Seminar series nr 195

Comparison and Validation of Five Land Cover Products over the African Continent

Ling Bai

2010
Department of Earth and Ecosystem Sciences
Physical Geography and Ecosystems Analysis
Lund University
Sölvegatan 12
S-223 62 Lund
Sweden

Comparison and Validation of Five Land Cover Products over the African Continent

---

Ling Bai, 2010

Degree-thesis in Physical Geography and Ecosystem Analysis
Supervisors
Jonathan Seaquist
Harry Lankreijer

Department of Earth and Ecosystem Science
Physical Geography and Ecosystem Analysis
Lund University

Abstract

Earth surface has always been an interesting scientific study area. it is tightly connected with other researches such as hydrology, ecosystem, atmosphere and climate change. Among other options, satellite collected earth surface information has several advantages including its objectivity, synoptic view, large scale and relatively short time intervals. A series of satellite derived land cover products were generated to provide for the science community, some of them are free of access to all users. This study chooses five free land cover products over the African continent to find out the similarities (differences) among them, and to find out their classification accuracy by using Google Earth derived reference data. The five land cover products are: MODIS, USGS, UMD, GLC2000 and GlobCover. The results of this study show understandable agreement across the five land cover products. Discrepancies mainly attributed to the different data source and generation process used by each land cover product, furthermore the data pre-process procedures applied to these products in this study may also share some responsibility. Accuracy assessment shows relatively low accuracy of about 54% as an average. Reasons for the low accuracy could be the quality and availability of reference data, and possible biases introduced during visual interpretation and labeling of validation scenes. The findings of this study suggest users be cautious about any particular land cover product, aware of their weakness and strength in their applications.

Acknowledgment

I would like to give special thanks to my supervisors Dr. Jonathan Seaquist and Dr. Harry Lankreijer at the Department of Earth and Ecosystem Science at Lund University, for their guidance, valuable advices and feedbacks.

I would also like to thank the technical and moral support of PhD student Qin Yuchu, my dearest friends and families.

Table of Content

Abbreviations

AVHRR: Advanced Very High Resolution Radiometer;
BATS: Biosphere Atmosphere Transfer Legend
BRDF: Bidirectional Reflectance Distribution Function
CEOS: Committee on Earth Observation Satellite
DMSP: Defense Meteorological Satellite Program
EEA: European Environment Agency
ENVISAT: Environmental Satellite
EOS: Earth Observation System
EROS: Earth Resources Observation and Science
ERS: European Remote Sensing Satellite
ESA: European Space Agency
EVI: Enhanced Vegetation Index
FAO: Food and Agriculture Organization of the United Nation
fPAR: Fractional of Absorbed Photosynthetically Active Radiation
GEIS: Global Environment Information System
GHG: Greenhouse Gas
GLC2000: Global Land Cover 2000
GLCC: Global Land Cover Characterization
GLCTS: Global Land Cover Test Sites
GOFC-GOLD: Global Observation of Forest and Land Cover Dynamics
GPS: Global Positioning System
IGBP: International Geosphere-Biosphere Programme
IGBP-DIS: International Geosphere-Biosphere Programme-Data and Information System office
IWMI: International Water Management Institution
JERS-1: Japanese Earth Resources Satellite 1
JRC: Joint Research Centre
LAI: Leaf Area Index
LCCS: Land Cover Classification System
LCWG: Land Cover Working Group
LISS: Linear Imaging Self-Scanning Sensor
LUCC: Land-Use and Land-Cover Change
MERIS: Medium Resolution Imaging Spectrometer
MERIS FR: Medium Resolution Imaging Spectrometer Full Resolution imagery
MODIS: Moderate Resolution Imaging Spectro-radiometer
MODLAND: MODIS Land
MSS: Multispectral Scanner System
NASA: National Aeronautics and Space Administration
NBAR: Nadir BRDF-adjust Reflectance
NDVI: Normalized Difference Vegetation Index
NOAA: National Oceanic and Atmospheric Administration

NPP: Net Primary Production
OLS: Operational Linescan System
PAL: Pathfinder Land
QA: Quality Assurance
SiB: Simple Biosphere Model
SIN: Sinusoidal projection
SPOT: Satellite Pour I'Observation de la Terre
SSU: Secondary Sample Unites
SRTM: Shuttle Radar Topography Mission
STEP: System for Terrestrial Ecosystem Parameterization
SWBD: External SRTM Water Body Data
SWIR: Short Wave Infrared
TM: Thematic Mapper;
UCSB: University of California, Santa Barbara
UMD: University of Maryland land cover product
UNEP: United Nations Environment Program
UNL: University of Nebraska-Lincoln
USGS: US Geological Survey
VATS: Validation and Test Sites
VGT: Vegetation
VITO: Flemish Institute for Technological Research (http://www.vito.be/VITO/EN/HomepageAdmin/Home/Homepage last date of access: 2010/10/20)
WGS84: World Geodetic System 1984
WRS: Landsat World Reference System

Comparison and Validation of Five Global Land Cover Products Over the African Continent

Ling Bai

Earth Science Department—Physical Geography and Ecosystem analysis,

Lund University, Sweden

Scientific Abstract

As the increasing attentions drawn to the environment and climate change issue, the profound impact on the earth system made known to nearly every corner of the world. A great variety of global protocols and conventions has been established aiming to reduce global environmental risks and maintain a healthy earth system. In order to monitor, supervise these protocols and conventions, science communities have expressed their urgent need for accurate and up-to-date land cover database. Land cover products play a very important role in various global change researches such as climate change, biodiversity conservation, ecosystem assessment, environment modeling and is in many aspects a foundation platform. This study compares five freely available and in common used satellite derived land cover products: MODIS map, USGS-IGBP map, UMD map, GLC2000 map, GlobCover map. They are produced by different working groups using different sources, characterization algorithms, and different classification schemes for the same purpose namely to provide accurate land surface data for the scientific communities. This study put these land cover products together, compare them with each other and assess them against an independent set of validation data aiming to find out how different they are, and how well these land cover product represent the land cover of Africa. The result shows reasonable agreement among the five land cover products, and reasonable over all accuracies of 54%. Although substantial discrepancies do exist, to some extent they can be explained by the data origins and data processing applied in this study. From analyzing possible reasons that cause the differences， the aim of this study is to try to provide an insight in these products, reveal their characteristics, explore their strengths and weaknesses. Hopefully, it could serve as indications to potential users and provide for future improvement of similar product.

Key words: Geography; Land cover products; classification algorithm; classification legend; land cover product validation

1. Introduction

Climate and biogeochemistry of the earth are deeply influenced by land cover and the alterations made by both human and nature (Strahler et al., 1999). On the other hand the terrestrial biogeochemical cycle also has major effect on the condition of land surface. The feedback mechanisms are motivated through the factors such as radiative properties of the ground surface features, the greenhouse gases. Thus it is very necessary to produce precise land cover datasets at large and regional scales, to provide for relevant researches.

Global land cover data plays a very important role in the process of understanding of ecosystems, hydrology and atmospheric systems as well as the feverish issue such as the climate change. One of the major data sources for the generation of land cover datasets is satellite information. Satellite data provides the only true synoptic view of earth surface, facilitate tasks of mapping and monitoring many areas that are difficult or unable to access. For example, one important application of satellite data is associated with the global protocols and conventions that are established in order to mitigate global environment risks. Until 2003, there are over 700 multi-lateral environment agreements and over 1000 bilateral agreements focusing on different aspects of the environment and global changes (Mitchell, 2003) that ranging from global scale protocols and conventions such as the climate change associated Kyoto Protocol, the biodiversity preservation associated Convention on Biological Diversity, to regional agreements like the Convention on the Conservation of European Wildlife and Natural Habitats and the Convention for Co-operation in the Protection and Development of the Marine and Coastal Environment of the West and Central African Region. Major information sources support the implementation, monitoring and compiling of those conventions and agreements including field data, models and remote sensing data. Earth observation-derived data are so important in this domain, remote sensing data such as Land cover maps have been viewed as a foundation data source, a crucial parameter of the ecosystem information (McCallum, 2006). Remote sensing can deliver suitable land cover information and other earth surface observational data in a transparent, repeatable fashion without bias (McCallum et al., 2006). The objectivity of remote sensing data is of high value for the studies developed upon it. Especially for studies on large scales, land cover products provide information of both regional and global scale at a relatively short time interval, which enables users to detect land cover changes of different temporal scales, derive information for various purposes.

Researchers have been studying on different land cover products to reveal the difference and possible reasons causing the discrepancies, to better understand the characteristics of each product, and providing information to improve the quality of similar products in the future. Studies have been done at global levels or sub-regional areas, but regional area like Africa received much less attention comparing research hot spots such as North America and Europe. Therefore, this study is focusing on the continent of Africa.

Africa, the second largest continent of the world, has its own geographical and ecological features. This great continent is particularly vulnerable to growing vicious climate changes. According to the investigations of United Nations Environment Program (UNEP, 2008), Africa is suffering from deforestation at twice of the average world rate. This very high rate of habitat lose may endanger various vegetation and animal species, damaging the unique biodiversity, risking the balance of the ecosystem on this continent. The wide spread poverty of Africa leads to an extremely low capacity of the ability to adaptation, which make it even more susceptible to climate changes (Hulme et al., 2000). There is a pressing need for information, data such as land cover and land use, to serve other researches to better understand the continent and interactions between climate, ecosystem and human activities. To help them reducing effects brought by climate changes, to protect them from being victims of climate change. But in reality, lack of ground truth data is a crucial obstacle for generating high accuracy or validating dataset for most large scale land cover maps (Muchoney et al., 1996). This study will try to gather as much information, use appropriate method to find out how do land cover products perform on representing Africa.

This study is focusing on land cover products over Africa to explore their performances and discrepancies, and tries to provide an insight on how the different land cover products help potential user's making wiser choices for different applications. Five widespread land cover products are chosen for this study to explore their character and differences. They are:

(1) Moderate resolution imaging spectro-radiometer (MODIS) 1km land cover product;

Table 1. A brief introduction to the five studied land cover products.

	MODIS	USGS-IGBP	UMD	GLC2000	GlobCover
Sensor	Terra MODIS	AVHRR	AVHRR	SPOT Vegetation	MERIS
Time of data collection	Jan2003-Dec2004	Apr1992-Mar1993	1981-1994	Nov1999-Dec2000	Dec 2004-Jun2006
Classification technique	Supervised decision–tree classification	Unsupervised classification combine with post-classificat ion refinement	Supervised classification decision tree	Generally unsupervised classification	Generally unsupervised classification
Classification scheme	IGBP (17 classes),	USGS IGBP (17 classes)	Simplified IGBP (14 classes)	FAO LCCS (23classes)	FAO LCCS (22 classes)
Validation	High resolution images and other ancillary data	Use other satellite images	Other digital datasets	High resolution satellite images	Statistical sampling, other satellite images

(2) The U. S. Geological Survey (USGS) land cover characteristics data base IGBP

(3) University of Maryland land cover product (UMD);

(4) Global Land Cover 2000 project data (GLC2000);

(5) GlobCover land cover product.

Table 1 shows brief information about the five land cover products. Some of the products are made available freely to all users in recent years. Since the access to these advanced land cover dataset has opened to a wide range of users, it requires better understanding of the characteristics of these land cover products, to find a feasible way to meet the needs of a great variety of applications.

In order to do this, the project investigated these land cover products from 3 aspects:

(1) To find out the differences of class coverage and spatial pattern among the five land cover maps, and try to better understand the strengths and weaknesses of each product.

(2) To carry out an classification accuracy assessment for each product: compare to available reference information, what accuracy result this study can generate.

(3) To find out the generation process of each land cover product, and try to find reasonable explanations to the discrepancies.

2. Background

2.1 Study Area

Africa (Fig. 1) is the second-largest and second-populous continent (UN Statistic Division, 2002), and it covers over 20% of the earth terrestrial surface. The extent of this continent ranges from its most northerly point (37°21' N) to most southerly point Cape Agulhas (34°51'15" S) with a distance of approximately 8000 km; From the westernmost Cape Verde (17°33'22" W) to the easternmost (51°27'52" E) projection, is a distance of approximately 7400 km (Liu et al., 1984). This continent is surrounded by the Mediterranean Sea to the north, both the Suez Canal and the Red Sea along the Sinai Peninsula to the northeast, the Indian Ocean to the southeast, and the Atlantic Ocean to the west. It straddles the equator, is the only continent that stretching from the northern temperate to southern temperate zones. The northern half is dominated by desert and arid area, while the central and southern part is primarily savanna and dense rainforest.

Geographical location and topography determine the unique climate system of Africa. Most parts of Africa are fairly warm. The average temperature and extreme

Fig. 1. Africa reference map (2007).

temperature are higher than any other continent, though it also have permanent snow cover but only on a very limited high mountain areas (Liu et al., 1984). Due to the comparative the comparatively mild topography pattern across the whole continent, the climate system of Africa is mostly regulated by latitudinal gradient, and mainly consists of equatorial climatic zone, tropical climatic zone and subtropical climatic zone. Precipitation amount gradually decrease with latitude till the arid and desert area, and increase again beyond that, by the Northern edge and Cape area of South Africa, where humid Mediterranean climate appears. Beyond the very humid equatorial rain forest area, natural land cover in most parts of the continent are controlled by precipitation, significant dry and wet season prevalent. The dominant vegetation type, according to Liu et al., (1984) includes evergreen sclerophyll trees and shrubs at Mediterranean climatic areas, tropical grasslands and savannas beyond the equatorial rain forest area, herbaceous wetlands mainly around White Nile basin and Chad Lake. Small amount of montane vegetation also exists along major mountains where the altitude gradient is large enough. Evergreen broadleaf and evergreen needleleaf mixed forest and spruce normally exist around these areas.

2.2 Land Cover Products

Five well known land cover products were chosen mainly because of their availability. All five land cover products studied here are free of charge for non-commercial use. Users can simply download them from websites (information are given in the online data source part). Their free and convenient accessibility enables a large users group. These land cover products are widely applied by the international science community, lots of studies and researches are developed based on these products and their conditions and characterizations directly influence the studies built upon. Several previous studies have been done in concern of some of these products, this study will put all five product together to have a closer look on them on a continental scale—Africa.

2.2.1 MODIS Land Cover Product (MODIS)

The objective of MODIS Land Cover Project is to exploit the spectral, temporal, spatial and directional information content of MODIS data and identifying a set of amenable land cover types to it (Strahler et al., 1999).

The Land Cover product derived from NASA website is the MODIS Land Cover yearly L3 (gridded variables in derived spatial and/or temporal resolutions) global 1 km SIN grid version 4.0 data, ID MOD12Q1. This product primarily identifies 17 classes of land cover with the International Geosphere-Biosphere Programme (IGBP) global vegetation classification scheme (Belward, 1996). Detailed class descriptions are given in Appendix 1. It includes 11 natural vegetation classes, 3 developed land classes including one natural vegetation mosaic, permanent snow or ice, barren or sparsely vegetated, and water. For convenience utilization by community, additional science data set layers for other classification schemes were adopted and performed, including the University of Maryland modification of the IGBP scheme, the MODIS LAI/fPAR (MOD15) scheme, and the MODIS Net Primary Production (MOD17) scheme (Table 2). A supervised decision tree classification method was applied to distinguish these classes on a continental basis. MODIS land cover product is produced quarterly and the observations used are during the prior year (12 months of input data). Quarterly production of this "annual" product is an advantage to make new land cover maps with more accurate classification techniques and more mature

Table 2. Available versions of MODIS land cover product with different classification schemes.

IGBP (Type 1)	**UMD (Type 2)**	**LAI/fPAR (Type 3)**	**NPP (Type 4)**
Water	Water	Water	Water
Evergreen needle-leaf forest	Evergreen Needle-leaf forest	Needle-leaf forest	Evergreen Needle-leaf vegetation
Evergreen Broad-leaf forest	Evergreen Broad-leaf forest	Broad-leaf forest	Evergreen Broad-leaf vegetation
Deciduous Needle-leaf forest	Deciduous Needle-leaf forest		Deciduous Needle-leaf vegetation
Deciduous Broad-leaf forest	Deciduous Broad-leaf forest		Deciduous Broad-leaf vegetation
Mixed forest	Mixed forest		Annual Broad-leaf vegetation
Closed shrub-lands	Closed shrub-lands	Shrubs	
Open shrub-lands	Open shrub-lands		Non-vegetated land
Woody savannas	Woody savannas		
Savannas	Savannas	Savanna	
Grasslands	Grasslands		Annual grass vegetation
Permanent wetlands			
Croplands	Croplands	Broad-leaf crops	
Urban and built-up	Urban and built-up	Urban	Urban
Cropland/Natural vegetation mosaic		Grasses/Cereal crops	
Snow and ice			
Barren or sparsely vegetated	Barren or sparsely vegetated	Non-vegetated	

training site database. MODIS classification training sites where developed by analyzing high resolution imagery (e.g. Landsat TM) in conjunction with ancillary data (Muchoney et al. 1999). The full MOD12Q1 products contain 16 science data sets including 5 classification schemes layers, confidence assessment for each scheme, quality flags for land cover types, one secondary class layer, one secondary class percentage file and 3 science data sets files. The dataset used in this research is the one with IGBP classification scheme. Information about MODIS product mainly derived from MODIS land cover product description, by Strahler et al. (1999).

