FORESTRY REMOTE SENSING IN SWEDEN

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ABSTRACT

The development of remote sensing for forestry in Sweden since the start of test with the use of digital data in the mid-1970s is summarised. The key possibilities was realised quite early. Around 1980, it was evident that clear-felled areas and broad forest classes could be detected with Landsat multispectral data. The operational use of Landsat and SPOT data for national level applications at authorities was then implemented around year 2000. The use of automated remote sensing in operational forest management planning at company level was however not widely spread until laser scanner data became available in cost efficient way. The potential to use airborne laser scanner data for estimation of tree height and stem volume became evident at a test already in1991. The national land survey started a national laser scanning in 2009 and the large forest companies started year 2011 to use this data for operational estimates. In 2015, the Swedish Forest Agency and the Swedish University of Agricultural Sciences released a freely available national raster data base with forest variables made from the national laser scanning. A current issue is how to keep the raster data bases made from laser scanner data updated, given that there are no current plans for repeating the national laser scanning. There is an increase of data sources that are less information rich than the laser scanner data when used alone, but that frequently can provide data about the canopy height and spectral response. A transfer to a data assimilation paradigm where each new data set is blended with growth functions and used for updating a model of the forest in proportion to the information content in the respective data source is therefore foreseen.

INTRODUCTION

A brief history of the development of remote sensing of forests in Sweden in the period 1975 to 2015 is given. The emphasis is on the operational use of satellite remote sensing and other digital data sources. Finally, the use of remote sensing in the Swedish forest sector today is summarized and some outlooks given.

THE 1970S

In the 1970s, there were high expectation on the usefulness of digital multispectral data for forestry and land cover mapping. A campaign where data were acquired with an airborne multispectral scanner was launched in Sweden in 1975. The campaign was named MSS75 and was led by the Swedish Space Corporation (SSC) and researchers from several universities, as well as forest companies, participated. The data were processed by the national defence research agency (FOA) in their image processing system PICCOLA (1, 2). The results from the MSS-75 campaign was however not very successful from a forestry point of view. There were several technical factors contributing to this limited success. The geometry of the scanner images was not good since this was before the introduction of INS and GPS. Disturbances such as aircraft roll could therefore not be compensated on scan line level. Furthermore, the large view angle of the scanner images caused variation in the radiometry across the scan lines; the small pixel size made it difficult to analyse the scanner data with simple methods such as pixelwise classification and finally, the PICCOLA system was batch oriented, running on a central main frame computer, which made more interactive image analysis difficult.

Also data from the Landsat 1 MSS sensor was analysed in the mid-1970´ths. The results were more promising since several of the above mentioned problems with airborne scanner data not is present with optical satellite data, which has smaller scan angle, more stable platforms and larger pixels. During the period 1972 – 1976 only occasional images, recorded with the tape recorder on-board Landsat 1 was available over Europe. From year 1976, images over most of Europe up to southern Sweden, could be directly downlinked from the receiving station at Fucino in Italy.

A major step for Sweden was taken in 1979 when a Landsat receiving station at Esrange, outside Kiruna in northern Sweden was opened. Landsat images over all of northern Europe could be received from the Kiruna station. The station was operated by the SSC, under contract with ESA. At the same time, SSC also acquired the first interactive system in Sweden for image analysis of remote sensing data. The system, which was placed at the SSC main office in Solna was called IAS and developed at MDA in Canada.

THE 1980S

The 1980s was a decade with strong emphasis on the development of the capacity for satellite remote sensing. These efforts were led by SSC, a state owned company which got funding for remote sensing development from the Swedish National Spaceboard (SNSB). Sweden became part owner of the SPOT satellites and Esrange became one of the two main receiving stations for the SPOT system. The first SPOT satellite was launched 1986. A daughter company to SSC, Satimage, was formed in Kiruna, with the task to sell value added products from the SPOT data. As a preparation for this, the capacity for development of remote sensing products was increased also at the SSC office in Solna. Also several university groups started to work with interactive image processing of remote sensing data, often with funding from SNSB. Also a series of PC-based image processing systems, called EBBA and manufactured by SSC, helped to start research in more groups.

It was already around 1980 obvious that clear-felled areas and major forest classes could be detected with the digital satellite images, but it did not emerge any substantial operational use of the satellite data in the forest sector until about 20 years later.

