Modelling forest eco-system services with multi-sensoral data

Modelagem de funções do ecossitema florestal com dados mutisensoriais

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Abstract

This paper presents the potential of remote sensing data for modeling different forest eco-system services. In future the estimation of forest ecosystem services will become more and more important for the management of forests. Dependent on the management objectives alternatives for different decisions are possible. With the support of remote sensing an information basis can be provided as input for a decision support system in which different scenario can be tested before the operations taking place. The potential to model is high using different remote sensing data. The advantages and short comings are discussed and examples are presented which demonstrate different applications.

Key words: remote sensing; florest; model.

Resumo

Este artigo apresenta o potencial dos dados de sensoriamento remoto na modelagem de diferentes funções do ecossitema florestal. No futuro a estimativa das funções do ecossistema florestal se tornará cada vez mais importante para o manejo das florestas. Dependendo do objetivo do manejo alternativas para distintas decisões são possíveis. Com o apoio do sensoriamento remoto uma base de informação pode ser fornecida como entrada para um sistema de suporte de decisão no qual diferentes cenários podem ser testados antés das operações ocorrerem.O potencial de modelagem é alto usando diferentes dados de sensoriamento remoto. As vantagens e desvantagens são discutidas e exemplos apresentados que demostram diferentes aplicações.

Palavras-chave: sensoriamente remoto; floresta; modelo.

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Recebido para publicação em 22/06/2012 e aceito em 11/09/2012

DOI:10.5777/ambiencia.2012.04.01nt

Introduction

Forests fulfill many functions and as such have complex inter-relationships with other ecosystem services. Forests are central to the economies of the local communities as well as large enterprises, yet they also play an important role beyond, as they provide extended region with water storage, nutrients, prevention of landslides and also trade such as timber or herbs. Therefore the management of forest has to take into consideration the full range of ecosystem services to make the best balanced decision. Regato and Salman (2008) identify four basic services (Table 1) which apply to forest ecosystems – each of which has forestry as main component and which in turn interacts with other services.

Table 1. List of forest ecosystem services as defined by Regato and Salman, 2008

Forest ecosystem services			
Provisioning Services	**Regulating Services**	**Cultural Services**	**Supporting Services**
freshwater fresh air timber food	climate water, air, erosion and natural hazard regulation carbon sequestration	recreation/tourism aesthetic values cultural and spiritual heritage	ecosystem functions including energy and material flow water and nutrient cycling soil accumulation provision of habitats

In regard to this competing multifunctional service character of forests a new methodological base for decision making in forest resource management is needed. This methodology needs to be supported by technologies to represent knowledge for multi-criteria decision-making. The knowledge needed on forest, land cover and landform requests a three-dimensional modeling of forest areas. Only a multi-sensoral use of remote sensing data can provide this three-dimensional information of forest land to describe different ecosystem services and their relevance as needed for multi-criteria decision systems in order to support a management which respects all ecosystem services of forests.

Gaps and Needs for the Assessment of Ecosystem Services

Today, forest mapping techniques employed by different user communities rely mainly on ground-based surveys or two dimensional remote sensing data (satellite data). This information often provides poor quality and for the modeling and valuation of forest ecosystem services in many cases three-dimensional input data are needed. For example, most of the available ground based information is not or poorly geo-referenced and therefore has limited use for detailed regional planning. Nearly all remote sensing information used in inventories is two-dimensional. Advanced remote sensing technologies allow the build-up of three-dimensional data base which can serve best for the modeling of a variety of forest eco-services. The following highlights some forest eco-system services and the connected information needs from remote sensing.

Especially the measurement of landform is highly important for input to the forest eco-service models. Topography can be a limiting factor for activities such as timber extraction and tourism but can also indicate certain habitat structures. In timber extraction the terrain has an impact on operational harvesting, wood transportation and forest road construction. In forest planning, the landform information impacts silvicultural decisions on the choice of planting and type of species, for example. Leisure/tourism planning requires information for instance, on steepness, aspect and sun hours per day. Habitat modeling and nature conservation both require information on the terrain and the surface of the vegetation (like height distribution in stands) to determine the natural conditions and quality of potential biotopes and plan the necessary strategies to further develop, connect and protect such areas (KOCH; IVITS, 2010). Finally, slope and aspect are important factors for the assessment of risk areas in terms of natural hazards.

