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Monitoring tropical peat swamp deforestation and hydrological dynamics by ASAR and PALSAR

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1. Introduction

Thick deposits of peat underneath tropical peat swamp forests are among the world's largest reservoirs of carbon. Although occupying only about 0.3% of the global land surface, they contain as much as 20% of the global peat soil carbon stock, representing 63-148 Giga ton of carbon (Rieley and B. Setiadi, 1997; MacDicken, 2002). A value of approximately 70 Giga ton of carbon is cited by (Sabine *et al.*, 2004). This wide range of values illustrates a large uncertainty. The uncertainty is large as peat depth and carbon densities are poorly described. Tropical peat swamp forests have an uneven global distribution. Most of the areas occur in South-East Asia. The carbon stored in South-East Asian peatlands is estimated to be over 42 Giga ton (Hooijer *et al.*, 2007). The tropical peat swamp forests of South-East Asia account for approximately 26.5 million ha of the total tropical resource of approximately 38 million ha, with Indonesia alone contributing an estimated 17-27 million ha (Waldes and Page, 2002).

Tropical peat swamp forests are threatened by large scale deforestation, canal drainage and forest fire, causing enormous carbon emissions (Goldammer, 1999; IUCN/WWF, 2000; Hooijer *et al.*, 2007; Van der Werf *et al.*, 2008). Large scale conversion of peat swamp forest into, for example, oil palm or Acacia plantations, requires draining. The associated sustained low soil water levels cause oxidation of the peat and, consequently, large emissions of carbon dioxide (e.g. Fargioni *et al.*, 2008). Forest and peat fires are an additional source of carbon dioxide emission. Emissions from peat swamp fires in Indonesia during the strong 1997-1998 El Niño Southern Oscillation (ENSO) event, for example, have been estimated at 0.8-2.5 Giga ton of carbon. This was equivalent to 13-40% of the global annual emission from anthropogenic fossil fuel combustion (Page *et al.*, 2002).

Despite the relevance of this ecosystem for biodiversity and climate, relatively little is known about its functioning and existing maps are often outdated and of poor quality. However, unique observing capabilities of L-band satellite radar may provide a powerful

tool to observe seasonal dynamics of flooding, the impact of drainage by canals and the condition of the peat swamp forest cover.

The use of L-band radar for wetlands monitoring was first demonstrated on large scale with SAR (Synthetic Aperture Radar) data from the Japanese JERS-1 satellite acquired in the period 1992-1998. For all major tropical rain forest areas of the world multi-temporal (2-3 dates) radar mosaics were created, including South-East Asia (Shimada and Isoguchi, 2002), thus providing a benchmark overview for the past decade. Locally, more data were acquired allowing in-depth studies of tropical forest inundation patterns (e.g. Rosenqvist *et al.*, 2002) and tropical coastal vegetation (e.g. Simard *et al.*, 2002). Recently, some first results have been published for tropical peat swamp forests (Hoekman, 2007; Hoekman and Vissers, 2007).

With the launch of the Advanced Land Observing Satellite (ALOS) on January 24, 2006, a new Japanese spaceborne L-band radar system became available. The Phased Array L-band Synthetic Aperture Radar (PALSAR) on-board ALOS has several observations modes. The PALSAR observation strategy has been designed to provide consistent wall-to-wall observations at fine resolution (Fine Beam mode) of all land areas on Earth on a repetitive basis. For the world's major wetlands areas up to eight additional observations per year in ScanSAR mode are made to capture seasonal dynamics (Rosenqvist *et al.*, 2007a; Rosenqvist *et al.*, 2008). The entire island of Borneo is one of these major wetland areas. Of particular interest is the ability of PALSAR to contribute to objectives of the Ramsar (wetlands) UN convention (Davidson and Finlayson, 2007; Rosenqvist *et al.*, 2007b).

In this chapter methodologies are discussed for mapping biophysical parameters, hydrological modelling and monitoring based on historical JERS-1 radar data, and currently available ALOS PALSAR. Also the use of C-band ENVISAT ASAR, which is of special interest for peat swamp deforestation monitoring, is discussed. Unique features of radar for observation of peat swamp forests are briefly outlined in Section 2. A test site located in the Mawas peat swamp conservation area in Central Kalimantan is used for method development and features a 23 km long research bridge, which crosses an entire intact peat dome. This test site is discussed in Section 3. Sections 4 until 7 discuss various methodologies and results.

2. Radar observation

The use of spaceborne radar to map and monitor peat swamp forests has certain unique advantages. In the first place, observation by radar systems is unimpeded by cloud cover, which is an advantage over optical data in the humid tropics. In the second place, radar can penetrate vegetation cover to a certain extent, depending on wavelength. The JERS-1 and ALOS imaging radar (or SAR) systems use a relatively long wavelength (23.5 cm, or 1.275 GHz), also referred to as L-band. It allows observation of flooding under a closed forest canopy. Hence, in principle, seasonal flooding dynamics can be revealed well. The ENVISAT ASAR C-band radar has a shorter wavelength (5.6 cm, or 5.331 GHz) and, compared to L-band, observes higher parts of the vegetation canopy. Though ASAR, for this reason, is less suitable to observe hydrological features of wetlands, it is still of large interest to monitor deforestation for technical reasons to be discussed later.

A certain level of understanding of the physical interaction between the radar wave and the terrain is necessary to allow for an accurate interpretation of L-band SAR images. Biomass and flooding are the two main terrain parameters and polarisation is one of the most important radar wave parameters describing this interaction. The effect of biomass is an increase of the radar echo (or backscatter) intensity with increasing biomass up to a level of around 100 ton/ha. Notably the so-called HV-polarisation is sensitive for biomass variation. Above this biomass level the radar image intensity saturates and the radar wave does not penetrate the vegetation well. Below this biomass level, or in open canopies, the effect of flooding is noticeable. In this case the interaction mechanism is somewhat different. Since radar instruments are side-looking and the water surface acts as a mirror, smooth open water surfaces yield no radar return, i.e. these areas appear black in the image. However, when vegetation is present it causes additional reflection (mainly by tree trunks) in the direction of the radar, or the so-called backscatter direction. This effect is particularly strong for the HH-polarisation. In practice, for forested peat domes, the combined effect of flooding and biomass is a variation in the image intensity for which the range of variation is mainly determined by the biomass level (i.e. low biomass areas show large variations in time; high biomass areas small variations) and for which the relative brightness is mainly determined by the intensity of flooding (i.e. dry terrain shows a relatively low intensity; flooded terrain a relatively high intensity). Examples for a variety of vegetation cover will be shown later.

Both PALSAR and ASAR are useful for detection of deforestation. Though the contrast between forest and recently deforested terrain is highest for the L-band with HV-polarisation, also L-band with HH-polarisation and C-band shows a certain level of sensitivity. The contrast also strongly depends on the elapsed time since deforestation. Depending on the vigour of regeneration the contrast fades away quickly in L-band (within approx. 4-6 months), and even faster in C-band (within approx. 2-3 months). The preference for C-band is related to the fact that L-band HV observations are only made once a year, L-band HH observations are less sensitive and ASAR C-band dual-polarisation data (APP mode) can be observed routinely every 35 days. Moreover, ASAR data can be made available very quickly, within two days of satellite overpass, which allows fast response to supposed illegal logging. Table 1 summarises the main characteristics of the radar systems discussed in this chapter.

