THE USE OF POLARIZED L-BAND ALOS PALSAR FOR IDENTIFYING FOREST COVER IN PENINSULAR MALAYSIA

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ABSTRACT: Currently there are about 5.89 million ha of forest occur in Peninsular Malaysia, which covers about 44.7% of its land area. Out of this, 4.92 million ha falls under Permanent Reserved Forest (PRF), 0.58 million ha is Totally Protected Area (TPA) and the remaining 0.39 million ha belongs to state/alienated land. These figures are officially used by the Forestry Department Peninsular Malaysia (FDPM) in its reports. These official figures are derived from several mapping techniques from several responsible departments in Peninsular Malaysia for management and reporting purposes, which are sometimes not representing the forest cover on the ground at real state. Information on the distribution of these forests is critical for decision-making and significant in climate stabilization, biodiversity conservation and social-related issues. The majority of tropical nations need high-resolution, satellite-based maps of their forests managing and maintaining their forests intact and therefore addressing their forests accordingly. This study was conducted to identify the extents of forests in Peninsular Malaysia, which comprise mainly inland dipterocarp, peat swamp and mangroves. Advanced Land Observing Satellite (ALOS) featuring the Phased Array L-Band Synthetic Aperture Radar (PALSAR) was used for this purpose. Fine Beam Dual mosaic of PALSAR images that has spatial resolution of 25 m was acquired in year 2010 and was provided by the Japan Aerospace Exploration Agency (JAXA) through Kyoto and Carbon (K&C) Initiatives. A combination of texture measure and polarizations manipulation of dual polarizations, HH and HV from PALSAR was applied to the images. Object-based classification or segmentation method was adapted to classify forest cover in the study area. The ability of PALSAR to support large area of tropical forest cover was assessed. The strong performance achieved indicates that the L-band dual polarization from PALSAR has greatly improved forest identification and classification. The result also indicated that the use of texture measure on dual-polarization were able to average out random speckle noise, and the use of ratio instead of absolute quantities, due to its well known ability to reduce forest structural and terrain effects.

INTRODUCTION

Tropical forests are among the most biomass and carbon rich but are the most structurally complex ecosystems in the world. For a systematic observation at different scales, radar remote sensing is considered as a major component of forest monitoring programmes (Lu 2006). Researches indicate that Synthetic Aperture Radars (SAR) has a significant role to play in forest observations (Khali 1997; Austin et al. 2003; Toan et al. 2001; 2004; Quinones and Hoekman 2004; Chenli et al. 2005; Chen et al. 2009).

Satellite SAR data have been continuously available since 1991, provided by ERS-1 and ERS-2, JERS, RADARSAT-1 & -2, and ENVISAT can ensure operational data provision well into this modern forest management and conservation activities (Sgrenzaroli et al. 2004). However, as far the forest is concerned, the extents and distribution of forest cover over the earth's surface remains one of the major uncertainties that are continuously being studied (Gullison et al. 2007). Phased array type L-band SAR (PALSAR) on board the Japanese Advanced Land Observing Satellite (ALOS) (2006 – 2011) has been identified as an appropriate sensor system in assessing forest cover as well as biomass contents in tropical ecosystem (Baccini et al. 2008; Hamdan et al. 2011; Cartusa et al. 2012; Petrokofsky et al. 2012). For this reason, this study is therefore conducted to assess the ability of PALSAR imagery for forest cover classification.

The interest in radar remote sensing for monitoring forest cover raise from the two advantages of SAR data, which are; (i) radar can provide information related to the canopy volume, which cannot be produced by other means, and (ii) radar has possibility to acquire data over areas frequently with free cloud cover and free-weather conditions. The information that can be derived from SAR data have been identified as (Shi et al. 2012): forest and other landuse cover, aboveground biomass, annual increment of stand biomass, vertical distribution of biomass and forest stand volume.

