Nordic Network on

Physically-based remote sensing of forests

[PHYSENSE]

Workshop
June 3-4, 2008
Helsinki, Finland

PHYSENSE is a Nordic network which focuses on the development, validation and application of physically based approaches in the interpretation of remotely sensed data of forest ecosystems.

Program

Tuesday June 3, 2008
Opening session

09.00	Opening words and practical arrangements *Tiit Nilson and Miina Rautiainen*
09.15	What is SNS? *General secretary Sune Haga*

Session 1: Retrieval of biophysical vegetation variables

Chair: Miina Rautiainen

09.30	Towards an LAI-based remote sensing method for forest health monitoring *Svein Solberg*
09.50	On remote sensing of forest productivity in Järvselja, Estonia *Tiit Nilson*
10.10	Coffee
10.40	Subarctic boreal forest albedo estimation using ENVISAT ASAR for BRDF determination *Aku Riihelä*
11.00	Airborne discrete-return LiDAR in the mapping of understory lichens *Ilkka Korpela*
11.20	Vegetation classification of the European Russian tundra and taiga ecosystems using multiple spatial scale satellite images *Sannamaija Susiluoto*
11.40-13.10	Lunch

Session 2: Radiative transfer and physically-based models

Chair: Lauri Korhonen

13.10	Remote sensing of vegetation based on spectrally invariant structure parameters *Pauline Stenberg*
13.30	Contribution of multiply-scattered radiation to multi-angular forest reflectance *Matti Mõttus*
13.50	Simulation of the effect of forest floor on forest albedo *Terhikki Manninen*
14.10	Structural parameterization of Norway spruce trees in radiative transfer of high spatial resolution *Zbyněk Malenovský*
14.30	Coffee

Session 3: Key note

15.00 Keynote: A new satellite for monitoring forests
Professor Tuomas Häme, VTT Earth Observation

Session 4: Field measurements of reflected and transmitted radiation fields

Chair: Mait Lang

15.40 Hyperspectral reflectance of boreonemoral forests in a dry and normal summer
Joel Kuusk

16.00 Hyperspectral laser measurement system: application to coniferous needles and branches
Henri Niittymäki

16.20 Reflectance of snow in forests: field measurements, modelling, and applications
Jouni Peltoniemi

16.40 Measurement of scattering function and polarization from pine and spruce shoots
Eetu Puttonen

19.00 Workshop dinner at Restaurant Viola
(Botanical garden, Kaisaniemenranta 2)

Wednesday June 4, 2008

Session 5: Characterization of forest 3D structure

Chair: Matti Mõttus

09.00 Combining LAI-2000 PCA and digital camera for gap fraction measurements
Mait Lang

09.20 Automated estimation of LAI from hemispherical canopy images
Lauri Korhonen

09.40 A model-based approach for ALS-based forest inventory
Lauri Mehtätalo

10.00 Quantifying tree crown shape and structure using alpha shape metrics of ALS data
Jari Vauhkonen

10.20 *Guest talk:* Effects of forest ownership and change on forest harvest rates, types, and trends in northern Maine
Aaron Weiskittel

10.40 Closing words
Tiit Nilson

10.50 Coffee

Session 1: Retrieval of biophysical vegetation variables

Towards an LAI-based remote sensing method for forest health monitoring

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In an on-going project, we work on development of a method for remote sensing of forest health. We use variations in leaf area index as a measure of variations in forest health, as an indicator of defoliation. The data are gathered at three levels; ground measurements, airborne sensors and satellite sensors. Data from one level is validated and calibrated with data from the level below. Effective leaf area index (LAIe) is measured at a number of points using LAI2000 and hemispherical photography. A larger area around the sites is covered by airborne laser scanning (LIDAR). The penetration rate of the LIDAR first returns is used as a sample of the canopy gap fraction. Based on Beer's law, together with the ground based LAIe data, the LIDAR penetration rate around each point is recalculated into LAIe including estimation of an extinction coefficient for each tree species. With this at hand, an LAI map is generated for the entire LIDAR scanned area. The spatial resolution of the map is adjusted to fit the spatial resolution of any satellite data, i.e. with an LAI value for every pixel. This is then used as a large scale ground truthing for the satellite data. We have used insect (Neodiption sertifer) outbreaks on Scots pine as test cases with data gathering at all three levels both before and after the insect defoliation. The outbreak areas were roughly forecasted based on the previous year's attack together with field surveys of egg galleries in the pine needles. Damage areas extending outside the LIDAR area have then been identified using MODIS and SPOT data. A provisional method for early detection of insect damage has been developed with MODIS data.

