GOFC-GOLD GLOBAL OBSERVATION OF FOREST AND LAND COVER DYNAMICS

Report of the Workshop on Boreal and Temperate Forest Monitoring

as part of the
Third GOFC-GOLD Land Cover Symposium

Friedrich-Schiller University
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Global Observation of Forest and Land Cover Dynamics (GOFC-GOLD) is a coordinated international effort to ensure a continuous program of space-based and in situ forest and other land cover observations to better understand global change, to support international assessments and environmental treaties and to contribute to natural resources management.

GOFC-GOLD encourages countries to increase their ability to measure and track forest and land cover dynamics by promoting and supporting participation on implementation teams and in regional networks. Through these forums, data users and providers share information to improve understanding of user requirements and product quality.

GOFC-GOLD is a Panel of the Global Terrestrial Observing System (GTOS), sponsored by FAO, UNESCO, WMO, ICSU and UNEP. The GOFC-GOLD Secretariat is hosted by Canada and supported by the Canadian Space Agency and Natural Resources Canada. Other contributing agencies include NASA, ESA, START and JRC. Further information can be obtained at http://www.fao.org/gtos/gofc-gold

Executive summary

On 13 October 2008, the Workshop on Boreal and Temperate Forest Monitoring was held as part of the 3rd GOFC-GOLD Land Cover Symposium (13-17 October 2008) at the University Jena, Germany. An international group of 30 forest and remote sensing experts attended the meeting to discuss the topic of multi-source and multi-scale sampling for large area forest characterizations.

The intention of the workshop was to bring together a group of expert practitioners and data users to consider wide-area forest monitoring from a number of different perspectives. Monitoring, as opposed to mapping, provides an ability to capture and depict change over time in a systematic manner. The capture and depiction of the dynamics occurring over the globe's temperate and boreal forests enable operational, reporting, and science objectives to be met.

The speakers at the workshop illustrated how different data sources and processing options are appropriate to meet different information needs. High-density repeat surveys with LIDAR instruments can help determine on growth and development of individual trees in the context of on climate change. Optical remote sensing, over a range of spatial resolutions, was shown as an operational data source for mapping land cover and depicting change over large areas. RADAR instruments were shown to have the capacity for the characterization of biomass over large areas. The integration of data capturing information at different scales also showed current capacity and great potential for future applications. The ability to use a sub-set of ground plot data to train intermediate sources of data (i.e., high spatial resolution airborne or satellite imagery, or LIDAR) was demonstrated, which in turn can calibrate and validate a lower spatial resolution data source that covers an even larger area. These types of data integration approaches enable users to capitalize upon the information content of a given data source and integrate this data through modeling to produce desired large area depictions. Further, sampling with high spatial resolution image source or LIDAR provides opportunities to monitor conditions and dynamics over large areas in an efficient and cost effective manner. The processing of long time series imagery was also shown to provide otherwise unavailable information on forest disturbance and recovery over large areas.

The presentations and breakout groups provided a valuable platform to share knowledge and to discuss future opportunities. While no single approach or data type exists to meet all large area monitoring needs, scientists and users that communicate sensor and modeling potentials with actual information needs have a wide variety of options that may be followed. This workshop on temperate and boreal forest monitoring exposed the participants to; ongoing activities, future plans, and provided a successful forum for information sharing. All participants are thanked for their insightful contributions and unbridled enthusiasm.

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Acronyms

BOG	Breakout Group
CFS	Canadian Forest Service
GOFC-GOLD	Global Observation of Forest Cover and Global Observation of Land Dynamics
EC-JRC	European Commission Joint Research Center
FAO	Food and Agriculture Organization
FRA	Forest Resources Assessment
LC-IT	Land Cover Implementation Team
LIDAR	Light Detection and Ranging
MODIS	Moderate Resolution Imaging Spectro-radiometer
PO	Project Office
RSS	Remote Sensing Survey
SAR	Synthetic Aperture Radar
SDSU	South Dakota State University
SUNY	State University of New York

1 Background and objectives

The objective of the workshop was to present the context, issues, examples, and opportunities for using hierarchical analysis or sample based approaches for forest monitoring over large areas, in order to explore notions for continued developments and identification of opportunities.

