Operational SAR Monitoring: From Snow to Tropical Rainforest

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Abstract – Like in high latitudes, persistent cloud covers in the tropics prevent a reliable observation of the rainforest with optical sensors. Norut has developed a prototype operational monitoring system to detect snow cover, floods and sea ice using cloud-penetrating synthetic aperture radar (SAR). This system includes several modules that range from accurate geolocation of SAR images, producing reference data sets, applying change detection and automatic classification algorithm, combining multi-sensor results and producing thematic maps. For example, change detection is applied to detect wet snow in SAR images by a strong backscatter decrease compared to dry-snow or bare-ground reference images. Similarly, completely deforested areas appear with a lower radar backscatter signature compared to forest areas. However, there are several challenges in monitoring tropical rainforest, which makes it difficult to reliable detect changes, like the strong seasonal backscatter variations between dry and wet seasons and the approach of selective logging, which keeps the main forest canopy intact. In this presentation, we will first present the operational monitoring system and then evaluate the possibilities and limitations with this system, and how it can be adapted to the monitoring of tropical rainforest to detect deforestation and forest degradation.

Keywords: SAR, snow, tropical rainforest, operational monitoring, change detection.

1. INTRODUCTION

Tropical rainforest, and in particular the Amazon and the Congo Basin Rainforests, play a crucial role in regulating the world's climate. Still, deforestation of tropical rainforest accounts for about 20% of the annual man-made greenhouse gas emissions (Stern, 2006) and the international community therefore aims to include deforestation in the future climate discussions as a follow-up of the Kyoto Protocol. Political action has already been taken by establishing the United Nation initiative of the UN Reduced Emissions from Deforestation and Forest Degradation Program (UN REDD), the Brazilian Amazon Fund and the Congo Basin Fund. One important task for enhancing and verifying REDD activities is to improve operational rainforest monitoring, in order to better fight illegal logging and promote sustainable forest management.

The Brazilian Institute for Space Research (INPE) has been quantifying annual deforestation in Amazonia since 1988 based mainly on optical Landsat Thematic Mapper (Landsat TM) satellite imagery through its PRODES project (INPE, 2002). In 2004, INPE started to run the DETER Project (Shimabukuro et al., 2006) as an operational alert system to detect new deforestation fronts using visible/near infrared satellite imagery from NASA's Moderate Resolution Imaging Spectroradiometer (MODIS). However, since both, PRODES and DETER, are based on optical satellite sensors, persistent dense cloud covers and haze in the tropics prevent a reliable near-real time operation of these systems during most of the year. Persistent dense cloud cover is therefore the common unifying problem for satellite remote sensing in the Arctic and the tropics and methods used in polar research can therefore well be useful in the tropics. In addition, MODIS's 250m resolution only allows the detection of deforested areas larger than 25 hectares, while medium resolution SAR should be able to detect logging at smaller scales.

One possibility to improve rainforest monitoring is therefore to combine optical sensors with cloud penetrating active microwave sensors and in particular with high-resolution SAR. Currently, X, C, and L-band SAR sensors are in orbit. L-band from ALOS Palsar is theoretically best suited for this task, because of its capability to penetrate the forest canopy. The advantage of C-band however is its high availability with currently three operational satellites (Envisat ASAR, Radarsat-1&2) and additional follow-up missions (Radarsat-3 and Sentinel-1) planed. Almeida-Filho et al. (2005, 2007, 2008) demonstrated the use of L-band SAR of the Japanese Earth Resources Satellite (JERS-1) and the dual-polarized ALOS Palsar in Amazonia. C-band SAR capabilities from the European Envisat ASAR for rainforest monitoring were presented in Haarpaintner et al. (2009).

Norut has developed prototypes of fully automatic operational SAR monitoring systems for detecting snow cover (EC FP5 Envisnow; Malnes, 2005), floods (EC FP5 FloodMan) and sea ice. For snow cover area detection this SAR monitoring system has been run operationally for several winters using Envisat ASAR data. We believe that this SAR processing line can be applied to operationally detect deforestation in tropical rainforest, and it would therefore complement and improve current rainforest monitoring systems, such as PRODES and DETER. In this paper we will first present Norut's operational SAR monitoring system and its application for snow cover area monitoring and then discuss the possibilities and limitations how this system can be adapted to tropical rainforest monitoring.

