The Global Forest Observations Initiative
Research & Development Coordination
component

GFOI R&D Programme

–

Technical Progress Report

16 April 2018

GFOI
Global Forest Observations Initiative

Table of Contents

Group 1

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ESTIMATING FOREST DEGRADATION IN THE BRAZILIAN AMAZON DUE TO SELECTIVE LOGGING AND FOREST FIRES

GFOI PRIORITY R&D TOPIC(S):
• Forest degradation assessment due to selective logging and forest fires
• SAR/Optical interoperability and complementarity studies

RESEARCH OBJECTIVE:
Develop and apply a semi-automated procedure based on fraction images from multi-temporal data for mapping and differentiating forest degradation caused by selective logging and fires.

STATUS February 2017:
The objective of this work is to develop and apply a semi-automated procedure based on fraction images from multi-temporal data for mapping and differentiating forest degradation caused by selective logging and fires. For this, we have been analyzing different remote sensing data as Landsat series, Sentinel-2, Proba-V, etc.

The proposed method has been performed according to the following steps: 1) generation of a forest mask to prevent mapping areas already deforested previously to the first image acquired for the study period; 2) generation of fraction images for the sensor images utilized; 3) image segmentation applied to a multi-temporal dataset composed of soil and shade fraction images derived from the sensor data; 4) mapping of new deforested areas using the soil fraction images; 5) mapping of burned areas using the shade fraction images; 6) mapping logging areas using the soil fraction images; and 7) combination of the results to generate a map with four classes: old deforestation, new deforestation, degradation forest areas due to fire (areas of forest that has been burned but not clear cut), and due to selective logging. The methodology developed is consistent for the different remote sensors images.

The preliminary results of the methodology using multitemporal Landsat images were presented at the IGARSS 2017 in Forth Worth, Texas, USA and prepared to be submit a Scientific Journal; and the results of the methodology using Sentinel-2 images were presented at SBSR 2017 in Santos, São Paulo, Brazil. (copies of the articles attached).

We also did the field work in July/August period in order to validate our preliminary results. A fieldwork was performed between July 17 and August 2, 2017 for the allocation of forest inventory plots and verification of areas of forest degradation, either by selective logging or by fire. In each plot, information of the individuals with DAP ≥ 30 cm, total height (Htot), commercial height (Hcom), the position in relation to canopy (emergent, dominant or dominated trees), if the tree was alive or dead, and the location of the trees with GPS navigation, as well as the X and Y location of each tree in the plot were collected During the field campaign it was travelled approximately 2,200 km, visiting points in the forest management areas and points in the degraded forest areas caused by fire.

Plans and milestones for 2018/19: Next activities will be to start analyzing radar data. For this we plan to use ALOS-PALSAR 2, RADARSAT and Sentinel-1 images acquired over our study site.

Publications (published/submitted/planned)
- "Monitoring deforestation and forest degradation using multi-temporal fraction images derived from Landsat sensor data in the Brazilian Amazon" – IGARSS 2017 Proceedings. (PDF copy available)
- "Monitoring deforestation and forest degradation in the Amazon basin using multi-temporal fraction images derived from Sentinel-2 sensor data" - SBSR 2017 Proceedings. (PDF copy available)
- "Monitoring deforestation and forest degradation using multi-temporal fraction images derived from Landsat sensor data in the Brazilian Amazon" – Completed for submission to scientific journal. (PDF)

Group 2

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MAPPING FOREST DISTURBANCE IN DENSE HUMID AND DRY FOREST LANDSCAPES

GFOI PRIORITY R&D TOPIC(S) ADRESSED:
- Forest degradation from selective logging, subsistence agriculture and fire
- Forest type mapping including humid and dry forest
- SAR/optical integration studies

RESEARCH OBJECTIVES:
1. Methodology development for mapping forest types and characterising forest disturbance in complex landscapes (MAL-1).
2. Investigation of near real-time forest disturbance monitoring based on the integration of optical and SAR data streams (GAB-1)

STATUS March 2018:
The activities over the last 12 months have focused on implementing some of the methods previosuly developed over test areas primarily in dense humid forest focusing on objective (2). Objective (1) is currently on hold and will be fulfiled over the next 12 months. Tests were carried out over a 30,000km² area in the central part of Gabon. The following products were generated:
- Status information service
  - Forest Cover 2010, 2015, 2016 and 2017
  - Land Use 2010 and 2015 (see example below)
- Fast response information service
  - Forest Disturbances 2016 and 2017
- Change Information Service
  - Deforestation change 2010-15, 2015-16 and 2016-17
  - Land use change 2010-15
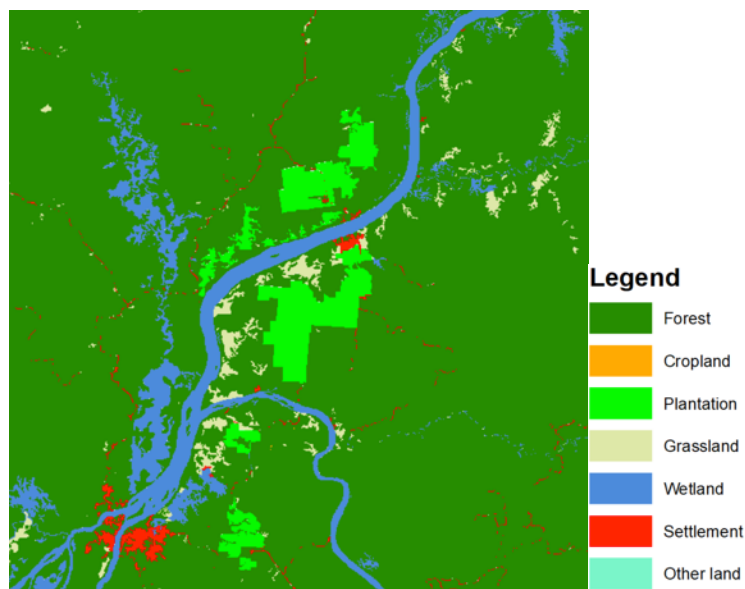
Figure 1. Land use Product extract for 2015 in central Gabon

The BFAST was initially tested in Gabon, but the level of cloud cover is such that it is difficult to collect sufficient cloud free obsqervations. Therefore, a simple NDVI diffierencing transect based approach

was developed and implemented over the 2015-2017 time period to detect forest disturbance in near real-time. The detection of forest disturbances was performed based on times series of Landsat-8 and Sentinel-2 images. The methodology was based on paired image comparison with the use of transects to calibrate the identification of suitable thresholds:

1. A radiometric correction of the newest image is applied based on a histogram comparison to get comparable NDVI values.
2. The difference between the 2 NDVI is calculated ande a suitable threshold is applied based on transect based data as illustrated below.
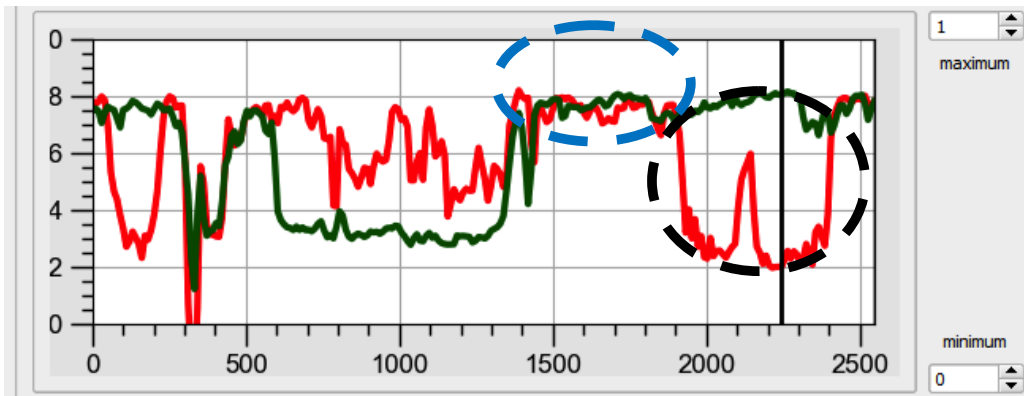
Figure 2. Identification of suitable NDVI threshold for detecting deforestation based on the comparison of image pairs

Original Images

NDVI Difference
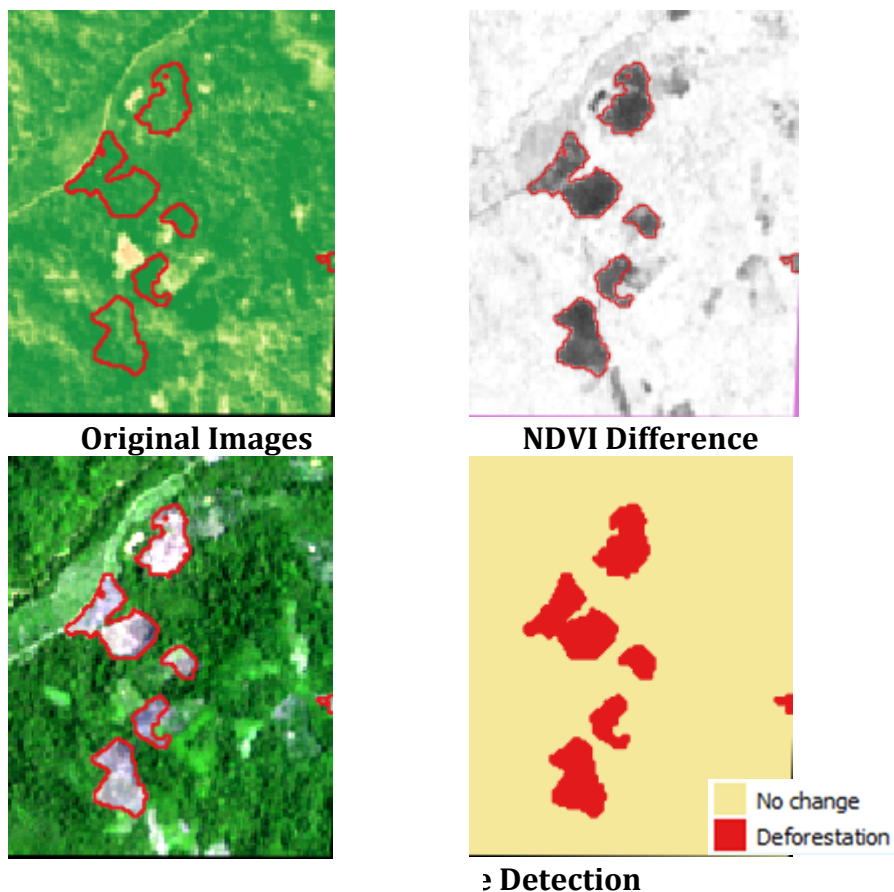
e Detection

Figure 3. Change detection based on NDVI differentiation of image pairs

For the next 12 months, the work will focus on the integration of the Sentinel 1 data stream into the fast response information service to improve the frequency of near-real time forest disturbance detection.

5

GFOI R&D Group 3

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TIME SERIES-BASED MONITORING OF IPCC LAND CATEGORY CONVERSIONS USING MULTI-SENSOR DATA

GFOI PRIORITY R&D TOPIC(S) ADRESSED:
- Time-series SAR/Optical data for monitoring forest and land cover change
- Time-series SAR/Optical methods development for monitoring degradation
- Optical-optical interoperability: use of SPOT and Sentinel-2 data to fill gaps in Landsat monitoring
- SAR-SAR complementarity: use Sentinel-1 to complement ALOS-1/2 L-band time series

RESEARCH OBJECTIVE:
Time series-based monitoring of IPCC land category conversions using data from multiple sensors. More specifically, we investigate the aspects of time-series fusion of optical (Landsat/Spot/Sentinel-2) and SAR (ALOS ½, Sentinel-1) data for monitoring of forest disturbance and recovery.

STATUS March 2018:
Continued progress is made in the test sites in Colombia and Mexico to study the fusion of optical and SAR time series for activity data monitoring. This work is conducted in collaboration with Boston University as Ph.D. research (Chris Holden) under a NASA Grant (PI Kellndorfer, Earth Big Data LLC). We continue production and analysis of Sentinel-1 time series with generation of radiometrically corrected products based using SRTM-1 DEM for calibration. RTC production includes multi-temporal speckle filter reduction and radiometric terrain correction based on the facets methods (Small, 2012). Preliminary analysis with the Sentinel-1 data time series shows a variable coverage which improves now with the launch of Sentinel-1B. Logging detection can be achived with Sentinel-1 time series and timing of logging is improved over Landsat only monitoring. Example of logging detection is given in Figure 1.
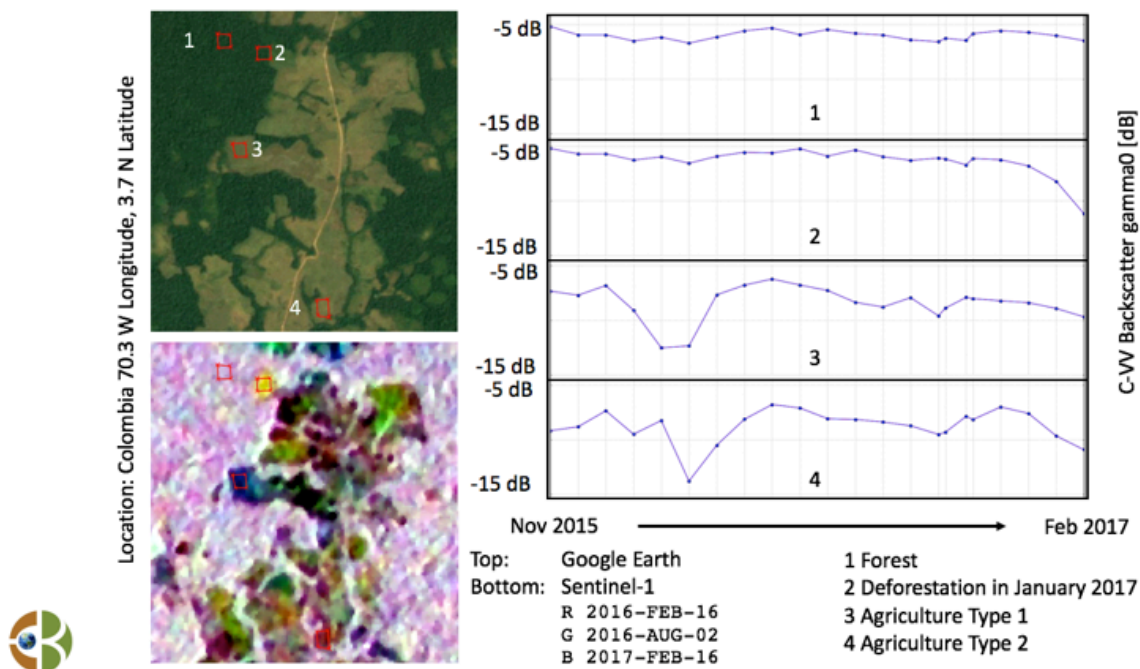
Figure 1: Example of Sentinel-1 CVV time series signals over a forest/agriculture site in Central Colombia. (Kellndorfer, 2017, for submission).

