EMMA T1 initial report

Visual interpretation of vegetation characteristics in laser data

EMMA T1 is a project within the research programme EMMA (Environmental Mapping and Monitoring with Airborne laser and digital images, financed by the Swedish Environmental Protection Agency 2009-2012

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Introduction

This report is a deliverable from work package *T1 Visual interpretation* within the research programme EMMA (Environmental Mapping and Monitoring with Airborne laser and digital images). EMMA T1 is a joint effort between Stockholm University, Department of physical geography and quaternary geology, Swedish University of Agricultural Sciences, Department of forest resource management, and Swedish Geotechnical Institute.

The outcome of WP T1 will be implemented both as support to visual classification of aerial imagery and as components in semi-automated procedures targeting Swedish operational environmental monitoring.

WP T1 mainly uses examples and study areas within the agricultural and mountain landscape, where ground structures and field and shrub layer vegetation are of fundamental importance for the conservation values. This is also where the potential use of visual interpretation is greatest, because of the diversity of small scale structures and patterns that are relevant to interpret the effects of site conditions, land use and environmental impact. WP T1 will also extend the work to include coastal issues of relevance to nature conservation. The coastal transition zone is currently poorly dealt with in vegetation mapping, and yet, many of its habitats are included in environmental monitoring efforts. The intersection between water and land is dynamic and ambiguous and a more precise and common delineation of the shoreline and improved classification of shore habitats and their biotic and abiotic characteristics would benefit terrestrial, coastal, as well as aquatic applications.

It would also be immensely useful if recognition of former land use and human influence could be diversified, to distinguish ditches, former arable fields, and structures of former grazing (Doneus et al. 2008), and also extended to characterizing natural site conditions concerning topography, hydrology and soil.

Objectives

The first task of the work package (Task 1, 2009-2010) is the focus of this initial report. The aim of the task is to visually assess and explore key properties in vertical and horizontal vegetation structure from point laser data, with the main emphasis on ground structures and vegetation up to 3 m above the ground.

A number of test sites, covering a variation in the occurrence of key structures and landscape elements have been selected and described by normalization of point data (basic filtering by elevation) and classification procedures for visual interpretation of 3D laser data, and validated by CIR aerial imagery, independently collected field data and photographs.

The main focus has been on identifying such structures that may have the potential to be described by semi-automatic methods over large areas or that cannot reliably be identified from aerial photographs alone, because of overlayering tall vegetation and limited visibility from spectral information or because of shadow effects.

From this, a number of landscape elements and structures related to effects of land use, ecological site conditions and conservation values are identified for further testing and evaluation by a group of interpreters. Special attention will be given to variables such as man-made linear and point features, encroachment/afforestation, dead wood and field layer characteristics. Our main questions are:

1. Which landscape structures and features can be identified from laser data, and how is this affected by the density of the tree canopy?
2. What resolution can be acquired in describing the ground vegetation and shrub layer up to 3 m height?
3. What can visual interpretation with different combination of methods and treatment of laser data add to the vegetation mapping normally performed by visual interpretation of aerial photographs?

Background

There is a great need to map and monitor vegetation and landscape qualities on a detailed scale but with regional or even national coverage. Nature conservation and management need accurate delineation of vegetation and habitats along with descriptive characteristics and dynamics in distribution and driving forces to meet the demands of international agreements and conventions concerning biodiversity and landscape sustainability (Käyhkö & Skånes 2006). Today, vegetation mapping is either on a coarse level derived from satellite imagery or local with great detail but with few opportunities for updates. Extant data with low or unknown precision are often used to assist in the interpretation process. This is not an effective way forward for high-quality environmental monitoring. To speed up the mapping and increase the quality and detail, we need sophisticated tools and assistance to enhance quality and consistency. This calls for the development of new methods for creating future vegetation data that can be used for habitat modelling and monitoring.

The Swedish agricultural landscape is a complex mosaic of different land uses, successions and dynamic processes, including actively used or abandoned grasslands and arable fields. To take into account different processes and small-scale structures at the ground level, also under a tree canopy, a detailed description of site conditions, including land use history, and vegetation structure is needed. In agricultural grasslands, one interest is to obtain detailed maps of variation in vegetation types (Söderström et al. 2001) and large single trees, another is to screen for areas with potential new overgrowth with bushes (Naturvårdsverket 1999).

The vegetation in the mountain landscape is influenced by climate change (Kullman, 2001), reindeer grazing, and locally also tourism. There is a great interest in monitoring these changes (e.g. Grahn, 2008), and especially the change in the ecotone between mountain birch forest and the dwarf-shrub dominated heaths in the low alpine zone, the cover of bare ground, willow scrub and saplings of mountain birch growing out of the dwarf shrubs and becoming a bush layer. Such monitoring is difficult to perform with traditional methods, as the mountain birches have similar spectral properties as the dwarf shrubs, and scattered willow saplings are not spotted as individuals until they are large enough to be distinguished. Both become “hidden” in the heath vegetation. Another difficulty is due to the extreme patchiness of the mountain vegetation, shaded hillsides and extensive cloud coverage. It is thus likely that multi-temporal laser scanning will be the most efficient and objective method to map and monitor changes of the alpine tree line.

Potential use of laser to aid nature conservation applications

Reviews on the usability of laser-derived vegetation structure properties relevant for land cover and habitat characterization, such as stem volume, canopy cover and gaps, tree height, vertical structures, etc., have been recently published and they all indicate great potential for the approach to be further explored (cf. Hill et al. 2002, Tickle et al. 2006, Wallerman & Holmgren 2007, Antonarakis et al. 2008, Vepakomma et al. 2008, Vierling et al. 2008). In open environments, such as grasslands, wetlands and coastal plains, a detailed vertical accuracy is important to resolve low vegetation heights, which calls for great attention to how data are treated (Streutker & Glenn 2006, Sadro et al. 2007).The classification accuracy is enhanced if laser data are integrated with multispectral imagery (Bork & Su 2007).

Important qualities of the vegetation are often hidden from visual and automatic classification in high resolution remote sensing imagery since they are typically covered by a forest canopy (Figure 1). Laser data can to a large extent penetrate the canopy and add crucial information that will increase the degree of detail and consistency in a vegetation mapping effort. One of the aims at European level is to establish a vegetation classification system that can be used over many countries and many different kinds of vegetation communities, and the BioHab classification system, which relies heavily on vegetation height in, for example grasses or woody vegetation is one attempt to meet that requirement (Bunce et al. 2005, 2008, 2010). Also the NILS program, National Inventory of Landscapes in Sweden uses different vegetation heights deduced from colour infrared (CIR) aerial photos (Ståhl et al. 2010) would benefit greatly from new techniques. The hope in this work package is to find ways of enhancing the detail and completeness of the aerial photo interpretation in the NILS program, and optimise cost and effectiveness wherever possible. Another issue is to continue the work with the existing vegetation maps of Sweden in a comprehensive way. In recent studies, laser has also shown to be useful in distinguishing subtle human-made structures at the bare-earth level under the forest canopy (Bailly et al. 2008; Doneus et al. 2008; Gallagher and Josephs 2008). One of the few studies where the use of laser scanning for detection of man-made linear features (e.g., ditches) in the agricultural landscape has been studied is Bailly et al. (2008). It appears that the relationship between the width of the features and the scanning density is critical for these applications.

Figure 1. *Many structures in the vegetation and traces from former land use are hidden under the canopy in most optical data. Using laser data with penetration properties will enhance interpretation of these structures.*

For classification and mapping of mountain vegetation, quite reliable results can be reached already with available optical information such as CIR aerial imagery. The concern is that scattered shrubs of willows in a dwarf-shrub heath will have to be quite dense before they are detected in CIR photos. Dense laser data can provide valuable textural information and improved detailed elevation and terrain models generated from these data will increase the precision and the ecological interpretation of environmental changes. The most important contribution of laser data will probably be to detect subtle changes in tree and shrub vegetation, especially for low-growing and newly established plants, and to provide an accurate digital elevation model, where boulders can be detected and where the moisture of the ground can be automatically calculated through a more reliable wetness index than has existed before (Sørensen & Seibert 2007).

Laser data have also been used in coastal applications to test if classification of shoreline indicators and shore type can be improved by a combined use of laser data and other remote sensing sources although the concept of shoreline is ambiguous and broad in its definition (Boak & Turner 2005). Results show that a combination between laser derived altimetry and multi spectral information improves the classification of coastal habitats and holds significant potential for improving the management planning to meet the impact of climatic changes (Chust et al. 2008). Also the classification of coastal landforms has been successfully tested (Lucieer & Stein 2005).

The prospect of using automatic or semi-automatic methods for mapping ground structures and vegetation is especially important in open, mosaic habitats such as mires and mountain heaths. In such habitats, the number of vegetation elements is limited, but the small-scale mosaic makes the use of manual mapping techniques either extremely time-consuming or generalised to a rather arbitrary level of detail. Automatic or semi-automatic methods would allow the formulation of distinct quantitative rules to describe the mosaic pattern, which could be applied over large areas and monitored over time.

Supportive extant data in vegetation mapping that would greatly improve both the consistency and detail of vegetation data, but also speed up the mapping process considerably, would be to create complete coverage of laser-generated information regarding shrub and tree cover in percentage, shrub and tree height, canopy structure (layers and structure), wetland (peat depth), detailed topography for wetness index and slope angles, ground surface structures (boulders etc), border between land and water, etc., to be used as extant data (e.g. Sørensen et al. 2006).. The long-term ambition of EMMA in general and T1 in particular can contribute to the development of such important laser data derivates.

Material and methods

Study areas

In the original program application, a number of potential study areas were listed. Due to factors such as data availability and time, a limited number of training sites were selected for T1. One of the major reasons for choosing Remningstorp in Västra Götaland and Abisko in Norrbotten was that these sites are also used in other T-projects within EMMA (Figure 2). Below are listed a number of information needs for the respective areas that we have set out to explore during the EMMA program. In this report we will assess some of these questions. Still major work, also beyond EMMA is needed before all the questions are addressed and resolved.

Figure 2. *Study areas, 1 Remningstorp, Västra Götaland, 2 Abisko, Norrbotten, and 3 Åhus, Skåne.*

1 Agricultural landscape – study area Remningstorp

The agricultural landscape in a broad sense includes managed or successional grassland, actively used or abandoned arable fields, but also farm yards, gardens and landscape elements such as farm roads, ditches and field islets. The tree and shrub cover changes rapidly if management is ceased or changed, and successional trees and shrubs are often intermixed with older, established woody plants. The changes occur in a small-scale mosaic of varying site conditions and land use history.

Information needs

The main focus in the agricultural landscape is on the following:

1. Characterizing field layer properties that provide indications of management, such as grazing pressure etc.,
2. Detection of early overgrowth/afforestation, and successional changes,
3. Characterisation and amount of valuable trees and shrubs formed by traditional management, including thorny shrubs and deciduous trees with broad crowns,
4. Classifying site conditions (topography, boulders, rocky outcrops) and some aspects of land use history (e.g., former arable fields), in both open and tree-covered land.

The largest information needs concern management impact and succession at intermediate tree cover and the detection of newly established shrubs that are too low or sparse to be reliably detected by visual interpretation in CIR imagery (Figure 3).

For the interpretation of changes and interactions with management, former land use and site conditions are of great importance, which can be indirectly inferred from topography and ground structure. For example, flat land on sediment with signs of ploughing indicates productive former arable land with a lower potential for developing high species diversity.

Remningstorp landscape

We have concentrated our efforts in a sharply delimited pasture site in the north-eastern part, surrounded by arable fields and containing a large number of old oaks with wide and stag headed crowns. In 2008 there was an extensive clearing of hazel shrubs below and around the oaks, causing a distinct change in the vertical structure. Today, the regenerating hazel shrubs are all in a suppressed state of about 30-70 cm in height, distributed over a large part of the pasture. Furthermore, the field layer is of varying height because of moderate grazing, and the ground surface has a large number of boulders similar in size, 30-100 cm in diameter and up to about 60 cm in height, contributing to the small-scale structural variation in ground surface and vegetation. Small patches with moist vegetation dominated by the tussock-forming grass *Deschampsia cespitosa* adds yet another component to the mosaic. Approximately half of the oak wooded pasture is covered also by a laser registration from before the clearing which is of major importance to our study.