2. NORUT'S OPERATIONAL SAR MONITORING SYSTEM FOR SNOW COVER AREA

Norut's prototype of fully automatic operational monitoring systems for detecting snow cover, floods and sea ice based on cloud-penetrating SAR data is built up as a processing line of several modules and algorithms (Figure 1). They include software for precise geolocation and calibration of SAR satellite data, producing consistent reference data sets, applying different change detection and automatic classification methods, combining multi-temporal and multi-sensor (optical and microwave) results and exporting results into thematic maps. A short description of the main modules used for snow cover detection follows.

2.1 Geolocation and calibration of SAR data

Since in the past, commercial geolocation software for satellite data has been based only on simple projection on earth geoids, Norut has developed a precise geolocation and calibration software for SAR data taking into account the local topography using digital elevation models (DEM) in the process. This allows us to accurately geolocate high resolution data from different satellites, satellite tracks and orbits. This is especially important when applying change detection algorithms on high resolution data sets. Calibration coefficients are also used in the process to calibrate the SAR correctly into dB values.

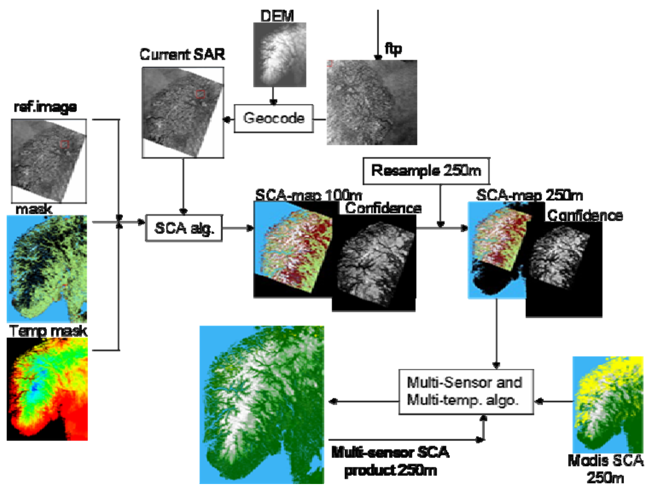

Figure 1. Schematic view of the SAR based snow cover area processing line. For snow cover area detection it is then combine with a MODIS snow cover in a multi-sensor product.

2.2 Consistent reference data sets and auxiliary data

In the case of snow cover area detection, the algorithm to detect wet snow is based on change detection comparing a “new” SAR scene to a snow-free (or only dry-snow) reference image that has the same acquisition geometry, i.e. the same satellite track. This means that a whole set of reference images needs to be built to cover all SAR tracks over the region of interest. This SAR processing line includes methods that combine several snow-free (or dry snow) images into one complete (covering the whole satellite track) and final reference image by weighted averaging using confidence levels dependent on a temperature map for each pixel of each snow-free image. The daily temperature maps are built by interpolating temperature measurement from the Norwegian Meteorological Institute (met.no) using a DEM. This process allows us to reduce speckle effects and noise from seasonal variability due to vegetation growth and precipitation in the reference data set.

Daily temperature maps are also constructed using near-real time, i.e. one day old, meteorological measurements during the operational use of the processing line. These temperature maps are used to estimate the confidence of the results and to infer dry snow at altitudes above the detected wet-snow. A land mask, dividing between water (rivers, lakes and ocean), urban, forested and non-forested areas is used since the wet snow detection is only reliable in non-forested areas.

2.3 Change detection algorithm for snow cover area detection

The snow cover area (SCA) algorithm is mainly based on change detection. The SAR backscatter σ_0 is strongly decreased by wet snow in comparison with dry snow and bare ground and the algorithm will therefore classify pixels as wet snow if they show a backscatter decrease ($\Delta\sigma_0$) of -3dB or less between a new “snow” and reference image. In order to do this based on single pixels at high resolution, a prior precise collocation of the new and reference images is necessary. Using a current temperature map and a DEM, dry snow is then inferred at altitudes high than the average wet snow cover in a certain vicinity. A confidence image is also built in the algorithm as a function of $\Delta\sigma_0$, the surface temperature and the altitude.

