Erdsicht - Einblicke in geographische und geoinformationstechnische Arbeitsweisen

Schriftenreihe des geographischen Instituts der Universität Göttingen, Abteilung Kartographie, GIS und Fernerkundung

Herausgegeben von Prof. Dr. Martin Kappas

Anke Gleitsmann

Exploiting the Spatial Information in High Resolution Satellite Data and Utilising Multi-Source Data for Tropical Mountain Forest and Land Cover Mapping

ibidem

Anke Gleitsmann

Exploiting the Spatial Information in High Resolution Satellite Data and Utilising Multi-Source Data for Tropical Mountain Forest and Land Cover Mapping

ERDSICHT - EINBLICKE IN GEOGRAPHISCHE UND GEOINFORMATIONSTECHNISCHE ARBEITSWEISEN

Schriftenreihe des Geographischen Instituts der Universität Göttingen,
Abteilung Kartographie, GIS und Fernerkundung

Herausgegeben von Prof. Dr. Martin Kappas

ISSN 1614-4716

7 *Jobst Augustin*
Das Seegangsklima der Ostsee zwischen 1958 und 2002 auf Grundlage numerischer Daten
ISBN 3-89821-572-5

8 *Martin Kappas*
Naturraumpotential und Landnutzung im Oudalan – eine Fallstudie aus dem Sahel Burkina Fasos zur Anwendbarkeit von Fernerkundungsmethoden im regionalen Maßstab
ISBN 3-89821-664-0

9 *Ortwin Kessels*
Qualitätsanalyse verschiedener digitaler Geländemodelle und deren Eignung für die Prozessierung von Satellitenbilddaten in den Tropen
ISBN 3-89821-603-9

10 *Christian Knieper*
Remote Sensing Based Analysis of Land Cover and Land Cover Change in Central Sulawesi, Indonesia
ISBN 3-89821-646-2

11 *Mareike Lehrling*
Klimaentwicklung in Alaska - eine GIS-gestützte Erfassung und Analyse der raum-zeitlichen Entwicklung von Temperatur und Niederschlag
ISBN 3-89821-670-5

12 *Daniel Karthe*
Trinkwasser in Calcutta
Versorgungsproblematik einer indischen Megastadt
ISBN 3-89821-661-6

13 *Enrico Kalb*
Landnutzungsinterpretation und Erosionsmodellierung der Küstenregion von Nordost Bali, Indonesien
ISBN 3-89821-666-7

Anke Gleitsmann

EXPLOITING THE SPATIAL INFORMATION IN HIGH RESOLUTION SATELLITE DATA AND UTILISING MULTI-SOURCE DATA FOR TROPICAL MOUNTAIN FOREST AND LAND COVER MAPPING

ibidem-Verlag
Stuttgart

Bibliografische Information Der Deutschen Bibliothek

Die Deutsche Bibliothek verzeichnet diese Publikation in der Deutschen Nationalbibliografie; detaillierte bibliografische Daten sind im Internet über <http://dnb.ddb.de> abrufbar.

∞

ISBN-13: 978-3-8382-5727-3

Vorwort des Herausgebers

Die Reihe „Erdsicht – Einblicke in Geographische und Geoinformationstechnische Arbeitsweisen“ soll Forschungsergebnisse und Arbeiten im Bereich der Erdsystemforschung vorstellen. Die Betrachtung der Erde als System ist als Inhalt heutiger und zukünftiger Geowissenschaftlicher Gemeinschaftsforschung dringend gefordert. Die Herausforderungen liegen zum einen in der Erforschung der vielfältigen Interaktionen zwischen den verschiedenen Teilbereichen des Systems Erde. Hierzu zählen Wechselwirkungen zwischen fester Erde und Atmosphäre, zwischen der Landoberfläche und der Hydrosphäre oder zwischen Biosphäre, Hydrosphäre und Atmosphäre. Der Mensch steht dabei mit seinen zentralen Nutzungsansprüchen (Ernährung – landwirtschaftliche Nutzung – Ressourcennutzung) im Mittelpunkt eines vielfach vernetzten Erdsystems. Der Mensch verändert Landschaften und Atmosphäre und greift somit in alle Skalenbereiche des Erdsystems ein. Insofern müssen diese Veränderungen beobachtet und bewertet werden, damit Konzepte für ein nachhaltiges Erdsystemmanagement auf den unterschiedlichen Raum- und Zeitskalen entwickelt werden können. Die neuen Geoinformationstechniken (Geostatistik; Geographische Informationssysteme – GIS; luft- und Satellitengestützte Fernerkundungssysteme – Remote Sensing) helfen dabei das System Erde zu beobachten und zu begreifen. Ohne diese Techniken ist eine ganzheitliche Betrachtung der Erde und eine flächenhafte Bereitstellung von Informationen über das Erdsystem nicht möglich.

