THE ROLE OF EARTH OBSERVATION IN THE GOOD PRACTICE GUIDANCE FOR REPORTING LAND USE, LAND-USE CHANGE AND FORESTRY ACTIVITIES AS SPECIFIED BY THE KYOTO PROTOCOL

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ABSTRACT

The Good Practice Guidance for Land Use, Land-Use Change and Forestry (GPG-LULUCF), published by the Intergovernmental Panel on Climate Change (IPCC), is laid out to assist countries in preparing their greenhouse gas inventories by providing definitions and methodological advice especially for the sector land use, land-use change and forestry. This paper gives a short review of GPG-LULUCF, presents how remote sensing is taken into consideration and briefly discusses the potential of three remote sensing techniques (MERIS, SAR and airborne laser scanning).

1. INTRODUCTION

The Kyoto-Protocol, which aims to combat the uncontrolled increase of atmospheric greenhouse gases (carbon dioxide, methane, nitrous oxide, etc.), allows for the accounting of biological sinks. A "sink" is defined as a process, activity or mechanism that removes a greenhouse gas from the atmosphere. An ecosystem represents a sink for carbon if its assimilation of carbon through photosynthesis exceeds its loss through respiration and disturbances (e.g. harvest). Correspondingly, a "source" is a process, activity or mechanism that releases carbon dioxide to the atmosphere. There are several articles in the Kyoto Protocol (Articles 3.3, 3.4, 6, 12 and 17) that deal with the so-called "land use, land-use change and forestry" (LULUCF) activities such as afforestation, reforestation, and deforestation and management practices, including "forest management", "cropland management", "grazing land management" and "revegetation".

The measurement of national carbon stocks below and aboveground is a challenging task and many countries do not have the financial resources to carry out national-scale inventories of carbon stocks in forests and soils. Even for smaller countries like Austria, where national forest inventories are carried out at regular intervals (every 5–10 years), the uncertainties are comparably high as a result of using uncertain conversion factors to convert forest inventory data into carbon stocks [1]. The concern is that the high uncertainties of the LULUCF sector veil the emission reductions to which the signatory countries of the Kyoto Protocol have committed themselves [2]. It is therefore important to fully utilize existing technologies and methods, and/or to develop new ones that may help to decrease the uncertainty of LULUCF reports.

Remote sensing has been identified as a potential technology to provide inputs (estimates of independent variables such as deforested or burnt areas, biomass, etc.) to carbon models, and as such to the Kyoto Protocol. However, it is not yet clear which role remote sensing will actually play for reporting and verifying LULUCF activities. In this paper we analyse how the role of remote sensing is seen in the *Good Practice Guidance for Land Use, Land-Use Change and Forestry* (GPG-LULUCF), which was adopted at the 21st plenary session of the Intergovernmental Panel on Climate Change (IPCC) held in Vienna, 3-7 November, 2003. GPG-LULUCF provides supplementary methods and good practice guidance for estimating, measuring, monitoring and reporting on carbon stock changes and greenhouse gas emissions from LULUCF activities. Since this report gives advice on which techniques should be employed, it is important that the remote sensing community is informed. Before discussing the

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GPG-LULUCF in section 4, basic data requirements of the Kyoto Protocol are reviewed in section 2 and recent development in remote sensing in section 3. In section 4 the contents of the GPG-LULUCF is shortly reviewed, followed by a discussion of three different remote sensing techniques in section 5. The conclusions are given in section 6.

2. KYOTO REQUIREMENTS

The basic data requirements are prescribed by the Kyoto Protocol text and in decisions taken at subsequent meetings of the Conference of the Parties (COP). A review of all relevant decisions up to COP 7 (Marrakesh) showed:

- For Article 3.3 "Afforestation, Reforestation, and Deforestation" the target quantity of interest is the change in forest carbon stocks between 2008 and 2012 due to direct human-induced afforestation, reforestation and deforestation activities. Not only carbon stocks of aboveground biomass need to be known (incl. litter and dead wood on the forest floor) but also the soil organic content. Initial quantities mentioned in the Kyoto Protocol and COP decisions are forest area, and for the purpose of the definition of forests, crown cover, stocking level and tree height. The accounting unit for forests shall be smaller than 0.05 - 1.0 ha.
- For Article 3.4 "Additional Human-Induced Activities" the target quantities are the changes in carbon stocks between 2008 and 2012 due to additional human-induced activities related to management of forests, crop land and grazing land. In addition to initial quantities already mentioned under Article 3.3, areas where such activities take place must be identified. Also, like for Article 3.3, the aim is to factor out not-direct human induced activities.
- Article 3.3 activities are eligible under Joint Implementation (Article 6) and Clean Development Mechanism (Article 12) projects; Article 3.4 activities only under Article 6. Target and initial quantities are required accordingly.
- The principal reporting unit is at country level.

