RETRIEVAL OF ENVIRONMENTAL FOREST PARAMETERS USING THE POLARIMETRIC PALSAR

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1. INTRODUCTION

Earth observation data are required to support the activities of communities interested in the state of forest cover, carbon modeling and forest cover change. Earth observation has so-far failed to provide a realistic alternative to the labor-intensive methods by which the environmental or commercial value of this natural resource is assessed. In reality, both communities have approximately the same requirements: cost-effective and repeatable estimates of basic forest biophysical parameters such as timber volume. Forests are complex targets and it might be expected that only multi-band or multi-polarization data should be able to decouple the effects of variations in such characteristics as timber volume, tree density and species distribution. Furthermore, the impacts of soil and vegetation moisture need to be understood to decouple the signal and enable improved retrievals of forest parameters.

2. AIMS AND OBJECTIVES

By utilizing the dual polarized data, we aim to understand the potential for retrieval of forest properties of repeat-pass ALOS PALSAR L-band SAR data. The retrieval is supported with field data and other secondary information. Recently developed tools and techniques are also becoming available to process and interpret the nature of polarized scattering at L-band. Techniques will be developed that utilize this extra information content for the estimation of useful biophysical parameters from forests. This proposal has the following objectives:

1) Analyze the temporal variations in the dual polarization signal over a four-year period of a tropical peat swamp forest in Indonesia.

2) Plot relationships between polarimetric scattering intensity and coherence with physical attributes of forests (biomass, tree height, stocking volume etc.) to try and improve estimates of these parameters.

3. DEVIATION FROM ORIGINAL PROPOSAL

The intention of the original proposal was to investigate the ALOS PALSAR signal over a number of different forested ecosystems (boreal, temperate and tropical). Due to staffing changes and funding issues, the project eventually settled on making investigations of the signal over two regions of tropical peat swamp forest in Indonesia, located in C. Kalimantan and Sumatra. Although data for the Thetford (temperate) and Siberia (boreal) were requested, ordered and downloaded from JAXA, these data remain unused (they will be used to teaching). Once an appointment was made to a PhD position to work on the ALOS PALSAR data in Indonesia in 2008, this became the focus of the work and further orders for data orders were made in this region. The PhD student is now in the final year of their research and a significant component of their work includes the use of ALOS PALSAR. It is expected that a number of peer-reviewed publications will be made towards the end of 2011 that refer to results derived from PALSAR data. Acknowledgements will be made to JAXA.

4. LITERATURE REVIEW

Calculating the amount of carbon stored in a forest requires knowledge of the area covered by a forest and the amount of carbon contained per unit area. The latter value is usually calculated from sampling biomass in plots from which average wood volume per unit area is calculated using allometric equations. Wood volume (m^3) is then multiplied by the oven dried wood density ($g\ m^{-3}$) to give dry biomass (g) and finally this is multiplied by the carbon content of wood (typically ~0.5). There is a concerted effort to catalogue some of these variables, particularly carbon content and wood density which is species specific (see UNFCCC AFOLU good practice guidelines). Hence the values that are most often need to be measured in the field are forest area and forest volume.

The FAO has collected forest resource assessments since 1948. However the accuracy of these statistics have been called into doubt due to problems of declining data quality and changes in methodology. Hence recent estimates of forest cover have most often been performed using remote sensing techniques. Estimates of the area covered by tropical forests range from 1116*106 ha [1] to 1768*106 ha [2].

Estimates of the carbon content of tropical forests are beset with difficulties because of the problems of measuring forest area and estimating carbon content over large areas. No current remote sensing system can produce direct measures of forest biomass so estimates of forest area must be combined with work done at a much smaller scale in experimental plots to produce estimates of carbon content. There is currently a very poor understanding of the factors controlling the variation in biomass across large areas such as the Amazon River basin. Different estimates often provide estimates that are diametrically opposite in their description of biomass spatialisation [3]. This is further complicated when measures of dead (litter) biomass and below ground biomass (roots) are included. These are usually calculated as additional percentages of the live woody biomass, but such blanket estimates are often overly simplistic. Soils also contain carbon but are only occasionally included in estimates of tropical forest carbon content. Values given for the carbon content of the Amazonian rainforest vary from 39-93 Pg [3], 86 +/-20 Pg ([4] both including estimates of below ground and dead biomass) to 93+/-23 Pg excluding roots and dead biomass for [5].