	JERS-1	PALSAR Fine beam	PALSAR ScanSAR	ASAR Alternating polarisation
Centre frequency	1275 MHz	1270 MHz	1270 MHz	5331 MHz
Image mode (Polarisation)	(HH)	- FBS (HH) - FBB (HH/HV)	WB (HH)	APP (VV/HV)
Incidence angle	36°~42°	36.6°~40.9°	18.1°~43.0°	- IS2: 19.2°~26.7° - IS4: 31.0°~36.3°
Swath width	75 km	70 km	360 km	- IS2: 105 km - IS4: 88 km
Ground resolution	~18 m	~10 m ~20 m	~100 m	~30 m

Table 1. Brief overview of radar system characteristics

3. Field station and hydrological characterisation

To study peat swamp hydrology, ecology and radar wave interaction in a systematic way a dedicated research station has been established in the Mawas peat swamp forest conservation area, which is located some 80 km east of Palangkaraya, in the province Central Kalimantan. The main feature is a research bridge, 23 km in length, crossing an entire peat dome (Figure 1). Instruments placed along this bridge automatically measure rainfall and water level every hour. In December 2004, an airborne radar survey (the ESA INDREX-2 campaign) was carried out along this bridge to test a variety of advanced imaging radar techniques (Hajsek *et al.*, 2005; Hajsek and Hoekman, 2006). The intention is to collect data over an extended period (i.e. 10 years) to develop hydrological modelling, examine relationships between hydrological, soil and vegetation characteristics, study carbon sequestration and to relate biomass and water (flooding) levels to L-band radar observations of the ALOS PALSAR instrument.



Fig. 1. Field photograph of a section of the 23 km long research transect in the Mawas peat swamp conservation area. The transect crosses an entire ombrogenous peat dome. Along the transect ground water level dynamics are recorded.

Peat domes are formed in ombrogenous peat swamp areas, which are purely rain-fed and, consequently, nutrient poor. Vegetation types are located in concentric zones, with the 'poorer' forest types located towards the centre of the dome. Typically, the outer ring consists of relatively dense and high 'mixed' peat swamp forest, which gradually changes in a lower, more open, 'pole' peat swamp type. At the top the open 'padang' shrubland type may be found. To characterize the hydrology of such a dome, where water is flowing from the top in the centre towards the edges, the water level variation along the flow is monitored. An example result for one of the instruments along the bridge is shown in Figure 2 (Hoekman, 2007).

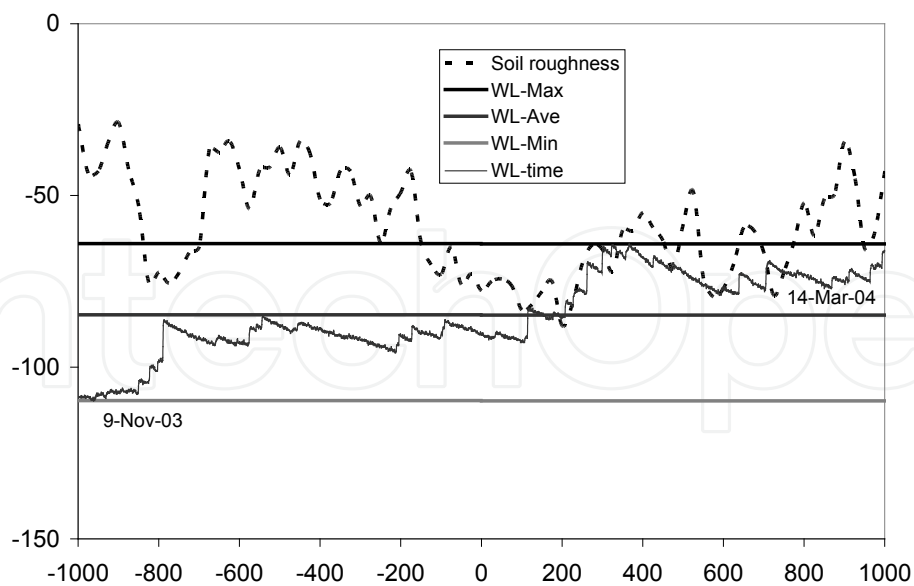


Fig. 2. Water table variation WL-time (solid curve) and peat soil surface roughness (dashed curve). The vertical axis shows water level and soil surface height (both in cm). The horizontal axis shows horizontal distance (in cm) along the soil surface roughness profile (i.e. from -1000 to 1000 cm) as well as time (i.e. from 9-Nov-03 to 14-Mar-04). The position of the water table measurement is at the centre of this profile. These measurements are made every hour. The results for the period 9 Nov2003 until 14 March 2004 are shown (also along the horizontal axis). The three horizontal lines show the maximum (WL-Max), average WL-Ave) and minimum (WL-Min) water level. The percentage terrain flooding, thus, can be deduced from the combined roughness and water table measurements.

4. Observation of severe peat dome degradation events by JERS-1

Time series of L-band radar data can provide information on hydrology in peat swamps. For many peat swamp areas in Borneo and Sumatra large series of JERS-1 images (i.e. 15-30) collected in the period 1992-1998 exist. Figures 3 and 4 give examples of biophysical characteristics and events observed for the Mawas conservation area and the adjacent Kahiyu area. Figure 3 shows temporal dynamics in flooding, which reveals three large domes. The areas labelled as A are a complex of two flooded domes divided by a river originating from a central depression (B). The feature labelled as C is a relatively flat and wet fringe of a dry dome. Since tropical rainfall can be very localised and surface run-off is fast, the availability of large time series strongly supports proper interpretation.

Another combination of three images, all collected in the dry season, is shown in Figure 4. It shows deforestation caused by excess drainage as the three large blue areas intersected by canals labelled as A and B in the image. These areas appear blue because the radar echo strength in the third image (of this composite time series image) is much higher due to the combined effect of flooding and presence of sparse vegetation, while in the first two images (the red and green channels) the vegetation was still dense. Smaller blue areas labelled as C along rivers relate to fire scars and shifting cultivation in secondary forest.

The large blue area labelled as B in Figure 4 is one of the domes. In this area all trees died of drought and ground fires, which burned the root system causing the remaining trunks to fall down. The dome's destruction is shown in more detail in the time sequence of events in Figure 5. Until 1996 the dome was still hydrologically intact. In 1997 the construction of a very wide canal is visible. A low-altitude aerial photograph of this canal is shown in Figure 6. In Figure 5(c) (September) the canal is filled with water (the canal becomes black) and a small somewhat brighter area appears. This area grows very fast and becomes even brighter as shown in Figure 5(e) until the destruction is completed (January 1998). The physical interpretation of the radar brightness changes in the dome area can be associated with an initial period of excess drought under a dense canopy, i.e. the area becomes somewhat darker, like in Figure 5(b), followed by a period in which trees collapse and the brightness increases due to direct radar reflections from exposed trunks, like in Figures 5(d-e). It is interesting to note that the spatial extent of the destruction halted at the relatively flat and wet fringe well visible in Figure 3. The obvious cause of the destruction is the huge drainage caused by the wide canal. The coinciding strong El Niño Southern Oscillation (ENSO) period may have accelerated the process.