In Malaysia, forest is defined as land spanning more than 0.5 ha with trees higher than 5 m and a canopy cover of more than 10 %, or trees able to reach these thresholds *in situ*. It does not include land that is predominantly under agricultural or urban land use (FRA 2010). Major forest types in Malaysia are lowland dipterocarp, hill dipterocarp, upper hill dipterocarp, montane, ericaceous, peat swamp and mangrove forests. In addition, there also smaller areas of freshwater swamp forest, heath forest, forest on limestone and forest on quartz ridges. Currently there are about 5.89 million ha of forest occur in Peninsular Malaysia, which covers about 44.7% of its land area. Out of this, 4.92 million ha falls under Permanent Reserved Forest (PRF), 0.58 million ha is Totally Protected Area (TPA) and the remaining 0.39 million ha belongs to state/alienated land. PRF can be further classified into four major types of forest which are inland, peat swamp, mangrove forests, and plantation forest which have extents of 4.39, 0.24, 0.10, and 0.19 million ha, respectively (FDPM, 2011). However, these official figures are used only for management and reporting purposes, which are sometimes not representing the forest cover on the ground at real state. Furthermore, there is no such map that shows spatially distributed map of forest cover (except PRF) over the Peninsular Malaysia. Defining the real forest cover as occur on the ground at national scale is remaining challenging despite many remote sensing data resources available.

In March 2011, Forest Research Institute Malaysia (FRIM) and Japan Aerospace Exploration Agency (JAXA) have set up a collaborative research under the ALOS Kyoto & Carbon (K&C) Initiative. It is originally an international collaborative project led by JAXA Earth Observation Research Center (EORC) since year 2006 and now already in Phase 3. The ALOS K&C Initiative is set out to support data and information needs raised by international environmental Conventions, Carbon Cycle Science and Conservation (CCCs) of the environment (Rosenqvist et al. 2007). The objective of the initiative is to define, develop and validate thematic products derived primarily from ALOS Phased array type L-band SAR (PALSAR) data that can be used to meet the specific information requirements relating to the CCCs. Relevant to the establishment of the K&C Initiative is the unique suitability of ALOS PALSAR to support acquisition of the type of regional-scale information needed, given the L-band SAR sensitivity to vegetation structure and inundation, and the microwave cloud-penetrating capacity to ensure global observations. The K&C Initiative aims to provide (i) systematic global observations and consistent data archives, and (ii) derived and verified thematic products. Being one of the objectives of this initiative, this study is conducted and the first step is to identify forest cover and update the global forest cover that was developed by using local information over Peninsular Malaysia.

MATERIALS AND METHODS

Satellite data

ALOS, an enhanced successor of the JERS-1, was launched from JAXA's Tanegashima Space Center in January 2006. It then stopped it mission in May 2011 after 5 years observing. ALOS operates from a sun-synchronous orbit at 691 km, with a 46-day recurrence cycle carrying a payload of three remote sensing instruments: (i) the Panchromatic Remote Sensing Instrument for Stereo Mapping (PRISM), (ii) the Advanced Visible and Near-Infrared Radiometer type 2 (AVNIR-2) and (iii) the polarimetric Phased Array L-band SAR (PALSAR). PALSAR image, which is one of the ALOS systems used in this study was acquired in year 2010. The image was supplied by the Remote Sensing Technology Center of Japan (RESTEC) - the designated Primary Distributor of ALOS satellite data – downloaded via file transfer protocol (FTP) server of RESTEC through permission as a research team member of the K&C Initiatives. This product was obtained in Level 1.5 format in HV and HH polarisations in Fine Beam Dual (FBD) mode having spatial resolution of 25 m. The image was also geometrically corrected and topographically normalised.