The majority of global peatlands (90% by area) are found in the boreal zone where they are maintained by low temperatures as well as waterlogged soils. However peatlands also occur in poorly drained areas of the tropics where they are maintained purely by water logging. Seventy per cent of tropical peatlands occur in SE Asia mainly in Malaysia, Indonesia and Papua New Guinea where they support a forest type called peat swamp forest (the remaining 30% of tropical peatlands are scattered through Africa, Central & South America). Peat swamp forests function in largely the same way as other types of forest with the exception that instead of decaying, the dead plant material remains intact due to the anaerobic conditions within the high water table of the swamp. Peatlands can build up into large and, if left intact, stable stocks of carbon, with maximum recorded peat thickness in SE Asia of up to 20m [6], much thicker than boreal peatlands. Estimating the total area and amount of carbon stored in tropical peatlands is difficult as peat thickness requires intensive ground survey, though a conservative estimate of 55 Gt is give by [7] with a relatively large uncertainty of +/- 10 Gt. A larger value of 65.2Gt (or 15-20% of the global peat carbon pool) is estimated making tropical peatlands a globally significant pool of carbon.

Peat swamp forest also provide benefits other than carbon storage such as water storage and regulation and biodiversity, being both a refuge for endangered species such as the Orangutan and many other species endemic to peat swamp forests. However, peat swamp forests are threatened by selective logging, clearing for plantations (mainly of Elaeis guineensis for palm oil and Acacia sp. for wood pulp) and drainage for agriculture. These threats, particularly drainage, lower the peatland water table leading to oxidation of the peat [8] and an increased risk of fire. Both of these processes result in the release of CO2 into the atmosphere from tropical peatland. Fires in particular lead to a rapid loss of forest cover, accumulation of dead wood and an increased likelihood of further fires [6].

Prior to the 1960s, although there had been large scale degradation of peatlands in peninsular Malaysia due to plantations associated with the colonial period, the insular peatlands in Borneo and Sumatra had remained relatively untouched, largely due to the agricultural practices of the indigenous populations which were confined mainly to alluvial soils along river channels. Undisturbed forests are resistant to degradation and disturbance by fire occurs only very rarely. However policies of transmigration of human populations by the Indonesian government resulted in a large scale loss of forest cover in Kalimantan with significant fire events starting to occur in the 1980s [9]. Degraded peatlands are vulnerable to fire particularly in years of below average rainfall associated with ENSO variations [10] when the level of water tables become greatly reduced. A strongly non-linear relationship between burnt area and the length of the dry season in degraded peatlands has been shown by [11] in Kalimantan with fires occurring further away from drainage canals in drier years. This was further exacerbated during the 1990s when the Mega Rice Project (MRP) was begun in Central Kalimantan and drainage canals were constructed over an area of 1,000,000 ha. Fires during the 1997 El Nino year have been estimated to have released 0.81-2.75 Gt of C from the peat to the atmosphere equaling 13-40% of fossil fuel emissions in the same year [12]. Major fires also cause thick smoke haze which affects the health of local populations and lowers surrounding sea surface temperatures by intercepting solar radiation [13]. Because tropical peatlands represent such a large pool of carbon their continuing degradation represents a significant input into the increasing levels of atmospheric CO_2. Of course forests even in an apparent steady state are only in a dynamic equilibrium between photosynthesis and respiration, growth and decay. Anthropogenic disturbances to this balance have caused forests to act as both large sinks and sources of CO_2 to the atmosphere.

The majority of studies of tropical data have been performed at a decadal scale using optical satellites ([1]; [14]). However optical systems are of limited use for more frequent monitoring of the tropical forests (as is required for REDD) as they are frequently obscured by persistent cloud cover and smoke haze. Hence it is necessary to wait for an occasional cloud free scene or to composite multiple images together to produce useful data. Despite these limitations most of the current literature concerning the implementation of REDD suggests the use of optical systems (e.g. IFCA methodology, [15]) for monitoring purposes. Another current limitation is that the highest resolution freely available satellite imagery (from Landsat 7) is currently degraded by the failure of its scan line corrector.

Detecting the degradation of forests using remote sensing is challenging due to the scale at which it occurs [16]. It has been estimated that including estimates of selective logging doubles the amount of forest estimated to be affected by human activity. Remote sensing studies of forest degradation are few and use either very high (e.g. IKNONOS, [17]) or heavily processed medium resolution optical sensors (e.g. Landsat [18]; [19]). Applying such measures on a catchment wide scale would be extremely computer intensive.