Applied methodologies must be temporally consistent. Non-permanence, additionality, leakage, uncertainties, socio-economic and environmental impacts (including impacts on biodiversity and natural ecosystems) are further criteria particularly related to Article 12 that need to be taken into consideration from a measurement point of view.

The Kyoto Protocol exhibits a number of conditions that are difficult to meet. One problem is the separation of direct human-induced (or additional human-induced) changes in carbon stocks from changes in carbon stocks that are indirect human-induced, natural and/or took place prior to the reference year. Another problem is that definitions are based on land use rather than on land cover. For the correct identification of afforestation and reforestation land use needs to be known for 31 December 1989 and beyond 1990. Probably the most serious problem is that the Kyoto Protocol considers only a subset of carbon stores and fluxes. Steffen et al. [3] point out that only a full carbon budget, over sufficient time scales to reflect changes in long-term carbon-storage, is the appropriate basis for any accounting system for terrestrial carbon. Partial accounting systems, such as that described in the Kyoto Protocol, should be logical subsets of the whole-system approach.

3. REMOTE SENSING

From the beginning of the Kyoto-process remote sensing has been considered as an important technique, which may provide basic input data for inventorying and verifying carbon stores and fluxes. This has reinforced the need of developing robust remote sensing techniques for deriving land cover, land cover change and aboveground biomass. Rosenqvist et al. [4] review recent advances in remote sensing in light of Kyoto requirements and come to the conclusion:

> "While remote sensing technology stands alone in being able to provide regional-global scale data acquisition schemes and comparable datasets, it cannot yet be considered operational in more than a handful of applications relevant to the Kyoto Protocol."

In fact, there have been few studies that successfully used both remote sensing and *in-situ* data in a modelling framework. One such study was by Coomes et al. [5] who proposed a three step approach for monitoring national carbon stocks: (a) measuring the dimensions of trees, shrubs and coarse woody debris in a network of permanent plots; (b) converting the measurements into per-hectare carbon stocks using regression relationships; and (c) multiplying these carbon stocks by the spatial area of these vegetation types, obtained from high-resolution satellite imagery. In another study Schuck et al. [6] compiled a European forest map by calibrating a

1:6 million forest map derived from Advanced Very High Resolution Radiometer (AVHRR) data with national forest inventory data.

While these two examples suggest that satellite-based area estimates start to be used by the carbon modelling community, remote sensing techniques to more directly assess aboveground biomass are still perceived to be in their infancy [5]. The largest potential for biomass retrieval is held by two active remote sensing techniques, radar and lidar. Both sensor types emit short electromagnetic pulses and measure some properties of the backscattered echoes. Radars are operated in the microwave domain (generally in the range 1-10 GHz), lidars at infrared frequencies (0.8 - 1.5 μm). For example, Hyyppä and Inkinen [7] demonstrated in 1999 that airborne lidars can map forest parameters with an accuracy comparable or even superior to traditional ground based forest inventories. However, even though lidar technology has matured and large-area land inventories are now being carried out, the required knowledge and techniques to process lidar data for applications in forestry is not yet sufficiently developed for direct application by the forest industry [8].

In addition to the assessment of relatively static, structural parameters such as land cover or biomass, remote sensing is also capable of monitoring highly dynamic land surface parameters, such as soil moisture or the fraction of absorbed photosynthetically active radiation (fAPAR), albeit only at regional to global scales [9]. Given the Kyoto-Protocols emphasis at fine scales (0.05 - 1.0 ha) it is not straightforward to recognise the relevance of such data for meeting Kyoto Protocol requirements. Still, it is clear that these data are important for addressing science questions, e.g. to improve dynamic global vegetation models which are needed to quantify the impact of weather and climate variability on carbon fluxes [10]. Recently, a number or research projects have been initiated which investigate full carbon accounting methods based on the integration of remote sensing and ground observations in carbon models at various scales. For example, the on-going EU project SIBERIA II aims at demonstrating the viability of full carbon accounting over a 3 million km^2 large region in central Siberia at a scale of 1:1 million. It considers a wide variety of remote sensing data sets such as land cover, fire scars, wetlands, vegetation phenology, freeze/thawing cycles, snow, etc. at different spatial and temporal scales [11].