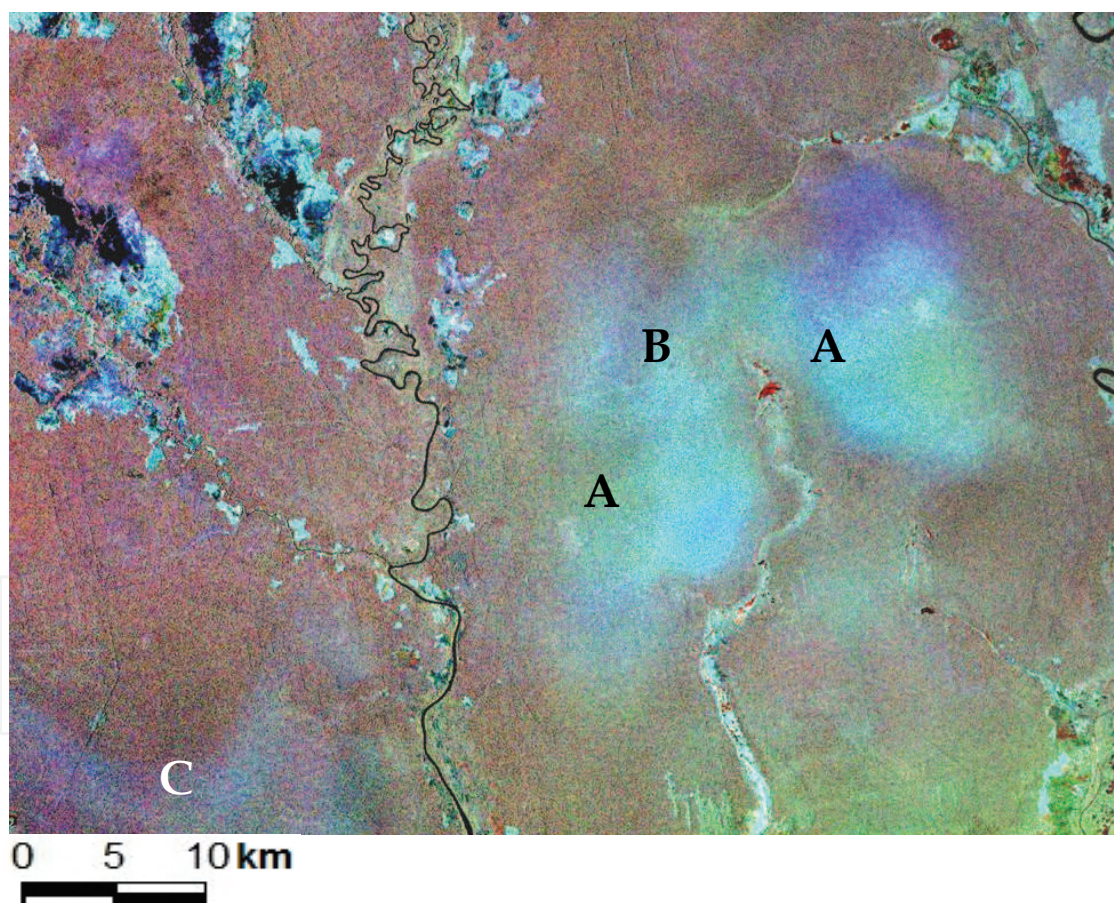


Fig. 3. Temporal dynamics in flooding intensity can be related to the hydrology of ombrogenous peat swamp forests and, indirectly, to peat depth. The blue areas labelled as A are flooded parts of the relatively flat tops of a complex of two peat domes, with a river originating from a central depression (B). The feature labelled as C shows the relatively flat and wet fringe of a dry peat dome. Mawas area, Central Kalimantan; JERS-1 SAR multi-temporal composite image (Red 7 Sep 1994; Green 12 Jul 1995; Blue 4 Jan 1996).

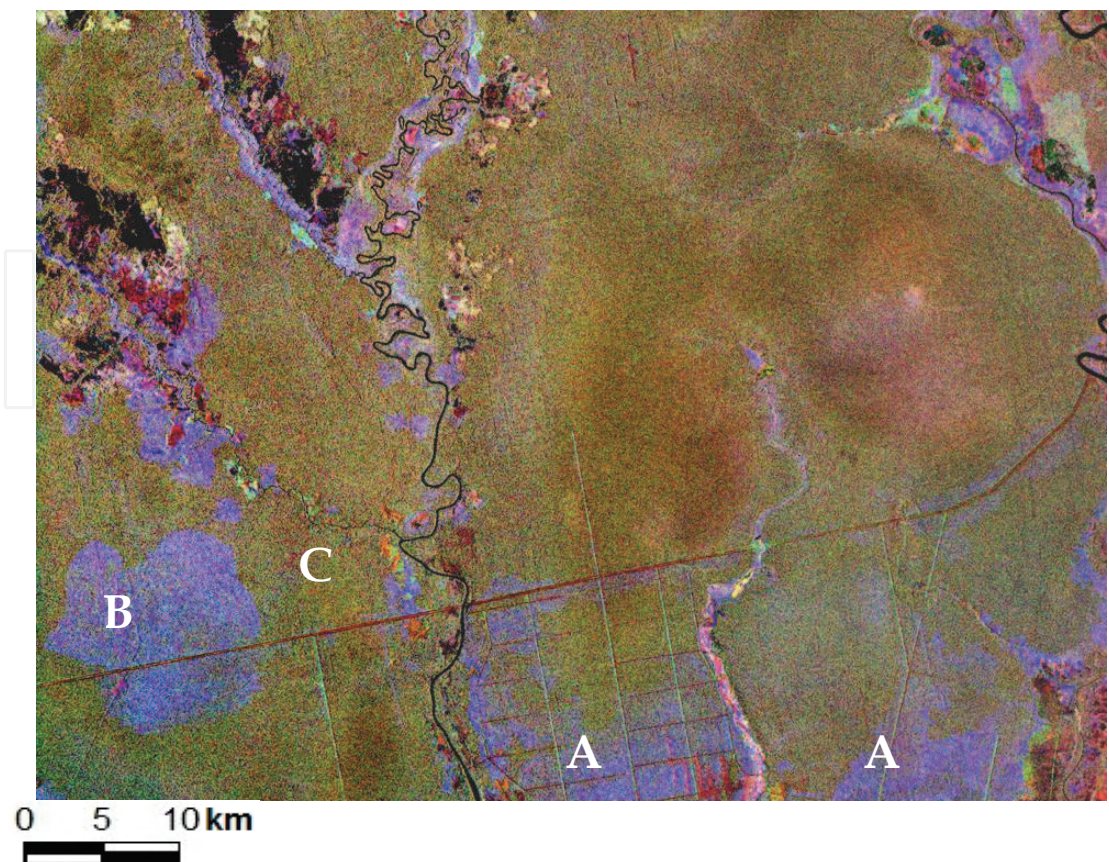


Fig. 4. Deforestation in Central Kalimantan caused by excess peat swamp forest drainage shows up as the three large blue areas intersected by canals labelled as A and B. Smaller blue areas along rivers labelled as C relate to fire scars and shifting cultivation in secondary forest. JERS-1 SAR multi-temporal composite image (Red 25 Jul 1994; Green 24 Jul 1997; Blue 16 Jul 1998).

