Integrated Carbon Sequestration Project
2-day training course – 1st and 2nd of April 2019
Khartoum – Sudan

Introduction to forest carbon inventory, GHG reporting and MRV

	Monday, 1st of April	Tuesday, 2nd of April
am	**INTRODUCTION**: presentation of participants and their expectations; presentation of objectives and agenda Presentation **#1: CONTEXT** – United Nations Framework Convention on Climate Change (UNFCCC) context and requirements, and introduction to Intergovernmental Panel on Climate Change (IPCC) guidelines Presentation #**2: MONITORING OF LAND USE CHANGE** - Monitoring Activity Data (AD) for forest-related Land Use Change (LUC) Quiz	Presentation **#5: ESTIMATING GHG** - UNFCCC context and requirements, and introduction to IPCC guidelines Presentation #**6: ESTIMATING UNCERTAINTIES** - Identifying and minimizing uncertainties (lack of precision and/or accuracy) Quiz
	Lunch break	Lunch break
pm	Presentation **#3: MONITORING OF DEGRADATION** - Monitoring Activity Data (AD) for forests remaining forests Presentation **#4: ESTIMATING EMISSION FACTORS** - Estimating Emission Factors (EFs) for Land Use, Land Use Change, and Forestry (LULUCF) activities Quiz	Presentation **#7: REPORTING OF GHG** - Reporting LULUCF performance using IPCC 2003 Good Practice Guidance for LULUCF and 2006 Agriculture, Forestry and Other Land use (AFOLU) Guidelines Quiz **DEBATE**: Way forward to design and implement a LULUCF inventory in Sudan? **CLOSING**: Satisfaction questionnaire, evaluation of achievement of participants' expectations

ACRONYMS

AD	Activity Data
AFOLU	Agriculture, Forestry, and Other Land Use
AGB	Above Ground Biomass
BGB	Below Ground Biomass
BUR	Biennial Update Report
C	Carbon
CO_2	Carbon Dioxide
COP	Conference of the Parties of the UNFCCC
DBH	Diameter at Breast Height
EF	Emission Factor
ELE	Extracted Log Emissions
FAO	Food and Agriculture Organization (United Nations)
FCPF	Forest Carbon Partner Facility (World Bank)
FR(E)L	Forest Reference (Emission) Level
GFOI	Global Forest Observation Initiative
GHG	Greenhouse Gas
GOFC-GOLD	Global Observation of Forest Cover - Global Observation of Land Dynamics
GPG	Good Practice Guidance
ICA	International Consultation and Analysis
IPCC	Intergovernmental Panel of experts on Climate Change
JRC	Joint Research Centre (European Commission)
KP	Kyoto Protocol
LANDSAT	Land Satellite (US satellite series)
LDF	Logging Damage Factor
LIF	Logging Infrastructure Factor
LULUCF	Land Use, Land Use Change, and Forestry
MRV	Measuring, Reporting and Verification
NDFI	Normalized Differencing Fraction Index
NFI	National Forest Inventory
NFMS	National Forest Monitoring System
NPV	Non-Photosynthetic Vegetation
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
RSS	Remote Sensing Survey
SBSTA	Subsidiary Body for Scientific and Technological Advice of the UNFCCC
SOP	Standard Operation Procedure
UNFCCC	United Nations Framework Convention on Climate Change

CREDITS

Elements compiled in the training manual are sourced from diverse SalvaTerra's studies, but also from the "*MRV REDD+ Training Materials*" produced by GOFC-GOLD, Wageningen University, World Bank FCPF (and licensed under a Creative Commons Attribution-NoDerivatives 4.0 International License).

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SUMMARY

Page

1 CONTEXT

UNFCCC context and requirements, and introduction to IPCC guidelines

After the course the participants should be able to:

- Understand the UNFCCC context and requirements for monitoring and reporting of REDD+ activities
- Explain fundamental concepts of the IPCC guidelines for national GHG inventories and for reporting on forest-related activities

GHG	*Greenhouse Gas*
IPCC	*Intergovernmental Panel on Climate Change*
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*
UNFCCC	*United Nations Framework Convention on Climate Change*

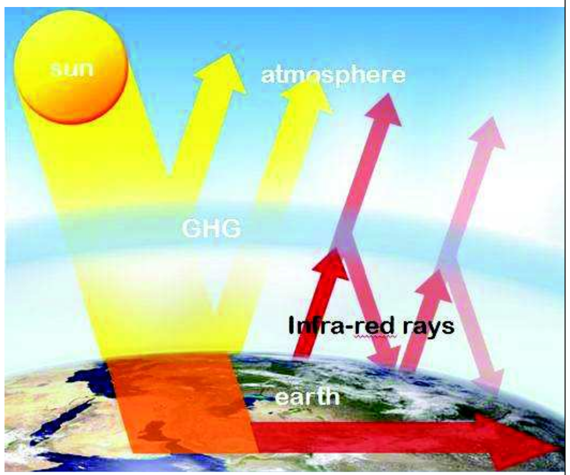
CONTEXT

1. **Introduction to UNFCCC REDD+ process**
2. UNFCCC context and requirements for measurement and reporting of REDD+ activities
3. IPCC guidelines for national GHG inventories and reporting for forest land
   a. Reporting principles
   b. Estimation of GHG emissions/removals

Tropical forests and climate change

Tropical forests store significant amounts of carbon in above- and belowground biomass, dead wood, litter, and soil.

Deforestation impacts global GHG emissions by massively releasing carbon dioxide (CO_2) to the atmosphere, as well as CH_4 and N_2O(biomass burning, soil oxidation, etc.)



GHG emissions by economic sectors in 2010

Electricity and Heat Production 25%

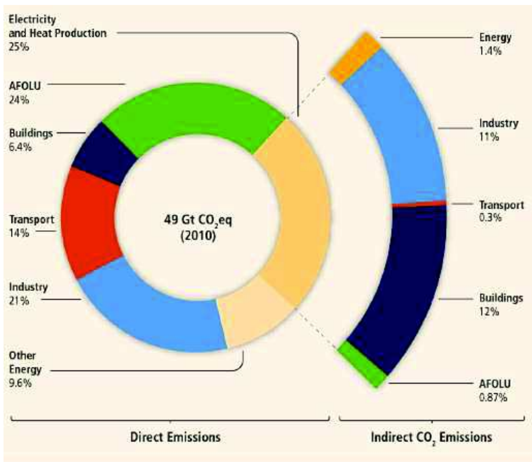
AFOLU 24%

Buildings 6.4%

Transport 14%

Industry 21%

Other energy 9.6%



Energy 1.4%

Industry 11%

Transport 0.3%

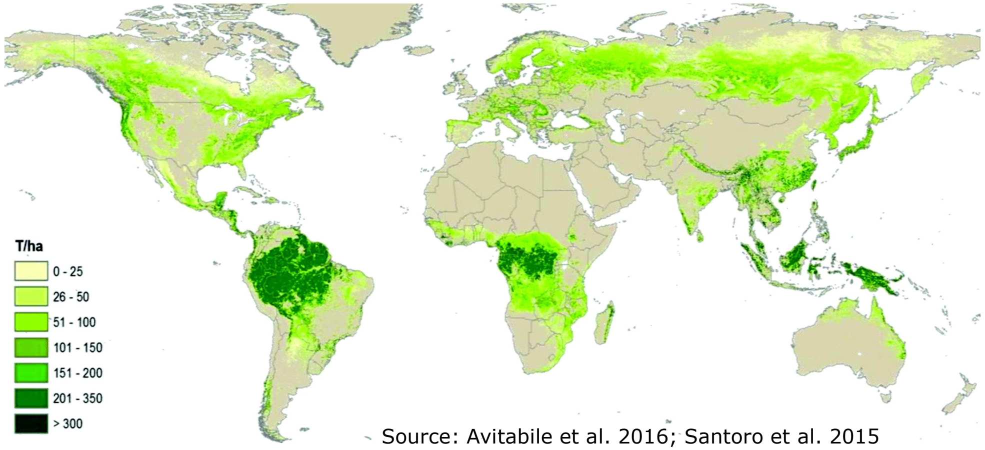
Buildings 12%

AFOLU 0.87%

Source: IPCC, 2014

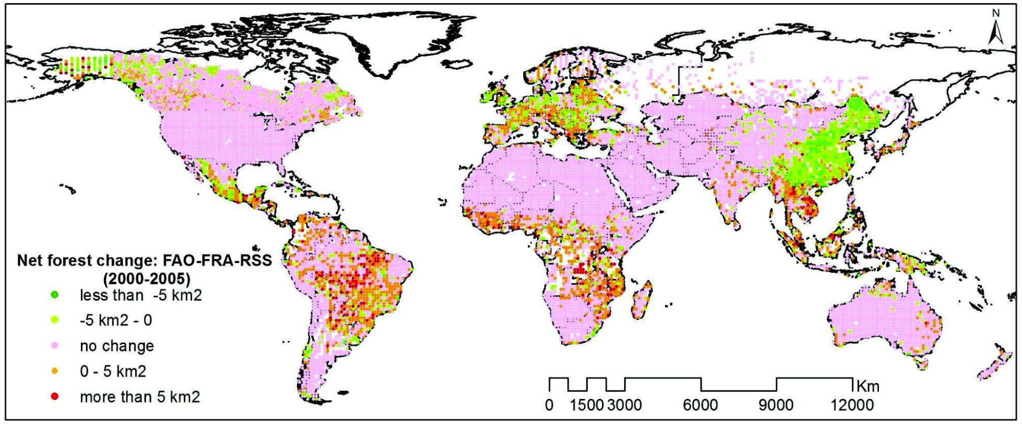
AFOLU: Agriculture, Forestry and Other Land Use
Indirect GHG emissions: electricity and heat production are attributed to sectors of final energy use

Distribution of Aboveground forest Biomass (AGB)



Source: Avitabile et al. 2016; Santoro et al. 2015
http://lucid.wur.nl/

Deforestation & afforestation, 2000–2005



Source: FAO & JRC 2012

JRC: Joint Research Centre (of the European Commission)
RSS: Remote Sensing Survey

Mitigation of CC and forests in DCs: REDD+

- UNFCCC, Cancun Agreements on REDD+ (Dec.1/CP16, 2010)
  "Policy approaches and positive incentives on issues relating to Reducing Emissions from Deforestation and forest Degradation in DCs; and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in DCs"

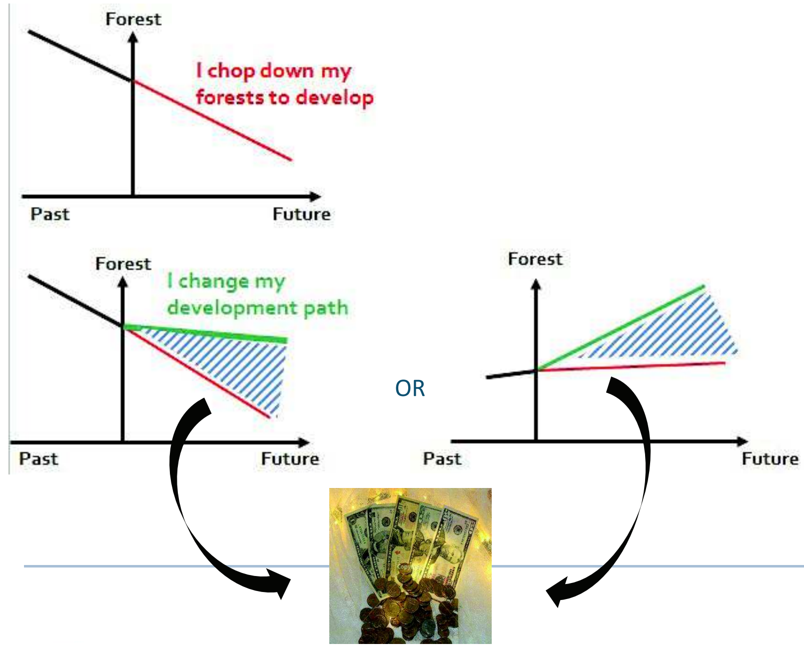
- Following activities are included:
  - Reducing emissions from **deforestation**
  - Reducing emissions from **forest degradation**

  } **REDD**

  - **Conservation** of forest carbon stocks
  - **Sustainable management** of forest
  - **Enhancement** of forest carbon stocks

  } **+** ICSP

In other words…



Milestones of the REDD+ mechanism

2005 **COP11 Montreal** RED discussions started. Papua New Guinea and Costa Rica asked for new agenda item: "*Reducing emissions from deforestation in developing countries: Approaches to stimulate action*."

2007 **COP13 Bali** Bali Action Plan was provided, in which the RED concept was broadened to REDD+ (pressure of China, India, and Congo Basin).

2009 **COP15 Copenhagen** Methodological guidance for REDD+ activities was developed.

2010 **COP16 Cancun** Cancun Agreements were established, including policy approaches and positive incentives on issues relating to REDD+.

2013 **COP19 Warsaw** REDD+ package was developed, including modalities for establishing NFMS, MRV, FR(E)L and addressing safeguards

FR(E)L : Forest Reference (Emission) Levels
MRV: Measuring, Reporting, and Verification
NFMS : National Forest Monitoring Systems

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The Paris Agreement (1/CP.21, 2015) (1/2)

- A new legally-binding framework for an **internationally coordinated effort to tackle climate change** that replaces the Kyoto Protocol.
- Overall goal: to hold increase in global average temperature **well below 2°C** on pre-industrial levels and to reach global peaking as soon as possible.
- Countries have to formulate their adaptation and mitigation measures in **Nationally Determined Contributions (NDCs)**, to be updated every five years.
- **REDD+ action and support** need to be included in the NDCs.

The Paris Agreement (1/CP.21, 2015) (2/2)

- Parties have to **provide information** to track progress made in implementing their NDCs and keep track of their emissions in **National Inventory Reports (NIR)**
- Information submitted will undergo a **technical expert review**.
- **Global stocktaking** takes place every five years ➔ Is collective mitigation action (as expressed in NDCs) consistent with meeting the 1,5°C / 2°C target?

Specificities for REDD+

- Parties should collectively aim to **slow, halt, and reverse forest cover loss and carbon loss**, thereby addressing the five REDD+ activities.
- Participation is voluntary and in accordance with respective **capacities and national circumstances**.
- **Performance-based payments** are based on the difference between actual forest emissions and a FR(E)L, which requires:
  - Methodologies to estimate actual emissions and removals
  - Establishment of a FR(E)L with the same coverage of emissions and removals
- REDD+ results-based actions should be **Measured, Reported, and Verified (MRV)**

UNFCCC guidance on REDD+ activities

Developing country parties are requested to develop:

- A **National Strategy or Action Plan** (including ways to address drivers of deforestation and forest degradation and ensuring safeguards)
- A robust and transparent **National Forest Monitoring System (NFMS)**
- A **national FR(E)L**, based on data provided by the NFMS
- A **System for providing Information on the Safeguards (SIS)**, respecting the role of local people and ecosystems

REDD+ phased approach

Countries may follow a phased approach for implementing REDD+ in steps, which allows them to gradually build capacities and acquire data

Implementation phase		Characteristics	MRV activities
Phase 1	Readiness	National strategy or action plan formulation, development of policies and measures and capacity building	Capacity-development needs; Roadmap, including for MRV
Phase 2	Transition, implementation, and capacity building	Implementation of national policies and measures and national strategies or action plans (further capacity building); technology development and transfer and results-based demonstration activities	Demonstration activities; Design of the MRV system, pilot test and upscaling
Phase 3	Full implementation	Implementation of national policies and measures on the whole national territory; results-based actions that should be fully measured, reported, and verified	national performance monitoring system; Fully operational MRV system to report REDD+ mitigation performance in CO_2eq

CO_2eq: Different Global Warming Potentials (GWPs)… → 1 tCH_4 = 21 tCO_2eq, 1 tN_2O = 310 tCO_{2eq}

Modalities for FR(E)L (12/II CP.17 and Annex)

- **Benchmarks** for assessing each country's performance. Fr(E)L are:
  - Expressed in **tCO_2eq** per year
  - **Consistent** with anthropogenic forest-related GHG emissions and removals from the **GHG inventories**
- They should be **transparent**, taking into account **historical data** and **adjusting** for national circumstances.
- They may be **improved** over time, incorporating better data, improved methodologies, and/or additional carbon pools.
- Submission of a FR(E)L is subject to a **technical assessment**.

Modalities for MRV of REDD+ (14/CP.19)

- Results (reduced emissions and/or increased removals) are expressed in **tCO_{2eq}** per year, consistent with the FR(E)L
- Data and methodologies may be **improved** over time, while maintaining consistency with FR(E)L.
- Data and information should be provided through **Biennial Update Reports (BURs)** by Parties that include:
  - Summary information on assessed FR(E)Ls
  - Results in CO_{2eq} per year consistent with FR(E)L
  - Methods used for establishing FR(E)L and results (to be consistent)
- Land Use, Land-Use Change, and Forestry (LULUCF) experts will perform a **technical analysis** of the submitted results

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   a. **Reporting principles**
   b. Estimation of GHG emissions/removals

Reporting of GHG emissions and/or removals

- Within UNFCCC REDD+ context, DCs should:
  - **Identify** Land Use, Land Use Change, and Forestry (**LULUCF**) **activities** and related **drivers** of deforestation / forest degradation
  - Use a combination of **remote sensing** and **ground-based forest carbon inventory** approaches for estimating anthropogenic forest-related GHG emissions and removals
- Estimating emissions / removals should be done using the **IPCC Good Practice Guidance (GPG) and Guidelines**

IPCC Good Practice Guidance (GPG) & Guidelines

Most relevant is **2003 IPCC GPG** (Good Practice Guidance for LULUCF), which refers to 1996 IPCC Guidelines.

Countries may wish to refer to the updates in the **2006 IPCC GL** (Guidelines for AFOLU)

The **2014 GFOI MGD** (Methods and Guidance Document) provides systematic linkage between IPCC GPG and GL, and each of the REDD+ activities. Countries may also wish to refer to this.

GFOI: Global Forest Observation Initiative

The five IPCC reporting principles

- ***Consistency*** – Same definitions and methodologies used over time
- ***Comparability*** – *S*tandard methodologies and formats, provided by IPCC and agreed within UNFCCC
- ***Transparency*** – Assumptions and methodologies clearly explained and appropriately documented
- ***Accuracy*** – Estimates neither over- nor underestimated, uncertainties reduced as far as is practical
- ***Completeness*** – Estimates include all agreed categories, gases, and pools for all relevant geographical areas

*NB: "**Conservativeness**" to complement the last principle ➔ possible to omit a category/gas/pool if only it does not lead to an over- or underestimation **benefiting** to the reporting Party*

Forest definitions

- 6 IPCC **Categories** : Forest land, Cropland, Grassland, Wetland, Settlements, Other.
- A Party may use its **own definition for forest land**. Need to be **consistent**: UNFCCC asks for an explanation if the forest definition for REDD+ differs from the one used for other international reporting (e.g. FAO FRA).
- **FAO** forest definition:
  - Minimum forest **area**: 0.5 ha
  - Minimum trees **height**: 5 meters
  - Minimum tree **crown cover**: 10%
  - Forest use should be the **predominant land use** in the area
- **Considerations** for establishing forest definition:
  - **Thresholds** of minimum **area / crown cover / tree height**
  - Including/excluding **plantation forests** (forests or crops?)
  - Define **subcategories** for forest

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   b. **Estimation of GHG emissions/removals**

Basic formula

GHG emissions/removals, expressed in tCO_{2eq} = **Activity Data (AD)**, expressed in ha (more rarely in other units, e.g. m^3 for biomass burning) X **Emission Factor (EF)**, expressed in tCO_{2eq}/ha (more rarely in other units, e.g. tCO_{2eq}/m^3

Example: GHG emissions due to deforestation in various forest types

$$C_{gr\_em} = \left(\sum_{i=1}^{m} A_{loss(i)} \cdot C_{loss(i)} \right)$$

C_{gr_em} = Gross carbon emissions

A_{loss} = AD = Area of deforestation (ha)

C_{loss} = EF = Change in carbon stock per unit area (t/ha)

i = Forest type, varying from 1 to m

AD: Approaches and accuracy/precision

3 **approaches** for estimating AD, with increasing accuracy and precision

Approach 1	Approach 2	Approach 3
Total area for each land use category, but **no information on conversions**	Same as 1 + tracking of conversions between land-use categories on **non-spatially explicit basis**	Same as 1 + tracking of conversions between land-use categories on **spatially explicit basis**
e.g. Area of forest known in year n and year n-5. Nature (Cropland? Grassland? Etc.) and location of deforestation unknown	e.g. Area of forest known in year n and year n-5. Nature of deforestation known. Location of deforestation unknown	e.g. Area of forest known in year n and year n-5. Nature and location of deforestation known.

➢ Remote sensing data (satellite) always needed for Approach 3

EF: methods to estimate vegetation biomass

Biomass is defined as mass per unit area of above- or belowground live plant material. Nearly **half** (47%) of the biomass is carbon.

