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Asia-Pacific Network for Sustainable Forest Management and Rehabilitation

Technical Report

Forest Cover and Carbon Mapping in the Greater Mekong Subregion and Malaysia

September, 2011 to February, 2014

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Summary

Forests play a vital role in sustainable development and provide a range of economic, social and environmental benefits, including essential ecosystem services such as climate change mitigation and adaptation. The major goal of this project is to map forest coverage and carbon storage in the Greater Mekong Subregion (GMS) and Malaysia, which comprises of Cambodia, the People's Republic of China (Yunnan province and Guangxi province), Lao People's Democratic Republic, Malaysia, Myanmar, Thailand, and Viet Nam. This region is rich in forest resources, but the forests are undergoing rapid changes due to human activities.

The project was achieved by making intensive use of recent satellite remote sensing technologies, establishing regional forest cover maps, documenting forest change processes and estimating carbon storage in the GMS and Malaysia. The main outputs of the project are including 1) Remote sensing database, 2) Mid-resolution (30 m) forest map product in 2005 and 2010, 3) Annual forest map product at coarse resolution (500 m) during 2005～2010, and 4) Forest carbon storage mapping product (300 m) of 2005. From our mapping products, most countries had high forestry coverage over 50%. The needle-leaf forests were mainly distributed in Northern Myanmar, Yunnan and Guangxi of China. The forests in Malaysia, Cambodia, Laos, Viet Nam, Thailand and middle-south of Myanmar were dominated by broadleaf forests. Forest coverage was 48.4% and 46.2% in 2005 and 2010 respectively for the whole region. The forest net loss was 2.2% from 2005 to 2010. The forest loss were mainly located in northeast of Myanmar, Laos, Malaysia, and Yunnan province of China. The Forest gain were mainly occurred in eastern Malaysia, northern of Viet Nam, central-north of Myanmar, and Yunnan of China. The high carbon density forests were mainly distributed in the Northern Myanmar and the Northwest Yunnan, the Northeast of Guangxi, border regions of Myanmar-China-Laos and the southern part of Myanmar-Thailand, the center and south of Laos and border regions with Viet Nam, a large part of Malaysia forest.

Content

1 Introduction

1.1 General introduction of project

Forests play a vital role in sustainable development and provide a range of economic, social and environmental benefits, including essential ecosystem services such as climate change mitigation and adaptation. Forest monitoring is important for the estimation and evaluation of the state of forest resources, carbon sequestration, and the results of forest program implementation. It provides a key source of information used to for the crackdown on illegal logging, forest fire monitoring and early warning for forest degradation, the reduction of deforestation, forest gain of afforestation and reforestation, and the improvement of forest quality. Also, forest monitoring to support sustainable forest resources management can provide the earth observation data and technical support needed by countries to fulfill their obligations effectively arising from international environmental agreements (e.g., UNFCCC).

The project will be achieved by making intensive use of recent satellite remote sensing technology, establishing regional forest cover maps, documenting forest change processes and estimating carbon storage in the GMS and Malaysia. Three main objectives of the project are to:

i) develop a framework and methods for forest mapping and carbon estimation using remote sensing technology;

ii) produce forest cover change maps from 2005 to 2010 and a forest above ground biomass map; and

iii) enhance institutional capacity in GMS countries and Malaysia to perform forest mapping and assessment.

1.1.1 Background

This proposal comes from the discussion of the International Workshop on Forest Monitoring in Support of Sustainable Forest Management in the Asia-Pacific Region, April 29-30, 2010, Beijing, China. 35 scientists and officers from the Asia-Pacific countries, i.e., Cambodia, China, Indonesia, Laos, Myanmar, Malaysia, Thailand, Viet Nam, Australia, Canada, and USA, as well as from international organizations including FAO and GOFC-GOLD attended the workshop. Capacity building and demonstration projects were agreed activities in the workshop. In the Training Workshop on Forest Mapping using Geospatial Technology in the Asia-Pacific Region, January 3-12, 2011, Nanning, China, 16 forestry technical officers and researchers from Cambodia, China Yunnan and Guangxi provinces, Laos, Malaysia, Myanmar, Thailand, and Viet Nam attended. As a follow-up activity of the International Workshop on Forest Monitoring in April 2010, the Training Workshop focused on enhancing the capacity of regional technicians in forest monitoring and promoting technical exchanges and cooperation in the proposed demonstration project. This proposal was discussed thoroughly in the 2 days in-workshop seminar. The activities and tasks were agreed.

The main users of the proposed project are economies in the GMS and organizations interest in the region, which include the scientific community (e.g. national forest institutes, IPCC, GEO-FCT, GOFC-GOLD), policy makers of each economies' forestry and/or environment agencies, education community (e.g. the Forestry University of Viet Nam, Southwester Forestry University of China, AIT), commercial companies (e.g. pulp companies like APP), and – in the context of cooperation and scientific support – also international or regional organizations (e.g. FAO, APFNet, ASEAN or MRC).

1.1.2 Goal and objectives

The primary goal of the project is to estimate forest coverage and above-ground carbon stock in the Greater Mekong Subregion (GMS) and Malaysia. The proposed approach will integrate multi-sources remote sensing data, ground measurements and other thematic geographic data. The outcomes of this project will help to clarify how, when and where the forests changes in the GMS and Malaysia. Our proposed approach will determine forest coverage and biomass estimates through the following specific objectives:

1) To develop pan-GMS and Malaysia forest cover mapping techniques to monitor forest cover type changes in the region, using both optical and radar remote sensing techniques.
2) Develop a framework for forest carbon estimation using ground measurements, spaceborne lidar sampling data and imaged remote sensing data.
3) Produce forest cover maps of 2005, and 2010 at 30-50m spatial resolution and forest cover maps annually from 2005 to 2010 at 300-500m spatial resolution.
4) Produce a forest carbon storage map for 2005 in the GMS and Malaysia at 300-500m spatial resolution.

1.1.3 Structure and process

A project steering committee comprised of national representatives and international experts will be established. This committee will communicate and make top-level design for the whole project. One recommended national representative was recommended. Milestones and main deliverables will be discussed by this steering committee.

Institutes with intensive remote sensing technologies and forest resources will be organized as an algorithm development and training group. The common data processing and forest information extraction methods will be explored and developed. Technical progress and innovative methodologies will be regularly synthesized and feed to support operational data processing through training workshops and progress meetings. Some funds for visiting scientists are planned for attendees to visit or study at CAF.

The reference database and middle resolution forest mapping activities will be carried out by each country's organizations. Annual forest map of coarse resolution and forest carbon storage map will be done by the methods development team. After each forest coverage and carbon storage map generated, they will be evaluated by a validation team. Then the steering committee will do analysis with other related information. A report will be prepared for APFNet and released to related communities.

The working packages are as

WP1: Project design and management (including training)

WP2: Methods development (including Algorithms)

WP3: Remote sensing data acquisition and pre-processing

WP4: Ground truth database development (compiling existing data)

WP5: Mid-resolution forest mapping product

WP6: Coarse-resolution forest mapping product

WP7: Forest carbon storage mapping product

WP8: Reporting and dissemination

WP1, WP2, WP7 and WP8 will lead by the Chinese Academy of Forestry, GOFC-GOLD and the University of Maryland with inputs from involved countries. The data of WP4 will be distributed in each country but serve for this project. WP4, WP5, WP6 and WP7 will be carried out by the national forest institute or university of each country in the GMS and Malaysia. Relevant forest mapping techniques and software tools will be developed into a streamlined production system in WP1 and WP2. And the production system will be distributed to the team of each country through training courses/workshops. The data will be distributed to each team, who will do the mapping and validation by themselves. Classification and mapping activities are proposed to be done by each county's team for their country task.

1.2 Introduction of GMS+ region

The area of the GMS and Malaysia demonstration project ranges from 92.2° to 119.3° east longitude and 0.8° to 29.2° north latitude, with total land area of 317,242,000 ha and total population of 348 million. It includes Cambodia, the People's Republic of China (Yunnan province and Guangxi province), Lao People's Democratic Republic, Malaysia, Myanmar, Thailand, and Viet Nam. The total forest area is 148,128,000 ha reported by FRA 2010 (Yunnan & Guangxi data were from the 7th national forest inventory of China).

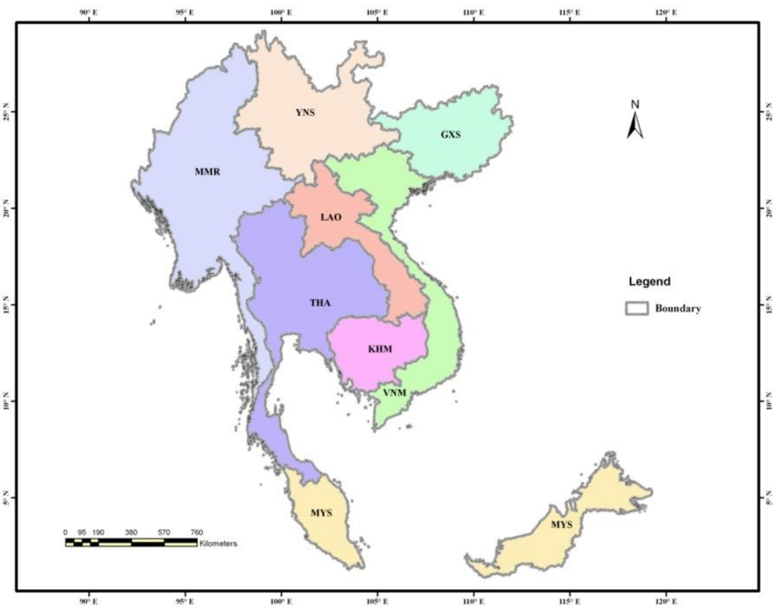


Fig. 1-1 Study Area of the GMS and Malaysia Demonstration Project.

1.3 General forest resources of GMS+ region

The project area has a diverse geographic landscape including massifs, plateaus and limestone karsts, lowlands, fertile floodplains and deltas, forests (evergreen and semi-evergreen, deciduous, dipterocarp, mangroves, and swamp), and grasslands. The region's geographic variety and consequent variety of climatic zones supports significant biodiversity, with more than 1068 new species discovered during the last ten years. The geographic region encapsulates 16 of the WWF Global 200 ecoregions. The region's biodiversity is ranked as a top-five most threatened hotspot by Conservation International. High forest coverage and rich forest resource result in large amounts of wood export from this region. The WWF states that the region is particularly vulnerable to global climate change.

Table 1-1 Basic data on the region of GMS and Malaysia

No.	Economy	Land area (k ha)	Forest area (k ha)	Population (~2008, k)	Per capita GDP (~2008, $)
1	Cambodia	17652	10094	14562	1951
2	Guangxi, China	23670	14400	55180	4911
3	Lao	23080	15751	6205	2124
4	Malaysia	32855	20456	27014	14215
5	Myanmar	65755	31773	49563	1200
6	Thailand	51089	18972	67386	8086
7	Viet Nam	31007	13797	87096	2787
8	Yunnan, China	39400	24760	45966	2243
9	Project area	284508	150003	352972	

The subregion embraces flora and fauna that have expanded northward along the Malay Peninsula into Thailand, encroached upon the high mountains from the Himalayas, or advanced along the broad river valleys as dry deciduous forests similar to those of India. Ten million years of changing sea levels have left a rich legacy of unique life forms that have evolved in isolation on the Cardamom and Annamite Mountains of Cambodia, Lao PDR, Thailand, and Viet Nam.

These resources provide both income and sustenance to the great majority of people in the subregion who are leading subsistence or near subsistence agricultural lifestyles. The land yields timber, minerals, coal, and petroleum, while water from the many rivers supports agriculture and fisheries and provides energy in the form of hydropower. The coal reserves of the subregion are abundant, and the oil and gas reserves considerable. Most of these are in Myanmar, Thailand and Viet Nam. These abundant energy resources are still relatively underused.

Increasingly, modernization and industrialization are emerging from a process of transition and transformation. The Mekong countries are gradually shifting from subsistence farming to more diversified economies, and to more open, market-based systems. In parallel with this are the growing commercial relations among the six Mekong countries, notably in terms of cross-border trade, investment, and labor mobility. Moreover, natural resources, particularly hydropower, are beginning to be developed and utilized on a subregional basis.

The rich human and natural resource endowments of the Mekong region have made it a new frontier of Asian economic growth. Indeed, the Mekong region has the potential to be one of the world's fastest growing areas.

2 Databases

2.1 Remote sensing database

Since the beginning of the Project“Mapping in the Greater Mekong Subregion and Malaysia”, IFRIT had collected the satellite images of Landsat TM/ETM+ at mid-resolution 30 m in 2005 and 2010 covering the whole study area, RapidEye imageries with 5m spatial resolution in 2010 for 18 test sites, ICESat GLAS data at coarse resolution 300~500 m in 2005 for test site, and time series of MODIS data from 2005 to 2010 for the whole study area. These RS data had been distributed to each implementing agency of the project and are compiled and kept in a standard raster database.

2.1.1 Fine-resolution remote sensing data

RapidEye data is used in this project for classification validation. RapidEye is a geospatial information provider focused on integrating customized solutions into the workflow of global customers in agriculture, forestry and related markets. RapidEye owns a constellation of five identical Earth observation satellites and can quickly and reliably deliver multi-temporal data sets in high resolution. The RapidEye satellite system can image more than 4 million km2 of earth daily, reach any point on earth daily, produce imagery with 5 meter pixel size and collect imagery in five spectral bands: Blue, Green, Red, Red-Edge and Near Infrared. Examples of the project RapidEye data for test sites are shown in Figure 2-1. Table 2-1 below outlines general mission characteristic for the RapidEye system.

Table 2-1 Mission characteristic for the RapidEye system

Mission Characteristic	**Information**	
Number of Satellites	5	
Spacecraft Lifetime	7 years	
Orbit Altitude	630 km is Sun-synchronous orbit	
Equator Crossing Time	11:00 am (approximately)	
Sensor Type	Multi-spectral push broom imager	
Spectral Bands	Capable of capturing any of the following spectral bands:	
	Name	Spectral Bands (nm)
	Blue	440-510
	Green	520-590
	Red	630-685
	Red Edge	690-730
	NIR	760-850
Ground Sampling Distance (nadir)	6.5 m	
Pixel size (orthorectified)	5 m	
Swath Width	77 km	
On Board Data Storage	Up to 1500 km of image data per orbit	
Revisit Time	Daily (off-nadir) / 5.5 days (at nadir)	
Image Capture Capacity	4 million sq km / day	
Dynamic Range	Up to 12 bit	

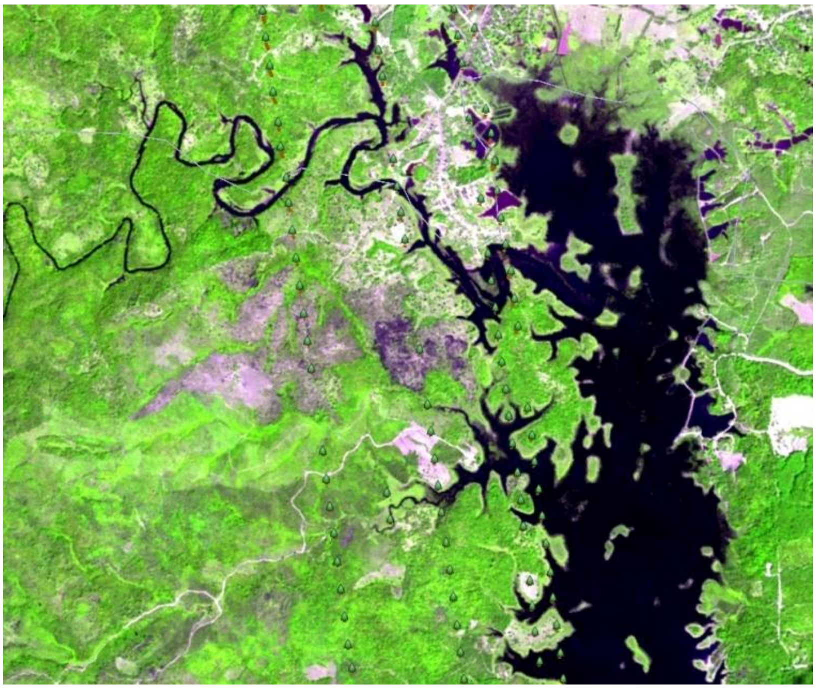


Fig. 2-1. Project RapidEye image for Sangthong test site – Lao PDR

RapidEye data have been collected for a 500 sq km area for each test site. The RapidEye data of test site has been distributed to each implementing agency. Information of RapidEye data in test site sees Table 2-2.

Table 2-2 Information of RapidEye data in test sites

Economy	**Test Site**	**UL**		**LR**		**AOI-area (km^2)**	**Acquired Date of RapidEye data**
Cambodia	Kratie	105.744	13.013	105.835	12.922	100	2010-3-29
Laos	Namet	103.143	20.23	103.272	20.12	164	2010-2-13
	Sangthong	102.08	18.343	102.189	18.255	113	2011-4-2
	Songkhon	105.311	16.24	105.454	16.126	192	2010-12-27
Malaysia	PITC	101.545	5.587	101.636	5.496	102	2011-7-6
	Matang	100.577	4.862	100.667	4.772	100	2011-3-28
	Semangkok	101.707	3.716	101.797	3.626	101	2011-3-16
	Pasoh	102.268	3.03	102.358	2.94	101	2011-1-19 & 2012-2-6
	Loagan Bu	114.087	3.029	114.175	2.941	96	2011-9-29
	Klias Pen	115.572	5.321	115.659	5.232	95	2011-7-31
	Danum Val	117.324	4.881	117.411	4.792	95	2011-7-26
	Sepilok F	117.89	5.864	117.977	5.775	95	2011-6-22
Thailand	Ngao	99.829	18.75	99.923	18.66	100	2012-2-27
	Pha	105.524	15.657	105.617	15.567	100	2011-3-6
	Vein	102.286	12.413	102.377	12.322	100	2010-3-11
Viet Nam	Tamdao	105.585	21.49	105.695	21.397	100	2010-11-1
	Xuanthuy	106.49	20.301	106.582	20.211	98	2011-4-12
	Yokdon	107.758	12.977	107.849	12.884	103	2010-3-22

2.1.2 Mid-resolution remote sensing data

Through contribution from USGS, UMD, and some remote sensing agencies in China, we have already collected Landsat TM/ETM+ data of 2005 and 2010. These images have been processed with atmospheric correction by IFRIT, CAF and UMD. Path and row information of Landsat data for the whole area is shown in Figure 4. The mosaic images of GMS+ area in 2005 and 2010 are shown in Figure 2-2 and Figure 2-3.

	135	134	133	132	131	130	129	128	127	126	125	124	123	121	120	119	118	117	116
40			133040	132040	131040	130040	129040	128040											
41		134041	133041	132041	131041	130041	129041	128041											
42		134042	133042	132042	131042	130042	129042	128042	127042	126042	125042	124042	123042						
43		134043	133043	132043	131043	130043	129043	128043	127043	126043	125043	124043	123043						
44	135044	134044	133044	132044	131044	130044	129044	128044	127044	126044	125044	124044	123044						
45	135045	134045	133045	132045	131045	130045	129045	128045	127045	126045	125045	124045	123045						
46	135046	134046	133046	132046	131046	130046	129046	128046	127046	126046		124046							
47		134047	133047	132047	131047	130047	129047	128047	127047	126047									
48			133048	132048	131048	130048	129048	128048	127048	126048	125048								
49			133049	132049	131049	130049	129049	128049	127049	126049	125049	124049							
50					131050	130050	129050	128050	127050	126050	125050	124050							
51						130051	129051	128051	127051	126051	125051	124051	123051						
52						130052	129052		127052	126052	125052	124052	123052						
53						130053	129053			126053	125053	124053							
54						130054	129054				125054								
55							129055	128055										117055	
56								128056	127056	126056							118056	117056	116056
57								128057	127057	126057						119057	118057	117057	116057
58									127058	126058					120058	119058	118058		
59										126059	125059			121059	120059	119059	118059		

Fig. 2-2. Path and Row information of Landsat data for whole area

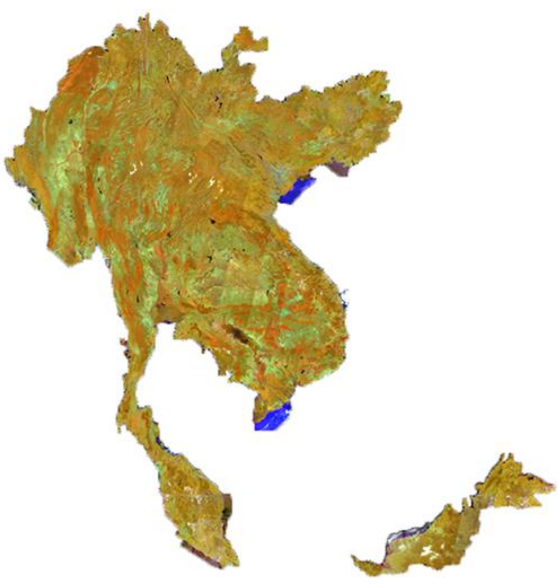


Fig. 2-3. The mosaic images of GMS+ area in 2005

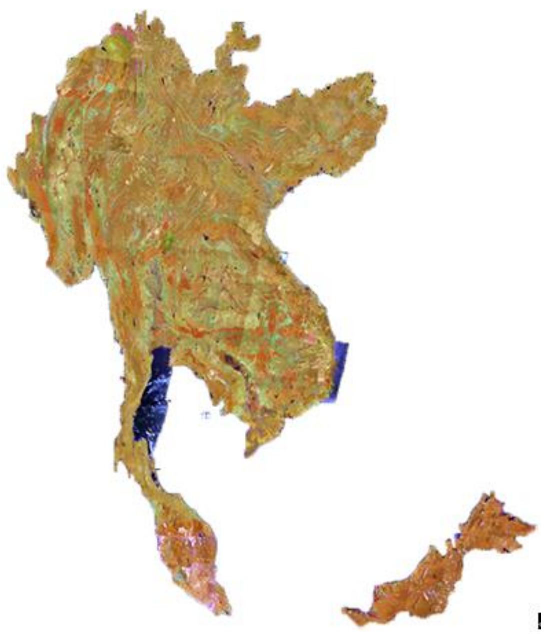


Fig. 2-4. The mosaic images of GMS+ area in 2010

2.1.3 Coarse-resolution remote sensing data

MOD09A1 and MOD13Q1 data products that cover the research area from 2005 to 2010 were acquired from USGS EROS Data Center. Tile numbers covering this area are H26V06, H26V07, H27V06, H27V07, H27V08, H28V06, H28V07, H28V08, H29V08. The coordinates of GMS are as following: coordinates of upper left is (29.220857, 92.189213), lower right is (0.855222, 119.267502). MODIS data for whole area which acquired in 1st November, 2005 is shown in Figure 2-5. The projection of this data is Albers Conic Equal Area, WGS-84.

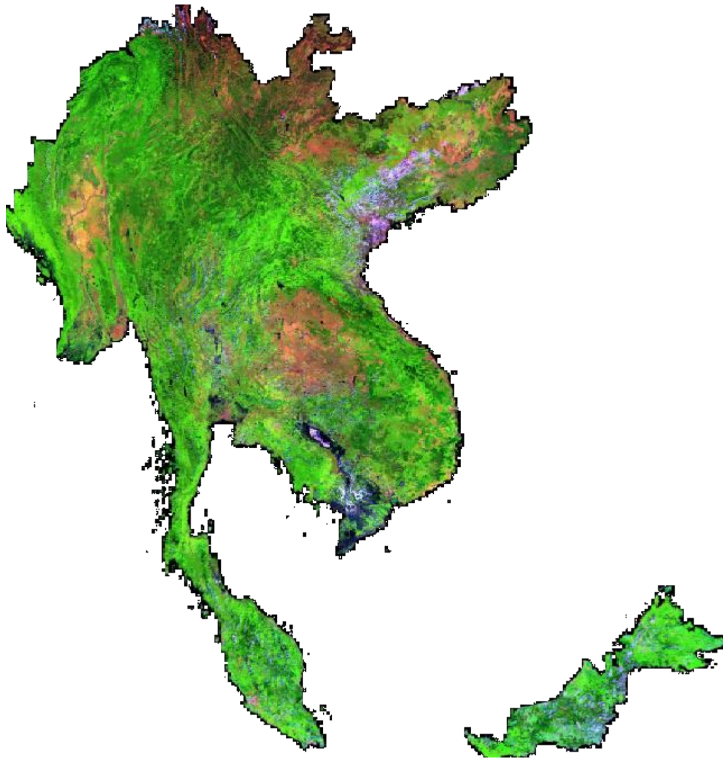


Fig. 2-5. MODIS multi-spectral remote sensing data（2005305）for whole area

2.1.4 Spaceborne Lidar data for whole region

GLAS Level-1A altimetry data (GLA01), level-1B waveform parameterization data (GLA05) and level-2 land altimetry product (GLA14) were used to estimate forest height and biomass. The GLA01 data include the transmitted and received waveform from the altimeter. The GLA05 data contain waveform-based range corrections and surface characteristics. The GLA14 data contain the land elevation and land elevation distribution data. The data from L3b to L3g were acquired for this project. Space borne Lidar data for whole region is shown in Figure 2-6. GLAS data distribution around test sites is shown in Figure 2-7.

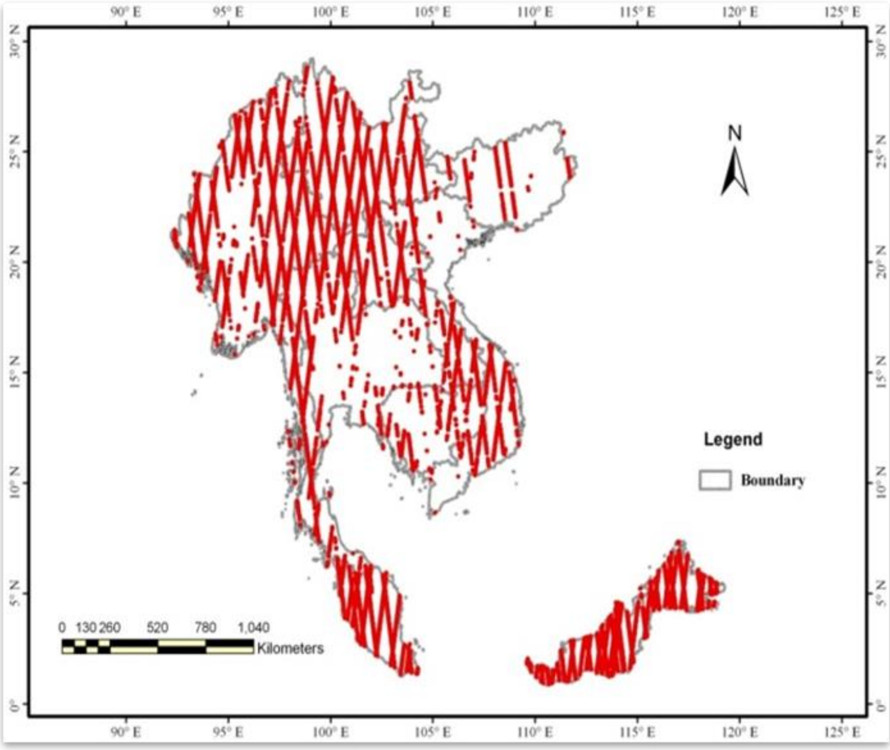


Fig. 2-6. Space borne Lidar data for whole region

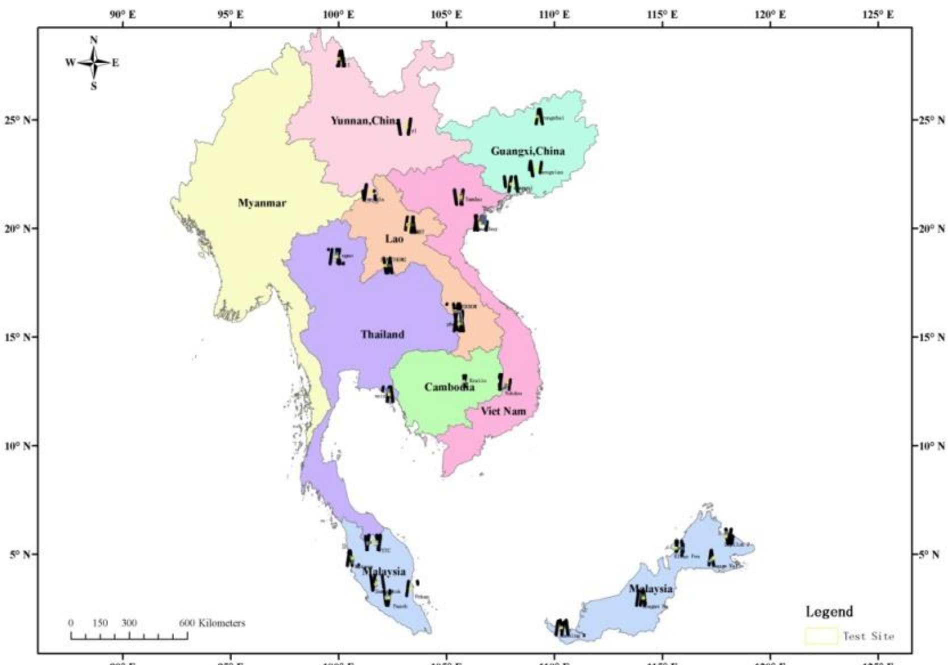


Fig. 2-7. GLAS data distribution around test sites

2.2 National-institute-owned ground truth database

2.2.1 General information

Creation of accurate forest maps from remote sensing satellite data requires use of reference data to aid in interpretation or to verify map results. Reference data may be taken from field visits, aerial photo-interpretation, ground-based inventories or other available information sources. For the various means of reference data collection, the structure of reference data may be different. In order to harmonize the reference data from various resources for providing useful information and promote the collaboration, we make this guide. The metadata of the reference database is shown in table 2-3.

Reference Database Guide mainly intends to know the available information that already collected in each countries or regions, including field inventories, thematic maps, biomass data, statistical reports, available forest maps, field photos or pictures. Please fill in the following form. All geospatial data should be transformed to the projection of Albert Conical Equal Area for supporting our project forest mapping and validation. Vector datasets include the Administration map, Forest Map, Inventories, Ground Truth Data, etc. Reference data sharing could save time and eliminate cost for data acquisition.