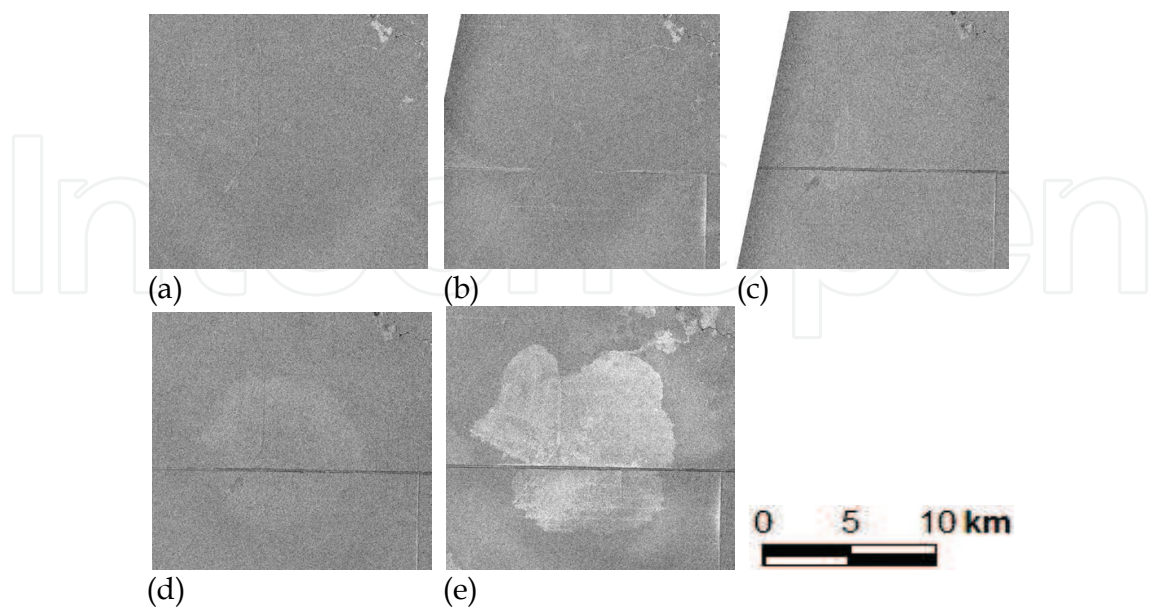


Fig. 5. JERS-1 SAR time series of the collapse of the peat dome in Kahiyu: (a) 12 Jul 1995; (b) 19 Mar 1997; (c) 11 Sep 1997; (d) 25 Oct 1997; (e) 21 Jan 1998.



Fig. 6. Low altitude aerial photograph of the main East-West oriented double canal system passing South of Mawas. It shows the crossing of the Mentangai river, canal blocking activities and stretches of burnt forest areas along the canal, covered with small bushes and ferns. January 2005. Courtesy: Ruandha Agung Sugardiman, Indonesian Ministry of Forestry.

The possibility to observe peat swamp forest hydrology ceased at the end of the lifetime of the JERS-1 SAR instrument in 1998. Only since the year 2006, with the launch of ALOS, a new window of opportunity has been opened. During this eight year time span drastic changes occurred in many of the South-East Asian peatlands. This is illustrated in Figure 7 where new PALSAR observations are compared with the historical JERS-1 SAR data shown in Figs 3 and 4. The most striking features are the wet *padang* vegetation areas on top of two of the three domes (A, C). Compared to Fig. 3 the second dome (B) is now dryer, which may be an effect of local rainfall. The top of the Kahiyu dome (C) is wet. It shows regeneration of *padang* peat swamp bush (bright centre) and denser vegetation (the red fringe around this bright centre, D). South of the main East-West canal the presence of a dry and low biomass peat area (blue area, E) is an indication of further degradation of the vegetation cover.

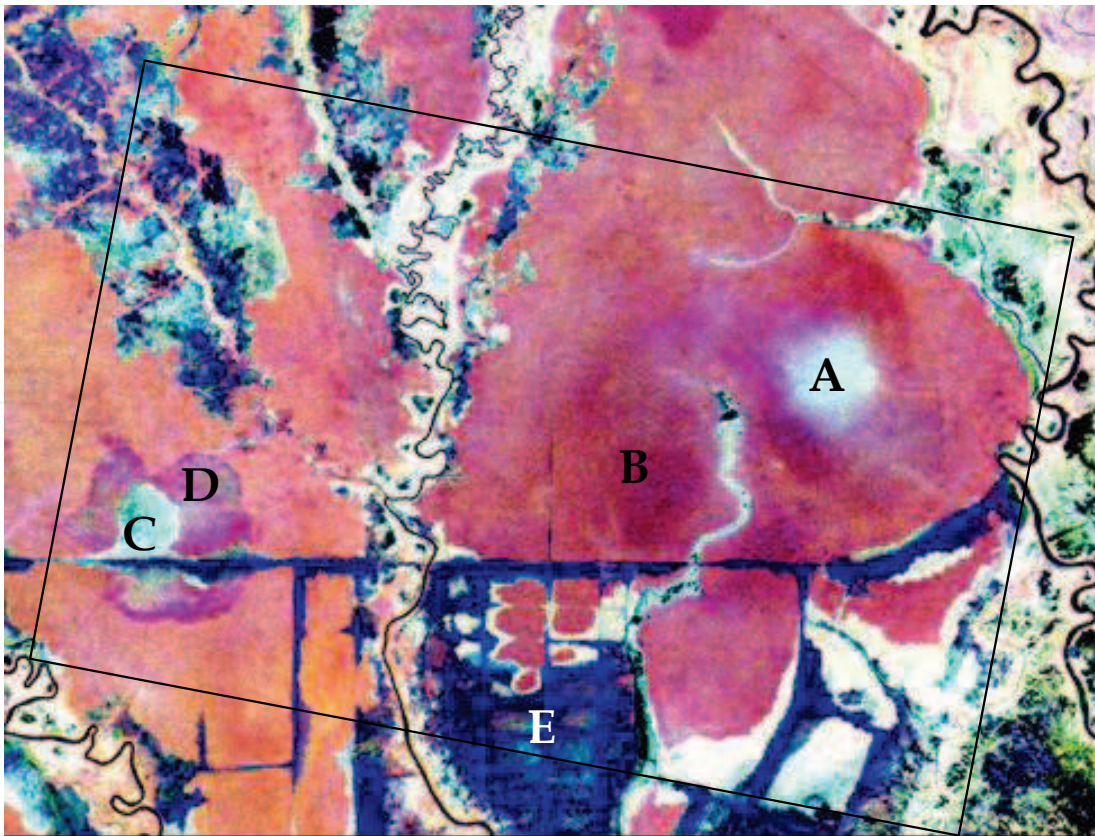


Fig. 7. Decadal change as observed by PALSAR data in 2007. The black frame outlines the area of Figs 4 and 5. The most striking features are the wet *padang* vegetation areas on top of the domes (A, C); a dry dome top (B); indications of re-generation on the top of the Kahiye dome (D); and the dry low biomass peat area (blue area) indicating further degradation of the vegetation cover (E). PALSAR multi-temporal composite (Red FBD HV; Green FBD HH; Blue WB HH; FBD 7 and 24 Aug 2007 (2 images); WB 29 Mar 2007). Courtesy: ALOS K&C © JAXA/METI.

5. Monitoring of fire damage and deforestation by ENVISAT ASAR

Due to smoke and persistent cloud cover optical satellite sensors fail to detect forest cover area change in a timely manner. To monitor deforestation over large areas in a feasible way, a system using both traditional satellite imagery (i.e. Landsat ETM+) and ASAR APP radar imagery from the European Space Agency's ENVISAT satellite has been proposed, developed and implemented. This was done for a 60,000 km² area of peatland in Central-Kalimantan to support peatland restoration and protection activities carried out in the framework of the Central Kalimantan Peat Programme (CKPP, 2009).

For this area more than 90 ENVISAT ASAR APP radar images were collected between 2005 and 2007 and systematically analysed using semi-automated computer techniques to detect change. The approach works best using two polarisations (HH and HV or VV and HV) and incorporates analysis of changes in both the strength and polarisation of the radar return signal both within a small timeframe (every 35 days, which is the revisiting cycle of the satellite) as well as in a large timeframe (1 year). This is necessary to improve accuracy of the

changes and reduce false alarms. For this system a relatively small incidence angle was used (IS2; see Table 1; see footnote¹) to provide continuity with the predecessor of ENVISAT ASAR, viz. the ESA ERS-2 SAR. Whenever available, Landsat ETM+ was integrated. Output of this change detection process is a consistent series of change maps showing forest, forest cover change (deforestation, fire damage, road building etc.), other land and water. These results have been used to support law enforcement and projects for the generation of voluntary carbon credits. Some results are shown in Figs 8-10.