The main mapping activity in the forest sector is collection of data for forest management plans. This is done by delineation of stand boundaries and assignment of forest variables, such as stem volume, stand age, site index and species proportions, to the delineated stands. The mapping for forest management planning is the responsibility of the land owners, who often use consultants for this task. There have traditionally not been any wall-to-wall forest maps done by the authorities in Sweden. In the 1980s the Swedish Forest Agency did however a general forest inventory for the half of the forest land that is owned by private persons. Two methods are traditionally used for the standwise forest mapping. The most used method is to manually delineate the forest stands with the aid of orthophotos, and then collect most of the forest variables in the field, using measurements and judgements at a few subjectively chosen places in each stand. The other method, which often has been used by large forest companies, is to collect as much as possible of the forest data by interpretation and measurements of stereo air photos in photogrammetric work stations. Both these methods were present already in the 1980s and are still in use today even if the introduction of laser scanner data has decreased the amount of manual work to some degree.

THE 1990S

During the 1990s, several of the persons that were involved in the development of satellite remote sensing at the Swedish Space Cooperation and at the universities in the 1980s, moved to different authorities, and companies. One example is that the company Space Metric (http://www.spacemetric.com/) that is specialised in correction and distribution of image data was formed by former employees from SSC. Another example is Anders Persson, a forester that moved from SSC to the Swedish Forest Agency and became their remote sensing expert. Much effort during the 1990s was directed towards product development led by end-user organisations, where the former employees of SSC often became key persons. Examples are the development routines for mapping of clear felled areas made in cooperation between the Swedish Forest Agency and SSC within the EU project ENFORMA. Another example is the development of methods at the Swedish University of Agricultural Sciences (SLU) for producing nationwide raster data bases by combining satellite data and National Forest Inventory (NFI) plots, which also was inspired by pioneering work at the Finnish NFI (3).

An important research achievement during this decade was the development of methods for measuring forests with data from airborne laser scanning. Mats Nilsson at SLU successfully measured forest with a military laser system from FOA already in 1991 (4). The research towards operational methods for using laser scanning in forest inventory was then pioneered in Norway, where professor Erik Næsset cooperated with surveying companies that operated airborne laser scanners (5).

THE 2000S

Satellite remote sensing became operational in the Swedish forest authorities around year 2000. The most important component was that the Swedish Forest Agency started to annually map all, about 50 000, new clear felled areas with optical satellite data. This became a “bread and butter” application, which needed a yearly nationwide coverage of geocorrected SPOT, Landsat, or IRS data. These yearly satellite data sets are now stored in a national satellite database called SACCESS (https://saccess.lantmateriet.se/portal/saccess_se.htm). Images from the SACCESS database are available free of charge within the Nordic countries.

The free availability of yearly geocorrected satellite images has lowered the threshold for development of satellite data applications also for other organisations. One important example is that SLU has made nationwide raster databases with forest variables for the years 2000, 2005 and 2010. The 25 * 25 m grid cells has been trained with about 50 000 NFI field plots using the kNN algorithm (6). The kNN maps are available freely over internet (skogskarta.slu.se/) and have been used for a multitude of purposes, in particular among authorities and researchers, since this is the first nationwide data bases with forest variables. The accuracy on stand level for estimates based on one-time optical satellite data is however lower than the forest sector is used too using their traditional methods. Thus, the “kNN-maps”, has not been much used for operational forest management planning.

In opposite to “2D” optical satellite data of “Landsat type”, airborne laser scanning provide “3D” data about the forest. Essential variables such as stem volume and tree height are thus much better estimated using laser scanning data. Laser scanning was introduced as an operational method for forest inventory in Norway already 2002 (7). In 2003 the conference Scandlaser was arranged by SLU in cooperation with researchers from Norway and Finland. This was the first conference of its kind in Europe and is counted as the second of the present Silvilaser series of conferences. The first large area test of laser scanning of forest in Sweden was made for a 10 000 ha area in the region of Dalarna that was successfully estimated by SLU in 2003 on behalf of the Swedish Forest Agency. Several consultant companies started activities in the Nordic market for laser scanning of forests and during the coming years most major forest companies and forest owner organisations evaluated automated estimates based on laser scanning and field reference plots. The results were generally encouraging regarding estimation accuracy for “tree size related” variables such as height, stem diameter, basal area and stem volume. However, there were questions about the cost for both laser scanning and field reference plots.

The issue regarding cost was reduced when Lantmäteriet in year 2009 started a laser scanning of all of Sweden. The purpose of this scanning was primarily the creation of a new national elevation model, but the forest companies could access this laser data to a marginal cost. In year 2011 the forest company Bergvik declared that they will use laser scanning operationally for all their holdings.

In the early 2000s did also Lantmäteriet switch to digital air photos. They first acquired a Z/I DMC camera and have now acquired an UltraCam Eagle. They have also implemented an ambitious air photo program where Sweden in average is photographed every third year.