Image pre-processing

The provided image was built on 16-bit data type and all pixels have digital numbers (DN) ranging from 0–65,535. This DN however does not represent the radar signal of features or objects on the ground. Therefore, the DN was converted to backscatter coefficients (σ) known as Normalised Radar Cross Section (NRCS) and represented in decibels (dB). The equation that was used for the calculation of PALSAR NRCS are slightly different from other sensors in that the usual sine term has already been included in the DN values. Thus, for the data stored in Level 1.5 products, the equation for NRSC of any of the polarisation component can be obtained by the following formula with single calibration factor, which can be expressed as equation 5 for distributed scatterers. The conversion factor (CF) used in the equation is valid for the data obtained after 9 January 2009 (Shimada et al. 2009).

$$\sigma\ (\text{dB}) = 10 \times \log_{10}(DN^2) + CF \quad (1)$$

where CF = -83.0

Sarker et al. (2012) found that manipulation of dual-polarised image can produce more effective classification results. Therefore instead of using only the original backscatter HH and HV polarisations, an attempt has been also made to derive other image variables derived from PALSAR HH and HV images. Image variables namely i) simple band ratio (HH/HV), (HV/HH), ii) average (HH+HV/2), and iii) square-root of products (√(HHxHV)) were produced. Altogether six (6) image variables were derived and used in this study as shown in Table 1.

Table 1: Image variable used for forest classification.

Image variable	Description
HV	An image containing pixels values of original backscattering (σ, dB) from HV polarization.
HH	An image containing pixels values of original backscattering (σ, dB) from HH polarization.
HH/HV	Simple ratio generation by dividing HH to HV polarizations (unitless)
HV/HH	Simple ratio generation by dividing HV to HH polarizations (unitless)
(HH+HV)/2	Average of HH and HV (unitless).
√(HHxHV)	Squared root of HH and HV multiplicative product (unitless).

Gray-level co-occurrence matrix

Gray-level co-occurrence matrix (GLCM) was applied to refine the spatial distribution of estimated AGB on the HV backscatter image. Studies (e.g. Haralick 1973, Franklin et al. 2000, Kandasawamy et al. 2005, Amini & Sumantyo 2009) have shown that the incorporation of texture measure can improve classification of spatially distributed pixels on an image. GLCM uses a gray-tone spatial dependence matrix to calculate texture values. This is a matrix of relative frequencies with which pixel values occur in two neighbouring processing windows separated by a specified distance and direction. For this purpose texture has been defined as repeating pattern of local variations in image intensity which is too fine to be distinguished as separate class at the observed resolution. Thus, a connected set of pixels satisfying a given gray-level properties which occur repeatedly in an image region constitute a textured region (Anys 1994). It shows the number of occurrences of the relationship between a pixel of row (i) and column (j) and its specified neighbour. Mean GLCM was applied to the AGB image derived from the above process and it can be defined as

$$\text{GLCM mean} = \mu_{i,j} = \sum_{i,j=0}^{N-1} i\,(P_{i,j}) \tag{2}$$

Segmentation

Remotely sensed data is one of the primary data sources for landscape patterns recognition. Therefore, it requires interpretation theories and methods to identify and abilities to link these pattern components or objects at their respective scales, within the appropriate hierarchical structures. Classical pixel-based approaches of pattern recognition have shown some difficulties to adequately address such kind of expert knowledge or contextual information from satellite imagery, especially for high resolution imagery (Franklin et al. 2000). Intra-class spectral variations and inter-class spectral confusion have been increased in high resolution satellite imagery. Due to higher pixel to pixel variability and information contained in patch based landscape structures, classical methods of image analysis are becoming out of date (Abbas et al. 2008).

According to Sarker et al. (2012), a necessary prerequisite for object oriented image processing is successful image segmentation. As each image analysis problem deals with structures of a certain spatial scale, the average image objects size must be free adaptable to the scale of interest. This is achieved by a general segmentation algorithm based on homogeneity definitions in combination with local and global optimization techniques. A scale parameter is used to control the average image object size. For this purpose, Baatz segmentation algorithm (Baatz and Schape 2000) was applied to the image variables to delineate and extract the forest cover within the study area.