Active microwave remote sensing (also known as radar) is not hampered by cloud cover since water vapor does not absorb the frequencies used. Being an active system it is also able to gather information both day and night and is not complicated by differences in illumination angle that can complicate multi-date optical imaging. Radar energy also penetrates into forest canopies rather simply reflecting, with longer wavelengths penetrating furthest. This allows radar remote sensing to measure structural variables of forests. For example, radar remote sensing has been shown to correlate well with forest volume in Siberia ([20], >80m3/ha using a dual sensor technique), with forest cover [21] and with canopy height ([22], again using a dual sensor technique). However detecting the biomass of tropical forests directly is made difficult by the tendency of the radar returns to saturate at relatively low biomass levels compared to mature forest [23]. Civilian space borne applications of radar remote sensing are still at a relatively early stage and yet to become widely utilized outside of specialist remote sensing. However the potential for obtaining regular mapping of both forest area and structure makes it an area of growing interest for forest conservation.

The ALOS (Advance Land Observation Satellite) was launched in 2006 by the Japanese space agency (JAXA). It carries a Phased Array L-band Synthetic Aperture Radar (PALSAR) instrument which is the longest wavelength space borne radar instrument currently operational.

4. STUDY AREA AND DATA USED

The focus of the research are the tropical peat swamp forests in Indonesia (Sumatra and Kalimantan). The Leicester team has conducted field work in the region. The region is of great interest to the international community because of the huge amounts of Carbon locked into the peat soil and above ground biomass. Furthermore, there are a number of REDD projects in the region as well as plantations of oil palm. In addition, there is a wealth of field data including high resolution digital aerial photography (Sumatra), information about forest biomass, height, biodiversity and density (Sumatra and Kalimantan) and also data on water table depth, soil characteristics and disturbance maps. Figure 1 shows the study area in Sumatra and Figure 2 shows the study area in Kalimantan. The Kalimantan field site is especially important as it is an area that is under regular disturbance from fire and drainage. In 2010, a full re-processing of the data already in our possession was granted following the discovery of the problem with the raw data processing being undertaken at JAXA that resulted in offsets being visible in the data between successive along track images. We are grateful to JAXA for undertaking this re-processing step.

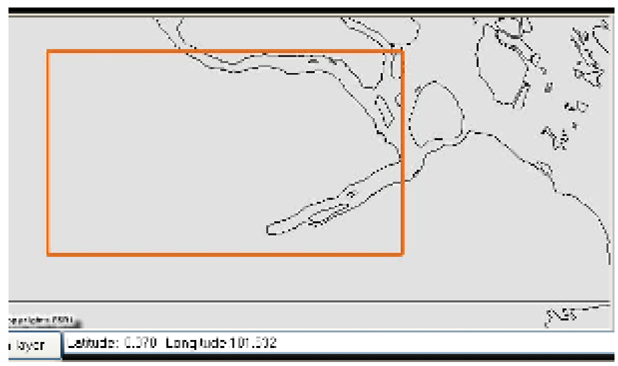


Fig. 1 The test site in Sumatra (Kampar Peninsula)

Fig. 2 The test site in Central Kalimantan (Block C)

The following data sets have been used in this study.

Table 1. PALSAR data ordered for the Kampar Peninsula (date format is yyyymmdd)

Kalimantan		**Kampar**	
Track	Date	Track	Date
421	20070622	442/489	20070727
2 scenes	20070807	2 scenes	20070911
	20070922		20080729
	20080509		20080913
	20080809		20090616
	20080924		20090801
	20090627		20090916
	20090812		20100619
	20100630		20100804
	20100815		20100919
	20100930		
	20101115	443/488	20070628
		3 scenes	20080630
422	20070709		20080815
3 Scenes	20070824		20090703
	20071009		20100706
	20080526		20100821
	20080711		20101006
	20080826		20101121
	20081011		
	20090714	443_7190	20071113
	20090829	1 scene	20071229
	20091014		20080930
	20100717		20090818
	20100901		20091003
	20101017		20071113
	20101202		20071229
423	20070610		
3 scenes	20070726		
	20090910		
	20080427		
	20080612		
	20080728		
	20080912		
	20090615		
	20090731		
	20090915		
	20100618		
	20100803		
	20100918		
	20101103		

The collection of in situ data on forest condition is essential in order to know what is represented in remotely sensed images. As detailed in the previous section forest assessment methodologies require information on the areas of forest being affected by degradation, but also the intensity of degradation. As remotely sensed images are easily georeferenced area is easily measured. Therefore the information which needs to be collected during ground surveys mainly concerns the intensity of degradation, or the change in the amount of biomass following a degradation event. Since degradation events are unpredictable both spatially and temporally we must content ourselves with measuring biomass in areas with different degradation histories. Areas with different histories can be identified from pre-existing data but also can also be approximated from field visits. Once we have selected areas describing a range of scenarios we can begin to sample the biomass in each of these areas.