4 main methods to estimate biomass:

- *In situ* **destructive direct measurement**

- *In situ* **non-destructive estimation** (using allometric equations or conversion factors)

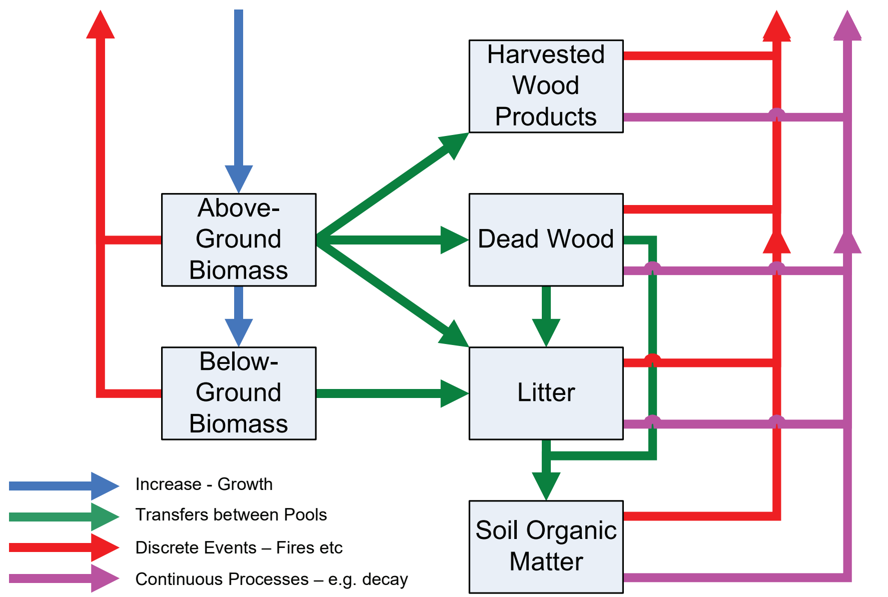
- **Inference** from **remote sensing** (can be problems with saturation)

- **Models** calibrated to the ecosystem under consideration

EF: Estimating EFs for forest-related GHGs

- Identification of different forest **sub-categories**, with different **mean carbon stocks**
- Assessment of 5 carbon pools for each forest sub-category:
  - **Aboveground biomass** (AGB) – trees and shrubs
  - **Belowground biomass** (BGB) – root biomass
  - **Dead wood** – logs and fallen branches
  - **Litter** – fine woody debris, dead leaves and humus
  - **Soil organic matter** – carbon that has been incorporated into the mineral soil

EF: Pools and fluxes in forests



EF: Tier and accuracy/precision

3 **tiers** for estimating **EF**, with increasing accuracy and precision

Tier 1	Tier 2	Tier 3
IPCC default factors (i.e., biomass in different forest biomes, carbon fraction, etc.)	**Country-specific data** for key EFs (e.g., from field inventories, permanent plots)	Data produced through (i) detailed national inventory of key C stocks and their **repeated measurements** through time, (ii) modeling, tailored to national circumstances

In summary

1. Mitigation actions in the LULUCF sector in DCs shall follow the UNFCCC **REDD+ COP Decisions**.
2. Following COP Decisions require use of **IPCC 2003 GPG and 2006 Guidelines.**
3. Countries can measure and report on the **five REDD+ activities**.
4. **Significant carbon pools and activities** should not be omitted.
5. National forest monitoring systems (**NFMS**) are needed for Measuring, Reporting, and Verifying (**MRV**) REDD+ activities.

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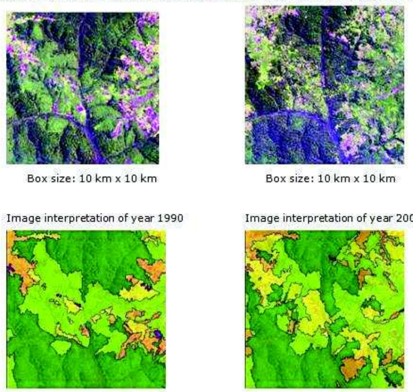
2 MONITORING OF LUC

Monitoring Activity Data (AD) for forest-related Land Use Change (LUC)

After the course the participants should be able to differentiate between different (remote sensing) approaches to monitor changes in forest areas

Box 3.2.2. Example of results of interpretation for a sample in Congo Basin



Legend: green = Dense forest, light green = degraded forest, yellow = forest/agriculture mosaic, orange = agriculture & fallow.

2 AD & MONITORING OF LUC

1. **Introduction**
2. Selection of a monitoring approach
3. Image classification and analysis
4. Accuracy assessment
5. Limitations to using satellite data

IPCC requirements

- IPCC methodologies aim for **complete, accurate, transparent, consistent, and comparable** reporting of GHG emissions and removals (5 IPCC reporting principles)
- 2 basic inputs with which to calculate GHG inventories: **Activity Data (AD)** and **Emissions Factors (EFs)**.
- Estimating AD can be achieved using 2 mapping approaches:
  - **Sampling ➔** analysis of LUC on discrete plots, and generalization to the entire region of interest. Data are not spatially explicit, unless additional information on land use dynamic are available
  - **Wall-to-wall ➔** analysis of LUC on the entire region of interest
- For Activity Data, spatially explicit land conversion information is encouraged: **Approach 3**.

Use of satellite in monitoring tropical forests

- **Fundamental requirement** of National Forest Monitoring Systems are that they:
  - i. Measure changes throughout **all forested area**
  - ii. Use **consistent methodologies** at **repeated intervals** to obtain accurate results and
- The only practical solution to implement such monitoring systems in tropical countries, often with low accessibility to forest areas, is through **interpretation of remotely sensed data supported by ground-based observations**.

Issues affecting the choice of a monitoring approach

- **National circumstances**: existing definitions for forest, satellite images available at different dates, etc.
- **Methodological choices** : Sampling vs wall-to-wall coverage, Fully visual vs semi-automated interpretation, etc.
- **Available resources**: Hard- and software resources, human resources (and required training), etc.

2 AD & MONITORING OF LUC

Choices in terms of forest definition

- **Annex I Parties** (**Developed Countries**) use the Kyoto Protocol definition (for implementation of Art. 3.3 and 3.4):
  - Minimum forest area: 0.05 to 1 ha
  - Potential to reach a min height at maturity: 2 to 5 m
  - Minimum tree crown cover: 10 to 30 %
- For **Non-Annex 1 Parties (Developing Countries)**:
  - **FAO FRA** are often based on a **default standard definition**: min. crown cover of 10%; min height of 5 m; min area of 0.5 ha; forest use should be predominant
  - Under the **UNFCCC**, Countries can choose their **own forest definition** (as long as they clearly describe it and it remains consistent with existing ones).
  - NB : remote sensing imagery allows **land cover** to be observed; field information is needed to derive **land use**

Designation of forest area

- Ideally, **wall-to-wall assessments** would be carried out to identify forested area according to UNFCCC forest definitions.
- Alternatively, in case of **sampling assessments**, existing forest maps for a relatively recent time could be used to identify the overall forest extent.

Important principles in identifying the forest area:

- The area should **include all forests** within the national boundaries
- A **consistent** forest area should be used for monitoring all forest changes during assessment period

Choices in terms of categories to be monitored

- **Basic ➔** 2 categories = forest / non–forest (cropland, grassland, wetlands, settlements, others) ➔ Allow for estimating GHG emissions from **deforestation**
- **More complete ➔** same as basic, but forest category detailed into sub-categories ➔ Allow for estimating GHG emissions from **deforestation and forest degradation**
- **Complete ➔** 6 categories ➔ Allow for estimating GHG emissions/removals from **all possible LUC** (in theory)

➔ The more **detailed the categories/sub-categories**, the better in terms of **completeness**

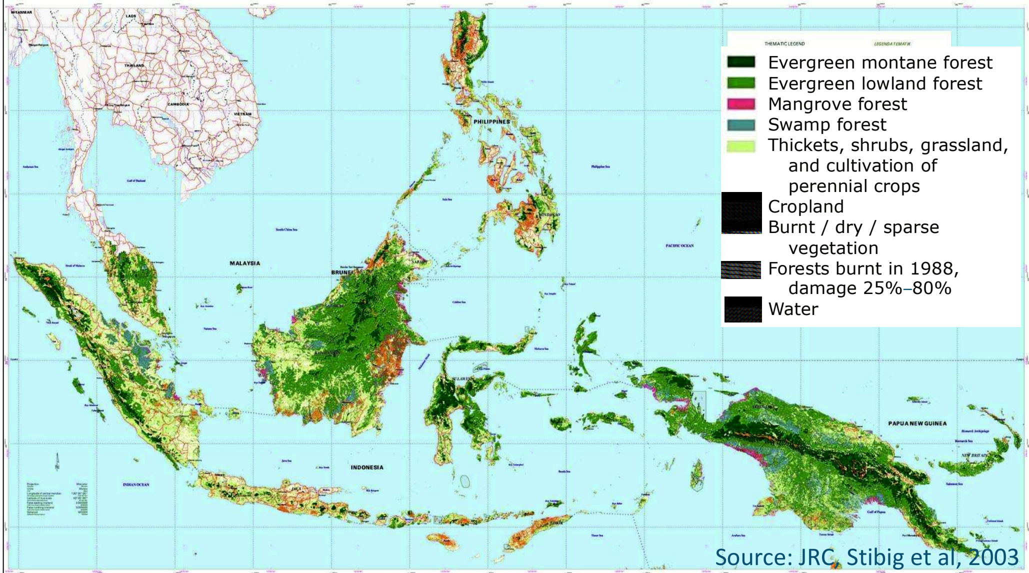
Choices in terms of satellite images

Depend on **size** of the country, availability of **cloud free** images for **repeated years**, for **different seasons** (if deciduous forests), **availability of funds** to buy HR or VHR images, etc.), etc. NB : **Sentinel-2** images are **free** and now **widely used** to monitor LULUCF.

Here below the most common **optical sensors** (NB: also exist radar sensor, LiDAR, drone, etc.)

Resolution	Examples of sensors	Minimum mapping unit (change)	Cost	Primary utility for deforestation monitoring
Coarse (250-1000 m)	SPOT-VGT Terra-MODIS Envisat-MERIS Suomi NPP - VIIRS	~ 100 ha ~ 10-20 ha	Low or free	Consistent pan-tropical annual monitoring to identify large clearings and locate "hotspots" for further analysis.
Medium (10-60 m)	Landsat TM, ETM+ and OLI Terra-ASTER IRS AWiFs or LISS III CBERS HRCCD DMC SPOT HRV ALOS AVNIR-2 Sentinel-2 MSI (2015→)	0.5 - 5 ha	Landsat & CBERS are free; for others: <$0.001/km² for historical data $0.02-0.5/km² for recent data	Primary tool to map deforestation and estimate forest area change.
Fine (<5 m)	RapidEye IKONOS QuickBird Aerial photos	< 0.1 ha	High to very high $2 -30 /km²	Validation of results from coarser resolution analysis, and training of algorithms.

Ex. Forest map in Indonesia (1 km SPOT VGT)



Source: JRC, Stibig et al, 2003

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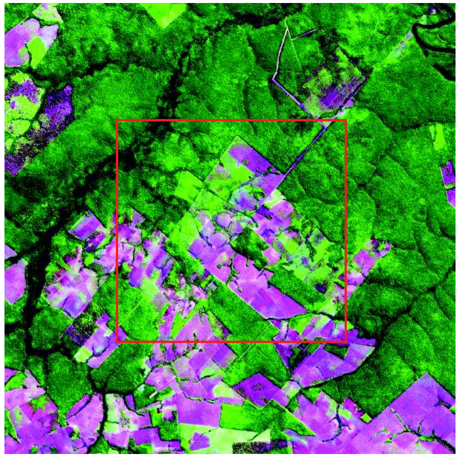
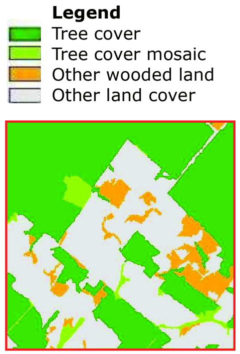
Ex. Forest map in Brazil (30 m Landsat TM)



Landsat-5 TM image of 15 June 2005: 20 km x 20 km extract

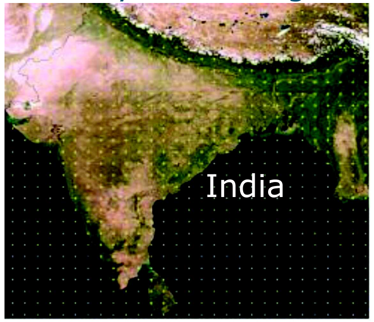


Forest cover map
10 km x 10km window size
Centered at 12°S, 58°W

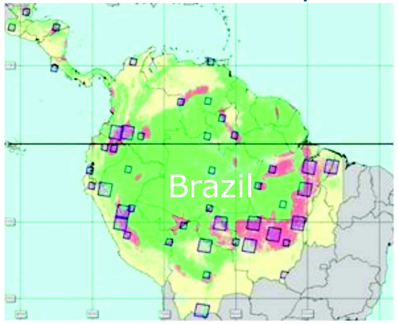
Sources: USGS 2015; Eva, et al. 2012.

Choice for wall-to-wall vs sample coverage

- **Wall-to-wall** is a **common** approach, but sampling can be more **cost-efficient** for **large countries** and can produce **more accurate estimates** of activity data
- **Sampling** can be (i) **Systematic** (regular interval, e.g. every 10 km), (ii) **Stratified** (samples are distributed based on proxy variables derived from coarse resolution satellite data or by combining other geo-referenced or map



Systematic sampling design



Stratified sampling design

Source: GOFC-GOLD Sourcebook 2013, box 2.1.2.

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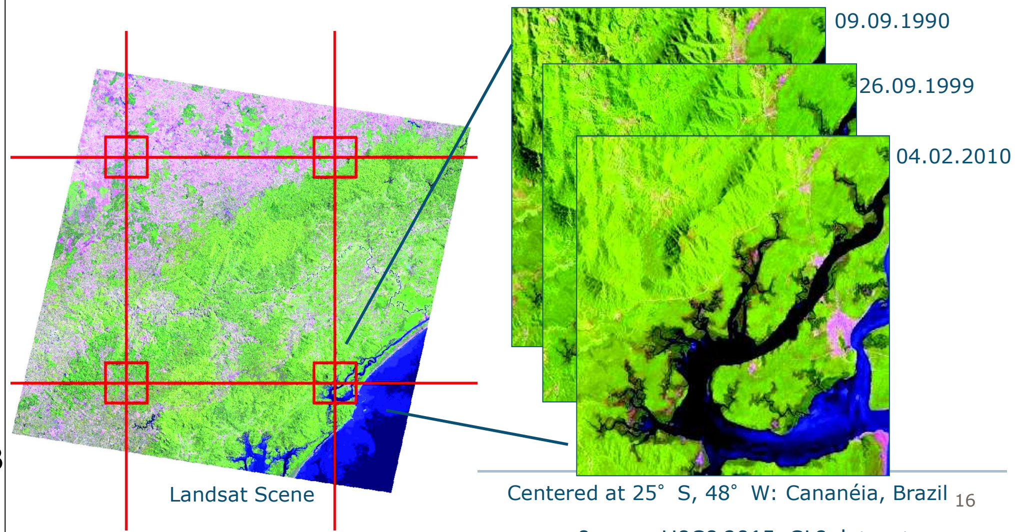
3 main pre-processing steps for satellite data

- **Geometric corrections**: Needed to ensure that images in a time series **overlay properly**. Location error should be < 1 pixel. Baseline datasets (e.g. **global land survey**) can be used as alternative to **ground control points** or image-to-image registration
- **Cloud and cloud shadow masking**: **Contamination** by cloud/haze is frequent in tropical regions (e.g. Congo Basin). Use of automated or visual methods to ensure **meaningful-ness** of image interpretation
- **Radiometric corrections**: Needed to guarantee having the **same spectral values for same objects.** Not needed for visual single scene interpretation but **crucial** for **automated multitemporal analysis.** Done by identifying a water body or dark object and calibrating other objects to the first

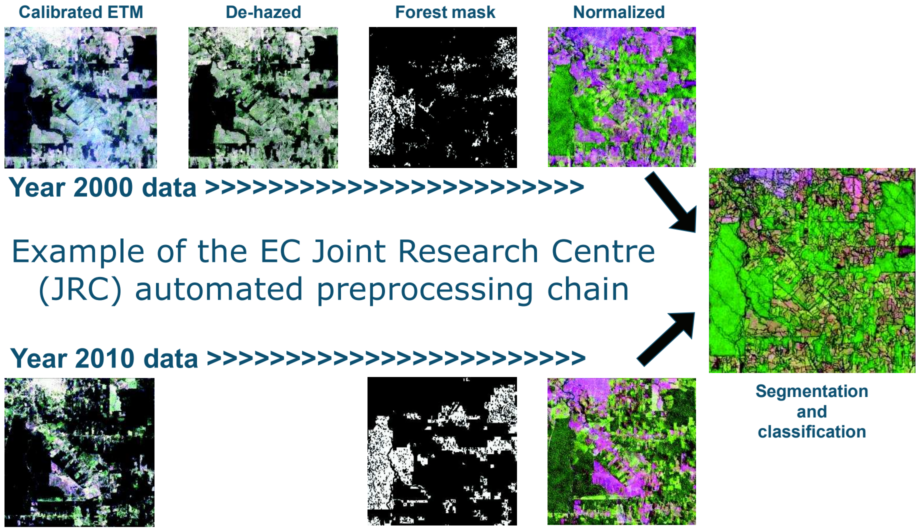
Geometric correction

Ex: use of GLS dataset for image-to-image co-registration. All Landsat data from USGS archive are available for free. These datasets can be used as baseline for image geo-registration.



Source: USGS 2015, GLS dataset.

Atmospheric and radiometric correction (2/2)



Example of the EC Joint Research Centre (JRC) automated preprocessing chain

Source: Bodart et al. 2011.

Analyzing the satellite data

- The selection of the image interpretation method depends on **available resources** (images, software, RS/GIS experts). Whichever method is selected, the results should be **repeatable** by different analysts.
- **Visual interpretation** can be **simple** and **robust**, although it is **time-consuming**. A **combination** of automated methods (classification or segmentation) and visual interpretation can **reduce the work load**. **Automated** methods are generally **preferable** where possible because the interpretation is **repeatable** and **efficient**
- Even in a fully automated process, **visual inspection** of the result by an **analyst familiar with the region** should be carried out to ensure appropriate interpretation.
- NB: it is generally **more difficult** to identify forestation than deforestation. Forestation occurs **gradually** over a number of years while deforestation occurs more rapidly.

Main analysis methods for MR images (~ 30 m)

Method for delineation	Method for class labeling	Practical minimum mapping unit	Principles for use	Advantages / limitations
Point interpretation (points sample)	Visual interpretation	< 0.1 ha	- multiple date preferable to single date interpretation - On screen preferable to printouts interpretation	- closest to classical forestry inventories - very accurate although interpreter dependent - no map of changes
Visual delineation (full image)	Visual interpretation	5 – 10 ha	- multiple date analysis preferable - On screen digitizing preferable to delineation on printouts	- easy to implement - time consuming - interpreter dependent
Pixel based classification	Supervised labeling (with training and correction phases)	<1 ha	- selection of common spectral training set from multiple dates / images preferable - filtering needed to avoid noise	- difficult to implement - training phase needed
	Unsupervised clustering + Visual labeling	<1 ha	- interdependent (multiple date) labeling preferable - filtering needed to avoid noise	- difficult to implement - noisy effect without filtering
Object based segmentation	Supervised labeling (with training and correction phases)	1 - 5 ha	- multiple date segmentation preferable - selection of common spectral training set from multiple dates / images preferable	- more reproducible than visual delineation - training phase needed
	Unsupervised clustering + Visual labeling	1 - 5 ha	- multiple date segmentation preferable - interdependent (multiple date) labeling of single date images preferable	- more reproducible than visual delineation

Source: GOFC-GOLD Sourcebook 2013, table 2.1.3.

Visual delineation of land entities

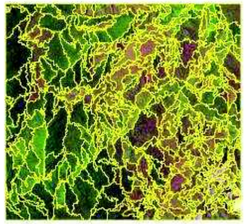
- Visual delineation of land entities is a **viable** approach for forest-area monitoring, particularly if **image analysis tools and experiences are limited.**
- The visual delineation of land entities on **printouts** (used in former times) is **not recommended**; on screen delineation should be preferred as **producing directly digital results**.

Multidate image segmentation

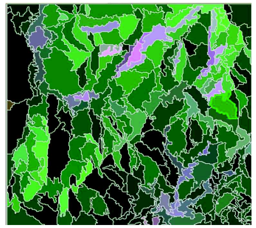
- Image segmentation = **grouping** pixels that are **spectrally similar and spatially adjacent**.
- Carried out in much the **same way a human analyst would do** based on shape, tone, and texture…
- However, it is **more objective, accurate, and repeatable**, since it is carried out at the pixel level based on quantitative values. It also **reduces processing time**
- Ideally, analysis process would include:
  - Multidate image **segmentation on image pairs** (justified by the final objective: to determine change.)
  - **Training area/class** signature selection
  - **Supervised clustering** of individual images
  - **Visual verification** and potential editing

Ex. of semi-automatic multidate segmentation and change labeling

Paired segmentation



Automatic change label



NB: areas where land cover has changed over the period will form separate segments

Sources: USGS 2015, GLS dataset; Bodart et al. 2011; and Raši et al. 2011.