THE PRESENT SITUATION

Lantmäteriet has now scanned 97% of all forest land in Sweden. In addition to Bergvik two of the other major forest companies, Holmen and SCA, have also acquired raster data bases for all their forest holdings, using the laser scanner data from Lantmäteriet. SCA did also acquire wall-to-wall estimates for all forest land in northern Sweden regardless of landownership. Other forest companies and the forest owner organisations often use products from the national laser scanning as an aid in their work with more manual collection of data for forest management planning.

The Swedish Forest Agency and SLU has also got an assignment from the government to make a raster data base with 12.5 * 12.5 m grid cells for all of Sweden except the mountain areas, based on the laser scanner data from Lantmäteriet. This has been done by regression analysis, using field reference plots from the NFI (8). The estimated variables are stem volume, above ground tree biomass, basal area, and basal area weighted tree height and stem diameter. The accuracies obtained for these variables are generally as good as, or better, than with the traditional manual methods. The national laser scanner based raster database has therefore been well accepted by the foresters. The Swedish Forest Agency has also, in cooperation with consultants, made a number of additional products based on the national laser scanning. This includes a 2 * 2 m tree height raster and digital maps over wet areas, slope and hillshading. All these data are available from the homepage of the forest agency (http://www.skogsstyrelsen.se/), however, so far the instructions are only available in Swedish.

RESEACH FRONTIERS

The laser scanner data provided by Lantmäteriet has revolutionised the use of automated remote sensing in Sweden, but three questions are now frequently asked by the users*, i)* how can we get updated data that is as information rich as the laser scanner data; *ii)* how can we get information about site index; and *iii)* how can we get information about tree species.

Regarding question *i)* data for updating the forest estimates. The current laser scanning is so far a one-time effort, the ideal solution would be to have a government program for repeated laser scannings, but no such program yet exists in Sweden. There are several research results that indicates that good estimates of for example stem volume can be obtained by using information of the tree height, possibly also in combination with spectral data (9) and there are several data sources that could provide information related to forest height, if they are combined with the ground elevation model that now is available from laser scanning, and calibrated with forest reference data. Good results have been obtained with canopy surface models obtained from matching of high resolution multi view angle optical satellite images (10). Also 3D data from radar satellites analysed by radargrammetry (11) or InSAR (12) has provided good results. A key factor for practical use in the forest sector is however the operational availability of data. The most promising data source for obtaining 3D data about the forest is at present therefore matching of digital air photos which also have provided good estimates in research studies (13). Laser scanner data is however superior to the mentioned techniques, especially regarding the possibility to separate forests with different density and there is not yet any operational use of other 3D techniques in the Swedish forest sector.

Regarding questions *ii)*, estimation of site index, there are some recent results where site index have been estimated by using time series of canopy height data obtained by matching of time series of aerial photos, or InSAR images. The InSAR results are presented by Henrik Persson in this session (14).

Regarding questions *iii)*, classification of tree species, the success using satellite images, or standard air photos, from one time point has been moderate. There are however several promising possibilities. These include: use of optical satellite data from several dates which becomes more realistic with the launch of the Sentinel 2a satellite: use of data from multispectral laser scanners such as the newly released Optech Titan; and analysis of the branch pattern in very high resolution aerial photos with about 5 cm pixel size (15).

Another research frontier that is worth mentioning is forest mensuration with ground based laser scanners. With a ground based scanner the 3D shape of forest stems can be measured. The stem measurements obtained from the side in field can then be matched with corresponding trees found in airborne laser scanner data and used as training of the relationship between stem shape and canopy shape (16). The ground based laser scanners are quickly becoming smaller and less expensive, and there is now a development where this type of scanners are placed in I backpack and carried manually while scanning. It is also possible to use stem shape data from harvesters for training of remote sensing data, in a similar way as the terrestrial laser scanner data (17).

We are now entering an era of Big Data, where data about the forest will be available from a multitude of sources: frequent satellite images, 3D point clouds from air photos with a few years interval, occasional laser scannings, and ground based measurements with laser scanners and harvesters. None of these data sources will provide all the information needed for forest planning and the data flow is more frequent than needed in the traditional forest management planning. The solution we believe in at SLU is to establish a new data assimilation paradigm in forest remote sensing, where each new observation from remote sensing, or ground based observations, is used for updating a model of the forest in proportion to the information content in the respective data sources. Early results from this work is presented at this symposium by Mattias Nyström (18).

CONCLUSIONS

The use of optical satellite has been fully operational for national level applications among authorities in the Swedish forest sector since about year 2000. The use of laser scanner data for obtaining information for forest management planning has been operational since year 2011. The time from first discovery of the potential in early studies to full operational applications was for both techniques 20 years. There are several new data sources which frequently will provide data of high relevance for forestry but none of these will solve the information requirement alone. Thus, it is foreseen that a new paradigm utilising data assimilation is needed in forest remote sensing.

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