The basic plots are 1ha in size (100*100m). This has been chosen so that when each plot is identified on a remotely sensed image it will contain >5 pixels of a medium resolution satellite (e.g. Landsat, ALOS PALSAR, etc) image once edge effects have been removed. Plots are laid out using an initial GPS waypoint and then a distance of 100m (as measured on the GPS) will be walked on a constant compass bearing before the next corner is marked as a waypoint. The next bearing is then walked at 90 degrees to the original. Plots do not need to be permanently marked as they will not be used to measure changes through time (e.g. growth), but are intended to 'give a snapshot' of biomass.

In order to measure biomass the 1ha plots are hypothetically divided into 25 20m2 subsampling plots each identified by a pair of co-ordinates. Plots are subsampled sequentially according to a pre-prepared list of random co-ordinates which are located using the GPS. Once located the plots are laid out with the aid of a compass and delineated using 40m measurement tapes. The diameter of all living trees (i.e. displaying green leaves) >1.5m in height is measured at a height of 1.2m (dbh) using a tape measure. The height of tree is also measured using a 2m graduated height pole if under 4m or using an angle device and the distance from the base of the tree. In forests with high numbers of trees where this would be excessively time consuming tree height is classified as belonging to one of three categories (emergent, canopy and sub canopy; tropical forests are noted for this stratification). Average heights for these layers are then measured for each subsampled plot. The current number of sub sampled plots in each 1ha plot is currently three. Plot data will be used to calculate biomass using allometric equations, stem density and basal area per hectare.

4. RESULTS

Multi-temporal observations of the Kalimantan study area is shown in Figure 3. The RGB combination is R=2009, G=2008 and B=2007 with HH intensity. The colors in the image demonstrate the changes that have occurred in the region mainly as a result of fire. Care has to be taken not to mistake change as a result of flooding.

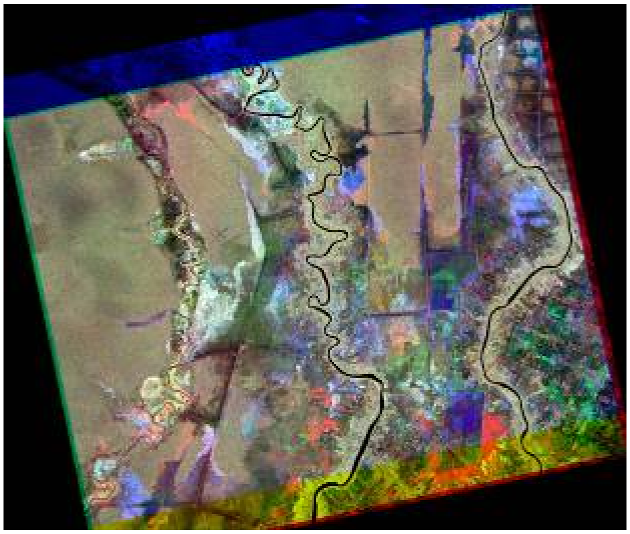


Fig. 3 The Kalimantan study area shown as RGB 2009, 2008 and 2007 HH intensity

The use of coherence and the HV polarized intensity as a source of information allowed us to understand the land cover in more details as shown in Figure 4. In this figure, located in the Kalimantan study area, areas of high coherence (shown in red) can be clearly seen against the green of intact tropical forest. The dark areas indicate regions of flooding. The PALSAR image is compared against a Landsat TM image.