Die vorliegende Dissertation beschäftigt sich mit den Möglichkeiten des Informationsgewinns aus räumlich hochaufgelösten Satellitendaten, wie sie beispielsweise mit den IKONOS-Daten seit 1999 verfügbar sind. Das Untersuchungsgebiet ist ein Gebirgsbereich in der Dominikanischen Republik, wo tropische Bergwälder und landwirtschaftliche Nutzung aufeinandertreffen. Genaue räumliche Informationen sind hier wichtig, um Resourcenschutz und Resourcennutzung sinnvoll miteinander kombinieren zu können.

Martin Kappas

Abstract: Exploiting the Spatial Information in High Resolution Satellite Data and Utilising Multi-Source Data for Tropical Mountain Forest and Land Cover Mapping

The heterogeneous, fragmented land cover pattern of the upper catchment area of the Río Yaque del Norte, in the Cordillera Central of the Dominican Republic, is typical for many tropical mountain areas. Parts of the catchment area have been colonised in the course of the 20th century, in spite of their marginality for agricultural land use purposes. At the same time, there are still several types of primary mountain forests remaining in this mountain range, among them fragmented cloud forest areas with threatened endemic species. Deforestation and unsustainable land use methods on the steep slopes of the study area have led to erosion and land degradation. There are efforts to foster more sustainable land use practices, to reforest some areas and to protect the threatened ecosystems. Detailed spatial land cover information would be important for improving the basis of the necessary land management decisions.

The study area is challenging for forest and land cover mapping. The usefulness of medium resolution (e.g. Landsat) satellite data for mapping its vegetation types is limited, because the small-scale mix of land cover types leads to a large proportion of mixed pixels in such data. The introduction of a new generation of commercial high spatial resolution satellites like IKONOS has led to new possibilities for more detailed classifications of special interest areas, but the high resolution data also pose new challenges for automated land cover mapping. Single pixels in these data fail to integrate the elements of the target classes (e.g. forest types) and the increased amount of spatial information contained in the data cannot be fully extracted by using the per-pixel multispectral classification approaches which are common for medium resolution satellite data. To make use of the high resolution spatial information contained in the IKONOS panchromatic channel in automated classifications, customised texture parameters were created and used as additional channels in the classification. At the same time, several methods for the spatial integration of the multispectral data were tested and compared, in

order to make the spectral signals of the image primitives more representative of the target classes. Both the spatial integration of the multispectral data (especially low pass filtering) and the introduction of texture parameters led to significantly increased classification accuracies. The integration of multi-source data as input for the classifiers (combining additional Landsat multispectral channels or DEM-derived topographic models with the IKONOS data sets) did not lead to significantly improved results, compared to the results which were achieved with IKONOS data alone. However, the elevation data did show some potential to increase the separability of some classes. They could probably have been more useful if a higher resolution DEM had been available. The Maximum-Likelihood-Classifier produced better results than the tested non-parametric classifiers. With the optimised methods, a detailed land cover classification (13 classes, six of which represented forest types) was possible using information derived from the IKONOS data. There were some inherently problematic classes like open pine forest and agro-forestry, but for most forest classes, good classification accuracies could be achieved, particularly for the ecologically important cloud forest class.