Table 4-3 Reference database

No.	Product Name	Data Type	Projection	Coordinates of Upper Left Corner	Coordinates of Lower Right Corner	Data Description	Resolution or Scale	Contact Person	Tel.	Fax.	Email
1		Raster/ Vector/ Report	Albert Conical Equal Area	（X1,Y1）	（X2,Y2）	（Data Items, including the brief introduction or definition，data quality, etc.）					
2	MYS_ MODIS_ LULC_2010	Raster	Albert Conical Equal Area	(98.93, 7.36)	(119.27, 0.855)	MODIS data 500m resulotion, classification legend include Evergreen Needleleaf Forest, Deciduous Needleleaf Forest, Evergreen Broadleaf Forest, Deciduous Broadleaf Forest, Mixed broadleaf/needleleaf forest, Bamboo, Wetland forest, Shrub land, Grassland, Urban and Built-Up, Water, Other unclassified, etc..	500m				

2.2.2 Metadata note

1) Product Name

The name of the product should include country information, products time period, the sensor information or inventories information, or others. The pattern should be like CountryCode_Sensor_ProductName_TimePeriod, The items in bold must be included. For example, MYS_MODIS_LULC_2010 means Land Use / Land Cover Map of Malaysia, produced in 2010.

Table 4-4 Code of each economy

Country	**Code**		**Country**	**Code**
Myanmar	MMR		Cambodia	KHM
Viet Nam	VNM		Malaysia	MYS
Lao	LAO		Yunnan, China	YNS
Thailand	THA		Guangxi, China	GXS
Large Areas or Others (across country border)	GMS			

2) Data Type

Data type should include the data categories and detail data format, just like the following pattern.

Table 4-5 Data Type

Data Type				
Vector	Raster	Report	Photos	Others …
… Type: Point/ Line/ Polygon … Format: shp/ e00/ mif/ …. Others	Geotiff/ img/…	word/ excel/…		

3) Projection

The common projection should be Albert Conical Equal Area. The details of the projection parameters are in the followings:

Projection Type: Albert Conical Equal Area
Spheroid Name: WGS 84
Datum Name: WGS84
Latitude of 1st standard parallel: 0 N
Latitude of 2nd standard parallel: 20 N
Longitude of central meridian: 110 E
Latitude of origin of projection: 0 N
False easting at central meridian: 0 meters
False northing at origin: 0 meters

Note: For this project involves large area, we use the projection of Albers Conic Equal Area, you can add original projection and parameters information in data description section.

4) Data Description

Data Items, including the brief introduction or definition

5) Resolution or Scale

The resolution of the satellite data or mapping scale

6) Contact Person

Family name, first name

7) Tel.

Country code: + Region code + Tel. number，eg.+86-10-xxxxxxxx

8) Fax.

Country code: + Region code + Fax. number，eg.+86-10-xxxxxxxx

Main References

http://www.eomf.ou.edu/photos.
http://confluence.org/index.php.

Xiangming Xiao, Pavel Dorovskcy, etc. a library of Georeferenced photos from the field, EOS, Transactions, American Geophysical union, 2011,12, 92(49):453-454.
Jim Penman, Michael Gytarsky, Taka Hiraishi, etc. Good Practice Guidance for Land Use, Land-Use Change and Forestry, Published by the Institute for Global Environmental Strategies (IGES) for the IPCC, 2003 (ISBN 4-88788-003-0).

3 Forest coverage maps of 2005 and 2010 at national scales

3.1 Classification system for GMS+ project

Land cover classification system is decided considering the purpose of the land cover mapping objective of specific project. Usually classification systems of different projects vary. There is no one ideal classification system of land use and land cover, and it is unlikely that one could ever be developed.

For GMS project, the primary goal is to estimate forest coverage and above-ground biomass in the Greater Mekong Subregion (GMS) and Malaysia. One of the outcomes is to produce forest cover maps of 2005, and 2010 at 30-50m spatial resolution and forest cover maps annually from 2005 to 2010 at 300-500m spatial resolution. Based on this project mapping purpose, we need to define land cover classification system for GMS+ independently. According to the discussion on the inception workshop, hierarchical classification system is decided by the working group (see Table 3-1). The detailed definition of each types see Table 3-2.

Table 3-1 Forest Types System for the Forest Cover and Above Ground Biomass Mapping in the Greater Mekong Subregion and Malaysia Project

Level I	Level II	Level III	Level VI*
1Forest	1Needleleaf forest	1Evergreen Needleleaf Forest	1Nature
			2Plantation
		2Deciduous Needleleaf Forest	1Nature
			2Plantation
	2Broadleaf forest	1Evergreen Broadleaf Forest	1Nature
			2 Plantation
		2Deciduous Broadleaf Forest	1Nature
			2Rubber 3Dipterocarp 4Other plantation
	3Mixed forest		
	4Bamboo		
	5Wetland forest	1Mangrove Forest	
		2Peat Swamp Forest	
		3Fresh Water Swamp Forest	
	6Gallery Forest		
2Non-Forest	1Shrub land		
	2Savannas		

	3Grassland		
	4Crop land		
	5Urban& Built-Up		
	6Water		
	7Bare land		
	8 Snow		
3Cloud/cloud shadows	Cloud/cloud shadows		
4No data	Other unclassified		
Notes	**Open to add other types**		

For each class, a label was given according to the class level (Table 3-2)

Table 3-2 Labeled and definition of the classes for GMS+ Project

No.	Labeled	Class Name	Class Definition
1	**11**	**Forest**	Forest with > 30% tree canopy cover.
2	**21**	Non-Forest	Other land, with < 30% tree tree canopy cover.
3	**121**	Needleleaf forest	Natural or plantation forest with > 30% canopy cover, in which the canopy is predominantly (> 75%) needleleaf
4	**122**	Broadleaf forest	Natural or plantation forests with > 30% canopy cover, in which the canopy is predominantly (> 75%) broadleaves
5	**123**	Mixed forest	Natural or plantation forests with > 30% canopy cover, in which the canopy is composed of a more or less even mixture of needleleaf and broadleaf crowns (between 50:50% and 25:75%).
6	**124**	Bamboo	Lands with bamboo types with >30% canopy cover .
7	**125**	Wetland forest	Natural forests with > 30% canopy cover, composed of trees with any mixture of leaf type and seasonality, but in which the predominant environmental characteristic is wetland.
8	**126**	Gallery Forest	are forests that form as corridors along a road

			or watercourse in a region otherwise devoid of trees
9	**131**	Evergreen Needleleaf Forest	Natural or plantation forest with > 30% canopy cover, in which the canopy is predominantly (> 75%) needleleaf and evergreen
10	**132**	Deciduous Needleleaf Forest	Natural or plantation forests with > 30% canopy cover, in which the canopy is predominantly (> 75%) needleleaf and deciduous
11	**133**	Evergreen Broadleaf Forest	Natural or plantation forests with > 30% canopy cover, the canopy being > 75% evergreen and broadleaf.
17	**134**	Deciduous Broadleaf Forest	Natural or plantation forests with > 30% canopy cover, in which > 75% of the canopy is deciduous and broadleaves predominate (> 75% of canopy cover).
18	**135**	Mangrove Forest	Natural forests with > 30% canopy cover, composed of species of mangrove tree, generally along coasts in or near brackish or salt water.
19	**136**	Peat Swamp Forest	Natural forests with > 30% canopy cover, composed of trees with any mixture of leaf type and seasonality, but in which the predominant environmental characteristic is a peat soil.
20	**137**	Fresh Water Swamp Forest	Natural forests with > 30% canopy cover, below 1200m altitude, composed of trees with any mixture of leaf type and seasonality, but in which the predominant environmental characteristic is a waterlogged soil.
21	**140**	Nature Evergreen Needleleaf Forest	Evergreen Needleleaf Forest, which are growing naturally.
22	**141**	Plantation Evergreen Needleleaf Forest	Evergreen Needleleaf Forest ,which have been planted by people
23	**142**	Nature Deciduous Needleleaf Forest	Deciduous Needleleaf Forest ,which are growing naturally.
24	**143**	Plantation Deciduous Needleleaf Forest	Deciduous Needleleaf Forest ,which have been planted by people

25	**144**	Nature Evergreen Broadleaf Forest	Evergreen Broadleaf Forest, which are growing naturally.
26	**145**	Plantation Evergreen Broadleaf Forest	Evergreen Broadleaf Forest ,which have been planted by people
27	**146**	Nature Deciduous Broadleaf Forest	Deciduous Broadleaf Forest, which are growing naturally.
28	**147**	Rubber	Plantation forest with > 30% canopy cover, composed of species of Rubber tree.
29	**148**	Dipterocarp	Plantation forest with > 30% canopy cover, composed of species of Dipterocarp tree.
30	**149**	Other plantation	Forest plantations showing extent only with no further information about their type.
31	**221**	Shrub land	Woody vegetation < 3m in height, with at least 10% ground cover.
32	**222**	Savannas	Closed to open (>15%) herbaceous vegetation (grassland, savannas).
33	**223**	Grassland	Upland herbaceous grasses >10% ground cover.
34	**224**	Crop land	Cultivated and pasture land, except paddy agriculture.
35	**225**	Urban & Built-Up	Includes residential, commercial and industrial, transportation, sport facilities.
36	**226**	Water	Permanent open water bodies.
37	**227**	Bare land	<10% ground cover by other LC classes .
38	**228**	Snow	Includes glaciers and permanent snow fields on mountains.
39	**31**	Clouds/cloud shadows	Areas coved by cloud or cloud shadows.
40	**41**	Other unclassified	Areas where land cover interpretation was not possible.
		Open to add other types	

3.2 Procedures for supervised LULC classification

The general guide for LULC mapping using mid-resolution multi-spectral remote sensing for the GMS+ project has been discussed during the project inception meeting and the document could be considered as the summary of the answers to the key issues raised by all the partners through detailed discussion.

The general methodology of land cover or land use mapping for global / region area consists of the following steps:

(1) Determination of classification system;

(2) Preparation of ground truth data based on the predetermined classification system;

(3) Preprocessing of satellite data;

(4) Classification by satellite data;

(5) Correction and modification;

(6) Validation using ground truth data.

In this chapter, our main purpose is how to do the image classification and extract the information that we need. According to the steps of the general methodology for land cover or land use mapping using remote sensing data, the general procedures for LULC classification can be summarized as that shown in Fig. 3-1. A brief description of the major steps is as follows.

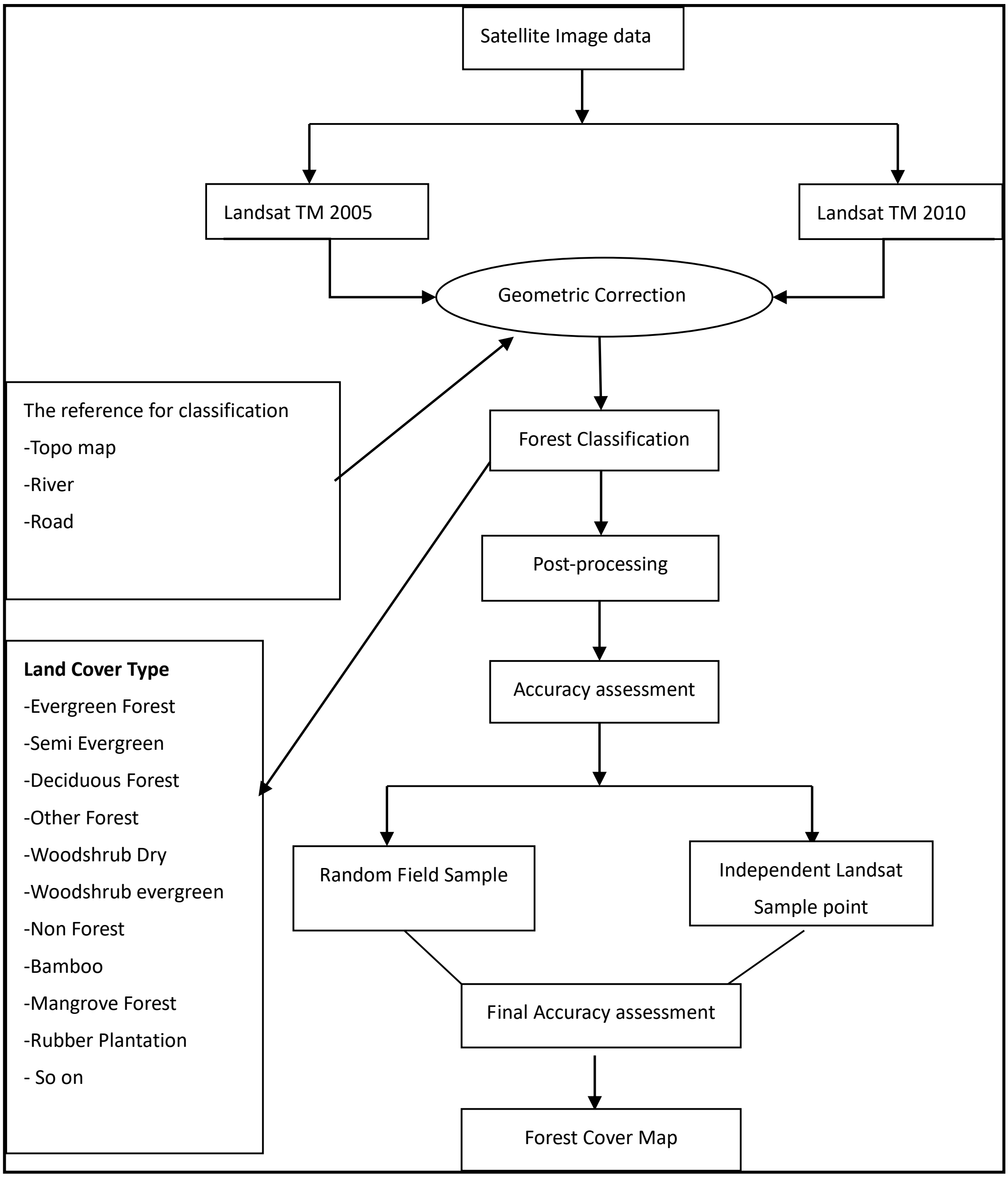


Fig.3- 1 General procedures of images classification

3.3 Classification Accuracy Assessment

A validation process was carried out in order to assess the classification accuracies of the classified map. The accuracy assessments of classification results should be made through a confusion or error matrix. A confusion matrix contains information about actual and predicted classifications done by a classification system. The pixel that has been categorised from the image was compared to the same site in the field. The result of an accuracy assessment typically provides the users with an overall accuracy of the map and the accuracy for each class in the map. The percentage of overall accuracy was calculated using following formula:

Overall accuracy = Total number of correct samples/Total number of samples*100

Besides the overall accuracy, classification accuracy of individual classes was calculated in a similar manner. The two approaches are user's accuracy and producer's accuracy. The producer's accuracy is derived by dividing the number of correct pixels in one class divided by the total number of pixels as derived from reference data. In this study, the producer's accuracy measures how well a certain area has been classified. It includes the error of omission which refers to the proportion of observed features on the ground that is not classified in the map. Meanwhile, user’s accuracy is computed by dividing the number of correctly classified pixels in each category by the total number of pixels that were classified in that category. The user’s accuracy measures the commission error and indicates the probability that a pixel classified into a given category actually represents that category on ground. Producer’s and user’s accuracy are derived from following formula:

Producer’s accuracy (%) = 100% - error of omission (%)

User’s accuracy (%) = 100% - error of commission (%)

More details about the validation, as the number, location and type of sample were selected as the guide ‘**General guide for LULC mapping using mid-resolution remote sensing data for GMS+ project**’.

3.4 Forest Coverage Map of 2005

3.4.1 **Satellite imagery**

A total of 163 Landsat imageries have been used as a base map in this project to map forest and land cover for the years 2005. The example list of Landsat imageries used in this project is shown in Table3-3.

Imageries dated ranges from 2004 to 2006 were used to produce forest and land cover map series of 2005. The Landsat imageries used as a base map for 2005 series are shown in Figures3-2.

Table 3- 3 Example list of Landsat imageries used to map 2005 forest and land cover maps of GMS +

No.	Landsat Data Series	Path/Row	Date
1	p116r056_5dt20060727sr	116/056	27 June 2006
2	p116r057_5dt20060305sr	116/057	5th Mar 2006
3	p117r055_5dt20060803sr	117/055	3rd August 2006
4	p117r056_5dt20041117sr	117/056	17 November 2004
5	p117r057_5dt20050917sr	117/057	17 September 2005
6	p118r055_5dt20060607sr	118/055	7th June 2006
7	p118r056_5dt20040617sr	118/056	17 June 2004
8	p118r057_7dt20070704sr	118/057	4th July 2007
9	p118r058_7dt20070805sr	118/058	5th August 2007
10	p119r057_5dt20050611sr	119/057	11 June 2005
11	p119r058_5dt20050814sr	119/058	14 August 2005
12	p119r059_5dt20050814sr	119/059	14 August 2005
13	p120r058_5dt20060925sr	120/058	25 September 2006
14	p120r058_7dt20040810sr	120/058	10 August 2004
15	p120r059_5dt20060925sr	120/059	25 September 2006
16	p121r059_5dt20040622sr	121/059	22 June 2004
17	p125r058_5dt20070510sr	125/058	10 May 2007
18	p125r059_5dt20050504sr	125/059	4th May 2005
19	p126r056_5dt20060530sr	126/056	30 May 2006
20	p126r057_5dt20041202sr	126/057	2nd December 2004
23	p126r058_5dt20040422sr	126/058	22 April 2004
24	p126r059_5dt20060903sr	126/059	3rd September 2006
25	p127r056_5dt20040803sr	127/056	3rd August 2004
26	p127r057_5dt20050806sr	127/057	6th August 2005
27	p127r058_5dt20061215sr	127/058	15 December 2006
28	p128r055_5dt20040623sr	128/055	23 June 2004
29	p128r056_5dt20040319sr	128/056	19 Mar 2004
30	p128r057_5dt20061104sr	128/057	4th November 2006
31	…….	…….	…….
32	…….	…….	…….

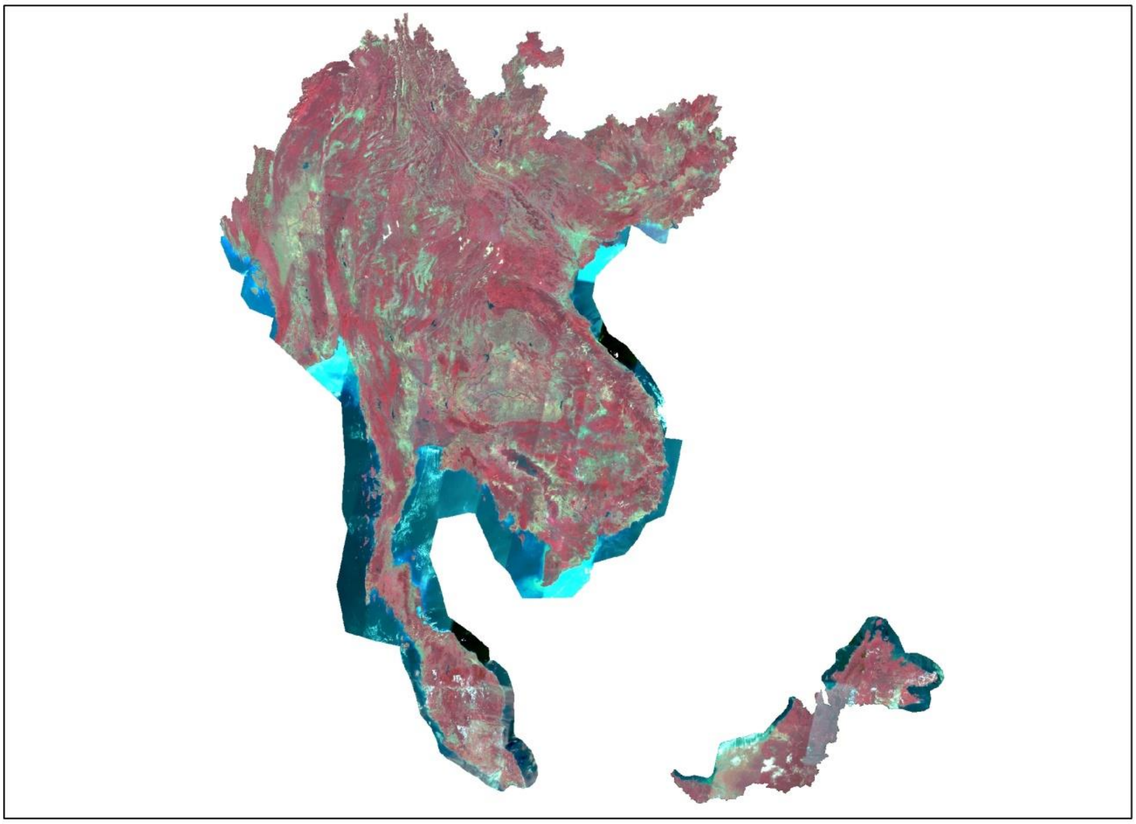


Fig. 3-2 Landsat imageries of 2005 series of GMS+

3.4.2 The results of Classification

A total of 40 land cover classes for whole test site were determined and used in this project. All the imageries of 2005 were classified and labeled based on these land cover classes. Land cover classes that have been determined and used in this project are shown in Table 1. However, in different country, the number of forest cover classes used was different. For example, there were 16 classes mainly found within Lao PDR country; For Malaysia, 13 land cover classes were determined and used; 16 classes were determined and used in Myanmar.

As a result of the classification, the forest cover map in 2005 was produced based on the Landsat 5 (Figure3-3). The percentage of forest cover was calculated and shown in Table 3-4.

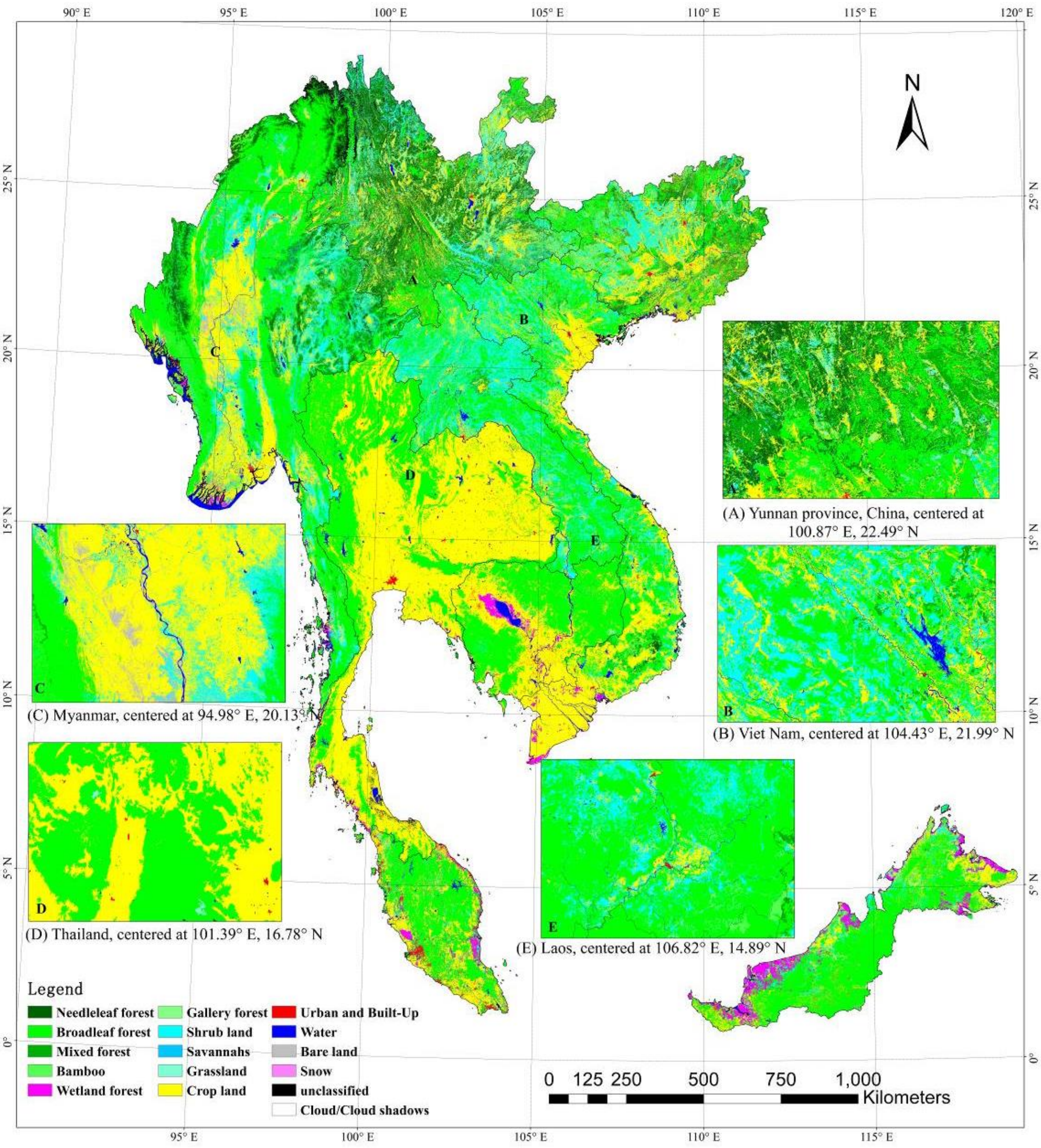


Fig. 3-3 Forest cover map in 2005

Table 3-4 The area of land cover classes for GMS+ **in 2005**

No.	Land cover class	Area in 2005 (ha)	Percentage
1	Bamboo	1982260.62	0.01
2	Bare land	1529639.28	0.01
3	Broadleaf forest	108870547.2	0.38
4	Cloud/Cloud shadows	939563.82	0.00
5	Crop land	92598050.16	0.32
6	Grassland	5590013.49	0.02
7	Mixed forest	9959726.52	0.03

8	Needleleaf forest	18542296.26	0.06
9	Savannahs	33169.14	0.00
10	Shrub land	36955830.87	0.13
11	Snow	271693.8	0.00
12	Urban and Built-Up	1986974.64	0.01
13	Water	5274911.52	0.02
14	Wetland forest	4120804.35	0.01
	Total	288655481.7	1.00

3.5 Forest Coverage Map of 2010

3.5.1 Satellite imagery

A total of 163 Landsat imageries have been used as a base map in this project to map forest and land cover for the years 2010. A list of Landsat imageries used in this project is shown in Table 3-5.

Table 3-5 Example list of Landsat imageries used to map 2010 forest and land cover maps of GMS +

No.	Landsat Data Series	Path/Row	Date
1	L5128055_05520091112	128/055	5th May 2009
2	L5128056_05620100216	128/156	6th May 2010
3	L5128057_05720100216	128/057	6th May 2010
4	L5127056_05620100601	127/056	5th June 2010
5	L5127057_05720100601	127/057	5th July 2010
6	L5127058_2010152	127/058	2010
7	L5126056_05620090522	126/056	5th June 2009
8	L5126057_05720090420	126/057	5th July 2009
9	L5126058_05820100202	126/058	5th August 2010
10	L5126059_05920100202	126/059	5th September 2010
11	L5125058_05820091209	125/058	5th August 2009
12	L5125059_05920090208	125/059	5th September 2009
13	L8121059_2013166l	121/059	2013
14	L5120058_05820090731	120/058	5th August 2009
15	L5120059_05920090731	120/059	5th September 2009
16	L5119057_2009253sub	119/057	2009
17	L5119058_05820090910	119/058	5th August 2009

18	L5119059_05920090910	119/059	5th September 2009
19	L5118055_05520100210	118/055	5th May 2009
20	L5118056_05620090428	118/056	5th June 2009
21	L5118057_05720090615	118/057	5th July 2009
22	L5118058_05820090615	118/058	5th August 2009
23	L5118059_2010041	118/059	2010
24	L5117055_2009223	117/055	2009
25	L5117056_05620090811	117/056	5th June 2009
26	L5117057_2009223	117/057	2009
27	L5116056_05620090719	116/056	5th June 2009
28	L5116057_05720090804	116/057	5th July 2009
29	…….	…….	…….
30	…….	…….	…….

Imageries dated ranges from 2009 to 2010 were used to produce forest and land cover map of 2010. The Landsat imageries used as a base map for 2010 series are shown in Figure 3-4.

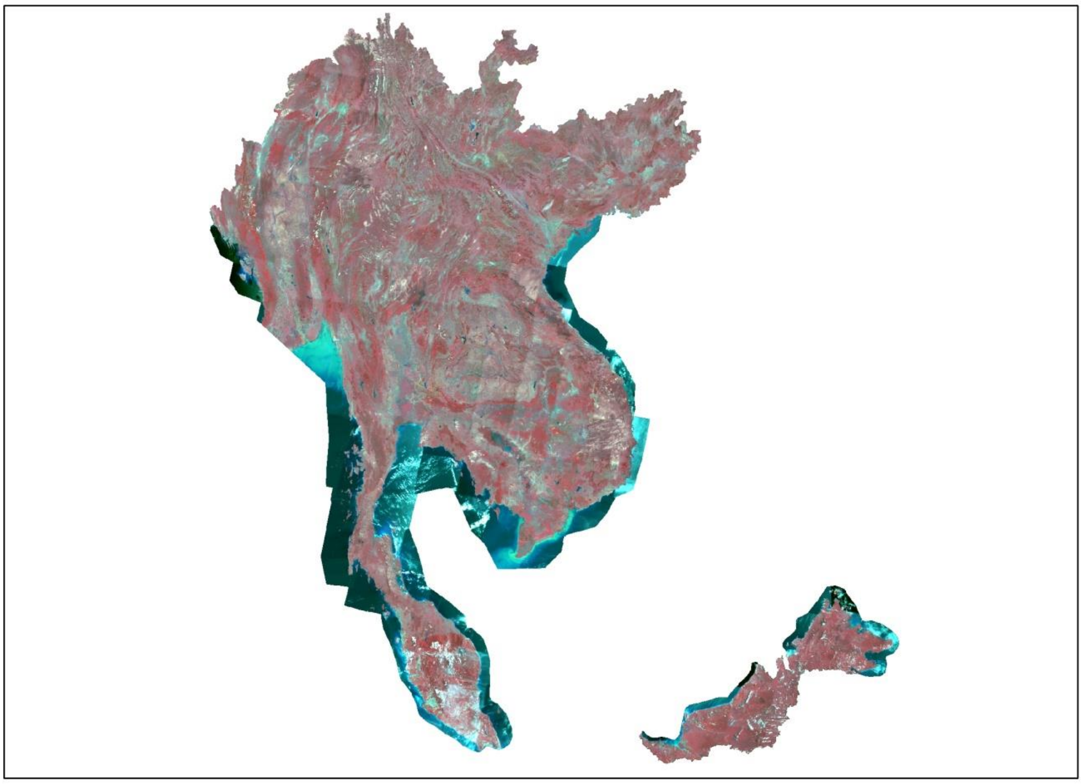


Fig. 3-4 Landsat imageries of 2010 series of GMS+

3.5.2 **The results of Classification**

A total of 40 land cover classes for whole test site were determined and used in this project. All the imageries of 2010 were classified and labeled based on these land cover classes. These land cover classes that have been determined and used in this project are shown in Table 3-1. However, the number of forest cover classes used might have slight difference in different country. For example, there were 8 land cover classes in Thailand, while there were 11 classes in Malaysia.

