Comparison of Envisat ASAR deforestation monitoring in Amazônia with Landsat-TM and ALOS PALSAR images

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Abstract. Envisat ASAR image mode (IMS) and wide-swath (WS) scenes were studied for their usability for monitoring deforestation in the Amazon Rainforest. High-resolution (30m) IMS of the dry season (August) of two subsequent years, 2004 and 2005, showed unambiguous changes in the land-cover with a strong decrease in backscatter for deforested areas. In addition, SAR shadows of trees bordering the deforested areas, as well as strong backscattering from trees that act as corner reflectors on the opposite side of the deforestation field were clearly visible. 100m-resolution WS data from dry and wet seasons were also visually analyzed in comparison with Landsat TM and ALOS PALSAR images. Dry season WS images showed good agreement, but wet season WS images showed little agreement between low backscatter and deforestation areas by visual interpretation. Because of the 100m-resolution as well as the weak vegetation penetration of C-band, single WS scenes do not seem reliable for detecting deforestation if the area is not completely cleared. We suppose that using the high revisit capability of Envisat ASAR would however improve its capability. A multi-sensor approach, combining optical, L- and C-band SAR data, could help to detect different stages of deforestation and would definitely improve the all-weather capability of an operational deforestation monitoring system.

Keywords: Remote sensing, tropical rainforest, synthetic aperture radar, Envisat ASAR, change detection.

1. Introduction

Being a major carbon stock, tropical rainforest and in particular the Amazon Rainforest play a crucial role in the world's climate and climate change. Protecting the rainforest from illegal deforestation is an important task in fighting against carbon emissions and the monitoring of deforestation, afforestation and reforestation is necessary to calculate the overall carbon budget of the earth.

The Brazilian Institute for Space Research (INPE) has been quantifying deforestation in Amazônia since 1988 based dominantly on optical Landsat Thematic Mapper (TM) satellite imagery through its "Monitoring of Deforestation in Amazonia Project" (PRODES, http://www.obt.inpe.br/prodes/) (INPE, 2002). In addition, the DETER (http://www.obt.inpe.br/deter/) Project (Shimabukuro et al., 2006) has been started in 2004 at INPE as an operational alert system to detect new deforestation fronts using optical visible/near-infrared data from the Moderate Resolution Imaging Spectroradiometer (MODIS). However, since both these observation systems are based on optical satellite data, the dense cloud cover in the region and haze in the forest represents a major obstacle for a reliable near-real time alerting system. Also the moderate resolution of 250m of MODIS prevents to detect deforestation areas smaller than 25 hectares. Recently, deforestation activities have moved from the "Arc of Deforestation" towards Central Amazônia, where cloud cover conditions are even more severe (Asner, 2001).

The only possibility to overcome cloud cover problems is by using microwave sensors and in particular high-resolution active synthetic aperture radar (SAR). Currently, there are both, L and C-band SAR sensors in orbit. Due to its longer wavelength (23.6 cm), L-band SAR penetrates better the forest canopy and can better estimate the wooden components of the forest. Additionally, slashed areas behave like smooth surface in L-band systems, enhancing the contrast between forest and non-forest. Thus, in general, L-band is therefore better qualified for rainforest monitoring than C-band (5.6 cm). However, the only current L-band SAR is the PALSAR sensor on the Japanese research satellite ALOS, programmed to cover the world's surface only once or twice a year. The higher availability of C-band SAR data from the three satellites, the Canadian RADARSAT-1 & 2 and the European Envisat is therefore an important advantage, making it possible to cover areas on a weekly to monthly bases.

Using L-band SAR from the Japanese Earth Resources Satellite (JERS-1), Almeida-Filho et al. (2005, 2007) showed that when acquired consistently on a repetitive basis, L-band SAR could effectively complement optical data in an operational program of mapping and monitoring deforestation in Amazônia. They extended their study by comparing data from the new dual-polarized (HH and HV) PALSAR sensor with Landsat Thematic Mapper (TM) imagery (Almeida-Filho et al., submitted).