Acknowledgements

This study was conducted in the Cartography, GIS and Remote Sensing Department at the Geographical Institute of the University of Göttingen. My supervisor was Professor Dr. Martin Kappas, who also introduced me to the Dominican Republic. I would like to thank him for suggestions, support and being always open for discussions. I am also grateful to my other colleagues at the department, particularly Dr. Stefan Erasmi for discussions, suggestions and occasional technical support and Glenda Rodriguez for having been such a friendly room (office) mate. In the Dominican Republic, I was kindly assisted by Ramón Elias Castillo (PROGRESSIO) and Dr. Thomas May with their local botanical knowledge, and by staff members of the PROCARYN-Project, particularly Thomas Heindrichs, Pablo Ovalles, Humberto Checo, Henning Peter and the ‘Extensionistas’ (field workers), among others. I’d also like to thank the PROCARYN freelancers Pai Spehs and Wieland Künzel, and Wieland and his wife Shoko for their hospitality in Santo Domingo. During the first field work campaign, the PROCARYN interns Anja and Randy (University of Göttingen) und Vivien und Dassa (Students of the agricultural and forestry college ISA in Santiago) helped me to collect field data. During a part of the second field work campaign, I could share field work resources and some of the generated photos with Nicole Erler. I’m grateful that my husband Lars accompanied me during the second field work campaign. He contributed his back-country driving skills, some of the ground photographs and particularly the oblique aerial photographs. His support and suggestions were very important for me during my work for this study. I’d also like to give special thanks to my parents, whom I could always rely on while exploring the world, and whose support enabled me to study an interesting subject. Wiebke Dietrich, my parents, Stefan Erasmi and Lars helped me with the proof-reading of the thesis script.

This work was financed for the most part by a graduate grant of the state of Lower Saxony (Graduiertenförderung), together with financial travel support by the DAAD (German Academic Exchange Service) and the DFG (German Science Commission).

Contents

List of Figures

List of Tables

List of Plates

List of Abbreviations

ANN: Artificial Neural Network

a.s.l.: above sea level

ASM: Angular Second Moment (GLCM texture feature)

AVHRR: Advanced Very High Resolution Radiometer

BD: Bhattacharyya Distance

C: Celsius

CONT: Contrast (GLCM texture feature)

CORR: Correlation (GLCM texture feature)

CRIES: Comprehensive Resource Inventory and Evaluation System

D: Divergence

DED: Deutscher Entwicklungsdienst (German Development Service)

DEM: Digital Elevation Model

DTM: Digital Terrain Model

DGF: Dirección General de Foresta

DIRENA: Departamento de Inventario de los Recursos Naturales (Department for the Inventory of Natural Resources)

DISS: Dissimilarity (GLCM texture feature)

DN: Digital Number

DNP: Dirección Nationál de Parques

e.g.: for example

ENT: Entropy (GLCM texture feature)

ETM+: Enhanced Thematic Mapper Plus

FAO: Food and Agriculture Organisation of the United Nations

FRA 2000: Global Forest Resources Assessment 2000

GCP: Ground Control Point

GIS: Geographical Information System

GLCM: Grey-Level Co-occurrence Matrix

GLCV: Grey-Level Co-occurrence Vector

GMT: Greenwich Mean Time

GPS: Global Positioning System

GSD: Ground Sample Distance

GTZ: Deutsche Gesellschaft für Technische Zusammenarbeit GmbH

ha: hectare

HOM: Homogeneity (GLCM texture feature)

ICEC: International Classification of Ecological Communities

ICM: Instituto Cartográphico Militar

i.e.: that is

IFOV: Instantaneous Field Of View

IHS: Intensity, Hue, Saturation

INDHRI: Instituto Nacional de Recursos Hidráulicos (National Institute for Water Resources)

IRS: Indian Remote Sensing

ISA: Instituto Superior de Agricultura (in Santiago de los Caballeros, Dominican Republic)