As a result of the classification, the forest cover map in 2010 was produced based on the Landsat 5 TM data (Figure 3-6). The percentage of forest cover was calculated and shown in Table 3-6.

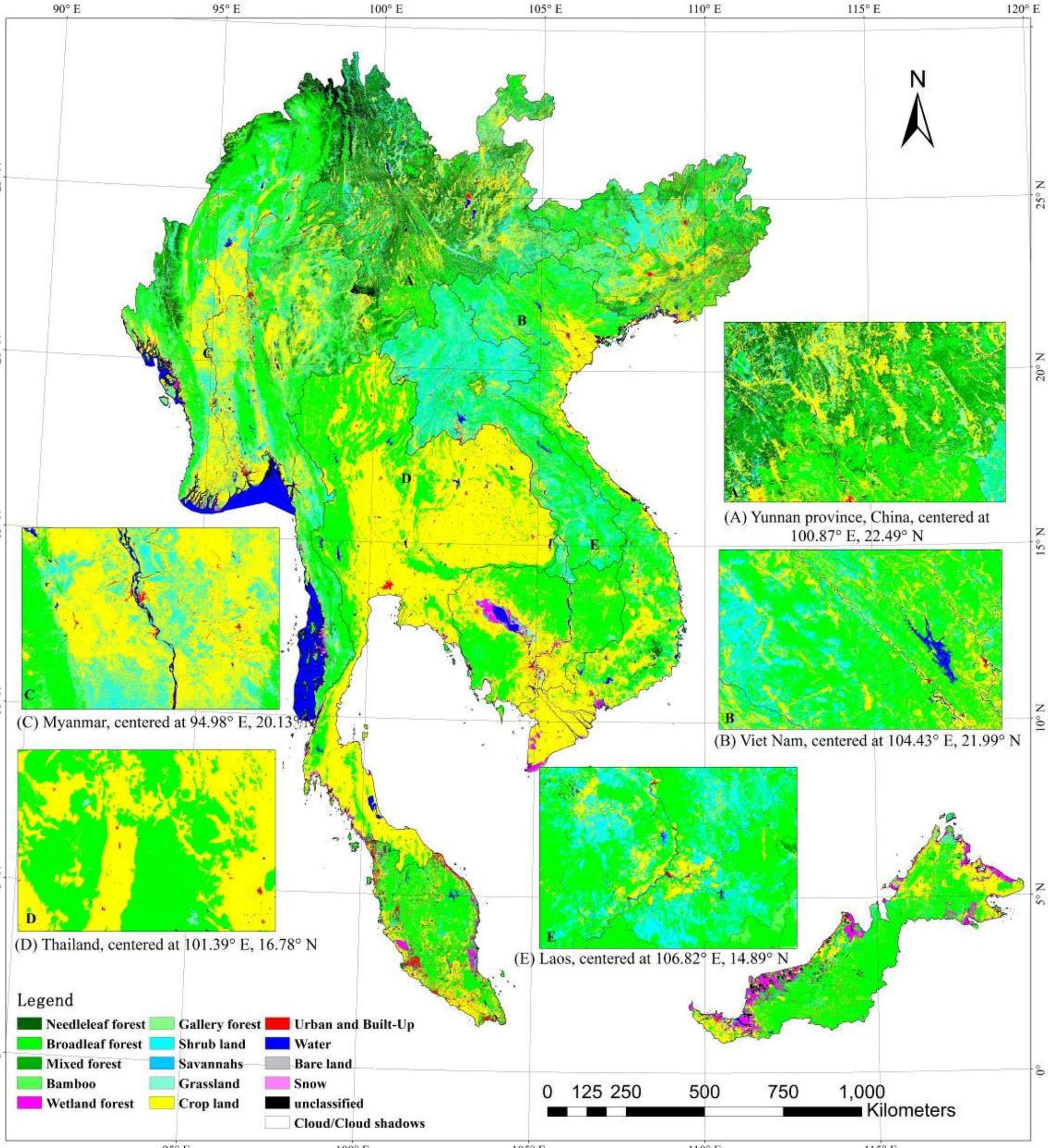


Fig. 3-5 Forest cover map in 2010

Table 3-6 The area of land cover classes for GMS+ in 2010

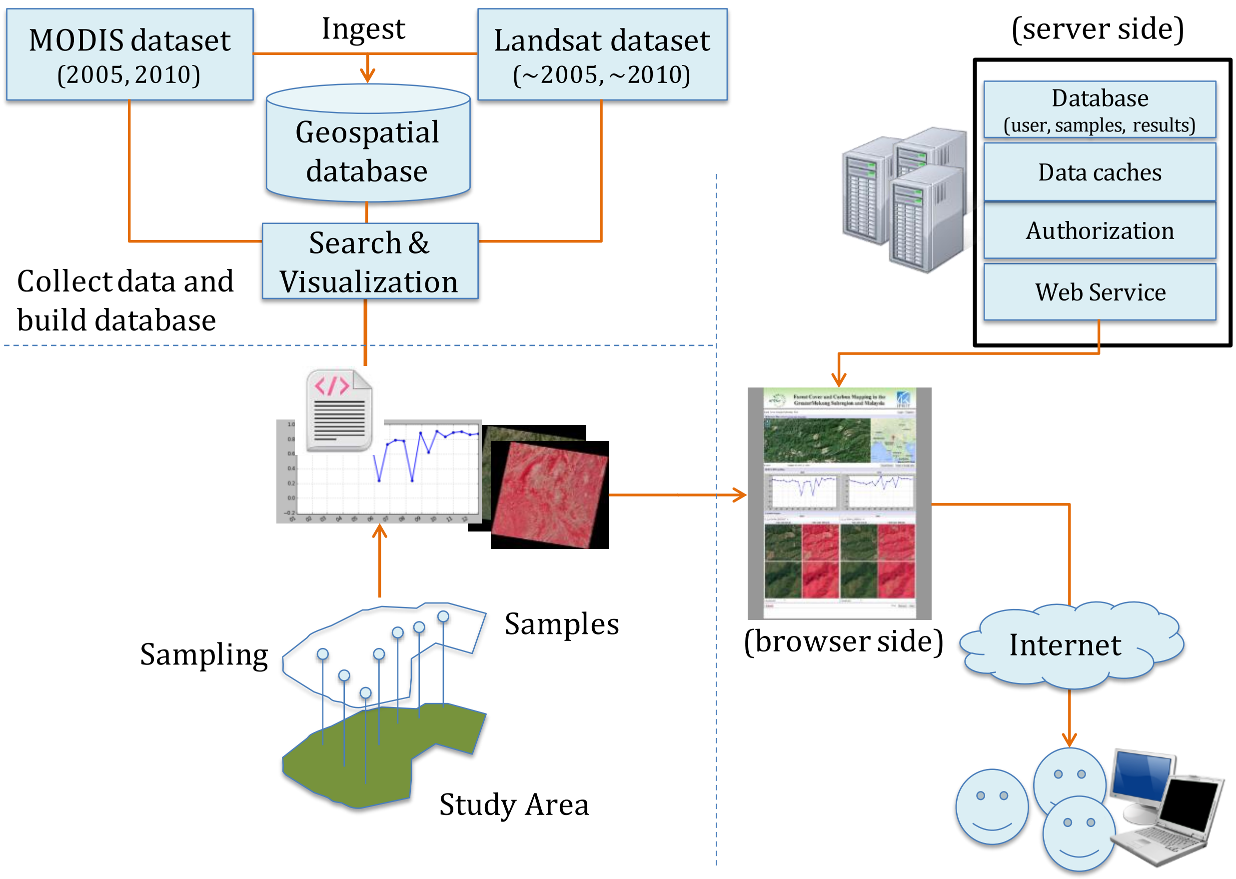
No.	**Land cover class**	**Area in 2010 (ha)**	**Percentage**
1	Bamboo	1361597.67	0.00
2	Bare land	1467309.78	0.01
3	Broadleaf forest	98167416.84	0.34
4	Cloud/Cloud shadows	1236737.7	0.00
5	Crop land	106014051.4	0.36
6	Grassland	4441663.44	0.02
7	Mixed forest	7321759.74	0.03
8	Needleleaf forest	17853155.01	0.06
9	Savannahs	1026920.7	0.00
10	Shrub land	38509586.82	0.13
11	Snow	137988.9	0.00
12	Urban and Built-Up	2520004.14	0.01
13	Water	8900727.39	0.03
14	Wetland forest	3637326.78	0.01
	Total	292596246.3	1.00

3.6 Land Cover Sample Collection Tool

Use of field plot data to validate land cover change products is challenging. Field data collection is expensive and time consuming, and can be substantially delayed during the rainy season or other bad weather conditions. More importantly, data collected during a field trip only reflect the condition at the time the field trip was conducted. It's hard to obtain reliable information on historical conditions. Therefore, it is difficult, if not impossible, to rely on data collected through field work to validate land cover change products.

Satellite images, especially Landsat images, are available for up to 40 years in many areas. These images can provide information on historical land cover conditions, and therefore may allow validation of land cover change products. In addition, Landsat images are often available for an entire study area, making it possible to implement any probability based sampling design methods, which are required for deriving unbiased accuracy estimates.

The land cover sample collection tool is designed to facilitate reference data collection using Landsat and other available datasets. While in some cases Landsat data alone allow reliable determination of the land cover type at a location, in other cases, high resolution images available from GoogleMap or Bing Map and phonological information from MODIS can provide valuable information for determining the land cover type. This tool automatically loads all related datasets for a sample location to a web browser so that an image analyst can focus on analyzing the data in determining the appropriate land cover type. The results derived using this tool are stored in a database, and can be downloaded as an Excel CSV file. This Web based tool can be used with any Web browser, and no client installation is required.



Collect data

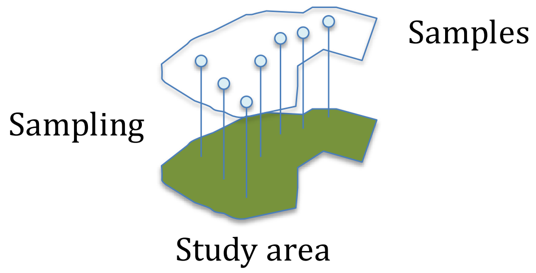
MODIS and Landsat data are collected for the study area. The Landsat data need to be processed for atmospheric correction. MODIS NDVI product is needed for producing NDVI profiles.

Build database

A geospatial database is built to indexing the satellite data and other data products as well as the interpreted results. PostgreSQL 9.3 is adopted as the database platform.

Samples

Samples are collected randomly or systematically within a study area. The sample collection strategy can be designed and adjusted according to the regional land cover types.



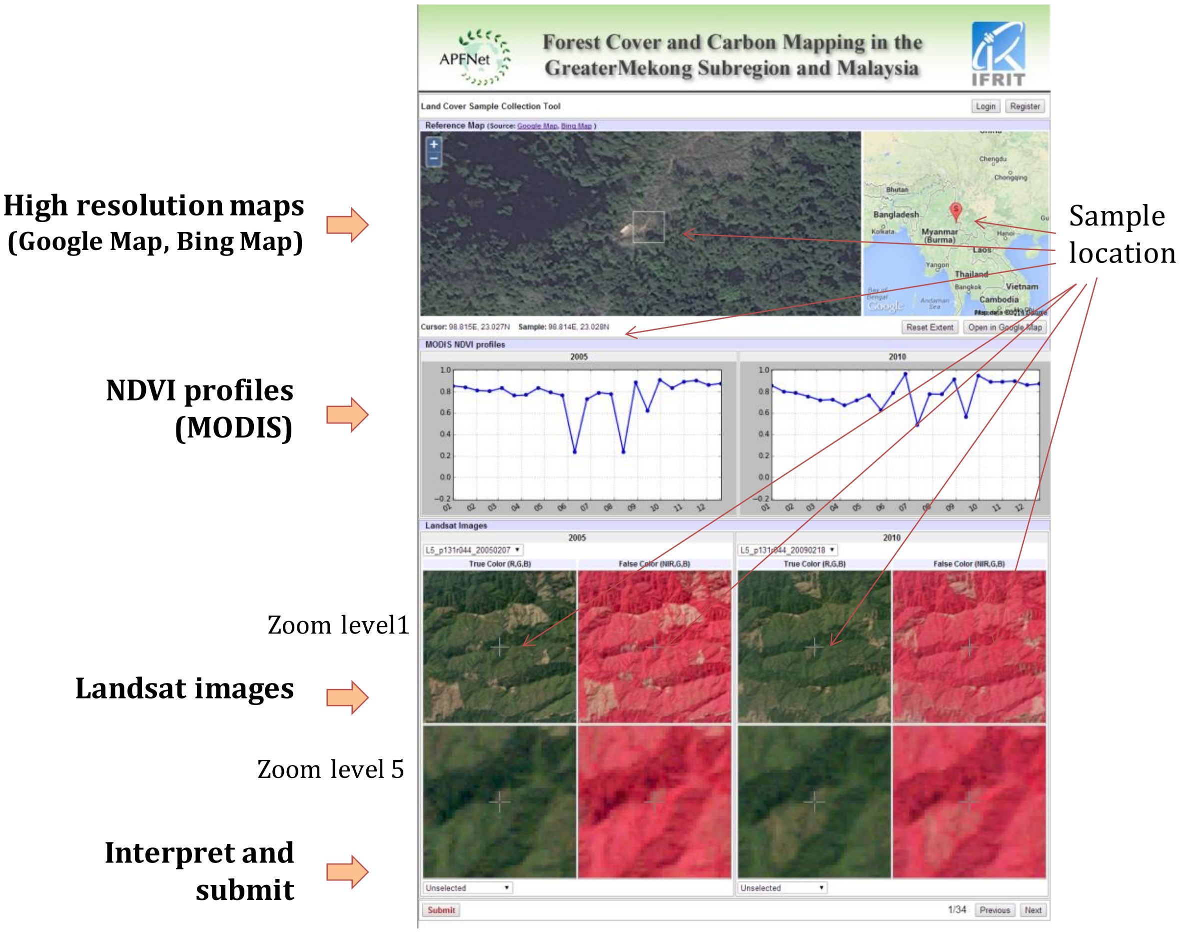
A command is provided to deploy the samples to the online tool.

Server side

The service side of the tool provides the capability for data processing and providing Web services.

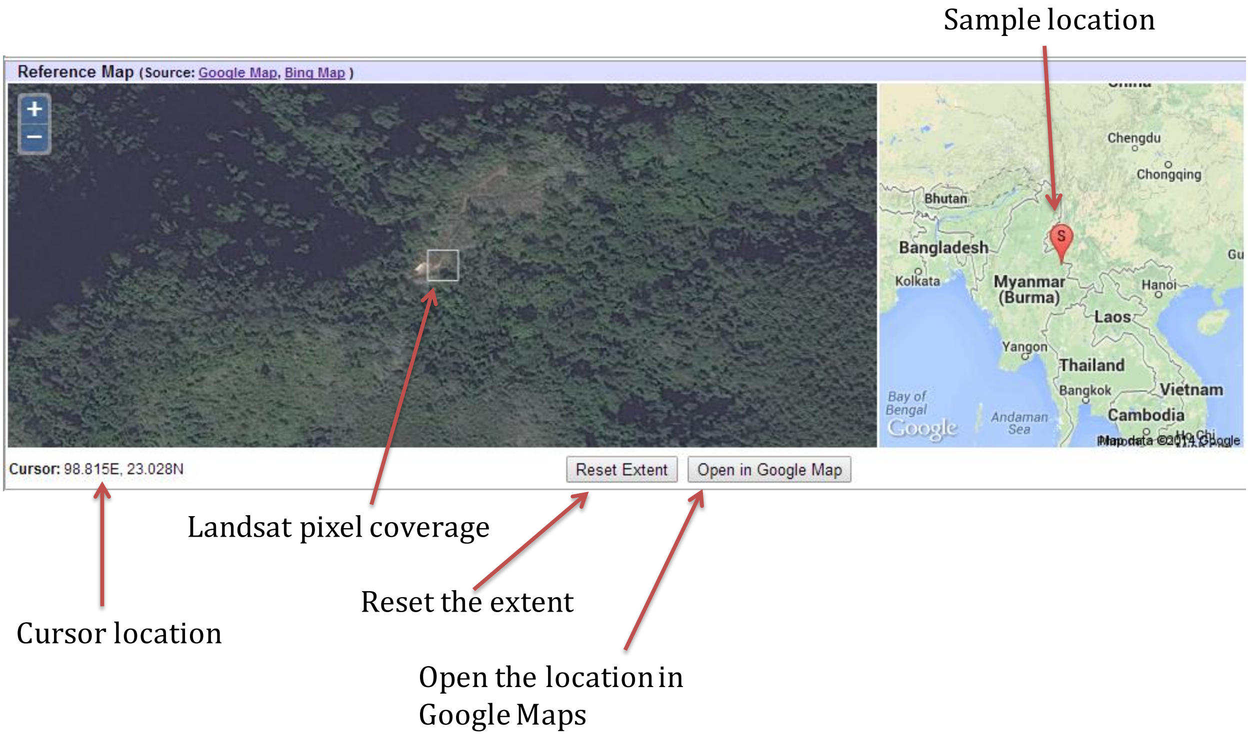
Client side

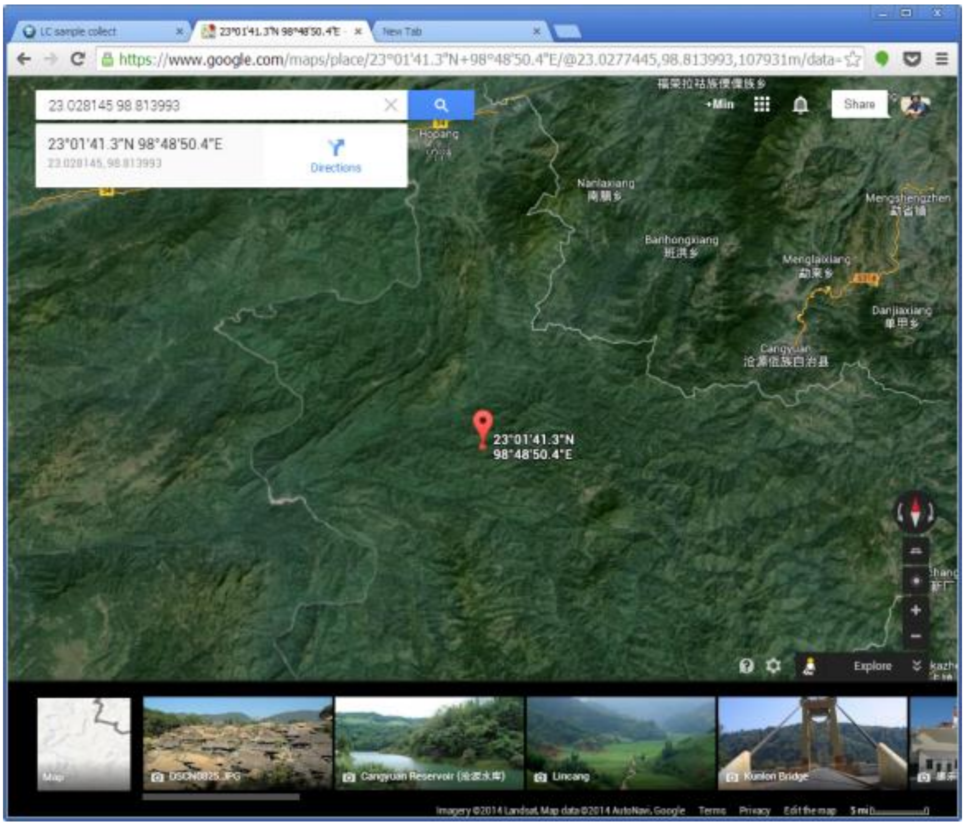
The client side provides a Web page interface for user to browse maps and interpret the land cover types for the selected samples.



1) High Resolution Maps

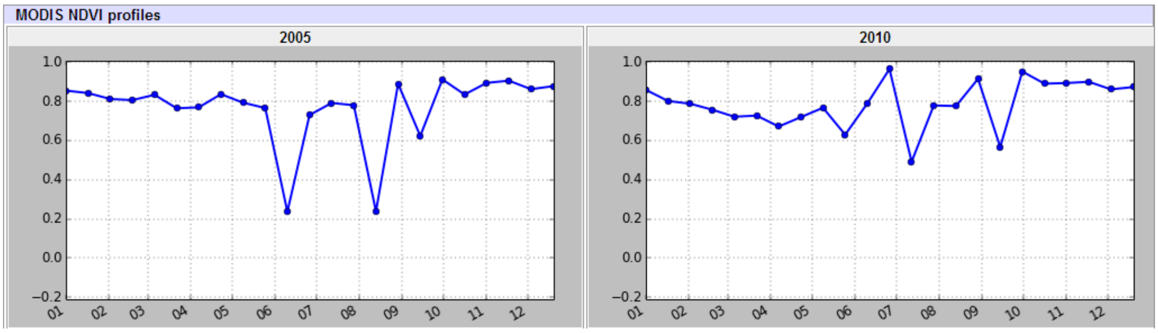
Google Maps and Bing Map are integrated as the high resolution maps, providing satellite image with possibly higher resolution than Landsat data. The left map shows the high resolution satellite image; the right small map shows the location of the sample. The high resolution satellite map can be zooming in/out or pan with the mouse. The cursor location is showed at the bottom of the map. Two utility buttons are provided to return to the initial map extent or open the location in Google Map window.





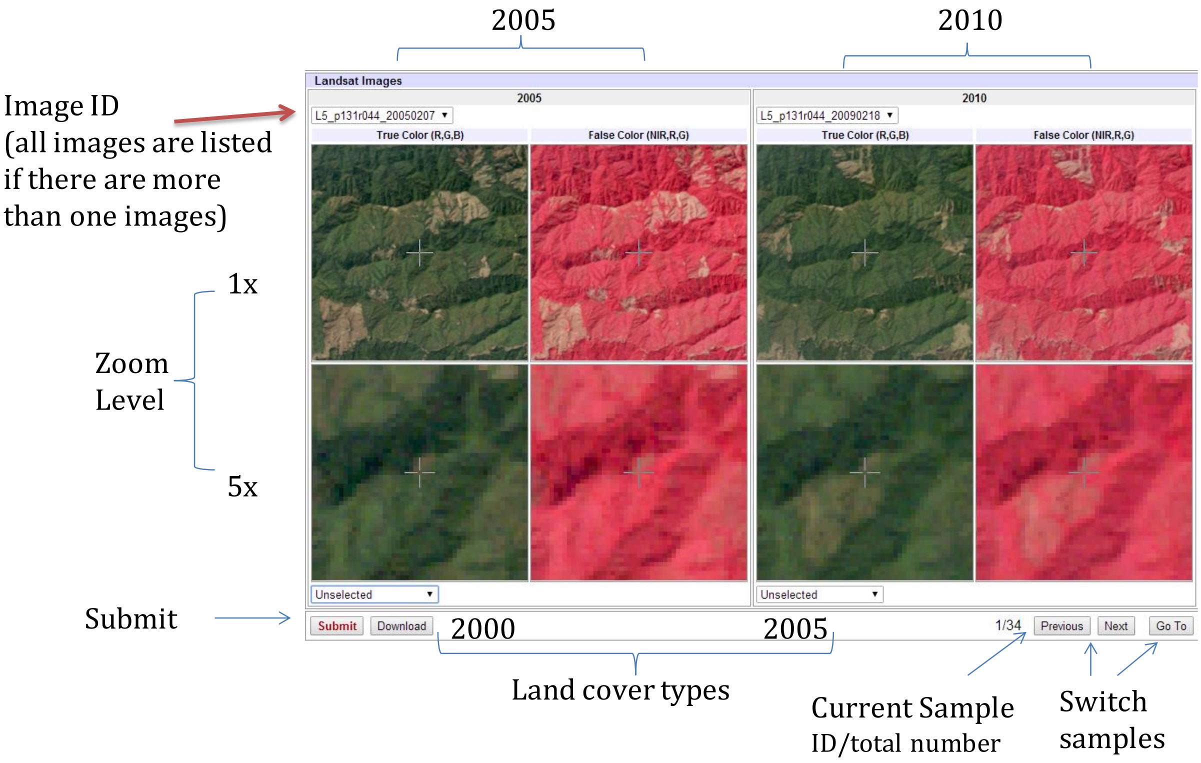
NDVI profiles

The NDVI profiles for 2005 and 2010 are retrieved at the sample location from MODIS NDVI products (MOD13Q1).



Landsat images

The Landsat data is atmospherically corrected to surface reflectance because the SR maps are consistent between images. True color (R-G-B) and false color (NIR-R-G) band combination images are presented for each epoch. The sample pixel is located at the center of the crossings.



Classification Scheme

A comprehensive classification scheme was adopted

- Needleleaf Forest
- Broadleaf Forest
- Mixed Forest
- Wetland Forest
- Gallery Forest
- Bamboo

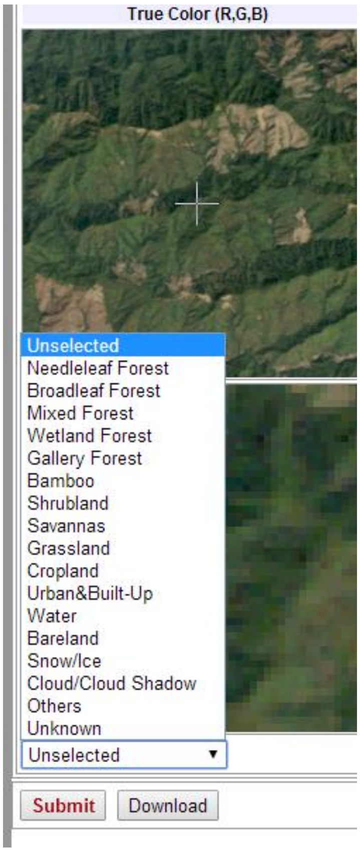
- Shrubland
- Savannas
- Grassland
- Cropland
- Urban&Built-Up
- Water
- Bareland
- Snow/Ice
- Cloud/Cloud Shadow
- Others
- Unknown

Note: the classification scheme can be adjusted according to regional land cover types.

Interpret Land Cover Types

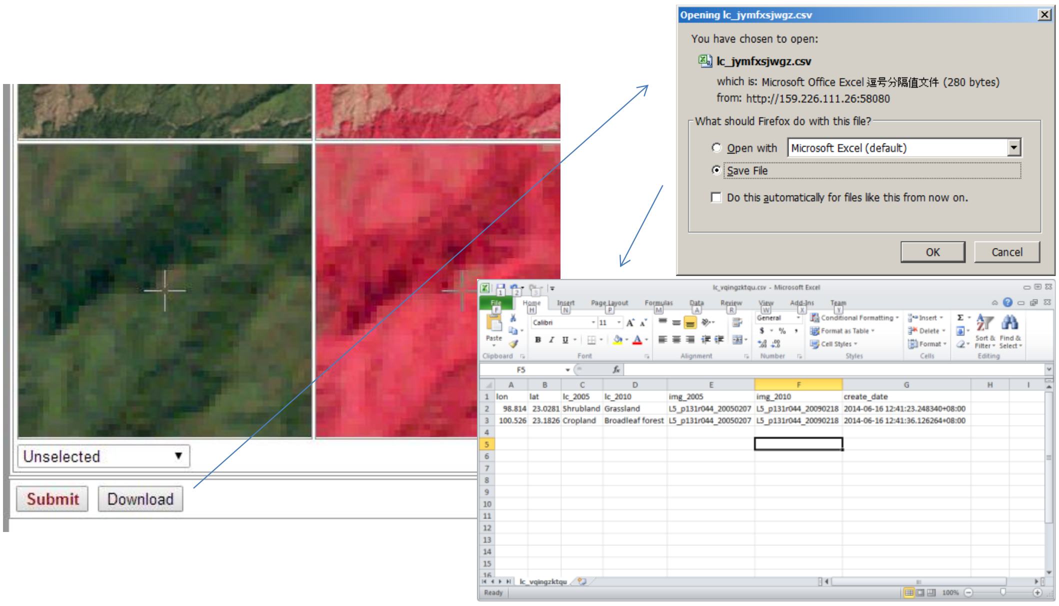
Interpreters can determine the land cover types at the sample location by checking all the maps. After select the land cover types for the epoch at the dropdown box, interpreters can lick the “submit” button to submit.

Note: the tool will switch to the next sample after submission. The submitted results can be viewed by downloading the results or check it when navigate back to the sample.



Download Results

The submitted results can be downloaded as an CSV file with coordinates, which can be viewed in Excel or ArcGIS.



3.7 Classification results validation

A validation process was carried out in order to assess the classification accuracies of the classified map. The accuracy assessment of the results of forest cover mapping using satellite images was mostly based on filed validation.

According to the guide '**General guide for LULC mapping using mid-resolution remote sensing data for GMS+ project**', the total number of ground visited points should be at least 50 points per type in every country. The location of samples will be distributed homogenized in land. All these points collected from ground filed were then compared in order to access the classification accuracies for 2005 and 2010 maps.

As a result, the average overall classification accuracy is 80 % approximately for the forest cover map in 2010, and with kappa coefficient 0.78 for the whole test site of the GMS+ project.

