MONITORING LAND USE AND LAND USE CHANGES IN FRENCH GUIANA BY OPTICAL REMOTE SENSING

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• French overseas “Department” ~84 000 km²
• Human activity concentrated in a narrow coastal strip and along main rivers
• French Guiana forest
  – ~80 000 km² of tropical forest.
  – ~ 95% of the total territory
  – ~ 1/3 of total French forest (including mainland)
• Deforestation causes in French Guiana
  – Traditional shifting cultivation:
    Small individual areas (0.3 to 1 ha)
  – Extension of modern agriculture
  – Gold mining: Small individual areas - Legal or illegal –
    About 12 000 ha since 1990 - Along streams and rivers
  – Petit Saut dam: Hydroelectricity – reservoir about 30 000 ha, Dam filling in 1994

➢ Limited deforestation concerning small parcels:
a challenge for monitoring
• Reporting on GHG emission and sinks in LUCF Sector
  – Article 3.3 : Aorestation /deforestation/reforestation since 1990
  – Article 3.4 : Forest management
  – Has to be carried out on the whole national territory, including overseas departments

• Specific constraints in French Guiana
  – France is the only Annex 1 country with tropical forests
  – No preexisting systematic and exhaustive land use survey
    • Very recent and partial Land use inventory from the Ministry of agriculture (TERUTI LUCAS)
    • French NFI permanent inventory of forest resources is limited to mainland France
  – Impossibility to carry out a systematic ground based survey
  – No exhaustive Aerial photography mission
  – Important cloud cover
Use of Satellite Imagery

- High resolution Radar Imagery
  - All-weather acquisition (even through cloud cover)
  - ESA satellites ERS-1/2 (since 1991) & ENVISAT (since 2002)
  - About 20m pixel size but necessity to filter the images in order to minimize a systematic noise (speckle) in the data
  - Filtering degrades the actual resolution
  - Difficulties to detect small changes (< 1ha)

- French Guiana LUCC inventory ongoing in the framework of GMES SE Forest Monitoring project: performed by VTT (Finland)

- High resolution Optical imagery
  - Previous research projects have demonstrated a good potential:
    - Gond and Brognoli, 2005
    - Tsayem, 2002
  - 1990 Landsat Global coverage (GLCF) – 30m resolution
  - Limited number of good quality images in Tropical areas

Images:
- Landsat 1990 - GLCF
- ENVISAT ASAR 2006/2007 mosaic
- VTT GSE FM
- Landsat 1990 mosaic - GLCF
Multiple partner Project leaded by IRD
Technologic platform for acquisition and processing of High resolution satellite data (SPOT et ENVISAT)
- 2005: Installation of a new SPOT/ ENVISAT Ground Receiving Station in Cayenne

Dramatic Increase of SPOT image acquisition capacities over the region
In 2006 the French Ministry of agriculture put in charge the NFI of designing and testing a new LUCC inventory for French Guiana.

Objectives of the project

- To produce a first global cloudless SPOT mosaic over French Guiana for year 2006
- To test a first LUCC inventory for the 1990-2006 period
- To define the inventory methods and process for the commitment period 2008/2012

Methods

- Statistical inventory ≠ wall to wall mapping
- On the basis of stratified sample points
- By visual photo-interpretation of the 2006 SPOT and 1990 GLCF Landsat Mosaic

To be combined with emission factors

- Dendrometric expertise carried out in 2005 by ONF, CNRS and CIRAD
- From existing inventory data and experimental protocols
  - One global of Volume per hectare for French Guiana forest 350 t/ha
  - Above and below ground dry biomass – soil biomass
Emission factors

• ONF / CIRAD/ CNRS Dendrometric expertise
  – Dispositifs

- Biomasse épigée totale des arbres de plus de 10cm
  > Volume sur écorce, densité, facteurs d’expansion
  > Terre ferme 350 T/ha ± 25
  > Marécages 290 T/ha ± 30

- Autres compartiments - étude bibliographique :
  > Biomasse épigée vivante autre que les arbres > 10 cm :
    15 à 30 T/ha ;
  > Biomasse épigée morte (litière et bois mort) :
    20 à 40 T/ha ;
  > Matière organique du sol :
    75 à 100 TC/ha
• Several thousands SPOT scenes acquired at the Cayenne Ground station during 2006

Satellite Data: SPOT 2006

Cloud cover < 75 %

• Selection of 2 to 7 images per frame (depending on the cloud coverage)
  – 65 SPOT 2 20m multispectral
  – 63 SPOT 4 20m multispectral
  – 47 SPOT 5 10m multispectral
  – Mean acquisition date: September 2006

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- **SPOT Images Orthorectification**
  - All 175 selected images processed in one spatiotriangulation block
  - 134 GCPs from The National Geographic institute IGN; more than 4500 tie points

- 148 manual tie points
- 4460 automatic tie points
- 134 IGN Ground control Points

- 20 m resolution resampling with use of SRTM 2000 Digital Terrain Model (90 m resol.)