Remningstorp is part of a forest research area, but also comprises a large proportion of agricultural land. Centrally located, there is a large, semi-open pasture area, with variable topography, moisture conditions and a great diversity of broad-leaved trees characteristic of the agricultural landscape. The pasture has formerly contained a large number of agricultural household sites, and the remnants of human settlement can still be clearly seen, in the form of abandoned roads, house basements and remaining fruit trees and shrubs still surviving from the former gardens. This site has been used for some exploratory studies, but also has a great potential for further study of cultural remnants and vegetation structures.

Figure 3. *Early encroachment of open grasslands or forest plantation on former arable fields is threatening the area of open and semi-open landscape needed by many species. Encroachment of this kind is important to monitor on a landscape level.*

2 Mountain region, study area Abisko

The Scandinavian mountains contain a small-scale vegetation mosaic (Rafstedt 1984; Carlsson et al. 1999). The mountain heath types on nutrient-poor soils have been singled out as sensitive to changes due to trampling and mechanical damage (e.g. Allard 2003, Renman 1989, Emanuelsson 1984). The sloping fens in the mountains are intermixed with wet grass and mesic grass patches, which at times are very hard to separate from each other in aerial photos. The warmer climate is a general concern for research, and a number of climate studies also in the fields of plant ecology and potential changes have been performed in the Abisko area during several decades, directed from the Abisko Scientific Research Station (e.g. Callaghan et al. 1995; Barnekow 1999). The site is situated at the valley of Stordalen, 9 km east of Abisko, and part of the site is Nature reserve due to a large mire complex with palsa mire, which has been in focus for major research. The site is also one of the so called Flagship squares in the NILS program, which means that the coordinates of the site can be published, and that the NILS information collected is not in the reported national data of Sweden.

Information needs

The main focus of the mountain studies is on the following:

1. Vertical structure of the field and bottom layer, also addressing boulders and exposed substrate, in the context of Swedish vegetation maps, BioHab classes and NILS variables
2. Monitor increased cover of willows, mountain birch, spruce and pine at higher altitudes

Environmental changes and decreasing reindeer grazing can be predicted to lead to a denser shrub layer, both by willows and by a denser cover of mountain birches. This may alter the conditions for long term biodiversity in the mountain region. Secondly, there are concerns that physical disturbance of the ground vegetation from vehicles may cause erosion or act as water courses down a mountainside.

Abisko landscape

The Abisko area is a site with a long gradient, which comprises several of the important habitat types, from the lake where the mires (fens and bogs), through a boulder-rich mountain birch forest, uphill to mountain birch forest of both heath and meadow types. Towards the top, the tree line gradually changes into heath vegetation with a mixture of moisture regimes and small groups of trees and at the crests the extremely dry heaths turn into bare soil and frost shattered rock. Willow thickets appear all along the mountainside where the surface water is sufficient. An old railway runs through the area and a road that was built in the 1980´s affecting the water runoff into the lower mire area. The entire site is within the reindeer grazing-area and in these parts the reindeer are grazing all the year around and do not have the more common migratory pattern of the southern grazing areas.

3 Coastal zone – study area Åhus, Kristianstad

The studies in the coastal zone will focus on the development of methods for mapping and evaluation of important conditions and characteristics of Natura 2000 areas in accordance with the EU Habitat Directive, coastline changes, erosion and sediment transport and wetlands. EMMA will conduct an integrated coastal project involving several of the A and T projects coordinated by A2 and T1. This has just been launched and the work will mainly be undertaken during 2011 and 2012. However, some initial results also from this study will be presented here.

Coastal zones (shallow water, beaches, dunes and hinterland) are transitional areas in which processes are controlled by complex interactions and fluxes of material between the terrestrial, aquatic and atmospheric systems. As a result, coastal zones are among the most dynamic, rapidly changing and vulnerable environments on earth. Through a combination of laser scanning and digital aerial imagery, these areas can be assessed.

Information needs

The delineation, characterization, and monitoring of the coastal zone is an essential and shared issue between aquatic and terrestrial applications and will therefore be also a focus for the EMMA programme. The shoreline is highly dynamic and dependent on conditions both above and below the present water level. Ongoing climatic changes will have a severe impact on the coastal transition due to expected raise in sea level influencing both aquatic and terrestrial conditions. It is therefore an important challenge to bridge the gap between aquatic and terrestrial application of remote sensing in this zone. Some vegetation features, such as the extent of the reed belts, can partly be monitored with existing methods, but needs to be related to bathymetry and other characteristics of the shore gradient. This can also benefit the detection and classification of wet fens, for example the ones in the Abisko site, where the water level varies and therefore also vegetation height.

The main focus of the coastal studies will be put on the following:

- Establish a common border between land and water and assess the dynamics of this border. This problem is common between the aquatic and terrestrial groups since a common definition would be valuable when an integrated aquatic-terrestrial approach is adapted to the coastal areas.
- How well does today's laser technique cover the transition zone? We know that HawkEye used for seamless land and water registration has a minimum depth of 0.3 m to register information under water. On the other hand the topographic scanner is highly sensitive to water and will not register properly near water.
- How to incorporate the aquatic habitats of importance to nature conservation into a future improved vegetation map and thereby optimize the attention to and solving of transitional coastal issues. Examples of these habitats are: 1110 Sub-littoral sand bancs, 1130 Estuaries, 1140 Periodically exposed clay- and sand bottoms, 1150 Lagoons, and 1160 Large shallow bays and sounds.
- Reed stands – detection, distribution and height, density.
- Simulation of future changes in sea level and its implications for society and nature conservation.

Åhus landscape

Äspet nature reserve is located by the Baltic coast near the outlet of Helge Å River. The area is located completely on postglacial sand with fossil and recent dune forms. The fossil dunes are mainly covered by forest. The forests are a mixture of pine dominated areas and patches with broadleaved deciduous forests of both beech and oak type and mixtures in between. The embryonic young dunes in the open area are mostly exposed sand, covered by grass vegetation towards the inland. The eastern tip of Äspet consists of a lagoon that has been formed over the past decades due to land fill and activities near the river outlet. Äspet is a well chosen example area since it includes many of the above mentioned coastal habitats in one confined area.

Data and software

The data used in this project were mainly laser data of various origin and resolution (table 1) together with high resolution (0.25-0.5 m) CIR aerial photographs. Laser data are extremely large and sets new demands on computers for efficient use in visualizing software.

There is various software that can be use to visualize laser data. Some examples of free-wares are Quick Terrain Reader (www.appliedimagery.com) and Fugro Viewer (www.fugroviewer.com). Note that although these free-ware packages are very useful, they often handle only smaller data sets and have very limited access to tools for analysis and data manipulation.

For this project, the market of commercial software packages was scanned and the most powerful visualization system in combination with analysis capacity to a limited cost was chosen. Also, the degree of complexity and the user interface was considered. Quick Terrain Modeler by Applied Imagery was finally purchased. Even though this is potent software, it has some major limitations for analytical use. This has been communicated to the manufacturer's support in hope to get improved functionality in future releases.

Table 1. *Laser data used in EMMA T1. The data have varying quality in terms of density and coverage. Note that the minimum registration depth for HawkEye is 0.3 m. This means that there will inevitably be a zone between land and water that will be without efficient data coverage*

Study area	Scan date	Point density pts/m2	Laser scanner	Flight height (above ground)	Operator
Abisko	2008-08-01	6-13	TopEye MKII (S/N 425) mounted on Helicopter (SE-HJC)	?	?
Remningstorp					?
	2007-04-24	13-30	TopEye system S/N 425	130-200	?
	2008-09-04	5	TopEye system S/N 724	250	Blom Swe AB/TopEye AB
	2010-09-24	?	?	?	?
Åhus	2010-04-01	1-4 topo 0.1-0.3 bat	HawkEye II, both bat and topo	250-500	Ahab
	2010-04-12	0-0.5	Leica ALS60	2210	LM
	2010-04-15	0-0.5	Leica ALS60	2210	LM

Data manipulation and visual interpretation

Using the point cloud for visual interpretation without prior manipulation is of limited value. Before spending time in search for structures and properties in the vegetation, some basic filtering and classifications are needed (Figure 4).

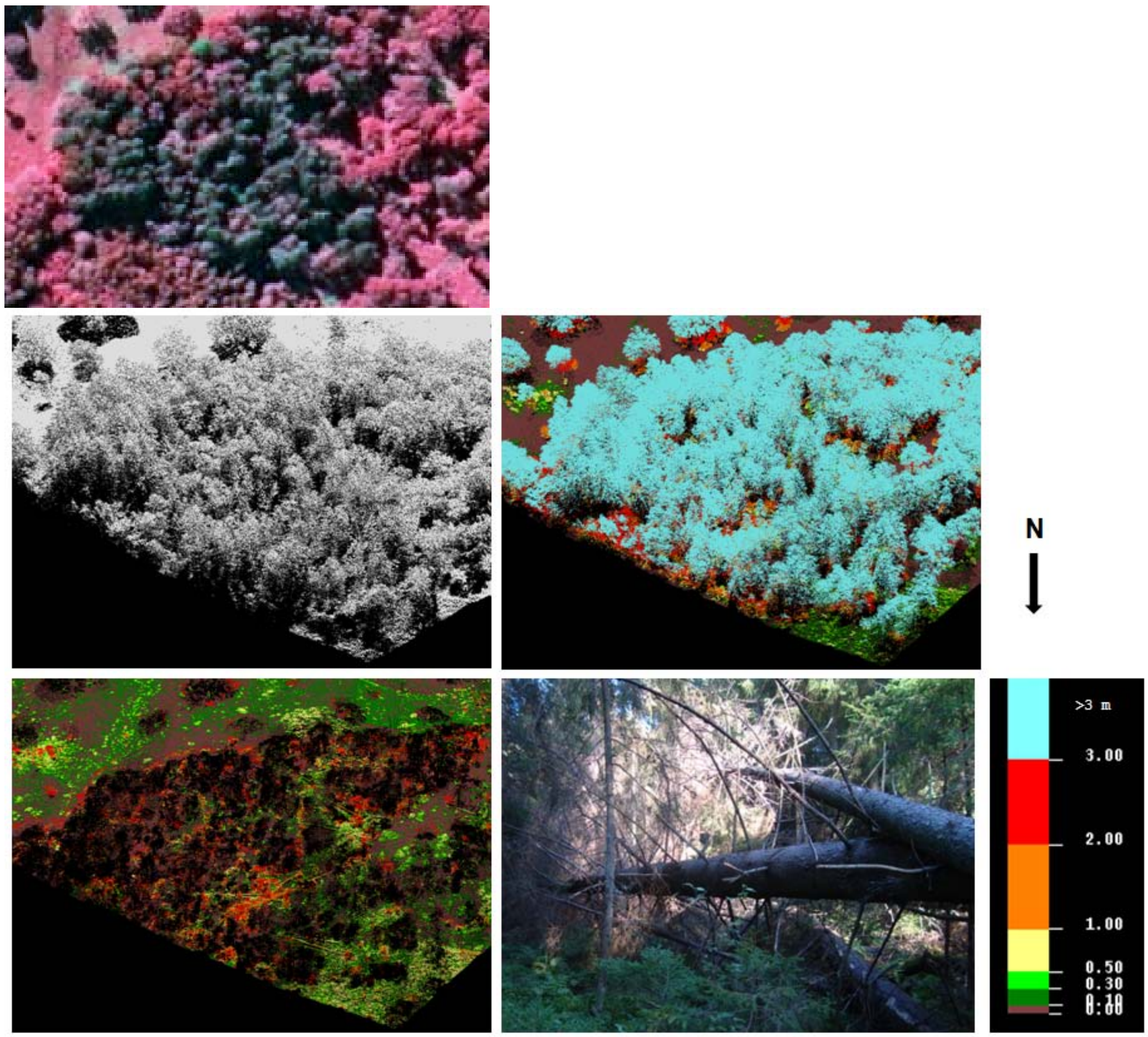


Figure 4. *Enhancement of interpretation through normalization of points and colouration according to height interval above ground (lower left). Removal of points >3m reveals structural details of the lower height intervals hidden by upper canopy, in this case several fallen trees.*

As clearly seen in figure 4, a dense canopy will completely hide the information in optical CIR data. Mainly the canopy surface will be interpreted. With the aid of a high quality bare-earth model generated from the same laser data set, the point in the cloud can be normalised to show height above ground surface instead of relative elevation according to the coordinate system chosen. After this normalisation, the points of the higher vegetation can be “peeled” off to reveal the information about the lower vegetation. This slicing in combination with the 3D view offered by the visualization system, where the data can be turned and examined from any angle, opens up for new and exciting possibilities to examine structures and properties in the vegetation previously restricted to field work.

