Report 16/2011

from Skog og landskap

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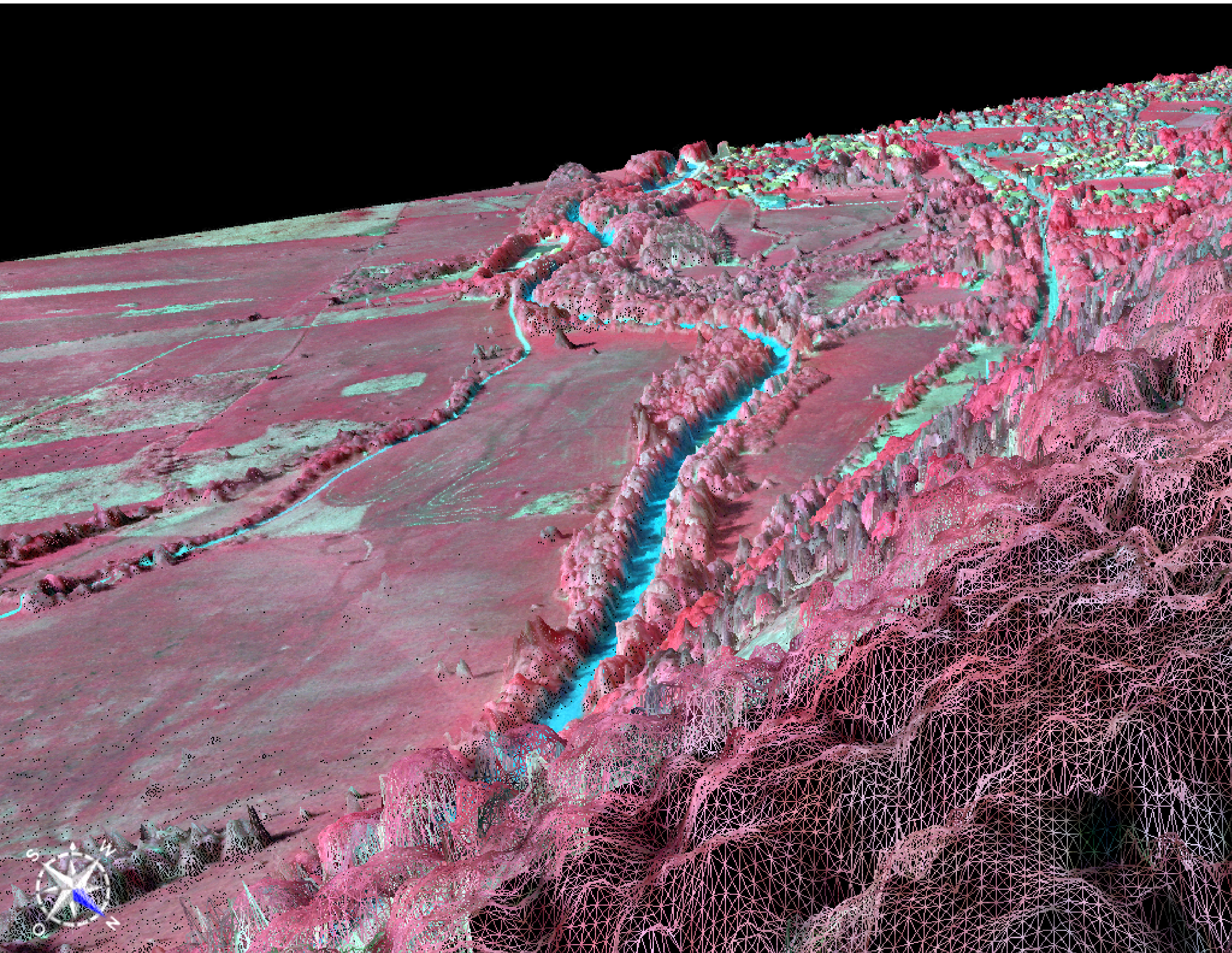
Proceedings, 9. june 2011, Ås, Norway

Johannes Breidenbach and Rasmus Astrup

NORWEGIAN FOREST AND LANDSCAPE INSTITUTE



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ISBN: 978-82-311-0140-6
ISSN: 1891-7933

Cover Photo: Photogrammetric digital surface model overlaid with CIR images in Ettaler Berg, Germany.
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SUMMARY
Vegetation height information is one of the most important variables for predicting forest attributes such as timber volume and biomass. Although airborne laser scanning (ALS) data are operationally used in forest planning inventories in Norway, a regularly repeated acquisition of ALS data for large regions has yet to be realized. Therefore, several research groups analyze the use of other data sources to retrieve vegetation height information. One very promising approach is the photogrammetric derivation of vegetation heights from overlapping digital aerial images. Aerial images are acquired over almost all European countries on a regular basis making image data readily available.

The Norwegian Forest and Landscape Institute (Skog og Landskap) invited researchers and practitioners that produce and utilize photogrammetric data to share their experiences. More than 30 participants followed the invitation and contributed to a successful event with interesting presentations and discussions. We wish to thank the speakers for their contributions and hope that all participants found the seminar useful. These short proceedings of the seminar include summaries of the talks. The presentations, which provide more information, can be found at the end of this document.

SAMMENDRAG
Informasjon om vegetasjonshøyde er en av de viktigste variablene for å estimere skogattributter som tømmervolum og biomasse. Selv om data fra flybåren laserskanning (ALS) brukes driftsmessig i skogplanlegging i Norge, utføres ikke repetiv innsamling av ALS-data for store områder. Derfor arbeider flere forskningsgrupper med å analysere bruken av andre datakilder for å hente informasjon om vegetasjonshøyde. En svært lovende tilnærming er den fotogrammetriske avledning av vegetasjonshøyder fra overlappende digitale flyfoto. Flyfoto er anskaffet over nesten alle europeiske land på en jevnlig basis. Bildedata er derfor lett tilgjengelig.

Norsk institutt for skog og landskap inviterte forskere og praktikere som produserer og bruker fotogrammetriske data til å dele sine erfaringer. Mer enn 30 deltakere bidro til et vellykket arrangement med interessante presentasjoner og diskusjoner. Vi ønsker å takke foredragsholderne for deres bidrag, og håper at alle deltakerne fant seminaret nyttig. Denne publikasjonen omfatter sammendrag av samtalene. Presentasjonene, som gir mer informasjon, er vedlagt bakerst.

Key Words: Photogrammetry, digital elevation models, digital surface models, digital aerial images, forest inventory, forest monitoring, small area estimation, EBLUP

Nøkkelord: Fotogrammetri, digitale høydemodeller, digitale overflatemodeller, digitale flyfoto, skogtaksering, skogovervåking, small area estimation, EBLUP

CONTENT

COMPARISON OF A PHOTOGRAMMETRIC CANOPY HEIGHT MODEL (CHM) WITH A LIDAR DERIVED CHM IN VESTFOLD COUNTY

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Introduction and material

Digital aerial images over Vestfold county were acquired by TerraTec in summer 2007 with a Vexcel UltraCamX sensor. The flying height above-ground was approximately 2800-3000 m which resulted in images of approximately 1880x2880 m size. The images were acquired in north-south oriented flight strips with a 20% side and 60% within-strip overlap. Panchromatic image data were acquired in 20 cm ground sampling distance (GSD). Near infrared, red, green and blue image bands were acquired in 60 cm GSD but were pansharpened to a 20 cm pixel size by the data vendor. The original radiometric resolution of the images (12 bit) was resampled to 8 bit for archival storage. The plane location and orientation during image acquisition were logged using a GPS and an inertial navigation system (INS). To increase the accuracy of the external orientation, an aerial triangulation was performed based on 34 ground control points using the software Match-AT.

BLOM ASA was commissioned to generate a photogrammetric canopy height model (CHM) from the digital aerial images. Using the image matching software SocetSet version 5.5.0 with the default NGATE strategy parameter setting, a photogrammetric point cloud of matched pixel locations with 1 m spacing was calculated from the red, green and blue bands of overlapping images. A digital surface model (DSM) with 20 cm pixel size was calculated from the photogrammetric point cloud using bilinear interpolation. Except for the municipality of Lardal where an airborne laser scanning (ALS) digital terrain model (DTM) with one meter resolution was available, the standard Norwegian DTM with a resolution of 10 m was available in the study area. The DTM was resampled to match the DSM resolution using bilinear interpolation and was subtracted from the DSM to yield a CHM.

ALS data with a density of approximately 10 points per m^2 were acquired for the municipality Lardal between 21 and 25 May 2009 using an Optech Gemini sensor from a fixed-wing aircraft. The ALS point cloud which included elevation and height (delta-z) data was provided by the data vendor (BLOM ASA). One tile of approximately 500x500 m was randomly selected for comparison with the photogrammetric CHM (Figure 1). The data contained first, single and last return data. A CHM with 20 cm pixel size was derived from the ALS height data using the software tool FUSION. FUSION basically uses the largest return height as the pixel value.

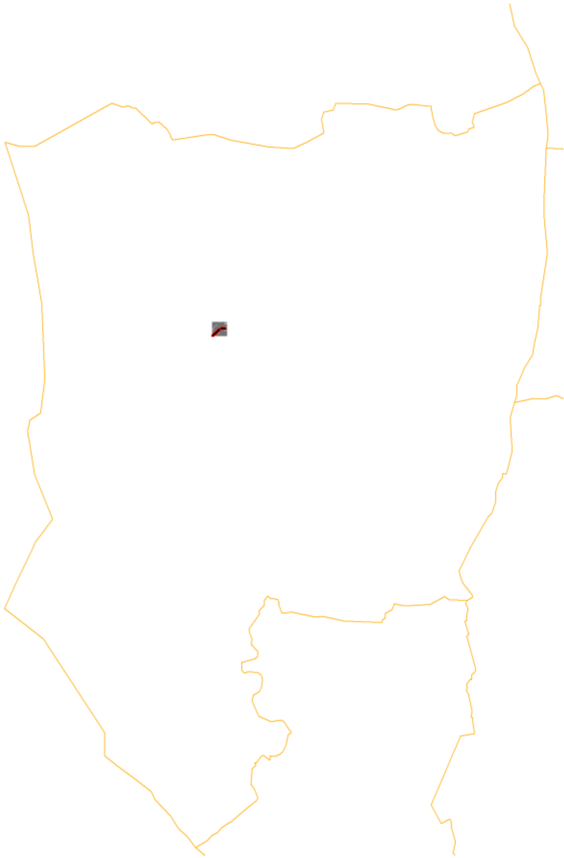

Figure 1: Outline of the municipality of Lardal and location of the randomly selected sub-area where the photogrammetric and ALS CHMs were compared.

Results

The photogrammetric CHM (photo CHM) has less details (small gaps and single trees are often missing) and is smoother than the ALS CHM (see Figures 2-6). In tendency, the photo CHM is higher than the ALS CHM. Shadows in the images have obviously resulted in problems for the matching algorithm. Matched points were therefore missing in shadow-areas at forest borders. Due to the interpolation, the photo CHM is therefore much larger than the ALS CHM in these areas. More results can be found in the presentation at the end of the proceedings.

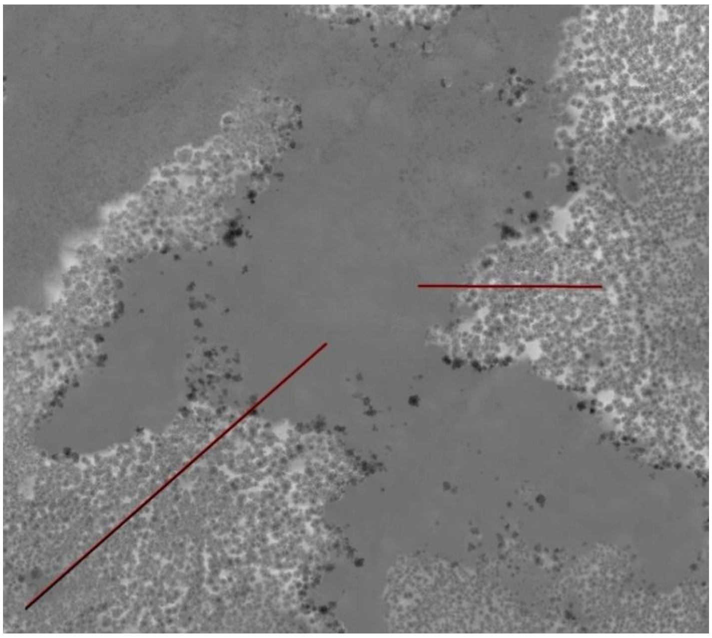

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Figure 2: Photo CHM minus ALS CHM.
Black = ALS>photo (-24 m), white = photo>ALS (30 m).

Figure 3: True ortho-photograph.

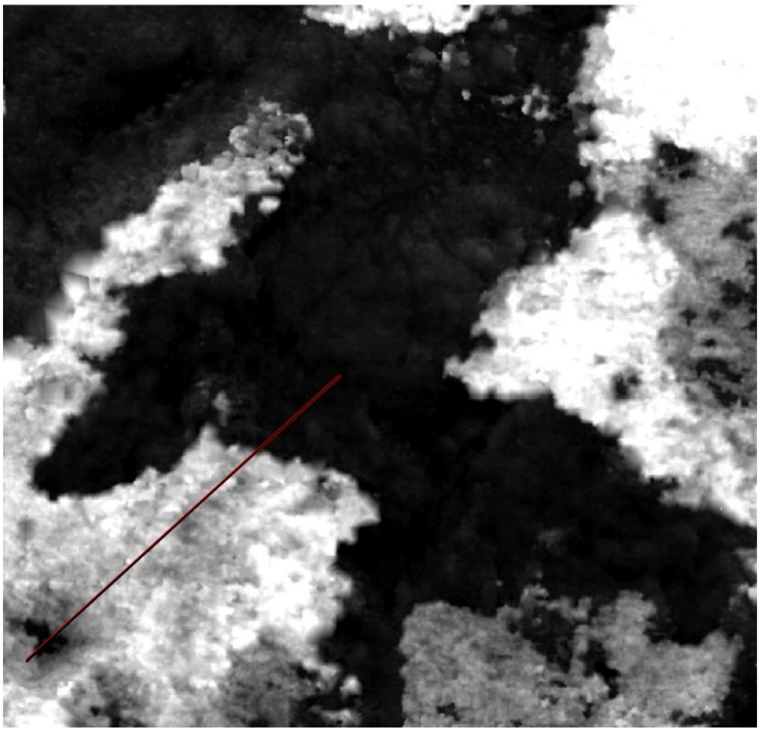

Figure 4: Photogrammetric CHM.

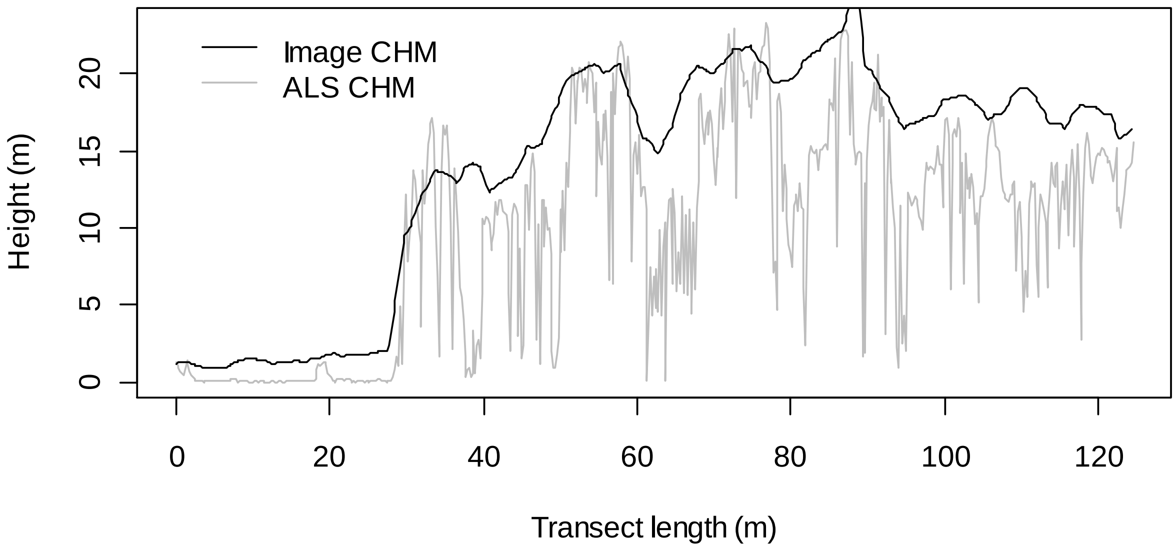

Figure 5: Transect 1.

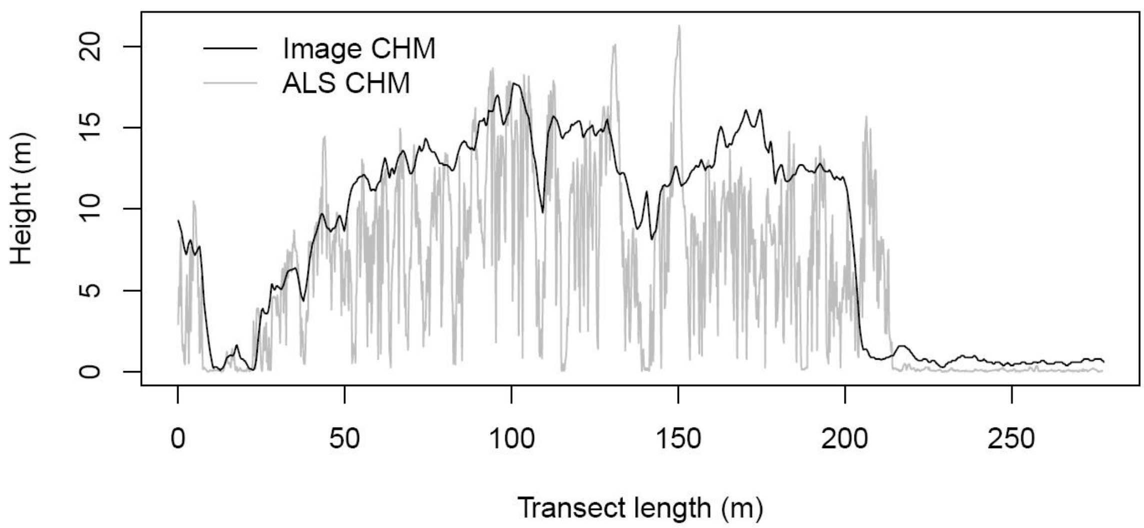

Figure 6: Transect 2.

SMALL AREA ESTIMATION OF FOREST ATTRIBUTES IN THE NORWEGIAN NATIONAL FOREST INVENTORY

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The Norwegian National Forest Inventory (NNFI) provides estimates of forest parameters on national and regional scales by means of a systematic network of permanent sample plots. One of the biggest challenges for the NNFI is the interest in forest attribute information for small sub-populations such as municipalities or protected areas. Frequently, too few sampled observations are available for those small areas to allow an estimate with acceptable precision. However, if an auxiliary variable exists that is correlated with the variable of interest, small area estimation (SAE) techniques may provide means to improve the precision of estimates.

This study aimed at estimating the mean above-ground forest biomass for small areas with high precision and accuracy by using SAE techniques. Therefore, the simple random sampling (SRS), the generalized regression (GREG) and the unit-level empirical best linear unbiased prediction (EBLUP) estimators were compared. Mean canopy height obtained from a photogrammetric canopy height model (CHM) was the auxiliary variable available for every population element. The small areas were 14 municipalities within the 2184 km^2 study area for which an estimate of the mean forest biomass was sought. The municipalities were between 31 and 527 km^2 in size contained one to 35 NNFI sample plots within forest.

The mean canopy height obtained from the CHM was found to have a strong linear correlation with forest biomass. Both, the SRS and GREG estimator result in imprecise estimates, if they are based on too few observations. Although this is not the case for the EBLUP estimator, the estimators were only compared for municipalities with more than five sample plots. The SRS resulted in the highest variances in all municipalities. While the GREG and EBLUP variances were similar for small areas with many sample plots, the EBLUP variance was usually smaller than the GREG variance. The difference between the EBLUP and GREG variance increased with a decreasing number of sample plots within the small area. The EBLUP estimates of mean forest biomass within the municipalities ranged between 95.01 and 153.76 Mg ha^{-1} with standard errors between 8.20 and 12.84 Mg ha^{-1}.

More information on this study can be found in the presentation at the end of the proceedings. A manuscript describing all details of the study (Breidenbach and Astrup, submitted 2011) is currently under review. The estimators are implemented as functions of the R software for statistical computing and can be obtained from CRAN (Breidenbach 2011).

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DERIVATION OF DIGITAL SURFACE MODELS FROM AERIAL IMAGES IN BAVARIA

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The remote sensing team of the Bavarian State Institute of Forestry develops largely automated methods to extract forest characteristics from digital aerial photographs such as vegetation height and canopy closure with the aim to provide essential information for forest management.

The potential to derive high-resolution digital surface models (DSMs) in forest areas using image matching techniques was analyzed in the present study. Different study sites were selected within Bavaria, Germany, which are characterized by different terrain situations and forest types. Stereo images with four spectral channels were provided by the Bavarian Office for Surveying and Geographic Information. The images were acquired in the year 2009 with different airborne sensors: Vexcel UltraCam X and XP.

Surface models were computed using the novel commercial software module LPS eATE which was developed to derive dense elevation information from stereo imagery using a pixel-by-pixel matching technique. The point cloud from image matching was converted into a digital surface model (DSM) using an active surface algorithm implemented in the software TreesVIS. A canopy height model (CHM) was derived by subtracting a terrain model derived from airborne laser scanning (ALS) data.

The Photogrammetric CHM was compared to an ALS CHM. For this purpose the study site was subdivided into cells - each with a size of 500 m². Several height metrics (height percentiles) were computed within the cells. In addition, the surface roughness was characterized: Firstly, by fitting a plane to the height values within each cell and by computing the standard deviation of height differences to the plane. Secondly, by extracting the total number of canopy gaps for both models. The height percentiles were compared for both models and yielded high Pearson correlation coefficients (between 0.88 to 0.96 for the 90th height percentile). Concerning the surface roughness a greater height variation was determined for the ALS models. In addition, more canopy gaps were extracted in the ALS canopy height models, which are mainly very small gaps with a size < 200 m².

In one study site, a time difference of 2-2½ years between the aerial survey and ALS flight caused a systematic shift in the compared height metrics. This may partly be explained by the tree growth.

