GFOI Expert Workshop 1:
Sensor interoperability
(and sensor complementarity)

Combining Landsat and SAR imagery for forest change detection in the tropics

Johannes Reiche, Dirk Hoekman, Veronique De Sy & Martin Herold
Wageningen University
(johannes.reiche@wur.nl)

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GROUP ON EARTH OBSERVATIONS

GFOI Global Forest Observations Initiative

Satellite-based RS methods for monitoring tropical DD at medium resolution:

- **Optical** (Landsat-like) approaches exist, but applicability limited in cloud covered regions
- **SAR** RS provides continuous, but sparse TS; TS methods are limited
- **Multi-sensor SAR-optical** approaches demonstrated increase in forest mapping accuracy
- **Multi-sensor SAR-optical change detection** methods are very limited *(e.g. Lehmann et al., 2012, Reiche et al. 2013)*

- Upcoming stream of free-of-charge medium resolution optical and SAR imagery -> Need for SAR-optical multi-sensor time series approach!

Research projects @ Wageningen University

- Assessing opportunities and limitations for sensor interoperability/ complementarity in support of REDD and forest land cover products
  - Sy,V. De, Herold,M., Achard,F., & Asner,G. (2012). Synergies of multiple remote sensing data sources for REDD+ monitoring. *Current Opinion in Environmental Sustainability*, 1–11.
  - Reiche, J. & M. Herold (2012): Concepts and processing techniques for a global Sentinel 1-3 Land Cover Dynamics and Change (LCDC) product. ESA SP-707. Sentinel 2 Preparatory Symposium

- **Method project 1:** Combining multi-temporal Landsat and PALSAR data at feature level for mapping tropical DD (Guyana)
  - Reiche, J., Souza, C., Hoekman, D., Verbesselt, J., Persaud, H., D., Herold, M. (2013): Feature level fusion of multi-temporal ALOS PALSAR and Landsat data for mapping and monitoring of tropical deforestation and forest degradation. *JSTARS*.

- **Method project 2:** Fusing Landsat and SAR time series for monitoring forest change in the tropics (Method validation site: Fiji)
  - Reiche, J., Verbesselt, J., Hoekman, D., Herold, M. (submitted): Fusing Landsat and SAR image time series for forest change detection in the tropics. *Remote Sensing of Environment*

Key synergy potential for generating improved forest information products *(De Sy et al. 2012)*

RS Product	Key synergies in REDD+ context
Forest area change monitoring	Use of Optical medium resolution (Landsat) and SAR time series
Near-real time deforestation detection	Combining high temporal (coarse optical data) and medium resolution optical data
Sub-national hotspot monitoring	Combining optical medium resolution and high resolution data
Land use change patterns and tracking of human activities	High temporal (coarse optical data) and medium resolution optical data - dense time series data with ancillary datasets
Forest degradation monitoring	Multiple remote sensing sources necessary depending on processes and activities e.g. commercial versus locally driven degradation processes
Monitoring of wildfires and burnt areas	Use of thermal and optical remote sensing data
Biomass mapping	Combination of LiDAR, SAR and/or optical data with in-situ data
Forest type mapping	Optical data and LiDAR or SAR

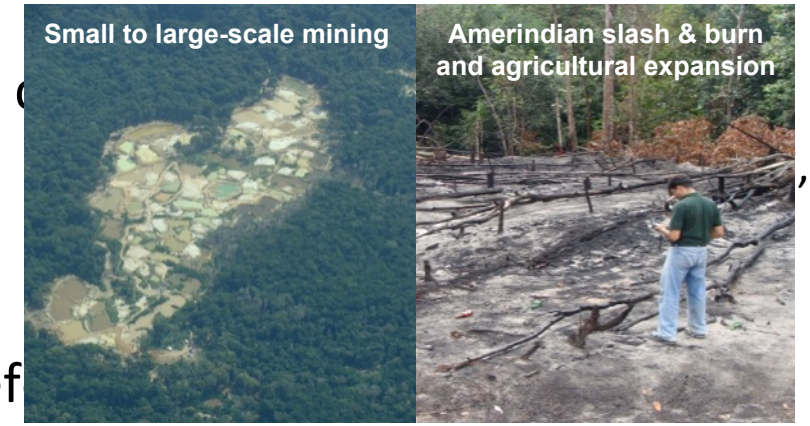
Method Projects 1: Combining multi-temporal Landsat and PALSAR data at feature level for mapping tropical DD (Guyana)

Reiche, J., Souza, C., Hoekman, D., Verbesselt, J., Persaud, H., D., Herold, M. (2013): Feature level fusion of multi-temporal ALOS PALSAR and Landsat data for mapping and monitoring of tropical deforestation and forest degradation. *JSTARS*.