Table 3-7 Evaluation of Forest Cover Map of 2005

	Overall accuracy in 2005	Kappa Coefficient
Cambodia	92.00	0.88
Chian-Guangxi	80.70	0.7514
China-Yunnan	73.25	0.6845
Lao PDR		

Malaysia	91.00	
Myanmar	91.23	
Thailand	84.00	0.82
Vietnam		

Table 3-8 Evaluation of Forest Cover Map of 2010

	Overall accuracy in 2010	Kappa Coefficient
Cambodia	90.00	0.85
Chian-Guangxi	82.1	0.7708
China-Yunnan	71.04	0.6579
Lao PDR	89.66	0.88
Malaysia	93.00	
Myanmar	94.11	
Thailand	85.00	0.81
Vietnam	85.00	

3.8 Forest changes analysis

3.8.1 Forest cover change analysis

The forest coverage of each economy was shown in table 3-9. Forest coverage is 48.4% and 46.2% in 2005 and 2010 respectively for the whole region. So the forest net loss is 6% from 2005 to 2010.

Table 3-9 The forest coverage of each economy between 2005 & 2010 in the GMS and Malaysia

country/area	forest cover 2005(%)	forest cover 2010(%)
Cambodia	**59.04**	**57.01**
Guangxi, China	**42.88**	**40.81**
Lao	**51.50**	**37.81**
Malaysia	**67.81**	**62.82**
Myanmar	**54.63**	**39.17**
Thailand	**33.87**	**31.57**
Viet Nam	**40.37**	**43.78**
Yunnan, China	**53.41**	**52.19**

We further made the change map using the forest cover map of 2005 and 2010. The land cover classes were recoded into forest, non-forest, and others (include cloud, shadow, unclassified types). Then the forest change map was generated as shown in Fig. 3-6. Table 3-10 showed the acreage of different forest change types between 2005 & 2010 in the GMS and Malaysia. Even most forest areas were kept as forest type, the forest loss (forest in 2005 with non-forest in 2010) and forest gain (non-forest in 2005 with forest in 2010) are also distributed in most regions.

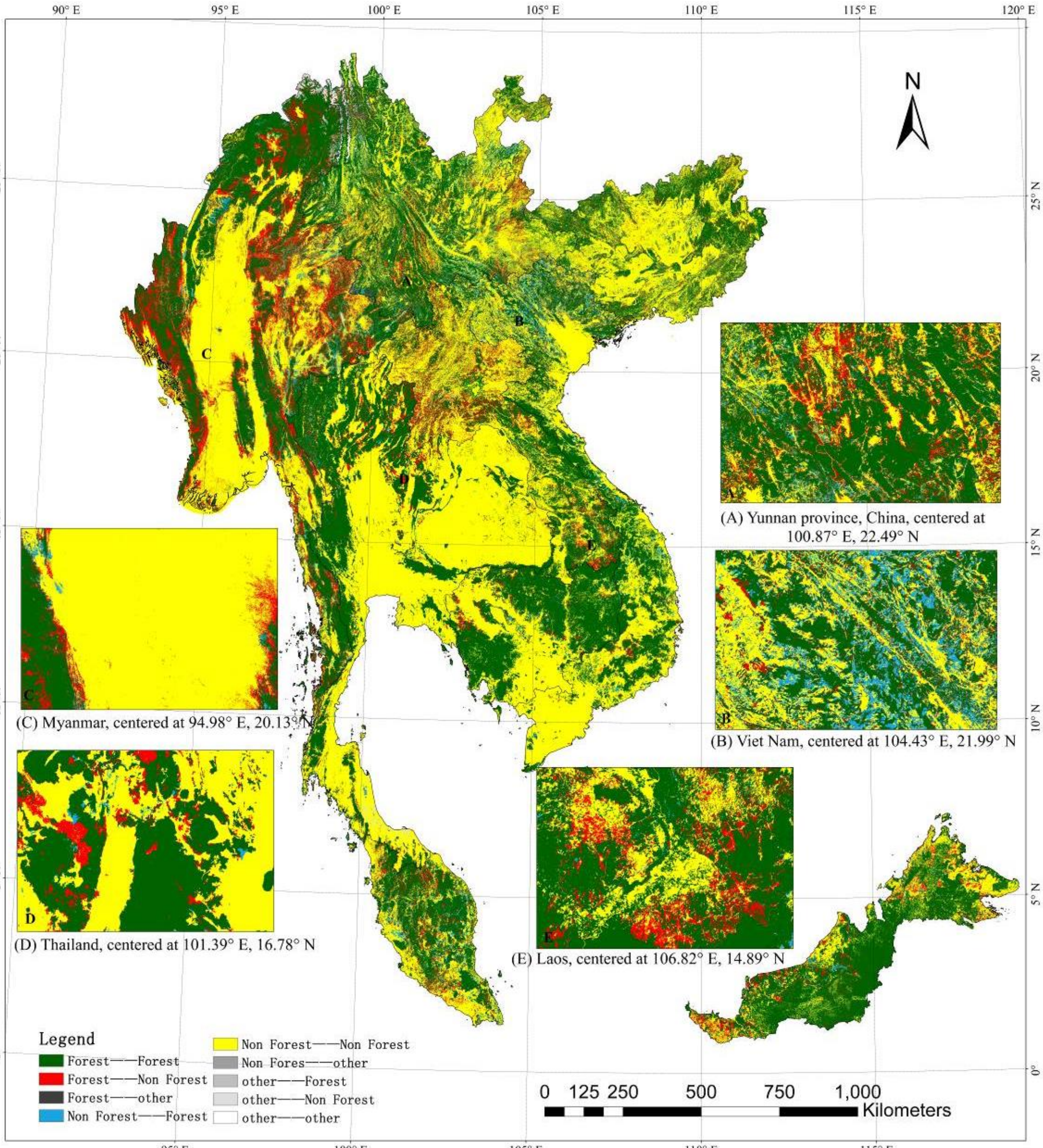


Fig. 3-6 Forest change between 2005 & 2010 in the GMS and Malaysia

3.8.2 Forest gain and loss distribution analysis

Fig. 3-7 shows the forest gain and loss thematic map. There are much more forest loss than forest gain, which caused the decreasing of forest coverage of this region. Overall, forest loss and gain happed in every economy. The forest loss mainly occurred in Laos and Myanmar. The forest gain mainly occurred in Yunnan of China, the north of Viet Nam, central part of Myanmar, and the east part of Malaysia.

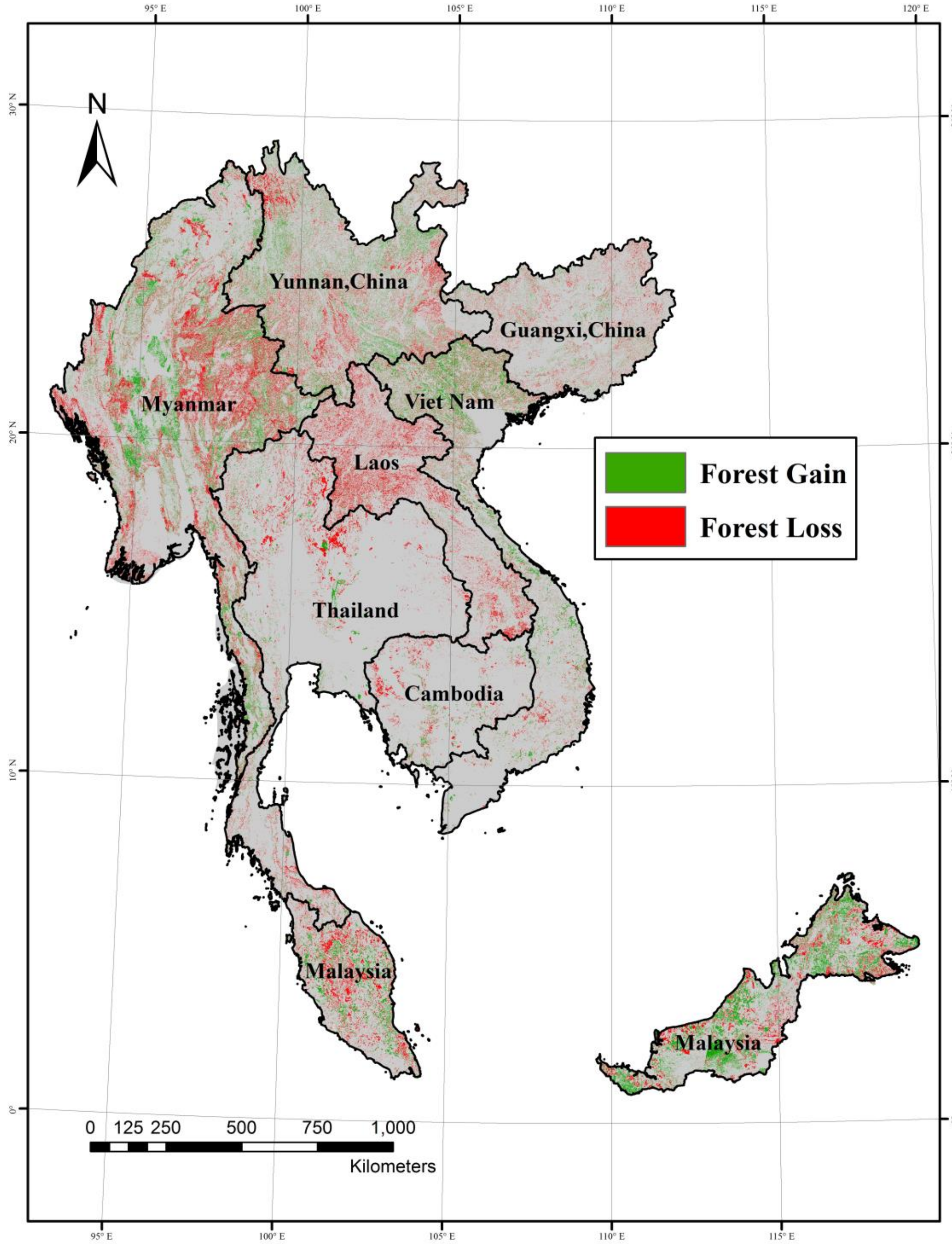


Fig. 3-7 Forest gain and loss between 2005 and 2010 in GMS & Malaysia

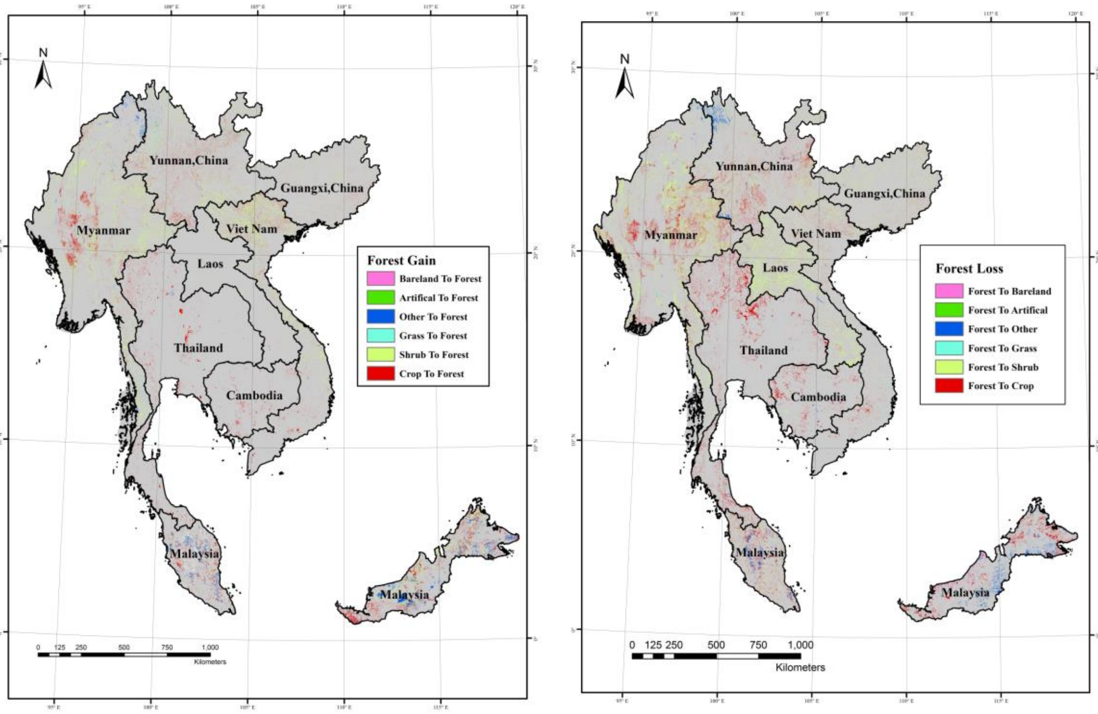
Table 3-10 The forest change between 2005 & 2010 in the GMS and Malaysia

Land cover change type	Area (ha)	Percentage
Forest----Forest	115681624.1	0.40
Forest-----Non Forest	26965371.51	0.09
Forest-----other	551944.17	0.00
Non Forest----Forest	11915863.2	0.04
Non Forest----Non Forest	131557795.7	0.46
Non Forest-----other	335153.07	0.00
other----Forest	299498.4	0.00
other-----Non Forest	428870.88	0.00
other-----other	468383.76	0.00
Total	288204504.8	1.00

3.8.2 Forest gain and loss sources analysis

With the support of other detailed land cover types described in 3.4 and 3.5, we further mapped the sources of forest gain and loss between 2005 and 2010 in GMS & Malaysia (Figure 3-8). The transform of forest with shrub, grassland and cropland are dominated types in this region. This shows that the competition of crop land extension and forest recovery is still a critical issue. Meanwhile, some afforestation and conservation policies helped the forest recovery and extension. As shown in Fig. 3-8(a), the forest gains from cropland are mainly in the central of Myanmar and Yunnan of China. The forest gains from shrub are mainly in the North part of Viet Nam and Myanmar, the southeast and northeast part of Yunnan. As shown in Fig. 3-11(b), the forest loss types are mainly in Laos, northeast of Myanmar, northwest of Thailand, and the south of Yunnan. In Laos and the north part of Viet Nam, the dominate type of forest loss is forest degraded into shrub. In Thailand and Cambodia, the dominate type of forest loss is forest changed into cropland. For Myanmar and Yunnan of China, the transforms to shrub and cropland are both happed. Malaysia shows a lot of transforms between forest and other types, which might be caused by the cloud and shadow areas.

When we compare Fig. 3-8(a) and (b), most areas have forest loss and gain simultaneously. For those areas with large number of forest gain and loss, forest plays a very import role to local people and economy. For Laos, forest loss happened much more than forest gain, especially for forest degradation.

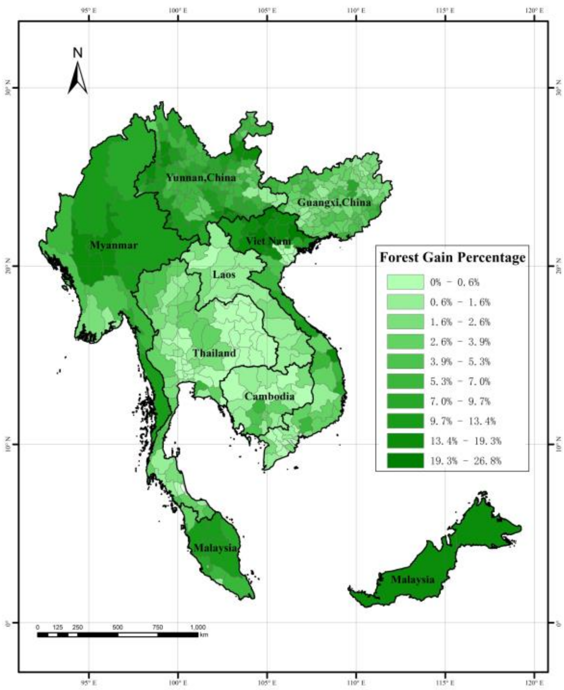


(a) The Sources of Forest Gain (b) The Sources of Forest Loss

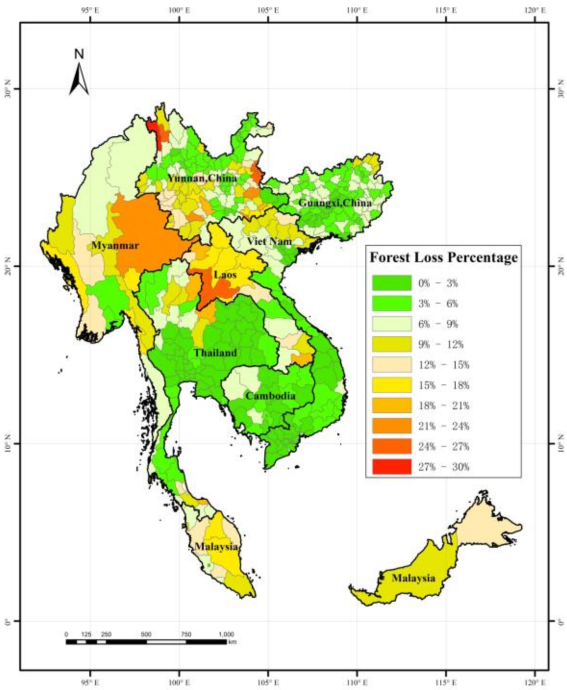
Fig. 3-8 The sources of forest gain and loss between 2005 and 2010 in GMS & Malaysia

3.8.4 Provincial level forest gain and loss analysis

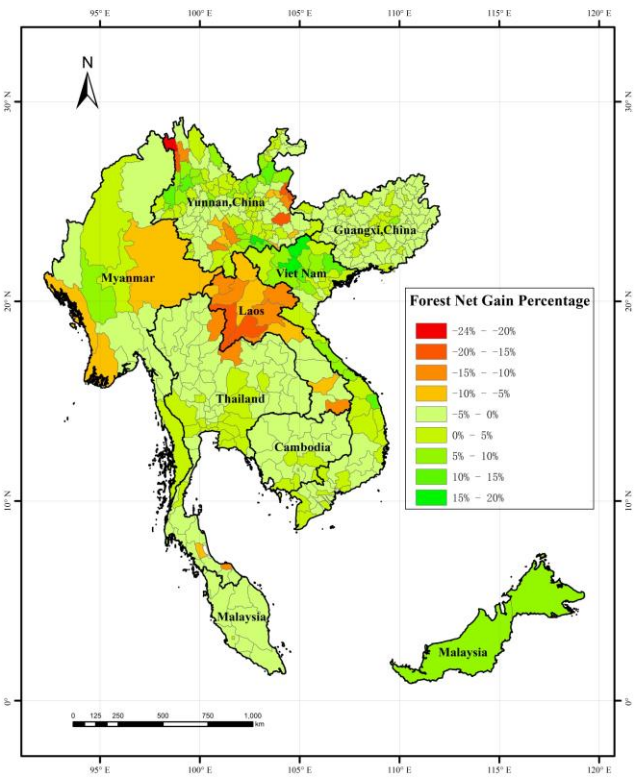
To link these forest gain and loss to administration unit, we summarized the change map at province level (for Myanmar, Laos, Viet Nam, Cambodia, Thailand, and Malaysia) and county level (for Yunnan and Guangxi of China) in Figure 9. From 2005 to 2010, the Xaignabouri, Vientiane and Attapeu provinces of Laos are mainly forest loss area. The Magwe of Myanmar, Ha Giang, Yen Bai, and Lang Son provinces of Viet Nam, show significant increase of forest. Pattani in the south of Thailand also shows significant forest loss during this period.



(a) Forest Gain Percentage Between 2005 and 2010 at Province/County Level in GMS & Malaysia



(b) Forest Loss Percentage Between 2005 and 2010 at Province/County Level in GMS & Malaysia



(c) Forest Net Gain/Loss Percentage Between 2005 and 2010 at Province/County Level in GMS & Malaysia

Fig. 3-9 The Provincial level forest gain and loss analysis between 2005 and 2010 in GMS & Malaysia

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4 Annual forest map product at coarse resolution (500 m) during 2005～2010

4.1 Introduction

Forest vegetation, as a part of the landscape, represents an important natural resource for mankind and other living organisms. Currently, the forestry sector is being considered an appropriate option for limiting greenhouse gases (GHG) concentration in the atmosphere. Deforestation has a great impact on global or regional carbon emissions or uptakes, and is thus of concern to scientists and policy-makers around the world. Previous research on global carbon stocks showed that 55% of global net carbon flux during the period 1850-2000 is from tropical region due to forest cover changes (Achard et al. 2004). Meanwhile, it is also possible to mitigate climate change through conserving existing forests, expanding carbon sinks, substituting wood products for fossil fuels and reducing emissions from deforestation and degradation (known as the Reducing Emissions from Deforestation and Degradation (REDD) mechanism). REDD is an instrument that could reward countries with carbon credits for preserving their forest cover. Under the recent initiative, known as Forest Carbon Partnership Facility (FCPF), 14 developing countries will receive grant support as they build their capacity for REDD through measure including establishing emissions reference levels, adopting strategies to reduce deforestation and designing monitoring systems (DeFries et al., 2007; Vogelmann et al. 2009). Therefore, determining the types and quantifying the extent of forest vegetation, and understanding forest cover and its changes are important for resource management and issues regarding climate change.

There is general agreement that remote sensing is an adequate tool for producing reproducible and reliable information on forest cover at different scales (Mulders, 2001). Forest cover mapping has been perhaps the most widely studied problem employing satellite data, beginning with Landsat 1. Remote sensing overcomes problems associated with excessive topography and large spatial extent, and therefore represents a cost-efficient way of locating different land cover types (Paivinen et al., 2000). On the other hand, in complex mountainous terrain the highly fragmented landscape and very terrain specific features, i.e. shadows, orographically increased cloud cover and its related shadows and snow cover with rapid changes in its spatial extent, causes considerable difficulties in mapping forest vegetation (Paivinen et al., 2000).

However, most of the studies using “fine” resolution data (i.e. 20–100 m) were methodological in nature, exploring various information extraction techniques and applying these over limited areas. Applications over large areas were hampered by the lack of suitable technology, an absence of a user community with a strong need for such information, a lack of appropriate analysis methodologies, and the cost of data. Thus, large-area forest cover datasets compiled from ground surveys or various national sources were, for a number of years, the major source of information.

Since the late 1990s increased attention has been paid to the use of coarse resolution optical data, represented primarily by NOAA (National Oceanic and Atmospheric Administration) Advanced Very High Resolution Radiometer (AVHRR) images. These were initially available at 8 km resolution and later, through the initiative of the International Geosphere–Biosphere Programme (IGBP) (Townshend et al., 1994) and a project involving many AVHRR receiving stations at the nominal resolution of 1 km for all land areas of the globe. Through these efforts, first satellite-based global land cover maps have already been produced (Hansen et al. 2000, Loveland et al. 2000). The launch of new satellite sensors such as SPOT 4 VEGETATION (VGT), Moderate Resolution Imaging Spectroradiometer (MODIS), and Medium Resolution Imaging Spectrometer (MERIS) with a systematic global acquisition strategy will inaugurate a new era in large-area forest cover mapping during which computer speed is no longer an obstacle to processing large volumes of data by a small team.

This chapter introduces a method of using coarse spatial resolution data to map forest cover over a large area.

4.2 Study area and materials

4.2.1 Study area

The study area of the annual forest map production at coarse resolution satellite images covers whole ranges of the GMS and Malaysia demonstration project, which includes from 92.2° to 119.3° east longitude and 0.8° to 29.2° north latitude, with total land area of 317,242,000 ha and total population of 348 million. It includes Cambodia, the People's Republic of China (Yunnan province and Guangxi Zhuangzu Autonomous Region), Lao People's Democratic Republic, Malaysia, Myanmar, Thailand, and Viet Nam. The total forest area is 148,128,000 ha reported by FRA 2010 (Yunnan & Guangxi data were from the 7th national forest inventory of China).

4.2.2 Materials

The main assumption behind forest mapping using satellite data is that the signal is closely related to measures of forest vegetation. For this reason, seasonal variations in forest growth activities can be characterized using their seasonal variations in the NDVI time-series. Thus, large forest mapping by remote sensing is based on tracking significant changes on temporal trajectories of spectral vegetation indices which are more stable over time than single bands.

In this study, the time-series MODIS NDVI data was used to map large-area forest cover for the GMS and Malaysia demonstration project. Some previous studies indicate that moderate spatial resolution products from MODIS instrument are highly desirable for mapping regional land covers and identifying the changes of extensive vegetation ecosystem, although it cannot identify the subtle land cover patches. For our target, time-series of MOD13A1 product (MODIS Level 3 16-day composite of NDVI at 500m resolution) for the period of January to December, from year 2005 to 2010 were collected and acquired from the MODIS observations aboard Terra satellite. The used titles of MOD13A1 product include the V06-V08 and H26-H29, which have been showed in figure 4-1.

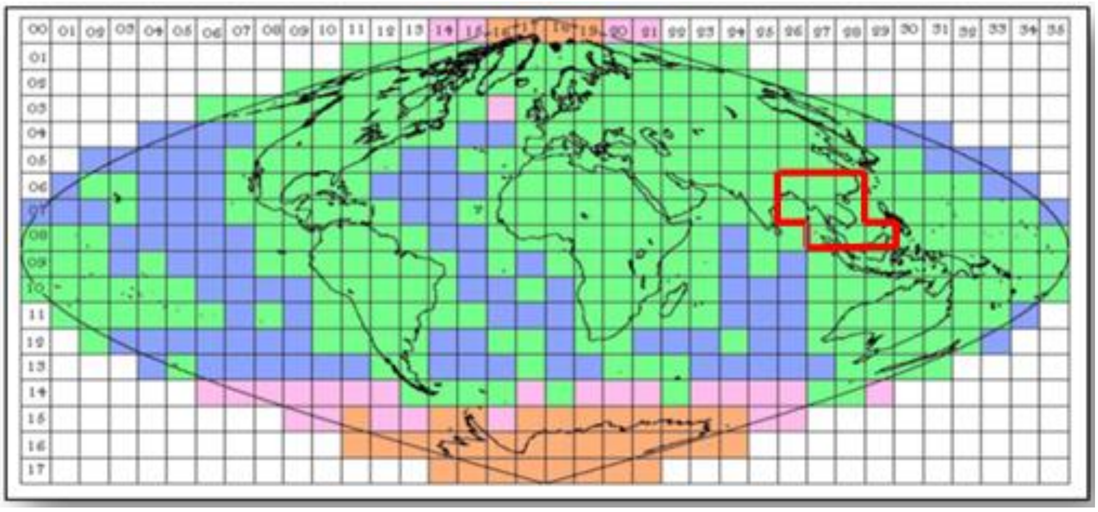


Fig. 4-1 The used MOD13A1 titles for forest mapping

A list of used MOD13A1 images in this project is shown in Table 4-1.

Table 4-1 List of used MOD13A1 for forest mapping during year 2005~2010

Year	Files	Data Size
2005	207	7.0G
2006	207	7.0G
2007	207	7.0G

2008	207	7.0G
2009	207	7.0G
2010	207	7.0G
Total	**1242**	**42.0G**

Furthermore, the spatial distribution of forest cover patterns is strongly dependent on environmental conditions and the terrain (Grabherr et al., 1994). Thus, except for the time-series MODIS NDVI datasets, some non-remote sensing data, such as the DEM data, was also taken into account in order to obtain the high accuracy of forest cover maps. DEM data was taken from SRTM 90m Digital Elevation Data (http://srtm.csi.cgiar.org/) and used to generate the slope information. These DEM and slope data were finally stacked together with monthly NDVI data to get a full set of data for forest classification.

In addition, some ancillary remotely sensed products for training sample selection and classification accuracy assessment were also used and listed in Table 4-2.

Table 4-2 Five global land cover datasets

No.	Data name	Data source	Specification
1	MODIS global land cover dataset	NASA (http://www.geog.umd.edu/landcover/1km-map.html)	Spatial resolution: 1 km Source image:2000/2001
2	IGBP-DISCover global land cover dataset	http://edcsns17.cr.usgs.gov/glcc/globe_int.html	Spatial resolution: 1 km Source image:1992/1993
3	GLC 2000 global land cover dataset	EU Joint Research Centre (http://www-tem.jrc.it/glc2000/)	Spatial resolution: 1 km Source image:1999/2000
4	MERIS GLOBCOVER global land cover dataset	CNES, CNRS, IRD, Météo-France, and INRA (http://postel.mediasfrance.org/en/DOWNLOAD/)	Spatial resolution: 300m Source image:2005/2006
5	Vector datasets	Administration map, topographic map, DEM	

4.3 Processing for forest mapping

4.3.1 NDVI Processing

In this study, the processing for the time-series of MOD13A1 product included the re-project, mosaic, ROI subset, and noise filtering.

Reproject and Mosaic

The project of level-1, 2, 3, 4 of MODIS production is ISIN (Integerized Sinusoidal), and the file format is HDF-EOS (Hierarchical Data Format -Earth Observing System). Those files were mosaicked by MODIS re-projection tool (MRT), and the nearest sampling method was performed to re-sample the data into exact 500m pixel size. The parameters of project have been set as following.

Project type: Albert Conical Equal Area
Spheroid Name: WGS 84
Datum Name: WGS84
Latitude of 1st standard parallel: 0 N
Latitude of 2nd standard parallel: 20 N
Longitude of central meridian: 110 E
Latitude of origin of projection: 0 N
False easting at central meridian: 0 meters
False northing at origin: 0 meters

Subset

To get the images of the project, the mosaicked images have been masked by using the "extract by mask" function of ArcGIS.

4.3.2 Noise Filtering

Using remote sensing to map forest cover requires NDVI time-series with good time resolution, over homogeneous area, cloud-free and not affected by atmospheric and geometric effects and variations in sensor characteristics. Cloud cover is the most serious problem in optical remote sensing of earth's surface. The MOD13A1 NDVI dataset used in this study was developed by the Maximum Value Composite (MVC) technique which produces composite image over a fixed period of time by retaining for each pixel the maximum NDVI value from daily images acquired over this period. Although it is widely accepted that composite NDVI images can greatly reduce cloud and other atmospheric noise while retaining dynamic vegetation information, residual atmospherically related noise, as well as some noise due to other factors, e.g., surface anisotropy, still remain in the NDVI dataset. These problems tend to create data drop-outs or data gaps, and make it difficult to identify forest cover successfully. It is thus necessary to generate smooth NDVI time-series data from noisy sensor data.