KfW: Kreditanstalt für Wiederaufbau

KIA: Kappa index of agreement

km: kilometre

k-NN: k-Nearest-Neighbour

LAI: Leaf Area Index

m: metre

MLC: Maximum Likelihood Classification

MODIS: Moderate Resolution Imaging Spectroradiometer

ms: multispectral

MSS: Multispectral Scanner

NOAA: National Oceanic and Atmospheric Administration

NGO: Non-Governmental Organisation

NIR: Near Infra-Red

NNC: Neural Network Classification

No.: Number

NP: National Park

OA: Overall Accuracy

OEA (OAS): Organización de los Estados Americanos (Organization of American States)

PROCARYN: Proyecto Maneja y Conservación de la Cuenca Alta Río Yaque del Norte (Project for the Management and Conservation of the Upper Catchment of the Río Yaque del Norte)

RGB: Red, Green, Blue (display colour channels)

RMSE: Root Mean Square Error

SAR: Synthetic Aperture Radar

SD: Standard Deviation (GLCM texture feature)

SEA: Secretaría de Estado de Agricultura (Ministry of Agriculture)

s: second

SEMARENA: Secretaría de Estado de Medio Ambiente y Recursos Naturales (Ministry for Environment)

SPOT HRV XS: SPOT High Resolution Visible Multispectral

SR: Scientific Reserve

StNN: Standard Nearest Neighbour Classification

TD: Transformed Divergence

Tex: Texture

TM: Thematic Mapper

TMCF: Tropical Mountain Cloud Forest

UCRYN: Upper Catchment Area of the Río Yaque del Norte

UNESCO: United Nations Educational, Scientific and Cultural Organization

USAID: United States Agency for International Development

USGS: United States Geological Survey

UTM: Universal Transverse Mercator

VAR: Variance

Abbreviations of Land Cover Class Names

AF: Agroforestry

BG: Bare ground

brn: Burnt areas

BRF: Broadleaved riparian forest

bu: Built-up areas

Cal: *Calimetal* / fern

CF: Cloud forest

Cof: Coffee without shade

Cr: Other crops

GL: Grassland

Mat: Matorral

MF: Mixed forest

PFd: Dense pine forest

PFo: Open pine forest

PmF: Palm dominated forest

SF: Secondary forest

SFd: Dense secondary forest

SFo: Open secondary forest

W: Water

Copyright Notice

1 Introduction

Tropical ecosystems are changing rapidly as a result of human activity. Land cover changes in the tropics include deforestation and landscape fragmentation, often in connection with the colonisation of marginal areas. Achard et al. (2002) state that between 1990 and 1997, 5.8 ± 1.4 million ha of humid tropical forest were lost per year and 2.3 ± 0.7 million ha were visibly degraded. The world-wide loss and degradation of tropical forests has far-ranging ecological and climatic consequences. Tropical mountain forests in particular play a central role in many aspects of sustainable development. They can be linked with soil conservation and the prevention of land degradation, water supply and climate change, biodiversity, and tourism development, apart from providing timber and other forest products (Price & Butt 2000).

The Caribbean islands are a region where the population density is much higher than in many continental tropical countries and the proportion of forests which have survived on these islands is accordingly low (Lugo 1995). The Dominican Republic has seen the destruction of most of its forests in the course of the 20th century, but due to its mountainous relief and historically relatively low population density, some considerable parts of its rich and varied natural vegetation are still remaining – in contrast to its disastrously degraded neighbouring country Haiti.

The problems of deforestation, especially in the mountain areas, are recognized in the Dominican Republic and there are efforts to protect selected areas of natural forests and to reforest mountain areas which are degraded or in danger of further degradation. However, as in many developing countries, there is a lack of information on forest resources. More information would be needed for forest management planning and for monitoring the sustainable development of forests in agreement with Agenda 21 of the Rio Earth Summit 1992 (Lund 1996). According to Saket (2002), most developing countries were unable to provide detailed information to the Global Forest Resources Assessment 2000 (FRA 2000), and only 10 % could provide information on changes in area. None of the countries in Latin America and the Caribbean reported information based on country-wide field sampling, but most could provide area estimates based on remote sensing. The "*Inventario de Cobertura Forestal*" (inventory of forest coverage) published by the Dominican ministry of the environment in 2001 (SEMARENA 2001a) is based mostly on the classification of several Landsat scenes from the 1990s.

