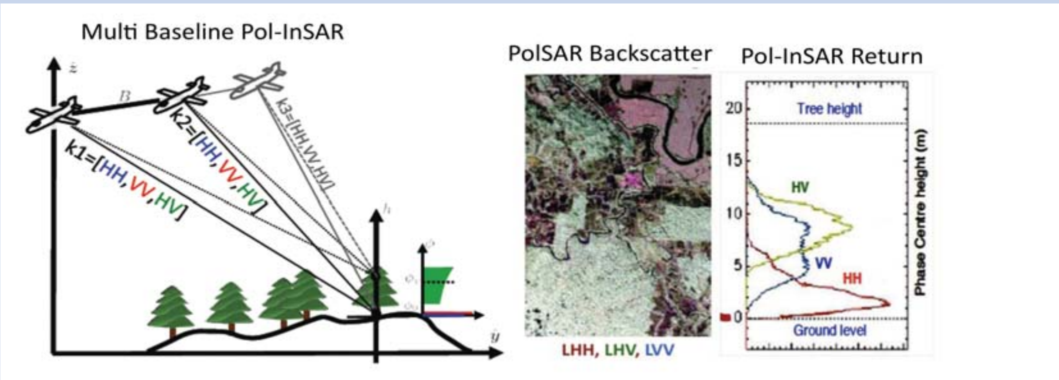
To adequately answer these questions, both communities require:

- accurate measurements of ecosystem state.
- accurate measurement of changes in ecosystem state.

Future Directions:

Using repeated remotely sensed imaging to constrain process error (vegetation dynamics)

Radar (Pol-InSAR) measurements of vegetation structure:



Acknowledgements

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Collaborators: Andes Amazon Initiative Consortium
Steve Wofsy, Bill Munger, David Foster, D. Hollinger, Andrew Richardson, Xiaoyang Zhang, Mark Friedl.

References:

Moorcroft *et al.* 2001. *Ecological Monographs* 74:557-586.
Moorcroft 2006. *Trends in Ecology and Evolution* 21:400-407
Medvigy et al. (2009) *JGR Biogeosciences 114: G01002*
Medvigy et al. (2010) *Proceedings of the National Academy of Sciences* 107:8275-8280.

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National Science Foundation
Moore Foundation

Obtaining reliable fine-scale estimates of biomass using ground-based methods

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GHG accounting in the land sector

- Special challenges of large and heterogeneous areas, long (multi-decadal) time-scales
- Complex drivers of net GHG emissions – bio-physical environment, and range of managed and natural disturbances
- Need to estimate change against a variable background
- Remote-sensing in combination with ground observations and models to estimate emissions/removals are needed

Spatial variability

Components of Net GHG balance

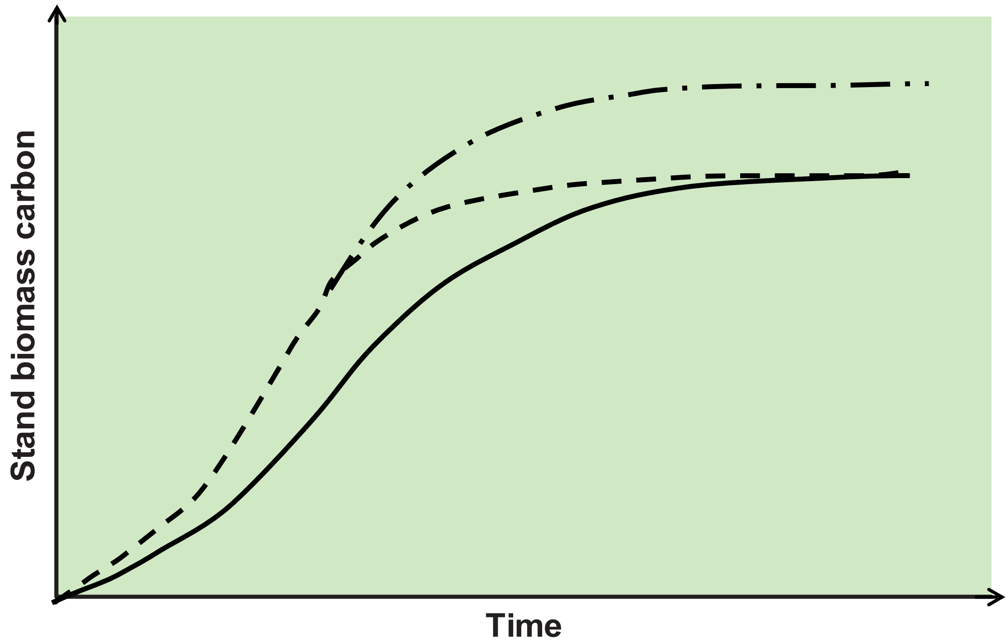
Land areas with different vegetation/management/disturbance have different GHG balance due to:

- Change in C stocks in **biomass** (above –ground & roots) and dead OM
- Change in **soil C** and non- CO_2 GHG emissions
- **Fire** emissions - mostly CO_2 , but also non- CO_2 GHG gases

Biomass carbon change (~ 50% C)

- **Removal** of biomass due to harvest, LUC, and fire
- **Replacement -** the pattern of biomass accumulation over time in regenerating or planted forests – '**C accumulation curves**' for different forest types

Forest biomass Carbon accumulation (and loss) curves can inform removals and emissions factors



Weighing large eucalypt trunk

Broad approaches to estimating forest biomass

- Use 'default' values from IPCC or other studies – Very uncertain at local scales!
- Develop site-level equations to estimate biomass from simpler tree or stand measures. Try to 'generalize' these
- Weigh whole stand biomass, and use to check estimation methods such as equations – rarely done
- Try to develop a model that can be used for spatial estimation of biomass (Aust. NCAS)

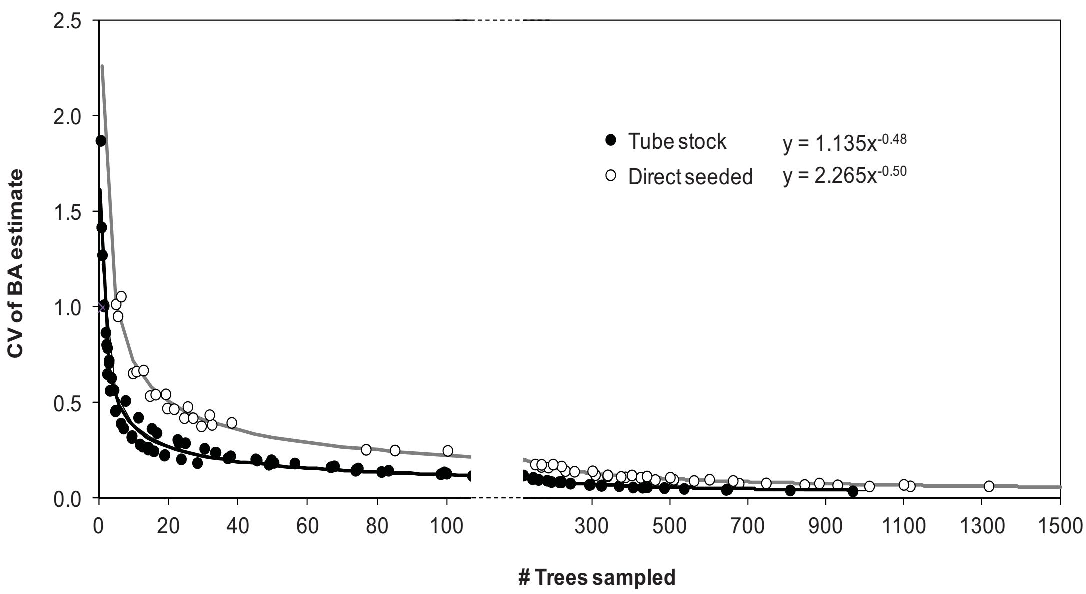
Key uncertainties in estimating forest biomass

- **Sampling design**
- **Forest inventory**
- **Development of equations to convert inventory measures to biomass**
- **Application of equations across species and sites**
- **Scaling from trees to plots to the landscape**

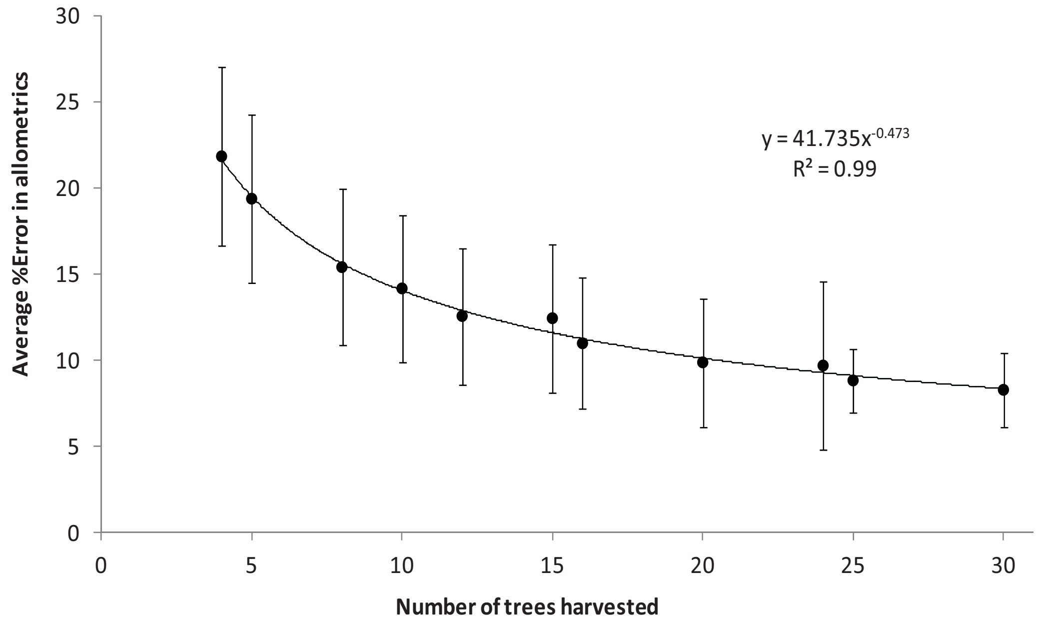
Insights from a major study of forest biomass

- Data on plantings up to 30 years of age from ~ 1500 sites across Australia
- Allometric equations for > 100 species
- Total site survey and associated destructive harvest of total above- and below-ground biomass on sample plots in 13 contrasting plantings. Data used to **test the reliability** of alternative methods to estimate the **directly measured** biomass
- Monte Carlo simulations to estimate the components of uncertainty of biomass estimates

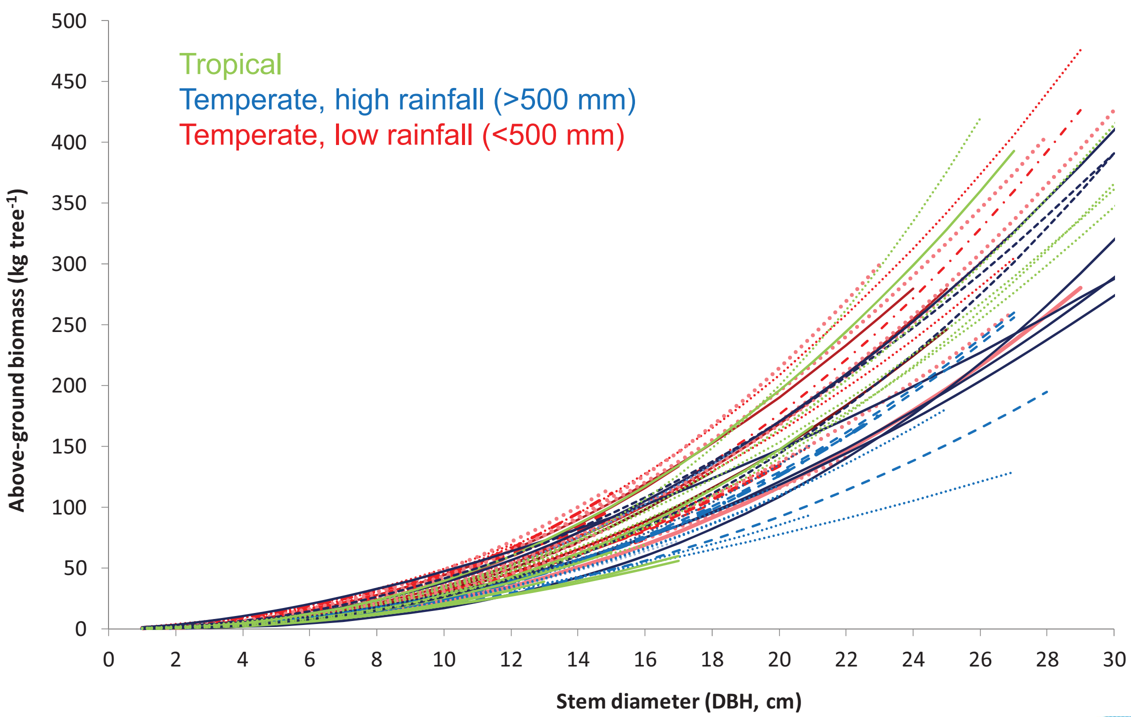
Effect of sampling intensity (# trees) on the coefficient of variation (CV) of sampled basal area (~ biomass)



Effect of sample number on average percentage error in allometrics (absolute difference in biomass derived from the estimated allometric cf the 'true' allometric)



Variation in allometrics of eucalypt trees caused by species and site factors

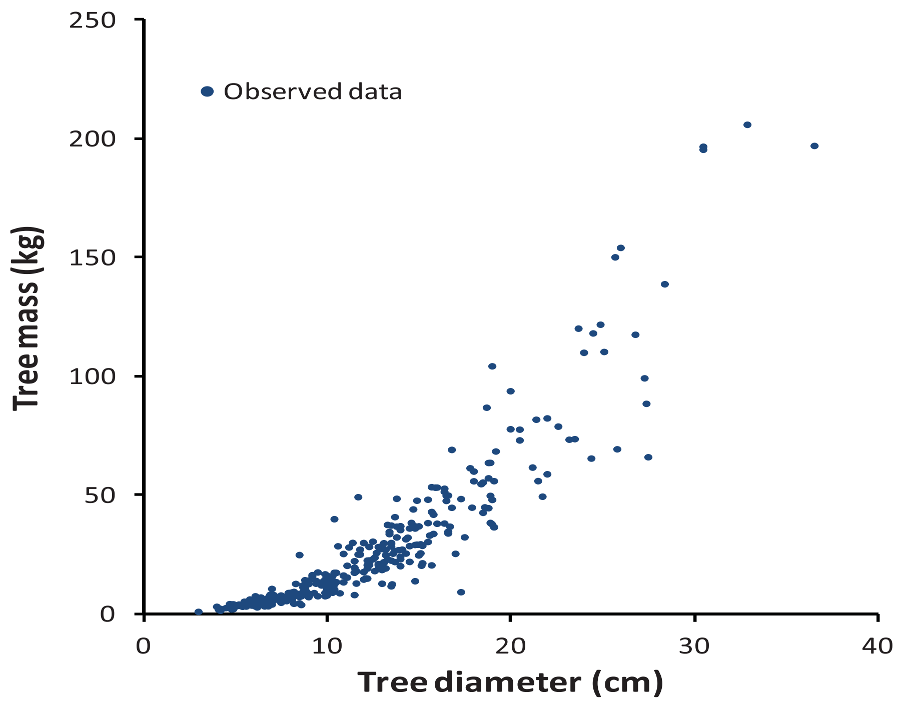


Errors in estimates of above-ground Biomass (t) of mixed tropical lowland Dipterocarp forest caused by using different allometrics (Basuki et al, FEM, 2009)

- **Measured** **average tree biomass (122 sample trees, diameter 6- 200 cm)   2.28 t**
- **Estimated** **using site-specific allometrics   2.28 – 2.46**
- **Estimated** **using other tropical allometrics**
  - **Brown 3.83 (+ 68%)**
  - **Chave 4.18 (+83%)**
  - **Ketterings 1.24 (- 46%)**

CSIRO.

Eucalyptus viminalis – field observations



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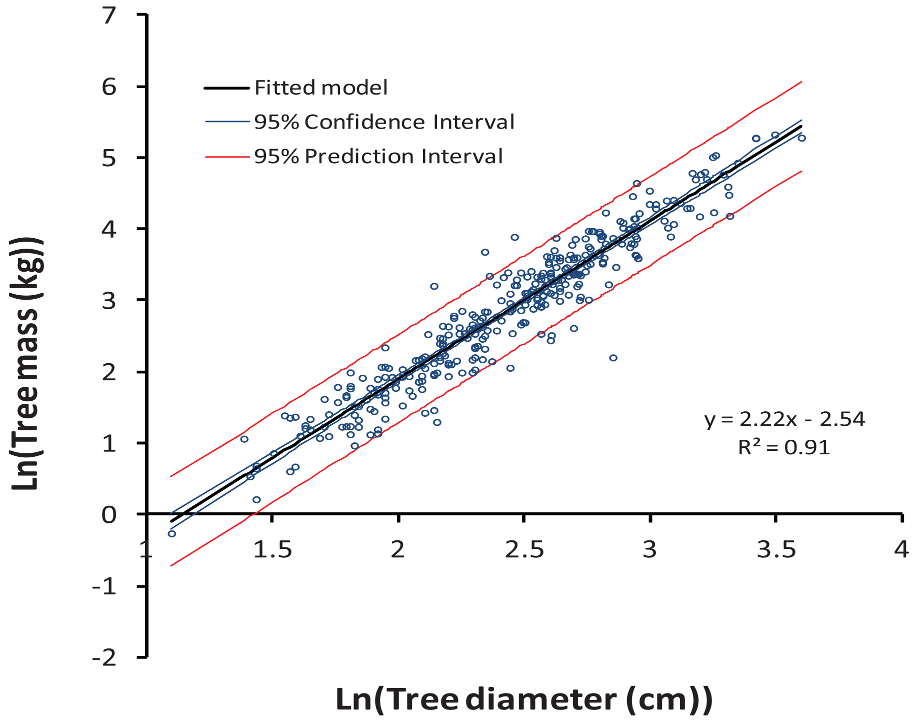
Fitted allometric equation



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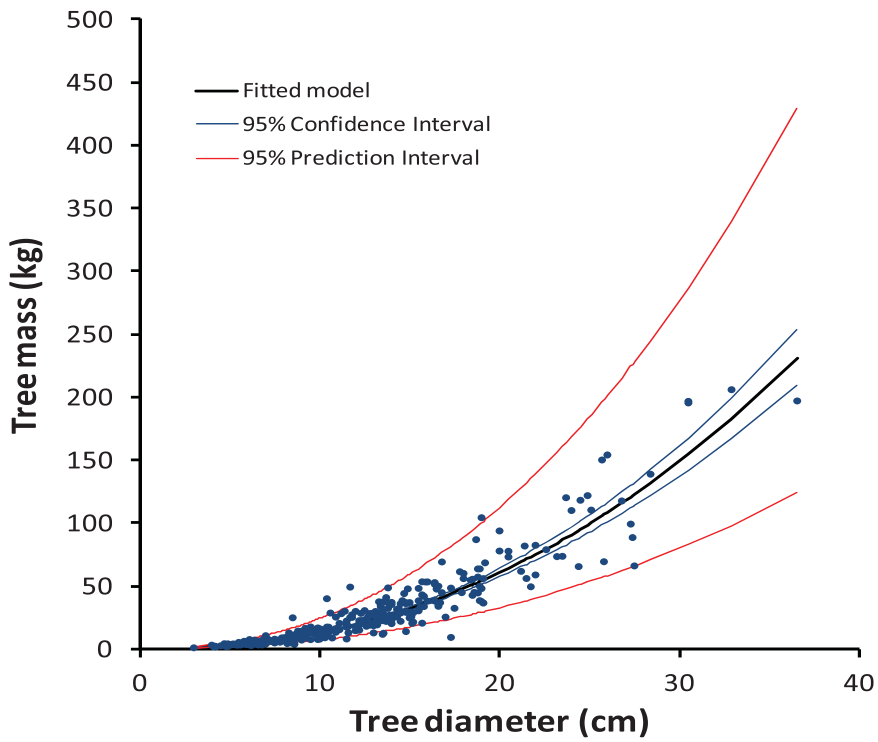
Untransformed data – problem of large trees!



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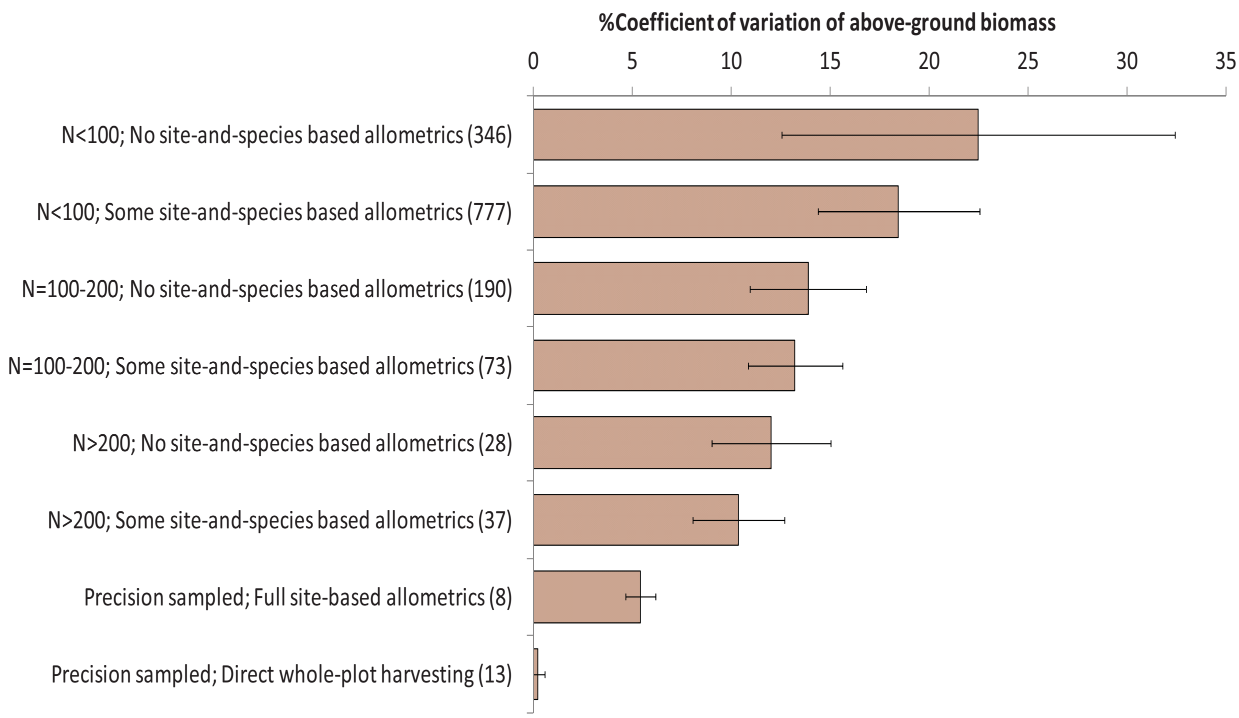
Large trees are very important!

- Large trees dominate stand biomass
- Large trees are often poorly represented when developing allometric equations
- Serious errors arise when estimating biomass for large trees that are outside the size range used to develop allometric equations

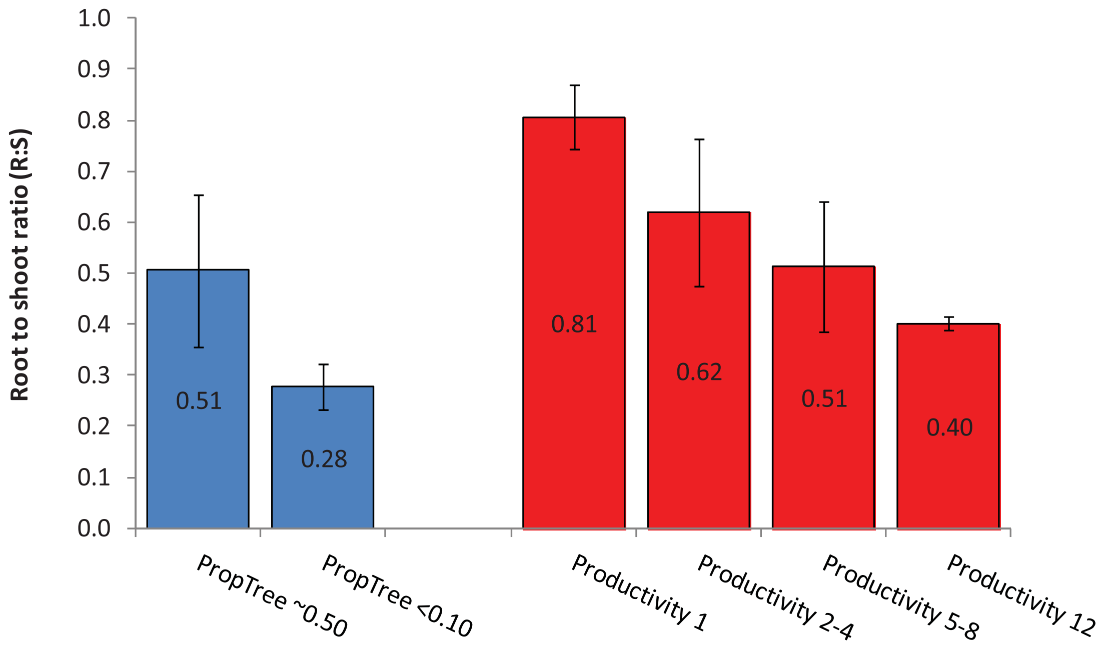
Effect of estimation method on the coefficient of variation in estimates of above-ground biomass.



Estimating root biomass

- Destructive sampling in contrasting forests is needed to establish a basis for prediction at other locations
- Root:Shoot ratios (e.g. IPCC defaults) are often used to estimate root mass from above-ground biomass for different 'classes' of forest
- Forest type, age, and site conditions markedly affect root:shoot ratios

Variation in Root:Shoot ratio with proportion of trees and site productivity in young plantings



Effect of Root:Shoot ratio on % of total biomass that is below-ground

- If R:S ratio is 0.2, **17%** of biomass is below-ground
- If R:S ratio is 0.5, **33%** of biomass is below-ground
- If R:S ratio is 0.8, **44%** of biomass is below-ground

Direct measurement of root biomass

Conclusions

- Reliable estimation of biomass at fine scales is required for a range of uses, including calibration of remotely- sensed imagery
- Considerable care and effort is required to gain reliable estimates of biomass at fine scales, particularly in complex tropical forests. Application of inappropriate, or generalized allometrics can produce very uncertain biomass estimates
- Estimates of the biomass of single large trees (or small patches of trees) will be highly uncertain even when using site-specific allometric equations. Biomass estimates over larger areas (> 1 ha?) may result in more reliable calibration of remotely-sensed imagery
- Root are an important biomass component (~ 20-50 % of total biomass) – uncertainties are high

UNIVERSITY OF DUNDEE

School of the Environment

Estimating tropical forest biomass with multisource remote sensing data: predictions between regions

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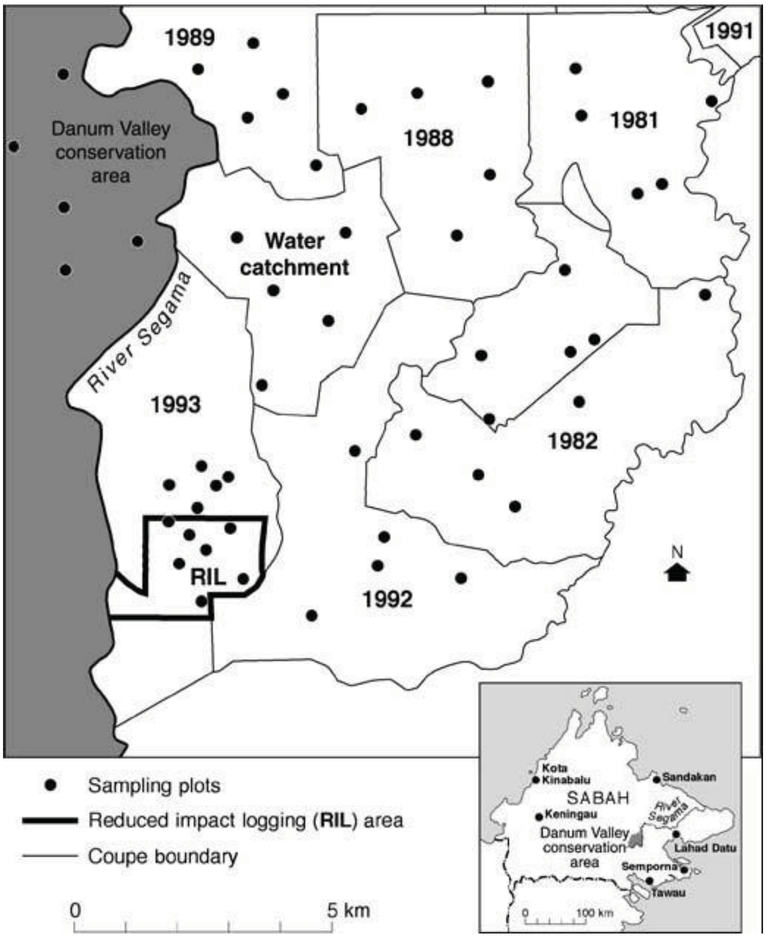
Anand Vetrivel (UoD), Prof. Giles Foody & Dr Doreen Boyd (Univ. of Nottingham)

A little history……

1. Estimate tropical forest biomass at one site (Danum Valley, Malaysia)



A little history……

Estimate tropical forest biomass at one site (Danum Valley, Malaysia)

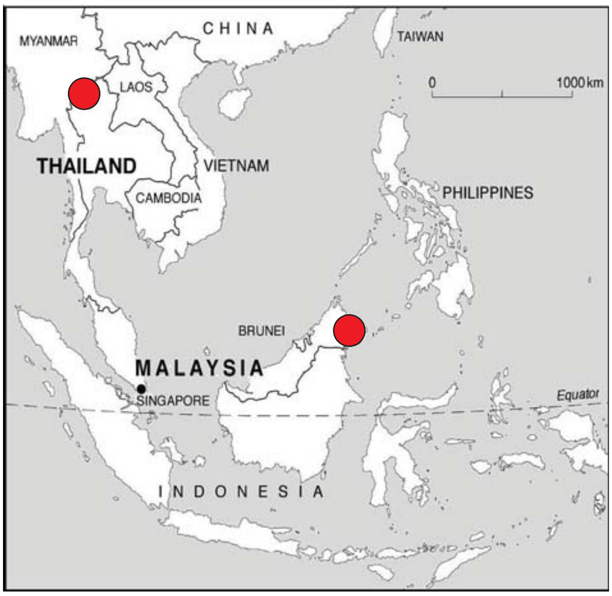
- Multispectral (Landsat Thematic Mapper (TM)) used to estimate AGB by deriving a relationship between field measured AGB and remotely sensed response
- ANN performed better than vegetation indices (r = 0.8, n = 12)

- Question: could this relationship be applied to estimate biomass at other sites?

Foody, G.M., Cutler, M.E.J., McMorrow, J., Pelz, D., Tangki, H., Boyd, D.S. and Douglas, I., (2001), Mapping the biomass of Bornean tropical forest. *Global Ecology and Biogeography*, **10** (4), 379-387.

Study sites

Danum Valley, Malaysia	**Primary & logged lowland dipterocarp forest**
Manuas, Brazil	**Biological Dynamics of Forest Fragments Project (BDFFP) sites**
Khunkong Thailand	**Plantation / tropical deciduous forest**

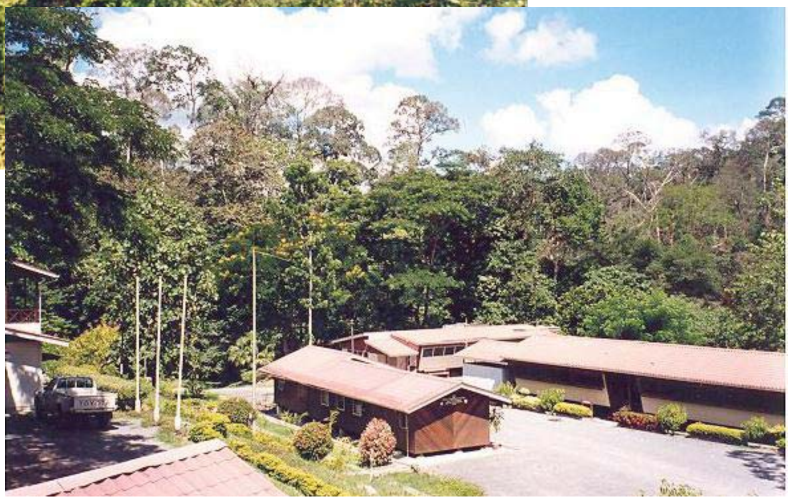


ANN results

Site used in training	Site(s) network applied to:			
	Thailand	*Brazil*	*Malaysia*	*Combined*
Thailand	0.71	-0.13	0.12	-0.21
Brazil	-0.2	0.84	-0.3	0.16
Malaysia	0.21	0.59	0.83	0.24

- Poor generalisation when applied to other sites i.e. very limited ‘transferability’ of relationships
- Worked better when ANNs trained with data from all sites AND a label telling the network from which site the data were from (r=0.48, significant at 95%)

Foody, G.M., Boyd, D.S. and Cutler, M.E.J., 2003, Predictive relations of tropical forest biomass from Landsat TM data and their transferability between regions. *Remote Sensing of Environment*, **85**, 463-474.



Lowland *Dipterocarp* forest at Danum Valley, Sabah, Malaysia

Forest disturbance in the Khunkong catchment, N.E. Thailand

Why combine SAR with multispectral data?

- SAR can be used to estimate AGB directly, but saturates at relatively low biomass
- SAR texture can provide information relating to forest structure and geometry
- Replace country label with SAR texture to give an independent observation of forest structure/functional type?

Cutler, M.E.J., *et al*., 2012 Estimating tropical forest biomass with a combination of SAR image texture and Landsat TM data: an assessment of predictions between regions. *ISPRS J. of Photogrammetry & Remote Sensing*, 70, 66-77.