Geometric Alignment of KC_Scansar tiles

Before Alignment
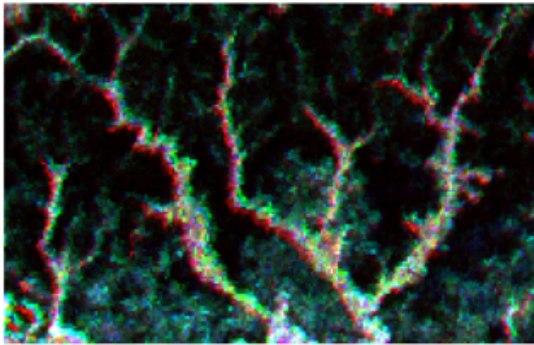
After Alignment
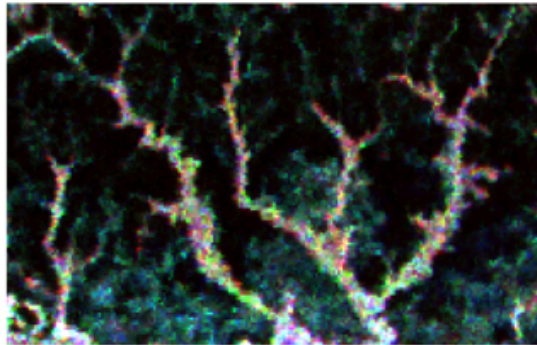
Figure 2: Geometric alignment of post-processing of KC-ScanSAR mosaic data over Colombia. Note the slight offsets on three time steps forming the RGB mosaic and it's realignment after application of our alignment algorthim.

Once our KC ScanSAR data are aligned, we will conduct the change detection analysis in our fusion framework with optical data sets, expected to be accomplished in the first third of the extension phase. The time series profiles for flooding cycle detection and deforestation detection over initial studies in Colombia look promising (Figures 3 and 4).

River Flooding from ALOS-2 L-Band ScanSAR

RGB 07-Jul-15 / -3-Jul-16 / 31-Jul-16
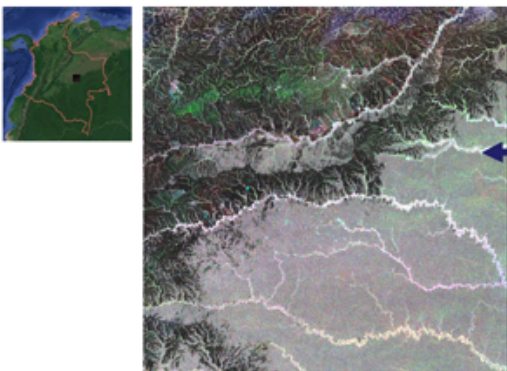
Backscatter Temporal Signal 12-Apr-15 to 26-Feb-2017
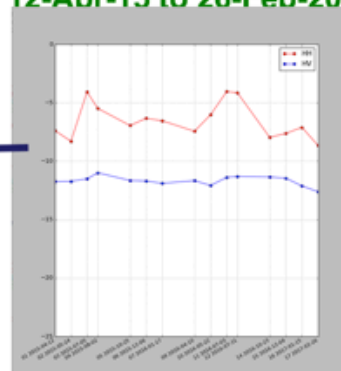
ALOS-2 ScanSAR 1degree tile N04W072 (upper left corner)

Figure 3: Seasonal Inundation patterns in ALOS-2 ScanSAR L-HH are prominent, while L-HV has a flat temporal signature, as expected.

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Logging Detection from ALOS-2 L-Band ScanSAR
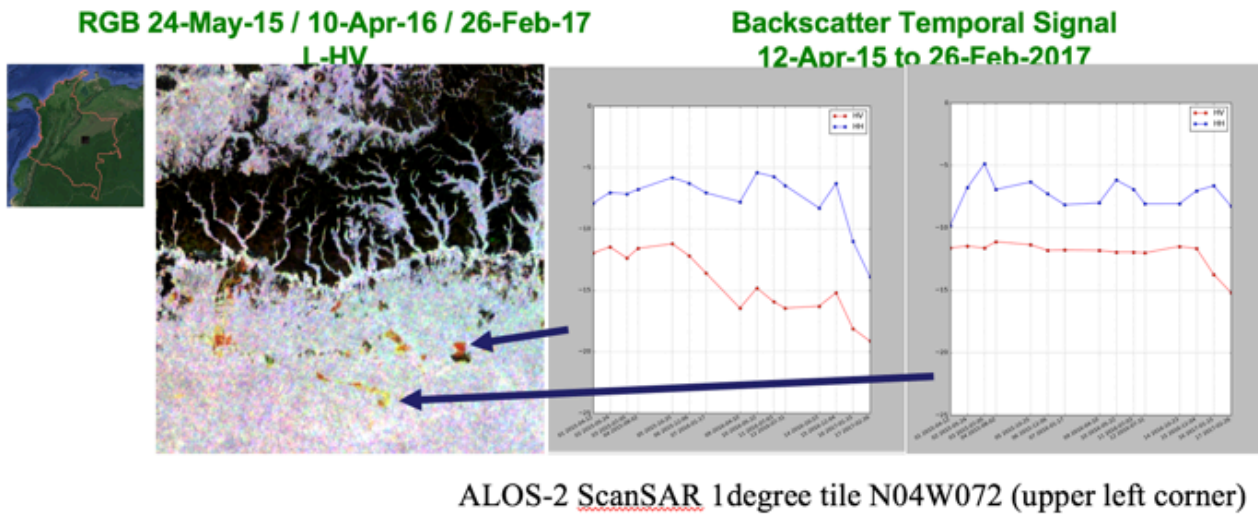
Figure 4: Logging detection with ALOS-2 ScanSAR data over the northern edge of the Amazon Forest in Colombia. The distinct drop in L-HV cross-polarized data is visible in the deforested patches while L-HH like-polarized data have lags in the detection in degradation processes.

Next Steps:
The following next steps will be focus of our R&D work:

• Complete preprocessing of all L-band data sets:
• RTC processing of ALOS-2 data
• Finalize geometric alignment algorithm of ScanSAR tiles
• Fuse Landsat, Sentinel-1, and ALOS-2 ScanSAR data into a joint classification system

Milestones:
• Complete Time series production of Landsat, Sentinel-2, Sentiel-1, ALOS-2 ScanSAR data over all test sites with processing of geometric alignment
• Run change detection algorithm based on the time series metrics
• Validate Change with colleagues in Colombia, Per
• Obtain reference data sets from the commercial data providers as needed for validation.
• Finalize comparison of SAR, optical and Fusion analysis
• Report on results and write publications

Group 4

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COMBINING SAR AND OPTICAL TIME SERIES WITH COMMUNITY BASED ACTIVITY DATA FOR MONITORING TROPICAL FOREST CHANGES

GFOI PRIORITY R&D TOPIC(S):
- Deforestation and degradation monitoring
- SAR/optical integration
- Sensor interoperability
- (Community based forest monitoring)

RESEARCH OBJECTIVES:
1. Exploit the potential of Sentinel-1 for near-real time forest disturbance monitoring.
2. Expand and improve recently developed SAR-optical time series fusion methods (Reiche et al., 2015a/b) to combine C-band SAR, L-band SAR and optical time series.
3. Exploit synergies between optical & SAR time series and community based activity data (collected through mobile phone technologies) to monitor forest disturbances (in near real-time).

Methods will be developed and tested for three different (and representative) tropical forest environments in order to improve their robustness and applicability.
• ETH-1: Seasonal Afromontane forest with small area changes due to smallholder agriculture, fuelwood harvesting.
• FIJ-1: Managed pine plantation with large and well documented changes; regularly affected by landslides.
• BOL-1: Dry tropical forest strongly affected by large area commercial deforestation

STATUS March 2018:

Project 1: "Near-real time deforestation detection in tropical dry forest combining Landsat, Sentinel-1 and ALOS-2 PALSAR-2 time series"
Site: BOL-1
Research objectives: 1 and 2
Data: Landsat, Sentinel-1, PALSAR-2
Work progress: Data pre-processing completed; Research completed; Method and results are published in:
Reiche, J., Hamunyela, E., Verbesselt, J., Hoekman, D. & Herold, M. (under review): Near-real time deforestation detection in tropical dry forest combining Landsat, Sentinel-1 and ALOS-2 PALSAR-2 time series. Remote Sensing of Environment
Key findings: Our results for a dry forest site in Bolivia show that deforestation events were detected with a higher spatial and temporal accuracy when combining observations from multiple sensors than when using observations from a single sensor. We quantified how the near real-time deforestation detection is associated with a trade-off between the confidence in detection and the temporal accuracy. When aiming for a high confidence in change area estimates for example, deforestation was detected with a user's accuracy of 88% and producer's accuracy of 89% (low area bias) and a mean time lag of 31 days using all sensors. This is on average 7 days earlier than when using only Sentinel-1 observations and six weeks earlier than when relying on Landsat observations only. We show that confident near real-time deforestation alerts can be provided with a mean time lag of 22 days but these are associated with a higher commission error.

Project 2: "Developing a method for integrating remote sensing and community based data (CBD) data streams for deforestation detection"
Site: ETH-1
Research objectives: 1 and 3

Data: Landsat, Sentinel-1, PALSAR-2, Community-based data, Pleiades (reference)
Work progress: MSC topic Christos Sotiropoulos "Developing a method for integrating remote sensing and CBD data streams for deforestation detection" to be submitted by latest 06/2018
Key finding: Results for a dry forest site in Africa shows that combining CBM and multi-sensor SAR+optical data provides new opportunities to improve forest monitoring in the tropics. The developed integration-method builds upon an existing probabilistic (Bayesian) approach that was initially designed to combine optical and SAR time series (Reiche, de Bruin, Hoekman, Verbesselt, & Herold, 2015). Results indicated the high contribution of CBM observations to detect forest changes more timely.

Project 3: "Near real-time Detecting post-cyclone forest disturbance"
Site: FIJ-1
Research objectives: 1 and 2
Data: Landsat, Sentinel-1, Pleiades (reference)
Work progress: MSC topic Jan Pokorn "Integration of Sentinel-1 SAR and Landsat NDVI time series for abrupt disturbance detection on Fiji's Mangrove forests (Study case: Tropical Cyclone Winston)" to be submitted by latest 06/2018
Key finding: Results show that the Bayesian approach for NRT monitoring (Reiche et al. (2015)) enables us to combine multi-sensor time series to improve near real-time change detection in mangrove areas. Here, it was used and adapted for assessing near real time capacities for immediate damage estimation on mangrove forests after the Winston cyclone on Fiji in February 2016. We show that dense Sentinel-1 C-band SAR in combination with Landsat data allows for timely and accurate detection of mangrove damage. To estimate the accuracy of our result, emphasis was given on using a set of "good practice" recommendations for implementing accuracy assessment of the produced disturbance maps and derive our own reference data from independent available satellite imagery according to Olofsson et al., 2015.

Project 4: "Combining Sentinel-1 data and active fire alerts for characterising fire-related forest change"
Site: SUM-2
Research objectives: 1
Data: Sentinel-1
Work progress: Data pre-processing completed and research is undergoing

Outputs:
Published:
Reiche, J., Hamunyela, E., Verbesselt, J., Hoekman, D. & Herold, M. (2017): Improving near-real time deforestation monitoring in tropical dry forests by combining dense Sentinel-1 time series with Landsat and ALOS-2 PALSAR-2. Remote Sensing of Environment. http://dx.doi.org/10.1016/j.rse.2017.10.034

Hamunyela, E., Reiche, J., Verbesselt, J., & Herold, M. (2017). Using Space-Time Features to Improve Detection of Forest Disturbances from Landsat Time Series, 1–17. http://doi.org/10.3390/rs9060515

Reiche, J., Lucas, R., Mitchell, A.L., Verbesselt, J., Hoekman, D.H., Haarpaintner, J., Kellndorfer, J.M., Rosenqvist, A., Lehmann, E.A., Woodcock, C.E., Seifert, F.M. & Herold, M. (2016): Combining satellite data for better tropical forest monitoring. Nature Climate Change, 6, 2, 120-122. DOI:10.1038/nclimate2919.

Planned:
Reiche et al.,(in preparation): Combining dense Sentinel-1 data and active fire alerts to characterize fire-driven deforestation.

Group 5

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ADVANCING THE NATIONAL MRV SYSTEM OF GUYANA TO INCLUDE ELEMENTS OF FOREST DEGRADATION

GFOI PRIORITY R&D TOPIC(S) ADRESSED:
• Methods of detecting and monitoring forest degradation arising from mining and shifting agriculture/rotational farming
• SAR/Optical interoperability and complementarity studies

RESEARCH OBJECTIVES:
1. To advance Guyana's national MRV System to include crucial elements of forest degradation monitoring, specifically in the areas of monitoring small scale mining and shifting agriculture
2. Use of VHR data for Cal/Val of products

STATUS March 2018:
Funding for the Guyana MRV recommenced in October 2017. This has allowed the GFC team to collect the relevant high-resolution imagery to evaluate the changes detected from the sensors being evaluated. The on-ground field work will be conducted in April 2018. A standard operating procedure has been developed to enable standardized field measurements and processes to be applied. The objective of this field work is to test the ability of the Cosmo Skymed to detect small scale changes associated with degradation activities – those associated with mining and selective forest harvest.

Plans and milestones for 2018/2019]
Field work April 2018 and provisional results provided July 2018 and final results 31/12/2018

Publications (published/submitted/planned)
A technical report and powerpoint presentation that outlines results and conclusions as relevant to the Guyana context.

Site 1: Active mining   Site 2: Rotational cultivation

Overview of the satellite data
Repeat observations of Cosmo Skymed images have been acquired over the Guyana sites. In addition, high resolution aerial imagery has also been collected Nov/Dec 2017. This allows 'ground truthing' of the Cosmo Skymed images. No SPOT Pleiades data was captured over the nominated sites.

Group 6

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MONITORING FOREST DISTURBANCE IN DRYLAND DIPTEROCARP AND PEAT SWAMP FOREST

GFOI PRIORITY R&D TOPIC(S) ADRESSED:
- Forest degradation by X-band SAR
- Sensor synergy - SAR- and LiDAR-based methods of forest and carbon accounting
- Above ground biomass

RESEARCH OBJECTIVES:
Mawas, Kalimantan –
1. Forest degradation, sensor interoperability, above-ground biomass. Study of dense time-series of Sentinel-1 and TerraSAR-X/ COSMO-SkyMed data to monitor degradation processes (related to fire damage, encroachment and illegal logging).
2. Study of improved land cover mapping capability of bi-static TanDEM-X data and utility for improved biomass mapping.
3. Peat swamp hydrology.
Harapan, Sumatra –
4. Forest degradation, sensor interoperability. Study of dense time-series of Sentinel-1 and TerraSAR-X for near-real time highly automated degradation and logging detection.