For this project, the general height of 3 m in the lowlands and 2 m in the mountains, have has been selected to represent the shift between trees and lower vegetation. T1 has then completely focused on the lower vegetation representing field and bush layers. The reasons for this are firstly time issues, and secondly the fact that other efforts within EMMA will focus on the use and development of canopy matching techniques from aerial imagery and laser data to deal with variables such as canopy density and height. It is also for the various structures indicating site properties and land use effects in the ground structure and field-layer vegetation that visual interpretation from laser data has the greatest potential to be of use.

The use of CIR imagery

All of the study areas have CIR aerial photo coverage. The CIR photos give an additional understanding of what is there, and the distinction between boulders and thick bushes is easy to spot. Laser data draped with a CIR orthophoto is a very convenient way to improve the interpretability of laser data, adding the crucial spectral information that is only available in the CIR imagery (Figure 5). However, a warning is needed. It is very important to use imagery and laser data that are collected close in time. If considerable time has passed between the two, colouring the point cloud with CIR spectral information can be directly misleading. For some conditions such as forestry (clearcuts) major changes can occur in short time that completely alters the spectral properties. As an example, if a forest is cut down after CIR registration but before laser registration, the spectral information of the old forest canopy will colour the new clear cut’s open ground, giving the laser points completely false spectral properties.

It could be useful to try the NDVI, Normalized Difference Vegetation Index, to distinguish between vegetated and non-vegetated patches (Mücher et al. 2010), in our case for example where the heath vegetation turns into very low vegetation cover and then to no vegetation cover in the higher parts of the mountains, or to show differences between moist and very exposed heaths, maybe even between the mostly woody vegetation of the heaths from the grasses and herbs. All of these types of vegetation may change with a changing climate, which means that the NDVI index may be of great use. However, this technique has evident problems attached to it since the demand on synchronous images/laser data is an absolute demand in environments with quickly changing conditions (forests, pastures, coastal areas).

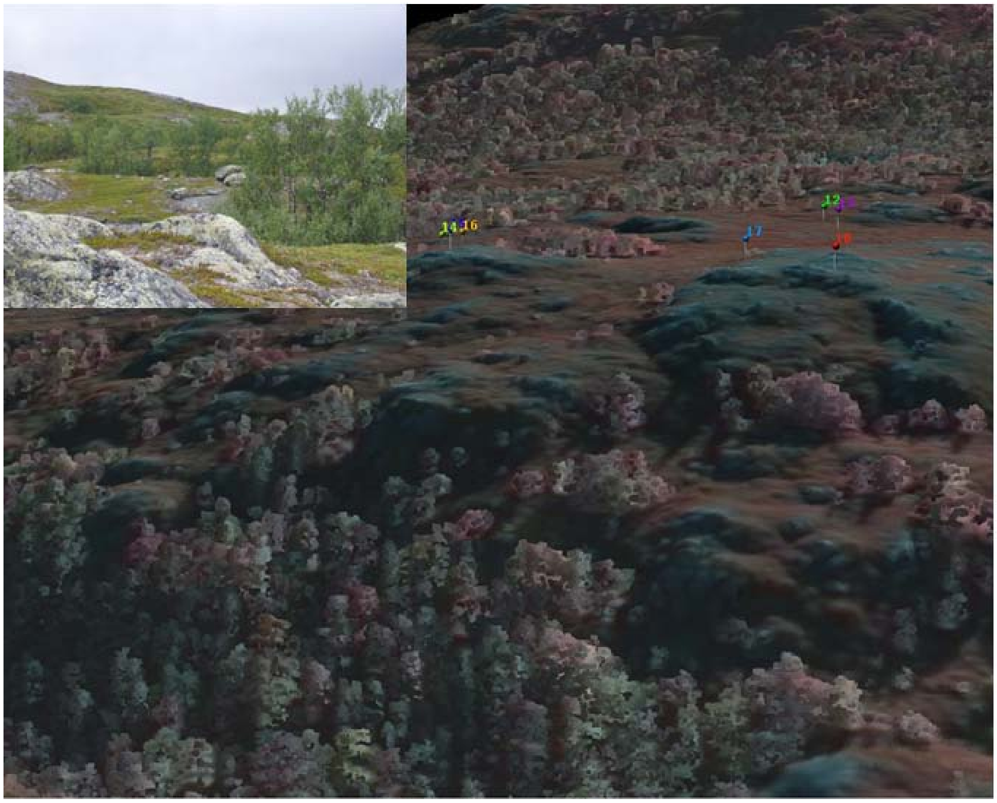


Figure 5. *A representation of the data of the Abisko site. The laser point cloud is draped on the Digital Elevation Model, and each point is coloured by the corresponding point in the ortho photo from the colour infrared aerial photos. In the upper corner there is a corresponding field photo. The numbered markers show field plots.*

Field work

The field work aimed at providing a control and basis for validation of the features and patterns that might be possible to distinguish from visual laser data interpretation. The field work can be divided into five main components:

- Circular plots and belt transects for evaluation of resolution in vertical structure of field and shrub layer vegetation (<3m) – Remningstorp and Abisko
- Identification of different types of vegetation communities, or vegetation types - Abisko
- Mapping and photo documentation of landscape features such as logs, large boulders, stone walls, ditches and fences – Remningstorp and Abisko
- Mapping and detailed type and size description for small-to-medium-sized shrubs and boulders under a variable tree cover – Remningstorp and Abisko
- Identification and photo documentation of coastal habitats in 80 m grid circles to get a first evaluation of the data concerning reed stands, logs and under story vegetation in forests, filed layer and shrub properties and sand dunes – Åhus

Vertical and horizontal structure of field layer vegetation in plots and transects

The circular plots were used as a standard procedure to describe the vertical structure of the ground vegetation and shrubs <3m height, as delimitation of the project in relation to other T-projects. By using plots of 3 m radius with detailed dGPS-positioning, we had the possibility to look at detailed variation in the field layer in comparison with laser data (Figure 14). In Remningstorp, the plots were distributed within the same overall grid as used by T2 and T3, to allow for comparisons. In Abisko, the plots were laid out so that at least 5 plots should fall within a representative area of each vegetation type occurring in the vegetation map of the area. A quantitative comparison was made by dividing laser data into the same height intervals as used in the field inventory and calculating the share of each height interval. As a complementary description, conspicuous structures in the plots such as boulders and shrubs were mapped, to allow for a visual comparison of spatial pattern between field observations and laser visualisations (Figure 14).

In Remningstorp, a complementary approach was used to describe more large-scale patterns in vegetation by the use of belt transects. In the field, the transect was divided into segments (with carefully positioned start and end points) with homogeneous vegetation structure, and a similar description of vegetation cover within each height interval as in the circular plots was done. As in the plots, this was compared with corresponding values for the segments calculated from laser data (Figure 6).

Visual detection of landscape features

The various landscape features in Remningstorp are quite sparsely and unevenly distributed over the area, so we could find no realistic possibility to use a strictly structured sampling design. Instead, we positioned and photo documented a number of more or less conspicuous features in the field, as we came across them, to get more experience on the potential for future detail studies (e.g. Figure 20, 21). The point of departure was to locate key features for validation purposes. In Abisko, the selection was within the different vegetation types, and the ambition was to acquire a good representation of the variety within each type. Boulders were positioned within each field plot and boulder fields were noted, both in the field and in the CIR aerial photos. The boulder fields were all smaller than the mapped units in the vegetation map, and therefore generalised into the surrounding sparse forest.

Distinguishing between low shrubs and boulders in laser data

A potential problem in describing the vertical and horizontal structure of the lower vegetation layers is that the bare-earth model or any analysis tool using laser data may not be able to distinguish between small-scale variations in ground structure from the actual vegetation. To explore this topic, we used the small-scale variation of small hazel shrubs and similarly-sized boulders of the oak pasture in the eastern Remningstorp area to make an extensive, detailed map of both structures over the area (Figure 13, 15, 16).

Table 1. *Key features selected as important variables in T1*

	Field and shrub layer	Ground structures	Landscape features	Tree layer
Forests	Shrubs and understory		Logs	Shading
Grasslands	Vegetation height, tussocks, encroachment*	Stones and boulders, field edges boundaries between moisture regimes	Stone walls, ditches, paths, mounds	Shading, variation in coverage
Mountains	Vegetation height, mosaic, encroachment (willow)	Stones/boulders, exposed substrate	Paths	Mountain birch - coniferous
Shores	Vegetation height,	Sand dunes	reed, shrubs, logs	

Results and discussion

The effect of canopy closure

The initial studies show that several of the variables we searched for could in fact be detected also under some canopy closure and with varying point resolution. Below some of the major findings are presented and illustrated. To quantify the upper limit of canopy closure to allow mapping features under the canopy, would need further studies together with the other T-projects.

Vertical vegetation structures <3m

One main aim of the work in 2009 and 2010 was to investigate what resolution and precision could be achieved in classifying the field layer vegetation according to height from laser data. This was investigated by comparing cover of vegetation height classes both estimated directly in the field and calculated from laser data.

Field and laser data in belt transects and circular plots, Remningstorp and Abisko

The cover distribution from field estimation of transect segments correspond to some extent closely with visual representation of the classified points in the point cloud (Figure 6). The lower grassland vegetation in the western part (which is also partly shaded by a dense oak canopy) is clearly lower, below 10cm, in both laser data and the field estimated data. The eastern, more open part with taller grass tussocks is considerably taller, often >25cm (Figure 6).

Even if there are some examples of good correspondence in the belt transects (Figure 6), in general our efforts to separate low vegetation of varying height were somewhat problematic, which was apparent both from other data of the transects and the data of our circular plots. There seems to be an evident confusion between vegetation < 10 cm and vegetation 10-25 cm in the belt transects. In Abisko the separation was ever lower, < 5 cm and between 5 – 30 cm, and the distinction seems even less relevant.

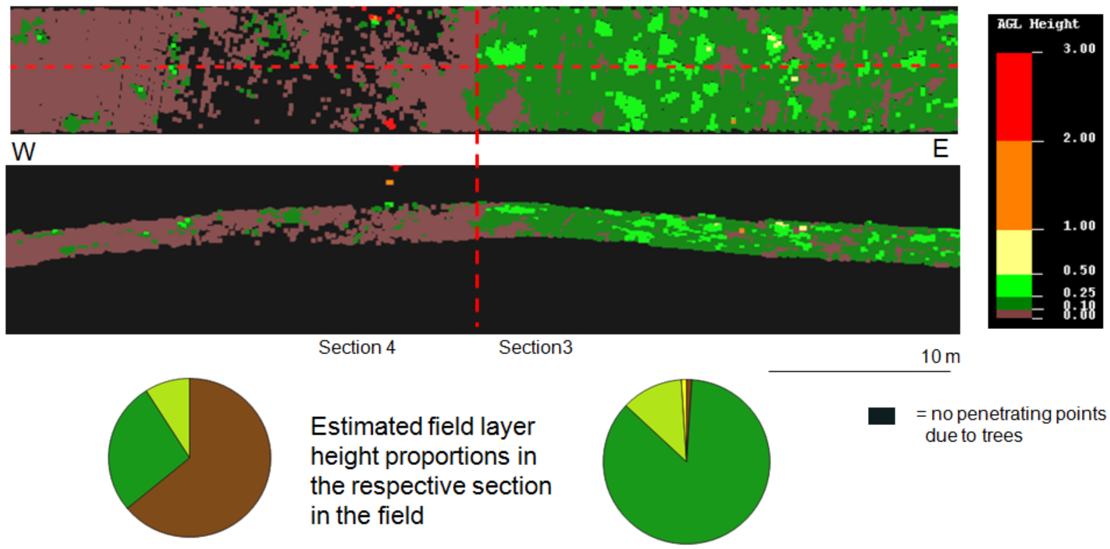


Figure 6. *To facilitate the visual interpretation, the point cloud has been normalized to show height above the ground (AGL height). Height intervals (see legend) have been coloured to promote visual interpretation. In the field the transects were divided into different parts and examined. The example given here shows the field-estimated proportion of transect section area for each height category.*

It seems difficult to ensure that narrow height intervals are correctly displayed in the data using normalization of data from a bare earth model (Figure 7). According to the laser data, there is a substantial area of points <10 cm that was not reflected in a corresponding cover of that height class in the field. This generalization makes field estimation and laser data summary more compatible

In the circular plots from the northern pasture of Remningstorp, there was a systematic difference in how the height was estimated in field and laser data (Figure 8, 9). The laser data gave a high cover of the lowest vegetation cover, whereas the field observer favoured the class 10-30 cm. This may be a general trend, that an average of all laser pulses from the lower vegetation layers gives low values in this type of estimations.