Project 1: Combining multi-temporal ALOS PALSAR and Landsat data at feature level for mapping tropical DD (Guyana) (*Reiche et al. 2013)*

- Context
  - Mahdia mining are in central Guyana (main area for DD)
  - Very important for Guyanese REDD+ MRV
  - Heavily cloud contaminated (even with compositing Landsat images over 1-2 years, no cloud free information for some areas)

    -> Guyana faced series issues when reporting to Norway



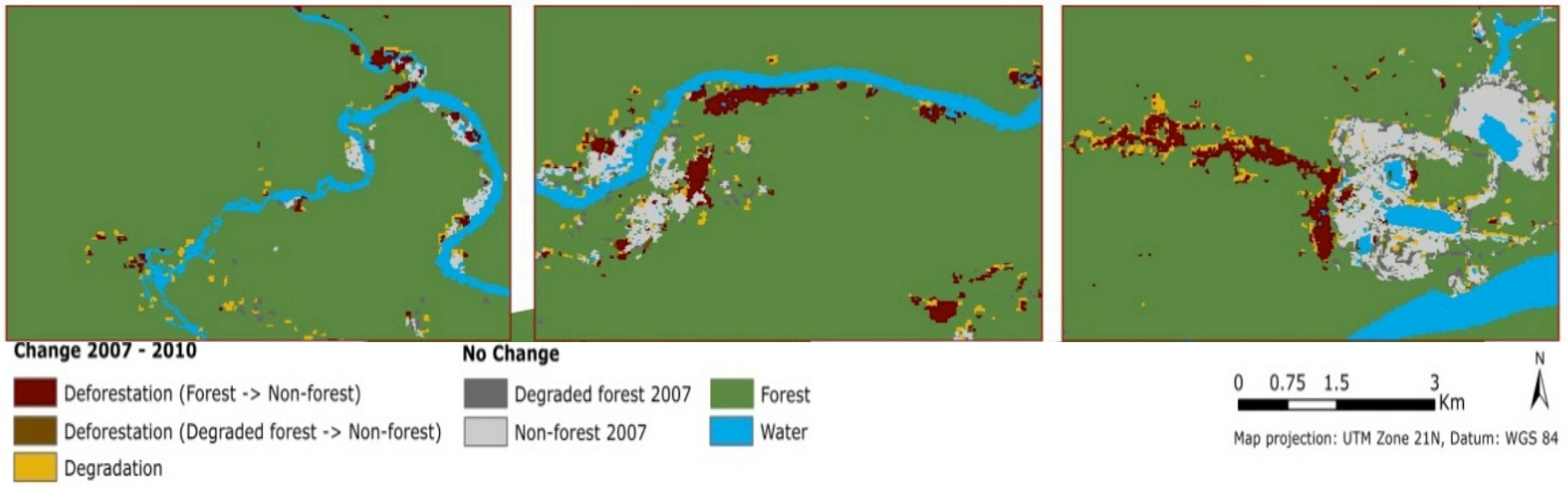
- RS
  - , 2010)
  -
- Ref
  - VHR data
  - GIS data set from Guyana Forestry Commission, Ground data from field trips

Project 1: Combining multi-temporal PALSAR and Landsat data at feature level for mapping tropical DD (Guyana) (*Reiche et al. 2013)*