Figure 8 is a low altitude aerial photograph of sub-surface peat forest fires along a canal in the Sebangau National Park. This photograph clearly illustrates the need for radar. Optical observation fails to detect the ground fires because the forest seems intact, and observation is obscured by smoke, haze, and or clouds. Thermal infrared (hot spot) observation, such as from the MODIS, AVHRR or AATSR instruments, fail because the fire is underground and under the forest. L-band radar (HH-polarisation) works because it detects the excess drought in the soil. ENVISAT APP radar detects damage very fast because it registers falling trees directly (with an update frequency of 35 days). Figure 9a shows the cumulative damage for the year 2006 as recorded by ASAR, which was a dry year because of a moderate El Niño. Figure 9b shows fire hot spots which are detectable as soon as the ground fires have developed in open fires. The correspondence is large. Figure 9c shows the first available cloud free Landsat ETM+ scene of the same area after the fire period. It shows the burned forest area (in cyan) at exactly the same locations where ENVISAT already mapped deforestation 10 months (!) earlier.



Fig. 8. Low altitude aerial photograph of sub-surface peat forest fires along a canal in the Sebangau National Park. 6 September 2004. (Photo: Dirk Hoekman).

¹ Though IS2 images were used here, and demonstrated to be suitable for deforestation monitoring, it is noted that IS4 images are even better suited because of a higher incidence angle, which increases the contrast between forest and non-forest. Even higher incidence angles are possible (from IS5-7 modes) but these provide no full coverage at the equator.

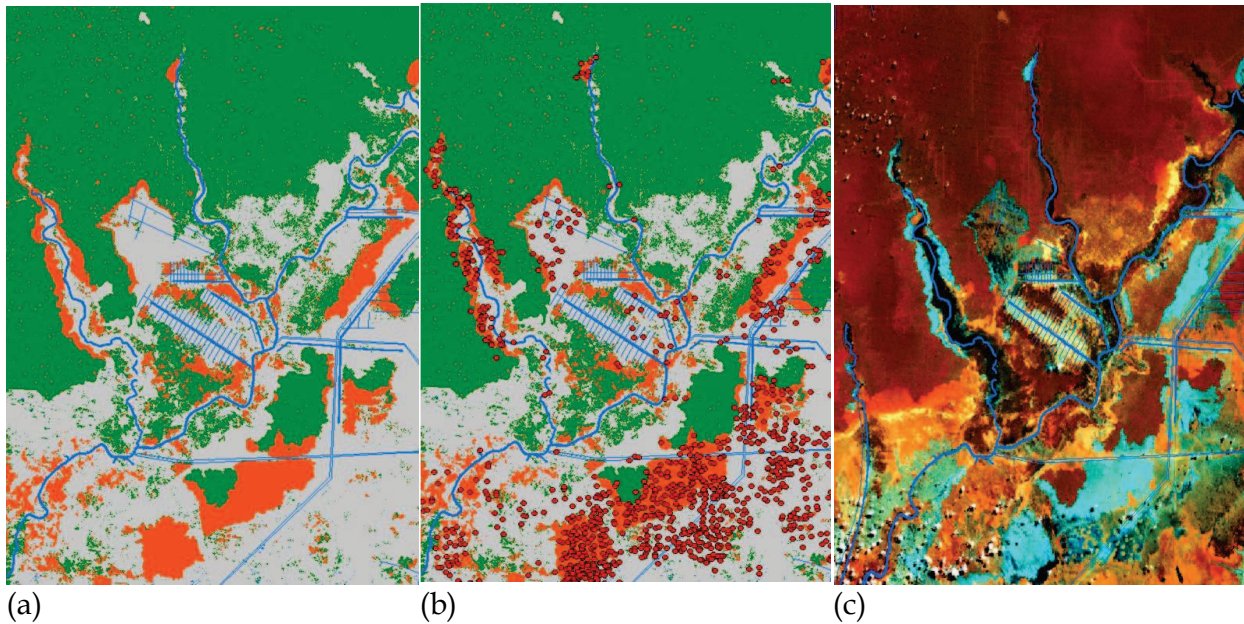


Fig. 9. South-East section of Sebangau National Park, East-Kalimantan. (a) Cumulative deforestation recorded in the year 2006 by ENVISAT ASAR (Green: forest; Orange: forest loss); (b) Idem, with MODIS hot spot fire detections (small red circles) of the 2006 dry season superimposed; (c) Landsat ETM+ image of 4 July 2007 (RGB: bands 4-5-7). Central Kalimantan Peatlands Programme. ASAR APP data courtesy ESA. Image processing and analysis by SarVision & Wageningen University, 2007.

This unique capability on ASAR APP to follow deforestation patterns nearly real time (i.e. within ± 5 weeks) is nicely illustrated in Figure 9. It shows the development of a (probable illegal) road from an already deforested area in the direction of a small rock outcrop in the Sebangau National Park. Already in December 2005 the first section is visible and construction work is proceeding until September 2006. Good trafficability on a road in peat swamp forest requires the construction of canals for drainage on both sides of the road. However, these canals drain a large area of the surrounding peat soil and make it vulnerable to fire. The October-December map sequence shows the damaging effects of forest fire.

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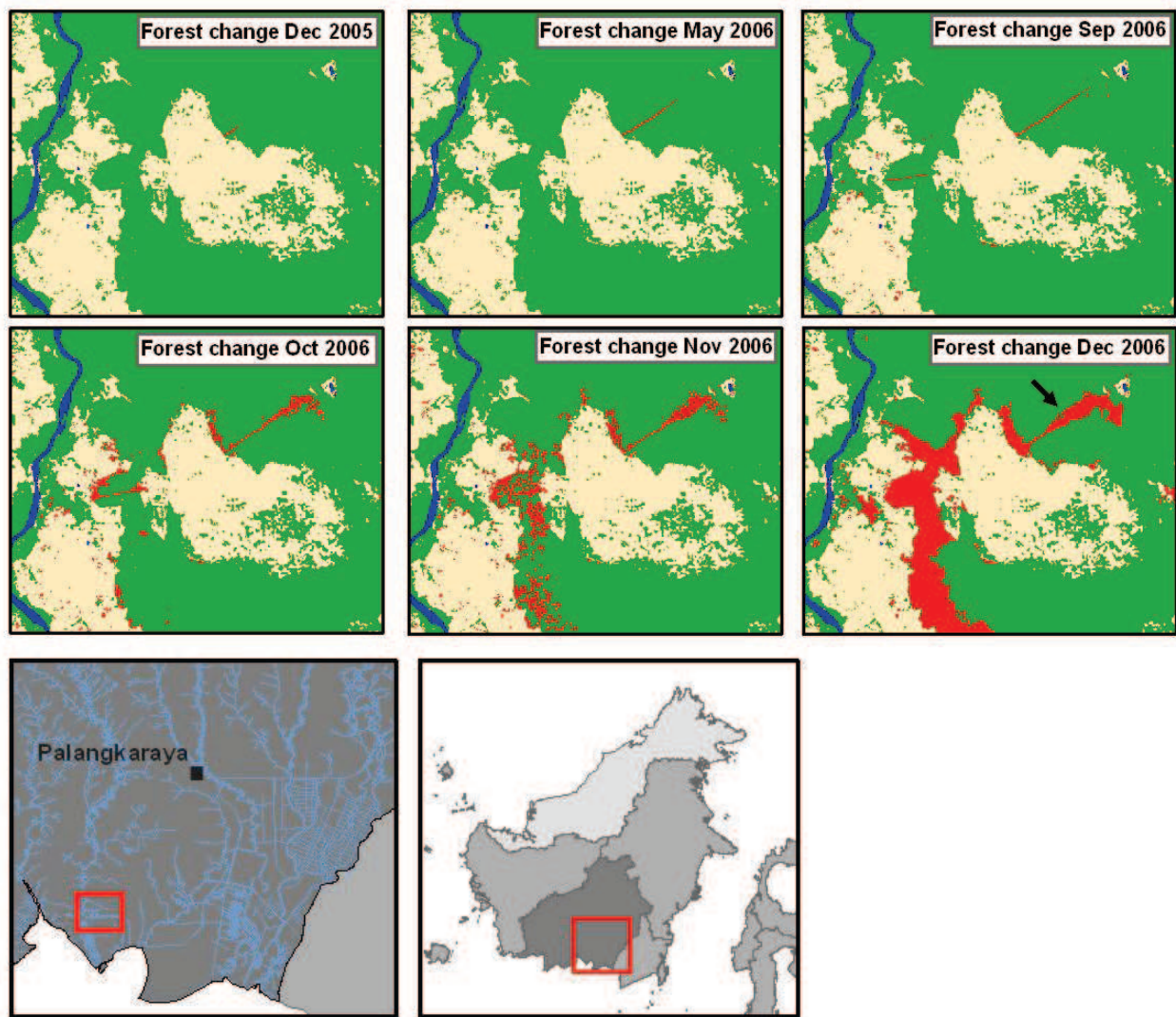