Similarly, in this paper we report on the possibility to complement optical rainforest monitoring with C-band data from the advanced synthetic aperture radar (ASAR) from Envisat.

2. Envisat ASAR data and the study area

ASAR was launched onboard the European satellite Envisat in March 2002 as a follow-up to the successful ERS-1/2 SAR missions. As its predecessors the ASAR operates at C-band (5.3 GHz), but has enhanced capability in terms of coverage, range of incidence angles, polarization, and modes of operation. In this study we examined the capabilities of two modes: the image mode (IMS) with a spatial resolution of 30m, and the wide-swath mode (WS) with a spatial resolution of 100m. We acquired two IMS scenes during the dry season (24 Jul 2004 and 13 Aug 2005, with same satellite geometry, i.e. track 461), as well as five WS scenes, of which three during the dry season (19 Aug 2005, 4 Aug 2006 and 24 Aug 2007, with same satellite geometry, i.e. track 53) and two during the wet season (20 Dec 2006 and 11 Jan 2008).

Our study area is the same as in Almeida-Filho et al. (submitted), located in the municipality of Lábrea, a new front of deforestation in the southwestern part of Brazilian Amazônia (Figure 1). The NW and SE corner positions are [8°31' S, 67°8' W] and [9°2' S, 66°33' W].
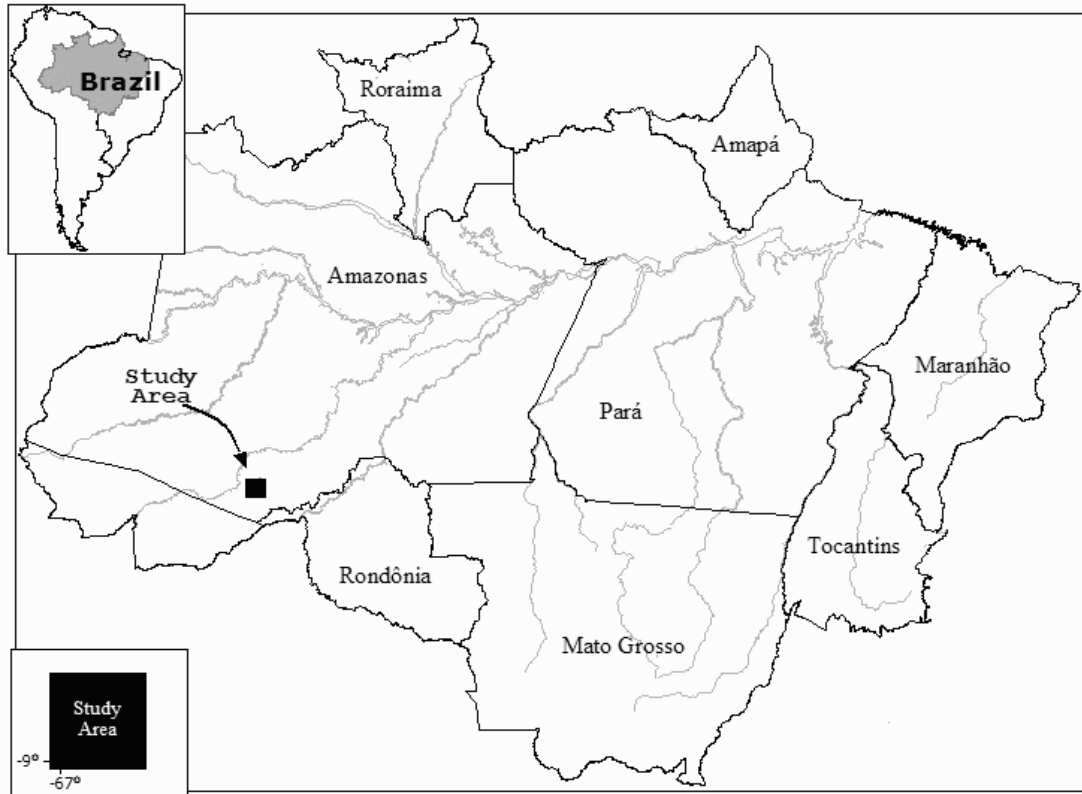
Figure 1: Location of the study area in the southwestern portion of Amazonas State, Brazil.