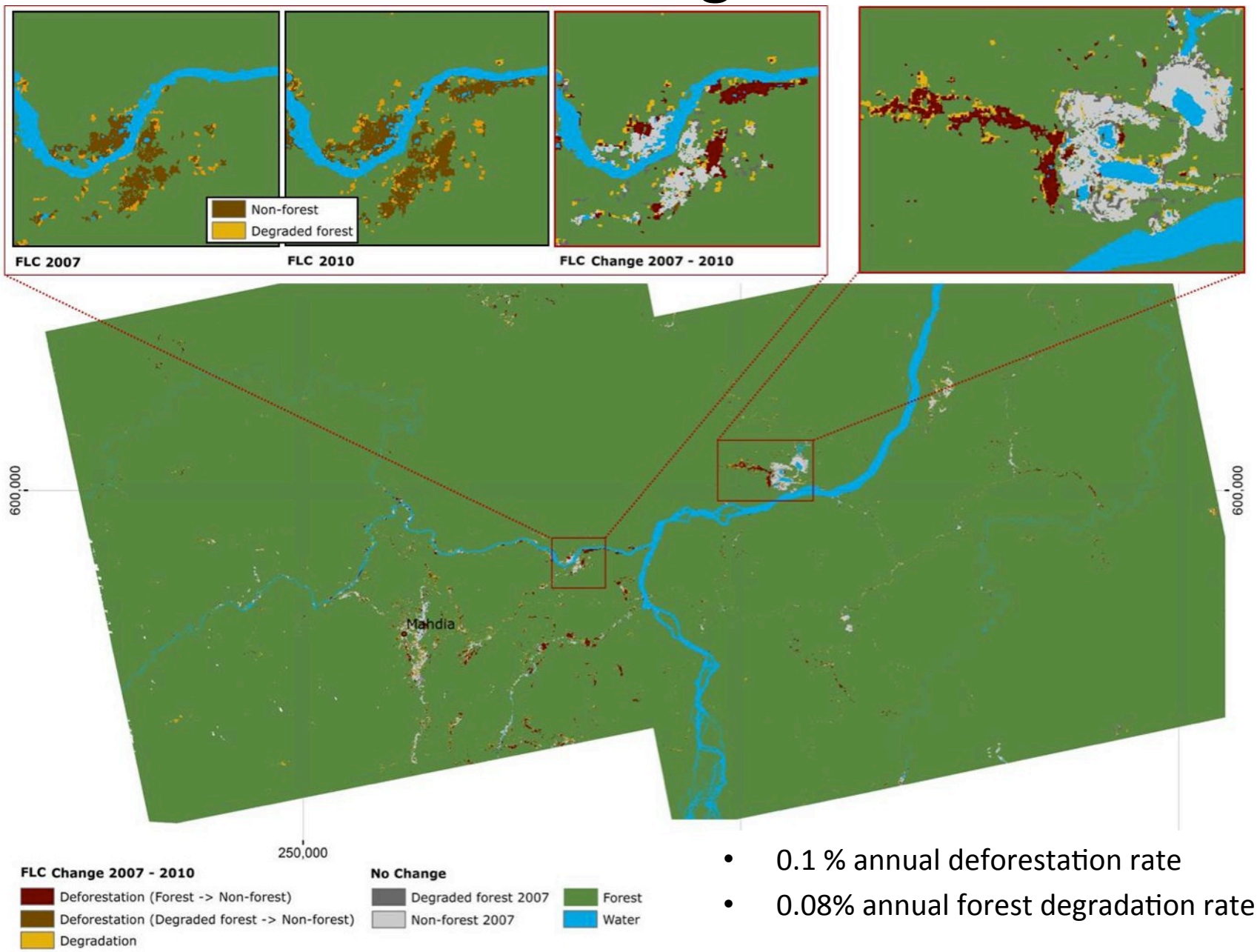
- Methods
  1. Independent processing of multi-temporal Landsat & PALSAR input data streams
     - **Landsat:** Pre-processing and cloud masking with ImgTools software (IMAZON), Temporal compositing
     - **PALSAR:** Standard pre-processing with Gamma, Multi-temporal SAR speckle filtering (*Quegan & Yu, 2001)*
  2. Extracting features
     - **L-band HV, HH, HVHH (multi-temporal & multi-channel filtered)**
       + Spatially complete
       - Limited capabilities for detecting forest degradation
     - **Landsat sub-pixel fraction information - NDFI (Normalised Difference Fraction Index, Souza et al., 2009, ImgTools Software)**
       + Capability of detecting degraded forest
       - Persistent cloud cover -> spatially incomplete data
  3. Fusing features, using a decision tree (alternatively Bayesian approach)

Project 1: Combining multi-temporal PALSAR and Landsat data at feature level for mapping tropical DD (Guyana) (*Reiche et al. 2013)*

- Results
  - Forest change (Deforestation & Degradation) 2007 – 2010
  - Annual deforestation (0.1%) and forest degradation (0.08%) rate for Mahdia
  - 89.4% OA
  - **Sensor Complementarity** of Landsat and PALSAR led to reduced missing data
    - Landsat (cloud cover, SLC off) and PALSAR (SAR layover and shadow)
    - < 0.01% for deforestation, 7.9 % for forest degradation
    - Quality flag indicates area