4. GOOD PRACTICE GUIDANCE FOR LAND USE, LAND-USE CHANGE AND FORESTRY

In order to give professional advice for Parties establishing their greenhouse gas inventories, the IPCC published in the year 2000 its Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories, which, however, did not cover the LULUCF sector [12]. As discussions about LULUCF gained more and more weight in on-going negotiations, the IPCC completed its suite of reports and published the GPG-LULUCF [13]. Following the advantages of transparency, consistency and accuracy, the GPG-LULUCF can be regarded as an extensive set of instructions for signatory parties, ranging from guidance on choice of methodologies, sampling design, estimation of greenhouse gas changes, reporting techniques, quality checks and supplementary specific recommendations.

When talking about the sector land use change it is obvious to utilize a specific sort of categorization; GPG-LULUCF therefore presents six broad land use categories for greenhouse gas inventory reporting (forest land, cropland, grassland, wetlands, settlement, and other land) which can be regarded as top-level categories for representing land areas within a country. These categories are '*…broad enough to classify all land areas in most countries…*' and furthermore '*…reasonably mappable by remote sensing methods […]*'. It must be stated that countries are granted to use their own definitions of these categories (in the style of FAO, Ramsar etc.), which might lead to the problem of incomparability of individual national inventories. The six categories are further subdivided by activity data (land area, management regime, lime and fertilizer use etc.), climatic zone and ecosystem type. The generic guidance then is to multiply these category-data by carbon stock coefficients or "emission factors" to provide the source/sink estimates.

It is the main intention of GPG-LULUCF that estimates of carbon stock changes, emissions and removals by sinks are *bona fide estimates*, reducing the uncertainties as far as practicable and considering national circumstances. Therefore, a hierarchical system of three tiers is introduced, which ranges from spatially coarse activity data and default emission factors (Tier 1), country-defined activity data and emission factors (Tier 2) to data being highly appropriate for national circumstances with the consideration of climate dependencies, soil dynamics and validation routines (Tier 3). Utilized properly, the application of these tier methods allows a step-by-step reduction of uncertainties and, in return, an increase of accuracy. All countries should strive for improving inventory and reporting approaches by advancing to the highest tier possible given national circumstances. For the final reporting, consistent terminology has to be followed: emissions are always denoted positive (+) and removals negative (-), and are reported in gigagrams (Gg) using specific reporting tables.

A variety of remote sensing approaches is merely introduced casually, giving a basic overview of remote sensing for data collection (types of data, criteria for selecting data, availability and ground reference) and presenting a number of international datasets for cross-checking land-use categories (e.g. the Global Land Cover Dataset or the CORINE land cover database) including some examples for illustration.

Special attention to remote sensing is paid when it comes to the field of verification, even stating that '*…remote sensing is the most suitable method for the verification of land areas…*'. Five different verification approaches are compared according to their applicability. Remote sensing holds strong potential to verify land-cover/land-use attribution as well as the detection of land-cover change. Furthermore, remote sensing appears suitable for estimating aboveground biomass, but only if ground data are provided. Nevertheless, certain drawbacks are mentioned concomitantly: remote sensing is identified as not applicable to the verification of belowground biomass, litter, dead wood or soil organic matter. When using remote sensing as tool to verify land use and land-use changes it has also to be remarked that techniques are capable of detecting changes in land-cover (e.g. from forest to non-forest), but possibly inaccurate information on changes in land use (e.g. from crop A to crop B). The GPG-LULUCF suggests here a combination of frequent observation (with moderate spatial resolution platforms) assisted by detailed punctual observation (with high-resolution sensors). The possibilities for remote sensing to verify changes in living biomass are described in the provision of vegetation indices (e.g. NDVI) or by using correlation equations where biomass can be estimated using image data.

5. DISCUSSION

The non-committal discussion of different remote sensing techniques in the GPG-LULUCF (examples are given for Synthetic Aperture Radar, airborne photography, optical sensor systems, and laser profiler) does not allow to draw firm conclusions about which techniques should be pursued with priority. Therefore, it is still up to the remote sensing community to demonstrate the usefulness of remote sensing for verifying changes in living biomass or to improve existing terrestrial carbon cycle models, together with the integration of ground truth data through Geographic Information Systems (GIS).