In conclusion, the photogrammetric models are less detailed. The surfaces are more smoothed and small gaps in addition to single trees are frequently not detectable. Nevertheless, vegetation heights can be measured with a high precision. Thus, stereoscopic aerial photographs are an economically efficient alternative if a terrain model from ALS is available for the derivation of an accurate canopy height model.

SEMI-AUTOMATIC EXTRACTION OF FOREST AREA, TYPE AND COMPOSITION FROM ADS40/80 IMAGES AND DERIVED CHMS FOR THE SWISS NFI

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Introduction: This short paper summarizes an approach to semi-automated extraction of tree area and tree species classification on regional / state level for different types of forests using multispectral ADS40/ADS80 data to support some tasks of the Swiss National Forest Inventory NFI (Brändli, 2010). For more detailed information see the publications listed beow. In Switzerland, the airborne digital sensors ADS40/ADS80 offer new opportunities as they can provide entire image strips with high geometric, radiometric and temporal resolution and cover the entire country (40'000 km^2) every three years. Several studies have integrated multi-sensoral data to estimate forest attributes such as tree area (WASER ET AL. 2008A AND 2008B) and tree species (HEINZEL ET AL. 2008; CHUBEY ET AL. 2009; WASER ET AL. 2010, WASER ET AL. 2011). Recently, the usage of digital sensors has become more popular. In WASER ET AL. (2010) four different airborne digital sensors (ADS40, DMC, JAS-150 and Ultracam-X) were tested to extract tree area and to classify tree species classification. Until now, most (semi)-automated tree extraction and species classification methods have been developed for small study areas of a few hectares with few field plots and for relatively homogeneous forests with only a few tree species. In the present study a robust model has been developed for an area located in the East of Switzerland with an extend of approx. 300 km^2. The objective of this study is to present the potential and limits of ADS40/80 images as input for semi-automated extraction of tree area and classification of tree species.

Study area: The study area *Appenzell* is located in the pre-alpine zone of Central Switzerland (approx. 46°46' N and 10°16' E, 700 m – 2000 m a.s.l.) and is approx. 300 km^2 in area. It is a heterogeneous mixture of forest, grasslands, pastures, agricultural and urban areas. The forest itself covers approx. 130 km^2 and is mostly characterized by mixed forest with a dominance of deciduous trees along rivers and coniferous trees above 1400 m a.s.l. The forests are partly managed with clearings and both deforestation and afforestation in several parts of the area.

Remote sensing data: Second generation Airborne Digital Sensor ADS40-SH52 andADS80-SH82 RGB and CIR images (2008-2009, 11 Bit, l level 1 pre-processed), were used with a special resolution of 25 cm. The entire study area consists of six strips (50% side-overlapping). From these six strips, three orthoimages were calculated. For each image strip a digital canopy height model (CHM) was produced subtracting a LiDAR DTM (2003, 0.8 points / m^2, ARTUSO ET AL., 2003) from the DSMs. Since the commercial available photogrammetric software SOCET SET 5.4.1 doesn't offer a DSM strategy for forests, two different DSM strategies were used in this thesis instead: 1. the default strategy, which was originally designed for urban and rural areas (*ngate-strategy*), and 2. the modified and combined strategy (*ngate-ssscript-strategy*), which was especially designed at WSL for vertical vegetation, i.e. single trees and forests. In fact, it is a combination of modified forest and desert strategies, and improves DSM generation within forests and mainly reduces noise and artefacts in open land (see Fig. 1).

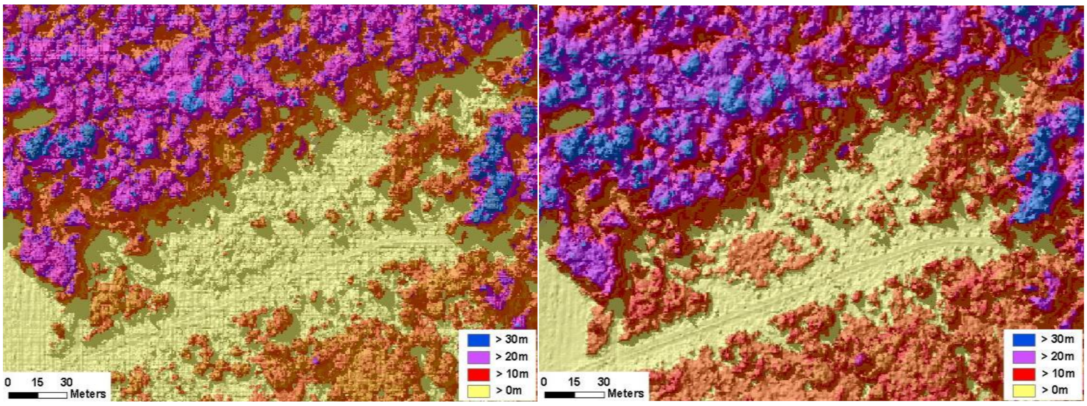

Figure 1. example of coloured hillshade of the normalized DSM. The 0.5 m – DSM was derived from ADS40-SH40 NIR channels using the default *ngate-strategy* (left) and the *ngate-ssscript-strategy* (right). Large underestimation of single trees mainly occur within the afforested area as well as light noise effects (regular patterns) are clearly visible in the left figure.

1st goal: Tree area: The ground truth data to validate the tree area consists of 400 tree crowns and non-tree samples (in open land) which were delineated on the ADS40 orthoimages. Image pixels representing trees were to be assigned to the two classes (tree / non-tree) by predictive modeling. The modeling was performed using *the R statistics version 2.11.0*. A fractional tree cover was produced using a logistic regression approach (according to e.g. MC CULLAGH & NELDER 1983) with a probability for each pixel to belong to the class "tree". The step-wise selected explanatory variables consist of four commonly used topographic parameters derived from the CHMs (slope, curvature, and two local neighbourhood functions). This approach and the extraction of explanatory variables are described in detail in WASER ET AL. (2007) and WASER ET AL. (2008A). In our case, probability for each pixel belonging to a "tree" ranges between 0 and 1. Image segments with a tree probability of 0.2 or more were assigned to the class "tree", the others to the class "non-tree" (see Fig. 2).

The accuracy of the two tree covers was assessed by applying confusion matrices based on the digitized tree / non-tree polygons, and by a photo-interpreted 10 m point raster of selected areas (approx. 5% of the strips) with a discrete tree / non-tree decision. A ten-fold cross-validation based on the digitized polygons revealed overall accuracies of 0.99 and Cohen's kappa of 0.98 for all image strips. The photo-interpreted point raster reveals an overall accuracy of 0.98 and a Kappa of 0.91. Visual image inspection shows that forest gaps are slightly underestimated and especially single trees and shrubs are precisely extracted.

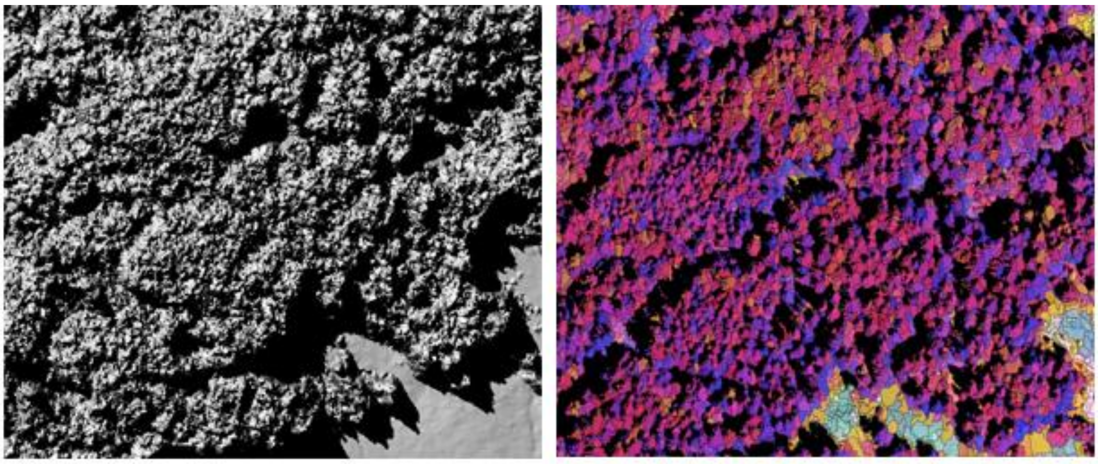

Figure 2. Example of the hillshade of the canopy height model (left) and the fractional tree cover (right) where violet=high probability and yellow=low probability.

The most significant achievement is the demonstration that the high accuracies of the models for the fractional tree cover based on both geometric and spectral variables indicate that the models are reliable. The fact that the geometric variables alone almost suffice for the generation of the fractional tree covers, underlines the importance of dense and accurate DSMs. Thus, the adapted *ngate-ssscript-strategy* proved to be very suitable for the extraction of forested areas (tree- / non-tree decision) and also for forest borders and clearings.

2nd goal: Tree species: Ground surveys were carried out in summer 2009 and 2010, focusing on the most frequent tree species (at least 5% coverage in Switzerland). The dominating deciduous tree species are *Fagus sylvatica* and *Fraxinus excelsior* and less frequently *Acer sp., Alnus sp.,* and *Betula sp.* The main coniferous trees are *Abies alba*, *Larix deciduas, Picea abie,* and *Pinus sylvestris*. The crowns of up to nine different tree species were delineated in the field on the corresponding printouts of the orthoimages and then also digitized using ArcMap (380 digitized polygons in total). Prior to the object-oriented tree species classification, homogenous image segments of individual tree crowns and tree groups were obtained using a multi-resolution segmentation procedure.
In a first step, image segments representing single trees were to be assigned to classes (species) by predictive modeling. As the response variable has more than two possible states, a multinomial model had to be applied (see e.g. HOSMER AND LEMESHOW, 2000). In a second step, several variables (geometric and spectral signatures) were derived from the ADS40 / 80 orthoimages using standard digital image processing methods (including arithmetic combinations, colour transformation (IHS), linear discriminance analysis (LDA), and principal components analysis (PCA)). To obtain good predictions, a small set of powerful variables has to be selected using a stepwise variable selection (AIC, both-directions, for details see WASER ET AL. 2010, WASER ET AL. 2011). The final input variables used in this study consist of original image bands, IHS, their PCAs and LDAs. Ten-fold cross-validation revealed overall accuracies between 0.7 and 0.85 and Cohen's kappa values between 0.6 and 0.75. Lower accuracies (kappa < 0.5) were obtained for small samples of species such as non-dominant (mostly deciduous) tree species with similar spectral properties. Overall, the accuracies obtained for these three orthoimages are in line with or higher than those in similar studies. An example of the predicted tree species are shown in Fig. 3.

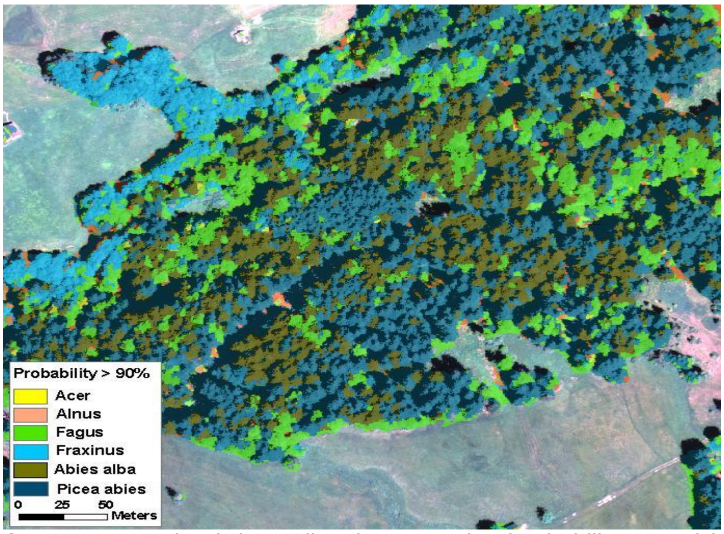

Figure 3. Example of six predicted tree species (probability > 90%) in a typical mixed forest.

Conclusions: Multispectral ADS40 imagery with logistic regression models have a high potential for extraction of tree area and tree species classifications with a minimum amount of effort involved in image acquisition, data pre-processing, derivation of explanatory variables and field work. However, further work is needed to improve distinguishing non-dominant, small and covered tree species. This should also include multi-temporal imagery for a better distinction of deciduous trees with spectral similarities. Further development is needed with the harmonization of the several image strips recording trees with a different phenological status. For this, radiometric correction at least within images stripes will be taken into account.

For the Swiss NFI, the extent of tree area and tree species composition of larger areas, preferably on the national scale is required. Therefore the findings of this study provide a first important contribution. Furthermore, the continuity of this approach will be guaranteed since the required input data (field samples, images) is being provided every three years by other national campaigns or monitoring programs. Currently, NFI sample plots are being implemented for validation of the tree species classifications.

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EXTRACTING DATA FOR SINGLE TREES FROM PHOTOGRAMMETRIC CANOPY HEIGHT MODELS AND TRUE ORTHO PHOTOGRAPHS

Svein Solberg and Johannes Breidenbach

Norwegian Forest and Landscape Institute

Top dieback and mortality of Norway spruce is a particular forest damage that has severe occurrences in scattered forest stands in southeast Norway. As a part of a project to study the extent and causes of the damage we are working on an algorithm for automatic detection dead and declining spruce trees for an entire county, - Vestfold. The data set is aerial imagery. The county was covered in 2007. Preliminary tests showed a considerable confusion between dead trees and bare ground. In order to avoid this confusion we have had the imagery automatically processed into a photogrammetric digital surface model (DSM) and true orthophotos. The data set derived from this processing was a 5 layer file, containing blue, green, red, and near-infrared, as well as the height above ground of the canopy height model (a DSM normalized by the terrain height, nDSM).

The idea is to detect single trees. We combine one spectral band (NIR) and the nDSM band by multiplying them, smooth this combined image, and identify local maxima to detect single trees. In this way we utilize the advantages of the nDSM, which represents canopy height of the stand, and the advantage of the NIR which contains brightness maxima close to tree tops. We then classify these local maxima, based on the 4 spectral bands, and for each of them using one pixel only. We made a training data set for 4 classes, i.e. 3 forest species classes (spruce, pine and broadleaves) as well as dead trees. The algorithm was developed using the national forest inventory (NFI) data set. This is a 3x3 km grid of permanent plots, all of which have accurate coordinates from dGPS measurements. We have compared various algorithms, including spectral angle mapper (SAM), a Bayesian classifier, as well as heuristic models.

Best results were obtained with the Bayesian classifier, with a simple Kappa =0.76 and overall accuracy of 81% for 4 classes of trees (spruce, pine, deciduous and dead). A major problem has been confusion between pine trees and dead trees. The Bayesian classifier was found to be superior compared with the others, as it has the ability to include prior probabilities. In this way dead spruce trees could be assigned with a low prior probability, which largely removed ‘false positives’, i.e. mainly live pine trees misclassified as dead trees.

Single Pixel Correlation
DSM seminar, Ås June 9 2011

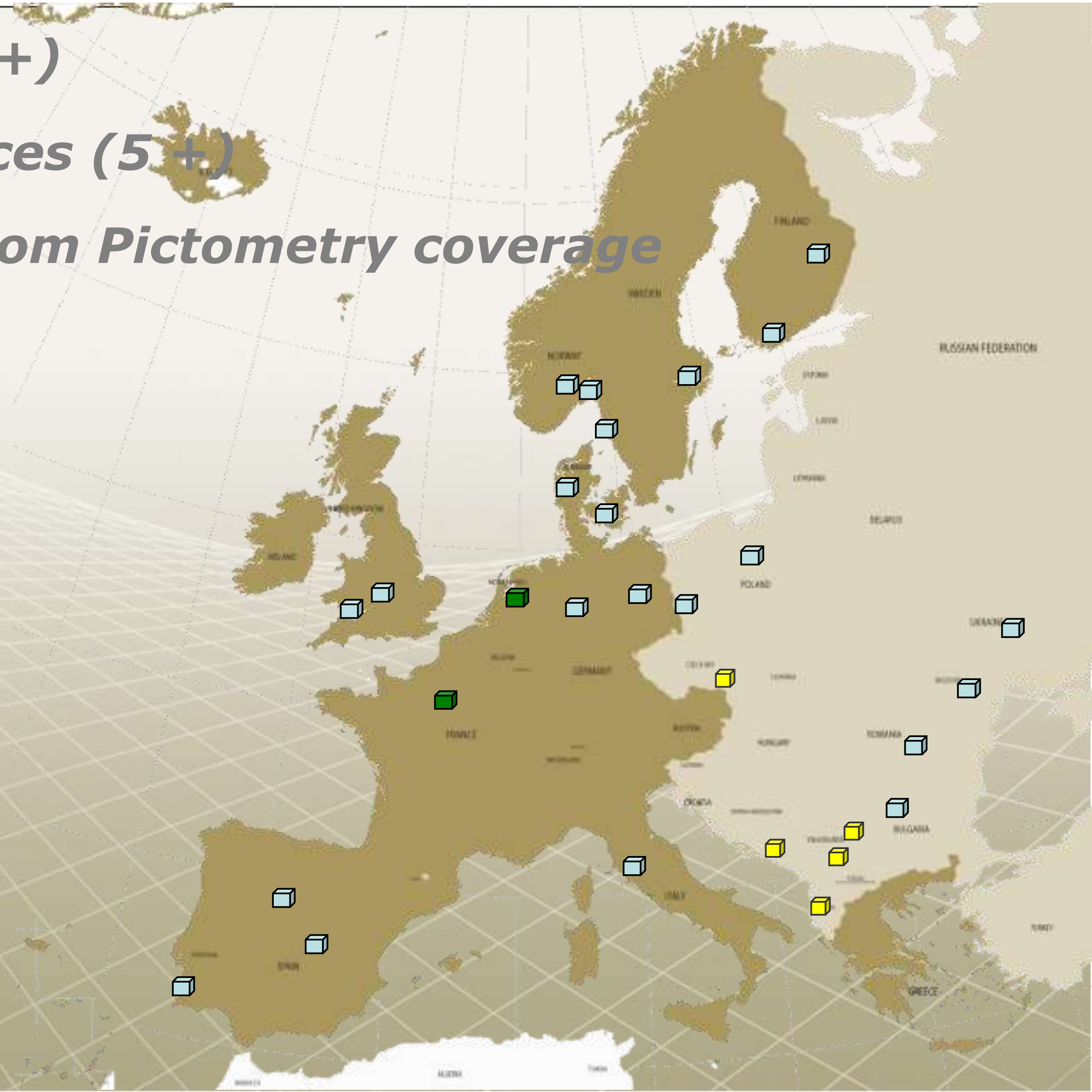
Inge Myklebust
Blom

Agenda

- Brief overview of Blom
- Historical overview of correlation in photogrammetry
- Today’s use of correlation
- Case study: DSM in Vestfold county
- Summary

Blom Offices in Europe

- *Blom offices (22 +)*
- *Blom Branch offices (5 +)*
- *Countries with Blom Pictometry coverage*
- *Sales Offices*

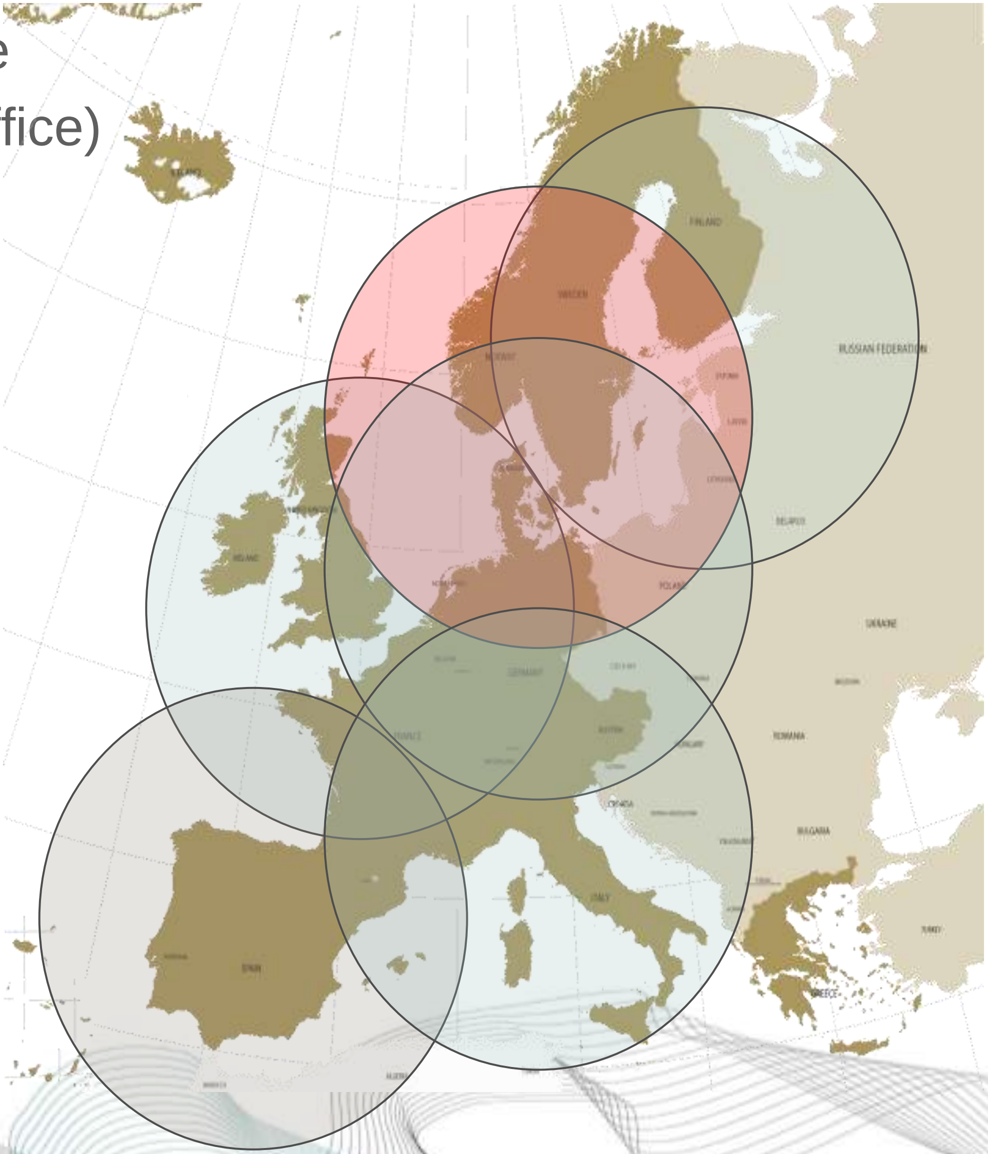


Resources at Rakkestad airport

BLOM
IMAGING THE WORLD

Flight operations

- 3 flying hours from base
- (i.e. airport with Blom office)



Correlation: What is it?