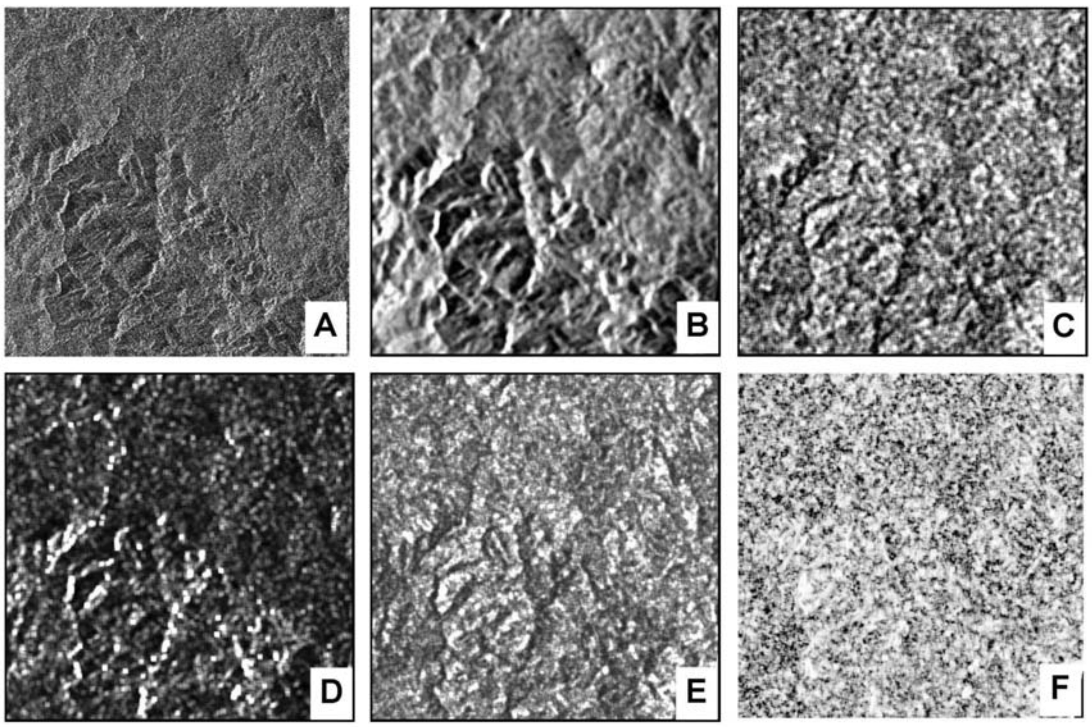
Ground & Remotely Sensed Data

Site	*Field Survey*	*No. of plots (used)*	*Landsat TM*	*JERS-1*
Brazil	July / August 1993 & 95	27 (27)	Landsat 4 July 1992	December 1995
Thailand	December 1997	65 (40)	Landsat 5 January 1997	March 1997
Malaysia	Nov. & Dec. 1996	52 (27)	Landsat 5 March 1997	December 1996

- All data pre-processed in same way
  - Landsat TM: radiometric, atmospheric & topographic corrections applied
  - JERS-1: radiometric calibration & topographic normalisation

SAR Image Texture Measures

- SAR image texture relates to forest structure and geometric properties, which can be correlated with AGB or used to discriminate between forest types
  - Grey Level Co-occurrence Matrix (GLCM)
    - Based upon spatial distribution of grey level pairs of pixels
    - Can derive texture measures including entropy, variance, dissimilarity, homogeneity, correlation, second moment and energy (Haralick, 1979)
  - Wavelet (discrete wavelet frame transform)
    - Decomposes image into four frequency component
    - Approximation (low frequency), Details (high frequency) in vertical, horizontal & diagonal directions



(A) Raw backscatter; Texture measures derived from JERS-1: (B) energy, (C) homogeneity, (D) contrast, (E) second moment, and (F) contrast

AGB estimation

- AGB estimated using ANNs trained under four separate training 'scenarios':
  1. ANNs trained and tested with samples from same site only (SAR texture measures only)
  2. ANNs trained with data from a single site and used to estimate AGB at other two sites (SAR texture measures only)
  3. ANNs trained and tested with samples drawn from all three sites (SAR texture measures only)
  4. As scenario 3, but trained using a combination of SAR texture and multispectral data

- Method
  - ANNs trained with:
    - 8 GLCM texture measures
      - Variable window sizes (3x3 – 13x13)
    - 3 levels of Coiflet wavelet decomposition
      - Four frequency component images
    - All 6 non-thermal Landsat TM bands (scenario 4)
  - Brazil (18 training samples; 9 testing), Malaysia (34;18), Thailand (42;21)
  - MLP, GRNN & RBF networks tested
  - Correlation between ANN predicted and field AGB used to select best performing network

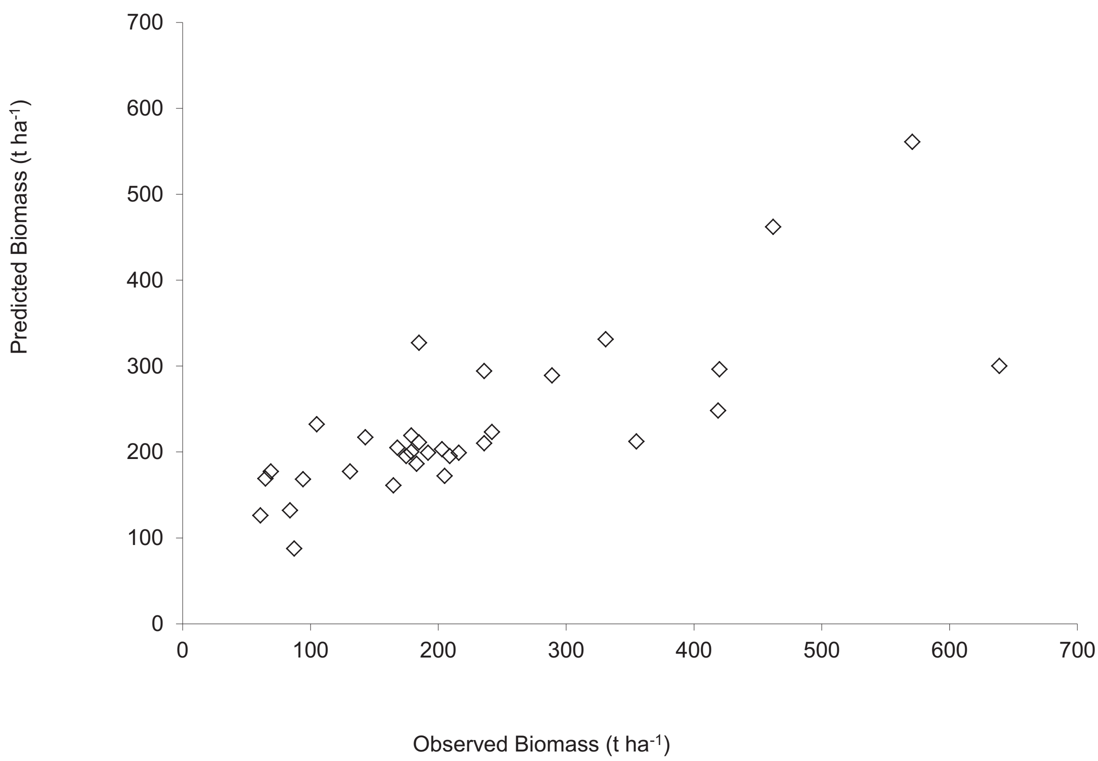
- Scenario 1 – trained & tested on same site
  - Strong correlations noted:
    - Brazil: MLP, 13x13 window, 6 texture measures; r=0.84
    - Malaysia: RBF, 7x7 window, 7 texture measures; r=0.79
    - Thailand: MLP, 7x7 window, 5 texture measures; r=0.83
  - GLCM texture consistently produced stronger relationships than wavelet texture BUT lack of consistency in network type, window size and texture measure combinations used

- Scenario 2 – trained with one site and applied to other sites
  - Networks trained with data from Brazil able to estimate AGB in Malaysia (r=0.74) and *vice versa*
  - Poor 'transferability' to Thailand
  - Again, lack of consistency in network type and combination of texture measures for strongest performing networks

- Scenario 3 – trained & tested with SAR texture from all sites
  - r=0.53 (significant at 95% confidence level)
  - Compares to r=0.49 when Landsat TM data only used to estimate same AGB (Foody et al., 2003)
  - Underestimation of biomass in high-biomass plots

- Scenario 4 – trained & tested with SAR & Landsat TM data from all sites
  - r=0.77 (sig. at 99% confidence level)
  - ☺ addition of SAR texture leads to stronger correlations and ability to estimate AGB at all three sites
    - Fishers r-to-z transformation suggests increase in correlation coefficient not significant BUT small samples numbers (34,31)

Scenario 4: training and testing with SAR GLCM-texture & Landsat TM data from all sites



Observations

- Multispectral and SAR data independently exhibit strong correlations when trained & tested with data from same site
- Limited ability to 'transfer' relationship derived at one site, to other sites
- Strongest results when trained and tested with data from all sites, and when SAR texture and multispectral data combined
- Network type & texture features included in strongest networks not consistent

Factors limiting transferability

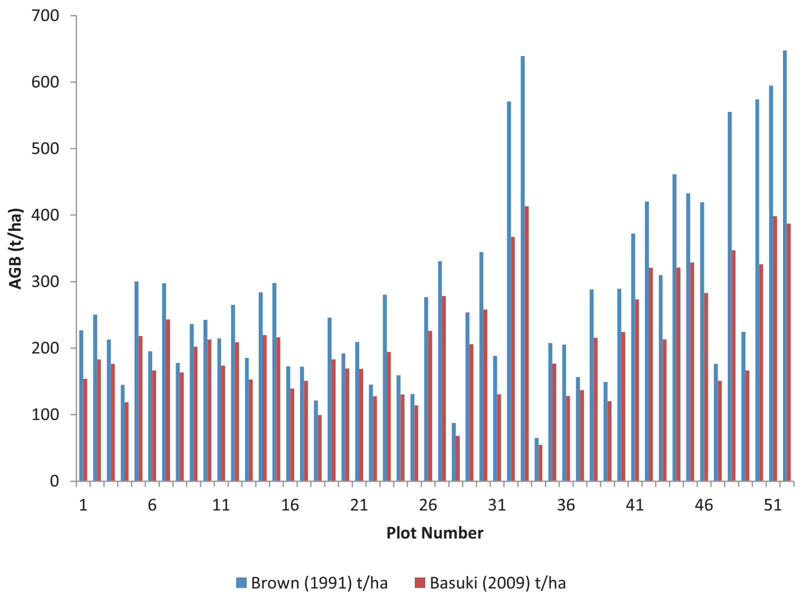
- Allometry and ground data

Uncertainty in AGB estimation

Author and model	Applied to			
	Malaysia	Thailand		Brazil
		Pinus	Other species	
Brown et al. (1989), Brown (1997) $Y = \exp(-2.134 + 2.53\ln(D))$	•		•	•
Brown et al. (1989), Brown (1997) $lnY = -1.201 + 2.196\ln(D))$		•		
Basuki et al. (2009) $lnY = -1.201 + 2.196\ln(D)$	•			
Baishya and Barik (2011) $Y = 1.3503 - 3.4145(D) + 4.8678(D)^2 - 1.352(D)^3$		•		
Chambers et al. (2001) $\ln(Y_1) = -0.37 + 0.333\ln(D) + 0.933(\ln(D))^2 - 0.122(\ln(D))^3$			•	
Uhl et al. (1988) $\ln Y = -2.17 + 1.02\ln(D) + 0.39\ln(H)$				•

Where *Y* is Total Above Ground Biomass, *D* is Diameter at breast height and *H* is height.

Uncertainty in allometry



- Brazil - max. difference of 239 t ha^{-1} (60%)
- Malaysia – up to 260 t ha^{-1} (50%)
- Thailand – up to 74 t ha^{-1} (27%)

Uncertainty in allometry

- AGB values seen to vary particularly for high biomass / large tree plots
- ANNs estimates showed similar *r* values to previous AGB estimates

ANN type and architecture	Training site	Correlation coefficients for each testing site			GLCM texture variables used as inputs to ANN
		Brazil	Malaysia	Thailand	
MLP 2:6:1	Brazil	**0.85**	0.70	0.57	3,4
RBF 2:4:1	Brazil	**0.78**	0.76	0.44	3,4
RBF 2:4:1	Malaysia	0.74	**0.81**	0.42	1,3,4,8
MLP 1:2:1	Thailand	0.49	0.45	**0.79**	3,
MLP 5:7:1	Thailand	0.53	0.49	**0.86**	1,3,4,7,8

- Clearly implications for other direct methods!

Factors limiting transferability

- Allometry and ground data
- Lack of consistency in texture measures included in best performing networks
  - Recently implemented a Genetic Algorithm to select optimal texture features for each site
- Lack of ground data
  - Coupling r.s. data with ecosystem simulation models under test
- Data processing
  - Atmos. Correction, co-location of plots, co-registration of SAR-multispectral data etc.
  - Disparity between JERS-1 & Landsat TM data collection (Brazil)
  - Radiometric correction of SAR
    - Now looking at topographic correction / speckle suppression and effects on derived texture measures

Conclusions

- Both multispectral data and SAR texture on their own showed strong relationships with tropical forest AGB at single sites
- Accuracy of predictive relationships declined when applied to different sites
  - lack of consistency in optimum input texture measures, type of network & window size
  - Stronger relationships when applied to forests of similar 'type', suggests relationships may transfer between regions to forests of similar functional type
- Should we be aiming for universally applicable relationship in the tropics or a 'bank' of relationships segmented by forest type, structure etc.

Acknowledgements

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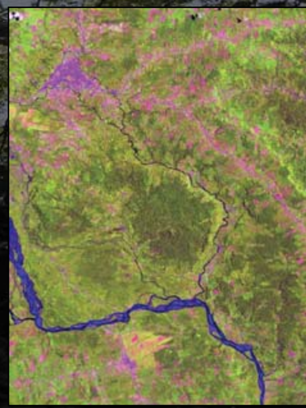
This research benefited from involvement in the Royal Society's Southeast Asia Rainforest Research Programme

THE WOODS HOLE RESEARCH CENTER

Satellite-based carbon stock measurements in the tropics

The Woods Hole Research Center

Pieter S. A. Beck, A. Baccini , S. J. Goetz, et al.



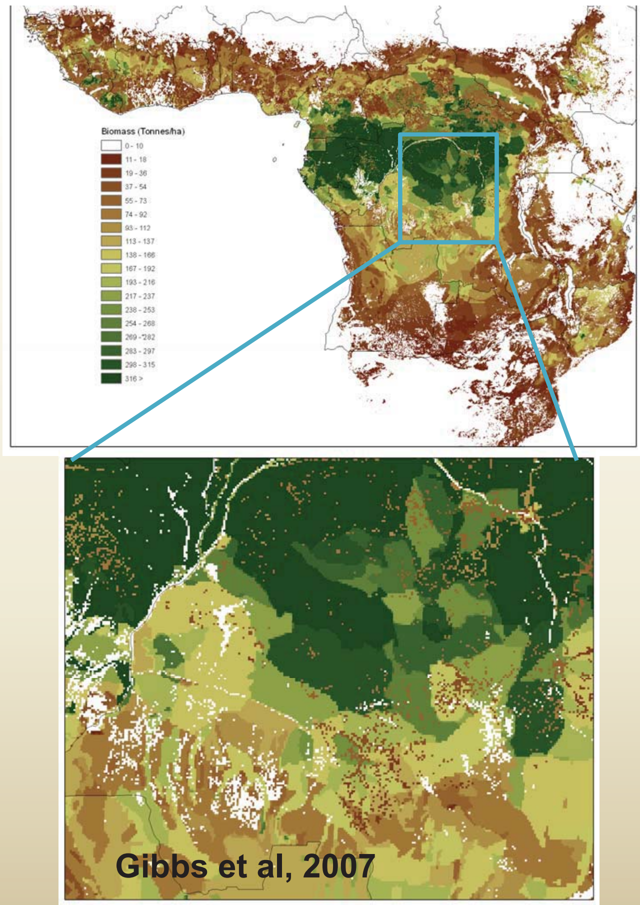
Large-area Carbon Stock Estimation

"Combine & assign approach"

Average biomass values are assigned to land cover strata

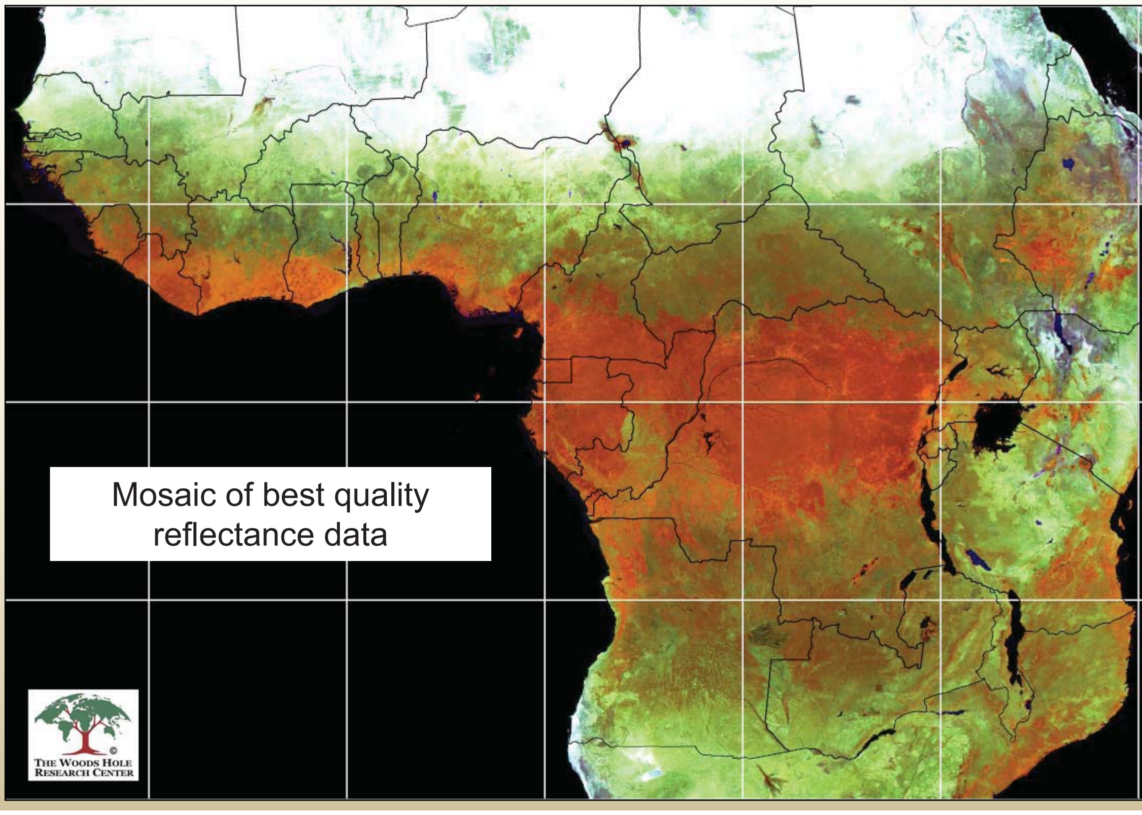
Resulting maps are semi-continuous depictions of spatial variation in carbon stocks.

Recently, advances have been made in "Direct Remote Sensing" of biomass.



Goetz et al. 2009, CBM

Composite of MODIS Reflectance Images



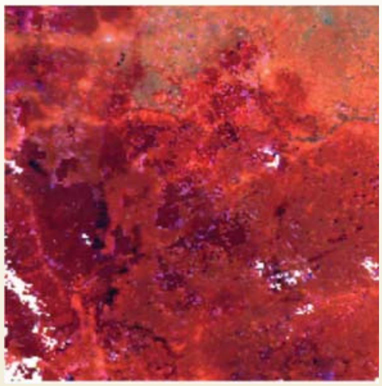
MODIS processing and compositing

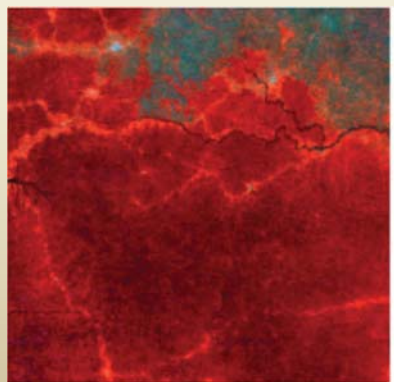
Removes artifacts associated with variable view geometry

Atmospherically corrected and cloud screened

Artifacts due to residual clouds and shadows are present

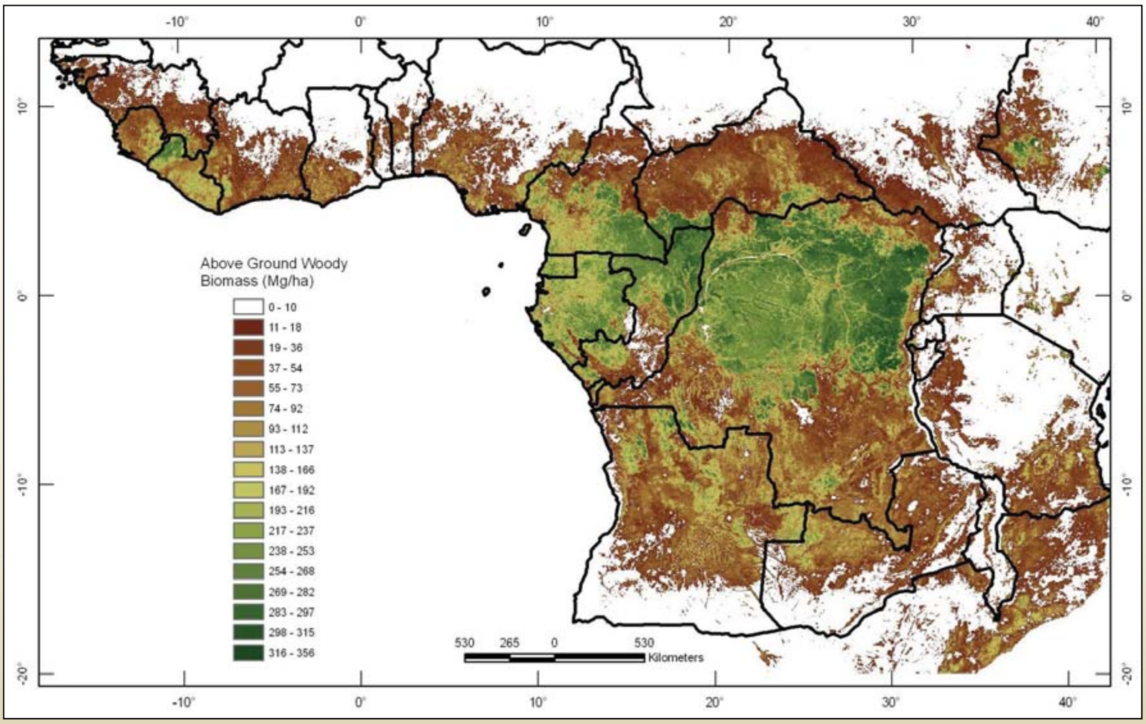
Compositing over time successfully removes artifacts





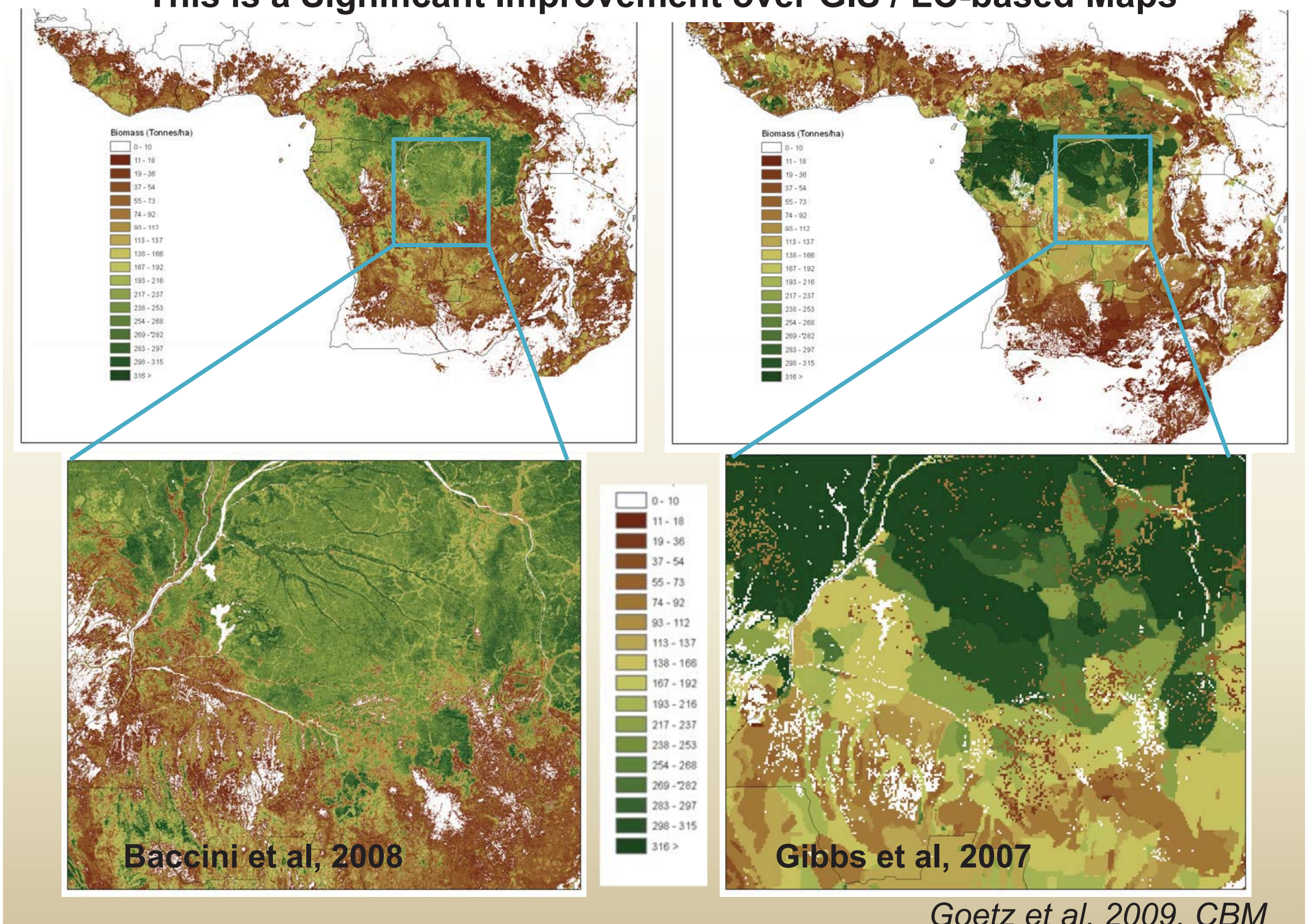
(Schaaf et al. 2002 RSE & Ju et al. 2010 RSE)

Aboveground biomass from MODIS calibrated with Inventory Data



The model explained 82% of the variance in above-ground biomass density, with an RMS error of 50.5 Mg/ha
(data available for download at www.whrc.org/Africa)

This is a Significant Improvement over GIS / LC-based Maps

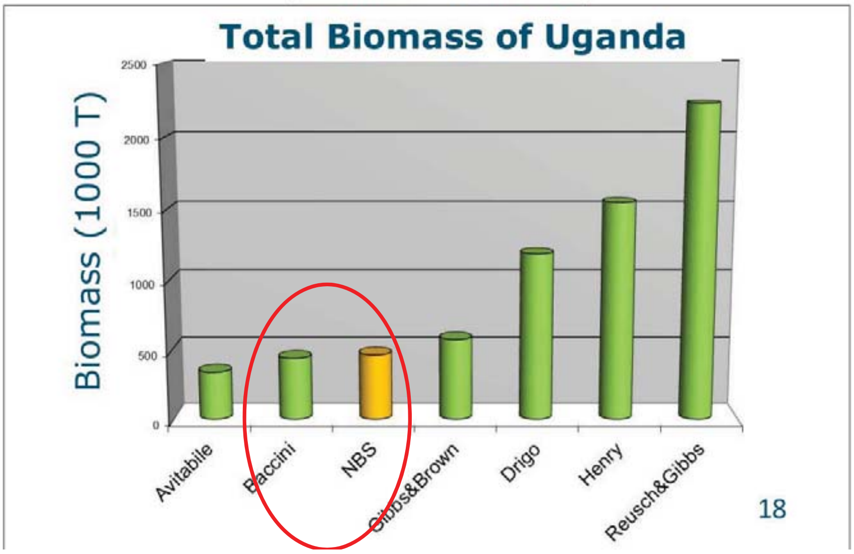


Goetz et al. 2009, CBM

Biomass maps comparison in Uganda

	Spatial Data	Biomass data	Reference
1.	Landsat	+ Field data *	Avitabile et al., 2012
2.	MODIS	+ Field data *	Baccini et al., 2008
3.	National LC	+ Field data	NBS, 2003 *(Reference map)*
4.	Global LC	+ Biome Av.	Gibbs & Brown, 2007
5.	National LC	+ Biome Av.	Drigo, 2006
6.	Global LC	+ Field data	Henry et al., 2010
7.	Global LC	+ IPCC Tier 1	Reusch & Gibbs, 2008

(* = subset of NBS field data)

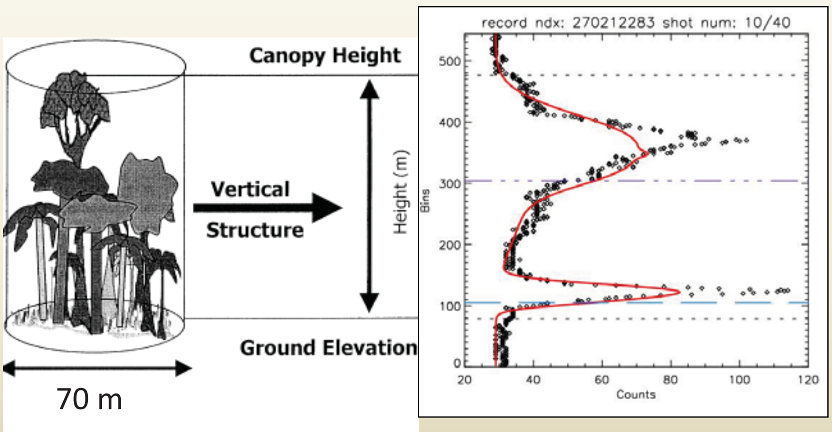


Avitabile et al., 2011 (CBM)

18

Vegetation structure from Lidar

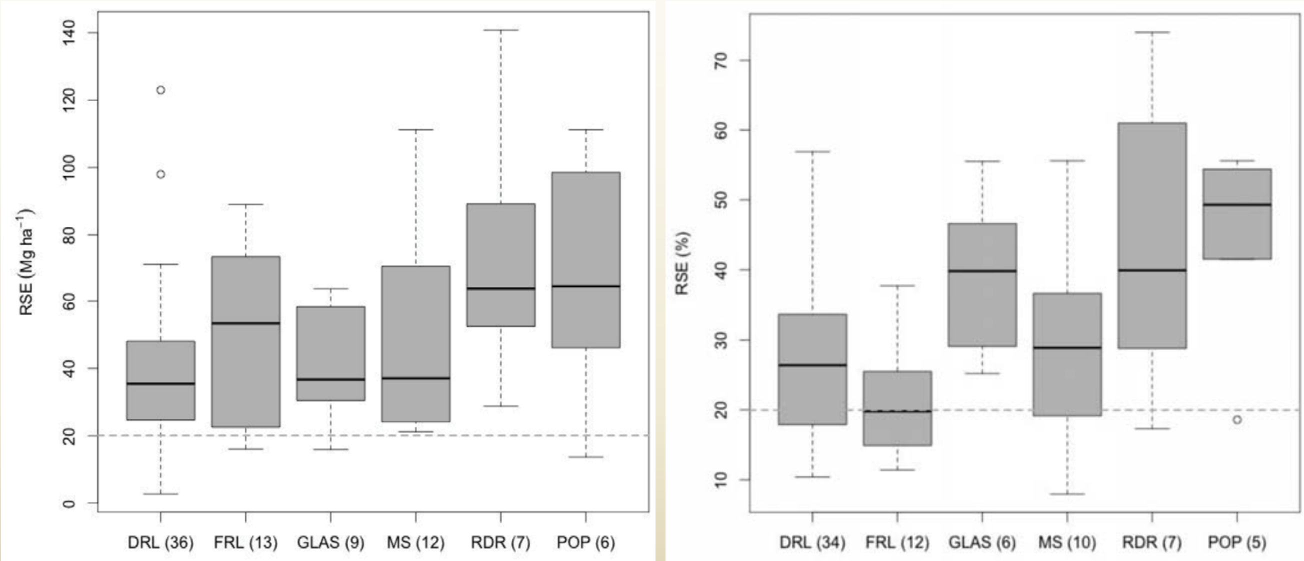
Lidar metrics have been used extensively to characterize vegetation structure and to estimate AG Biomass



Lidar shows no sign of saturation even at very high biomass density

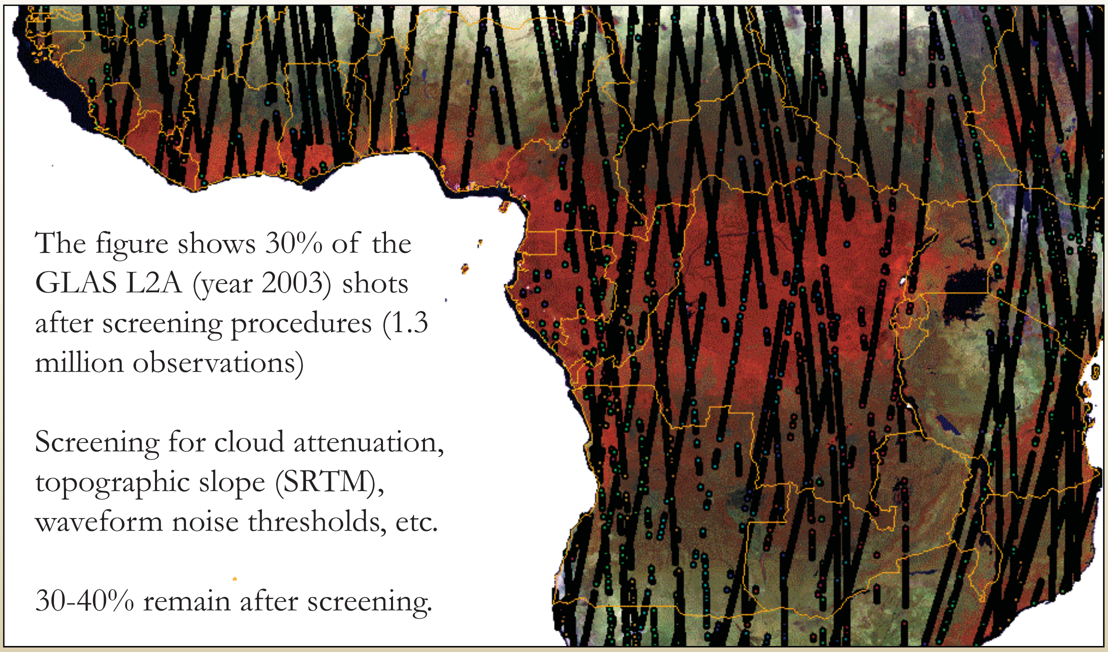
L-band Radar saturates ~100 Mg/ha
P-band may extend this range (to 200? Mg/ha)

The advantage of Lidar for AGB estimates



Zolkos et al. in press, Rem. Sens. Env.

The Geoscience Laser Altimeter System (GLAS)



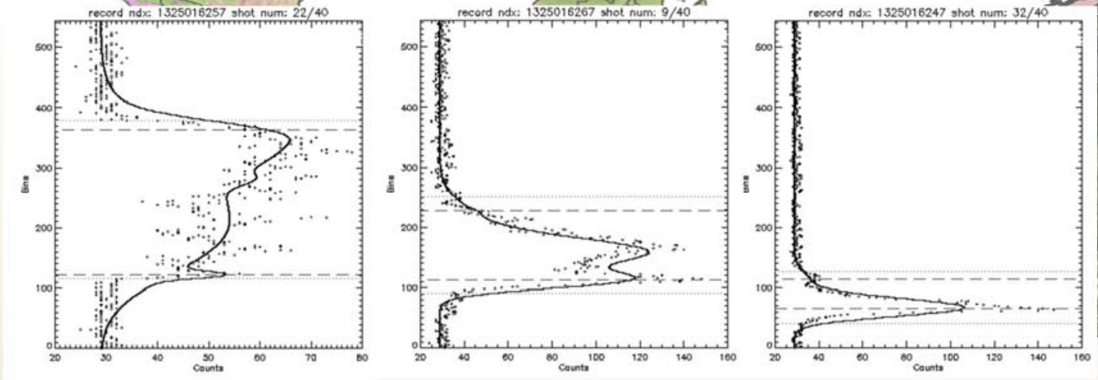
The figure shows 30% of the GLAS L2A (year 2003) shots after screening procedures (1.3 million observations)

Screening for cloud attenuation, topographic slope (SRTM), waveform noise thresholds, etc.

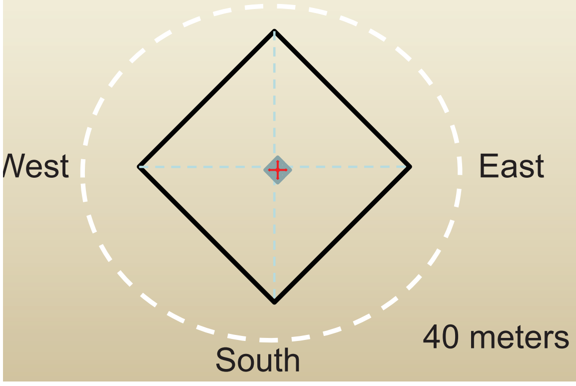
30-40% remain after screening.

THE WOODS HOLE RESEARCH CENTER

Co-located Field Measurements

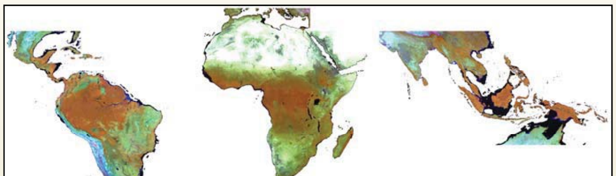


Biomass = 205 (t/ha)　Biomass = 78 (t/ha)　Biomass = 30 (t/ha)



Pan-Tropical Biomass Map

- Best quality MODIS mosaic
  - Multiple years
  - cloud free


MODIS 500 m composite year 2007-2008

- Screened GLAS metrics
  - Series of metrics (tree height, height of median energy, etc.)