3. ASAR image mode observations

Figure 2 shows a 15x15 km^2 area of two collocated ASAR IMS scenes from 24 Jul 2004 and 13 Aug 2005, where two new deforestation areas are clearly visible on 13 Aug 2005 as areas of lower backscatter compared to 24 Jul 2004.

An interesting aspect at this high resolution (30m) is that it is even possible to detect the SAR shadow of the trees bordering the deforestation areas due to the incidence angle of the satellite (Figure 2). This means that the higher the incidence angle is (with the vertical being 0), the larger (and therefore clearer) should the shadow be visible. On the other side of the deforestation field the bordering trees act as corner reflectors and appear as bright lines. This aspect could be taken into account when detecting deforested areas that are not completely cleared after being logged. Of course, it is necessary that the bordering trees have a certain height to be able to make this shadow.

Figure 3 shows another 15x15 km^2 area from the scenes where large areas were already logged in 2004 and then appear with a higher contrast (lower backscatter) in 2005. This could be due to both sensor-dependant variations over time and/or environment-dependant variations, like ground humidity after a rainy period, different clearing and regrowth stages and different crop stages in case of agricultural land.
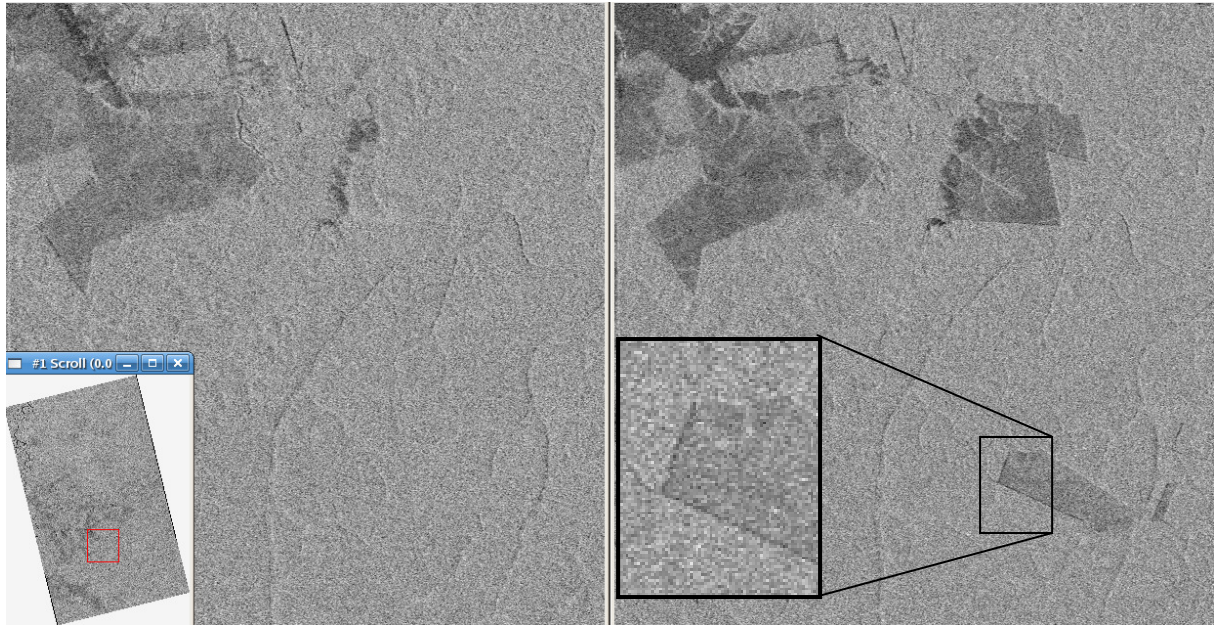
Figure 2: Co-located Envisat ASAR IMS sub-scenes (15km x15km) from 24 Jul 2004 (left) and 13 Aug 2005 (right). The red rectangle shows the position in the overall IMS scene. The enlargement (black frame) shows SAR shadow (west) and corner reflector effects (east) of the trees on the border of the deforestation field.