2.2.1.1 MODIS Map Classification Algorithm & Validation

In order to generate the MODIS land cover map, a series of MODIS products was assembled:

(1) EOS Land/water mask that restricts classification to land regions and shallow water regions.

(2) Nadir BRDF-adjusted Reflectances (NBARs) derived from the MODIS BRDF/Albedo product (MOD43B4) in the MODIS Land Bands (1-7), adjusted to nadir view at the median sun angle of each 16-day period;

(3) Spatial texture derived from Band 1 (red, 250-meter) at 1000m resolution (MODAGTEX);

(4) Directional reflectance information at 1 km for 16-day periods (MOD43B1)

(5) MODIS Enhanced Vegetation Index (EVI) at 1 km for 16-day periods (MOD13);

(6) Snow cover at 500 m for 8-day periods (MOD10);

(7) Land surface temperature at 1 km for 8-day periods (MOD11);

(8) Terrain elevation information (MOD03);

The aim is to generate a suite of parameterized land cover types by investigating the spectral, temporal, spatial and directional information content of MODIS data. The classification algorithm is developed on a network of test sites chosen to represent major global biomes and cover types. In order to meet the requirement of a multivariable site model and database for training, testing and validation, a classification free site database: the System for Terrestrial Ecosystem Parameterization (STEP) was developed and used for the global Validation and Test Sites (VATS) (Strahler et al., 1999). The global site net-work was supported and coordinated by MODLAND, EOS and the larger remote sensing community, especially IGBP. Important sources of test site data including Landsat Pathfinder Global Land Cover Test Sites (GLCTS) program, IGBP-DIS Global 1-km Land Cover Database project, international field experiments such as the SALT transect (Savanna on the Long-Term) in West Africa. Despite the data richness for completed sites, the consistency in the level of land cover information at each site is not guaranteed. The classification process used a supervised model of decision tree and artificial neural net classification algorithms based on the training sites. The tree-structures rules recursively divided the input dataset into increasingly homogeneous subsets based on a splitting rule (Breiman et al., 1984).

MODIS land cover product quality control follows the MODLAND Quality Assurance (QA) Plan, which outlines run-time and post run-time QA procedures for MODLAND standard products.

Validation process of MODIS land cover product is similar to that applied to the IGBP-DIS Land Cover Database (Loveland and Belward, 1997; Belward, 1996). For further information about IGBP DISCover validation also see chapter 2.2.2.1. Constrained by cost and effort, test sites with high-resolution land cover information were employed again as validation data. Thus, the accuracy statistics derived from this biased validation process can not be regarded as a final statement of global accuracy but an indicator to the weakness and strength in the datasets, allow users to anticipate how errors might affect their owe researches. The MODIS land team has been working continuously and providing the most recent results for the accuracy assessment for the MODIS land product through their website (http://landval.gsfc.nasa.gov/ProductStatus.php?ProductID=MOD12). By the latest update (September 2009) the general accuracy at global scale is 75%, and 70-85% by continental region.

Strahler et al., (1999) also indicated possible sources of error and uncertainty. Both pre-processing of the source data provided to the land cover product and the land cover development process could introduce errors and uncertainties to the product. The nature of input data and also their influences on the algorithms and process could affect the final product. Errors might also be introduced during data compositing and analysis of the land cover dataset, misregistration of geo-location, as well as elevation which influences path length from the aspect of view angle, etc.

2.2.2 USGS Global Land Cover Characteristics Data V2.0 (USGS-GLCC)

USGS global land cover product is part of the 1 km resolution global land cover characteristics data base generated by the USGS national center for Earth Resources Observation and Science (EROS), the University of Nebraska-Lincoln (UNL) and the Joint Research Centre (JRC) of the European Commission (Loveland et al., 2000). It is part of the National Aeronautics and Space Administration (NASA) Earth Observing System Pathfinder Program and has been adopted by the International Geosphere-Biosphere Programme-Data and Information System office (IGBP-DIS) (Global Land Cover Characterization Background http://edc2.usgs.gov/glcc/background.php last date of access: 2010/10/22).

All USGS continental products are provided with the same two map projections: Interrupted Goode Homolosine and Lambert Azimuthal Equal Area projections, at 1-km nominal spatial resolution. USGS land cover data derived from 1km Advanced

Very High Resolution Radiometer (AVHRR) data spanning 12 months from April 1992 through March 1993. The products are based on a flexible data base structure and seasonal land cover regions concepts, which plays the role of framework for presenting the temporal and spatial patterns of vegetation in the database. The classification methods used can be described as a multi-temporal unsupervised classification of NDVI data with post-classification refinement using multi-source earth science data on a continental basis. Monthly AVHRR NDVI maximum value composites for April 1992 through March 1993 are used to define seasonal greenness classes. Other reference data and a collection of other land cover/vegetation information were used for the post-classification refinement. This process involved the skills of the human interpreter to make the final decisions regarding the relationship between spectral classes defined using unsupervised methods and landscape characteristics that are used to make land cover definitions. The USGS land cover characterization conceptual strategy aims to produce a "multi-dimensional database" that can be modified on a case by case basis to meet the specific needs of each intended applications. Thus, USGS land cover characteristics database is available with 6 different classification schemes: they are (1) IGBP Legend; (2) Biosphere Atmosphere Transfer Legend (BATS); (3) Simple Biosphere Model Legend (SiB); (4) Simple Biosphere 2 Model Legend (SiB2); (5) USGS Land Use and Land Cover Classification Legend (USGS) and (6) Vegetation Lifeforms Legend. The dataset used in this study is with IGBP scheme also known as IGBP-DISCover 2.0 map. Information for the IGBP classes, please refer to MODIS IGBP scheme in Table 2 or for more detailed description please refer to Appendix 1. Information on other legend product can be found via Loveland et al. (2000). Information about USGS land cover product mainly derived from USGS global land cover characteristics data information: http://edc2.usgs.gov/glcc/globdoc2_0.php#intro (last date of access: 2010/10/22).

2.2.2.1 USGS IGBP Map Classification Algorithm & Validation

Instead of basing on precisely defined mapping units in a predefined land cover classification scheme, USGS-IGBP land cover classification is developed on the seasonal land cover region. The regions are composed of relatively homogeneous land cover associations (e.g. similar floristic and physiognomic characteristics) exhibit distinctive phenology and have common levels of primary production (Loveland et al., 2000). These seasonal land cover regions serve as both description and quantitative attributes. Considering the unique elements different continents have, the characterization processes were carried out on a continent-to-continent basis. Other than 1 km AVHRR NDVI data, digital elevation, eco-regions data, country or regional level vegetation and land cover maps were also used in the land cover characterization process. They played important part when identifying land cover types and serve as guide to class labeling.

The classification method can be described as multi-temporal unsupervised classification with post-classification refinement (USGS GLCC product specification, 2008). The NDVI data was first filtered to eliminate water, snow and ice, and barren or sparsely vegetated areas, and then unsupervised clustering is performed to generate seasonal greenness classes. The resulting clusters for each continent were predetermined based on an empirical evaluation of clustering trials. The results were then went through a post-classification step to separate clusters with disparate land cover types based on various available ancillary data sets, and labeled by at least three interpreters per class. At last an exhaustive comparative analysis was conducted between the seasonal land cover regions and a great variety of ancillary data to determine the final attribute, land cover types and again at least three interpreters were participated to insure the consistency and translated in to the Global Ecosystem framework (Olson, 1994a, 1994b). Based on the Global Ecosystem framework, the Global Ecosystem type was cross-referenced to the other 6 land cover classification systems including the IGBP. Lastly, information of urban areas was extracted from the Digital Chart of the World (Defense Mapping Agency, 1992) and added to three of the derived data sets: Global Ecosystems, IGBP, and the USGS Land Use/Land Cover system.

The IGBP Land Cover Working Group established an accuracy assessment only for the IGBP dataset version 1.0 due to limited cost and effort. The validation was performed by researchers at the University of California, Santa Barbara (UCSB). In short, GLCC IGBP land cover product validation consists of two parts—a core sampling activity and a confidence site activity (Loveland and Belward, 1997). First a comprehensive evaluation based on confidence sites where high resolution satellite imagery or solid ancillary data was available. Secondly, a probability-based sampling strategy performed at global scale. Core samples were derived from Landsat TM or SPOT images through a stratified random sample design (Loveland and Belward, 1997). A total of 379 Landsat TM or SPOT images were obtained, and the goal was to identifying 25 samples per DISCover class (FAO, Rome 2000). Three interpreters participated in the interpretation, and the Land Cover Working Group (LCWG) developed an accuracy statistic system that sample figures qualified for this use are the ones with at least two out of three interpreters agree on the cover type. For the 15 DISCover classes (excluded Water, Snow and Ice classes), the average class accuracy was 59.4%, and the overall area weighted accuracy of the data set was determined to be 66.9% (FAO, Rome 2000). The highest individual class accuracies are class 16 (Barren or sparsely vegetated), class 2 (Evergreen Broadleaf Forest) and class 7 (Open Shrublands), while class 4 (Deciduous Broadleaf Forest) and class 9 (Savannas) were the lowest. The validation is only performed on DISCover version 1.0. Thus it does not provide conclusive accuracy for version 2.0 product, but a general indication of the quality, shed light on the quality and characteristics of the classification of the USGS project, and may provide insights into future global land characterization initiatives.

2.2.3 University of Maryland Land Cover Product (UMD)

The Geography Department of University of Maryland generated this global land cover collection in 1998 initially aimed to develop a coarse resolution, global land cover data set from satellite data for use in climate models. The 1km UMD land cover product is building on a much coarser 8km land cover dataset (De Fries et al., 1998). It is also another 1km resolution land cover data layer included in the MODIS at-launch product. This finer land cover product, according to the data description (*http://www.landcover.org/data/landcover/index.shtml* last date of access: 2010/10/22), developed from NASA/NOAA Pathfinder Land (PAL) AVHRR imageries acquired between 1981 and 1994. Data collection of 14 years allows an ability to test the classification algorithm stability. Additional red, infrared and thermal bands help to improve the delineation between cover types. A simplified IGBP classification scheme was adopted to distinguish 14 classes (Table 2 UMD type2). Main classification technique employed here was supervised decision tree classification. Multi-temporal AVHRR metrics were used to predict class memberships (e.g. NDVI). For training site they collected over 200 high resolution scenes globally that the surface type is assured. Most of the scenes were adopted from Landsat Multispectral Scanner System (MSS), and a few by Landsat Thematic Mapper and the LISS (Linear Imaging Self-Scanning Sensor).

Hansen et al. (2000a) hoped through the development of UMD 1km land cover product to explore objective, reproducible and feasible methodologies for global land cover classifications with an additional long temporal dataset, and provide for the global change research community. Information about UMD product is mainly derived from UMD land cover product guide, by Hansen et al. (2000a).

2.2.3.1 UMD Map Classification Algorithm & Validation

The UMD map was processed by supervised classification tree algorithm on a global scale at once which gives the advantages of the consistency of feature characterization, but a second regional relabeling was applied to avoid the obvious errors (Hansen et al., 2000a). Most of the training data were collected through overlay of co-registered coarse-resolution and interpreted high-resolution data sets by De Fries et al. (1998). However, restricted by the computing resources, a subset of the entire data set was extracted from the full resolution dataset—roughly every fifth pixel was samples across each row and column. A subset of 7205 pixels by 3122 lines was generated, and from this subset, 27031 pixels were taken from 156 high-resolution scenes which previously interpreted during the development of 8km dataset as training sites. Plus 10218 pixels developed from a new set of MSS images as compensation to the 156 scenes, in the end 37249 training pixels were generated.

Preliminary work including e.g. a maximum NDVI composite, which was created for associated channel values every month to reduce data volumes and cloud contamination, standard deviation check, atmospheric correction. For classification process, a decision tree classifier was adopted in this classification. To better generalize the predictive ability of the tree i.e. avoid the errors and noises introduced by overfiting to the training data, a pruning procedure was performed by visual interpretation. Couple of classes was directly taken from other dataset, including EROS Data Center 1km IGBP classification for urban and built-up class; water layer was taken from the preliminary water mask made for the MODIS sensor (Hansen et al., 2000a). Basically the UMD classification legend is conformed to IGBP classification system, however, a large portion of the training data for the UMD 1km land cover map was originally prepared for the 8km UMD maps, which does not include agricultural mosaic, wetlands or snow and ice classes (Hansen et al., 2000a). As a result, 3 IGBP classes: permanent wetlands, cropland/natural vegetation mosaic and ice and snow (included into bare ground class) classes are absent from the UMD map. Due to different definitions used by ancillary sources during the interpretation procedure, differences between the UMD and IGBP scheme such as height of trees are irreconcilable and differs quite largely (Appendix 1).

Although it is important to statistically evaluate the maps for the sake of future applications, an independent global validation dataset for UMD land cover product does not exist. As a substitute, UMD land cover product was examined against its training dataset. The total accuracy is 69%. Classes performed very well in training accuracy including Broadleaf Evergreen Forest (80%), Open Shrubs (84%) and Bare Ground (99%). Mixed classes are the most problematic ones due to ancillary data. More evaluation also been done through comparisons against other high-resolution sourced regional datasets. A measure of concurrency between products respectively was produced to help characterize the map.

2.2.4 Global Land Cover 2000 Project (GLC2000)

The GLC2000 map has been produced as part of the Global Land Cover mapping exercise and the Global Burnt Area mapping exercise, organized and led by the JRC's Global Vegetation Monitoring Unit, based on the Institute for Environment and Sustainability, Ispra, Italy. It is part of European Commission project called Global Environment Information System (GEIS) (Fritz et al., 2003). In this project they divided the world into 19 regional windows, more than 30 research teams involved in and contributing to these regional windows. Regional information was provided by regional experts on two conditions to guarantee consistency of the data. All data had to be based on SPOT-4 VEGETATION VEGA2000 dataset, and all the participants had to use the FAO LCCS (Di Gregorio and Jansen, 2000) classification system. The African window, which was studied in this article, was mapped at the JRC by Philippe Mayaux with contributions from a number of regional experts (Mayaux et al., 2003).

Different from other land cover products, GLC2000 product used four sets of satellite information as data sources. Each of the sources contribute to mapping a specific ecosystem or land cover, seasonality or water regime:

(1). SPOT VEGETATION data: The VGT data were provided by VITO in both S1 (single-day mosaics) and S10 (ten day composites based on maximum NDVI);

(2). JERS-1 and ERS Radar data: this data source mainly contributes on detection of humidity and texture measurements;

(3). The Defence Meteorological Satellite Program (DMSP) data: The DMSP Operational Linescan System (OLS) has a unique low light imaging capability originally developed for the detection of clouds using moonlight, by monitoring the frequency of the light sources, the location of human settlements can be determined, so-called “stable lights”;

(4). Digital elevation model: for setting up threshold for certain land cover type(s).

GLC2000 global product adopted a so called bottom-up approach to directly translate regional maps provided by regional experts in to global legend. FAO LCCS classification scheme is the one could fulfill the requirements of this global mapping, whilst remaining thematically accurate at the local level. Thus, GLC2000 land cover product is available in two levels of classifications: global and regional (continental). The dataset used in this study only confined to African continent extracted from the global level data. The global level classes and their code in GLC2000 products are listed in Table 3. (Information about GLC2000 map is mainly derived from GLC2000 data description by Fritz et al. (2003).)

2.2.4.1 GLC2000 Map Classification Algorithm & Validation

As mentioned above, GLC2000 global data consisted of 19 regional windows. More than 30 teams lead by regional experts provided information about their specialized region based on SPOT-4 VEGETATION VEGA2000 data with FAO LCCS regional classification scheme. High levels of understanding of their particular region guarantees a certain level of quality; various mapping method with hierarchical LCCS classification scheme that applied by regional experts allows choice for most appropriate approaches for their respective region; more available reference material on a regional scale (Fritz et al., 2003).

Close collaboration with the GLC2000 partners is crucial in this approach. First the regional land cover map provided by the GLC2000 partners went through a first quality check from the JRC. Same eco-regions on overlapped areas were particularly investigated. Than the processing chain was started by extracting relevant areas from regional products and translate regional to the global legend. After that, it mosaics together each extracted area, area windows with highest quality were chosen when dealing with overlapped areas (Fritz et al., 2003). Due to the hierarchical feature of LCCS classification system, coding each class with LCCS allows a map legend to be progressively more detailed for regional and possibility to translate the regional classification into a more general global legend.

The regional map of Africa was produced by Philippe Mayaux with other regional

Table 3. GLC200 LCCS classification legend.