Remote sensing is a necessary data source for mapping, spatial analysis and geo-referenced information (Kleinn 2002). Even if remote sensing technologies cannot provide the same information that would be the result of a complete forest inventory based on extensive field sampling as conducted in many developed countries, they can provide information about some core attributes like forest area and area by forest type, among other things. Only remote sensing can provide full-cover, spatially explicit information on the location of forest types, changes of forest cover and forest fragmentation. The resulting land cover maps can serve as one basis for forest management and protection. They could also help to choose an optimized sample, reducing the necessary intensity of field sampling if further forest inventory efforts were to follow. Land cover maps are also needed as an input for the analysis and modelling of interrelationships of landscape processes.

Classifications based on Landsat or similar medium-resolution satellite data can give a first overview over the spatial distribution of the major vegetation units, but they are often inadequate when dealing with the heterogeneous land cover patterns that are characteristic for many tropical mountain areas due to topographic, climatic, geologic and edaphic variations and land use patterns including subsistence agriculture and shifting cultivation.

The recent introduction of commercially available high spatial resolution satellite imagery has brought about new possibilities and new challenges for the field of satellite remote sensing of the environment. Before the launch of IKONOS-2 in 1999 imagery of a comparable spatial resolution was only available from airborne sensors. Changing the spatial resolution of the measurement changes the information content and statistical properties of image data (Marceau et al. 1994a), and digital image analysis methods used with medium resolution satellite images are not always applicable. Increasing the spatial resolution of an image reduces the integrating effect of larger pixels and thus the homogeneity within land cover classes. High (and very high) spatial resolution imagery such as aerial photographs is traditionally interpreted by manually delineating vegetation boundaries (Coulter et al. 2000). In these cases, the human interpreter does not only use the information of grey levels or colours, but also attributes like texture, patterns, location, form, and size. Correspondingly, automated digital analysis of high spatial resolution images should include methods which use not only the per-pixel spectral information but also the spatial information present in these images.

One way to utilise the spatial information from high resolution imagery is to extract texture parameters which can then be included in the classification process. Texture in digital image analysis is the variability or the spatial relationship of grey levels in a pixel neighbourhood or window. Image texture parameters can be derived from a variety of first- and second-order statistics. Texture is related to the size and distribution of objects in the scene and to the spatial resolution of the imagery. In high resolution cases, where the pixels are smaller than the size of the objects in the image (which is the case for IKONOS images of forest), texture information can be expected to be especially valuable for class discrimination.

The spatial resolution of high resolution imagery may be too high for optimal per-pixel classification results of heterogeneous land cover classes like forest, because the different elements of a class (e.g. illuminated crowns, shaded crown parts and understorey vegetation) are not integrated in the single pixels. It may thus be necessary to perform some kind of spatial integration before classification, e.g. by reducing the spatial resolution of the imagery or using a low pass filter. Another way to incorporate the spatial context is image segmentation, followed by object oriented image analysis. Image segmentation divides an image into separated, spatially continuous regions which are homogeneous with respect to some characteristic or characteristics. The resulting image objects are more meaningful than single pixels and allow for object-oriented or per-parcel image classification.

Given the influence of elevation and other terrain variables on vegetation, valuable ancillary information for forest classifications in mountainous areas can be derived from digital elevation models (DEM). Appropriate data integration methods are needed to be able to use multi-source data (satellite and DEM-derived), data of different spatial resolutions, as well as spectral and textural data in the classification process. The established maximum likelihood classification method has some limitations as to the types of data it is appropriate for and it is not adapted for using data of different scales. Therefore, other (non-parametric) classification methods or ways to incorporate ancillary data in pre- or post-classification processes have to be considered.