Visual verification

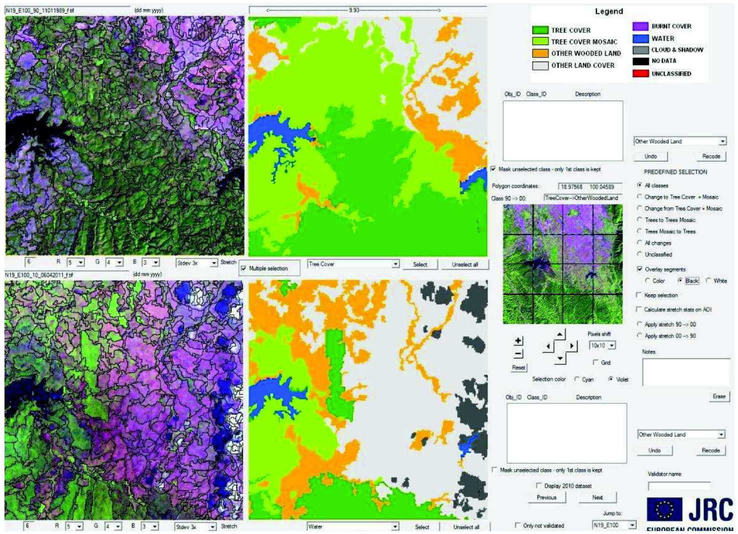
- Given the **heterogeneity** of forest **spectral signatures** and occasionally **poor radiometric conditions**, the visual verification by a skilled interpreter is indispensable to map LULUF with **high accuracy**
- It should focus on LUC with **interdependent visual assessment of two multidate images** (image pairs).
- **Existing maps** may be used as **support**.
- Spectral, spatial, and temporal (seasonality) **characteristics of the forests** have to be considered.

Ex of visual validation

Screenshot of a visual validation interface used by JRC and FAO for the FRA 2010 Remote Sensing Survey

➔ Visual Control and Interpretation of automated mapping

Source: USGS 2015, GLS dataset; JRC; Simonetti et al. 2011



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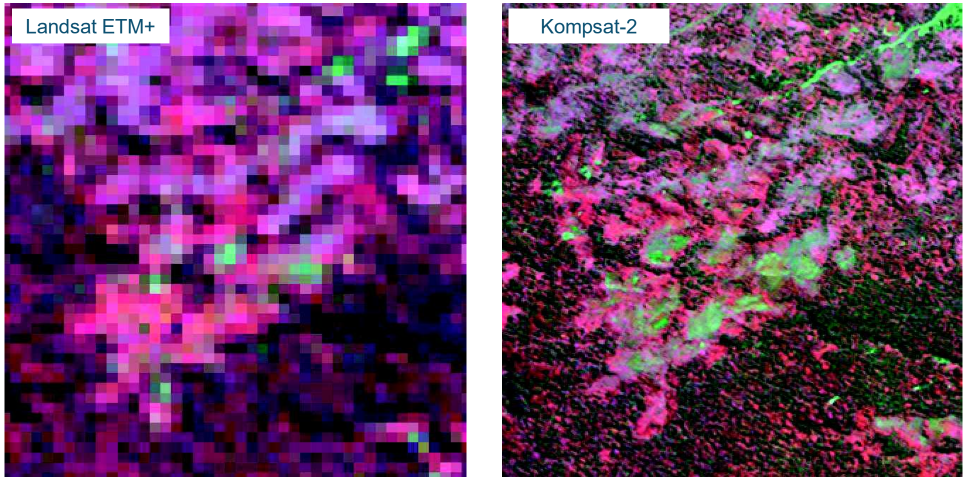
Accuracy assessment: Basic concepts

- Reporting accuracy and verification of results are **essential components** of a IPCC compliant monitoring system.
- Accuracy assessment should be based on **higher quality data**, e.g., ***in-situ* observations** or analysis of **very high resolution aircraft or satellite data.**
- Attention needs to be given to the **timing of the reference dataset**, so that it matches temporally to the dataset that has been used for the forest cover mapping.
- Ideally, a **statistically valid sampling procedure should be used** to quantify accuracy.

Ex. Use of VHR image for accuracy assessment

LANDSAT 30 m versus Kompsat-2 4 m resolution (RGB: NIR-R-G)



Source: USGS 2015, GLS dataset; ESA/JRC TropForest project (Kompsat).

Bing Maps or GoogleEarth images may also be useful

Considerations regarding accuracy assessment

- Monitoring should work **backward** from a recent year to use the **highest quality data first**
- Since areas of land-cover change are **significant drivers of emissions**, providing the best possible estimates of these areas is **critical**.
- It is possible to use the results of a rigorous accuracy assessment to **adjust area estimates** and to **estimate the uncertainties for the areas for each class**.
- If a **statistical approach** is **not achievable**, information obtained through **other means** can be used to understand the accuracy of the map. Such information may include:
  - **Comparisons to other maps**
  - Systematic review and **judgment by local experts**
  - Comparisons to **non-spatial statistics**

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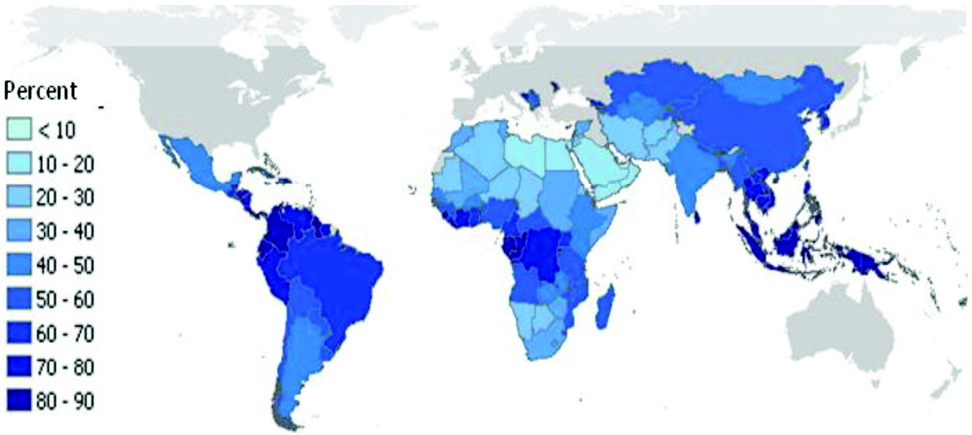
Major sources of limitations

- Clouds and cloud shadows
- Other atmospheric effects (e.g., haze and smoke)
- Effect of topography on reflectance
- Insufficient observation frequency (e.g., humid tropics)
- Scarcity of historical data
- Tradeoff between spatial resolution and coverage
- Problems of intersensor comparability (e.g., in historical time series)

Ex. Of limitations: Cloud cover



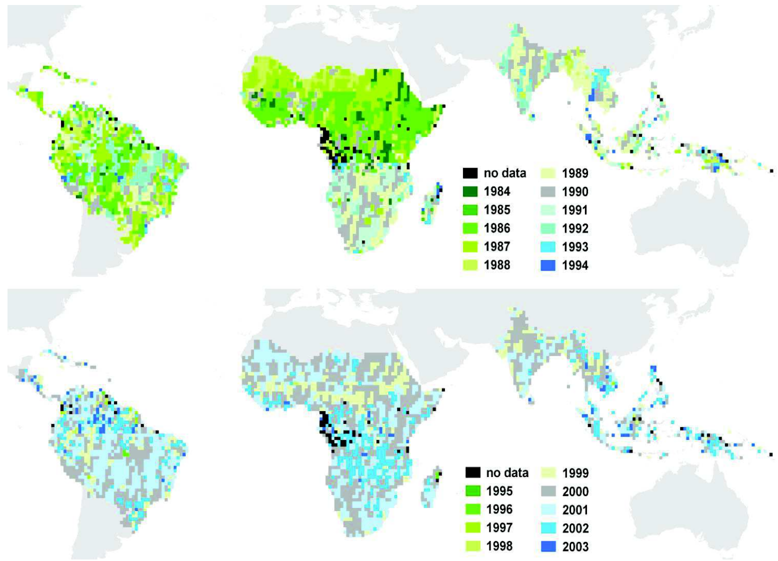
Mean annual cloud cover based on MODIS M3 Product (Cloud Fraction Mean) and EECRA (Extended Edited Cloud Report Archive)

Source: Herold 2009.

Ex. Of limitations: Scarcity of historical data

Actual acquisition year for target year 1990

Actual acquisition year for target year 2000



Source: JRC; Beuchle et al. 2011

In summary

- The **IPCC guidance and UNFCCC decisions** provide general guidelines that should be used to develop national forest definitions and monitoring approaches for REDD+
- **Numerous remote sensing data and methods** can be used to monitor activity data for forests, preferably with:
  - **Multidate image analysis** to detect changes
  - **Supervised, repeatable classification** approaches
  - **Visual verification** and **rigorous accuracy assessment** of the resulting maps
- Even with the **limitations** of satellite observation, remote sensing is **indispensable** for monitoring activity data for forests in tropical countries.

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3 MONITORING OF DEGRADATION

Monitoring Activity Data (AD) for forests remaining forests

After the course the participants should be able to

- Describe different types of forest degradation and the approaches to monitor degradation
- Map and analyze various forest degradation processes using ground surveys and remote sensing tools

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1. **Definition of forest degradation and IPCC GPG* context**
2. Types of forest degradation
3. Approaches to assess forest degradation areas
   - i. Field observation for selective logging
   - ii. Field observation for fuelwood collection
   - iii. Remote sensing approaches
     - a) direct methods
     - b) indirect methods
4. Software requirements

*GPG = Good Practice Guidance

2

Defining forest degradation

- Over **50 definitions** have been identified in the scientific literature (Simula 2009; Herold 2011).
- Broadly speaking, forest degradation is a type of **anthropogenic intervention that leads to changes in forest cover, structure, composition, and function** of the original forest.
- Changes can be **temporary** or **permanent**.
- Changes can affect biodiversity, **carbon stocks**, hydrological and biogeochemical cycles, soil structure, and other environmental services.

Example of forest degradation caused by recurrent logging and fires in Sinop region, Mato Grosso state, Brazil.

3

Definitions in the context of IPCC and REDD+

- IPCC, 2003: "*A direct, **human-induced, long-term loss** (persisting for X years or more) or **at least Y%** of forest carbon stocks [and forest values] **since time T** and **not qualifying as deforestation***". NB: X, Y, T are not defined.
- *UNFCCC/SBSTA, 2008: "Degradation leads to a **loss of carbon stock** within **forests that remain forests**"*

➔ ***Several processes** lead to forest degradation: logging, fuelwood collection, fire, forest grazing, etc.*

➔ *It is important to consider **what process** of degradation to be assessed. **Different processes** may require **different methods and data** for monitoring*

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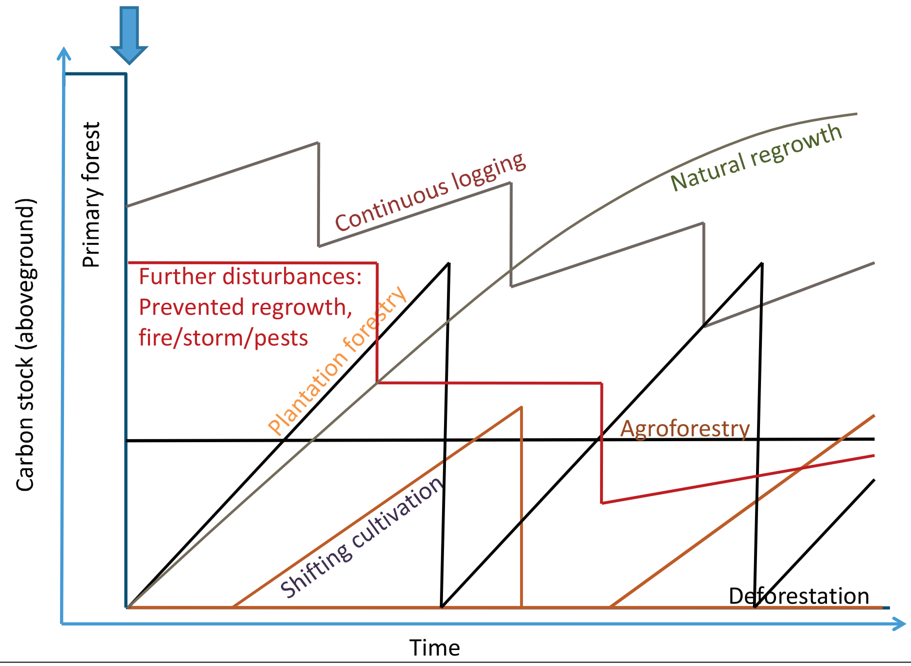
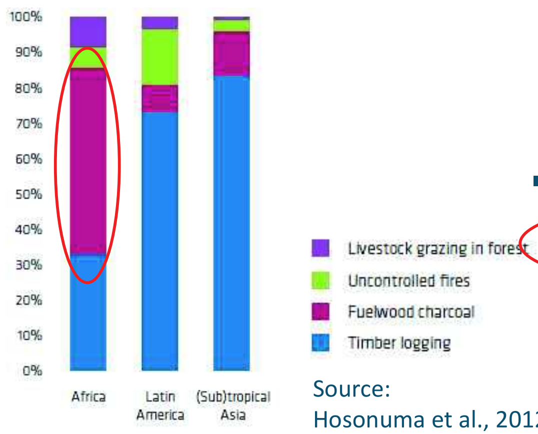
Types of forest degradation & carbon impact



Direct drivers of degradation

Proportion of forest degradation drivers



Source:
Hosonuma et al., 2012

- **Latin America and (sub)tropical Asia:** Commercial timber production > 70% of total degradation
- **Africa:** Fuel wood collection, charcoal production, followed by timber production

Detectability of forest degradation

Detectability using medium-resolution images

Readily detectable	Marginally detectable	Not detectable
Deforestation	Recent selective logging	Hunting or defaunation
Habitat fragmentation	Surface fires	Harvests of many nontimber forest products
Major forest fires	Effects of climate change on plant phenology	Effects of pathogens
Major highways	Small-scale gold mining	Compositional shifts in plant communities from climate change
	Wider roads (6–20 m width)	Nonrecent selective logging
	Some invasions of exotic plant species	Narrow roads (<6 m width)
		Most secondary effects

Source: Laurence and Peres 2006.

➔ **Marginally detectable threats** = can be detected, at least partially, using high-resolution methods or specialized detection algorithms… **expensive, complex, available for limited areas**

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Options for monitoring forest degradation

Activity/driver of degradation	Activity data (on national level)
Extraction of forest products for subsistence and local markets, such as fuel wood and charcoal	• Limited historical data • Information from local scale studies or using proxies (population density, household consumption, etc.) • Only long-term cumulative changes may be observed from historical satellite data
Industrial/commercial extraction of forest products, such as selective logging	• Harvest data and statistics • Historical satellite data (Landsat time series) analysed within concession areas • Direct approach should be explored for recent years
Other disturbances such as (uncontrolled) wildfires	• Historical satellite-based fire data records (since 2000) to be analysed with Landsat-type data

Source: Herold et al. 2011.

Sources of information

1. **Field observations:**
   - Field data from **forest inventory**
   - **Commercial forestry data** (logging concessions & timber extraction)
   - Field data from **targeted surveys** (charcoal, firewood, food crops…)
   - **Proxy data** (number of households, distance from urban areas, etc.) for estimating domestic demands (charcoal, firewood, food crops…)

2. **Remote sensing:**
   - **Direct** detection (forest canopy damage, burnt area)
   - **Indirect** detection (human infrastructures)

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Equation for AD of selective logging (1/2)

Activity data for this method is total volume extracted from the forest per year : **EF (tC/m^3) = ELE + LDF + LIF**

Where:

- ELE = **Extracted Log Emissions** (tC/m^3 extracted)
- LDF = **Logging Damage Factor**, or dead biomass carbon left behind in gap (tC/m^3 extracted)
- LIF = **Logging Infrastructure Factor**, or dead biomass carbon caused by construction of infrastructure (tC/m^3)

Field data are collected from multiple logging gaps to quantify the ELE and LDF

Equation for AD of selective logging (2/2)

LIF
=
C stock estimates of unlogged forest
X
area of infrastructures (skid-trails + roads + decks)
/
harvested volume in m^3



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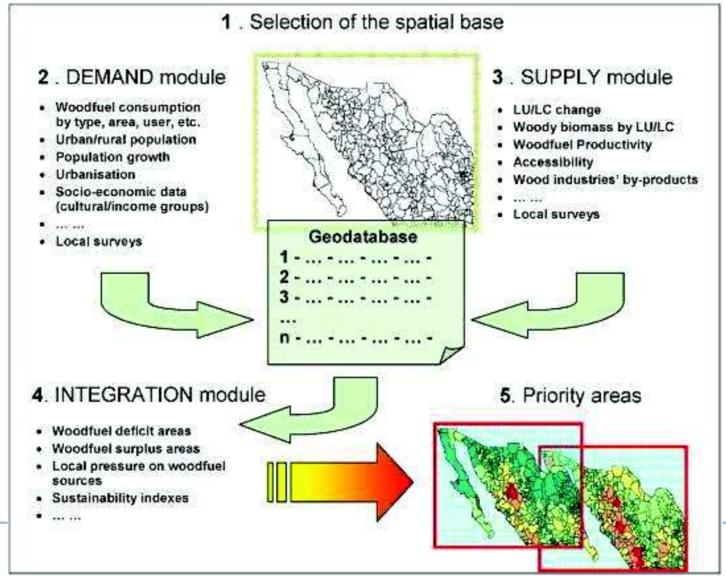
Modelling firewood supply and demand (1/2)

S & D are quantified and spatialized with field surveys



Source: Ghilardi et al. 2007.

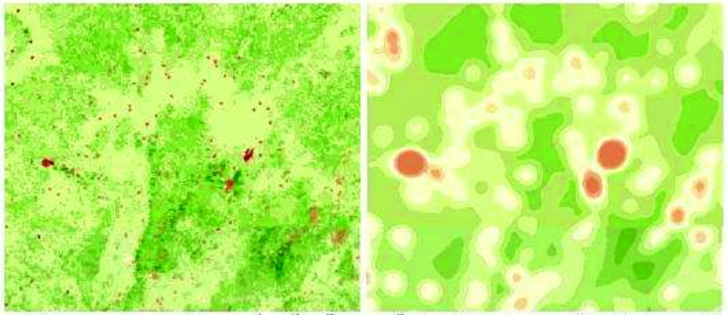
LU/LC = Land Use / Land Cover

Modelling firewood supply and demand (2/2)

Something already carried out in Sudan, in 2011

WISDOM Sudan

Spatial analysis of woodfuel supply and demand in Sudan based on WISDOM methodology and new land cover mapping



Activity carried out in the framework of the: Sudan Institutional Capacity Programme: Food Security Information for Action (SIFSIA) FAO OSRO/SUD/620/MUL

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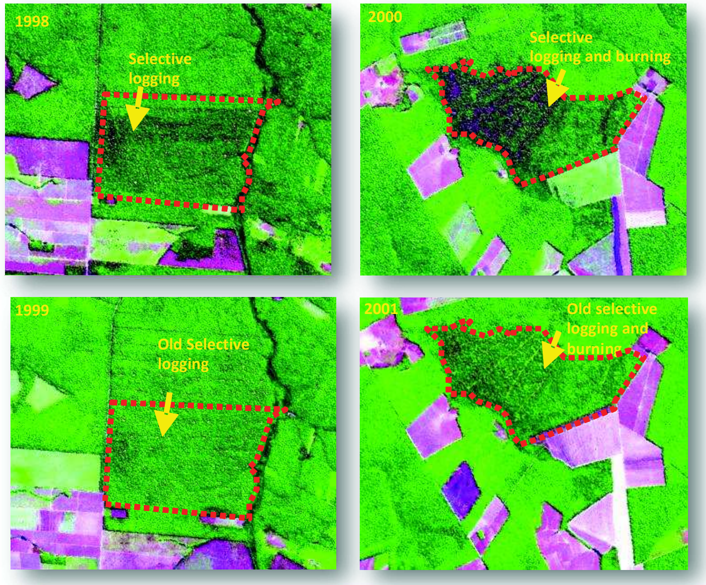
      b) indirect methods
4. Software requirements

*GPG = Good Practice Guidance

Challenges of visual interpretation

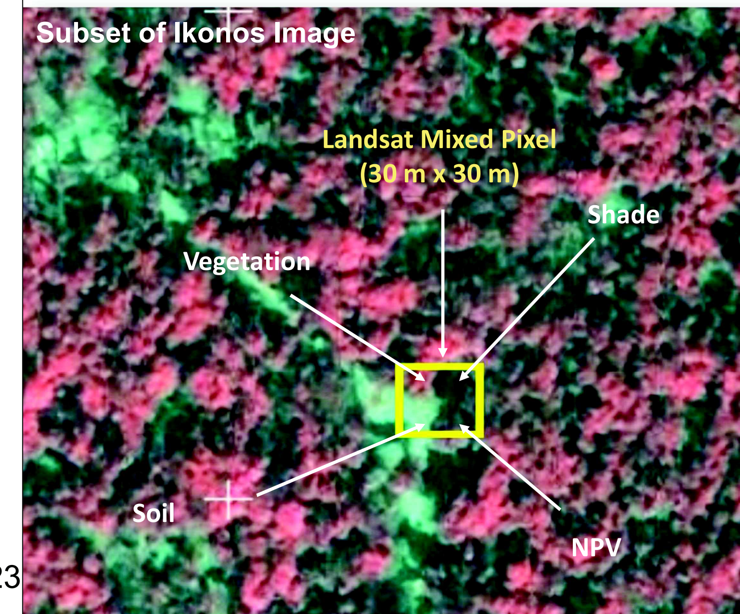


Defining the boundary between degraded and undisturbed forests is **subjective**.

