GEOSS POSSIBILITIES AND CHALLENGES RELATED TO NATION WIDE FOREST MONITORING

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ABSTRACT:

The Global Earth Observation System of Systems (GEOSS) is structured into nine societal benefit areas, which all will require information related to the forest cover. Utilisation of methods that combine satellite remote sensing and *in-situ* observations are the focus of GEOSS. The best way to feed forest information into GEOSS is most likely from the national level. In Sweden and Finland, nationwide raster based estimates of forest resources are already being made operationally by combining Landsat / SPOT type of satellite images with National Forest Inventory (NFI) sample plots. Another example of combined use of image data and local observations is that the Swedish forest administration yearly maps all new clear felled areas (about 50 000 in total), using multitemporal satellite data. The image analysis work done by the district foresters in 60 forest districts. Detected fellings are compared with cutting permits and verified in field if needed. A similar routine could also be used for Kyoto reporting of deforestation areas. The coordination of observation systems that will be achieved trough GEOSS is essential also for the continuation of these national level inventories. Satellite systems have global capacity, but each nation that relies on satellite systems for their operational monitoring would benefit from long-term coordination plans between nations that ensure a redundant capacity of future remote sensing satellites. Nations could also supply GEOSS with field plot information. This opportunity would motivate an increased harmonisation of the field observations made for example among the NFI's.

1. INTRODUCTION

The Group of Earth Observation (GEO) is an international partnership which aims to build a Global Earth Observation System of Systems (GEOSS). GEO was established in 2005 after a 1.5 year ad-hoc period. At present are 62 nations, the European Union, and 43 international organisations participating in the partnership. More information about GEO can be found on: http://www.earthobservations.org/. Important documents are the 10 Year Implementation Plan; the 10 Year Plan Reference document; and the GEO 2006 Work Plan.

The aim of this paper is to illustrate how forest monitoring systems on the national level, which use a combination of in-situ and satellite remote sensing data, will need the coordination of observations that hopefully will emerge trough GEOSS and also how such national systems will be potential sources of data for GEOSS.

2. FORESTS MONITORING NEEDS IN GEOSS

GEOSS is initially structured into nine societal benefit areas (Table 1). Although forestry as such is considered a part of the Agriculture area, Table 1 shows observations related to forests are need in all the nine areas.

	GEO Societal benefit area								
	Disasters	Human health	Energy	Climate	Water	Weather	Ecosystems	Agriculture	Biodiversity
Land cover/Vegetation type		X	X	X	X		X	X	X
Vegetation height/structure					X		X		X
Biomass				X			X	X	
Carbon				X					
FAPAR				X					
Leaf Area Index				X		X	X		
Fuel characteristics	X							X	
Change related variables:									
Fellings or Deforestation	X						X	X	
Fire disturbance				X			X		

Table 1. Observational requirements related to forests, for each of the nine GEOSS societal benefit areas, compiled from GEO 10 Year plan Reference Document.

Among the outcomes of GEOSS are "multi system information capabilities" envisioned for, among other things, sustainable land use and management; plus biodiversity conservation. Also the improved availability of information from *in situ* networks and the integration of *in situ* data and satellite data are mentioned as intended outcomes of GEOSS.

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Systems for observation of the terrestrial environment are however generally less developed towards common global systems than systems for observation of the ocean and atmosphere (GCOS, 2004). Among the reasons are that terrestrial monitoring is mostly carried out at national level, by several different authorities and with limited coordination among the nations.

GEOSS is primarily focused on observations of Earth System Processes which encompass larger areas than individual countries. Thus, there is a need for more harmonised and regular terrestrial observations

More local observations may be addressed through GEOSS if they have global scale consequences or global scale causes or if their observation is enhanced by global systems (GEOSS 10-year implementation plan Reference Document). These prerequisites could be argued to be true for mapping of forests on national level. Furthermore, information about forests to be used at the international level is best captured by the nations themselves, which have access to the necessary field observations and GIS data. The nationally collected information can then be forwarded to the international level. This procedure is for example favoured by the FAO Forest Resource Assessment (FRA, 2003).