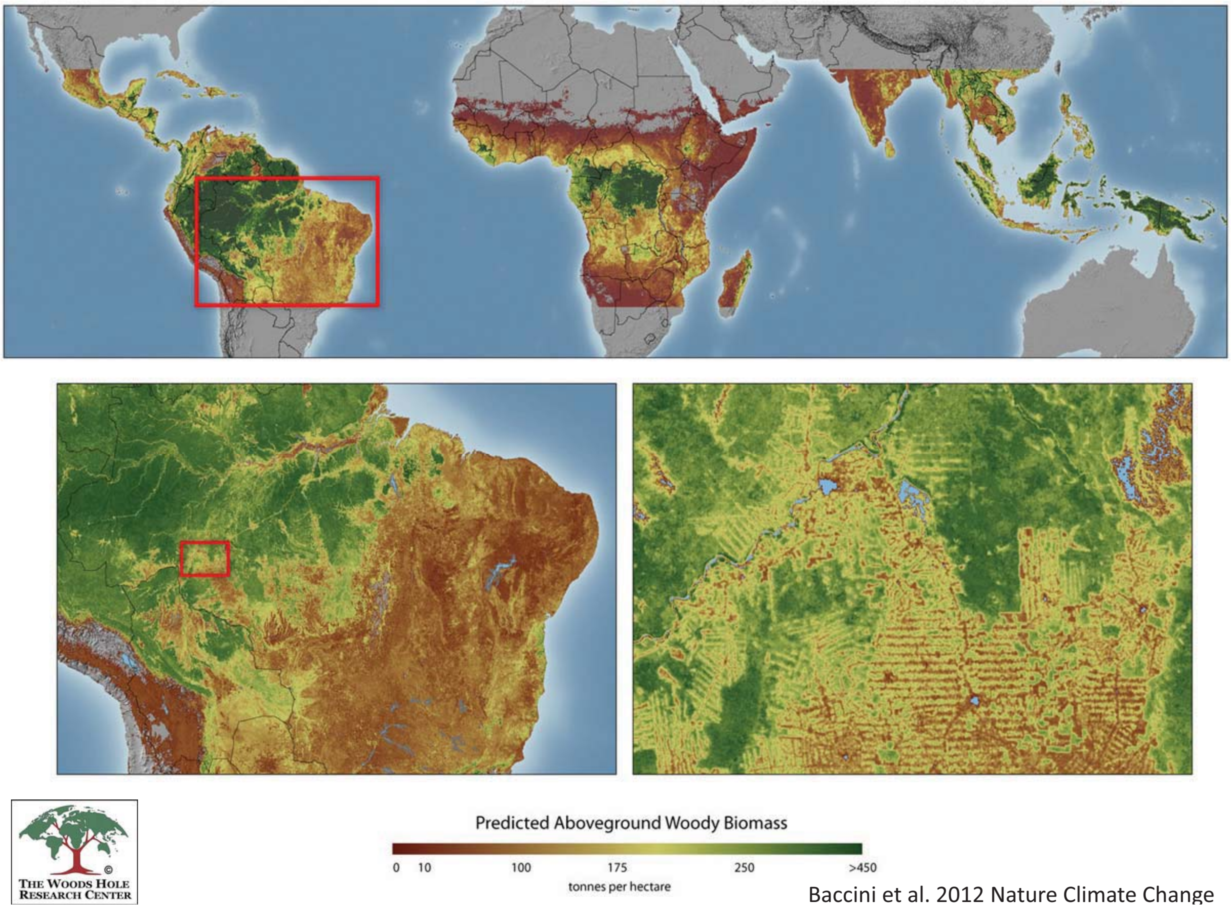
- 2 –stage model

Field observations ~ GLAS metrics

GLAS-based estimates ~ MODIS


GLAS year 2007

Pantropical Vegetation Carbon Stocks

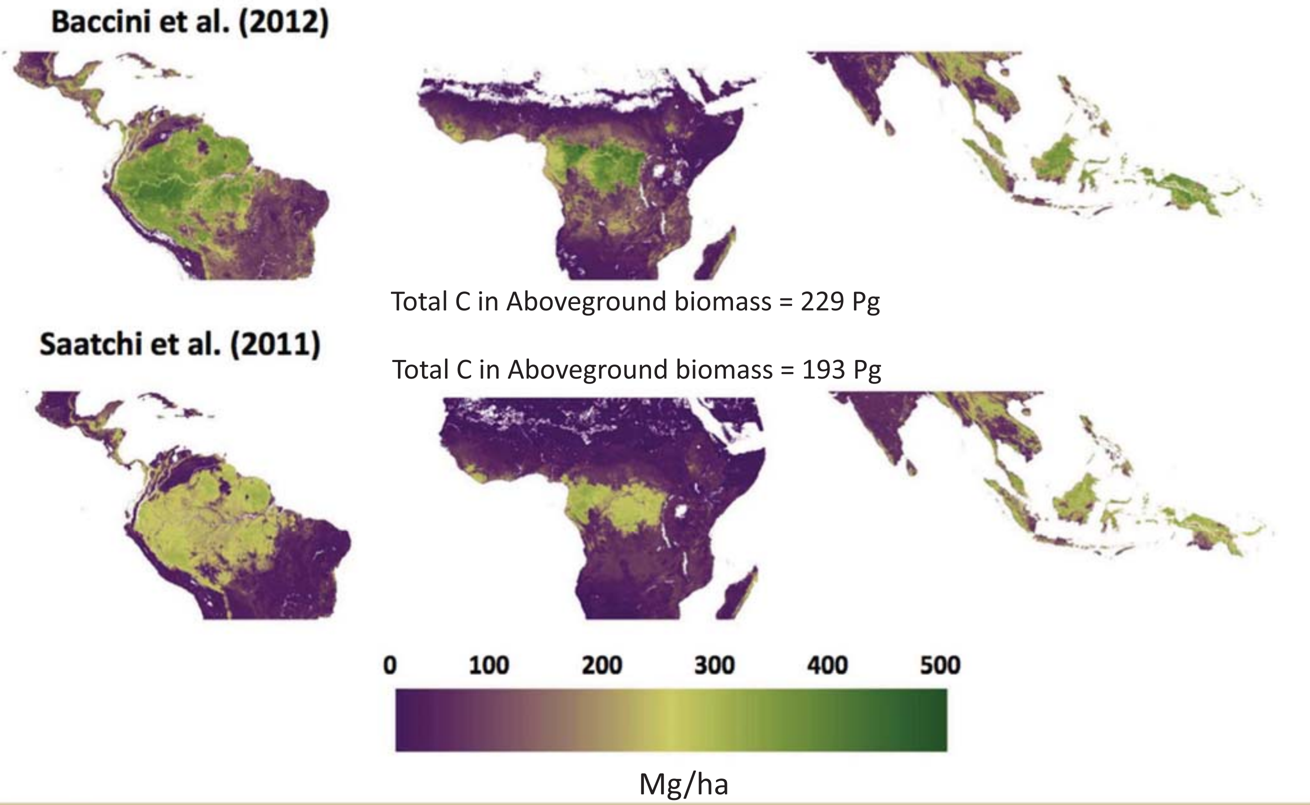


THE WOODS HOLE RESEARCH CENTER

Baccini et al. 2012 Nature Climate Change

Recent maps of Pantropical Carbon Stocks

(both partly based on linking satellite lidar and field data)



Baseline Map of Carbon Emissions from Deforestation in Tropical Regions

Nancy L. Harris,[1]* Sandra Brown,[1] Stephen C. Hagen,[2] Sassan S. Saatchi,[3,4] Silvia Petrova,[1] William Salas,[2] Matthew C. Hansen,[5] Peter V. Potapov,[5] Alexander Lotsch[6]

REPORTS

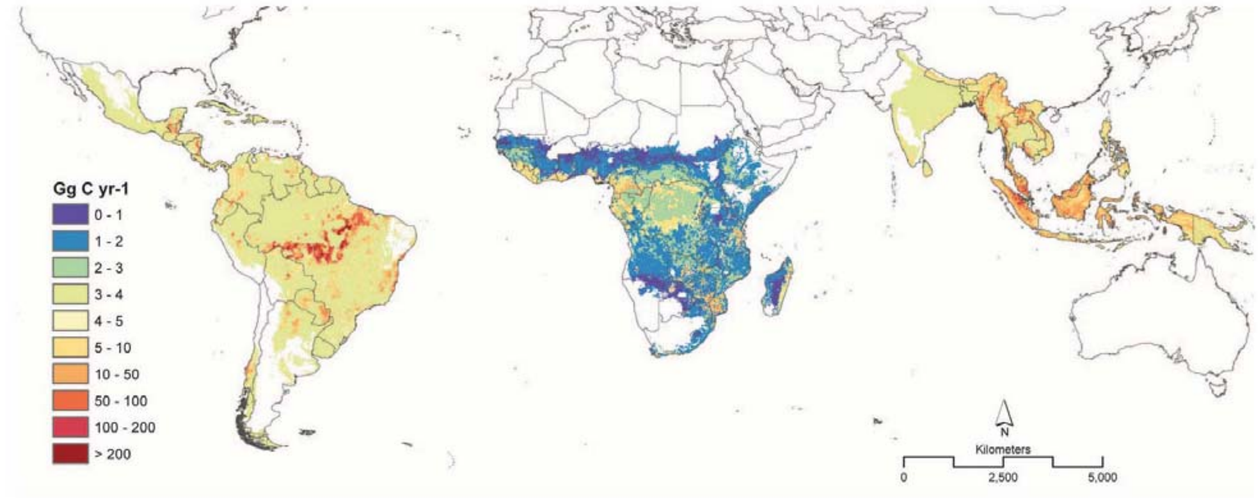


Fig. 2. Distribution of annual carbon emissions from gross forest cover loss between 2000 and 2005 mapped at a spatial resolution of 18.5 km.

Harris et al. 2012 Science

Baseline Map of Carbon Emissions from Deforestation in Tropical Regions

Nancy L. Har
William Sala

ATMOSPHERIC SCIENCE

Carbon from Tropical Deforestation

Estimates of carbon emissions from tropical deforestation differ widely.

Daniel J. Zarin

How much carbon is emitted from tropical deforestation? Attempts to answer this question have generally relied on data from national inventories. More recently, sufficient satellite data have become available to provide independent estimates. On page 1573 of this issue, Harris *et al.* (*1*) report a global estimate of tropical deforestation emissions derived entirely from satellite data. For the period from 2000 to 2005, those emissions are much lower than previously reported.

In 2007, the Intergovernmental Panel on Climate Change (IPCC) concluded that the "best estimate" of net carbon emissions from tropical land use change in the 1990s was 1.6 ± 0.6 petagrams of carbon per year (Pg C year^{-1}), equivalent to ~20% of greenhouse gas emissions from human activities during that decade (*2*). That and most other estimates have relied to varying degrees on national self-reporting to the Global For-

Gross deforestation emissions. Harris *et al.* provide an independent benchmark for national gross deforestation emissions for 2000 to 2005 [see table S2 in (*1*)], shown here for the top five emitting countries ...rval around those emission estimates is substantial. ...her-resolution satellite data to estimate forest cover ...ongo.

...emissions from tropical deforestation—as ...opposed to net emissions, which include forest regrowth—without resorting to the FAO ...data. (Gross carbon emissions from defor-

"A difference of this magnitude in tropical deforestation emission estimates between two state-of-the-art analyses is also cause for concern in climate policy circles"

A case of apples and oranges

	Gross emissions	Net emissions
Deforestation	960	960
Afforestation		-15
Wood harvest (industrial)	450[1.]	4[2.]
Fuelwood harvest	230	84[3.]
Shifting cultivation	640[4.]	82[5.]
Sub-total for degradation	1320	170
Total	2280	1115

1. Emissions from logging debris and wood products
2. Emissions from logging debris and wood products, and uptake by recovering forests
3. Both emissions and uptake by recovering forests
4. Emissions from the re-clearing of fallows

"Emissions from deforestation in the Baccini et al. study (0.96 $PgCyr^{-1}$) are 19% higher than in the Harris et al study (0.81 $PgCyr^{-1}$), rather than 180% higher.

Concluding thoughts

- Full wave-form Lidar emerges as a critical tool for biomass mapping
- Pan-tropical direct mapping of carbon stocks is now a reality
- Despite methodological differences stock estimates reported from direct mapping are relatively consistent at the national scale, and converging. The same is true of estimates of pan-tropical emissions from deforestation.
- Carbon density maps come with uncertainty estimates, but not necessarily at the grid cell-scale.
- There is considerable room for improvement in the error quantification – but ultimately ground data might be as limiting than models relating them to remotely sensed observations.

Thank you!

The Woods Hole Research Center · Gordon and Betty Moore Foundation · google.org · the David & Lucile Packard Foundation · Boston University · NASA

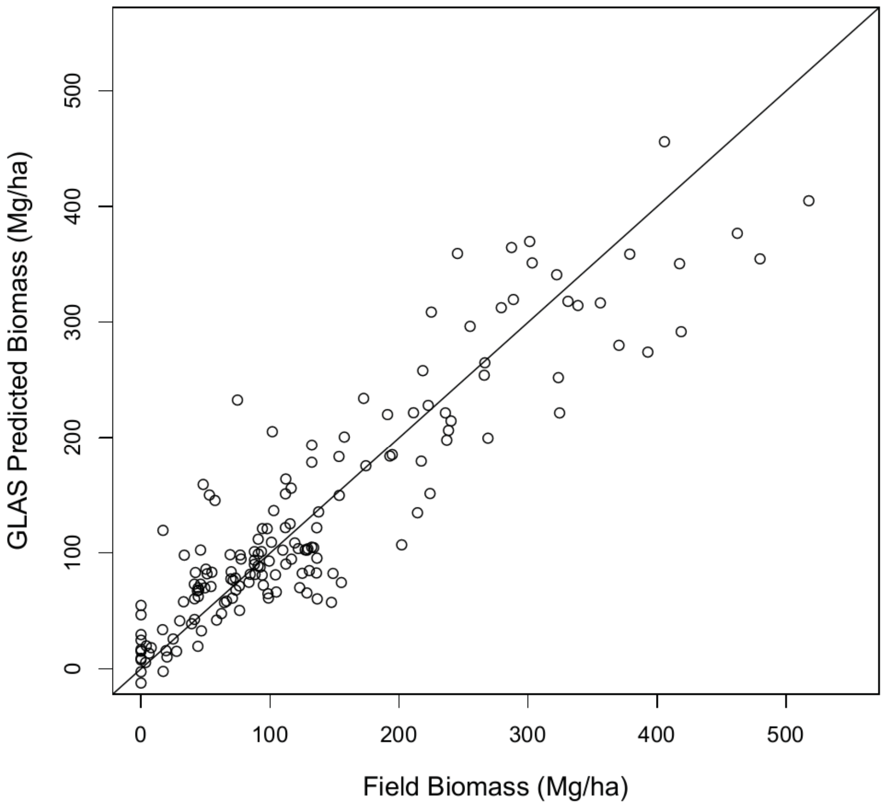


Figure S9 | GLAS predicted biomass versus field derived biomass.

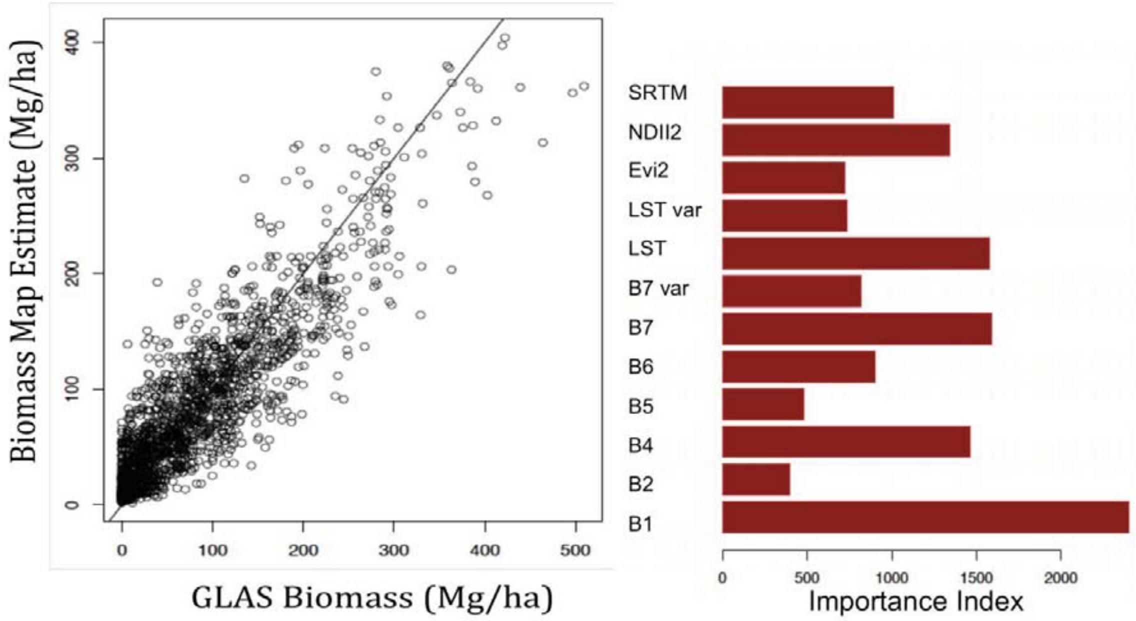
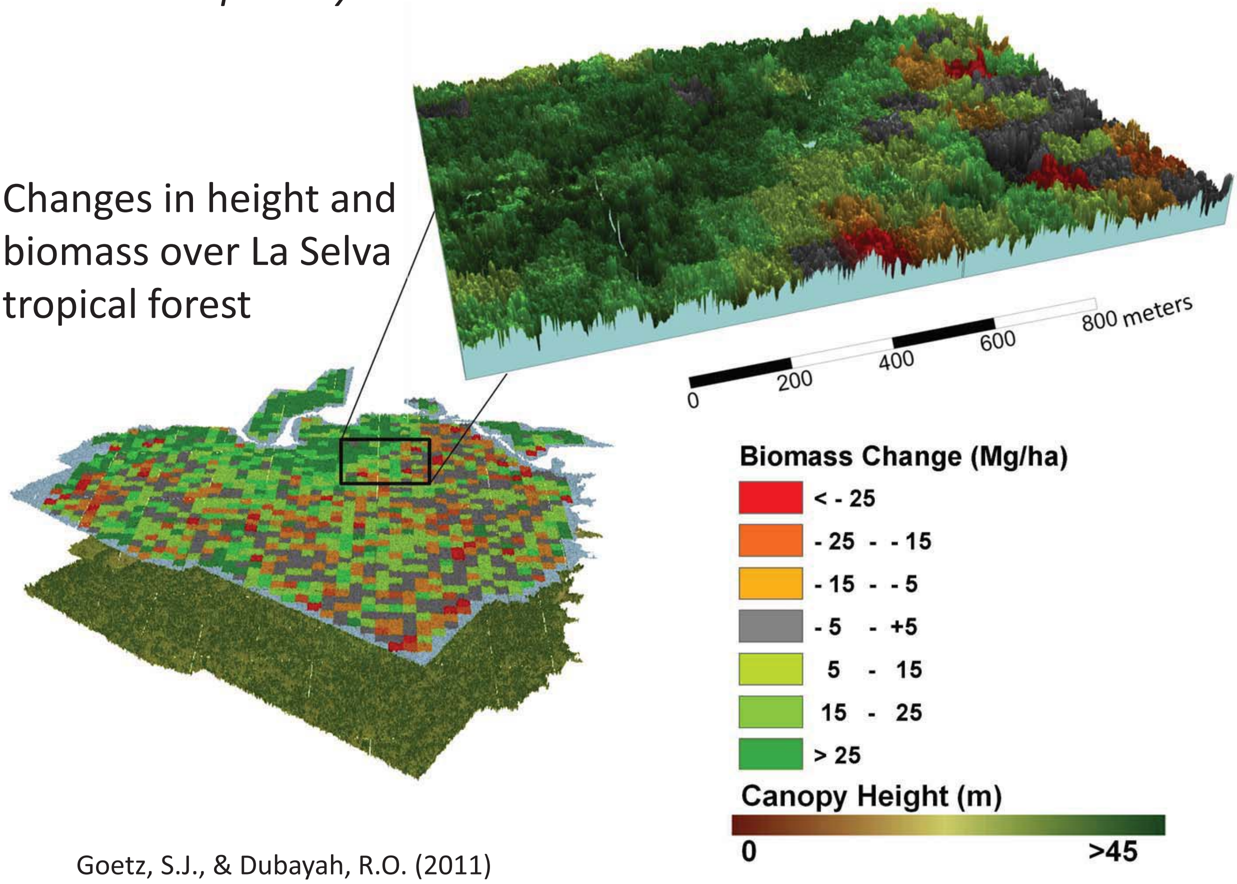


Figure S13 | The plot on the left includes a scatter diagram of the pixel-level estimates (for Tropical Africa) of biomass derived from GLAS versus the pixel-level estimates in the biomass map. The a root mean squared (RMS) error for the scatter diagrams are 25, 19, and 24 Mg C Ha^{-1} for tropical America, Africa, and Asia, respectively. The plot on the right illustrates the relative importance of the predictor variables.

This is the capability we would like to have..

Changes in height and biomass over La Selva tropical forest



Goetz, S.J., & Dubayah, R.O. (2011)
Carbon Management 2(3): 231-244

Global and Regional CO2 Flux Estimation Using Atmospheric CO2 Data Obtained by GOSAT, GOSAT-2, and Other Future Satellites

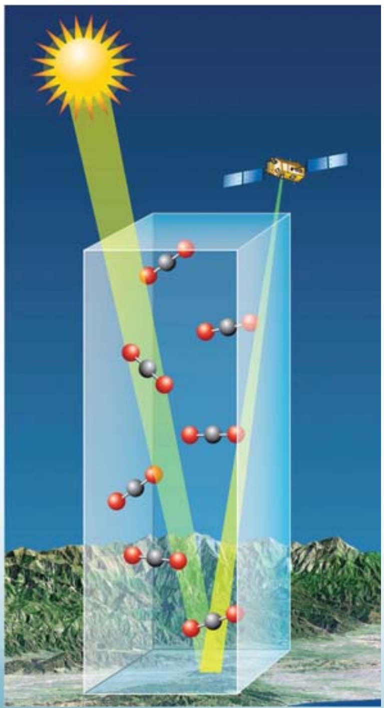
Tsuneo Matsunaga
GOSAT-2 Project Preparation Team
National Institute for Environmental Studies (NIES), Japan

Presented at IPCC Expert Meeting: Role of Remote Sensing (RS) in Forest and National GHG Emission Inventories,
October 23-25, 2012, Hayama, Japan

Today's Presentation

- Introduction
  - Satellite remote sensing of greenhouse gases(GHGs)
  - Top-down flux estimation using satellite GHG data
- 2010 Utrecht meeting
  - "Expert Meeting on Uncertainty and Validation of Emission Inventories" (March 23-25, 2010)
- 2010 – 2012 Progress
  - GOSAT CO2 concentration products from Japan, US, and Europe
  - GOSAT flux intercomparisons
- Future Prospects
  - New satellites focusing on regional flux estimation

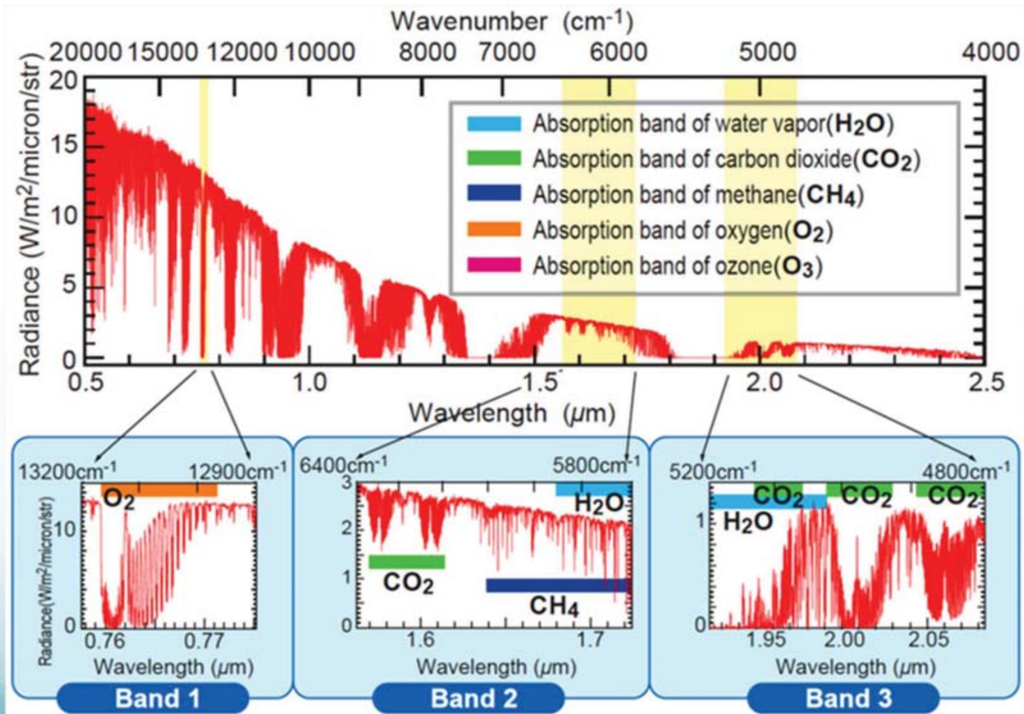
How do satellites observe carbon dioxide in the atmosphere?



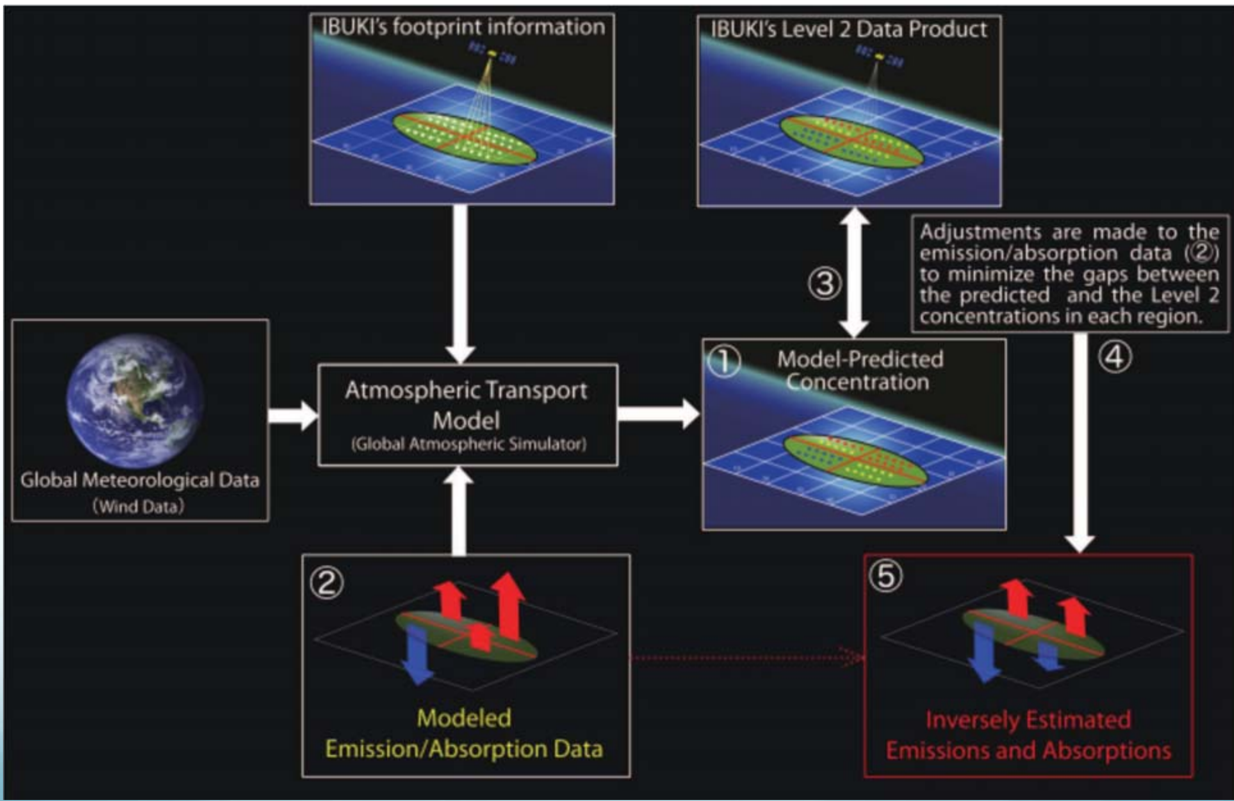
http://oco.jpl.nasa.gov/images/oco/OCO_column.jpg

- The sunlight goes downward through the Earth's atmosphere, reflects at the surface, then goes upward through the atmosphere, and reaches to satellites.
- CO2 molecules in the atmosphere absorb the sunlight at specific wavelengths.
- The absorption strength is a function of the number of CO2 molecules in the light path.
- By analyzing the absorption features, the (column) amount of CO2 in the atmosphere can be estimated.
- **We need cloud/aerosol free high signal-to-noise ratio data.**

Visible to Shortwave Infrared Radiance Spectrum Obtained by Satellites



Inverse Modelling for Flux Estimation



GOSAT

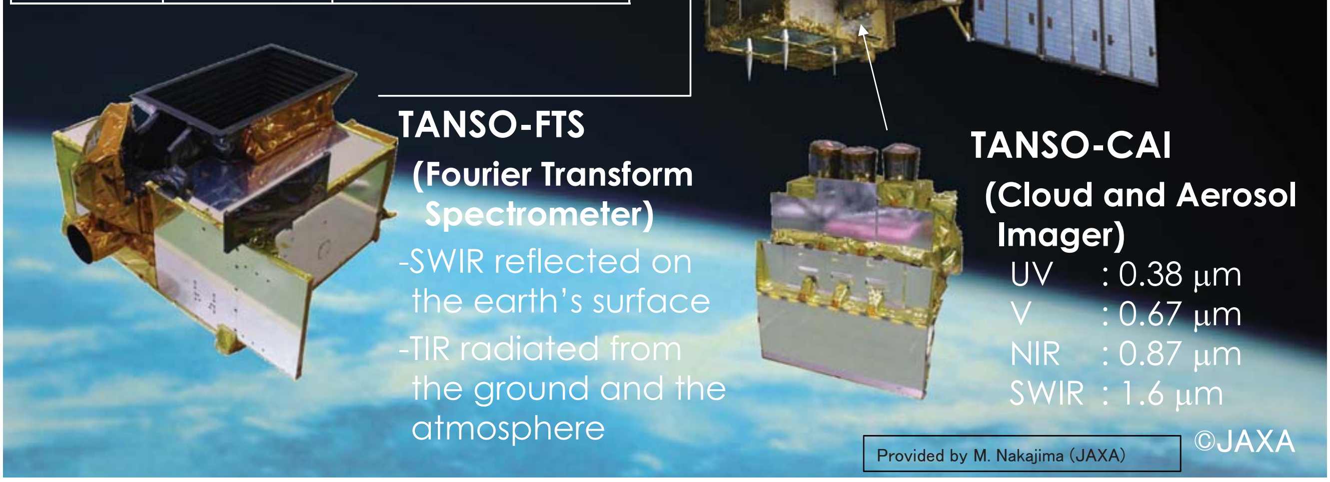
Objectives of GOSAT

- To obtain the global distributions of GHG concentrations (CO2 and CH4) and their temporal variations.
  - To visualize changing global GHG distributions
  - To fill the blanks in the network of ground monitoring stations
- To improve accuracy of the carbon flux (sources and sinks) estimation on a sub-continental scale.
- To develop technologies for future GHG observing satellites

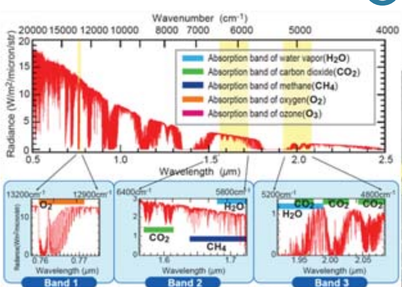
GOSAT and TANSO onboard GOSAT

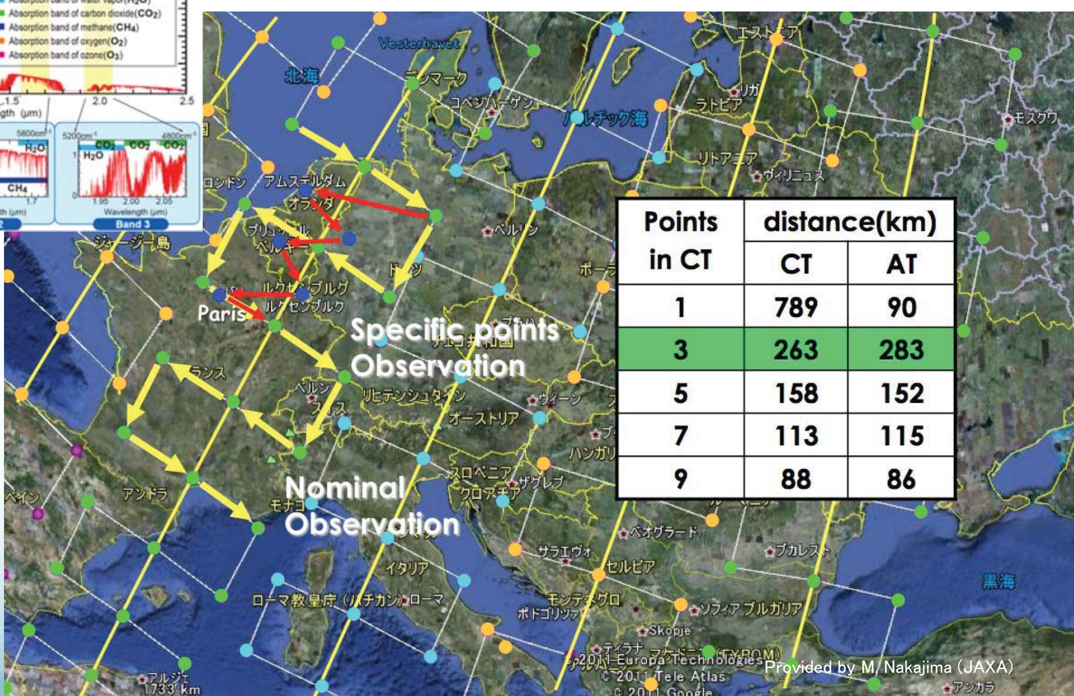
TANSO=Thermal And Near infrared Sensor for carbon Observation

Size	Main body	3.7 m x 1.8 m x 2.0 m (Wing Span 13.7m)
Mass	Total	1750kg
Power	Total	3.8 kW (EOL)
Life Time		5 years
Orbit		sun synchronous orbit
	Local time	13:00+/-0:15
	Altitude	666km
	Inclination	98deg
	Repeat	3 days (44 revol.)
Launch	Vehicle	H-IIA
	Schedule	Jan. 23, 2009



Current GOSAT FTS Observation Pattern





Points in CT	distance(km) CT	distance(km) AT
1	789	90
3	263	283
5	158	152
7	113	115
9	88	86

2010 Utrecht Meeting

2010 Utrecht Meeting

Executive Summary

There was consensus that, while remote sensing, ambient measurement and inverse modelling techniques have been successfully demonstrated they are currently not sufficiently developed to provide comprehensive verification at the required accuracy, much is to be gained from working together, to improve verification techniques as well as gain better understanding of inventory estimates, and of natural emissions and removals.