Forest degradation signal **disappears fast**, making visual interpretation **challenging**.

Sinop region, Mato Grosso, Brazil

Spectral Mixture Analysis (SMA) (1/2)



The most common spectrally pure materials (i.e., endmembers) found in degraded forests are:

Green vegetation

Non-photosynthetic vegetation (NPV)

Soil

Shade

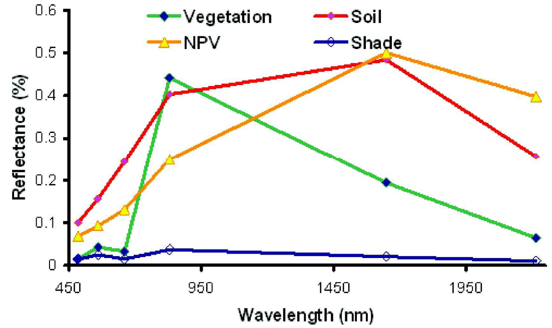
→ Mixed pixels predominate in degraded forests.

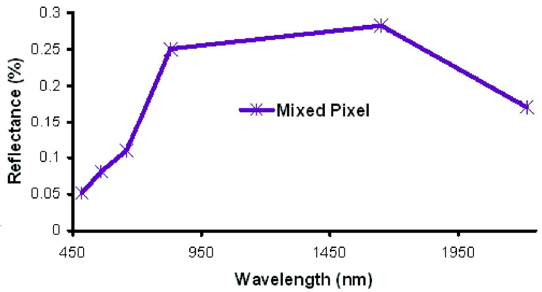
Spectral Mixture Analysis (SMA) (2/2)

SMA has been proposed to overcome the **mixed pixel problem**

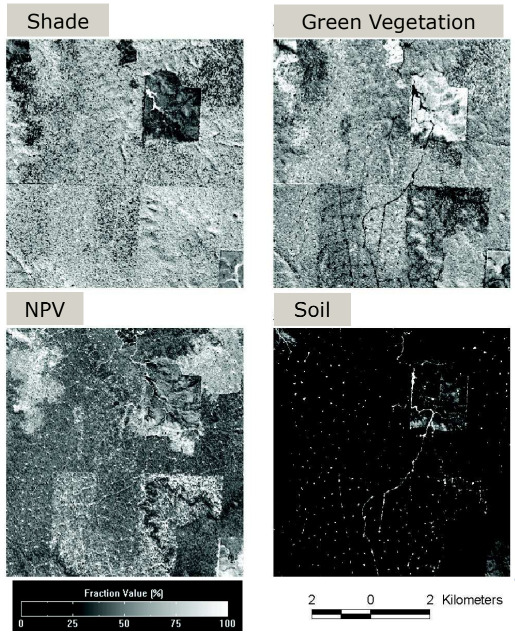
Mixed pixels can be **decomposed into fractions** of endmembers.

The mixed pixel reflectance is the **sum of the reflectance of the endmembers'** components found in the pixel.





Interpreting endmember fractions



Shade: topography, forest canopy roughness and large clearings

Green vegetation: canopy gaps, forest regeneration and clearings

NPV: canopy damage and burning scars

Soil: logging infrastructure (roads and log landings)

Source: Souza Jr. et al. 2003

Combining fraction information

Normalized Differencing Fraction Index (NDFI)

$$NDFI = \frac{GV_{Shade} - (NPV + Soil)}{GV_{Shade} + NPV + Soil}$$

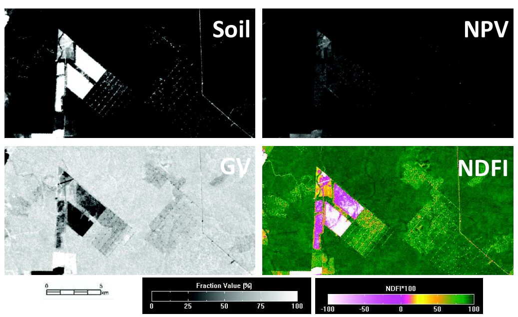
$$GV_{Shade} = \frac{GV}{100 - Shade}$$

Where GV is green vegeation, NPV is the non-photosynthetic vegetation

$-1 \leq NDFI \leq 1$

NDFI values from 0.70 to 0.85 indicate canopy change that can be associated with forest degradation.

Paragominas,Pará State



Source: Souza Jr. 2005

3 AD & MONITORING OF DEGRADATION

1. Definition of forest degradation and IPCC GPG* context
2. Types of forest degradation
3. **Approaches to assess forest degradation areas**
   - i. Field observation for selective logging
   - ii. Field observation for fuelwood collection
   - **iii. Remote sensing approaches**
     - a) direct methods
     - **b) indirect methods**
4. Software requirements

*GPG = Good Practice Guidance

Intact/non-intact forest approach

Intact forest: fully-stocked = any forest with its natural canopy cover between 10% and 100%

Non-intact forest: not fully-stocked = the forest has undergone some level of degradation

Distinction to be applied in **any subcategory** reported under UNFCCC, e.g., intact lowland forest / non-intact lowland forest, intact mountain forest / non-intact mountain forest.

Need to collect **carbon stock data for each subcategory**.

See www.intactforests.org for global mapping of intact forests

Detailed definition of intact forest land

Country-specific definition could be, e.g.:

Area situated **within the forest land** according to UNFCCC definitions and with a **buffer zone** inside the forest

Containing a **contiguous mosaic** of natural ecosystems

Not fragmented by **infrastructure** (road, navigable river, etc.)

Without signs of significant **human transformation**

Without **burnt lands** and **young tree sites** adjacent to settlements

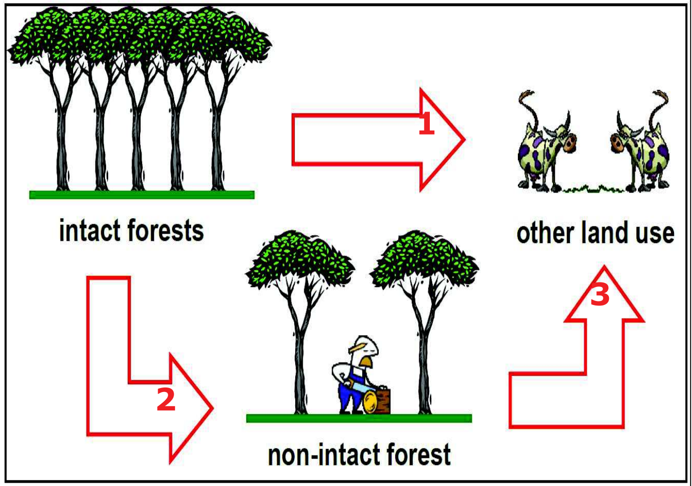
Source: Potapov et al. 2008.

Application to carbon accounting

1 and 3 ➔ Deforestation

2 ➔ Forest degradation

Emissions for Deg = ΔC intact vs non-intact (EF) x Area degraded (AD)



Source: Mollicone et al. 2007.

Synthesis: Land use change matrix

From ↓ / To →		Forest land: "Intact (natural) forest"	Forest land: "Non-intact forest"	Other land
Forest land	"Intact (natural) Forest"	*Forest conservation*	*Forest degradation*	*Deforestation*
Forest land	"Nonintact forest"	*Enhancement of C stocks (forest restoration)*	*Sustainable management of forests*	*Deforestation*
Other land		-	*Enhancement of C stocks (A/R)*	

Source: Bucki et al. 2012.

Delineation of intact forests

A two-step procedure, using the "negative approach":

1/ **Exclusion** of areas around settlements and infrastructure and fragments of landscape smaller than 1,000 ha, based on topographic maps, GIS database, thematic maps, etc.

*This first (potentially **fully automated**) step result in a **set of fragments** with **potential intact forests***

2/ **Further exclusion** of non-intact areas is based on **visual or semi-automated interpretation** methods of high-resolution satellite images (~ 10-30 m pixel spatial resolution).

***Intact forests** are the left landscapes (explaining the term "**negative** approach")*

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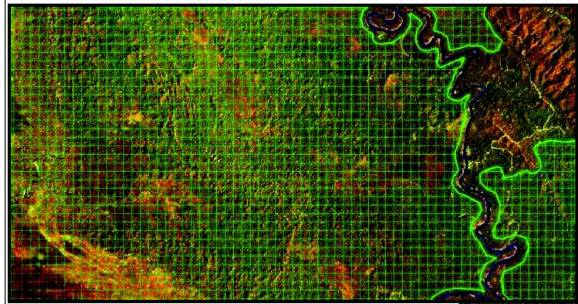
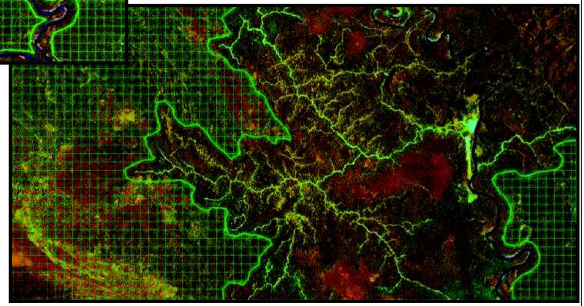
Ex of delineation in PNG



(a) Papua New Guinea
December 26, 1988

(b) Papua New Guinea
October 7, 2002



Hashed areas = intact forests

In 14 years:

- **51%** of intact forests have been **degraded**
- **1%** of intact forests have been **deforested** (roads).

Source: Potapov et al. 2008.

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3 AD & MONITORING OF DEGRADATION

*GPG = Good Practice Guidance

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Software to map forest degradation

- **Commercial software** such as ENVI, ERDAS, PCI, and ArcGIS can be used to implement most of the methods discussed above.
- **Specialized software** has been developed to deal specifically with the monitoring of forest degradation:
  - CLASlite (see http://claslite.ciw.edu/en/)
  - ImgTools (see https://imazon.org.br/PDFimazon/Portugues/congressos%20e%20anais/p1235.pdf)

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In Summary

- Need to **clearly define forest degradation** and to set a **benchmark** for measuring forest carbon stock changes
- **Detection** of forest degradation by **earth observation** is **not always possible.**
- **Different methodologies** can be used to assess different types of forest degradation:
  - **Field observations**
  - **Direct remote sensing** methods
  - **Indirect remote sensing** methods
- Diverse **commercial and open source software** available for mapping forest degradation

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4 ESTIMATION OF EFs

Estimating Emission Factors (EFs) for LULUCF activities

After the course the participants should be able to describe the procedures and methods to develop estimates of EFs the major LULUCF activities

4 ESTIMATION OF EFs

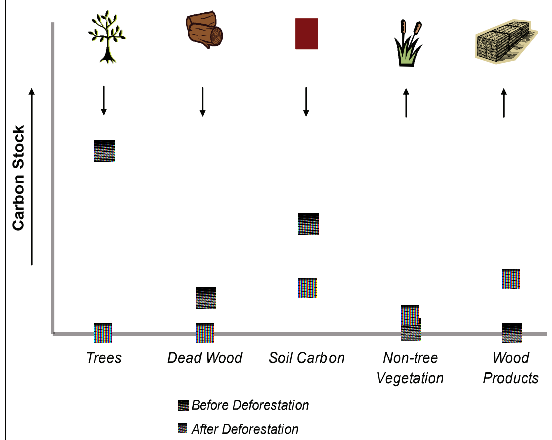
1. **Context: LULUCF activities, C pools and levels of tier**
2. Estimating EFs using stock-difference and gain-loss methods
3. Field inventory: stratification and sampling
4. Estimating C pools
5. Errors and QA/QC

1st type of LULUCF activity: Conversion - ex of deforestation (1/2)

Potential C storage in wood products

CO_2 and non-CO_2 emissions from combustion and decomposition of dead biomass and soil

1st type of LULUCF activity: Conversion - ex of deforestation (2/2)



Magnitude and **speed** of change **vary by pool**

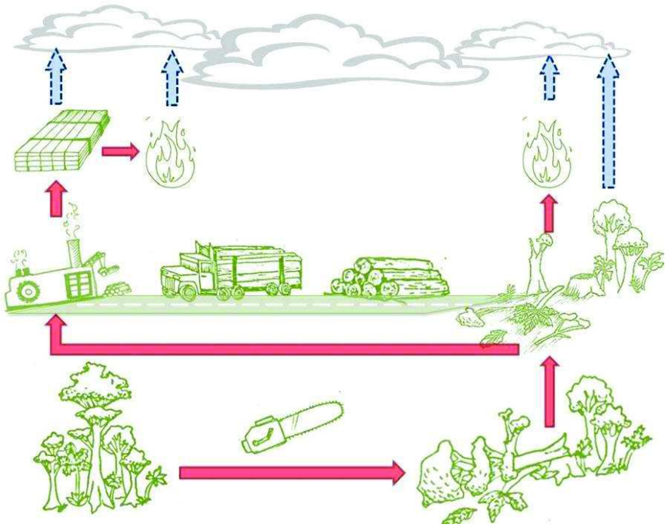
Need to know **initial and final C stocks** of **all selected pools**

2nd type of LULUCF activity: F remaining F - ex Forest degradation

Selective logging is **diffuse** : a few trees are felled.

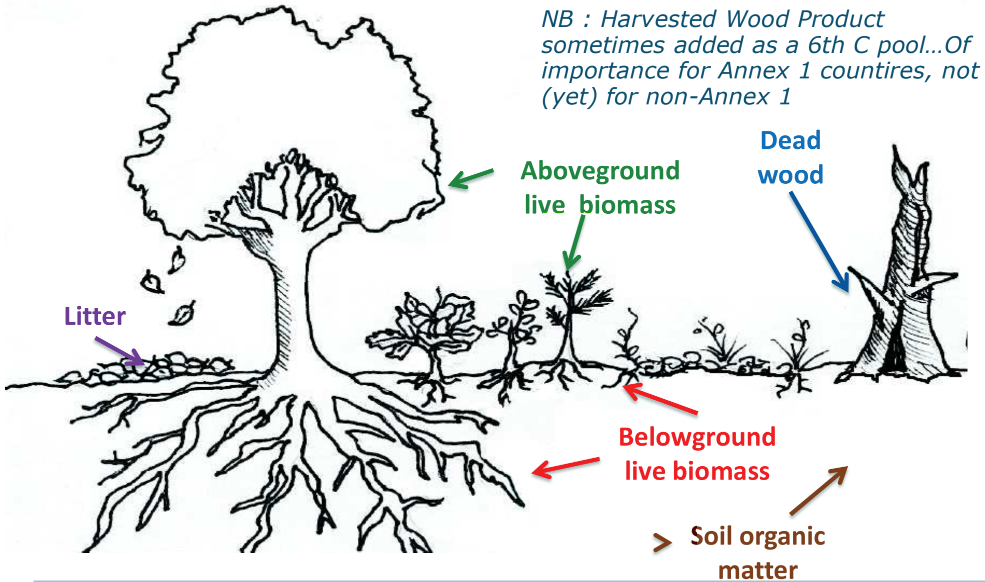
Difficult to capture C stock changes with **field inventories**

Significant emissions if it covers **large areas.**



Five forest carbon pools to monitor

NB : Harvested Wood Product sometimes added as a 6th C pool…Of importance for Annex 1 countires, not (yet) for non-Annex 1



IPCC Tiers for estimating EFs

	Tier 1	Tier 2	Tier 3
Data granularity	Default values for broad continental forest types	Country-specific	Region/forest specific
Data Sources	IPCC Emission Factor Data Base (EFDB)	Country-specific data for key factors (e.g. from field measurements)	Comprehensive field sampling repeated at regular time intervals, soils data, and use of locally calibrated models
Cost & Uncertainty	Low cost and High uncertainty	Medium to low cost and uncertainty	High cost and Low uncertainty
Fate of pools post deforestation	Assume immediate emissions at time of event—i.e. committed emissions	Can use disturbance matrices to model retention, transfers, and releases	Model transfers and releases among pools to reflect emissions through time

Default value (Tier 1): available in IPCC 2003 GPG & 2006 GL

IPCC encourages the **use of higher tiers** to estimate EFs for **significant activities and pools**

4 ESTIMATION OF EFs

1. Context: LULUCF activities, C pools and levels of tier
2. **Estimating EFs using stock-difference and gain-loss methods**
3. Field inventory: stratification and sampling
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2 approaches: stock-difference and gain-loss

	Stock-Difference	Gain-Loss
Description	Difference in C stocks in a particular pool in pre- and post–forest cover change	Net balance of additions to and removals from a carbon pool
Data requirements	Data needed on forest carbon stocks in key pools before and after conversion	Annual data needed on C losses and gains, e.g., annual tree harvest volume and annual rates of forest growth post–tree removals
Applications	Appropriate for deforestation and afforestation and for reforestation	Appropriate for forest degradation caused by tree harvest and the regrowth of carbon stocks postdisturbance

Standard equation for conversion: stock-difference

→ Most commonly applied for estimating emissions from deforestation or removals from afforestation

$$EF = \left(C_{bio,pre} - C_{bio,post} + \{[CS_0 - CS_D]/D\}\right) \times \frac{44}{12} + E_{oth}$$

Where:

EF = Emission factor, t CO_2-e ha^{-1}

$C_{bio,pre}$ = C stock in biomass prior to conversion, t C ha^{-1}

$C_{bio,post}$ = C stock in biomass post-conversion, t C ha^{-1}

CS_O = Initial or reference soil organic carbon,

CS_D = Soil organic carbon at default time D, t C ha-1

D = Default time period to transition to a new equilibrium value (20 year)

44/12 = Conversion factor for C to CO_2

E_{oth} = Emissions of non-CO_2 gases, such as CH_4 & N_2O released during burning, t CO_2-e ha^{-1} (in the case of deforestation)

Standard equation for degradation: gain-loss

→ Particularly useful for estimating emissions from forest degradation

$$EF = (\Delta C_G - \Delta C_L) \times \frac{44}{12} + E_{oth}$$

Where:

EF = Emission factor (t CO_2-e ha^{-1})

ΔC_G = Carbon stock gains in all pools (t C ha^{-1}) = function of harvest (roundwood, firewood)

ΔC_L = Carbon stock losses in all pools (t C ha^{-1}) = function of annual increment and regrowth after harvest

44/12 = Conversion factor for C to CO_2

E_{oth} = Emissions of non-CO_2 gases, such as CH_4 & N_2O released during burning, t CO_2-e ha^{-1}

4 ESTIMATION OF EFs

1. Context: LULUCF activities, C pools and levels of tier
2. Estimating EFs using stock-difference and gain-loss methods
3. **Field inventory: stratification and sampling**
4. Estimating C pools
5. Errors and QA/QC

Assessing the need for new data

- Quality, quantity, and availability of existing data **must be assessed**, to see whether **new data** need to be collected
- Criteria that existing data need to meet are:
  - **Less than 10 years old**
  - Derived from **multiple measurement** plots, in **different strata**
  - **All species** must be included in inventories
  - **Minimum Diameter** at Breast Height (DBH) is 20 cm or less
- If **new data** needed:
  - **Full inventory**: time consuming and expensive. Not recommended for forests> 10 ha.
  - **Statistical inventory** (= by **sampling**): plots measurements are **extrapolated** to the whole massif. Need **defining strata** and designing a **sampling plan**

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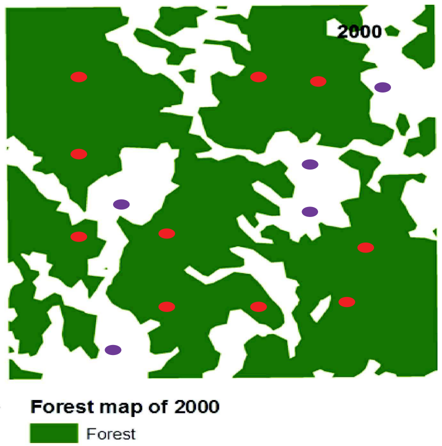
Purpose of stratification

The purpose of stratification is to organize a ***heterogeneous*** area into "strata" that form relatively ***homogenous*** units.



Overall sampling **effort** is **reduced**:

- More homogeneous strata mean that **fewer samples** are needed to achieve a given target for **accuracy/precision**
- **Efforts** are focused on strata with a **higher heterogeneity** (e.g., a higher standard deviation for C stocks, calculated after a pre-inventory)

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Stratification plan

1. Develop **initial stratification plan** based on biophysical or human factors influencing the **distribution of C stocks**:
   - Land use
   - Vegetation/forest type
   - Elevation/slope
   - Drainage
   - Proximity to human infrastructure

2. Collect preliminary data on **AGB** (proxy) to extrapolate the **heterogeneity of C stock** in each stratum

   (at least 20 plots per stratum. PICARD, 2006)

AGB = Above-Ground Biomass

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Plots – Number (1/3)

The number of plots should be large enough to have an **accurate estimate**, but small enough to **minimize costs**.