- Objective of Correlation/Matching: Find the same pixel(detail) in at least two images > Height can be calculated

Different algorithms:

Least square matching(LSM),

Feature based matching(FBM)

Software often use a combination of algorithms:

SocetSet NGATE

Inpho Match-T DSM

Historical overview

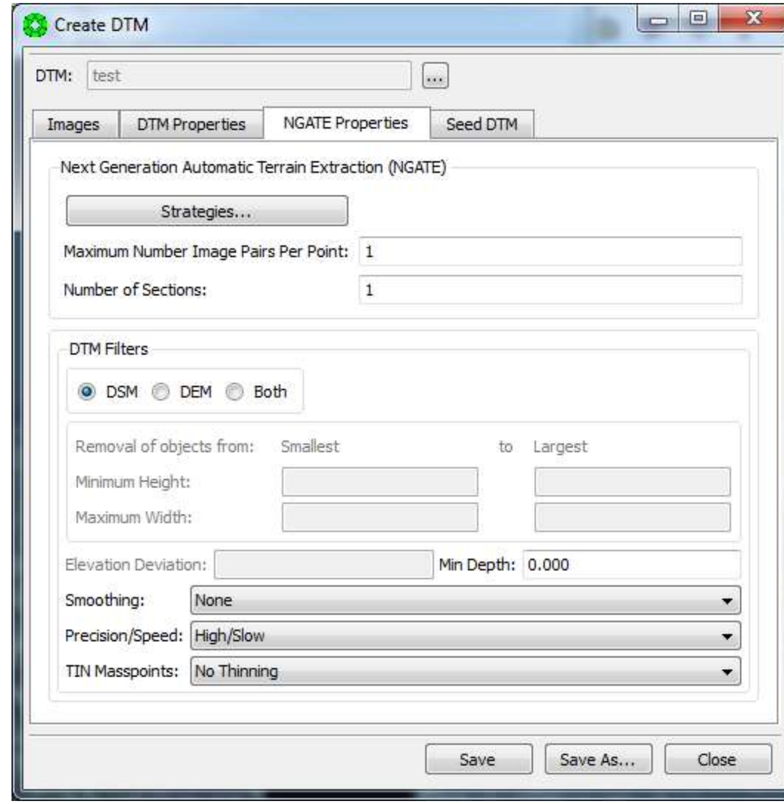
- DPWs common from the early 1990s
- Digital images from scanned film imagery
- High expectations to automatic measurements
  - DTM grids
  - Contour generation
  - Automatic feature extraction(roads, houses)
- Cumbersome software with many parameters
- Attempts to use correlation for DSM creation within forestry
  - Poor results

Historical overview

- Digital sensors from 2000+, extensive use 2005 >

Historical overview

- Re-designed software for the new “true” digital images
  - Adaptive algorithms
  - Image analysis, trends
- Hardware boosts new correlation techniques
  - Per-pixel-correlation(software correlates height at each pixel in an image)
    - Easier to adapt to terrain changes
    - More homogeneous output results



Today’s use

- DTM collection in non-vegetated areas
  - Contour generation
- “Bare earth” filtering techniques
  - Requires manual user intervention

- Grid size 0.5m >
  - Rule of thumb: Not better than 3 x image GSD

- LiDAR superior for overall DTM generation
  - “Sees” through vegetation

- Microsoft using correlation to create 3D city models

DSM creation: Requirements

- Poor image quality gives poor results
  - Color differences, shadows
  - Different dates of image acquisition

- Accurate exterior orientation for the aerials
  - Aerial triangulation with surveyed GCPs

- Existing DTM(“Seed” DTM)
  - Will improve the results by giving good initial values for the correlation

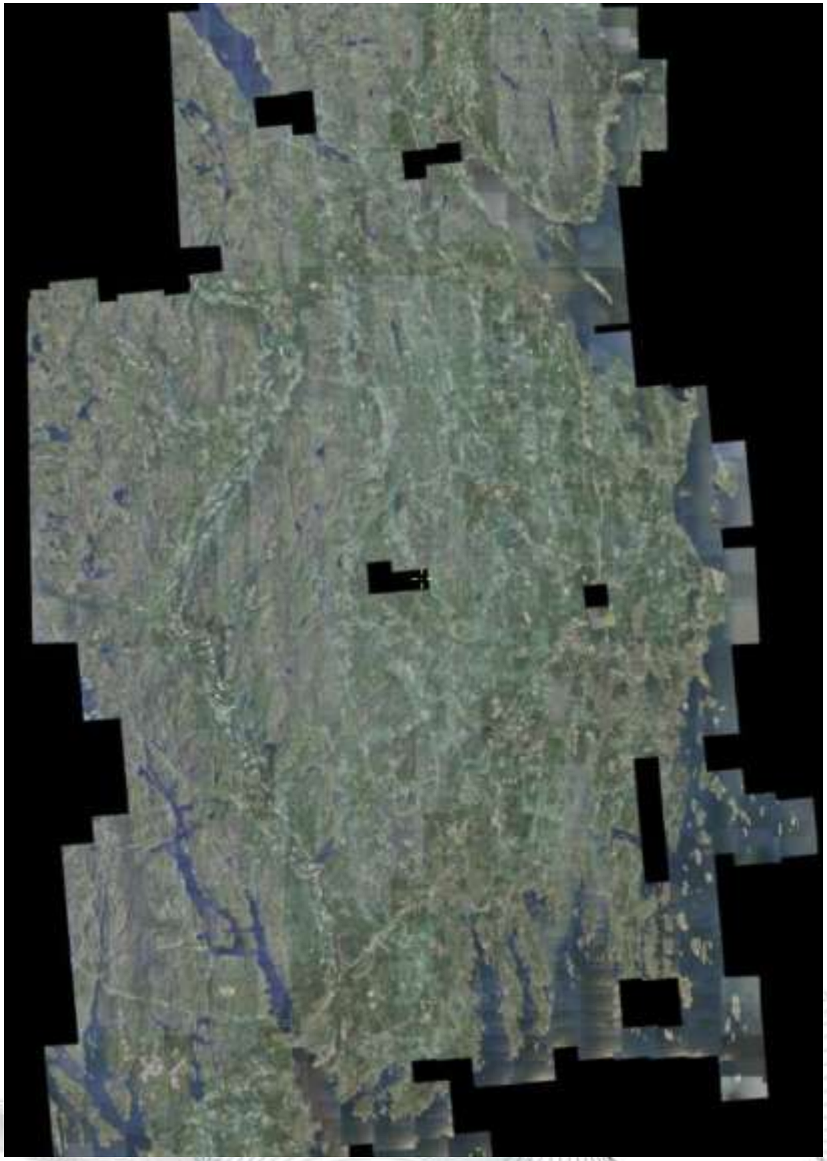
DSM creation for forestry purposes

- Case study: Vestfold

- 3000 sqkm
- 1600 images
- UltraCamX, GSD 20cm
- Exterior orientation from aerial triangulation with field surveyed GCPs
- Existing DTM: 10mx10m grid, some areas densified with data from LiDAR
- Correlation software: Socet Set NGATE
- Grid size 1m x1m

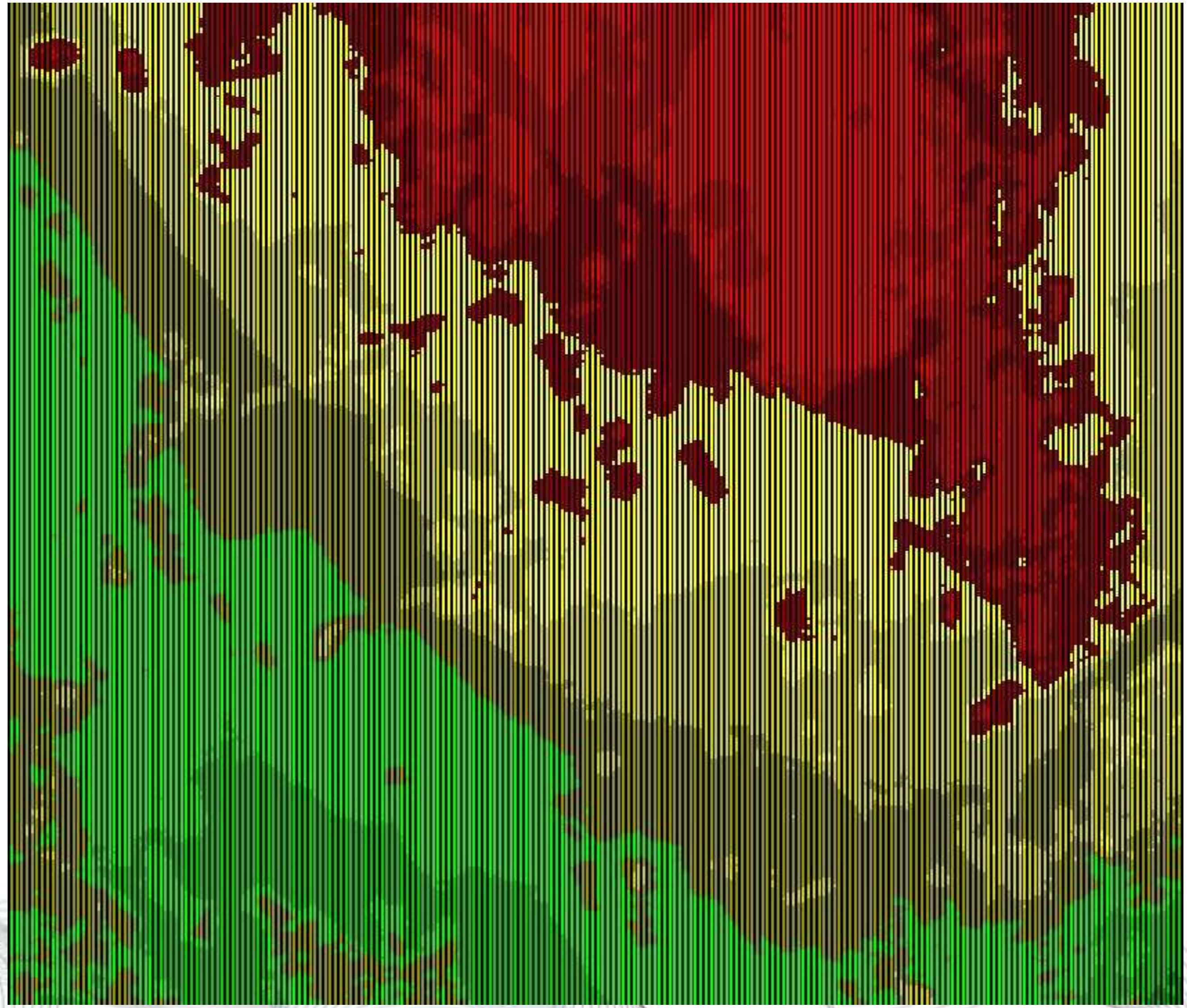
Samples

Vestfold area



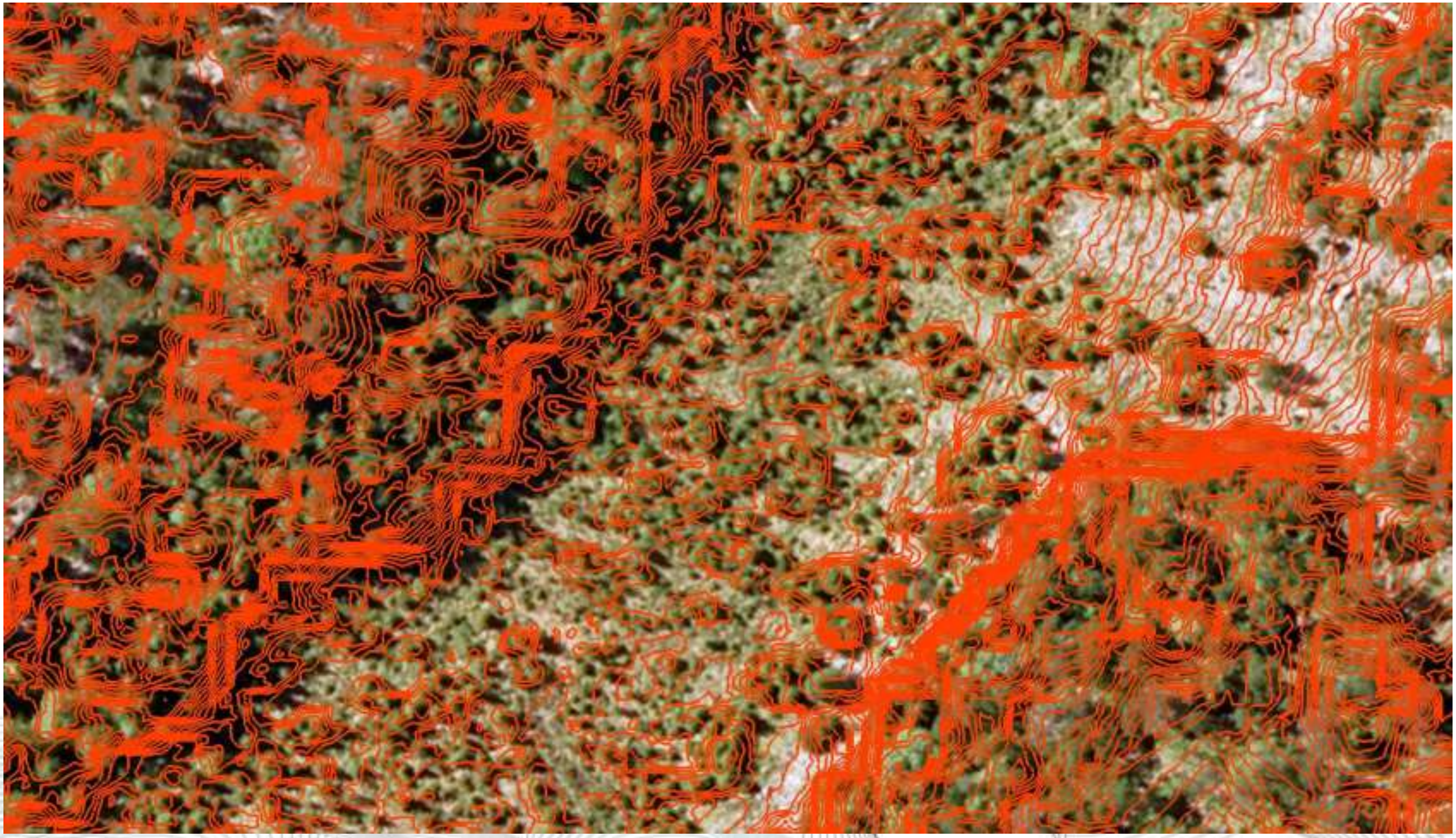
Samples

1m grid



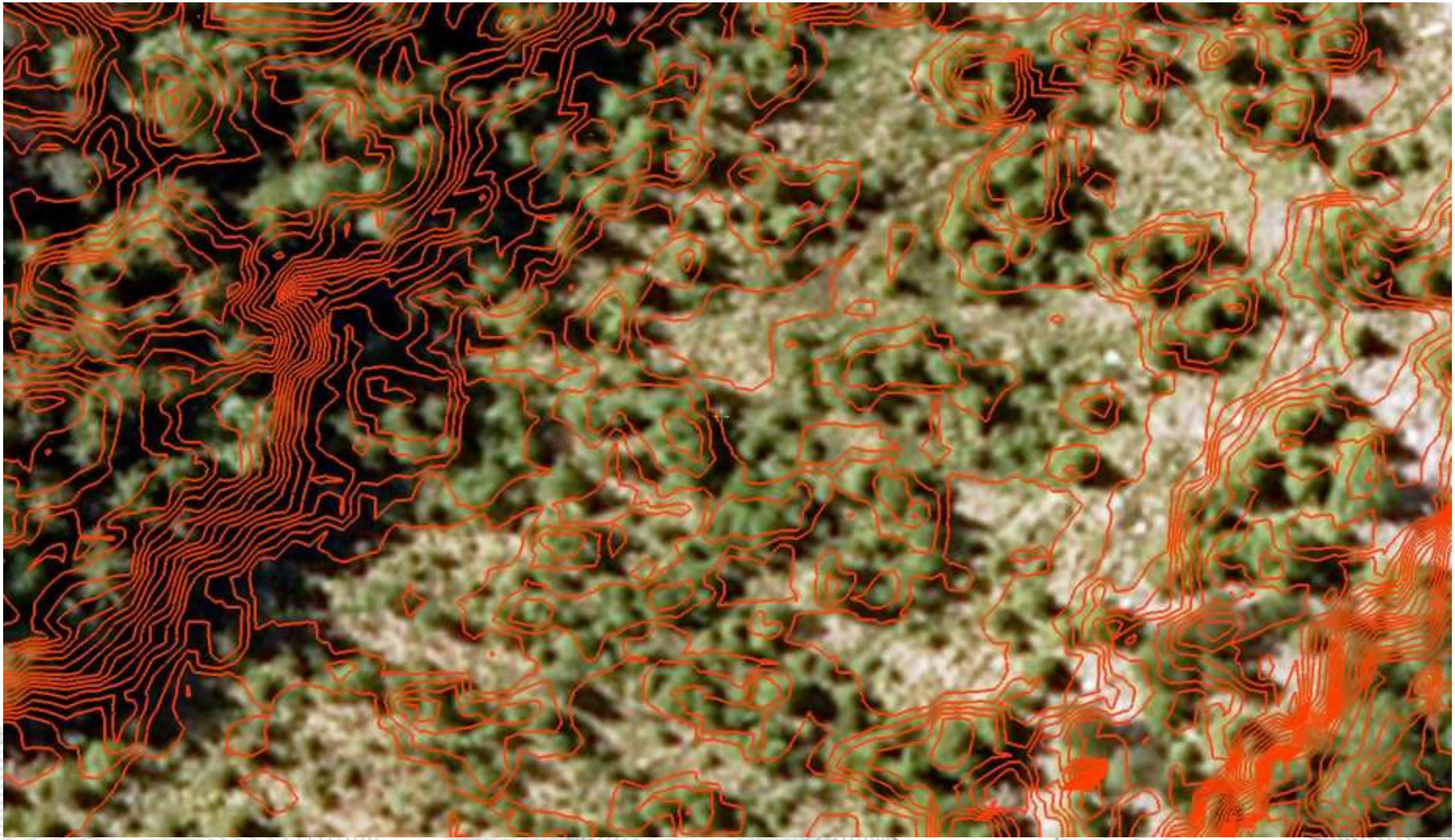
Samples

0.5m contours



Samples

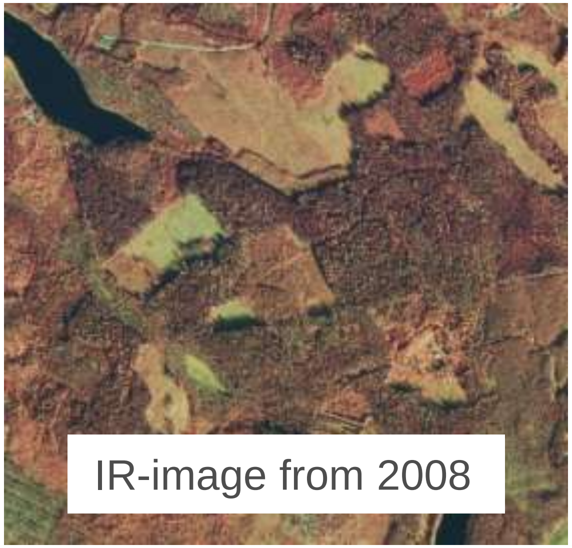
0.5m contours

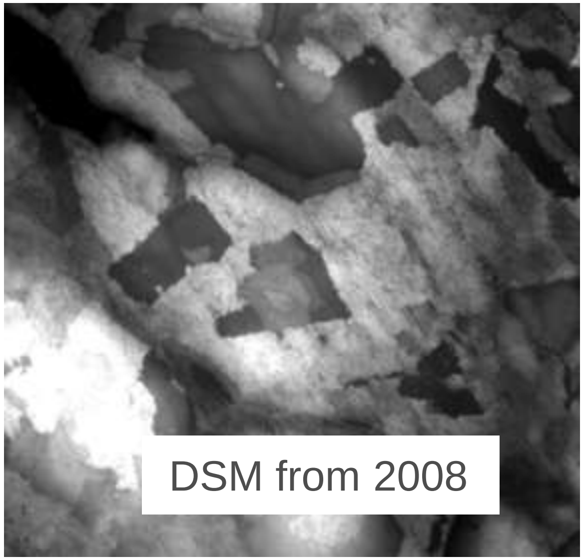


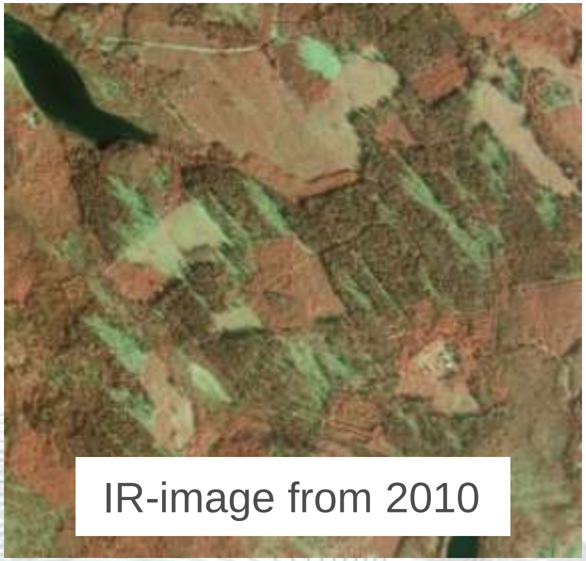
Challenges

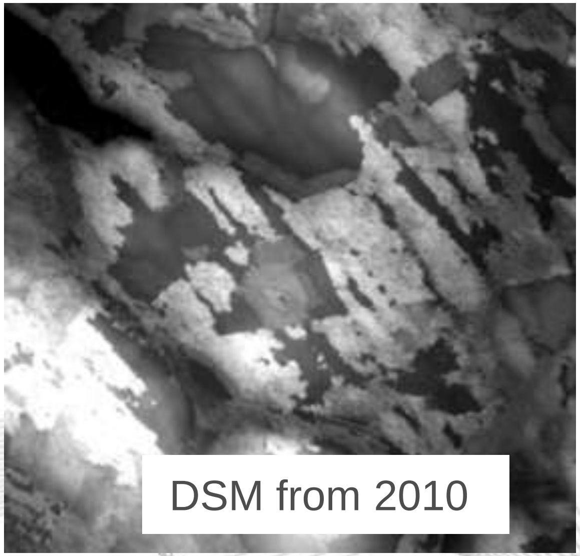
- Data handling
  - Total of 3 billion points
- Limitations of processing software
  - Number of images, need to split the correlation
  - Poorer results at the edges of correlation blocks
  - Large water areas can lead to erroneous data(software dependent)
- Low resolution DTM: DTM points above DSM
  - Different resolution of DSM and DTM