Value	Class description	Value	Class description
1	Tree cover, broad-leaved, evergreen	13	Herbaceous cover, closed-open
2	Tree cover, broad-leaved, deciduous, closed	14	Sparsely herbaceous or sparse shrub cover
3	Tree cover, broad-leaved, deciduous, open	15	Regularly flooded shrub and/or herbaceous cover
4	Tree cover, needle-leaved, evergreen	16	Cultivated and managed areas
5	Tree cover, needle-leaved, deciduous	17	Mosaic: Cropland/Tree cover/Other natural vegetation
6	Tree cover, mixed leaf type	18	Mosaic: Cropland/Shrub and/or grass cover
7	Tree cover, regularly flooded, fresh water	19	Bare areas
8	Tree cover, regularly flooded, saline water	20	Water bodies
9	Mosaic: Tree cover/Other natural vegetation	21	Snow and ice
10	Tree cover, burnt	22	Artificial surfaces and associated areas
11	Shrub cover, closed-open, evergreen	23	No data
12	Shrub cover, closed-open, deciduous		

experts in 2003 (Mayaux et al., 2003). The map was created with a multi-sensor approach, including SPOT VGT-for vegetation formations, Defence Meteorological Satellite Program (DMSP) stable lights for urban areas, JERS-1 and ERS Radar data for the world humid ecosystem data and last the US Geological Survey's 30 arc-second database "GTOPO30" for montane forest data. Classification process is divided in to three parts to cater for the data sources:

1. 100 spectral classes were produced through unsupervised clustering algorithm (ISODATA) from the VEGETATIOPN mosaics. The labeling process was done by visual interpretation aided by thematic maps and class spectral statistics.
2. The classification of JERS-1 and ERS radar data is based on the rules defined by inference from training sets in Congo floodplain from the work of Mayaux et al. (2002). The training data sets were chosen through visual inspection upon the national forest maps.
3. The characteristics of the DMSP data made it a seeding layer on SPOT VGT data set to extract urban areas that match the two data sets, and classified using ISODATA into ten classes.

After this regional product reaches the JRC, adjustment of geo-projections and cell size (if any modification was applied), DMSP based urban classification correction, vegetation modification based on elevation data and necessary gap filling along boundaries was made and finale. Along with the process, ancillary data such as literatures and maps have the information on spatial distribution and characteristics of ecosystem were used to help the identification of land cover types and played quite important role (Mayaux et al., 2003). Previous studies proved the advantages of using multi data sources and collaboration of regional working groups over a centralized approach relying on a single data set (Pohl and Van Genderen, 1998; Mayaux et al., 2000).

GLC2000 land cover map validation also facing the common problem of all large scale maps: impracticable for classical ground-truth validation. As a result, a validation procedure similar to that designed for IGBP-DISCover map (Belward et al., 1999), which mainly depends on high resolution satellite data and ancillary information was adopted for GLC2000 product. First, Confidence-building (also called quality control) sites on a regional scale and then probability-based sampling at the global scale (Mayaux et al., 2004). As complement to each other, they provide different information about this product. On one hand the quality control evaluated this data from a regional level tells exhaustive information on the nature of errors, their location and relationship with spatial pattern; on the other hand, statistics validation provides a quantitative figure of the map from a global scale (Mayaux et al., 2006). This process prevent macroscopic errors usually observed in global land cover maps but poorly detected by statistical accuracy assessment, and also improved the global acceptance by the customers associated in the process (Mayaux et al., 2004). Comparison with different data sets was also conducted in order to gain better understanding of the thematic content and the spatial detail of the classes.

GLC2000 land cover map quality control was processed at regional level, just the same geographical scale as the map production. Cells of the map were visually compared with reference according to a systematic descriptive protocol. Each cell associated in this procedure were characterized with detail information including: cell composition and spatial pattern; the comparison with other global land cover products; the overall quality of the cell; the nature of any problems occur.

For the statistical accuracy validation, a two-stage stratified clustered sampling was applied on the Landsat World Reference 2 System (WRS-2) which provides a sampling frame for Landsat scenes. An 1800 by 1200 km sample grid was overlaid on GLC2000 map, within each grid block 6 fixed points were extracted, each point was selected at a distance of 600 km on two directions. Within each of the Landsat scene 5 boxes of 3*3km were extracted as Secondary Sample Unites (SSU) (Mayaux et al., 2006). The validation dataset (SSU) was then analyzed and interpreted by interpreters with regional ecological knowledge and expertise with fine resolution data interpretations, a series of ancillary data like aerial photographs, thematic maps, coarse resolution NDVI profiles were used to support the Landsat interpretation process. In the end the interpretations were translated in to GLC2000 map classification scheme to measure the map accuracy. The over all global accuracy is $68.6 \pm 5\%$.

2.2.5 GlobCover Land Cover Product (GlobCover)

GlobCover land cover product is the result of the European Space Agency (ESA)-GlobCover project, its objective is the generation of a land cover map of the world using an automated processing chain from the 300m Medium Resolution Imaging Spectrometer (MERIS) time series. This project was started in April 2005 by an international consortium and based on abundant feedbacks and comments from ESA internal assessment and a large group of partners and end users: JRC, FAO, EEA, UNEP, GOFC-GOLD and IGBP.

Table 4. GlobCover LCCS classification legend.

Value	Global GlobCover legend (level 1)	Value	Global GlobCover legend (level 1)
11	Post-flooding or irrigated croplands	120	Mosaic Grassland (50-70%) / Forest/Shrub-land (20-50%)
14	Rain fed croplands	130	Closed to open (>15%) shrub-land (<5m)
20	Mosaic Cropland (50-70%) / Vegetation (grassland, shrub-land, forest) (20-50%)	140	Closed to open (>15%) grassland
30	Mosaic Vegetation (grassland, shrub-land, forest) (50-70%) / Cropland (20-50%)	150	Sparse (>15%) vegetation (woody vegetation, shrubs, grassland)
40	Closed to open (>15%) broadleaved evergreen and/or semi-deciduous forest (>5m)	160	Closed (>40%) broadleaved forest regularly flooded - Fresh water
50	Closed (>40%) broadleaved deciduous forest (>5m)	170	Closed (>40%) broadleaved semi-deciduous and/or evergreen forest regularly flooded - Saline water
60	Open (15-40%) broadleaved deciduous forest (>5m)	180	Closed to open (>15%) vegetation (grassland, shrub-land, woody vegetation) on regularly flooded or waterlogged soil - Fresh, brackish or saline water
70	Closed (>40%) needleleaved evergreen forest (>5m)	190	Artificial surfaces and associated areas (urban areas >50%)
90	Open (15-40%) needleleaved deciduous or evergreen forest (>5m)	200	Bare areas
100	Closed to open (>15%) mixed broadleaved and needleleaved forest (>5m)	210	Water bodies
110	Mosaic Forest/Shrub-land (50-70%) / Grassland (20-50%)	220	Permanent snow and ice

GlobCover land cover product is based on ENVISAT's MERIS Level 1B data with a spatial resolution of 300 meters. It was derived by an automatic and regionally-tuned classification of a time series of MERIS FR mosaics cover the period of December 2004 to June 2006. 22 land cover global classes are defined with the FAO LCCS classification scheme (Table 4). In addition GlobCover also provides regional land cover maps at continental scale, and the land cover classes have been extended to 51 types. The quality of the GlobCover product is highly dependent on the reference land cover database used for the labeling process and on the number of valid observations available as input. (Information about GlobCover land cover product is mainly derived from GlobCover data specification by Bicheron et al. (2008).)

2.2.5.1 GlobCover Map Classification Algorithm & Validation

In short, GlobCover land cover product was processed in two major modules: the first step—a pre-processing module produce global mosaics at 300m resolution; step 2—a classification module leading to the final 300m resolution GlobCover land cover map.

Before the classification, GlobCover world map was stratified in equal-reasoning areas that mainly based on natural discontinuities to increase classification efficiency by reduce the land surface reflectance variability and to better utilize regional characteristic information. The classification process of GlobCover map is composed of four main steps (Bicheron et al., 2008).

1. Supervised classification was conducted at badly represented land cover classes, i.e. urban and wetland areas. Then an unsupervised classification is applied on the rest parts.
2. Temporal characterization of the spectral cluster results of the unsupervised classification, to smooth out the seasonality.
3. Classification of the spectro-temporal clusters according to their temporal similarity.
4. Automatic labeling procedure based on the global reference land cover database that compiled from GLC2000 and some high accuracy local reference land cover maps. Each spectro-temporal class has assigned to a unique label through the rules that developed with the help of international land cover experts. The hierarchical feature of FAO LCCS classification scheme was also appreciated in this land cover product. For detail information about the class description see Appendix 1.

Post-classification process was applied after the fourth step to solve particular deficiencies. Programmatic constrains resulting in gaps in the coverage of MERIS FR acquisitions and land cover product, and lack of short wave infrared (SWIR) band in the MERIS sensor led to large underestimation of flooded vegetation cover types. Reference land cover database were directly introduced to fill these gaps and to compliment underestimated classes e.g. "Closed broadleaved forest regularly flooded with fresh water" and "Closed broadleaved semi-deciduous and/or evergreen forest regularly flooded with saline water”. External SRTM Water Body Data (SWBD) was used to improve water body delineations in this process (Fritz et al., 2003).

The quantitative validation of GlobCover land cover product is designed based on the document of CEOS Land Cover Product Validation subgroup: “Global Land Cover Validation: Recommendations for Evaluation and Accuracy Assessment and of Global Land Cover Maps” (Strahler et al., 2006). The data collection tool and data analysis was developed and completed by an independent private company: Infram B.V. 16 dedicated experts with rich experiences and expertise from different well-known international networks were invited to work on the “ground truth” interpretation. For equal sampling reason, the GlobCover product was divided into 5 regions (Africa, Australia & Pacific, Eurasia, North America and South America), and three experts: André Nonguierma, Bruno Gérard and Philippe Mayaux were responsible for the Africa region (Bicheron et al., 2008). During the interpretation, experts were allowed to report at maximum 3 land cover types for each validation sample with the most LCCS classifiers and Infra B.V. will transform the collected LCCS classifier values into single GlobCover classes. Validation sites were selected using a stratified random sampling strategy. NDVI time series profiles were extracted for each validation sample from SPOT-VEGETATION and for probably the first time, on-line datasets—Virtual Earth and Google Earth were used for the purpose of validation exercise. A 5*5 MERIS pixels observation unit system was adopted instead of only the sample point, each unit equals a surface area of 225 ha around the point. This process generated more than 3000 highly confident points. The GlobCover product overall accuracy resulting from this validation exercise is 67.1%. Bare areas, Forests and Snow and Ice classes are the most accurate ones considering their homogeneous and unambiguous nature. Wetlands, grasslands and shrublands classes, however showed disagreement among the experts’ interpretations.

Table 5 is a brief summary of the main characteristics of the five land cover product introduced above.

Table 5. Summary of the main characteristics of the five land cover products.

	MODIS	USGS-IGBP	UMD	GLC2000	GlobCover
Sensor	Terra MODIS	AVHRR	AVHRR	SPOT Vegetation	MERIS
Data temporal	Jan2003 - Dec2004	Apr1992 - Mar1993	1981- 1994	Nov1999 – Dec 2000	Dec 2004 – Jun 2006
Input data	EOS land/water mask; Nadir BRDF-adjusted Reflectances (NBARs); Spatial texture; 6-day Directional reflectance information; 16-day MODIS Enhanced Vegetation Index (EVI); 8-day Snow cover; 8-day Land surface temperature; Terrain elevation information	Monthly AVHRR NDVI maximum value; digital elevation; ecoregion data; a collection of other land cover/vegetation information; Digital Chart of the World urban information;	AVHRR imageries; red, infrared and thermal bands data; EROS Data Center 1km IGBP urban and built-up class; water mask made for the MODIS.	SPOT-4 VEGETATION VEGA2000 dataset; JERS-1 and ERS Radar data; DMSP data; Digital elevation.	ENVISAT's MERIS FR data; SWBD data.
Training data	STEP, high resolution imagery, field data.		over 200 high resolution scenes		
Classification method	supervised decision tree and artificial neural net classification algorithms	Continental based unsupervised classification with post-classification refinement	supervised decision tree classification	Regional based unsupervised classification	Generally unsupervised classification
Interpreter	MODLAND, EOS, remote sensing community	Post-classification refinement by three interpreters for each class			16 experts for validation data interpretation
Map legend & resolution	IGBP (17 classes) 1km	USGS IGBP (17 classes) 1km	Simplified IGBP (14 classes) 1km	FAO LCCS (23classes) 950m	FAO LCCS (22 classes) 300m
Validation reference data	high-resolution training site land cover information	Landsat TM and SPOT images	Training data	high resolution satellite data and ancillary information	SPOT-VEGETATION NDVI data; Virtual Earth and Google Earth data
Accuracy	Globally 75%	Globally 66.9%	Globally 69%	Globally 68.6±5%	Globally 67%

3. Methodology

This research is mainly focusing on understanding the differences among the five land cover products and their respective characteristics. Through comparison with each other and checking their accuracies against a reference dataset developed from Google Earth to achieve the study objective, and hopefully give some indications that help future users getting a better understanding of the differences among these products, be aware of their strength and weakness and help them making choices for appropriate applications at different field of interest.

3.1 Data Pre-processing

3.1.1 Geographical Projection Transformation

Unification of different geographic projections and coordinate systems is the first big pre-condition of all investigation associated in this research.

These five land cover products were generated form different program for different applications, it is reasonable that they all are characterized with different map projections (see Table 6). This means that there are different distortions existing among them. Thus, geographical projection transformation is very crucial to insure the comparability among the five datasets. To maintain their area, Albers Equal area projection for Africa continent with Latitude-Longitude coordinate system (WGS_84) was adopted in this study.

Table 6. Original map projections of the studied land cover products.

	Map projection	Datum
MODIS	MODIS sinusoidal	WGS_1984
USGS	Lambert Azimuthal Equal Area Projection	WGS_1984
UMD	Interrupted Goode's Homolosine	WGS_1984
GLC2000	Geographic (Lat/Lon)	WGS_1984
GlobCover	Plate Carrée	WGS_1984

3.1.2 Classification Scheme Conversion

To make the five products comparable, unification of class legend is the second crucial pre-condition of this study. All five land cover products must be converted to the same classification system. Considering the wide spread and consistent application of the IGBP legend system, the five products were translated into IGBP classification system. According to the data sources descriptions, except the MODIS map (IGBP 17classes) and the USGS IGBP Africa map (IGBP 17 classes) the other three products adopted different classification scheme. Although the UMD map classes basically conform to the IGBP classification scheme, it only possesses 14 classes (Hansen et al., 2000a). The GLC2000 map is with FAO LCCS, which has as many as 23 classes and the GlobCover map is also with the LCCS classification scheme, also has 22 classes (Table 5 and Appendix 1).

Since the MODIS and USGS datasets were downloaded with an IGBP classification scheme, only the other 3 datasets needed class conversion. The translation is presented in Table 7, for detail description of each class under different classification scheme please refer to Appendix 1. The UMD datasets as mentioned above is provided with a modified IGBP classification system, the reclassification is relatively straightforward. On the other hand, the GLC2000 map and GlobCover map required more efforts. The GLC2000 map was "translated" into the IGBP Classification system based on the previous study of McCallum et al. (2006), and according to the GlobCover Products Description and Validation Report (2008) "the typology of GlobCover map classification system has been defined using UN LCCS to be as much as possible compatible with the GLC2000 map." Thus GLC2000 is an intermediate connection to the GlobCover LCCS legend system and IGBP legend. GlobCover classes were first compared and related to GLC2000, and than converted into IGBP system. In this study, no attempt was made to modify the classes in any of the dataset. The intention is to show the difference between the target products using IGBP classification by assigning one or more whole classes to the most suitable IGBP class. In the end all five land cover maps sharing the same IGBP classification scheme with same class value and corresponding class names.

3.1.3 Unification of Map Resolution and Map Coverage

Among the five land cover products, GlobCover land cover product is with a higher map resolution of 300m and GLC2000 is 950.79m. To be comparable, these two maps were processed using nearest neighbor resampling method, aggregated their resolution to 1000m to be consistent with the other three products.

Due to different initial application purpose, all five maps were produced with its own map coverage for the African continent. For further quantification analysis in this study, an approximate outline along the African continent with Albers Equal Area projection was generated and applied to all the dataset to exclude areas out of this range and make sure they have, at least, the same total coverage area.

3.2 Comparison of Land Cover Fractions

As a first step, a total percent area comparison of all five land cover maps was performed to have a general sense of how different they are in a broad-base. This number is computed by sum the total area of one class of the five maps up, then divided it by the same class total area of each map. All 17 classes of each map were all counted and computed to generate percent area numbers.

Table 7. Map Legend translation table. The UMD map, GLC2000 map and GlobCover map class values and their corresponding class names are converted into the IGBP classification scheme in the first column (e.g. after transition, GLC2000 class 4 and class 10 will become IGBP class 1.). For detail descriptions of classes of different classification scheme see Appendix 1.

