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Evaluation of forest loss in Balikpapan Bay in the end of 2015 based on Sentinel-1A polarimetric analysis

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Abstract. Satellite remote sensing has proved to be efficient for forest change monitoring. In tropical areas, polarimetric satellite images have a great potential given their ability to see through clouds, smoke and atmospheric haze. For Balikpapan Bay (Borneo, Indonesia), Sentinel-1A acquired images every 24 days during 2015 in both vertically co-polarized and cross-polarized modes. Using series of polarimetric radar images taken before and after an observed event (in this case a fire), information about changes in native forest can be delivered. In this work we detect and delineate areas burnt or damaged by catastrophic fires in autumn 2015. This work demonstrates a potential of satellite radar imagery using a relatively simple method for identification of forest changes. The whole processing chain as presented has been prepared for using open-source software (mainly ESA SNAP). Presented results were compared to both global services (GLAD and FIRMS databases) and local observation (UAV image over burnt area at Bugis canal).

1. Introduction

Balikpapan bay represents one of the last units of complex highly diversed and relatively intact ecosystems along the East Kalimantan (Borneo). Primary dipterocarp rainforest (approx. 50 km^2), coastal mangrove (approx. 170 km^2) and shallow sea with patches of coral reefs (approx. 150 km^2) are still present in Balikpapan bay, providing living environment for Irrawaddy dolphins, dugongs, proboscis monkeys, orangutans and many other rare and endangered animals, as well as plants [1]. On the contrary, series of illegal activities systematically leading to the extinction of the entire ecosystem occur in the area. Therefore, a program of regular monthly monitoring from a boat along the bay coast is active since 2008, collecting data about industrial expansion, oil palm plantations, coal mines, shrimp farms, illegal logging and other suspicious activities. The situation on the ground is systematically and regularly documented by photographic records and the processed data are transmitted to responsible officials in the local government.

Land and marine surveys are very expensive and besides, some remote tropical forests have never been examined in terms of biodiversity due to difficult and inaccessible terrain. Also, not the entire territory is accessible or visible from boat. This complicates insitu efforts to detect some essential information that leads to a successful identification of illegal activities and entities responsible for these activities. Monitoring of territorial changes using satellite images helps overcoming the handicaps of monitoring from boats and land surveys. The monitoring using satellite images may lead to the detection and eventual cessation of illegal activity before an irreversible damage to the rare and unique ecosystem of Balikpapan bay.

Multi-spectral satellite data from Landsat or Sentinel-2 are very valuable for evaluation of forest and land use parameters. However these cannot be universally recommended for monitoring forest changes in a regular basis. Over three-quarters of intact tropical forests in the world have over 70% cloud cover on average [2], disallowing application of passive observation instruments working in optical or near-optical wavelengths. This problem is tackled by satellite imaging radars (e.g. Sentinel-1) using microwaves of wavelengths that penetrate through cloud cover.

During the autumn of 2015, Indonesia was affected by the worst environmental disaster in the world that year [3] – uncontrolled fires that were widespread due to El Niño phenomenon. The fires spread into a protected reserve, Sungai Wain, and burnt a part of primary rainforest. Due to the lack of large-scale fires over last 17 years, the fire protection measures had been slack during 2015, and only environmental activists initiated fire fighting activities on voluntarily basis [4]. This work demonstrates the potential of using Sentinel-1 images for detection of deforestation, based on results of analysing the fire event in Balikpapan bay. Only open-source GIS/Remote Sensing tools were applied within the work.

2. First SAR applications in the area of interest

Previous works on topic of identification of deforested areas in Balikpapan Bay include analyzes of Landsat data [1]. The data was acquired via USGS LandsatLook service (http://landsatlook.usgs.gov). It was found that Landsat images are not sufficient to monitor the cloudy region (the average rainfall in the area is around 2400 mm annually [5]). Our first attempts to apply SAR images (TerraSAR-X via DLR LAN1903 project) successfully demonstrated the potential to achieve sufficient information throughout rainy conditions – energy in the microwave spectrum used in SAR penetrates clouds. ESA's Sentinel-1A SAR satellite and its observation scenario was prepared in the view of forestry application. With its 24-days continuous revisits and an open access policy, the Balikpapan bay began to be observable periodically and the acquisition of images became barrier-free.

This cloud-penetrating advantage of Sentinel-1 SAR imagery in comparison to Landsat is demonstrated in Figure 1. The observed area includes a road in construction that is easily identified in a false-colour composite of polarimetric indices – a combination of bands VV (red), VH (green) and a ratio VV/VH (blue) has been used, as recommended in [6]. The time series captures the progress of construction of a road that is being built mainly for industrial purposes, to lower the cost of transporting materials using water channels. However, this road construction is criticized by environmental activists mainly because splitting the migration area between mangrove and rainforest further risks lives of many endangered animals, e.g. the proboscis monkeys [7].