3. COMBINING SATELLITE DATA AND NATIONAL FOREST INVENTORIES

The combined and operational use of National Forest Inventory sample plots and Landsat-type satellite data for improving the outcome from National Forest Inventories was pioneered in Finland (Tomppo, 1991). Using the kNN-method, wall-to-wall forest cover maps were obtained, as well as the possibility to produce statistics for much smaller areas (McRoberts and Tomppo, 2006). Such Nationwide forest data bases have also been tested in many other countries, such as the USA (McRoberts et al., 2002a). Even if the procedure works well, is should be observed that the results are not sufficient for forest management planning on stand level, especially in mountainous countries like Norway (Gjertsen, 2005) or Austria (Koukal, 2005). However the up-to-date databases obtained in this way are often the only overviews of all the forest resources that are available. They are therefore much appreciated by authorities and researchers.

Landsat-type of satellite data are well suited for the above application for a number of reasons:

- the pixels are large enough to represent “many trees per pixel” mean values which could easily be analysed and compared to field plot information, using empirical statistical methods;
- the pixels are small enough to enable a “many pixels per stand” imaging situation;
- the satellite scenes are large enough to cover many national forest inventory field plots;
- the SWIR band which is well correlated with tree size is included.

3.1 Combining National Forest Inventory plots and satellite image data in Sweden

3.1.1 The NFI plots

The Swedish National Forest Inventory (NFI) design is based on an annual systematic sample of field plots across Sweden (Ranneby et al., 1987, Ståhl 2004). On each plot are about 200 different variables measured. The aim is to allow reliable summary statistics for each of Sweden’s 21 counties, or parts of them, using 5 year averages of field plot data. Plots are located in square shaped clusters that consist of either 6 or 12 temporary plots of 7 m radius or 8 permanent plots of 10 m radius. In total, about 5300 permanent and 3500 temporary plots are inventoried across Sweden every year. Permanent plots are re-inventoried every 5-10 years. The plots have been GPS-positioned since 1996, which further enables their use in combination with satellite imagery.

3.1.2 The Munin Production Line

An automated production line has been developed for combining NFI plot data with Landsat satellite data. In a first step, the NFI plots are used for preprocessing of the satellite data. The local geometrical errors between the satellite data and each field plot are modelled and the most likely pixel values given this modelling are selected (Hagner and Reese 2006). Furthermore, the correspondence between NFI plot data and the image data is also used for parameterization of a slope correction and for reducing haze differences within the individual satellite scenes (Hagner and Olsson 2004).

The first use of the Munin production line was for a nationwide classification of forest land into seven different forest classes. This work was done by SLU during 2002 - 2003 under contract with the Swedish National Land Survey and it was used as input to national and European land cover databases. In total 50 Landsat ETM+ scenes and 34000 NFI plots were used. The forest classification was based on “calibrated” maximum likelihood algorithm which made use of prior probabilities derived from the NFI plot statistics. The classification of each Landsat scene was iterated until the frequency for each forest class corresponded to the frequency according to the NFI plots within the scene (Hagner and Reese 2006).

In addition to NFI field plot data, and satellite data, there is also a need for digital map masks which define the forest covered areas to constrain the estimation procedure. Such masks are unfortunately so far seldom constructed with the same definitions of forest land used in forestry and they are not yet harmonised between countries.

3.1.3 The kNN Product

The Landsat ETM+ images and the NFI plots used for the previously mentioned land cover classification were also used to produce a nationwide forest parameter database using a version of the Finnish kNN method, (Reese et al. 2003). The first “kNN Sweden” database was produced with images from around the year 2000, and is available as a raster product with estimates of total stem volume, stem volume for different tree species, stand age, and mean tree height for each pixel. Estimates were made for all pixels defined as forest land according to the 1:100 000 topographic map. With the MUNIN production line, generating such a database for all forest land in Sweden takes about one man-year including all data handling and quality checking.