Result outputs can then be resampled as desired with different sampling methods in order to combine them directly with results from other sensor in a multi-sensor approach. During resampling the border pixels of snow covers are averaged into snow cover fractions.

2.4 Multi-temporal and multi-sensor algorithm

The operational processing line also includes modules to combine results from SAR with results from other satellites, which for the operational SCA line is optical MODIS data. The algorithm for SCA detection from MODIS has been developed by the Norwegian Computing Center. The two snow cover fraction results from SAR and MODIS are combined in a multi-sensor product by using a weighted average method using confidence flags for each pixel and each sensor. A multi-temporal approach combines the results over a certain period of time, updating the current snow cover area map continuously with the newest daily results. The final results can be exported into several different product formats as simple jpg, png and tiff images or specified products for GIS and image processing software like ArcView or ENVI/IDL.

3. ADAPTING THE SAR SYSTEM TO DETECT DEFORESTATION OF TROPICAL RAINFOREST

Norut’s SAR monitoring system can be easily adapted both to other applications than snow, flood or sea ice monitoring, as well as to other SAR sensors. Currently, Radarsat-1&2 and Envisat ASAR data have been used in this system, but as long as calibration parameters and parameters of the exact satellite path during acquisition are available, other sensors like ALOS Palsar or the future ASAR on Sentinel-1 can be easily digested into the system to produce precise geolocated and calibrated data sets.

3.1 Rainforest reference data and auxiliary data

One main methodological difference between detecting deforestation instead of a seasonal snow cover is that complete deforestation is a continuous process over a time period that can take up to years (going through selective logging, slashing, timber removal, burning, etc.), and once deforestation has taken place, the old reference is out of date. This means that continuous processing is not only necessary for near-real time monitoring results, but also to update the reference base-line. This iterative process means that deforestation maps can later serve as auxiliary data to mask areas that do not need to be considered in future monitoring. However, another problem is regrowth of the vegetation and the question is, when can these areas be considered as forest again in the future? This issue, however, is out of the scope of this paper.

Ground humidity or precipitation maps might also be necessary to use instead of temperature maps as auxiliary data since observations presented in Haarpaintner et al. (2009) showed significant differences in rainforest backscatter during the dry and rainy seasons.

Hence, a first approach to demonstrate this system is to consider only a simplified case of complete deforestation compared to undisturbed forest area observed during dry seasons.

3.2 Development of new algorithms to detect deforestation

Mainly three different types of methods are possible to detect deforestation from SAR: change detection, feature detection and classification techniques.

Change detection: Similar to wet snow, which can be detected by a strong decrease in radar backscatter relative to dry snow or bare soil, deforested areas of the Amazon also show specific changes in the SAR backscatter. SAR backscatter can temporarily increase after the slashing of the forest when tree trunks can act as corner reflectors, but afterwards the backscatter will strongly decrease when the logged areas are completely cleared (Almeida-Filho et al., submitted). Figure 2 shows an example of change detection, i.e. a simple subtraction, of two Envisat ASAR image mode data of rainforest in Boca do Acre in Amazonas State, Brazil.

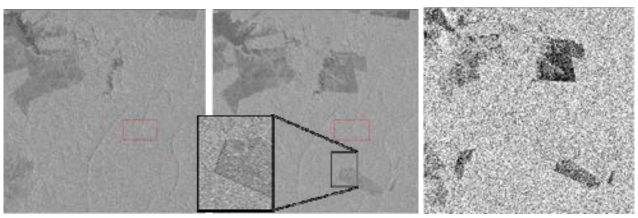

Figure 2. Envisat ASAR IMS sub-scenes from 24 Jul 2004 (left) and 13 Aug 2005 (center) and the thresholding result at -2.5dB of a simple subtraction (right) of the two scenes. The enlargement (black frame) shows SAR shadow (west) and corner reflector effects (east) of the trees on the border of the deforestation field. Images © ESA

Feature detection: Studies of high resolution SAR data showed that the border of deforestation fields show lines of low and high backscatter that result from SAR shadow or corner reflection from bordering trees (Figure 2, Haarpaintner et al., 2009). Detecting such lines might help to detect deforestation also during wet seasons.

