REMOTE SENSING OF FOLIAR MASS AND CHLOROPHYLL AS INDICATORS OF FOREST HEALTH: PRELIMINARY RESULTS FROM A PROJECT IN NORWAY

S. Solberg[a], E. Næsset[b], L. Aurdal[c], H. Lange[a], O.M. Bollandsås[b] and R. Solberg[c]

[a] Norwegian Forest Research Institute, Ås, Norway, email: svein.solberg@skogforsk.no
[b] Norwegian University of Life Sciences, Ås, Norway
[c] Norwegian Computing Centre, Oslo, Norway

ABSTRACT

Variations in foliar mass and chlorophyll concentration are likely to reflect temporal variation in forest health well, by capturing both defoliation and discoloration symptoms. Canopy chlorophyll mass is the product of foliar mass and chlorophyll concentration. In the current project, we try to model these two variables using airborne LiDAR and hyper-spectral data, respectively. On ground we have data on foliar mass and chlorophyll concentrations from 16 sample plots dominated by Norway spruce (*Picea abies*). Based on the models, we use the airborne data to scale up estimates for both variables to a larger forest area. Up-scaled estimates are correlated to satellite data. The results are preliminary

Keywords: remote sensing, forest health, LAI, foliar mass, chlorophyll, laser scanning, spectral data.

1 INTRODUCTION

On the global scale, forests are threatened by population growth and human activities, including deforestation, air pollution; climate change; and spread of pests and diseases across continents. There is a need for quantitative information on forest health, and how it varies in space and time. Important here is the need for a quantitative and general health variable integrating across diagnoses, because the above mentioned threats to forest health may be manifested by a wide range of different damage types. Remote sensing might now provide useful tools for forest health monitoring at large scale. Remote sensing has already demonstrated its ability to provide forest health-relevant data, such as Leaf Area Index (LAI) and leaf loss (Brandtberg *et al.,* 2003; Lefsky *et al.,* 1999; Schaepman *et al.,* 2004), chlorophyll (Malenovský, 2002, Zarco-Tejada *et al.,* 2004), foliar nutrients (Martin and Aber, 1997), and identification of trees having root diseases (Leckie *et al.,* 2004). In the current project we try to develop methods for remote sensing of foliar mass per unit ground area (or LAI) and chlorophyll concentration, as suitable measures of variation in forest health. We intend to estimate the two variables using airborne LiDAR and hyper-spectral data, respectively. The two variables correspond to the traditional, ground based forest health variables defoliation and discoloration, as used by the European forest monitoring program UN-ECE/ICP-Forests since 1986 (Anon., 2002). The product of foliar mass and chlorophyll concentration is canopy chlorophyll mass per area, and is one general variable integrating effects across any type of forest damage. The aim of this paper is to present the outline and preliminary results from our project.

2 MATERIALS

The area for this study is located near Oslo, in south-eastern Norway (59º 50´N, 11º 02´E, 190–370 m a.s.l). The size of the area is 6 km^2, comprising mainly Norway spruce (*Picea abies* L. Karst.) and some Scots pine (*Pinus sylvestris* L.). A large part of the area consists of old forest stands only. This area is a forest reserve, where no clear-cuttings have been executed since 1940 and it is considered as a primeval forest, being partly multi-layered. The data were collected during summer 2003, except the airborne hyper-spectral data that were acquired in June 2004.

We subjectively selected 16 circular spruce sites (1000 m^2) as sample plots, being in four age-classes from young plantations to old stands. We used differential GPS/GLONASS for determining plot coordinates in field according to the procedures proposed by Næsset (2001; 2004). Positions of all trees were obtained by additional measurements of their polar coordinates within the plot. We recorded diameter at breast height (dbh), defoliation, discolouration, social status, and species of the trees. On each plot, four of the non-suppressed trees were systematically selected as sample trees, in total 64 sample trees, with additional measurements and branch sampling for foliar mass and chlorophyll measurements. Branches were sampled from the lower, the middle and the upper parts of the crown. For 11 of the sample plots, we measured optical Leaf Area Index using a LiCor LAI-2000 plant canopy analyzer. For each plot, five LAI readings were obtained by measuring at the centre and 3 m away from the centre in each of the four cardinal directions. These LAI measurements were done as a measure of foliar mass, being an alternative approach to the foliar mass measurements of the sample trees. The forest area was classified into stands, with tree species and age class given for each stand. This was done as part of an operational forest inventory by a commercial company in Norway (Prevista).