STATUS March 2018:
A methodology to detect logging of canopy trees at tree level has been developed for TerraSAR-X StripMap data. This technique is useful for degradation mapping as well as for monitoring illegal and legal selective logging in tropical rain forest. These results have been presented at the GFOI R&D meeting in The Hague, October 31, 2016. Publication is in progress.

New data have been collected to study degradation monitoring with COSMO-SkyMed HIMAGE and Pleiades (BOR3 and SUM2) and peat swamp hydrology with P2 ScanSAR (BOR3 only). For both sites S1 time series have been collected routinely at 24-day repeat initially and is currently done at a 12-day repeat. COSMO-SkyMed data collection has been successful, however Pleiades data collection (used for validation) is difficult because of persistent cloud cover. In December 2017 two Pleiades images for each site have been selected and requested but these still have not been delivered. Therefore the analysis of the new BOR3 and SUM2 data is still in an early phase.

The "Starling" system for deforestation monitoring was developed in cooperation with Airbus and TFT. The system is available for operational application since the launch of the Starling service in June 2017. This system uses a combination of optical (including SPOT) and Sentinel-1 radar data. Methodology was developed for integration of optical and radar data time series. For the radar component new techniques for deforestation detection in mountainous terrain has been developed successfully.

Research at a new test site commenced in Brazil, in the Northern parts of the state of Para, the so-called Calha Norte. The TSX tree logging technique was successfully demonstrated in a timber concession area. First steps for operational implementation are made.

New results Calha Norte test site: Three TerraSAR-X radar images were acquired at the following dates: 2017-12-03, 2018-01-05 and 2018-02-07. Almost all tree-logging detections were made in the area indicated by the yellow box (Fig.1). Enlargements are shown in Figures 2-3.
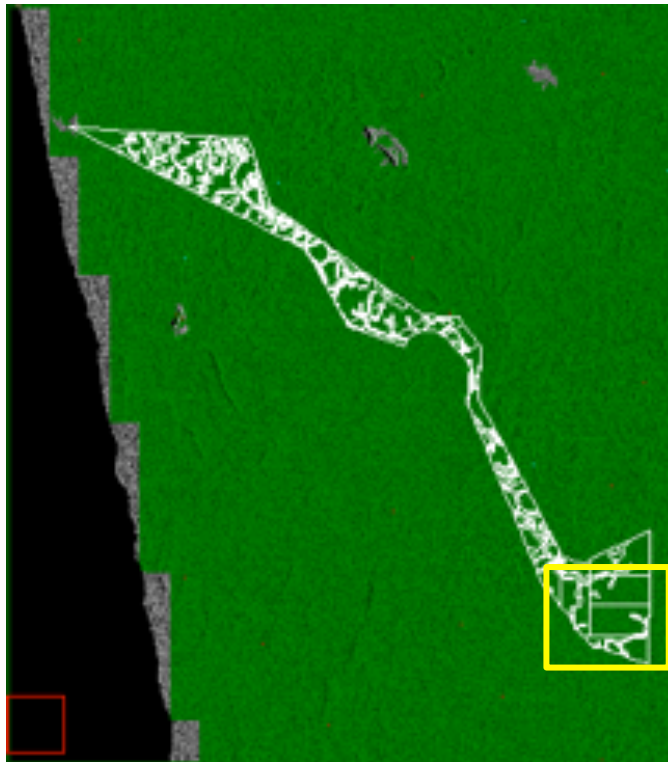

Fig 1. Tree logging compartments for 2017-2018 in a timber concession area in the Calha Norte. In the period of TSX acquisition tree logging detections were made in the yellow box.
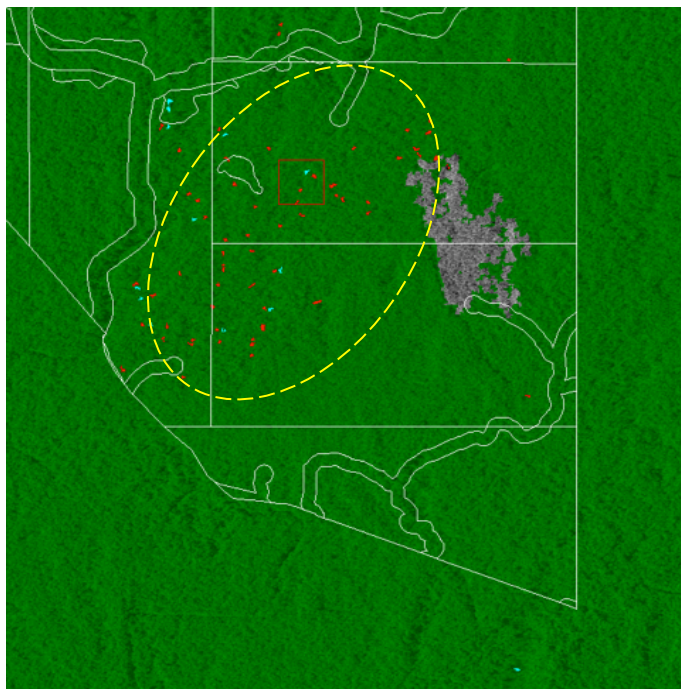
Fig 2. First period (December-January) logged tree detections (red and cyan dots); Forest in background is green or grey.
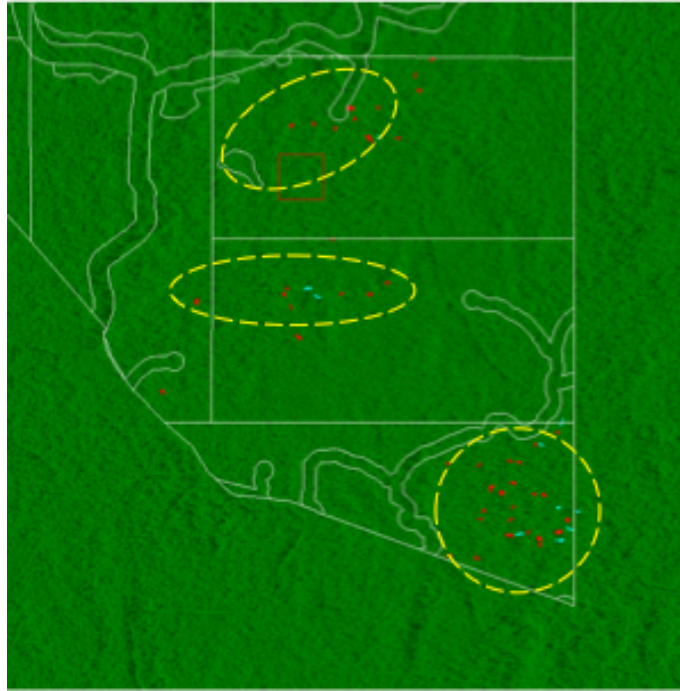
Fig 3. *Second period (January-February) logged tree detections (red and cyan dots).*

COSMO-SkyMed data provision:

For both test sites time series of HIMAGE data at a one-month interval was provided for a period of two years.

Mawas site COSMO-SkyMed (ASC)

1.	CSKS4_SCS_B_HI_06_HH_RA_SF_20160318222503_20160318222510.h5	2016-03-18
2.	CSKS1_SCS_B_HI_06_HH_RA_SF_20160423222450_20160423222457.h5	2016-04-23
3.	CSKS1_SCS_B_HI_06_HH_RA_SF_20160525222438_20160525222445.h5	2016-05-25
4.	CSKS1_SCS_B_HI_06_HH_RA_SF_20160626222426_20160626222434.h5	2016-06-26
5.	CSKS4_SCS_B_HI_06_HH_RA_SF_20160724222414_20160724222421.h5	2016-07-24
6.	CSKS4_SCS_B_HI_06_HH_RA_SF_20160825222402_20160825222410.h5	2016-08-25
7.	CSKS4_SCS_B_HI_06_HH_RA_SF_20160926222353_20160926222400.h5	2016-09-26
8.	CSKS4_SCS_B_HI_06_HH_RA_SF_20161028222343_20161028222351.h5	2016-10-28
9.	CSKS4_SCS_B_HI_06_HH_RA_SF_20161129222333_20161129222340.h5	2016-11-29
10.	CSKS1_SCS_B_HI_06_HH_RA_SF_20170104222319_20170104222326.h5	2017-01-04
11.	CSKS4_SCS_B_HI_06_HH_RA_SF_20170201222309_20170201222317.h5	2017-02-01
12.	CSKS4_SCS_B_HI_06_HH_RA_SF_20170305222302_20170305222309.h5	2017-03-05
13.	CSKS1_SCS_B_HI_06_HH_RA_SF_20170410222253_20170410222301.h5	2017-04-10
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19.	CSKS4_SCS_B_HI_06_HH_RA_SF_20171015222240_20171015222247.h5	2017-10-15
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21.	CSKS4_SCS_B_HI_06_HH_RA_SF_20171218222244_20171218222251.h5	2017-12-18
22.	CSKS4_SCS_B_HI_06_HH_RA_SF_20180220222248_20180220222254.h5	2018-02-20

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Harapan site COSMO-SkyMed (DESC)
1. CSKS4_SCS_B_HI_09_HH_RD_SF_20160319103543_20160319103551.h5 2016-03-19
2. CSKS4_SCS_B_HI_09_HH_RD_SF_20160506103529_20160506103537.h5 2016-05-06
3. CSKS1_SCS_B_HI_09_HH_RD_SF_20160526103518_20160526103525.h5 2016-05-26
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5. CSKS4_SCS_B_HI_09_HH_RD_SF_20160725103454_20160725103502.h5 2016-07-25
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12. CSKS4_SCS_B_HI_09_HH_RD_SF_20170306103342_20170306103350.h52017-03-06
13. CSKS2_SCS_B_HI_09_HH_RD_SF_20170419103332_20170419103340.h52017-04-19
14. CSKS1_SCS_B_HI_09_HH_RD_SF_20170513103326_20170513103333.h52017-05-13
15. CSKS4_SCS_B_HI_09_HH_RD_SF_20170610103323_20170610103330.h52017-06-10
16. CSKS4_SCS_B_HI_09_HH_RD_SF_20170712103320_20170712103327.h52017-07-12
17. CSKS4_SCS_B_HI_09_HH_RD_SF_20170813103318_20170813103325.h52017-08-13
18. CSKS4_SCS_B_HI_09_HH_RD_SF_20170914103319_20170914103325.h52017-09-14
19. CSKS4_SCS_B_HI_09_HH_RD_SF_20171016103321_20171016103328.h52017-10-16
20. CSKS4_SCS_B_HI_09_HH_RD_SF_20171117103323_20171117103330.h52017-11-17
21. CSKS4_SCS_B_HI_09_HH_RD_SF_20171219103325_20171219103331.h52017-12-19
22. CSKS4_SCS_B_HI_09_HH_RD_SF_20180221103328_20180221103335.h52018-02-21
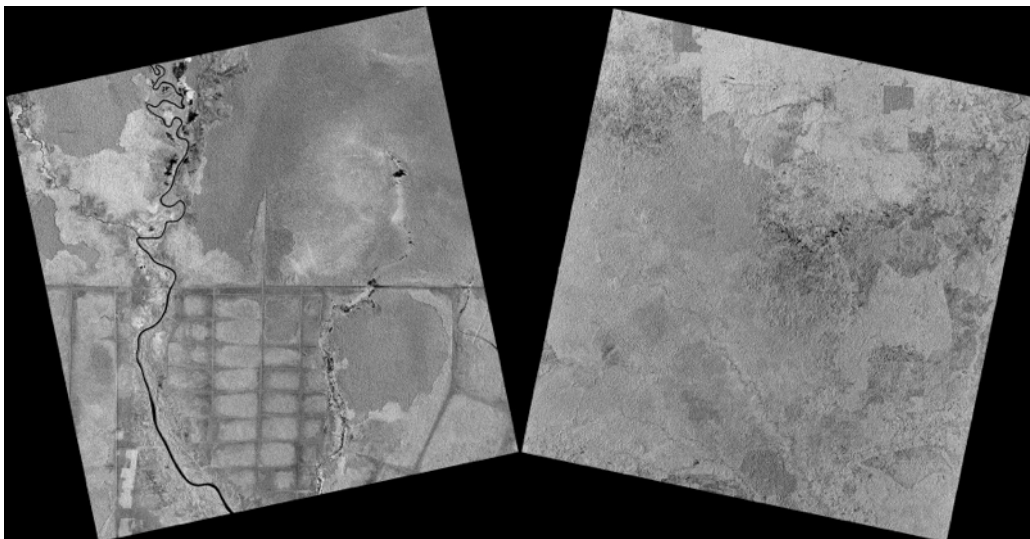
Fig 4. Processed COSMO-SkyMed scenes for BOR3 and SUM2

Status Pleiades data provision:

Persistent cloud cover poses a large problem. For both test sites two images were selected. For the BOR3 test site the acquisitions of 2017-06-07 and 2017-09-20 and for the SUM2 test site those of 2016-12-03 and 2017-09-14. *These data were requested in December 2017, but still have not made available.*