On remote sensing of forest productivity in Järvselja, Estonia

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Estimates of vegetation gross and net primary productivity are being produced by several remote sensing systems, such as global estimates on 1km grid by the MODIS team. Most of the methods of estimating forest productivity are based on the Monteith relation between the yearly NPP and absorbed PAR and assumption that the fraction of absorbed PAR is linearly related to the NDVI index. This study tries to evaluate the applicability of these two relations for estimating the forest productivity in Järvselja, Estonia using the higher resolution Landsat and SPOT images. Two main sources of information are used:

1. An extended set of Landsat and SPOT images over the Järvselja site from years 1987-2007 arranged as the seasonal series. A special smoothing procedure was applied and seasonal series of reflectance in the spectral bands of Landsat were produced for a selection of different forest types. In addition, seasonal course of the NDVI was derived.

2. Stem volume increment data from the forestry database over Järvselja were used to describe the dry matter production.

In addition, the average seasonal course of incident PAR as measured in the Tartu Meteorological station was used.

The seasonal courses of the NDVI index for birch-dominated stands of different site fertility showed different shapes, so that the measurement of the NDVI seasonal peak in midsummer is not sufficient to describe the differences in stem mass yearly increment. It can be concluded that the differences in yearly productivity are to a large extent caused by time lag in the springtime development for the less productive birch forests.

Weighted by the incident PAR seasonal sums of NDVI indices were related to the stem mass yearly increment from the forestry database. The correlation between the weighted seasonal average of NDVI and stem mass increment was found to be linear for the forest types of small and medium productivity, however, the relation saturated for the stands of highest productivity. At the other extreme, pine bogs showed considerably lower PAR use efficiency compared with other types of forests in the region. Reflectance factors within some individual spectral bands were better related to the FAPAR and NPP compared with NDVI. The smoothed seasonal reflectance series of higher resolution images is a good tool for analyzing the productivity of forest stands by remote sensing.

Subarctic boreal forest albedo estimation using ENVISAT ASAR for BRDF determination

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The boreal zone land cover has very significant influence to northern hemisphere albedo and it is the main factor in northern hemisphere carbon budget. Boreal forest is also a sensitive indicator to changes in local and global climate. Forest type borders react to changes in mean temperature and moisture conditions in long term; forest leaf area index and defoliation indicate stress factors in shorter time scale. Also the time of the phenological phase transitions are important indicators of global climatological processes. Surface albedo is one of the Essential Climate Variables (ECV) defined in the Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC. Surface albedo is also one of the ECVs that are largely dependent on satellite observations. Parameters describing, on one hand the land cover classes in general and, on the other hand the forest properties in detail, are related to the bidirectional reflection distribution function (BRDF) affecting the surface albedo, which is needed as input for climate change modelling. The BRDF of land cover is estimated for operational surface albedo products using optical satellite images and land use class information. For vegetated land cover semi-empirical relationships depending on the leaf area index (LAI) are used. Recently a method for boreal forest LAI retrieval using the VV and HH polarization of ENVISAT/ASAR has been developed. Thus, there is potential also for finding a direct relationship between BRDF and the microwave essence of land cover. Because microwave instruments do not suffer from cloud cover and lack of sunlight, they enable automatic regular updating of the description of the surface frequently enough, whereas nowadays the updating of the land use class information using optical data takes place about every ten years and the instantaneous BRDF determination is often impossible because of cloud cover or too small sun elevation angle. Using also microwaves it is possible to detect environmental changes in large areas more quickly and they help improving the reliability of the climate change predictions and timely adaptation to the economical impacts of climate change caused environmental alteration.