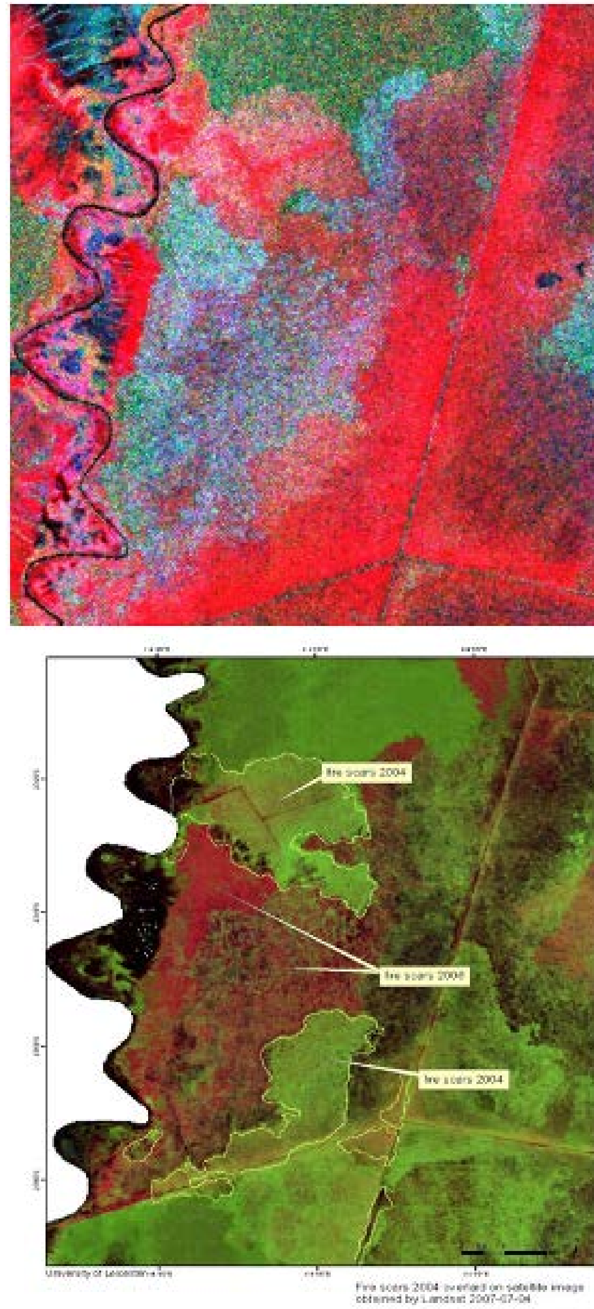


Fig. 4 ALOS PALSAR imagery (top) covering a region of C. Kalimantan, Indonesia. RGB = coherence, HV pol., HH pol. compared to a Landsat TM image with interpretations (bottom)

In fact it appears as if the coherence derived from the 440-day repeat pass interferometry shows great sensitivity to disturbed forest of varying degrees. This is shown in Figure 5 for the Kalimantan study area.

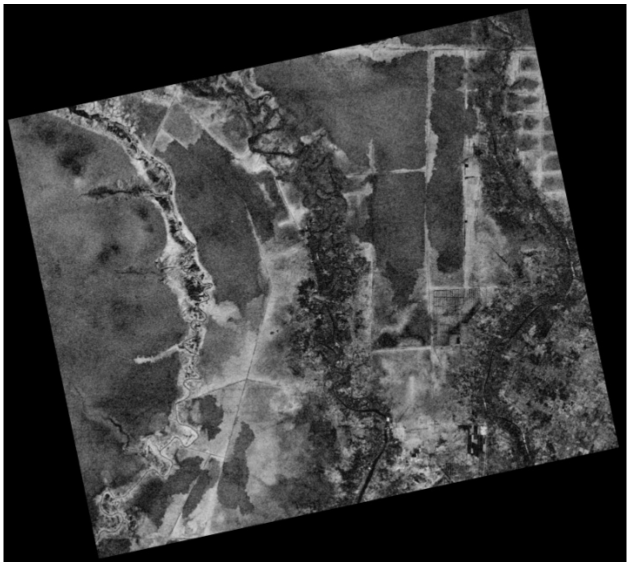


Fig. 5 ALOS PALSAR coherence image covering a region of C. Kalimantan, Indonesia. The values range from around 0.1 and 0.8 (upper)

The data were also regressed against field data. 2355 trees were sampled in 17 plots across a gradient from intact forest to completely degraded forest in July and August 2009 (Figure 6).