Mawas site Pleiades data (quick-looks)
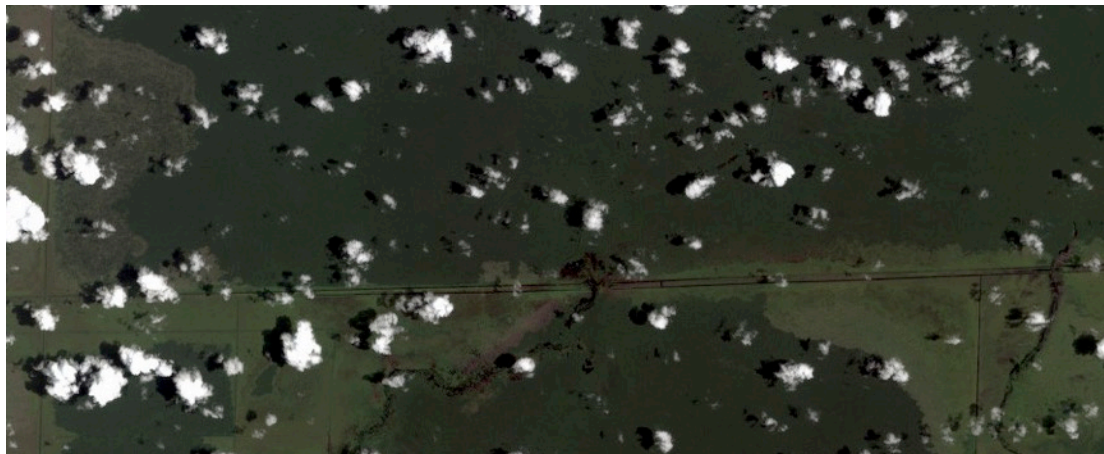
Fig 5. *Pleiades quick-look for BOR3 2017-06-07*
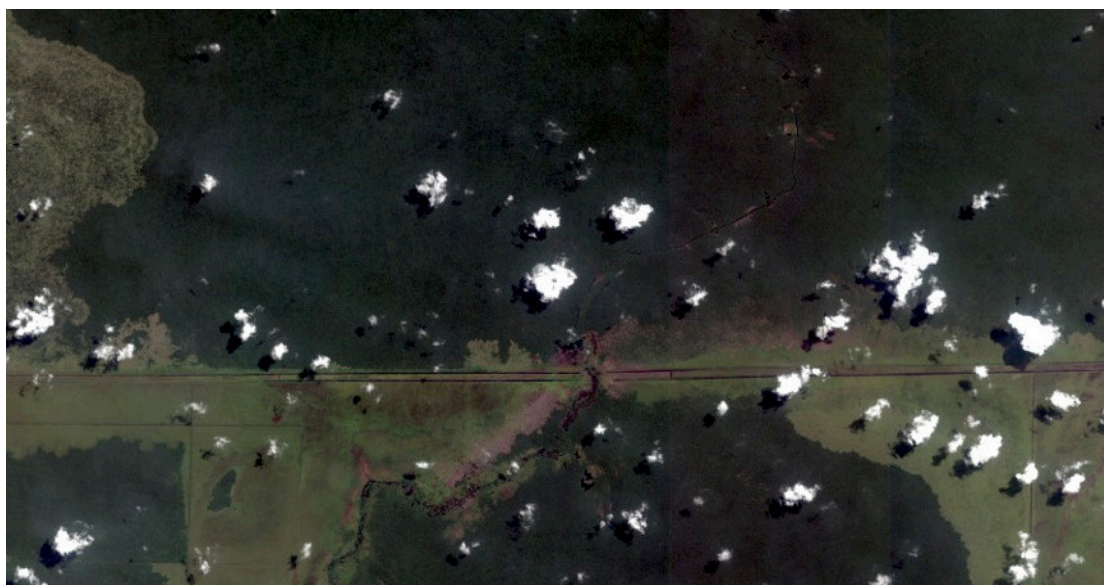
Fig 6. *Pleiades quick-look for BOR3 2017-09-20*

Harapan site Pleiades data (quick-looks)

Fig 7. *Pleiades quick-look for SUM2 2016-12-03*

Fig 8. *Pleiades quick-look for SUM2 2017-09-14*

Plans and milestones for 2018/2019

1.   Algorithm tuning and completion of analysis of the COSMO-SkyMed datasets over the BOR3 and SUM2 test sites *pending availability of the selected Pleiades data (2018)*

2.   Further developments of operational monitoring systems for selective tree logging based on TSX and COSMO-SkyMed (2018-2019)

3.   Refinement of the Sentinel-1 component of the Starling deforestation monitoring system, notably for mountainous areas (2018)

4.   Analysis of PALSAR-2 data over peat areas in Indonesia, with emphasis on the peat restoration areas, and in collaboration with LAPAN and the Indonesian Peat Restoration Agency

Publications (published/submitted/planned):

1.   António Ferraz, Sassan Saatchi, Liang Xu, Yifan Yu, Victoria Meyer, Stephen Hagen, Carlos Silva, Orbita Roswintiarti, Ari Samboko, Sangram Ganguly, Dirk Hoekman, Plinio Sist, Jerome Chave, Sarah Walker, Timothy Pearson, Arief Wijaya, Carbon Storage in Remaining forests of Kalimantan, Indonesia, special issue of the *Environmental Research Letters* on Carbon Monitoring Research and Applications (submission April 2018)

2.   TSX selective tree logging detection at primary forest sites in Indonesia and Brazil (planned September 2018)

Group 7

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MONITORING FOREST COVER CHANGE AND CARBON DYNAMICS IN SAVANNAH AND TROPICAL RAINFOREST

Research overview

Research in this group is carried out through two PhD projects focusing on method development in multimodal image analysis with forest remote sensing as the primary application. These are:

1. Change detection in heterogenous remote sensing images (Heterochange)
2. Biophysical parameter retrieval with heterogeneous predictor data (Heteregress)

The first project aims to develop algorithms that enables change detection in pairs and time series of images of different modality (different sensor types, sensor modes/parameters and/or environmental conditions). By removing the constraint that the images must be from the same sensor and perfectly co-calibrated, we may utilise larger data amounts and facilitate analyses with higher temporal resolution (rapid change) and extended time frame.

The second project aims to develop algorithms that produce consistent estimates of biophysical parameters, with above-ground biomass as the main target, even if the image data used in as predictors in the regression analysis may be spatially nonstationary since we may have to mosaic images acquired on different dates, with different sensor configurations and under different environmental conditions. The goal is to produce estimates with higher precision and accuracy.

Overview of acquired satellite data

Both projects use the data repository acquired during 2011-2016 by the project *Enhancing the monitoring, reporting and verification of forests in Tanzania through advanced remote sensing techniques* by the support of GFOI. This repository has been supplemented by new acquisitions through GFOI.

I am not able to produce an account of what I have ordered in recent years. I have not kept an own account of this, since this is registered in the order history which can be accessed through the AUIG2 interface. However, a search of my order history produces the message «No order found», which is wrong. I ordered a batch of data in June 2017, but do not have the capacity to count the scenes base don the emails from JAXA.

Research status

The Heterochange project is in its second year (running August 2016 – July 2019). The PhD candidate has produced one conference paper (reported below) and is currently producing another one. Some preliminary results are available, but not in a form which justifies presentation in this report. The developed methodology is on par with state-of-the-art supervised algorithms from the literature. We are currently trying to extend the methods to the unsupervised case to minimise the requirement of manual interaction.

Paper production is behind schedule, but it is foreseen that the candidate will produced three journal papers before defending his Ph.D. thesis. The project proceeds according to plan with supervision at UiT in addition to collaboration with the University of Genoa, Italy. A master student from CentraleSupélec in France will join the project group on an internship, and will implement reference algorithms base on deep learning for comparison with our develop methods and as a potential starting point for further developments base don deep learning.

The Heteregress project (running February 2017 – July 2021) has been on hold for half a year as the candidate has been on leave. Research so far has focused on reviewing algorithms from multitask learning that seem adaptable to the problem at hand. The candidate has obtained a scholarship to visit Professer Gustau Camps-Valls at the University of Valencia in 2018/19. Professor Camps-Valls is an expert in the field and runs a similar ERC Anvanced Grant project which focuses on estimation of clorophyll. Project is running according to plan, but no paper submissions are expected this semester, and probably not this year.

Plans and milestones for 2018/2019

- Outcome 1 and 2 report to GFOI and CEOS/SDCG [Q1 2018]
- One paper submitted to peer-reviewed journal [Q2 2018]
- Progress presentation at 2018 GFOI Science meeting [Q4 2018]
- Three paper submitted to peer-reviewed journals [Q2 2019]
- Outcome 1 and 2 report to GFOI and CEOS/SDCG [Q1 2019]

Publications

L. T. Luppino, S. N. Anfinsen, G. Moser, R. Jenssen, F. M. Bianchi, S. Serpico & G. Mercier: **«A Clustering Approach to Heterogeneous Change Detection, Proc.** Scandinavian Conference on Image Analysis 2017, Tromsø, Norway (published).

L. T. Luppino, S. N. Anfinsen, G. Moser, R. Jenssen, F. M. Bianchi, S. Serpico & G. Mercier: **«A study of heterogeneous change detection based on supervised image regression», Proc. 2018 IEEE International Workshop on Machine Learning for Signal Processing**, Ålborg, Denmark (in preparation).

L. T. Luppino et al. (three journal papers expected in 2018/19)

S. M. Björk et al. (one conference and one journal paper expected in 2018/19)

Group 8

Principal Investigator:
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DEFORESTATION AND DEGRADATION MONITORING IN PAPUA NEW GUINEA

GFOI PRIORITY R&D TOPIC(S):
- Deforestation monitoring using SAR
- Forest degradation detection using SAR

RESEARCH OBJECTIVES:
- Optimising the use of SAR for the detection and monitoring of deforestation and forest degradation.
- Recovery of forest biophysical parameters.
- Support the development of an MRV/REDD+ system for PNG

STATUS March 2018:
Funding for our proposed PNG projects was reallocated following a major grant from the Japanese International Cooperation Agency (JICA) to the PNG Forestry Authority aimed at improving its remote sensing and GIS capabilities. As a result HGC's activity in PNG was severely curtailed.

We were however able to make some progress on the recovery of biophysical parameters with existing datasets in the Milne Bay area (no data were received by HGC under GFOI as a result of our "commercial" status). Data from the GeoSAR airborne dual-band InSAR system from the JICA-funded collection in 2012 were used to generate a land cover classification in which Low Altitude forest types were split into two categories: (i) Low Altitude Forest on Plains and Fans, roughly below 400m above sea level, and (ii) Low Altitude Forest on Uplands, roughly below 1000m above sea level (Figure 1.)

Mg/ha
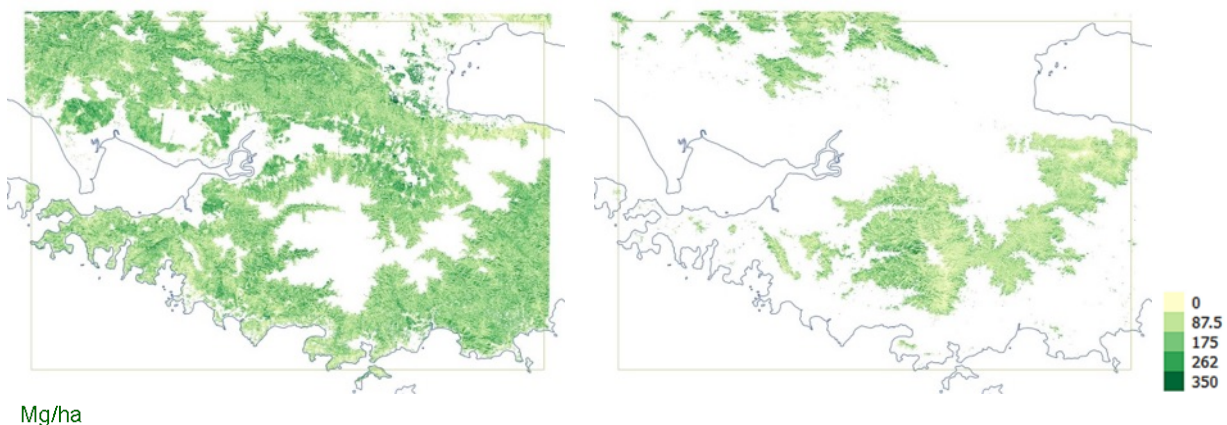
Figure 1. Forest classification in the Milne Bay study area, left: Low Altitude Forest on Plains and Fans, and right: Low Altitude Forest on Uplands. Forest biomass indicated was estimated from GeoSAR 2012 data.

An initial estimate of the 2012 biomass in the low altitude forest was recovered using the method described in [1] based on the P-band – X-band InSAR height difference (h_{XP}) observed with the terrain-corrected 2012 GeoSAR InSAR data (Figure 1.) This approach expresses AGB as $\log B = \log a + n \log h_{XP}$, where a and n are model parameters, and which model is functionally equivalent to that described in [2]. This method of AGB estimation was shown to be at least statistically equivalent in another area of PNG to that employed in [3].

L-band FBD PALSAR-1 data from 2011 was ortho-rectified and terrain-corrected LHV Gamma0 values were correlated against the AGB estimates from the GeoSAR calculation over masked areas corresponding to the two Low Altitude forest categories derived from the land cover classification (Figure2.)
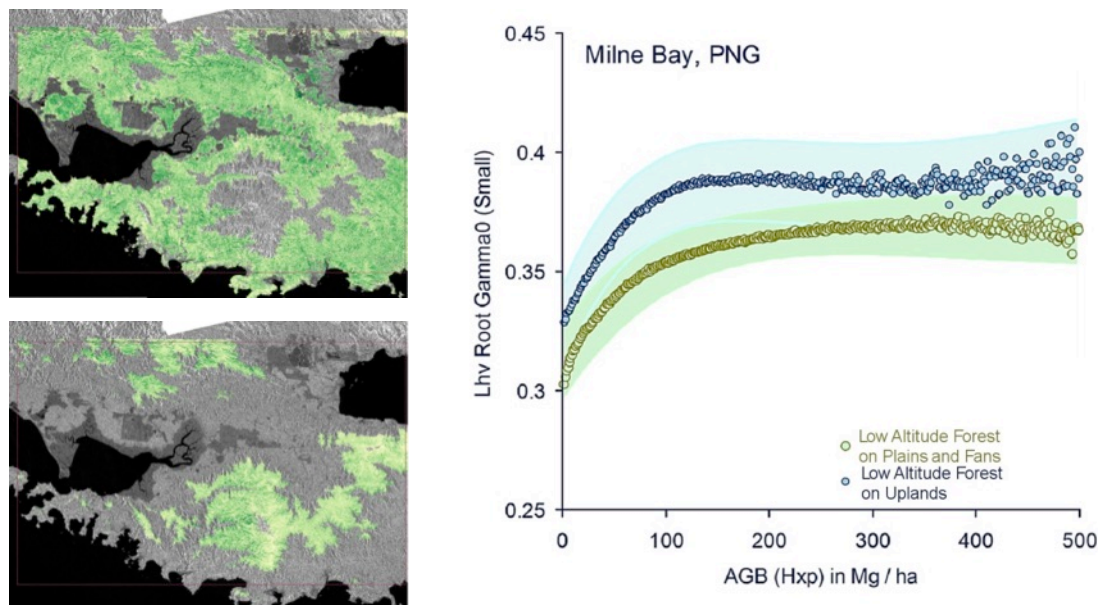
Figure 2. left: forest AGB overlaid onto terrain corrected ALOS-1 LHV root Gamma0 for (left-upper) low altitude forest on plains and fans and (left-lower) low altitude forest in uplands and right: the recovered relationship between this estimate of AGB and the mean value of the terrain-corrected LHV root Gamma0 value.

As a result of the large number of independent samples (GeoSAR data were posted at 5m and the area of interest was approximately 3000km^2 of which ~1800km^2 were forest), the recovered relationship between LHV and GeoSAR AGB appears to extended significantly beyond the traditional "saturation" limit of around 100 Mg/ha. These relationships could in principle be inverted and applied over wide areas using PALSAR-I data, and PALSAR-II data matched to PALSAR-I.
We also observed that upland low altitude forest appears brighter than plains forest at the same AGB value. This is possibly due to either (i) some artefact of the terrain correction, although the same correction was applied to both forest types one is on predominantly flat terrain, or (ii) a real difference in scattering behaviour resulting from differences in terrain and forest architecture between the two land cover classes. Further investigations are warranted.