Ground based BRDF measurements are based on small samples and are very time consuming. In practice they can not be performed in large areas. Therefore, it was decided to measure instead the broadband surface albedo, which is the product of the reflectance of the material and its BRDF. The test site is in the immediate vicinity of the Arctic Research Centre of FMI, which is situated about 100 km north of the Arctic Circle. The subarctic boreal forest in the area is relatively sparse and the maximum tree height is less than 15 m. In August 2006 the incoming and reflected radiation was measured at about 1 m height in a grid of about 80 points with a spacing of 50 m using a portable albedometer consisting of two separate pyranometers. The leaf area index (LAI) values had been measured earlier in the summer at the same grid points. One cloud free SPOT image and a few ASAR images were available at the test site in summer 2006. Algorithms found in literature for the relationship of broadband and spectral albedo values of SPOT were used to derive visible and NIR albedo values of the forest bottom on the basis of the pyranometer measurements and the SPOT reflectance values in the area. The global radiation measured continuously at the meteorological mast above the canopy and a photon recollision probability based canopy radiation model was used to convert the forest bottom albedo values to the forest top albedo values. The obtained spectral forest albedo values were compared to the product of the SPOT reflectance and the VV/HH backscattering coefficient ratio of the ENVISAT ASAR. A linear relationship was found between the SPOT/ASAR and pyranometer based albedo estimates in the NIR band. The coefficient of determination for the linear regression was better than 0.7. The albedo based on both SPOT and ASAR data had also a higher correlation with the albedo based on pyranometer measurements than the albedo based only on SPOT data and current BRDF models. No significant regression existed for the NIR reflectance derived from SPOT and the pyranometer based albedo estimate. In the visible band there was no marked relationship between the SPOT and/or ASAR and pyranometer based albedo estimates. According to canopy radiation model results for the Tähtelä test site the visible band albedo is dominated by the forest bottom and the NIR band albedo by the canopy. Hence the results of this study support previous results that the VV/HH backscattering ratio in C-band is related to the leaf area index (LAI) of boreal forest canopy and is not typically related to the forest bottom properties. Since the broadband surface albedo of vegetation is dominated by the markedly larger NIR band albedo, the broadband albedo of boreal forest can be reasonably estimated using microwaves for the BRDF determination. The summer 2006 was extremely dry, in fact the driest summer ever measured in Finland since 1900. This was also manifested by the large amount of completely brown needles of the coniferous trees. This also reduced the number of images possible to use from seven to two. The first good image was taken in late May and the other one in August after a rain fall. This gives additional support to the result that in normal moisture (permittivity) conditions the needles dominate the backscattering of boreal forest.

Airborne discrete-return LiDAR in the mapping of understory lichens

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High backscatter reflectance at the NIR wavelengths has been observed for Reindeer lichens (Cladina sp.) in laboratory. The results have suggested that that lichens could be separated from soil and other forest understorey using this property. An experiment was carried out to test this hypothesis in situ. Lichen vegetation of a 960 m2 plot in a barren pine stand in Juupajoki, Finland was mapped in 3D using methods of close-range photogrammetry. Data of two airborne discrete-return sensors were compared for their ability to classify understory lichen vegetation. Normalization of the LiDAR intensities was carried out using natural targets. The results showed that lichen surfaces had, on average, a higher intensity. Normalization of the intensities improved separability of lichens from other surfaces, and the best-case classification accuracy was 75%. Detailed analysis of geometric errors revealed small, dm-level planimetric offsets in the LiDAR data sets that affected the results notably.

Vegetation classification of the European Russian tundra and taiga ecosystems using multiple spatial scale satellite images

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Our work is part of the EU funded Carbo-North project (http://www.carbonorth.net), which goal is to quantify the carbon budgets in Northern Russian taiga and tundra environments in a changing climate. Our aim is to classify the vegetation and allocated biomass in the area using Quickbird, Aster and Landsat images. In a later phase, also MODIS images will be used. The field work for the project was started in summer 2007 in the tundra region and will continue on 2008 in the taiga region. Vegetation biomass in the area is analysed using multiple 900 m long transects – each transect consists 30 biomass collection points. Vegetation classification of the first Quickbird images has been done using eCognition. The information from biomass transects was used as reference data for the classification, and additional collected ground truth data was used in accuracy analysis. The problem of mixed pixels was treated with fuzzy classification method. The classification results of the Quickbird images will be used as training areas for Aster and Landsat images; which classification results will then be used as training areas for MODIS images. The results of classification will be used in carbon flux measurement upscaling, soil carbon studies, and in ecosystem-climate models.

