TWO REMOTE SENSING EXAMPLES FROM THE FOREST PRACTICE IN FRANCE

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ABSTRACT

This paper presents two examples from remote sensing applications in the French forest practice. The first one describes the use of data from SPOT and Landsat-Sensors for mapping clear cuts. Annual clear-cuts maps have been produced for the period 1990 - 1999. The positive results obtained clear the path for the development of an operational clear cut mapping service in other French regions. The second one deals with the use of laser scanning data or identifying single trees and on the basis of that the estimation of the total basal area in a stand. The laser scanning data was used to create a digital terrain model (DTM) and a digital surface model (DSM), both with a resolution of 1 m × 1 m. By simply subtracting the DTM from the DSM the tree or vegetation height can be estimated in the form of a "crown height model" (CHM). In the CHM, we identified individual tree crowns and tree tops with a mean error of less than 20%. Position errors of the trees that were automatically identified in the CHM were on average 2 m, when comparing to on-site GPS measured positions. In addition, a good relationship between the measured tree heights and tree diameters could be used to assign tree diameters to the detected tree, on the basis of their height. The study showed us that airborne laser scanning provides reliable information on the forest structure.

Keywords: SPOT, Landsat, Change detection, Laserscanning, Single tree detection

1. INTRODUCTION

To explain roughly the situation in France with regards to the forest practice it is important to provide some key figures on the forest cover and introduce the main organisations that deal with the forest practice. In total, 28% of the state surface is covered by forest. Important forested areas in France are the Landes region (North of Bordeaux), the Pyrenees, the Alsace and the Alps. The latter cover 6,6% of the state surface. Forest cover in mountainous areas in France is between 35% und 45%. Forest types vary enormously from Mediterranean pine forest to beech-oak forests and pure coniferous forests in mountainous areas. The main part of the forest in the French Alps is public property, in contrast to the rest of the country where forest is mainly privately owned. For the national forest inventory, the institute called IFN - Inventaire Forestier National' is responsible. The ONF – Office National des Forêts, deals with the management of publicly owned forests. Cemagref is an institute for applied agricultural and environmental research and deals as such with applied forest research. ENGREF ist the national superior school for water, land and forest management and educates forest engineers.

The IFN uses a sample grid consisting of 58158 sample points for their national forest inventory. These terrestrial data are combined with aerial photograph interpretation to obtain spatially continuous data. Satellite based remote sensing is being used for obtaining additional information, as for example, the monitoring of clear cuts and the estimation of the loss of wood resources due to windstorms. The applied methods include pixel-based,change detection methods and combinations of the former methods with segmentation based ones. Cemagref, ENGREF and the IFN developed and test such methods.

In addition, airborne laser scanning data are increasingly used for forest planning. For the ONF it is important to estimate the growing stock and to obtain detailed maps of the forest road network in mountainous areas. laser scanning offers a cost-efficient opportunity for obtaining such data. The combination of the growing stock and the forest road network simplifies the planning of future cuttings. Due to rising wood prices as a result of the increasing demand for fuel wood and biomass, it might be possible in the near future to use the forest in the Alps lucratively. Cemagref develops methods for automatic estimation or mapping of single trees positions and heights, forest stand volumes, horizontal and vertical forest structures as well as forest stand types, on the basis of airborne laser scanning data (cf. Maier et al., 2008).

This paper presents two examples from remote sensing applications in the French forest practice. The first one describes the use of data from SPOT and Landsat-Sensors. The second one deals with the use of laser scanning data. Logically, the spatial scales of both examples vary from a regional one to a very local one.

2. EXAMPLE I: MONITORING MARITIME PINE RESOURCE IN AQUITAINE

IFN and Cemagref have been working on forest applications of remote sensing for 15 years. They have focused their research on change detection methods and have tested them with success in different applications like forest maps updating, defoliation monitoring or deforestation mapping (Bartalev et al 1997; Durrieu & Boureau 1997). Clear cutting is one of the obvious changes that can be detected from satellite data. Moreover, clear cuts maps are not produced with other methods and can be used in association with forest growth models to monitor wood resource evolution as well as to update inventory data. With the development of forest certification, clear cut mapping can contribute to monitor the sustainability of forest management in relation with the Helsinki criteria.