Application of DSM: Forestry Analysis

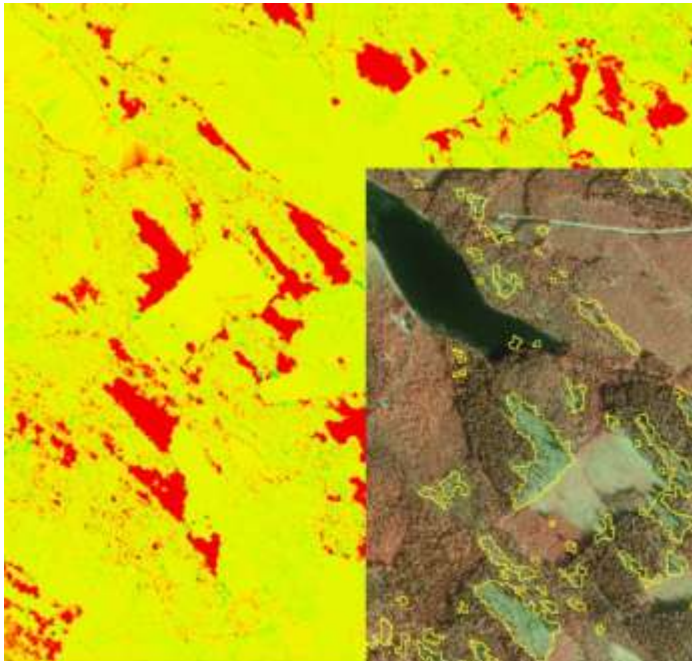




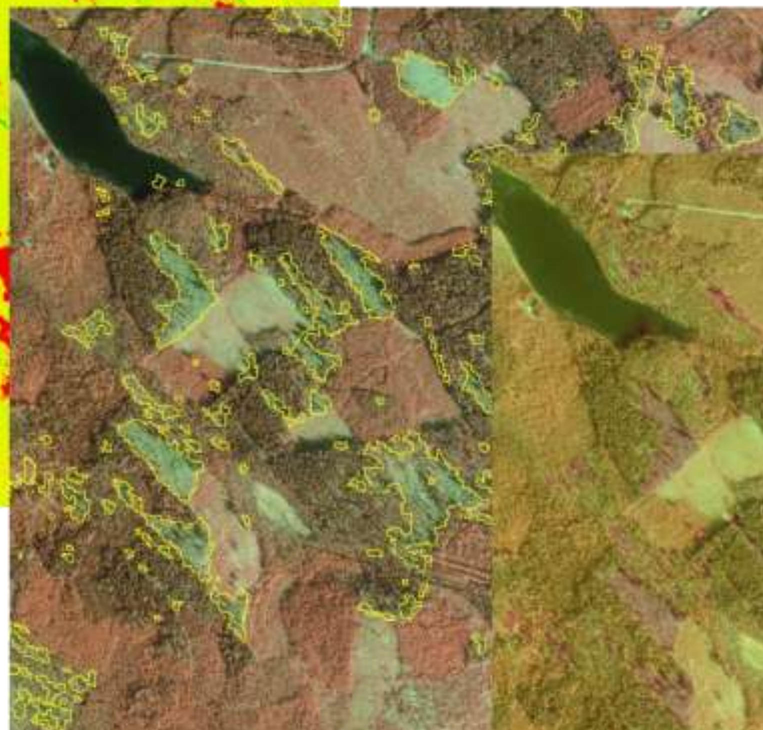




Forestry Analysis – Storm Damages



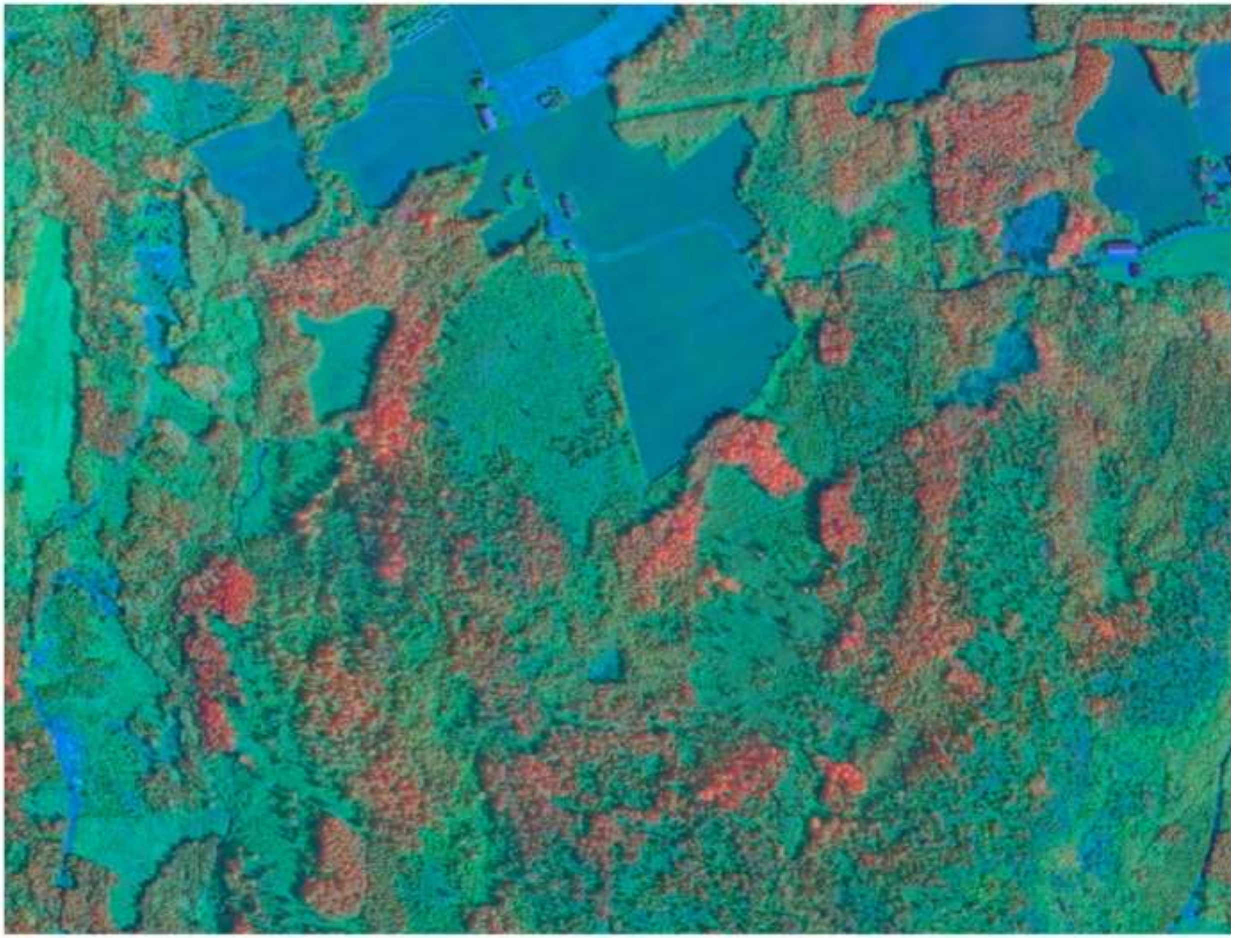
DSM difference



Derived polygons on IR

Samples

5-band TIFF image: R G B CIR dZ, 20cm



Summary

- Supplementary technique to LiDAR

- Cheaper than doing a new dense LiDAR data capture
  - Can make DSM's from old datasets

- Results dependent on:
  - Image quality
  - Accuracy of exterior orientation
  - Image GSD(grid size)

Questions?

inge.myklebust@blomasa.com

Small area estimation of forest attributes in the Norwegian National Forest Inventory using digital surface models as auxiliary variables

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9.06.2011

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Contents

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Contents

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A small area for the Norwegian NFI

- The Norwegian NFI started in the 1920ies
- Permanent sample plots on 3x3 km raster, 8.92 m radius
- Rotating inventory: Yearly visit of 20% of the plots
- A county is a small area (inaccurate estimates)

⇒ Additional temporary sample plots for the "county-inventory" every 5 years

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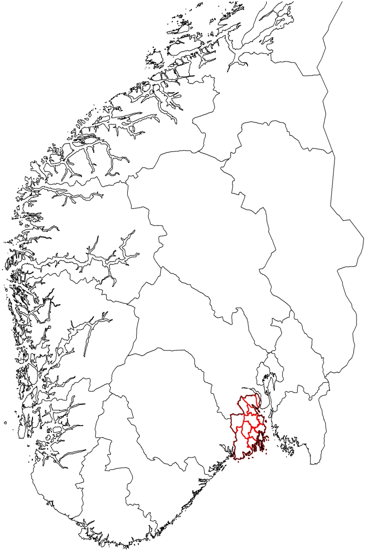
Aims of the study

- Generation of a map for biomass/ha over Vestfold county
- Statistically sound estimates on the municipality level (including uncertainty)

⇒ Adjust and apply Rao's (2003) estimators



Contents

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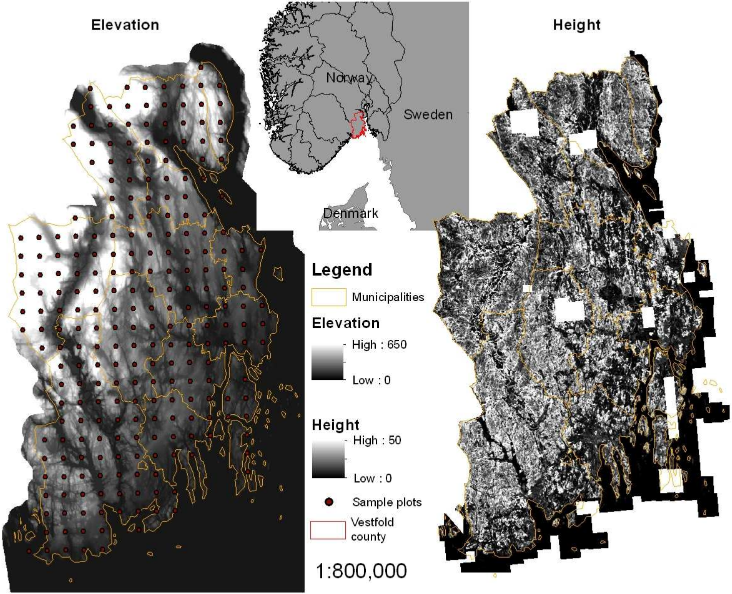
Vestfold county

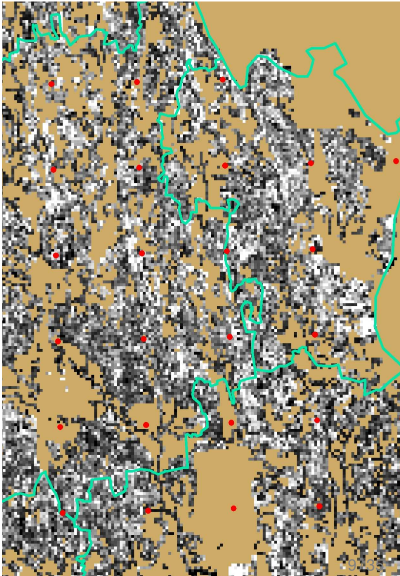


Contents

Some definitions

Let $N = \sum_i N_i$ be the number of population elements j (16x16 m tiles). Grouped in the small area i, $i = (1, ..., m)$ $n = \sum_i n_i$ the number of a random sample thereof.

Let $\mathbf{X}_{ij}$ be a vector of p auxiliary variables available for every population element.

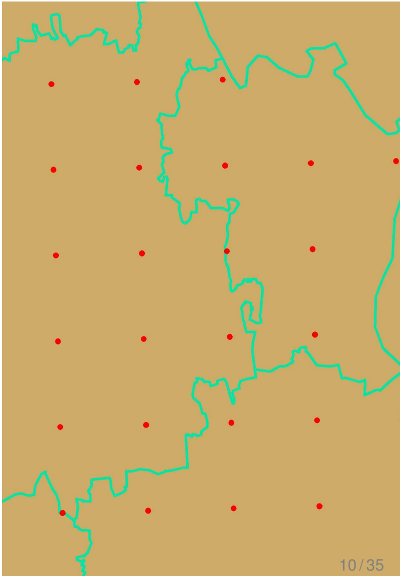


The direct estimator

$$\bar{Y}_{D,i} = \bar{y}_i = \frac{1}{n_i}\sum_j y_{ij}, \qquad i = 1, ..., m. \quad (1)$$

with

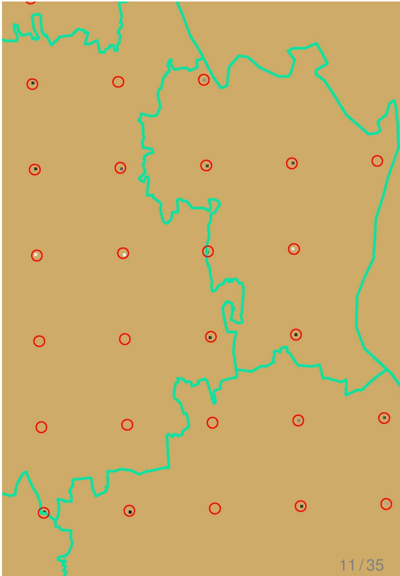
$$\mathrm{var}(\bar{Y}_{D,i}) = \left(\frac{N_i - n_i}{N_i}\right)\frac{\hat{\sigma}_i^2}{n_i}$$



The regression model

Linear model on the sampled population elements

$$y_{ij} = \mathbf{x}_{ij}^T \beta + \varepsilon_{ij}, \quad j = 1, \ldots, n_i, \quad i = 1, \ldots, m. \tag{2}$$

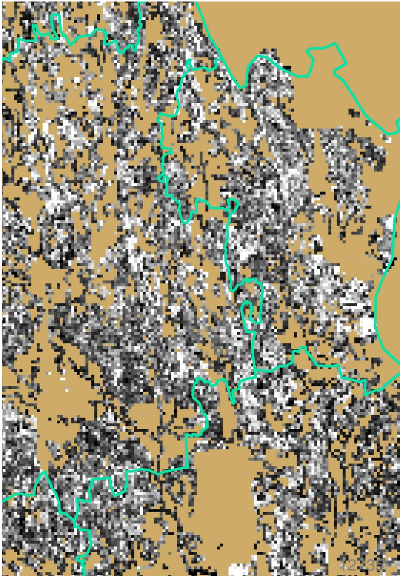


The synthetic regression estimator

Synthetic regression estimator – mean of the model predictions for the small area *i*

$$\bar{Y}_{S,i} = \frac{1}{N_i} \sum_{j} x_{ij}^T \boldsymbol{\beta} = \bar{\mathbf{X}}_i^T \boldsymbol{\beta}. \qquad (3)$$

can be biased, if model does not hold.



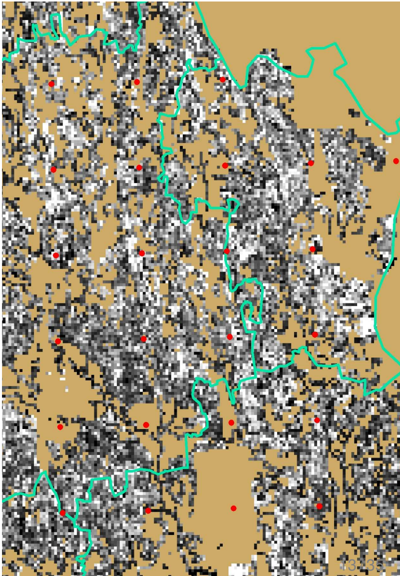
The GREG estimator

Bias correction factor based on the residuals within small area *i*

$$\bar{Y}_{G,i} = \bar{\mathbf{X}}_i^T \beta + \frac{1}{n_i} \sum_j \varepsilon_{ij}. \qquad (4)$$

Variance based on residuals within the small area *i*

$$\mathrm{var}(\bar{Y}_{G,i}) = \frac{1}{n_i} \mathrm{var}(\varepsilon_{ij}). \qquad (5)$$

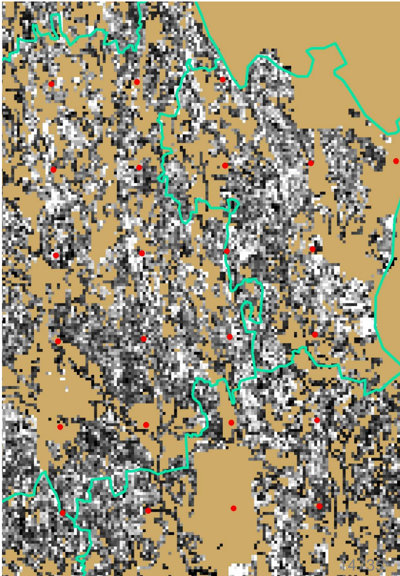


The EBLUP estimator

Sum of synthetic estimator and realization of a random effect on the small area level i

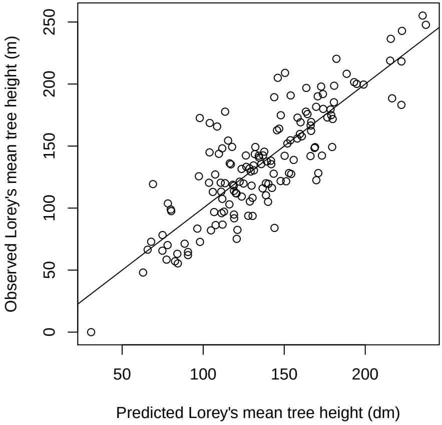
$$\bar{Y}_{B,i} = \bar{\mathbf{X}}_i^T \boldsymbol{\beta} + \upsilon_i. \tag{6}$$

Closed-form variance estimators exist (omitted), model-based, stable even for $n_i = 1$.



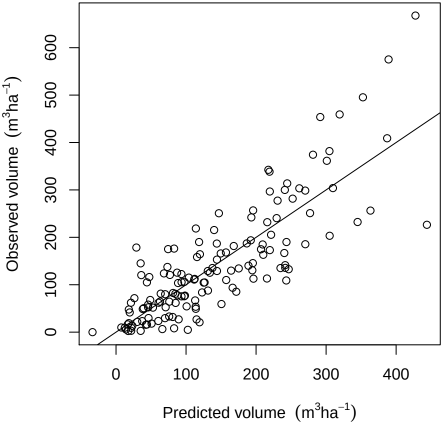
Contents

Lorey's tree height



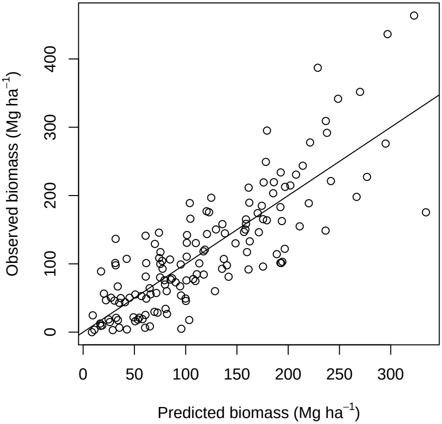
RMSE=2.5 m (18%), R^2=0.7

Timber volume



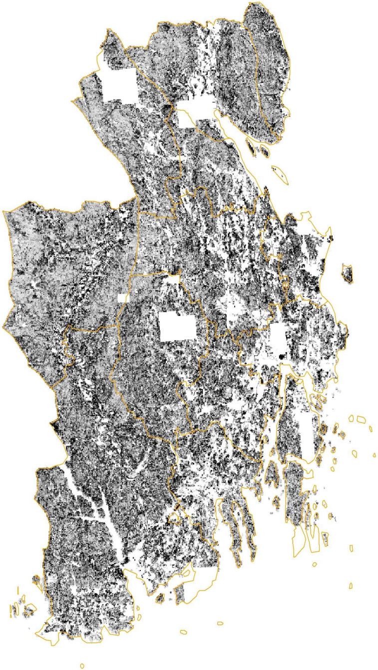
RMSE=67.7 m^3/ha (47%), R^2=0.68

Biomass



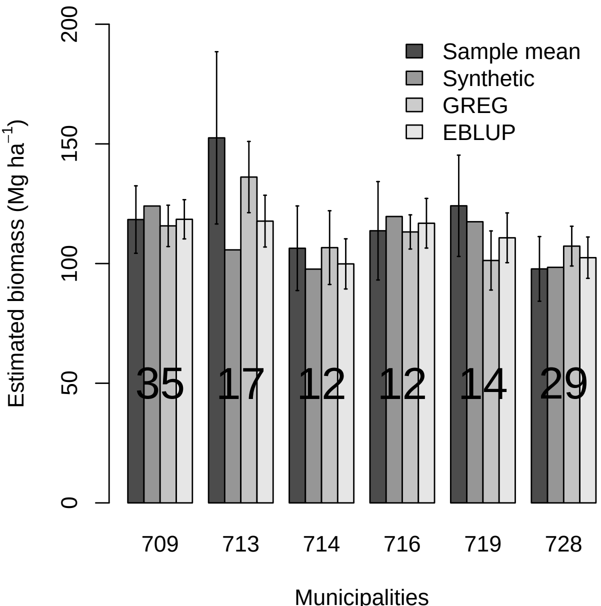
RMSE=50.7 Mg/ha (42%), R^2=0.68

Contents



Contents

Mean and standard error - Large municipalities



Coefficient of variation - Large municipalities

Municipality	n_i	Direct	GREG	EBLUP
709	35	14.09	8.64	8.20
713	17	35.99	14.88	10.82
714	12	17.67	15.41	10.48
716	12	20.56	7.14	10.37
719	14	21.16	12.35	10.39
728	29	13.51	8.30	8.63

Table: Coefficient of variation (%) of the mean estimate

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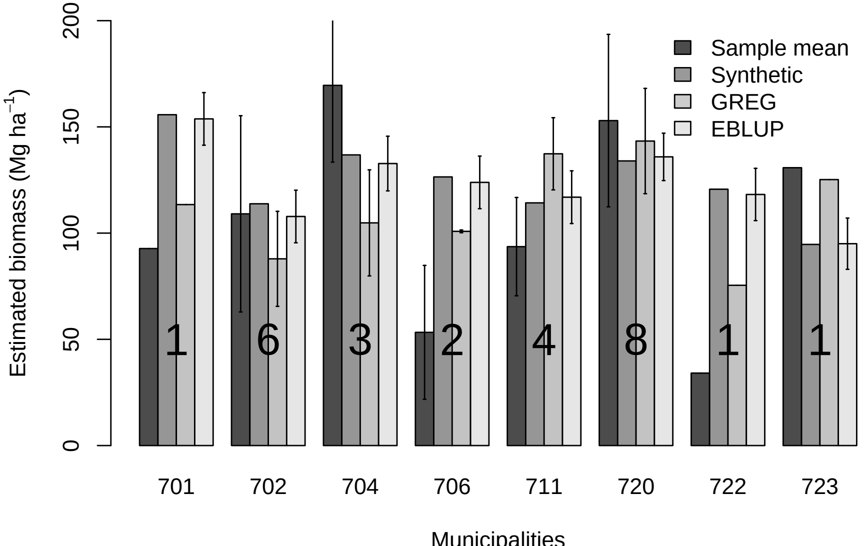
Mean and standard error - Small municipalities



Coefficient of variation - Small municipalities

Municipality	n_i	Direct	GREG	EBLUP
701	1	-	-	12.38
702	6	46.19	22.36	12.38
704	3	36.10	24.96	12.87
706	2	31.51	0.65	12.37
711	4	23.14	16.98	12.40
720	8	40.58	24.78	11.15
722	1	-	-	12.31
723	1	-	-	12.06

Table: Coefficient of variation (%) of the mean estimate

Contents

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Possible improvements

- Improvement of the DTM
- Improvement of the vegetation height information (other algorithms, other RS sources)
- Increasing the number of sample plots
- ...