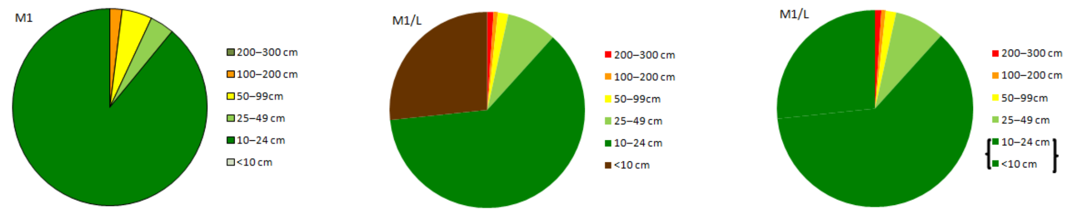


Figure 7. *The circle to the left (M1) represents shares of the transect section M1 estimated in the field. The mid circle (M1/L) is a summary of all the laser points in the same section divided into the corresponding height categories. To the right is the laser summary where the two lowest categories have been generalized into one.*

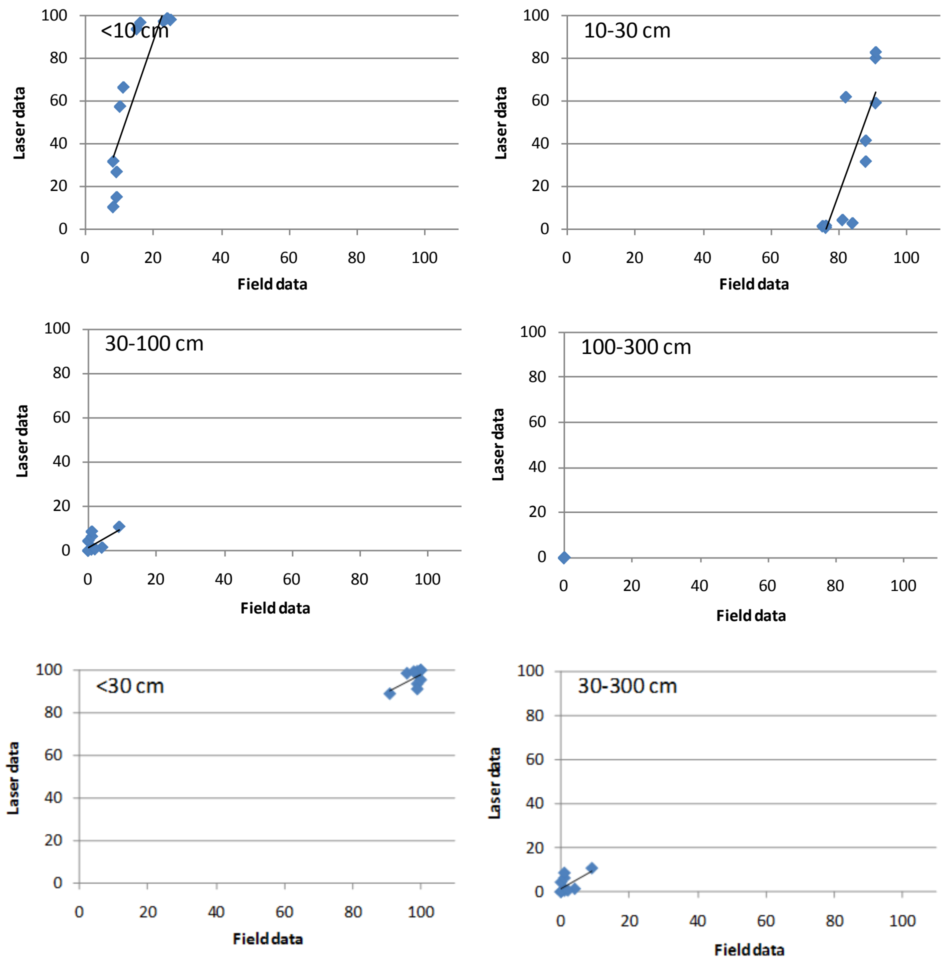


Figure 8. *Remningstorp <u>northern</u> pasture, vegetation cover in different height intervals from field and laser data in circular plot (3 m radius). Cover for all field estimated height intervals are presented individually (upper four figures) as well as summarized above and below 30 cm (lower two figures).*

However, it may also only indicate that the laser point data cannot sufficiently discriminate the ground surface from the lowest vegetation well enough. This explanation is very plausible since there are fundamental restrictions attached to point data that are not attached to full waveform data. On the other hand, the use of full waveform data for visual interpretation is not recommended at this stage in the project, because of time and resource limitations. Further analysis of such data done in T2-T3 and T1 anticipate that we will be able to work on derivates from full waveform laser data that these projects will produce.

In the southern pasture of Remningstorp, when the classes <30 cm was used instead of the two detailed classes (<10 and 10-29 cm), all plots yielded values close to 100% (Figure 9), reflecting that there was little cover above 30 m. This is consistent with our field observations (see also Figure 10).

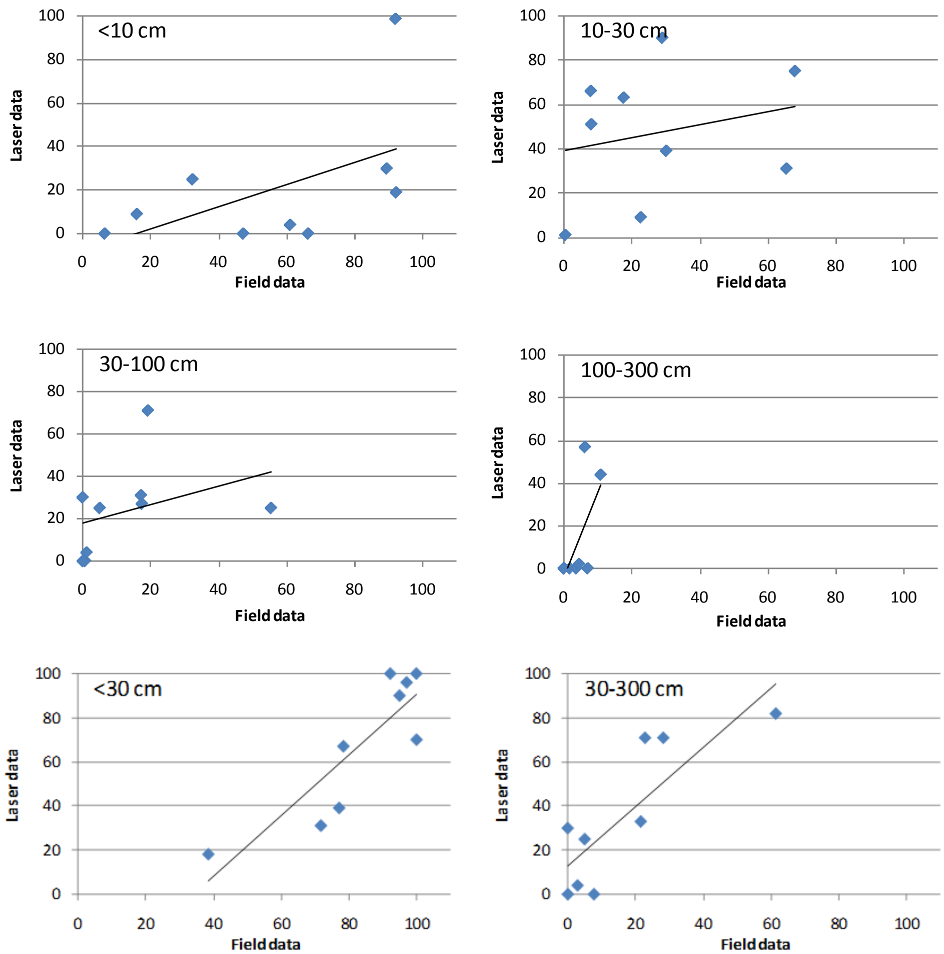


Figure 9. *Remningstorp <u>southern</u> pasture, vegetation cover in different height intervals from field and laser data in circular plot (3 m radius). Cover for all field estimated height intervals are presented individually (upper four figures) as well as summarized above and below 30 cm (lower two figures).*

Figure 10. *Overview over parts of the northern pasture in Remningstorp with a relatively high grazing pressure.*

The circular plots in the mountain heath, wetland and mountain birch forest in Abisko show quite a large variation in field-estimated cover of different height classes, in contrast to the Remningstorp grassland plots (Figure 11). Also here, laser data seems to give higher values for vegetation with low height, below 5 cm, compared to taller vegetation, above 5 cm. This is in correspondence with results in Figure 9 from Remningstorp. When the two height classes <5 cm and 5-30 were added, the cover was close to 100%.

The results from Abisko can also be presented for each main vegetation type. For mountain birch forest, for example (Figure 12), the patterns were similar as for mountain vegetation in general, that laser data “overestimate” cover of low-height vegetation and “underestimate” cover of taller vegetation compared to field estimation, at least within the range of 0-30 cm.

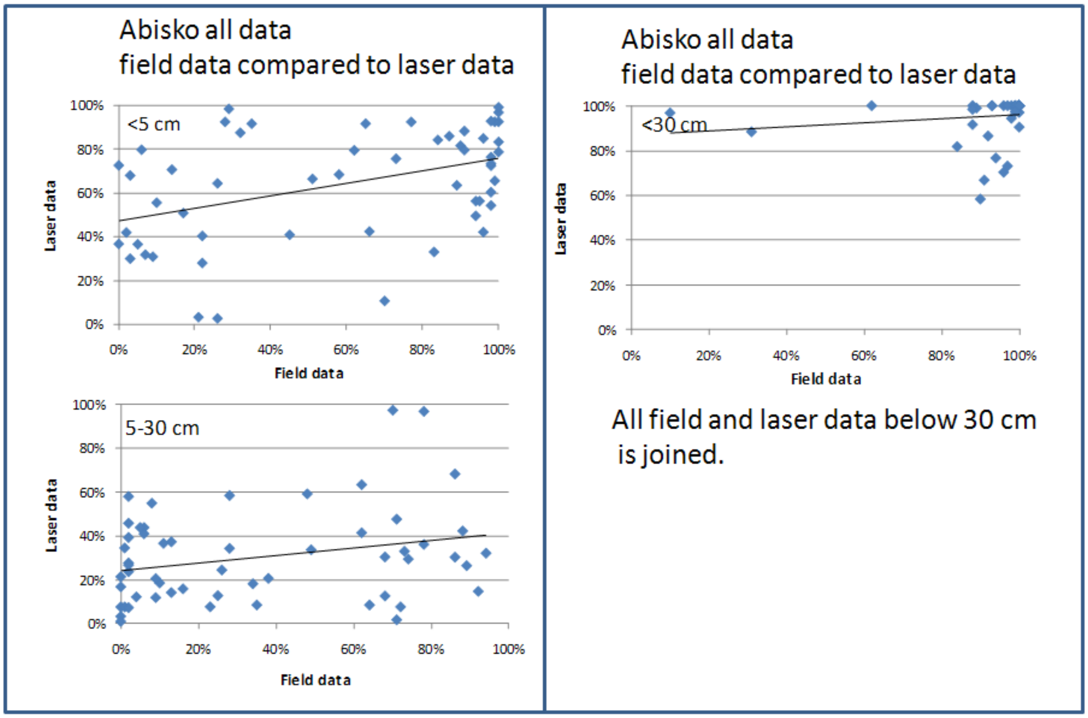


Figure 11. *The field plots with corresponding laser data from Abisko. The two graphs to the left show the correspondence between cover calculated from field and laser data, presented separately for vegetation height intervals below and above 5 cm, and the graph to the right show data joined for all vegetation below 30 cm height.*