Laser data were acquired on October 10, 2003, by a Hughes 500 helicopter carrying the ALTM 1233 laser scanning system produced by Optech, Canada. The leaf conditions were in an intermediate state, i.e. the deciduous trees were still foliferous at the time of the flight. The average flying altitude was approximately 600 m. First and last returns were recorded. The last return data were used to model the terrain surface. Hyper-spectral data were acquired on June 30, 2004, by a Cessna 172 airplane carrying the ASI (Airborne Spectral Imager) developed by Norsk Elektro Optikk AS, Norway (Anon., 2004). The average flying altitude was 900-1200 m above the ground. The data set was radiometrically calibrated to obtain radiance. We used the VNIR module of the ASI instrument, which is a pushbroom scanner covering 400-1000 nm in 160 bands. For both flights, GPS and inertial navigation system data were logged continuously to provide geometric correction and geo-referencing.

We have one SPOT quarter-scene aquired on August 17, 2003. The image is a level 3 SPOT image with a spatial resolution of 10x10 m; four spectral bands: green, red, NIR and SWIR. The image was geo-referenced and radiometrically corrected.

3 METHODS

In order to assign pixels from the airborne hyper-spectral data set uniquely to sample trees, the crown outlines were modelled using the LiDAR point cloud. This was done by filtering out the uppermost LiDAR points; making a digital canopy surface model (DSM) by smoothing these points into a grid; and applying a watershed algorithm to identify the tree crown outlines for each local maximum. These outlines (polygons) were then linked to the tree numbers from the ground data, based on the stem coordinates of the trees. Hyper-spectral pixels were then derived from an overlay of these polygons on the hyper-spectral images.

We estimated LAI from LiDAR data assuming that laser pulses penetrate the canopy layer in a similar way as solar radiation. The penetration of visible light through a canopy approximates the Beer-Lambert law:

$$\ln I_z / I_0 = -k\text{LAI},$$

where I_z and I_0 are light intensity below and above the canopy, respectively, and k is an extinction coefficient being species specific (Waring and Schlesinger, 1985). We assumed that the same applies for penetration of laser pulses through the canopy, and estimated a transformed version of this model:

$$\text{LAI} = a \ln N/n_g,$$

i.e. a linear, non-intercept regression model where N were the total number of LiDAR points and n_g the number of LiDAR points below the canopy (ground hits). We parameterized this equation using the eleven plots with ground based LAI-2000 measurements, together with LiDAR data for the circular 1000 m^2 sample plots. Recalculating the LiDAR data according to this model provided LiDAR based LAI estimates for the entire area, i.e. for every 10x10 m square matching the 10x10 m pixels in the SPOT data.

We selected chlorophyll concentrations measured in the upper part of the tree crowns for correlating with hyper-spectral data. In general, green plants have a very specific spectral signature, with low reflectance in visible light, and high reflectance in the near infrared range, i.e. the red-edge effect. We correlated chlorophyll concentrations to spectral variables that reflect this red-edge effect, i.e. so far NDVI. We calculated NDVI by summing channels in accordance with the wavelengths used in SPOT 5, i.e. red = 610-680 nm, and NIR = 780-890 nm.

We search for empirical relationships between satellite data and foliar mass and chlorophyll concentrations, where the latter two variables are estimated at a large scale using airborne data together with models between airborne data and ground data.

3 RESULTS AND DISCUSSION

The modelling of the digital canopy surface model (DSM) based on LiDAR data was quite successful, although some of the plots had a rather heterogeneous structure (Fig. 1). The tree segmentation algorithm used identified the ground based trees fairly well. All predominant trees were identified, around 70% of the dominant trees and 45% of the co-dominant trees.