Fig. 10. ASAR Alternating Polarisation radar deforestation time series example showing forest (green), water (blue), non-forest areas (yellow) and recent deforestation (red). The top 3 images show the development of a new road in the forest (period December 2005 until September 2006). The lower 3 images show major deforestation because of forest fires in the dry season along this new road and along the forest boundaries (period October-December 2006). This example covers an area of ~ 30 km by 20 km and is part of a larger area of ~ 300 km \times 200 km where this new radar monitoring technique has been applied pre-operationally. Central Kalimantan Peatlands Programme. ASAR APP data courtesy ESA. Image processing and analysis by SarVision & Wageningen University, 2007.

6. Peat swamp restoration impact assessment using L-band backscatter change

Historical JERS-1 L-band radar data provide insight in the pre-disturbance or early disturbance state of the hydrological functioning of peat domes and may be used as a baseline for restoration planning. In Mawas, in the framework of CKPP, canal blocking was performed. The effect of such activities may be assessed and monitored by PALSAR images,

and auxiliary data. An example is given in Figures 11 and 12. In the JERS-1 image of January 1998 (dry period) shown in Figure 11 the area demarcated by the red line is an area within the Mawas area suffering from excess drought. In the PALSAR image of 9 November 2006 (dry period) this area has decreased above the main East-West canal because of the construction of dams in the canal going North (canal Neraka). In the area south of the main East-West canal a large network of canals is still present and the continued drainage has worsened the situation. Note the very low radar backscatter (intense black) caused by very dry bare peat areas and the bright white area, which is a strongly degraded open forest with fire damage. The areas demarcated in blue are hydrologically intact, allowing forests previously damaged to regenerate. The fire damage is visible in the PALSAR area as a very bright area (B) associated with sparse open vegetation with many dead standing trunks. This area is also visible in the ENVISAT deforestation map created directly after the fire damage (Fig.12a) and Landsat ETM+ 10 months later (Fig.12b).

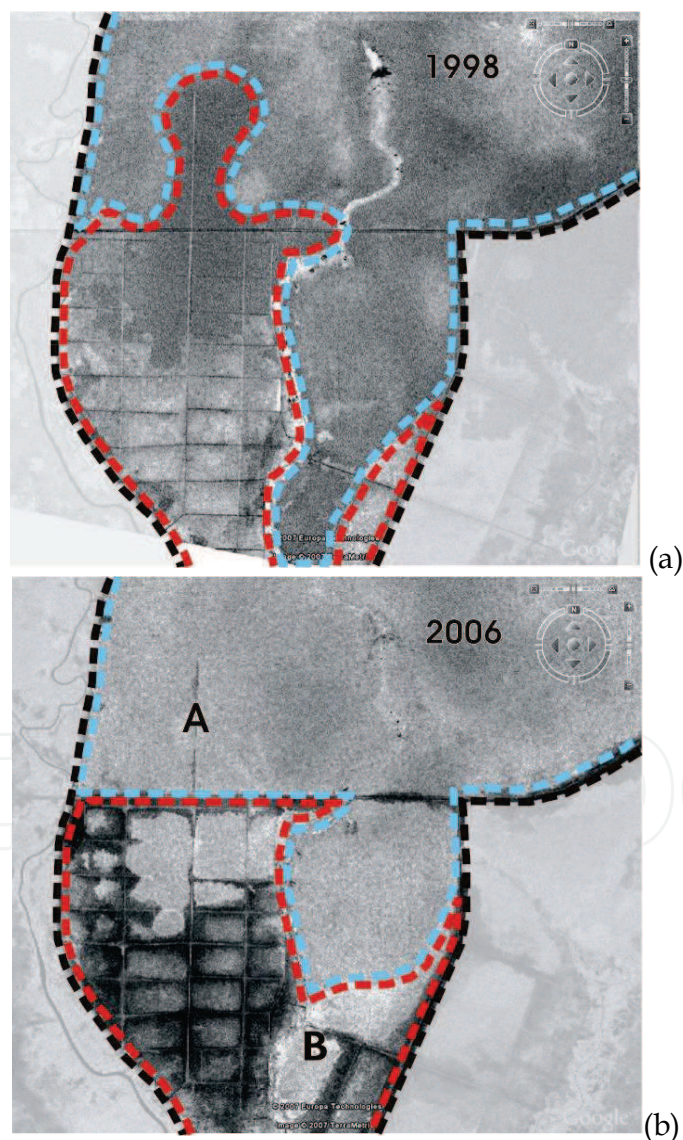


Fig. 11. Peat swamp degradation (B) and restoration (A) in the Mawas area between 1998 (JERS-1) (a) and 2006 (PALSAR) (b). The red area is degraded; the blue area is intact or regenerating. Courtesy: ALOS K&C © JAXA/METI.