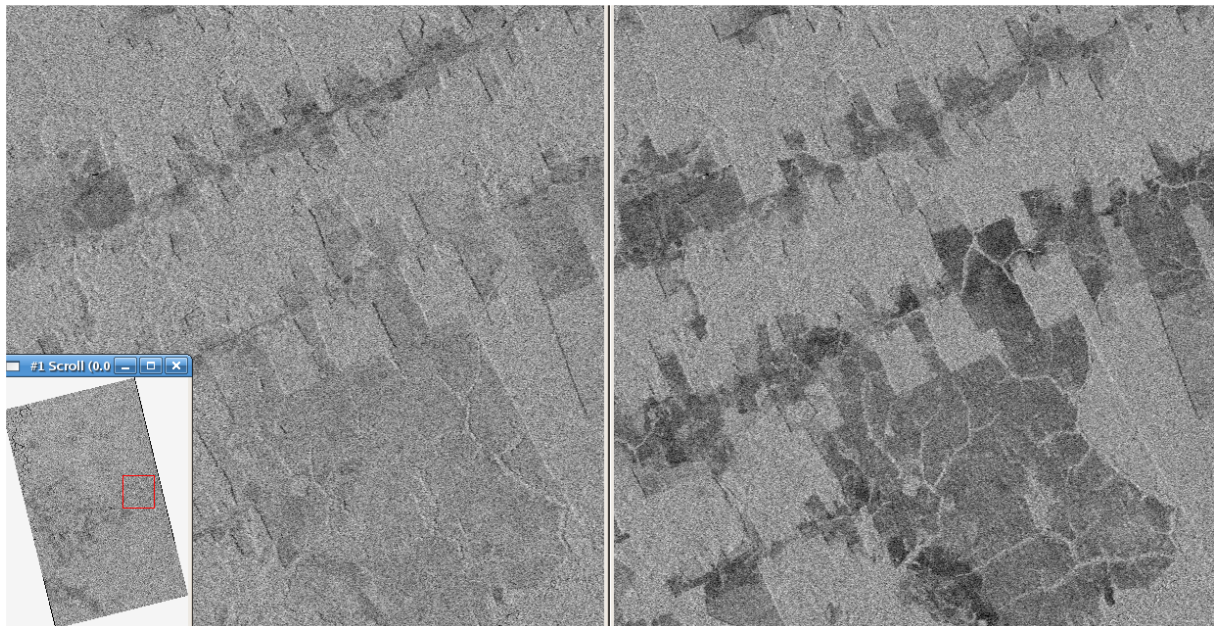

Figure 3: Another 15km x 15km location indicated by the red rectangle in the ASAR IMS from 24 Jul 2004 (left) and 13 Aug 2005 (right). After already been logged in 2004, the contrast between logged and forested areas appears stronger in 2005.

4. ASAR wide-swath observations

For an efficient operational rainforest monitoring, frequent satellite coverage is essential. The WS mode, with a swath-width of 500 km, makes it possible to have weekly observation of any place on earth. However, the resolution of 100m makes it more difficult to detect small feature changes than the IMS mode.

4.1. Dry season (August)

Figure 4 shows the wider region that includes the ASAR IMS observation seen with ASAR WS data for three successive years 2005 to 2007 (19 Aug 2005, 4 Aug 2006, and 24 Aug 2007) during the dry season. At first sight, the 2005 scene shows more low backscatter regions, indicating more deforested areas than 2006 and 2007. The vast deforested (low backscatter) region in 2005 (black rectangle, corresponding to about the area covered in figure 3), has nearly disappeared in the 2006 scene and reappears partly in 2007. In comparison, the Landsat TM scenes from 2006 and 2007 (Figure 4e & 4f) indicate regrowth (light green), especially in 2006, of which lot seems to have been cleared (magenta) again in 2007. The small red rectangle in figure 4 shows an area with an increasing region of lower backscatter between 2005 and 2007, which corresponds to an increasing deforestation, as indicated in the Landsat scenes from 2006 and 2007.