IGBP (MODIS, USGS) (FAO Rome 2000)	**UMD IGBP** (Hansen et al., (2000)a)	**GLC2000 LCCS** (GLC2000 LCCS standard class description)	**GlobCover LCCS** (Bicheron et al., 2008)
1. Evergreen Needle-leaf Forests	1. Evergreen Needle-leaf Forests	4. Tree cover, needle-leaved evergreen, closed to open	70. Closed (>40%) needle-leaved evergreen forest (>5m).
		10. Tree Cover, burnt (mainly boreal forests)	
2. Evergreen Broadleaf Forests	2. Evergreen Broadleaf Forests	1. Tree cover, broadleaved evergreen, closed to open	40. Closed to open (>15%) broadleaved evergreen and/or semi-deciduous forest (>5m).
		8. Tree cover, closed to open, regularly flooded, saline water	170. Closed (>40%) broadleaved semi-deciduous and/or evergreen forest regularly flooded - Saline water.
		7. Tree cover, closed to open, regularly flooded, fresh water	160. Closed (>40%) broadleaved forest regularly flooded - Fresh water.
3. Deciduous Needle-leaf Forests	3. Deciduous Needle-leaf Forests	5. Tree cover, needle-leaved deciduous, closed to open	90. Open (15-40%) needle-leaved deciduous or evergreen forest (>5m)
4. Deciduous Broadleaf Forests	4. Deciduous Broadleaf Forests	2. Tree Cover, broadleaved deciduous, closed	50. Closed (>40%) broadleaved deciduous forest (>5m)
5. Mixed Forests	5. Mixed Forests	6. Tree cover, mixed leaf-type, closed to open	100. Closed to open (>15%) mixed broadleaved and needle-leaved forest (>5m)
6. Closed Shrub-lands	8. Closed Bushlands or Shrublands	9. Mosaic of tree cover and other natural vegetation (with possible croplands)	110. Mosaic Forest/Shrub-land (50-70%) / Grassland (20-50%)
		11. Shrub cover, closed to open evergreen	
7. Open Shrub-lands	9. Open Shrub-lands	14. Sparse Herbaceous or sparse Shrub cover	150. Sparse (>15%) vegetation (woody vegetation, shrubs, grassland)
8. Woody Savannas	6. Woodlands	3. Tree cover, broadleaved deciduous, open	60. Open (15-40%) broadleaved deciduous forest (>5m)

9. Savannas	7. Wooded Grasslands/Shrub-lands	12. Shrub cover, closed to open, deciduous	120. Mosaic Grassland (50-70%) / Forest /Shrub-land (20-50%)
			130. Closed to open (>15%) shrub-land (<5m)
10. Grasslands	10. Grasslands	13. Herbaceous cover, closed to open	140. Closed to open (>15%) grassland
11. Permanent Wetlands	(Absent class on the UMD map.)	15. Regularly flooded Shrub or Herbaceous cover, closed to open	180. Closed to open (>15%) vegetation (grassland, shrub-land, woody vegetation) on regularly flooded or waterlogged soil - Fresh, brackish or saline water
12. Croplands	11. Croplands	16. Cultivated and managed areas	11. Post-flooding or irrigated croplands
			14. Rain-fed croplands
13. Urban and Built-up	13. Urban and Built-up	22. Urban Areas	190. Artificial surfaces and associated areas (urban areas >50%)
14. Croplands/Natural vegetation	(Absent class on the UMD map)	17. Mosaic of Cropland / Tree cover/ Other Natural Vegetation	20. Mosaic Cropland (50-70%) / Vegetation (grassland, shrub-land, forest) (20-50%)
		18. Mosaic of Cropland / Shrub or Herbaceous cover	30. Mosaic Vegetation (grassland, shrub-land, forest) (50-70%) / Cropland (20-50%)
15. Snow and Ice	(Absent class on the UMD map)	21. Snow or Ice	220. Permanent snow and ice
16. Barren or Sparsely Vegetated	16. Barren	19. Bare Areas	200. Bare areas
17. Water Bodies	14. Water Bodies	20. Water Bodies	210. Water bodies

3.3 Per-pixel Comparison

In order to test the level of agreement among the five land cover maps, a pixel based comparison process was performed. However, due to the huge amount of per-pixel data volume, from a cost and time efficiency aspect, it is impractical to process every single pixel of every map. To carry out this assessment, a series of random samples were extracted from the maps. Each sample consists of 20*20 pixels, and every map has the exact same sample locations (column and row numbers) that spread all over the African continent (Fig. 2b). In the end 101 samples for every map was collected that is 101*20*20*5=2020000 pixels in total, and each $1km^2$ pixel in the samples were compared with their counterparts. Inspired by McCallum et al. (2006), five levels of agreement grade were defined.

1. no-agreement—pixels containing a unique IGBP class in each dataset.

2. low-agreement—pixels where two of the five datasets are in agreement.

3. medium-agreement—pixels where three of the datasets are in agreement.

4. high-agreement—pixels where four of the datasets are in agreement.

5. full-agreement—where all five datasets within a pixel were in agreement.

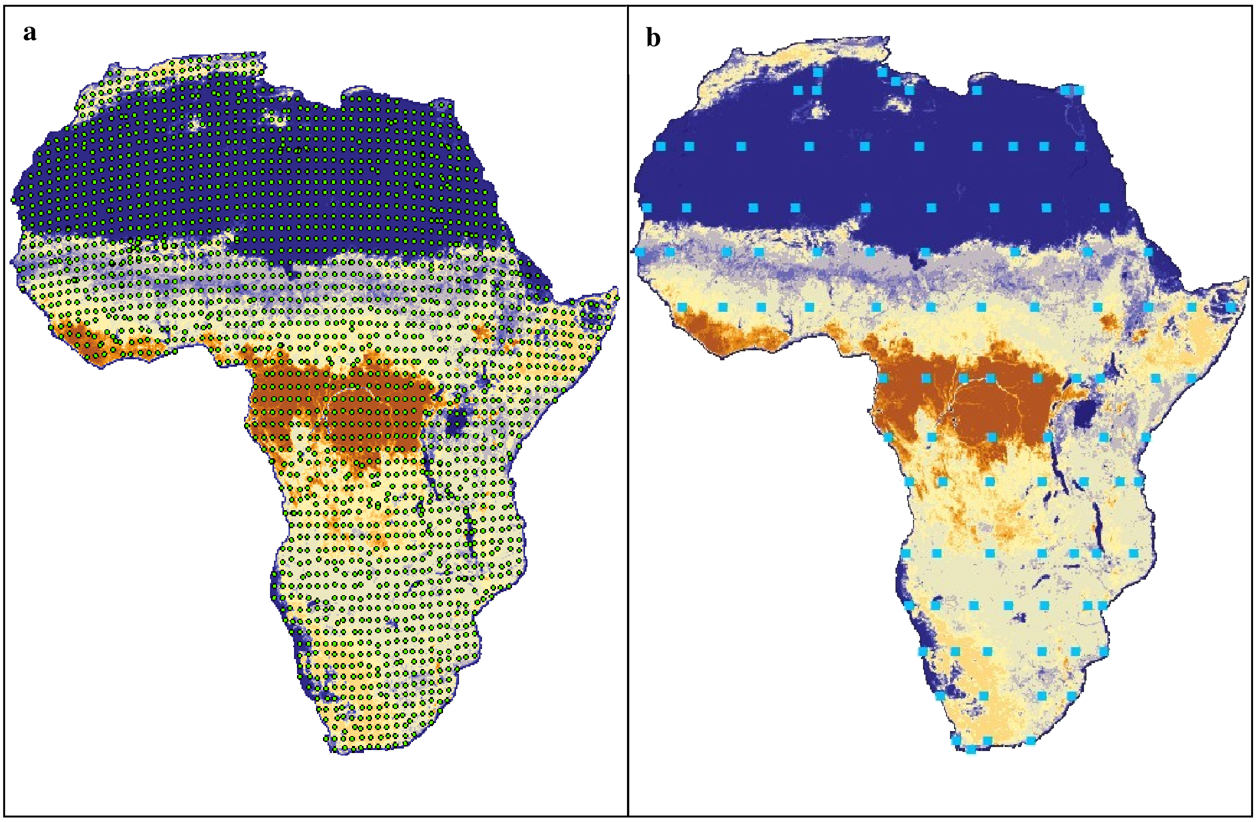

Fig. 2. a. Locations of Google Earth derived validation sites; b. Locations of the 101 area comparison samples.

3.4 Validation

Accuracy assessment has always been stressed by researchers for its importance to the scientific investigations and policy decisions made based on land cover maps (Stehman and Czaplewski, 1998). Land cover validation provides indications or evaluations of confidence that a pixel or segment has been correctly assigned to a thematic class (Scepan et al., 1996). One of the most common means of expressing classification accuracy is the classification error matrix (sometimes called a confusion matrix or a contingency table). Error matrices compare, on a category-by-category basis, the relationship between known reference data (ground truth) and the corresponding results of an automated classification. Several characteristics about classification performance are expressed by an error matrix. For example, one can study the various classification errors of omission (exclusion) and commission (inclusion) (Lillesand et al., 2004). User's accuracy is the measure of commission error and indicates the probability that a pixel classified into a given class actually represents that class on the ground. It is computed by dividing the number of correctly classified pixels in each (on the major diagonal) class by the total number of pixels that were classified in that category (the row total). Producer's accuracy indicates how well training set pixels of the given cover type are classified. It is computed by dividing the number of correctly classified pixels in each class by the number of training set pixels used for that class (the column total) (Lillesand et al., 2004).

Brief introductions about the original validation process for the five studied land cover datasets can be found in chapter 2. 2. The accuracy assessments were modified to adapt to each dataset. To get the most from the constrained practical reality, they adopted different validation methods, used different reference data from a great variety of sources that identified by different people or identification mechanisms. There was no consistency among the validation results; some even do not have a strict independent validation dataset. Furthermore, validation processes rely greatly on the definition of the "true" land cover information (Scepan et al., 1996). However, during most of validation dataset collection process, the ground truth information were gathered with different sample strategies from a great variety of sources, and the interpretation and/or characterization mechanisms were based on different interpreters following different rules and labeling system. Thus, the different validation datasets and accuracy assessment designed respectively for the five land cover products are not universal and the results only speak for the specific products under specific conditions. Therefore it is necessary to develop a new set of validation sites in this study independently for all of the five land cover products without any bias and test how they perform on representing Africa. It is necessary to mention that this validation dataset is exclusively designed for this study, it may not meet the requirement for other applications.

3.4.1 Reference Data Sources

Like all the other large scale land cover product accuracy assessment, the restricting factors of practical condition such as time, cost and effort leading to the fact that it is impossible to collect ground truth information through direct investigations on the vast African continent for this research. Thus an alternative way is inspired by lots of previous studies (Kloditz et al., 1998; Gong, 2008; Bicheron et al., 2008): high resolution remote sensing imageries aided by a series of ancillary data. High resolution remote sensing imageries can be deemed as a surrogate of the ground truth (Kloditz et al., 1998). For the huge potential of using the on-line sources for relevant researches (Bicheron et al., 2008), and relatively abundant high resolution imageries source, the on-line dataset Google Earth is chosen for the reference data collection process of this study. A series of ancillary data including the International Water Management Institution (IWMI) Degree Confluence Project and CarboAfrica project site reports were used.

Google Earth is a virtualized glob of earth that provides geographic content including satellite imagery, maps, terrain, 3D model of earth topography and buildings. One can move around inspecting almost every corner of the earth surface from different angles and scales. The high resolution satellite images available through Google earth can be used for this study as a source of reference data. Google Earth acquires and adds data to their primary database with best imagery available on a regular basis (Google Earth Help http://earth.google.com/support/ last date of access: 2010/10/22). This virtualized glob of earth is very convenient to move around among locations and observe remote sensing imageries with zooming function. Its vast coverage of high resolution remote sensing images is a vital source to collect ground truth information for this study.

The second important source of information is from the Degree Confluence Project of the IWMI (http://www.confluence.org/ last date of access: 2010/10/22), which provides degree convergence point land surface cover information gathered by volunteers from around the world. The information registered through the Degree Confluence Project including precise GPS reading of the location, photographs and short descriptions on site. By now more than 4000 confluence points have been registered in their database. 88 points located on the African continent were collected to aid the interpretation of land cover types.

As additional ancillary information, CarboAfrica site report is also included in the procedure. The aim of CarboAfrica project is to set up a greenhouse gas (GHG) fluxes monitoring network of Africa to build on the state of art of the carbon studies, to better understand the environmental and climatic changes on this continent. This project provides a land cover/use description report of each 25 sites (only 18 sites documented with precise latitude-longitude positions.) that favors this research (http://www.carboafrica.net/sites_en.asp last date of access: 2010/10/22).

3.4.2 Sampling Strategy and Interpretation

A semi-random sample strategy was applied to collect high resolution scenes to provide information of the ground surfaces. A proximately 1 degree by 1 degree grid was generated to guide the validation sites selection (Fig. 2a), and each scene has a diameter of at least 3km of single land cover type coverage centered from the site. Due to different levels of data availability on Google Earth, variable land cover distribution and sometimes cloud contaminations, it is not always presented with interpretable or eligible scenes right at the convergence points, as a result the validation sites are more tend to be a random distribution to settle on the locations with highest resolution that are close to the convergence points. Furthermore, a series of confidence label (high, medium, low) was flagged during the interpretation process. The visual interpretation and labeling of validation scenes was followed the IGBP classification scheme (Appendix 1). In the end this process generated 2289 validation sites with 14 different classes (absent classes including: class 1 Evergreen Needleleaf forest, class 3 Deciduous Needleleaf Forest and class 15 Snow and Ice.), and 1881 of them were flagged with high confidence labels during the interpretation process.

The interpretation process is done by visually inspections of site scenes at a range of $3km^2$ to $4km^2$ that centered from the validation points. Labeling process was completed by only one person with the help of ancillary data and relevant literatures. The visual interpretation mainly based on a limited understanding of the IGBP classification scheme, and limited knowledge of the African continent.

4. Results

The result of the pre-processed five land cover maps (Fig. 3) show that in general there is an understandable similarity on distributional pattern of different land cover classes, especially for large, homogenous patches. Undeniable differences can also be seen on the maps especially for small fragmented patches and on the edges. However, these differences among the five studied land cover products were expected. Not only the total areas occupied by different classes vary among datasets, but also the spatial distributions patterns, as well as accuracy levels of the five datasets are expected to vary from each other.

4.1 Percent Area Comparison Results

First of all, a total percent area comparison of the five land cover datasets that assigned to each with IGBP land cover classes was performed. Result shows reasonable agreement across the reassigned IGBP classes across the five land cover datasets (Fig. 4) although substantial differences also exist. High agreement could be found within class Evergreen Broadleaf Forest, Open Shrublands, Woody Savannas, Savannas, Grasslands, notably Barren and Water bodies. Without doubt, discrepancies also appeared, major differences exist across the datasets among the Evergreen Needleleaf Forest, Deciduous Forest and Mixed Forest, Closed Shrublands, Croplands, Urban and Built-up, Cropland/Vegetation Mosaics and Snow and Ice classes.