The first operational application of clear cut mapping on a large area in France was developed in the Aquitaine maritime pine massif. Three factors enabled the development of this application: the very favourable forest conditions for using remote sensing tools, a scientific context with numerous researches on remote sensing and forest modelling, and the need of local foresters for yearly updated data.

The aim of the project was to develop an integrated tool based on satellite imagery, inventory data and forest growth model to monitor maritime pine resource and its evolution.

2.1 AQUITAINE’S MARITIME PINE FOREST MASSIF

Aquitaine region is the largest continuously forested area in Western Europe. It represents 9 380 km² of regular maritime pine high forest on a flat area. The total wood volume reaches more than 145 million m3 and the annual yield is about 9.6 millions m3. The Aquitaine pine forest is privately at 94%. This forest is principally managed in a perspective of wood production. It provides the resource for a very large economic activity. In December 1999, Aquitaine’s forest has been seriously affected by the Martin storm that blew down about 26 million m3 of wood in this region (about 170 million m3 in France).

2.2. CLEAR CUT MAPPING METHOD

The first component of the application developed in Aquitaine is clear cut mapping from satellite imagery. The satellite images used are Landsat 5 TM and Landsat 7 ETM data since the Aquitaine pine forest can practically be covered by one scene and a quarter, as provided by both sensors. The change detection method uses two images acquired at one year interval. The method includes image georeferencing, relative radiometric normalization, image differencing and difference-image thresholding. All the processes are performed on the TM5 channel as coniferous clear cut detection performs better in SWIR spectral domain (Jolly et al., 1996). Multispectral images are only used in colour composition for visual control of the results.

Relative radiometric normalization of images is achieved with an original method developed at IFN (Durrieu and Boureau, 1997). A normalization model is calculated for each forest-type. For each Digital Count in the first image (DC Date 1), its target normalized value is defined as the modal value of the Digital Counts of the corresponding pixels in the second image (DC Date 2)(Figure 1).

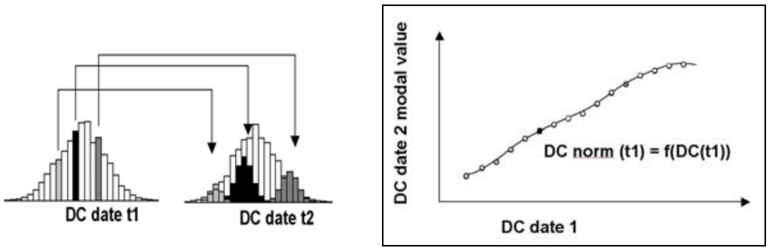

Figure 1. Relative normalization of an image channel.

A difference-image is produced calculating the pixel to pixel difference between the second TM5 channel and the normalized first TM5 channel and centering the values on 128. A change probability image is then calculated by comparison of actual values frequencies of the difference-image and values frequencies of a theoretical no-change image. A theoretical frequency is calculated by fitting a Gaussian distribution function on the 6 values surrounding the mode of the real distribution (128). The probability of change is calculated for each pixel as the difference between real frequency and theoretical frequency divided by the real frequency (Fig. 2).

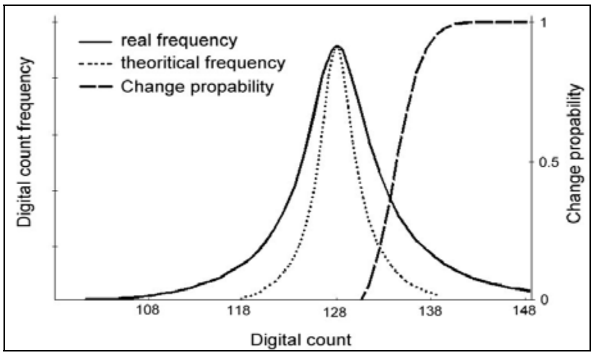

Figure 2. Digital count frequencies in difference-image and change probability.