Some small areas indicated by red arrows in the 2007 ASAR WS images appear as bright regions, which could be newly deforested areas where the branches and small debris have been cleared/burned and the remaining wood materials acts as corner reflectors, as explained by Almeida-Filho et al. (2007, 2008).
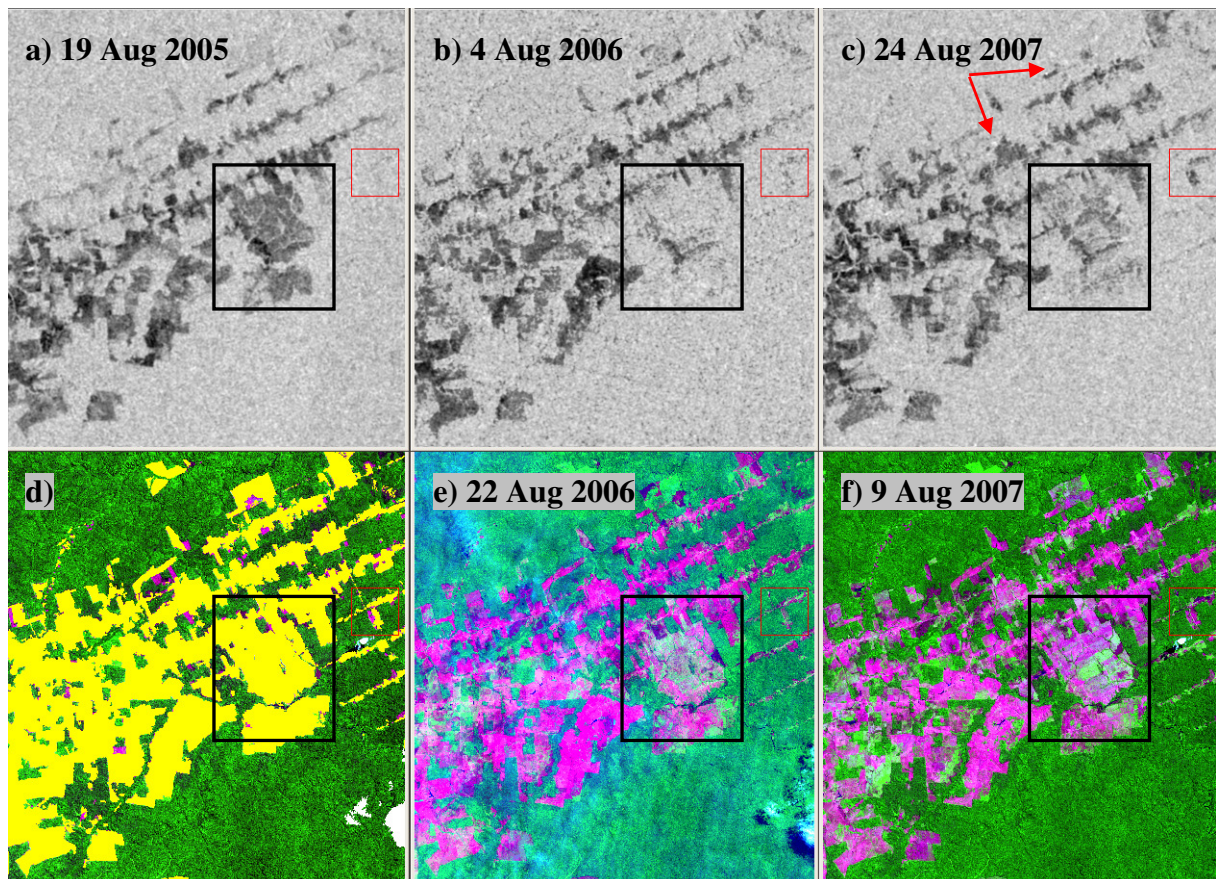