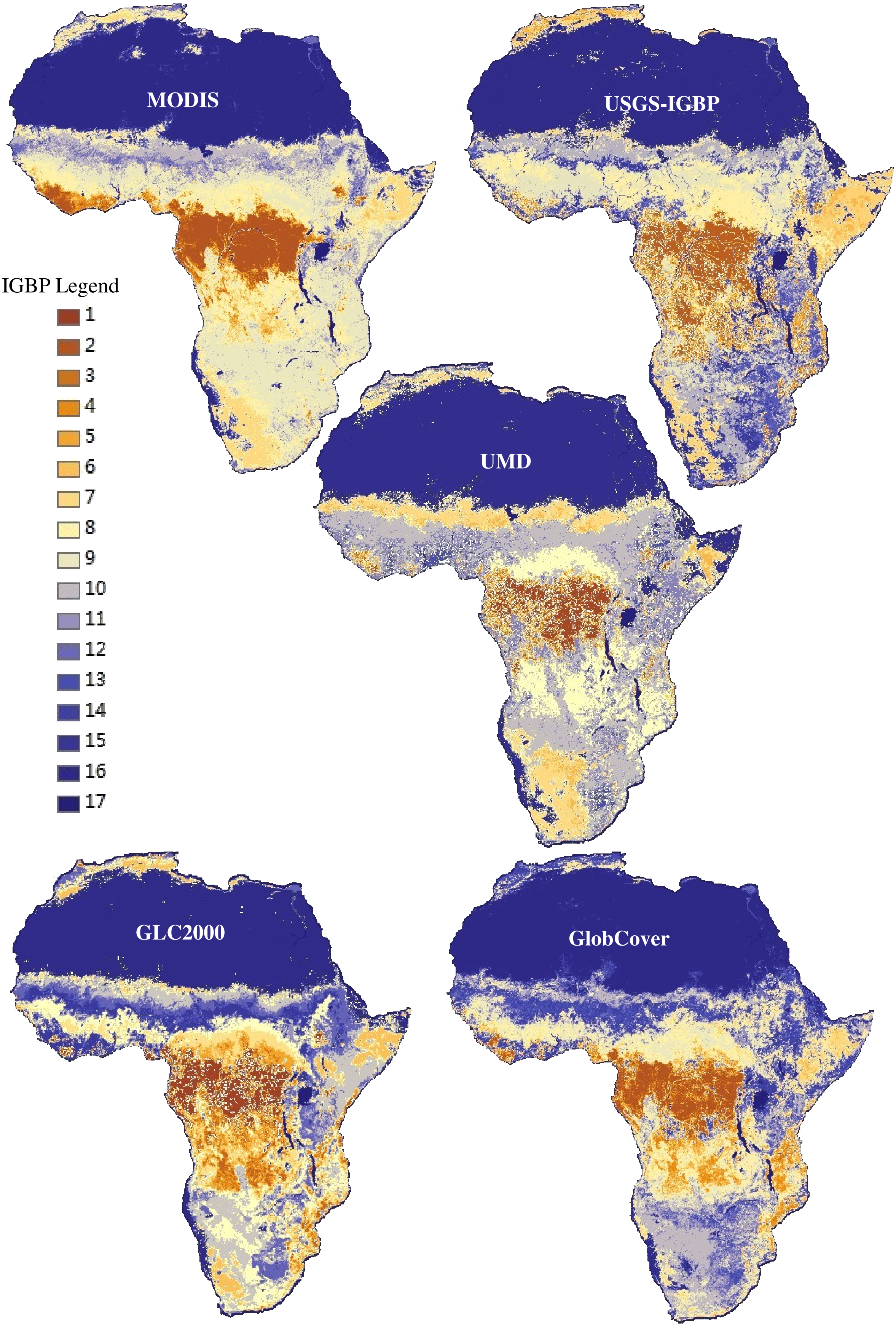

Fig. 3. Data processing results: five land cover maps with the same projection system, the same classification scheme. Legend on this figure is shown with IGBP class values. Corresponding class names and descriptions is given in Appendix 1.

How ever, not all classes appear on every land cover dataset. Deciduous forest, Snow and Ice classes are not presented in the USGS IGBP dataset. Deciduous Needleleaf Forest, Cropland/Natural Vegetation Mosaics, Snow and Ice classes are not presented in UMD dataset and Deciduous Needleleaf Forest, Snow and Ice classes are not presented in GLC2000 dataset. It is noteworthy that although classes like Deciduous Needleleaf Forest and Snow and Ice appear in MODIS and GlobCover datasets, coverage of these classes are very small.

A visualization of the distributional pattern and the percent area composition of different assigned IGBP land cover types across five products are shown in Fig. 5. In general, the land cover pattern over the African continent is obvious at this scale. The main forest types on this continent—Evergreen Broadleaf Forest (class 2) and Deciduous Broadleaf Forest (class 4) are similarly identified across the five datasets, most of the large patches are located around the central part of the continent, expanding from the equator. Similar distribution patterns also can be observed across the datasets among Woody Savannas (class 8), Savannas (class 9) and Grasslands (class 10). Distribution pattern of Barren or Sparsely Vegetated (class 16) and Water Bodies (class 17) are exceptionally consistent across all five datasets. Major differences appear across the datasets between class 3 (Deciduous Needleleaf Forest) and class 15 (Snow and Ice). The USGS IGBP map and reassigned UMD, GLC2000 maps do not have Deciduous Needleleaf Forest class and Snow and Ice class, what's more UMD dataset is also missing class 11 (permanent wetlands) and class 14 (cropland/natural vegetation mosaics).

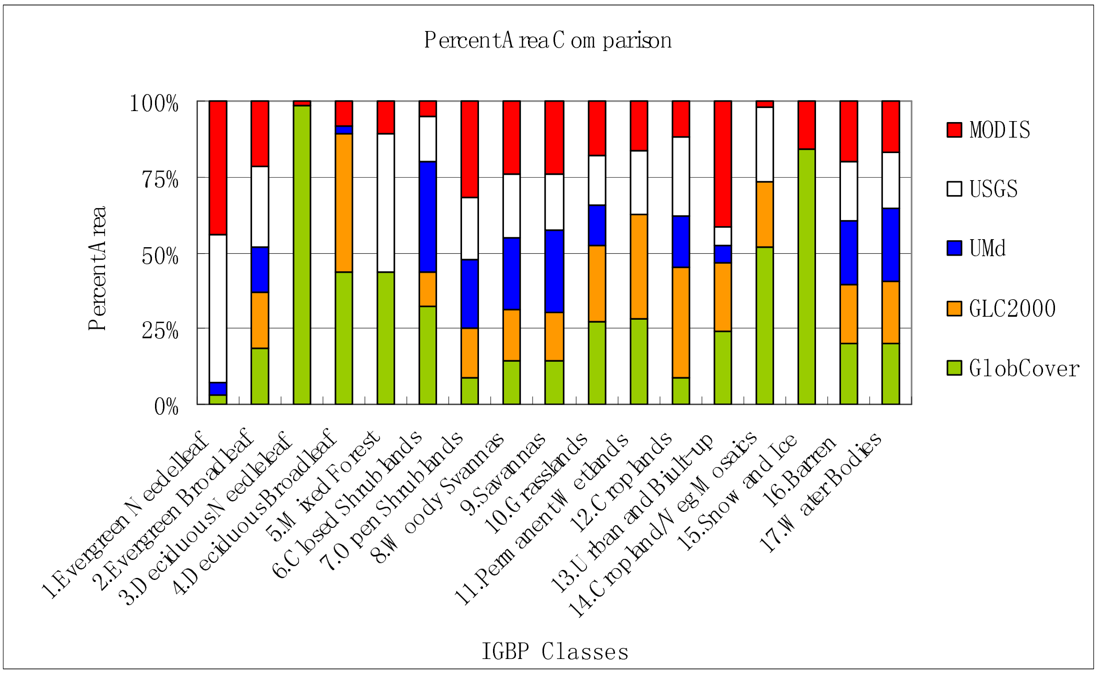

Fig. 4. The percent area comparison of MODIS, USGS, UMD, GLC2000 and GlobCover land cover datasets over Africa, classified according to IGBP classification.

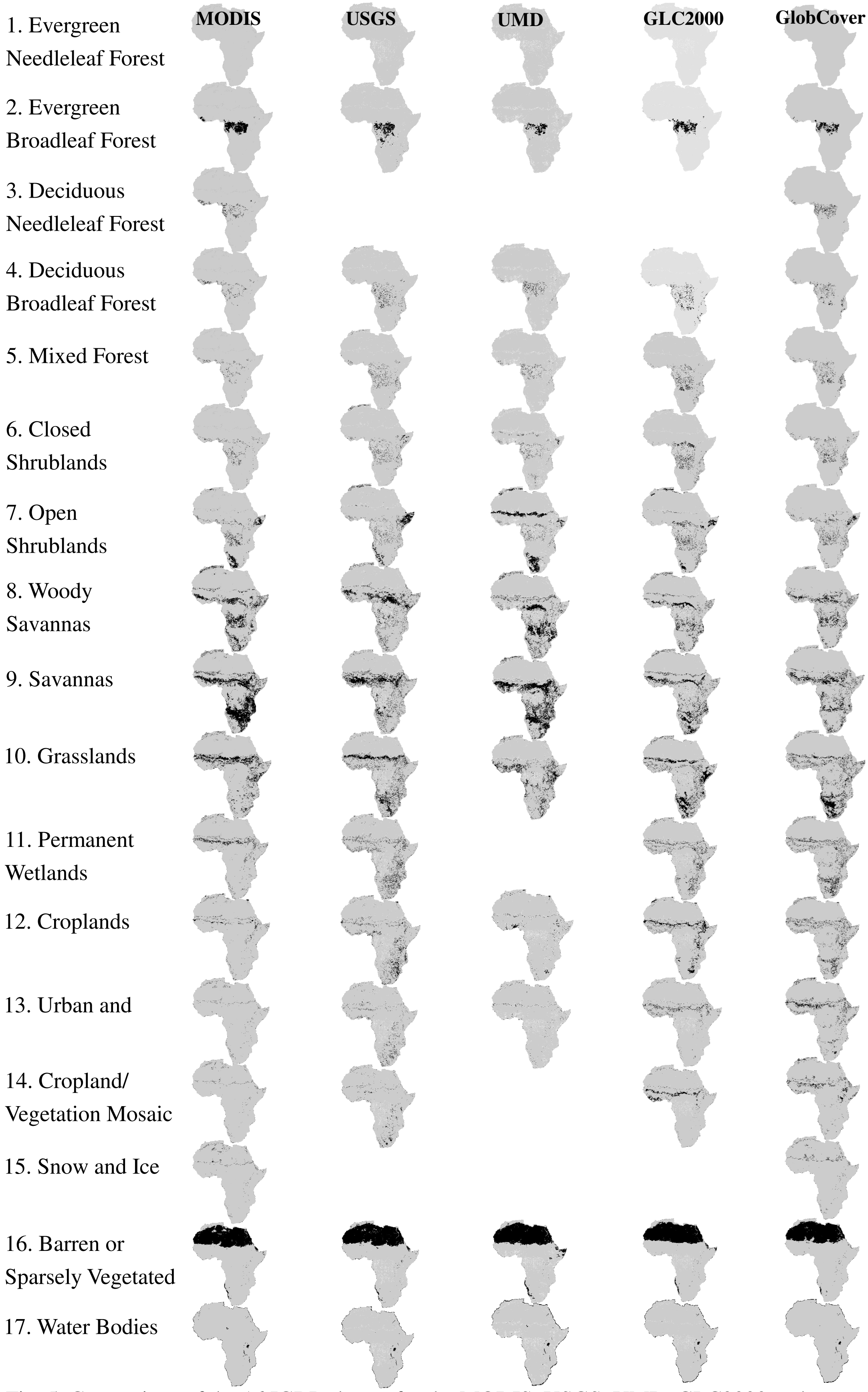

Fig. 5. Comparison of the 16 IGBP classes for the MODIS, USGS, UMD, GLC2000 and GlobCover land cover datasets.

4.2 Per-pixel Comparison Results

The result of the per-pixel sample comparison show substantial spatial disagreement among the products. Just judging from the class assignment maps of Fig. 3, it is visible that both the distribution and density (patchiness) of each class vary among the products. However in general, the statistical comparison of per pixel based random samples shows acceptable agreement across the five datasets (Table 8). Low agreement (only two out of five pixels agree) takes up less than one third of the tested areas; however, it is possible that there are 2 pixels within the remaining 3 pixels also agree. Medium to full agreement take up to 66%, no agreement takes up just a little more than 3%.

Table 8. Per-pixel based spatial comparison results.

Agreement Level	Number of pixels	Percentage
No agreement	1357	3.36%
Low agreement (2of 5 agree)	12222	30.25%
Medium agreement(3of 5 agree)	10072	24.93%
High agreement(4of 5 agree)	5500	13.61%
Full agreement	11249	27.84%
Total	40400	100%

4.3 Validation Result

Error matrixes between each land cover map and the Google Earth derived validation dataset are given in Appendix 2. Results show different levels of accuracies. Table 9 is a summary of the five error matrixes, which shows the user's accuracies, producer's accuracies and overall accuracies. The average overall accuracy is around 54%. Both User's accuracies and Producer's accuracies among classes vary considerably.

From the user's point of view, the most accurate classes are (extracted from Table 9):

(1). MODIS class 16, 2 and 17;

(2). USGS class 16, 17 and 2;

(3). UMD class 2, 16, 17 and 13;

(4). GLC2000 class 16, 2 and17;

(5). GlobCover class 13, 17, 2 and 16.

Other classes all fall below 50%, some even have no agreement at all.

From the producer's view of point, the highest accuracies are:

(1). MODIS class 16, 17 and 7;

(2). USGS class 16;

(3). UMD, GLC2000 and GlobCover all performed best with class 16 and class 17. Others classes all fall below 50% and some even have zero accuracy.

In general, the validation results shows all five datasets performed best in representing class 16 Barren or Sparsely Vegetated and class 17 Water Bodies; also performed quite well with class 2 Evergreen Broadleaf Forest. In GlobCover dataset, class 13 Urban and Built-up land cover type shows an extremely high accurate of 100%.

On the contrary, some classes show much less satisfactory results. From the user's aspect, zero accuracy appeared in:

(1). MODIS class 1, 3, 4, 5 and 11;

(2). USGS class 1, 5, 11 and 13;

(3). UMD class 4;

(4). GLC2000 class 11;

(5). GlobCover class 3, 4, 5 and 11.

From the producer's aspect zero accuracy classes are:

(1). MODIS class1, 3, 4, 5 and 11;

(2). USGS class 1, 4, 5, 11 and 13;

(3). UMD class 4 and 14;

(4). GLC2000 class 11;

(5). GlobCover class 3, 4, 5 and 11.

Sum it up, class 1 Evergreen Needleleaf Forest type, class 3 Deciduous Needleleaf Forest type, class 4 Deciduous Broadleaf Forest type, class 5 Mixed Forest type and class 11 Permanent Wetlands type performed poorly on most of these land cover maps, on USGS map class 13 Urban and Built-up type has no agreement, and on UMD map class 14 Cropland/Natural Vegetation Mosaic class has no agreement.

Table 9. Summary of five Error Matrixes.

Class	MODIS		USGS		UMD		GLC2000		GlobCover	
	User's accuracy	Producer's accuracy	User's accuracy	Producer's accuracy	User's accuracy	Producer's accuracy	User's accuracy	Producer's accuracy	User's accuracy	Producer's accuracy
1	0%	0%	0%	No data	No data	No data	No data	0%	No data	No data
2	85%	46%	71%	90%	41%	93%	40%	47%	91%	36%
3	0%	0%	No data	No data	No data	0%	0%	No data	No data	No data
4	0%	0%	0%	1%	9%	0%	0%	0%	0%	0%
5	0%	0%	0%	No data	No data	0%	0%	0%	No data	No data
6	25%	6%	0%	25%	10%	12%	19%	2%	3%	6%
7	33%	57%	28%	36%	29%	36%	15%	27%	28%	36%
8	17%	21%	14%	23%	19%	24%	16%	16%	21%	28%
9	9%	29%	7%	12%	26%	5%	8%	16%	9%	28%
10	11%	19%	16%	7%	14%	11%	25%	28%	8%	12%
11	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
12	42%	14%	22%	40%	44%	49%	14%	15%	39%	18%
13	44%	17%	0%	80%	17%	100%	33%	0%	50%	4%
14	46%	7%	9%	21%	21%	15%	44%	10%	0%	0%
15	No data	No data	No data	No data	No data	No data	No data	No data	No data	No data
16	90%	94%	88%	93%	95%	93%	95%	92%	90%	96%
17	83%	58%	75%	80%	73%	99%	93%	48%	75%	65%
Over all accuracy	55%		51%		53%		56%		54%	

5. Discussion

5.1 Percent Area and Per-pixel Comparison

Due to the diversity of the five land cover maps, differences of each class's coverage and distribution pattern among the datasets can be expected. Similar studies of comparisons among different land cover maps have suggested some sources for the disagreement (Giri et al., 2005; See et al., 2006; McCallum et al., 2006; Hansen and Reed, 2000b). These sources can be divided into two groups—internal sources and external sources.

The internal sources are embedded in every different land cover dataset from the very beginning of its generation. These sources are part of their properties and characteristics. From Table 5 we can see that first these land cover products were developed from the data collected by a variety of remote sensors, each sensor has its own way of collecting ground signals. Each sensor has its own set of parameters to regulate every step of the generation of remote sensing imageries. Secondly, the land cover datasets were developed from remote sensing data that derived at very different temporal intervals, during which portions of land cover changes over Africa continent is highly possible (e.g. forest logging, reclaim natural vegetation covered or even barren surface and turned them into croplands). Third, all land cover datasets have their own set of training and validation datasets, which land cover characterization relied on and developed into the final land cover maps. The quality and quantities of training/validation datasets varies greatly. They were generated according to a variety of rules, and rely greatly on the skills and experiences of interpreters. The primarily affecting factor of the quality of reference data is the underlying accuracy of the ground truth classification which may not be known (Strahler et al., 1999). Errors might be introduced when training and validation data are not temporally coincident with sensor's observations, geolocation error, spectral similarity, limited training and validation data, cloud cover. The quality and availability of training/validation data are the most limiting factor to land cover validations (Muchoney et al., 1996). Lots of land cover data description mentioned the effect of lack of cloud-free data (Mayaux et al., 2003; Strahler et al., 1999), especially when this study is targeting Africa continent where almost permanent cloud cover exist at the central part. These errors and limitations are normal parts of the classification process and they can be minimized, but not excluded entirely (Muchoney et al., 1996). These internal factors eventually lead to substantial discrepancies among land cover products.

The second cause should attribute to the modifications done to the products to meet the need of this study: classification legend conversion, map reprojections and resolution modifications.