Method

Numerous techniques for filtering cloud cover, noise removing and reconstructing a high-quality NDVI time-series datasets have been formulated, applied and evaluated in the last two decades. These methods can be broadly grouped into three general types: threshold-based methods, such as Best Index Slope Extraction (BISE); filtering methods, such as mean value iteration filter, Fourier analysis, Savitsky–Golay filter, Wavelet-based filter; and function fitting methods, such as Asymmetric Gaussian function fitting, Logistic function fitting.

In this study, Savitsky–Golay filter was used to minimize the perturbations and reduce contamination in the NDVI time-series data. These processed 16-day NDVI dataset were then composited to get the monthly NDVI data, and each monthly NDVI data was saved a layer. The general equation of the simplified least-squares convolution for NDVI time-series smoothing can be given as follows:

$$Y_j{}' = \frac{\sum_{i=-m}^{i=m} C_i Y_{j+i}}{N} \qquad (1)$$

Where: Y is the original value; Y' is the estimation value; Ci is the filter coefficient of NDVI at i; N is the size of filter windows (2m+1)。j is the value of NDVI time-series at j.

The flowcharts of Savitsky–Golay filter for NDVI time-series datasets is showed in Figure 4-2.

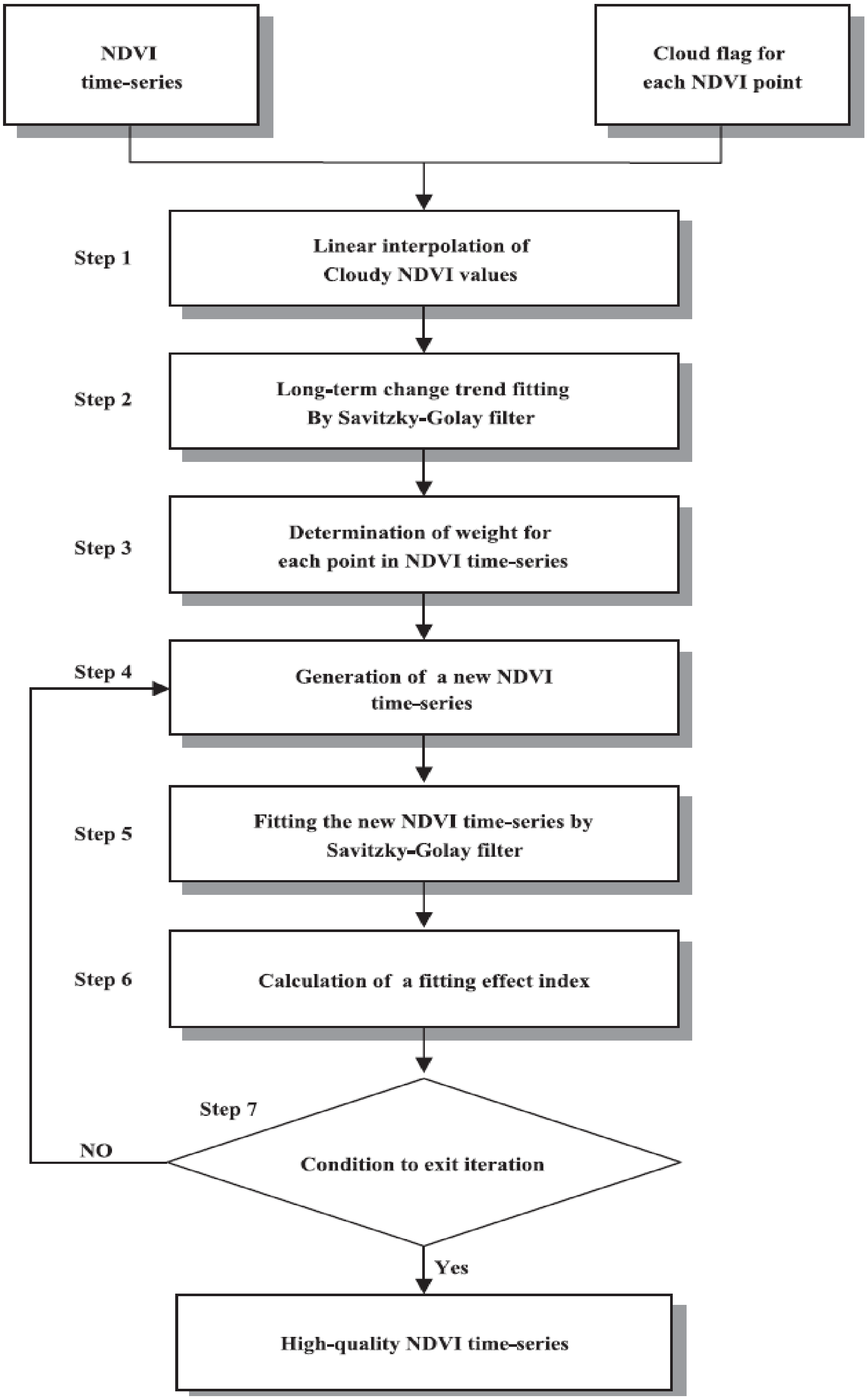


Fig. 4-2 The flowchart of Savitsky–Golay filter for NDVI time-series datasets

Results

Part of results of Savitsky–Golay filter for NDVI time-series datasets showed in Figure 4-3.

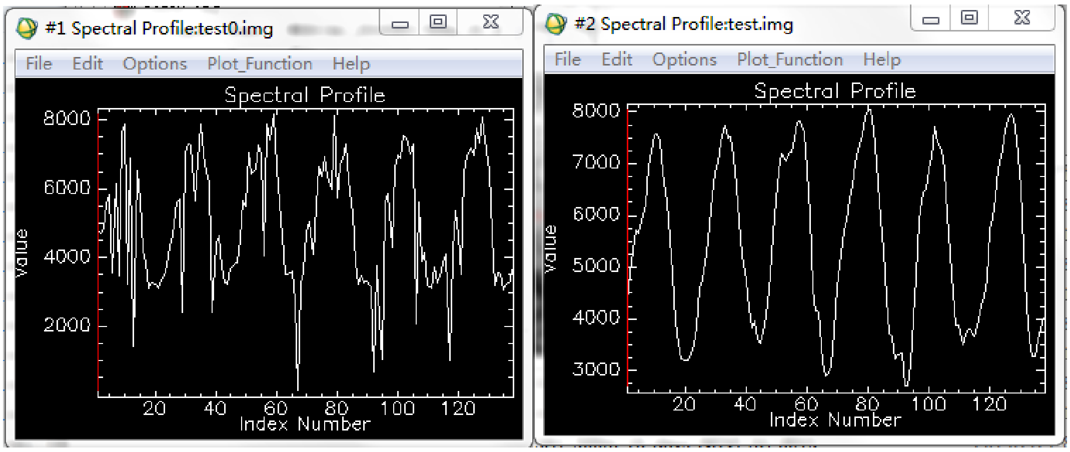


Fig. 4-3 The change of NDVI time-series datasets

(Left: according to the original value, right: after Savitsky–Golay filter processing)

4.4 Forest cover classification scheme

This study followed the FAO Land Cover Classification System (LCCS) and IGBP classification to define forest cover types for our study. The LCCS is a comprehensive, standardized a priori classification system, designed to meet specific user requirements, and created for mapping exercises, independent of the scale or means used to map. Land cover classes are defined by a combination of a set of independent diagnostic criteria - the so-called classifiers - that are hierarchically arranged to assure a high degree of geographical accuracy. Because of the heterogeneity of land cover, the same set of classifiers cannot be used to define all land cover types. The hierarchical structure of the classifiers may differ from one land cover type to another. Table 4-3 shows the land cover classification scheme applicable to this study.

Table 4-3 Land cover classification scheme for this study

Forest types	Land cover types	Class Id
Forest cover	Evergreen needleleaf forest	131
	Evergreen broadleaf forest	133
	Deciduous needleleaf forest	132

	Deciduous broadleaf forest	134
	Mixed forest	123
Non-forest cover	Shrublands	221
	Grasslands	223
	Croplands	224
	Urban and built-up	225
	Water bodies	226
	Wetlands	125
	Bare Land	227
	Other unclassified	41
	Unused lands	13

4.5 Forest cover classification method

For large-area forest mapping, it is relatively difficult to make a field survey to collect ground truth data, which is a great challenge for forest identification and classification, as well as for accuracy assessment, using coarse resolution remotely sensed data. In view of the above obstacles, a method of combing together remotely sensed data and non-remote sensing data to map forest cover have been proposed in the GMS+ project. To do that, training samples of forest were first selected from the existing 1 km global land cover dataset and then used to build a decision tree algorithm. This decision tree classifier was finally applied to time-series of MODIS NDVI data to obtain the forest cover map in the region of GMS+ project. Figure 4-4 shows the general framework of forest cover mapping using coarse resolution data. Each part was described later in details.

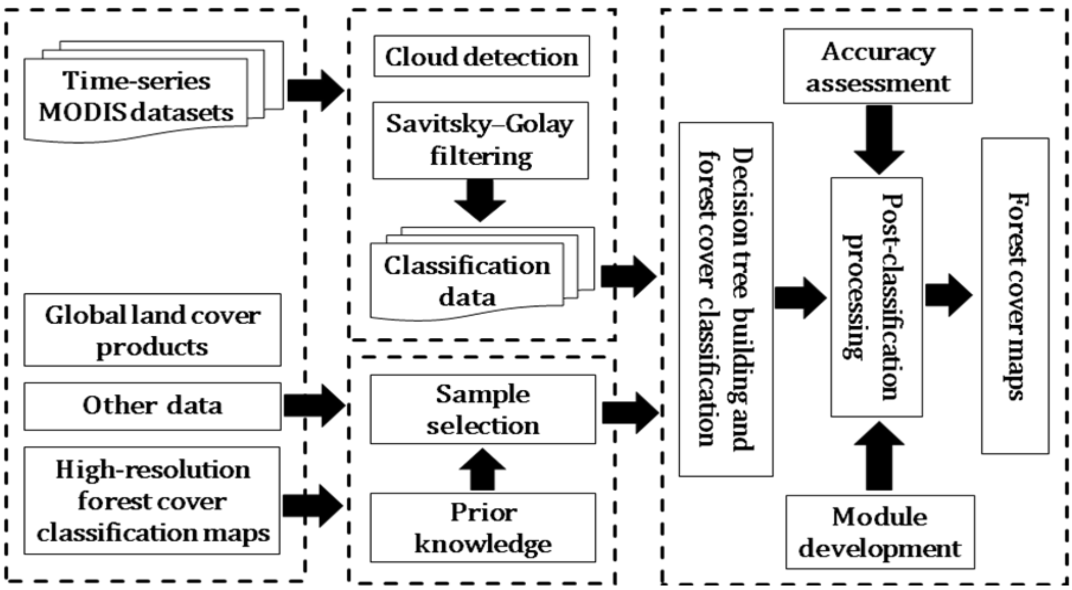


Fig. 4-4 The general framework of forest cover mapping

4.5.1 Sample selection

It can be found from analyzing the existing global land cover datasets that although there are some differences between these global land cover datasets in land cover mapping, most global land cover datasets can accurately forest cover in typical forest vegetation areas where there is a small change in forest cover over time and space. Thus, it is possible to collect training samples from the existing global land cover datasets, which may provide a practical solution to solve the problem of lacking ground truth data for large-area forest cover mapping.

The initial step involved clipping the four 1 km global land cover maps (UMD, IGBP-DISCover, MODIS and GLC2000 (Table 12)) to the coverage of the official boundary of southeast Asia according to the digital version of the GMS+ project Administration Map. All datasets were then re-projected and co-registered to a simple geographic (latitude/longitude, Plate Carree) projection with a spatial resolution of 500m using the nearest-neighbour method, as all datasets were available with this projection.

These global maps utilized diverse classification systems to characterize different land cover types including one or more forest classes, and this hindered direct analysis of the land cover datasets. It was thus necessary to harmonize and convert the various classification schemes into a common legend. Since this study focused on forest, we used the above-mentioned forest cover classification scheme to reclassify the land covers in the four global datasets to enhance the comparison. Figure 4-5, 4-6, 4-7, and 4-8 showed the remapped classification data for land cover and forest cover in the GMS+ project region.

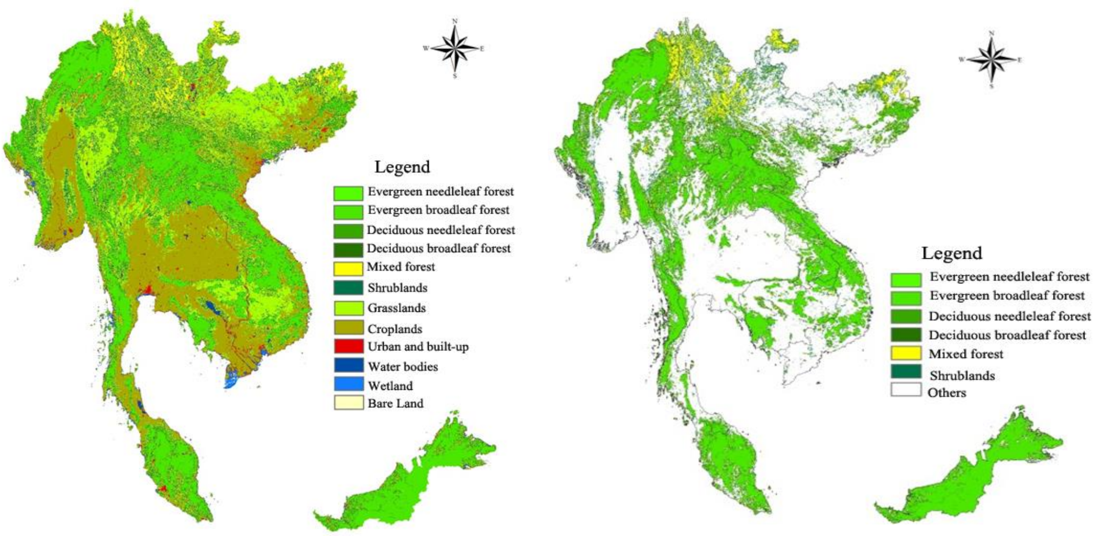


Fig. 4-5 The remapped classification results of IGBP-DISCover2005 of the GMS+ project region

(left: Land cover; right: forest)

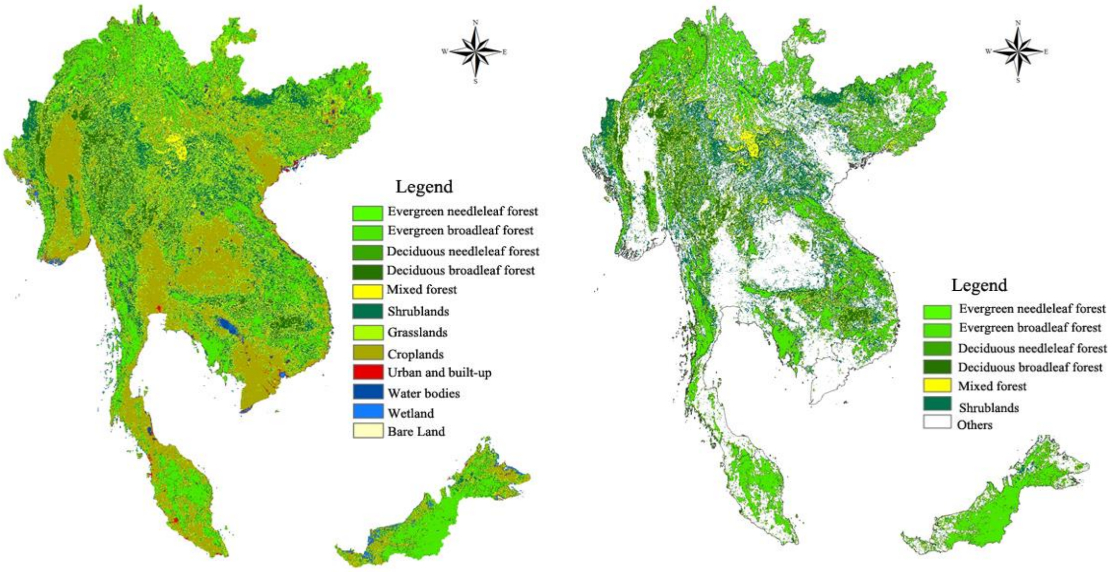


Fig. 4-6 The remapped classification results of GLC 2000 of the GMS+ project region (left: Land cover; right: forest)

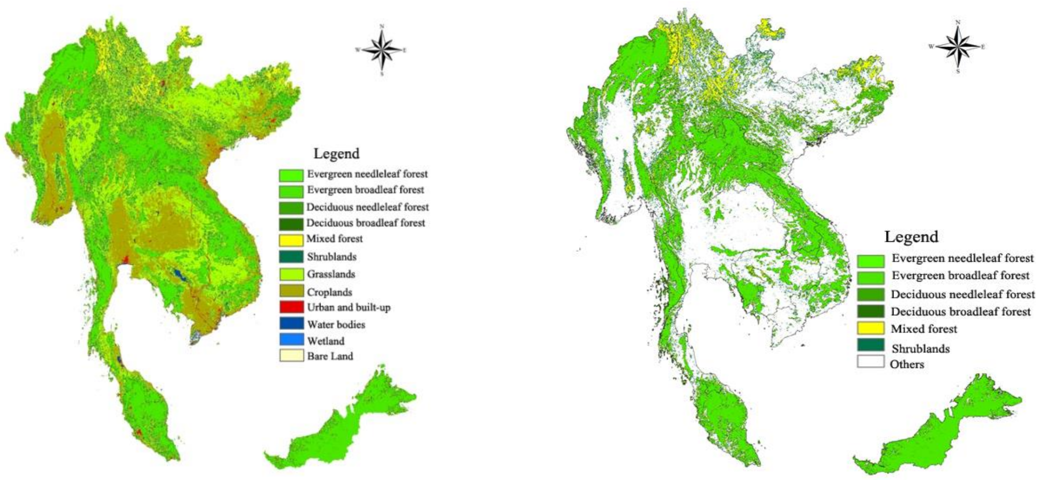


Fig. 4-7 The remapped classification results of UMD2005 of the GMS+ project region (left: Landcover; right: forest)

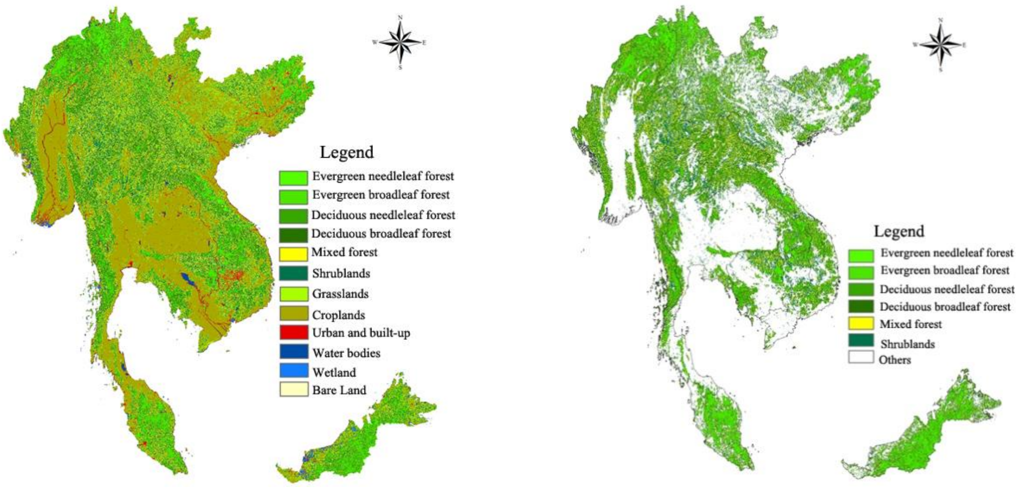


Fig. 4-8 The remapped classification results of GLOBCover2005 of the GMS+ project region (left: Landcover; right: forest)

Spatial overlay was then applied to the preprocessed four global land cover datasets to produce a composite map revealing whether and where the original maps agreed on land cover locations. In the new composite land cover map, we excluded other land cover types from our analysis, and each pixel was assigned a value based on whether four, three, two, or none of the corresponding pixels on the original maps were classified as the same land cover. To the full agreement pixels of the four global land cover datasets, their original classification cord have been kept and used to select the training sample. To the pixels belong to different land cover in the four global land cover datasets, the cord of land cover have been recorded. Figure 4-9 shows the new generated land cover map. The selected samples distribution for training and validation showed in Figure 4-10, and the number of every type showed in table 4-4.

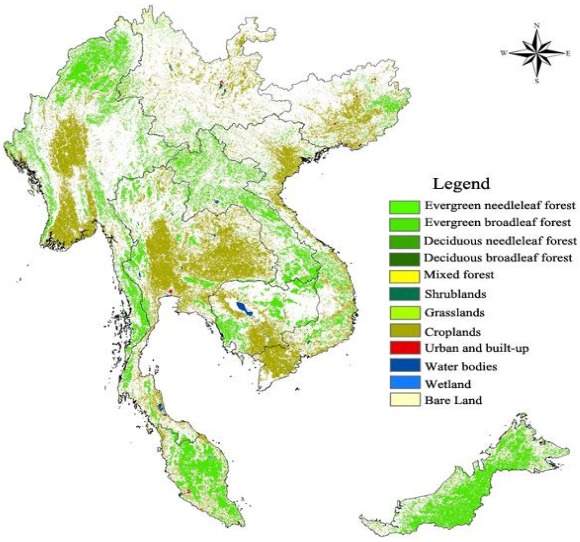


Fig. 4-9 The new composite land cover map

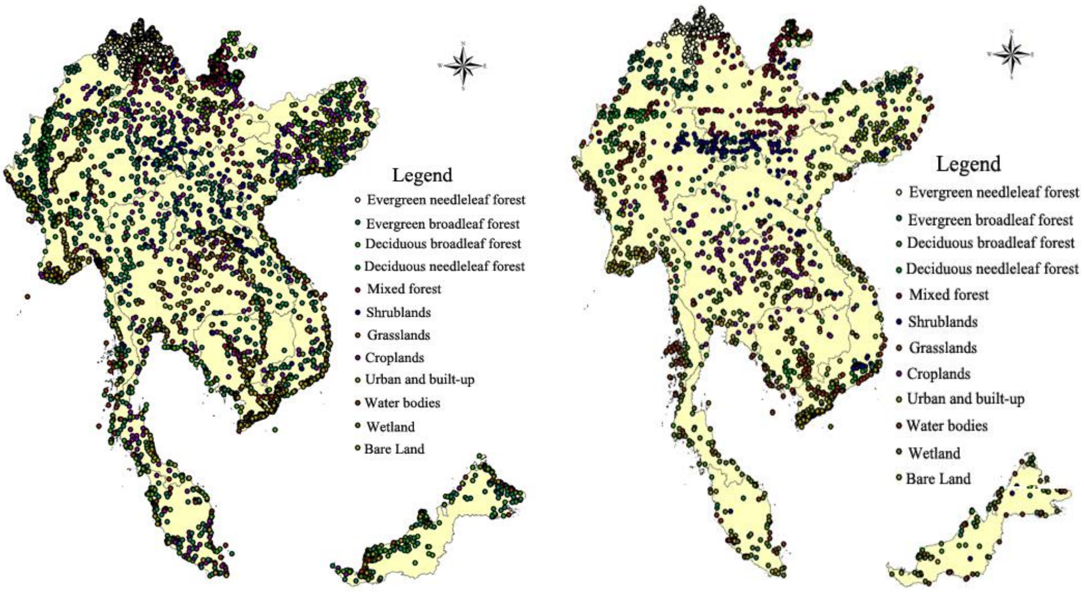


Fig. 4-10 Selection of samples for forest cover mapping (Left: for training; Right: for validation)

Table 4-4 The selected samples for forest cover mapping

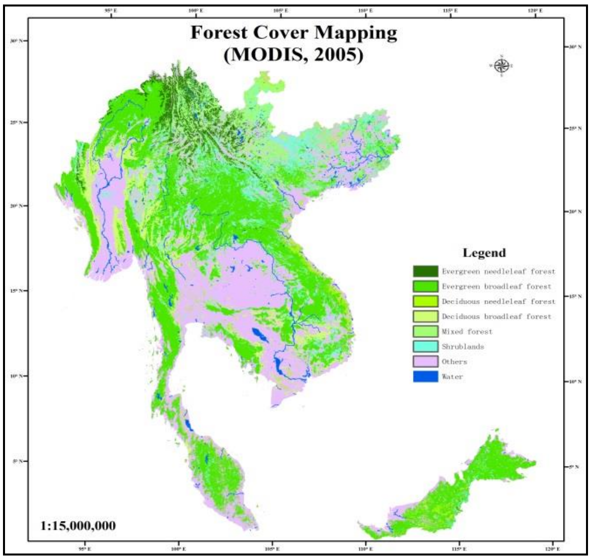
Land cover types	Training Samples	Validation Samples	Total Samples
Evergreen needleleaf forest	414	178	592
Evergreen broadleaf forest	590	254	844
Deciduous needleleaf forest	506	218	724
Deciduous broadleaf forest	304	131	435
Mixed forest	571	246	817
Shrublands	443	191	634
Grasslands	471	203	674
Croplands	446	192	638
Urban and built-up	430	185	615
Water bodies	452	194	646
Wetlands	479	206	685
Bare Land	496	213	709
Total	5602	2411	8013

4.5.2 Classification algorithms

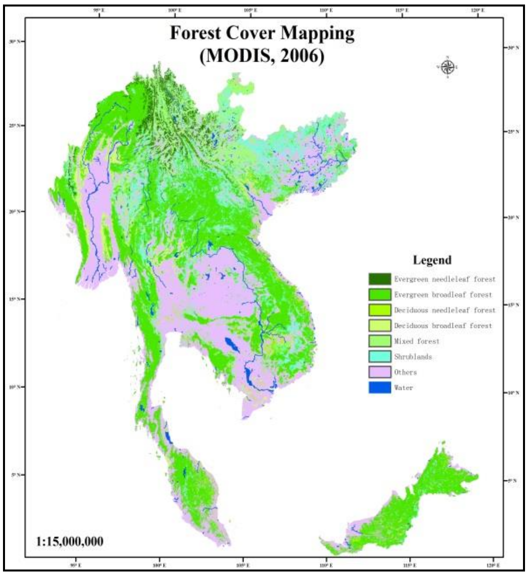
In the usual classification approach, a common set of features is used jointly in a single classification step. An alternative approach is to use a multi-stage classification decision scheme. The basic idea involved in any multi-stage approach is to break up a complex classification decision into a union of several simpler decisions, hoping the final solution obtained in this way would resemble the intended desired solution. Hierarchical classifiers are a special type of multi-stage classifier that allows rejection of class labels at intermediate stages. Classification trees offer an effective implementation of such hierarchical classifiers. Indeed, classification trees have become increasingly important due to their conceptual simplicity and computational efficiency. A decision tree classifier has a simple form which can be compactly stored and that efficiently classifies new data. Decision tree classifiers can perform automatic feature selection and complexity reduction, and their tree structure provides easily understandable and interpretable information regarding the predictive or generalization ability of the classification. In this study, a decision tree was used to classify the forest cover so as to make a full use of samples and the non-spectral prior-knowledge.

To construct a classification decision tree, it is assumed that a data set consisting of feature vectors and their corresponding class labels are available. The decision tree was then constructed by recursively partitioning a data set into purer, more homogenous subsets on the basis of a set of tests applied to one or more attribute values at each branch or node in the tree. A number of approaches have been developed to split the training data at each internal node of a decision tree into regions that contain examples from just one class, and this is the most important element of a decision tree classifier. These algorithms either minimize the impurity of the training data or maximize the goodness of split. QUEST was used in this study to build the decision tree classifier. QUEST stands for “Quick, Unbiased, Efficient Statistical Trees” and is a program for tree-structured classification. The algorithms were described in Loh and Shih (1997). The main strengths of QUEST are unbiased variable selection and fast computational speed. Some comparison studies showed its good performance of QUEST over other classification methods.

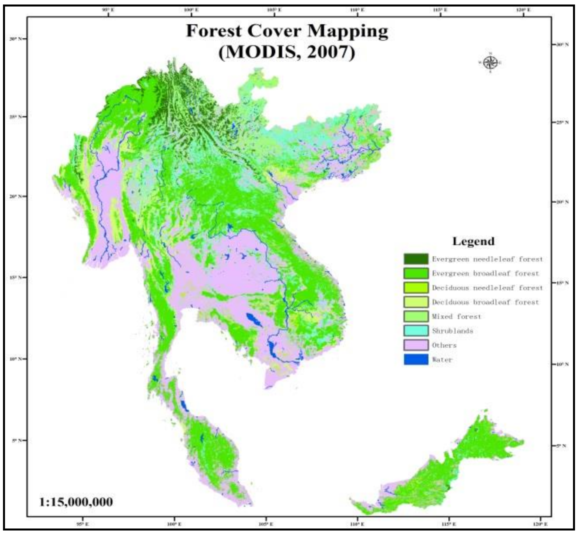
Training Samples of forest types selected in Section 4.5.1 were used as input to generate classification decision tree as shown in Fig.6. The procedure of creating a tree classifier involves three steps: splitting nodes, determining which nodes are terminal nodes, and assigning class label to terminal nodes. The assignment of class labels to terminal nodes is straightforward: labels are assigned based on a majority vote or a weighted vote when it is assumed that certain classes are more likely than others. A tree is composed of a root node (containing all the data), a set of internal nodes (splits), and a set of terminal nodes (leaves). Each node in a decision tree has only one parent node and two or more descendent nodes. A data set is classified by moving down the tree and sequentially subdividing it according to the decision framework defined by the tree until a leaf is reached. Decision tree classifiers divide the training data into subsets, which contain only a single class. The result of this procedure is often a very large and complex tree. In most cases, fitting a decision tree until all leaves contain data for a single class may over-fit to the noise in the training data, as the training samples may not be representative of the population they are intended to represent. To reduce this problem, the original tree can be pruned to reduce classification errors when data outside of the training set are to be classified. Eventually, the decision tree was applied to the classification data and to split the data in to individual forest cover types. The forest cover map of the GMS+ project has been produced from year 2005 to 2010 by using the decision tree. Parts of the forest cover mapping results have been showed in Figure 4-11.