In order to avoid false detection in young plantations or recently logged stands, a second criteria is introduced in combination with change probability. Both images (date 1 and 2) are classified in 3 classes of crown cover (open, intermediate and closed stands) by thresholding TM5 band. The thresholds are determined from training stands operated by the national forestry board (ONF). A multicriteria decision rule combining probability of change and crown cover in first and second images is applied to produce an initial classification with 3 classes : clear cut, uncertain clear cut and no clear cut. Morphological filters are applied to eliminate isolated pixels and to regroup contiguous certain and uncertain clear cut pixels in clumps. A second classification, at the clump level, is produced by classifying each clump in one of the three classes (clear cut, no clear cut or uncertain clear cut) depending on the clump shape and the proportion of “clear cut” pixels and “uncertain clear cut” pixels in the clump. At the end, a visual control using both original Landsat images in colour composition allows to definitively affect “uncertain clear cut” clumps to “clear cut” or “no clear cut” class.

Annual clear cut maps have first been produced with this method for the 1990 - 1999 period. In 2000, IFN adapted its method to map the damages caused by the December 1999 storms on the massif. In 2001 and 2002, the method was again used to map the windfall logging areas in the wind damaged areas at the behest of the Aquitaine timber industry. And for the 2003 - 2006 period the processing is to be carried over again at the request of the timber and forest industries, as an aid to a sustainable forest management within the framework of a PEFC approach. At the moment, the 2002/2003 clear cut map has been produced and the 2003/2004 map is in process.

The clear cut maps have been crossed over with IFN ground sample plots on which the tree ages are measured. For each detected clear cut with a sample plot, the age of the stand at clear cut has been calculated by incrementing the stand age when it was measured with the difference between the year of clear cut detection and the year of plot measurement.

2.3. CLEAR CUT MAPPING RESULTS

The mean annual clear cut area derived from satellite clear cut maps for the period 1990/1998 is 17 507 ha. It is very close to the area derived from IFN results for the period 1988/1996 which is 17 754 hectares. Accuracy assessment with ground reference data provided by the national forestry broad (ONF) and an industrial company (SMURFIT) revealed an omission rate varying from 5% to 7.5% depending on the year and a very low false detection rate (< 1%).

Beyond the estimation of global clear cut area, the rate of clear cut area depending on stand age is a major result of the clear cut mapping application as it is used as an input of the pine growth model. Fig. 3 presents the results of clear cut rates depending on age classes for the 1990 - 1994 and 1994 - 1998 periods.

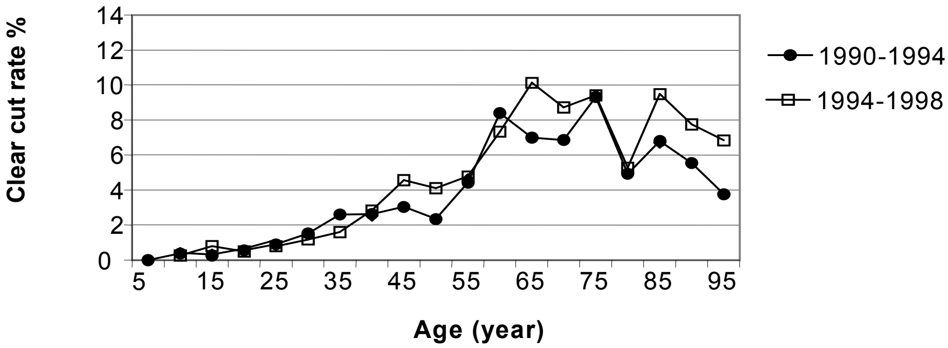

Figure 3. Clear cut rate depending on stand age derived from satellite clear cut maps and IFN sample plots.

3. EXTENSION OF CLEAR CUT MAPPING IN OTHER FRENCH REGIONS

After the satisfactory results obtained on the Aquitaine maritime pine forest, IFN and Cemagref have studied the generalization of satellite based clear cut mapping on other French regions with more complex situations: presence of relief, mixture of species and forest structures. To this aim they studied the necessary adaptations of the method and tested it in various forest conditions.