While the pixel- and stand-level accuracy for the kNN product can be quite poor, the accuracy for aggregated areas is still acceptable for many applications. Typically, the estimation accuracy (relative RMSE of field measured mean) for stem volume is on the order of 60% at pixel level, 40% at stand level, and 15% when aggregated over a 100 ha area (Fazakas *et al.* 1999, Reese *et al.* 2002, Reese *et al.* 2003

The kNN database has been used by forest authorities, environmental authorities and the tax agency in order to obtain an overview of forest resources for large areas. It is also used in many research projects, such as species habitat modelling; as a baseline for landscape scenarios, and together with change images also for analysis of storm damaged areas. During 2006, a new version of the nation-wide kNN database, using SPOT images from the summer of 2005 is being produced.

3.1.4 Post-stratified NFI estimates

Post-stratification of NFI plots using satellite images is a robust method to derive improved forest statistics that has been applied in the USA (Mc Roberts et al., 2002b) A similar procedure is presently being introduced as an operational routine in the Swedish NFI (Nilsson et al. 2006). Tests in Sweden show that the standard errors for estimates of total stem volume, stem volume for pine, spruce, and deciduous trees, as well as tree biomass can be reduced by 10% - 30% on a county level by using post-stratification based on Landsat ETM+ products compared to using field data alone for the estimation (Nilsson et al. 2003; Nilsson et al. 2006). Post-stratification has proven to be a straightforward and efficient method for combining satellite data and NFI data. Most problems that might lead to biased estimates are avoided, which might not be the case using other methods.

4. MAPPING OF FINAL FELLINGS

Clear felling of forest can effectively be monitored using multitemporal satellite data. The key is to have an operational routine with data supply and preferably local analysis of the data. Below, it is described how such a system has been implemented in Sweden.

4.1 Mapping of Final Fellings made by the Swedish Forest Agency

The current system of clear-cut monitoring in Sweden is based upon the use of data from satellites like SPOT or Landsat. Satellite data covering the entire country are used on an annual basis since 1999 to follow-up all cutting activities in Sweden by change detection. This routine is an integrated part of the regeneration system where all final cuttings in Sweden are handled and monitored according to the forest legislation. By knowing *where*, *when* and the *size and shape* of the cuttings, better and more effective regeneration follow-up activities can be performed by the Forest Agency.

The image change detection and all the regeneration follow-up activities are performed by the Agency's local forest staff. Cutting permits have been digitised in a GIS and are compared with clearfelled areas which are identified by a tailor made PC-based image processing software called ENFORMA developed by METRIA.

However, even though the system of using satellite data is a complete success story, the lack of data is threatening the continuation of the clear-cut monitoring system. A short vegetation period (about 3-5 months), and a normal weather situation with a lot of clouds narrows the time frame in which suitable images are available. It takes approximately 6000-7000 attempts to get around 220 useful SPOT scenes annually!

4.2 Follow on products from the yearly data set acquired by the Swedish Forest Agency

The yearly image supply of satellite data has opened several doors for new application at the Swedish Forest Agency. For instance, by using a vegetation index it is possible for the Agency to detect those areas in the forests that have a need for pre-commercial thinning of mostly deciduous shrubs. The technique is simple and relies on both the index and the interpretation made by the human eye. The goal is to make forest owners aware of the need for pre-commercial thinning in their forests.

Another add-on application is that the Samí reindeer herders are digitizing their areas of interest for reindeer grazing. This is done locally by the reindeer herders themselves, using a satellite image as background for the manual delineation of areas of interest. The maps are then used in negotiations with forest companies regarding cuttings, which strongly affect the amount winter forage available for the reindeer.

5. DISCUSSION

As shown above, the experiences from Sweden, Finland and USA are that Landsat / SPOT type of satellite data in combination NFI sample plots is an efficient way to produce raster data bases of the forest variables that are correlated with satellite spectral data. These data bases are of great value for national authorities since they are often the only available wall-to-wall databases of the national forest resource. It is, for example, possible to obtain information related to all forest state related variables in Table 1. Such raster databases can also be brought to the international level. This is an appealing solution since the raster databases can be viewed as maps and analysed using GIS tools, to produce summaries for larger areas of interest for example. Furthermore, National Forest Inventories are most often reluctant to give away the exact coordinates of their permanent sample plots since this could cause a biased treatment of them. This problem will be circumvented by distributing raster estimates based on the sample plots instead. (McRobert et al, 2005).