Forest Cover Mapping
(MODIS, 2005)
Legend
Evergreen needleleaf forest
Evergreen broadleaf forest
Deciduous needleleaf forest
Deciduous broadleaf forest
Mixed forest
Shrublands
Others
Water
1:15,000,000

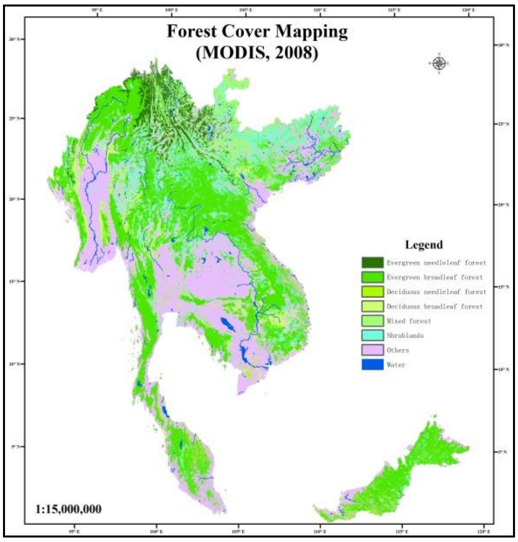
a


Forest Cover Mapping
(MODIS, 2006)
Legend
Evergreen needleleaf forest
Evergreen broadleaf forest
Deciduous needleleaf forest
Deciduous broadleaf forest
Mixed forest
Shrublands
Others
Water
1:15,000,000

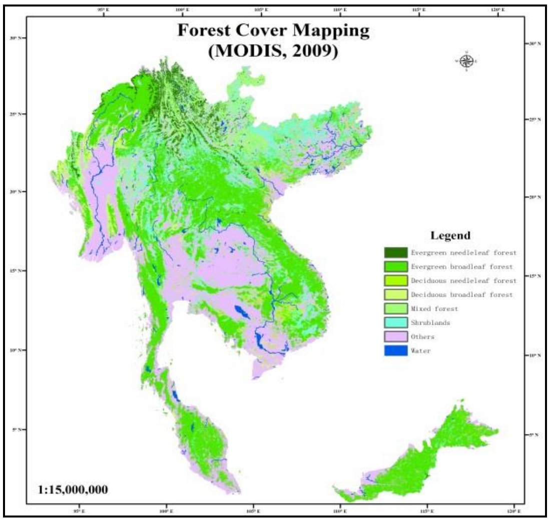
b


Forest Cover Mapping
(MODIS, 2007)
Legend
Evergreen needleleaf forest
Evergreen broadleaf forest
Deciduous needleleaf forest
Deciduous broadleaf forest
Mixed forest
Shrublands
Others
Water
1:15,000,000

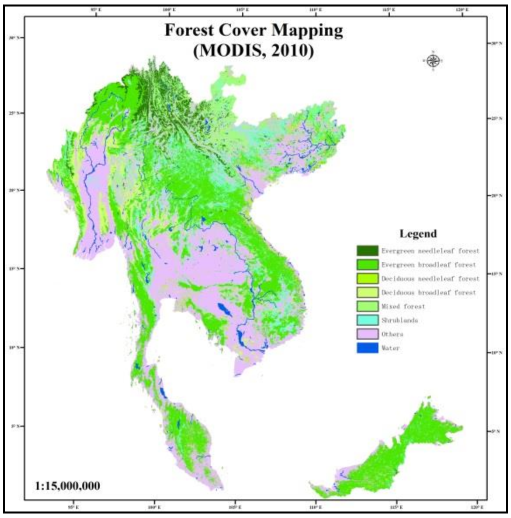
c


Forest Cover Mapping
(MODIS, 2008)
Legend
Evergreen needleleaf forest
Evergreen broadleaf forest
Deciduous needleleaf forest
Deciduous broadleaf forest
Mixed forest
Shrublands
Others
Water
1:15,000,000

d


Forest Cover Mapping
(MODIS, 2009)
Legend
Evergreen needleleaf forest
Evergreen broadleaf forest
Deciduous needleleaf forest
Deciduous broadleaf forest
Mixed forest
Shrublands
Others
Water
1:15,000,000

e


Forest Cover Mapping
(MODIS, 2010)
Legend
Evergreen needleleaf forest
Evergreen broadleaf forest
Deciduous needleleaf forest
Deciduous broadleaf forest
Mixed forest
Shrublands
Others
Water
1:15,000,000

f

Fig. 4-11 Forest cover map of the GMS+ project (year 2005 ~2010 from a to f)

4.5.3 Accuracy assessment

The analysis results of regression accuracy of samples based on the QUEST decision tree method listed in table 4-5, 4-6, 4-7, 4-8, 4-9, and 4-10. The accuracy of all classes was higher than 68%, and the average accuracy of year 2005-2010 is 85.88%. The minimum classification accuracy appeared year 2007, with 84.61%. The maximum classification accuracy was year 2005, with 87.39%. The average classification accuracy of the deciduous needleleaf forest was lowest for all forest cover types, with 71.48%. The average classification accuracy of deciduous broadleaf forest was highest among them, with 93.15%.

Table 4-5 The analysis result of regression accuracy of samples of year 2005

Types	Evergreen needleleaf forest	Evergreen broadleaf forest	Deciduous needleleaf forest	Deciduous broadleaf forest	Mixed forest	Shrublands	Grasslands	Croplands	Urban and built-up	Water bodies	Wetlands	Bare Land
Evergreen needleleaf forest	168	3	1	0	3	1	0	0	0	0	0	0
Evergreen broadleaf forest	0	230	1	1	0	3	0	0	0	0	7	0
Deciduous needleleaf forest	1	3	163	0	0	5	0	1	1	1	0	0
Deciduous broadleaf forest	0	3	0	126	0	1	0	0	0	0	0	0
Mixed forest	5	0	8	0	231	11	0	4	0	0	0	0
Shrublands	0	1	5	0	3	156	0	4	1	0	0	0
Grasslands	1	0	9	0	1	1	182	4	0	7	0	15
Croplands	0	2	4	2	4	5	1	160	10	0	5	2
Urban and built-up	2	0	4	0	3	6	4	18	166	4	2	7
Water bodies	0	0	5	0	0	0	5	1	3	162	0	13
Wetlands	0	12	12	2	0	2	0	0	0	3	190	3
Bare Land	1	0	6	0	1	0	11	0	4	17	2	173
Accuracy	94.38%	90.55%	74.77%	96.18%	93.90%	81.68%	89.66%	83.33%	89.73%	83.51%	92.23%	81.22%
Overall Accuracy	**87.39 %**											

Table 4-6 The analysis result of regression accuracy of samples of year 2006

Types	Evergreen needleleaf forest	Evergreen broadleaf forest	Deciduous needleleaf forest	Deciduous broadleaf forest	Mixed forest	Shrublands	Grasslands	Croplands	Urban and built-up	Water bodies	Wetlands	Bare Land
Evergreen needleleaf forest	159	4	1	0	3	5	0	0	0	0	0	0
Evergreen broadleaf forest	0	227	3	0	0	6	0	0	0	0	5	0
Deciduous needleleaf forest	0	1	156	0	0	3	0	3	3	3	6	2

Deciduous broadleaf forest	0	4	1	124	0	2	0	1	0	2	2	0
Mixed forest	14	0	9	0	225	7	0	1	0	1	0	0
Shrublands	3	2	5	0	9	159	0	4	0	0	0	0
Grasslands	0	0	7	0	3	0	183	3	1	10	0	18
Croplands	0	2	7	6	4	5	0	161	16	0	3	3
Urban and built-up	2	0	3	0	1	0	3	17	154	0	1	3
Water bodies	0	0	2	0	1	0	5	1	5	156	0	6
Wetlands	0	14	12	1	0	4	0	1	1	1	187	1
Bare Land	0	0	12	0	0	0	12	0	5	21	2	180
Accuracy	89.33%	89.37 %	71.56%	94.66%	91.46%	83.25%	90.15%	83.85%	83.24%	80.41%	90.78%	84.51%
Overall Accuracy	**85.90 %**											

Table 4-7 The analysis result of regression accuracy of samples of year 2007

Types	Evergreen needleleaf forest	Evergreen broadleaf forest	Deciduous needleleaf forest	Deciduous broadleaf forest	Mixed forest	Shrublands	Grasslands	Croplands	Urban and built-up	Water bodies	Wetlands	Bare Land
Evergreen needleleaf forest	154	6	0	0	3	2	0	0	0	0	0	0
Evergreen broadleaf forest	0	225	6	7	0	9	0	0	0	0	6	0
Deciduous needleleaf forest	0	2	152	0	0	2	0	0	1	0	2	1
Deciduous broadleaf forest	0	6	2	118	0	1	0	2	0	0	0	0
Mixed forest	20	0	8	0	226	11	0	6	0	2	0	0
Shrublands	0	4	4	2	7	153	0	5	0	0	1	0
Grasslands	3	0	10	0	4	0	187	2	4	16	1	24
Croplands	0	1	5	2	2	6	0	150	5	2	4	2
Urban and built-up	1	1	6	0	3	4	2	24	159	1	1	4
Water bodies	0	0	5	0	1	0	6	1	0	159	0	13
Wetlands	0	9	11	0	0	3	0	2	4	3	189	1
Bare Land	0	0	9	2	0	0	8	0	12	11	2	168
Accuracy	86.52%	88.58%	69.72%	90.08%	91.87%	80.10%	92.12%	78.13%	85.95%	81.96%	91.75%	78.87%
Overall Accuracy	**84.61%**											

Table 4-8 The analysis result of regression accuracy of samples of year 2008

Types	Evergreen needleleaf forest	Evergreen broadleaf forest	Deciduous needleleaf forest	Deciduous broadleaf forest	Mixed forest	Shrublands	Grasslands	Croplands	Urban and built-up	Water bodies	Wetlands	Bare Land
Evergreen needleleaf forest	164	2	0	0	4	3	0	0	0	0	0	0
Evergreen broadleaf forest	2	227	7	2	0	10	0	0	0	0	1	0
Deciduous needleleaf forest	5	1	160	0	0	3	0	2	7	0	6	3
Deciduous broadleaf	0	7	3	123	0	4	0	4	0	0	1	0

forest												
Mixed forest	3	0	6	0	216	8	0	8	0	0	0	0
Shrublands	3	5	3	2	15	152	0	3	0	1	0	0
Grasslands	1	0	11	0	3	0	177	1	4	14	2	16
Croplands	0	3	5	3	4	7	1	156	9	2	4	1
Urban and built-up	0	0	3	0	2	0	3	14	159	1	0	7
Water bodies	0	0	5	0	0	0	5	0	0	160	0	15
Wetlands	0	9	9	1	0	4	0	4	2	3	191	3
Bare Land	0	0	6	0	2	0	17	0	4	13	1	168
Accuracy	92.13%	89.37%	73.39%	93.89%	87.80%	79.58%	87.19%	81.25%	85.95%	82.47%	92.72%	78.87%
Overall Accuracy	**85.15 %**											

Table 4-9 The analysis result of regression accuracy of samples of year 2009

Types	Evergreen needleleaf forest	Evergreen broadleaf forest	Deciduous needleleaf forest	Deciduous broadleaf forest	Mixed forest	Shrublands	Grasslands	Croplands	Urban and built-up	Water bodies	Wetlands	Bare Land
Evergreen needleleaf forest	168	6	0	0	2	2	0	0	0	0	0	0
Evergreen broadleaf forest	0	227	7	3	0	9	0	0	0	0	6	0
Deciduous needleleaf forest	0	0	150	0	0	1	0	0	0	1	1	1
Deciduous broadleaf forest	0	1	1	123	0	1	0	0	0	0	1	0
Mixed forest	4	0	9	0	230	11	0	6	0	0	0	0
Shrublands	2	10	6	1	7	157	0	8	0	0	0	0
Grasslands	4	0	9	0	2	0	180	2	2	14	1	19
Croplands	0	1	6	3	3	3	1	161	8	0	1	1
Urban and built-up	0	0	5	0	0	2	1	14	158	1	2	2
Water bodies	0	0	10	0	1	0	8	0	7	162	1	16
Wetlands	0	9	11	1	0	5	0	1	2	2	190	2
Bare Land	0	0	4	0	1	0	13	0	8	14	3	172
Accuracy	94.38%	89.37%	68.81%	93.89%	93.50%	82.20%	88.67%	83.85%	85.41%	83.51%	92.23%	80.75%
Overall Accuracy	**86.19 %**											

Table 4-10 The analysis result of regression accuracy of samples of year 2010

Types	Evergreen needleleaf forest	Evergreen broadleaf forest	Deciduous needleleaf forest	Deciduous broadleaf forest	Mixed forest	Shrublands	Grasslands	Croplands	Urban and built-up	Water bodies	Wetlands	Bare Land
Evergreen needleleaf forest	164	1	1	0	5	4	0	0	0	0	0	0
Evergreen broadleaf forest	1	235	11	2	0	15	0	1	0	0	6	0
Deciduous needleleaf forest	0	1	154	0	3	1	0	1	5	2	2	2
Deciduous broadleaf forest	0	6	0	121	0	0	0	1	0	0	1	0

Mixed forest	9	0	6	0	226	12	0	5	1	0	0	0
Shrublands	0	1	3	2	3	146	0	4	0	0	0	0
Grasslands	3	0	9	0	3	1	174	1	0	8	0	7
Croplands	0	2	5	5	3	6	2	155	4	1	1	4
Urban and built-up	1	0	3	0	3	3	1	19	161	1	1	1
Water bodies	0	0	4	0	0	0	7	0	4	161	1	13
Wetlands	0	8	12	1	0	3	0	2	2	1	192	1
Bare Land	0	0	10	0	0	0	19	3	8	20	2	185
Accuracy	92.13%	92.52%	70.64%	92.37%	91.87%	76.44%	85.71%	80.73%	87.03%	82.99%	93.20%	86.85%
Overall Accuracy	**86.02 %**											

GlobCover global land cover dataset is extensively used as reference data in many research projects. It affords the opportunity to make an overall comparison in the GMS+ project region, reveal the spatial pattern and the difference amount of thematic forest classes, and indicate the clues for further works.

To do that, GlobCover land cover product with 300 m spatial resolution was re-sampled to 500m pixels and compared with the results from this study. The difference of classification schemes was considered and all the forest classes in GlobCover were merged according to the Table 4-2. The number of forest pixels and areas was calculated and compared with the MODIS-based forest cover classification results of year 2005. Table 4-11 shows the comparison on forest cover percentage between these two results for individual countries.

Table 4-11 Comparison on forest cover percentage between MODIS and GlobCover estimations in the GMS+ project of year 2005 (a: MODIS, b: GlobCover)

Forest cover types	**Yunnan**		**Guangxi**		**Cambodia**		**Laos**	
	a	**b**	**a**	**b**	**a**	**b**	**a**	**b**
Evergreen needleleaf forest	20.34	36.90	0.04	21.87	0.00	1.48	0.50	3.79
Evergreen broadleaf forest	11.02	15.70	9.08	45.95	27.36	46.11	72.79	47.52
Deciduous broadleaf forest	1.02	0.00	12.55	0.00	1.33	0.00	1.09	0.00
Mixed forest	0.68	9.86	1.64	6.14	15.70	12.02	2.03	2.79
Forest cover types	**Malaysia**		**Myanmar**		**Thailand**		**Viet Nam**	
	a	**b**	**a**	**b**	**a**	**b**	**a**	**b**
Evergreen needleleaf forest	0.39	0.00	2.84	4.85	0.04	1.01	0.59	8.74
Evergreen broadleaf forest	57.22	97.93	43.02	43.36	25.64	44.44	30.55	35.28
Deciduous broadleaf forest	5.46	0.00	0.18	0.00	2.26	0.00	8.25	0.00

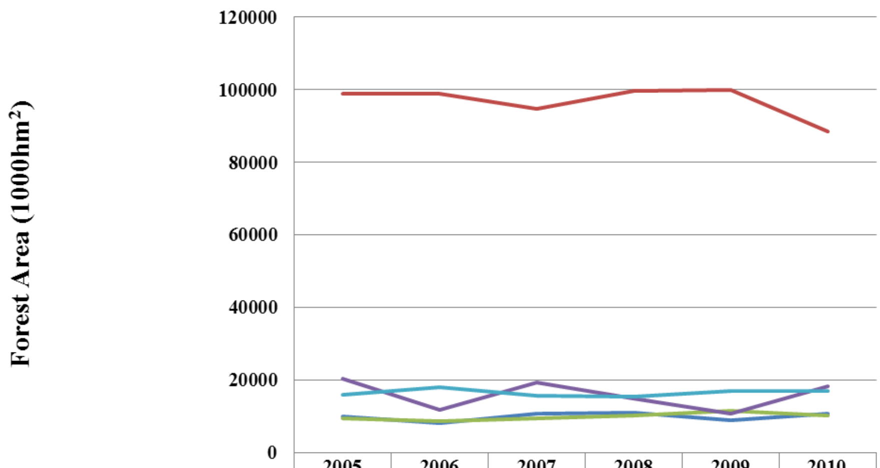
Mixed forest	0.87	0.00	15.35	9.70	7.67	10.52	6.31	5.42

It can be seen that MODIS-based estimation for evergreen needleleaf forest, evergreen broadleaf forest and deciduous broadleaf forest is generally lower than GlobCover land cover product. This difference between MODIS and GlobCover map can be attributed to spatial resolution. MODIS images has a lower spatial resolution of 500m, but in many forested areas of the tropics the landscape is heterogeneous, and forest classes are highly intermixed with other vegetation types such as grasslands or scrublands at a pixel level. Spectral signatures also overlap with other categories and the pixel homogeneity is significantly lower. When allocating these mixed classes to a certain land cover category, it is difficult to some extent because the maps are forced to fit the real world into categories. Thus, the results overestimate the forest cover.

4.6 Forest cover change analysis in the GMS+ region

4.6.1 Characters of forest cover change

The character of forest cover change of the GMS+ region from year 2005 to 2010 showed as Figure 4-12, and table 4-12, 4-13, 4-14, 4-15, and 4-16.



	2005	2006	2007	2008	2009	2010
Evergreen needleleaf forest	10172.1	8272.325	10820.025	11228.15	8982.65	10909.575
Evergreen broadleaf forest	98943.075	98969.925	94691.525	99743.325	100051.575	88525.875
Deciduous needleleaf forest	9623.4	8680.6	9448.025	10417.225	11755.675	10340.6
Deciduous broadleaf forest	20530.55	11887.05	19546.15	15096.875	10919.475	18352.05
Mixed forest	16065.975	18021.2	15668.975	15594.7	17102.325	17219.4

Fig. 4-12 Area of forest cover change of the GMS+ project (year 2005 ~2010)

Table 4-12 The change of forest cover between year 2005-2006 ($1000hm^2$)

TYPES	Evergreen needleleaf forest	Evergreen broadleaf forest	Deciduous needleleaf forest	Deciduous broadleaf forest	Mixed forest	Shrublands	Others
Evergreen needleleaf forest	6807.13	929.43	0.03	1.58	2207.25	72.20	154.50
Evergreen broadleaf forest	786.60	85223.33	1687.70	2034.03	292.90	6043.35	2875.18
Deciduous needleleaf forest	1.25	2109.25	1691.10	174.13	157.08	2048.23	3442.38
Deciduous broadleaf forest	0.08	3544.95	1118.03	7476.88	16.78	3992.90	4380.95
Mixed forest	600.03	329.20	31.60	10.95	11877.60	1654.38	1562.23
Shrublands	22.35	3761.08	1147.80	883.30	1093.60	15398.48	4829.33
Others	54.90	3072.70	3004.35	1306.20	2376.00	5702.90	89014.23

It shows that the 90.55% original forest area didn't change during year 2005-2006 from table 21; but there were 14.84% transformation from other land cover types to the forest cover.

Table 4-13 The change of forest cover between year 2006-2007 (1000hm^2)

TYPES	Evergreen needleleaf forest	Evergreen broadleaf forest	Deciduous needleleaf forest	Deciduous broadleaf forest	Mixed forest	Shrublands	Others
Evergreen needleleaf forest	7080.55	552.58	0.88	0.10	542.28	37.85	58.10
Evergreen broadleaf forest	1218.10	82859.30	1415.53	5079.48	203.65	4397.53	3796.35
Deciduous needleleaf forest	0.08	1852.15	1712.53	698.73	35.55	1344.18	3037.40
Deciduous broadleaf forest	0.03	1419.85	221.15	7691.33	5.50	1183.03	1366.18
Mixed forest	2337.03	504.53	105.08	12.98	11823.90	1472.15	1765.55
Shrublands	59.08	4675.50	2164.70	2682.48	1364.70	18884.25	5081.73
Others	125.18	2827.63	3828.18	3381.08	1693.40	5705.20	88698.13

It shows that the 91.64% original forest area didn't change during year 2006-2007 from table 22; but there were 16.53% transformation from other land cover types to the forest cover.

Table 4-14 The change of forest cover between year 2007-2008 (1000hm^2)

TYPES	Evergreen	Evergreen	Deciduous	Deciduous	Mixed	Shrublands	Others

	needleleaf forest	broadleaf forest	needleleaf forest	broadleaf forest	forest		
Evergreen needleleaf forest	8778.55	563.88	0.68	0.15	1322.60	49.35	104.83
Evergreen broadleaf forest	863.95	81641.00	2160.75	1610.45	498.00	4026.15	3891.23
Deciduous needleleaf forest	17.45	1685.70	1847.23	610.20	43.73	2041.85	3201.88
Deciduous broadleaf forest	0.05	5764.93	262.65	8705.65	8.45	2290.38	2514.05
Mixed forest	1338.95	295.13	96.90	15.78	10840.70	1296.65	1784.88
Shrublands	117.38	6495.83	1782.15	1573.65	1534.75	17594.23	3926.20
Others	111.83	3296.88	4266.88	2581.00	1346.48	6860.88	85339.50

It shows that the 91.58% original forest area didn't change during year 2007-2008 from table 23; but there were 17.79% transformation from other land cover types to the forest cover.

Table 4-15 The change of forest cover between year 2008-2009 ($1000hm^2$)

TYPES	Evergreen needleleaf forest	Evergreen broadleaf forest	Deciduous needleleaf forest	Deciduous broadleaf forest	Mixed forest	Shrublands	Others
Evergreen needleleaf forest	7692.68	1268.08	1.10	0.10	2016.43	109.93	139.85
Evergreen broadleaf forest	483.05	83851.20	2431.33	3201.60	314.23	6813.43	2648.50
Deciduous needleleaf forest	2.80	2635.55	1608.18	132.05	75.00	1961.55	4002.10
Deciduous broadleaf forest	0.03	1990.68	1356.40	5066.68	36.90	3104.73	3541.48
Mixed forest	705.03	590.03	45.13	5.55	11218.43	1474.38	1556.18
Shrublands	30.35	4973.00	2091.55	1014.65	1467.68	17937.93	6644.33
Others	68.73	4743.05	4222.00	1498.85	1973.68	5002.08	83254.18

It shows that the 90.05% original forest area didn't change during year 2008-2009 from table 24; but there were 17.38% transformation from other land cover types to the forest cover.

Table 4-16 The change of forest cover between year 2009-2010 ($1000hm^2$)

TYPES	Evergreen needleleaf	Evergreen broadleaf	Deciduous needleleaf	Deciduous broadleaf	Mixed forest	Shrublands	Others

	forest	forest	forest	forest			
Evergreen needleleaf forest	7474.63	627.40	0.08	0.13	746.88	41.93	91.63
Evergreen broadleaf forest	1198.60	79205.45	2128.23	4703.33	435.38	7171.38	5209.23
Deciduous needleleaf forest	0.28	1377.08	2268.10	430.03	154.23	2120.35	5405.63
Deciduous broadleaf forest	0.05	995.45	134.25	6828.78	6.13	790.48	2164.35
Mixed forest	2075.95	295.00	42.23	43.50	11717.70	960.90	1967.05
Shrublands	88.40	3890.73	2088.83	3755.15	1905.70	15301.55	9373.65
Others	71.68	2134.78	3678.90	2591.15	2253.40	3796.38	87260.33

It shows that the 86.93% original forest area didn't change during year 2009-2010 from table 25; but there were 14.27% transformation from other land cover types to the forest cover.

4.6.2 Forest area percent of different region

At the same times, the forest cover percent of different region has been analyzed according to the classification results from year 2005 to 2010. The analysis results have been showed in table 4-17, 4-18, 4-19, 4-20, 4-21, 4-22, 4-23, and 4-24 and Figure 4-13, 4-14, 4-15, 4-16, 4-17, 4-18, 4-19, and 4-20.

Yunnan province of China

From table 4-17, it shows that the percent of evergreen needle-leaf forest area was obviously decreasing in year 2006 and 2009. In addition, the percent of mixed forest area was increasing and the others kept stabilization during the six years.

Table 4-17 The vegetation cover percent of Yunnan province of China in 2005-2010

Types	2005	2006	2007	2008	2009	2010
Evergreen needleleaf forest	20.36	16.69	21.78	22.07	17.60	21.55
Evergreen broadleaf forest	11.04	9.72	9.53	10.21	10.73	9.89
Deciduous needleleaf forest	1.02	0.52	0.72	0.90	0.75	0.60
Deciduous broadleaf forest	0.68	0.34	0.33	0.45	0.12	0.75
Mixed forest	36.77	39.69	35.20	35.22	38.33	37.81
Shrublands	13.49	16.61	18.32	16.88	17.33	13.39

Others	16.64	16.42	14.12	14.27	15.15	16.02

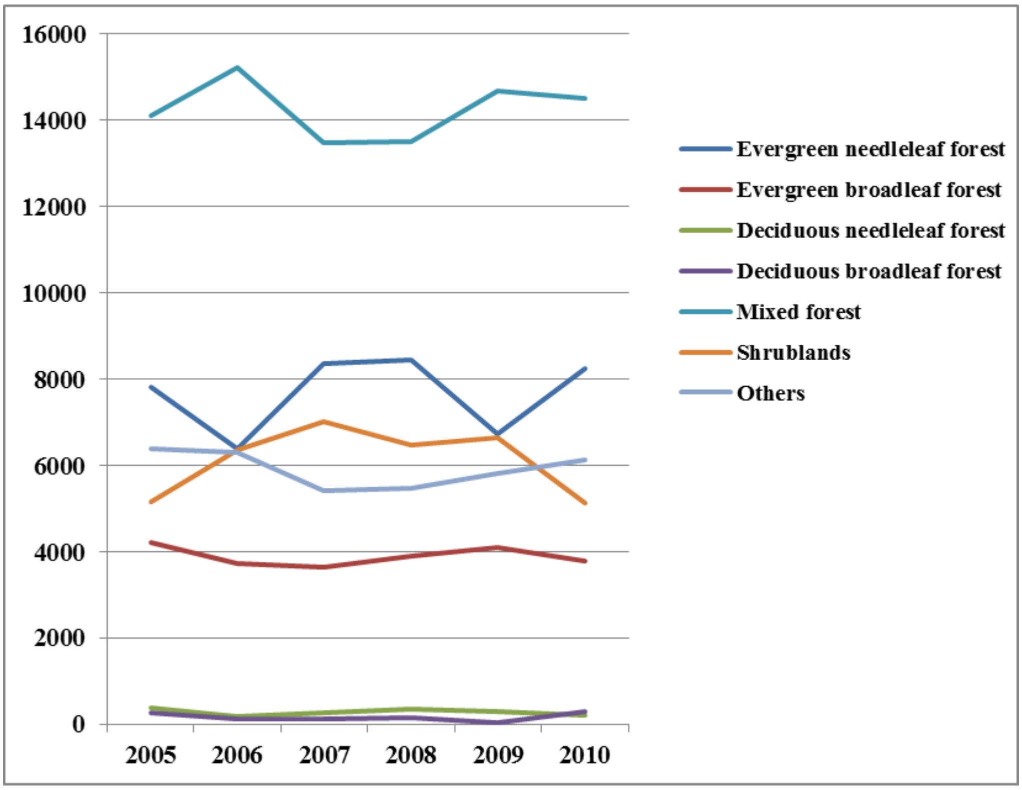


Fig. 4-13 The change of forest area of Yunnan province during year 2005-2010 ($1000hm^2$)

Guangxi Zhuangzu Automatic Region of China

From table 4-18, it shows that the percent of deciduous needle-leaf forest area was obviously decreasing in year 2006 and 2009. In addition, the percent of shrublands was clearly increasing and the others kept stabilization during the six years.