RESULTS AND DISCUSSION

Forest Areas Identification

The primary objective of this research was to evaluate the suitability of the ALOS/PALSAR sensor for large-area mapping of tropical forest cover. The study found that ALOS PALSAR backscatter is best in delineating forest from other landuse classes as the canopy structure of tropical forest reflects strong backscatter in HV polarised image. The backscattering coefficients generally ranged from -14 to -5 for inland, -17 to -11 dB for mangroves, and -14 to -8 for peat swamp forests. However, it has limitation in distinguishing further detailed classes of forest as shown in Table 2. PALSAR HV showed best performance up to level 2 of classification. But this does not preclude the study as the detailed forest classes are generally depending on land elevation, which can be derived from other supporting data such as digital elevation model (DEM) from Shutter Radar Topography Mission (SRTM) or ordinary contours from national topographic maps. Results also shown that the L-band HV has limitation in distinguishing forest plantation (mainly teak, timber latex clone, Aquilaria & Acacia plantations) as it confused by common rubber plantation. Information from the Forestry Department and Landuse map from the Department of Agriculture were used to overcome this limitation by assigning a specific training dataset for forest plantation.

Table 2: Typical levels of landuse classifications.

Level 1	Level 2	Level 3
Forest	Inland	Lowland dipterocarp
		Hill dipterocarp
		Upper hill dipterocarp
		Montane
		Ericaceous
		Plantation forest
	Peat swamp	Peat swamp
	Mangroves	Mangroves
	Fresh water swamp	Fresh water swamp
Non-Forest	Agriculture	Detailed classes of agriculture
	Urban area	Detailed classes of developing area
	Water body	Water body

The results also showed that the L-band in HV polarisation has very good capability in detecting deforestation. A quick assessment has been made for the whole study area by using dataset from two time series, which are in year 2009 and 2010. The deforested areas or commonly referred to as harvesting regimes were obviously show up when these images were displayed in RGB combination as shown in Figure 1. In single HV polarisation information about general forest cover condition (Beuchle et al. 2011). Very recent deforestation areas presented as dark patterns, older deforested areas are lighter where trees are growing, and mature forest is discernible at L-band SAR as light polygons. Besides the clear-cut pattern, forest degradation is also detected with PALSAR of this fine resolution mode.

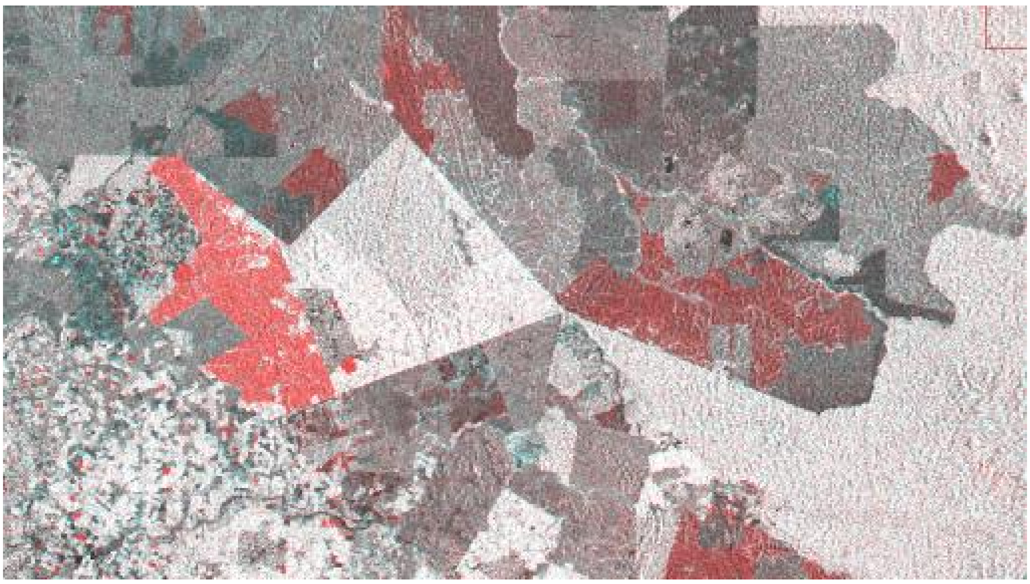


Figure 1: Changes of forest cover as appear on PALSAR images from year 2009 to 2010. The image is displayed in a combination of channels HV 2009 (R), HV 2010 (G) and HV 2010 (B). Changes of forest cover can be identified from the intensity of red colour. Bright red represents a dense forest area that was just cleared, due to harvesting or new development regimes. The dark red means forest area that has some

vegetation in year 2009 but totally cleared in year 2010. The remaining gray and white areas are not changing much.