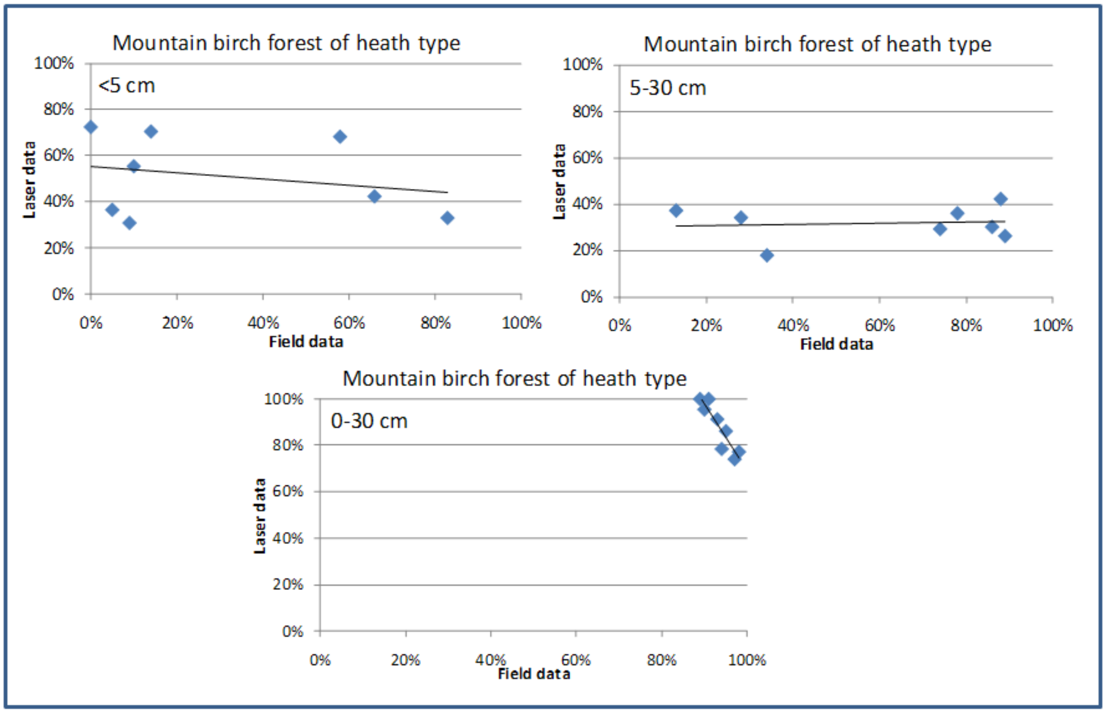


Figure 12. *Data from one of the vegetation types, where the two upper graphs show the correspondence between cover calculated from field and laser data, presented separately for vegetation height intervals below and above 5 cm, and the lower graph with the data joined for all vegetation below 30 cm height*

Shrubs and boulders

Our initial studies have shown that shrubs and boulders can in fact be detected in both high resolution laser data and in low resolution data such as our new national elevation data (NHH). Still there needs to be more studies to see how well shrubs can be distinguished from boulders. So far, it is clear that large heaps of boulders such as clearance cairns end up in the bare earth model (Figure 13). In CIR imagery, all clearance cairns that are not covered by trees or shadows is readily identified by visual interpretation due to both their positive form and the distinct difference in spectral properties (Figure 13). All the tree-covered cairns were easily detected in the bare earth model.

To give data for evaluating to what extent different structures close to the ground surface can be distinguished; a large number of boulders and cut hazel bushes were mapped and measured (Figure 13, 15). The cairns, with an area of 30 m² or more, were mostly clearly visible in the bare-earth model (Figure 13), whereas the smaller boulders and shrubs were excluded from the bare-earth model. Further analysis will show how reliably such structures can be mapped, either visually or automatically, from laser data. To clearly distinguish boulders from bushes is of fundamental importance for the use of laser data to describe encroachment and management intensity in grassland.

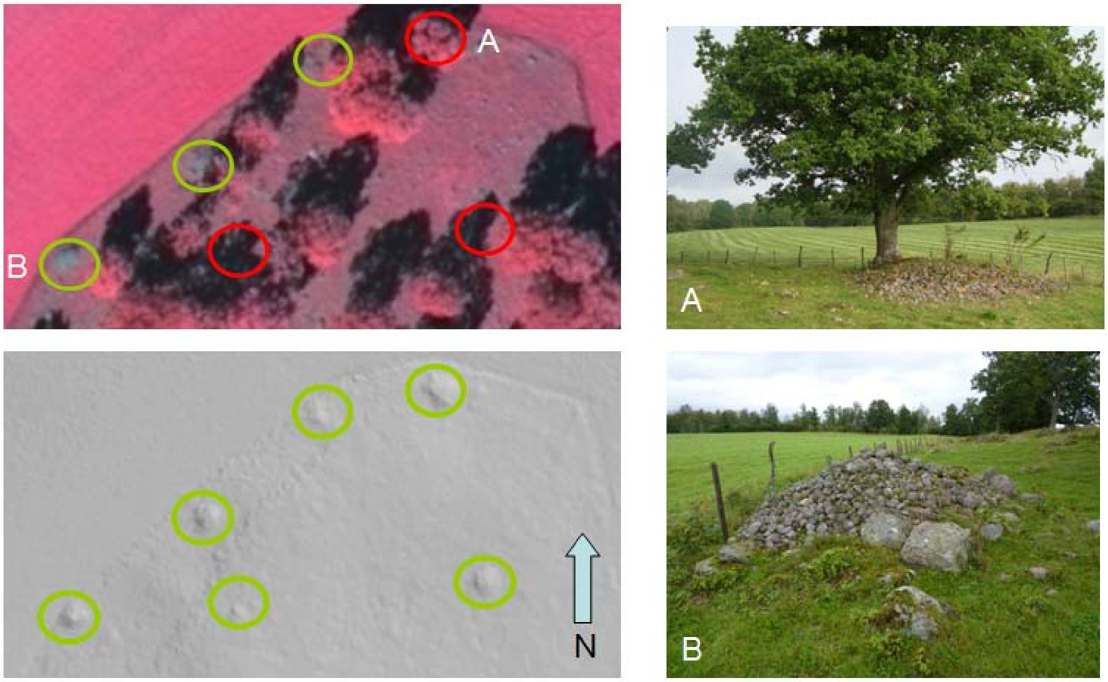


Figure 13. *Laser data bare earth model helps identifying boulders and clearance cairns that are hidden from visual interpretation in CIR imagery due to either canopy coverage incl. displacement or shadows. Green = detectable and red = not detectable in the respective data.*

Figure 14. *Field work was carried out in circle plots and observation of field layer, shrubs, and boulders were drawn in a sketch. Photos were taken and plot was registered using dGPS. Later on the laser data in each plot was examined to see if recorded structures were detectable. In this example the resemblance was high.*

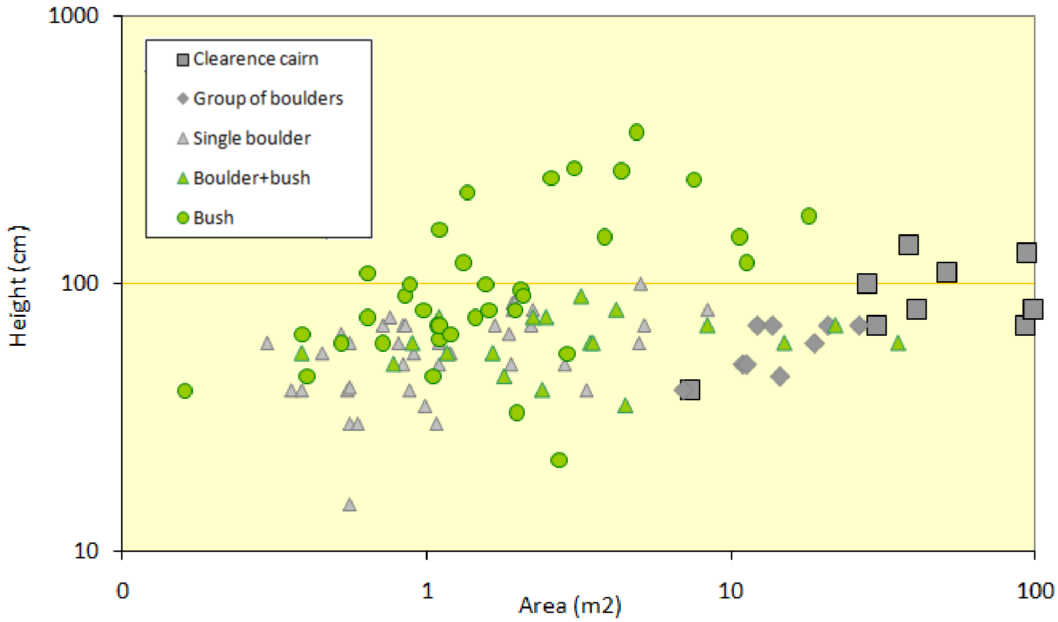


Figure 15. *Horizontal size and height of cairns, boulders and bushes mapped in the field, in the northern pasture, Remningstorp.*

These data will be used both for illustrative examples how such structures (shrubs and boulders) are represented in laser data, but can also be used in further analysis of the classification accuracy by either visual interpretation in laser data or from more elaborate evaluation of bare-earth model parameters. If the boulders can be differentially treated depending on how the bare-earth model is defined, this allows for more elaborate automatic or semi-automatic procedures for mapping small scale variation in ground structure such as boulders, as well as increasing the reliability and accuracy considerably in the detailed description of the lower vegetation layers. Visual inspection of the laser cloud indicates that there indeed is great potential for both visual identification and mapping and semi-automatic methods to identify boulders and separating them from shrubs and other vegetation (Figure 17).

Encroachment and management effects, one of the main focuses of this project, can be illustrated by results from the northern pasture at Remningstorp, where we have laser data both before and after the drastic clearing of hazel shrubs and some trees (Figure 18 and 19). This represents a unique example, where we have two sets of laser data, the first (to the left in both Figure 18 and 19) is before clearing of bushes and the second (to the right) is registered after the pasture was cleared from underbrush. Also note the difference in registration date in Figure 19.