3.1. STUDY AREAS

The first test site is the Corrèze '*département*', covering 5900 km² with more than 2600 km² of forest. It is an hilly region located on the western border of the Massif Central. Important plantations programs have been carried out in Corrèze since 50 years, mainly with conifers : douglas fir and spruce. Broad-leaved forests nevertheless still represent more than 75% of the forest, principally in coppices or mixed coppice and high forest stands.

The second test site is located in Ariège '*département*', in the Pyrenean mountain massif close to the Spain border. Its area is 1300 km² with a 280 km² forest area. Different forest types can be found: conifer high forest (26%), broad-leaved high forest (8%), mixed high forest (14%), coppice and broad-leaved high forest mixture (26%) and coppices (10%).

3.2. DATA AND METHODS

SPOT 1 to 4 images providing a full coverage of the Corrèze '*département*' were acquired for years 1991, 1994 and 1999 (10 scenes). Change detection was performed between 1991 and 1994 images and then between 1994 and 1999 images.

On the Ariège test site, the satellite data used are 2 SPOT 4 images from 1999 and 2000 and 2 SPOT 5 multispectral 10-meter images from 2002 and 2003. Methodological investigations have concerned pre-processing with correction of topographic effects on radiometry , adapting multicriteria detection rules to SPOT1 to 3 data (without SWIR band) and adapting morphological filters to the highest resolution data (SPOT 5, 10 meters). After testing different topographic correction models proposed by different authors (Riaño *et al*, 2003), the statistical empirical model from Teillet (Teillet *et al* , 1982) was found to be the more efficient and the more robust.

The expression of normalized reflectance is $L_H = L_T - (a \cos i + b) + \overline{L}_T$, where L_T is the original reflectance, i is the local incidence angle and a and b are two parameters to be determined from image data.

3.3. RESULTS

Bad results were obtained on the Ariège test site. These disappointing results are not only due to the significant relief in this mountainous area but rather to the type of logging that is realized: clear cutting is very rare, while most of the logging is done through thinning or progressive regeneration fellings. Most of these partial fellings can be easily seen in very high resolution SPOT 5 images but the method adapted for clear cut mapping failed to detect them.

Satisfactory results were obtained on the Corrèze test site. The total clear cut area derived from satellite imagery for the 1991/1999 period is 12884 ha whereas it was estimated to 13975 ha by IFN inventory results, showing an underestimation of about 7.8%. The accuracy assessment was realized with ground reference data provided by forest owners (CRPF) and a sample of reference clear cuts delineated on aerial photos. It shows an omission rate (non detected clear cut area divided by the reference clear cut area) of 15% and a commission rate (falsely detected clear cut area divided by the total detected area) of 13%.

4. EXAMPLE II: ASSESSING PROTECTION FOREST STRUCTURE WITH AIRBORNE LASER SCANNING

Many forests in the Alps cover steep to very steep slopes (gradients of 35 - 70 degrees) and have an important protective function against natural hazards, such as rockfall, snow avalanches, shallow landslides and erosion (Dorren et al., 2004). In order to sustain the protective effect of these forests, they have to be managed. This requires reliable forest data with high spatial resolution, which could be delivered by LiDAR (Lim et al. 2003). The aim was to retrieve information on the structural characteristics of a protection forest stand, especially, the tree positions and the tree height using airborne LiDAR (Light Detection And Ranging, also called laser scanning), which has been shown to be feasible in less steep terrain by Popescu et al. (2002) and Zimble et al. (2002). We specifically investigated whether reliable information of trees growing on steep slopes can easily be obtained. As most foresters use raster data in standard Geographical Information Systems (GIS) instead of 3D point clouds, we tested two methods that are based on the identification of local maxima on raster data in this study.

5. SINGLE TREE DTECTION METHODS

5.1 TEST SITE AND DATA

The test site for this study is situated in the 'Combeloup' catchment, located near Grenoble in the French Alps. During the spring of 2007 a test site of 2 km^2 has been scanned with an airborne laser scanner or LiDAR (Light Detection And Ranging). The forest consisted of 95% beech trees, 2% silver firs and 3% other species. It covers a slope with a gradient up to 40 degrees. This site has been scanned in April 2007 with an airborne full waveform LMS-Q560 laser scanner made by Riegl Inc. The pulse rate of the LMS-Q560 is 140 kHz, which resulted in an average point density of 7 points m^2 at an average fly altitude of 600m above ground level. The maximum laser beam divergence is 0.5 mrad; the average footprint on the ground was about 0.29 m; the average ground swath width was about 426 m, the maximum scanning angle 60º.