Planned outcomes of the workshop include; a statement of context, identification of possible elements of a multi-scale monitoring framework, identification of possible and existing data sources, data acquisition and analysis opportunities, plus statistical and other technical considerations. As an outcome of the workshop, a report is planed to describe the state-of-the-art, opportunities, and limits for the use multi-source, multi-scale data for large-area forest characterization. The goal is to document and communicate potential practices and opportunities, based upon the nature of the information needed, rather than develop or promote a single approach.

2 Participants

Near 30 recognized scientists and experts in the field of boreal forest monitoring attended the workshop. Participants included GOFC-GOLD LC-IT members, representatives from research institutes, and national forest institutions. Appendix A provides the full list of participants.

3 Agenda

The workshop was structured in three sessions of presentations. The topics covered general requirements for forest monitoring systems, approaches and methods, and the application of new technologies and sensors. The afternoon was dedicated to group discussions on the topics; issues and opportunities, evolving technologies, capacity building and long term monitoring needs.

Appendix B provides the detailed agenda. With permission of the speakers, all presentations of the workshop are available as Adobe PDF on the Website of the LC-IT PO under: http://www.gofc-gold.uni-jena.de/sites/Jena08.php.

4 Summary of presentations and discussed topics

4.1 Session I: Introduction and requirements

The workshop organizers **Mike Wulder** (CFS; GOFC-GOLD LC-IT) and **Christiane Schmullius** (GOFC-GOLD LC-IT Co-Chair) welcomed the participants and opened the meeting.

To start, **Mike Wulder** provided context information on the multi-source and multi-scale monitoring of boreal and temperate forests. He emphasized that different data types provide unique information for forest monitoring and reporting. Therefore, new strategies are needed for data processing, analysis and storage to enable the integrated use of the different sensors. The long-term vision is to have a real-time, multi-scale global monitoring providing high-spatial resolution land cover and change information. The presentation addressed the different issues that need to be considered to reach this goal, such as an integration framework that includes frequent coarse spatial resolution and periodic fine spatial resolution. For example, data blending of Landsat and MODIS imagery was shown to generate high-spatial resolution synthetic image time series. Furthermore, new sensor types need to be integrated in such a framework e.g. LIDAR (LIght Detection And Ranging) from which additional information such as canopy height and biomass can be derived.

Matthew Hansen (South Dakota State University) gave a presentation on recent results from biome-scale monitoring of forest cover and forest cover loss in the Boreal zone, based on annual MODIS and Landsat data for 2000 and 2005. The MODIS time series analysis using annual metrics and results from different regions were shown. He concluded that a monitoring strategy that combines sensors of multi-temporal and -spatial resolution is a feasible and cost-effective method to produce timely, precise and internally consistent estimates of biome-wide forest cover loss. The results show the regional and temporal variability of forest cover loss in the boreal zone (POTAPOV et al. 2008). In combination with available carbon stock data, this information will improve carbon accounting. In future, this analysis will be applied to the complete temperate and the dry tropical biomes.

Steve Stehman (State University of New York) focused on the sampling design applied in monitoring forest loss and compared complete data coverage versus data sampling. Both approaches have advantages and disadvantages with respect to costs, time and inherent errors. The comparison was based on measuring the accuracy of the change classification, where the bias is defined as the difference between mapped and real change. For example, the biome monitoring in the Boreal zone was analysed (same area as Hansen above). The results showed that the applied sampling approach yielded precise estimates of forest loss in the Boreal zone and that the stratification of the sampling design (using MODIS-derived changes) has further improved the precision.

Lucia Reithmaier (EU-JRC) spoke on Pan-European forest cover mapping activities of the Joint Research Centre. The objective is to develop harmonized European forest maps based on high-resolution imagery and with high geometric and thematic accuracy for 1990, 2000 and 2006. An object-oriented supervised classification is applied on Landsat (1990, 2000) and SPOT (2006) data, using CORINE land cover as training information (PEKKARINEN et al. 2009). The validation of the forest-/non-forest map product 2000 using LUCAS data (Land Use/Cover Area frame statistical Survey) results 84 to 91 % overall accuracy (all or homogenous points). Data sets and further information are available at: http://forest.jrc.it/ForestResources/.