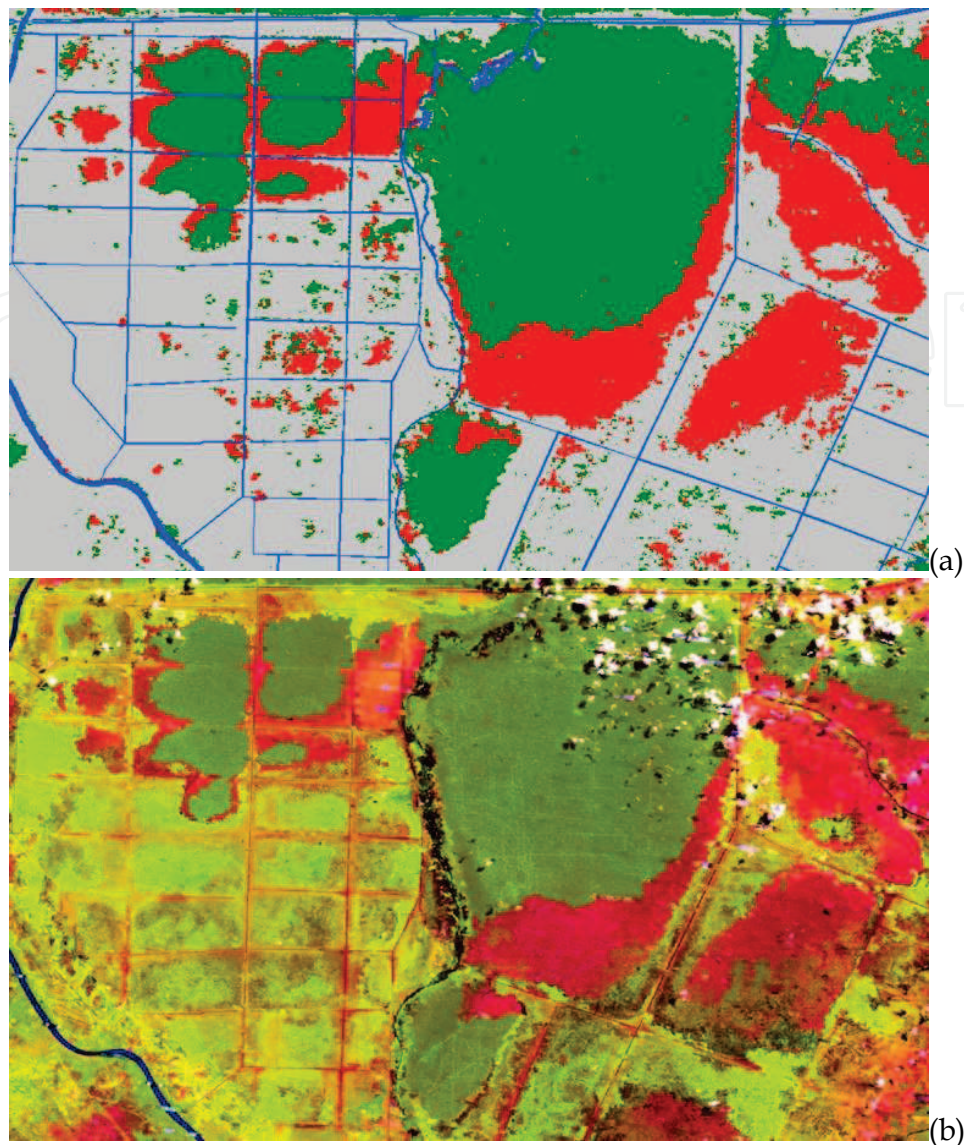


Fig. 12. Forest loss south of Mawas during the 2006 moderate El Niño period. (a) ENVISAT ASAR deforestation map (Forest: green; Burnt forest: red); (b) Landsat ETM+ image of 4 July 2007 (RGB: bands 5-4-3). The correspondence between both images is striking. The burnt forest areas mapped by ASAR directly after the fires (September 2006) are also observed in the first available Landsat image acquired 10 months later.

7. Flood frequency map Central Kalimantan

To support peatland restoration efforts knowledge on hydrological dynamics are imperative. The PALSAR ScanSAR mode provides a unique capability to assess these dynamics. As explained before (Section 2) the effect of flooding on the radar image intensity depends on the amount of vegetation and the height of vegetation. This is exemplified in Figure 13 where the temporal signature of HH-polarisation backscatter is plotted for the nine observations made in the period November 2006 until December 2007, as listed in Table 2. Terrain with moderate but high vegetation cover shows a strong increase in backscatter because of flooding. Terrain with low vegetation shows a decrease in backscatter because of

flooding. Mangrove, mixed peat swamp forest and pole peat swamp forest show a moderate increase during the wet season. Therefore, it is necessary to make a classification of the area first (this can be done with PALSAR) before thresholding the backscatter intensities (per class) to determine the incidences of flooding. Figure 14 shows a mapping result of the flood frequency or flood duration.

11-Nov-2006	29-Mar-2007	29-Sep-2007
27-Dec-2006	14-May-2007	14-Nov-2007
11-Feb-2007	14-Aug-2007	30-Dec-2007

Table 2. ALOS PALSAR ScanSAR HH (WB1) input data of nine consecutive (46 day) cycles used for the production of the Central-Kalimantan flood frequency map.

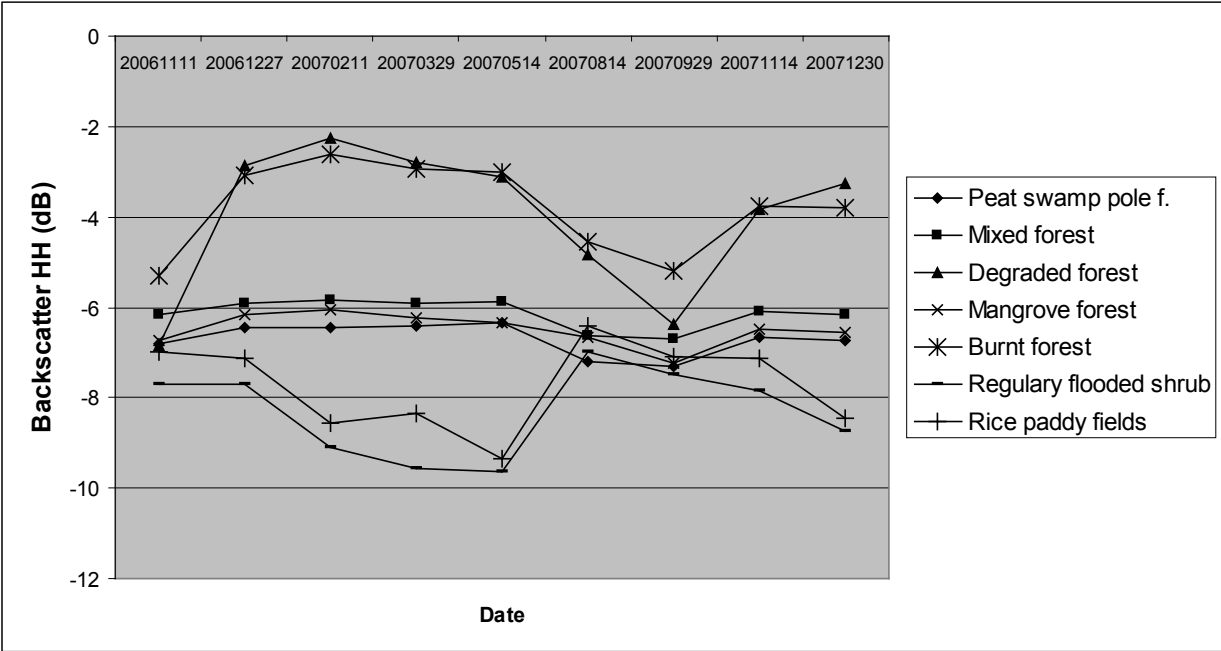


Fig. 13. Temporal signatures of L-band HH-polarisation backscatter for several key vegetation types. The first observation is made at the end of the dry season, at 11 November 2006. During the next wet season terrain with moderate but high vegetation cover shows a strong increase in backscatter because of flooding. Terrain with low vegetation shows a decrease in backscatter because of flooding. Mangrove, mixed peat swamp forest and pole peat swamp forest show a moderate increase during the wet season. Also the return to dry conditions during the 2007 dry season is well visible. PALSAR ScanSAR, period November 2006 until December 2007.