The obtained data have been filtered and interpolated by the data providing company to create a digital terrain model (DTM) and a digital surface model (DSM), both with a resolution of 1 m × 1 m and a size of 300 × 300 cells (Figure 4). Since most users of LiDAR data would obtain similar data, we used these two rasters as the basis data for our study.

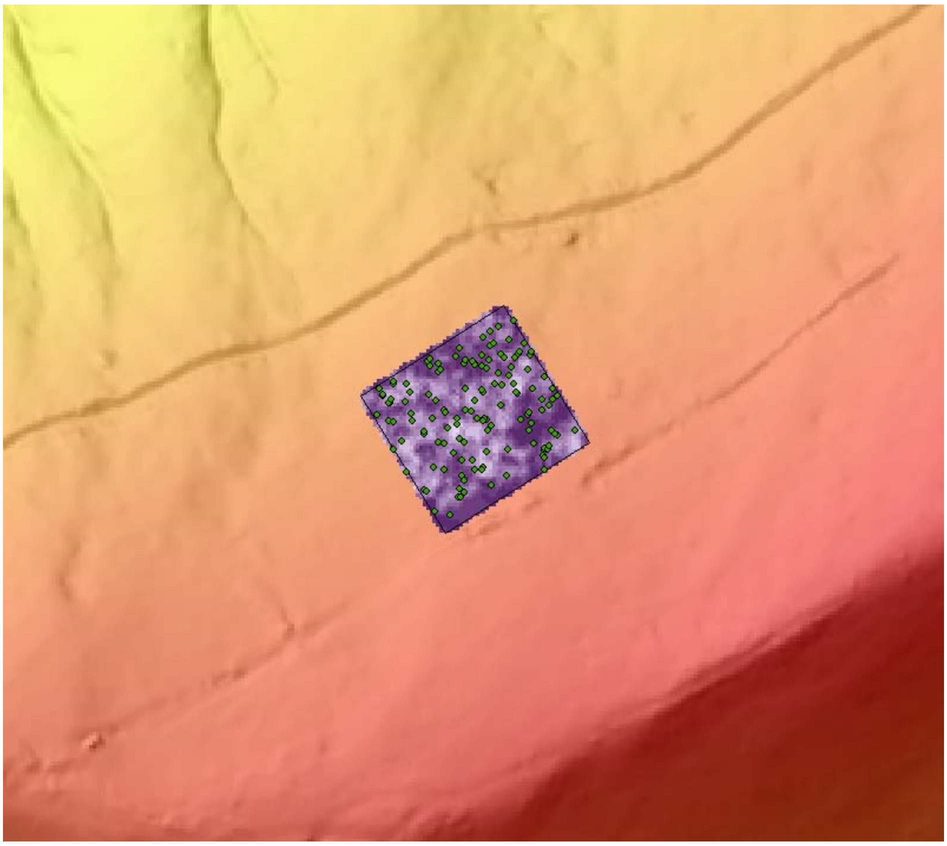

Figure 4. The DTM of the study area (background), the CHM (in violet) and the measured trees in the validation plot).

By subtracting the DTM from the DSM we obtained a Crown Height Model (CHM), which gives an estimate of the height of vegetation or similar obstacles. We subsequently smoothed the obtained CHM by calculating mean values in the raster using a spherical moving window with a radius of 1, 2 and 3 m to avoid problems with branches and irregular shaped tree crowns. Visual inspection showed that the 1m smoothed raster should be used for further analysis, because a large window would smooth the canopy surface to much and tree tops disappeared (Fig. 5).