One main challenge is the sustainable and adapted use of wood resources. For this more about the quantity and quality of wood in the forest needs to be known. New remote sensing technologies and processing tools for three-dimensional information allow to provide a more accurate and up-to-date measurement, but also the modeling of forest parameters, of wood quantity and quality, which was not possible in the past. At the same time, information processing is becoming less time consuming and more affordable and so this information can be integrated into harvesting planning.

It is difficult to survey and sample non-wood forest products (NWFP), but in order to derive benefit from NWFP in a sustainable manner, an inventory on the amount, spatial distribution and potential areas is needed and the information on NWFP must be integrated into a decision support system. With models and tools for information extraction based on remote sensing, high quality knowledge on habitat and terrain can be established, which provides means indirectly to assess information on NWFP.

Currently a lack of a methodology for measuring the value of carbon exists. Even though there are number of projects approaching this problem a clear method compendium is not established. A three-dimensional approach can support a methodology towards monitoring and modeling of carbon pools.

The new data sources which became available in remote sensing (RS) permitted the derivation of substantially improved information to enable the assessment of protective functions of forests. Therefore, even existing concepts of protection (e.g. effects of forests on rock fall and snow avalanches) can now be improved with remote sensing information (BERGER, 2004). With regard to the integration of further hazardous processes (e.g. landslides and debris flows), however additional indicators still have to be evaluated and new concepts have to be developed (GRANICA et al., 2006). In this context one of the main challenges still is the task of combining field data with innovative remote sensing data.

Forests are a key repository for biological diversity. They provide ideal habitats for many species of flora and fauna – particularly some rare mammals and birds. The sensitivity, rarity and possible reduced regeneration means that forest areas require special consideration. Investigations on high resolution satellite data (NUSKE et al., 2007), aerial photography and airborne laser show that remote sensing can support the monitoring of biodiversity and biodiversity changes providing structural and species information. Especially structural information can be extracted to a degree which is not possible without remote sensing. This becomes especially obvious while using laser scanner data. The main problem is to find the link-up between structural information and biodiversity parameters.

Tourism and recreation are often key economic features for forested regions, in terms of employment and investment in infrastructure. The development and management of tourism and recreation needs careful forest management planning to maintain the natural conditions. The information from remote sensing data can be a basis for powerful scenario development because high quality information on the landform, infrastructure and land cover with more detailed information on forest types can be delivered.

Algorithms already exist for the extraction of three-dimensional data from remote sensing, however the challenges faced are still manifold. Different data sources (maps, in-situ measurements, digital elevation models) as well as different types of remote sensing data (Airborne Laser Scanning data, aerial images, optical satellite and Synthetic Aperture Radar (SAR) data need to be integrated. Methods and models need to be transformed from an experimental stage to pre-operational stage for running operational services. IT architecture around web-services built with standard components (mySQL data base, Javascript, HTML, CSS and PHP) is needed to make the information easily useable.

The Contribution From Remote Sensing as Basis for the Modelling of Forest Ecosystem Services

New Inventory Technologies

Almost all decisions made in managing the forests refer to a specific location and time. This is why reliable geo-referenced, multi-temporal data is so important for successful and sustainable planning and management. Very High Resolution (VHR) satellite imagery and airborne laser scanner data are two examples which allow the derivation of substantially improved quality of information. However the real advances in remote sensing providing better information basis for forest eco-systems service modeling is the increasing availability of 3-D data. This is combined with the existent of algorithms to analyse those data and the increased computer capacity to process these data. These new products have the potential to improve significantly the assessment of terrain, landcover and forest parameters all needed to model forest eco-system services (Figure 1 and 2).

Besides the automatic extraction of information from different remote sensing data to access this information on different levels of resolution the combination of information from terrestrial data with airborne or space borne remote sensing data (Figure 3) will become an essential to build fully informed models for forest eco-system services.