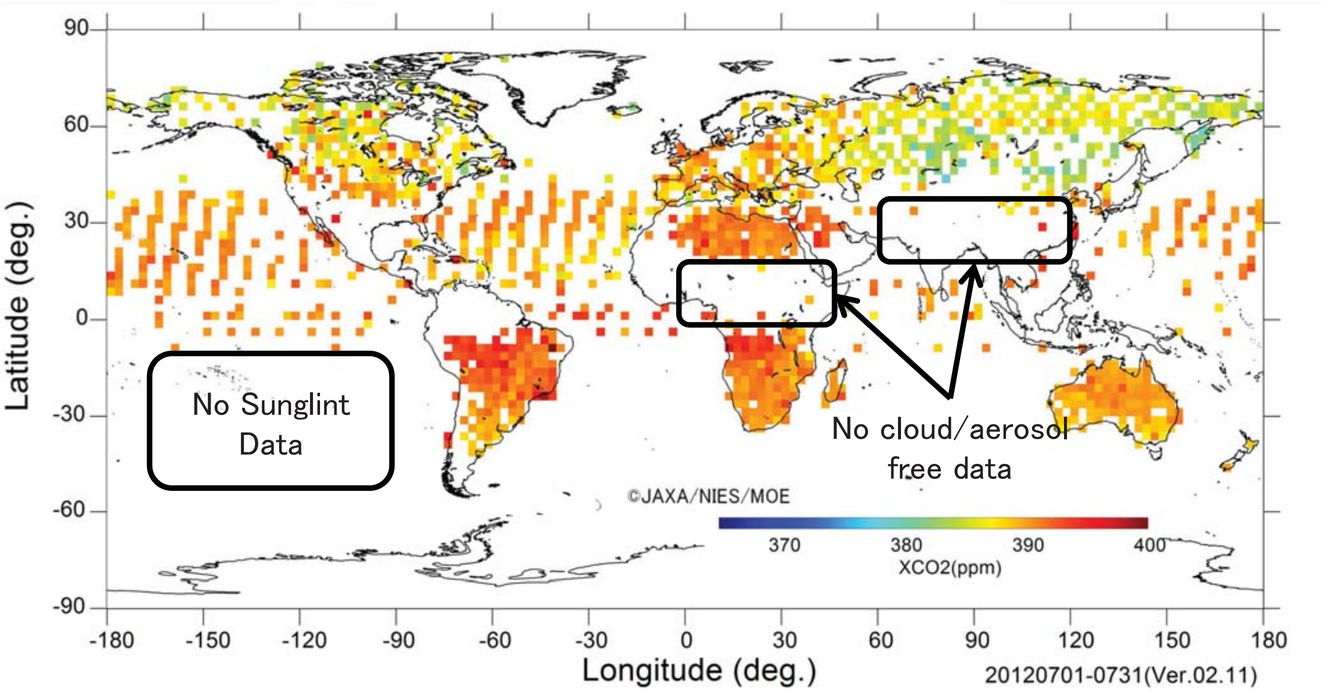
2010 – 2012 Progress

GOSAT Timeline

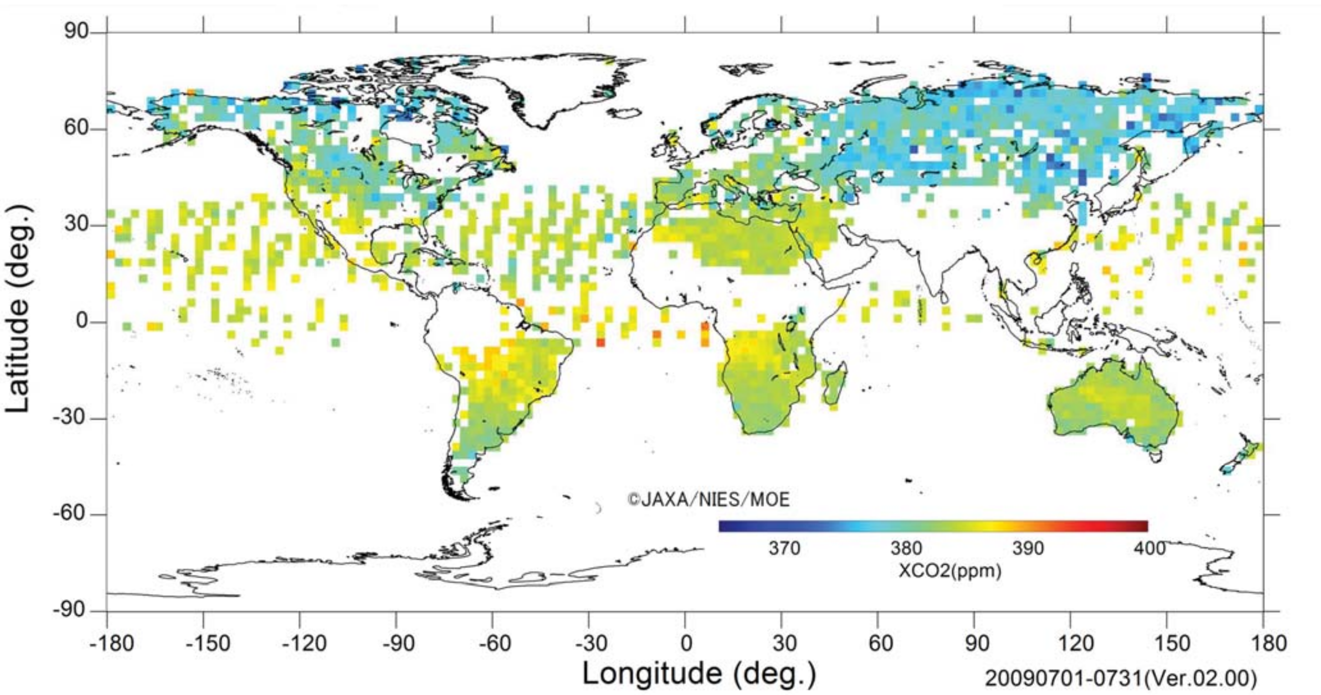
- January, 2009 GOSAT Launch (Lifetime = 5 years)
- February 2010 Public release of NIES GOSAT Level 2 product (XCO2, XCH4 : Column-average concentration)
- June 2012 Public release of new NIES GOSAT Level 2 product
  - ・CO2 Bias ≈ 1.2 ppm, Std. Dev. ≈ 2.0 ppm at selected validation sites
- June 2012 IWGGMS-8
  - ・Flux estimate intercomparison
    - – Five concentration data sets
    - – Five flux estimation schemes
- September 2012 GOSAT Level 4 product (CO2 flux from 64 regions) release to RA researchers

RA : GOSAT research annoucement

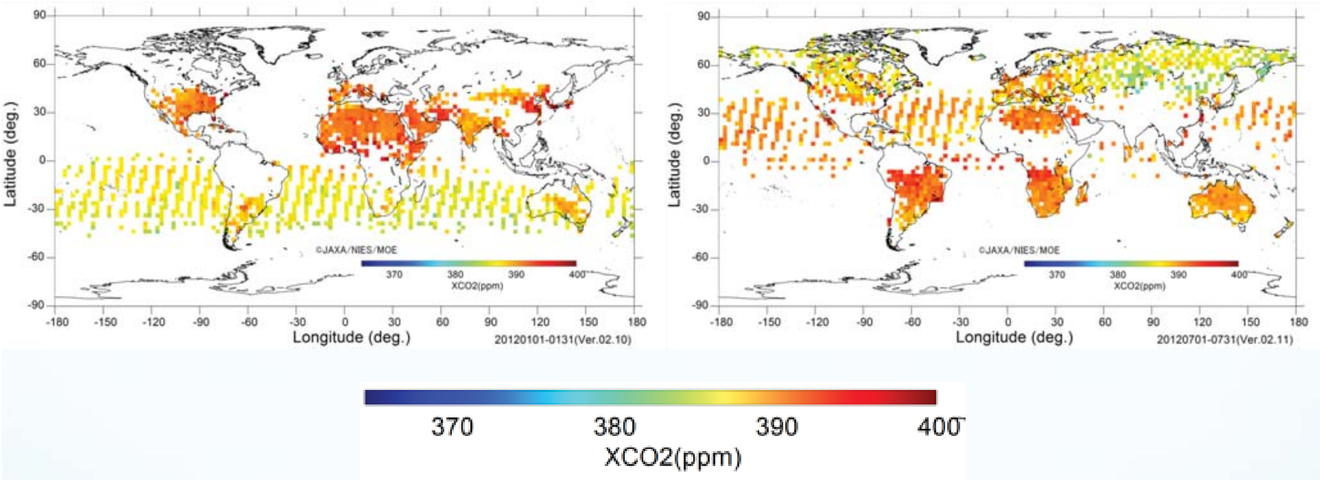
GOSAT XCO2 (July 2012)



GOSAT XCO2 (July 2009)



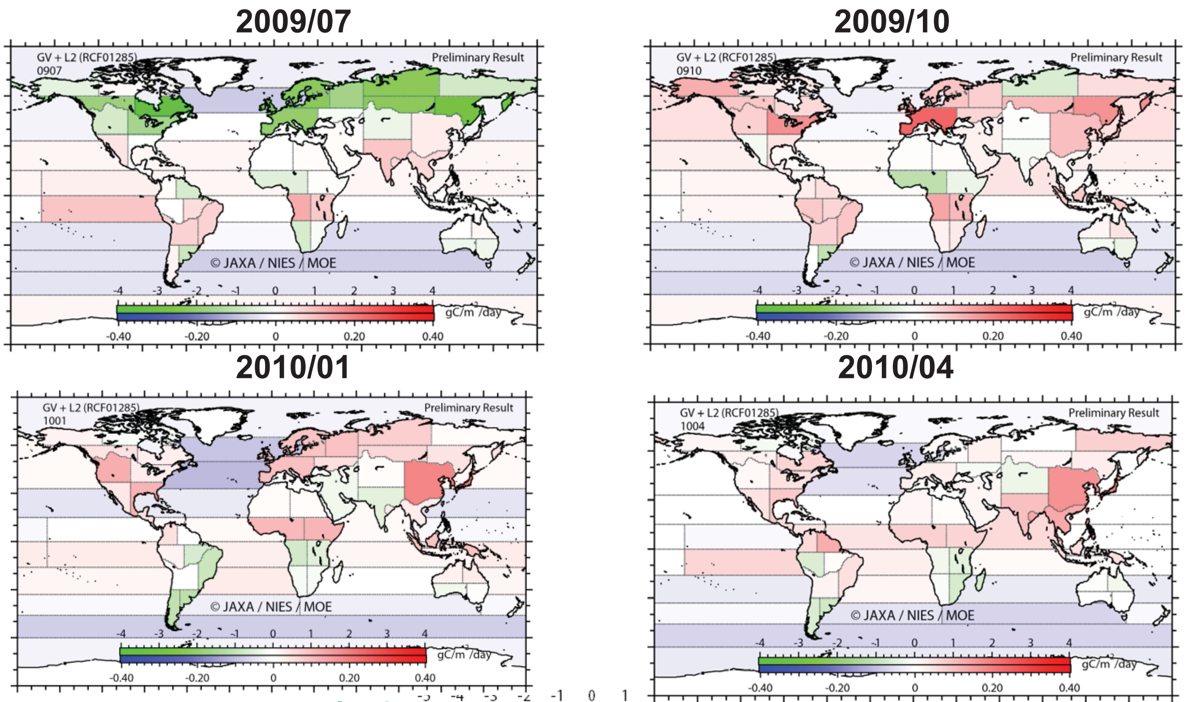
GOSAT XCO2 (January / July 2012)

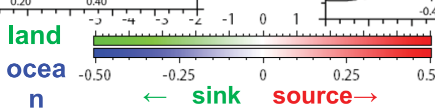


January 2012 **July 2012**

These GOSAT point or grid data are used to control/adjust/modify existing surface flux models in the inversion analysis.

64-region's CO_2 fluxes estimated from both ground-based and GOSAT data

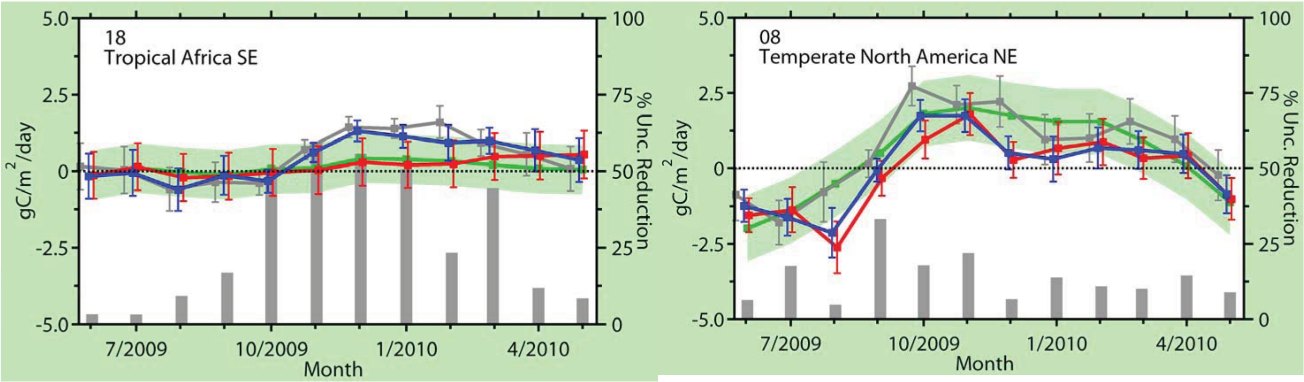




Maksyutov et al. IWGGMS-8

Time Series of Monthly CO2 Flux

Tropical Africa SE and Temp N America NE



Green: A priori flux and its uncertainty、**Red**: Flux and its uncertainty estimated from the ground-based data only, Blue: Flux and its uncertainty estimated from both the ground-based and GOSAT data、**Grey**: GOSAT only
Bottom **Grey bar**: Uncertainty reduction rate in percent (right axis)

Forward Modeling of the CO2 in the atmosphere with a set of surface fluxes

GOSAT SWIR L2 data and ground-based observations

JMA JCDAS meteorological analysis data

Atmospheric Transport Model NIES-08.1i

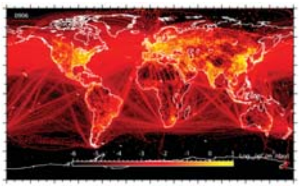
Belikov et al. (2011)

Surface CO2 flux models and inventories

Anthropogenic

Combines DMSP nightlights, BP annual country level reports, CARMA LPS database, EDGAR shipping, and AER2k upper air data

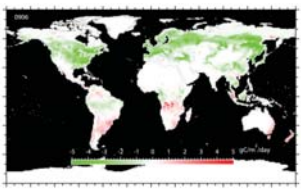
Oda and Maksyutov(2010)
Andres et al. (2011)



Terrestrial biosphere NEE

Simulated by VISIT model optimized to fit Globalview seasonality, IIASA biomass maps and Osnabruk NPP database, GFED fire

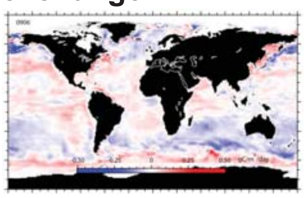
Saito et al. (2010)
van der Werf et al. (2010)



Ocean-atmosphere exchange

Shipborne pCO2 observations by LDEO dataset are optimized with an offline ocean transport model using 4D-var data assiimilation system

Valsala and Maksyutov. (2010)



3

Questions

- What causes differences among"ground-based data only" flux, "GOSAT only" flux, and "ground-based data and GOSAT" flux ?
  - Does GOSAT bring new information to regions where ground-based data are not enough?
  - Do errors in GOSAT data cause the flux difference ?
- Before answering these questions, we must understand the behaviours of flux estimation systems.

IWGGMS-8

8th International Workshop on Greenhouse Gas Measurements from Space

Pasadena, CA, United States
June 18 – 20, 2012

Group photo of the IWGGMS-8

https://sites.google.com/site/iwggms8/home

Flux Estimation Comparison Studies at IWGGMS-8

Influence of differences in current GOSAT X_{CO2} products on surface flux estimates

H. Takagi[1], T. Oda[2], M. Saito[3], V. Valsala[4], D. Belikov[1], T. Saeki[1], R. Saito[5], I. Morino[1], O. Uchino[1], Y. Yoshida[1], Y. Yokota[1], A. Bril[1], S. Oshchepkov[1], R. J. Andres[6], C. O'Dell[2], A. Butz[7], H. Boesch[8], and S. Maksyutov[1]

Global CO_2 flux estimation using GOSAT: An inter-comparison of inversion results

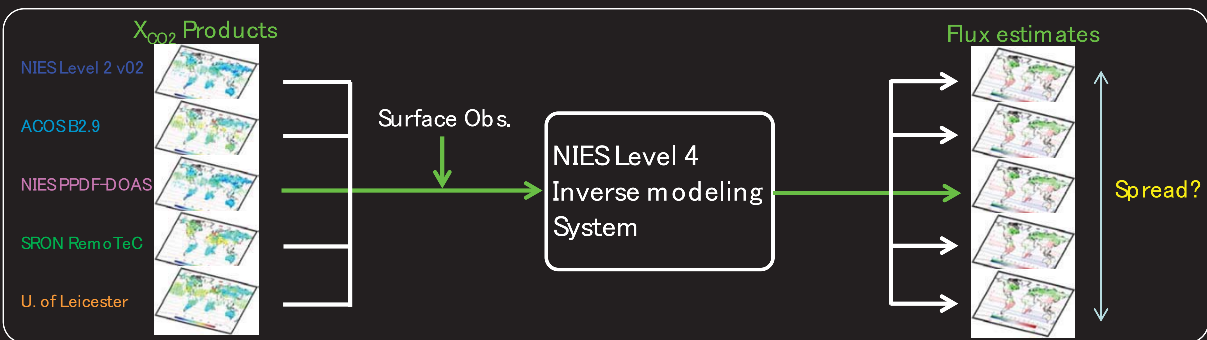
S. Houweling[1,2], S. Basu[1,2], F. Chevallier[3], L. Feng[4], A. Ganshin[7], S. Maksyutov[5], P. Palmer[4], P. Peylin[3], Z. Poussi[6], H. Tagaki[5], R. Zhuravlev[7]

Content of this talk

- Currently there are five independently-retrieved GOSAT X_{CO2} datasets:
  1. NIES SWIR Level 2 v02.**
  2. ACOS B2.9
  3. NIES PPDF-DOAS
  4. SRON-KIT RemoTeC
  5. U. of Leicester FP

  All products under continual improvement

- Estimated monthly regional CO_2 fluxes from these current datasets using a single inverse modeling system and evaluated the spread



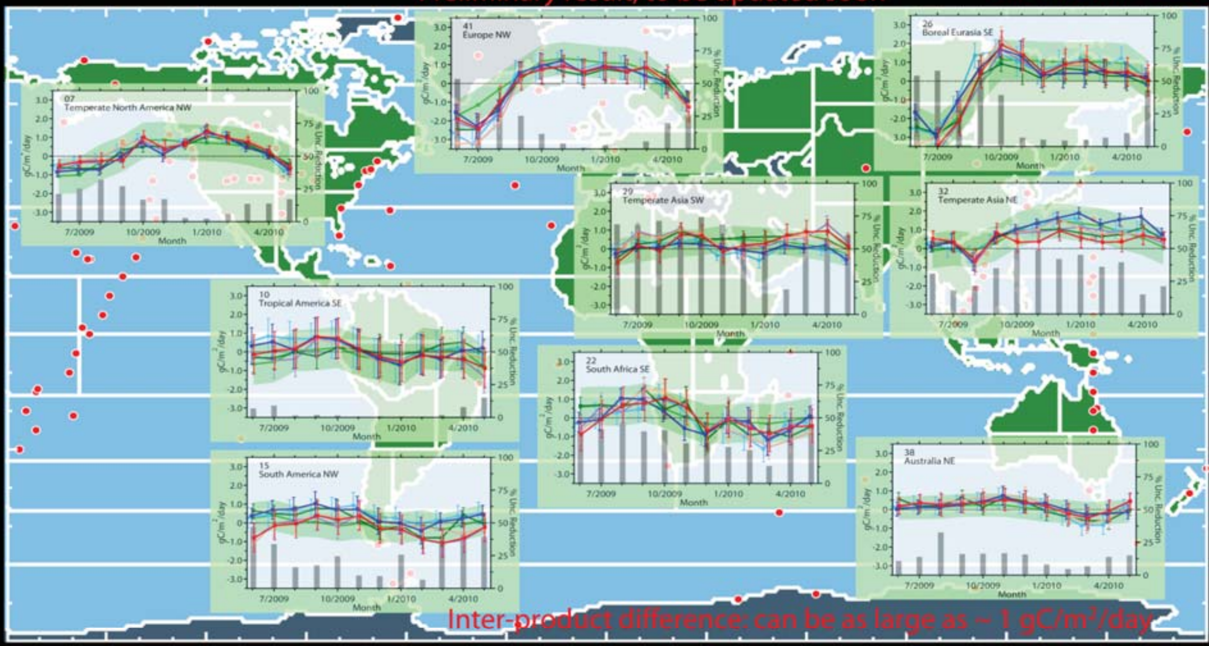
- Motivation: Need to provide the users of GOSAT-based surface CO_2 flux data with additional information on the degree of uncertainty associated with the flux estimates
  → as part of flux inter-comparison campaign lead by S. Houweling (this PM)

GOSAT PROJECT

1 yr. time series of monthly flux for selected regions

Preliminary result, to be updated soon

• GV sites (#=220)



Lt. Green: Apriori and unc.
Red: GV only
Blue: GV+NIES
Lt. Blue: GV + ACOS
Purple: GV + PPDF
Green: GV + SRON
Orange: GV + UOL
Gray bar: Unc. Reduction (%)

Annual Global Total Flux (in GtC/year)

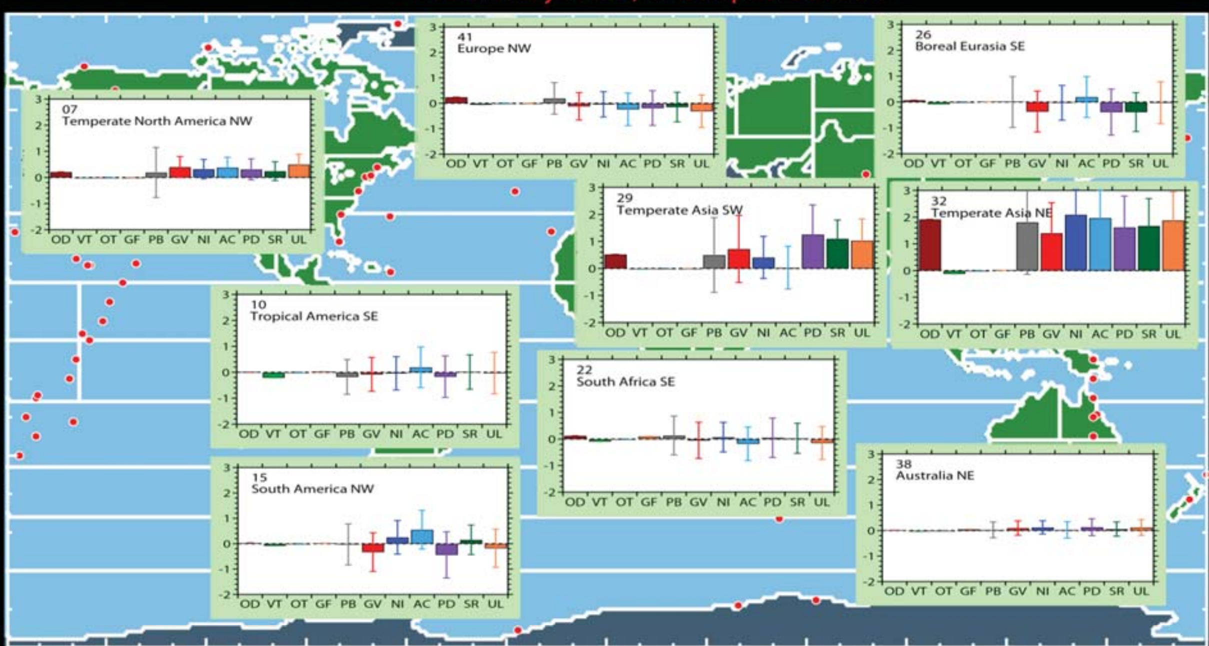
	NOAA Growth Rate	GV only	NIESv2	ACOSB29	PPDF	SRON	UOL
Land	-	-2.04	-1.41	-1.26	-2.14	-1.85	-1.58
Ocean	-	-2.14	-2.06	-2.65	-2.16	-2.31	-2.49
Global Total	4.14 ~ 4.63	4.66	5.00	4.94	4.55	4.69	4.78

Takagi et al, IWGGMS-8

GOSAT PROJECT

Annual mean flux for selected regions (unit: GtC/reg./yr)

Preliminary result, to be updated soon



Red: GV only
Blue: GV+NIES
Lt. Blue: GV + ACOS
Purple: GV + PPDF
Green: GV + SRON
Orange: GV + UOL

Inter-product differences: can be as large as ~1GtC/reg/yr, but all are within the level of uncertainty.

Takagi et al, IWGGMS-8

Current!Submissions!!

- 5!models:!NIES,!LSCE,!UoE,!SRON,!CAO^NIES!!

Model	Driving Meteo	Model Resolution	Inversion method	Measurements	Contact person
GELCA v1.0	JAM-JCDAS	2.5°x2.5°x32lev	Kalman smoother	PPDF-DOAS NOAA (60 sites)	R. Zhuravlev (CAO)
GEOS-CHEMv8.2	GEOS 5.1.0.	2.5°x2.0°x47lev	EnKF	ACOSv2.9 Globalview CO2	L. Feng (Uni. Edinburgh)
LMDZ4	ECMWF	3.8°x2.5°x19lev	Variational techn.	ACOSv2.9# NOAA/WDC/CE-IP	F. Chevallier (LSCE)
NIES08.1	JMA-JCDAS	2.5°x2.5°x30lev	Kalman smoother	NIES L2v01 139 sites Globalview	H. Tagaki (NIES)
TM5-4DVAR	EC ERA Interim	6°x4°x60lev	Variational techn.	RemoteC NOAA (60 sites)	S. Basu (SRON/IMAU)

#: LMDZ4 GOSAT inversion does not include surface measurements

Inter^comparison!results:!Flux!maps!!

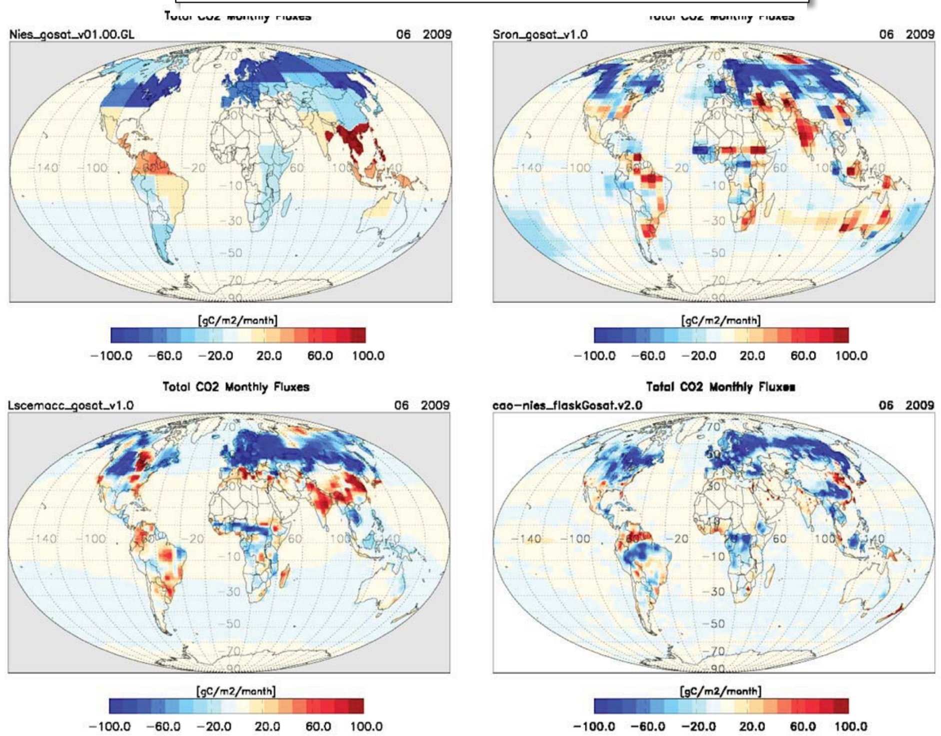
GOSAT^only!inversions,!June!2009!

NIES:!

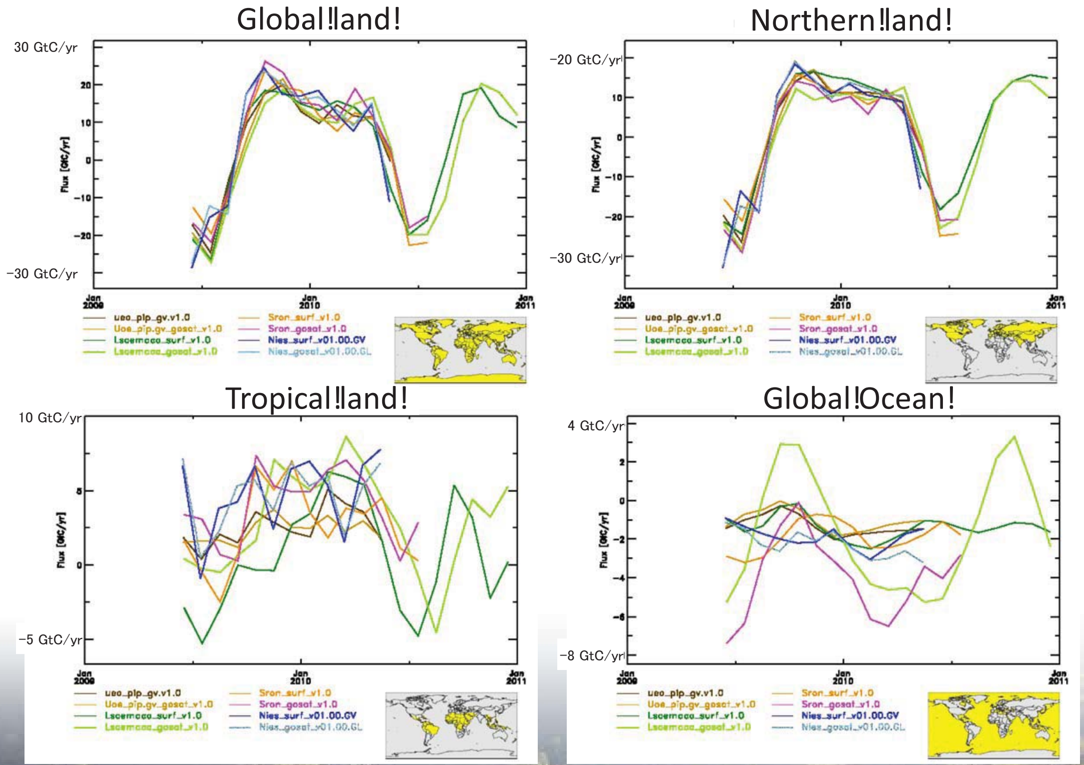
:!SRON!

LSCE:!!

:!CAO!



Time!series!of!regional!integrals!



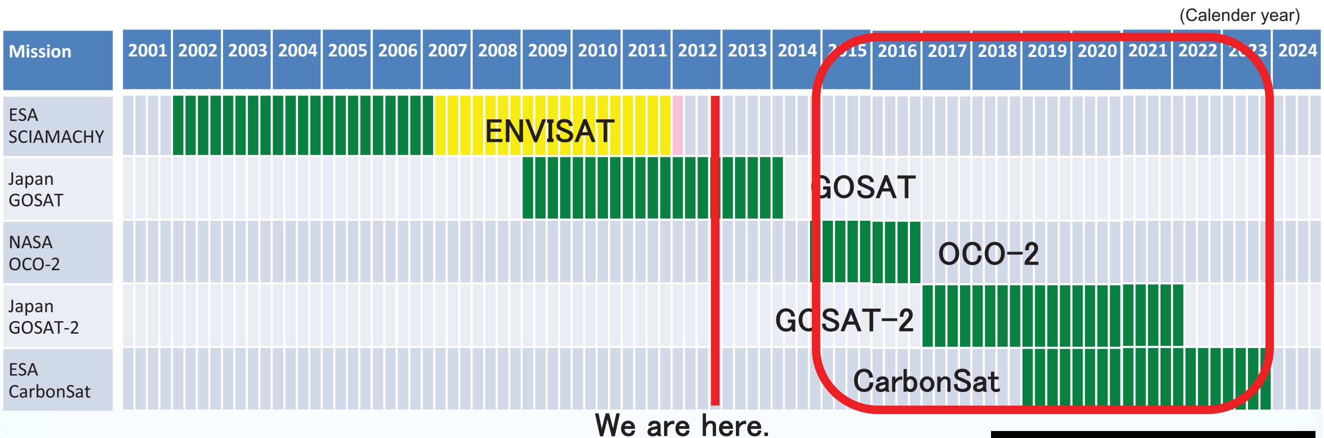
IWGGMS-8, 19-6-2012 | Houweling et al., IWGGMS−8 | GOSAT CO_2 ICE

Current Status of Satellite Flux Estimation

- Global CO2 net flux distributions are obtained only from GOSAT data as well as from both ground-based and GOSAT data.
- Differences between satellite flux and ground-based flux are found.
- The behaviors of satellite flux estimation systems are being investigated.
  - Input GHG concentration data dependency
  - Inverse modelling scheme dependency

Future Prospect

World GHG Observation Satellites*

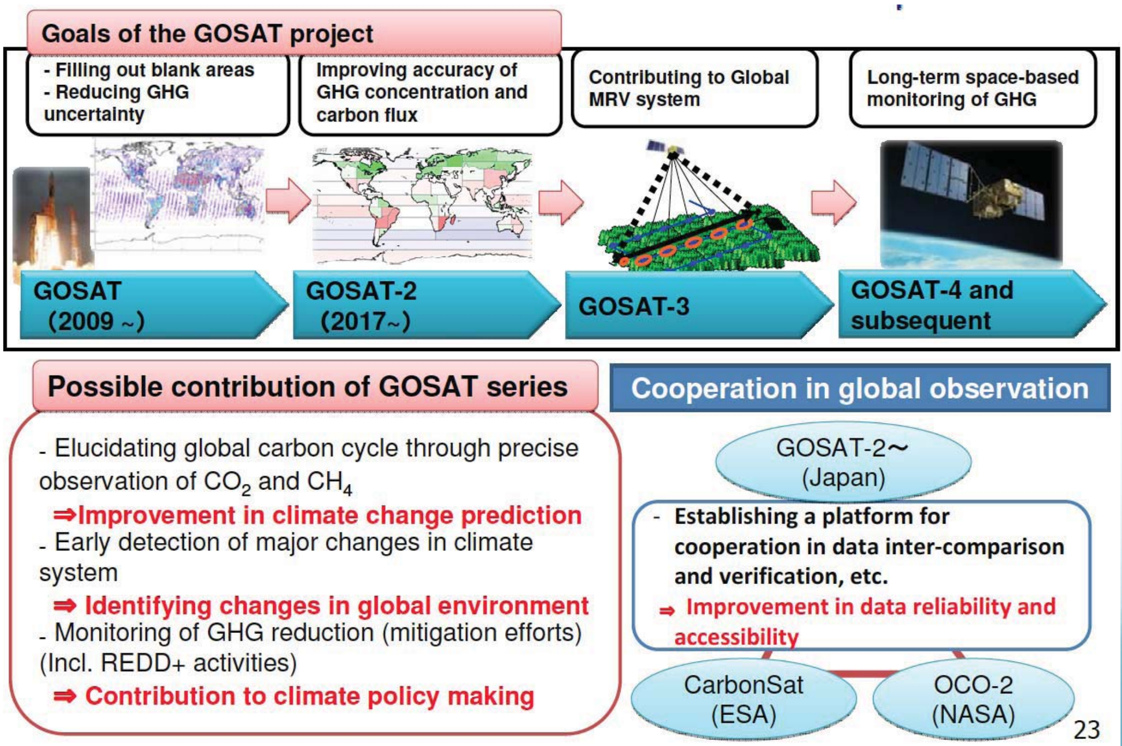


Green	Designed life time
Yellow	Extended operation
Pink	End of mission

*Satellites which measure column CO2 amount.

Tsuneo Matsunaga, National Institute for Environmental Studies, Japan
Presented at Presented at IPCC Expert Meeting: Role of Remote Sensing (RS) in Forest and National GHG Emission Inventories, October 23-25, 2012, Hayama, Japan

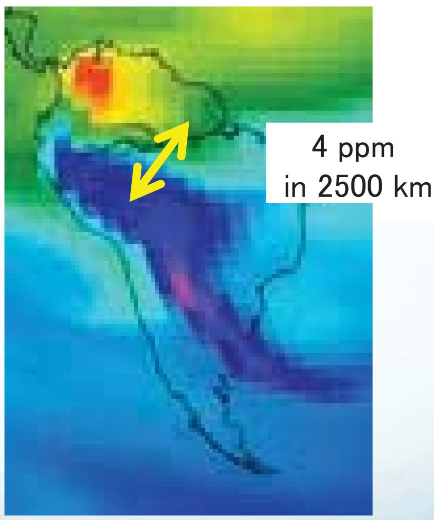
Ministry of the Environment's Perspective on Future GOSAT Missions and International Cooperation Presented at UN Rio+20



GOSAT-2 Challenges

Detection of small CO2 variations

- GOSAT achieves a "single shot" precision of ≈2 ppm.
- GOSAT-2 Goal : 0.5 ppm precision of monthly column CO2 for 5 degree mesh (500km x 500 km) to reveal regional CO2 behaviours (e.g. in tropical rain forests).
- This goal will be achieved by averaging sixteen "single shot" column CO2 data in a month.
- This goal requires signigicant (3 times or more) increase of satellite CO2 data in a month.