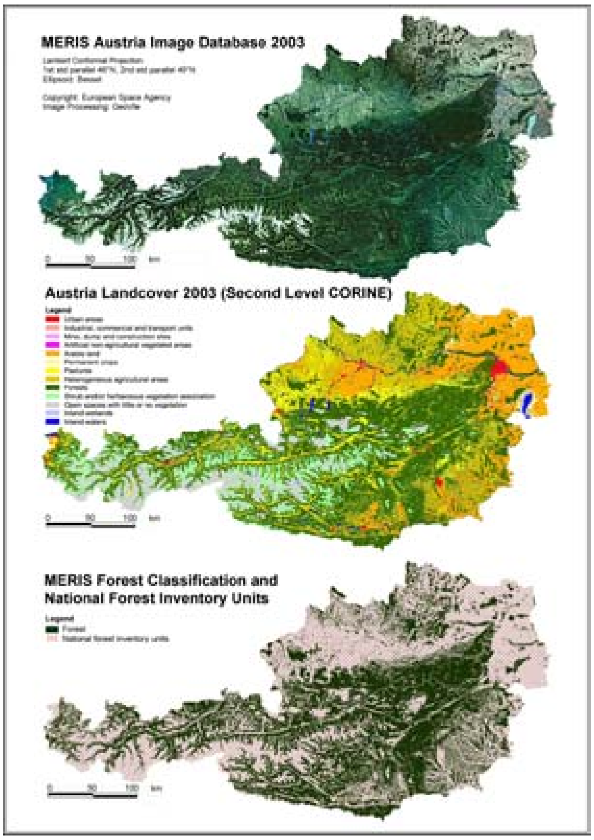

Fig. 1. Nation-wide land cover classification using ENVISAT-MERIS data to derive second-level CORINE and forest maps. MERIS image mosaic and maps were produced by GeoVille.

Serving as one demonstration of remote sensing capabilities for the LULUCF sector is the on-going project NEOS-QUICK, which examines the potential of remote sensing as a verification tool for LULUCF reporting based on a multi-sensor approach, integrating GIS and ground observations (see www.geoville.com/

neos/home.html). The project focuses on satellite imaging systems such as SPOT and ENVISAT Advanced Synthetic Aperture Radar (ASAR), but also considers airborne systems (airborne imaging, airborne laser scanning) and medium resolution satellite monitoring systems (e.g. ENVISAT-MERIS).

As Schuck et al. [6] have demonstrated for the case of AVHRR, medium resolution optical satellite systems can be used to produce regional to global scale land cover maps. These sensors do not meet the spatial resolution requirements as specified by the Kyoto Protocol, but allow yearly updating at low costs. Possibly, such information would be useful to identify “hot spot” areas experiencing rapid changes e.g. caused by large-scale forest fires or wind throw. More technically advanced sensor systems such as MERIS (Fig. 1) would certainly be useful for improving on the quality of the forest cover maps derived from AVHRR. The relevance of such information for individual country reports is not obvious, at least for small countries like Austria. However, for large country surveys (Russia, Canada, Australia, etc.) and regional to global scale country-to-country intercomparisons there are no alternative data sources which meet the same standards everywhere.

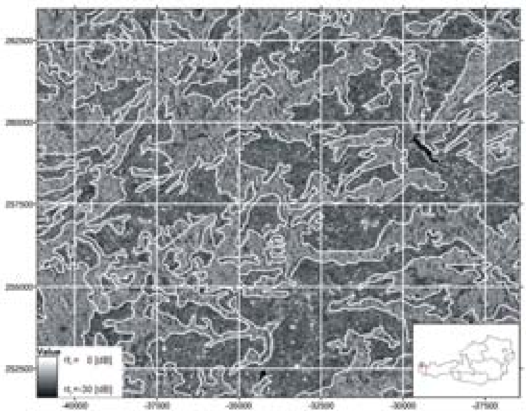

Fig. 2. ENVISAT-ASAR Alternate Polarization backscatter image overlaid with forest polygons from the CORINE land cover data, level 2 (Federal Environment Agency, Vienna, Austria). Coordinates are in Gauß-Krüger (reference meridian M28). The radiometric normalised image shows the northern part of the federal state of Vorarlberg, Austria.