Geographical entities such as forests are not only scale-dependent in their definition, but they are also inherently fuzzy, with indeterminate boundaries (Cheng 2002). Detailed classifications of natural and semi-natural vegetation in particular entail fuzziness in the class definitions and the spatial delineation of class areas. In addition, the occurrence of mixed pixels on class borders can never be completely avoided even in high resolution imagery. Therefore, the concept of fuzziness is important when addressing the unavoidable uncertainties in class definition, classification and the resulting maps.

1.1 Aims and Objectives

This study aims at finding, testing and comparing methods for forest and land cover mapping in tropical mountainous terrain using automated classifications of recent optical satellite data, comparing the usefulness of medium and high resolution satellite data and combining multi-source data in order to improve classification results.

The main objectives are

- to produce a regional land cover base map using Landsat ETM+ data;
- to evaluate high resolution satellite data (IKONOS) for mountain forest and land cover mapping;
- to test the usefulness of spatial information (texture) for improving the discrimination of forest and other land cover classes;
- to test the usefulness of different kinds of spatial integration of high resolution data, including segmentation;
- to produce an integrated data set as a basis for an optimised classification;
- to test and compare suitable classification methods;
- to generate optimised land cover maps of the study area, discriminating forest formations and other physiognomic vegetation units.

1.2 Central Hypothesis

Digital image classification of high spatial resolution satellite data can contribute to improved results in (localised) tropical mountain forest mapping compared to medium resolution satellite data. The successful use of high resolution data for automated land cover classifications requires that the spatial characteristics of these data are taken into consideration and that the spatial information contained in the high resolution data is extracted and used in the classification process as well as the spectral information.

1.3 Outline

In the following chapters, I will present the theoretical framework of this study and then describe the land cover (especially the forests) and the land use in the study area, including the physical and historical basis for the current situation. The next chapter describes the data that were available to me for this study. The first methodological chapters describe the field work and the pre-processing methods used. Chapter 7 explores the possibilities and limitations of a land cover classification without high resolution data. After that, the methods used to extract additional information from high-resolution data are described and, subsequently, the results of the analysed issues (questions of spatial resolution and spatial integration, use of texture, multi-source data integration, classification methods, assessment of results) are described and discussed. The tenth chapter presents the conclusions of this study. It is followed by a summary in German.

2 Methodical Background

2.1 Use of Remote Sensing in Forest Mapping

In many countries outside the tropics, remote sensing is an established tool used in forest mapping and, in combination with ground sampling, in forest inventory (Tomppo 1996, Sutter 1990, Magnussen 1997, Tickle et al. 1998) as well as in forest damage surveys (Thomas 1990). Most of these practical applications involve the use of high spatial resolution remote sensing data, and aerial photographs are still the most common data source used, even though digital air-borne data have gained in importance in recent years (Kayitakire et al. 2002). The analysis of these high resolution images is dominated by manual, non-automated methods (Magnussen 1997, Biggs 1996, Sutter 1990), although this is time-consuming and can lead to inconsistent results (Green 2000). The automatic analysis of aerial imagery is mostly still in the experimental rather than the operational stage (Pouliot et al. 2002, Kadmon & Harari-Kremer 1999, Atzberger & Schlerf 2002).

Until 1999, only airborne sensors and cameras provided high resolution data for forestry applications, while multispectral high resolution satellite data with a repetitive coverage were not commercially available. Since then, a number of high resolution satellites have been put into orbit. Satellites like IKONOS-2 and QuickBird represent a new generation of remote sensing satellites, delivering multispectral imagery with spatial resolutions of 4 m and less. The advent of high resolution satellite data since 1999 provides new incentives to develop automated analysis methods for digital high resolution remote sensing data. Automated methods for forest classification and the mapping of biophysical stand parameters with digital airborne data have been tested for example in North America (Quackenbush et al. 2000, St-Onge & Cavayas 1995, Franklin et al. 2001a, Cosmopoulos & King 2004, Leckie et al. 2003, Kellndorfer et al. 2003) and Europe (Baulies & Pons 1995). IKONOS high resolution satellite data were used by Goetz et al. (2003) to map tree cover and by Hirata et al. (2002) and Franklin et al. (2001b) to test techniques for the extraction of information about coniferous forest stands.