In this study no attempt was made to change the classes in these land cover data, whole classes were reassigned to the most suitable IGBP classes based on previous studies (chapter 3.1.2). Appendix 1 lists out detailed class descriptions of the four classification schemes applied by the five land cover datasets in this study. From the table we can see even great effort has been done to transform land cover types of LUCC classification schemes and simplified IGBP scheme into the standard IGBP classification scheme as accurate as possible. The fact that substantial differences of identification criteria are undeniable. For example:

(1) The IGBP height threshold for dividing trees and shrubs is 2m, while in the UMD simplified IGBP it is 5m, GLC2000 LCCS is 3m and GlobCover LCCS is 5m;

(2) For coverage thresholds, closed coverage is defined in IGBP as more than 60%, open coverage is between 10% and 60% while the coverage in the other classification schemes are:

a. UMD simplified IGBP, closed coverage is defined as > 40%, open coverage is between 10% and 40%;

b. GLC2000 LCCS, closed coverage is > 40%, open coverage is between 15% and 40%. Furthermore, in GLC2000 LCCS, many land cover types are not differentiated from open to close, such as class 1: Tree cover, broadleaved evergreen, closed to open; class 4: Tree cover, needle-leaved evergreen, closed to open and class11: Shrub cover, closed to open evergreen. Classes like these included the corresponding land cover as long as its coverage reaches over 15%;

c. GlobCover LCCS, closed coverage is defined as > 40%, open coverage is between 15% and 40%, and similar to the GLC2000 LCCS map, the GlobCover LCCS map also have several land cover types that did not differentiated from open to close, such as class 40: Closed to open (>15%) broadleaved evergreen and/or semi-deciduous forest (>5m) and class 130: Closed to open (>15%) shrub-land (<5m).

These examples explain that when classification scheme transformation was performed, along with it, biases were introduced. Take the conversion of the "most straight forward" UMD simplified IGBP scheme in to IGBP class 9 Savannas as an example: According to IGBP Savanna land cover type description, it is the kind of land lands with herbaceous and other understorey systems, with forest canopy cover between 10% and 30% and tree height is over 2 meters. From the conversion Table 7, one can see that UMD class 7 wooded grasslands/shrublands is reclassified in to IGBP savanna land cover type. On one hand, according to UMD IGBP class description, the original UMD Wooded Grass/Shrublands class, tree coverage is between 10% and 40%, which means there is the possibility that some patches or parts of patches where tree coverage is between 30% and 60% should be reclassified into IGBP class 8 woody savannas. The direct result from this conversion is an over estimation of savannas on the reassigned UMD IGBP land cover map. On the other hand, UMD simplified IGBP classification defined tree height is more than 5 meters, which means that the reclassified UMD IGBP Savannas class might lose some coverage on the land that contain savanna land but with trees only grown into a height between 2 and 5 meters. Since the IGBP tree height threshold is 2m, this conversion might cause an under estimation of savannas on the reassigned UMD IGBP land cover map. Same problem can happen to almost every class when performing the conversion due to the different criteria settings for the original classification schemes. Even though, in order to ensure the comparability in this study, classification conversions have to be done, the possible degradations of classification accuracy are inevitable sacrifices.

The five original datasets were all provided with different map projections (Table 6) and were all reprojected to Albers Equal Area (Africa) projection in this study. It is also an inevitable process to guarantee comparability. This procedure may bring significant distortion of original pixel values especially when dealing with large areas reprojections (Steinwand et al., 1995; Mulcahy, 1999; Seong, 2003). Steinwand et al. (1995) found distortions in the reprojection of raster image dataset caused by the distortion inherent in projection change and the resampling of discrete pixel values. According to their study the distortion and changes introduced through reprojection in some cases can reach 50% and even more. In the similar study of Yang et al. (1996), for certain reprojection, they found image area expansion with maximum duplication as high as five times, and data loss due to area reduction could also reach 31%. White (2006) tested reprojections from sinusoidal to other eight common map projections and also found the accuracies of represented pixels could ranging from as low as 58% to 83%. These studies all revealed one undeniable truth that reprojection will affect on the original land cover datasets. Even though the reprojection procedure is carefully conducted in this study, it is a fact that the resulting dataset have all been altered at different degrees.

For GLC2000 and GlobCover datasets, there is one more possible cause for alterations of the original data: Resolution aggregation. The original GlobCover land cover map was downloaded from the European Space Agency (ESA) website with fairly high resolution of 300 meters, which is the highest resolution for a global land cover product. For the GLC2000 dataset, despite the data description is 1km, according to inspections from different GIS and remote sensing process software, the actual resolution of GLC2000 map is 950.79m. To maintain the consistency and guarantee the compatibility with the other datasets, resolution aggregation of these two higher resolution datasets was necessary. However, several earlier studies (Henderson et al., 1985； Moody and Woodcock, 1995 and 1996) have confirmed that substantial effects of spatial scaling changes on the proportion of some land cover types. In general, the proportions of smaller, more fragmented cover types would decrease with aggregation, while those classes of larger patches would increase. Mulcahy (1999) also found pixel loss and pixel duplication result from scale reduction and expansion. Thus, scale degradation could have added more uncertainties to the reassigned GLC2000 IGBP and GlobCover IGBP maps.

In conclusion, the differences among these land cover datasets can be explained by a combined action of their own nature and data processes conducted for this study.

5.2 Accuracy Assessment

The validation procedure shows relatively low accuracies of these land cover datasets. However, this assessment is neither a diagnostic conclusion to the accuracies of these products nor suggesting one dataset is better than the other. The purpose of this assessment is to reveal the variations among the studied five land cover datasets and try find out the reason behind. Try to provide background information, help potential users better understand the differences among the five products.

Many factors could potentially affect the final results. Accuracy assessment of land cover products has always been tightly tied with reference data i.e. “true” cover type (Muchoney et al., 1996). They addressed that the most limited factor for land cover and land cover change validation process is the quality and availability of adequate training/validation data. This study also faced the same problem. First of all the “ground truth data” used in this study were not the classical-way collected ground truth information. Because of the limitation of efforts and cost, field work to gather ground truth information on the vast African continent is beyond practicability. Instead, high resolution satellite imageries provided through Google Earth played as a “surrogate” to the ground information, and reference data was collected and interpreted through it. Secondly, although the reference dataset has a collection of over 2000 validation sites to support a sound statistical representative, it is still not strictly thorough enough to take equal consideration for every land cover type. Third, the interpretations of validation sites might not necessarily always be “true” especially when handled by less experienced interpreters. The interpretation of validation scenes in this study is conducted only by one person’s visual inspection aided by very limited ancillary data, with limited experience with remote sensing image interpretation and limited knowledge about the climate, bio-environment and geographical pattern of the African continent. It is very likely that chances of errors and biases exist.

Beside possible errors introduced during the process, there are also some other causes lie behind the surface stemming from the characteristics of the product or the nature of certain land cover types.

Land cover types such as class 2 Evergreen Broadleaf Forest, especially class 16 Barren or Sparsely Vegetated class and class 17 Water Bodies class have much higher accuracy than the average level across all datasets. Possible explanations could be the significant spectral signals of these land cover types picked up by satellite sensors, the reflectance signal of bare ground and water bodies are very different from vegetated surface, especially when their presence is in a large homogeneous pattern e.g. Sahara, it is easier to depict them on coarse resolution maps. Similar traits can also be found with class 2, its major domain is equatorial African area, with a steady, significant reflectance signal and wide consecutive spread pattern. Furthermore, these three land cover types are relatively steady ground features. The characteristics of these classes allow them nearly immune to seasonality, most short term and minor ambient changes. These characters facilitate accurate depiction by satellite sensors and characterizations during classification process. Their distribution patter also helped their high levels of representative. It has been proved that the spatial pattern of the landscape influences its performance at varying resolution maps (Woodcock and Strahler, 1987) and area estimations especially from coarse resolution maps (Moody and Woodcock, 1994; Mayaux and Lambin, 1995).

On the other hand, land cover types such as class 4 Deciduous Broadleaf Forest, class 5 Mixed Forest and class 11 Permanent Wetlands are just on the contrary. First, these land cover types are regulated by seasonality, precipitation, temperature changes and can be quiet easily influenced and fluctuate with ambient factors. Secondly, the latitudinal range of Africa is not as great as for other continents (e.g. North America) and the topography over this continent is rather mild, therefore it does not contain as many ecosystems (Reed, 1997; Liu et al., 1984), the variety of vegetation types and their distributions on the African continent are restricted. Habitats for vegetations such as evergreen broadleaf forest and deciduous needleleaf forest are cool to cold high latitude regions or high altitude alpine regions, which is quite rare in Africa. It explains the small and scattered coverage of these two land cover types, especially for deciduous needleleaf trees which are normally only seen in extreme cold regions. The absence of class 3 from three of the five land cover maps is understandable. Class 5 Mixed Forest has similar problem, on this warm continent, its domain is restricted to mountain areas which are confined to a small and fragmented distributional pattern. As for Snow and Ice class (class 15), despite its distinctive spectral signal, is also suppressed by the prevalent warm to high temperature across the continent. There are only few high mountains in Africa with permanent snow cover on the top, which adds difficulties on the detection and characterization of this land cover type on coarse resolution maps. This explains why only two of the five land cover datasets identified extremely small amount of snow and ice cover. Class 11 Permanent Wetlands is also having a relatively small and scattered coverage over the continent. Furthermore, considering the combination of water surfaces and vegetation, it is highly suspectible that this cover type might be drawn into other vegetation type classes or even water body type on coarse resolution maps. One more possible cause for low accuracies with those classes could be the under representative in reference dataset. Considering their small and scattered location pattern, less or even zero coverage on these classes is highly possible.

The main resource of reference data used in this study is Google Earth, which provide recent remote sensing imageries with zooming function. However, availability of high resolution imageries varies with regions, certain amount of interpretations have to be made based on low resolution images. Another potential source of errors is the temporal differences between land cover datasets and the acquisition time of reference dataset. Google Earth provides most recent and high resolution remote sensing images that available to them, a various acquisition time can be found (different years, different months) at different regions. During the temporal gaps, what is presented on the studied five land cover datasets and what could be found on the "most recent" Google Earth images may have changed a lot. Anthropogenic influences on natural land covers can be massive in a very short period. Human activities such as forest logging, reclamations, city development, mining etc. can alter a large earth surface area in several years, even months. Natural seasonal change is another non-ignorable factor. Ground surface information collected at different season different month varies greatly. Dry / wet season prevalent over most part of Africa (Liu et al., 1984.), vegetation experiences drastic changes leading to a very variable land cover according to the period, the number and duration of the vegetation flushes. Without tremendous knowledge of Africa and its regional/local climate, errors are very likely be introduced during interpretation process. Another deficiency of using Google Earth high resolution imageries is the lack of flexible image visualization function. During interpretation procedure, image processing techniques including image enhancement, color compositions, contrast stretching could help the interpreter to identify ground features, but this kind of imagery processing are not operable to Google Earth imageries. This made the interpretation even harder.

Insufficient ancillary data is another limiting factor. Restricted by cost, time and energy in this study, few ancillary data were used to help the interpretation of validation sites. The field report provided by IWMI Degree Confluence Project were collected by volunteers from varied background, the on site photos only cover few hundreds meters of the ground surface, to some degree they helped interpret some of the validation sites, but the accuracy is open for discussion. As to the CarboAfrica CO2 flux monitor site reports, it covers very limited area, and only 18 of the sites are valid.

6. Conclusion

The purpose of this comparative analysis is to provide an insight of land cover products over Africa. The aim here is not to determine if one dataset is better than the others, but to present and discuss major similarities and differences, outline characters of each product, highlight their strengths and weaknesses. It is crucial to understand their nature and characteristics before using them for any particular applications.

Although substantial differences do exist among these land cover products for variable reasons, but they all are produced with the same purpose, i.e. providing accurate land cover information for the scientific communities. This result is not surprising given the fact that these land cover products are produced through very different approaches. The observed discrepancies might have stemmed from variable data sources, availability of ground-truth information, variations of class definitions, variable classification approaches, cloud contaminations, mis-registrations. Errors might also have been introduced during the comparison preparation processes including map reprojections, resolution degradations and class aggregations. However, while discrepancies do exist, there is also an amount of thematic agreement. These findings suggest users' caution when using any one particular product, and be prepared for the possible influences on the application results. McCallum et al. (2006) suggested that multiple large scale land cover products should be used in analysis researches to show the magnitude of possible differences. Since this study have found possible deficiencies associated with class aggregations, further research is very necessary to reduce ambiguity in land cover definitions. The finding of classification accuracies reduction caused by the transferability of classes from one legend to another in this study, suggests the necessity to improve data agreement through further study of class conversions.

Hansen and Reed (2000b) indicated that two of the studied land cover products (USGS IGBP and UMD) present the first venture into mapping global land cover at a moderate spatial resolution. The pursuit of more appropriate methodologies, data sources and evaluation techniques is never going to stop. The determination of identifying reasons for the disagreements, how to improve map accuracy respectively and the correlation among maps are important research topics. Past experiences with additional evolving infrastructures and techniques will improve the consistency and accuracy of global and regional land cover data. The demand of discerning areas of weakness within the present set of products and identify ways to produce improved iterations of these maps or even new land cover products will be fulfilled in the near future.

These findings may encourage development of a solid foundation in generating consistent and accurate land cover characterization data base not only for Africa, but also on a global scale.

References

Belward A. S., 1996. The IGBP-DIS Global 1 km Land Cover Data Set (DISCover): proposal and implementation plans. IGBP-DIS Working Paper 13, International Geosphere–Biosphere Programme Data and Information System Office, Toulouse, France.

Belward A.S., Estes J.E., and Kline K.D., 1999. The IGBP-DIS 1-Km Land-Cover Data Set DISCover: A Project Overview. *Photogrammetric Engineering and Remote Sensing* , 65(9), 1013-1020.

Bicheron P., Defourny P., Brockmann C., Schouten L., Vancutsem C., Huc M., Bontemps S., Leroy M., Achard F., Herold M., Ranera F., Arino O., 2008. GLOBCOVER: Product Description and Validation Report. *Medias France*.

Breiman L., Friedman J.H., Olsen R.A. and Stone C.J., 1984. Classification and Regression Trees. *Chapman & Hall/CRC*, Wadsworth, Belmont, CA.

Defense Mapping Agency, 1992. Development of the Digital Chart of the World: Washington, D.C., U.S. Government Printing Office.

De Fries R.S., Hansen M., Townshend J.R.G., Sohlberg R., 1998. Global land cover classifications at 8 km spatial resolution: the use of training data derived from Landsat imagery in decision tree classifiers. *International Journal of Remote Sensing*, 19(16), 3141-3168.

Di Gregorio A. and Jansen L., 2000. Land cover classification system, classification concepts and user manual. ISBN 92-5-104216-0, Food and Agriculture Organization of the United Nations: Rome.

FAO: Forest Cover Mapping & Monitoring with NOAA-AVHRR & Other Coarse Spatial Resolution Sensors. Forest Resources Assessment Programme, Rome 2000, Working Paper 29.

Fritz S., Bartholomé E., Belward A., Hartley A., Stibig H-J, Eva H.. 2003. Harmonization, mosaicking, and production of the Global Land Cover 2000 database. Joint Research Center, Ispra, Italy.

Giri C., Zhu Z., Reed B., 2005. A comparative analysis of the Global Land Cover 2000 and MODIS land cover data sets. *Remote Sensing of Environment*, v.94, p.123-132.

GLC2000 land cover product—LCCS standard class description http://bioval.jrc.ec.europa.eu/products/glc2000/legend/GLC2000_Lccs_110604.pdf (last date of access: 2010/10/22)

Gong P. 2008. Accuracies of Global Land Cover Maps Checked against Fluxnet Sites. *Science Foundation in China*. 16(1).

Hansen M.C., Defries R.S., Townsend R.G., Sohlberg R., 2000a. Global land cover classification at 1km spatial resolution using a classification tree approach. *International Journal of Remote Sensing*, 21 (6/7), 1331–1364.

Hansen M.C. and Reed B. 2000b. A comparison of the IGBP DISCover and University of Maryland 1 km global land cover products. *International Journal of Remote Sensing*, 21(6/7), 1365-1373.

Henderson S.A., Wilson M.F. and Thomas G., 1985. The effect of spatial resolution on archives of land cover type. *Climatic Change*, 7, 391–402.

Hulme M., Doherty R., Ngara T., New M., Lister D., 2000. Africa Climate Change: 1900-2100. *Revised Manuscript for Climate Research*.

Kloditz C., Van Boxtel A., Carfagna E., Van Deuresen W., 1998. Estimating the accuracy of coarse scale classifications using high scale information. *Photogrammetric Engineering and Remote Sensing*, 64, 127-133.

Latifovic R. and Olthof I., 2004b. Accuracy assessment using sub-pixel fractional error matrices of global land cover products derived from satellite data. *Remote Sensing of Environment*, 90, 153-165.