4.2 Session II: Background and applications

In the first talk of the second session, **Håkan Olsson** (Swedish University of Agriculture Science) spoke about the application of dense time series analysis for forest monitoring in Sweden. The Swedish Forest Agency holds a national database of Landsat and SPOT data and the presentation showed different examples of its operational use. Trained by nationwide forest inventory plots, various forest parameters have been mapped for all of Sweden with SPOT and Landsat data using a k-Nearest-Neighbor approach (TOMPPO et al. 2008). Further applications are plantation monitoring and the assessment of reindeer grazing areas. It was emphasized that dense (yearly) time series provide recent data that are valuable for authorities and enterprises for updating and surveillance. They further document the yearly landscape changes, which can be used for studies of change processes, as well as for forecasting of landscape development.

Warren Cohen (USDA) presented the North America Forest Dynamics (NAFD) study using Landsat time series. A main objective of this monitoring is to nationally estimate disturbance and regrowth metrics from sample Landsat scenes and then to convert the observed forest change to biomass change (GOWARD et al. 2008). The presentation focused on the sampling design, the annual time series analysis and the validation approach. TimeSync (Synching Automated and Human Interpretations of Landsat Time Series) and LandTrendr (Landsat-based Detection of Trends in Disturbance and Recovery) are two new tools that have been developed for Landsat time series analysis. It was emphasized that Landsat is the ideal sensor for mapping spatially-detailed, long-term trends in forest dynamics. Appropriate reference data for change detection is still a challenge but analysts can take advantages of existing, independently derived data opportunistically or use the Landsat times series itself.

Adam Gerrand (FAO) spoke about the Remote Sensing Survey of the FAO Forest Resources Assessment 2010 (FRA RSS, http://www.fao.org/fra). Expected outputs of the RSS are MODIS tree cover maps, regional and global trends of land use dynamics and baseline data for research and modelling. The RSS sampling framework comprises wall-to-wall MODIS data and Landsat sample data at 1-degree latitude-longitude intersections. The Landsat samples will be used to assess the forest change from 1990 to 2000. The approach employs object-based, multi-date segmentation and classification (done by FAO and partners). National experts will do the supervised labelling and validation. Currently, the methodology is tested in a pilot study. An online information gateway (developed by SDSU) provides access to the imagery: http://globalmonitoring.sdstate.edu/projects/fao/index.html. The RSS includes a radar component that will assist with SAR (Synthetic Aperture Radar) data in areas with permanent cloud cover and enhance the national and trans-national forest inventories (FRA-SAR, http://www.frasar2010.uni-jena.de/).

Mike Falkowski (CFS) presented the National Forest Inventory of Canada where samples of high spatial resolution satellite imagery are used for large area characterization. Canada's forests represent 10 % of the world's forest resources. The traditional National Forest Inventory (NFI) is based on systematic sampling of air photos or Landsat scenes and ground sample plots every five to ten years to assess various forest parameters characterizing the structure and origin of the stands (GILLIS et al. 2005). Currently, new monitoring protocols and remote sensing tools are in development using samples of high spatial resolution imagery (QuickBird, WorldView) and automated image processing techniques to inventory and monitor northern Canada. The presentation introduced the workflow and showed first results from a pilot study, where automated image segmentation technique on IKONOS data is compared to results from traditional photo interpretation (WULDER at al. 2008).

4.3 Session III: Evolving and upcoming issues

Curtis Woodcock (LC-IT Co-Chair) focused on effects of land use change on terrestrial carbon dynamics in countries of the Black Sea Region and in New England. Objective of the project is to minimize the uncertainties associated with the carbon cycle dynamics, particularly associated with land-use change. Based on remote sensing data, national forest changes are measured and than used in a carbon book-keeping model (developed by HOUGHTON et al. 1983) to estimate related carbon dynamics. Recent results from Romania, Turkey and Georgia have been presented and discussed in the context of worldwide forest transition processes (RUDEL et al. 2005, KAUPPI et al. 2006). The same approach was applied in New England showing that after a period of stabilization the forest area of New England is now again decreasing due to urban growth.