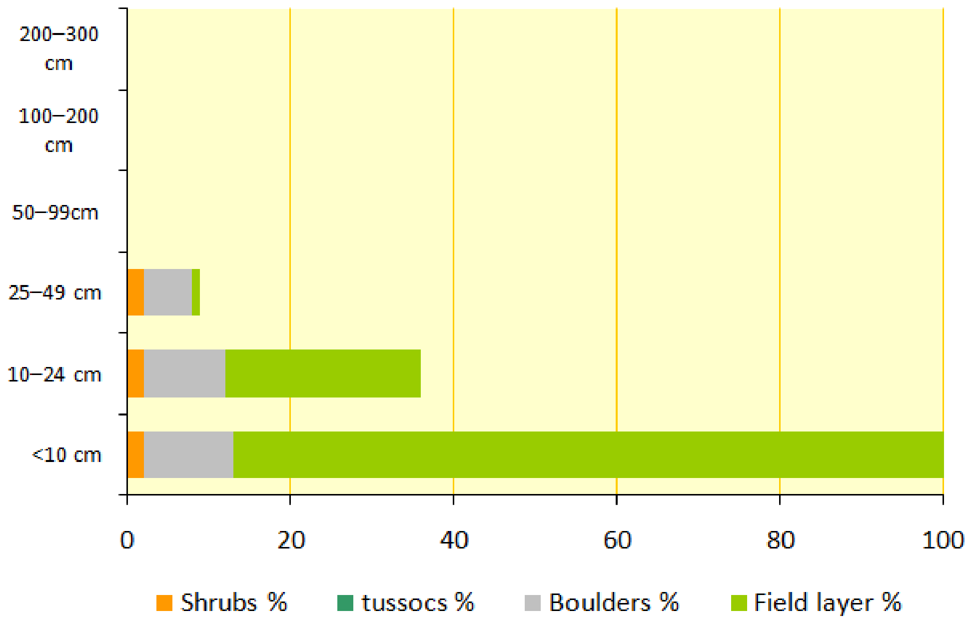


Figure 16. *Example of how the vertical structure of the vegetation can be visualised in a quantitative way, based on laser data. Field estimated accumulated proportion of field layer, shrubs and boulders in the sections along the belt transects in Remningstorp*

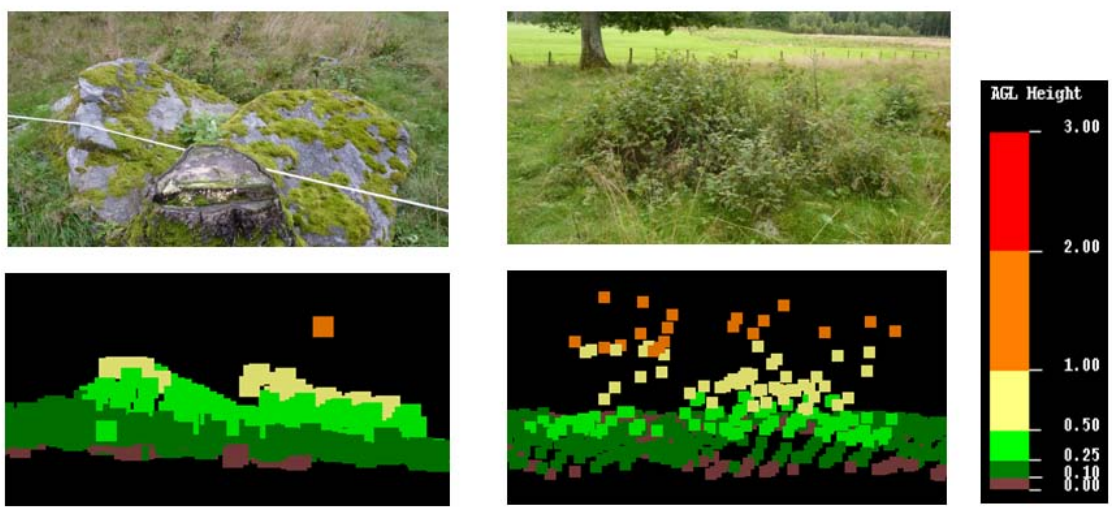


Figure 17. *Boulders and shrubs can be distinguished in densely scanned laser data. Different ways of generating the bare earth might give provisional information about vegetation and encroachment near or on top of boulders.*

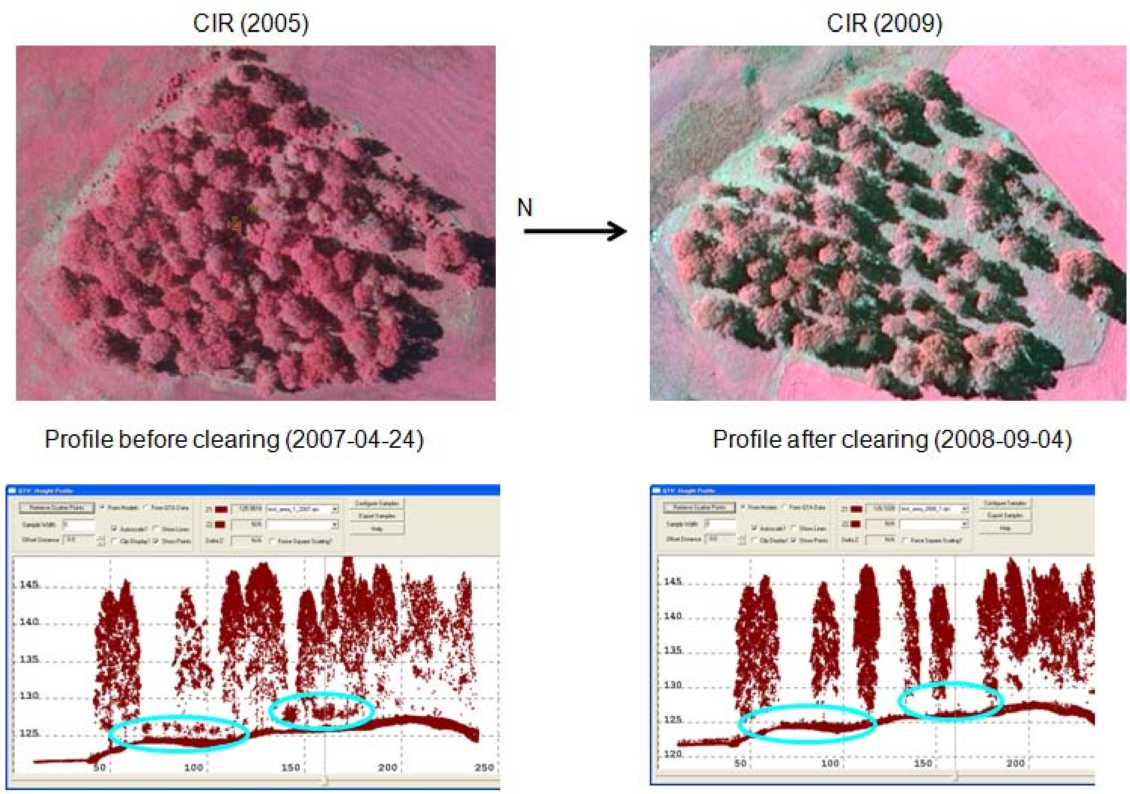


Figure 18. *These shows a pasture centrally in the Remningstorp data, where we have two sets of data, both in laser and in colour infrared aerial photos. The first, to the left is before the pasture was cleared of underbrush, and the second is after clearing.*

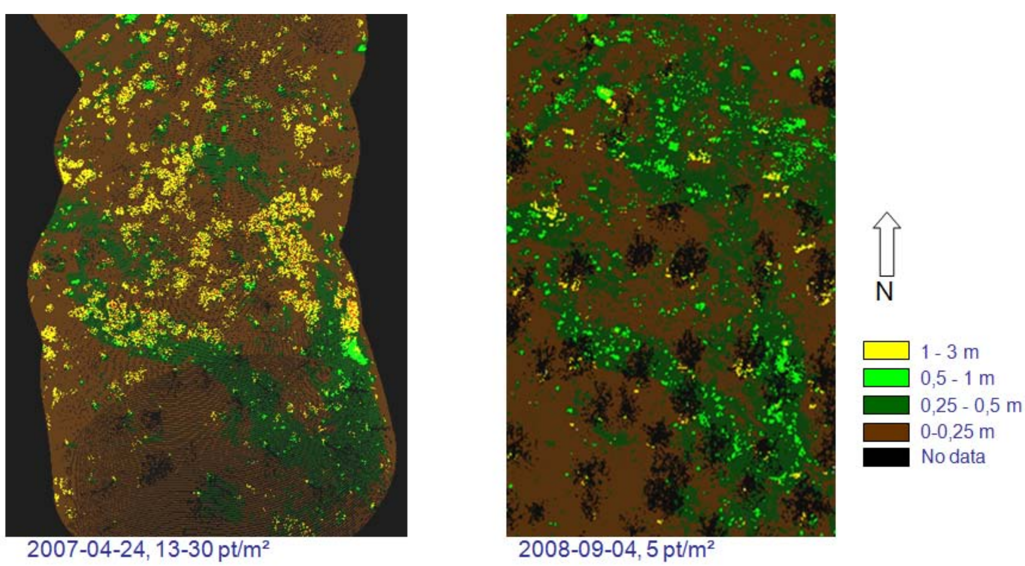


Figure 19. *The northern pasture at Remningstorp before clearing of bushes (to the left) and after the pasture was cleared from undergrowth of hazel (to the right). To the left the registration was already in April and to the right in September. In the September registration the oaks are "shading" the ground more than in April.*

Dead wood/logs

The initial results from this study shows that dead wood in the form of fallen logs is possible to detect, both in open environment and also in semi-closer environment (Figure 4, 20). Initial studies in the low resolution NHH data reveals that some logs in the forest and open glades is in fact detectable even in a resolution as low as 0.5 p/m². This will be further investigated during 2011.

Logs were found in several sites with varying tree cover, which means that we can to some extent relate the visibility to the tree canopy. Other features were found mainly in open land. These experiences will be used as examples useful for the planning of more detailed studies of landscape features.

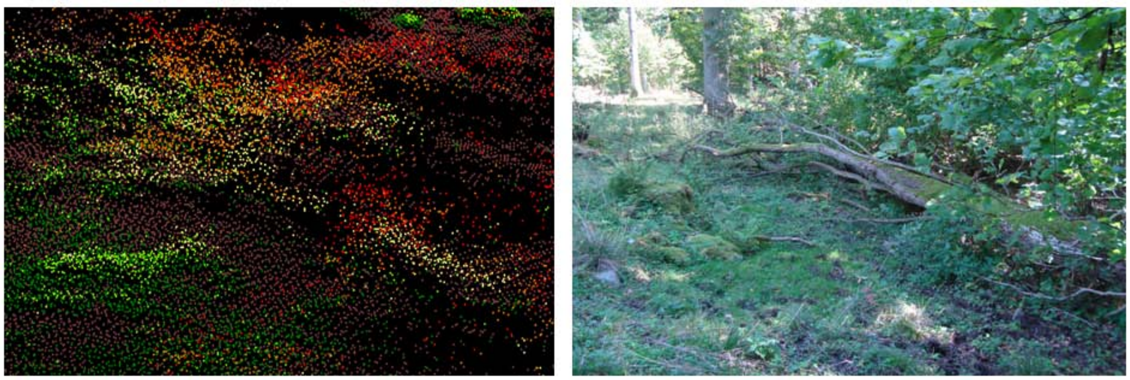


Figure 20. *An example of dead lying wood under a semi-closed canopy. The long trunk of the tree makes it possible to detect in interpretation.*

Remaining artefacts and curiosities

There are many structures and artefacts that can be detected in the laser data. Many of them are important and others are more of curiosities. Examples of such are single wooden fences (Figure 21). This is interesting but will not be systematically detected in all places. One of the curiosities is that cars can successfully be detected (Figure 22). Grazing animals have also been spotted (Figure 23). They even moved between flight line registrations and were doubled in the data. Even if the use of this knowledge is limited it certainly shows the potential of the laser data to depict all kind of traces and structures on the ground.

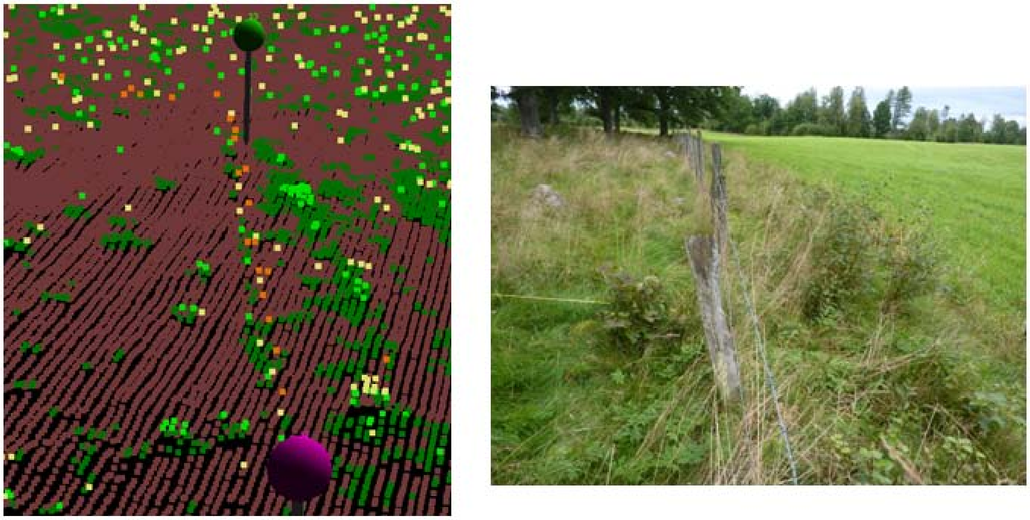


Figure 21. *In this figure a narrow fence is shown. The dots in orange colour represent 1- 2 meters in height, and the field-measured height between 0.1 – 1.2 meters.*