Session 2: Radiative transfer and physically-based models

Remote sensing of vegetation based on spectrally invariant structure parameters

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The theoretical basis and applicability of the recollision probability for use in physically based optical remote sensing of vegetation is discussed based on results from the SPRINTER project. The recollision probability p is defined as the probability that a photon scattered from a leaf in the canopy will interact within the canopy again. It belongs to a small set of wavelength-independent canopy structural parameters, so called spectral invariants, which link together canopy and leaf optical properties. The spectral invariants allow for a simple and accurate parameterization for the canopy shortwave radiation budget, i.e. the partitioning of the incoming radiation into canopy absorption, transmission and reflection at all wavelengths of the solar spectrum.

A forest reflectance model based on the recollision probability concept is developed in the SPRINTER project. The dependence of p on canopy structure is investigated from the perspective of being able to (1) quantitatively describe the spectral reflectance of a plant canopy in terms of its structural properties and the single scattering albedo of its basic elements, the leaves, and (2) extract canopy structural characteristics from the reflected, remotely sensed multispectral signal when leaf albedo is known.

Contribution of multiply-scattered radiation to multi-angular forest reflectance

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It has been widely acknowledged that the information content (possibly hyperspectral) multi-angular vegetation reflectance measurements is larger than that of remote sensing data obtained at one view angle only. Thus, multi-angular data is expected to contain additional information on canopy structure, ground reflectance or other factors influencing the shape of the bidirectional reflectance factor. As a first step to retrieve such information, an attempt is made to decompose the reflected signal into contributions of first- and higher-order scattering inside the forest. The higher-order reflectance component is expected to give a picture of the diffuse scattering characteristics, related to, for example, the photon recollision probability. First-order scattering inside a canopy, on the other hand, depends linearly on the leaf single-scattering albedo.

Simulation of the effect of forest floor on forest albedo

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An existing forest reflectance model based on photon recollision probability is extended to be applicable also for snow covered forest floors. In summer conditions (small forest floor albedo), as is normally assumed, the part of the total forest albedo originating from the forest floor is mainly from bidirectional transmission through gaps in the canopy (photons transmitted without interaction through the canopy first downwards and then upwards after being reflected at the forest floor). The extended model developed in this paper additionally takes into account multiple scattered photons which have interacted within the canopy prior to or/and after being reflected by the forest floor. The bidirectional reflectance distribution function (BRDF) of the forest floor is assumed to be a mixture of Lambertian and purely forward/backward scattering surface. Results show that snow covered forest floor affects the total canopy albedo to a large extent via this multiple scattered component included in the model. If it is not taken into account the canopy albedo estimate may be up to 0.2 units too small. Lambertian and forward/ backscattering forest floors caused practically similar total forest albedo values for moderate sun zenith angle values. The black and white sky albedo values are very similar. The developed albedo model was successfully used to simulate the main features of measured albedo values.

Structural parameterization of Norway spruce trees in radiative transfer of high spatial resolution

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The chronic environmental stresses are responsible for the long term, but significant changes in architecture of Norway spruce (Picea abies /L./ Karst.) crowns. The acute stress events (e.g., bark beetle outbreaks) can cause a rapid and severe defoliation of spruce trees in very short time, resulting in forest canopy of dead (fully defoliated) and surviving (partially defoliated, but photosynthetically active and regenerating) trees. A physical radiative transfer modelling through such a structurally heterogeneous forest canopy can be required for quantitative retrievals of canopy structural and biochemical properties from the optical remote sensing data of high spatial resolution.

Advanced geometrical and structural parameterization reflecting eco-physiological features of the forest canopy has been implemented in last versions of the Discrete Anisotropic Radiative Transfer (DART) model (Gastellu-Etchegorry et al., 2004). Apart from basic tree allometric characteristics (i.e., tree height, stem diameter and length, crown length and shape, etc.), several parameters adjusting spatial distribution of the green foliage and the woody elements (trunks, branches of first order, and small twigs) can be specified (Malenovsky et al., 2008). However, representative parameterization of these structural variables is quite a technical challenge, especially for a fully grown mature forest canopy.