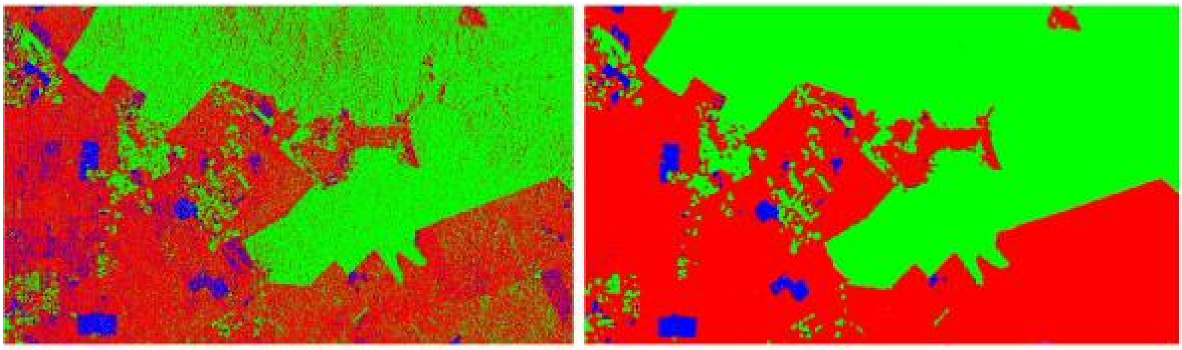
Forest Distribution and Extents

With an appropriate classification method and the helps from several supporting data, the study has successfully classified the forests into four major types, which are inland, peat swamp, mangroves, and forest plantation. The extent of each forest type is shown in Table 3. Inland dipterocarp forest is the major type of forest in Peninsular Malaysia with, spanned about 5.5 million ha and accounted for more than 90% of the total forest cover. The spatial distribution of these forests was mapped as shown in Figure 4. In addition to the identified major forest types, 'gelam' was also found within the study area. Gelam (*Melaleuca cajuputi*) is a monospecific, lesser-known commercial timbers (LKCT), which occurs in swamp forest behind beaches and mangroves. This forest – although in a small proportion – is found dominant, fringing behind the mangroves in the north eastern part of Terengganu, a state that resides in the East Coast of Peninsular Malaysia. However, due to difficulty in delineating this forest from inland forest, it was grouped together into inland forest. The total of some 6.06 million ha indicates that the study produced an extra 170,000 ha more as compared from the total extents reported by the Forestry Department. The additional occurred might due to different year of assessment. Furthermore this study has included many small patches found in the classification, which when summed gave a considerable number of extents. These small patches - which probably bushes or small faction of forest - were retained to fulfil the original definition of forest but remained uncertain. More ground thruthing points should be placed in these patches for conformation.

Table 3: The extents of forest cover by forest types in Peninsular Malaysia

Forest type	**Inland**	**Peat swamp**	**Mangroves**	**Forest plantation**	**Total**
Extents (ha)	5,485,912	265,712	115,180	193,415	6,060,219
Percentage (%)	90.5	4.4	1.9	3.2	100

The study also found that object-based classification method/segmentation gave better classification results. These methods also enabled post-processing and editing for further refinement and redefining the classification results. Figure 2 compares the classification results generated from traditional and object-oriented methods.



(a) (b)

Figure 2: The difference of classification results generated from traditional classification method (a) and object-oriented classification approach (b).