Results: FLC change 2007-2010



- 0.1 % annual deforestation rate
- 0.08% annual forest degradation rate

Project 1: Combining multi-temporal PALSAR and Landsat data at feature level for mapping tropical DD (Guyana) (*Reiche et al. 2013)*

- Technical challenges
  - Decision tree needs to be adapted individually for each region
  - PALSAR data access policy hinders wide-spread use
  - Data processing not yet fully automated
  - + Low processing capacities needed

- R&D requirements
  - Method expansion for time-series use & C-band
  - Approach is transferable in a tropical/REDD+ monitoring context

- Future actions
  - FAO intern is currently implementing the method in R, and plans to apply it for large areas in Laos/Cambodia

- Status: R&D -> pre-operational

Projects 2: Fusing Landsat and SAR time series for monitoring forest change in the tropics

(Method validation site: Fiji)

Reiche, J., Verbesselt, J., Hoekman, D., Herold, M. (submitted): Fusing Landsat and SAR image time series for forest change detection in the tropics. *Remote Sensing of Environment*

Project 2: Fusing Landsat and SAR time series for monitoring forest change in the tropics (*Reiche et al., submitted, RSE*)

- **Study:**
  - A novel multi-sensor time series fusion approach is proposed
  - Landsat NDVI and ALOS PALSAR backscatter time series are fused
  - Change detection framework is used to detected abrupt forest changes in the tropics
  - Spatial and temporal accuracy validated with 3-monthly wall-to-wall reference data

  - Per-pixel missing data (MD) in Landsat NDVI TS stepwise increased to 95% to evaluate robustness of forest change monitoring when dealing with persistent cloud cover
  - Multi-temporal SAR filtered vs. unfiltered (PALSAR) times series compared

Project 2: Fusing Landsat and SAR time series for monitoring forest change in the tropics (*Reiche et al., submitted, RSE*)

- **RS data**
  - Landsat NDVI time series:
    - All images between 2004-2012
    - Fully automated processing, using Ledaps/FMASK
    - NDVI calculation and TS stacking
  - ALOS PALSAR FBD time series:
    - All FBD images between 01/2007 – 09/2010
    - Standard processing with Gamma software & 25 m local DEM
    - TS stacking
    - Multi-temporal SAR filtering (Quegan & Yu 2001)
    - Resampling to 30m Landsat pixel resolution

Project 2: Fusing Landsat and SAR time series for monitoring forest change in the tropics (*Reiche et al., submitted, RSE*)

- **Spatial and temporal accuracy assessed**
  - Wall-to-wall reference data allowed map comparison
    (no sampling errors introduced!, Number of pixel in forest change map = sampling unit)
  - Equal distribution of stable forest/change areas (~15 000 pixel each class)
  - Spatial accuracy: OA, OE, CE
  - Temporal accuracy: Mean time lag of detected changes (month)

Project 2: Fusing Landsat and SAR time series for monitoring forest change in the tropics (*Reiche et al., submitted, RSE*)

- Results
  - Fused NDVI-PALSAR results significantly better than NDVI- and PALSAR-only results, also for increasing missing data
  - **Sensor Interoperability** of NDVI and $HVHH_{mt}$ TS for abrupt forest changes
  - Multi-temporal filtered PALSAR HVHH backscatter ratio time series ($HVHH_{mt}$) was most strongly correlated with the NDVI time series
  - Multi-temporal SAR filter is a mandatory pre-processing step
  - Approach can be adapted for other time series
  - R-package including example data set is under development

Project 2: Fusing Landsat and SAR time series for monitoring forest change in the tropics (*Reiche et al., submitted, RSE*)

- Technical challenges
  - PALSAR data access policy hinders wide-spread use
  - Data processing and method is automated in R, but needs to be more efficient
  - Still high processing capacities needed

- R&D requirements
  - Test approach over forest degradation
  - Test for C-band
  - Expand the method to fuse multiple time-series
  - Data requirements: Landsat TS data (free), PALSAR TS data (high costs)
  - Approach is transferable in a tropical/REDD+ monitoring context

- Future actions
  - Complete R-package (available at R-Forge by end 2014)
  - Expand approach to fuse multiple TS (optical, C- and L-band), e.g. Landsat, S1, PALSAR-2
  - Country-wide application (RS and reference data needed!)

- Status: R&D -> pre-operational

Thank you!