Carbon Tracker
April 14, 2010

CarbonSat - Spatial resolution & coverage

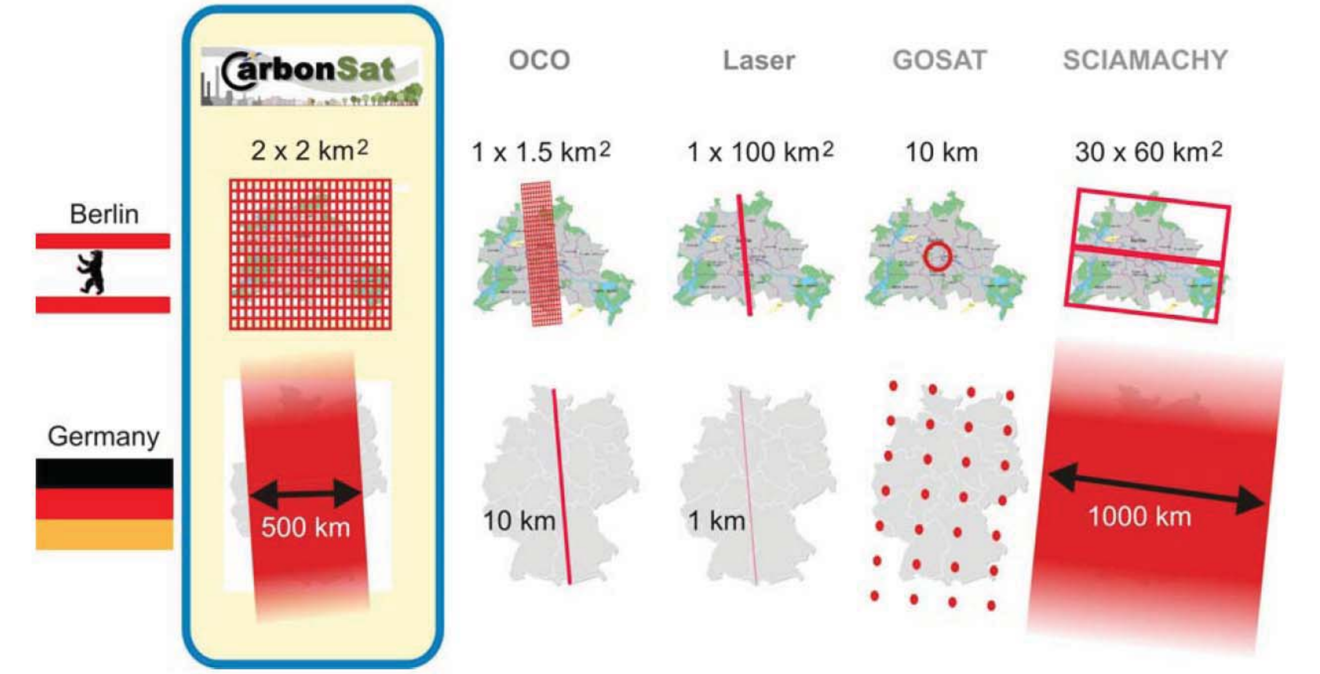
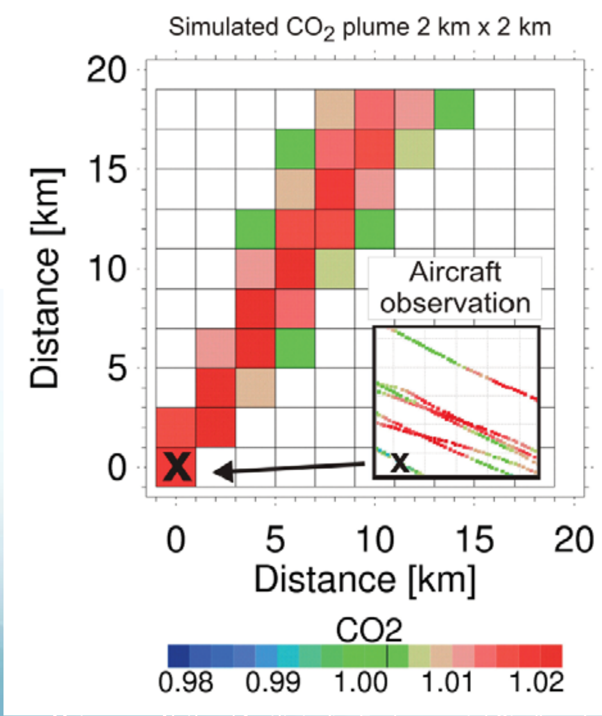


Figure 4: *Examples of the spatial resolution of CarbonSat (top row; as illustrated the city of Berlin) and orbital coverage (bottom row; as illustrated for Germany) compared to a potential LIDAR instrument, the existing GOSAT and SCIAMACHY missions as well as to the planned OCO-2 mission.*

Bovensmann et al. (2010)

ESA CarbonSat: XCO2 Gradient near Anthoropogenic Source



Simulation of the atmospheric CO2 column enhancement due to CO2 emission of a power plant.

The wind speed is 1 m/s.
The assumed power plant emission is 13 MtCO2/yr.
(Bovensmann et al. (2010))

Upto 2% (≈8 ppm) anomaly of column CO2 in 10 – 20 km spatial scale.

Bovensmann et al. (2010)

Satellite Flux and Inventory

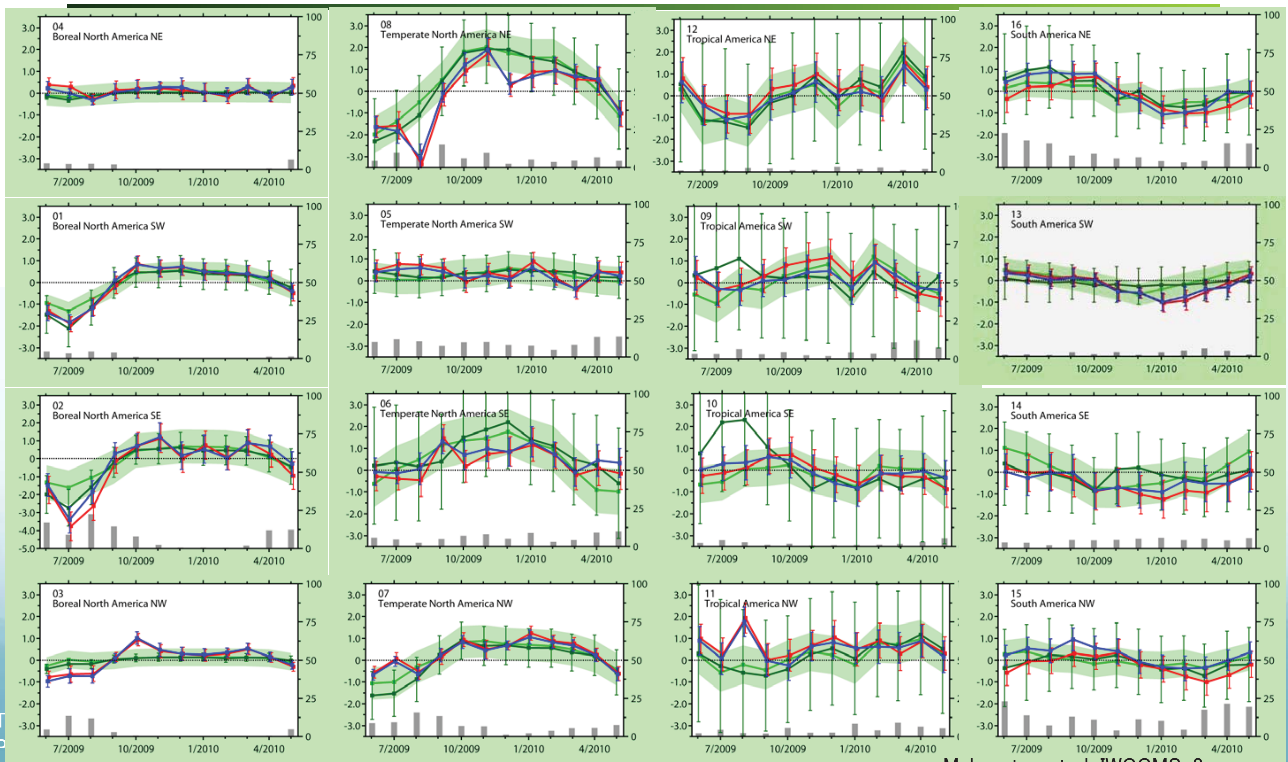
Satellite Flux and Inventory

- Difference of spatial scale
  - Satellite : 64 regions or several degree grid
  - Inventory : national, sub-national, and (REDD+) project levels
- Difference of time scale
  - Satellite : monthly – annual
  - Inventory : annual?
- Difference of components included in "flux"
  - Satellite : Net flux including fossil fuel and forest/peat fire emissions
  - Inventory :
- Difference of precisions (error bars)
  - Satellite :
  - Inventory :

Thank you for your attention.

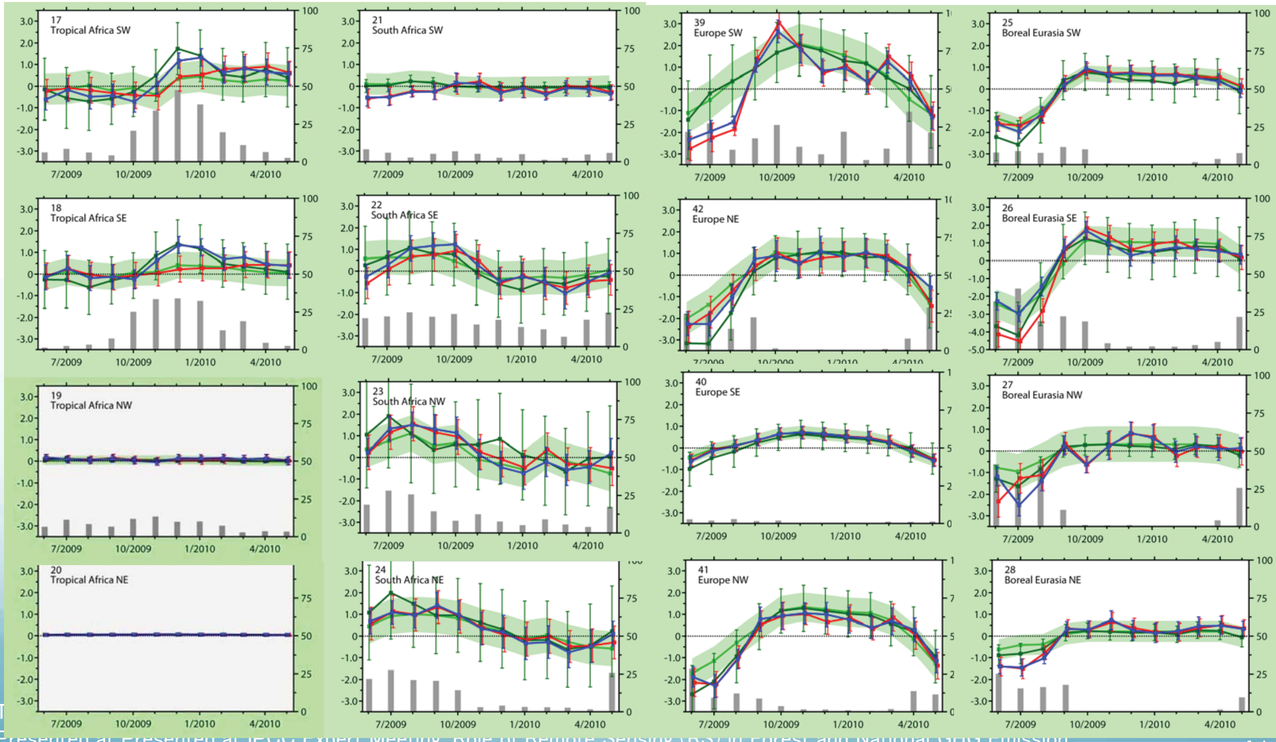
Time Series of Monthly CO2 Flux

America : Boreal, Temperate, Tropical , South



Time Series of Monthly CO2 Flux

Trop. Africa, S. Africa, Europe, Siveria



Inverse Modeling Setup

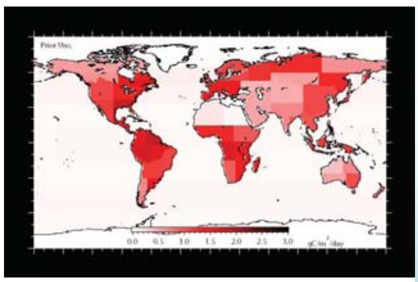
Inverse modeling scheme : Fixed-lag Kalman Smoother (Bruhwiler et. al., 2005 ACP)
Assimilation window: 3 month
Number of source regions: 64
Tracer transport model: NIES08.1i (Belikov et al., 2011 GMD)

Prior flux uncertainty
Land : Std. dev. of VISIT model monthly NEE about past 30-year mean
Ocean : Std. dev. of assimilated ocean flux about 2001-2009 mean and ocean flux climatology

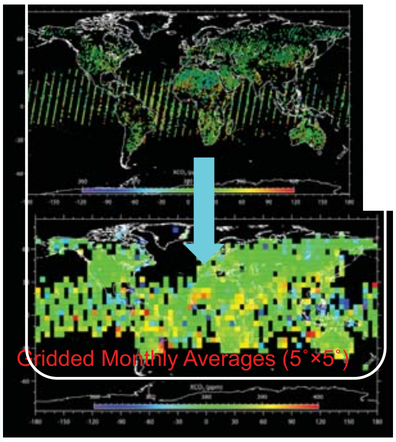
Model-observation mismatch errors
GLOBALVIEW : RSD of observations vs smoothed curve
GOSAT L2: Std. dev. of XCO_2 values found in a 5°× 5° grid in a month, with min uncertainty of 3 ppm

64 Base Regions

Prior Flux Uncertainty



Preprosessing of Observational Data



GOSAT Level 2 XCO_2

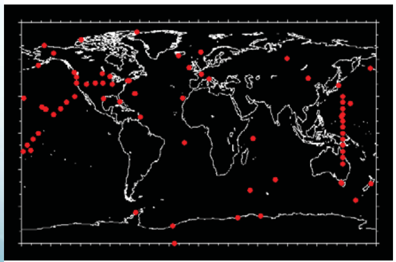
Data version: ver. 2.0

Data period: 2009/06 – 2010/07 (14 months)

Offset optimized by inversion at first step (2009/6-8 time window)

Data screening:

- Prediction-Observation mismatch: > 3 ppm Rejected
- Outliers rejected based on Gap-filled Ensemble Model Climatology (GECM) Saito et. al., 2011 JGR



GLOBALVIEW 2011

The weekly analyses were averaged to monthly values.

Choice of data sites: Followed Law et al. (2003, TC3 paper) + all available aircraft sites (139 data records total).

5

Maksyutov et al. IWGGMS-8

Validation of GOSAT TANSO FTS SWIR XCO2 and XCH4 Products

- The GOSAT Level 2 XCO2 data retrieved from the TANSO-FTS SWIR Level 1B data were lower than the TCCON data by ≈ 0.3 % (1.2 ppm) and the standard deviation of the Level 2 XCO2 data was ≈ 0.5 % (2.0 ppm).
- The GOSAT Level 2 XCH4 data were lower than the TCCON data by ≈ 0.4% (7 ppb) and the standard deviation of the Level 2 XCH4 was ≈ 0.7 % (12 ppb).

https://data.gosat.nies.go.jp/GosatWebDds/productorder/distribution/user/V02XX_FTS_L2_Validation_Document_GU_en.pdf

High spatial resolution remote sensing improves forest carbon stock estimation in dry forests

Amon Murwira (PhD)
Tawanda W. Gara

University of Zimbabwe
Department of Geography and Environmental Science

IPCC Expert Meeting: Role of Remote Sensing (RS) in Forest And National GHG Inventories, Hayama, Japan, 23-25 October 2012

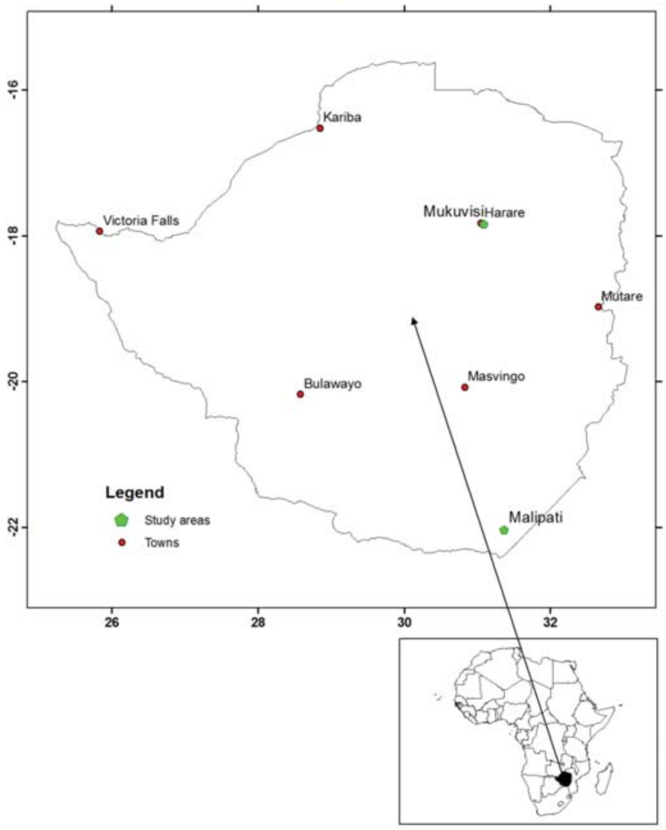
Introduction

- Forests important in the global carbon cycle
- Savannas constitute 30 % of world vegetation and 50% of Africa's vegetation
- Most work on forest carbon stocks done outside of the dry savanna forests.
- It is important for science to narrow this knowledge gap particularly in African savannas.

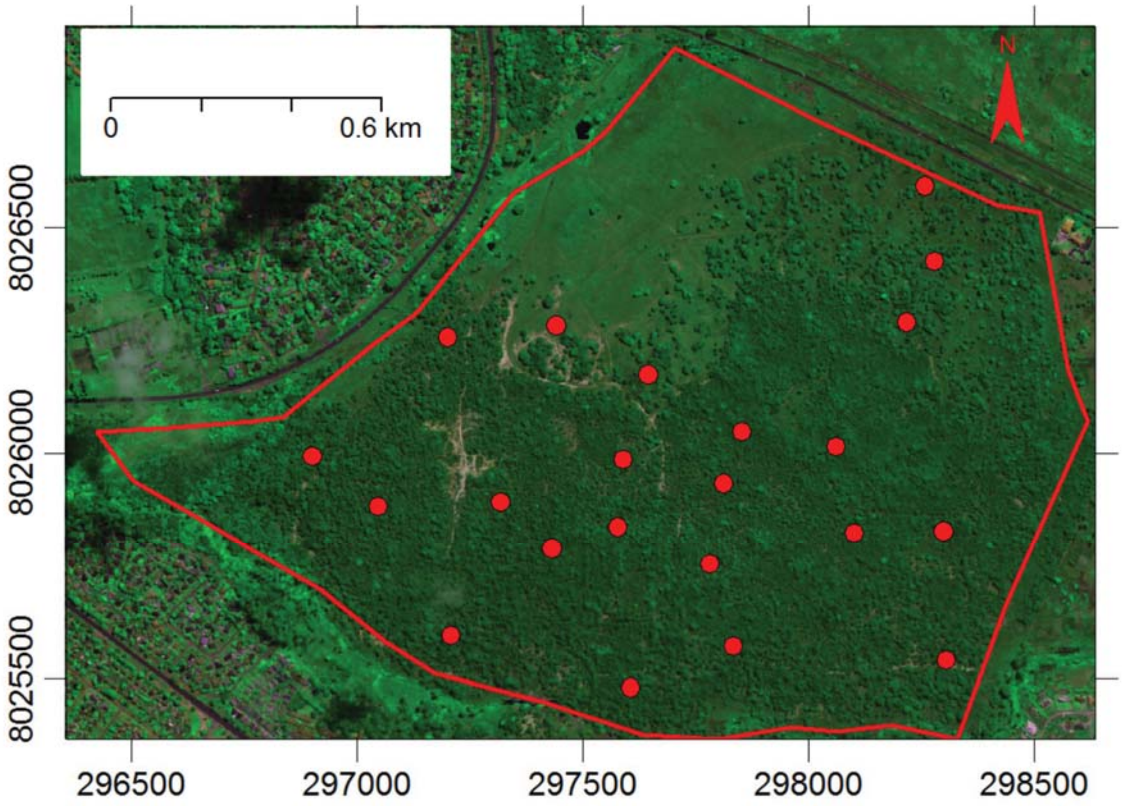
Objectives

- We tested whether and to what extent vegetation indices derived from high spatial resolution satellite imagery (GeoEye-1, WorldView-2) can predict forest carbon stocks in dry forests
- We tested this in two Southern African savanna woodland types with contrasting annual rainfall amounts

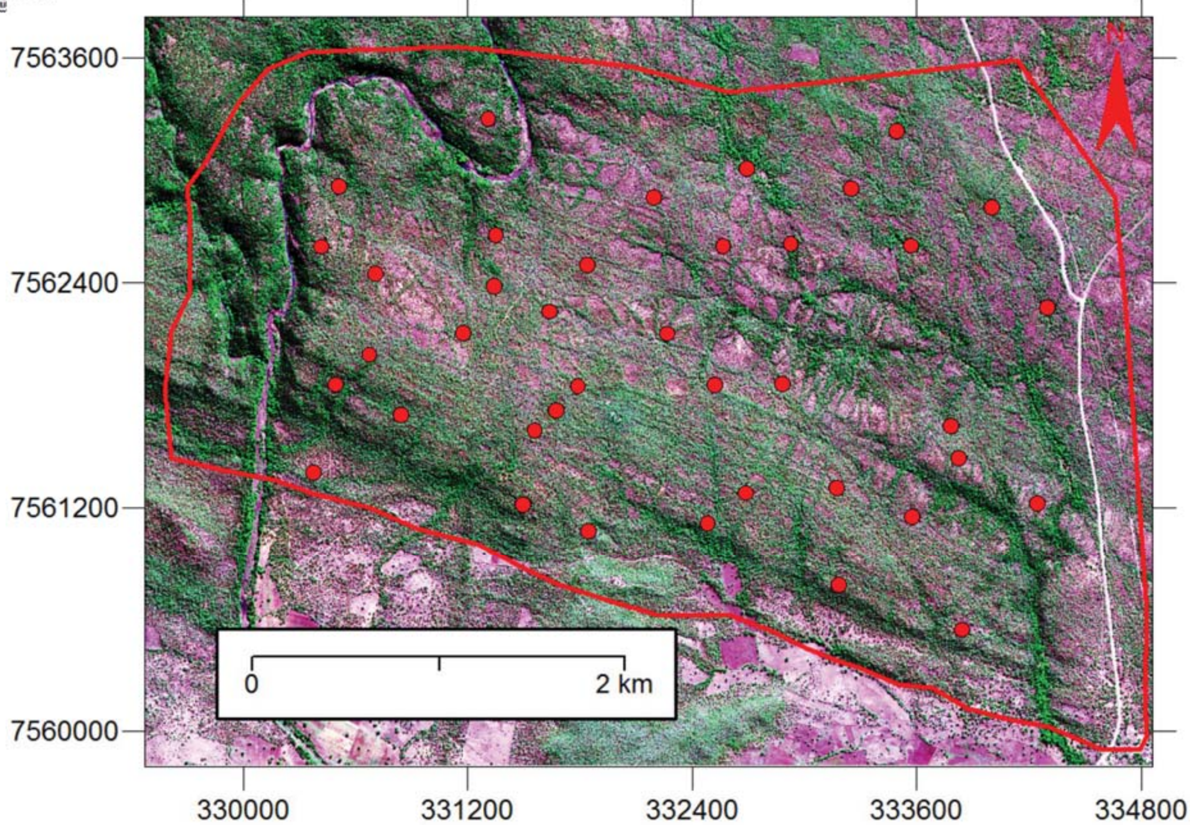
Study Sites



Mukuvisi (Geoeye-1: 23/04/2010)



Malipati (WorldView-2: 15/05/2011)



Study Site Characteristics

Characteristics	Mukuvisi	Malipati
Longitude	31°04'-31°06'E	31°20' -31°24'E
Latitude	17°49'-17°51'S	22°01'-22°03'S
Altitude (m)	1400-1500	300-600
Rainfall (mm)	800-1 000	300-600
Rain season	Oct-April	Nov-March
Temperature range (^{0}C)	5-26	5-33
Vegetation type	Dry miombo	Mopane
Soil classification	Fersiallitic	Lithosols, Vertisols

Field Sampling

- Images classified into woodland and other cover types
- Random samples generated in woodland
- 22 samples Mukuvisi
- 38 samples Malipati

Field Measurements

- At each random point, a north-oriented plot measuring 30m x 30m (0.09ha) was marked using a tape measure.
- Plots were oriented to the north using a magnetic compass.
- The plot size determined following Rahman *et al* (2008) 30m x 30m plot size recommendation for primary forests.

Field Measurements

- For tree >5cm DBH and 3m in height we identified the tree species and measured DBH (at 1.3m above ground surface)
- We also measured and total tree height using a the trigonometric principle with clinometer data

Forest Carbon Estimation

$$AGB(t/ha) = VOB \times WD \times BEF$$

- Where VOB is wood volume over bark estimated from allometric equations,
- WD is wood density and BEF is biomass expansion factor.
- WD and BEF were determined following Brown (1997).
- Finally, we multiplied the above-ground biomass by a conversion ratio of 0.5 to obtain forest carbon (IPCC, 2003)

Volume Equations

Site	Woodland type	Species	Allometric Equation	Reference
Mukuvisi	miombo	Generalized equation	$V/ha = 6.18 * BA^{0.86}$	(Frost, 1996)
Malipati	mopane	Colophospermum mopane	$V = 0.0001065 * DBH^{2.471}$	(Henry *et al.*, 2011)
		Combretum apiculatum	$V = (0.0132 + 0.00079DBH^2 + 0.0103H_t)^2$	(Abbot *et al.*, 1997)
		Others species	$V = DBH^2 / 4 * \pi * H_t * \pi * fgross$	(ILUA, 2008)

Volume allometric equations

- Allometric equations for volume used because remote sensing indices and volume equations had high RMSE >18%

Remote sensing

- Radiometric and geometric correction
- Remotely sensed vegetation indices calculated:
- Simple Ratio (SR)
- Normalised Difference Vegetation Index (NDVI)
- Soil Adjusted Vegetation Index (SAVI)

Relating Field carbon data with RS vegetation indices

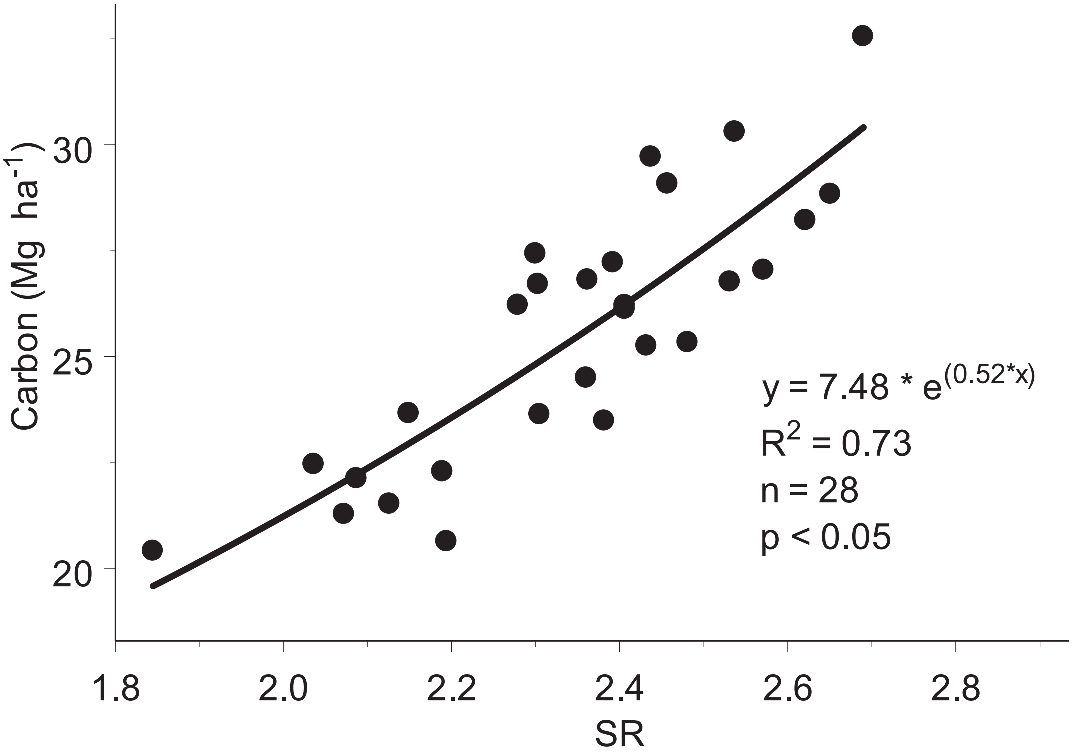
- Forest carbon data tested for spatial autocorrelation (result no evidence of spatial autocorrelation)
- Used regression analysis using 75% of data
- 25 % of data reserved as test data
- Root Mean Square Error (RMSE) used for model validation
- Used best regression model to map carbon

Results

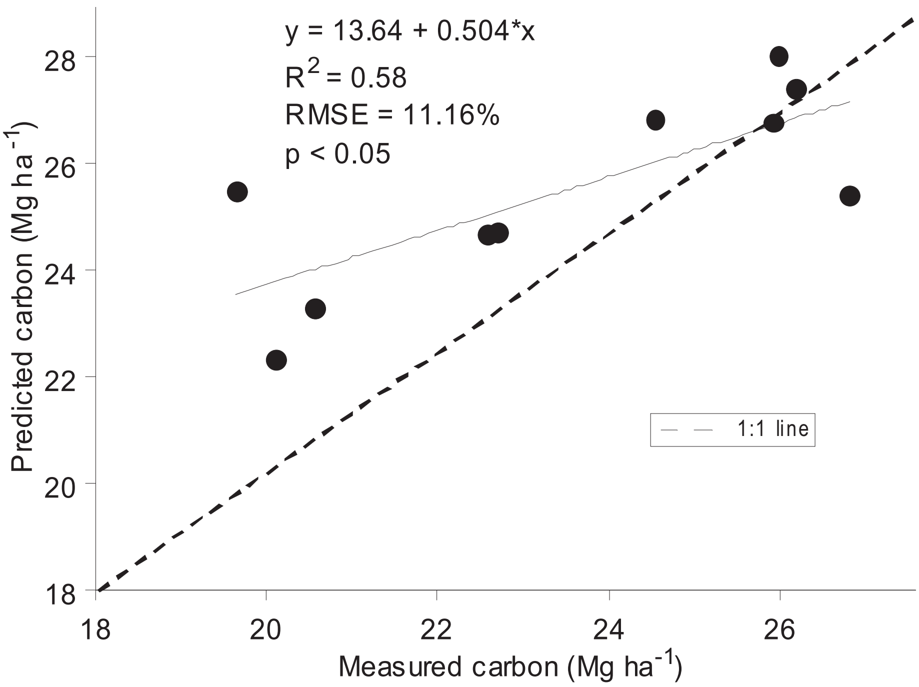
Amon Murwira (PhD)
Tawanda W. Gara

University of Zimbabwe
Department of Geography and Environmental Science

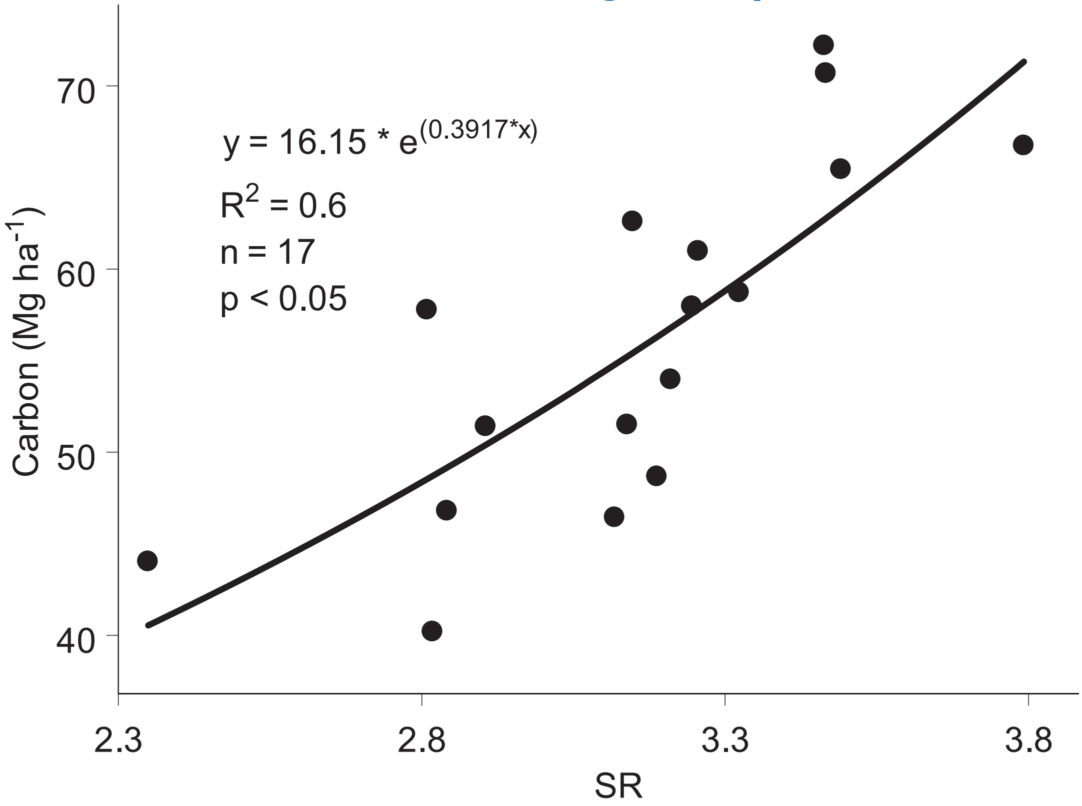
Regression Model: Malipati (SR WorldView-2)



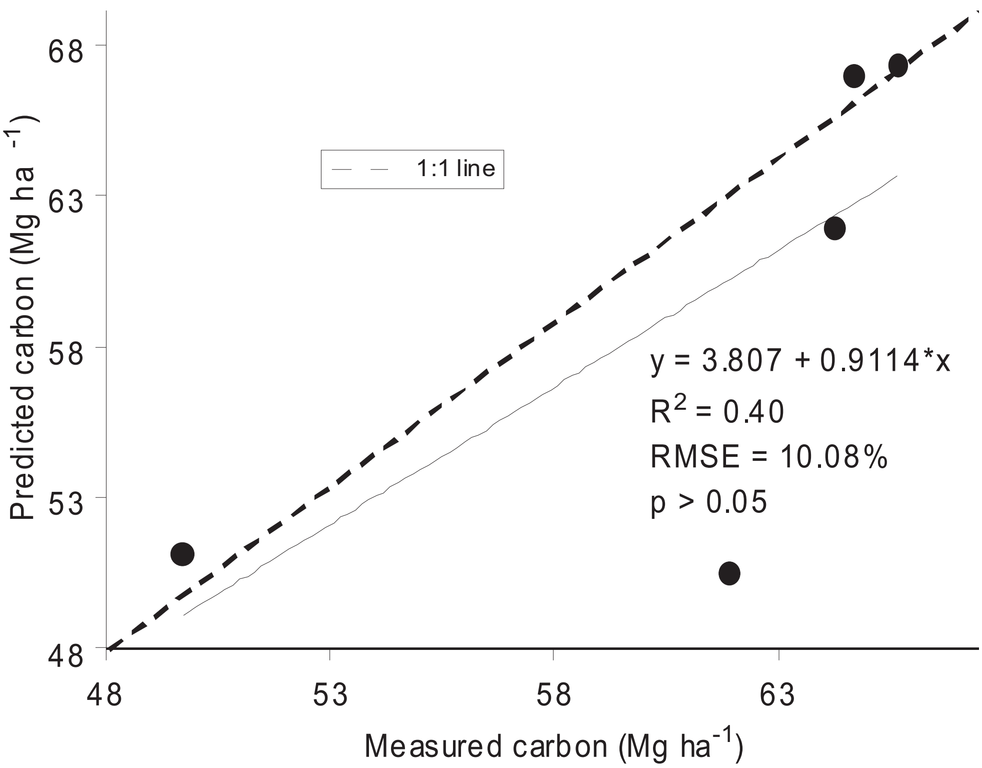
Regression Model Validation: Malipati (WorldView-2)