By using a number of ground thruthing points collected on ground and some information extracted from Landuse Map as well as data from the Forestry Department, the classification was accuracy assessed. All classification results produced from the image variables as described earlier were compared. Overall, the classifications that were applied on the single HV polarised image and modified HH and HV with GLCM of 5x5 window size gave the highest accuracy among others, with the HH was the lowest. This comparison is indicated in Figure 3. The study thus suggests that the use of texture measure could improve classification. The study also found that PALSAR imagery is the most appropriate, adequate satellite-based data resource for a national or regional scale forest cover mapping as agreed by previous research work e.g. Rosenqvist et al. (2007), Walker et al. (2010) and Keat et al. (2011).

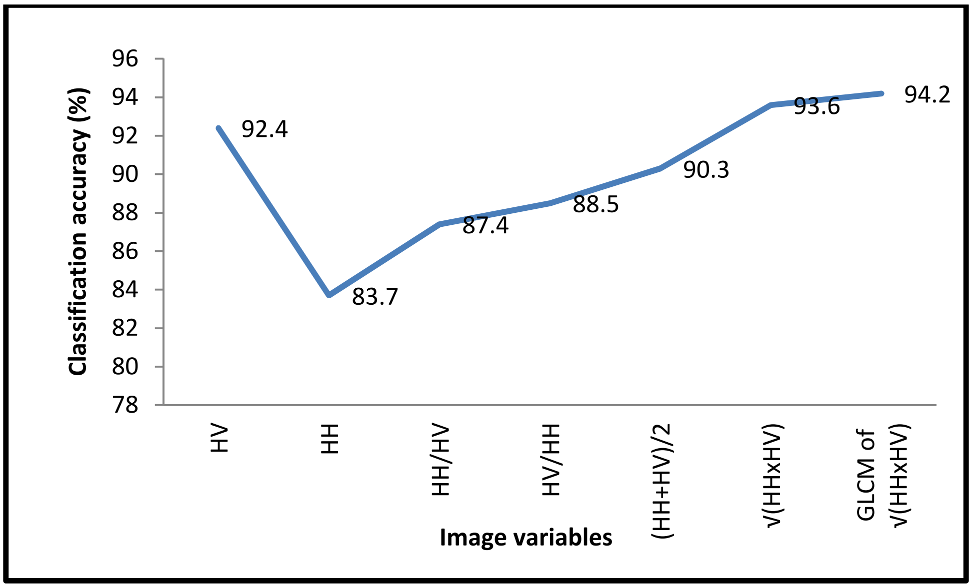


Figure 3: The accuracies of classifications resulted from varying image variables

CONCLUSION

The study has successfully classified the forests into four major types, which are inland, peat swamp, mangroves, and forest plantation. These encountered for about 6.06 million ha of forest cover in Peninsular Malaysia, which inland dipterocarp forest being dominant. The suitability of PALSAR data for classifying and mapping forest cover, i.e. to discriminate forested from non-forested areas, was examined in particular detail. HV polarised image has prevailed in discriminating forest and non-forest. The highest overall accuracy for the forest/non-forest classifications were achieved at 94.2%. The study found that the use of manipulation of HH and HV polarisation, which is (√(HHxHV)) introduced a new image enhancement technique and effective way of image interpretation for forest cover. This was further improved by GLCM image filtering technique. The study also demonstrated that a multiple series of L-band PALSAR could give the best performance for deforestation and degraded forest detection, which is simple yet effective.

The study provided further recognition of the expanding capacity of space-based remote sensing to meet the requirements of large-area forest mapping and monitoring activities at national to regional scales. Comparative test confirmed that the ability of L-band PALSAR, with an appropriate classification technique provide an accurate results for mapping and monitoring of forest cover, particularly in the tropics where optical sensors are often constrained by cloud covers. With longstanding technical challenges associated with radar properties largely mastered, PALSAR data is far more accessible to the applications user community than data from any radar sensor before it.