Conclusions – CHM from aerial images

- Not quite as good as known from ALS data but...
- Vestfold is a rather complex study area
  - Forest structure / tree species
  - Topography
  - Size
- Reduction of temporary sample plots in the “county inventory” appears possible

Conclusions – estimators

- EBLUP is applicable to all kinds of auxiliary variables (e.g., ALS, TanDEM-X)
- EBLUP is applicable to forest stands containing at least one sample plot
- Small area could also be a non-geographical domain

Outlook

- Multivariate prediction of biomass by tree species
- Considering more complex variance structures
- Estimation of forest area - updating of land-cover maps
- Implementation of the estimators; R-package
- Publication

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Thanks for your attention!

Pertinent literature

J.N.K. Rao
Small Area Estimation
Wiley Series in Survey Methodology, 2003.

The Mixed-effects model

$$y_{ij} = \mathbf{x}_{ij}^T \boldsymbol{\beta} + \upsilon_i + \varepsilon_{ij}, \qquad j = 1, ..., N_i, i = 1, ..., m. \tag{7}$$

$$\upsilon \sim \mathrm{N}(0, \sigma_\upsilon^2), \qquad \varepsilon \sim \mathrm{N}(0, \sigma_\varepsilon^2) \tag{8}$$

EBLUP and GREG

$$\bar{Y}_{B,i} = \bar{\mathbf{X}}_i^T \boldsymbol{\beta} + \gamma_i \left(\frac{1}{n_i} \sum_j \varepsilon_{ij} \right) \tag{9}$$

$$\gamma_i = \frac{\sigma_v^2}{\sigma_v^2 + \sigma_\varepsilon^2 / n_i} \tag{10}$$

EBLUP MSE

$$\mathrm{MSE}_{\bar{Y}_{B,i}} \approx C_{1,i} + C_{2,i} + 2C_{3,i} \tag{11}$$

$$C_{1,i} = \gamma_i(\hat{\sigma}^2_\varepsilon / n_i).$$

$$C_{2,i} = (\bar{\mathbf{X}}_i - \gamma_i \bar{\mathbf{x}}_i)^T \left(\sum_i \mathbf{X}^T \mathbf{U} \mathbf{X} \right)^{-1} (\bar{\mathbf{X}}_i - \gamma_i \bar{\mathbf{x}}_i)$$

$$C_{3,i} = n_i^{-2} (\hat{\sigma}^2_\upsilon + \hat{\sigma}^2_\varepsilon / n_i)^{-3} C_{31}$$

$$C_{31} = \hat{\sigma}^4_\upsilon \bar{V}_{\upsilon\upsilon} + \hat{\sigma}^4_\varepsilon \bar{V}_{\varepsilon\varepsilon} + 2\hat{\sigma}^2_\varepsilon \hat{\sigma}^2_\upsilon \bar{V}_{\varepsilon\upsilon}.$$

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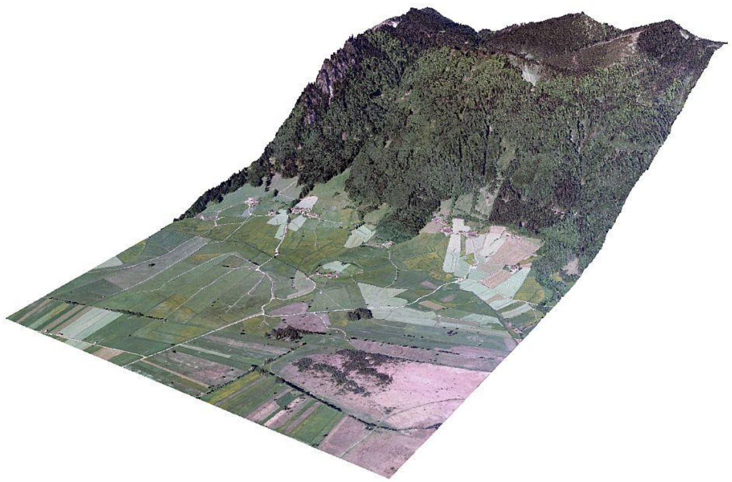
BAYERISCHE FORSTVERWALTUNG

Derivation of digital surface models from aerial images in Bavaria

Seminar: Creation of digital elevation models from aerial images for forest monitoring purposes · The Norwegian Forest and Landscape Institute · 9 June 2011

Christoph Straub
Bavarian State Institute of Forestry



Bayerische Landesanstalt für Wald und Forstwirtschaft

ZENTRUM WALD FORST HOLZ WEIHENSTEPHAN

Overview

- Introduction: Bavarian State Institute of Forestry (LWF) in Freising, Surface modeling in Bavaria
- Methodology
- Results for 3 different test sites in Bavaria
- Discussion and conclusion
- Outlook
- First results for a study site in Norway

Introduction

Bavarian State Institute of Forestry (LWF) in Freising, Weihenstephan

Bavarian State Institute of Forestry (LWF):

- Special agency within the Bavarian Forestry Administration
- Supports the Forestry Department of the Bavarian State Ministry of Food Agriculture and Forestry and its regional offices
- Staff:150 people (8 Departments)
- Member of the Weihenstephan Center of Forestry: Close cooperation with the Technical University of Munich and the University of Applied Sciences Weihenstephan-Triesdorf

Introduction

Guidelines for the research in the field of remote sensing at the Bavarian State Institute of Forestry:

1. Research with direct practical relevance → no research without practical benefit for the forest

2. If possible no additional costs for remote sensing data → data from project cooperations or from the Bavarian Office for Surveying and Geographic Information (Landesamt für Vermessung und Geoinformation (LVG) Bayern)

Introduction

Research Project SAPEX-DLB – objective: (Semi)-automatic extraction of forest characteristics from digital aerial photographs

1. Tree species classification

→ Forest- / Non-forest classification

→ Proportions of tree species groups

→ damaged trees

Verification with field data

2. Surface modeling

→ Vegetation height

→ Canopy closure

Verification with ALS and inventory data

↓ ↓

3. Estimation of further forest stand characteristics

- Different stand heights
- Timber volume in $m^3\ ha^{-1}$
- …

e.g. using inventory plots of an operational inventory as training data

Introduction

- Many studies have shown the great potential of ALS data for forestry applications → very precise height measurements

- Besides studies with ALS, different image matching techniques were tested to derive 3D information in forest areas from stereoscopic aerial images e.g. Baltsavias et al. (2008), Waser et al. (2008), Ofner et al. (2006) or Schardt et al. (2004)

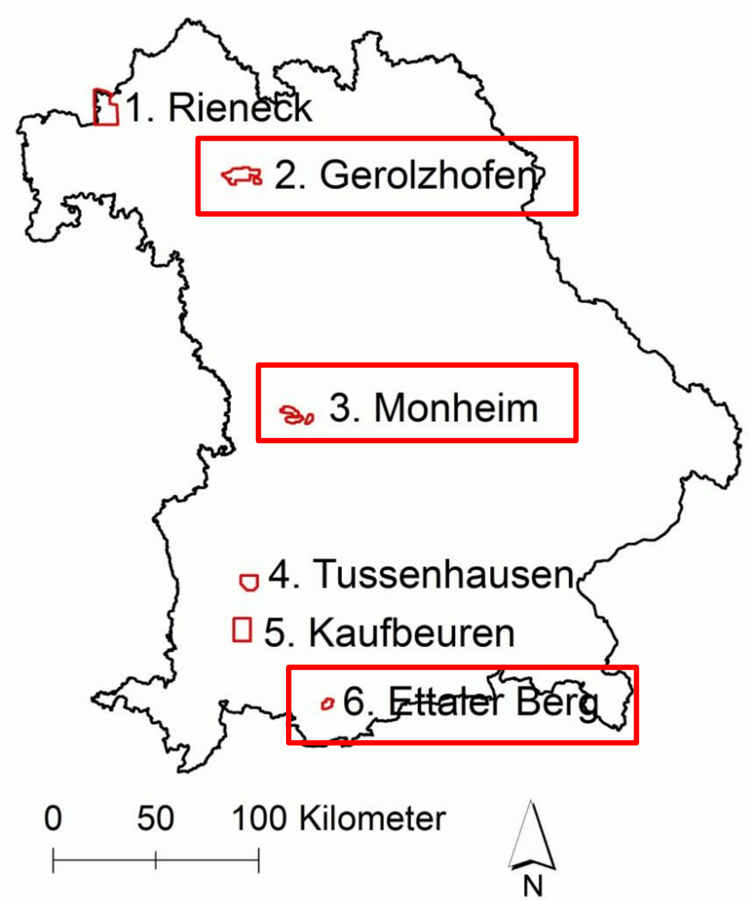
Main advantages of digital photogrammetry for surface modeling:

1. The costs for photogrammetric flights are lower.
2. Aerial photographs are updated on a regular basis by the different Land Survey Administrations in Germany → sustainable data source

→ Is it possible to derive high quality surface models in forests using digital aerial photographs?

Introduction

Test sites in Bavaria:



The test sites differ in:

- Forest type
- Topography
- Data source (different photogrammetric digital aerial cameras)

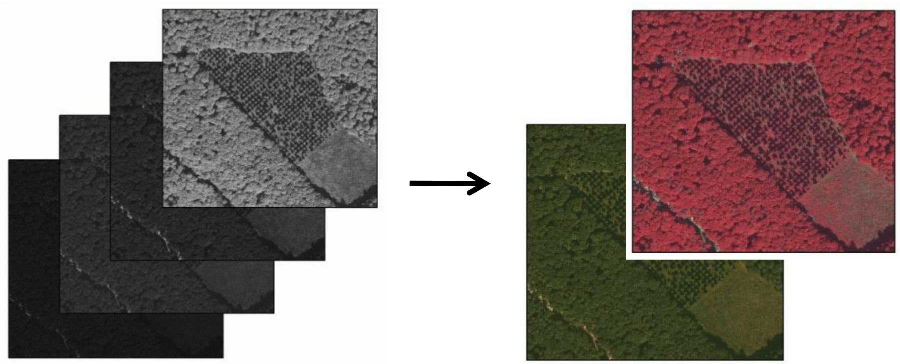
Test site	Deciduous trees [%]	Coniferous trees [%]
Gerolzhofen	85	15
Monheim	48	52
Ettaler Berg	35	65

Test site	Max. height difference [m]
Gerolzhofen	< 200 m
Monheim	< 100 m
Ettaler Berg	> 900 m

Introduction

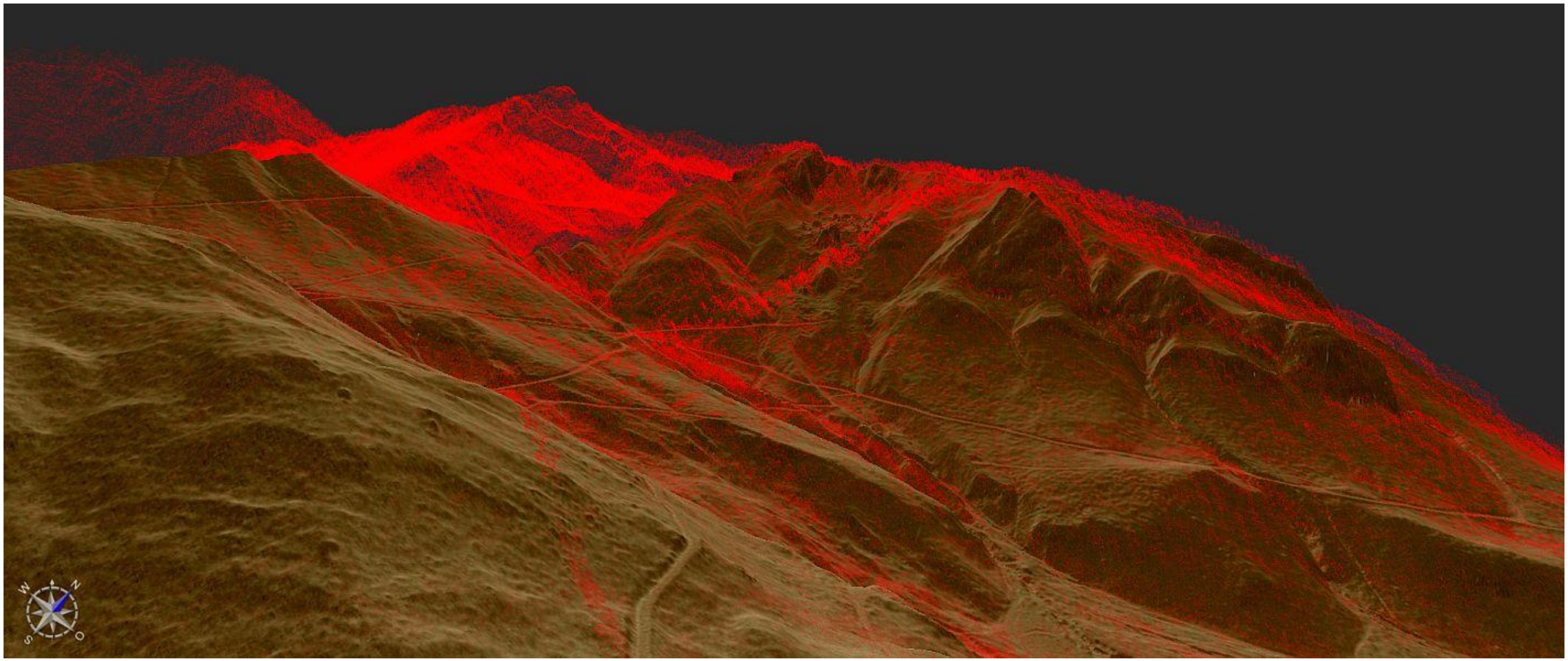
Aerial photographs (LVG 2011):

- Digital aerial photographs of the Bavarian Office for Surveying and Geographic Information (available since 2009)
- Four spectral channels (B, G, R and NIR)
- Ground resolution: 20 cm



Introduction

Airborne Laser Scanning (LVG 2011):



Vertical accuracy [m]: ± 0.20 m
Horizontal accuracy [m]: ±0.50 m

Methodology

<u>Processing steps:</u>

1. Orientation of the aerial photographs using LPS

2. Computation of a „photogrammetric point cloud“ using LPS eATE

3. Computation of a DSM using TreesVis → active surface algorithm (Weinacker et al. 2004, Elmqvist 2001)

4. Computation of a Photogrammetric CHM by subtracting an ALS DTM

5. Comparison of the Photogrammetric CHM with an ALS-CHM → Development of a validation software SquareMetrics based on HALCON and VB

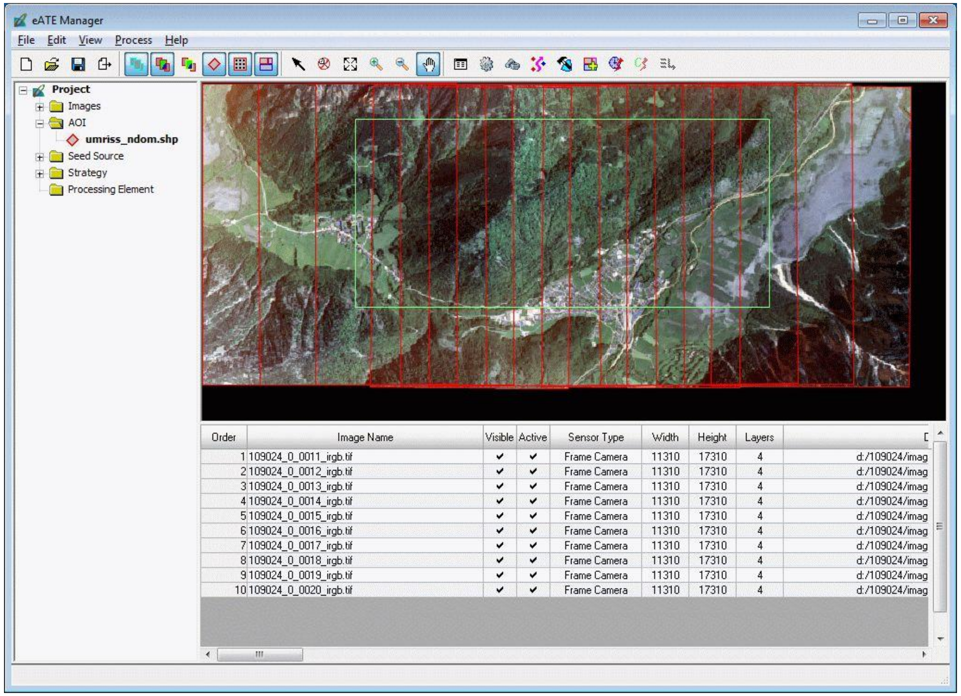
Methodology

<u>Some interesting features of LPS eATE:</u>

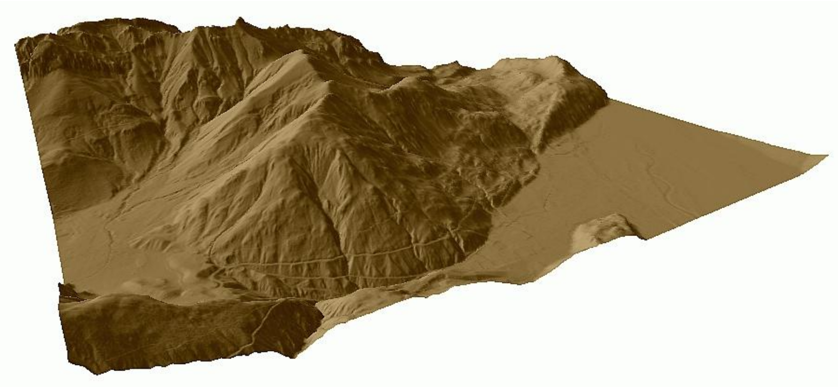
- Supports for pixel-by-pixel correlation to generate high-density elevation data
- Image pyramids → coarse-to-fine processing
- Multi-ray matching → increases the reliability of the matching process
- Multi-core processing on a single computer system
- Point cloud in*.las format with x, y, z and color information for each point

Results – study site 1: Ettaler Berg

<u>Aerial photographs in LPS eATE:</u>
Vexcel UltraCam X
Flying date: 2009
Size (forest area): 840 ha