Regression Model: Mukuvisi (SR Geoeye-1)



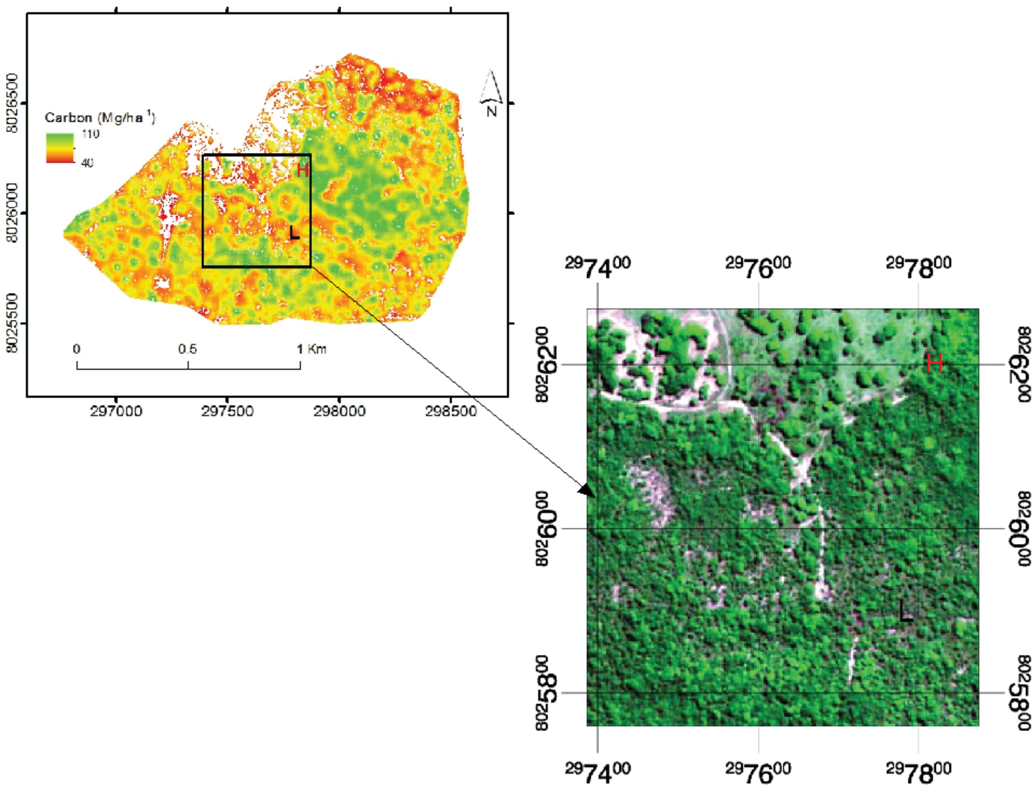
Regression Model Validation: Mukuvisi (Geoeye-1)



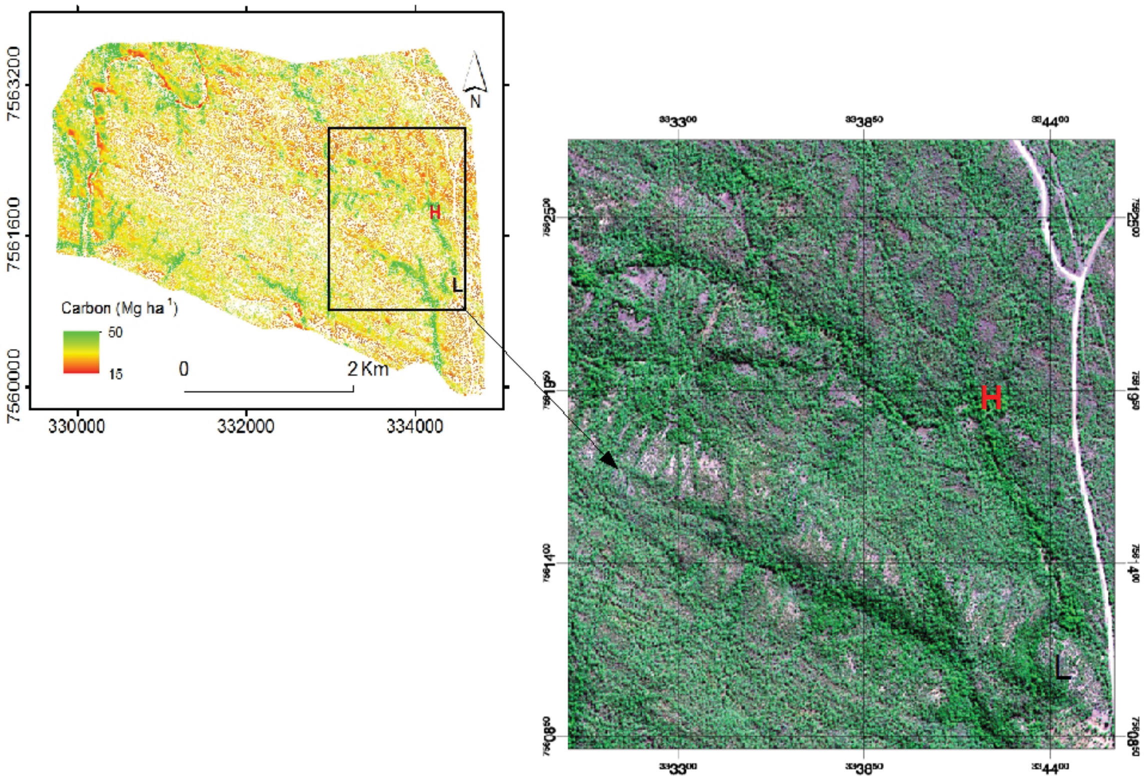
Forest Carbon for study sites (Descriptive statistics)

	Mukuvisi				Malipati			
	Min	Max	Mean	SD	Min	Max	Mean	SD
Carbon(Mg ha^{-1})	40	72	57	9	20	33	25	3
DBH (cm)	6	85	23	13	5	30	15	5
Tree density(	14	54	29	8	3	47	27	10

Mukuvisi Carbon estimate (Geoeye-1: 23/04/2010)



Malipati Carbon estimate (WorldView-2: 15/05/2011)



Discussion

- RMSE of between 10-11 % are an improvement from previous studies where RMSE values were significantly higher.
- Most studies on AGB have been based on medium to low spatial resolution imagery and have yielded low R^2
- The mean carbon density in this study compare well to carbon density estimates of 61 and 36 Mg ha^{-1} for dry forests (IPCC, 2003).

Discussion

- Findings validate the utility of our models in estimating and modelling forest carbon in savanna landscapes of Southern Africa.

Way Forward

- Important to test these relationships at multiple sites to increase confidence
- Currently, we have selected 8 sites in Southern Africa covering Mozambique, Zimbabwe and Zambia to further test these models.

Thank you

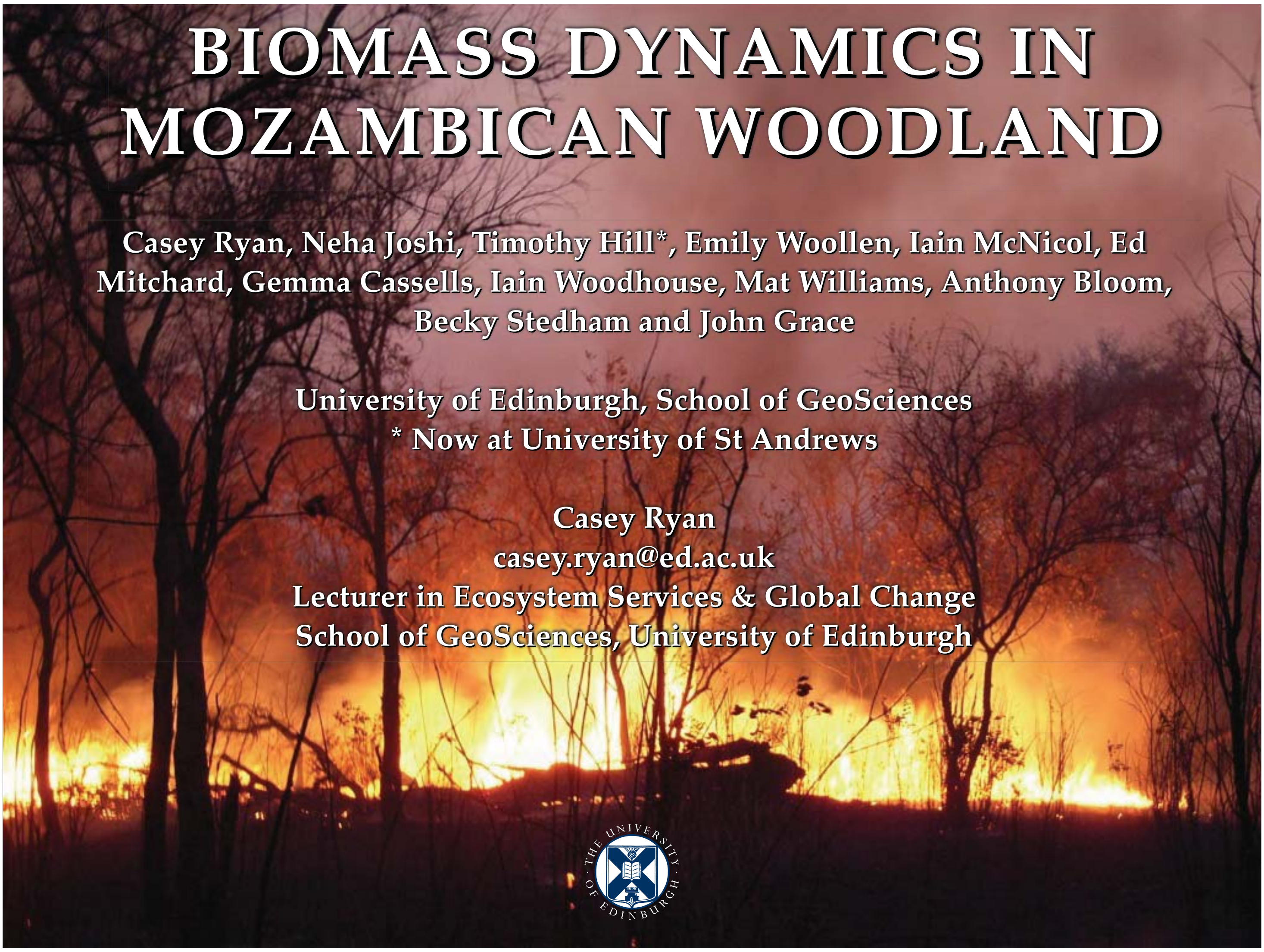
Image for Mukuvisi provided by GeoEye as an educational grant

BIOMASS DYNAMICS IN MOZAMBICAN WOODLAND

Casey Ryan, Neha Joshi, Timothy Hill*, Emily Woollen, Iain McNicol, Ed Mitchard, Gemma Cassells, Iain Woodhouse, Mat Williams, Anthony Bloom, Becky Stedham and John Grace

University of Edinburgh, School of GeoSciences
* Now at University of St Andrews

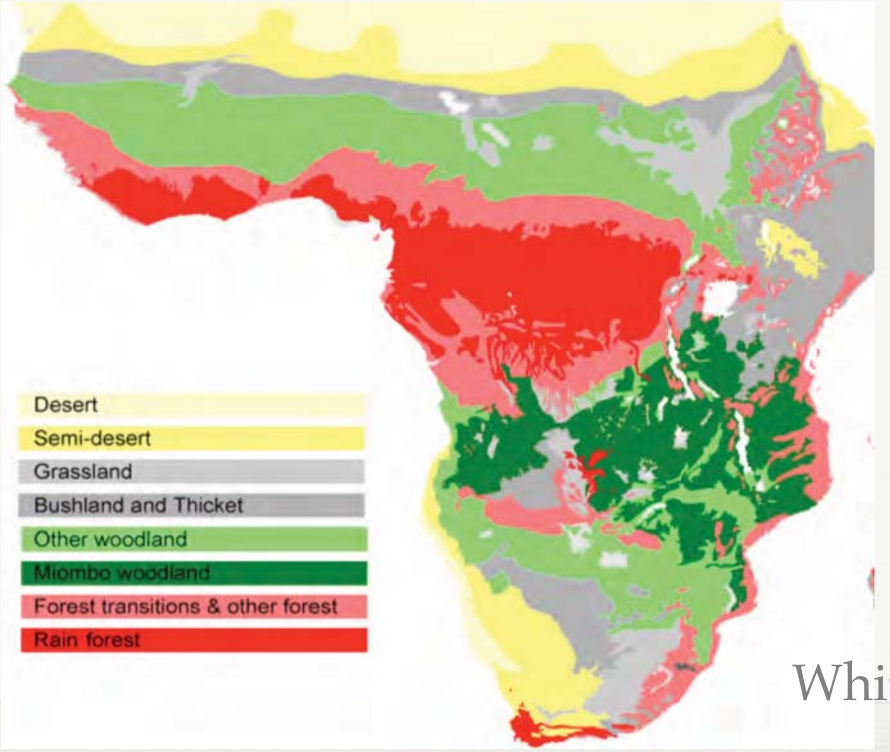
Casey Ryan
casey.ryan@ed.ac.uk
Lecturer in Ecosystem Services & Global Change
School of GeoSciences, University of Edinburgh



CONTENTS

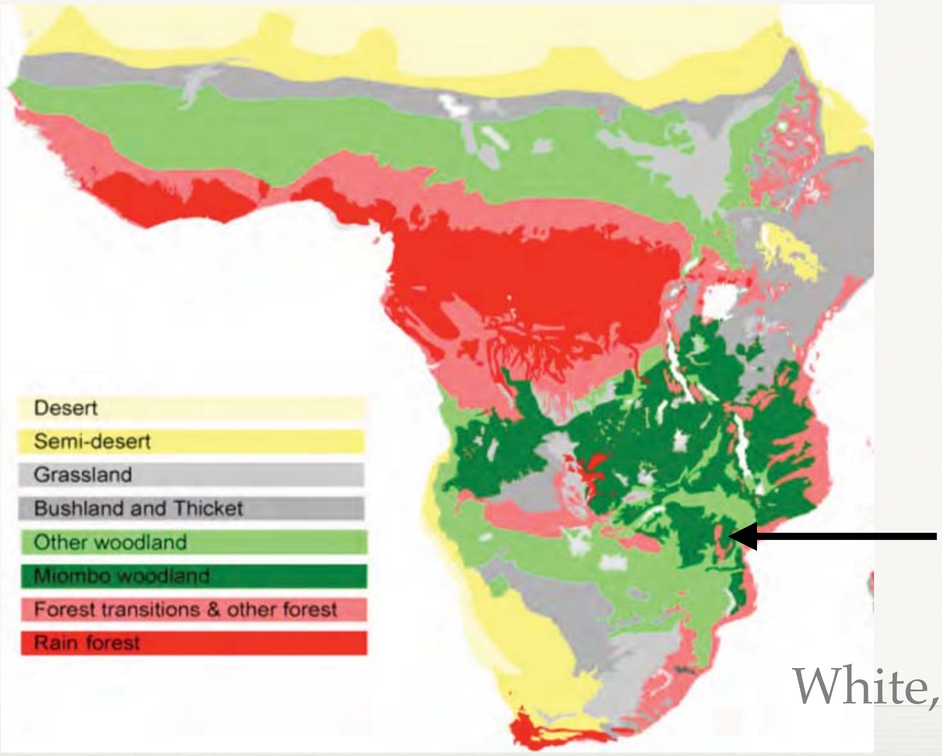
- 1. Miombo woodlands: current land use change dynamics
- 2. Measuring biomass stocks using ALOS PALSAR & ground data
- 3. Quantifying deforestation and degradation (and their causes)

AFRICAN WOODLANDS



White, 1983

AFRICAN WOODLANDS

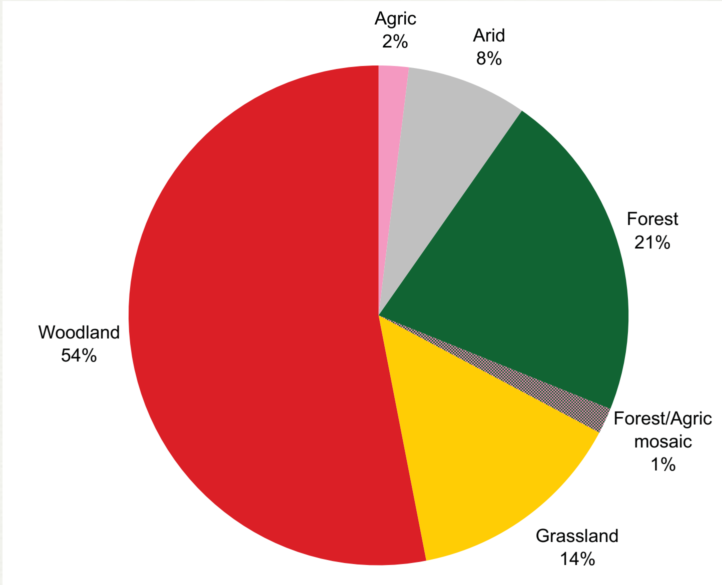


White, 1983

LUC EMISSIONS IN WOODLAND AFRICA

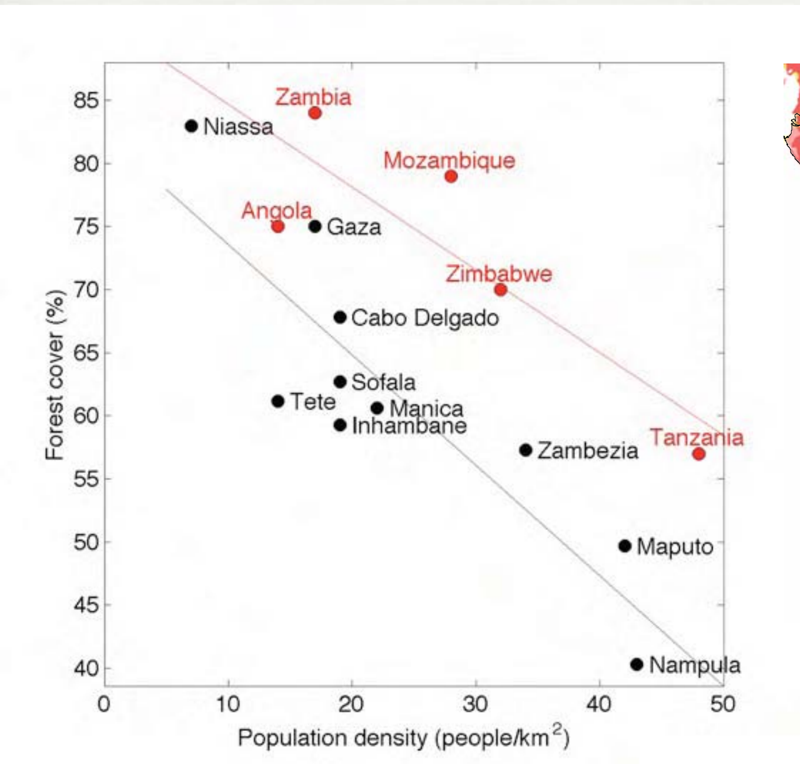
- Large area of low C density woodlands (2.4 M km²)
- Highly populated
- LUC driven by small scale agriculture, not global commodities
- Degradation likely to be substantial (Ahrends et al 2010)
- Few data on forest carbon stocks
- Losses from soil after deforestation?
- 0.3 PgC/yr ???

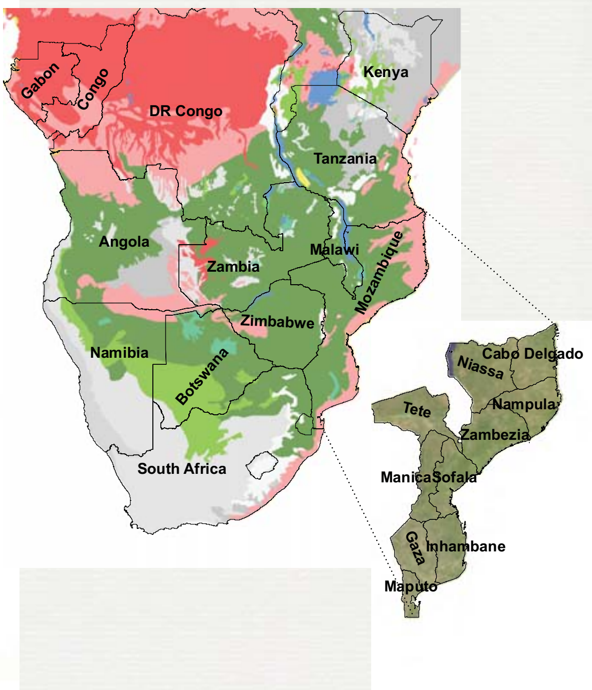
Deforestation emissions by national landcover



Based on data in FAO FRA 2010 and Mayaux's (2004) classification of national land cover

PEOPLE AND MIOMBO WOODLANDS



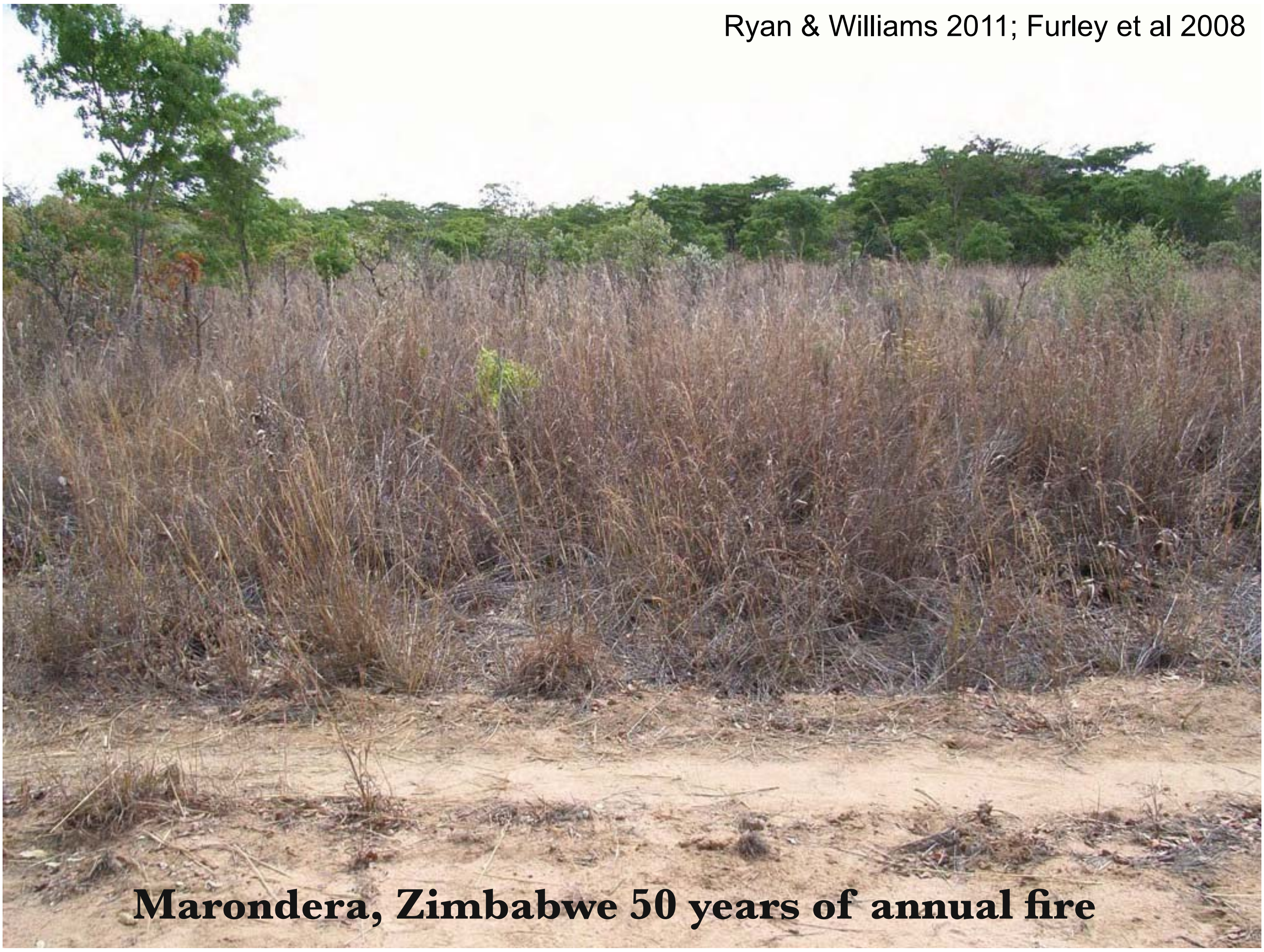


Marzoli (2007), FAO (2010)

Williams et al 2008

FOOD, FUEL..

Ryan & Williams 2011; Furley et al 2008



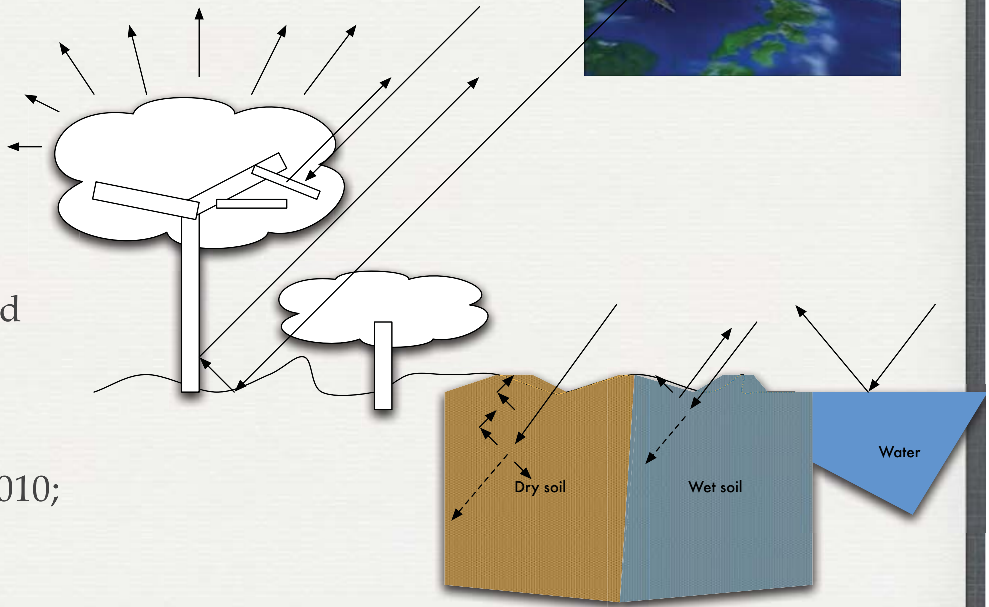
Marondera, Zimbabwe 50 years of annual fire

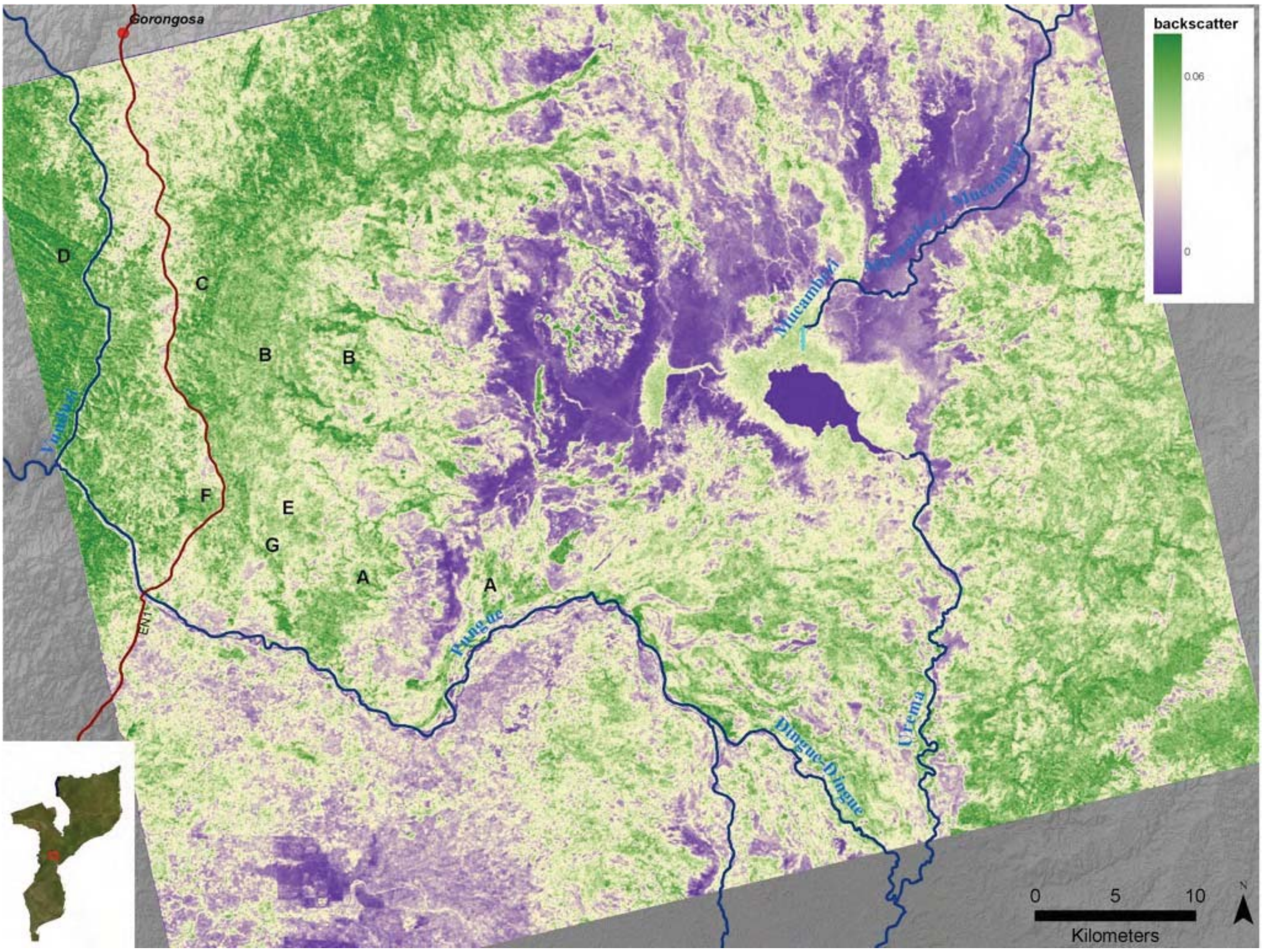
OVERVIEW OF OUR WORK IN CENTRAL MOZAMBIQUE

- Ground based estimates of stocks and flows of C
- Mapping biomass change with ALOS PALSAR (2007-10)
  - Project scale
  - District/Province scale
- Estimating the contributions of activities that cause forest loss
- REDD Baselines

RADAR IMAGERY FOR ESTIMATING ΔBIOMASS

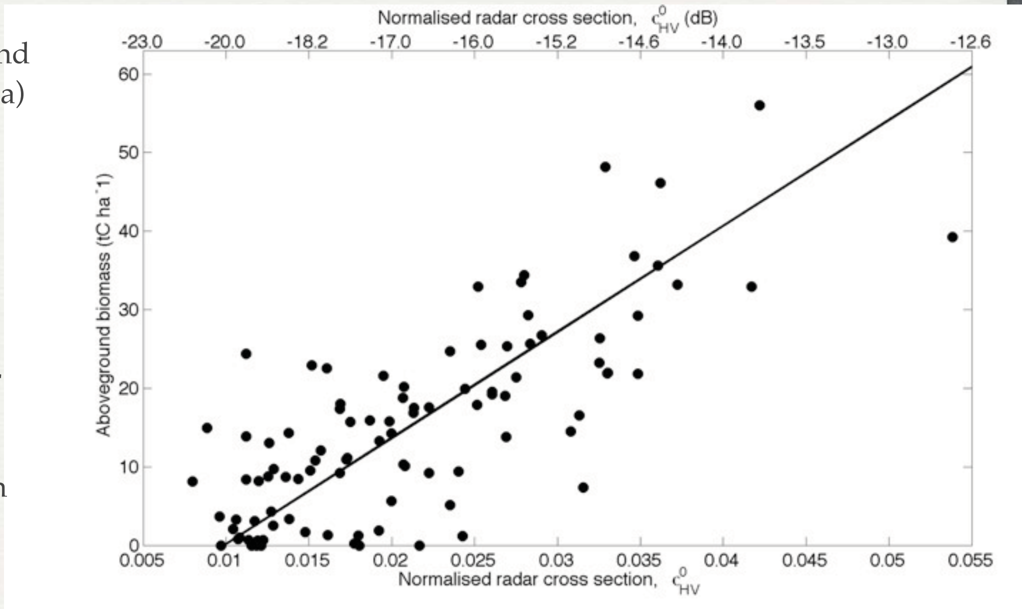
- ALOS PALSAR L-band (23 cm) radar.
- 12.5 m ground resolution
- no cloud or grass problems
- instead, terrain and speckle and soil moisture
- data from 2007 - 2010; 2014 onwards





BIOMASS-BACKSCATTER RELATIONSHIP

- 96 ground calibration and validation plots (0.2-3 ha)
- Forest, woodland and cropland
- 10 x images from 2007-2010
- Regression ~stable over time
- Temporal co-variance in biases: 2007-2010 ρ = 0.54



Mean $R^2 = 0.50$

Validation (holdout) RMSE = 9.8 tC/ha Bias = 1.6 tC/ha

Ryan et al (2012) GCB

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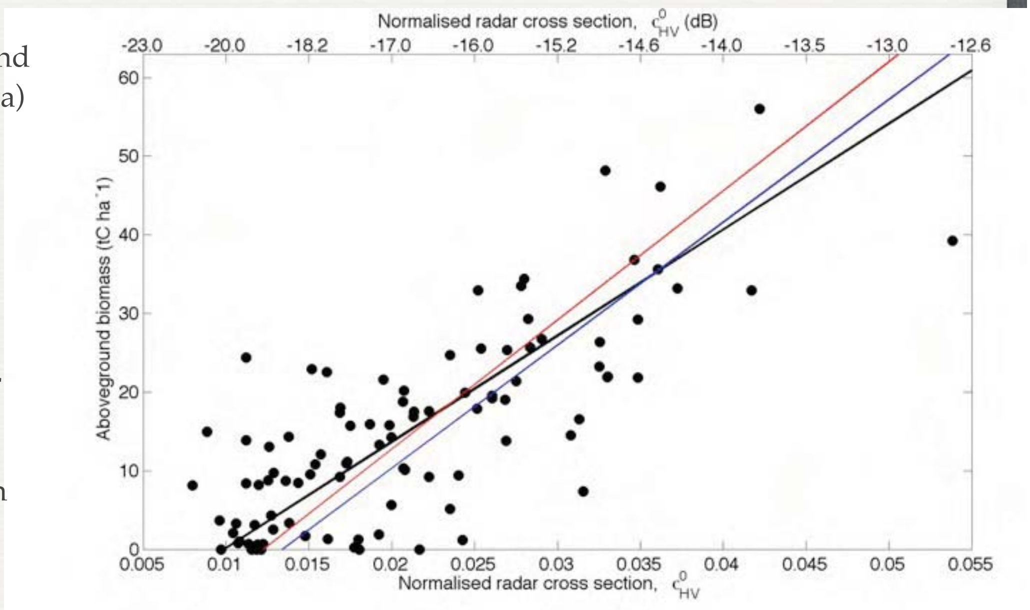

