Spatial and temporal characterization of tropical forests using remotely sensed data

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Context

Optical remote sensing is used in different manners in the context of tropical forests monitoring:

- Land-cover characterization (forest types)
- Measuring deforestation (change detection)
- Estimation of degradation (under development)

Objectives of this presentation are:

1. Show the potential of optical remote sensing for land cover characterization in space and time;
2. Check the deforestation information already available;
3. Make a review of what is done in terms of degradation;
4. Present perspectives in the scaling-up workflow we develop.
At global scale: a green leaf

Map showing in green the undisturbed forest area, in red the deforested area from 2000 to 2010, in dark grey the deforested area prior to 2000 and in light grey non-forested areas. The deforestation data are from the INPE/PRODES (2010b) project. Inset: a map of South America highlighting the Amazon biome within the boundaries of the Brazilian Legal Amazonia. Black lines indicate the political boundaries of Amazonian states. Aragao et al., 2014
At local scale: multiple complexity

Behind the green layer of the global maps, there are various tropical forest types
Spatial patterns on annual synthesis SPOT/VGT data

- Countries borders
- Brazilian states borders
- Protected areas

Spot-VEGETATION
Land use mapping using SPOT/VGT time series data
Validation: statistics with environnemental parameters
Phenology analysis using MODIS data time series

1st 16-day images of the data base

2008

2000

Annual synthesis on 23 EVI 16-day periods
Global Forest Change (Hansen et al.)

654,178 LANDSAT 7 ETM+ images from 2000-2012
Forest loss (red), forest extent (green), forest gain (blue)
Option for forest lost by year (0 to 12) and tree cover (% in 2000)
10x10 at 30m resolution, median (filter QA) for bands 3,4,5 and 7 (TOA)

http://earthenginepartners.appspot.com/science-2013-global-forest
Global Forest Change: locally (CIKEL)

More deforestation than degradation
Global Forest Change

It is really global and pan-tropical
Global Forest Watch

Compile several sources of information:
- UMD (Hansen et al.), FORMA alert, IMAZON, etc.
Global Forest Watch: FORMA alert on CIKEL

Humid tropical forest biome (WWF), Monthly alert since Jan. 2006
MODIS 500m
Global Forest Watch: IMAZON on CIKEL

Amazonia legal, Forest Transparency bulletin, Monthly alert since Jan. 2007
MODIS 250m and validation LANDSAT and CBERS
Gradient of forest degradation (INPE)

A figura acima mostra os padrões de degradação florestal por extração de madeira observados em imagens relacionadas: A) Degradção de intensidade moderada, área em regeneração após exploração madeireira, pôllos ainda evidentes; B) Degradação de intensidade alta, exploração madeireira ativa, grande proporção de solo exposto; C) Degradação de intensidade leve, evidência de abertura de estradas de acesso.
Forest degradation detection (Souza et al.,)

Flow of the image processing procedures as implemented with an ImgTools conceptual framework (a) including:
1) Pre-processing,
2) Spectral endmember library development,
3) Spectral Mixture Analysis (SMA);
4) Image Classification, and
5) Post-Classification processing and assessment.

Spectral Mixture Analysis (Souza et al.,)

\[ R_n = \sum_{i=1}^{n} F_i R_{i,b} + \varepsilon_b \]  

SMA equation

\[ \text{NDFI} = \frac{\text{GV}_{\text{Shade}} - (\text{NPV} + \text{Soil})}{\text{GV}_{\text{Shade}} + \text{NPV} + \text{Soil}} \]

\[ \text{GV}_{\text{Shade}} = \frac{\text{GV}}{100 - \text{Shade}} \]

GV=Green Vegetation
NPV: Non-Photosynthetic Vegetation
Soil and shade

When NDFI is close to
1 = forest; 0 = degradation; -1 = bare soil

Forest degradation detection (Asner et al.,)

Similar system using unmixed pixel modelling with forest cover estimation

CLASlite (Asner et al.,)

CLASlite image results for an 1500 km² region. (0–100%) canopy cover of live/forest vegetation, dead or senescent vegetation, and bare soils. Recently deforested, burned areas are red-magenta; forest regrowth is green; soils is yellow; selective logging is blue; intact forest is dark green.
False color composite subsets (RGB=NIR–Red–Green) of each image of the SPOT time series (1992–1995–2003) overlaid by the multidate segmentation result. Bright objects are clear-cuts while regions in reddish grey are regenerating areas. The hatched regions on the change map correspond to detected changed objects by the OB-Reflectance method.
Logging gap monitoring 2005-2007 with SPOT (2.5m). 7% of the surface is impacted (with 60% of gaps and 40% of road).