On behalf of Sergey Bartalev (Russian Academy of Sciences), **Christiane Schmullius** gave a presentation on a MODIS based approach for continental land cover mapping in Northern Eurasia. In comparison to the GLC2000 land cover product for Eurasia at 1 km resolution (derived from SPOT VEGETATION), an automated mapping approach was envisaged that facilitates repeated product generation and provides higher spatial resolution and thematic detail. The mapping method uses improved monthly and seasonal multi-spectral MODIS composites and involves spectral mixture modelling, con-textural maximum likelihood classification and class probabilities based on auxiliary data products. Mapping results have been shown for different regions in comparison to GLC2000. In the conclusion, it was emphasized that this approach can be applied easily for data with higher spatial resolution and for greater geographical extent.

Nelson Ross (NASA) presented outcomes of the Quebec Carbon LIDAR Project. The overall objectives of this project are to estimate biomass and carbon resources and to develop a realistic estimate of the variability of regional carbon estimates based on multi-phase sampling that integrates field observations with airborne and space based LIDAR data (Boudreau et al. 2008). It was shown that large area forest inventories can be done with ICESat/GLAS data, but significant problems have to be considered e.g. influence of topography, measurements in open forests or forest degradation and a future information gap (2011-2015). As an alternative, airborne laser scanning data with small-footprint and dense shots are suggested for measuring carbon and to locate and monitor intermittent, selective harvesting.

Erik Næsset (Norwegian University of Life Sciences) spoke about properties and the potentials of LIDAR data. He highlighted that LIDAR is probably the most precise remote sensing technique available for forest assessment as it allows precise measurements of forest canopy structure and can be applied at any geographical scale, from individual trees to regions and nations. This technology has thus a significant role in change detection and monitoring. Examples where shown for the application of LIDAR at different scales. In Norway, it is applied to assess recruitment, growth, mortality of small trees above tree line, estimating regional changes in mountain forest carbon pools and for mapping of forest damage (defoliation). For any monitoring, repeated ground calibration is required because many sensor and flight specifications influence the data.

5 Breakout groups and open discussion

Please find below discussion notes and thoughts related to addressing one of three breakout focus questions. To avoid mis-quoting or mis-representation names have been removed as possible from the individual comments.

Question 1: Please describe issues, opportunities, and other considerations related to Spatial sampling to combine fine and coarse resolution images.

Recommendations on sampling approach for fine resolution images. Use to:

1. Get training data for the analysis of coarse resolution images, in particular when a proper ground survey cannot be made.
2. Assess the quality of mapping with coarse resolution
3. Combine fine and coarse resolution to improve estimates

For uses 2 and 3, a statistical sample is essential. For use 1, it is recommended, but not essential. Random or systematic sampling are the main types of sampling, although other alternatives can be found in the literature.

The result of sampling can be assessed comparing the orders of magnitude of sampling errors with the commission/omission errors in coarse resolution. An idea of the sampling errors can be obtained by simulation using land cover maps as pseudo-truth.

Try to define priorities and stratify according to them. Avoid stratifications that are too complex, including:

- Avoid too many strata
- Each sampling unit should belong to a single stratum and not be shared by several strata.

Sample the strata in which you expect to have a higher variance in your priority variables with a higher rate.

When sampling, take into account potential distortions that can introduce bias in the estimation:

- Overlapping frames
- Distortion with the latitude (mainly in temperate and boreal regions).

Main approaches for combining coarse and fine resolution are: regression and calibration estimators.

- Calibration estimators are more adapted when sampling units are not clustered points (mainly ground data).
- Regression estimators and related approaches (e.g., ratio estimators) in other cases.

Small area estimators can be useful for estimates by sub-region (e.g., region, country), but can be complicated and are model-dependent.

