Module 2.1 Monitoring activity data for forests using remote sensing

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After the course the participants should be able to:

• Differentiate between different (remote sensing) approaches to monitor changes in forest areas
• Perform forest area change analysis using Landsat satellite data

Source: GOFC-GOLDSourcebook 2014, Box 3.2.2. V1, May 2015
Background material


  http://unfccc.int/resource/docs/2010/cop16/eng/07a01.pdf#page=2


Outline of lecture

1. Introduction
2. Selection of a monitoring approach
3. Image classification and analysis
4. Accuracy assessment
5. Limitations to using satellite data
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IPCC requirements for measuring and reporting of changes in forest area (1/2)

- The IPCC methodologies and UNFCCC reporting principles have been identified as the basis for the future REDD+ mechanism.

- IPCC methodologies aim for full, accurate, transparent, consistent, and comparable reporting of GHG emissions and removals (e.g., of changes in forest areas).

- Reporting also includes a detailed description of the used inventory approach and planned improvements.

See Module 3.3 on reporting REDD+ performance.
IPCC requirements for measuring and reporting of changes in forest area (2/2)

- IPCC guidelines refer to two basic inputs with which to calculate greenhouse gas inventories: **activity data** and **emissions factors**.
- For activity data, spatially explicit land conversion information, derived from sampling or wall-to-wall mapping techniques, is encouraged.
Key role for earth observation in monitoring tropical forests

- Fundamental requirement of national monitoring systems are that they:
  
i. Measure changes throughout all forested area
  
ii. Use consistent methodologies at repeated intervals to obtain accurate results and

iii. Verify results with ground-based or very high resolution observations

- 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 selection and implementation of a monitoring approach

- Multiple approaches are appropriate and reliable for forest monitoring at national scales. Issues affecting the design of the monitoring system include, for example:

  I. National circumstances, particularly existing definitions and data sources

  II. Decision on change assessment approach, defined by:
      a. Satellite imagery
      b. Sampling versus wall-to-wall coverage
      c. Fully visual versus semi-automated interpretation
      d. Accuracy or consistency assessment

  III. Available resources:
      i. Hard- and software resources
      ii. Required training
Outline of lecture

1. Introduction

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3. Image classification and analysis

4. Accuracy assessment

5. Limitations to using satellite data
Required activity data

- Depending on national decisions on the approach to be used, the following types of activity data/maps may be needed for reporting on the changes in forest cover:
  - Forest/nonforest map (+ change maps)
  - National land-cover/land-use map (+ change maps)
  - Forest stratification
  - Map of changes within forest land (see Module 2.2)
- A monitoring approach suitable for producing the required activity data in the particular conditions of the country needs to be selected.
Forest definition (1/2)

- Currently Annex I parties use the UNFCCC definition of forest and deforestation adopted for implementation of Articles 3.3 and 3.4 of Kyoto protocol.

- FAO uses a minimum cover of 10%, height of 5 m and area of 0.5 ha, stating also that forest use should be the predominant land use in the area.

- For the Kyoto Protocol, parties should select a single value of crown area, tree height, and area within following ranges:
  - Minimum forest area: 0.05 to 1 ha
  - Potential to reach a minimum height at maturity \textit{in situ} of 2–5 m
  - Minimum tree crown cover: 10–30 %
Forest definition (2/2)

- No agreement on a forest definition currently exists under REDD+.
- Countries can choose their own forest definition as long as they clearly describe the definition.
- Note that 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, existing forest maps for a relatively recent time could be used to identify the overall forest extent.

**Important principles in identifying the forest extent:**

- The area should include all forests within the national boundaries
- A consistent overall forest extent should be used for monitoring all forest changes during assessment period
Selection of satellite imagery

- Many different types of data from optical sensors at a variety of resolutions and costs are available for monitoring deforestation.

- The selection of the type of satellite data depends on national circumstances (forest types, size of the country, seasonality, available funds, etc.).

- The most commonly used types of satellite data for forest-cover monitoring are listed on the next slide with a summary of their usability for various purposes.
## Utility of optical sensors at multiple resolutions for deforestation monitoring

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

Source: GOFC GOLD Sourcebook 2014, table 2.1.1.
Example of a 1 km resolution SPOT VGT image composite for year 2000 covering Southeast Asia

Source: JRC, Stibig et al, 2003
Example of forest cover map for insular Southeast Asia derived from 1 km SPOT VGT imagery

Source: JRC, Stibig et al, 2003
Example of forest cover map derived from 30 meter Landsat TM imagery over a site in Brazil

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

Legend
- Tree cover
- Tree cover mosaic
- Other wooded land
- Other land cover

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

Decision for wall-to-wall versus sample coverage

- Wall-to-wall is a common approach if appropriate for national circumstances.
- If resources are not sufficient to complete wall-to-wall coverage, sampling is more efficient for large countries.
- Recommended sampling approaches are systematic sampling and stratified sampling. See GOFC-GOLD Sourcebook (2012, box 2.1.2), next slide.
- A sampling approach in one reporting period could be extended to wall-to-wall coverage in the subsequent period.
Systematic and stratified sampling

- Systematic sampling obtains samples on a regular interval, e.g., one every 10 km.
- Stratified samples are distributed based on proxy variables derived from coarse resolution satellite data or by combining other geo-referenced or map information.