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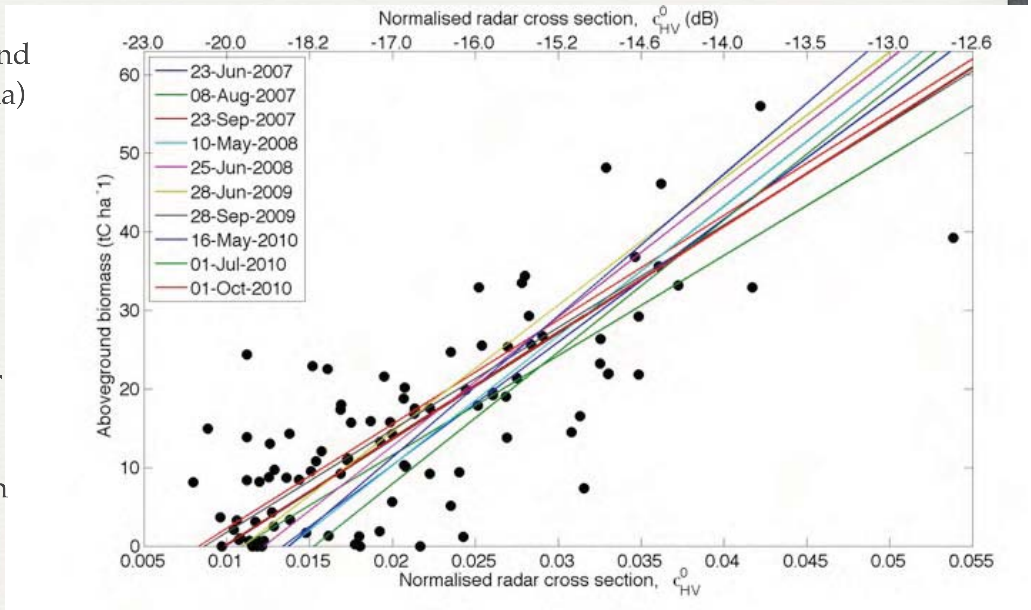

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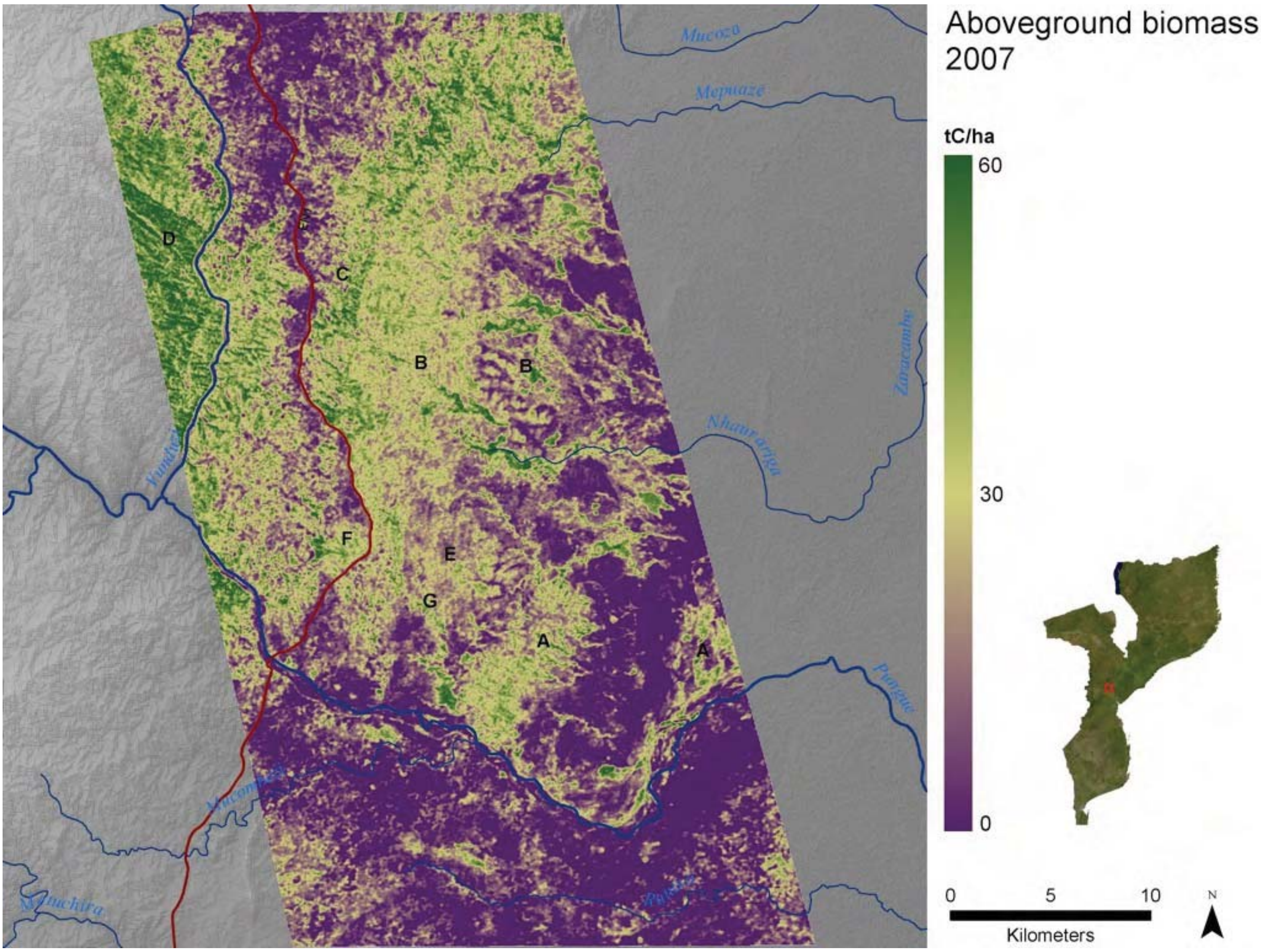
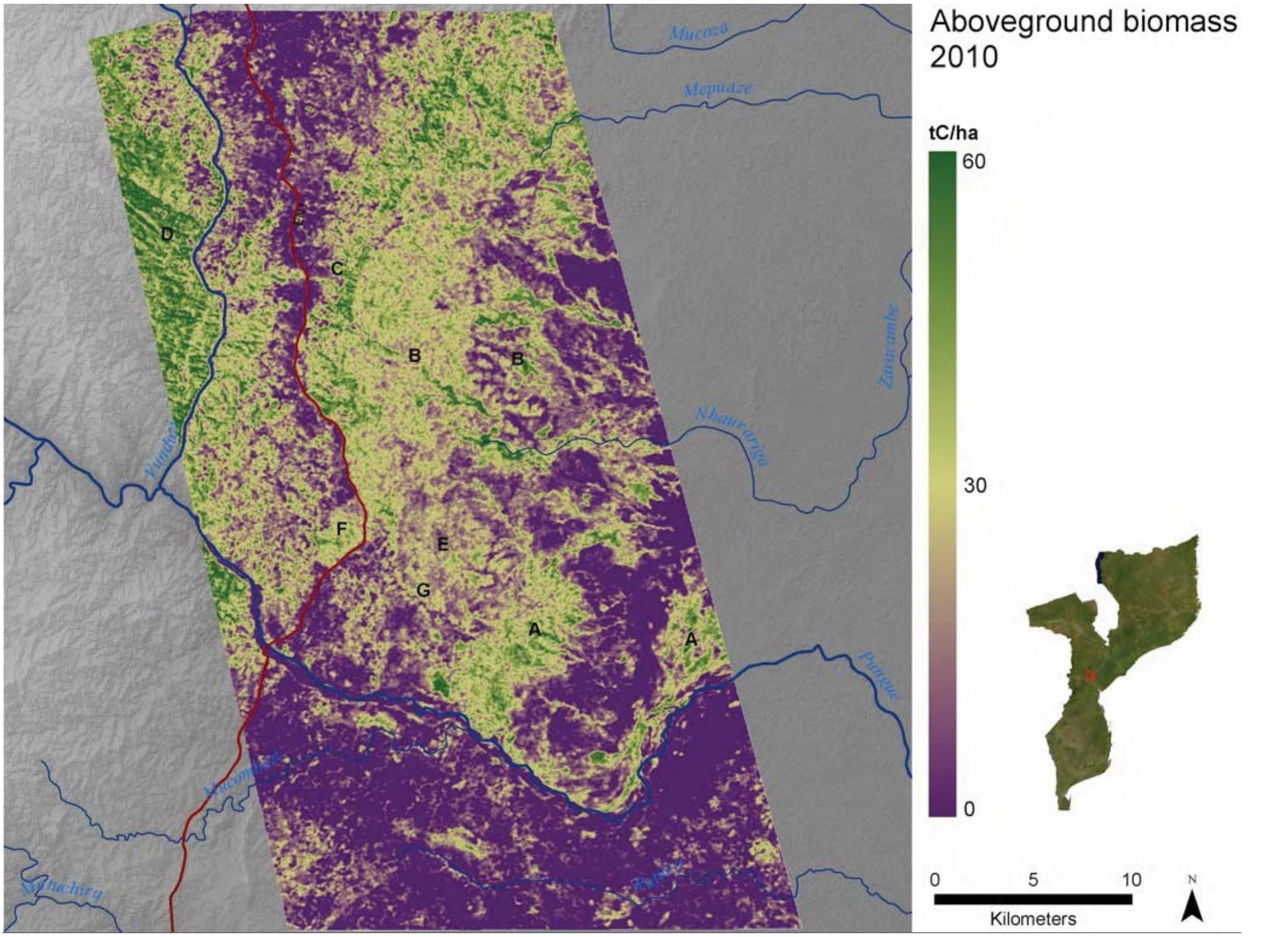
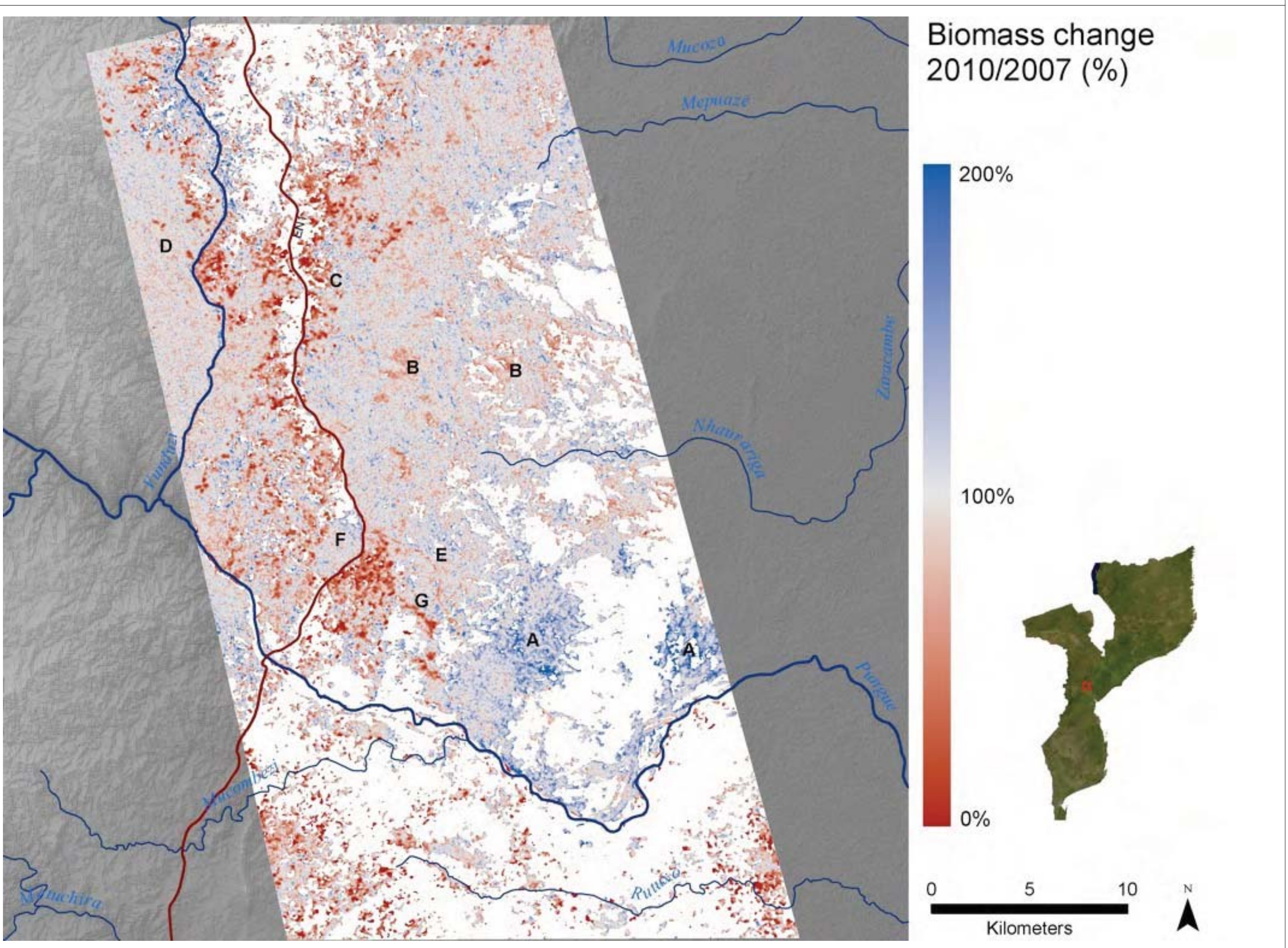



Aboveground biomass
2010
tC/ha
60
30
0
Mucoza
Mepuaze
Pungue
D
C
B
B
F
E
G
A
A
0
5
10
Kilometers
N


Biomass change
2010/2007 (%)
200%
100%
0%
Mucoza
Mepuaze
Pungue
D
C
B
B
F
E
G
A
A
0
5
10
Kilometers
N

DEFORESTATION AND DEGRADATION

- Over all the study area loss of 6.9±4.6 % of AGB in three years

	2007	2010	Δ
TgC	2.13±0.12	1.98±0.11	-0.15±0.10

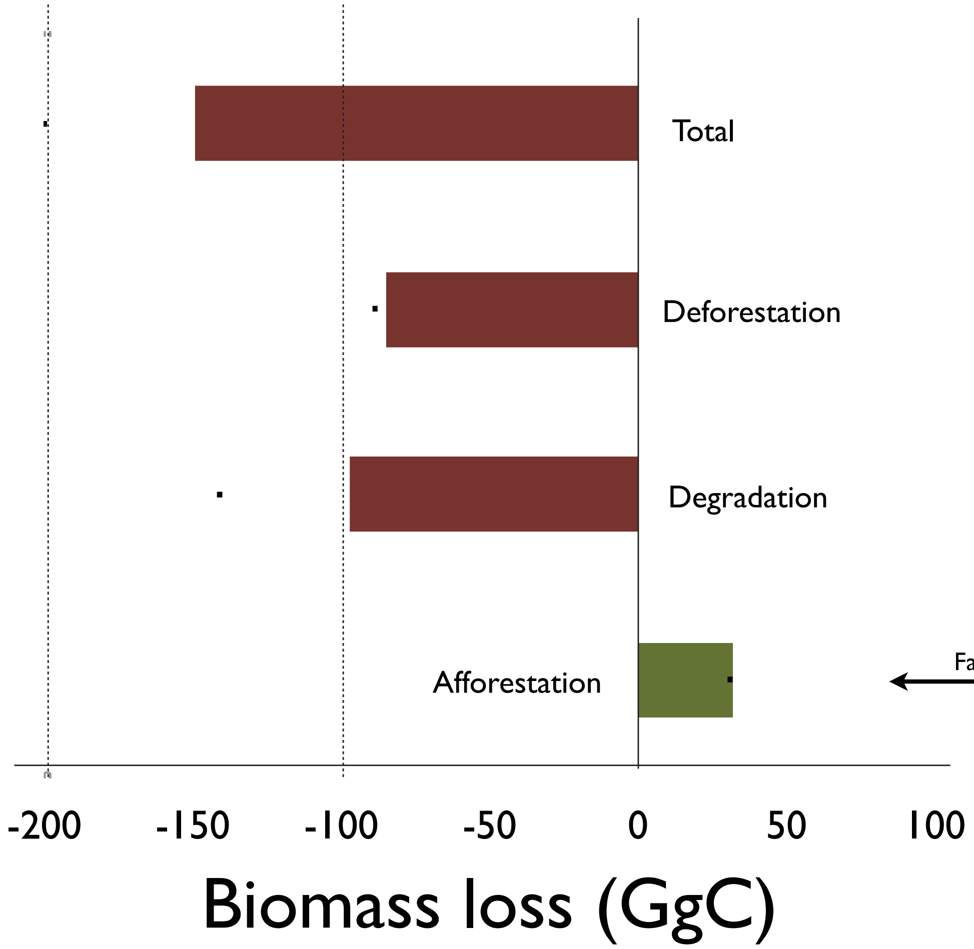
- But is this from deforestation or degradation?
- (need a 'forest' threshold, e.g. 15 tC/ha)
- Errors from bootstraping i.e randomly sampling 1/2 the regression data, and recalculating stocks and changes 30,000 times

DEGRADATION *VS* DEFORESTATION

- Definitions: forest is land > 15tC/ha *
- Deforestation is forest--> non-forest

		2007	
		Forest	Non-Forest
2010	Forest	Forest De/aggradation	Afforestation
	Non-Forest	Deforestation	Non-Forest De/aggradation

* for discussion. How do we link this to existing definitions?



errorbars show 1 standard deviation from the 30,000 bootstraps

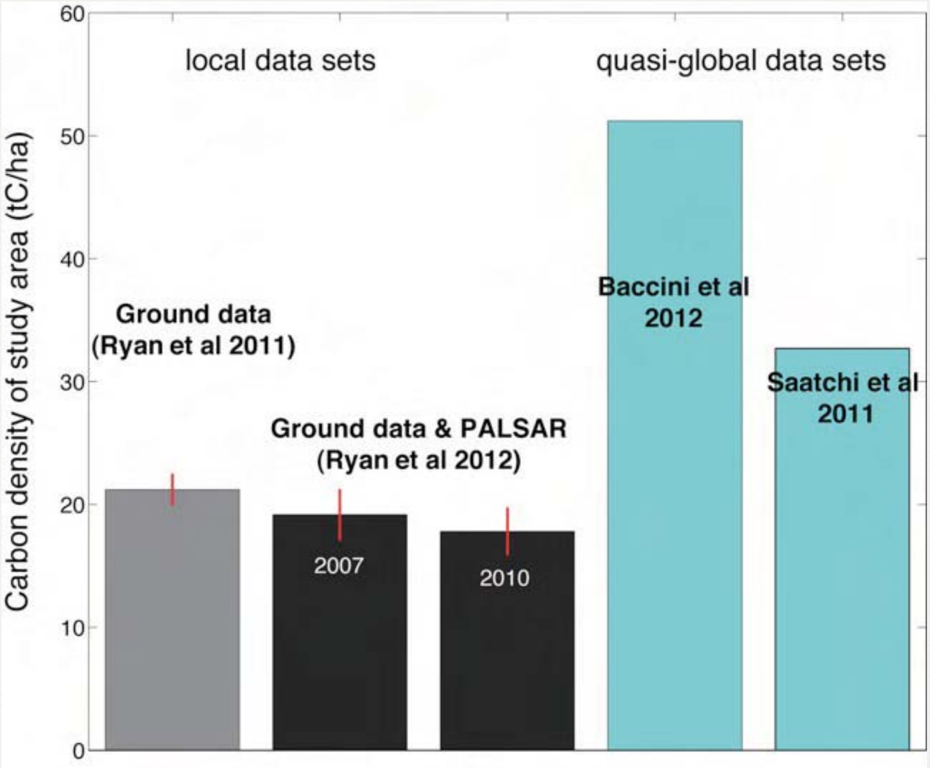
Ryan et al (2012) GCB

KEY FINDINGS

- Degradation loss ~= Deforestation loss
- Degradation uncertain
- Small clearances accreting over time - challenge for monitoring
- Biomass PDF has info on land use change? (Hill et al 2012)

BIOMASS STOCKS: COMPARISON

- Comparison over whole scene
- 1100 km^2
- NB: Dates different



Red lines show 95% CI

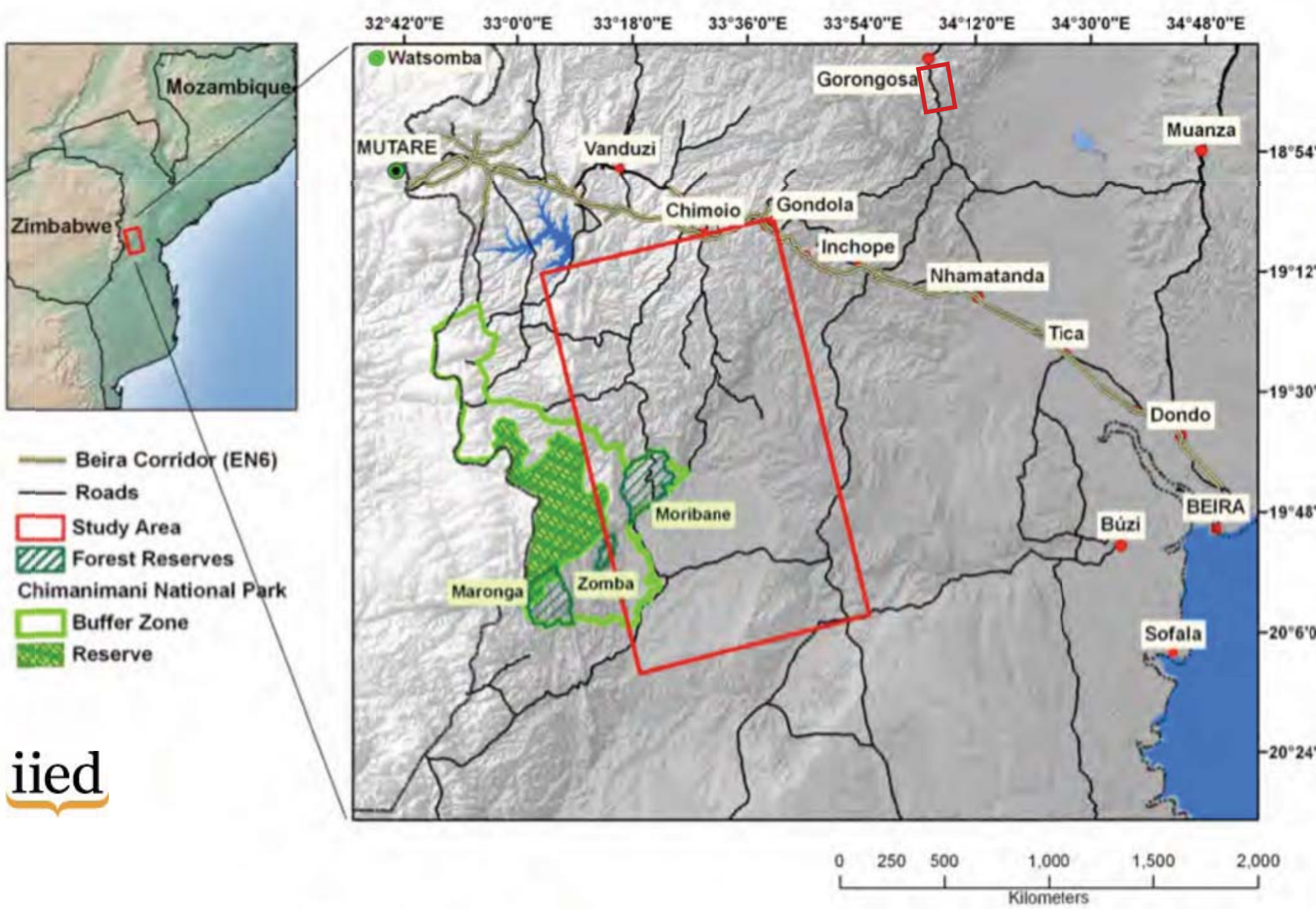
Hill et al, in prep

LIMITATIONS OF THE APPROACH

- Topographic correction needs good DEM
- Environmental effects need to be controlled for (regularly updated ground data)
- Detecting gradual change remains uncertain
- Saturates at high biomass
- Backscatter responds to stocking density, basal area **and** biomass. Brolly et al (2012)
- Availability of data

UNDERSTANDING THE CAUSES OF FOREST LOSS

- Moving from estimates of land cover change to land use change
- Goal: to utilise these hi-res change maps to quantify the causes of deforestation and degradation



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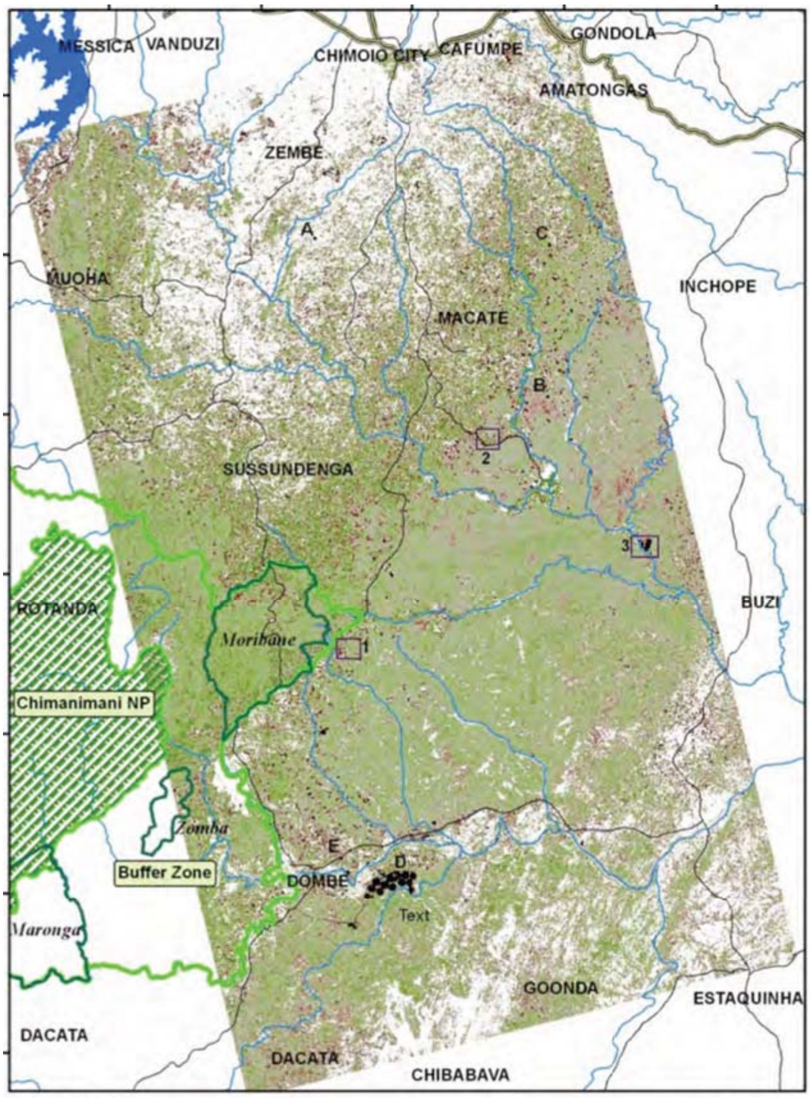
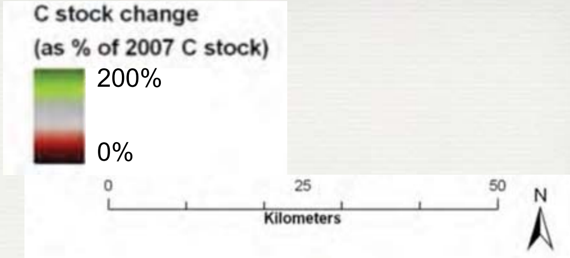
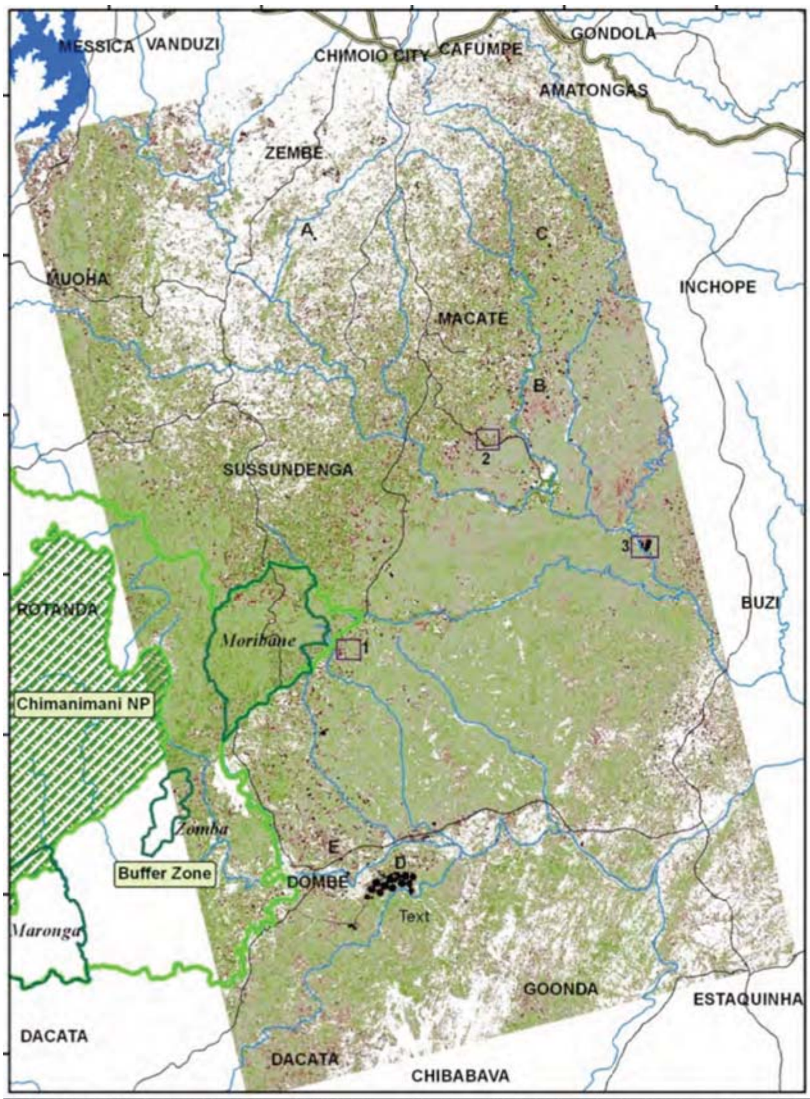
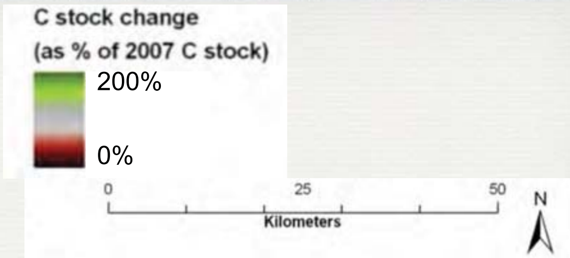
Joshi and Ryan, in revision, 2012

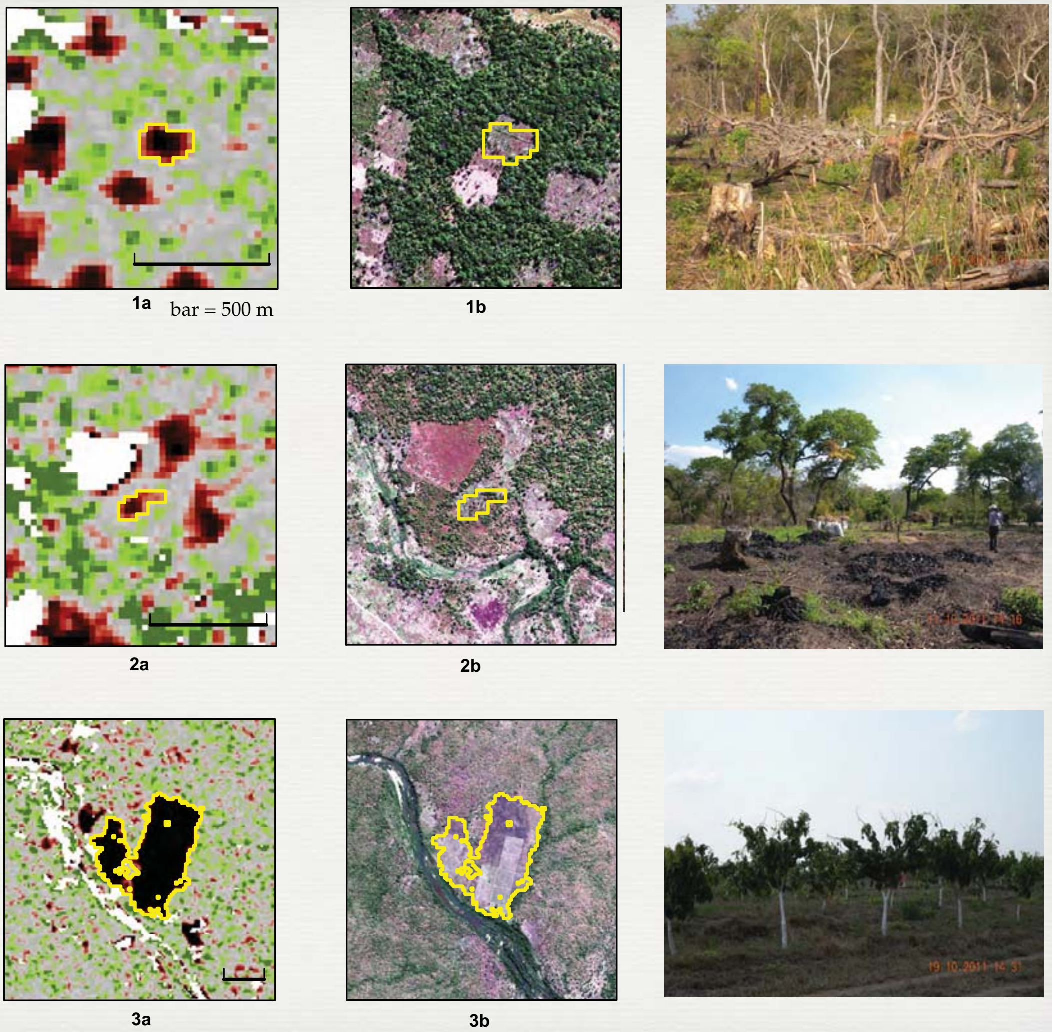


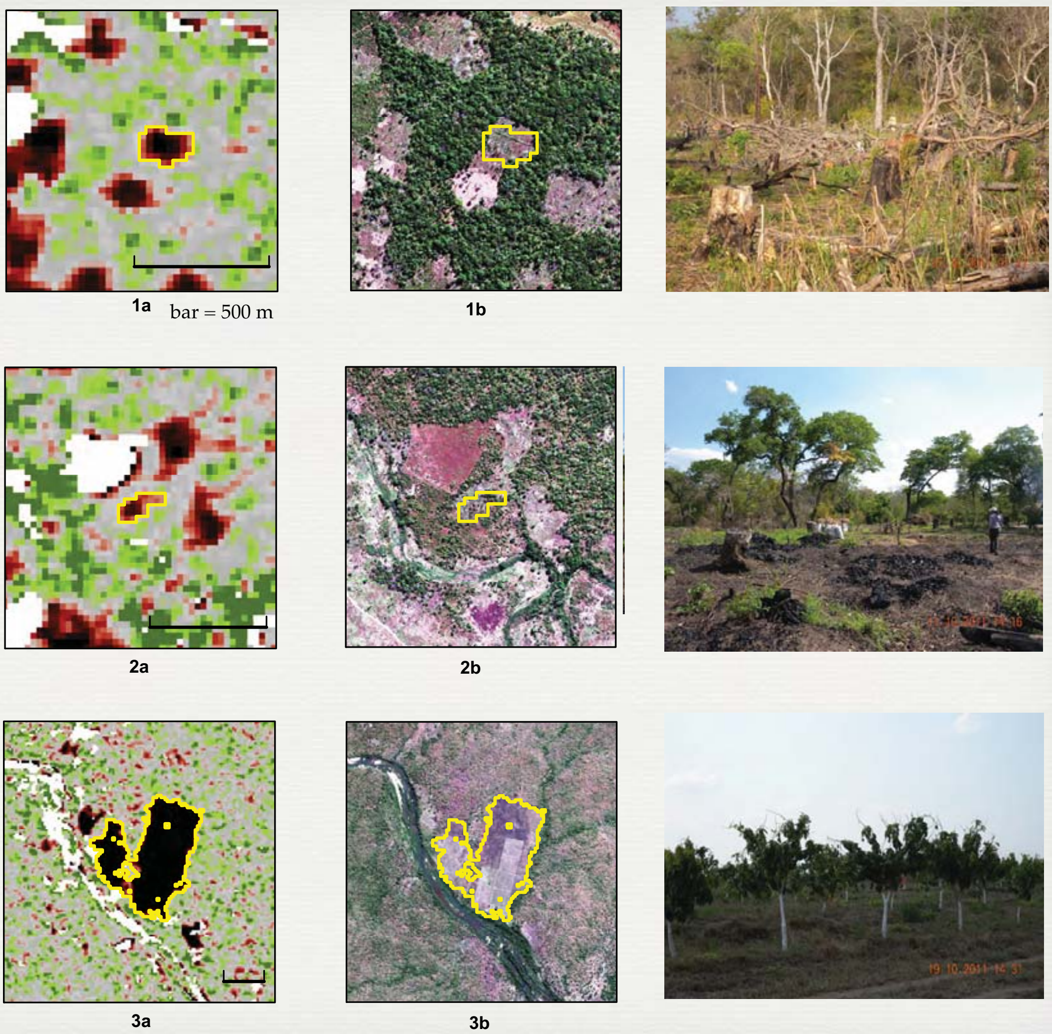




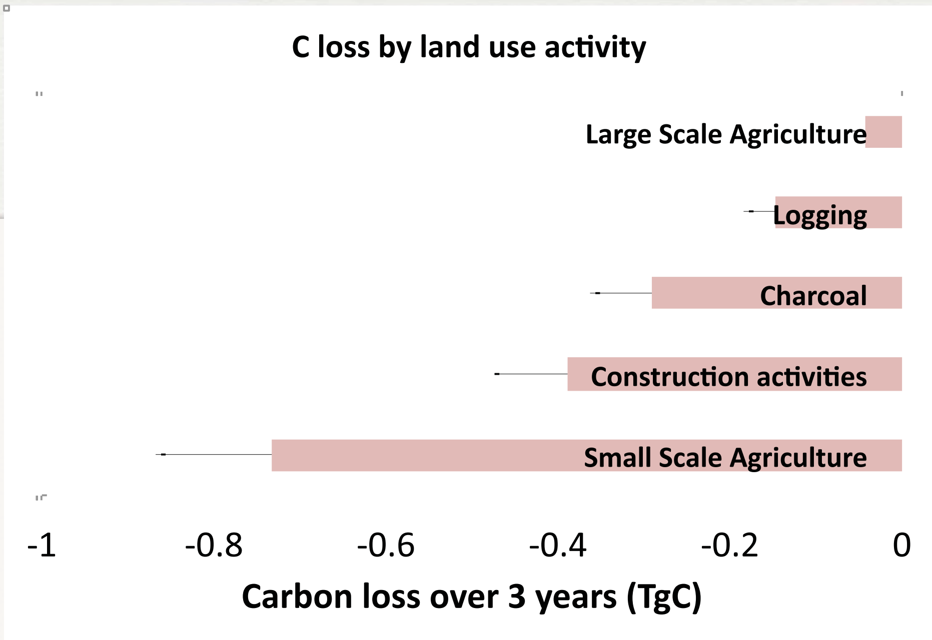


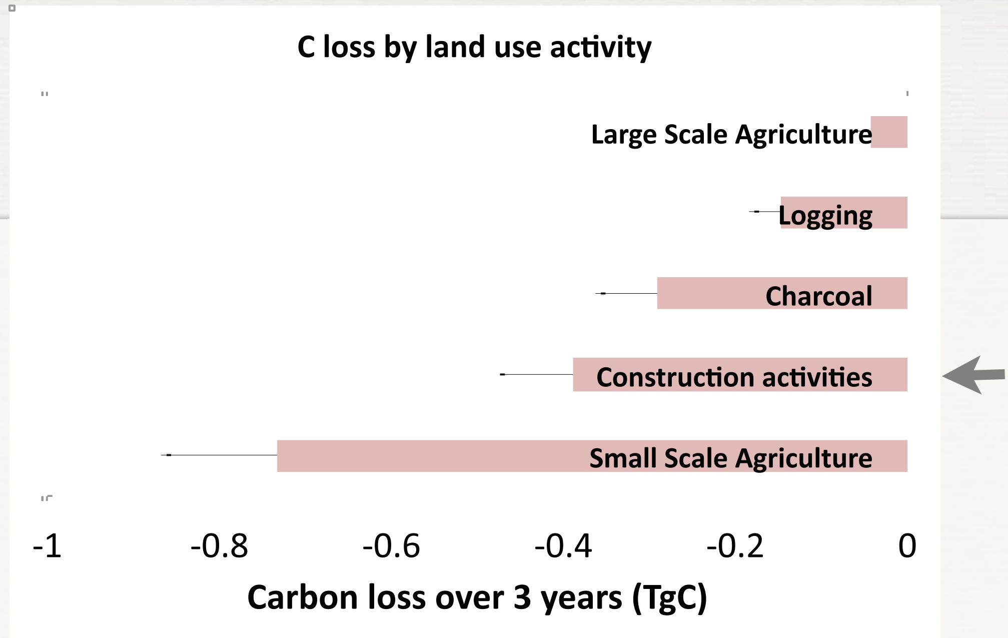
- Create discrete events
- Random sample (stratified by area, dist from rd, and intensity of loss)
- Visited $n = 76$
- Identify land use activities