Forest maps at scales 1:100,000 to 1:250,000 are commonly generated from optical satellite imagery (Landsat, SPOT). Also Synthetic Aperture Radars (SARs) have been considered due to their all-weather and day and night capabilities (important for tropical rainforest and boreal forest) and large penetration depth into the vegetation compared to optical systems. Particularly long-wavelength polarimetric SAR (P- and L-band) systems and SAR interferometry are considered to hold potential for aboveground biomass estimation. For example, Wagner et al. [14] demonstrated that ERS-1/2 interferometric data, combined with L-band SAR data from the satellite JERS-1, could be used for distinguishing low stem volume classes (up to 80 m^3/ha) for a 1 million km^2 large region in Siberia. Another example is presented in Fig. 2, which shows an ENVISAT-ASAR Alternate Polarization image (25 m spatial resolution) which allows distinguishing forest from non-forested areas reasonably well. However, even though SAR images can be obtained under any weather conditions, this does not mean that SAR data are weather independent. In fact, variable soil moisture conditions and other environmental effects have a large impact on the appearance of SAR images, which means that while one SAR image may turn out to be quite useful for forest mapping, the next SAR image of the same area may be of poor quality. Another problem are topographic distortions of SAR images. Currently, there are no robust methods for correcting SAR data in hilly to alpine terrain. This is a major limitation for the usefulness of SAR for forestry applications in Austria, simply because most of Austrian forests is situated in such difficult topography.

Airborne photography has long been used for forest inventory purposes. Recently, the technique of airborne laser scanning (ALS) has received growing attention [8]. This technique is capable of gathering information about the vertical height distribution of vegetation. As measurements densities of more than 10 points per m^2 can be achieved, the estimation of forest attributes is possible with high accuracies. For instance, the canopy height can be directly retrieved from a normalised difference surface model (nDSM) calculated from ALS data. Fig. 3 shows an example of nDSM data covering an alpine area in the south of the federal state of Vorarlberg, Austria. As the figure shows, not only the vertical information of the forest, but also the horizontal dimension of the wooded areas can be extracted. For the precise modelling of aboveground biomass, additionally to the canopy height, a detailed forest classification is required, which could e.g. be derived from high-resolution imagery. In the on-going project NEOS-

QUICK ALS data are used to study and validate SAR data. Amongst all systems, ALS in combination with high-resolution multi-spectral imaging data holds currently the largest potential for meeting Kyoto-Protocol data requirements. However, for national inventories, data standards and the costs issues need to be addressed.

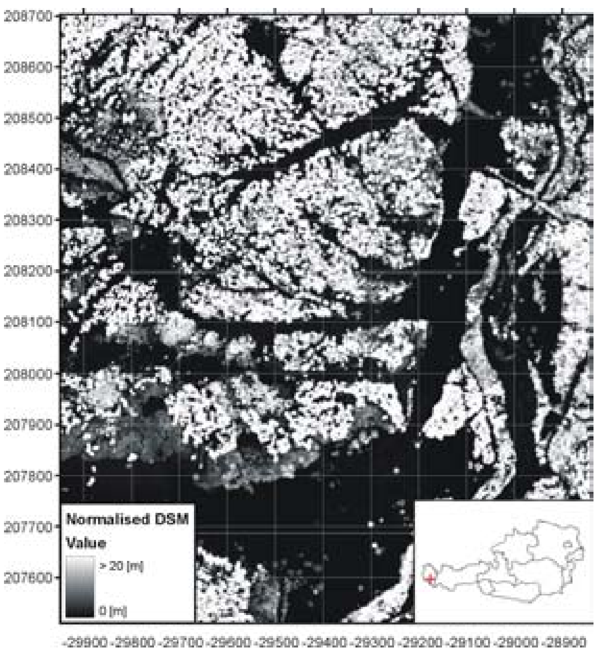

Fig. 3. Normalised difference surface model (nDSM) calculated from first/last-pulse ALS data. Coordinates are in Gauß-Krüger (reference meridian M28). Data are courtesy of the Landesvermessungsamt Feldkirch.

6. CONCLUSIONS

The GPG-LULUCF gives a good overview of main principles and procedures of all major inventorying topics concerning the wide range from definition of estimation, quality control to reporting processes. GPG-LULUCF repeatedly points out the significant potential of remote sensing to help parties to fulfil their inventory requirements, but further information on the concrete application of remote sensing technologies is left desirable. Besides, the standards presented in the GPG-LULUCF give rise to concern, as they do not give concrete incentives for improving reporting techniques in case individual countries do not have the motivation to do so. In fact, if not used for reporting, remote sensing data may be used as an independent source of information to check the plausibility of LULUCF reports.

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