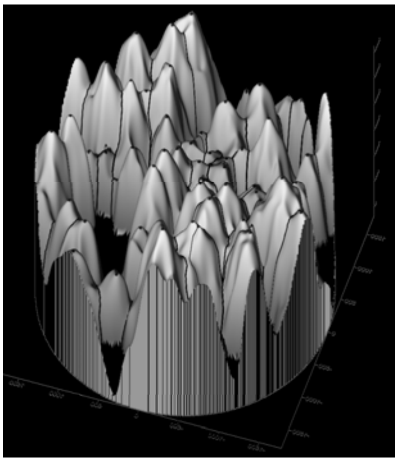

Figure 1. DSM model of a 1000 m^2 plot in an old Norway spruce stand, visualized in 3D. Local maxima, being tree top candidates, are marked.

As expected, the relationship between LiDAR data and ground based LAI values followed nicely the Beer-Lambert law, where the intercept was non-significant and was discarded, and with a high R-square (Fig. 2). This, together with SPOT satellite data and forest stand data produced a data set of 46,000 pixels having both LAI estimates and SPOT NDVI, and where the main tree species was Norway spruce (Fig. 3). There was a relationship between the two variables LAI and NDVI. High LAI values and high NDVI values were generally seen in dense or old forests, mostly in lower parts of the terrain, while low values were seen mostly in upper hillsides and hill tops, which are dominated by scattered pine and aspen trees, and on clear cuttings and young stands. A preliminary, non-linear model between LAI and NDVI, following the approach of Roberts *et al.* (2004), gave a weak but significant relationship (R^2=0.16), with a saturation point of ca. 0.8 for NDVI at LAI-values around 4 and higher, when excluding clear-cuttings.

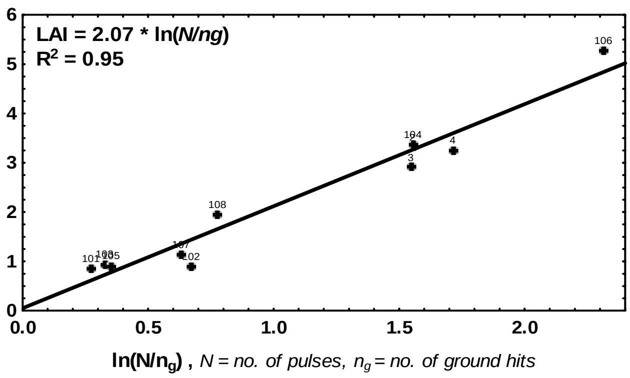

Figure 2. Linear regression of ground based LAI-2000 measurements against LiDAR 1. return data for eleven 1000 m2 circular plots of Norway spruce. Point labels = plot numberings.

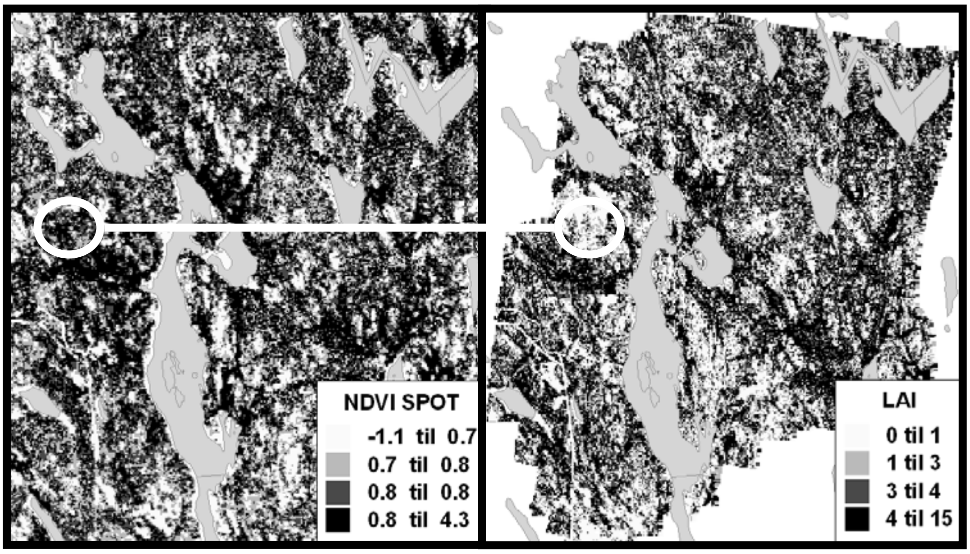

Figure 3. Comparison of SPOT NDVI (left) and LAI estimates based on airborne LiDAR (right) for the ~6km^2 forest area Østmarka. A general consistency is seen. However, also areas with low consistency are evident, one of which is marked with a white circle.