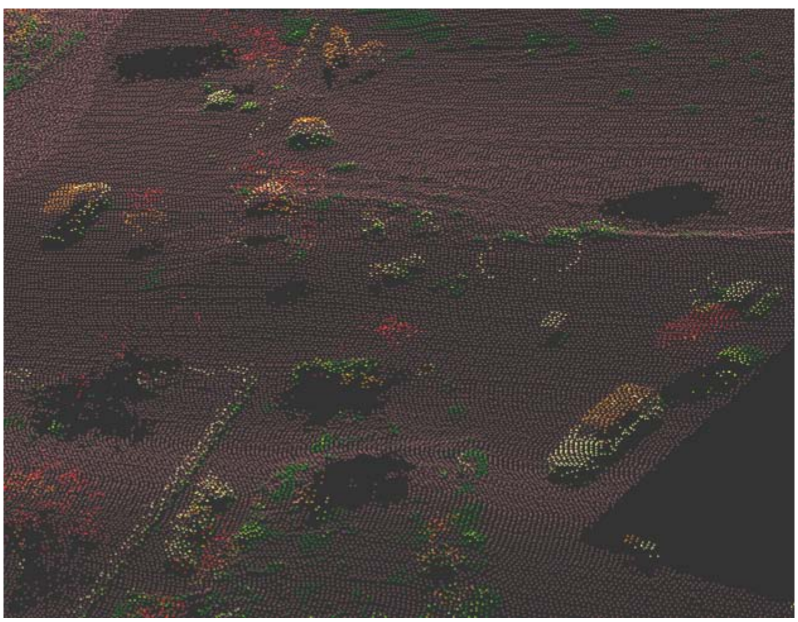


Figure 22. *In this figure some cars are shown, together with other artefacts such as a low wall. The colour of the different heights in the laser point cloud makes the shapes easier to make out.*

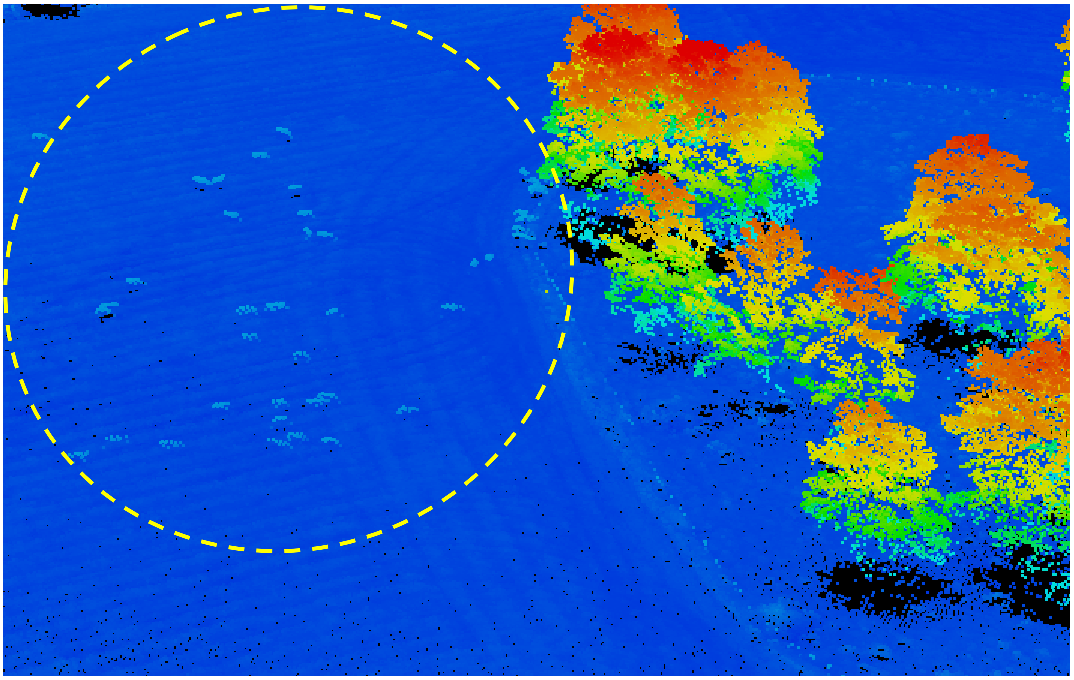


Figure 23. *A herd of large grazing animals, cattle or horses are clearly visible as light blue spots inside the marked polygon in the filtered data from 2010.*

Implications from software and methodology

The software used in EMMA T1 for basic manipulation and visual interpretation of point laser data works quite well, however it is important to keep the area of interest as small as possible in order to execute the necessary software commands. The software creates large temporary files that can slow down the system considerably, although the computer used is specifically configured to handle large data sets (x64 OS and 6 GB ram).

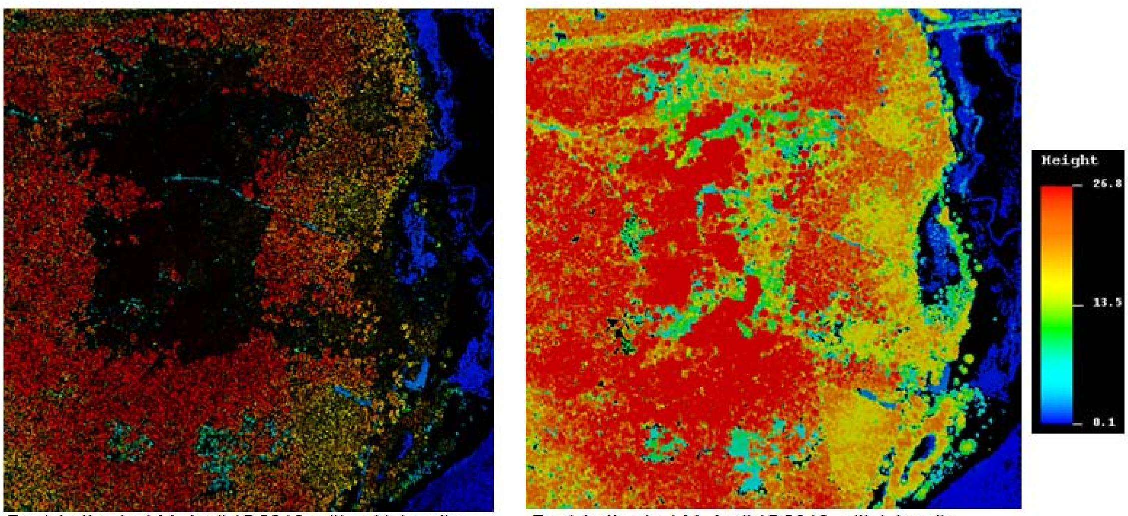
One important wish for future development on the laser software market is that also systems for visualization, such as Quick Terrain Modeler and Fugro will improve their functions for data capture and export from the system to other applications where further analysis can be performed. Frequent contacts with the support shows that the potential of getting these improvements are good since software developers cannot foresee all the possible applications of their software but are generally willing to develop on demand from the users.

Laser data quality and positioning issues

Our initial studies highlight the need to address some major issues regarding the quality of laser data and positioning of field observations. At the same time as landscape data get increasingly detailed, the demands on correct positioning in the field are increasing too. In the sections below, we will touch upon some of the most crucial issues; date of acquisition, information loss due to shading canopy, qualities and properties of the bare earth model, data density, and accurate positioning of field data.

Firstly, the date of registering the laser data is of crucial importance, as with the aerial photos (Figure 24). The important dates are the regional days of start of vegetative season, when the leaves are almost fully grown on the trees. This is of course an unwanted trait for the national height data, since the trees shadow even the laser points from penetrating, but is of high importance for the interpretation of vegetation communities and biodiversity variables. The second date is when the frost has taken the chlorophyll out of the leaves and the vegetation sags from its full summer height. This may cause a problem and must be addressed.

The registration in Åhus was conducted in early April. This has caused problems with detecting the deciduous forests that have not set their leaves yet. The major broad leaved deciduous forest in Äspet looks like a clear-cut with very few returns from the naked trees (Figure 24).



Registration by LM, April 15 2010, without intensity

Registration by LM, April 15 2010, with intensity

Figure 24. *One example of the problems with too early laser registrations for vegetation purposes. The black part in the middle of the left image shows mainly low elevation values representing open land. The same with intensity added increases the interpretability. The intensity data is not available in Ahab registration of Åhus.*

Sometimes a dense canopy can cause hollows in the data set for the lower vegetation layers, reducing the the possibilities of interpreting the point cloud. The reason for this is that hits on the canopy surface prevent hits from lower parts of the vegetation or ground surface. There is a common belief among persons working on laser data in Sweden that oaks are in particular known for creating a last and only return already high up in the canopy (Figure 25). However, a few hits on top of a clearance cairn might still make it possible for the software generating bare earth model to interpolate and create a distinct feature on the ground (Figure 26). Hence, for the best possible results of visual interpretation of laser data, one should use a combination of point data and bare earth models.

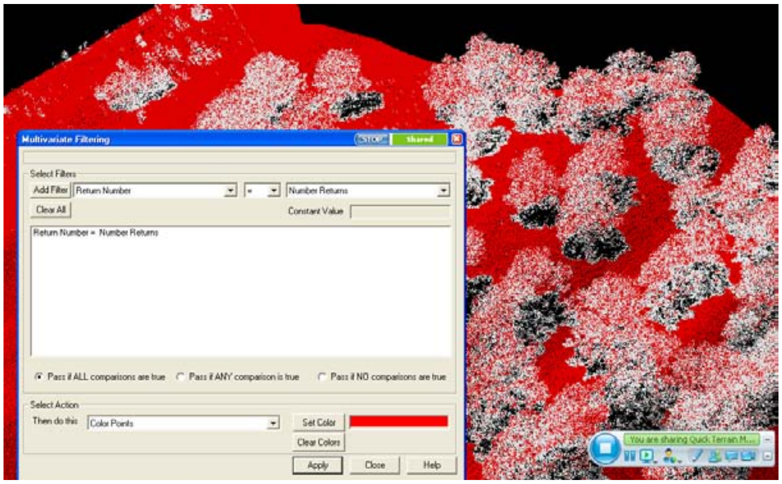


Figure 25. *The reason for black, no data areas, on the ground are because the trees, especially oaks, prevent the laser from reaching the ground. In this figure all the last return are coloured in red. Normally last return represents the ground, but in this case the leaves of the oak trees prevent the laser beams to go any further.*

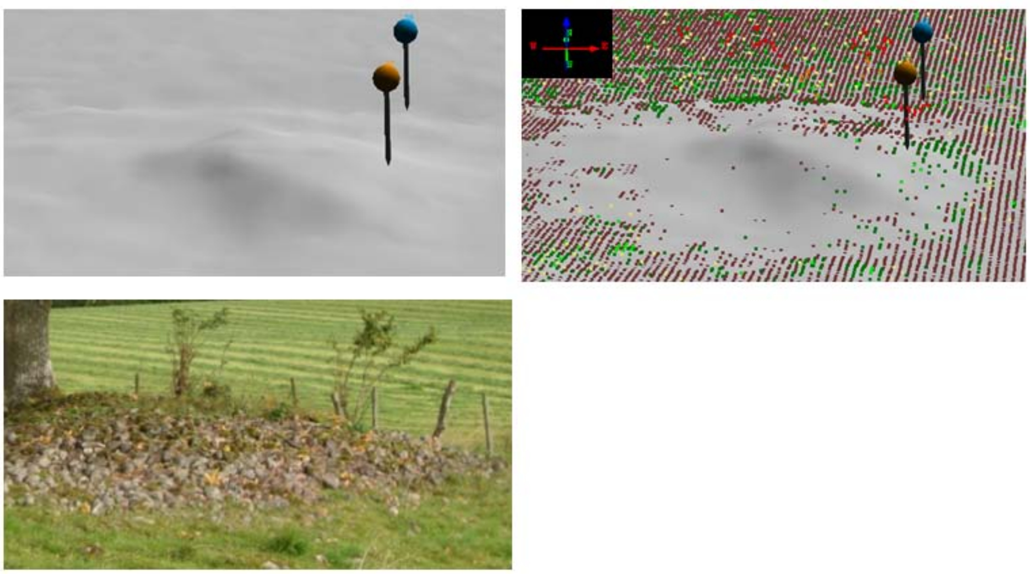


Figure 26. *This clearance cairn is the same as in the previous figure A. It is not visible in the point cloud due to the effect of a shading tree. However, even the few returns from this cairn (above to the right) will enable the software to add it into the bare earth model.*

When studying such small areas as we have done, it becomes evident that the laser data is gathered in uneven strokes (Figure 27), and this may be a smaller problem when the data is used as smoothed over a larger surface, but may cause some of the problems we have experienced in these quite sparsely forested grounds. These problems are common to all applications within EMMA and will be addressed in collaboration with T3.