Forest Parameter Modeling

Forest parameters (e.g. location, height, diameter, volume etc) can be extracted through models supplied with data from various sources, such as existing geographic data and terrestrial data. The advanced 3-D modeling of forest parameters has hardly been carried out to date. Consequently, there is a need to further enhance the models/ algorithms for forest conditions (Figure 4). Distributed processing of the models will be possible by requesting the data from the appropriate sources of the planning problem. Standards are important here to provide easy inter-operability. Another progress beyond

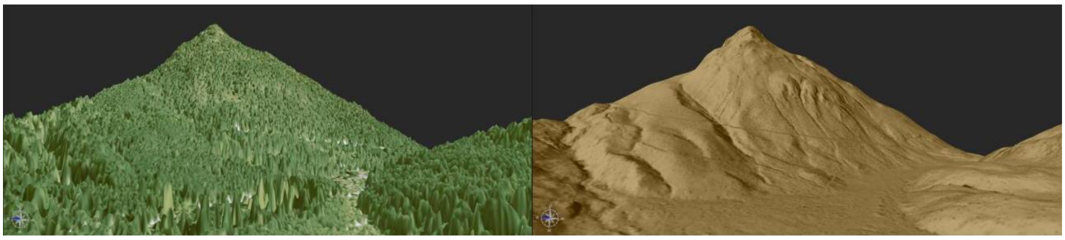

Figure 1. Digital surface and digital terrain model extracted from airborne 3D laser point cloud

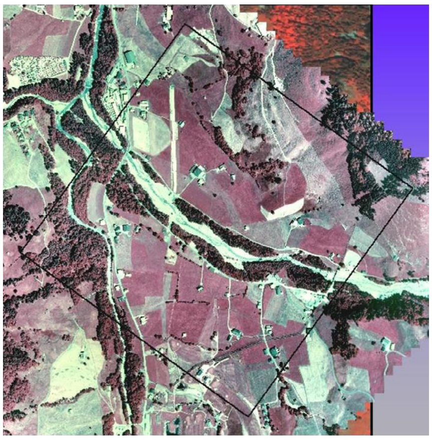

Figure 2. Very high resolution (0.6m) satellite data

Figure 3. Matched data from terrestrial and aerial laser measurements

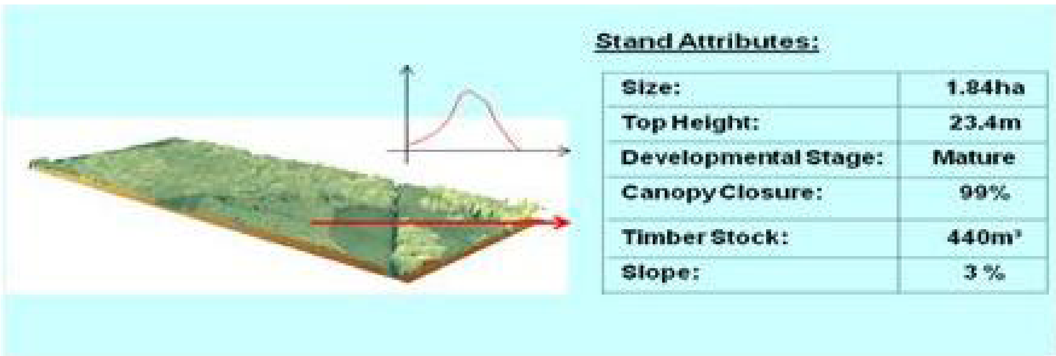

Figure 4. Modeling of forest parameter from remote sensing and terrestrial sample data

the state of the art in forest modeling is the implementation of different regional forest growth models.

Transferring Forest Parameters Into Ecosystem Service Parameters

The basic forest parameters, such as stem numbers, tree types, etc. have to be transferred into meaningful ecosystem service parameters. For each of the considered forest functions (wood products, non-wood products, protection against natural hazards, biodiversity, tourism and recreation, climate change and carbon), transfer functions have to be developed. For wood products, this is relatively easy, since timber volume is a commonly derived parameter. However, for many of the other functions, this transfer is a challenging task. It has to be decided, which forest parameters best describe specific forest functions. To further complicate the task, the local conditions have a strong influence on these transfer functions. Thus, first, it has to be generally assessed, which forest parameters are needed for each of the forest functions and then, for each demonstration site, the transfer functions need to be adjusted. As an example for the hazard protective function, tree species and crown coverage are the main forest parameters needed to model shallow landslide susceptibility. In Austrian alpine sites for example, the tree type 'spruce' has a low effectiveness in preventing shallow landslides, while 'larch' has a high stabilising function, due to its different root system.