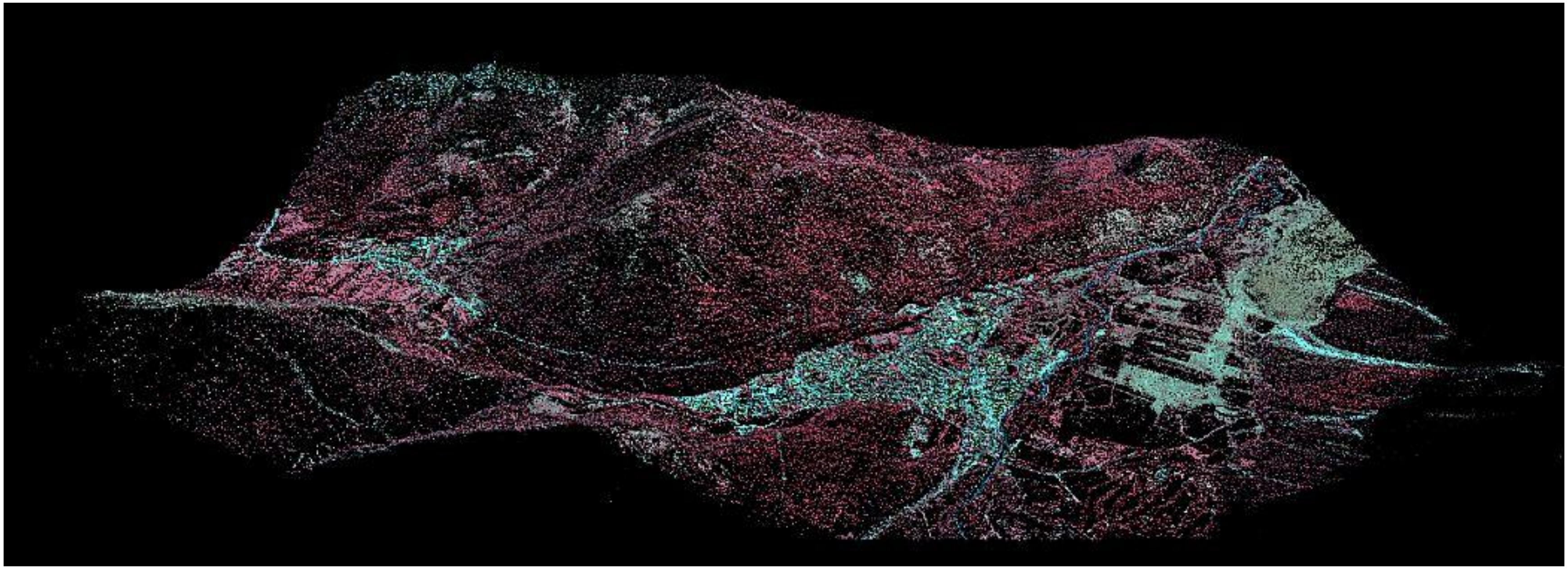


<u>Laserscan-DTM:</u>



Results – study site 1: Ettaler Berg

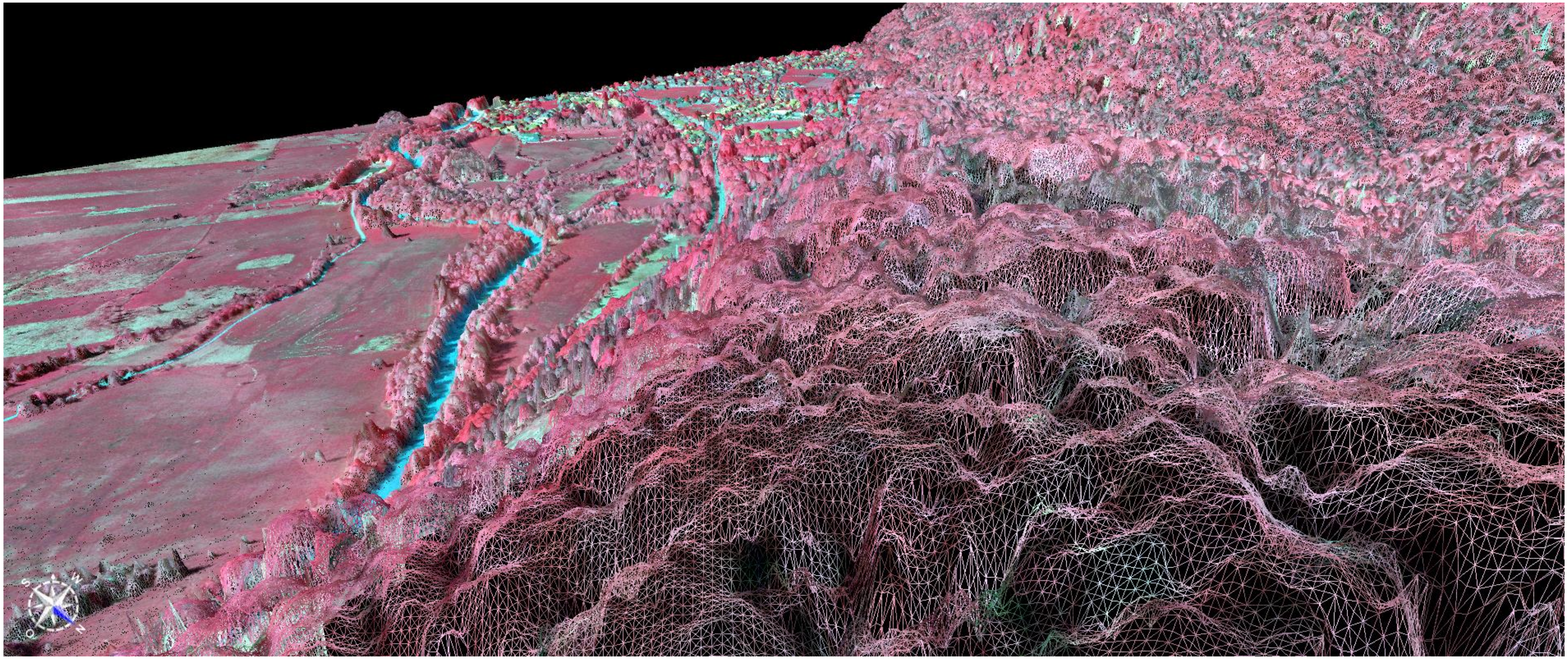
Photogrammetric point cloud:



125.794.981 points

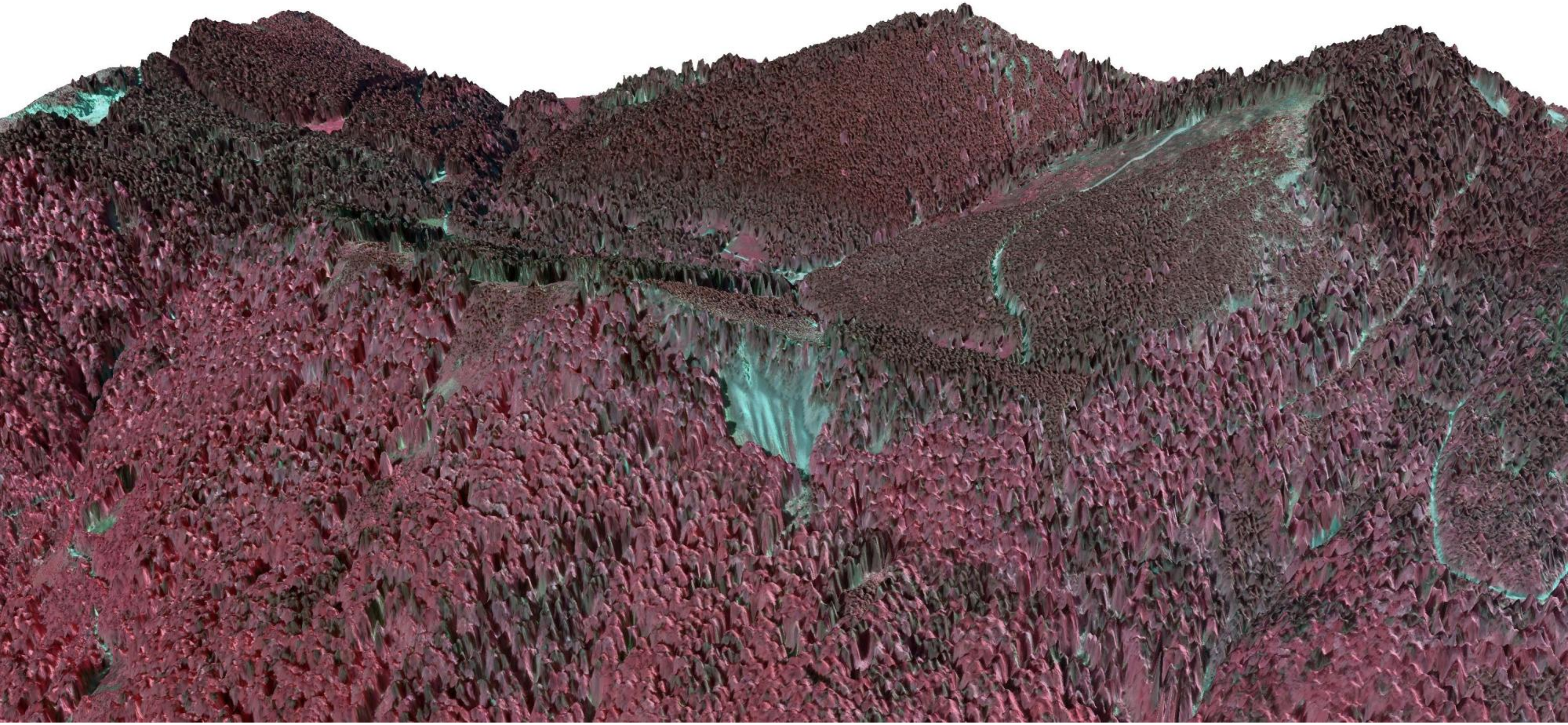
Results – study site 1: Ettaler Berg

Photogrammetric DSM with CIR-texture:



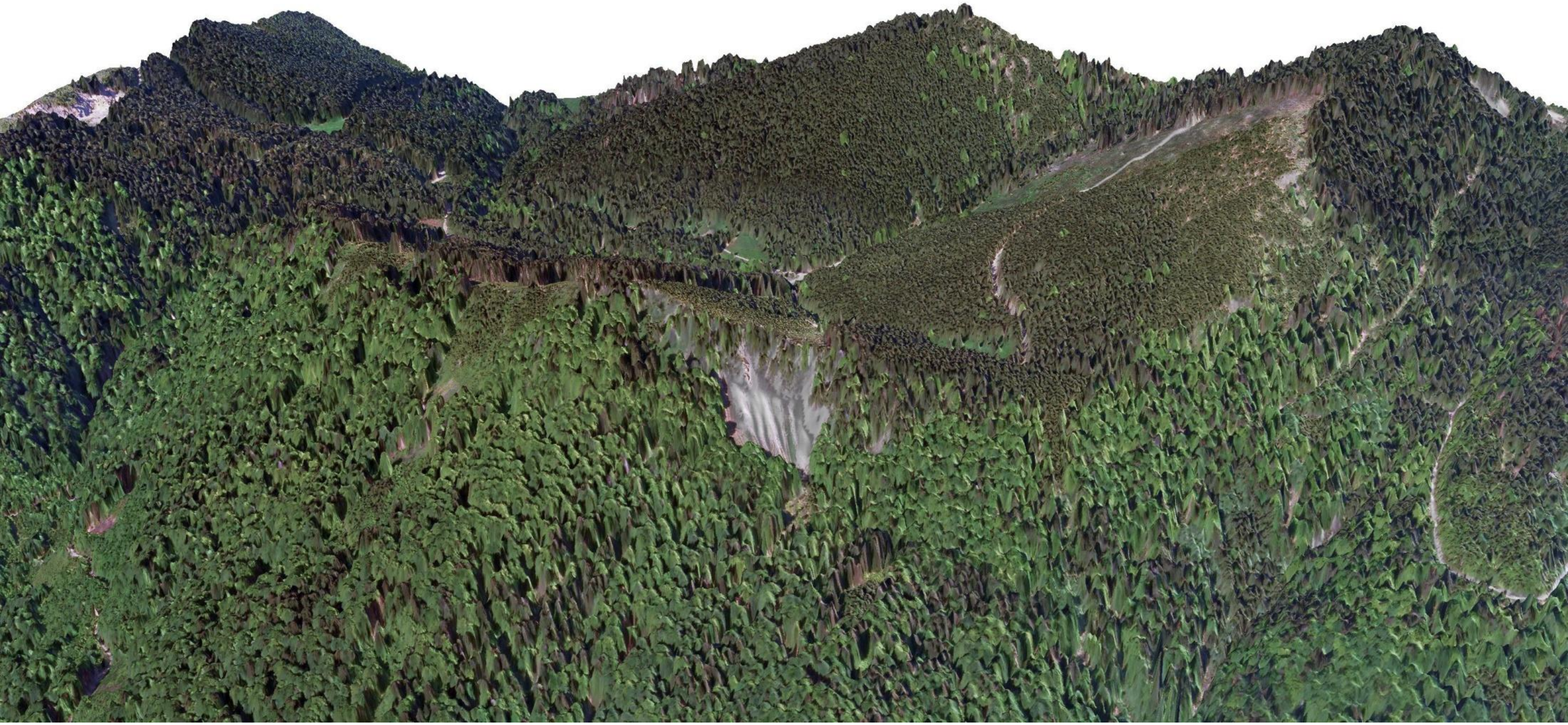
Results – study site 1: Ettaler Berg

Photogrammetric DSM with CIR-texture:



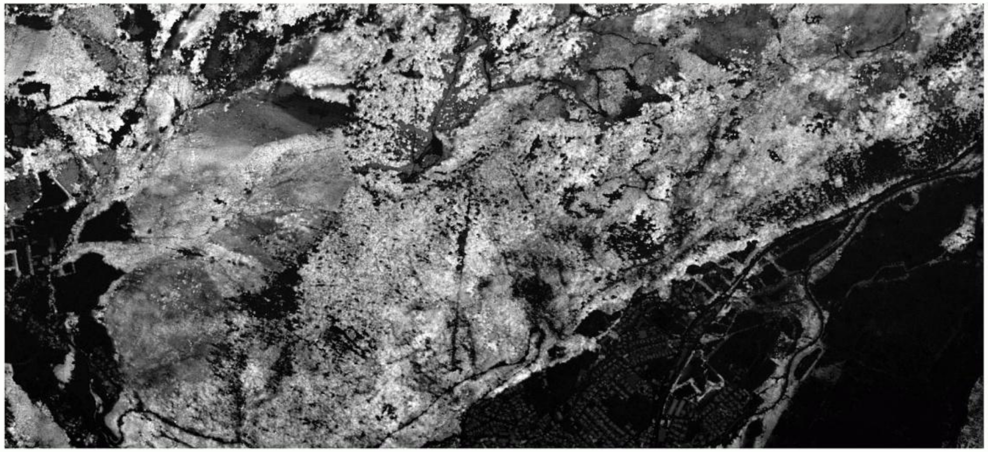
Results – study site 1: Ettaler Berg

Photogrammetric DSM with RGB-texture



Results – study site 1: Ettaler Berg

Photogrammetric CHM
(Flying date: 2009)

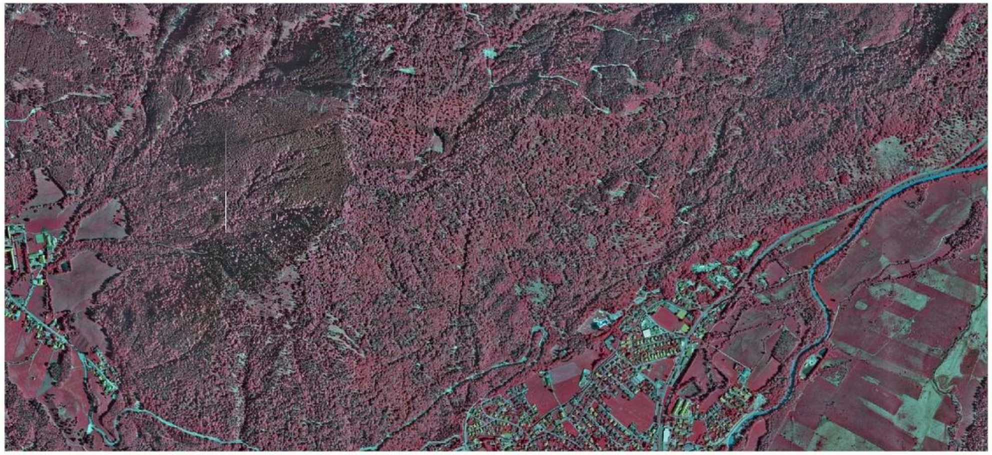


N

Height:

0 m **40 m**

CIR orthophoto
(Flying date: 2009)

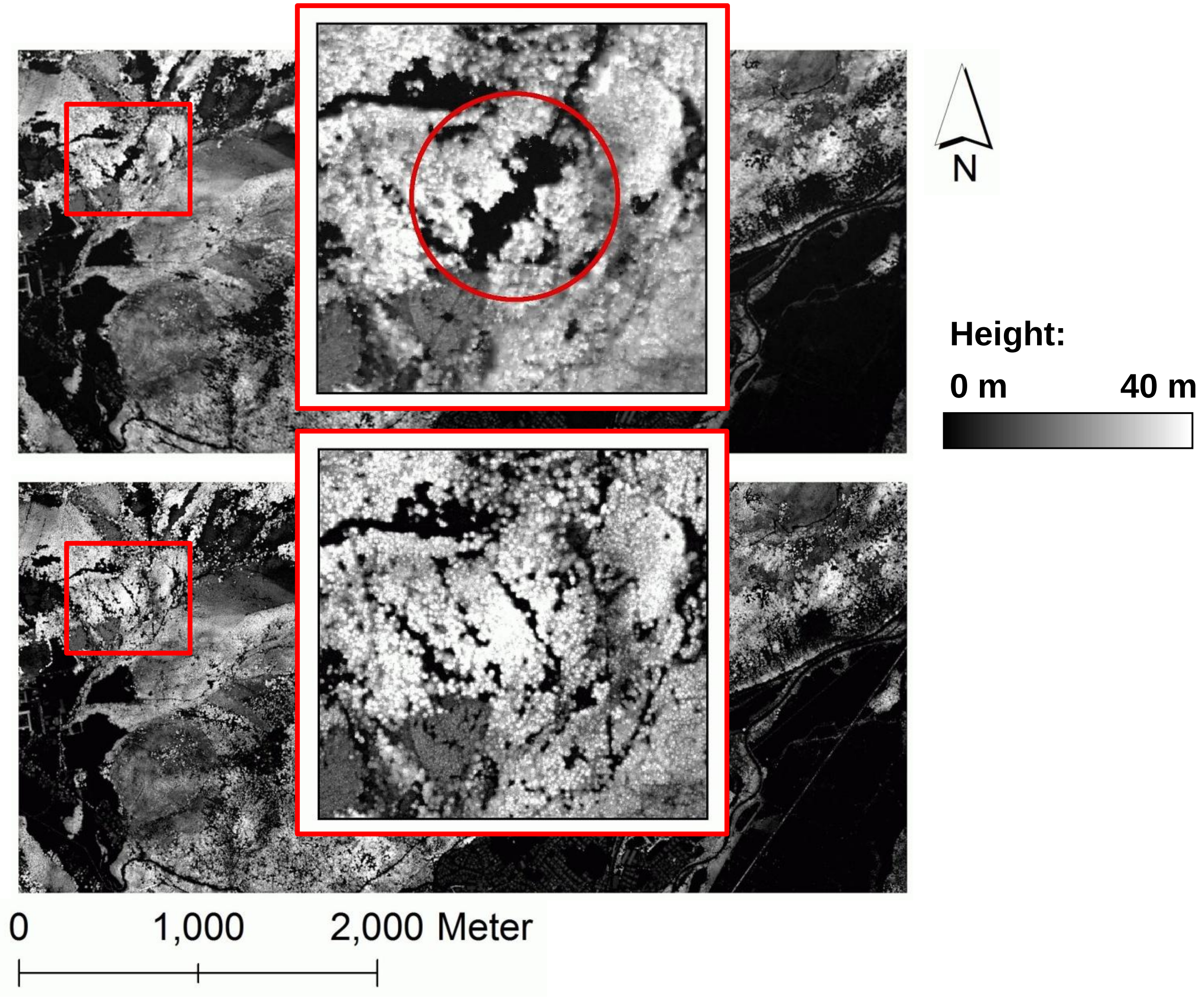


0 1,000 2,000 Meter

Results – study site 1: Ettaler Berg

Photogrammetric CHM
(Flying date: 2009)

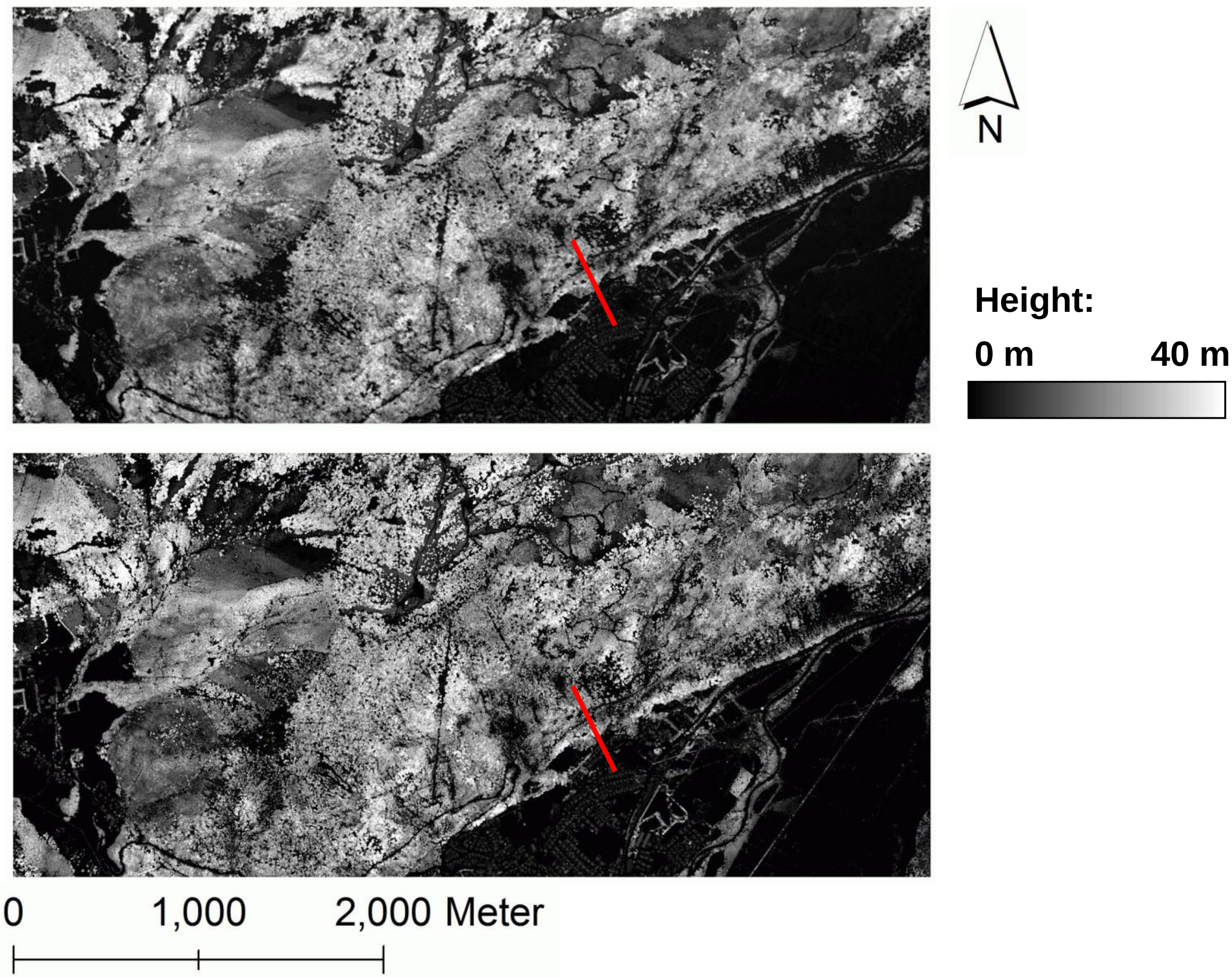
ALS-CHM
(Flying date: 2006)