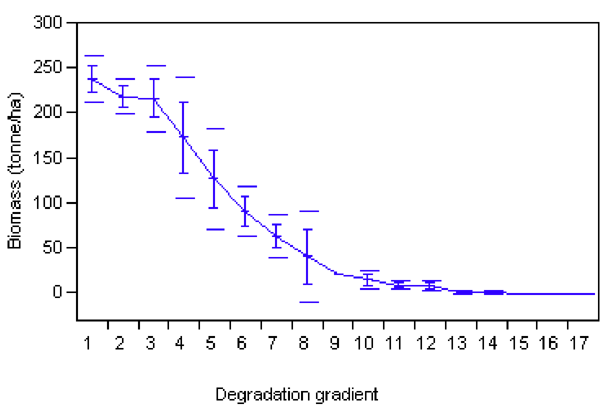
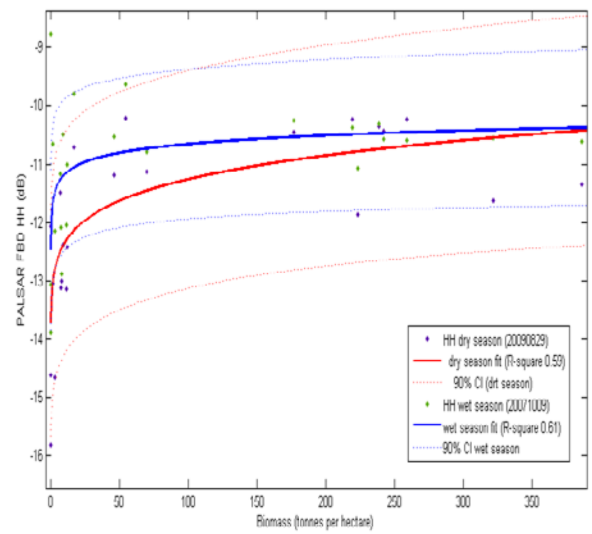


Fig. 6 Biomass in metric tones per hectare measured across a gradient of degradation from intact forest on the left to completely degraded areas on the right. Means and standard deviation is given by the connected bars and one standard error is given

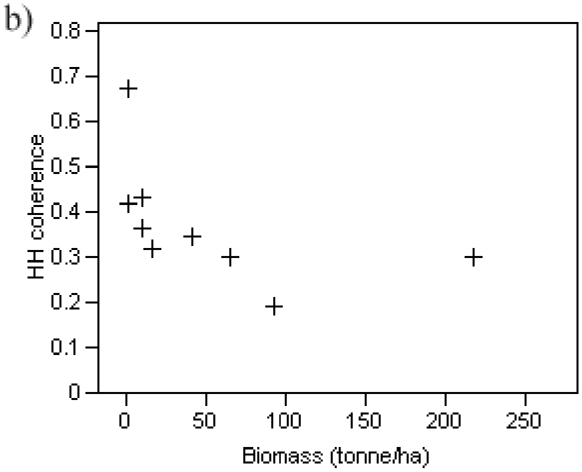
Plots were located with aid of a hand held GPS. Mean sub-sampled biomass in each 1 hectare plot is shown in Figure 6. Note the increasing heterogeneity of biomass in the middle of the curve, areas that are partially degraded and undergoing regrowth. The backscattered radar intensity of the biomass was measured using georeferenced ALOS PLASAR FBD images. Backscatter was calculated using both HH and HV modes. 46 days coherence was also calculated.

Figure 7 plots an average for each radar measure against an average of the pixels contained within each biomass plot. The best correlations between radar and biomass are for the HV backscatter and the HH coherence, but both of these relationships appear to saturate as biomass approaches 100 tonnes per hectare. However this analysis can be further improved in the following was: by the inclusion of further high biomass sites (already sampled) on a separate image tile and by using a PALSAR image concurrent wit the time of sampling (the image used to produce the above graphs was acquired 6 months before field sampling took place; concurrent images have now been obtained).

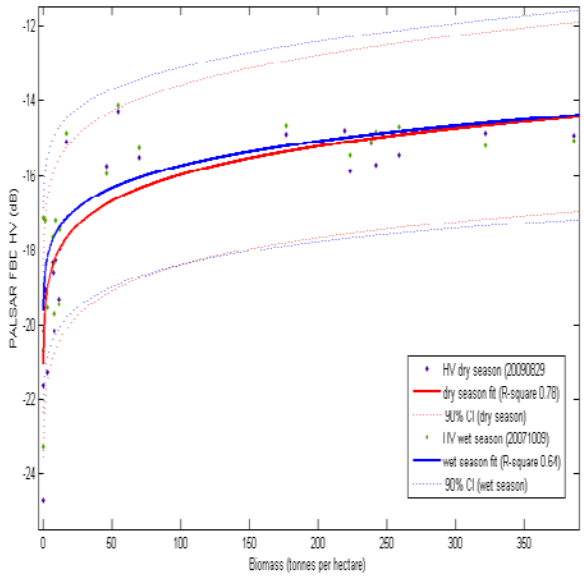
a)



b)



c)



d)