The **number of plots** to inventory depends on:

- **Strata** (number and surface of each strata)
- **Heterogeneity of AGB** (proxy for C stocks) in each strata, characterized by **standard deviation** (from pre-inventory or literature) ➔ The greater the heterogeneity, the more measurements needed to approach the mean precisely.
- **Level of precision** targeted for monitoring: **acceptable error = confidence interval** and **probability threshold = degree of confidence**.
- *For ex., choosing an acceptable error of 10% (± 5% confidence interval) with a 95% probability threshold means that there is a 95% chance that the result will be within a range of ± 5% around the "real" value.*

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Plots – Number (2/3)

Diverse formula exist to estimate the number N of sample plots. In Mali, for instance, this one is recommended to design Forest Management Plans (Manuel d'aménagement forestier - Nouvellet, 2002):

$$N = t^2 CV^2 / e^2$$

t = Student's t-value for the probability threshold p

CV = Coefficient of Variation (=standard deviation / mean)

e = Acceptable error

In general, p = 95% and e = 10%

Plots – Number (3/3)

CV known (here, for ex, 27%)

Student's t-values set in a table. Specific t-value to be determined, based on:

- the confidence interval (=acceptable error / 2) is 5% -> α = 0,05
- an infinite degree of freedom

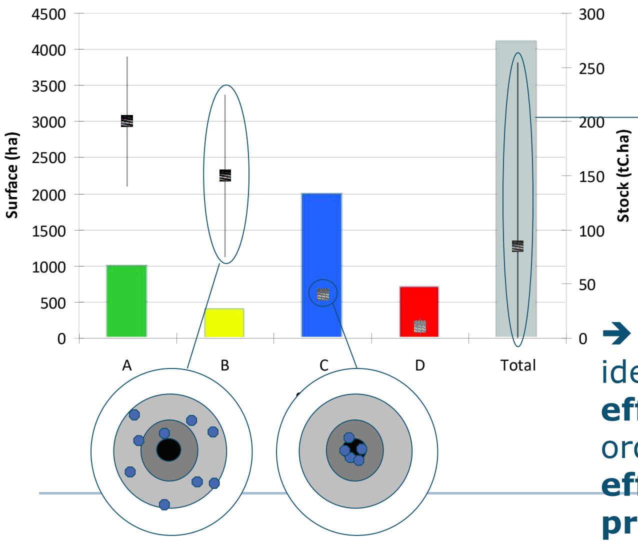
-> Here, for ex, t = 1,96

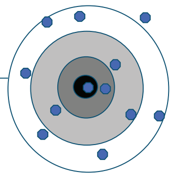
If the N estimated ($N = t^2 * CV^2/e^2$) is below 30 (for ex. 28), the calculation should be made with the t-value for N-1 degree of freedom (in our case, 27)

-> Here, for ex, t = 2,052

ddl \ α	0,90	0,50	0,30	0,20	0,10	0,05
1	0,158	1,000	1,963	3,078	6,314	12,706
2	0,142	0,816	1,386	1,886	2,920	4,303
3	0,137	0,765	1,250	1,638	2,353	3,182
4	0,134	0,741	1,190	1,533	2,132	2,776
5	0,132	0,727	1,156	1,476	2,015	2,571
6	0,131	0,718	1,134	1,440	1,943	2,447
7	0,130	0,711	1,119	1,415	1,895	2,365
8	0,130	0,706	1,108	1,397	1,860	2,306
9	0,129	0,703	1,100	1,383	1,833	2,262
10	0,129	0,700	1,093	1,372	1,812	2,228
11	0,129	0,697	1,088	1,363	1,796	2,201
12	0,128	0,695	1,083	1,356	1,782	2,179
13	0,128	0,694	1,079	1,350	1,771	2,160
14	0,128	0,692	1,076	1,345	1,761	2,145
15	0,128	0,691	1,074	1,341	1,753	2,131
16	0,128	0,690	1,071	1,337	1,746	2,120
17	0,128	0,689	1,069	1,333	1,740	2,110
18	0,127	0,688	1,067	1,330	1,734	2,101
19	0,127	0,688	1,066	1,328	1,729	2,093
20	0,127	0,687	1,064	1,325	1,725	2,086
21	0,127	0,686	1,063	1,323	1,721	2,080
22	0,127	0,686	1,061	1,321	1,717	2,074
23	0,127	0,685	1,060	1,319	1,714	2,069
24	0,127	0,685	1,059	1,318	1,711	2,064
25	0,127	0,684	1,058	1,316	1,708	2,060
26	0,127	0,684	1,058	1,315	1,706	2,056
27	0,127	0,684	1,057	1,314	1,703	2,052
28	0,127	0,683	1,056	1,313	1,701	2,048
29	0,127	0,683	1,055	1,311	1,699	2,045
30	0,127	0,683	1,055	1,310	1,697	2,042
40	0,126	0,681	1,050	1,303	1,684	2,021
80	0,126	0,678	1,043	1,292	1,664	1,990
120	0,126	0,677	1,041	1,289	1,658	1,980
∞	0,126	0,675	1,037	1,282	1,645	1,960

Ex. Relation between AGB or C stock heterogeneity and number of plots





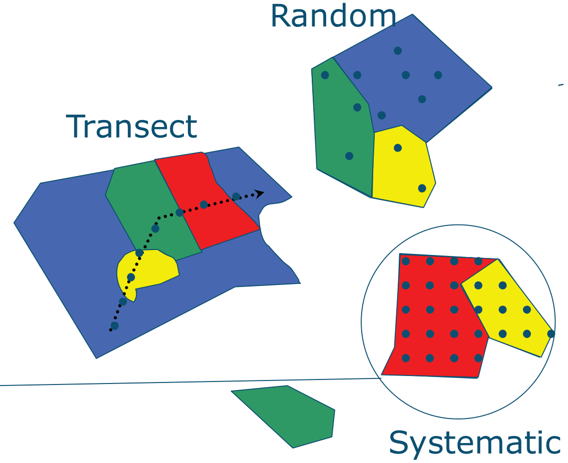
Poor precision for the overall forest area

➔ **Stratification** helps identifying **where to put efforts** (strata B), in order to have a **cost-efficient sampling** and **precise results**

Strata B: High SD / poor precision

Plots – Positioning (1/2)

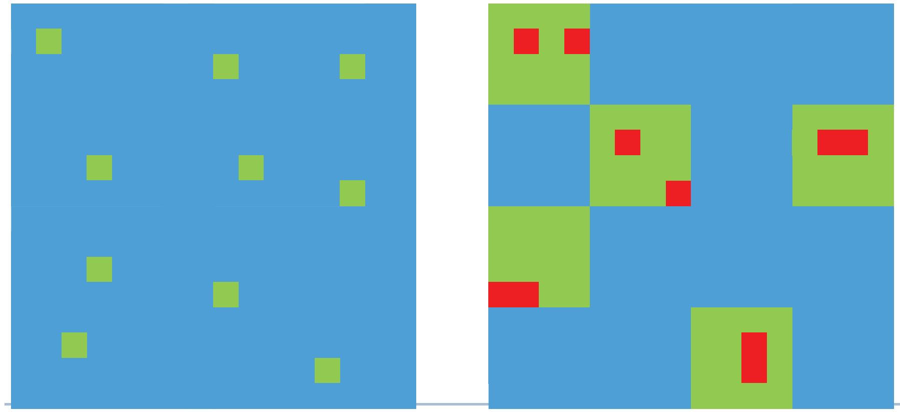
Most recommended: **systematic sampling**, with plot density depending on stratification (**more plots** for strata with **higher heterogeneity**) and **random starting point** for the grid



Plots – Positioning (2/2)

Possible to set up a **cluster sampling** for large forest inventories ➔ **spatial concentration** of field work: **saving of time and resources**

Simple sampling | **Cluster sampling**



Primary plots

Secondary plots

Plots – Size, shape, permanent vs non-permanent

Size : need to have enough trees to estimate the mean C stock with the lesser uncertainty: In Sahel, it is recommended to have **at least 8-10 trees/plot** (Pearson et al., 2005).

Thiombiano et al. (2016) provide indications for the minimum area per plot, depending on the type of vegetation:

Type de végétation	Superficie (m²)
Forêts denses et galeries forestières	500 (50 m x 10 m)
Savanes et forêts claires: placettes de forme carré	900 (30 m x 30 m)
Savanes et forêts claires: placettes de forme rectangulaire	1000 (50 m x 20 m)
Steppes	2500 (50 m x 50 m)
Systèmes agroforestiers	2500 (50 m x 50 m)
Formations contractées	2500 (100 m x 25 m))
Prairie aquatique	16 (4 m x 4 m)

They also provide indication for "subplots" (inner circle to assess regeneration)

Type de végétation	Superficie (m²)
Systèmes agroforestiers, steppe et formations contractées	25 (5 m × 5 m)
Savanes et forêts claires	25 (5 m × 5 m)
Forêts denses et galeries forestières	1 (1 m × 1 m)

Shape: No impact on calculations…Circle, square, rectangle…

Permanent or not: Depend on the objectives. NP plots can give **statistically sound results** in most cases.

4 ESTIMATION OF EFs

Which carbon pools to monitor? (1/2)

LULUCF activity to be monitored. For ex, SOC estimates needed for deforestation, not for degradation

Absolute level of C stocks in the pool

Relative change of C stocks in the pool, following human disturbance

Methods available to measure

Costs to measure

Attainable **accuracy and precision**

Which carbon pools to monitor? (2/2)

➔ **AGB** (trunks, branches, etc.): in all cases, **easy** to measure; represents a **large portion** of the total C stock

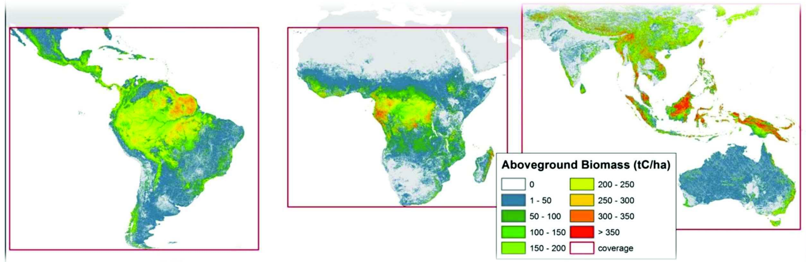
➔ **BGB** (roots): in all cases, **robust models/estimates** are provided in IPCC, 2006, AFOLU GL; represents a **large portion** of the total C stock

Other C pools? ➔ To assess **case by case**, but "*good practice*" according to IPCC (***completeness principle***) to include pools representing **5% or more** of total C stock:

- **Dead wood** (standing and lying): can represent up to 10% of the total C stock
- **Soil C**: (i) should be **included** if deforestation with soil **disturbance** (agriculture, roads, mines, etc.) (ii) could be **ignored** if conversion to **grassland**

For Tier 1: using IPCC default value or global Biomass C stock maps

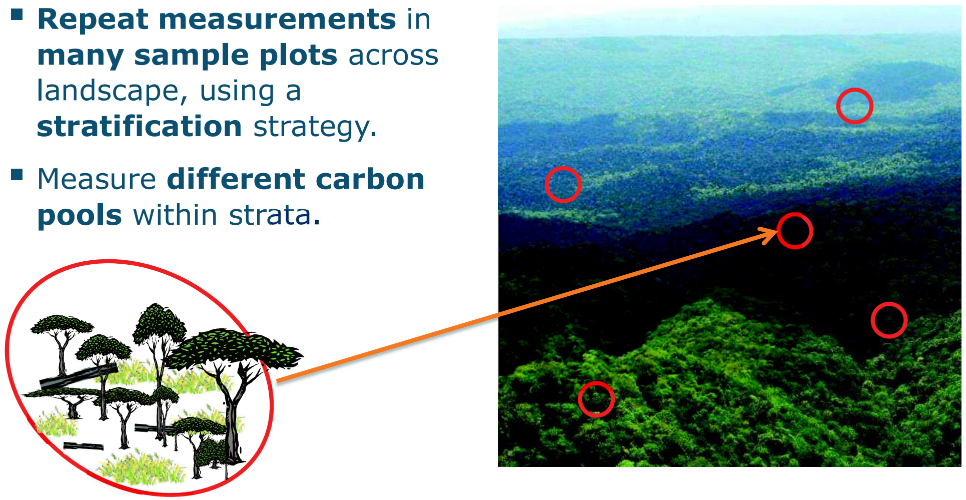
- Biomass C stock map shown below is an **improvement** over the IPCC Tier 1 values
- EFs can be developed using biomass C stock maps, which provide **estimates of C stocks by each strata**, with the **stock-difference** method.



Developed by S. Saatchi 2013, in collaboration with Winrock and Applied GeoSolutions; map at 250 m resolution.

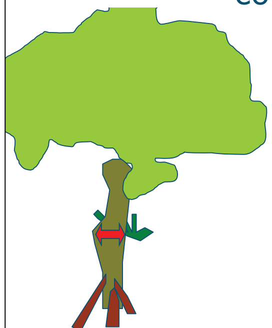
For Tier 2 and 3: traditional field measurements

- **Repeat measurements** in **many sample plots** across landscape, using a **stratification** strategy.
- Measure **different carbon pools** within strata.

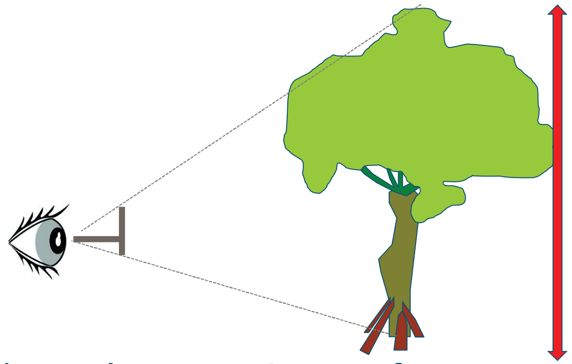


Common measures

Diameter at Breast Height (DBH) or circumference is commonly measured.



The height is more rarely measured.



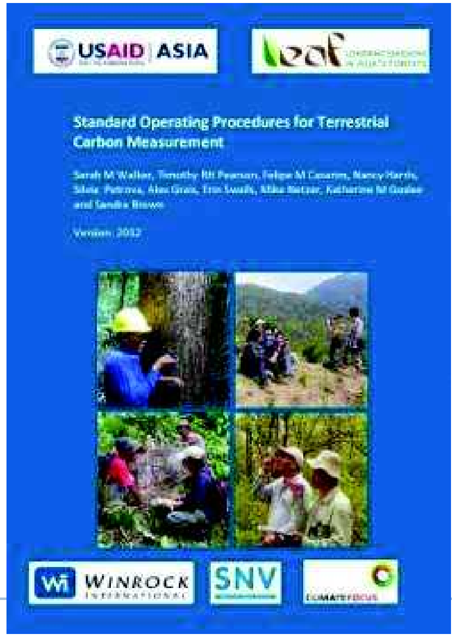
Woodcutter's cross. Distance from the observer to the tree = height of the tree

Importance of Standard Operating Procedures (SOPs)

Methods must be **standardized** to ensure measurements are implemented **consistently** between **field crews and inventories.**

➔ **Standard Operating Procedures (SOPs)**

For ex., Winrock SOPs for Terrestrial Carbon Measurements can be used to measure C stocks of forests and other land cover types.



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Estimating forest C stocks using field data (1/2)

- Measurements of carbon pools are recorded in the field.
- **Allometric equations** are used to estimate C stocks in **AGB**, based on field data.
- **BGB** is generally derived from AGB, using a **shoot-to-root ratio.** Other C pools are estimated with **other formula/models**.
- **Plot** results are **extrapolated** at **strata** level.

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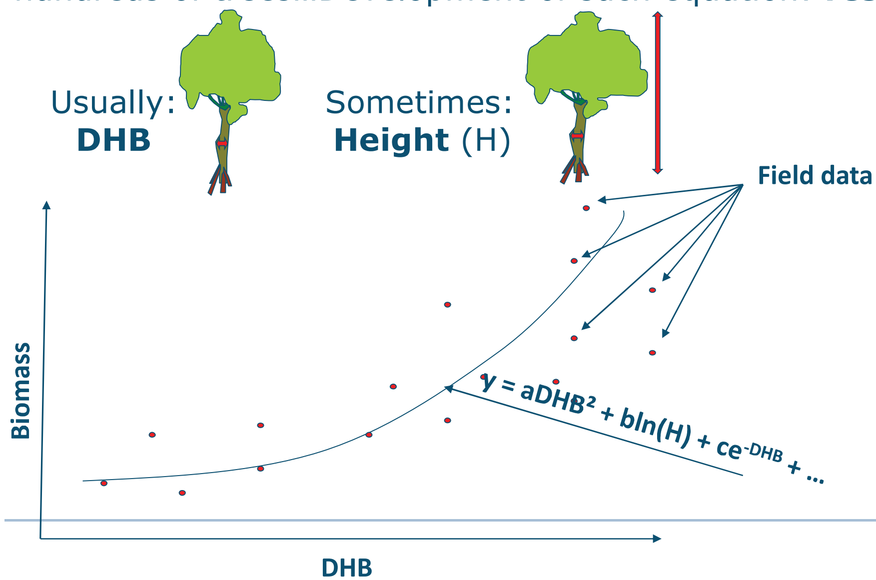
Estimating forest C stocks using field data (2/2)

Allometric equation: based on **destructive measurements** of hundreds of trees…Development of such equation: **research**



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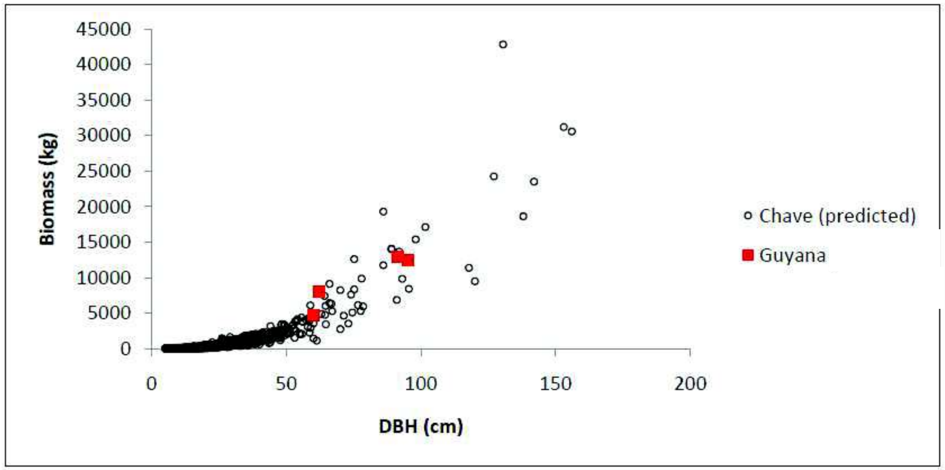
Validating existing allometric equations

Many allometric equations worldwide: **adequacy** needs to be **verified** with **local data** or through **destructive sampling**.



Ex: Chave et al. (2005) equation based on DBH and wood density, developed in the **Congo Basin** and tested in **Guyana**

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Estimating C in the BGB

BGB (roots) is **rarely measured**. A **root-to-shoot ratio** can be applied instead, such as those from IPCC.

Table 2.3.3. Root to shoot ratios modified* from Table 4.4. in IPCC GL AFOLU.

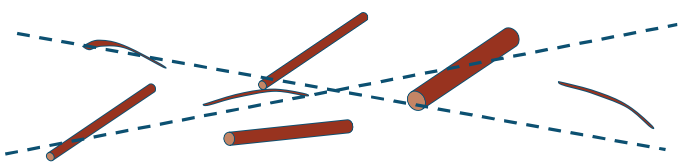
Domain	Ecological Zone	Above-ground biomass	Root-to-shoot ratio	Range
Tropical	Tropical rainforest or humid forest	<125 t.ha-1	0.20	0.09-0.25
		>125 t.ha-1	0.24	0.22-0.33
	Tropical dry forest	<20 t.ha-1	0.56	0.28-0.68
		>20 t.ha-1	0.28	0.27-0.28
Subtropical	Subtropical humid forest	<125 t.ha-1	0.20	0.09-0.25
		>125 t.ha-1	0.24	0.22-0.33
	Subtropical dry forest	<20 t.ha-1	0.56	0.28-0.68
		>20 t.ha-1	0.28	0.27-0.28

*the modification corrects an error in the table based on communications with Karel Mokany, the lead author of the peer reviewed paper from which the data were extracted.