- Small Scale Agriculture
- Construction activities
- Charcoal
- Logging
- Large Scale Agriculture
- Unknown


C loss by land use activity
Large Scale Agriculture
Logging
Charcoal
Construction activities
Small Scale Agriculture
-1
-0.8
-0.6
-0.4
-0.2
0
Carbon loss over 3 years (TgC)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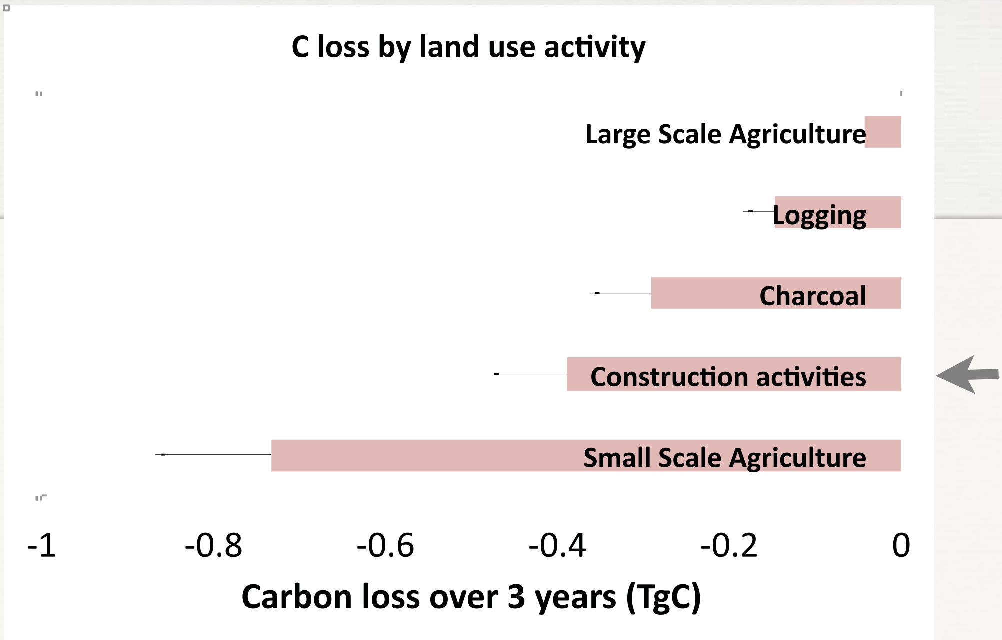


- Biomass loss rate: -2.8±2.0 %/yr, much higher than past estimates of *forest area* loss (0.75 %/yr)
- 50:50 split small scale agriculture vs all other activities
- 50:50 deforestation vs degradation
- Uncertainty on regrowth and fire

KEY FINDINGS

Stocks

- ALOS PALSAR is a useful tool for biomass estimation in woodlands, despite variations caused by e.g soil moisture
- Needs extensive ground data. Terrain correction can be a challenge.
- 'Plot&PALSAR' estimates are quite different from current global data sets. (How well do we understand the errors on both?)

Stock Changes (2007-10)

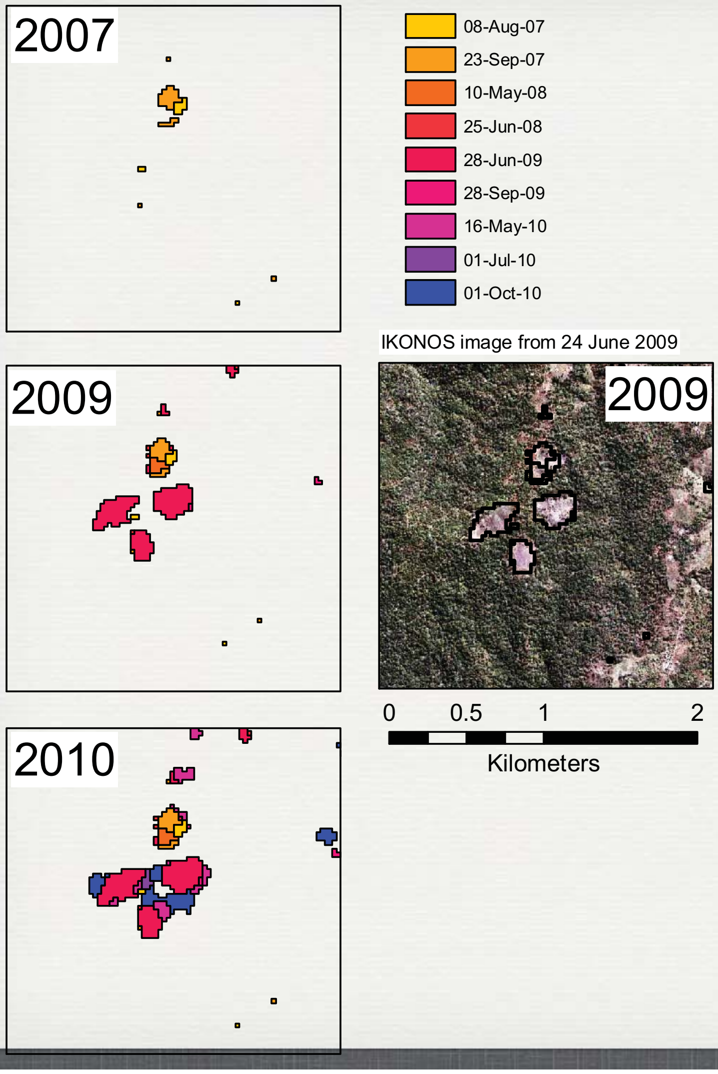
- Can detect sig. changes over 3 years. Much higher *biomass loss* rates than currently assumed *forest area* loss rate (x2-3): Degradation ~= deforestation losses
- EO data can be linked to ground-based observations of the activities causing forest loss: e.g. small scale agriculture = ~50% of losses.

SOME ISSUES:

1. How can we use targeted, detailed studies at a national scale? i.e
   - upscale deforestation : degradation ratio?
   - Understand processes causing forest loss (future scenarios / baselines)
2. Can we map larger areas accurately given data scarcity?
3. Inventory design: Different requirements for plot-based studies *vs* EO cal / val
4. Forest definitions (sigh!). Unclear how to link current definitions to carbon density.

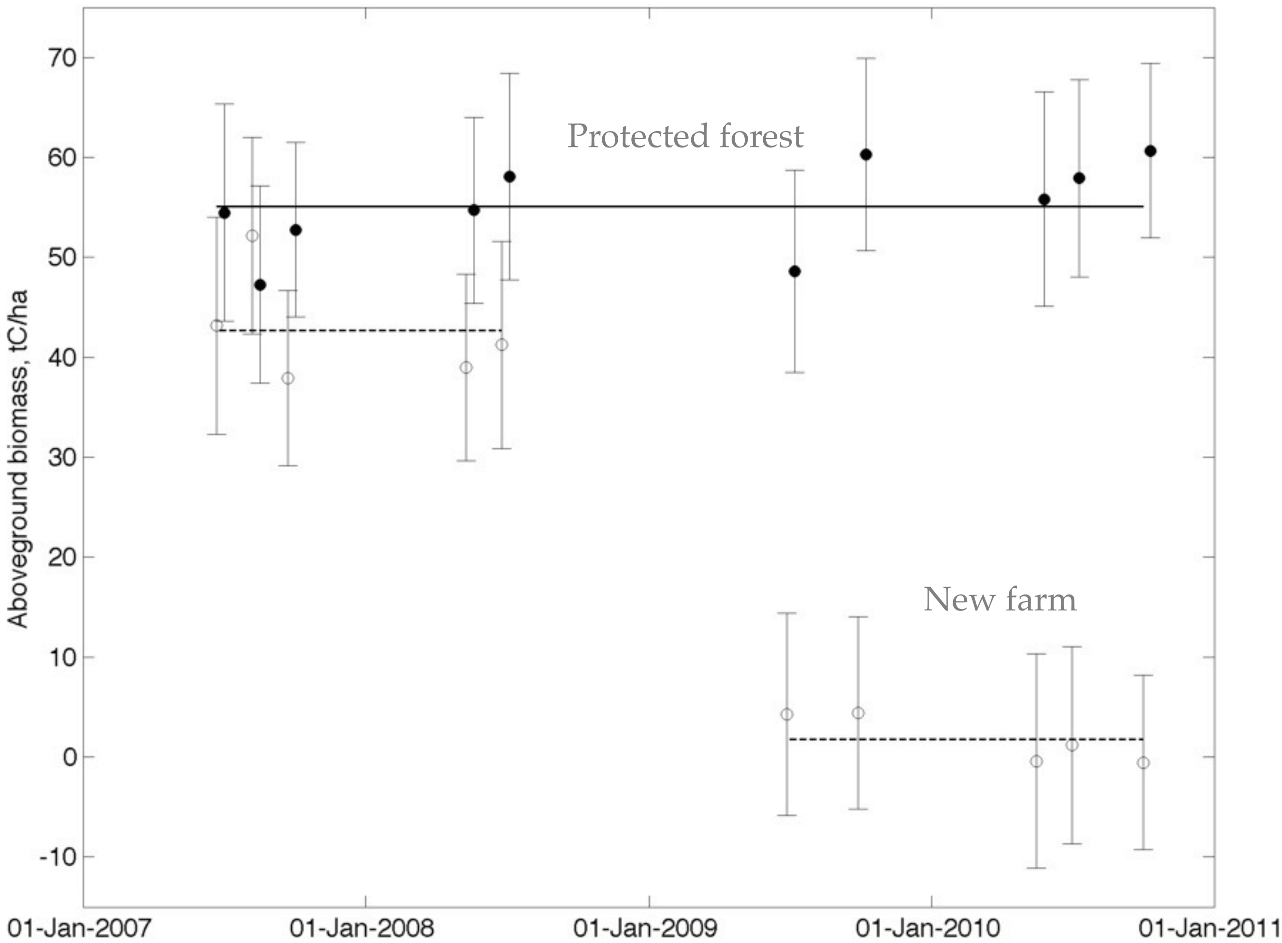
NATURAL ENVIRONMENT RESEARCH COUNCIL · esa · Miombo Conservation & Development Initiative · LTS INTERNATIONAL · iied

- **EO**
- Ryan, C. M., T. Hill, E. Woollen, C. Ghee, E. Mitchard, G. Cassells, J. Grace, I. H. Woodhouse and M. Williams (2012). "Quantifying small-scale deforestation and forest degradation in African woodlands using radar imagery." Global Change Biology 18(1): 243-257.
- Joshi, N. and C. M. Ryan (2012). "The causes of deforestation and degradation in African woodlands: a method for their quantitative assessment and a case study from central Mozambique." Journal of Applied Geography In review.
- Hill, T., M. Williams and C. M. Ryan (2012). "Estimating and characterising above ground forest disturbances using radar.." In review.
- Williams, M., T. C. Hill and C. M. Ryan (2012). "Using biomass distributions to determine probability and intensity of tropical forest disturbance." Plant Ecology and Diversity in press.
- **Stocks**
- Woollen, E., C. Ryan and M. Williams (2012). "Carbon Stocks in an African Woodland Landscape: Spatial Distributions and Scales of Variation." Ecosystems 15(5): 804-818.
- Ryan, C. M., M. Williams and J. Grace (2011). "Above- and Belowground Carbon Stocks in a Miombo Woodland Landscape of Mozambique." Biotropica 43(4): 423-432.
- Ryan, C. M. and M. Williams (2011). "How does fire intensity and frequency affect miombo woodland tree populations and biomass?" Ecological Applications 21(1): 48-60.
- Williams, M., C. M. Ryan, R. M. Rees, E. Sambane, J. Fernando and J. Grace (2008). "Carbon sequestration and biodiversity of re-growing miombo woodlands in Mozambique." Forest Ecology and Management 254(2): 145-155.
- Furley, P. A., R. M. Rees, C. M. Ryan and G. Saiz (2008). "Savanna burning and the assessment of long-term fire experiments with particular reference to Zimbabwe." Progress in Physical Geography 32(6): 611-634.

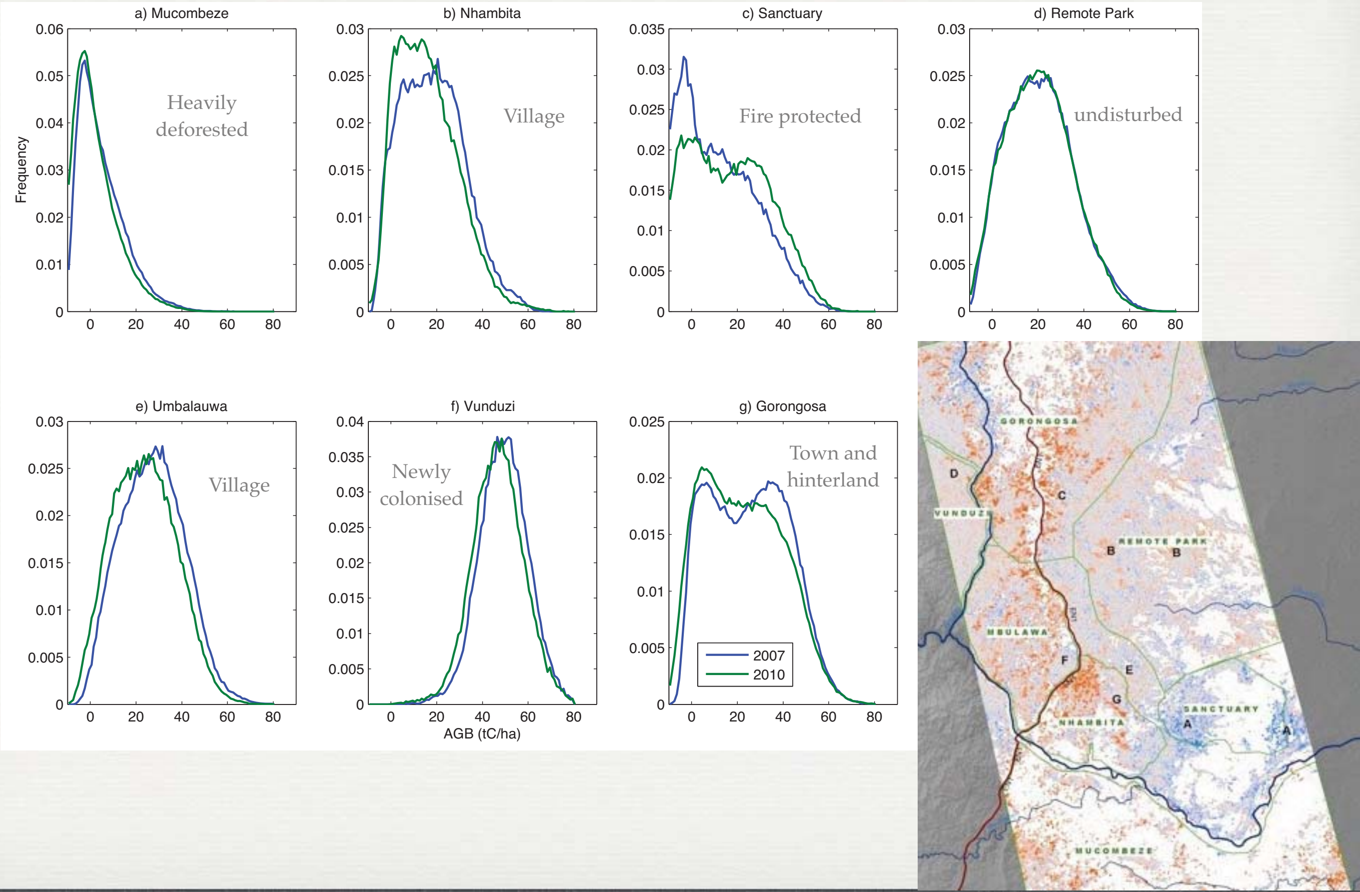


Accuracy assessment:

- False positive rate: < 0.01%
- Hit rate: 65% of pixels, 89% of events



SPATIAL DISTRIBUTIONS AND LAND USE



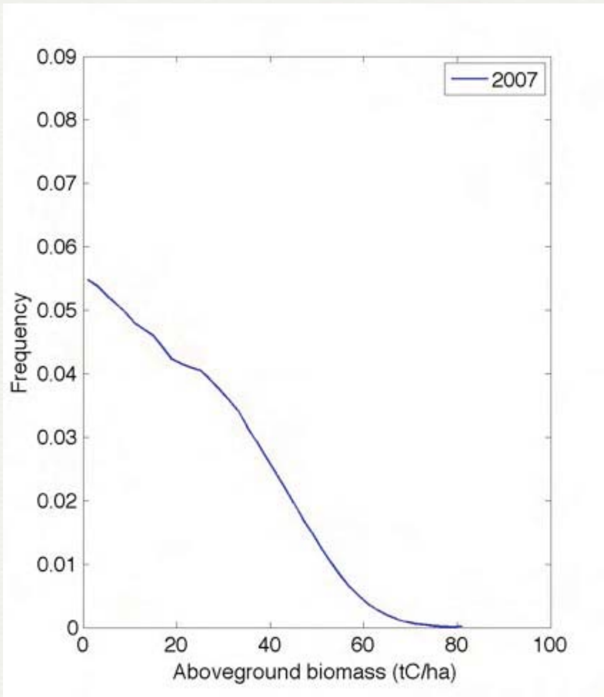
RESULTS

But:

- Deforestation can't happen on already cleared land
- Detection of deforestation may be easier at high biomass

So:

- Restrict to areas of "forest" (>20tC/ha)
- compare observations to a pseudo data set where H_0 is true



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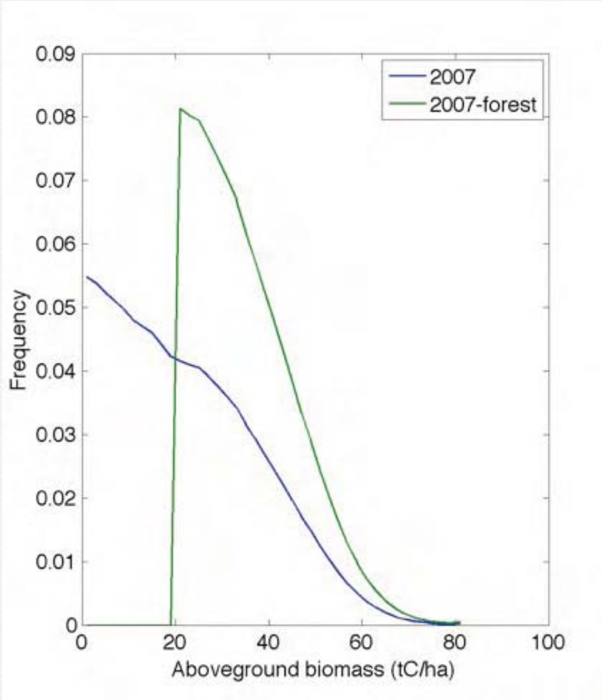

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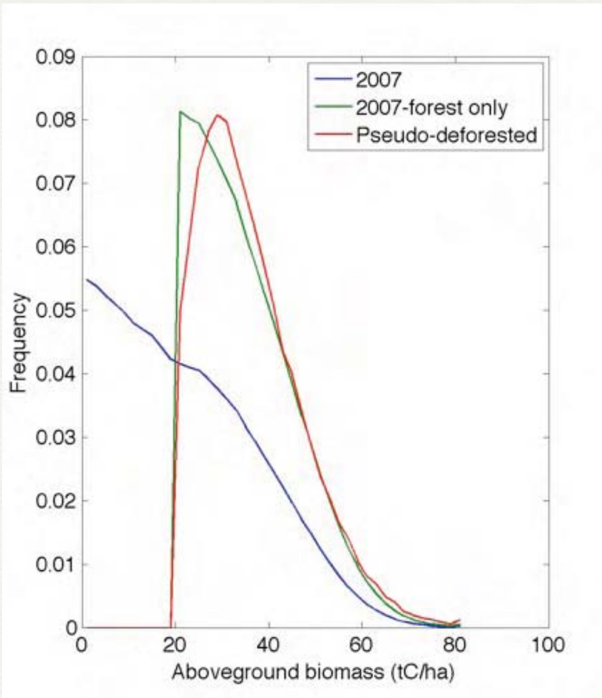

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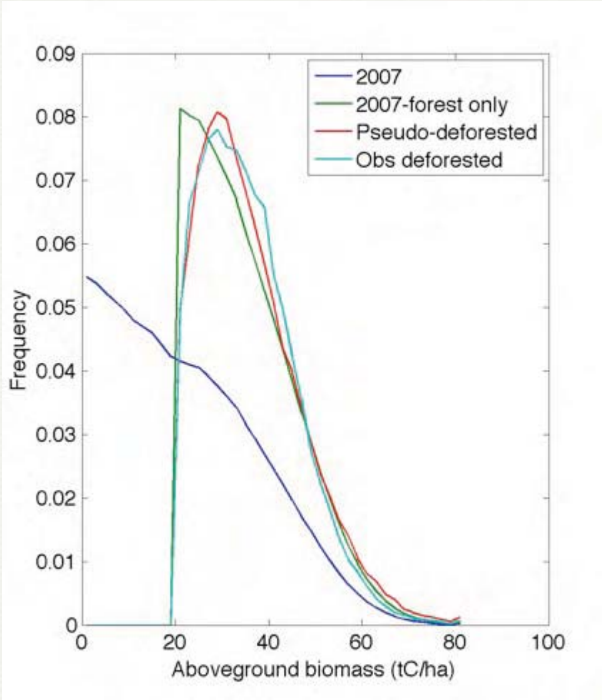

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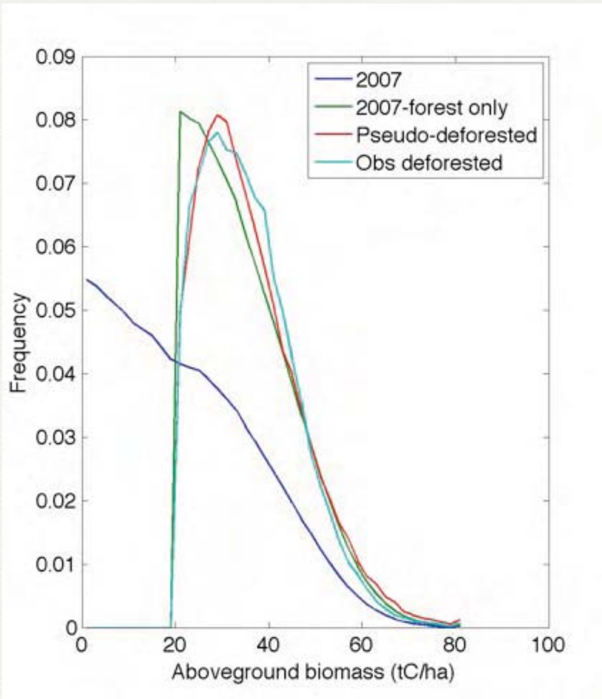
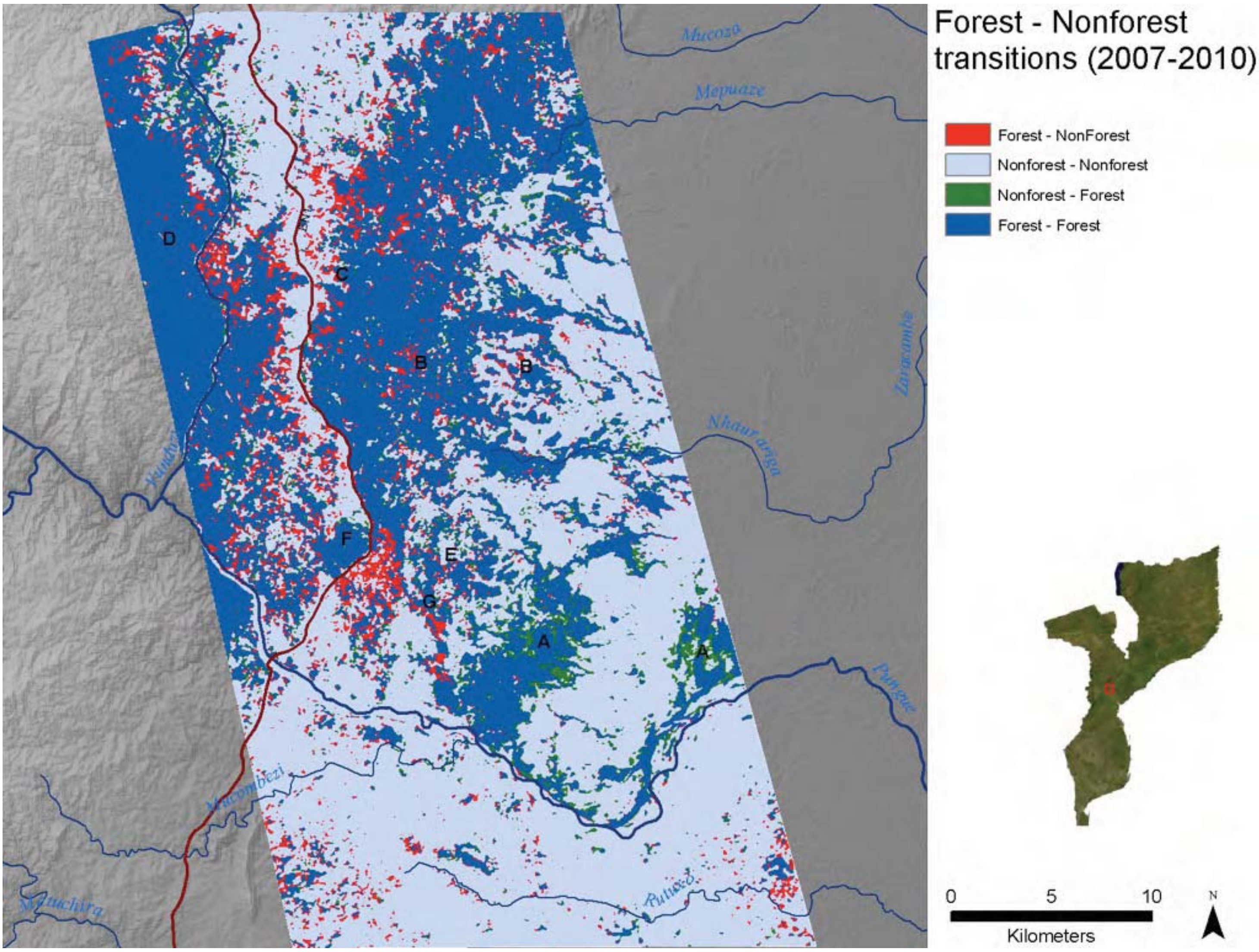
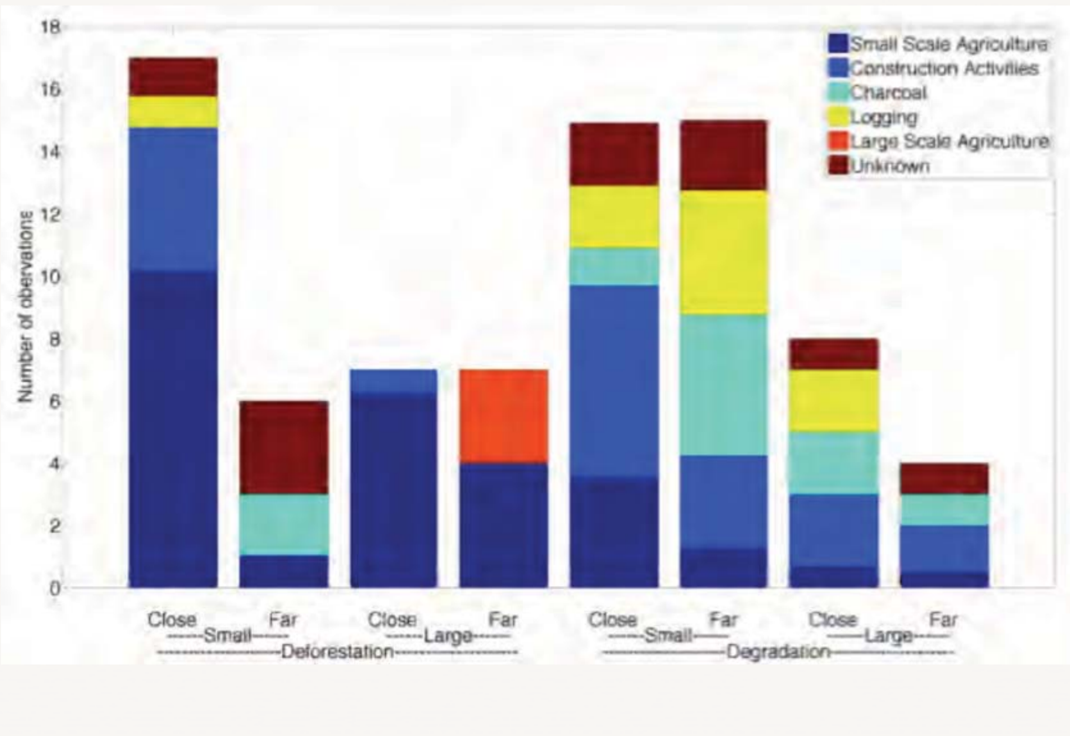
- compare observations to a pseudo data set where H_0 is true
- <1tC/ha difference between deforested land and comparable surounds





RESULTS: GROUND DATA



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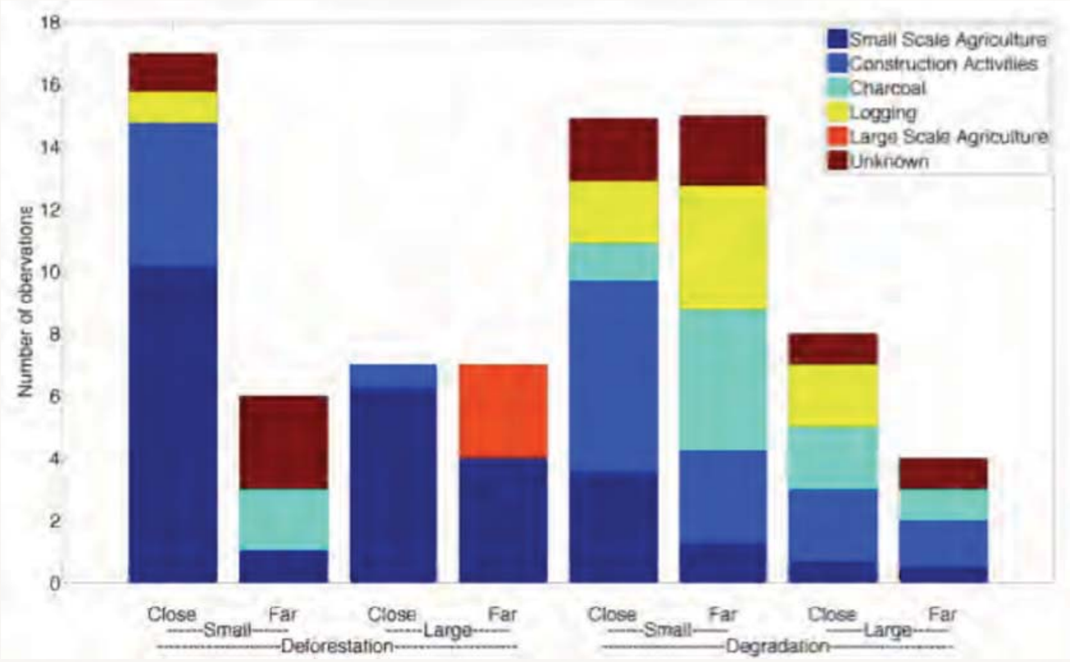

Deforestation:
mainly agriculture

Degradation:
many causes

RESULTS

	Area (km²)	ΔC GgC ± SD	% of total
Deforested	73	-84.8±9.7	35%
Afforested	47	32±4.1	
Forest Degradation	424	-55.3±79.9	65%
Non-Forest Degradation	615	-41.7±34.8	
Total	**1159**	**-149±100**	**100%**