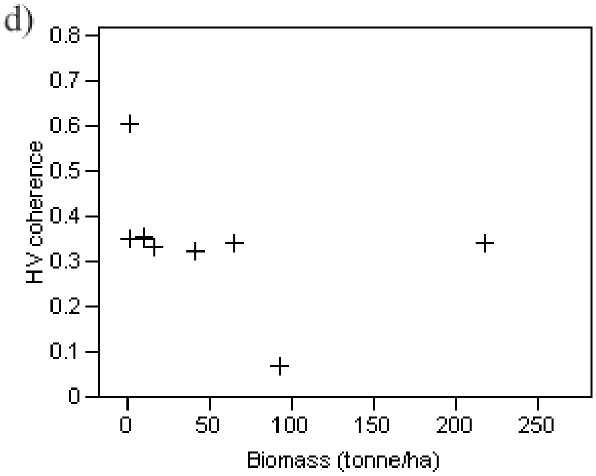


Fig. 7 Mean ALOS PALSAR backscatter in HH and HV polarizations (a & c) and 46 days coherence (b & d)

As can be seen from the plots, the relationships between biomass and SAR derived parameters are encouraging. Further work is currently being undertaken to increase the number of samples and the understand the influence of soil moisture and water table depth on the SAR signal.

For the Kampar region, a comparison with a land cover classification product derived from a SPOT 5 image was made. From this classification, mean intensity (backscatter coefficient) and coherence estimates were derived. The classification segmentation from the SPOT image is shown in Figure 8. The results of the comparison with radar parameters with each class are shown in Table 2.

Table 2. Mean coherence and intensity values computed for each class type (derived from a segmentation-based classification of a SPOT 5 image)

Class	Range of coherence (HH)	Mean coherence (HH)	STD coherence (HH)	Mean int. HH	Mean int. HV
plantation	0.73	0.09	0.12	-12.3	-20.2
medium degraded	0.77	0.11	0.12	-11.7	-19.8
water	0.68	0.08	0.12	-14.7	-24.0
heavily degraded	0.67	0.11	0.09	-11.3	-18.9
open green area	0.47	0.10	0.08	-10.7	-18.6
open bare ground	0.46	0.11	0.09	-11.0	-18.8
tall forest	0.60	0.14	0.11	-11.5	-19.0
low forest (type 1)	0.57	0.26	0.10	-11.1	-18.8
lightly degraded	0.39	0.14	0.09	-10.4	-17.9
Flooded forest	0.39	0.03	0.07	-16.6	-24.0
low forest (type 2)	0.54	0.34	0.07	-11.3	-19.1

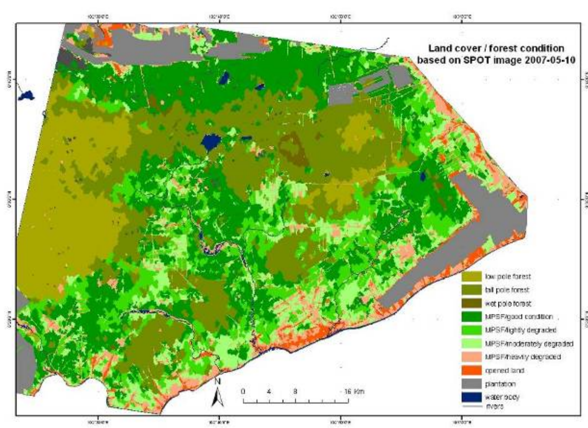


Fig. 8 Kampar classification map derived from SPOT 5 data

The results show that there are no strong relationships between land cover types and mean coherence and intensity values. Furthermore, the range of coherence values are considerable suggesting that there may be some differences in the information carried by the same class. More work is needed in relating the information derived from optical data and that carried in radar imagery.

However, the information displayed in a false colour composite of HH coherence (red), HV intensity (green) and HH intensity (blue) clearly shows the development of forested areas for oil palm and paper pulp plantations. Although the signature of the mature phase of these plantations resemble natural forest the outlines of the zones can clearly be seen. This is shown in Figure 9.