For instance, in **Tropical dry forest** with less than 20 t/ha of AGB (e.g., **steppes**):

BGB = **0.56** x AGB

Estimating C in the deadwood



Standing deadwood: Estimate a **% of AGB**

Lying deadwood: use the "***transect intersection method***" ➔ Diameters of deadwood elements are measured at the intersection of a transect established on the plots

Volume of deadwood per ha:

$$V_{BM} = \pi^2 * \left[\frac{(d_1^2 + d_2^2 \cdots d_n^2)}{8L}\right]$$

d_i: Diameter of element i

L: Sum of all transects

Estimating C in the soil (1/2)

Need to follow specific IPCC guidelines, depending on the LULUCF activity to monitor

For ex, for estimating soil C changes in deforested areas:

Soil carbon pool	Tier 1	Tier 2	Tier 3
Organic carbon in mineral soil	Default reference C stocks and stock change factors from IPCC	Country-specific data on reference C stocks & stock change factors	Validated model complemented by measures, or direct measures of stock change through monitoring networks
Organic carbon in organic soil	Default emission factor from IPCC	Country-specific data on emission factors	Validated model complemented by measures, or direct measures of stock change

organic soils*: dominated by the* ***remains of plants*** *that accumulate in significant amounts at the soil surface; commonly called* ***peats***

mineral soils*: mainly composed of* ***mixtures of sand, silt, and clay****, often with some enrichment of the surface layer with organic matter*

Estimating C in the soil (2/2)

Tier 2 equation to estimate ΔC: $[CS_0 - CS_D]/D$, where:

CS_O = Initial soil organic carbon, t C ha-1

CS_D = Soil organic carbon at default time D, t C ha-1

D = Default time period to transition to a new equilibrium value (**20 years**)

$CS_D = CS_O * F_{LU} * F_{MG} * F_I$, with F factors (dimensionless) related to Land Use system (**F_{LU}**), soil Management regime (**F_{MG}**), and organic matter inputs (**F_I**)

Converted to:	F_{LU}	F_{MG},	F_I
i. Conversion to permanent agriculture	0.48	1.0	1.0
(assumes continuous cultivation for 20 yr, full annual tillage, and <30% of ground covered with residues, and medium inputs typical of annual crops).			
ii. Conversion to unpaved roads:	0.82	1.0	0.92
(assumes idle land that is set aside with no further tillage, substantial initial soil disturbance and < 30% of surface covered by residues and low inputs).			
iii. Shifting cultivation	0.65/0.80	1.0	1.0
(short and long fallow)			

Source: IPCC, 2006, AFOLU GL

From sample plots to total biomass C

1. Estimate **biomass stocks for each pool**
2. **Scale** each sample to **per hectare level**
3. **Convert biomass values to carbon values** (C fraction = 0,5; CO_2 = 44/12 x C)
4. **Calculate mean and 95% confidence** interval of C stock in each pool within each stratum
5. **Sum mean stock per pool**

Example of EF development for deforestation

Conversion of forest to cropland

Carbon Pool	Carbon Stock (t C ha^{-1})
Aboveground tree biomass	190.6 ± 15.5
Belowground tree biomass	44.8± 3.7
Saplings*	5.2 ± 0.6
Dead wood (standing)#	3.3 ± 1.7
Dead wood (lying)#	19.3 ± 3.7
Total carbon stock	263.2
Soil to 30 cm	102 ± 23.7
Annual crops	3.0

Assume all emissions occur at time of event

EF for biomass components:

=(Cpre-Cpost)×44/12
=(263.2-3.0) x 44/12
= 954 tCO_2/ha

EF for soil:

= $(CS_o - CS_O*F_{LU}*F_{MG}*F_I)$
=(102- 102 x 0.48 x 1 x 1)x44/12
= 194 tCO_2/ha

Total EF = 1,148 tCO_2/ha

4 ESTIMATION OF EFs

1. Context: LULUCF activities, C pools and levels of tier
2. Estimating EFs using stock-difference and gain-loss methods
3. Field inventory: stratification and sampling
4. Estimating C pools
5. **Errors and QA/QC**

1st type of error: Sampling error

Sampling error reflects the **variability** in the **estimate** due to measuring **only a subset** of the population of interest.

A **large sampling error** can result from **incorrect distribution** or **number/size of plots** used for sampling.

Plot size, plot number and **distribution** must adequately and efficiently capture **spatial variability**.

2nd type of error: Measurement error

There are **many opportunities** to make measurement and recording mistakes during field inventory!

3rd type of error: Model or regression error

Regression equations are developed specifically for a **specific set of tree species** within a **specific DBH range**.

Large regression errors can occur if field inventory DBH values are applied to an **inappropriate** regression formula for the **DBH range** and **species range**.

Quality Assurance / Quality Control (QA/QC)

To minimize error, data collection and analysis should include **QA/QC** measures for:

- **Collecting reliable field data ➔** Data collection should follow a set of SOPs
- **Verifying methods used to analyze field data ➔** Regular checks by supervisor are needed
- **Verifying results ➔** Outliers and mistakes should be identified as far as possible, to see whether they relate to a problem in data entry and/or use of methods
- **Maintaining and archiving data ➔** Data should be stored in a secure / fire-proof location and backed up routinely

In summary

- The IPCC recommends that it is good practice to use higher Tiers for the measurement of significant sources/sinks.
- The **stock-difference** method is most commonly applied for estimating emissions from **conversion** (deforestation / afforestation)
- The **gain-loss** method is the most suitable method to estimate emissions from **forest remaining forest** (degradation / SFM).
- **Allometric equations** that link tree variables (DBH, height, wood density) to **AGB** are basis to estimate **C emissions/removals**
- The use of **SOPs** and **QA/QC** are important to **ensure the quality of estimates** and to **minimize errors**.

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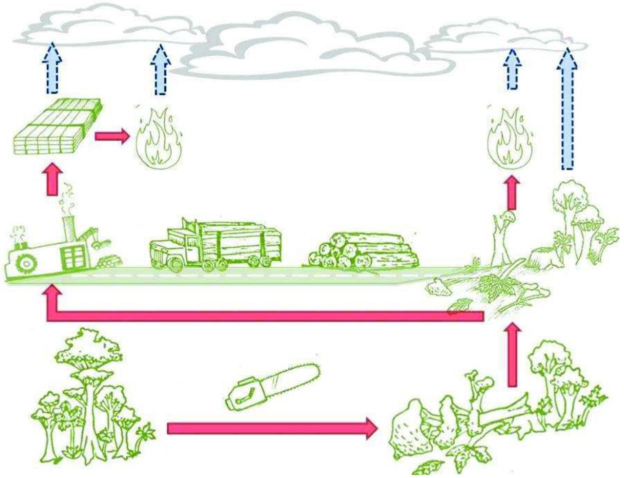
- UNFCCC. 2009. Methodological guidance for REDD+. http://unfccc.int/resource/docs/2009/cop15/eng/11a01.pdf#page=11
- UNFCCC. 2012. Decision 12/CP17. http://unfccc.int/resource/docs/2011/cop17/eng/09a02.pdf#page=16
- UNFCCC. 2013. Decision 1/CP18. http://unfccc.int/resource/docs/2012/cop18/eng/08a01.pdf#page=6

5 GHG Inventory

Estimating GHG emissions/removals from LULUCF activities

After the course the participants should be able to estimate GHG emissions and removals from LULUCF activities in accordance with the requirements from the IPCC GPG and GL

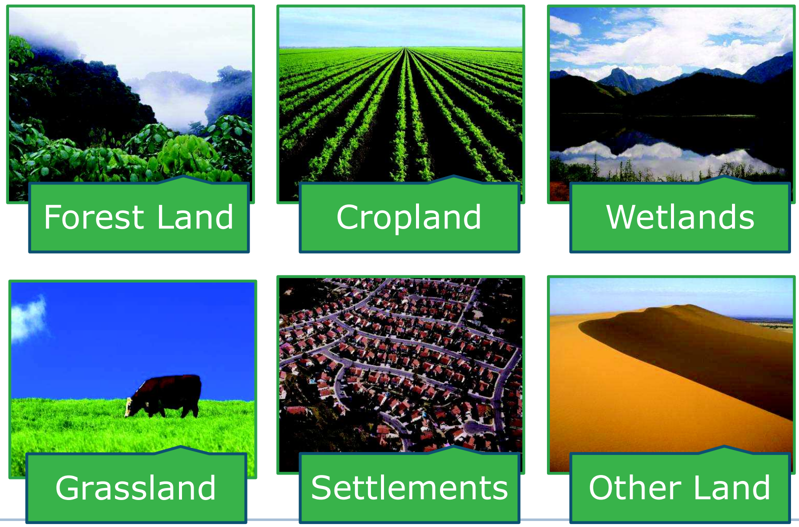


GHG Inventory

1. 2006 IPCC AFOLU Guidelines and 2003 GPG-LULUCF land-use categories and subcategories
2. Estimating emissions and removals: Combining emission factors (EFs) and activity data (AD)
3. Methods for estimating C emissions from deforestation (conversion of forests to nonforests): country example of Guyana

2003 IPCC GPG LULUCF (1/2)

Dividing landscapes into **categories** allow nations to track land-use changes over time in a **consistent** and **comparable** manner



GPG-LULUCF: Good Practice Guidance for Land Use, Land Use Change, and Forestry

IPCC : Intergovernmental Panel of experts on Climate Change

2003 IPCC GPG LULUCF (2/2)

Monitoring of emissions/removals from **any LU category remaining the same LU category**, as well as from **LUC between categories**

LU categories can be **divided** into as many **sub-categories** (**strata**) as required, to have the **most complete & accurate MRV possible**

For instance: 2 sub-categories for Forest Land **To →** **From ↓**		**Forest land**		**Other land**
		"Intact (natural) forest"	**"Non-intact forest"**	
Forest land	**"Intact (natural) Forest"**	**Forest conservation**	**Forest degradation**	**Deforestation**
	"Non-intact forest"	**Enhancement of C stocks (forest restoration)**	**Sustainable management of forests**	**Deforestation**
Other land		-	**Enhancement of C stocks (A/R)**	

2006 IPCC AFOLU Guidelines

Integrates Agriculture and LULUCF sectors from previous 2003 GPG-LULUCF into one sector called **Agriculture, Forestry, and Other Land Use (AFOLU)**:

- Maintains same **six land use categories** of 2003 GPG-LULUCF
- Covers **emissions and removals** from the terrestrial biosphere
- Provides updated **carbon/GHG estimation methodologies** for carbon pools in land-use categories

GHG Inventory

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3. Methods for estimating C emissions from deforestation (conversion of forests to nonforests): country example of Guyana

Basic equation: Combining AD and EFs

GHG emissions/removals per unit (Emission Factor)	**X**	**Area or volume (Activity Data)**	**=**	**GHG emissions/ removals**

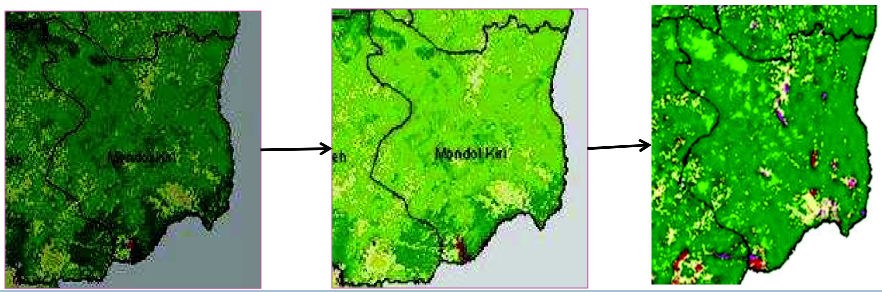
Activity Data (AD):

- **Spatial extent** of **land use** (e.g., sustainable forest management) or **land use change** (e.g., deforestation or afforestation). Expressed in **ha/yr**
- **Volume of harvested wood** (timber or fuel) in the case of forest **degradation**. Expressed in **m³/yr**

Emission Factors (EF): Emissions/removals of GHG per unit of activity, e.g., tCO_{2eq}/ha or tCO_2/m^3

Ex: Deforestation - Developing AD

- Create **multidates LULUCF maps**, differentiating different **Forest land sub-categories** if needed (e.g., mountainous intact forest, mountainous non-intact forest, lowland intact forest, lowland non-intact forest)
- Track **areas of change** in each **subcategories** (ha/yr).

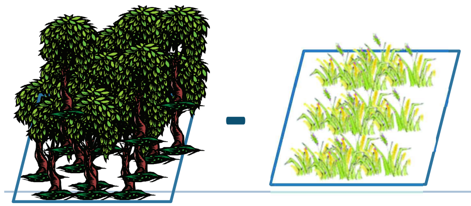


Ex: Deforestation - Developing EFs

- Analyze field data and estimate **carbon stocks** and associated uncertainty for each **subcategories**.
- Create EFs for **all types of LUC** (expressed in tCO_{2eq}/ha), e.g., lowland non-intact forest ➔ grassland, mountain intact forest ➔ cropland, etc.

Mountain intact forest C stock

Cropland C stocks



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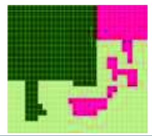
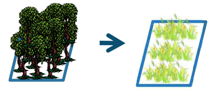
EF for deforestation of mountain intact forest to cropland

Ex. Deforestation - Estimating GHG emissions/removals

Area of change (AD)	*	Emissions per unit of change (EFs)	=	GHG emissions from mountain intact forest to cropland
1,000 ha	*	895 t CO_{2eq}/ha	=	895,000 tCO_{2eq}





Ex: Afforestation – Estimating C removals

- **AD**: same process than for tracking deforestation. Need to differentiate **subcategories: e.g., in the case of Turkey:** Afforestation on public land, Afforestation on private land, Assisted Natural Regeneration on public land, Erosion Control on public range land.
- **EFs**: Create EFs for **all types of afforestation** (expressed in tCO_{2eq}/ha). Ex for type I of A/R: EF_i (tCO_2/ha/yr) = Carbon Fraction (tC/tdm) x 44/12 x Basic Wood $Density_i$ (tdm/m^3) x $Increment_i$ (m^3/ha/yr) x Biomass Expansion Factor x (1+R), where R = Root-to-Shoot ratio (dimensionless).
- **GHG removals** from Afforestation = Σ (ADi x EFi)

Ex: Degradation – Estimating C emissions

- AD (m^3/ha): volume of timber removed (NB: over-bark)
- EF (tC/m^3):
  - Extracted Log Emissions (ELE)
  - Logging Damage Factor (LDF)
  - Logging Infrastructure Factor (LIF)
- C emissions = volume x (ELE + LDF+ LIF)

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Country example: Guyana

- A High Forest cover, Low Deforestation (HFLD) country
- Historically, lack of data on forest cover and deforestation
- Main driver of emissions from deforestation is mining
- Currently developing national-level REDD+ system

Source: http://news.mongabay.com/2006/0501-guyana.html

Gathering data to estimate AD

GIS and remote sensing data collection and processing for the monitored years, including:
- Mapping areas of forest change (per activity/driver)
- Mapping areas of forest loss due to wildfire

	Potential for Future Change strata (v. 2011)			
Driver Year 2	High	Medium	Low	Total
Agriculture	38	14		52
Degraded Burning	8	77	0	85
Forest Harvest	3,039	743	75	3,857
Forestry Roads	319	60	1	380
Infrastructure Roads	256	88	33	377
Mining	12,190	833	295	13,317
Mining Roads	971	157	10	1,138
Natural	208	60	124	392
Shifting Agriculture	113	142	62	317
Total	17,142	2,173	600	19,915

Satellite images analysed by Indufor and Guyana Forestry Commission (GFC).

Data for 1990–2010 are from Landsat.

Data for 2011 are from Landsat and RapidEye.

Data for 2012 and going forward are wall-to-wall RapidEye.

Gathering data to estimate EFs

C stocks in forest carbon pools were estimated through:

Collecting data from a **well-designed sampling plan**

Data derived from **multiple measurement plots**

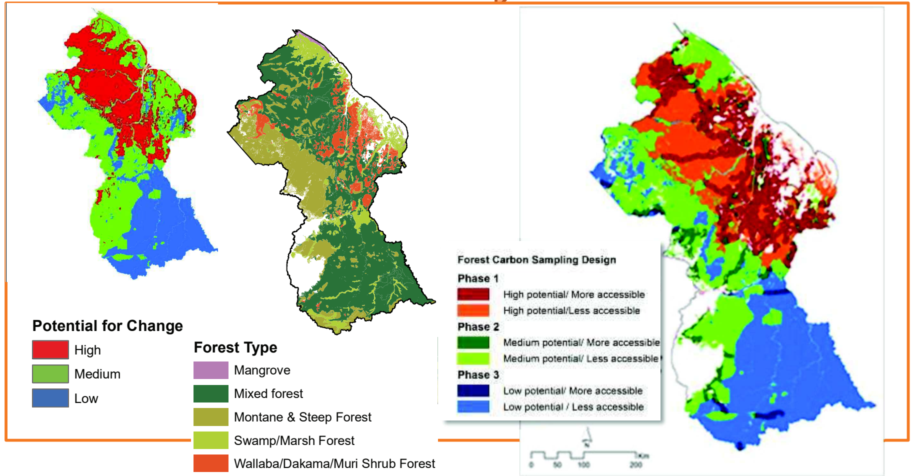
Including **all species** and **all 5 pools** in inventories

Minimum diameter at breast height (**DBH**) was **5 cm**

Stratified by threat to ensure **cost-effective sampling** while producing results with **low uncertainties**: **acceptable error** of +/-15%, set at **95% confidence interval**

Estimating EFs: Forest carbon stratification map

Potential for future change map ➕ Forest type map → Forest carbon stratification map



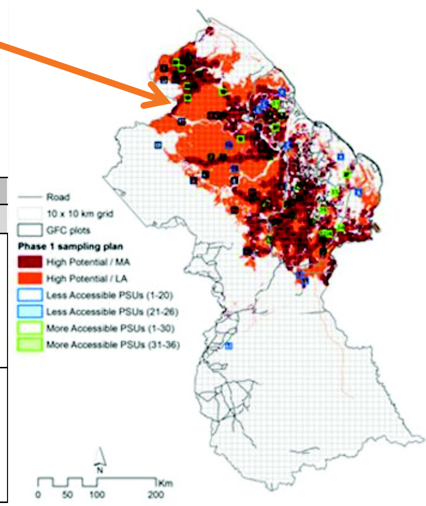
Estimating EFs for deforestation

EFs from field measurements of **35 cluster plots** established in sampling design

Precision of C stocks was **<12% of mean** at **95% confidence**

Stratum	Drivers	Emission Factors t CO_2e/ha
More Accessible (MA)	Forestry infrastructure	1,010.6
	Agriculture	1,116.8
	Mining (medium and large scale)	1,010.6
	Infrastructure	1,010.6
	Fire-Biomass burning	744.6
Less Accessible (LA)	Forestry infrastructure	1,448.0
	Agriculture	1,536.5
	Mining (medium and large scale)	1,368.9
	Infrastructure	1,448.0
	Fire-Biomass burning	1,108.6

Data collected and analyzed by Winrock and Guyana Forestry Commission



Estimation of C emissions from deforestation

A. AD from satellite imagery by Indufor and Guyana Forestry Commission (GFC)

Stratum	Drivers	Area of Change (ha) 2010	2011
More Accessible (MA)	Forestry infrastructure	70	172
	Agriculture	15	31
	Mining (medium and large scale)	1,423	4081
	Infrastructure	9	493
	Fire-Biomass burning		14
Less Accessible (LA)	Forestry infrastructure	224	61
	Agriculture	498	20
	Mining (medium and large scale)	7,955	4107
	Infrastructure	55	866
	Fire-Biomass burning	32	44

X

B. EF from field measurements of 35 cluster plots (precision about 12% of mean at 95% confidence) by Winrock International and GFC

Stratum	Drivers	Emission Factors t CO_2e/ha
More Accessible (MA)	Forestry infrastructure	1,010.6
	Agriculture	1,116.8
	Mining (medium and large scale)	1,010.6
	Infrastructure	1,010.6
	Fire-Biomass burning	744.6
Less Accessible (LA)	Forestry infrastructure	1,448.0
	Agriculture	1,536.5
	Mining (medium and large scale)	1,368.9
	Infrastructure	1,448.0
	Fire-Biomass burning	1,108.6

C. Emissions estimated as the **product of AD and EF** for each stratum by driver and summed across strata to given annual emissions

Assumes instantaneous oxidation—that is, occurs in year of event

Drivers	Emissions (tCO2) 2010	2011
Forestry infrastructure	395,594	261,657
Agriculture	781,258	66,215
Mining (medium and large scale)	12,327,673	9,746,426
Infrastructure	88,318	1,752,972
Fire-Biomass burning	35,605	58,738
Subtotal t CO2/yr	13,628,448	11,886,007

In summary

- Estimating C emissions and removals from LULUCF follows IPCC **2006 AFOLU GL**, using **2003 GPG LULUCF**
- Estimating emissions and removals is a **combination of AD and EFs**.
- The **stock-change approach** is commonly used to estimate C emissions from **deforestation** or removals from **afforestation**
- The **gain-loss approach** is commonly used to estimate C emissions from **degradation**

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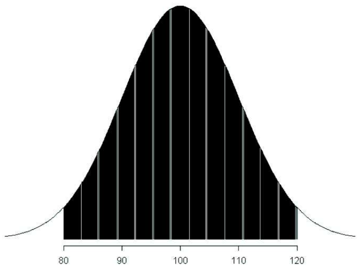
6 ESTIMATING UNCERTAINTIES

Identifying and minimizing uncertainties (lack of precision and/or accuracy)



After the course the participants should be able to:

- Identify sources of uncertainty in the estimates of area change (AD) and carbon stocks change or GHG flux (EF)
- Implement the correct steps to calculate uncertainties and minimise them in a conservative way

1

6 ESTIMATION OF UNCERTAINTIES

1. **General concepts**
2. Uncertainties in area-change estimates
3. Uncertainties in carbon stocks change estimates
4. Combination of uncertainties

2

Uncertainty in IPCC and UNFCCC context

Uncertainty is the lack of knowledge of the true value of a parameter (e.g., area and C stock estimates in LULUCF context)

Assessing uncertainty is **FUNDAMENTAL** in the IPCC and UNFCCC contexts: the IPCC defines GHG inventories consistent with "*good practice*" as those which "*contain **neither over- nor underestimates** so far as can be judged, and in which **uncertainties are reduced as far as practicable***."