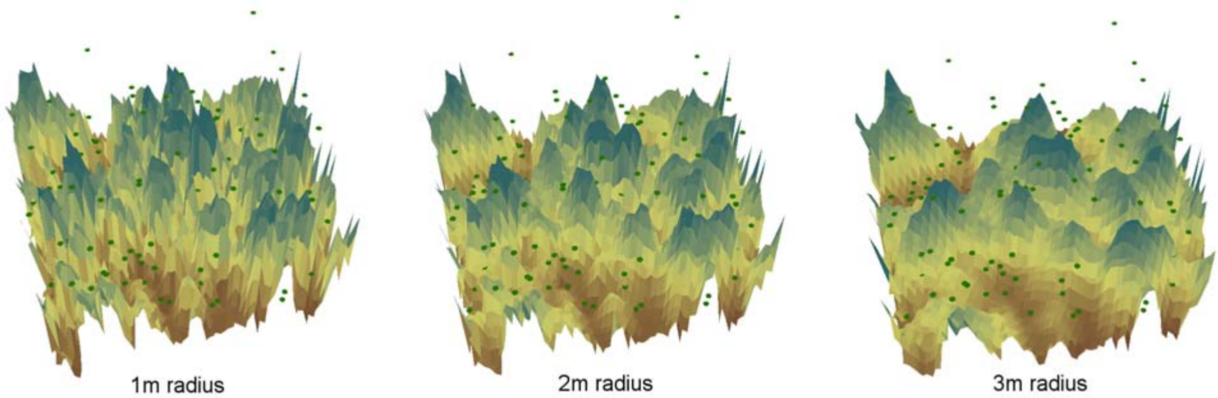

Figure 5: The smoothed NCM using mean value calculation in a spherical moving window with a radius of 1, 2 and 3 m. The green dots are the trees measured in the field representing their base positions and heights.

5.2 VALIDATION DATA

A detailed inventory within a sample plot that covered 50 by 50 m has been carried out. Here, we measured the diameter at breast height (DBH), the tree height and the exact position of 138 trees with a DBH > 2 cm using a compass and an ultrasonic vertex from the sample plot centre. The position of the centre has been measured with a differential GPS. Position errors were estimated to be 0.5 m and maximum tree height measurement errors of 2.5 m, due to the steep terrain and closed canopy cover.

5.3 TREE HEIGHTS AND POSITIONS

To extract tree heights and positions from the smoothed CHM using the moving window (radius 1 m), we tested a method that is based on the identification of local maxima, where those maxima are regarded as treetops. The method, called Tree-top Window Analysis (TWA), is programmed in Matlab and evaluates for each cell in the CHM, which has a value larger than the defined minimum tree height, whether it is a local maximum. Each cell is evaluated with a 3×3 window. If the evaluated cell is a local maximum, the window radius is enlarged with 1 cell (= 1 m). Then, the evaluation is repeated. As such the method assesses the dominance of the cell over all surrounding cells and it gives a value to each maximum that corresponds to the maximum window radius used. Here the user defines the maximum window radius. In this study we used 4 m. The TWA method also provides information on 'sub-maxima'. This is a cell that adjoins the local maximum with a height gradient less then 45º between the two. Condition for a sub-maximum is that all cells in the window have a lower value except for the local maximum. The sub-maxima are attributed a value of 0.5. Such a sub-maximum could represent a tree that grows in or near a tree collective. The final generated file provides x- and y-coordinate, dominance value (0.5, 1, 2, … maximum window radius) and height of the detected local- and sub-maxima.

5.4 DERIVING BASAL AREA

On the basis of the tree heights and their DBHs as measured in the field, we established a relationship between height and DBH. We used this relationship to calculate the total basal area (G) in the plot on the basis of the heights of the detected trees using the LiDAR data. We then compared the G measured in the field ($G_{terrain}$) and the G based on the LiDAR data (G_{LiDAR}).

6. RESULTS AND DISCUSSION

Figure 6 shows the relationship obtained between the measured DBHs and the heights for trees larger than 10 m (R^2 = 0.79).

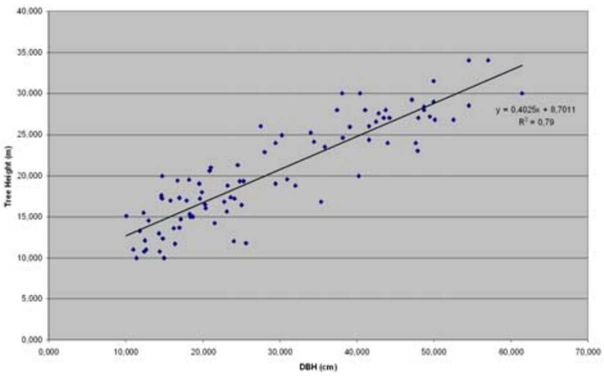

Figure 6: DBH versus tree height of the field measured trees larger than 10 m.