- 0.15 to 0.2 pixels residual errors (~2 to 3 meters geometric accuracy)
- 7 Images from Global Landcover Facility (GLCF – Uni. Maryland)
- + 1 image USGS
- All Images around 1990
  - From 1986 to 1992
  - 62% of the territory covered by 1990 images
  - Mean acquisition date October 1989

- Landsat images georeferenced again using SPOT orthos as references
  - 24 to 49 tie points between each Landsat scene and the corresponding SPOT images
  - Bilinear model between Landsat Coordinates and SPOT Coordinates

  ➢ Geometric accuracy from 19 to 27 meters
• **Objective**
  - Optimize the photo-interpretation by focusing on the areas with actual land use changes
  - Improve the accuracy of the estimates

➢ **Very critical in the French Guiana context**
  - Small changes concentrated in some areas

• **Definition of 3 strata from existing information and data**
  - Stratum R (Reinforced sampling) = all areas with a high pressure of human activity on the forest
  - Stratum P (Petit Saut) = large area around Petit Saut reservoir
  - Stratum N (Normal sampling) = forest or natural areas that do not suffer from human disturbance: all what is not in strata R or P
• ONF GIS analysis on existing information
  – Roads
  – Agriculture
  – Human settlements
  – Cities
  – Urban areas
  – Gold mining
  – Maroni villages
  – Camopi & 3 Sauts Villages

→ Strata R definition
Sampling design

- Localization of the 3 strata
- Systematic/random grid
  - Square grid - 932 m between points
  - Random origin and inclination
- Sample definition
  - Strata R: All Grid points
  - Strata P: All Grid points
  - Strata N: sub-sample 1 point out of 9

<table>
<thead>
<tr>
<th>Stratum</th>
<th>Total Area</th>
<th>Sampling type</th>
<th>Sample size</th>
<th>Sample points distance</th>
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<tr>
<td>N</td>
<td>7 021 597</td>
<td>Normal</td>
<td>973</td>
<td>8388</td>
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<tr>
<td>P</td>
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<td>2453</td>
<td>932</td>
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<td>R</td>
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<td>Reinforced</td>
<td>13360</td>
<td>932</td>
</tr>
</tbody>
</table>

- Permanent sampling: same sample in 1990 and 2006

Good estimation of Land Use areas AND Land Use Changes
Photo interpretation

Shifting Cultivation  Gold mining

SPOT 5 2006 – © CNES

Petit Saut Reservoir  Agriculture extension

SPOT 4 2006 – © CNES

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Land Use categories

Forest
- Mangroves
- Other forests
Settlements
- Gold mining
- Other Settlements
Cropland
Grassland
Wetlands
- Water
- Other wetlands
Other lands

Sample plot with land use conversion from forest to other land use between 1990 and 2006
Sample plot without land use change between 1990 and 2006 – or with another type of land use conversion
Statistical estimations

- **Land use area** estimation from Land use proportion in each strata

  \[ S_{ij} = P_{ij} \times S_j \]

  - Area estimate
  - Variance
  \[ V_{ij} = (S_j)^2 \times \frac{P_{ij} \times (1 - P_{ij})}{n_j} \]
  - Stand. dev.
  \[ \sigma_{ij} = \sqrt{V_{ij}} \]

  Standard error of the estimate

- **Land use conversion areas** estimated from Land use conversion proportions in each strata: Same formulas
  - Estimates + Precision of estimates

- Sample used = All points without clouds in 1990 and 2006.
  - 15744 points on 16786
Results: Land uses 1990 & 2006

- Forest
  - 1990: 24,400 ha
  - 2006: 46,428 ha
- Settlements
  - 1990: 19,368 ha
  - 2006: 37,052 ha
- Cropland
  - 1990: 14,503 ha
  - 2006: 15,719 ha
- Grassland
  - 1990: 141,973 ha
  - 2006: 175,821 ha
- Wetlands
  - 1990: 8,614 ha
  - 2006: 25,560 ha

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Results

- Analysis forest changes in French Guyana 1990-2006

Total forest / non forest conversion: 94 061 ha – standard error 12%

- Usual deforestation
  - 42 050 ha (standard error 4%)
  - 2 486 ha/year

- Punctual event
  - 1994 std. err. 4%

- Natural changes
  - St. err. 67%

Forest 1990 / Gold mining 2006: 11 087 ha
Forest 1990 / Other settlements 2006: 10 379 ha
Forest 1990 / Croplands 2006: 17 403 ha
Forest 1990 / Other Land uses 2006: 3 181 ha
Forest 1990 / P. Saut Reservoir 2006: 35 064 ha
Mangrove 1990 / sea 2006: 16 947 ha

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CONCLUSIONS

• A first Kyoto inventory based on Optical Satellite data
  – Made possible thanks to the new acquisition possibilities at the Cayenne SPOT/ENVISAT receiving station
  – Sampling approach compliant with the 2006 IPCC guidelines and NFI methods
  – 2008 / 2012 period Implementation with minor improvements

• Interest of the method in a REDD regime
  – Efficiency of the method to monitor Deforestation has been demonstrated
  – Possibility to monitor forest degradation? Further investigations needed
    • Use of SPOT 5 data (2.5 to 10 m resolution) or Very High Resolution sensors (< 1m)
    • Combination with radar data (sensitivity to biomass)
    • Combination with field data
  – Key issue: availability of high resolution satellite images around the world
    • SPOT Direct receiving stations: current implantations and new projects
    • Other High resolution optical sensors (DMC constellation, IRS, Future Sentinel II from ESA or Pleiades from CNES)
    • Possibility to combine Low resolution and High resolution satellite imagery in a sampling strategy
• SPOT Receiving station Network
Assessment of forest cover changes in French Guiana using satellite imagery
Annex

Assessment of forest cover changes in French Guiana using satellite imagery