Figure 4: WS scenes for three successive years 2005 (a), 2006 (b) and 2007 (c), and Landsat TM scenes from 2007 with the 2006 deforestation mask in yellow (d), from 2006 (e) and from 2007 (f). Deforested areas appear in hues of magenta, indicating contribution of bare soil. Regrowth in deforested areas appears in light green and burned areas in deep purple. The area covers approximately 40x40 km^2 with the upper-left and lower right corner coordinates being (UL) [8˚35.25'S, 67˚6.5'W] and (LR) [9˚0.0'S, 66˚44.75'W], respectively.

4.2. Wet season (December, January)

Figure 5 shows two ASAR WS images of the region during the wet season on 22 Dec 2006 and on 11 Jan 2008. Although the two WS images show different areas of low and high backscatter, it is visually difficult, if not impossible, to recognize neither older deforested areas from 2006 (yellow mask in the Landsat TM image), nor new deforested areas that have been logged between Aug 2006 and Aug 2007 (areas in hues of magenta).
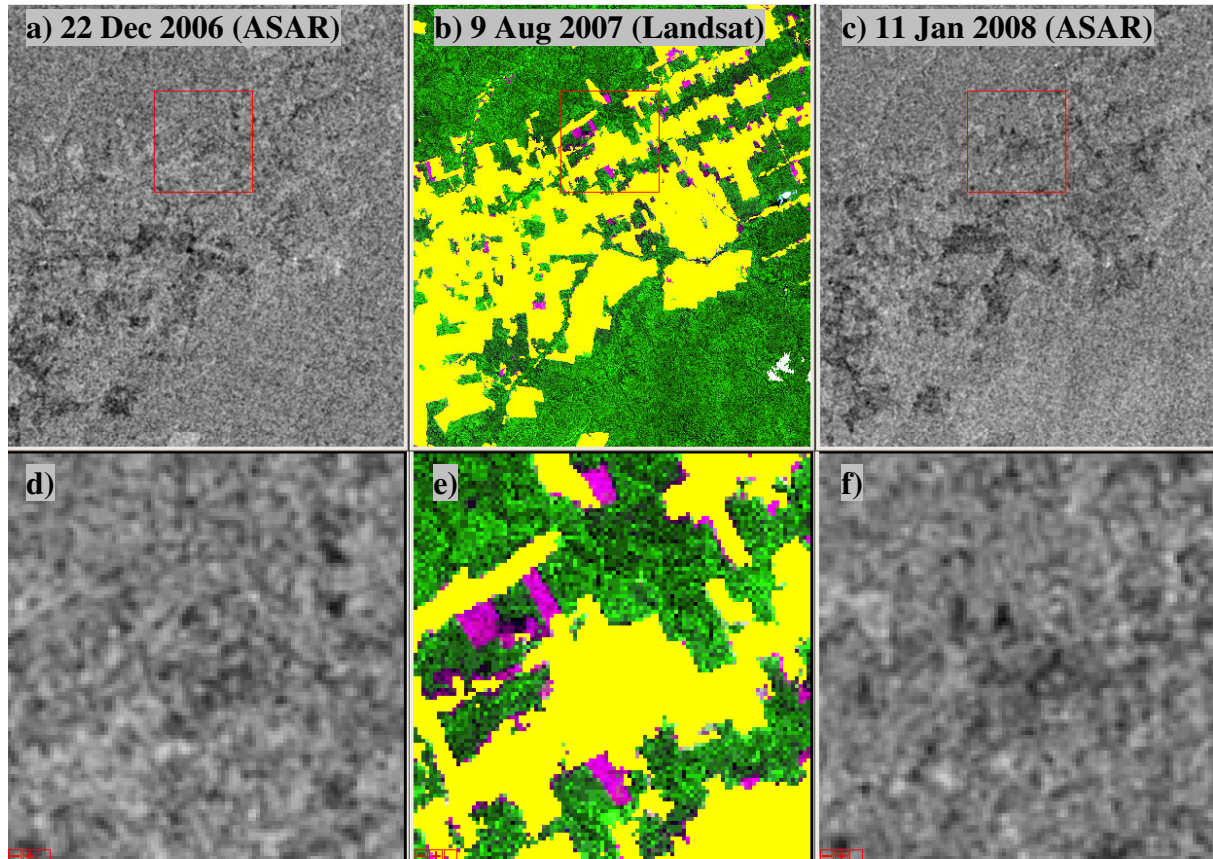