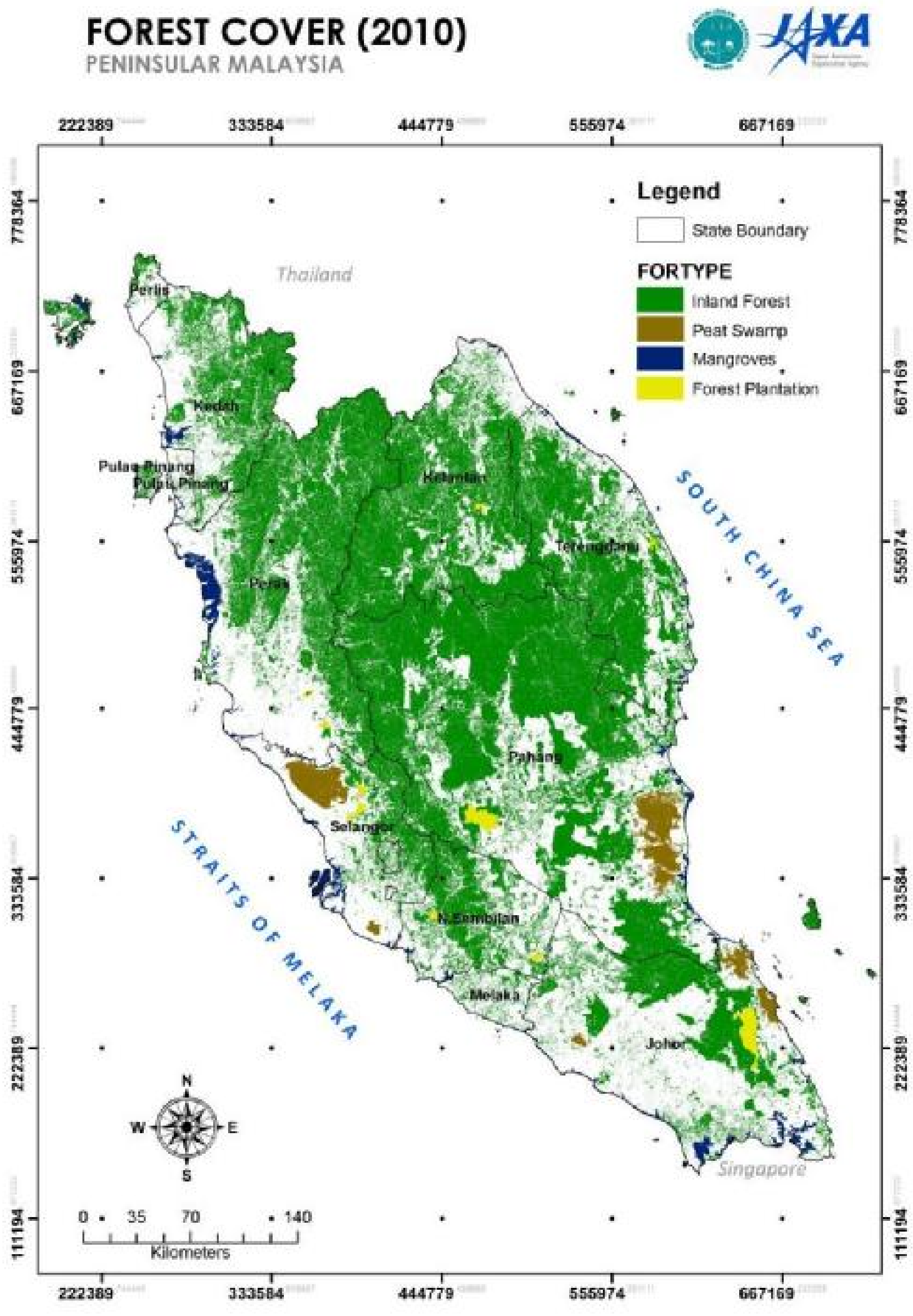


Figure 4: The distribution of forest cover in Peninsular Malaysia.

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