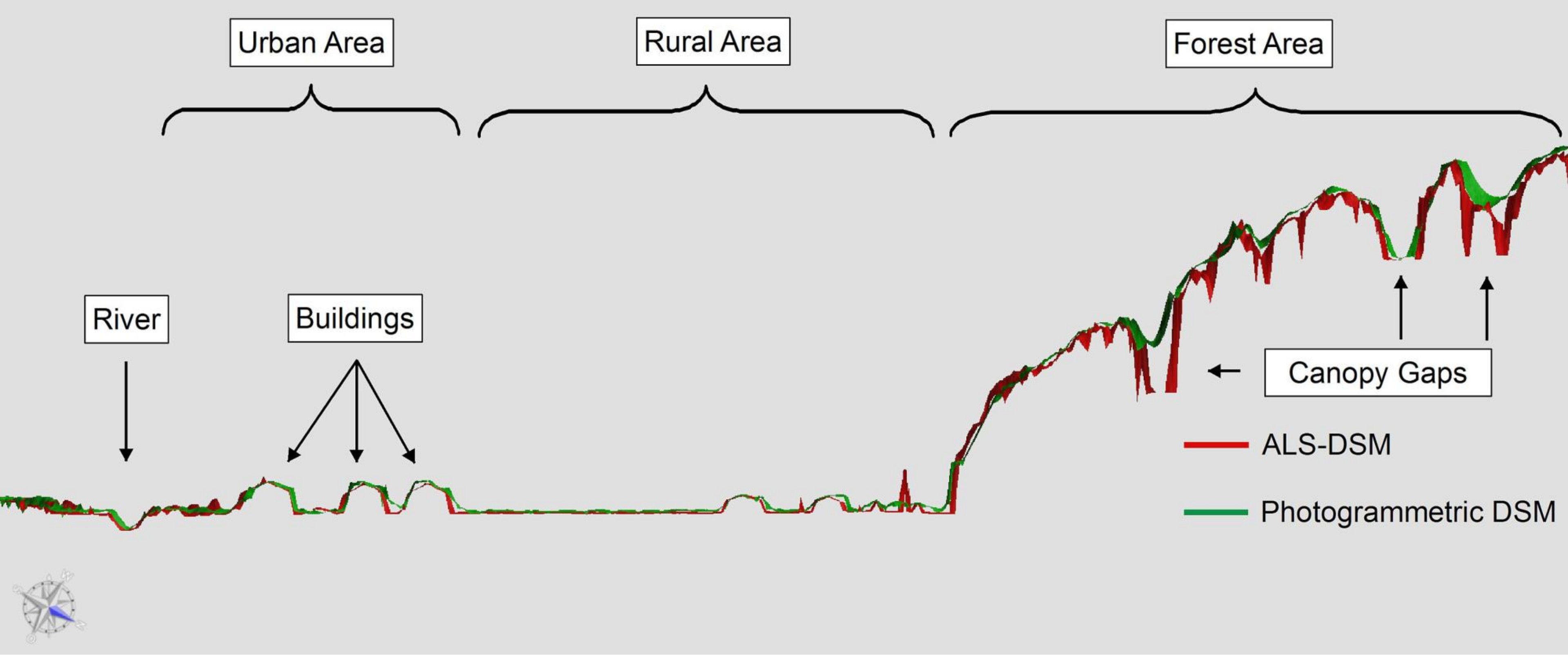
Results – study site 1: Ettaler Berg

Photogrammetric CHM
(Flying date: 2009)

ALS-CHM
(Flying date: 2009)



Results – study site 1: Ettaler Berg



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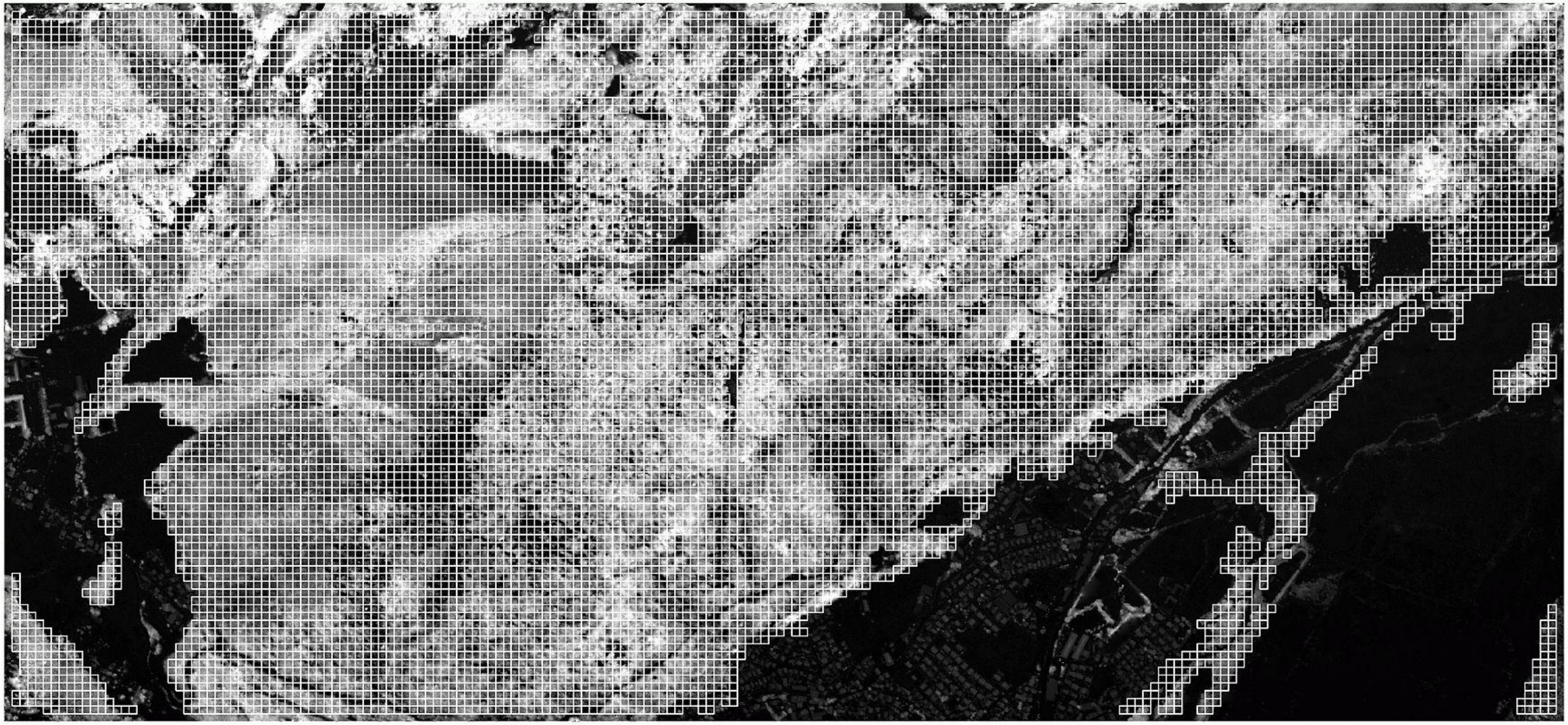
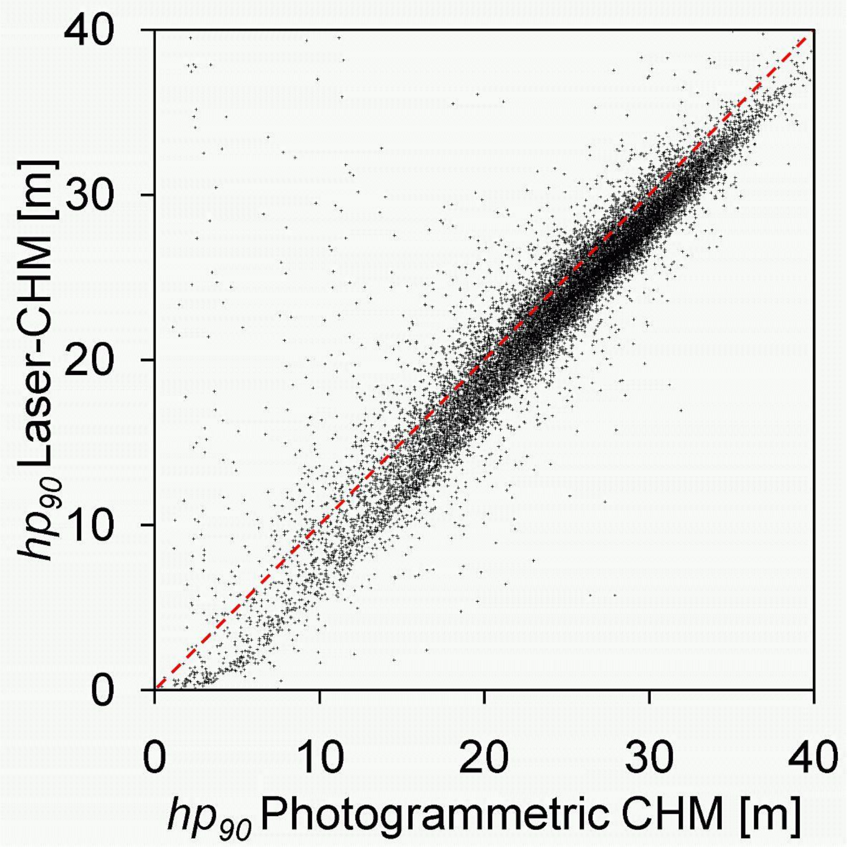
für Wald und Forstwirtschaft

Results – study site 1: Ettaler Berg

1. Subdivison of the forest area into cells (size: 500 m²)
2. Computation of height percentiles hp_{50}, hp_{60}, … hp_{90} and h_{max}
3. Comparison of the height percentiles for all cells



Results – study site 1: Ettaler Berg



n = 16225
r = 0,94
RMSE = 2,67 m (12%)
Bias = -1,17 m (-5%)
→Systematic deviation

Why?
1. Time difference
2. Photogrammetric CHM is less detailed
3. ALS flight during leaf-off conditions

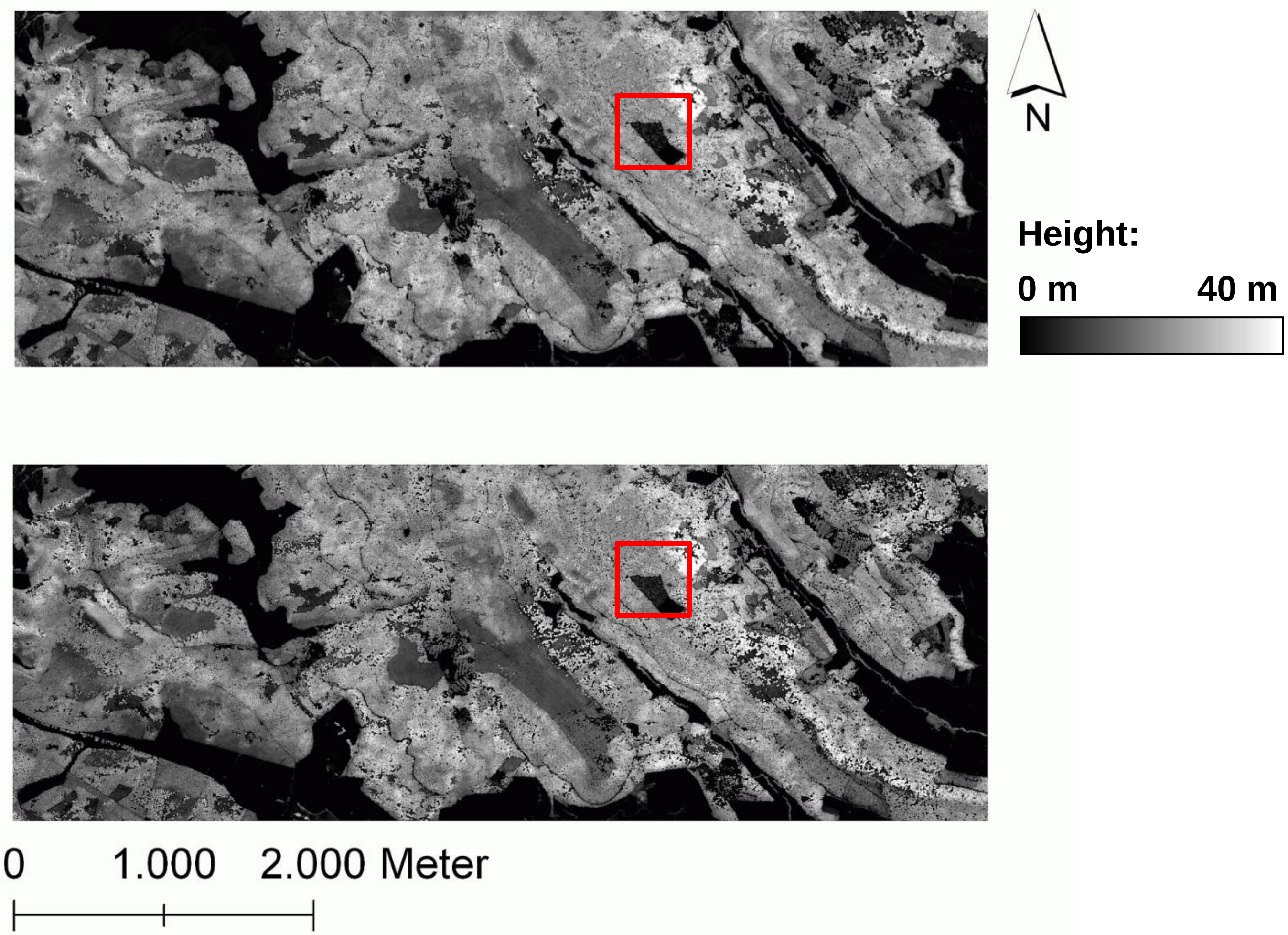
Results – study site 2: Gerolzhofen

Results – study site 2: Gerolzhofen

Size (forest area): 1250 ha

Photogrammetric CHM
(Flying date: 2008)

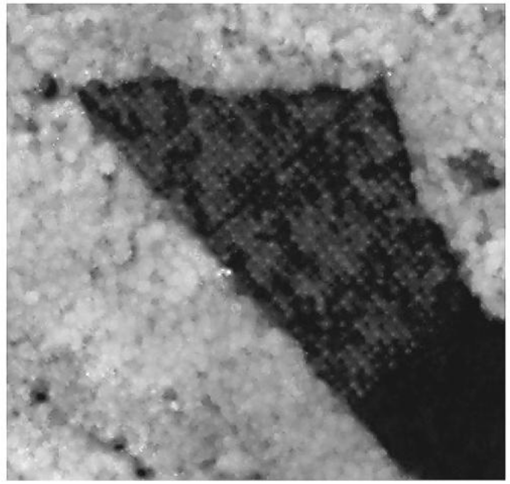
ALS-CHM
(Flying date: 2009)

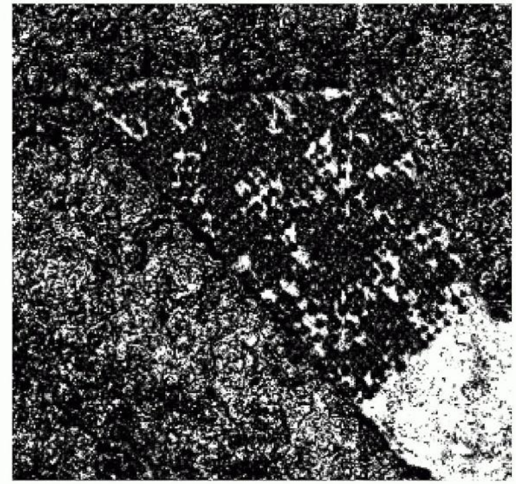


Results – study site 2: Gerolzhofen

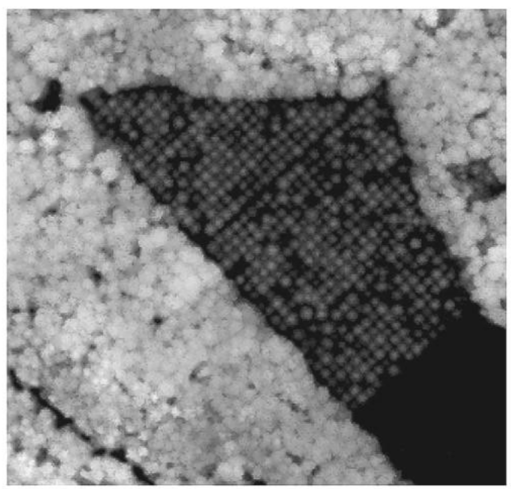
Number of points / m²:

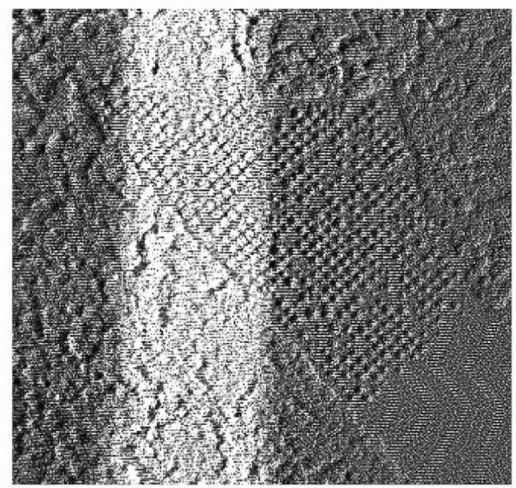
Photogrammetric CHM
(Flying date: 2008)



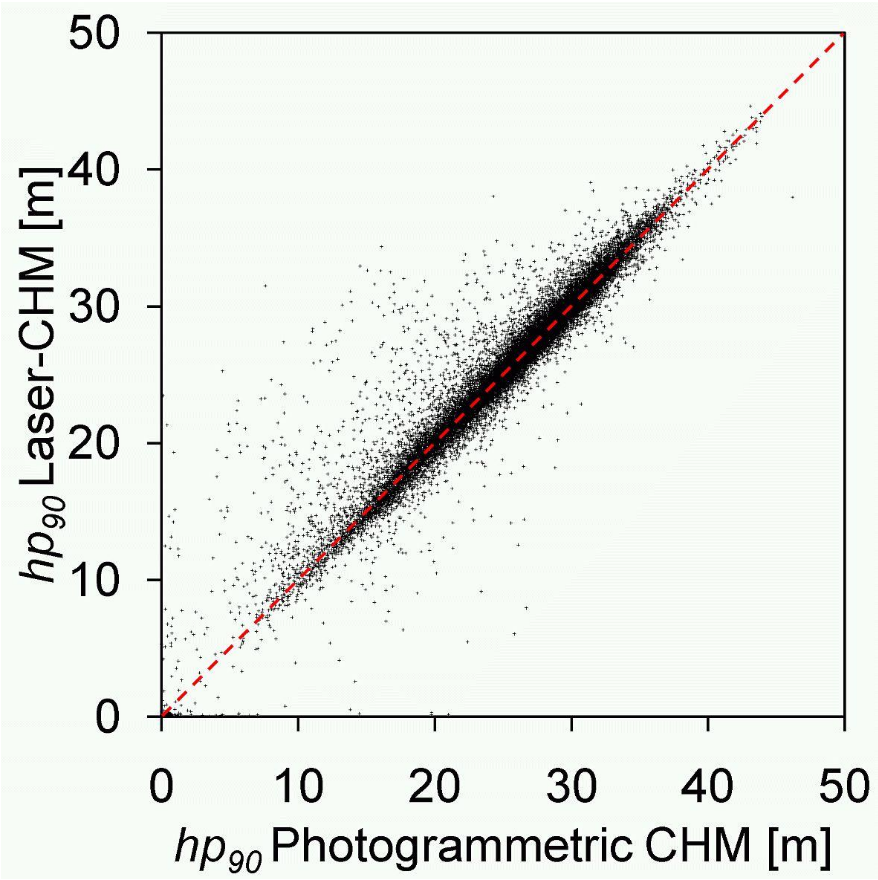


ALS-CHM
(Flying date: 2009)





Results – study site 2: Gerolzhofen



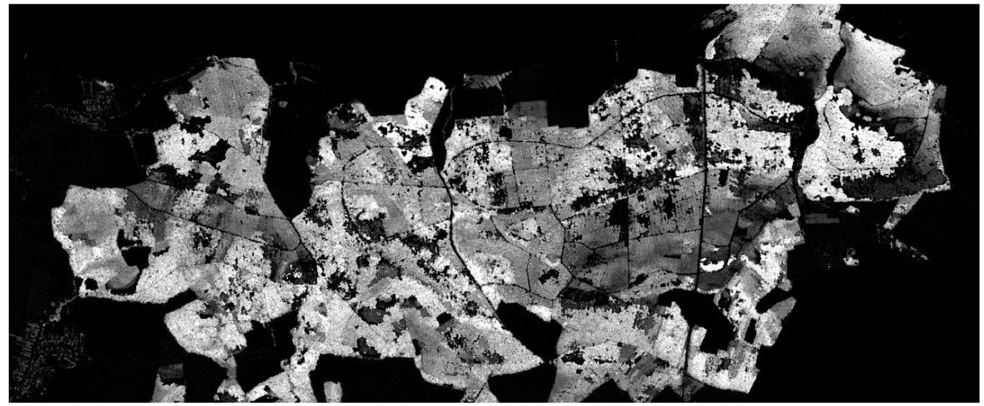
n = 24621
r = 0,96
RMSE = 1,63 m (6%)
Bias = 0,25 m (1%)