Figure 5: Comparison between ASAR WS images (same area as Figure 4) during the wet season (a) on 22 Dec 2006 and (c) on 11 Jan 2008 with (b) deforestation mask (yellow) from 2006 on a Landsat TM image from 9 Aug 2007 where areas in magenta show new deforestation. (d), (e), and (f) show the enlargements of the red rectangle covering 10x10 km^2.

4.3. ASAR wide-swath compared to ALOS PALSAR

Figure 6 compares the same study area seen from three different sensors, L-band ALOS PALSAR, optical Landsat TM and C-band Envisat ASAR. ALOS PALSAR and Landsat TM images have a resolution of about 50m, whereas the ASAR wide-swath only has 100m resolution. The ASAR and the PALSAR images show roughly the same features and both correspond well to the optical TM image. However, when looking into detail, as f.e. the area inside the red rectangle (Figure 6d, 6e and 6f), it shows that regrowth areas (light green in the Landsat scene) appear dark in the ALOS L-band scene, but bright in ASAR C-band. This is due to the fact that L-band SAR penetrates through the canopies of the regrowth areas with light vegetation cover, whereas ASAR WS does not, since these areas behave as rough surface in C-band wavelength. Additionally, due to the lower resolution, the ASAR WS data does not show all the details as Figure 6a and 6b. We assume that IMS images would show much greater detail and would also detect some deforested regions that were not detected with WS scenes.
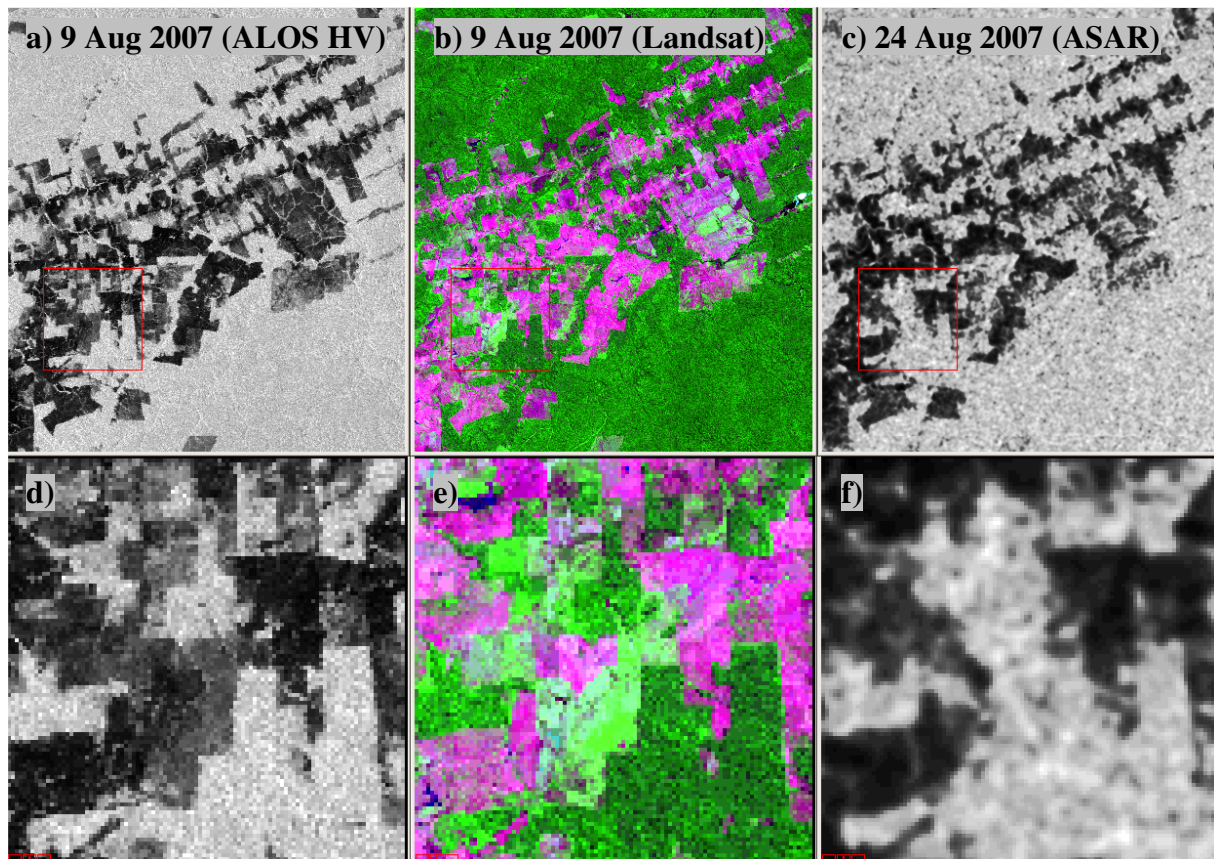
Figure 6: (a) ALOS PALSAR, (b) Landsat TM and (c) Envisat ASAR WS images (same area as Figure 4) and enlargement of the 10x10 km^2 area of the red rectangle (d,e,f).