Lillesand M. T., Kiefer W. R. and Chipman W. J., 2004. *Digital image processing*. Remote sensing and image interpretation. John Wiley & Sons. Chapter 7.16, 586-593.

Liu D.S., Li Z.G., Jiang C.Y., Jia W.Y., Ge Y.D., Gu L.R., Zhong Z.Q., Wu T.H., Peng Q.X., Liu Y.Y., Zhu D.F., Wang X.M., Tan C.Y., Sun L.H., Yang L.L., Xu S.J., 1984. Africa. *Global Physical Geography*. CH 6.

Loveland T.R. and Belward A.S., 1997. The International Geosphere Biosphere Programme Data and Information System Global Land Cover Data Set (DISCover). *Acta Astronautica*, 41(4-10), 681- 689.

Loveland T.R., Reed B.C., Brown J.F., Ohlen D.O., Zhu J., Yang L., et al., 2000. Development of a Global Land Cover Characteristics Database and IGBP DISCover from 1-km AVHRR Data. *International Journal of Remote Sensing*, 21(6/7), 1303-1330.

Mayaux P. and Lambin E.F., 1995. Estimation of tropical forest area from coarse spatial resolution data: A two-step correction function for pro-portional errors due to spatial aggregation. *Remote Sensing of Environment*, 53, 1-16.

Mayaux P., Grandi De G.F., Rauste Y., Simard M., and Saatchi S., 2002. Large Scale Vegetation Maps Derived from the Combined L-band GRFM and C-band CAMP Wide Area Radar Mosaics of Central Africa. *International Journal of Remote Sensing*, 23(7), 1261-1282.

Mayaux P., Bartholomé E., Massart M., Cutsem Van C., Cabral A., Nonguierma A., Diallo O., Pretorius C., Thompson M., Cherlet M., Pekel J-F., Defourny P., Vasconcelos M., Gregorio Di A., Fritz S., Grandi De G. , Elvidge C., Vogt P., Belward A., 2003. A Land Cover Map of Africa. European Commission, EUR

20665 EN, Joint Research Centre.

Mayaux P., Bartholome E., Fritz S., Belward A., 2004. A new land-cover map of Africa for the year 2000. *Journal of Biogeography*, 31, 861-877.

Mayaux P., Eva H., Gallego J., Strahler A.H., Herold M., Agrawal S., Naumov S., Miranda E.E.D., Bella C.M.D., Ordoyne C., Kopin Y., 2006. Validation of the Global Land Cover 2000 Map. *Geoscience and Remote Sensing*, 44(7).

McCallum I., Obersteiner M., Nilsson S., Shvidenko A. 2006. A spatial comparison of four satellite derived 1 km global land cover datasets. *International Journal of Applied Earth Observation and Geoinformation*, 8, 246-255.

Mitchell R.B., 2003. International environmental agreements: a survey of their features, formation and effects. *Annual Review of Environment and Resources*, 28, 429-461.

Moody A. and Woodcock C.E., 1994. Scale-dependent errors in the estimation of land-cover proportions: Implications for global land-cover datasets. *Photogrammetric Engineering and Remote Sensing*, 60, 585-594.

Moody A. and Woodcock C.E., 1995. The influence of scale and spatial characteristics of landscapes on land-cover mapping using remote sensing. *Landscape Ecology*, 10, 363-379.

Moody A. and Woodcock C.E., 1996. Calibration-based methods for correcting coarse resolution estimates of land-cover proportions. *Remote Sensing of Environment*, 58, 225-241.

Muchoney D.M., Borak J. and Strahler A., 1996. Global land cover classification training and validation issues and requirements. Center for Remote Sensing, Boston University, MA 02215 USA.

Muchoney D., Strahler A., Hodges J., and LoCastro J., 1999. The IGBP DISCover Confidence Sites and the System for Terrestrial Ecosystem Parameterization: Tools for Validating Global Land Cover Data. *Photogrammetric Engineering & Remote Sensing*, 65(9).

Mulcahy K.A., 1999. Spatial data sets and map projections: an analysis of distortion. PhD dissertation, Graduate School and University Center, City University of New York, New York, NY. DAI-A 60/01.

Olson, J.S., 1994a, Global ecosystem framework-definitions: USGS EROS Data Center Internal Report. Sioux Falls, SD, 37 p.

Olson 1994b, Global ecosystem framework-translation strategy: USGS EROS Data Center Internal Report. Sioux Falls, SD, 39 p.

Pohl C. and van Genderen J.L., 1998. Multisensor image fusion in remote sensing: concepts, methods and applications. *International Journal of Remote Sensing*, 19, 823-854.

Reed B., 1997. Applications of the U.S. Geological Surveys global land cover product. *Acta Astronautica*, 41(4-10), 67- 680.

Scepan J., Estes E.J., and Starmer J.W., 1996. Accuracy Analysis and Validation of Global 1 Km Land Cover Data Sets. Remote Sensing Research Unit, Department of Geography University of California, Santa Barbara.

See M.L. and Fritz S., 2006. A Method to Compare and Improve Land Cover Datasets: Application to the GLC-2000 and MODIS Land Cover Products. *Geoscience and Remote Sensing*, 44(7).

Seong J.C., 2003. Modelling the accuracy of image data reprojection. *International Journal of Remote Sensing*, 24(11), 2309-2321

Stehman S.V. and Czaplewski R.L., 1998, Design and analysis for thematic map accuracy assessment: fundamental principles. *Remote Sensing of Environment*, 64, 331-344.

Steinwand D.R., Hutchinson J.A., Snyder J.P., 1995. Map projections for global and continental data sets and an analysis of pixel distortion caused by reprojection. *Photogrammetric Engineering and Remote Sensing*, 61, 1487-1497.

Strahler A., Muchoney D., Borak, J., Friedl M., Gopal S., Lambin E., et al., 1999. MODIS land cover product: Algorithm Theoretical Basis Document (ATBD) Version 5.0. USA: Boston University.

Strahler A.H., Boschetti L., Foody G.M., Friedl M.A., Hansen A.C., Herold M., Mayaux P., Morisette J.T., Stehman S.V., Woodcock C.E., 2006. Global Land Cover Validation: Recommendations for Evaluation and Accuracy Assessment of Global Land Cover Maps. GOFC-GOLD Report No. 25.

UN Statistic Division Population and Vital Statistics Report, 2002. http://unstats.un.org/unsd/seriesa/introduction.asp (Last date of access: 2010/10/22)

USGS GLCC product specification: http://edc2.usgs.gov/glcc/globdoc2_0.php (Last date of access: 2010/10/22)

White D., 2006. Display of pixel loss and replication in reprojecting raster data from the sinusoidal projection. *Geocarto International*, 21 (2), 19-22.

Woodcock C.E. and Strahler A.H., 1987. The factor of scale in remote sensing. *Remote Sensing of Environment*, 21, 311-325.

Yang L., Zhu Z., Izaurralde J., Merchant J., 1996. Evaluation of North and South America AVHRR 1-km data for global environmental modeling, 21-26 January 1996. NCGIA Third International Conference/Workshop on Integrating GIS and Environmental Modeling Santa Fe, New Mexico, USA. http://www.ncgia.ucsb.edu/conf/SANTA_FE_CD-ROM/sf_papers/yang_limin/my_paper.html (Last date of access: 2010/10/22)

Online data sources

Africa reference map, 2007, produced by the U.S. Central Intelligence Agency. Provided trough Perry-Castañeda Library Map Collection.
http://www.lib.utexas.edu/maps/africa.html (Time of last access: 2010/10/5)

MODIS data are distributed by the Land Processes Distributed Active Archive Center (LP DAAC), located at the U.S. Geological Survey (USGS) Earth Resources Observation and Science (EROS) Center (lpdaac.usgs.gov).
Data access: http://modis-land.gsfc.nasa.gov/landcover.htm (Time of Last access: 2010/08/25)

USGS Africa Land Cover Characteristics Data Base Version 2.0 courtesy of the U.S. Geological Survey. The USGS home page: http://www.usgs.gov.
Data access: http://edc2.usgs.gov/glcc/glcc.php (Time of Last access: 2010/08/25)

UMD product citation: Hansen, M., R. DeFries, J.R.G. Townshend, and R. Sohlberg (1998), UMD Global Land Cover Classification, 1 Kilometer, 1.0, Department of Geography, University of Maryland, College Park, Maryland, 1981-1994. Source for this data set was the Global Land Cover Facility, www.landcover.org.
Data access: http://www.landcover.org/data/landcover/ (Time of Last access: 2010/08/25)

Global Land Cover 2000 database (GLC2000). European Comission, Joint Research Centre, 2003.
Data access: http://bioval.jrc.ec.europa.eu/products/glc2000/glc2000.php. (Time of Last access: 2010/08/25)

GlobCover product copyright: Product's covering the period Dec.2004-Jun.2006: © ESA GlobCover Project, led by MEDIAS-France.
Data access: http://ionia1.esrin.esa.int/index.asp (Time of Last access: 2010/08/25)

Appendix 1: Map Legends Conversion Table

IGBP (MODIS, USGS) (FAO Rome 2000)	UMD IGBP (Hansen et al., (2000)a)	GLC2000 LCCS (GLC2000 LCCS standard class description)	GlobCover LCCS Legend (Bicheron et al., 2008)
1. Evergreen Needle-leaf Forests-Lands dominated by trees with a percent canopy cover >60% and height exceeding 2 meters. Almost all trees remain green all year. Canopy is never without green foliage.	**1. Evergreen Needle-leaf Forests**-lands dominated by trees with a canopy cover >60% and height > 5m. Almost all trees remain green all year. Canopy is never without green foliage.	**4. Tree cover, needle-leaved evergreen, closed to open**- The main layer consists of needle-leaved evergreen closed to open trees. The crown cover is >15%. The height range is >3m.	**70. Closed (>40%) needle-leaved evergreen forest (>5m).**
		10. Tree Cover, burnt (mainly boreal forests)-mainly consists of closed to open trees. The crown cover is > 15%.	
2. Evergreen Broadleaf Forests-Lands dominated by trees with a percent canopy cover >60% and height exceeding 2 meters. Almost all trees remain green all year. Canopy is never without green foliage	**2. Evergreen Broadleaf Forests**-lands dominated by trees with canopy cover >60% and height >5m. Almost all trees remain green all year. Canopy is never without green foliage.	**1. Tree cover, broadleaved evergreen, closed to open**-mainly consists of broadleaved evergreen closed to open trees. The crown cover is >15%. The height range is >3m.	**40. Closed to open (>15%) broadleaved evergreen and/or semi-deciduous forest (>5m).**
		8. Tree cover, closed to open, regularly flooded, saline water-mainly consists of broad-leaved evergreen closed trees on permanently flooded land. The crown cover is > 15%. The height range is >3m.	**170. Closed (>40%) broadleaved semi-deciduous and/or evergreen forest regularly flooded - Saline water.**
		7. Tree cover, closed to open, regularly flooded, fresh water-mainly consists of closed to open broadleaved evergreen woodland on permanently or seasonally flooded land. The crown cover is >15%. The height range is > 3m.	**160. Closed (>40%) broadleaved forest regularly flooded - Fresh water.**
3. Deciduous Needle-leaf Forests -Lands dominated by	**3. Deciduous Needle-leaf Forests** -lands dominated by	**5. Tree cover, needle-leaved deciduous, closed to open**- mainly consists of needle-leaved deciduous	**90. Open (15-40%) needle-leaved**

trees with a percent canopy cover >60% and height exceeding 2 meters. Consists of seasonal needle-leaf tree communities with an annual cycle of leaf-on and leaf-off periods.	trees with canopy cover >60% and height >5m. Trees shed their leaves simultaneously in response to cold seasons.	closed to open trees. The crown cover is > 15%. The height is in the range of >3m.	**deciduous or evergreen forest (>5m)**
4. Deciduous Broadleaf Forests- Lands dominated by trees with a percent canopy cover >60% and height exceeding 2 meters. Consists of seasonal broadleaf tree communities with an annual cycle of leaf-on and leaf-off periods.	**4. Deciduous Broadleaf Forests**-lands dominated by trees with canopy cover >60% and height >5m. Trees shed their leaves simultaneously in response to dry or cold seasons.	**2. Tree Cover, broadleaved deciduous, closed-**mainly consists of broadleaved deciduous closed to open trees. The crown cover is > 40%. The height range is > 3m.	**50. Closed (>40%) broadleaved deciduous forest (>5m)**
5. Mixed Forests- Lands dominated by trees with a percent canopy cover >60% and height exceeding 2 meters. Consists of tree communities with interspersed mixtures or mosaics of the other four forest cover types. None of the forest types exceeds 60% of landscape.	**5. Mixed Forests**-lands dominated by trees with canopy cover >60% and height >5m. Consists of tree communities with interspersed mixtures or mosaics of needle-leaf and broadleaf forest types.	**6. Tree cover, mixed leaf-type, closed to open**-mainly consists of broad-leaved trees. The crown cover is between 100 and 15%. The height range is >3m. // The main layer consists of Needle-leaved closed to open trees. The crown cover is between 100 and 15%. The height range is > 3m.	**100. Closed to open (>15%) mixed broadleaved and needle-leaved forest (>5m)**

6. Closed Shrub-lands- Lands with woody vegetation less than 2 meters tall and with shrub canopy cover is >60%. The shrub foliage can be either evergreen or deciduous.	**8. Closed Bushlands or Shrublands**-lands dominated by bushes or shrubs. Bush and shrub canopy cover is >40%. Bushes < 5m in height. Shrubs or bushes can be either evergreen or deciduous. Tree canopy cover is <10%. The remaining cover is either barren or herbaceous.	**9. Mosaic of tree cover and other natural vegetation (with possible croplands)**-mainly consists of closed trees. The crown cover is (70-60)%. The height range is >3m. / Primarily vegetated areas containing >4% vegetation during at least 2 months a year. The vegetative cover is characterized by the presence of (semi)natural vegetation which species composition. The vegetative cover is natural. / (see class 16). **11. Shrub cover, closed to open evergreen**-mainly consists of broadleaved evergreen or needle-leaved evergreen closed to open thicket. The crown cover is > 15%. The height range is 5 - 0.3m.	**110. Mosaic Forest/Shrub-land (50-70%) / Grassland (20-50%)**
7. Open Shrub-lands- Lands with woody vegetation less than 2 meters tall and with shrub canopy cover is between 10-60%. The shrub foliage can be either evergreen or deciduous.	**9. Open Shrub-lands**-lands dominated by shrubs. Shrub canopy cover is >10% and <40%. Shrubs do not exceed 2m in height and can be either evergreen or deciduous. The remaining cover is either barren or of annual herbaceous type.	**14. Sparse Herbaceous or sparse Shrub cover**-mainly consists of sparse herbaceous vegetation or sparse shrubs.. The crown cover is between (20-10) and 1%.	**150. Sparse (>15%) vegetation (woody vegetation, shrubs, grassland)**
8. Woody Savannas- Lands with herbaceous and other understorey systems and with forest canopy cover between 30-60%. The forest cover height exceeds 2 meters.	**6. Woodlands**-lands with herbaceous or woody understories and tree canopy cover >40% and <60%. Trees height >5m and can be either evergreen or deciduous.	**3. Tree cover, broadleaved deciduous, open**-mainly consists of broad-leaved deciduous woodland. The crown cover is (15-40) %. The height range is >3m.	**60. Open (15-40%) broadleaved deciduous forest (>5m)**
9. Savannas- Lands with herbaceous and other understorey systems, and with forest canopy cover between 10-30%.The forest	**7. Wooded Grasslands/Shrub-lands**-lands with herbaceous or woody understories and tree canopy cover of >10%	**12. Shrub cover, closed to open, deciduous**-mainly consists of broad-leaved deciduous closed to open thicket. The crown cover is >15%. The height range is 5 - 0.3m.	**120. Mosaic Grassland (50-70%) / Forest /Shrub-land (20-50%)**