Figure 7 shows the sample plot with 89 field mapped trees that were larger than 10 cm and 71 trees detected in the smoothed CHM. These 71 trees are those local maxima that have a dominance value larger than or equal to 1 and a height larger than 10 m. Field mapped trees smaller than 10 cm were not detected. Sub-maxima (dominance value of 0.5) did not seem to be valuable indicators in a beech-dominant forest stand. Using these criteria, we were able to detect 80% of the trees. The plot also shows the positions errors (on average 2m, maximum 3.5 meters) between the measured tree positions (at breast height) and the detected treetops.

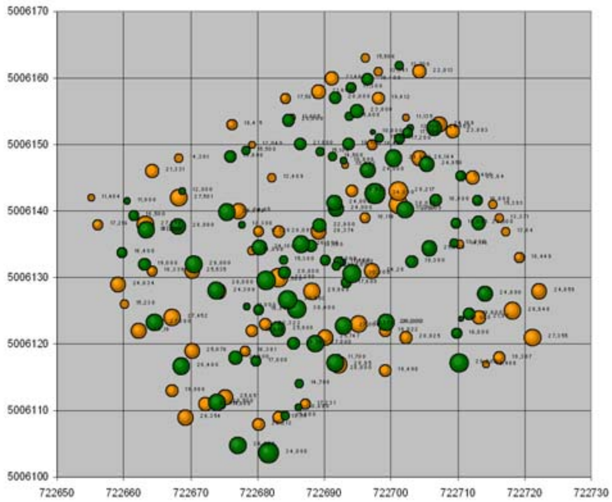

Figure 7: Mapped (green dots) and LiDAR (yellow dots) derived tree positions and heights.

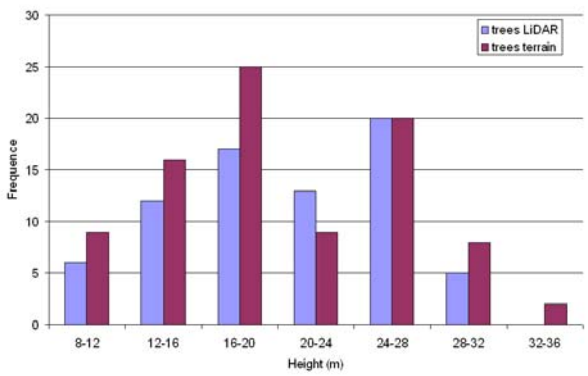

Figure 8: Histogram of the trees detected by LiDAR and those mapped in the field (height > 10 m).

Figure 8 shows that there is a good correspondence between the all the trees detected by LiDAR and those mapped in the field. Again, by using only the trees larger than 10 m and the Height-DBH relationship shown in Figure 3 we obtained a G_{LiDAR} of 5.9 m^2 and a $G_{terrain}$ of 7.2 m^2, which equals 81% of the G measured in the field.

7. CONCLUSION AND PERSPECTIVES

This paper presented two examples from remote sensing applications in the French forest practice. The first example, which dealt with clear cut mapping from satellite imagery was first developed and validated in Aquitaine maritime pine forest massif in order to monitor maritime pine resource evolution. After the satisfying results obtained in a first methodological stage, an operational service is provided to the local forest owners and forest industries to contribute to monitoring the sustainable management of the massif in a Pan European Forest Certification Process.

The second example, which presented methods for identifying the position and height of individual trees, based on the identification of local maxima, showed that they provide well usable results, also in steep terrain covered with predominantly broadleaved species. The final aim is to describe the structural characteristics of forest stands using LiDAR for (a) management planning, but also for (b) integrating stand characteristics (tree positions, tree heights and their DBH) in snow avalanche and rockfall simulation models and (c) to estimate the growing stock.

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