However, the match between NDVI and LAI was far from perfect. Some stands with young spruce trees had high NDVI values, but low LAI values. This is evident in the area marked with a circle in Fig. 3, being a spruce stand with tree heights around 1-2 m. A closer look on one of our sample plots in this area is shown in Fig. 4. The trees are evident in the normal black and white image, and they are also indicated by their crown segment polygons. However, in the NDVI-image the trees are no longer as clearly distinguishable from non-tree objects, likely due to chlorophyll-rich vegetation, seen as dark areas in-between the trees. This illustrates a possible limitation of the easily available spectral data from satellites.

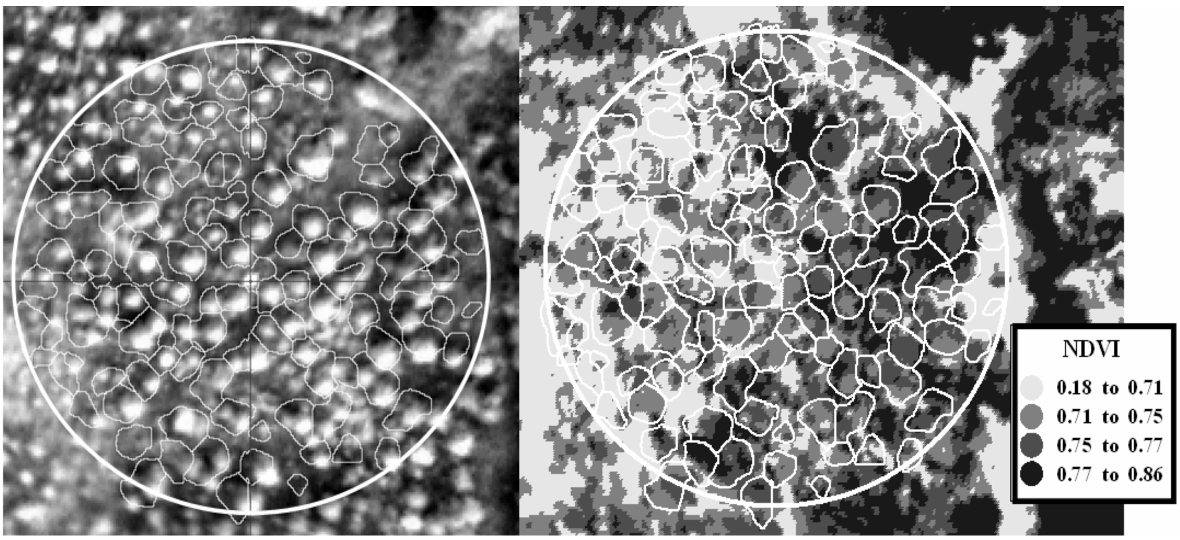

Figure 4. Polygons for the tree crown segments overlaid on black and white images of the airborne hyper-spectral data, normal black and white, i.e. visible light (left); and NDVI (right).

The second part of the work was the modelling of foliar chlorophyll concentrations using hyper-spectral data. Here we are in the beginning of the work only. We have started to overlay tree outline polygons on the hyper-spectral images, in order to derive hyper-spectral data for each of the 64 sample trees with chlorophyll concentration data. So far, we have data for 16 of the 64 sample trees. The spectral data followed the characteristic signature for vegetation, and this signature was quite stable within the entire tree crown, although the intensity varied from pixel to pixel (Fig. 5). Foliage chlorophyll concentrations in the upper canopy were positively, but only weakly (R^2=0.12) related to NDVI in the hyper-spectral data.