cover height exceeds 2 meters.	and <40%. Trees exceed 5m in height and can be either evergreen or deciduous.		**130. Closed to open (>15%) shrub-land (<5m)**
10. Grasslands- Lands with herbaceous types of cover. Tree and shrub cover is less than10%.	**10. Grasslands**-lands with continuous herbaceous cover and <10% tree or shrub canopy cover.	**13. Herbaceous cover, closed to open**-mainly consists of closed to open herbaceous vegetation. The crown cover is between 100 and 15%. The height range is 3 - 0.03m.	**140. Closed to open (>15%) grassland**
11. Permanent Wetlands- Lands with a permanent mixture of water and herbaceous or woody vegetation that cover extensive areas. The vegetation can be present in either salt, brackish, or fresh water.	**(Absent class on the UMD map.)**	**15. Regularly flooded Shrub or Herbaceous cover, closed to open**-mainly consists of closed to open shrubs on permanently or seasonally flooded land. The crown cover is between 100 and 15%. The height range is 5 - 0.3m./ mainly consists of closed to open herbaceous vegetation on permanently or seasonally flooded land. The crown cover is between 100 and 15%. The height range is 3 - 0.03m	**180. Closed to open (>15%) vegetation (grassland, shrub-land, woody vegetation) on regularly flooded or waterlogged soil - Fresh, brackish or saline water**
12. Croplands- Lands covered with temporary crops followed by harvest and a bare soil period (e.g., single and multiple cropping systems. Note that perennial woody crops will be classified as the appropriate forest or shrub land cover type.	**11. Croplands**-lands with >80% of the landscape covered in crop-producing □fields. Note that perennial woody crops will be classified as the appropriate forest or shrubs land cover type.	**16. Cultivated and managed areas-**Primarily vegetated areas containing more than 4% vegetation during at least two months a year. The vegetative cover is characterized by the removal of the (semi)natural vegetation and replacement with a vegetative cover resulting from human activities. This cover is artificial and requires maintenance. /or (partly) harvested at the end of the growing season.	**11. Post-flooding or irrigated croplands** **14. Rain-fed croplands**
13. Urban and Built-up- Land covered by buildings and other man-made structures. Note that this class will not be mapped from the AVHRR imagery but will be developed from the populated places	**13. Urban and Built-up**-land covered by buildings and other man-made structures. Note that this class will not be mapped from the AVHRR imagery but will be developed from the populated places	**22. Urban Areas**-The land cover consists of built up area(s).	**190. Artificial surfaces and associated areas (urban areas >50%)**

layer that is part of the Digital Chart of the World.	layer that is part of the Digital Chart of the World (Danko 1992).		
14. Croplands/Natural vegetation- Lands with a mosaic of croplands, forest, shrub-lands, and grasslands in which no one component comprises more than 60% of the landscape.	**(Absent class on the UMD map)**	**17. Mosaic of Cropland / Tree cover/ Other Natural Vegetation-**(see class 16) / The main layer consists of closed to open trees. The crown cover is between 100% and 15%. The height is in the range of 30-3m. / Primarily vegetated areas containing more than 4% vegetation during at least two months a year. The vegetative cover is not artificial and does not need to be managed nor maintained.	**20. Mosaic Cropland (50-70%) / Vegetation (grassland, shrub-land, forest) (20-50%)**
		18. Mosaic of Cropland / Shrub or Herbaceous cover- (see as class 16)/ The main layer consists of closed to open shrub-land. The crown cover is between 100 and 15%. // The main layer consists of closed to open herbaceous vegetation. The crown cover is between 100 and 15%.	**30. Mosaic Vegetation (grassland, shrub-land, forest) (50-70%) / Cropland (20-50%)**
15. Snow and Ice- Lands under snow and/or ice cover throughout the year.	**(Absent class on the UMD map)**	**21. Snow or Ice**-the land cover consists of artificial or natural snow or ice.	**220. Permanent snow and ice**
16. Barren or Sparsely Vegetated- Lands exposed soil, sand, rocks, or snow and never has more than 10% vegetated cover during any time of the year.	**16. Barren**-lands of exposed soil, sand, rocks, snow or ice which never have more than 10% vegetated cover during any time of the year.	**19. Bare Areas**-Primarily non-vegetated areas containing less than four percent vegetation during at least 10 months a year. The cover is natural.	**200. Bare areas**
17. Water Bodies- Oceans, seas, lakes, reservoirs, and rivers. Can be either fresh or salt water bodies	**14. Water Bodies**-oceans, seas, lakes, reservoirs, and rivers. Can be either fresh or salt water.	**20. Water Bodies**- The land cover consists of artificial or natural water bodies. A further specification can be made in flowing or standing water.	**210. Water bodies**

Appendix 2: Error Matrixes

MODIS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Total
1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
2	0	146	0	0	0	1	1	10	2	3	0	1	1	3	0	0	3	171
3	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
4	0	4	0	0	0	1	0	1	0	0	0	1	0	0	0	0	0	7
5	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
6	0	4	0	0	0	3	1	2	0	0	0	1	0	1	0	0	0	12
7	0	8	0	0	0	2	75	27	27	20	0	31	2	0	0	29	7	228
8	0	87	0	1	0	10	5	36	13	13	0	14	4	20	0	0	4	207
9	0	40	0	9	0	20	22	65	25	11	0	34	3	39	0	0	6	274
10	0	16	0	0	0	5	6	16	11	13	2	30	2	6	0	9	2	118
11	0	1	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	3
12	0	5	0	0	0	0	3	4	4	0	1	22	2	9	0	0	3	53
13	0	0	0	0	0	0	0	2	0	0	0	2	4	1	0	0	0	9
14	0	3	0	0	0	0	0	3	0	0	0	1	0	6	0	0	0	13
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	1	0	3	17	4	4	8	2	18	4	1	0	653	10	725
17	0	1	0	0	0	2	1	0	0	0	0	2	2	1	0	1	48	58
Total	0	315	0	11	0	48	132	172	86	69	5	157	24	87	0	692	83	1881
U.A*.	0%	85%	0%	0%	0%	25%	33%	17%	9%	11%	0%	42%	44%	46%	null	90%	83%	
P.A*.	null	46%	null	0%	0%	6%	57%	21%	29%	19%	0%	14%	17%	7%	null	94%	58%	

Overall accuracy 55%

USGS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Total
1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
2	0	147	0	1	0	0	1	27	10	7	0	3	2	6	0	0	2	206
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	3	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	9
6	0	7	0	0	0	1	5	10	3	2	0	9	1	2	0	26	0	66
7	0	6	0	1	0	6	35	16	14	7	0	9	3	1	0	0	3	101
8	0	64	0	1	0	19	13	27	14	6	1	20	2	22	0	2	3	194
9	0	28	0	5	0	13	13	34	14	7	1	37	3	25	0	21	5	206
10	0	4	0	0	0	4	24	9	11	19	1	18	1	5	0	0	3	99
11	0	3	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	5
12	0	19	0	1	0	3	7	23	5	3	0	24	3	15	0	0	5	108
13	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
14	0	25	0	2	0	1	15	14	8	7	0	18	1	9	0	1	2	103
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	2	0	0	0	1	18	5	5	10	2	18	6	2	0	640	20	729
17	0	7	0	0	0	0	1	1	1	0	0	0	1	0	0	2	40	53
Total	0	315	0	11	0	48	132	172	86	69	5	157	24	87	0	692	83	1881
U.A.*	0%	71%	null	null	0%	2%	35%	14%	7%	19%	0%	22%	0%	9%	null	88%	75%	
P.A.*	null	47%	null	0%	null	2%	27%	16%	16%	28%	0%	15%	0%	10%	null	92%	48%	

Overall accuracy 51%

UMD	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Total
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	113	0	0	0	1	1	3	2	1	0	1	0	1	0	0	1	124
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	2	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	4
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	5	0	0	0	3	28	10	10	9	0	22	0	7	0	0	1	95
7	0	1	0	0	0	4	47	12	16	14	2	29	4	3	0	24	9	165
8	0	108	0	4	0	12	9	48	13	10	0	9	1	13	0	0	2	229
9	0	53	0	4	0	23	12	66	24	9	1	37	3	45	0	0	1	278
10	0	20	0	2	0	2	13	13	10	8	0	12	5	8	0	0	2	95
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	10	0	1	0	1	3	9	3	7	0	29	3	8	0	0	0	74
13	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	2
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	19	9	6	10	2	13	3	1	0	667	13	743
17	0	3	0	0	0	2		2	1	1	0	4	4	0	0	1	54	72
Total	0	315	0	11	0	48	132	172	86	69	5	157	24	87	0	692	83	1881
U.A.*	null	91%	null	0%	null	3%	28%	21%	9%	8%	null	39%	50%	null	null	90%	75%	
P.A.*	null	36%	null	0%	null	6%	36%	28%	28%	12%	0%	18%	4%	0%	null	96%	65%	

Overall accuracy 53%

GLC2000	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Total
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	130	0	0	0	0	0	7	1	0	0	1	1	1	0	0	3	144
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	49	0	1	0	1	1	22	5	2	0	4	0	2	0	0	0	87
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	12	0	0	0	5	0	2	0	0	0	0	1	0	0	0	0	20
7	0	0	0	0	0	1	38	11	8	10	0	7	2	1	0	24	3	105
8	0	46	0	4	0	7	12	33	9	11	0	3	1	14	0	0	3	143
9	0	23	0	3	0	7	25	43	22	15	0	19	3	21	0	0	0	181
10	0	18	0	3	0	7	32	21	18	10	2	24	0	7	0	8	1	151
11	0	2	0	0	0	2	0	1	0	1	0	1	0	1	0	0	0	8
12	0	13	0	0	0	6	13	21	12	10	0	69	1	21	0	1	4	171
13	0	0	0	0	0	0	0	0	0	0	0	1	4	0	0	0	0	5
14	0	21	0	0	0	10	1	9	6	1	1	14	2	18	0	0	1	84
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	10	1	5	8	2	12	4	0	0	657	7	706
17	0	1	0	0	0	2	0	1	0	1	0	2	5	1	0	2	61	76
Total	0	315	0	11	0	48	132	172	86	69	5	157	24	87	0	692	83	1881
U.A.*	null	90%	null	1%	null	25%	36%	23%	12%	7%	0%	40%	80%	21%	null	93%	80%	
P.A.*	null	41%	null	9%	null	10%	29%	19%	26%	14%	0%	44%	17%	21%	null	95%	73%	

Overall accuracy 56%

GlobCover	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Total
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	126	0	1	0	3	0	3	2	0	0	0	1	0	0	0	0	136
3	0	1	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	4
4	0	49	0	0	0	0	0	23	3	1	0	1	0	1	0	0	0	78
5	0	2	0	0	0	0	1	6	1	2	0	0	0	2	0	0	0	14
6	0	7	0	0	0	9	8	18	9	4	1	9	2	2	0	4	0	73
7	0	0	0	0	0	0	20	8	7	6	0	2	2	1	0	9	0	55
8	0	44	0	1	0	7	4	28	7	10	0	3		12	0	0	0	116
9	0	39	0	7	0	8	10	24	7	4	0	15	1	22	0	0	2	139
10	0	2	0	1	0	5	49	8	22	17	0	24	4	5	0	22	0	159
11	0	3	0	0	0	2	0	0	0	1	0	5	0	0	0	0	0	11
12	0	3	0	0	0	2	2	6	5	0	0	22	0	4	0	0	1	45
13	0		0	0	0	0	0	0	0	0	0	0	8	0	0	0	0	8
14	0	39	0	1	0	10	21	45	18	15	1	65	2	38	0	1	1	257
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	1	17	0	5	9	3	11	4	0	0	656	2	708
17	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	77	78
Total	0	315	0	11	0	48	132	172	86	69	5	157	24	87	0	692	83	1881
U.A.*	null	93%	0%	0%	0%	12%	36%	24%	5%	11%	0%	49%	100%	15%	null	93%	99%	
P.A.*	null	40%	null	0%	null	19%	15%	16%	8%	25%	0%	14%	33%	44%	null	95%	93%	

Overall accuracy 54%

*"U.A." stands for User's Accuracy;
*"P.A." stands for Producer's Accuracy;
The numbers in first columns and first rows in the tables above represents corresponding IGBP classes on the maps (column) and on the reference scenes (row). Appendix 1 IGBP legend column lists out all the class numbers and their corresponding class names.

Lunds Universitets Naturgeografiska institution. Seminarieuppsatser. Uppsatserna finns tillgängliga på Naturgeografiska institutionens bibliotek, Sölvegatan 12, 223 62 LUND. Serien startade 1985. Hela listan och själva uppsatserna är även tillgängliga på http://www.geobib.lu.se/

The reports are available at the Geo-Library, Department of Physical Geography, University of Lund, Sölvegatan 12, S-223 62 Lund, Sweden.
Report series started 1985. The whole complete list and electronic versions are available at http://www.geobib.lu.se/

156 Cederlund, Emma (2009): Metodgranskning av Klimatkommunernas lathund för inventering av växthusgasutsläpp från en kommun

157 Öberg, Hanna (2009): GIS-användning i katastrofdrabbade utvecklingsländer

158 Marion Früchtl &Miriam Hurkuck (2009): Reproduction of methane emissions from terrestrial plants under aerobic conditions

159 Florian Sallaba (2009): Potential of a Post-Classification Change Detection Analysis to Identify Land Use and Land Cover Changes. A Case Study in Northern Greece

160 Sara Odelius (2009): Analys av stadsluftens kvalitet med hjälp av geografiska informationssystem.

161 Carl Bergman (2009): En undersökning av samband mellan förändringar i fenologi och temperatur 1982-2005 med hjälp av GIMMS datasetet och klimatdata från SMHI.

162 Per Ola Olsson (2009): Digitala höjdmodeller och höjdsystem. Insamling av höjddata med fokus på flygburen laserskanning.

163 Johanna Engström (2009): Landskapets påverkan på vinden -sett ur ett vindkraftperspektiv.

164 Andrea Johansson (2009): Olika våtmarkstypers påverkan på CH_4, N_2O och CO_2 utsläpp, och upptag av N_2.

165 Linn Elmlund (2009): The Threat of Climate Change to Coral Reefs

166 Hanna Forssman (2009): Avsmältningen av isen på Arktis - mätmetoder, orsaker och effekter.

167 Julia Olsson (2009): Alpina trädgränsens förändring i Jämtlands- och Dalarnas län över 100 år.

168 Helen Thorstensson (2009): Relating soil properties to biomass consumption and land management in semiarid Sudan – A Minor Field Study in North Kordofan

169 Nina Cerić och Sanna Elgh Dalgren (2009): Kustöversvämningar och GIS - en studie om Skånska kustnära kommuners arbete samt interpolations-metodens betydelse av höjddata vid översvämningssimulering.

170 Mats Carlsson (2009): Aerosolers påverkan på klimatet.

171 Elise Palm (2009): Övervakning av gåsbete av vass – en metodutveckling

172 Sophie Rychlik (2009): Relating interannual variability of atmospheric CH_4 growth rate to large-scale CH_4 emissions from northern wetlands

173 Per-Olof Seiron and Hanna Friman (2009): The Effects of Climate Induced Sea Level Rise on the Coastal Areas in the Hambantota District, Sri Lanka - A geographical study of Hambantota and an identification of vulnerable ecosystems and land use along the coast.

174 Norbert Pirk (2009): Methane Emission Peaks from Permafrost Environments: Using Ultra–Wideband Spectroscopy, Sub-Surface Pressure Sensing and Finite

Element Solving as Means of their Exploration
175 Hongxiao Jin (2010): Drivers of Global Wildfires — Statistical analyses
176 Emma Cederlund (2010): Dalby Söderskog – Den historiska utvecklingen
177 Lina Glad (2010): En förändringsstudie av Ivösjöns strandlinje
178 Erika Filppa (2010): Utsläpp till luft från ballastproduktionen år 2008
179 Karolina Jacobsson (2010):Havsisens avsmältning i Arktis och dess effekter
180 Mattias Spångmyr (2010): Global of effects of albedo change due to urbanization
181 Emmelie Johansson & Towe Andersson (2010): Ekologiskt jordbruk - ett sätt att minska övergödningen och bevara den biologiska mångfalden?
182 Åsa Cornander (2010): Stigande havsnivåer och dess effect på känsligt belägna bosättningar
183 Linda Adamsson (2010): Landskapsekologisk undersökning av ädellövskogen i Östra Vätterbranterna
184 Ylva Persson (2010): Markfuktighetens påverkan på granens tillväxt i Guvarp
185 Boel Hedgren (2010): Den arktiska permafrostens degradering och metangasutsläpp
186 Joakim Lindblad & Johan Lindenbaum (2010): GIS-baserad kartläggning av sambandet mellan pesticidförekomster i grundvatten och markegenskaper
187 Oscar Dagerskog (2010): Baösberggrottan – Historiska tillbakablickar och en lokalklimatologisk undersökning
188 Mikael Månsson (2010): Webbaserad GIS-klient för hantering av geologisk information
189 Lina Eklund (2010): Accessibility to health services in the West Bank, occupied Palestinian Territory.
190 Edvin Eriksson (2010): Kvalitet och osäkerhet i geografisk analys - En studie om kvalitetsaspekter med fokus på osäkerhetsanalys av rumslig prognosmodell för trafikolyckor
191 Elsa Tessaire (2010): Impacts of stressful weather events on forest ecosystems in south Sweden.
192 Xuejing Lei (2010): Assessment of Climate Change Impacts on Cork Oak in Western Mediterranean Regions: A Comparative Analysis of Extreme Indices
193 Radoslaw Guzinski (2010) Comparison of vegetation indices to determine their accuracy in predicting spring phenology of Swedish ecosystems
194 Yasar Arfat (2010) Land Use / Land Cover Change Detection and Quantification — A Case study in Eastern Sudan
195 Ling Bai (2010) Comparison and Validation of Five Global Land Cover Products Over African Continent
196 Raunaq Jahan (2010) Vegetation indices, FAPAR and spatial seasonality analysis of crops in southern Sweden