Next Steps:
The absence of funding to support further activity limits what we are able to do next. However we would seek to repeat the process using more recent ALOS-2 observations to recover change estimates if resources permit.

Milestones:
• Repeat analysis using recent ALOS-2 data.
• Compare findings with PNG FA data
• Report.

[1] M L Williams *et al*., *Tropical Forest Biomass Recovery using GeoSAR Observations*, proc. Geoscience and Remote Sensing Symposium, 2009 IEEE International, IGARSS 2009
[2] T R Feldpausch *et al*., *Tree height Integrated into Pantropical Forest Biomass Estimates*, Biogeosciences, 9, 3381-3403, 2012.
[3] T Neeff *et al*., *Tropical Forest Biomass Measurement by backscatter and DEM Information as Derived from Airborne SAR*, proc. Geoscience and Remote Sensing Symposium, 2003 IEEE International, IGARSS 2003.)

Group 9

Principal Investigator:
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FOREST AND CARBON RESOURCE ASSESSMENT IN TROPICAL AND BOREAL FOREST ECOSYSTEMS

GFOI PRIORITY R&D TOPIC(S):
- Carbon estimation using SAR/Optical/LiDAR
- SAR/Optical integration for forest degradation assessment
- SAR/Optical interoperability and complementarity studies for land use and change monitoring

RESEARCH OBJECTIVES:
- To create and test a novel method for forest area and biomass monitoring by combining earth observation data and modelling to support assessment of forest degradation, national forest inventories and forest management with a special reference to carbon balance (FCT-MEX-2).
- Improve methods to gain knowledge on the biomass and carbon stocks and predicted future growth of Durango state forest (MEX-8).
- To reduce the uncertainty in carbon and water balance assessment with the help of earth observation data and modelling, and provide more accurate up-to-date information on forest parameters (FIN-1, FIN-2).

STATUS March 2018:
Two new study areas were added compared to original FIN-1/FIN-2, FCT-MEX-2 and MEX-8, described in the proposal. Corresponding study sites are located in Nepal (within the Terai region), and in Gabon (covering the AirSAR campaign area). Incorporation of these auxiliary study sites was motivated primarily by lack of high quality reference data in Mexico (compared to our initial expectations) on one hand, and presence of reliable reference data within the new study sites on the other hand. Presently, the quota of ALOS PALSAR and ALOS-2 PALSAR-2 scenes allocated for this GFOI project is completely used.

Further, we describe the progress achieved compared to our interim technical progress report of March 2017. As both boreal and tropical forests were targeted in the framework of our GFOI R&D activities, the reporting is organized in two subsections, boreal forest sites and tropical forest sites, respectively.

Boreal forest sites
Forest above ground biomass (forest stem volume) methodologies with multiparametric L-band SAR data were further developed and polished in cooperation between VTT (Yrjö Rauste, Tuomas Häme) and Aalto University (Oleg Antropov, Jaan Praks). We pursued the two-fold goal of establishing a reliable relationship between forest inventory parameters and two modes of fully polarimetric SAR (PolSAR) data at L-band: multi-temporal PolSAR, and interferometric polarimetric SAR. The study sites were located in the Finnish taiga, and the research goal was achieved within two separate studies. Forest inventory data were acquired, and part of the study was performed in the context of the EU funded North State project. Developed methodologies are instrumental in reducing the uncertainty in carbon and water balance assessment with the help of Earth Observation data and modelling and provide more accurate up-to-date information on forest parameters (particularly forest tree height and stem volume).

In the first study, we examined multi-temporal behaviour of several popular PolSAR parameters (both established and recently introduced) observed at L-band in relation to stem volume of boreal forests. The satellite SAR data were represented by a time series of ALOS PALSAR scenes acquired during several seasons in 2006-2009. A relationship between forest stem volume and PolSAR parameters of interest was established via fitting several semi-empirical models of interest. Optimal ways to combine multi-seasonal PolSAR scenes in stem volume estimation were studied as well. This paper was published in "Remote sensing" journal in September 2017 (www.mdpi.com/2072-4292/9/10/999). To the best of our knowledge, this effectively appears to be first journal communication on the mapping of forest biomass from spaceborne L-band quad-pol SAR time series.

The second study uses an interferometric PolSAR pair acquired in 2015 over the boreal forest test site in Finland. The perpendicular baseline was relatively short thus decreasing sensitivity to vertical profile variations. Interferometric coherence and phase were used in forest tree height estimation using the so-called hybrid model-based retrieval. Advanced strategies of combining the PALSAR acquired PolInSAR data with TanDEM-X InSAR data and optical satellite data were studied as well. We expect this research to be reported at a remote sensing conference during this year, to be followed by a journal article.

Tropical forest sites

Methods for mapping land use and land use change are studied in Mexico in view of demonstrating a spatially explicit carbon accounting system in an area including rapid succession of agricultural and forest renewal stages. Primary satellite SAR data were ALOS ALSAR (and ALOS-2 PALSAR-2) scenes and Sentinel-1 time series. A change detection approach for monitoring forest removal was developed and validated. This research was done in the ESA DUE Innovator 2 project AccuCarbon in co-operation between VTT and Helsinki University, resulting in improved methodologies to estimate and monitor growth of forests in Chiapas and Durango, as well as to monitor deforestation and land-use conversion in the study area. A paper describing specific outcomes of the project is presently in preparation, with a goal of submitting it during the first half of 2018.

Research over auxiliary test sites (Nepal and Gabon) is presently done in cooperation between VTT and Aalto University.

Novel approaches towards forest biomass mapping are being developed using satellite and reference data acquired over Terai, Nepal. ALOS-2 PALSAR-2 quad-pol SAR scenes, as well as TanDEM-X bistatic InSAR coherence are the key imaging radar data in this study, with multifrequency (and multi-mode) SAR data fusion in the context of biomass estimation pursued as a primary gal. First results of this ongoing research are encouraging, with reduced levels of saturation observed compared to figures previously reported in the literature. An abstract has been submitted to IGARSS 2018, and a journal paper is presently in preparation.

One more additional study site is in Gabon, over the ESA AfriSAR campaign area. The idea is to compare the performance of presently available spaceborne L-band SAR data in forest biomass estimation versus the potential P-band data contribution, in the context of the BIOMASS mission. The analysis has been initiated, and we expect to have results ready for public presentation and discussion during 2018.

Plans for 2018/2019

We plan to finalize described above research activities and communicate our results on:
1. PolInSAR for forest variable retrieval based on ALOS-2 PALSAR-2 data (conference and journal paper)
2. Forest removal and land cover/use monitoring based on L- and C-band SAR data;
3. Tropical forest parameter assessment using combined multifrequency data over Nepal and Gabon (at least ALOS PALSAR, ALOS-2 PALSAR-2 and TanDEM-X)

Publications (published or submitted)

[1] Antropov, O.; Rauste, Y.; Häme, T.; Praks, J. Polarimetric ALOS PALSAR time series in mapping biomass of boreal forests. Remote Sens. 2017, 9, 999.
[2] Antropov et al., Tropical forest tree height and above ground biomass mapping in Nepal using TanDEM-X and ALOS PALSAR data, Intl. Geosci. Remote Sens. Symp. (IGARSS), 2018, submitted.

Overview of the satellite data

ALOS PALSAR (50 scenes) and ALOS-2 PALSAR-2 (30 scenes) acquired over several boreal and tropical forest study sites were used. All these data were successfully ordered, delivered and downloaded.

Group 10

Principal Investigator:
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FOREST AND CARBON RESOURCE ASSESSMENT IN TROPICAL AND BOREAL FOREST ECOSYSTEMS

GFOI PRIORITY R&D TOPIC(S):
- Forest disturbance monitoring
- SAR-Optical interoperability and complementarity

RESEARCH OBJECTIVES:
- To examine the potential for retrieving forest canopy profile information from a combination of radar and high resolution optical image data. Success would provide a lower cost alternative to LiDAR data and may enable REDD+ activities to be differentiated.
- Test the potential of methods in a range of forest conditions. Two sites have been identified.
- To evaluate the effect of forest disturbance on soil CO_2 fluxes.
- To assess the ecology and long-term impact of management vs. natural disturbance on eucalypt forests.

STATUS March 2018:
We have collated the available datasets over both sites. The time series we have available are shorter than we were hoping, and there are fewer coincident captures than we would ideally like. We are now processing a DEM from the available lidar data which we will use to correct some of the radar datasets.

Significant restructuring at CSIRO affected our capabilities aligned with this work, which was reported to the GFOI in 2016. These changes have essentially halted progress on this work for some time and no progress has been made on the analytical aspects of this task to date. Recently we have been able to reconsider this opportunity in light of planned future collaborative opportunities, and we intend to conduct the field assessments associated with this project between July and December 2017, with publication of our results by December 2018.

Data acquisition plans have prioritised the Warra site, with fewer datasets collected over the Robson Creek site. Further evaluation of the possibilities at the Robson Creek site will be undertaken in due course.

Overview of satellite data
There were some delays in gettitng the data.

Plans and milestones for 2018/2019

Calibrate the radar datasets once the DEM is made (mid march)
Calibrate models for understorey and canopy cover (possibly spatial rather than time series due to changes in the availability of the datasets)
Submit draft manuscript before 30 June

Publications (published/submitted/planned)

Joni and Neil plan to submit a manuscript before June 2018. This will concern the use of combining multiple radar and optical datasets for canopy structure retrieval. An international student also has an interest in using these data to retrieve forest biomass at our sites. Biomass may also be included in this manuscript. Joni and Neil are currently discussing how to formalise this arrangement.

Group 11

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FOREST DISTURBANCE MONITORING AND BIOMASS ESTIMATION IN SAVANNAH WOODLANDS

Project withdrawn.
No satellite data provided through GFOI.

Group 12

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MULTI-SOURCE EO MAPPING OF FOREST STRUCTURE AND FIRES IN POORLY INVENTORIED NORTHERN BOREAL FORESTS (Northwest Territories, Canada)

GFOI PRIORITY R&D TOPIC(S):
• Sensor interoperability/complementarity
• Above-ground biomass
• Forest change (fires)

RESEARCH OBJECTIVES:
Improvements to the mapping and monitoring of northern boreal forests through SAR/SAR & SAR/optical complementarity:Regional methods: to develop, test, and validate methods at the regional scale, for improved large area mapping of forest structural attributes (including biomass) and wildfires in poorly inventoried northern boreal forests in the Northwest Territories (NWT), Canada. Methods exploit multi-source optical (Landsat) and dual-polarized SAR (PALSAR-1/2) imagery, along with ICESAT-GLAS samples of modelled attributes and other datasets. The region includes CAN-1/2/3 sites and covers approximatively 450,000 km2.
Local methods: to develop, test, and validate methods at the local scale, for mapping forest height (CAN-1 site) using TanDEM-X data and for mapping wildfire burned areas (CAN-2/3 sites and beyond) using short time-series of optical (Landsat) and SAR data (PALSAR-1/2, Rsat-2, Sentinel-1).

STATUS March 2018:

Regional methods:
Structural attributes from PALSAR-1 and Landsat mosaics: a suite of five structural attributes, including biomass, were estimated and mapped over a large, additional study area measuring approximately 256 000 km^2 north of Can-1/2/3 sites in NWT (for a total mapped area of 450 000 km^2). An innovative 2007-2010 PALSAR-1 composite was created from PALSAR-1 Global Mosaics (JAXA). The kNN interpolation method was trained from a reference sample set of ICESAT GLAS modelled attributes. This method was employed to create attribute maps from the above mentioned PALSAR composites, and circa 2010 Landsat composites. Independent validation sources were used to perform an on-going accuracy assessment. In parallel, this regional modelling has been adapted and successfully applied at the national scale for biomass mapping.

Either over NWT sites or across all boreal forests of Canada, we first showed that composited annual PALSAR-1 Global Mosaics from JAXA can provide key regional or nationwide SAR datasets for biomass mapping. Such compositing was needed to deal with with gaps and detrimental acquisitions outside the growing season due to PALSAR Basic Observation Scenario (BOS). Secondly, the combination of these innovative PALSAR-1 composites and Landsat composites provided mapped predictions with significantly increased accuracy thanks to the synergy of optical and SAR data.

Wildfire burned areas mapping from PALSAR-1/2 and Radarsat-2 mosaics:

Pre-fire PALSAR-1 FBD and post-fire PALSAR-2 SM3 dual-polarized summer datasets were used to create a regional mosaic of Radar Burn Ratio (RBR) indices. To map burned areas using this mosaic, an unsupervised classification method was tested across CAN-2/3 sites, then extrapolated to a larger area of 68 200 km^2. Overall classification accuracy of burned areas reached 85-90 % relative to reference Landsat-based fire polygons from the Canadian Forest Service's National Burn Area Composite (NBAC) database. JAXA's PALSAR-1/2 Global Mosaics were also used to create RBR mosaics. Burned area maps from unsupervised classifications proved to be inconclusive due to late fall acquisitions, as per the PALSAR-2 BOS for boreal regions.

Furthermore, the unsupervised classification method was successfully tested using a regional mosaic (≈ 60 000 km^2) of four polarimetric features, derived from 142 post-fire Radarsat-2 SWQ scenes, with accuracy ranging from 77 to 85 % relative to reference NBAC fire polygons.

Wildfire burn severity mapping from PALSAR-1/2 and Landsat mosaics:

The integration of the regional summer mosaic of RBR indices with a mosaic of Landsat-based burn severity index proved to provide better estimates of various burn severity indices through generalized linear modelling. Relative improvements up to 35 % were obtained for R^2 and RMSE thanks to the optical and SAR synergy. This modelling approach is currently refined.

Local methods:
Wildfire burned area mapping and burn severity analysis from polarimetric ALOS-2 and Sentinel-1 scenes: Nine ALOS-2 FP scenes were acquired and processed over CAN-2/3 sites and over a broader area to explore the effectiveness of L-band polarimetric features in mapping burned areas. Unsupervised classification of burned areas using polarimetric decomposition parameters showed about 83% agreement relative to to CFS' NBAC fire polygons. The same scenes are currently used to evaluate the potential of L-band polarimetric features to estimate burn severity compared to various burn severity indices from the field plot data.

Dual-pol Sentinel-1 IW scenes were also acquired over CAN-2/3 sites to investigate the usefulness and effectiveness of Sentinel-1 C-band data in mapping the location and extent of wildfire burned areas.

Height mapping from TanDEM-X: Using TanDEM-X single-pass interferometric coherence data, forest canopy height was successfully estimated over the CAN-1 site, at a resolution of 25 m, over an area of 1730 km^2. Height accuracy and stability was assessed against ground inventory plots (R^2=0.78) and airborne LIDAR data (R^2=0.83); root mean square error was similar for both at approximately 2 m height, across different forest types. These results are promising for using radar interferometry for forest height mapping across high latitude sparse and low boreal forests.
Plans and milestones:

The plan for 2018-2019 is aligned with the plan of the companion ''Northern Forests'' GRIP project funded by the Canadian Space Agency, to be completed by the end of September 2018. The plan includes the completion of analytical tasks, the production of map products along with accuracy assessment and the production of a web page, reports and peer-reviewed papers.