In the **accounting context**, (i.e., if reduced GHG emissions or increased C removals are rewarded), information on uncertainty are used to develop ***conservative*** estimates, to ensure that **claims for reward are not overestimated**.

3

Systematic errors and random errors (1/2)

- **Uncertainty** consists of two components:
  - ***Bias or systematic error*** (lack of ***accuracy***) occurs, e.g., due to **flaws in the measurements or sampling methods** or due to **use of an EF that is not suitable**
  - ***Random error*** (lack of ***precision***) is a random variation above or below a mean value. **It cannot be fully avoided** but **can be reduced** by, for example, increasing the sample size.

Accuracy: agreement **between estimates** and the **true value**
Precision: agreement **among repeated estimates**

Accurate but not precise | **Precise but not accurate** | **Accurate and precise**

4

Systematic errors and random errors (2/2)

Systematic errors: to be **avoided** where possible, or quantified ex-post and **removed**.

Random errors: **cannot be avoided** but **can be reduced**. Tend to **cancel out** each other at higher levels of aggregation.

For ex., **estimates at national** levels (e.g., total biomass, total forest area) *usually** have a **lower impact** from random errors than **estimates at sub-national** levels.

Assuming that larger areas have **greater sample sizes which, in turn, lead to **greater precision** and **less uncertainty**.*

95% Confidence interval

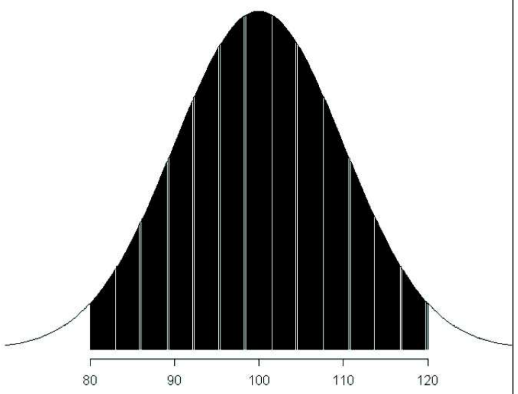
Uncertainty is usually expressed by a ***95% confidence interval***:

For ex, if a certain area is estimated at 100 ha (mean value) with a 95% confidence interval ranging from 80 to 120 ha, it means:

- The **uncertainty** in the area estimate is **±20%.**

  (or, in other words)

- There is **95% of chance** that the **true value** for the area is **between 80 and 120 ha**



Source: IPCC 2003 GPG-LULUCF

Correlation

- ***Correlation*** means **dependency** between parameters:
  - The "**Pearson correlation coefficient**" assumes values between [-1, +1]
  - Correlation coefficient of **+1** means a **perfect positive correlation**
  - If the variables are **independent** of each other, the correlation coefficient is **0**

Trend uncertainty

- The ***trend*** describes the **change** of emissions or removals **between two points** in time.
- ***Trend uncertainty*** describes the **uncertainty in the change** of emissions or removals.
- Trend uncertainty is expressed as **percentage points**: For ex, if the trend is +5% and the 95% confidence interval of the trend is +3 to +7%, we can say that trend uncertainty is **±2%** points.

6 ESTIMATION OF UNCERTAINTIES

1. General concepts
2. **Uncertainties in area-change estimates**
3. Uncertainties in carbon stocks change estimates
4. Combination of uncertainties

Accuracy assessment of land cover and changes (1/3)

Methods are **diverse**. In all case, the accuracy is assessed via ***independent reference data*** (greater quality than the map)

The aim is to characterize the **frequency of errors** (**omission** and **commission**) **for each land cover class**.

*Errors of **omission*** = excluding an area from a category to which it does truly belongs, i.e., area **underestimation**

*Errors of **commission*** = including an area in a category to which it does not truly belong, i.e., area **overestimation**

Differences in these two errors may be used **to adjust area estimates** and **to estimate the uncertainties** for each class.

Adjusting area estimates on the basis of a rigorous accuracy assessment represents an **improvement** over **simply reporting the areas of map classes**.

Accuracy assessment of land cover and changes (2/3)

- Example of accuracy measures for the **forest class**:
  - Error of **commission**: (13+45)/293 = 19.80%
  - Error of **omission**: (25+3)/263 = 10.65%
  - User's accuracy: 235/293 = 80.20%
  - Producer's accuracy: 235/263 = 89.35
- **Overall accuracy** = (235+187+215+92+75)/986 = 81.54%

	Reference data					
Class. data	**F**	**A**	**W**	**U**	**B**	**Total**
F	235	13	0	45	0	293
A	25	187	7	18	20	257
W	3	0	215	0	0	218
U	0	0	0	92	35	127
B	0	0	0	16	75	91
Total	263	200	222	171	130	986

Accuracy assessment of land cover and changes (3/3)

For **land-cover changes**, additional considerations apply:

- Reference data: It is usually **more difficult** to obtain suitable, **multitemporal reference data of greater quality** to use as the basis of the accuracy assessment, particularly for historical time frames.
- Commission vs omission: Since the changed classes are often **small proportions** of landscapes, it is **easier** to assess **errors of commission** (by examining small areas identified as changed) **than errors of omission** (by examining large area identified as unchanged).
- Multidate analysis: Other errors such as **geo-location of multitemporal datasets** and **inconsistencies** in **processing/analysis** and in **cartographic/thematic standards** are more frequent in change assessments.

Sources of uncertainty

- **Quality and suitability** of **satellite data** (i.e., in terms of spatial, spectral, and temporal resolution)
- **Radiometric / geometric preprocessing** (correct geolocation)
- **Cartographic standards** (i.e., land category definitions and Minimal Mapping Unit - MMU)
- **Interpretation procedure** (algorithm or visual interpretation)
- **Postprocessing of the map products** (i.e., dealing with no data, conversions, integration with different data formats)
- **Availability of reference data** (e.g., ground truth data) for evaluation and fine-tuning of the map

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Addressing uncertainties (1/5)

Many of these sources of uncertainty can be addressed using **widely accepted data and approaches**:

- **Satellite data**: Landsat-type data, for example, have been proven useful for national-scale land cover changes for MMU of 1 ha
- **Preprocessing features:** they are provided for most regions by some data providers (i.e., global Landsat Geocover)
- **Consistent and transparent mapping**: same cartographic and thematic standards and accepted interpretation methods should be applied transparently using expert interpreters

A **robust accuracy assessment** of land cover or land-cover change maps & estimates should include **three components**: (i) **sampling** design, (ii) **response** design, (iii) **analysis** design

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Addressing uncertainties: sampling design (2/5)

- Protocol for **selecting the locations** at which the **reference data** are obtained: It includes specification of
  - *Sample **size**,*
  - *Sample **locations**,*
  - ***Reference assessment units*** (i.e., pixels or image blocks).
- **Stratified sampling** should be used for rare classes (e.g., change categories).
- **Systematic sampling** (with density of reference plots based on stratification) with a **random starting point** is generally **more efficient** than simple random sampling and is also **more traceable**.

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Addressing uncertainties: response design (3/5)

- Reference information should come from **data of greater quality** than the map labels
- **Ground observations** are generally considered the standard, although **finer resolution remotely sensed data** are also used (e.g., Ikonos, Google Earth, Bing Map, etc.).
- **Consistency and compatibility** in **thematic definitions** and interpretation are required to **compare reference and map data.**

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Addressing uncertainties: analysis design (4/5)

Comparisons of map and reference data produce a suite of **statistical estimates** including

- ***error matrices***,
- ***class-specific accuracies*** (of commission / omission error),
- ***area and area-change estimates***,
- and **associated *standard-deviation and confidence intervals***.

Addressing uncertainties: Limitations (5/5)

- The techniques rely on **probability sampling designs** and the **availability of reference data** → Such approach **may not be achievable**, in particular for historical land changes.
- If accuracy assessment is **not possible**, it is recommended to perform, as a minimum, a ***consistency assessment*** (i.e., reinterpretation of small samples in an independent manner) which provides information of the **quality** of the estimates.
- Other procedures include: **review by local experts** or **comparisons** with **non-spatial and statistical** data

➔ In all cases, any uncertainty bound should be treated **conservatively to avoid producing a benefit for the country** (overestimation of removals or of emissions reductions)

6 ESTIMATION OF UNCERTAINTIES

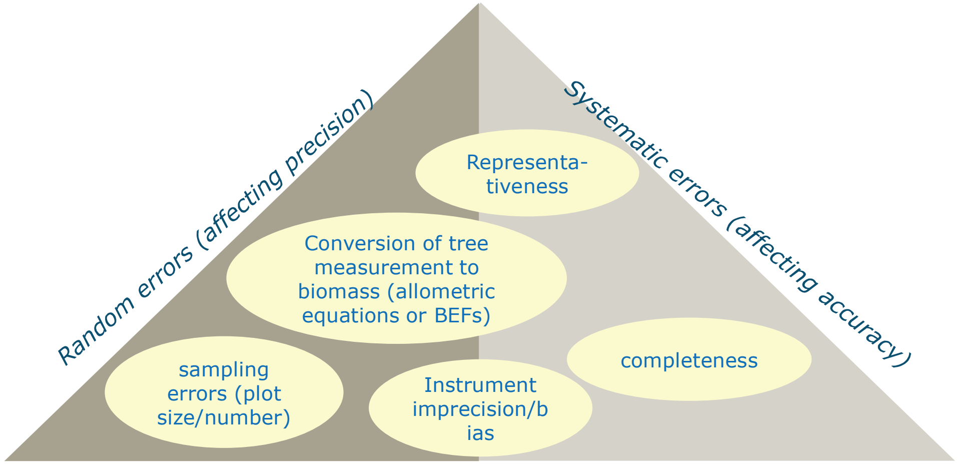
1. General concepts
2. Uncertainties in area-change estimates
3. **Uncertainties in carbon stocks change estimates**
4. Combination of uncertainties

Uncertainties in EF vs AD

- Assessing uncertainties of the **EFs** (estimates of C stocks and C stocks changes) is usually **more challenging** (and often **subjective**) than estimating uncertainties of the areas and area changes (**AD**)
- According to the literature, the **overall uncertainty for EFs** is usually **larger** than the uncertainty for **AD**.
- However, when looking at **changes** (i.e. trends) in C stocks and areas, the **picture *may* change**, depending on possible correlation of errors (see later)

Random errors and systematic errors

Uncertainty of carbon stocks can be caused by both ***random*** *errors* and *systematic errors,* but sometimes it may be **difficult to distinguish between the two**.



Uncertainties due to random errors

- ***Instrumental imprecision*** (noise, wrong handling, etc.)
- ***Sampling errors*** (i.e., plot size and number), **common** with **high natural variation of biomass** in tropical forests ➔ biomass= f(temperature, precipitation, forest type and species, stratification, spatial scale, natural and human disturbances, soil type, and soil nutrients)
- **Allometric model** or Biomass Expansion Factors (BEFs):
  - Selection of best-fitting allometric model for respective forest type → **≈ 20% error** of **tree** AGB estimate
  - Uncertainties on **plot** level (at 95% confidence interval): **5%** (-/+2,5%) **to 30%** (-/+15%)
  - Average range of uncertainties for **default AGB** of IPCC: **-60% to +70%**

Dealing with uncertainties due to random errors

- If feasible: **increase sample size** (may be problematic)
- High tree biodiversity → **regional/pan-tropical allometric models are better than site-specific models** (error ±5%)

Dry forest stands:

- $AGB = exp(-2.187 + 0.916 \times ln(pD^2H)) \equiv 0.112 \times (pD^2H)^{0.916}$
- $AGB = p \times exp(-0.667 + 1.784 ln(D) + 0.207(ln(D))^2 - 0.0281(ln(D))^3)$

Having H (height), estimates are more accurate

Moist forest stands:

- $AGB = exp(-2.977 + ln(pD^2H)) \equiv 0.0509 \times pD^2H$
- $AGB = p \times exp(-1.499 + 2.148 ln(D) + 0.207(ln(D))^2 - 0.0281(ln(D))^3)$

Equations from Chave et al., 2005

Further regional/pan-tropical allometric models

(error ±5%)

Moist mangrove forest stands:

- $AGB = exp(-2.977 + ln(pD^2H)) \equiv 0.0509 \times pD^2H$
- $AGB = p \times exp(-1.349 + 1.980 ln(D) + 0.207(ln(D))^2 - 0.0281(ln(D))^3)$

Wet forest stands:

- $AGB = exp(-2.557 + 0.940 \times ln(pD^2H)) \equiv 0.0776 \times (pD^2H)^{0.940}$
- $AGB = p \times exp(-1.239 + 1.980 ln(D) + 0.207(ln(D))^2 - 0.0281(ln(D))^3)$

AGB = aboveground biomass in kg

D = diameter in cm

p = oven-dry wood over green volume in g/cm³

H = height of tree in m

≡ = mathematical identity

Uncertainties due to systematic errors (1/2)

*2 types : lack of **completeness** ; lack of **representativeness***

***Completeness** of C pools (AGB BGB,* SOC, deadwood, litter):

≈15% of emissions may come from **deadwood** and **≈ 25-30%** may come from **soils** (more if organic soils)…These pools are **often not included** (lack of data)

"***Key categories***" (KC) (sources/sinks of emissions/removals that **contribute substantially** to the overall national inventory or are **key sources of uncertainty** in the overall **trend**) should be **included**.

Within a KC, a pool is "**significant**" if it accounts for **>25-30%** of emissions/removals from the KC

Emissions/removals from **KC** and **significant pools** should be estimated with **Tier 2 or 3** methods

Pools may be omitted under principle of ***conservativeness***

Uncertainties due to systematic errors (2/2)

***Representativeness** of sampling plots: significant bias if sample not representative of high variation of biomass content*

Sound statistical sampling necessary in "hotspots"

Distribution of samples across major soil/topographic gradients of landscape to allow landscape-scale AGB estimation with ±10% (95% CI)

If geographic position:

- Known ➔ global biomass maps (1km Saatchi / 500m Baccini) can be used for estimating AGB
- Unknown ➔ global biomass maps can be used to derive improved Tier 1 data values

Ex: Error propagation of AGB estimation for Central Panama

(Chave et al. 2004)

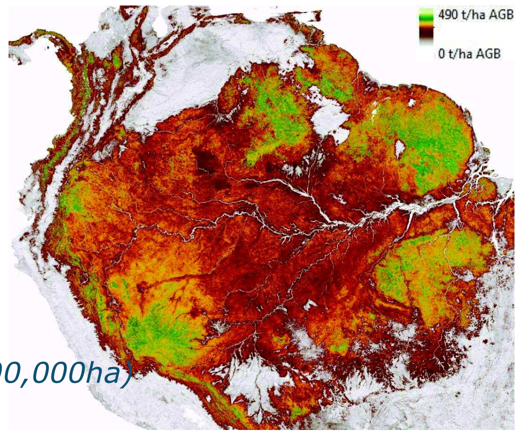
Table 3. Summary of the sources of error in the AGB estimation of a tropical forest. (Type 1 error refers to the error made in the estimation of the AGB held in a single tree; this error averages out in plots. Type 2 error is that caused by the choice of the allometric model. Types 3 and 4 are two types of sampling error, which can be minimized by large-sized, multi-plot, censuses. The reported values are examples for the forests of the Panama Canal watershed.)

error type		s.e.m. (percentage of the mean)	type of data
1. tree level error	trees > 10 cm diameter	48	BCI plot—pan-tropical allometric model
	trees < 10 cm diameter	78	
2. allometric model	before ρ correction	22	BCI plot—eight allometric models
	after ρ correction (gravity)	13	
	after large tree correction	11	BCI plot—pan-tropical allometric model
3. within-plot uncertainty	0.1 ha plot	16	
	0.25 ha plot	10	
	1 ha plot	5	
4. among-plot uncertainty		11	Marena plots—pan-tropical allometric model
total	50 1 ha plots, after ρ and large tree corrections	24	—

Ex. Uncertainties of recent AGB global maps (1/2)

<u>**Saatchi**</u> map at 95% CI:

- ***Overall** AGB uncertainty at pixel-level (averaged) **±30%** (±6% to ±53%)*
- ***Regional** AGB uncertainties: America ±27%; Africa **±32%** Asia ±33%*
- ***Total C stock** uncertainty at pixel-level (averaged) ±38%; ±5% (10,000ha); **±1%** (>1,000,000ha)*



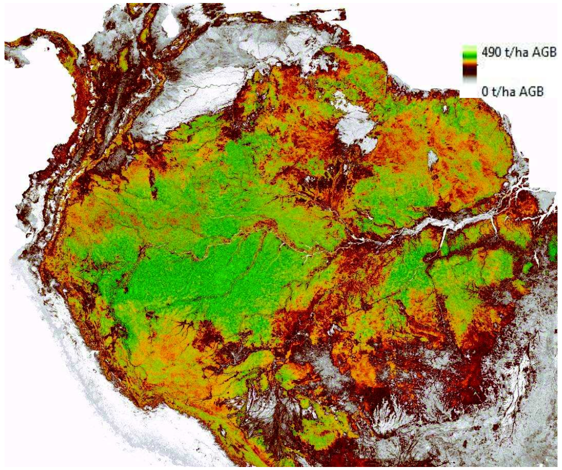
Uncertainties of recent AGB global maps (2/2)

Baccini map at 95% CI*:*

▪ ***Regional uncertainties*** *for carbon stocks:*

*America ±7.1%; Africa ±**13.2%***

Asia ±6.5%



6 ESTIMATION OF UNCERTAINTIES

Combination of uncertainties

2 methods:

➔ ***Error propagation*** (IPCC **Tier 1**),

- **Easy to implement** using a spreadsheet tool;
- **Certain conditions have to be fulfilled** before use.

➔ ***Monte Carlo simulation*** (IPCC **Tier 2**)

- Based on **modelling** and **requiring more resources** to be implemented;
- It **can be applied to any data or model**.

Tier 1 uncertainty level assessment (1/3)

Tier 1 should be used **only when**:

- Estimation of emissions and removals is based on **addition, subtraction, and multiplication**
- There are **no correlations** across categories (or categories are aggregated in a way that correlations are unimportant)
- Relative **ranges of uncertainty** in the EFs and AD estimates remain **the same over time**
- **No parameter** has an **uncertainty > ±60%**
- Uncertainties are **symmetric** and follow **normal distribution**

Even in the case that **not all of the conditions are fulfilled,** the Tier 1 method can be used to obtain **approximate results**

If **asymmetric** distributions → take higher **absolute** values for uncertainties to be combined

Tier 1 uncertainty level assessment (2/3)

Equation for **multiplication**

$$U_{total} = \sqrt{U_1^2 + U_2^2 + ... + U_n^2}$$

Where:

Ui = percentage uncertainty associated with each of the parameters

Utotal = the percentage uncertainty in the product of the parameters

Equation for **addition and substraction**

$$U_{total} = \frac{\sqrt{(U_1 * x_1)^2 + (U_2 * x_2)^2 ...(U_n * x_n)^2}}{|x_1 + x_2 ... + x_n|}$$

Where:

U_i = percentage uncertainty associated with each of the parameters

x_i = the value of the parameter

U_{total} = the percentage uncertainty in the sum of the parameters

Tier 1 uncertainty level assessment (3/3)

Examples

Multiplication

	Mean value	Uncertainty (% of the mean)
Area change (ha)	10827	8
Carbon stock (t C/ha)	148	15

Thus the total carbon stock loss over the stratum is:

10,827 ha* 148 tC/ha = 1,602,396 t C

And the uncertainty = $\sqrt{8^2 + 15^2} = \pm 17\%$

Addition

	Mean	95 % CI
	t (C/ha)	
Living Trees	113	11
Down Dead Wood	18	3
Litter	7	2

therefore the total stock is 138 t C/ha and the uncertainty =

$$\frac{\sqrt{(11\% * 113)^2 + (3\% * 18)^2 + (2\% * 7)^2}}{|113 + 18 + 7|} = \pm 9\%$$

The total uncertainty is ±9% of the mean total C stock of 138 t C/ha

Tier 1 uncertainty trend assessment (1/2)

Estimation of trend uncertainty (Tier 1) is based on the use of **two sensitivities**:

- **Type A sensitivity**, which arises from uncertainties that affect emissions or removals in the years 1 and 2 equally (i.e., the **variables are correlated across the years**)
- **Type B sensitivity**, which arises from uncertainties that affect emissions or removals in the year 1 or 2 only (i.e., **variables are uncorrelated across the years**)

Basic assumptions:

***EF** fully **correlated** across the years* (**Type A** sensitivity)

***AD uncorrelated** across years* (**Type B** sensitivity)

Tier 1 uncertainty trend assessment (2/2)

Table to combine level and trend uncertainties using Tier 1 (see GOFC-GOLDC (2014) *Sourcebook,* section 2.7, for explanation of notes.)