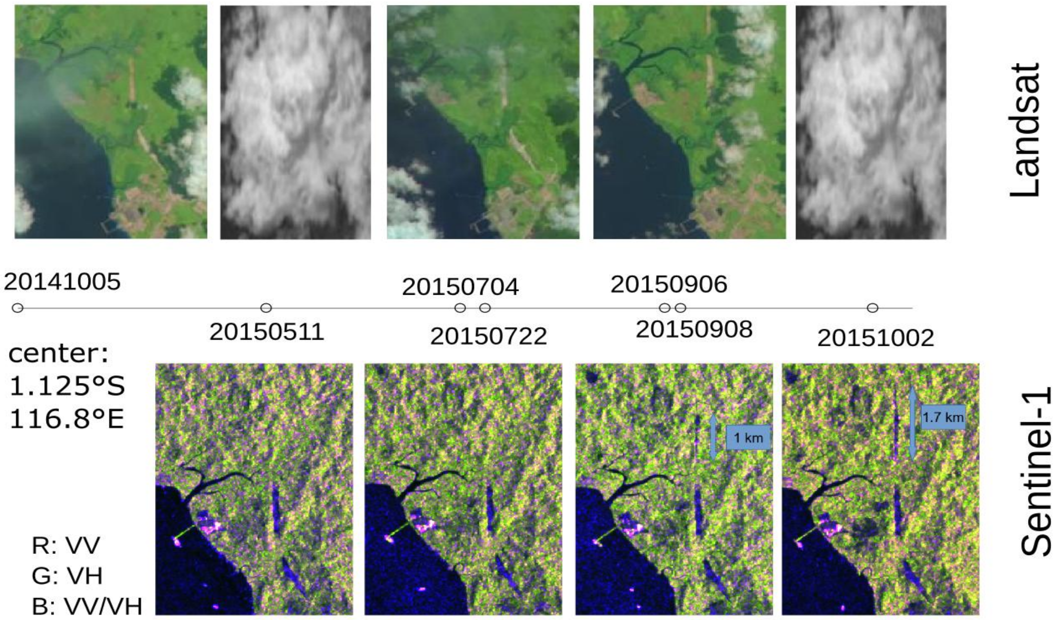

Figure 1. Comparison of Landsat and Sentinel-1 for the monitoring of the progress of road construction in Balikpapan Bay

3. Processing chain using Sentinel-1

A processing chain based on open-source technology has been prepared in order to efficiently process Sentinel-1 data, and then derive a map of deforested areas from a series of images. First of all, Sentinel-1 image products ground-projected using Earth ellipsoid model (so-called Level-1 GRD products) are downloaded and pre-processed using a Linux bash script. This script utilizes the ESA SNAP software toolbox (http://step.esa.int/main/toolboxes/snap) that facilitates tasks of SAR intensity image calibration (including terrain correction), speckle filtering, recomputation into WGS-84 ellipsoid coordinates and image filtering using a mean filter (can be changed to e.g. mDenoise algorithm [8]). Depending on the needs, one can choose to work with either a Sentinel-1 VH band or a ratio VV/VH band that is more suited to distinguishing different types of land cover [6]. The cross-polarization VH band is more sensitive to volumetric scattering of forest and therefore suitable for detection of deforestation itself. This pre-processing chain is figured in Figure 2.

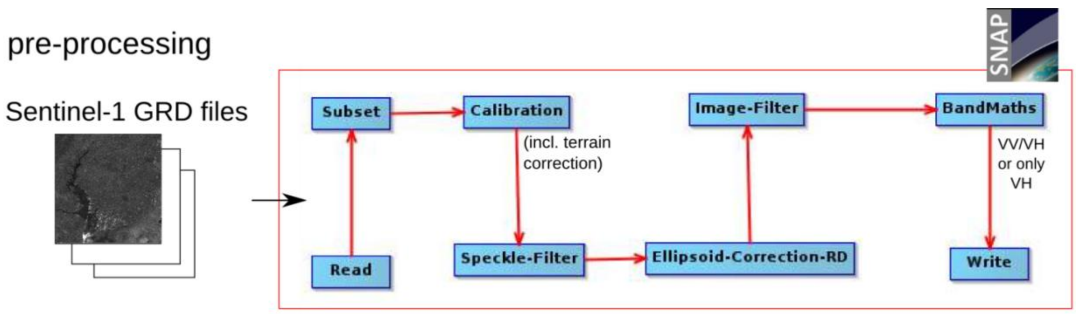

Figure 2. Pre-processing chain of Sentinel-1 images for analysis of forest change detection

For analyzing pre-processed images, we developed a script that uses a SAGA GIS (http://www.saga-gis.org) batch functionality to perform change detection analysis, as depicted in Figure 3. First, a set of pre-event images are averaged in order to create a reference image with minimized speckle. Then a diference analysis can be performed regarding either one or an averaged set of post-event images. The difference image should be thresholded and filtered - majority filter has been used in order to remove very small (noisy) pixel clusters.