Medium resolution satellite data like Landsat are used in some large area forest inventories for example in Finland (Tomppo 1996), but are not deemed to be suitable information sources for practical forest management purposes by Holmgren & Thuresson (1998) and Pitt et al. (1997). Remote sensing cannot deliver information about all the variables which field sampling produces for a forest inventory, but on the other hand, field sampling cannot produce geo-referenced information with complete coverage for a whole region. Spatially explicit information about the area and distribution of forest and land cover types can only be gained with the help of remotely sensed data (Kleinn 2002). Consequently, Landsat TM (Thematic Mapper) and similar optical satellite data are much used in regional forest type and land cover mapping (e.g. Franklin 1992, Koch et al. 2002). There are also efforts to estimate parameters like forest age and crown closure from Landsat TM data (Jakubauskas & Price 2000, Franklin et al. 2003, Xu et al. 2003). There are many more studies using satellite data for forest mapping, but an exhaustive review of the use of medium to low resolution optical data (e.g. Latifovic et al. 2004) and synthetic aperture radar (SAR) data (e.g. Dobson et al. 1996, Kellndorfer et al. 1998) for regional to global forest and land cover mapping would go beyond the scope of this overview.

Besides high spatial resolution satellite data, other new data sources for detailed forest information are airborne lidar (light detection and ranging), which can be used to provide measurements of the vertical canopy structure (Means et al. 2000, Hudak et al. 2002, Dubaya & Drake 2000), and airborne and satellite hyperspectral data (Ustin & Trabucco 2000, Martin et al. 1998). Specialized techniques like these, aiming to provide detailed information for forest managers, are usually developed in non-tropical countries like Canada and Finland, but the aims and conditions of boreal and temperate forest mapping and management are in many respects quite different from the situation in the tropics.

Remote sensing of tropical forests

In many tropical developing countries, there is a lack of even very basic forest information which would be needed for effective forest protection and management. For the Global Forest Resources Assessment 2000 (FAO 2001), none of the Latin American and Caribbean countries could provide forest information based on country-wide field sampling, while about half of these countries had mapped their forest resources using aerial photographs or satellite imagery, providing area estimates for more or less detailed or broad forest types (Saket 2002). Terrestrial surveys of tropical forests are usually difficult and expensive due to poor accessibility and the heterogeneous forest structure (Köhl 1996).

Many tropical forest studies using remote sensing are focused on deforestation. Tropical deforestation is typically studied over large areas using medium and low resolution satellite data, most commonly of the Landsat sensors MSS, TM and ETM+ (Skole & Tucker 1993, Sanchez-Azofeifa et al. 2002, Ichii et al. 2003). Deforestation studies are usually multitemporal studies where for a single date, often just the classes ‘forest’ and ‘non-forest’ are separated (Millington et al. 2003, Peralta & Mather 2000, Alves et al. 1999). Wang et al. (2003) refine these simple forest/non-forest classifications by trying to estimate the forest canopy cover fraction within Landsat pixels, Herrera et al. (2004) differentiate between forest, non-forest and trees outside forest, and Asner et al. (2003) differentiate between several land cover types in deforested areas, but they all treat the remaining forest as a single class. This is the case in many deforestation and tropical land cover classification studies, despite the large variety of tropical forest types.