Web-services Based Services for Modeling Ecosystem Services

For the modeling of forest ecosystem services based on remote sensing products IT architecture is needed which allows organizations and users based on applications of XML, to interchange, share and publish information much more effectively. For integrated environmental assessment like it is needed for the modeling of forest ecosystem services often data from several sources need to be brought together. Information on where to locate such data and how to understand them correctly must be available. In technology terms through the availability of an electronic infrastructure (the world wide web) distributed responsibilities are allowed and at the same time this eases the integration of different web-services through a common technical language (XML). To assure interoperability, simple HTTP and SOAP protocols can be used for communication. Today such systems can be deployed by the use of "Cloud Computing" facilities. This allows also to scale up, as provisioning of services becomes greater. This also releases the need having the host system dedicated to one place. It therefore enables collaboration and community computing for easier and faster information sharing. The facilities will be available all the time, be upgraded, have security imposed and so relieves the obligation on the hosting partner. The responsibility is reduces to the software, but no longer the hardware, security or operating systems.

This architecture allows to process remote sensing data and auxiliary geo-data over the Internet i.e. the required geo-information can be processed remotely on distributed servers. This service oriented architecture (SOA) is accessible to the user with an interface providing all functionality on the web without the need of investments in further software.

This has to be combined with an easy to understand user interface configurable for different stakeholders namely by their location and services they have access to. It should be an interactive interface so that the user can easily identify the location and extend of different forest ecosystem services. A very important means of conveying decision supporting scenarios to the end-user is the visualisation of the a) the Status-quo and b) the impact of the projected scenario on land use and landscape as well as on the community and its businesses itself. An advantage of the aforementioned OGC web services (like the Web Map Service) is their ease of integration into existing GIS solutions as well as their usage for 3D-visualisations. 3D globes like Google® Earth and NASA's worldwind provide programming frameworks (so called APIs – application programming interfaces) that allow one to overlay high resolution imagery over satellite imagery and/or thematic layers. FELIS is using this technology already in the "geo-wiki" (http://www.geo-wiki.org) (Figure 5), funded within the FP7-project EuroGEOSS and formerly in the FP6 funded project GeoBENE. Today Geo-wiki aims at engaging the broad public in validating global landcover datasets like GlobCover, MODIS and GLC2000 what is commonly referred to as "Crowd Sourcing" (FRITZ et al., 2009). However this can be easily enlarged by other mapping services and scenario development software.

information of forest parameters which are needed to model forest ecosystem services. This is especially true if different remote sensing types are used to cover a large range of scale levels and information needs. The increasing availability of 3-D remote sensing data supports decisively processing of information needed as input for forest ecosystem services. In addition the link between space-borne, airborne and terrestrial data sets has to be further developed to have a broad information bases as requested for the modeling of forest ecosystems services. However the information which can be provided based on remote sensing data will only have a strong impact the information is easily useable for manager to support them in their daily operational decisions. For this system architectures and web-services are needed which allow accessibility and interactivity through internet at their places including mobile devices. Only with the provision of the services in a user friendly way the full benefit of remote sensing information for modeling forest ecosystem services as basis for better decision making will be achieved.

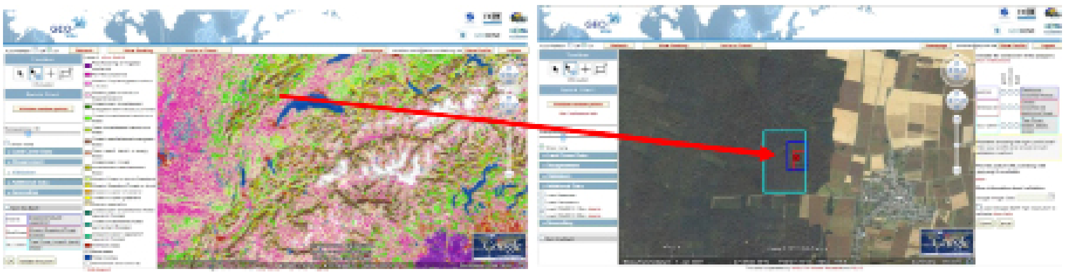

Figure 5. Geo-wiki with Google Earth imagery and a land-cover overlay (GlobCover left) Geo-wiki validation process (crowd sourcing approach to Landcover validation right)

Final Considerations

The assessment of forest ecosystem services is of increasing importance for a sustainable management of forests. Based on the existing inventory data only a very patchy valuation of forest ecosystem services is possible. This is due to either large data gaps or outdated information sets. Remote sensing can decisively improve the situation by providing area wide

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