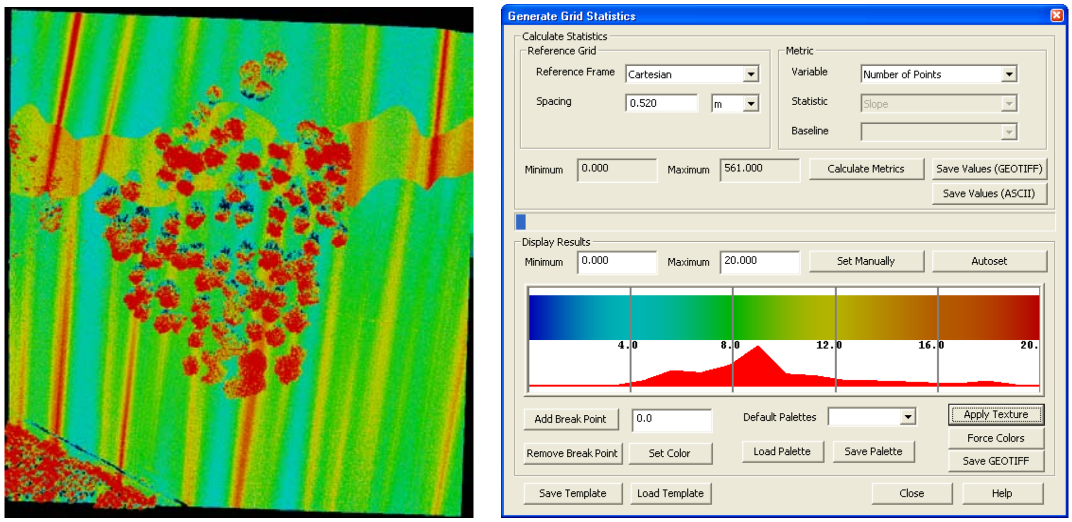


Figure 27. *Example of the uneven point cloud of the data, taken in swaths along the flight line. Also the overlap between flight lines. In this case, the point density per m² varies between 4 and 20 with a mean around 9 p/m².*

Figure 28 shows the important of a high quality bare-earth model to use for normalizing point clouds. It is of no use to use simple inbuilt functions to create estimations of bare earth and then using it for detailed analyses. The figure shows the outcome with various resolutions in relation to a high quality bare earth model generated in a specialized software (in this case Terra Solid).

Another example to illustrate the need to use the bare earth model in combination with point cloud data and available CIR imagery is the distribution of reed in coastal areas (Figure 29). The dilemma of ground vegetation getting caught in the elevation model will be further investigated during 2011. Unfortunately this is not traceable in the HawkEye topographic data, since this is very early in the vegetation season, the data are taken in April 2010.

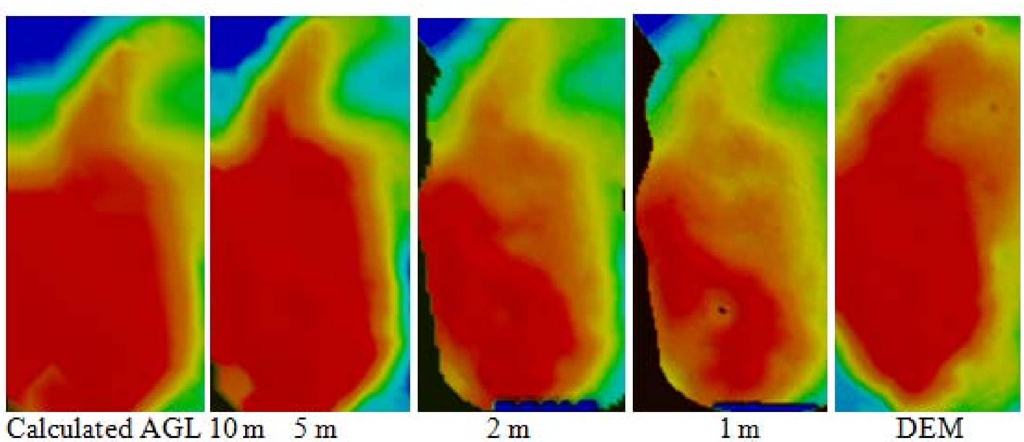


Figure 28. *The crucial importance of a high quality bare earth model is illustrated by the sequence of attempts to create one from Quick Terrain Modeler (the four to the left) and one created from the professional software TerraSolid.*

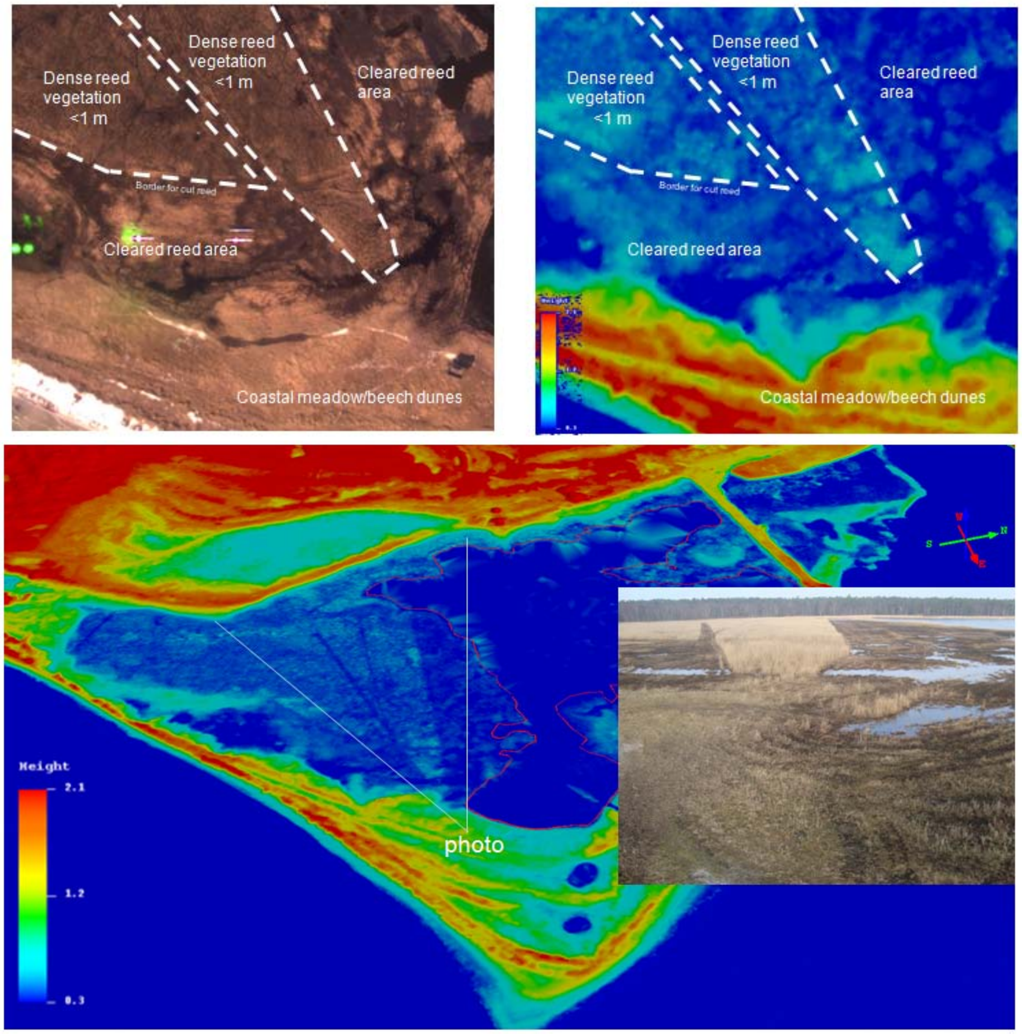


Figure 29. *An early analysis of data from the Swedish national laser scanning (NNH) shows that the management of the reed belts is fully visible in this 0.5- 1.0 points/m² data set; however, the reed is caught in the bare earth model, thus indicating higher ground instead of reed vegetation. Photo angle of the ground photo, is indicated in the perspective view of NHH DEM.*

In regards to positioning of field data, in Remningstorp, we succeeded very well in acquiring very good positioning, within only a few dm. Even if we experienced connection problems with the dGPS, we managed to position ourselves in relation to printed copies of details from the filtered laser data that proved to be excellent support data in the field. In Abisko, the positioning of the circular plots was mostly made by an ordinary Garmin GPS, because of technical problems with the dGPS apparatus. When switching to ordinary GPS and the accuracy of a few dm was no longer guaranteed, the design was adjusted to put out plots in sets of three within a limited range, so as to allow for comparing average cover over a larger area represented by the three plots, should that be needed. This will be treated more thoroughly in later analyses, so there still is the option to do comparisons at both scales.

Concluding remarks and looking ahead

The work has shown the crucial role of the bare-earth model in preparing the point data cloud for visual interpretation. In coarse data, relatively low vegetation such as reed belts can easily be included in the bare earth model, which means that vegetation height will be set to 0 in normalized data. However, initial examination of laser data with 0.5 – 1 returns m^2 from the new national laser scanning reveals that low reed vegetation (0.5-1.5 m height) could still be detected indirectly through a combination of interpretation of the bare earth model, the laser point cloud, and CIR aerial photos. Further, patches of encroachment and fallen trees in open forest are clearly detectable, as is single trees and shrubs in the open environment.

There still remains much work to validate and improve the methods of visual interpretation. Literature on e.g. archaeological applications suggests that full-waveform data can be used to increase the detail resolution considerably under a tree canopy and of the terrain model below the field layer (Ducic et al. 2006; Doneus et al. 2008). This can increase the potential for both visual interpretation and (semi-) automatic methods for ground vegetation and ground structures considerably and should be explored further.

In the evaluation of detailed ground structures and low vegetation, we have experienced what difference can be seen depending on the bare-earth model. The difference between boulders and shrubs of the same size, within the size interval of about 30-50 cm or more, can be easily distinguished by visual inspection, but for more well-developed automatic or semi-automatic mapping of such structures, further evaluation of the way these features can be extracted depending on alternative procedures and parameters for creating the bare-earth model would be very useful. Also, it should be noted that it will always be a discrepancy between the laser data and the field data collected since laser data are only truly valid during a very short period and it is extremely unlikely that we will ever manage to collect all the field data needed synchronously with laser registration and to the same level of detail that can be used for one to one validations. We need to accept and cope with uncertainties in this field. It is one of the exiting challenges working with all kinds of remotely sensed data.

The evaluation of more complex features such as vegetation type, land use and geomorphological traits will be an important extension of this work, in which the specific features of the work thus far can be put into context. For this topic, we have identified the need for other types of analysis tools, which can be addressed in later stages within the work package. Many of these patterns could very well be distinguished by visual interpretation, including the occurrence of abandoned arable fields under a (sparse-to-moderately dense) tree canopy, but probably the best way to visually identify such patterns would be from the bare-earth model rather than from the laser point cloud. Such alternatives should be explored and evaluated further.

This work on vegetation and ground structures, but also the more complex features mentioned above, would add important information to the vegetation type classification and segmentation approach used by EMMA WP T3, which has a focus mainly on the dominating layers of the tree canopy. In dense forest, the most important factors influencing the vegetation type classification relate to the composition and structure of the tree layer, but to extend this approach to more open habitats, more and more details of the lower layers and the ground vegetation will be needed.

To conclude

1. Many landscape structures and features can be identified from laser data. Naturally, the identification depends on a combination of data resolution and canopy closure
2. We are positively surprised to see that even low resolution data such as NHH seems to have a large potential in this respect.
3. The strong suggestion from these initial studies is to use a combination of methods including visual and semiautomatic procedures in laser data together with CIR aerial imagery for optimal outcome.

Acknowledgement

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