Systematic sampling design

Stratified sampling design

Source: GOFC-GOLD Sourcebook 2013, box 2.1.2.
Outline of lecture

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

- Geometric corrections:
  - Location error should be < 1 pixel; baseline datasets (e.g.; GLS) can be used as alternative to GCPs or image-to-image registration

- Cloud and cloud shadow masking:
  - Automated or visual methods to ensure meaningfulness of image interpretation

- Radiometric corrections:
  - Depend on the used image interpretation method, not needed for visual single scene interpretation but crucial for automated multitemporal analysis
Geometric correction: example of the use of GLS dataset for image-to-image co-registration

Landsat Scene

Centered at 25° S, 48° W: Cananéia, Brazil

Source: USGS 2015, GLS dataset.
Radiometric and atmospheric correction: Example of the EC Joint Research Centre automated preprocessing chain

Calibrated ETM  De-hazed  Forest mask  Normalized

Year 2000 data >>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>

Automated preprocessing chain

Year 2010 data >>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>

Source: Bodart et al. 2011.
Analyzing the satellite data

- The selection of the image interpretation method depends on available resources.
- Whichever method is selected, the results should be repeatable by different analysts.
- 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.
- The main types of available methods for ~30 m resolution datasets are listed on the next slide (GOFC-GOLD Sourcebook 2013, table 2.1.3), and a few important aspects of selected approaches are highlighted in the following slides.
### Main analysis methods for moderate resolution (~ 30 m) imagery

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

Source: GOFC-GOLD Sourcebook 2013, table 2.1.3.
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.

- When land entities are delineated visually, they should also be labeled visually.
Multidate image segmentation

- Automated segmentation reduces processing time and increases detail.
- It is objective and repeatable.
- It delineates changed areas as separate segments.
- Ideally, analysis process would include:
  i. Multidate image segmentation on image pairs
  ii. Training area/class signature selection
  iii. Supervised clustering of individual images
  iv. Visual verification and potential editing
Example of semi-automatic multi-date segmentation and change labeling

Sources: USGS 2015, GLS dataset; Bodart et al. 2011; and Raši et al. 2011.
Digital classification of image segments

- Digital/automatic classification applies only in the case of automatically delineated segments.
- Two supervised object classifications run separately on the two multidate images are recommended instead of a single supervised object classification on the image pair.
- A common predefined standard training data set of spectral signatures for each type of ecosystem should ideally be used to create initial automated forest maps.
- Supervised classification approaches are considered more efficient in the case of a large number of images than unsupervised clustering techniques.
Example of automatic classification using signature database

b) Automated classification of the year 2000 Landsat image based on signature database

Sources: USGS 2015, GLS dataset; Bodart et al. 2011; and Raši et al. 2011.
Example of forest cover change derived from Landsat TM imagery over a site in Brazil

Landsat-5 TM imagery

Sources: USGS 2015, GLS dataset; Eva et al. 2012.
Visual verification

- Visual verification (or classification) is indispensable.
- Verification should take advantage of image pairs.
- Existing maps may be used as support.
- Single image pairs are preferred over image mosaics.
- Spectral, spatial, and temporal (seasonality) characteristics of the forests have to be considered.
Example of visual validation of the automated JRC-FAO assessment results

Expert validation with tailored validation Tool

Visual Control and Interpretation of automated mapping

Source: USGS 2015, GLS dataset; JRC; Simonetti et al. 2011
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Basic concepts of an accuracy assessment

- Reporting accuracy and verification of results are essential components of a 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 determine accuracy; this should lead to quantitative description of the uncertainty of the forest area estimates.
Example of the usability of very high resolution imagery 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).
Considerations for reporting

- Since areas of land-cover change are significant drivers of emissions, providing the best possible estimates of these areas are 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 nonspatial 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)
Major sources 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.
Major sources 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+ activities.

- 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.
Country examples and exercises

Country examples

- Brazil (PRODES deforestation monitoring program)
- India (FSI: The Forest Survey of India)
- Democratic Republic of the Congo (JRC-FAO Systematic sampling)

Exercises

- Using Landsat time series data to derive forest area change estimates
Recommended modules as follow up

- **Module 2.2** to proceed with monitoring activity data for forests remaining forests (incl. forest degradation)
- **Module 2.8** for overview and status of evolving technologies, including, for example, radar data
- **Modules 3.1 to 3.3** to learn more about REDD+ assessment and reporting
References


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REDD+ Sourcebook training materials by GOFC-GOLD, Wageningen University, World Bank FCPF