A ground-based terrestrial LiDAR (Light/Laser Detection And Ranging) system Ilris-3D (Optech Inc., Canada) was employed in scanning of several front trees of mature montaine Norway spruce stands (Moravian-Silesian Beskydy Mts., Czech Republic; 18.54°E, 49.50°N) in order to retrieve their structural and geometrical parameters. Processing of the LiDAR data separated cloud points of leaf and wood biomass of each scanned tree, which revealed basic tree dimensions (tree and crown metrics and shape parameters), and branching architecture (number and prevailing zenith angle of main branches in respect to the tree stem). Statistical analyses of leaf biomass returned laser hits allowed to estimate spatial parameters of leaf vertical and horizontal distribution including foliage clumping. Nevertheless, spatial distribution of fine woody elements (small shoot twigs) could not be properly quantified.

Session 4: Field measurements of reflected and transmitted radiation fields

Hyperspectral reflectance of boreonemoral forests in a dry and normal summer

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Visible-near infrared (VNIR) reflectance of several mature boreonemoral stands in Estonia was measured in two sequent years which differed significantly in precipitation. Custom-designed VNIR spectrometer systems UAVSpec and UAVSpec2, boarded on a helicopter, were used for the measurements. The comparison of measured data for both years is presented.

Hyperspectral laser measurement system: application to coniferous needles and branches

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We have developed a method for laser-based spectral backscatter measurement enables a broad bandwidth and spectral research of the backscattered laser light. In the future this type of imaging instruments can be used for various applications forest remote sensing, e.g. recognition of plants and tree detection. The hyperspectral scanning intensity measurement system is based on the supercontinuum laser source and a spectrometer connected into a backscatter probe. Rotators are used to produce a scanning measurement over a target surface. The hyperspectral intensity at each point can be georeferenced with a range measurement (point cloud) from a terrestrial laser scanner. We demonstrate the method for hyperspectral measurements of coniferous needles and branches. The scanned hyperspectral intensity combined with laser scanner range data will provide an effective change detection and target recognition tool for laser remote sensing, which has thus far been mostly based on the use of monochromatic laser intensity.

Reflectance of snow in forests: field measurements, modelling, and applications

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Boreal forests are several months of the year covered by snow. Snow changes the reflectance properties remarkably. We have measured the bidirectional reflectance factors and linear polarisation of snow during several campaigns. We present some sample results. We can say at least that snow, as every other natural targets, is far away from ideal Lamberian scatterer, with a strong forward component. Different snow types have varying reflectance properties, allowing inverting for grain size rather well, and getting some hints of melting. We have developed physical reflectance model for snow (applying also to soil). We compare model and measurement results. We further discuss how the model interplays with forest modelling issues. We discuss the effects of snow and understorey vegetation for remote sensing of forests.

Measurement of scattering function and polarization from pine and spruce shoots

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We measured scattering functions of pine and spruce shoots in laboratory. Polarization level of the scattered light was also monitored during measurements. Aim of the experiment was to develop a working measurement setup for more systematic shoot research. Gathered data provides also a good basis for scattering model development.

Measured effective spectral region spanned from 400 to 2000 nm. The scattered light was measured at scattering angles from 20 to 160 degrees varying the inclination of the shoot in three spatial angles.

Several improvements considering the equipment and measurement setup were found out to be needed. Quality of the lighting and optics play vital role for acquiring a reasonable signal-to-noise ratio in measured data. Results from gathered data imply that the horizontal polarization is slightly dominant in backward direction. Vertically polarized component became stronger than horizontal one as angle of view was moved to forward direction. Variations in reflected radiance between different samples were large even when samples had been taken from the same tree. The forward and backward scattering seemed to depend on the orientation and tilt of a shoot. Reflection measured from pine shoot was higher than the one measured from spruce shoots.

Done experiment has a good potential to provide valuable information about scattering properties of individual coniferous shoots. It would be sound to extend this type of experiment for branches of deciduous trees as well. Data with good angular and spectral accuracy can be utilized well in tree crown and light ray simulation development.