5. **Discussion and conclusion**

In this study we investigated the usefulness of C-band Envisat ASAR data for monitoring deforestation in the Amazon Rainforest, based on visual interpretation and comparison with optical Landsat TM imagery and L-band ALOS PALSAR data.

Preliminary results indicate that Envisat ASAR's high-resolution (30m) IMS data have a strong potential for rainforest monitoring, showing small details in area segments of logging fields and a strong backscatter contrast between forested and logged areas. Due to the high-resolution it is also possible to detect low and high backscatter lines at the borders of logged areas. These lines indicate forest shadows (low backscatter) and trunks acting as corner reflectors (high backscatter) depending of their position relative to the radar looking direction. The higher the trees and the higher the incident angle are, the clearer should be the shadow and corner reflector signatures.

We also analyzed Envisat ASAR wide swath data, which would be especially useful for forest monitoring because of its frequent and wide coverage in space and time. Dry season WS showed good overall agreement compared to Landsat TM and ALOS PALSAR data and some newly logged areas were clearly visible. However, due to C-band's weak vegetation penetration capability and ASAR WS' 100m-resolution, it seems to be difficult with ASAR WS data alone to reliably detect partial logging and logged areas that have not been cleared yet. However, the weekly revisit capability could probably be used to detect backscatter changes, which might indicate logging over time. PALSAR and ASAR data combined could also give important information of the regrowth processes in certain areas. WS data from the wet season proved to be difficult to be analyzed in regard to rainforest and comparison with Landsat data showed little agreement between low backscatter and logged areas.

We should keep in mind that these are preliminary results with a limited data quantity. It would need more data sets and a thorough methodology to quantitatively analyze backscatter variations in order to establish robust relationships between variation in vegetation (partial logging, logging, burning, regrowth etc.) and variation in radar signatures. Ground truth data from field work and airborne observations could also be necessary.

This study showed nevertheless that Envisat ASAR data and in particular IMS data give useful information through visual interpretation and also has a strong potential to be used for automatic detection algorithms. A multi-sensor approach combining optical and radar (L- and C-band) remote sensing data seems to be the most promising way to follow in future in order to develop a reliable automatic rainforest monitoring system.

6. Acknowledgements:

7. References

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