Key milestones:
- Delivery of operational map products to the Gov. of NWT of five forest attributes (including biomass) along with accuracy assessment for their integration within the Multi-source Vegetation Inventory (spring 2018)
- Prototype map products of forest height, wildfire burned areas and burn severity along with accuracy assessment (Sept. 2018)
- Final reports to CSA (Sept. 2018) and GFOI (2019)
- Project web page (Sept. 2018)
- Peer-reviewed papers (2018-2019)

Publications:
A number of papers are planned for 2018-2019 submission for the following key topics previously described:
- Mahoney, C., R.J. Hall, C. Hopkinson, M. Filiatrault, Q. Chen, A. Beaudoin. A forest attribute mapping framework: a pilot study in remote Northern Canada. Remote Sensing (completing internal review)
- Beaudoin, A. et al. PALSAR Global Mosaic compositing method for forest applications over boreal forests of Canada (preliminary title)
- Beaudoin, A. et al. Regional mapping of five structural attributes over boreal forests of Northwest Territories from kNN interpolation using ICESAT-GLAS, PALSAR and Landsat composites (preliminary title)
- Forest Canopy Height from TanDEM-X Single-pass Interferometry Coherence Data for Northwest Territories, Canada (preliminary title)

GFOI
Global Forest Observations Initiative

OVERVIEW OF SATELLITE DATA

Free archived datasets: Landsat scenes (USGS) and PALSAR-1 global mosaic (JAXA) datasets were successfully processed and exploited. In addition, we obtained 40 dual-polarized FBD PALSAR-1 scenes (ASF). These datasets exclusively served objective 1.

Datasets from various sources: PALSAR-2 datasets were obtained through various channels. The 25 dual-polarized SM3 scenes were obtained from CSA-JAXA MOU. Additionally, 9 SM3 dual-pol scenes (GFOI) and 9 SM2 FP quad-pol scenes were obtained through JAXA's ALOS RA4 (#1053, PI: D. Goodenough). The 142 Radarsat-2 SQW quad-pol scenes were obtained through the yearly CSA Radarsat-2 allocation to Canadian federal departments. Forthermore, Sentinel-1 IW imagery were downloaded from ESA Copernicus Open Access Hub.

Group 13

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SENSE CARBON - SENTINELS SUPPORTING CARBON ESTIMATES AND REDD+

GFOI PRIORITY R&D TOPIC(S) ADRESSED:
- Forest degradation, deforestation and reforestation
- Proxy methods for reporting degradation and/or enhancement of carbon stocks
- Satellite sensor interoperability (Landsat, Sentinels, RapidEye, TerraSAR-X, ALOS PALSAR)

RESEARCH OBJECTIVES:
1. Characterizing land use, land use intensity and post-deforestation dynamics (regrowth, cyclic LU, gradients in LU)
2. Methods for forest degradation, deforestation and reforestation monitoring
3. Methods for enhanced aboveground biomass estimation

STATUS (Note – report as of March 2017):

Large area composite based mapping of forest dynamics
Annual composites and related pixel metrics where calculated from dense and long-term Landsat time series. These have been classified to derive maps of annual deforestation and regrowth of secondary vegetation for the Brazilian federal states of Pará and Mato Grosso.

- Griffiths, P., Hostert, P., 2016: Reconstructing three decades of deforestation and secondary forest dynamics in Para and Mato Grosso, Brazil, using the open Landsat archive. GEO European Projects Workshop 2016, Berlin.
- Hostert, P., 2016: Open archives and big data: Temporal depth and density in remote sensing. Memorial Colloquium Gunter Menz, Bonn.
- Hostert, P., Griffiths, P., Jakimow, B., 2016: Forest dynamics in Southern Amazonia since the 1980s. Landsat Science Team Meeting July 2016, Brookings.
- Griffiths, P., Jakimow, B., Hostert, P., in Prep., Reconstructing three decades of tropical forest clearing in Pará and Mato Grosso using the Landsat archive.

Post-deforestation land use events
We mapping tillage and fire events on post-deforestation land in the study region to describe agricultural land use intensity. Despite its low temporal coverage, Pleiades data helped to better understand the subpixel domain of Landsat by visual interpretation. For example, how pastures, secondary regrowth and adjacent forest borders which burnt in between 2013 and 2015 developed until 2016.

- Jakimow, B., Griffiths, P., Hostert, P., 2016: Characterizing land use intensity on deforested land in the Brazilian Amazon using dense Landsat time series. ESA Living Planet Symposium 2016, Prague.
- Benjamin Jakimow, Patrick Griffiths, Sebastian van der Linden, Patrick Hostert; in Review 2017, Mapping pasture management in the Brazilian Amazon from dense Landsat time series. Remote Sensing of Environment.

SAR based landcover classification
Multi-temporal datasets consisting of TerraSAR/TanDEM-X, RADARSAT-2, and ALOS-2 were acquired and processed over the Novo Progresso study area, and land cover classification products were generated using these datasets. Classifications of multi-temporal data covering a span of April-October and addressing five land cover classes show AL-2 to produce the highest accuracy outcome with regard to any forest and pasture class. It is followed closely by TS-X, and with some accuracy gap by RS-2 producing the lowest accuracy outcome. We further show that a multi-frequent approach is more

promising compared to multi-temporal, mono-sensor efforts. We further show the immense potentials of utilizing TD-X for classification compared to non-interferometric approaches. E.g., a classification also backed by texture using interferometric features achieves an OA of 89 % opposed to just 73.8 % for texture only efforts without interferometric components.

- Hagensieker, R. & Waske, B. 2016: Potentials of multi-temporal TerraSAR-X images for tropical land cover mapping, TerraSAR-X / TanDEM-X Science Team Meeting, Munich, Germany.
- Hagensieker, R. & Waske, B. 2016: Mapping Deforestation in Pará (Brazil) Using A Multi-Sensoral Time-Series And Expert Knowledge, ESA Living Planet Symposium, Prague, Czechia.
- Hagensieker, R.; Rosentreter, J.; Roscher, R.; Jakimow, B. & Waske, B. (revised): Tropical Land Use Land Cover Mapping in Pará (Brazil) using Discriminative Markov Random Fields and Multi-temporal TerraSAR-X Data, full paper manuscript submitted to the International Journal of Applied Earth Observation and Geoinformation
- Hagensieker, R. & Waske, B. (in review): Evaluation of Multi-frequency SAR images for Tropical Land Cover Mapping, full paper manuscript submitted to ISPRS Journal of Photogrammetry and Remote Sensing

Other issues

The direct to CNES was established and communication with our person of contact (Delphine Fontannaz) is good and helpful. Because of high cloud coverage in the Novo Progresso region the Pleiades tasking period was extended until May 2017. Today (2017-03-17) we received the last scene required to get full coverage of our area of interest. This scene from CNES is promising, as it covers an area where selective logging and deforestation has been visited in 2014 in field.

Sentinel-1 data is not sufficiently available over the Novo Progresso study site. S-1 data was downloaded and pre-processed for a large study site in northern Mato Grosso. While we have processed large amounts of S-1 and S-2 data, the integration remains challenging. This is mainly due to deficiencies with S-2's atmospheric correction and geometry

Group 14

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FOREST HEIGHT AND ABOVEGROUND BIOMASS ESTIMATION IN TROPICAL FORESTS IN INDONESIA

GFOI PRIORITY R&D TOPIC(S) ADRESSED:
• Above ground biomass and change
• Forest degradation and deforestation
• Specific forest types (peat swamp forest)

RESEARCH OBJECTIVE:
Methods for forest height estimation and aboveground biomass estimation.

STATUS (April 2018):
A field inventory campaign was conducted in July 2016 collecting forest inventories and drone data acquisitions. The calculation of AGB in t/ha is based on an allometric equation using height and species-specific wood density (Chave et al., 2008). By means of semi-global matching (SGM), a dense stereo matching process, which can be used for accurate 3D reconstruction from image pairs, a point cloud was created from the recorded aerial images. A DSM was created from this point cloud and vegetation and forest height was extracted by using an existing LiDAR based DTM.

The preprocessed images of TerraSAR-X, TanDEM-X and RADARSAT-2 of 2012 and 2015 were used as input within the in-house canopy height modeling software of our Canadian project partners AUG Signals. Following steps are achieved:
- speckle reduction,
- co-registration,
- interferogram generation,
- Random motion over ground model (RMoG).

Furthermore, an analysis of the canopy height results regarding different beam modes, baselines (temporal and perpendicular), height of ambiguity, polarizations and weather was conducted in order to find the best acquisition conditions. Besides, a comparison of the freeware SNAP and the commercial software GAMMA Remote Sensing with regard to the co-registration was done.

The LiDAR retrieved forest height was used as a reference height in order to validate the canopy height modeled from SAR data. In Figure 1 – 4 a comparison of a Landsat image and the results of the canopy height software for AOI1 (TerraSAR-X and RADARSAT-2) are shown. In a next step the biomass was modeled from the canopy height using a linear regression model. An example of the estimated biomass for AOI1 based on TerraSAR-X is displayed in Figure 4. The validation of the estimated biomass was achieved using reference data of LiDAR and inventory data of 2012 and 2015. It was shown, that AOI1 get better correlation results than AOI2. Canopy height of plantations was overestimated using TS-X and RS-2 data. Furthermore, results of TS-X show an underestimation of canopy height in forests. Since biomass is dependent from canopy height similar results are shown in biomass.
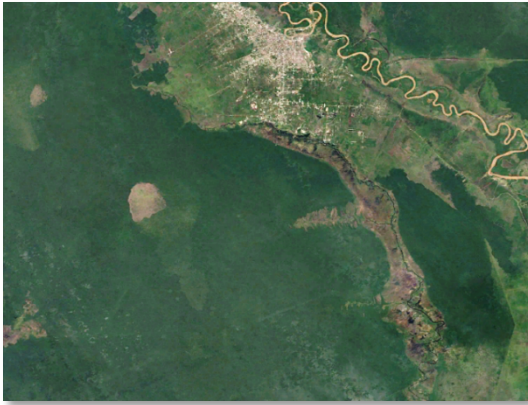
Figure 1: Landsat image 2015
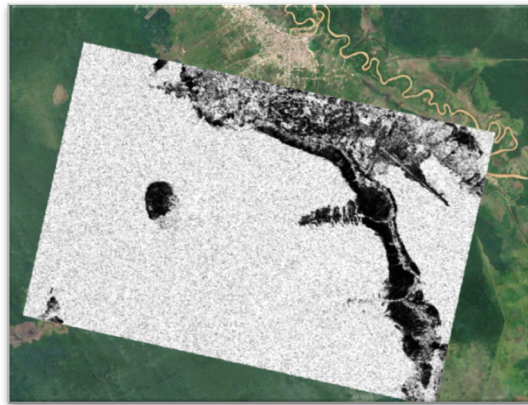
Figure 2: AOI1 RS-2 2015 (0903_0927), stretch: 0-33 m

Figure 3: AOI1 TS-X 2015 (0906-0917), stretch: 0-33 m

Figure 4: Estimated biomass and LiDAR biomass [t/ha] based on canopy height TS-X 2015 (0906-0917)

Issues

The temporal baseline of Radarsat-2 and Sentinel-1 is too long for interferogram generation and results in insufficient coherences. The modelling of the canopy height will thus be inaccurate.

Plans for 2018

• Implementation of Sentinel-1 in the canopy height software by AUG Signals
• Change detection 2012 – 2015, if data available
• Transferability of the model: the same processing steps will be repeated for the AOI3 located on Sumatra island
• Search for more suitable data for TandDEM-X and TerraSAR-X

Group 15

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TIMELY MULTI-SENSOR FOREST DISTURBANCE MONITORING

GFOI PRIORITY R&D TOPIC(S) ADRESSED:
- Near-Real Time forest disturbance mapping
- Assess changes in dense tropical forests to monitor forest degradation and regrowth
- Forest stratification

RESEARCH OBJECTIVES:
1. Develop and validate SAR based methods to frequently monitor forest degradation processes of dense tropical forests resulting from selective logging and small scale illegal mining.
2. Analyzing synergy-effects of Sentinel-2, SPOT 6/7 and TerraSAR-X/ TanDEM-X for baseline and forest disturbance mapping

1. Research status and satellite data (03/2018)
Research objectives: 1
Data: TerraSAR-X
Work progress: Research completed; Method and results documented in:
https://www.tib.eu/de/suchen/id/TIBKAT%3A89718081X/Untersuchung-der-Synergien-von-Sentinel-2-und-TanDEM/

Key findings: The main goal of the last project phase was to evaluate the performance of TerraSAR-X change indicator results in terms of selective logging detection. Further the influence of resolution (StripMap versus High resolution SpotLight mode), multi-looking and sensitivity to threshold value was investigated. 4291 GPS locations of fellled trees have been provided by an end user and supplemented by 5831 samples generated by stratified random sampling in the non-change region to estimate false alarms rate. The comparison of StripMap (3m) versus SpotLight (1m) mode proofed a considerable improvement of the detection rate for felled trees from 70% to 95% for tree felling locations buffered by 20m to acount for localisation errors. This is a valuable information to justify higher StripMap resolution for next generation X-band SAR systems.
In terms of threshold sensitivity the analysis showed that the overall accuracy can be improved up to 10% optimizing the change threshold. The best overall results optimizing detections versus false alarms achieved an overall accuracy of 89,2% (Kappa of 0,75) with a low false alarm rate of 12% using SpotLight data. StripMap based change detection was considerably less accurate with an overall accuracy of 66,5 % but still useful with a Kappa of 0,36. Also it should be considered that this validation is performed on tree level.
Criticality of acquisition intervals has been assessed comparing a recent logging event where acquisitions have been taken directly before and after the logging with a detection interval of 4 years. Comparing the differing detection intervals for the same stands shows as expected that detection intervals close to the logging event the detection rates raise by 10% to 16%. Nevertheless, the best results are achieved for stands where logging took place 3 years ago but with a factor 2 higher logging intensity.

Research objectives: 2
Data: Landsat, Sentinel-2 and SPOT6/7, TerraSAR-X
Work progress: First base map produced and quality assessed
In the context of objective 2 the forest destruction driven by illegal cocoa farming will be assessed. Preliminary results for the base mapping using Landsat, Sentinel-2 and SPOT6/7 together with TerraSAR-X look promising despite the challenge of cocoa farming under shade trees. Monitoring with TerraSAR-X has started. Evaluation will be available in Q3 2018. For Ghana the project plan is set up and field data collection will start in Q2 2018.