New data sources to consider or encourage operational collection of:

- Yearly Landsat, or Landsat-like
- Detailed laser over sample areas
    - o repeated regularly
    - o depending on design, consider independent samples instead
- Combine different sensors
    - o DTM from laser
    - o Canopy from X-band SAR
    - o Or from multi-view angle sensors
    - o *In situ* data is always needed

Question: How can large area land cover and change projects benefit from more detailed sample information, dense time series data, and alternate sensor data.

We started with a discussion about sampling using multiple data sources. It is obvious that sampling is our basic science in cases where we are after an estimate for an area and that this is true even in the case when we have new data sources, like affordable dense time series of Landsat data or sample areas with laser scanner data. These data sources are just potential additional contributions in a multi source sampling scheme, and an in situ sample, large or small, always have to be part of such a scheme.

Some sampling issues (e.g. sampling in time) are less studied than others, and there might be issues like autocorrelation in space or time, or missing data which are correlated with the parameters to be studied, that complicate things and need to be studied further when new methods should be applied. Wall-to-wall remote sensing products as such are also a good starting point for simulation of optimal sampling schemes.

We also discussed the possibility of using repeated laser scanner strips for change assessments. It was pointed out that it might be a problem to repeat the same laser strips, and that two independent samples might be preferable. This seems similar to the classical ways of analysing permanent versus temporary forest inventory plots.

Work has been ongoing and is about to be finalized regarding the statistical framework for strip sampling with lasers. This work has been going on since 2004. It may be an appropriate and consistent statistical approach for that. However, the statistical model also has some bearing on how we deal with the strips (fixed vs variable strip widths) and it also assumes that this will influence how we will treat a repeated over flight (to enable monitoring). Profile data can be problematic for obtaining overlap and enabling monitoring (without stratification of non-overlapping areas). But, scanning LIDAR data has a sufficiently wide swath, so that repeat pass studies should be possible and economical over large areas. Plots can be extracted from the repeat pass scanning LIDAR data after a stratification stage that includes a requirement for overlap (and then other considerations including laser scan angles through to balanced samples of forest structural conditions).

Also the dense time series is, when they are used for improved estimation, basically a way to obtain more dimensions from the spectral data. We have to learn how to use the time series, but they will require image database systems that keep track of all combinations of useable pixels from different time points, as well as special software. Experience so far shows that the time series contribute most in the young forest phase, as well as for detecting disturbances like damages and thinning cuttings. They also provide the spatial patterns of the yearly landscape changes. Yearly summer images are increasingly common in this use, but phenology confers information as well and points to the possible use of more than one image per year when available.

It was stated that we ultimately should work towards data assimilation schemes, like in meteorology, where all available data are assimilated in models as they become available, and used for what they are worth. We could also, already now work more with multi sensor solutions. One idea for monitoring a country could be to laser scan, say 1000 sample areas, this would provide a good DSM, as well as more importantly a good DTM for these sampled areas. There are then a number of techniques that could be used for obtaining DSM's of the tree canopy over time, including multi view angle matching of imagery from optical sensors looking forward and aft, or interferrometric X-band SAR data from the coming Tandem mission. A certain field sample, revisited with several years interval, would be needed for calibrating the different types of DSM's to forestry relevant measures. It was noted that it there might be practical problems with the SAR data, such as effects of atmospheric water vapour. This highlights the need for future practical studies.

The need for large scenes (at least the size of Landsat) was indicated, along with regular and frequent acquisitions, in order to get at least some cloud free data, and many field samples per scene. It was pointed out that there is a need to plan for operational satellite data continuity, a long-term perspective is required. We came then to the discussion that other communities, like atmosphere and ocean observations, mange to get their priorities through, in a much more efficient way than the scattered land community. It is up to the land community to get better organised and speak up for the needs for sustained and coordinated observation systems. The climate need is an opportunity to improve the situation. Things are also improving, as ESA and others will prioritize the monitoring of the climate variables and GMES which solves a lot. We also touched the discussion that overselling, especially from the commercial sector, has been a problem for remote sensing (due to frequent over-promotion of remote sensing). The need for a northern biosphere biomass map was mentioned. There is a need for further technology development, for example the development of space based laser systems that are dedicated to vegetation biomass studies that have a possibility to see degradation, was also mentioned.