Table 4-18 The vegetation cover percent of Guangxi zhuangzu automatic region of China in 2005-2010

Types	2005	2006	2007	2008	2009	2010
Evergreen needleleaf forest	0.04	0.03	0.02	0.02	0.01	0.01
Evergreen broadleaf forest	9.10	8.40	12.03	14.11	13.61	12.21
Deciduous needleleaf forest	12.58	5.88	12.43	11.81	12.45	14.74
Deciduous broadleaf forest	1.65	1.92	2.42	0.92	1.57	1.51
Mixed forest	1.81	1.78	1.70	1.36	1.47	2.15

Shrublands	26.69	32.78	29.03	32.45	30.43	21.63
Others	48.14	49.21	42.37	39.33	40.46	47.75

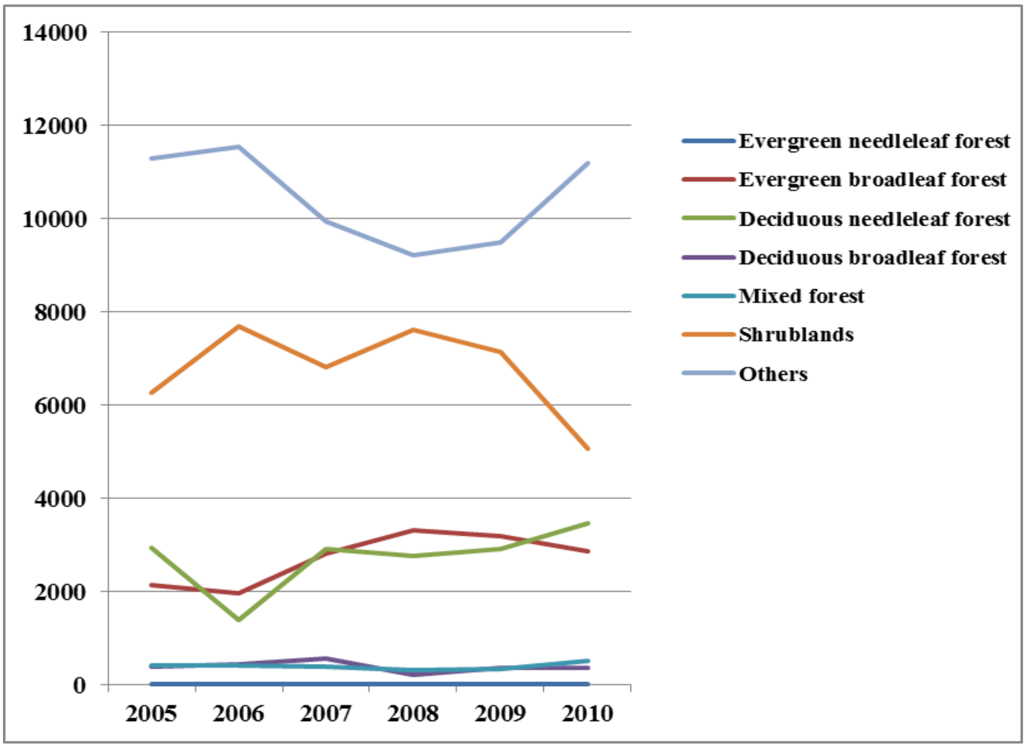


Fig. 4-14 The change of forest area of Guangxi zhuangzu automatic region during year 2005-2010 ($1000hm^2$)

Cambodia

From table 4-19, it shows that the percent of evergreen broadleaf forest area was increasing little by little from year 2006 to 2008; then decreasing to the level of year 2005 at the end of year 2010. In addition, the percent of deciduous needle-leaf forest was clearly fluctuating during the six years. However, it caused little change for the percent of whole forest cover because its' lower percent in the forest cover types.

Table 4-19 The vegetation cover percent of Cambodia in 2005-2010

Types	2005	2006	2007	2008	2009	2010
Evergreen needleleaf forest	0.00	0.00	0.00	0.00	0.00	0.00
Evergreen broadleaf forest	26.63	30.48	32.04	32.53	29.74	26.63
Deciduous needleleaf forest	5.26	8.11	6.76	2.87	12.04	5.26

Deciduous broadleaf forest	3.80	2.94	7.26	11.22	0.64	3.80
Mixed forest	0.01	0.00	0.01	0.01	0.01	0.01
Shrublands	7.92	6.28	5.00	4.22	7.21	7.92
Others	56.37	52.19	48.93	49.15	50.37	56.37

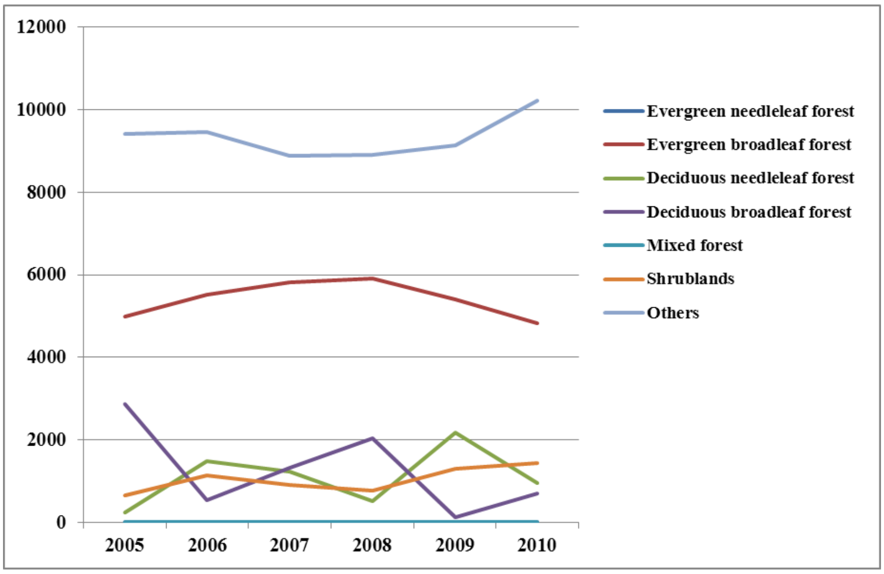


Fig. 4-15 The change of forest area of Cambodia during year 2005-2010 (1000hm^2)

Lao PDR

From table 4-20, it shows that the main forest type is evergreen broadleaf forest, with the percent more than 70% during the six years. The percent of forest vegetation area kept stabilization. However, the percent of total forest area obviously decreasing in year 2010.

Table 4-20 The vegetation cover percent of Laos in 2005-2010

Types	2005	2006	2007	2008	2009	2010
Evergreen needleleaf forest	0.50	0.24	0.15	0.40	0.45	0.26
Evergreen broadleaf forest	72.95	72.05	70.25	74.15	71.77	65.13
Deciduous needleleaf forest	1.09	1.54	2.17	1.29	2.71	2.57
Deciduous broadleaf forest	2.04	0.95	1.85	1.96	0.68	1.88

Mixed forest	0.42	0.49	0.55	0.22	0.42	0.56
Shrublands	11.72	14.53	14.10	11.90	13.54	16.88
Others	11.28	10.21	10.94	10.07	10.44	12.71

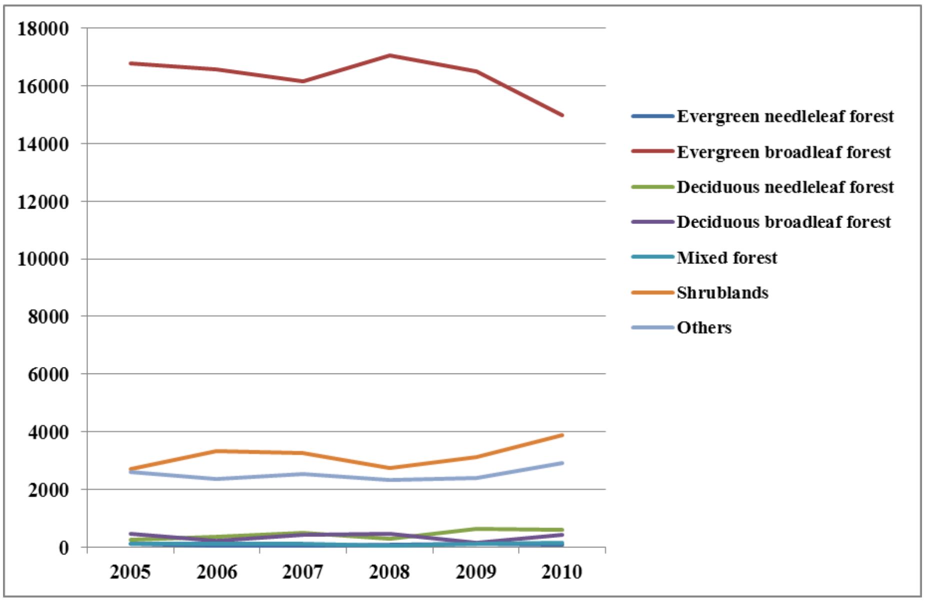


Fig. 4-16 The change of forest area of Laos during year 2005-2010 (1000hm^2)

Malaysia

From table 4-21, it shows that the main forest type is evergreen broadleaf forest, with the percent more than 50% during the six years. The percent of forest vegetation area kept stabilization. However, the percent of total forest area obviously decreasing in year 2010.

Table 4-21 The vegetation cover percent of Malaysia in 2005-2010

Types	2005	2006	2007	2008	2009	2010
Evergreen needleleaf forest	0.39	0.30	0.39	0.29	0.25	0.30
Evergreen broadleaf forest	57.31	57.82	58.78	53.23	63.67	59.42
Deciduous needleleaf forest	5.46	5.18	4.25	7.52	2.85	3.90
Deciduous broadleaf forest	0.87	0.73	0.76	1.09	0.63	0.74

Mixed forest	0.95	0.55	0.41	1.13	0.45	0.60
Shrublands	3.50	3.44	3.61	4.46	3.03	3.39
Others	31.52	31.98	31.81	32.29	29.12	31.64

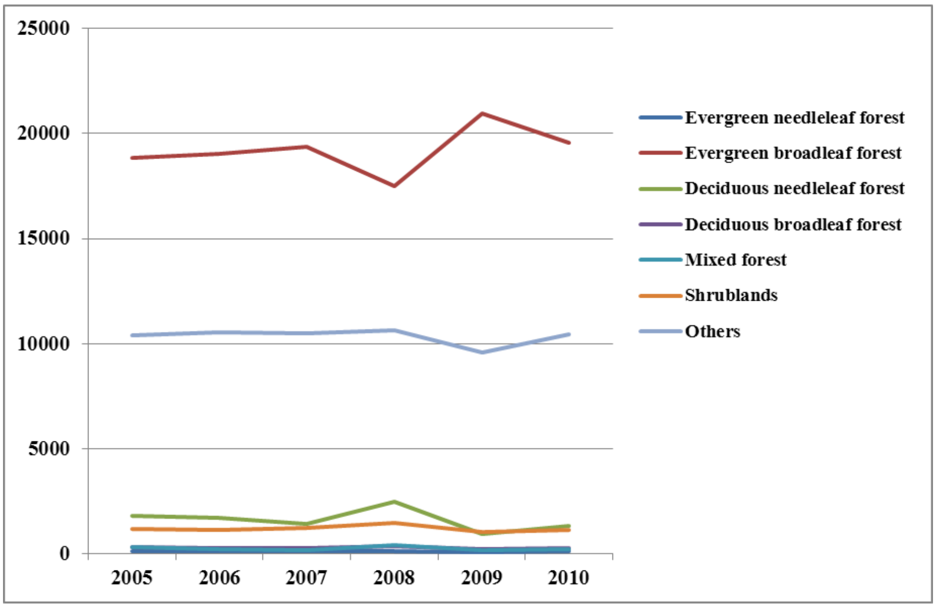


Fig. 4-17 The change of forest area of Malaysia during year 2005-2010 (1000hm^2)

Myanmar

From table 4-22, it shows that the main forest type is evergreen broadleaf forest, with the percent more than 30% during the six years. However, the percent of evergreen broadleaf forest area obviously kept fluctuating from year 2008 to 2010.The percent of forest vegetation area and the other types kept stabilization.

Table 4-22 The vegetation cover percent of Burma in 2005-2010

Types	2005	2006	2007	2008	2009	2010
Evergreen needleleaf forest	2.84	2.38	3.11	3.45	2.70	3.34
Evergreen broadleaf forest	43.06	42.71	38.15	42.06	37.88	34.24
Deciduous needleleaf forest	0.18	0.40	0.39	0.43	0.43	0.23

Deciduous broadleaf forest	15.37	9.75	16.09	10.53	11.43	17.35
Mixed forest	1.15	2.44	1.73	1.58	2.16	2.26
Shrublands	5.45	8.17	7.85	8.79	9.78	6.37
Others	31.96	34.15	32.68	33.15	35.63	36.21

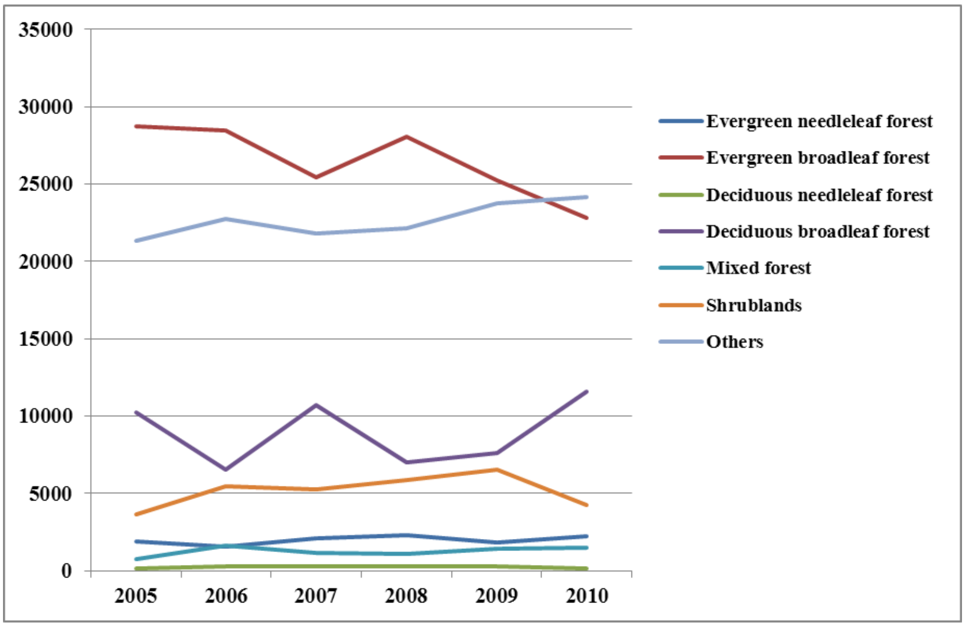


Fig. 4-18 The change of forest area of Burma during year 2005-2010 (1000hm^2)

Thailand

From table 4-23, it shows that the main forest type is evergreen broadleaf forest, with the percent more than 30% during the six years. However, the percent of evergreen broadleaf forest area obviously kept fluctuating from year 2008 to 2010.The percent of forest vegetation area and the other types kept stabilization.

Table 4-23 The vegetation cover percent of Thailand in 2005-2010

Types	2005	2006	2007	2008	2009	2010
Evergreen needleleaf forest	0.06	0.06	0.04	0.08	0.07	0.03
Evergreen broadleaf forest	35.63	34.93	30.73	37.50	35.78	27.77
Deciduous needleleaf forest	3.14	4.40	3.95	4.70	5.28	4.42

Deciduous broadleaf forest	10.66	5.18	8.73	6.90	3.52	9.29
Mixed forest	0.08	0.13	0.16	0.10	0.12	0.15
Shrublands	7.68	12.67	10.87	12.29	15.29	11.02
Others	81.58	81.46	84.34	77.25	78.77	86.15

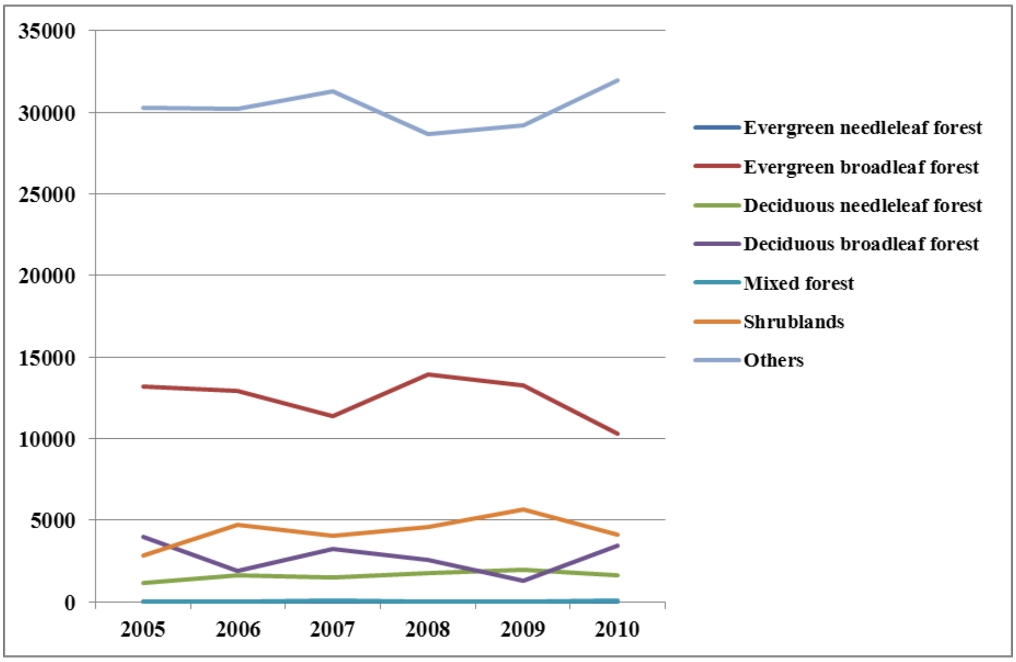


Fig. 4-19 The change of forest area of Thailand during year 2005-2010 (1000hm^2)

Viet Nam

From table 4-24, it shows that the main forest type is evergreen broadleaf forest, with the percent more than 30% during the six years. The percent of forest vegetation area and the other types kept stabilization.

Table 4-24 The vegetation cover percent of Viet Nam in 2005-2010

Types	2005	2006	2007	2008	2009	2010
Evergreen needleleaf forest	0.59	0.32	0.66	0.76	0.69	0.76
Evergreen broadleaf forest	30.60	32.64	30.67	30.75	34.64	28.56
Deciduous needleleaf forest	8.26	5.09	4.29	6.03	7.79	6.20
Deciduous	6.32	5.75	8.82	6.95	3.34	4.05

broadleaf forest						
Mixed forest	0.98	1.25	0.87	0.73	0.97	0.96
Shrublands	14.41	15.55	13.98	14.26	15.29	15.86
Others	38.85	39.40	40.71	40.51	37.27	43.62

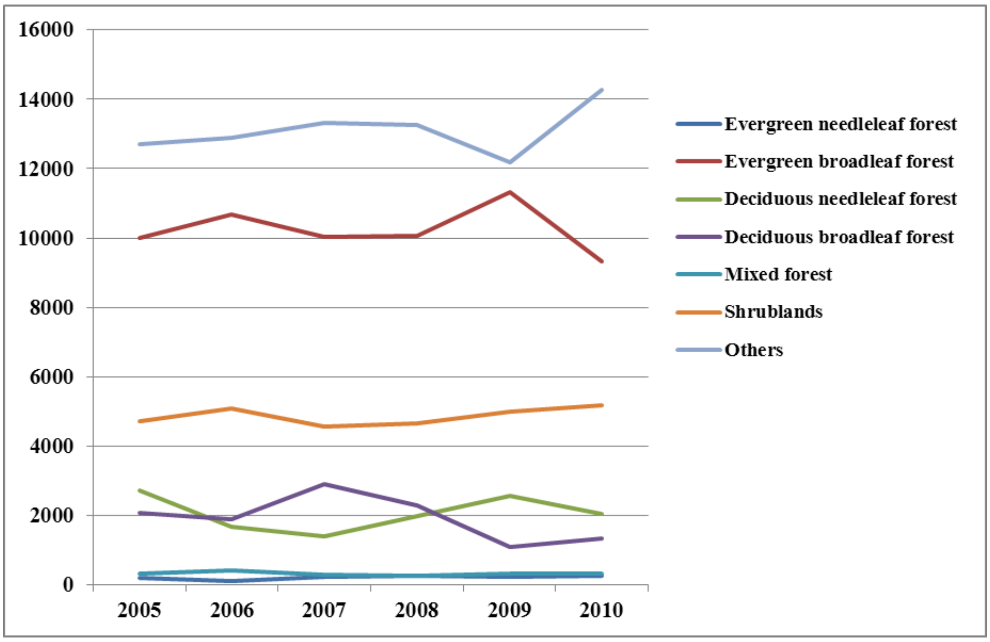


Fig. 4-20 The change of forest area of Viet Nam during year 2005-2010 (1000hm^2)

Glossary of terms and acronyms

MODIS	**Moderate Resolution Imaging Spectroradiometer**
REDD	**Reducing Emissions from Deforestation and Degradation**
FAO	**Food and Agriculture Organisation of the united Nations**
FCPF	**Forest Carbon Partnership Facility**
IGBP	**International Geosphere-Biosphere Programme**
GLC	**Global land cover**
UMD	**the University of Maryland**
LCCS	**Land Cover Classification System**
NDVI	**Normalized Difference Vegetation Index**
MVC	**Maximum Value Composite**
BISE	**Best Index Slope Extraction**
Quick, Unbiased, Efficient Statistical Trees	**QUEST**

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5 Forest carbon storage mapping product of 2005 (300 m)

5.1 Introduction

Forest is the most essential part of terrestrial ecosystem, because it is the largest land carbon pool, about 80% of the ground carbon stocks and 40% of underground carbon storage. Describing and quantifying forest above-ground biomass (AGB) and carbon storage (CS) has become of importance to many scientific and practical tasks such as sustainable forest management, eco-hydrology simulation, timber management, forest ecosystem productivity estimation, carbon sink evaluation, and studies of the role of forest in the global carbon cycle.

This information is also required to assist in meeting the greenhouse gas emission targets and commitment periods established by the Kyoto Protocol (United Nations Environment Program 1998). However, accurate information on forest biomass and distribution is generally lacking. Appropriate methods for estimating AGB/CS is intended to provide support for Reducing Emissions from Deforestation and Forest Degradation (REDD) project assessments in response to REDD-oriented government policies relating to forestry and land use planning. The full details of REDD implementation are still a matter for inter-governmental negotiation, but it is clear that the goal is a compensation package provided to countries having substantial areas.

Biomass is defined as "organic material both above-ground and below-ground, and both living and dead, e.g., trees, crops, grasses, tree litter, roots etc." Above-ground biomass consists of all living biomass above the soil including stem, stump, branches, bark, seeds, and foliage. Below-ground biomass consists of all living roots excluding fine roots (less than 2mm in diameter) and other soil organic matter,

$$B_{Tol} = B_{Ag} + B_{Bg}$$

where BTol is the total biomass, Bag and BBg are above-ground and below-ground biomass respectively.

The International Panel for Climate Change (IPCC) gave a clear definition for carbon pool in the Agriculture, Forestry and Other Land Use (AFOLU) sector.

Table 10.1 IPCC's definition for carbon pools used in AFOLU (IPCC 2006)

Pool		Description
Biomass	Aboveground Biomass	All biomass of living vegetation, both woody and herbaceous, above the soil including stems, stumps, branches, bark, seeds, and foliage. Note: In cases where forest understory is a relatively small component of the above-ground biomass carbon pool, it is acceptable for the methodologies and associated data used in some tiers to exclude it, provided the tiers are used in a consistent manner throughout the inventory time series.
	Belowground Biomass	All biomass of live roots. Fine roots of less than (suggested) 2mm diameter are often excluded because these often cannot be distinguished empirically from soil organic matter or litter.
Dead Organic Matter	Dead Wood	Includes all non-living woody biomass not contained in the litter, either standing, lying on the ground, or in the soil. Dead wood includes wood lying on the surface, dead roots, and stumps, larger than or equal to 10 cm in diameter (or the diameter specified by the country).
	Litter	Includes all non-living biomass with a size greater than the limit for soil organic matter (suggested 2 mm) and less than the minimum diameter chosen for dead wood (e.g. 10 cm), lying dead, in various states of decomposition above or within the mineral or organic soil. This includes the litter layer as usually defined in soil typologies. Live fine roots above the mineral or organic soil (of less than the minimum diameter limit chosen for below-ground biomass) are included in litter where they cannot be distinguished from it empirically.
Soil	Soil Organic Matter[1]	Includes organic carbon in mineral soils to a specified depth chosen by the country and applied consistently through the time series[2]. Live and dead fine roots and dead organic matter (DOM) within the soil, that are less than the minimum diameter limit (suggested 2 mm) for roots and DOM, are included with soil organic matter where they cannot be distinguished from it empirically. The default for soil depth is 30 cm.
1. Includes organic material (living and non-living) within the soil matrix, operationally defined as a specific size fraction (e.g., all matter passing through a 2 mm sieve). Soil C stock estimates may also include soil inorganic C if using a Tier 3 method. CO_2 emissions from liming and urea applications to soils are estimated as fluxes using Tier 1 or Tier 2 method.		

2. Carbon stocks in organic soils are not explicitly computed using Tier 1 or Tier 2 method, (which estimate only annual C flux from organic soils), but C stocks in organic soils can be estimated in a Tier 3 method.

The amount of forest biomass is influenced by changes in land use, land cover, land management, ecosystem disturbances, climate change, elevated carbon dioxide, nitrogen fertilization etc.. In a natural system, most of the biomass production contained in living plant material is eventually transferred to dead organic matter pools, such as dead wood and litter. Dead organic matter on the ground and plant biomass below the ground decompose and transform into soil organic matter (SOM), which is another primary pool and can have varying residence times in the soil.

In forest biomass studies, two biomass units are used, fresh weight and dry weight. Many biomass estimation studies conducted are focused on forest AGB because it accounts for the majority of the total accumulated biomass in the forest ecosystem. Therefore, in this material, only AGB is took into account.

Carbon storage in forest can be transformed from biomass on basis of the carbon content rate (CCR),

$$C = B * CCR \quad (5\text{-}1)$$

or $$C = V * VB * CCR \quad (5\text{-}2)$$

Where C is the forest carbon storage, B is the forest biomass, V is the forest stem volume and VB is the ratio of biomass to stem volume.

With the development of research on global change and carbon cycle, it becomes more and more important to get forest parameters, especially forest biomass over large area and in higher accuracy. Remote sensing technologies have been proved to be useful tools to obtain vegetation information in large areas.

In the past two decades, many researchers investigated the relationship between the forest biomass and radar backscattering under various forest conditions (Imhoff et al., 1995; Quinones et al., 2004).

Laser altimeter systems provide high-resolution geo-located measurements of the vertical structure of vegetation and the ground elevations beneath the canopies, which can characterize the vegetation and terrain surfaces with high accuracy (Lefsky et al., 2002). It brings new possibilities for forest stand map generation with its capability of highly accurate height measurements and high spatial resolution photographs collected simultaneously. Lidar provides direct measurements of vertical structure of vegetation and ground elevations beneath canopies. Small footprint lidar data has been widely used in high-resolution DEM generation, 3D mapping of urban area, monitoring erosion in coastal zenes, and measurement of the forest structural parameters such as tree height, crown size, fractional crown cover, timber volume and biomass. The lidar waveform signature from large footprint lidar has been successfully used to estimate the tree height and biomass. Fusion spaceborne lidar and imagery remote sensing data for regional forest biomass retrieval could provide a more reliable and quantitative information in regional forest biomass estimate (Boudreau et al., 2008; Nelson et al., 2009; Pang et al., 2011; Saatchi et al., 2011; Baccini et al., 2012).

5.2 Scheme design of GMS+ forest carbon storage estimation

Generally, there are two basic methods for estimating forest AGB or carbon stock (CS), which are inventory-based method and remote sensing method. A forest aboveground biomass (AGB) mapping method was developed for this project. This framework uses field measurements to calibrate airborne Lidar and sapceborne Lidar data. This will provide a spatial distributed forest biomass at Lidar covered area. These estimated biomass from Lidar and field plots are in discrete pattern. Then this discrete biomass will be fused with imagery remote sensing data.

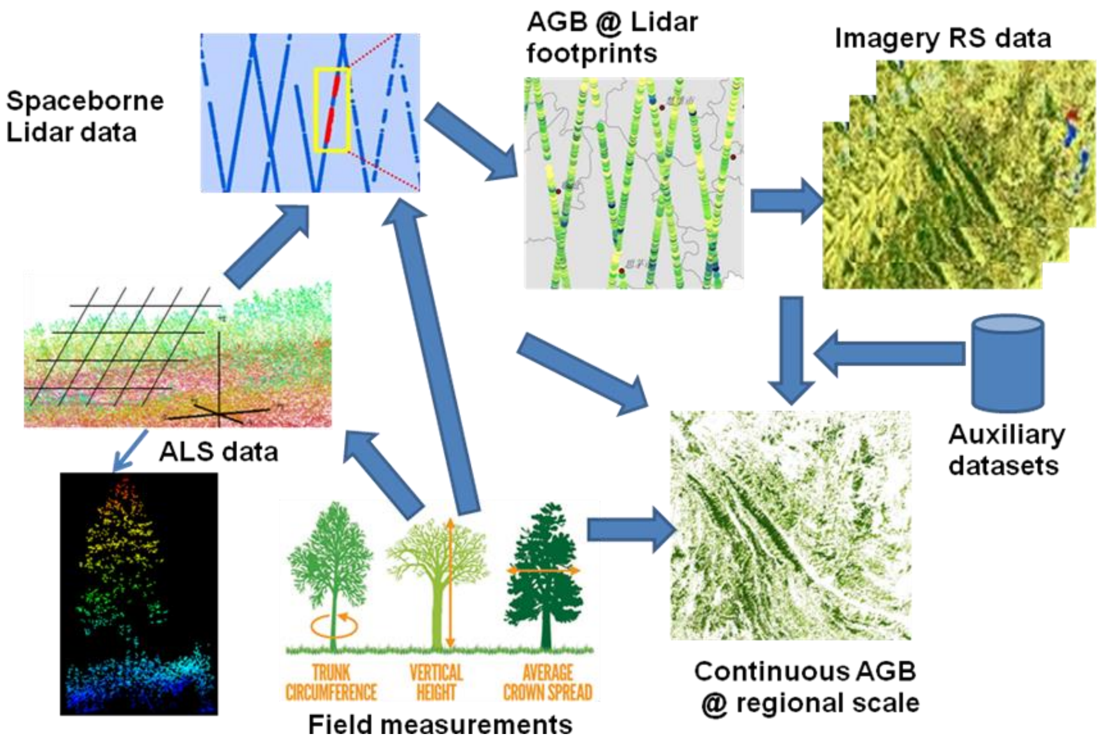


Fig. 5-1 Scheme for GMS+ AGB and carbon stock estimation

Forest biomass within GLAS footprints were estimated by airborne LiDAR by use of a predictive regression model between airborne LiDAR estimated biomass and GLAS waveform parameters. Models between GLAS waveform parameters and airborne LiDAR estimates of biomass were applied to quality-filtered GLAS footprints in the study area to estimate the biomass at these GLAS footprints.