2. Plans and milestones 2018/2019

MS1: Test transferability of method to Ghana test case and assess results
MS2: Project 2 results report to GFOI and CEOS/SDCG [October 2018]
MS3: Implementation of methodology for regional use [Dec. 2018]

Group 16

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STRUCTURAL ATTRIBUTE RETRIEVAL IN SOUTHERN AFRICAN SAVANNAHS, THICKETS AND INDIGENOUS FORESTS

GFOI PRIORITY R&D TOPIC(S):
- Degradation/enhancement of carbon stocks (Use of SAR for mapping degradation / Use of airborne LiDAR for deriving biomass/carbon stocks and changes)
- General forest mapping method improvements (Sensor interoperability / Uncertainty / Optimising information extraction using dense time-series C-band SAR)
- Above-ground biomass (Integration of ground,- and airborne LiDAR / SAR and optical data/ Integration of repeat LiDAR and SAR change across different forest types / Sampling design options)

RESEARCH OBJECTIVES:
1. Retrieval of vegetation attributes, including woody plant cover, height, biomass and changes over time due to land management, climate and ecological dynamics, both inside and outside of protected areas, assessment of uncertainties
2. Carbon sequestration in thickets, especially in relation to restoration of degraded sites; thicket structural and compositional complexity in relation to the conservation of rare species.

STATUS March 2018:

Objective 1: Retrieval of vegetation attributes, including woody plant cover, height, biomass and changes over time due to land management, climate and ecological dynamics, both inside and outside of protected areas, assessment of uncertainties

Data acquisition: 200+ scenea ALOS PALSAR-1&2 via the GFOI, K&C, and ALOS RA initiatives, ALOS PALSAR-1&2 are also used with Landsat and Sentinel-1 datasets.

Research and Developement

Current focus is on the establishment of methods for retrieving woody plant cover, height, and biomass in South African forests.

1) Mapping woody cover in SA woodlands and savannahs with ALOS PALSAR (GFOI site SA-1&3). Paper published Naidoo et al. 2016 "*L-band Synthetic Aperture Radar imagery performs better than optical datasets (Landsat) at retrieving woody fraction cover in Southern Africa savannahs*", International Journal of Applied Earth Observation and Geoinformation. Paper to be submitted early 2018 Ndyamboti et al. "*The utility of ALOS 2 PALSAR 2 data to monitor above ground woody biomass stocks across different forest types in South Africa*".
2) Use of hypertemporal C-band (ENVISAT ASAR, Sentinel-1) as a potential substitute or complement to L-band imagery (GFOI site SA-1). Paper published Main et al. 2016 "*Hyper-temporal C-band SAR for baseline woody structural assessments in deciduous savannas*", Remote Sensing. Paper submitted Mathieu et al (2018) "Detection of burned areas in southern African savannahs using time series of C-band Sentinel-1 data", Remote Sensing of the Environment. Paper to be submitted early 2018 Main et al "*Variable transmissivity improves savanna biomass estimation, using hyper-temporal Sentinel-1 C-Band SAR and a semi-empirical water cloud model*". High temporal frequency of C-band imagery (up to scenes / year) produces similar accuracy to single date ALOS PALSAR coverage for retrieving low biomass range in deciduous savannahs. Next step will research the potential of integrating coherence (beyond bacscatter intensity) derived from Sentinel-1 interferometric pairs in the water cloud model.
3) Tree height mapping with MISR, ALOS PALSAR, and LiDAR data (GFOI site SA-1 & 3). Paper submitted Nokuthula et al. 2018 "*Indirect estimation of tree height in South African woody vegetation using optical multi-view and LiDAR remote sensing data*", Remote Sensing.

4) Activities on GFOI site SA-1 led to two additional papers using ALOS PALSAR-1. Paper published Bouvet et al. 2018 "*An above-ground biomass map of African savannahs at 25 meters resolution derived from ALOS PALSAR*" Remote Sensing of Environment. Paper to be submitted early 2008 Rodriguez-Veiga et al. "*Mapping Aboveground Biomass at national and regional scale using Earth Observation: a comparison of methods*" Remote Sensing of Environment.

Seven conference papers were presented at the International Symposium on Remote Sensing of the Environment 2017 in May 2017, Pretoria, South Africa, including: Mathieu et al, Woody changes (2007-2015) in South African Lowveld savannahs with L-band SAR and LiDAR imagery; Naidoo et al, Guidelines for upscaling country-wide woody fractional cover - recommended amount of field plots and airborne LiDAR data coverage required across South Africa; Wessels et al, Mapping and monitoring woody vegetation cover for Namibia using LiDAR training data, machine learning and ALOS PALSAR data.

Product development

5) Tree cover maps have been produced for 2010-15 for the entirety of South Africa, using a combination of ALOS PALSAR-1&2 mosaics and LiDAR tracks, and change detection are currently analysed. Paper to be submitted mid 2018 Wessels et al "Mapping and monitoring woody vegetation cover for Namibia using LiDAR training data, machine learning and ALOS PALSAR data".
6) AGB map has been produced and extented from the SA Lowveld (GFOI site SA-1, see figure) to the entire South African savannah biome for the year 2010 (see figure below) based on ALOS PALSAR-1 images, LiDAR, and field data. Paper to be submitted in 2018 Mathieu et al. "Woody resources and land management in the South African Lowveld".
7) National AGB map currently under development for 1990s (JRES-1), 2010 (ALOS PALSAR-1), and 2015-16 (ALOS PALSAR-2). LiDAR and field woody AGB data are currently collected across a range of SA forest types, including mopane and bushveld savannahs, thicket, fynbos, indigenous forests, plantation, and alien invasive stands in GFOI site SA-1, 2, 3 and another three sites. The acquistion of concurrent field and LiDAR data across a variety of forest types, is intended to developed LiDAR-based AGB products for upscaling at national scale with the ALOS PALSAR mosaics.
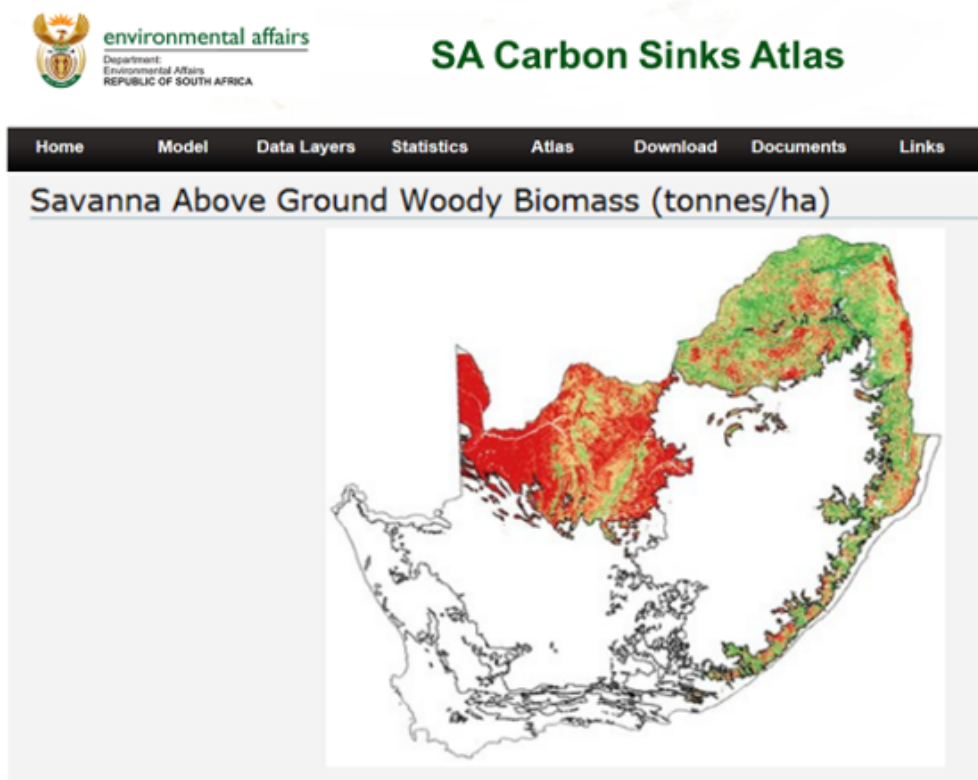

Figure. Above ground woody biomass map for the South African savannah biome (T/ha, red 0 T/ha, green ~100 T/ha) derived at 75m from 2010 ALOS PALSAR and airborne LiDAR tracks.

<u>Objective 2</u>: Carbon sequestration in thickets, especially in relation to restoration of degraded sites; thicket structural and compositional complexity in relation to the conservation of rare species.

Thickets are a special case of forest, which is widely ignored even though it covers a significant part of the Earth's surface. Thickets are low-growing forests (canopy cover 60-100%, height <5 m, often <3 m). As such they are an important case to consider in global analyses, both in their own right and as an outlier to test of the robustness of calibrations. The thickets of Eastern Cape of South Africa are an even more unusual case. They have high plant diversity, high biomass, high NPP (despite the aridity) and are touted as a carbon sequestration opportunity. The thicket is dominated by an evergreen, succulent tree (*Portulacaria afra*) which should have a very unusual radar return because of its high water content and unusual shape.

Work over the past decade has established a high resolution (30 m) map of extant thickets and areas of thicket degradation; allometric equations for the estimation of above and belowground biomass of the main species; over a hundred survey plots where biomass, height, species composition and stem diameters are known; and soil carbon contents. A campaign by the Carnegie Airborne Observatory around 2015 flew high resolution lidar and hyperspectral imagery over the Addo National Park, an area of thicket about 15000 ha in extent. This is repeated in 2018 by the CSIR Earth Observation team for the integration of thickets in national biomass maps. A PhD thesis on primary production and albedo in thicket was published by Dr Kathleen Smart in 2016, papers are in preparation. In nearby karoo biome at Middleburg, two flux towers have been operated by ARS Africae for two years and half months. Degraded thicket becomes karoo; the Middelburg experiment compares carbon fluxes at two levels of degradation. Over the past two year, there has been a campaign of eddy covariance NEE measurement over intact thicket by Dr Tony Palmer of the Agricultural Research Council in Grahamstown. The Department of Botany at Rhodes U is measuring physiological parameters on Portulacaria under ambient and elevated CO_2.

A large part of the ticket biome is likely to constitute the second established landscape of the newly announced South African Research Infrastructure (EFTEON). This will include further flux and water measurements, ongoing biodiversity surveys, and the compilation of a library of remotely-sensed products and historic land use and climate data.

The future needs are for radar coverage with instruments suited for estimating the cover, height and biomass of succulent, low-growing vegetation (Sentinel 1A&B, ALOS PALSAR, TerraSAR, TANDEM-X), and for mapping changes in thicket patches and for determining species composition (Sentinel 2a&B and Landsat 8). In all cases, one recent pass, at any time of year, is well suited.

Group 17

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MONITORING FOREST / LAND COVER AND FOREST COVER CHANGE IN TROPICAL RAINFOREST IN DRC

GFOI PRIORITY R&D TOPIC(S):
• Sensor interoperability/complementarity between optical, C- and L-band SAR for forest and forest change monitoring.
• Optimising information extraction using dense time-series C-band SAR and L-band SAR for forest monitoring

RESEARCH OBJECTIVES:
Investigate SAR/Optical interoperability and complementarity and dense C-band SAR time-series analysis to monitor forest area and change.

OVERVIEW OVER THE SATELLITE DATA (received through GFOI)
The DRC case is funded through the ESA DUE INNOVATOR III project "SAR for REDD" and has already received Envisat ASAR, Sentinel-1, ALOS PALSAR, ALOS-2 PALSAR-2 and SPOT5/TAKE5 data for validation through ESA and JAXA (ALOS-RA4 proposal) as well as it profits from results and data collected through the EU FP7 "ReCover" project.
In addition to these data and through GFOI, the DRC case received:
• 54 additional ALOS-2 images covering the periode of autumn 2016 and October 2017 and
• 7 VHR Pleiades scenes (from 2016).

JAXA has informed about an updated calibration of ALOS-2 PALSAR-2 data since 28 March 2017. All 2017 data (40 scenes) has been ordered after this calibartion update.

RESEARCH STATUS (March 2018):
Under the ESA DUE Innovator III project "SAR for REDD", the Mai Ndombe district in DRC, its forest cover and forest change has been mapped with several SAR sensors. Averaged SAR backscatter mosaics have been produces based on Envisat ASAR wide-swath and alternate polarization modes for the time periods 2005-2010 and 2010-2011, respectively , ALOS PALSAR (2007-2010), ALOS-2 PALSAR-2 (2014-2016) and Sentinel-1 (2015-2016). Forest cover maps were then produced based on these mosaics and validated with VHR data from the SPOT5TAKE5 program, Pléiades satellite, Google Earth data and aerial mosaics collected during a field mission in September 2016 with a small quadcopter remote piloted aerial system, (RPAS) (Haarpaintner et al., 2017) . C- and L-band SAR from Sentinel-1 and ALOS-2 were also combined. Forest changes were detected over three periods: based on ALOS PALSAR data from 2007 to 2010, based on ALOS and ALOS 2 data from 2010 to 2015 one year forest change by combining Sentinel-1/ALOS-2 data for each year 2015 and 2016. The field mission in September 2016 confirmed specific sites that were visited and mapped with RPAS. Burned areas were also visited and mapped during fieldwork and are clearly visible in dense Sentinel-1 times series. The SAR results are compared for interoperability with existing optical results from Global Forest Change (Hansen et al., 2013) and validated with VHR data from the Pleiades and SPOT-5 satellites.

The validation showed that:
•   Forest/non-forest maps based on ALOS PALSAR imagery showed the highest accuracies (92%), compared to 87-89 % accuracies for Sentinel-1 and global forest map products from JAXA and GFC data set (Hansen et al., 2013). ALOS-2 PALSAR-2 based results show also accuracies above 91% without having considered the updated calibration report from JAXA.
•   Accuracies of sub-classification into more land covers classes, i.e. dry/wet grassland, savannahs and inundated forest increase when combining C- and L-and SAR data.

- L-band data detects better forest loss over long periods as it is not as sensitive to regrowth as C-band SAR, but C-band might better be suited to detect burn scars of already deforest areas.
- Overall, the study showed that SAR data, specifically L-band, but also the dense time series of C-band Sentinel-1 data, can produce forest maps with similar if not higher accuracies than optical data.