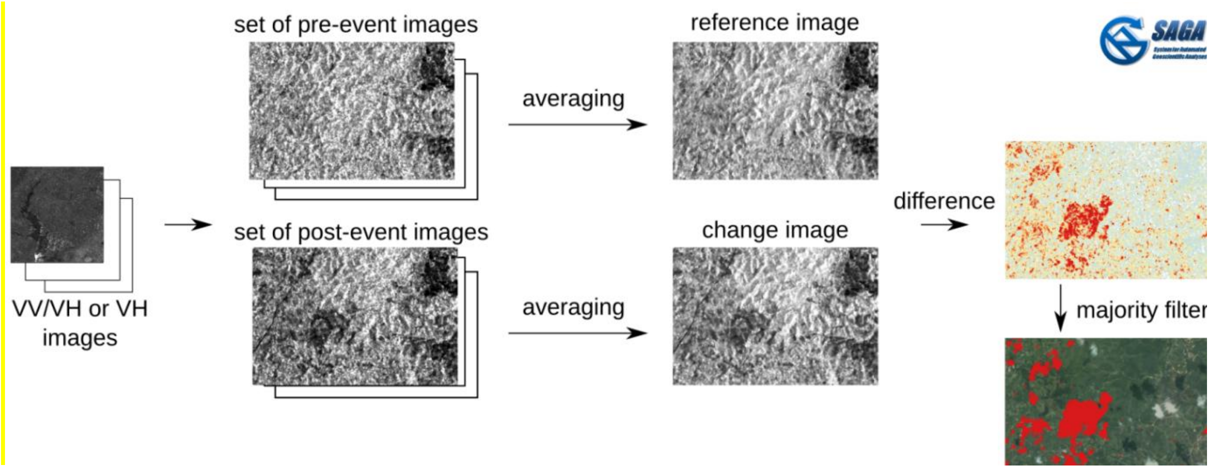

Figure 3. Processing chain of identification of forest loss using Sentinel-1 polarimetric images

4. Identification of burnt areas in 2015

While application of VV/VH ratio allows a clear identification of deforested areas, the approach had to be slightly modified in order to identify areas that are burnt. While scattering intensity differs significantly in deforested areas, tree trunks left by fire still keep the dominant scatter in co-polarized wave. However, the difference occurs in the cross-polarization due to loss of leaves by fire - small leaves scatter the radio signal in various directions and cause a larger scatter in cross polarization [9, 10]. Therefore, to identify burnt areas, only cross-polarization indices (VH) were used in the processing chain.

Three reference data sources were used for comparison with the detection using our approach. Fire hotspots data over whole Balikpapan Bay were achieved from Global Land Analysis & Discovery (GLAD) laboratory, based on combination of 30-meter Landsat and 250-meter MODIS data processing [11]. Only results considered as of high confidence were used for the comparison. Unfortunately only dataset containing fire hotspots during the whole 2015 was available (http://glad.geog.umd.edu). Another reference data were taken from NASA Fire Information for Resource Management System (FIRMS) [12]. These data were acquired as a vector layer of active fire locations detected from 1-kilometer grid based on MODIS. As the third reference, insitu information was acquired from two sites - location of field surveys in Sungai Wain where 11 active fire hotspots (ranging between 30-1000 m2) were found during 19-28th October mission [4]; and burnt forest in Bugis canal (around 45 ha of burnt area) where a UAV mapping has been performed by Dr. Graham Usher, PanEco/YEL. It must to be noted that also field visits cannot be considered sufficient since only a part of Sungai Wain rainforest is accessible relatively easily.

Two different approaches were performed for the analysis - results from both of them are shown together with reference dataset from GLAD and FIRMS in Figure 4. First approach was described before. To create a difference map, an average map of 8 Sentinel-1A HV images from 24th March to 8th September 2015 (before the fire period) was prepared, together with an average map of 4 HV images ranging 2nd October to 13th December 2015 that include fire activity. However, this approach did not detect smaller burnt areas known to appear in Sungai Wain. It is possible that due to filtering both in space and time, the sensitivity for change in scatter got lowered in the average map, so that the applied change threshold caused identification of only few pixels at the smaller fire hotspots in the dense rainforest of Sungai Wain. Afterwards, the strong Majority filter removed smaller detected hotspots that did not form a cluster of pixels.