Question 3: Opportunities and limitations for cross-scale data integration: consider plots of coarse spatial resolution satellite, and levels in-between.

Potential sources of data, in order of spatial resolution, and uses

High Resolution: in REDD context, defined as data that can "see" an individual tree
Ground plot data: ~200-500 m^2.
High spatial resolution air photos or optical digital data (e.g., QuickBird)
Small footprint resolution LIDAR data: >1-10 shot/m2,
dominant/codominant trees

Medium Resolution: multiple trees to 100m
Workhorses:
Landsat ETM (global, free via EROS after 12/31/08)
Radar: ALOS/PALSAR: 50m global product, policy of >1 acq/year, land
CBERS (great data policy if not global coverage)
Large-footprint LIDAR: ICESat/GLAS – free but tough to use, noisy, slope probs.
SPOT (available but costly, but no acquisition strategy)
Static - SRTM, ASTER-derived elevation data

Coarse Resolution: >100 m, global stratification, broad-scale mapping/biomass accounting, fire, phenology, LC/LUC
MODIS, AVHRR (250m, 500m, 1km)
MERIS (300m)
SPOT Vegetation (1 km)

We want to do one of three things when we start integrating across scales:

- Integrate data sets at different scales to improve measurements, calibration, regression estimation, map accuracy (one sensor covers area, other sensor(s) subsample area). Example: stratification of coarse-scale data to target high-resolution data
- validation of RS products. Example: IKONOS for Landsat in accuracy assessments
- fusion (all sensors image/measure same area). Example: MODIS/Landsat fusion (STARFM)

Limitations:

- -Cost,
- -availability (acquisition strategy or data access),
- coverage,
- data distribution policy,
- processing costs and sophistication of data processing (weak technical capacity in many countries and lack of critical mass of operators),
- calibration, and the
- inability to relate themes/definition s across scales and products

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Appendix B – Agenda

GOFC-GOLD Workshop on Boreal and Temperate Forest Monitoring **Theme: Multi-source, multi-scale, sampling for large area forest characterizations**		
Monday, 13.10.2008, Rose Halls, Room 103		
SESSION 1: Introduction and requirements		
09.00-09.10	Opening and meeting objectives	Wulder/Schmullius
09.10-09.30	Context for multi-source, multi-scale, boreal and temperate forest characterization	Wulder
09.30-09.50	Circum-boreal forest change mapping	Hansen
09.50-10.10	Accuracy of sample versus area-wide mapping (including for change)	Stehman
10.10-10.30	Forest cover mapping over Europe at 3 dates (1990, 2000, 2006)	Reithmaier and Pekkarinen
10.30-11.00 Break		
SESSION 2: Background and applications		
11.00-11.20	Dense time series analysis: applications / methods	Olsson
11.20-11.40	Sample based dense time series analysis for regional monitoring	Cohen
11.40-12.00	The 2010 remote sensing-based Forest Resource Assessment as a sample based monitoring example	Gerrand
12.00-12.20	Samples of high spatial resolution satellite imagery for large area characterization	Falkowski
12:20-12:30	Session summary	Wulder
12.30-13.30 Lunch		
SESSION 3: Evolving and upcoming issues		
13.30-13.50	Forest change and carbon dynamics in New England and the Black Sea Region	Woodcock
13.50-14.10	Continental Land Cover Monitoring for Russia	Bartalev
14.10-14.30	LIDAR based sampling for monitoring of large areas	Nelson
14.30-14.50	LIDAR based sampling for subtle change, developments, and status	Næsset
14.50-15.10	Operational multi-scale biomass products	Schmullius
15.10-15.40 Break		
SESSION 4: Breakout group discussions		
15.40-16.30	Discussion and definition of breakout groups Breakout group discussions Issue and opportunities Evolving technologies Capacity building Long term monitoring needs (e.g., spatial, temporal, attribution, etc.)	All/ Wulder All
16.30-17.00 Break		
SESSION 5: Breakout group reports and discussions		
17.00-17.30	Report from breakout groups	All
17.30-18.00	Open discussions	All
18.00-18.30	Synthesis (then closing remarks)	Wulder