Several authors have classified different successional stages of tropical forest regeneration (Thenkabail et al. 2004a, Kimes et al. 1999, Foody et al. 1996). Efforts to differentiate between different mature forest types are rare in comparison to forest/non-forest classifications. Tuomisto et al. (1994) and Paradella et al. (1994) used mainly visual interpretation of Landsat images to distinguish several tropical vegetation types. The statistical spectral separability of ecological forest types was studied by Singh (1987) using Landsat MSS data and by Hill & Foody (1994) and Foody & Hill (1996) using Landsat TM data. They came to the conclusion that between three and four groups of forest types were spectrally separable based on these multispectral data, but not all land cover classes which were identified in the field could be separated. Hill (1999) managed to classify six Amazonian forest types using segmented Landsat data. Riaza et al. (1998), García & Alvarez (1994) and Behera et al. (2001) also classified several tropical forest types on three different continents using medium resolution multispectral satellite data. Country-wide forest type and land cover mappings were conducted for Puerto Rico by Helmer et al. (2002) and for the Dominican Republic by Tolentino & Peña (1998) using Landsat TM and ancillary data, and for Mexico by Mas et al. (2002) using visual interpretations of Landsat ETM+ data. Low spatial resolution data (AVHRR) are used by Ferreira & Huete (2004) to monitor woodland, shrubland and grassland vegetation types in the Brazilian Cerrado.

Medium and low resolution optical satellite data are also used in the estimation of tropical forest biophysical characteristics like leaf area index (LAI) or biomass (Foody et al. 2003, Kalácska et al. 2004, Thenkabail et al. 2004a, Atkinson et al. 2000). Another application for these data is the mapping of burned areas resulting from tropical forest fires (Stibig et al. 2001, Fuller & Fulk 2001).

Newly available hyperspectral satellite data have not yet been used much in tropical forest applications (Thenkabail et al. 2004a), while there are a few examples for the application of the new high spatial resolution satellite data. IKONOS data have been used for the validation of products derived from lower resolution data (Wang et al. 2003, Morisette et al. 2003). They have also been tested for forest land use and land cover classifications as well as for the estimation of forest biomass and the detection of selective logging (Clark et al. 2004, Thenkabail et al. 2004a, Hurtt et al. 2003). High resolution remote sensing data is also needed to resolve the narrow mangrove fringes along tropical coastlines. Wang et al. (2004b) compare IKONOS and Quickbird images for mangrove mapping and achieve slightly better classification results with the IKONOS data. Davis & Jensen (1998) study the correlation between mangrove biophysical variables and airborne high resolution data. There are also examples of traditional aerial photograph interpretation for the mapping of tropical forests (e.g. Hudson 1991).

SAR data is often seen as a solution to the problem of frequent cloud cover in tropical areas which renders much of the optical satellite data unusable. However, the information about moisture and vegetation structure that is contained in radar data (Dobson et al. 1995) is not necessarily suitable for the separation of ecological forest types. Costa (2004) and Simard et al. (2000), using JERS-1 and Radarsat data, were successful mainly in separating different types of floodplain forest and aquatic vegetation in tropical river basins but did not map more than a single dense upland forest class. In addition, the classification of Simard et al. (2000) worked well only in the low topography region, while the terrain induced geometric and radiometric distortions in the radar data hampered the classification in a more mountainous area.

One of the challenges of tropical forest and land cover mapping is the discrimination of agroforestry (Hurtt et al. 2003). Agroforestry (main land use agriculture) is usually not included in the definition of forest (e.g. FAO 2001), but can look very similar from a remote sensing view point, with a more or less dense tree canopy and sometimes crops in the form of shrubs (e.g. coffee) below. Helmer et al. (2000) could not separate coffee cultivation from moist forest in Puerto Rico using Landsat TM data and ended up with a mixed class. Langford & Bell (1997) also find that their ‘coffee’ and ‘woodland’ classes are often confused. Hill (1999) managed to separate six different tropical forest types in segmented Landsat TM data but could not separate agricultural land containing trees from other open-canopied forest classes.

When forest is mapped it needs to be defined first. For the FAO's global forest resources assessment (FRA 2000), forest is defined as “lands of more than 0.5 hectares, with trees able to reach a minimum height of 5 meters maturity *in situ* and with a canopy cover of more than 10 percent, which are not primarily under agricultural or urban land use” while other wooded land