Session 5: Characterization of forest 3D structure

Combining LAI-2000 PCA and digital camera for gap fraction measurements

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Modern digital cameras equipped with hemispherical lenses provide an attractive opportunity for measuring canopy transmittance at high angular resolution. Since the cameras are intended rather for digital photography and not for precise radiation measurements, the prior calibration and special post-measurement data processing methods are needed. On more advanced cameras it is possible to save the CCD or CMOS sensor readings in raw format without any further corrections (gamma etc.) applied. Saved signal is linearly dependent on the radiation intensity and therefore directly comparable to that measured with LAI-2000 PCA. Issues related to calibration of digital cameras, some meteorological aspects during the field measurements and data processing are discussed. Results from the three stands from Järvselja, Estonia proposed for RAMI-4 (RAdiation transfer Model Intercomparison) experiment are presented.

Automated estimation of LAI from hemispherical canopy images

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Digital hemispherical canopy images are a popular method for field estimation of leaf area index (LAI), which is a key parameter in many physical reflectance models. A critical phase in the analysis of the images is the setting of a threshold to separate the sky and canopy pixels into a binary image. The threshold has traditionally been selected manually using some software with an interactive user interface, but in recent studies the use of automated thresholding algorithms has been recommended to hasten the process and decrease its subjectivity. In this study two suggested thresholding algorithms, Nobis & Hunziker 2005 and Ridler & Calvard 1978, were implemented with MATLAB and used to automatically analyze a set of images (n=80) obtained from Sodankylä, Northern Finland. For comparison, the LAI in the locations of the images was also measured with LAI-2000 Plant Canopy Analyzer, which is one commonly accepted instrument for acquiring reliable LAI estimates. When compared to LAI-2000, the Nobis & Hunziker algorithm obtained an RMSE of 0.12 (11.2%) and a bias of -0.04 (-4.1%) after clearly misclassified images (n=2) were removed. Correspondingly, the Ridler & Calvard algorithm yielded an RMSE of 0.38 (36.2%) and a bias of 0.31 (29.6%), i.e. it clearly underestimated the LAI but had no distinctive misclassified images. The results indicate that the Nobis-Hunziker algorithm can be used to obtain reliable LAI estimates provided that the binary images are checked and the clearly erroneous observations are removed.

Quantifying tree crown shape and structure using alpha shape metrics of ALS data

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Parameters of species-specific crown shape and structure are of great interest in the field of several different applications. In operative forestry, different crown structures and dimensions could be used for estimating the actual tree dimensions, the development, and the need for silvicultural operations of a forest stand. Parameters describing crown shape would be useful for discriminating between tree species, and for modeling plant architecture. It is known, that airborne laser scanning provides detailed information on the forest canopy in form of 3D points, with which the tree crowns could be reconstructed using proper methods. It is probable that an object adapting to small-level variations recorded by advanced scanners could in most cases be more useful a shape approximate than one based on simple geometrical shapes such as cones or ellipsoids.

Computational geometry is a branch of computer science, which deals with the study of algorithms and data structures for solving problems stated in terms of basic geometrical objects, such as points, line segments, and polygons. The alpha shape technique is a computational geometry approach to formalize the intuitive notion of "shape" for a set of points. The parameter alpha defines the level of detail in the resulting shape. It can form cavities and holes, and even be disconnected depending on the alpha value and the properties of the input point set. The purpose of this presentation is to demonstrate possible ways to use laser point clouds for approximating central dimensions of tree crowns and quantifying parameters of shape and structure by means of alpha shapes and other methods applied from computational geometry.

A model-based approach for ALS-based forest inventory

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In a recent submitted manuscript, we presented a new, model-based approach for estimating forest attributes using observations of canopy height. The paper derived a function that parameterizes the distribution of canopy height observations using stand density, species proportions, and two parameters for each species-specific distribution of tree heights. The approach is based on fitting that distribution to observations of canopy height by a method based on the maximum likelihood principle. The approach could provide an alternative to the currently available methods for estimating forest attributes using ALS data. The method was found promising in an evaluation with both simulated and real ALS-based sample plots. However, the approach is based on quite restrictive assumptions on spatial pattern of tree locations, species-specific distribution of tree heights, and characterization of individual tree crown. For example, the individual tree crowns are characterized by a simple species-specific function for crown shape, and tree size that scales the shape for trees of different shape. The next step in model improvement would be relaxing these assumptions. One of those challenges would be the development of a more realistic characterization of individual tree crowns. This development would surely benefit from utilizing the currently available models for the behavior of light in forest canopies.