A	B	C	D	E	F	G	H	I	J	K	L	M
Category	Gas	Emissions or removals in year 1	Emissions or removals in year 2	Area uncertainty	Emission factor uncertainty	Combined uncertainty	Contribution to variance by category in year 2	Type A sensitivity	Type B sensitivity	Uncertainty in trend introduced by emission factor uncertainty (Note ii)	Uncertainty in trend introduced by area uncertainty (Note iii)	Uncertainty introduced to the trend in total emissions/
		Mg CO_2	Mg CO_2	%	%	$\sqrt{E^2 + F^2}$	$\frac{(G * D)^2}{(\sum D)^2}$	Note i	$\frac{D}{\sum C}$	$I * F$	$J * E * \sqrt{2}$	$K^2 + L^2$
E.g. Forest converted to Cropland	CO_2											
E.g. Forest converted to Grassland	CO_2											
Etc	…											
Total		$\sum C$	$\sum D$				$\sum H$					$\sum M$
					Level uncertainty		$\sqrt{\sum H}$				Trend uncertainty	$\sqrt{\sum M}$

Tier 2 uncertainty level assessment: Monte Carlo simulation (1/2)

- Tier 2 method **can be applied to any equation** (whereas Tier 1 is applicable only for addition, subtraction, and multiplication). Tier 2 can also be applied to **entire models**.
- Tier 2 gives **more reliable results** than Tier 1, particularly where **uncertainties are large**, **distributions are non-normal**, or **correlations exist**.
- Application of Tier 2 requires **programming** or use of a **statistical software package**.

For more details, see IPCC (2003, ch. 5) guidance and IPCC (2006, vol. 1, ch. 3) guidelines.

Tier 2 uncertainty level assessment: Monte Carlo simulation (2/2)

- The principle of Monte Carlo analysis is **to select *random values*** of **EF, AD, and other estimation parameters** from within their individual probability density functions and **to calculate the corresponding emission values**.
- This procedure is **repeated many times** (e.g., 5,000 or 10,000), using a computer.
- This yields 5,000 or 10,000 values for emission, based on which the user can calculate the **mean value of emission** and its **95% confidence interval**.

Reporting of uncertainties (Tier 1 or Tier 2)

Uncertainties should be **reported** with a **standardized format**. See GOFC-GOLDC (2014, sect. 4) *Sourcebook* for explanation of notes.

A	B	C	D	E	F	G	H	I	J
Category	Gas	Emissions or removals in year 1	Emissions or removals in year 2	Area uncertainty	Emission factor uncertainty	Combined uncertainty	Inventory trend for year 2 increase with respect to year 1 (Note a)	Trend uncertainty of the category	Method used to estimate uncertainty (Note b)
		Mg CO_2	Mg CO_2	%	%	%	% of year 1		
E.g. Forest Land converted to Cropland	CO_2								
E.g. Forest Land converted to Grassland	CO_2								
Etc	...								
Total						Level uncertainty		Trend uncertainty	

In summary

- Assessing uncertainty is **fundamental** in the IPCC and UNFCCC contexts.
- Uncertainty consists of two components: ***systematic errors*** and ***random errors***.
- *Accuracy assessment* of **land cover and changes (AD)** is used to characterize the frequency of errors (**omission and commission**) for **each class** and the **overall accuracy** of the map using an **independent reference dataset**.
- Assessing uncertainties of **the estimates of C stocks and C stocks changes (EFs)** is usually **more challenging** due to **different types of random and systematic errors**.
- The uncertainties in individual parameters can be combined using either **error propagation (Tier 1) or Monte Carlo analysis (Tier 2).**

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7 REPORTING OF GHG

Reporting LULUCF performance using IPCC 2003 GPG-LULUCF and 2006 AFOLU GL

After the course the participants should be able to:

- Understand the general reporting and review principles
- Perform reporting of GHG emissions using the existing IPCC reporting tables
- Implement the conservative approach to address potential overestimation of achieved mitigation

AFOLU *Agriculture, Forestry and Other Land Use*
GHG *Greenhouse Gas*
IPCC *Intergovernmental Panel on Climate Change*
LULUCF *Land Use, Land Use Change, and Forestry*

7 REPORTING OF GHG

1. **UNFCCC reporting requirements**
2. Reporting REDD+ performance under the UNFCCC
3. Reporting principles under the UNFCCC
4. Structure of a GHG inventory

2

Reporting vs accounting?

Reporting: **Information** on **anthropogenic GHG emissions and removals**, and on **mitigation actions**. Information are included in a **GHG inventory**, composed of **estimates** in **Common Reporting Format (CRF) tables** and information on **methods** in a **National Inventory Report (NIR)**

Accounting: Use of the reporting to assess a **Party's performance** as compared to its **binding commitment** (e.g., under **Kyoto Protocol** (KP) for **Annex 1 Parties**) or **voluntary commitment** (e.g., FR(E)L in the context of **REDD+** for **Non-Annex 1 Parties**)

➔ Reporting is the **basis for accounting**, leading to **possible payments** for **REDD+ results** for **Non-Annex 1 Parties**.

3

Requirements: Annex 1 vs Non-Annex 1

- **Annex I**:
  - National Communications (NC, every 4yrs),
  - GHG Inventories (GHGI, annual),
  - Biennial Reports (BRs, every 2yrs),

  all subject to *review*

  \+ Forest Management Reference Level (FMRL, under Art. 3.4 / KP)
- **Non-Annex I**:
  - National Communications (NC, every 4 yrs),
  - Biennial Update Reports (BURs, every 2yrs)

  NB: LDCs (e.g. **Sudan**) and SIDS **may submit NC and BUR at their discretion.**

  \+ Forest Reference (Emissions) Level (FR(E)L, for REDD+)

Guidelines on requirements are **detailed** for Annex I (especially for GHGI), but are more **generic** for non-Annex I parties.

4

LDCs: Least Developed Countries
SIDS: Small Island Developing States

NCs and BURs for Non-Annex 1

NC:

Include information on national circumstances, the national GHGI, and information on strategies for mitigation.

Submitted every **4 years**, following adopted guidelines in Decision 17/CP.8 and IPCC methodologies (at least IPCC 1996 GL. More recent GL welcome !)

Sudan: 1NC submitted in 2003, **2NC** submitted in **2013**

BURs:

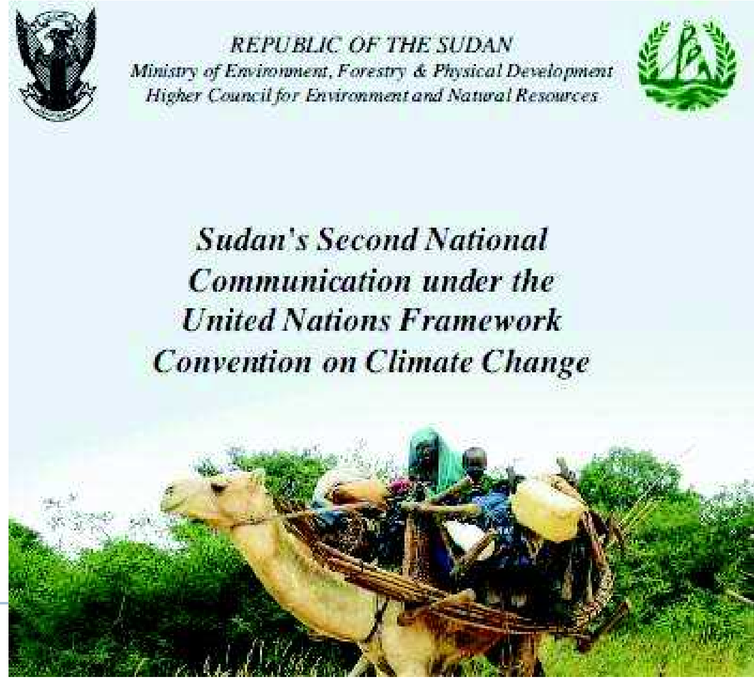
Include updated information on national circumstances, the national GHGI, and information on mitigation actions, i.e. Nationally Appropriate Mitigation Actions (NAMAs) and REDD+.

Submitted every **2 years** (starting Dec 2014), following adopted guidelines in Decision 2/CP.17 and IPCC methodologies (including **2003 GPG for LULUCF**)

BURs are subject to a ***technical assessment*** as part of the International Consultation and Analysis (**ICA**) process

Sudan: BUR **not yet submitted**

2NC (2013) of Sudan



Main COP Decisions relevant to UNFCCC reporting

	Decision/Document	Description
	Convention Text (UNFCCC)	It sets specific commitments for Parties to periodically and continually report information on their GHG emissions and removals and on mitigation actions implemented
3/CP.5	Guidelines for the preparation of national communications by Parties included in Annex I to the Convention, Part II: UNFCCC reporting guidelines on national communications	It establishes the structure of the NC; the information to be provided in the NC; the principles and methodologies to be applied to compile information and elaborate estimates
15/CP.17	Guidelines for the preparation of national communications by Parties included in Annex I to the Convention, Part I: UNFCCC reporting guidelines on annual greenhouse gas inventories	It establishes the structure of the GHGI; the information to be provided in the GHGI; the principles; and methodologies to be applied to compile information and elaborate estimates
24/CP.19	Revision of the UNFCCC reporting guidelines on annual inventories for Parties included in Annex I to the Convention	It will replace the version provided in Decision 15/CP.17
2/CP.17	UNFCCC biennial reporting guidelines for developed country Parties	It establishes the information to be provided in the BR (noting that principles and methodologies to be applied to compile information and elaborate estimates are those applied for NC and GHGI)
17/CP.8	Guidelines for the preparation of national communications from Parties not included in Annex I to the Convention	It establishes the structure of the GHGI; the information to be provided in the GHGI; the principles and methodologies to be applied to compile information and elaborate estimates.
2/CP.17	UNFCCC biennial update reporting guidelines for Parties not included in Annex I to the Convention	It establishes the information to be provided in the BUR (noting that principles and methodologies to be applied to compile information and elaborate estimates are those applied for NC and GHGI)
12/CP.17	Guidance on systems for providing information on how safeguards are addressed and respected and modalities relating to forest reference emission levels and forest reference levels as referred to in decision 1/CP.16	It provides guidance on information to be submitted on how safeguards have been addressed and respected
13/CP.19	Guidelines for technical assessment of submissions of information on reference levels	It provides guidance on information to be submitted on how the reference levels have been constructed
14/CP.19	Modalities for measuring, reporting and verifying	It provides guidance on information to be submitted on how the results of activities have been estimated

Main IPCC Guidelines relevant to UNFCCC reporting

Decision/Document	Description
2013 Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol (KP Supplement) (adopted by decision 6/CMP.9)	It provides good practices to be followed, in addition to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, in order to ensure accuracy of estimates of KP-LULUCF activities
2013 Supplement to the 2006 Guidelines for National Greenhouse Gas Inventories: Wetlands (Wetlands Supplement) (adopted by decision 23/CP.19)	It provides supplementary methods, to those provided in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, for collecting and compiling information and for preparing GHG estimates for wetlands and drained soils
2006 IPCC Guidelines for National Greenhouse Gas Inventories (adopted by decision 15/CP.17)	It provides methods for collecting and compiling information and for preparing GHG estimates, which are consistent with the reporting principles (transparency, completeness, consistency, accuracy and therefore, comparability). This represents the most recent guidelines for national GHG inventories published by IPCC
2003 IPCC Good Practice Guidance for Land Use, Land-Use Change and Forestry (adopted by decisions 2/CP.17, 17/CP.18)	It provides good practices to be followed, in addition to the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, in order to ensure accuracy of LULUCF estimates
2000 IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (adopted by decisions 2/CP.17, 17/CP.18)	It provides good practices to be followed, in addition to the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, in order to ensure accuracy of estimates
Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (adopted by decisions 2/CP.17, 17/CP.18)	It provides methods for collecting and compiling information and for preparing GHG estimates, which are consistent with the reporting principles

7 REPORTING OF GHG

1. UNFCCC reporting requirements
2. **Reporting REDD+ performance under the UNFCCC**
3. Reporting principles under the UNFCCC
4. Structure of a GHG inventory

REDD+ requirements for reporting (1/2)

- Need to follow Decision 14/CP.19 on "*Modalities for **MRV** of anthropogenic **forest-related GHG emissions by sources and removals by sinks***", consistent with Decision 4/CP.15 on "*Modalities for **MRV of NAMAs***"
- **Results**, against the FR(E)L, should be in **tCO_{2eq}/year**
- Data and methodologies should be **improved over time**
- Data and methodologies should be **transparent, consistent over time, and consistent with the FR(E)L**
- To claim for **result-based payments**, information should be submitted in a **technical annex** to the **BUR**, following agreed guidelines from Decisions 4/CP.15 and 12/CP.17

MRV: Measuring, Reporting and Verifying
NAMAs: Nationally Appropriate Mitigation Actions

REDD+ requirements for reporting (2/2)

- REDD+ **Technical Annex** to the BUR to be **verified** by **2 experts** (one from a developing country; one from a developed country), following the 5 IPCC principles: **transparency, consistency, comparability, completeness, and accuracy.**
- **Interactions** possible between the experts and the Party, to provide **clarifications and additional information**
- A **technical report** is published on the **UNFCCC web platform** (https://redd.unfccc.int/): Technical annex + Analysis of the annex + Recommendations for technical improvement + comments and/or responses by the Party

Reporting Guidance from the FCPF Carbon Fund Methodological Framework

Methodological steps
Forest definition
Definition of forest classes
Choice of Activity Data and (pre-)processing methods
Choice of emission factors and description of their development
Estimation of emissions and removals, including accounting approach
Disaggregation of emissions by Sources and removals by Sinks
Estimation of accuracy, precision, and/or confidence level
Discussion of key uncertainties
Rationale for adjusting FR(E)L
Methods and assumptions associated with adjusting FR(E)L

Maps and/or synthesized data
Accounting area
Activity data
Emission factors
Average annual emissions over the Reference Period
Adjusted FR(E)L
Any spatial data used to adjust FR(E)L

Source: World Bank FCPF 2013.

FCPF : Forest Carbon Partnership Facility

7 REPORTING OF GHG

1. UNFCCC reporting requirements
2. Reporting REDD+ performance under the UNFCCC
3. **Reporting principles under the UNFCCC**
4. Structure of a GHG inventory

Transparency

- All the assumptions and the methodologies used in the GHGI should be **clearly explained** and **documented**
- GHG estimates are reported in **CRF tables** at a level of disaggregation which allows **verifying calculations**
- Most relevant **background data** are provided in the **NIR**
- **Anybody** could verify the **correctness** of the GHGI

CRF: Common Reporting Format
NIR: National Inventory Report

Consistency

- The **same definitions and methodologies** should be used over time
- This should ensure that **differences** between years reflect **real differences** in emissions
- Under **certain circumstances**, estimates using different methodologies for different years can be considered **consistent** if calculations are **transparent**
- **Recalculations (retropolations)** of previously submitted estimates are possible **to improve accuracy and/or completeness**, providing calculations are **transparent** and **properly documented**

Comparability

- To insure **comparability across countries**, Parties should follow the **methodologies** provided by the IPCC and agreed within the UNFCCC

NB: Comparability is **not explicitly mentioned** in REDD+ related COP decisions…However, as long as estimates are **transparent, consistent, complete and accurate, and follow IPCC guidance**, they can be considered methodologically **comparable**

Completeness

- Estimates should include all the **significant** categories, gases, and pools
- **When gaps exist**, all the relevant information and **justification** on these gaps should be **documented** in a **transparent** manner

Accuracy

- Estimates should **not be systematically either over or under the true value**, so far as can be judged, and **uncertainties** should be **reduced so far as is practicable**
- Appropriate methodologies should be used, in accordance with the IPCC, to **promote accuracy** in inventories and to **quantify the uncertainties** in order to **improve future inventories**

7 REPORTING OF GHG

1. UNFCCC reporting requirements
2. Reporting REDD+ performance under the UNFCCC
3. Reporting principles under the UNFCCC
4. **Structure of a GHG inventory**

Structure of a GHG inventory (GHGI)

A national GHGI of anthropogenic emissions and removals is typically divided into **two parts**:

- **Common Reporting Format (CRF) tables:** A series of standardized data tables that contain mainly **quantitative information** (i.e., numerical estimates of emissions and removals)
- **National Inventory Report (NIR)**: Comprehensive and transparent (**qualitative and quantitative**) information about **how estimates have been calculated**

Key elements in the CRF tables

- ***Initial and final land-use category***: Additional stratification (**subcategories**) is encouraged according to criteria such as climate zone, soil type, vegetation type, ecological zones, etc.
- ***AD - Activity Data***: **area of land** (in ha) subject to deforestation, afforestation, etc. or **volume of harvest** (in m^3) subject to forest degradation, etc.
- ***EFs - Emission Factors***: **C stock changes or GHG fluxes** (CH4, N2O) per unit area or per unit volume, **separated for each carbon pool**
- ***Total change in C stock and GHG fluxes***: AD x EF
- ***Total GHG emissions/removals*** (expressed as CO_{2eq})

Ex of CRF table

Ex. of a CRF table to **report emissions from deforestation**

GREENHOUSE GAS SOURCE AND SINK CATEGORIES		ACTIVITY DATA	IMPLIED CARBON STOCK CHANGE FACTORS (2) Net carbon stock change per unit area in:					Implied emission/ removal factor per area (4)	CHANGE IN CARBON STOCK (3) Net carbon stock change in:					Net CO_2 emissions/ removals (3)
			biomass		dead org. matter		soils		Biomass		Dead org. matter		soils	
Land-Use Category	Sub-division (1)	Total area (kha)	above-ground	below-ground	dead wood	litter			above-ground	below-ground	dead wood	litter		
			(Mg C/ha)					(Mg CO_2/ha)	(Gg C)					(Gg CO_2)
A. Total Deforestation														
1. Forest Land converted to Cropland	(specify)													
	(specify)													
2. Forest Land converted to Grassland	(specify)													
	(specify)													

(1) Land categories may be further divided according to climate zone, management system, soil type, vegetation type, tree species, ecological zones, national land classification or other criteria.
(2) The signs for estimates of increases in C stocks are positive (+) and of decreases in C stocks are negative (-).
(3) According to IPCC, changes in C stocks are converted to CO2 by multiplying C by 44/12 and changing the sign for net CO2 removals to be negative (-) and for net CO2 emissions to be positive (+).

Notation keys for CRF tables

To ensure **completeness**, it is ***good practice* to fill all cells** of the table.

If emissions/removals **have not been estimated or cannot be reported**, the following qualitative "notation keys" should be used:

Notation key	Explanation
NE (not estimated)	Emissions / removals occur but have not been estimated or reported.
IE (included elsewhere)	Emissions / removals for this activity or category are estimated but included elsewhere (indicate where).
C (confidential information)	Emissions / removals are aggregated and included elsewhere in the inventory because reporting at a disaggregated level could lead to the disclosure of confidential information.
NA (not applicable)	The activity or category exists but relevant emissions and removals are considered never to occur.
NO (not occurring)	An activity or process does not exist within a country.

Additional CRF tables

In addition to tables like the one in the example, other typical tables include:

- Tables with **emissions of other gases** (e.g., CH_4 and N_2O from biomass burning)
- **Summary tables** (with all gases and emissions/removals)
- Tables with **emission trends** (covering data also from previous inventory years)
- Tables for illustrating the results of the **key category analysis**
- Tables for explaining **recalculations**

National Inventory report (NIR) (1/2)

An inventory report typically includes:

- **Overview of trends** by gas and by category
- Description of the **methodologies** used, the **assumptions**, the **data sources**, and **rationale** for their **selection**
- In the context of REDD+ reporting, **specific information** on land-use definitions, land-area representation, land-use databases, and datasets on C stock gains and losses
- A description of the **key categories***, including information on the level of disaggregation of the key category analysis

** Key categories": sources/sinks of emissions/removals that **contribute substantially** to the overall national inventory or are **key sources of uncertainty** in the overall trend (see IPCC 2003 GPG LULUCF, Ch. 5.4)*

National Inventory report (NIR) (2/2)

An inventory report typically includes (continued):

- Information on **uncertainties** (i.e., methods used and underlying assumptions), **time-series consistency**, **recalculations/retropolation** (justification for providing new estimates), **QA/QC procedures**, including verification, and archiving of data
- Description of the **institutional arrangements** for inventory planning, preparation, and management
- Information on **planned improvements**

Furthermore, all of the relevant inventory information should be **archived**, to allow **reconstruction** of the inventory

LULUCF Reporting challenges for non-Annex 1 Parties

- **Transparency, consistency, and comparability**: Achievable by most countries (after adequate capacity building if needed)
- **Completeness**: From official reports (NC, FAO FRA) only a few countries currently report data on **soil carbon**, although these emissions following deforestation are likely to be "**significant**"
- **Accuracy**: According to IPCC, ***key categories* and *significant pools*** should be estimated with **higher tiers (2 or 3)**, i.e., country-specific data stratified by climate, forest, soil, and conversion type at a fine/medium spatial scale → **big challenge**

In summary

- Non-Annex I countries should report to the UNFCCC through **National Communications (NCs)** and **Biennial Update Reports (BURs)** which include a **national GHG Inventories (GHGI)**
- The GHGI is made of **Common Reporting Format (CRF) tables** and a **National Inventory Report (NIR)**
- For claiming **REDD+ result-based payments**, a **technical annex** should be prepared and **attached to the BUR**
- **5 IPCC principles** guide the estimation and the reporting of GHGI under the UNFCCC, as well as the process of review or technical assessment of estimates: ***Transparency, Consistency, Comparability, Completeness,* and *Accuracy***

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