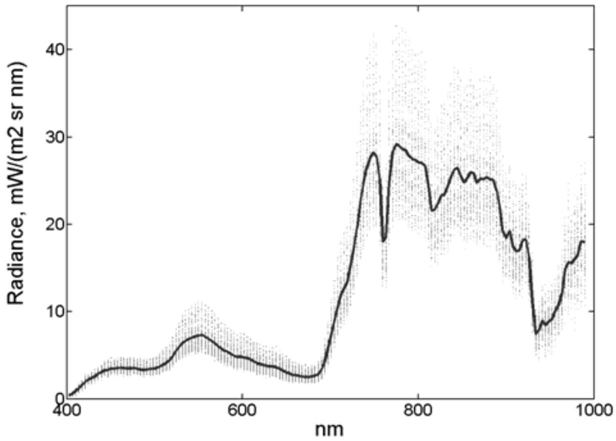

Figure 5. Spectral signature for one young spruce tree, comprising 116 pixels. Radiance for all pixels is shown as black dots, while the mean radiance across pixels is shown as a line.

ACKNOWLEDGMENTS

Norwegian forest research institute and Norwegian space agency are acknowledged for financing major parts of the study. Ivar Baarstad and Trond Løke from Norsk Elektro Optikk AS are acknowledged for recording and georeferencing of hyper-spectral images with the ASI sensor.

REFERENCES

Brandtberg, T., Warner, T., Landenberger, R. and McGraw, J., 2003. Detection and Analysis of Individual Leaf-off Tree Crowns in Small Footprint, High Sampling Density Lidar Data from the Eastern Deciduous Forest in North America, *Remote Sensing of Environment*, vol. 85, no. 3, pages 290-303.

Lefsky, M., Cohen, W., Acker, S., Parker, G., Spies, T. and Harding, D. 1999. Lidar Remote Sensing of the Canopy Structure and Biophysical Properties of Douglas-Fir Western Hemlock Forests, *Remote Sensing of Environment*, vol. 70, no. 3, pages 339-361.

Schaepman, M.E., Koetz, B., Schaepman-Strub, G., Zimmermann, N.E. and Itten, K.I. 2005. Quantitative retrieval of biogeophysical characteristics using imaging spectroscopy: a mountain forest case study. *Community Ecology*, in press.

Malenovský 2002. Investigation of functional parts and status of Norway spruce crowns using spectral remote sensing information. Thesis Report GIRS 25. Lab of Geo-Inf Science and Rem Sens, Wageningen Univ, pp. 1-74

Zarco-Tejada, P.J., Miller, J.R., Morales, A., Berjón, A. and Agüera, J. 2004. Hyper-spectral indices and model simulation for chlorophyll estimation in open-canopy tree crops. *Remote Sensing of Environment* 90, 463-476.

Martin, M.E. and Aber, J. D. 1997. High spectral resolution remote sensing of forest canopy lignin, nitrogen, and ecosystem processes. *Ecological Applications* 7: 431-443.

Leckie, D.G., Jay, C., Gougeon, F.A., Sturrock, R.N. and Paradine, D. 2004. Detection and assessment of trees with Phellinus weirii (laminated root rot) using high resolution multi-spectral imagery. *International Journal of Remote Sensing* 25, 793-818.

Anon. 2002. UN/ECE & EC. / Lorenz, M., Mues, V., Becher, G., Müller-Edzards, Ch., Luyssaert, S., Raitio, H., Fürst, A., and Langouche, D. Forest Condition in Europe - 2003 Technical Report, Geneva, Brussels

Næsset, E. 2001. Effects of differential single- and dual-frequency GPS and GLONASS observations on point accuracy under forest canopies, *Photogramm. Eng. Remote Sensing* 67, 1021-1026.

Næsset, E. 2004. Practical large-scale forest stand inventory using small-footprint airborne scanning laser. *Scand. J. For. Res*., 19, 164-179.

Anon. 2004. ASI – Airborne spectral imager. NEO (Norsk Elektro Optikk AS) http://www.neo.no/asi

Waring and Schlesinger 1985. *Forest ecosystems. Concepts and management.* Academic press. Orlando. 340 pp.

Roberts, D.A., Ustin, S.L., Ogunjemiyo, S., Greenberg, J., Dobrowski, S.Z., Chen, J. and Hinckley, T.M. 2004. Spectral and Structural Measures of Northwest Forest Vegetation at Leaf to Landscape Scales. *Ecosystems* 7, 545-562.