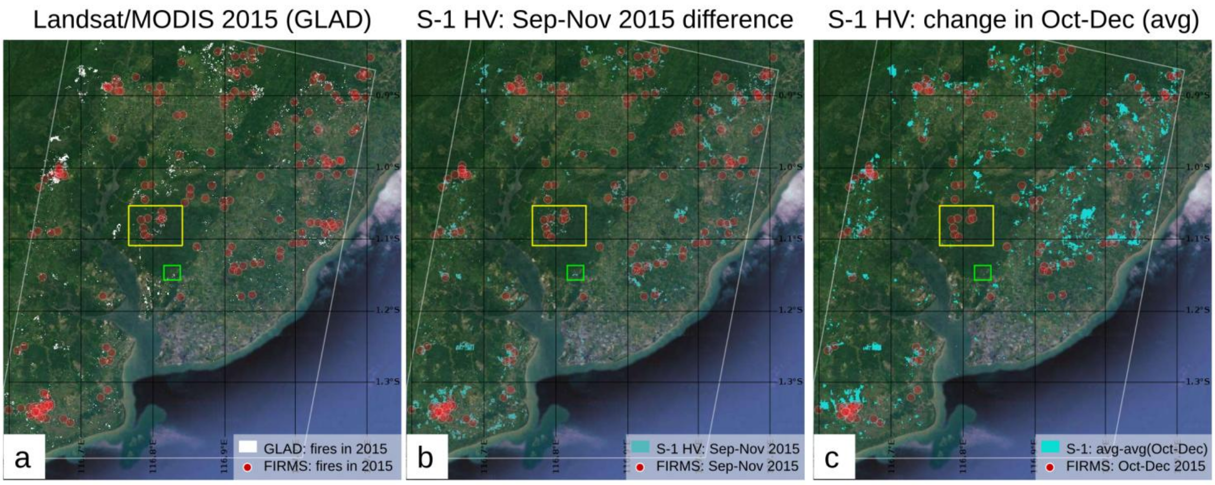

Figure 4. Fire hotspots in Balikpapan Bay identified by FIRMS and a) GLAD „Fires in 2015“ dataset, b) Sentinel-1 difference of 8th Sep - 19th Nov 2015 HV images, c) Sentinel-1 difference of averaged pre- and post-fire event in 2015

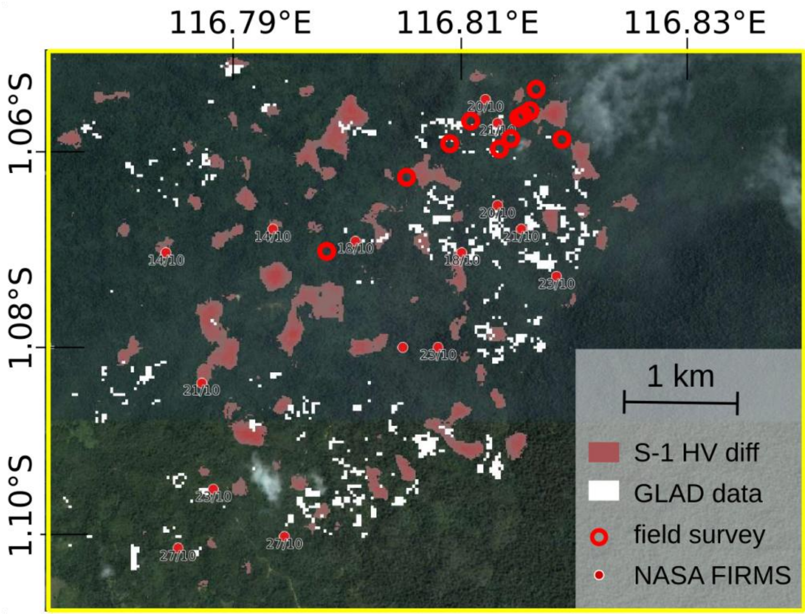

Figure 5. Burnt areas in Sungai Wain (NW part), identified in: GLAD „Fires in 2015“ dataset, Sentinel-1 HV difference between 8th Sep - 19th Nov 2015, FIRMS „Fire hotspots in Oct-Nov 2015“ dataset and field survey taken during 14th - 28th Oct 2015.