Unsupervised classification techniques: As part of the SAR monitoring system, automatic classification algorithms have been developed for flood detection and sea ice/ocean discrimination. They are based on texture analysis followed by Bayesian maximum likelihood classifiers (Haarpaintner, 2009). Dual-polarized SAR imagery will be especially relevant for multi-parameter classification method.

The SAR backscatter signatures and their variability depend on several geo- and biophysical factors. Biophysical factors would include the kind of original as well as regrowing vegetation, its density, state of growth and regrowth, water content and surface humidity. Geophysical factors would include human induced changes like the state of deforestation (selective logging, slashing, burning and clearing) and resultant changes in land-use, as well as bare soil properties and ground humidity. It is, therefore, important to acquire adequate ground truth data from fieldwork and auxiliary data to support the development of these methods.

3.3 Multi-temporal and multi-sensor algorithm

Like in the SCA processing line, deforestation monitoring from SAR data can then be combined with deforestation results from existing operational optical monitoring systems like PRODES and DETER. Another and maybe more efficient approach could be to combine the SAR and optical (i.e. Landsat TM and Modis) in a combined multi-parameter classification algorithm instead of combining their individual final results.

3.4 Schematic view of the SAR monitoring system adapted to deforestation monitoring.

Figure 3 shows a schematic view of a possible SAR monitoring system adapted to deforestation monitoring. Such systems could run in parallel for each SAR sensor, for example for a C- and a L-band SAR, and the multi-sensor and multi-temporal algorithm would then combine all the results into one final result. The dotted red arrow represents the iterative approach were deforestation maps might be used as masks in the analysis of the next acquired image.

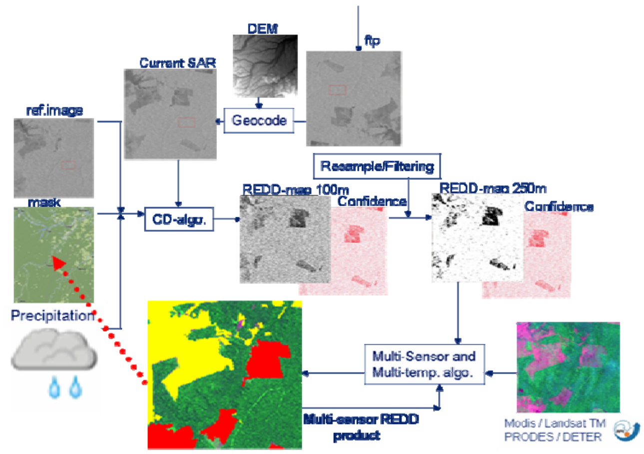

Figure 3. Schematic view of a possible new SAR based rainforest monitoring system that can complement existing operational optical monitoring systems. In the possible final result, old and new deforestation areas are yellow and red, respectively.

4. CONCLUSION

In this paper, we presented shortly Norut's SAR monitoring system developed for snow, floods and sea ice monitoring and how it could be adapted to tropical rainforest monitoring. Since dense cloud covers prevent optical satellite observations in both the Arctic and the Tropics, SAR monitoring is an important complement to optical data because of its cloud penetrating capabilities. Developed methods and learned lessons from Polar research can therefore be very effective for remote sensing research in the tropics. The overall framework of Norut's operational SAR monitoring system could serve as a baseline for an operation SAR system for rainforest. Geolocation and calibration modules of the SAR monitoring system can be directly applied without any major adaptations as long as a high resolution DEM is available. Other modules especially change detection and classification modules however need to be adapted to rainforest, deforestation and forest degradation characteristics. There are also several challenges considering the slow continuous process of deforestation, in comparison to more or less instantaneous snow fall for example. These challenges are related to methodologies regarding the choice of reference data, but they are also related to forest management and law enforcement issues, especially in the case of detecting not only deforestation, but also forest degradation. To be able to detect several stages of forest degradation, it will be necessary to support the development of new algorithms with ground truth observations.

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