However, it must be observed that for tree-size related variables such as biomass, LAI, etc, the relation with optical satellite data saturates for higher densities and closed canopies. Furthermore there is a risk for bias due to e.g. map mask definitions and weak correlations of optical data with some forest variables of interest. Thus there is also a need for reporting statistics derived directly from field plots, with a possible improvement by post-stratification. There is also a need to further promote the development of operational methods that use sensors with improved capacity for biomass mapping, e.g. lidar from space or airborne lidar possibly used in strip sampling designs, or low frequency SAR sensors.

The efficient system for detection of forest changes which is operated in Sweden is very valuable for verification of cutting permits and future monitoring of re-generation. Furthermore, it is clear that most forest changes, e.g, the ones specified at the end of Table 1 are detectable using satellite data, however, most often *local knowledge is essential for determining the type of change*. Referring to Table 1, other changes,such as. fire scars could also be mapped with change detection techniques, and this is actually being done in e.g. Portugal. Also areas which might be subject to deforestation according to the Kyoto protocol might be mapped using a similar procedure, but again, the type of change must be verified by some type of *in situ* procedure.

However, procedures for reporting to international conventions can not be designed to be dependent on satellite data before the data supply is secured. Since each satellite has a potential capacity to cover the whole earth but single satellites are vulnerable to failure and cloud cover; and since there is no stable commercial market for 10-30 m pixel satellite data, the supply of such data should be institutional and coordinated between countries. GEO is an ideal body to achieve this coordination.

In line with this need, the GEOSS 2006 work plan includes a task (AR-06-09) which is aimed to ensure continuity of Landsat-like data. Also the GCOS (2004) Implementation plan stresses the need for "continuity of key satellite sensors".

The GEO 2006 workplan also include the initiation of a project on forest mapping and forest change assessment, using the combination of satellite data and in situ data (Task AG-06-04 in the GEO 2006 work plan).

The Global Climate Observation System (GCOS) and the Global Terrestrial Observation System (GTOS) can be considered parts of the envisioned GEOSS. Also these initiatives state the need for land cover or forest mapping. For example Action T 27 in the GCOS implementation plan is global land cover mapping with 10 m – 30 m pixel size every 5 year (GCOS, 2004).

Furthermore, it should be recognised that GEOSS also addresses variables that must be inventoried *in situ* and where image data is of limited value, for example the geographical distribution of individual species, in the area of Biodiversity,

6. CONCLUSIONS REGARDING DATA NEEDS

The common feature of these successful monitoring programs at national level is that they use a combination of satellite data and *in situ* observations. These systems could be developed and introduced also in other countries and they have a potential to feed much of the forest observations required in GEOSS (Table 1) up to the international level. These national systems are threatened by the current lack of long term coordination among nations for the redundant supply of Landsat-like data. Considering the GEOSS criteria about *i)* observations that are enhanced by global systems, and *ii)* phenomena that taken together have global scale consequences, the national level needs would motivate a coordination of satellite data supply through GEO.

Furthermore, nations collecting forest inventory sample plot data will have the possibility to also feed this information (possibly with the exact coordinates removed) back to GEOSS. Since much more than forest information can be collected on such plots, they will also be valuable for many other issues addressed by GEOSS, for example species richness. Field plots of NFI-type have the potential to fill many of the data gaps in the current international observations of the terrestrial ecosystem It can therefore be envisioned that GEOSS in partnership with relevant UN Agencies also should help to coordinate an extended and more harmonised network of field plot observations.

As forums for the continued dialogue between GEO and different user communities a set of pilot "Communities of Practice" are presently being formed. (GEO 2006 Work Plan, Task US-06-02) One of these Communities of Practice will address Forest Observations. Hopefully, this activity will help to further refine the user needs and possibilities outlined in this paper.

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