Effects of forest ownership and change on forest harvest rates, types, and trends in northern Maine

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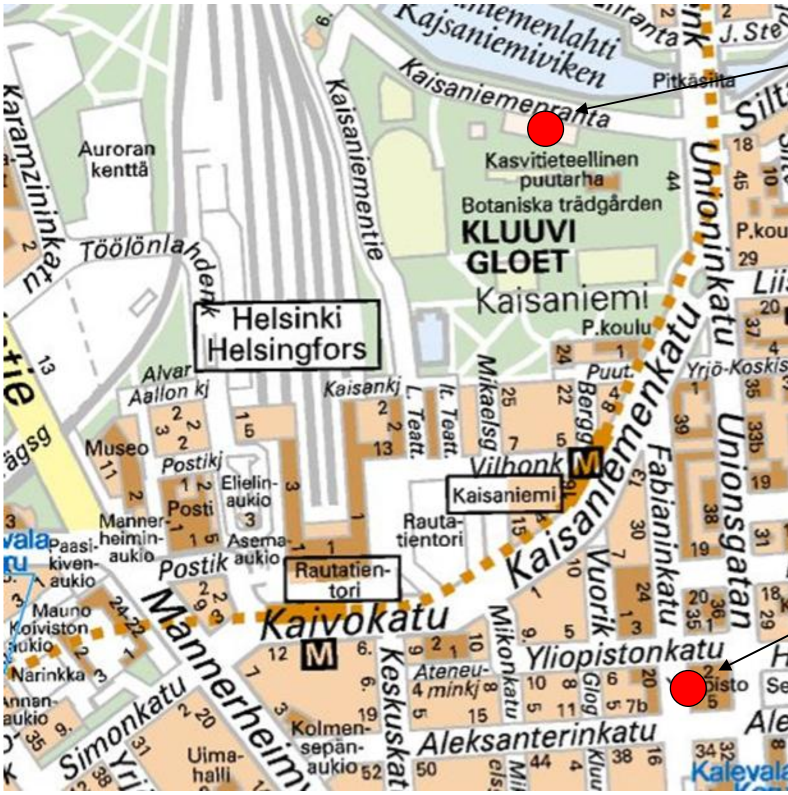
Forest ownership maps from 1994, 2000 and 2004 were analyzed with land cover maps (early 1990s) and forest change detection maps derived from Landsat imagery (1991, 2000, 2004). Between 1994 and 2000, roughly 80% of the Industrial forest ownership in a northern Maine study area changed hands. Approximately 75% of these forestlands were sold to Timber Investment Management Organizations (TIMOs) and 25% to other Industrial owners. Non-Government Organizations (NGOs) and Logger/Short-term Investors (LDs) purchased smaller parcels of forestland from the Industrial and TIMO sellers, from 1994 to 2004. Landsat change detection methods indicated a general trend in landowners' preference to harvest softwood and softwood–hardwood in the 1980s, softwood–hardwood and hardwood–softwood stands in the 1990s, and nearly a balanced proportion of four forest types between 2000 and 2004; however, these trends varied among individual landowners. Industrial ownership type harvested the highest percentage of forest in the 1980s, but not in the 1990s and early 2000s. The TIMOs and LDs harvested a higher percentage of forest in the 1990s and early 2000s, while the NGOs harvested less. The Non-Industrial Private Forest (NIPF) held more stable ownership through time and had more equal and intermediate harvest rates through time. Forest land that experienced no ownership change had significantly lower harvest rates than land that changed ownership between 1994 and 2000. Given the rates of past harvesting and current composition of forestland, the estimated average forest disturbance rotation on the 2004 Industrial ownership would be 51 years, compared to 70 years for NIPF forestlands.

WORKSHOP VENUES



Workshop dinner:
Restaurant Viola,
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Workshop:
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SNS - SamNordisk Skogforskning
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PHYSENSE
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