As it is difficult and costly to measure many field plots for biomass estimation, ALS data provided a bridge to link the in-situ measurements with spaceborne remote sensing data. A few field plots are enough to calibrate ALS data for building forest height and biomass models (Naesset et al., 2004; Pang et al., 2008). Following is the general model for biomass estimation from ALS data:

$$\ln W_i = \beta_0 + \beta_1 \ln h_5 + \beta_2 \ln h_{10} + ... + \beta_{19} \ln h_{95} + \beta_{20} \ln h_{max} + \beta_{21} \ln \mathrm{d}_5 + \beta_{22} \ln \mathrm{d}_{10} + ... + \beta_{39} \ln \mathrm{d}_{95} + \beta_{40} \ln \mathrm{c} + \varepsilon \quad (5\text{-}3)$$

where Wi is the forest aboveground biomass density per hectare. The h5, h10, …, h95 are heights (m) of percentiles corresponding to 5, 10, …, 95% of laserechoes); hmax is maximum of the laser canopy heights (m); d5, d10, …, d95 are the canopy densities corresponding to the proportions of laser echoes above height fraction to total number of echoes; c is the canopy density corresponding to the proportions of laser echoes with a height value > 2 m to total number of echoes; ε is a normally distributed error term [ε ~ N (0, σ2)].

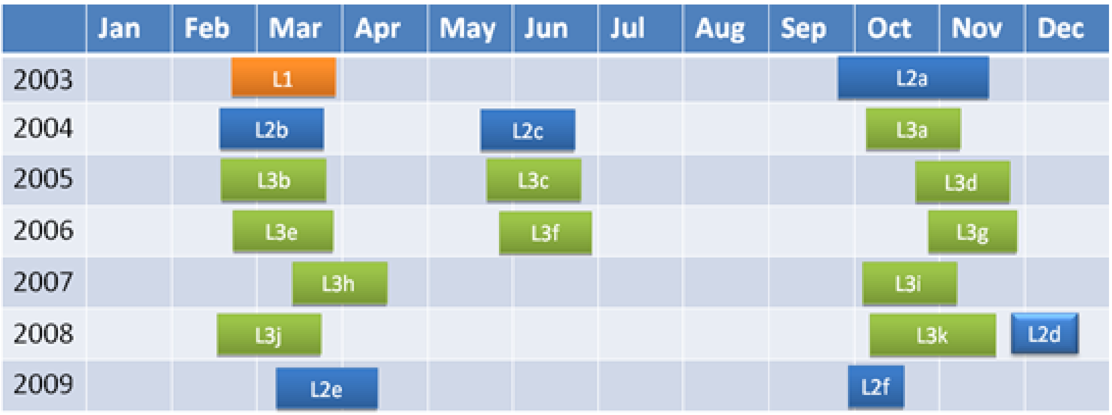
Stepwise method was used for variable selection and the maximum R2 improvement variable selection techniques were applied to select the ALS-derived variables to be included in the models.

The biomass within GLAS footprints of the study area and ALS estimated biomass were used to fusion with optical data to generate a wall-to-wall biomass map. The regression tree method (Pang et al., 2011) and maximum entropy method (Saatchi et al., 2011) was used to extend the AGB estimation from GLAS footprints and ALS strips to continuous mapping using imagery remote sensing data.

5.3 Field measurement for biomass/carbon estimation

To link spaceborne lidar data to forest biomass and carbon, 100 field plots centered by ICESat GLAS footprints were measured in each country. These 100 plots were selected according to the coverage and quality of GLAS waveform, forest type, and accessibility. As the ICESat GLAS sensors operated during 2003 to 2009 and we intend to estimate forest biomass in 2005, the GLAS data around 2005 were used. So the data from L3A to L3G are preferred. If there is leaf-off season in selected test sites, the data from leaf-on periods were used.

Table 5-1. ICESat GLAS operation periods



Some disturbances might happen in selected footprints. By checking the GLAS waveform overlay on the GoogleEarth, the changes were checked. If there was distinguished changes happened, this kind waveform was removed from field plot list as forest conditions changes dramatically. There might be some new disturbances which were not shown in Google Earth image. When we found some disturbances happened during the period between the GLAS data acquisition date and the time we measured, we noted in plot description of disturbance type and intensity and find another waveform instead.

According to the complicated tropical forest environment, two types of plots were selected, which include fixed area plot and angle-gauge (prism) plot. For each fixed area plot, two subplots will be measured. These two subplots are layout like Fig. 5-2. For each plot, an inner plot and an outer plot were measured.

- In inner plot, all trees of dbh>5 cm within 30 m diameter for circle plot or 30 m side length for square plot will be measured of dbh, species and height.
- In outer plot, all trees of dbh>20 cm within 70 m diameter for circle plot or 70 m side length for square plot will be measured of dbh, species and height.

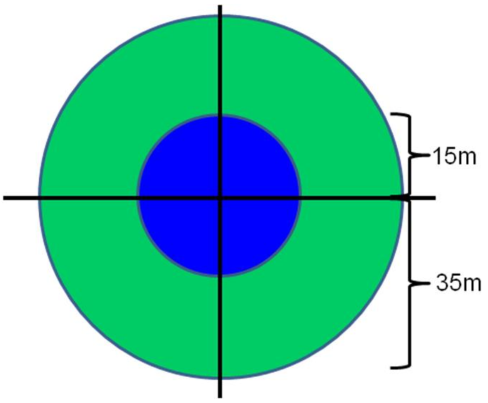


Fig. 5-2(a) Layout of circle plot

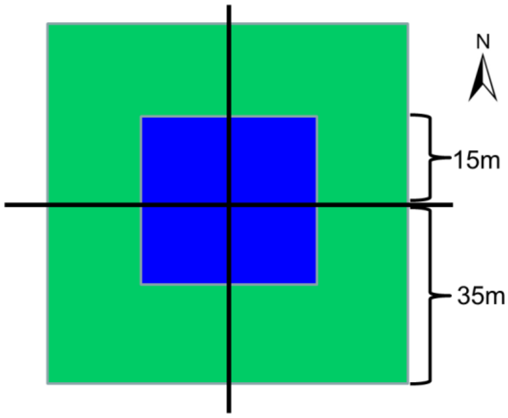


Fig. 5-2(b) Layout of square plot

For angle-gauge plot, 5 plots need to set up for each GLAS footprint. Central plot center is the location of GLAS footprint. The other 4 satellite plots are 20m away in the direction of NW, NE, SW, SE from central plot. For each plot, all trees forming an angle bigger than the critical angle of instrument were measured of dbh, species and height.

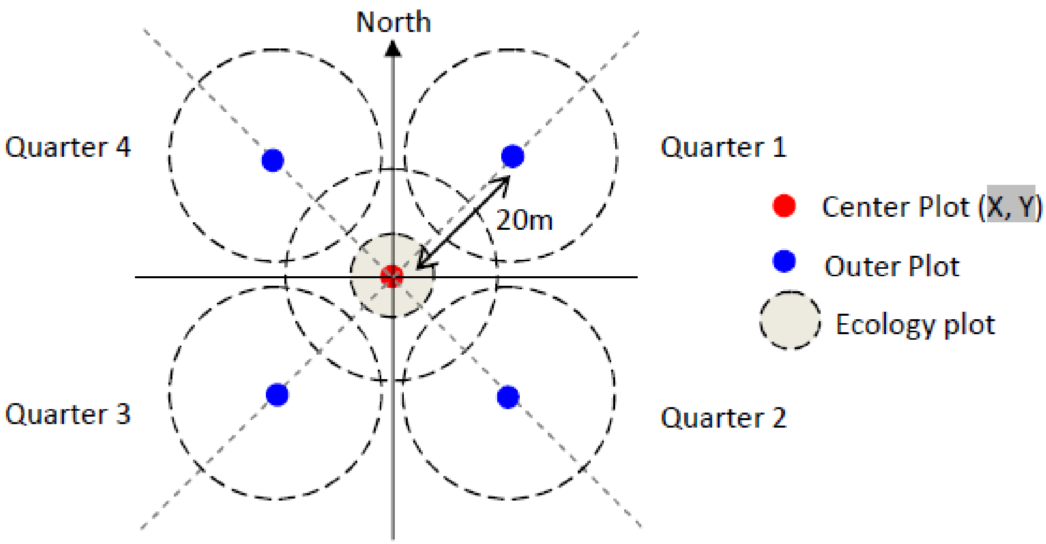


Fig. 5-3 Layout of angle-gauge plot

For each plot, the following information are needed to collect which including: Plot no., GLAS record no., GLAS shot index, GPS coordinates, forest type, canopy density, slope, descriptions, photo no.

A total of 639 plots have been measured, with each collocated with the center of a GLAS shot for estimating biomass through the combination of field inventory and GLAS signal. These plots covered different forest types in this region. All of these tallied trees were calculated into biomass or carbon stock using local allometry equations or the generalized allometry equations developed by Chave et al. (2005). Then the carbon density were calculated for each GLAS footprint.

Besides of these GLAS footprint centered plots, another three plot sets with 150 plots were used to calibrate airborne laser scanning (ALS) data into biomass. These plots were located according to ALS data flew in Kunming (2007) and Xishuangbanna (2009) of Yunnan province in China, and Paksong (2012) in the south of Laos.

5.4 Data processing

5.4.1 ALS data processing

Then the estimates of height for each ALS point were calculated as the difference between the point's elevation and the elevation of the DTM at that location. Then the lidar data were subset for each field plots and 1 km by 1 km tiles for further processing. The plot subsets were used for forest parameters estimation with field measurements.

Two sets of lidar indices were tested in this study. One is height indices and the other is density indices. The height indices evaluated included the maximum height of all points, mean height of all points, the quadratic mean height (the square root of the mean squared height of each lidar point) as well as height percentiles. Height percentiles are defined as the height at which a certain percent of data fall below – we evaluated 5% intervals from 5% to 95% (denoted as h5, …, h95). Those points with a height value > 2 m were considered to belong to the tree canopy and used for indices calculation (Pang et al., 2008; Næsset & Gobakken, 2008). The percentiles of the canopy height distributions for 5% (h5), 10% (h10), ..., and 95% (h95) were computed. Canopy density was then computed as the proportions of laser points above each percentile height to total number of points. Then the model between field measured AGB/CS and lidar metrics were built using equation 5-3.

5.4.2 ICESat GLAS data processing

The Geoscience Laser Altimeter System (GLAS) on the ICESat, lunched in January 2003, was the first spaceborne lidar altimeter system, which can record lidar returns from atmosphere and land surface. GLAS data provides new insight on the clouds, aerosols in the atmosphere and the vertical structure of the vegetation. The information on the vertical structure of the vegetation can help the global vegetation assessment and improving the accuracy of the vegetation parameters estimation from remote sensing data (Zwally et al., 2002). The footprint size of the GLAS instrument is about 70 m， with an interval of 170 m （Brenner et al., 2002）on ground between footprints. After its first laser broken, GLAS operated its two remaining lasers for three 33-day campaigns per year to maximize its duration and meet its main objectives. The spring, summer and fall data acquisition periods are from February to March, from May to June and from October to November, respectively. The data acquisition had lasted until late 2009. Table 5-1 shows operation periods of ICESat GLAS. The data has been successfully used for regional forest parameters estimation.

NASA ICESat ended its science mission in February 2010. The 2^{nd}-generation of the orbiting laser altimeter ICESat-II scheduled for launch in 2018. Currently, NSIDC (http://nsidc.org/index.html) archives and distributes 15 Level-1 and Level-2 data products (Table 5-2). GLA01, GLA05 and GLA14 were generally used in vegetation characteristics estimation.

Table 5-2. Standard GLAS Data Products

Short Name	Long Name
GLA01	GLAS/ICESat L1A Global Altimetry Data
GLA02	GLAS/ICESat L1A Global Atmosphere Data
GLA03	GLAS/ICESat L1A Global Engineering Data
GLA04	GLAS/ICESat L1A Global Laser Pointing Data
GLA05	GLAS/ICESat L1B Global Waveform-based Range Corrections Data
GLA06	GLAS/ICESat L1B Global Elevation Data
GLA07	GLAS/ICESat L1B Global Backscatter Data
GLA08	GLAS/ICESat L2 Global Planetary Boundary Layer and Elevated Aerosol Layer Heights
GLA09	GLAS/ICESat L2 Global Cloud Heights for Multi-layer Clouds
GLA10	GLAS/ICESat L2 Global Aerosol Vertical Structure Data
GLA11	GLAS/ICESat L2 Global Thin Cloud/Aerosol Optical Depths Data
GLA12	GLAS/ICESat L2 Antarctic and Greenland Ice Sheet Altimetry Data
GLA13	GLAS/ICESat L2 Sea Ice Altimetry Data
GLA14	GLAS/ICEsat L2 Global Land Surface Altimetry Data
GLA15	GLAS/ICESat L2 Ocean Altimetry Data

NSIDC provided IDL tools to read and processing binary data of GLA01, GLA05 and GLA14. GLAS waveforms contain lots of noise. In our work, the threshold was set to the background noise plus 4.5 times the standard deviation (Lefsky et al. 2005). We exclude abnormal data that with low signal to noise ratio or influenced by cloud (e.g., maximum intensity value of waveform under 80).

As the footprint size from large footprint Lidar system is usually greater than a single tree crown, the waveform includes information from multiple trees. With the increasing of footprint size, the terrain will affect waveform signals. A calibration from local reference information is often used. As shown in Fig. 5-4 and 5-5, the following waveform indices are often used for forest parameters estimation.

Waveform extent –The extent of waveform is defined as the distance between signal beginning and signal end;

Trailing edge – Reflects the vary of ground surface to a certain extent, is calculated from the waveform as the height difference between the lowest elevation at which the signal strength of the waveform is half of the maximum signal above the background noise value, and the elevation of the signal end;

Leading edge – Reflects vary of uppermost foliage, is determined as the height difference between the elevation of the signal start and the first elevation at which the waveform is half of the maximum signal above the background noise value.

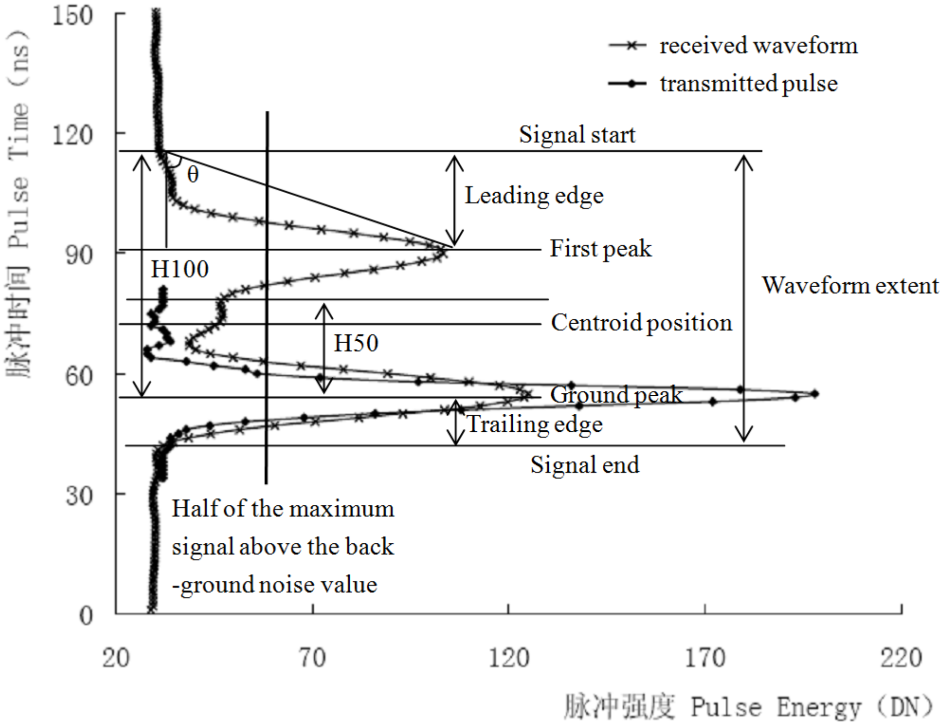


Fig.5-4 Definition of waveform indices.

The above waveform indices were the most frequently and valid used in forest parameters estimates. Following indices should also used in forest parameters estimates (Duncanson et al., 2010).

Wf_variance – The variance of the waveform, indicate landscape complexity within a footprint.

Wf_skew – The variance of the waveform, depends on the location of the bulk of the energy within the waveform, should be useful for terrain and canopy characterization.

The distribution of waveform energy both in terms of elevation and energy intensity is a function of the distribution of the terrain sensed by each GLAS pulse. As such, the proportion of energy in four equal elevation divisions and energy return divisions should act as useful descriptors of the waveform (Fig.5-5).

Ele_44 – Proportion of energy in highest elevation quarter.

Ele_34 – Proportion of energy in second highest elevation quarter.

Ele_24 – Proportion of energy in second lowest elevation quarter.

Ele_14 – Proportion of energy in lowest elevation quarter.

Energy_highest – Proportion of energy in highest energy quarter.

Energy_34 – Proportion of energy in second highest energy quarter.

Energy_24 – Proportion of energy in second lowest energy quarter.

Energy_14 – Proportion of energy in lowest energy quarter.

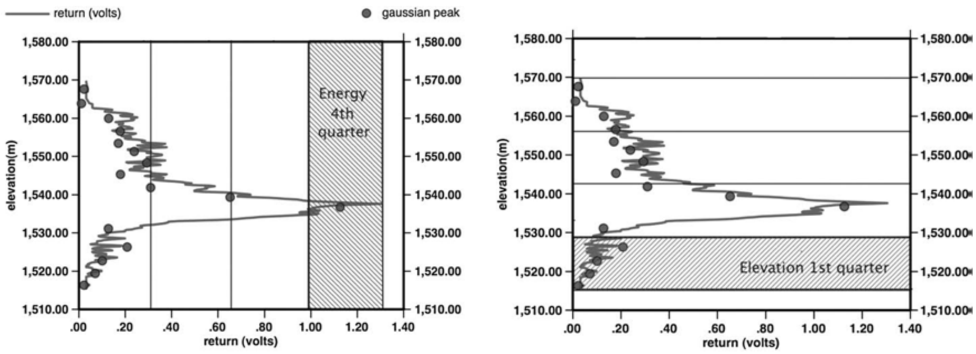


Fig. 5-5 The energy quarter divisions and the elevation quarters (Duncanson et al. 2010).

Then we developed a predictive regress model between airborne LiDAR estimated biomass, field measured biomass, and GLAS waveform parameters.

Models between GLAS waveform parameters and airborne LiDAR estimates of biomass were developed and applied to quality-filtered GLAS footprints in the study area to estimate the biomass. The biomass within GLAS footprints of the study area were used to fusion with optical data.

5.4.3 Imagery remote sensing data

Globcover Land Cover product of ENVISAT MERIS is produced in an automatic, repeatable and global way as a global land cover map at 300 m resolution with a legend defined and documented using the UN Land Cover Classification System (LCCS). The product can discriminate a great quality of the vegetation data from 22 different land cover classes at the global level (Defourny et al., 2006). Class ID for 40, 50, 60, 70, 100, 110 and 120 were defined as forest covers in this study (Table 5-3). This will be updated with our classification of 2005 with 30 m spatial resolution.

The GlobCover Land Cover product of central Asia for the period from Dec., 2004 to Jun., 2006 and GlobCover Annual MERIS FR mosaic product which computed by averaging the surface reflectance values of these bimonthly products generated over the year 2005 were used in this study.

Table 5-3. Forest Classes used in Globcover Product

Class ID	Globcover legend
40	Closed to open (>15%) broadleaved evergreen or semi-deciduous forest (>5m)
50	Closed (>40%) broadleaved deciduous forest (>5m)
60	Open (15-40%) broadleaved deciduous forest/woodland (>5m)
70	Closed (>40%) needleleaved evergreen forest (>5m)
100	Closed to open (>15%) mixed broadleaved and needleleaved forest (>5m)
110	Mosaic forest or shrubland (50-70%) / grassland (20-50%)
120	Mosaic grassland (50-70%) / forest or shrubland (20-50%)

MODIS Vegetation Continuous Field (VCF) (MOD44B) product of 2005 was used for extending the GLAS estimates. The VCF product shows the coverage of vegetation such as “forest” or “grassland” exists in each pixel. The product is estimated from MODIS 1-7 bands using supervised regression tree algorithm (Hansen 2003).

The 30-m resolution continuous fields of tree cover, which was developed by the University of Maryland using Landsat-based rescaling of MODIS vegetation continuous fields, will be used in the future (Sexton et al., 2013).

5.4.4 Auxiliary datasets

The terrestrial ecoregions data were used to stratify carbon modelling. An ecoregion is defined as a “relatively large unit of land or water containing a characteristic set of natural communities that share a large majority of their species, dynamics, and environmental conditions (Olson & Dinerstein, 2002).

The following auxiliary datasets were also used a layer in the maximum entropy prediction layer. I) The Digital Soil Map from FAO (Batjes, 2000). 2) The terrain slope derived from SRTM DEM (USGS), 3) The mean and seasonality of precipitation and temperature (Hijmans, et al., 2005).

5.5 Forest carbon storage mapping

5.5.1 Produce forest carbon storage map

According to different types of ecological zones, a set of categorical regression models was built between ICESat GLAS estimates and optical spectral variables. The cubist software was used for regression tree analysis (Pang et al., 2011). The MAXENT software was used for maximum entropy analysis (Philips, et al, 2006; Saatchi, et al, 2010). Both method gave similar spatial pattern of forest carbon distribution. We fused these two estimations as the estimated carbon product as shown in Fig. 5-6.

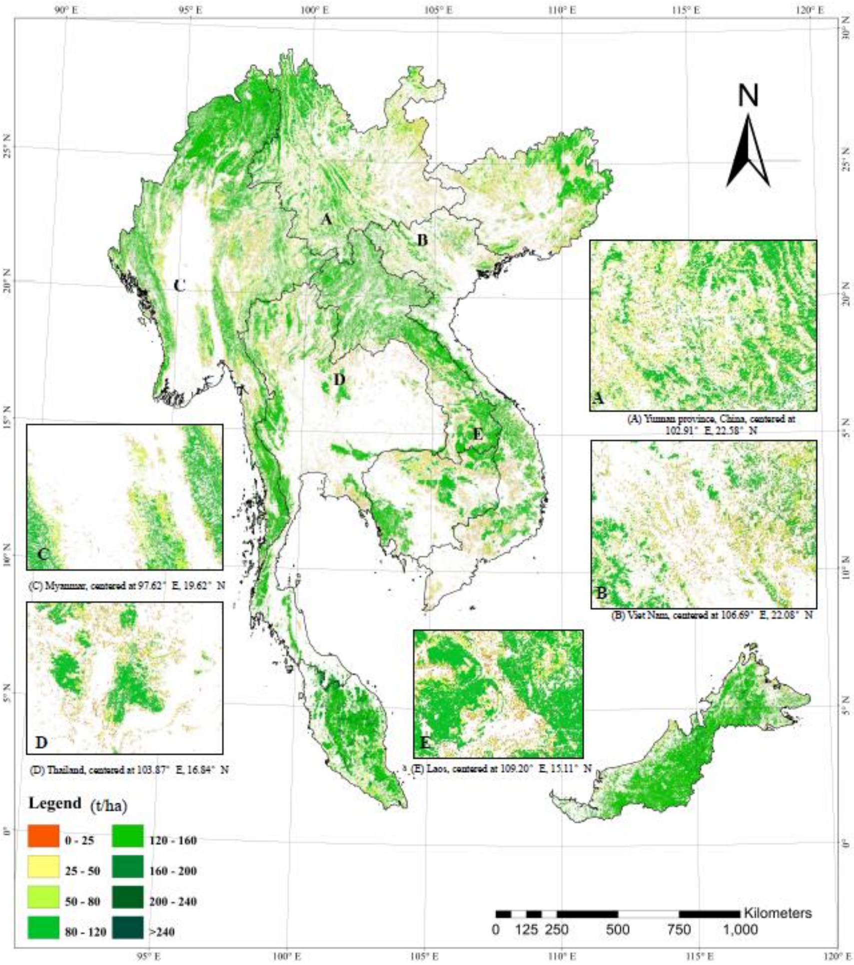


Fig. 5-6 Forest carbon estimation in the GMS & Malaysia

5.5.2 Compare forest carbon storage map with other reference data

The total estimated carbon stock by remote sensing in study area was 10,165 million tons. This estimation was comparable with FRA2010 report, whose carbon stock value was 10,207 million tons. The FRA2010 report estimation are from each country's report, which was based on traditional ground inventory method. The estimation of Yunnan and Guangxi of China was based on the data of the 7th National Forest Inventory during 2004-2008. As this data are from two different estimation methods, this comparison provided an independent data evaluation.

The we compared these two carbon values at country/economy level as shown in Figure 5-7 and 5-8. In this eight economies, these two estimations had good linear relationship which was close to 1:1 line. For different economies, the RS estimation showed different bias direction when comparing with FRA estimation. For Myanmar and Guangxi-China, RS estimations indicated larger carbon stock. For Malaysia and Viet Nam, RS estimations indicated less carbon stock. The other four economies showed RS estimations were close to FRA values.

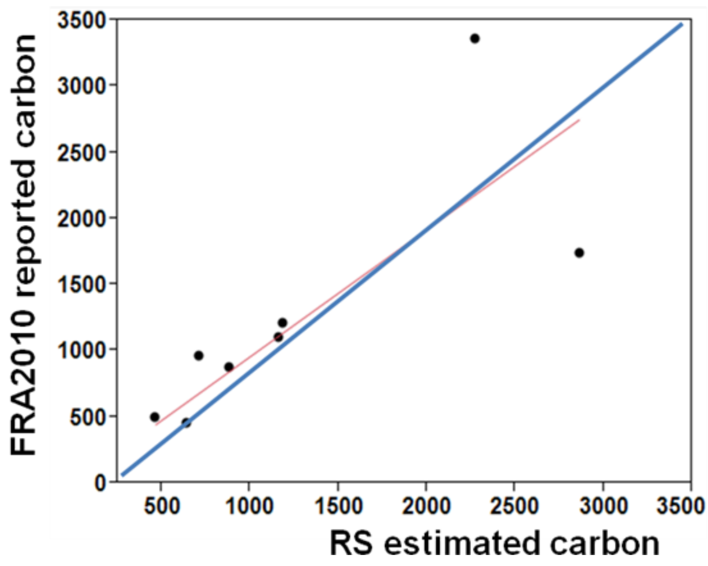


Fig. 5-6 Relationship of estimated forest carbon with FRA2010 at country/economy level (million ton) (The estimation of Yunnan & Guangxi was from the 7th National Forest inventory of China)

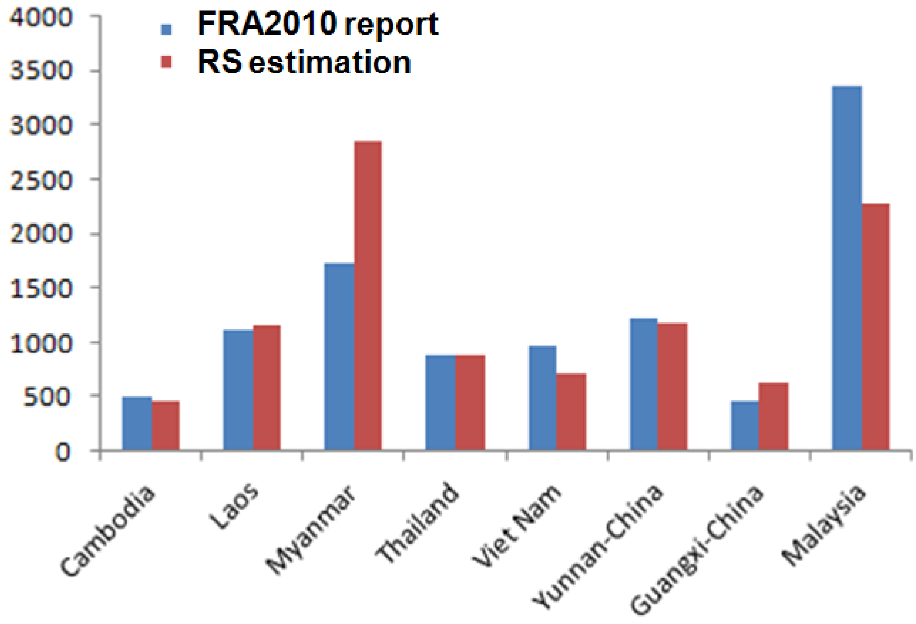


Fig. 5-7 Comparison of estimated forest carbon with FRA2010 (million ton) at country/economy level (The estimation of Yunnan & Guangxi was from the 7th National Forest inventory of China)

5.5.3 Compare forest carbon storage map with other reference data

As shown in Fig. 5-5, the high carbon density forests are mainly distributed in the Northern Myanmar and the Northwest Yunnan, the Northeast of Guangxi, border regions of Myanmar-China-Loas and the southern part of Myanmar-Thailand, the center and south of Laos and border regions with Viet Nam, a large part of Malaysia forest. As shown in Fig. 5-8, Malaysia and Myanmar had half of total carbon stock of this region.

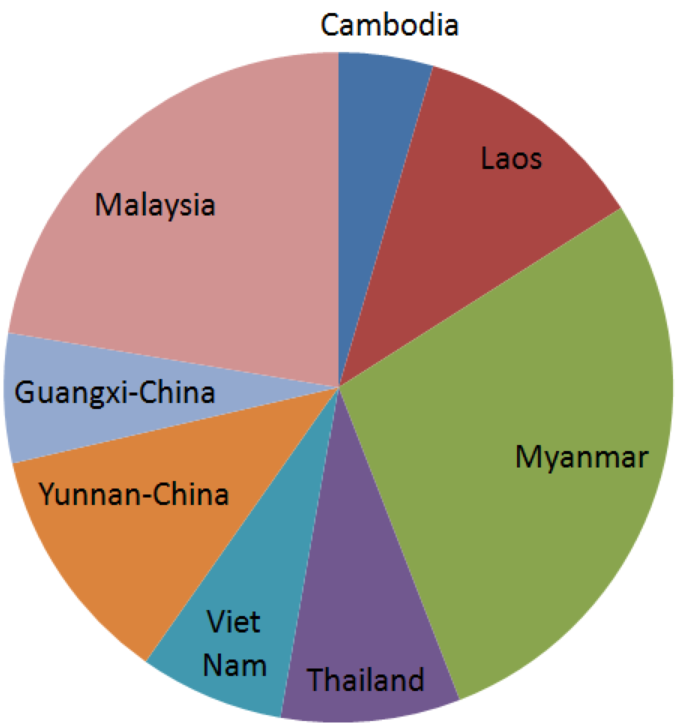


Fig. 5-8 The distribution of RS estimated forest carbon in the economies of GMS and Malaysia

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