All results are reported in the final report of the ESA DUE Innovator III project "SAR for REDD". Figure 2 shows the Sentinel-1 and ALOS-2 PALSAR-2 mosaic and the resulting forest/non-forest map over the period 2015-2016.
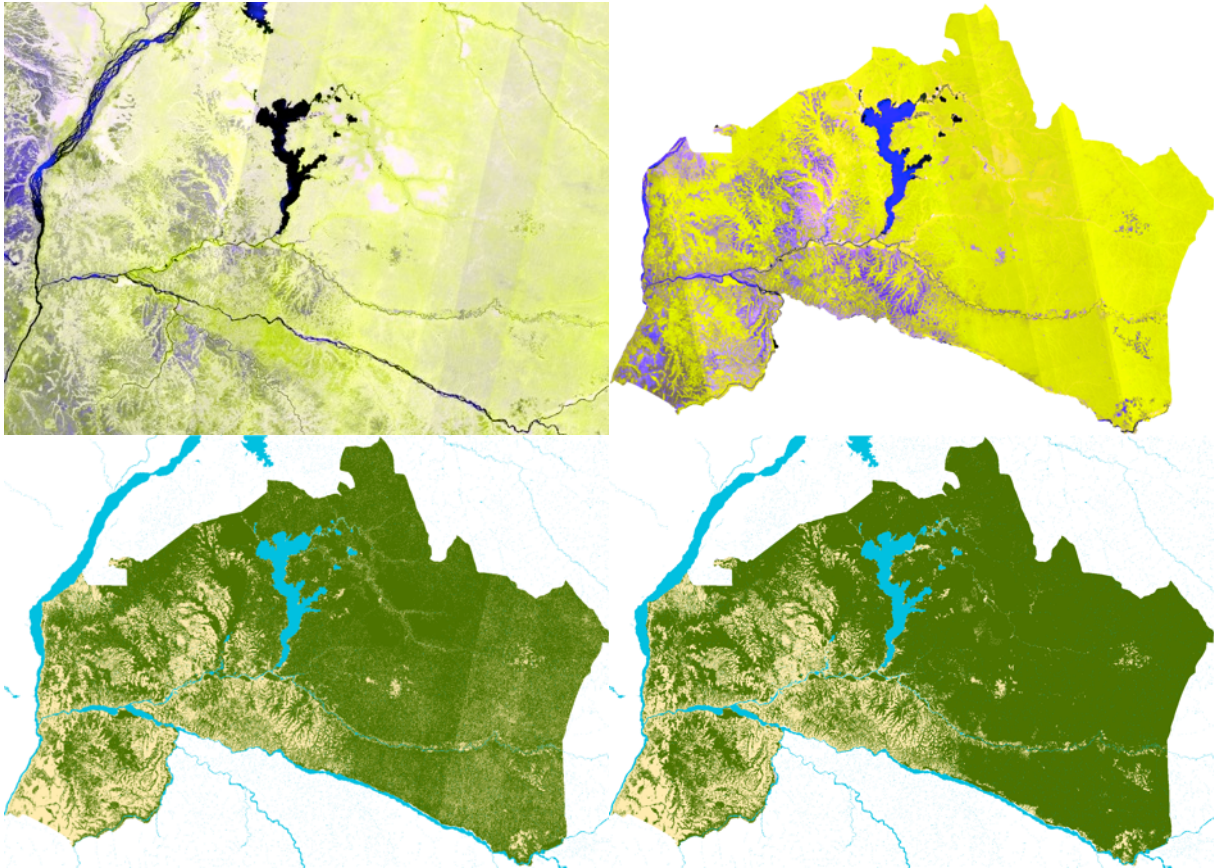

Fig.: Sentinel-1 and ALOS-2 PALSAR-2 mosaic and resulting forest/non-forest maps from 2015-2016.

PLANS and MILESTONES for 2018/2019
The funding through the SAR for REDD project ended and further investigation of the DRC case is dependant on further funding.
Howevere, some of the data might be reprocessed and at least one international scientific journal publication is planned in additional to the presentations, report and conference papers named in the references.

PUBLICATIONS
- Haarpaintner, J., (2018). Forest and forest loss mapping from ALOS to ALOS-2 in the Mai-Ndombe District, DRC. *Oral presentation at the 3rd PI Workshop of the Advanced Land Observing Satellite-2 Research Announcement (ALOS-2 RA), Tokyo, Japan, 22-25 Jan. 2018.*
- Haarpaintner, J. (2018). D2.3 – Final Report (FR), Delivery 2.3 for ESA DUE – Innovator III project "SAR for REDD", version 1.1*, January 2018, to be published as Norut Report.*
- Haarpaintner, J., A. Mazinga, and L. Mane (2017). Sentinel-1 Forest Land Cover Classification and Forest Change of the Mai-Ndombe District, D.R. Congo. *Poster at the Worldcover 2017 Conference, ESA/ESRIN, Frascati, Italy, 14-16 March 2017.*
- Haarpaintner, J. (2017). Forest and Forest Loss Mapping with SAR from the ENVISAT/ALOS era to the Sentinel-1/ALOS-2 present in the Mai-Ndombe District, DRC. *Oral presentation at the 37th*

International Symposium on Remote Sensing of Environment (ISRSE-37), Tshwane, South Africa, 8-12 May 2017.

- Haarpaintner, J. (2017). Validation of SAR-based forest land cover and forest change maps and detectability of slash-and-burn activities in the Kwamouth region, Mai-Ndombe District, DRC. *Oral presentation at the 37th International Symposium on Remote Sensing of Environment (ISRSE-37), Tshwane, South Africa, 8-12 May 2017.*

- Haarpaintner, J. (2016). SAR for REDD+ in the Mai Ndombe District (DRC). *Proc. 'Living Planet Symposium 2016', Prague, Czech Republic, 9–13 May 2016 (ESA SP-740, August 2016, ISBN 978-92-9221-305-3, ISSN 1609-042X).*

- Haarpaintner, J., (2016). SAR for REDD. *Oral presentation at GFOI Plenary Meetings, Frascati, Italy, 22-26 February 2016.*

- Haarpaintner, J., (2016). SAR FOR REDD+: Supporting GFOI R&D priorities using Synthetic Aperture Radar - SAR for REDD. *Oral presentation at GEO European projects' workshop, Berlin, Germany, 31 May – 2 Jun 2016.*

- Reiche, J., R. Lucas, A.L. Mitchell, J. Verbesselt, D.H. Hoekman, J. Haarpaintner, J.M. Kellndorfer, A. Rosenqvist, E.A. Lehmann, C.E. Woodcock, F.M. Seifert and M. Herold. (2016). Combining satellite data for better tropical forest monitoring. *Nature Climate Change 6(2),120-122, DOI: 10.1038/nclimate2919.*

- Haarpaintner, J. (2015). SAR for REDD+ - Providing Synthetic Aperture Radar Processing Capabilities to REDD Countries. *Oral presentation at BMZ-DLR International Conference on MRV of REDD, Bonn, Germany, 21-22 Sep 2015.*

- Haarpaintner, J. (2015). SAR for REDD+. *Oral presentation at 6th International Workshop on Retrieval of Bio- & Geo-physical Parameters from SAR Data for Land Applications, ESA/ECSAT, Harwell, Oxfordshire, UK, 17-19 November 2015.*

- Haarpaintner, J., D. de la Fuente Blanco, F. Enßle, P. Datta , A. Mazinga , C. Singa & L. Mane (2015). Tropical Forest Remote Sensing Services for the Democratic Republic of Congo inside the EU FP7 'ReCover' Project (Final Results 2000-2012). *Poster Presentation and Proceedings of the 36th International Symposium on Remote Sensing of Environment,11 – 15 May 2015, Berlin, Germany Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XL-7/W3, 397-402, doi:10.5194/isprsarchives-XL-7-W3-397-2015, 2015.*

- Hansen, M. C., P. V. Potapov, et al. (2013). High-Resolution Global Maps of 21st-Century Forest Cover Change. *Science 342 (15 November): 850–53. Data available on-line from:* http://earthenginepartners.appspot.com/science-2013-global-forest.

Group 18

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SYNERGISTIC USAGE OF SENTINEL-1 AND SENTINEL-2 DATA TO SUPPORT UNFCCC REDD+ MRV SYSTEMS

GFOI PRIORITY R&D TOPIC(S):
- **Forest degradation and regrowth**
- **SAR/optical integration**

RESEARCH OBJECTIVES:
1. Implementation of high temporal data coverage for more precise and rapid detection of degradation.
2. Achievement of high degree of automation.
3. Achievement of products of sufficient quality for REDD+.

Overview of satellite data

The following Pleiades data have been obtained through GFOI:

Study site	quisition Date
MEX-4_Kiuic	09-12-2016
	12-08-2017
	16-02-2018
EX-6_Hidalgo	24-10-2016
	04-05-2017
	23-10-2017
A-4_Skukuza	04-11-2016
	08-05-2017
	22-11-2017

We used the Pleiades data to derive manually stable forested areas, deforested areas and agricultural fields for the years 2016 and 2017. We found 13 and 28 deforested areas in Kiuic (tropical dry forests in the Yucatan Peninsula) and in Hidalgo (temperate forests in central Mexico) test sites in 2017, respectively. These areas vary between one to four hectares. Based on Pleiades data we selected further stable forests and agriculture areas of equal size to analyse time-series differences between these classes (Figure 1, 2).

Research status

We developed a new multi-temporal image transform for Synthetic Aperture Radar (SAR) time-series using Empirical Mode Decomposition (EMD) technique (Cremer et al. 2018). The algorithm works in time domain only, and therefore fully preserves the spatial resolution. We showed that this transform reduces speckle of Sentinel-1 data similarly as an 5x5 Quegan filter (based on Equivalent Number of Looks analysis) without blurring the spatial resolution. This is especially relevant for detection of small scale changes (e.g., forest degradation).
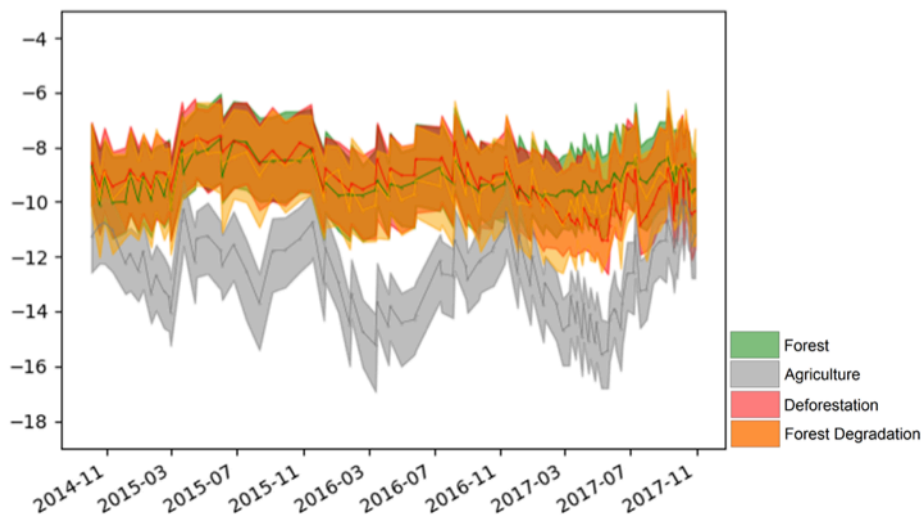
Figure 1: Time-series of original Sentinel-1 VV backscatter for different land cover change classes in Hidalgo
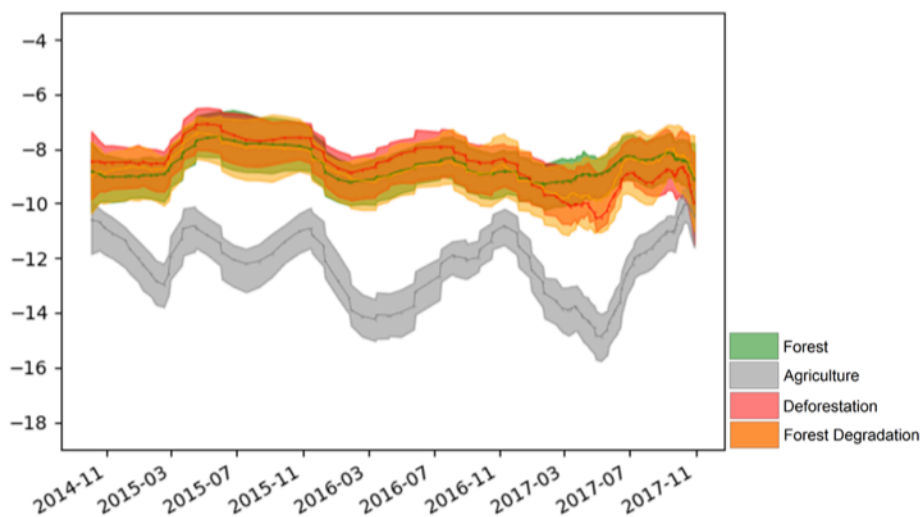

Figure 2: Time-series of EMD-filtered Sentinel-1 VV backscatter for different land cover change classes in Hidalgo

For the land cover (change) classes: stable forests, deforested areas and stable non-forest (agriculture), derived from the Pleiades data, we performed signature analysis of the Sentinel-1 time-series. Figure 1 and 2 show original and EMD-filtered Sentinel-1 time-series for different land cover classes in the Hidalgo test site at 10 m pixel spacing. The time-series consist of 99 Sentinel-1 scenes at VV polarizations acquired in ascending and descending orbits. Unfortunately, there are only a limited number of Sentinel-1 acquisition at cross-polarization (HV or VH) in order to generate time-series. The solid line is the mean of the medians of the 28 polygons per class. The shaded areas are delineated by the mean of the 25th and 75th percentile. At the polygon level a clear difference between the agriculture and forest classes can be found. Furthermore, a backscatter drop in the deforested area in the beginning of 2017 is detected. The backscatter intensities increased again in the middle of 2017. However, at the single pixel level the backscatter drop for deforested areas is not as clear as at the polygon scale.

Furthermore, in the original data a zig-zagging of the time-series at certain periods can be observed. This is due to the combination of ascending and descending acquisitions. However, these variations in

backscatter are reduced in the EMD-filtered time-series allowing therefore a combination of SAR data acquired in ascending and descending orbits. We performed similar signature analysis for the Kiuic test site. The results are similar to the Hidalgo test site, where deforested areas can be detected at polygon level.

We organized an SAR capacity building workshop in Pretoria, South Africa from May 4 till May 7 2017 beforehand the ISRSE conference. In total, around 20 participants from South African scientific institutions attended the workshop. A range of topics including SAR interferometry, polarimetry and time-series analysis with a special focus on land applications (i.e., agriculture, biomass, land cover mapping) was presented.

Plans and milestones

In the next months we continue SAR time-series analysis for both C- and L-band (from PALSAR-2) data. Currently we develop an algorithm to classify the time-series data into spatial information (e.g., land cover change maps). For this, we investigate SAR multi-temporal metrics and recurrence quantification analysis. Recurrence Quantification Analysis is a time-series method to derive multi-temporal metrics which also includes the temporal order of the time-series. Finally, an integration of optical Sentinel-2 data into SAR time-series analysis is intended.

Publications

Cremer, F., Urbazaev, M., Berger, C., Mahecha, M. D., Schmullius C. & C. Thiel: An Image Transform Based on Temporal Decomposition - *IEEE Geoscience and Remote Sensing Letters*, vol. 99. doi: 10.1109/LGRS.2018.2791658.

URL: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=8301575&isnumber=4357975