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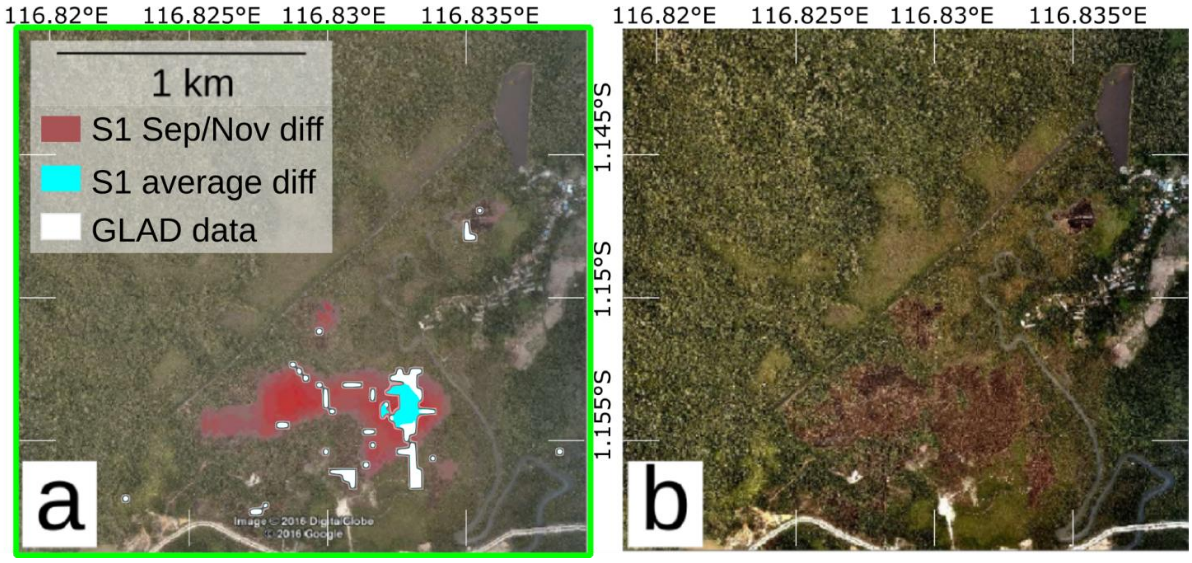

Figure 6. Burnt area at Bugis canal identified using a) Sentinel-1 difference between VH images from 8th Sep - 19th Nov 2015; difference of averaged VH images of pre- and post-fire event; GLAD "Fires in 2015", b) UAV imaging (Oct 2015, Dr. Graham Usher)

Therefore, another approach was applied, using the procedure directly on two VH images from 8th September and 19th November 2015 while in the same time slightly lowering the threshold for Majority filter. This approach should cause a higher rate of noise, but indeed identified the confirmed burnt locations in both Sungai Wain (see Figure 5) as well as in Bugis canal (see Figure 6). It should be noted that the fire hotspot in Bugis canal was not recognized in FIRMS dataset and only few pixels from GLAD dataset as well as the Sentinel-1 averaging approach represent this hotspot. The simple difference between September and November HV images show very high correlation with the burnt area as seen from UAV (Fig. 6b).

5. Conclusions

Optical (multi-spectral) images able to identify deforestation are often unavailable within tropical areas due to intense cloud cover. Active instruments, such as synthetic aperture radar, offer imagery that is unaffected by clouds. In this study, we demonstrated the potential of using Sentinel-1 SAR for the monitoring of forest changes in tropical areas. The simple approach used difference in polarimetric indices over deciduous forests and deforested areas. The deforested areas are easily distinguishable by co-pol/cross-pol wave ratio. However, it was found out that using only cross-polarized (VH) data could identify burnt areas better than using the ratio VV/VH.

Seasonal changes in forest cover and speckle in SAR images cause a higher ambiguity in interpretation. Presented multi-temporal averaging reduces these ambiguities, in exchange for a loss of temporal information. It was found out that multi-temporal averaging fails to detect smaller burnt areas - in order to capture those, we had to proceed by a simple difference between one pair of pre- and post-event images (that include also more noise and therefore may cause false identification of burnt areas).

Results were visualized together with FIRMS, GLAD and local reference data. Since none of these datasets could provide a 100% confident information, statistical comparison was not performed. Observed differences were mentioned in the text.

The advantage of Sentinel-1 images is its atmospheric penetrability and relatively high spatial and temporal resolution. Thanks to an open access policy, Sentinel-1 data are easily and freely available. The data is very often available within 24 hours after the image acquisition. This creates opportunities to arrange a system for a frequent and reliable identification of deforestation, using some advanced processing chain, e.g. BFAST project [13] or Open Foris SAR Toolkit [14].

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