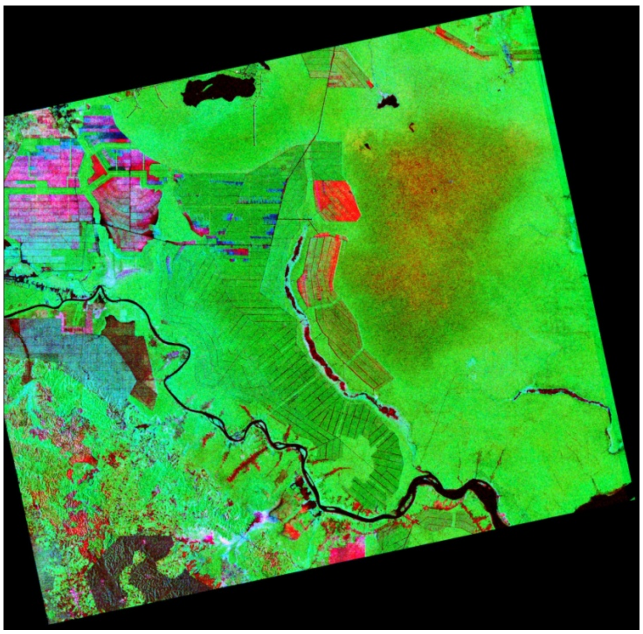


Fig. 9 ALOS PALSAR imagery covering a region of Kampar Peninsula, Sumatra, Indonesia. RGB = HH coherence, HV pol., HH pol.

Of particular interest is the dome of the peat swamp forest that is displaying higher values of HH coherence than surrounding tropical forests. Figure 10, shown in the same false color combination as Figure 9 shows a zoom in of this region. Without knowing that this is a natural feature that results in forest cover of lower biomass, there may be mis-interpretations of the reason why the biomass is lower (forest deforestation/degradation).

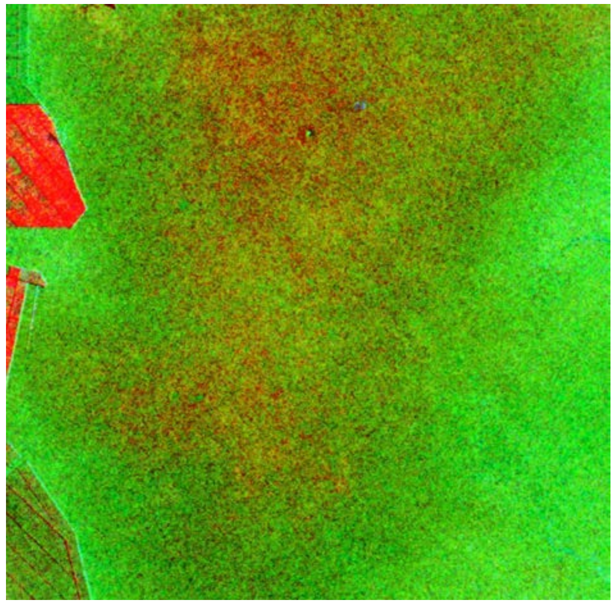


Fig. 10 ALOS PALSAR imagery covering a region of Kampar Peninsula, Sumatra, Indonesia. RGB = HH coherence, HV pol., HH pol. The top of the peat swamp forest dome is shown. This results in lower biomass, resulting in higher coherence values

One of the implications of the natural peat swamp forest having similar backscatter values to mature plantations is that they both will be classified as forest in any unsupervised or validated land cover mapping exercise. Such a product at 10m resolution was developed and disseminated by JAXA (Figure 11). The authors urge caution with the use of this product and advise that various disclaimers are distributed with the product. The alternative is to be very strict with the definition of forest.

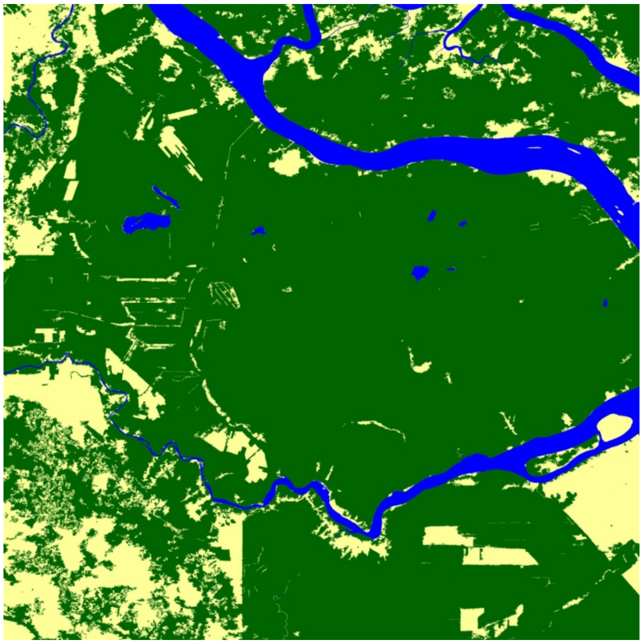


Fig. 11 JAXA 10m forest cover products of the Kampar Peninsula showing forest and non-forest cover

6. DISSEMINATION PLANS

The work was presented at the joint JAXA-ESA ALOS meeting in Rhodes, Greece in November 2008. In addition every effort will be undertaken to publish the results in peer-review journals.

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