Very High Resolution images

Quickbird images 2010 and 2012. The degradation map (in c) shows the percentage area difference of small patches of bare soil for the period 2010-2012; d) the whole 20x10km study area with black box indicating the location of the figures a, b and c (Source: REDDiness).
Combined approach (Cirad-ONF)

Development of tools to measure the degradation of harvested tropical forests:
(1) road network monitoring and (2) canopy gaps detection

Outcome:
These tools have to facilitate the post-harvesting control

Harvesting
Log yard
Tracks and roads
road network monitoring

1 - Radiometric calibration

2 - Spectral indices processing

NDVI = (NIR – Red) / (NIR + Red)
GR = (Green – Red) / (Green + Red)
NDVI + GR

Local contrast improved by the median spatial filter
3 – Bare soil identification using Red, GR, NDVI+GR channels

4 - Cloud and water masking using Blue and SWIR channels
Processing

5 - morphological filter

50 pixels size with an elongation rate of 3
6 – Yearly synthesis

Processing

Annual bare soil mapping in 2001
Landsat 30 m pixel

Original data TM3 (RED)

7 – Spatial synthesis

Annual bare soil mapping in 2001

47 bare soil pixels detected on a surface of 256 pixels = 18% of bare soil

Spatial indication of bare soil in 2001
Cell monitoring

Bare soil index decreasing 2/3 in 2 years
Monitoring logging activities using Sentinel 2 (perspective)

March 4th

30 days

Opening

April 3rd

10 days

April 13th

50 days

Logging

June 2nd

Location: North Congo
Spot-4 (Take-5) experiment
canopy gaps detection

Medium spatial resolution optical satellite images produced by SPOT 5 and 4 (10 and 20 meters)

4 locations ≈ main harvested forest

15 logged block (300 to 520 ha)
Remote sensing process

• Filter: Canopy (majority) vs. gap (minority) – all others objects are manually eliminated (clouds, shadows, water, etc…)
• Using 2 index NDVI (photosynthetic activity) and NDWI (moist content)
• Modeling a Gaussian distribution (least squares method) = detect a divergence threshold – significant difference between G function and effective histogram

Pixels values histogram → Gaussian function estimation → K divergence threshold
Results: impacts map

- Visible during 6 months to one year
- For a two years long logging operation – complete impacts can be mapped from the cumulative information collected on at least 6 images
Monitoring logging activities: logging impacts

In French Guiana, 10,000 ha are exploited per year.

Thanks to the SEAS reception station, these areas are regularly monitored using SPOT-5 (10m).

Development of a Timber Quality Index within the certification framework (PEFC and FSC).

From logger:
- 308 trees for 1550 m³

From Spot / Sentinel-2:
- 20.8 ha impacted (26.6%)

Timber statistics:
- 3.9 trees/ha and 19.8 m³/ha (5 m³/tree)
- 675 m² impacted per tree
- 134 m² impacted per m³

Production Unit (78 ha)

Multi-index color composite (NDVI, NDWI and MIR)

Impact areas digitalization
Land cover monitoring: from local to regional scale

Ecosystem services measurements
Ecosystems services modeling

From Land cover to carbon
Land cover spatialization to model ecosystems services
Conclusions and perspectives

- Remote sensing appears to be a powerful tool for monitoring in space and time

- Scaling-up from local log to regional degradation index evaluation is a challenge

- Improving tropical forest land cover classification is one key

- A second key is to better estimate the forest degradation using low resolution data (MODIS or associated sensors)

- It may be possible to do using MODIS (250m), Proba-V (100m) or Sentinel-2 (10, 20 and 60m)

All this within the climate change context (Zelazowski et al., 2011)
Thanks for your attention