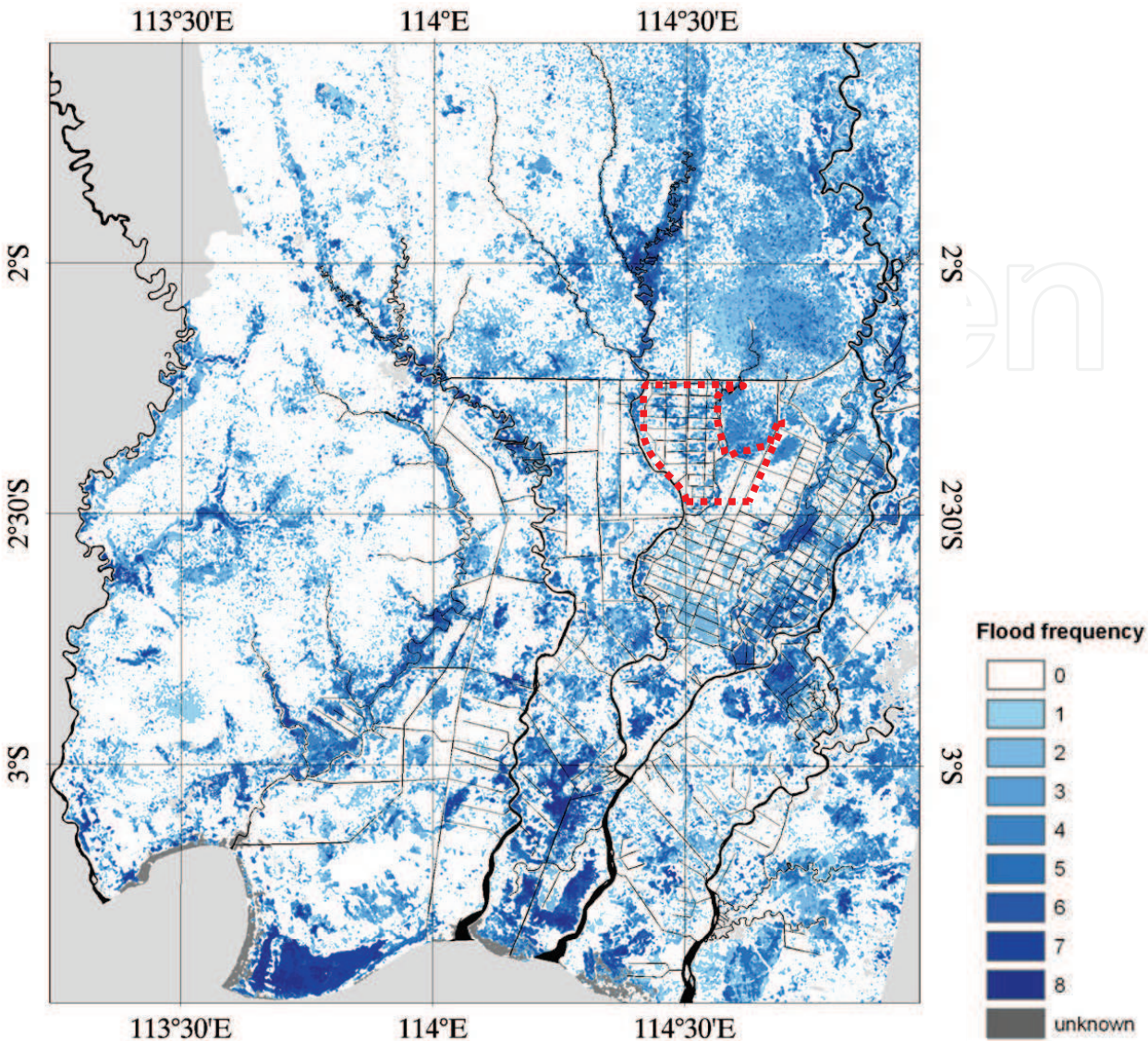


Fig. 14. Map of flooding frequency in 2007 for the Ex-Mega Rice Project (EMRP) area and Sebangau National park in Central Kalimantan based on nine PALSAR WB1 HH images. For ease of reference the degraded area indicated in Figure 11 is demarcated with red dots. PALSAR data courtesy: ALOS K&C © JAXA/METI.

8. Discussion

Many of the tropical peat swamp forests in Borneo and Sumatra are seriously threatened by (illegal and legal) logging and conversion to plantations for the oil palm and pulp and paper industries. In all cases the hydrology is affected by excess drainage, leading to destruction of remaining forests, notably in dry years. Beyond a certain point the hydrological integrity of ombrogenous areas is lost, leading to an irreversible process of total destruction and the combustion and oxidation of the remaining thick peat layers. Unless rigorous measures are taken very soon, this most likely will lead to major negative effects on biodiversity and global climate.

More information is needed to support protection and restoration efforts. The availability of better vegetation and peat depth maps may be very useful. However, the most crucial factors may appear to be the knowledge on the hydrological functioning and the relationships between hydrological and ecological characteristics. These latter points are still poorly understood. Radar, unimpeded by cloud cover, can provide continuous observations which can be related to hydrological characteristics, may become a key instrument in future protection and restoration efforts. Exploitation of PALSAR time series collected by the ALOS satellite may provide important support for peat land management, protection and restoration, such as described in the Ramsar "Guidelines for Global Action on Peatlands (GGAP, 2002)". Moreover, it may significantly support other international treaties, such as the CBD and the Kyoto Protocol, a possible post-Kyoto protocol, and carbon cycle science.

The methodology may eventually be applied on a large scale using systematic observations of PALSAR and ENVISAT, and its successors PALSAR-2 and SENTINEL-1. The latter two instruments may be available from 2013 onwards, providing continuity of L- and C-band radar observation. PALSAR-2 ScanSAR observations will be even powerful because it uses dual polarisation, providing HV-polarisation in addition, which is important to improve assessment of biomass level dynamics and deforestation. SENTINEL-1 is a major improvement over ENVISAT ASAR because it allows a 4 times higher temporal observation, i.e. (illegal) deforestation may be reported every 8 days, instead of the current 35 days.

PALSAR radar proved particularly useful for improving information related to flooded cover types and biomass levels. ASAR deforestation maps provide at least as much accuracy and detail as the best available maps based on visual interpretation of Landsat imagery, however, provide this information near real time. Many of the results shown in this chapter are operationally used by local governmental and non-governmental agencies for spatial planning of sustainable peatland management strategies.

9. Acknowledgments

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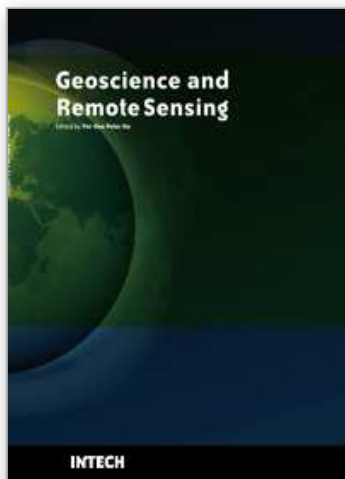
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Remote Sensing is collecting and interpreting information on targets without being in physical contact with the objects. Aircraft, satellites ...etc are the major platforms for remote sensing observations. Unlike electrical, magnetic and gravity surveys that measure force fields, remote sensing technology is commonly referred to methods that employ electromagnetic energy as radio waves, light and heat as the means of detecting and measuring target characteristics. Geoscience is a study of nature world from the core of the earth, to the depths of oceans and to the outer space. This branch of study can help mitigate volcanic eruptions, floods, landslides ... etc terrible human life disaster and help develop ground water, mineral ores, fossil fuels and construction materials. Also, it studies physical, chemical reactions to understand the distribution of the nature resources. Therefore, the geoscience encompass earth, atmospheric, oceanography, pedology, petrology, mineralogy, hydrology and geology. This book covers latest and futuristic developments in remote sensing novel theory and applications by numerous scholars, researchers and experts. It is organized into 26 excellent chapters which include optical and infrared modeling, microwave scattering propagation, forests and vegetation, soils, ocean temperature, geographic information , object classification, data mining, image processing, passive optical sensor, multispectral and hyperspectral sensing, lidar, radiometer instruments, calibration, active microwave and SAR processing. Last but not the least, this book presented chapters that highlight frontier works in remote sensing information processing. I am very pleased to have leaders in the field to prepare and contribute their most current research and development work. Although no attempt is made to cover every topic in remote sensing and geoscience, these entire 26 remote sensing technology chapters shall give readers a good insight. All topics listed are equal important and significant.

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