Results – study site 3: Monheim

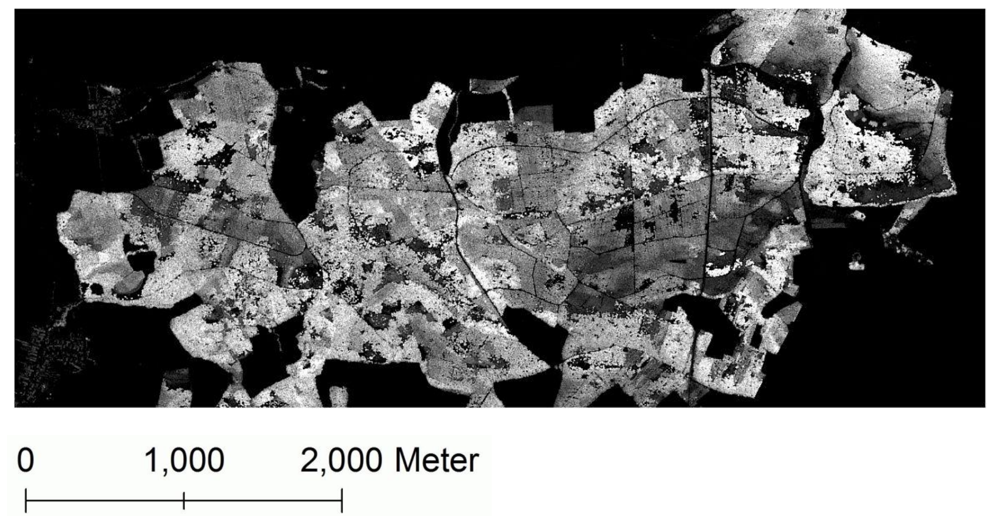
Results – study site 3: Monheim

Size (forest area): 818 ha

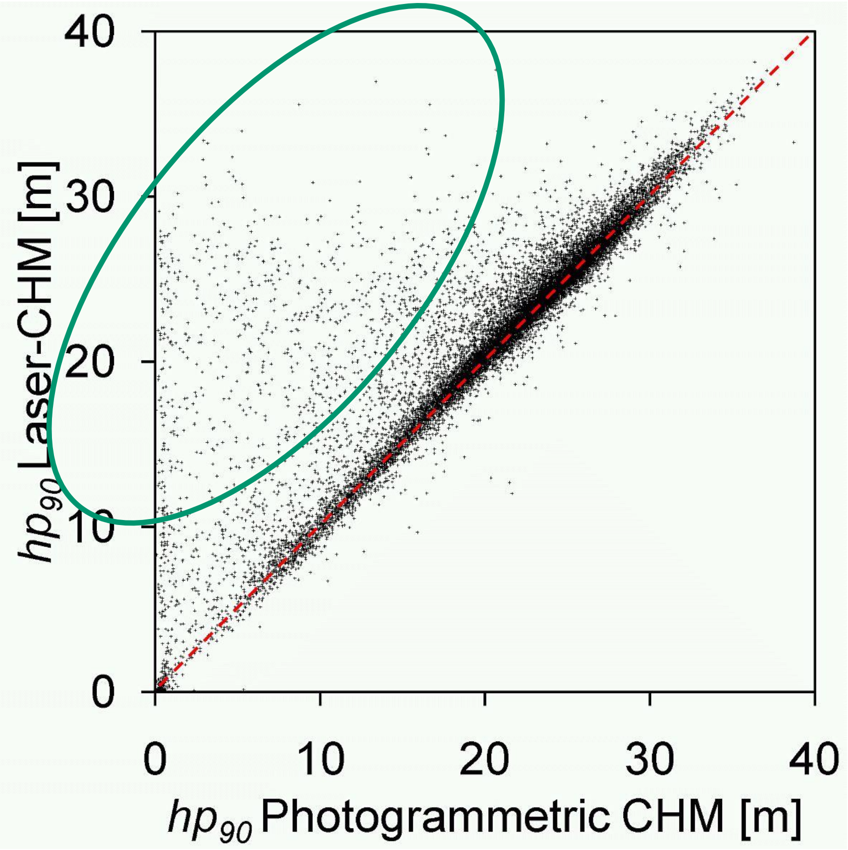
Photogrammetric CHM
(Flying date: 2009)



ALS-CHM
(Flying date: 2009)



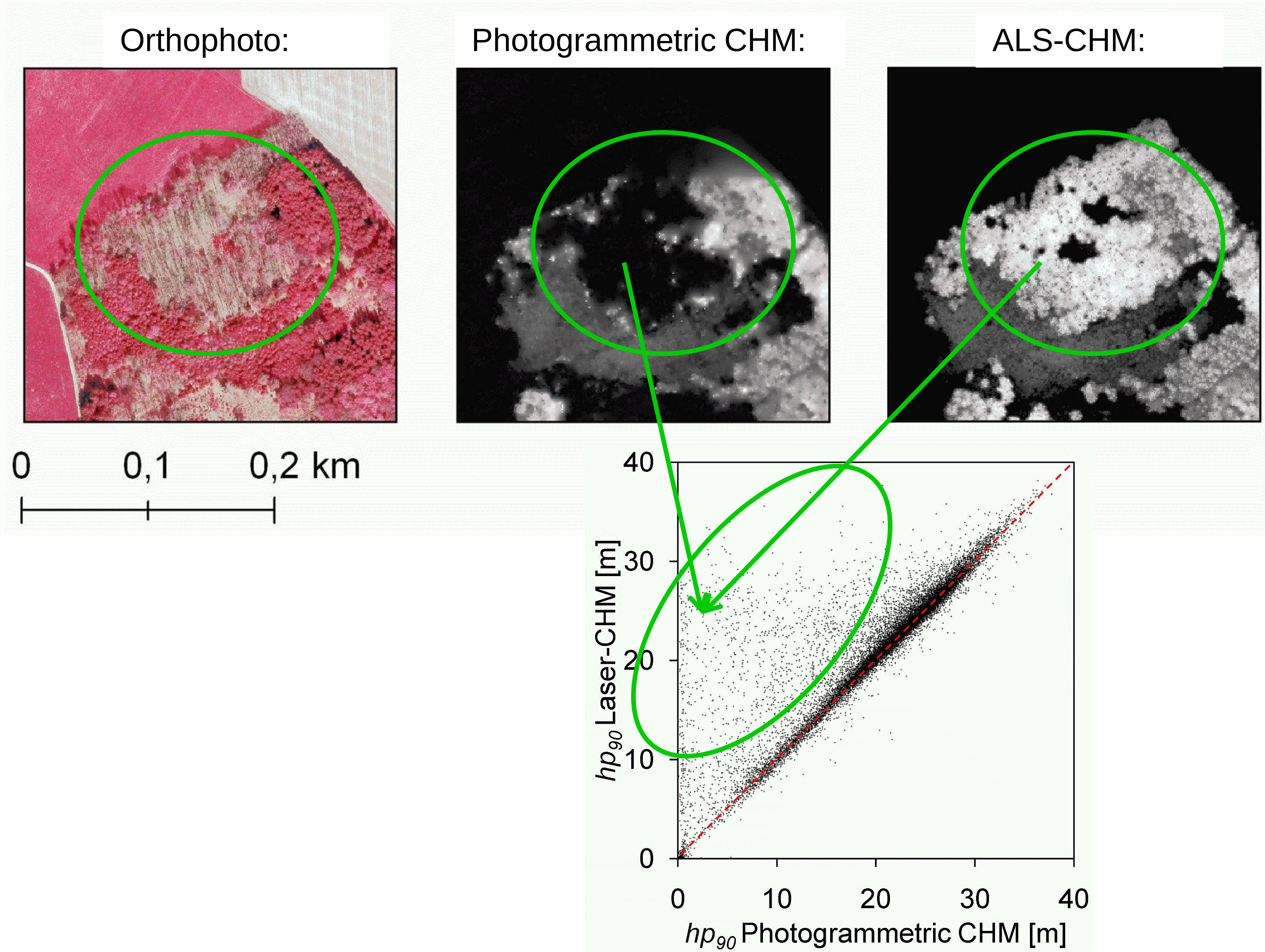
Results – study site 3: Monheim



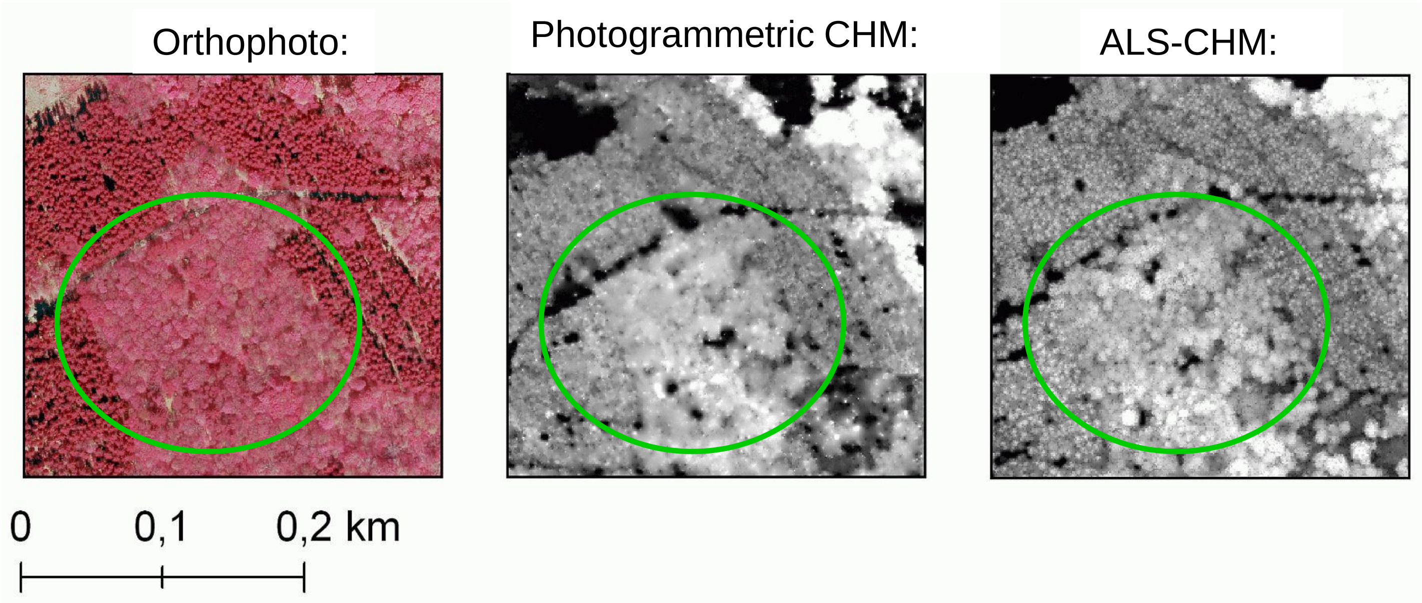
n = 16630
r = 0.88
RMSE = 3.55 (17%)
Bias = 1.21 (6%)

Results – study site 3: Monheim

Flying date:
25.04.2009



Results – study site 3: Monheim



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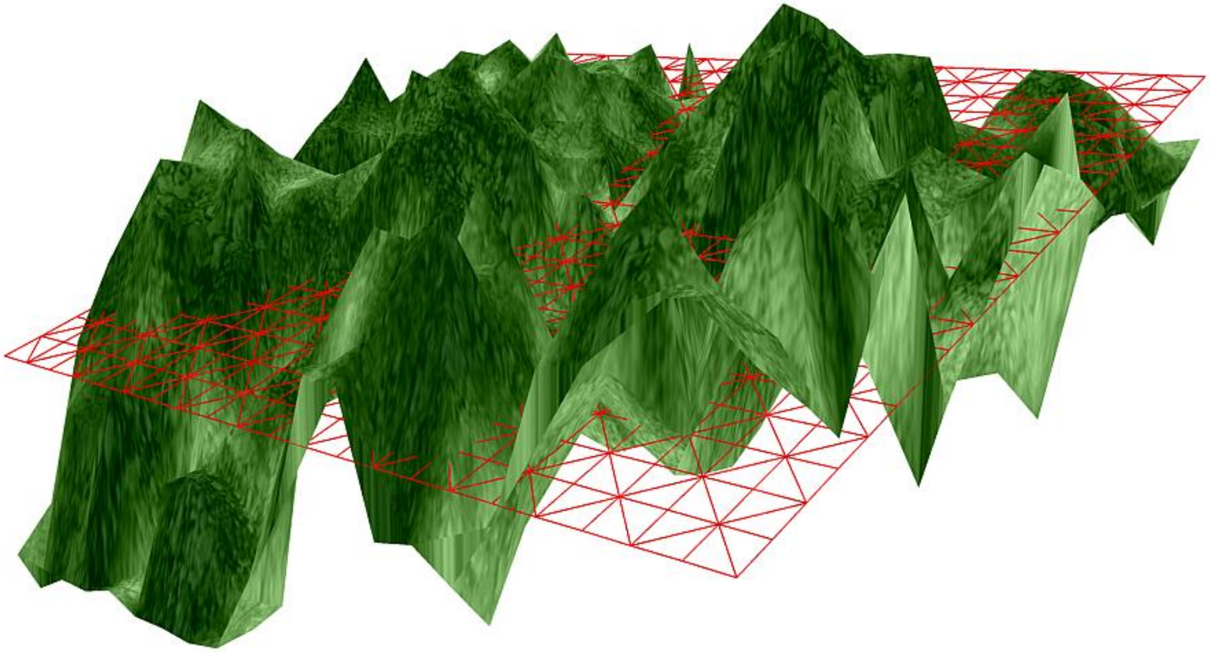
Methodology

<u>Characterization of the surface roughness *SR*:</u>

1. Within each cell a plane was fitted to the height values of the CHM
2. Computation of the standard deviation of height values to the plane



Results

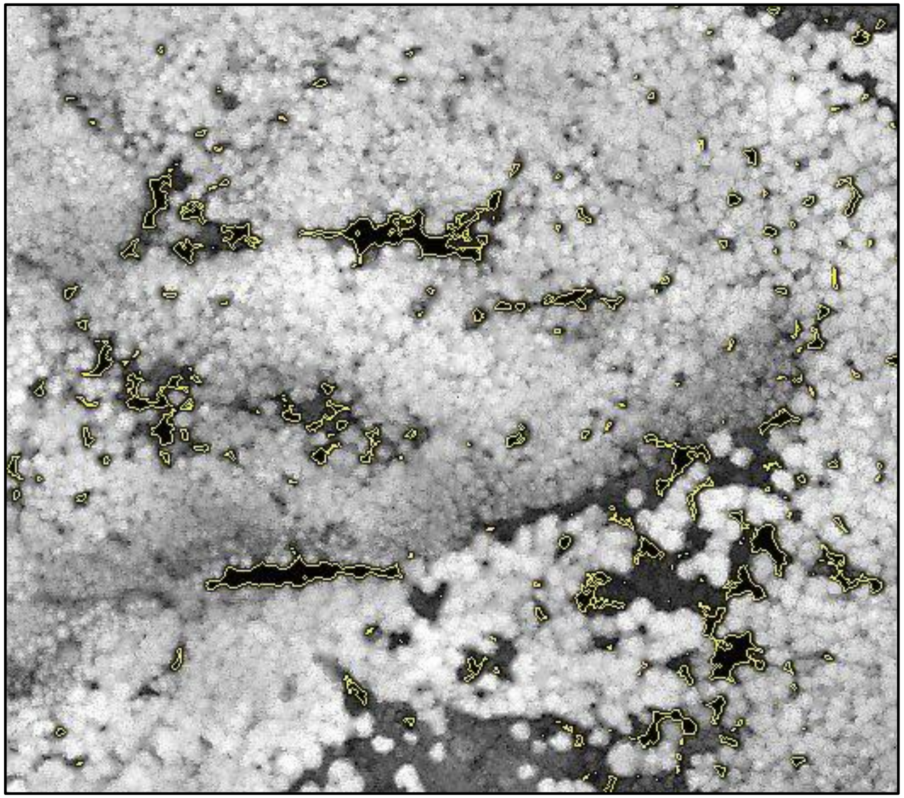
Mean standard deviation of height values of the CHM to a plane:

Test site	**Mean of *SR* ALS-CHM [m]**	**Mean of *SR* Photogrammetric CHM [m]**
Gerolzhofen	3.56	2.33
Ettaler Berg	4.71	3.33
Monheim	3.52	2.76

Methodology

<u>Automatic extraction of canopy gaps:</u>

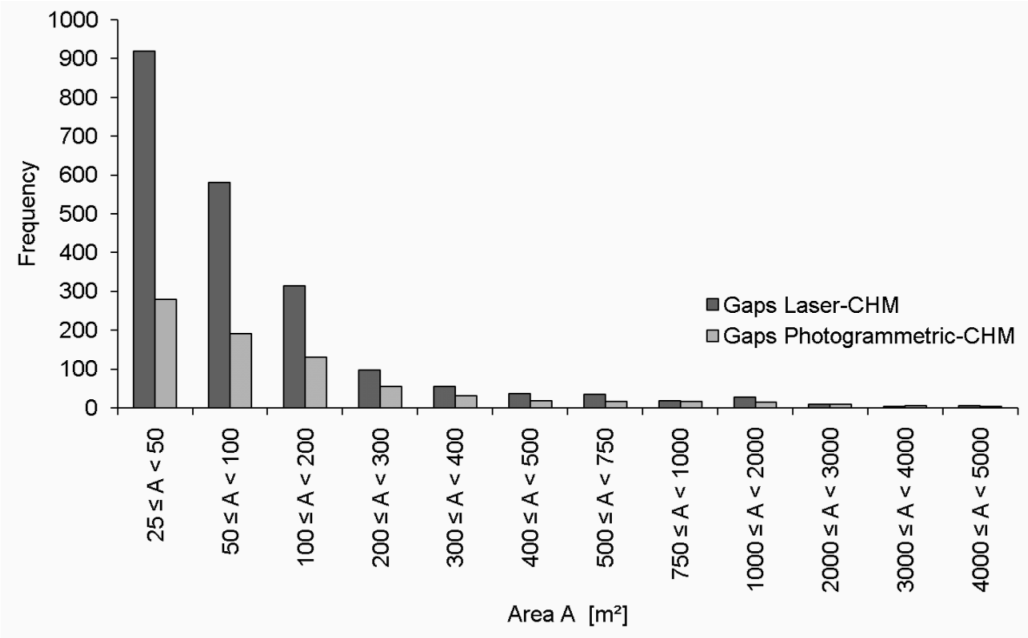
1. Extraction of ground pixels (< 3 m)
2. Adjacent ground pixels are grouped into connected regions
3. Selection of regions with size: 25 m² ≥ A ≤ 5000 m²



Results

Automatic extraction of canopy gaps:

Test site	Number of gaps ALS-CHM	Number of gaps Photogrammetric CHM
Gerolzhofen	2104	773
Ettaler Berg	3134	1704
Monheim	1753	1317



Discussion and conclusion:

- In all test sites it was possible to compute high quality surface models with one meter resolution
- Even for areas with a rough topography it was possible to model the top canopy surface appropriately
- It is necessary to make use of a DTM from ALS as an additional dataset to derive a CHM
- The photogrammetric models are less detailed. The surfaces are more smoothed and small gaps in addition to single trees are often not detectable
- Flying date is important (leaf-on conditions!)
- Forest stand heights can be measured with high precision
- Stereo-images are an economically efficient alternative
- Processing time is still a challenge

Outlook:

→ Optimization of the parameters for Image Matching

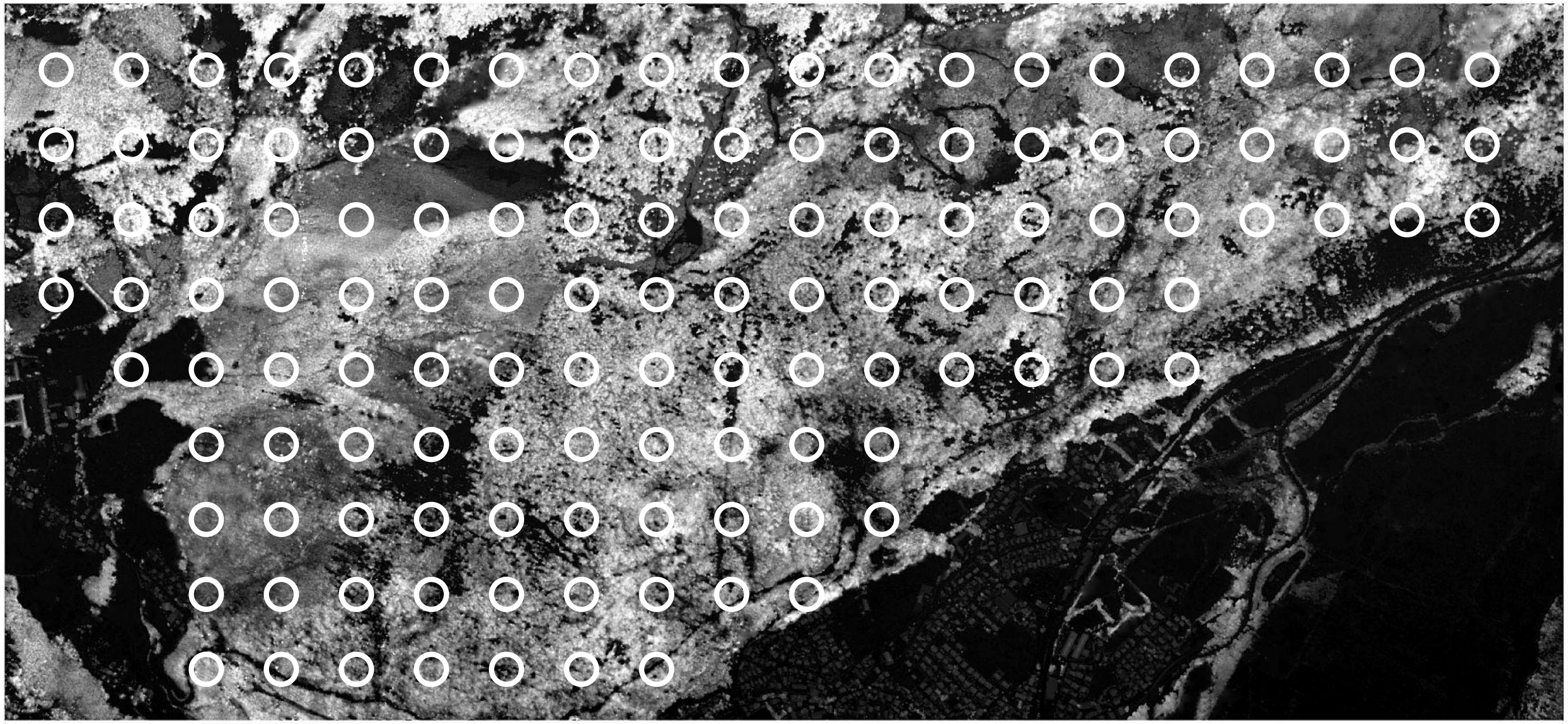
→ Comparison with field data

→ Surface Modeling for large areas

→ Test with DMC data

→ Sub-project 3: Estimation of further stand characteristics e.g. timber volume in $m^3\ ha^{-1}$

Outlook :



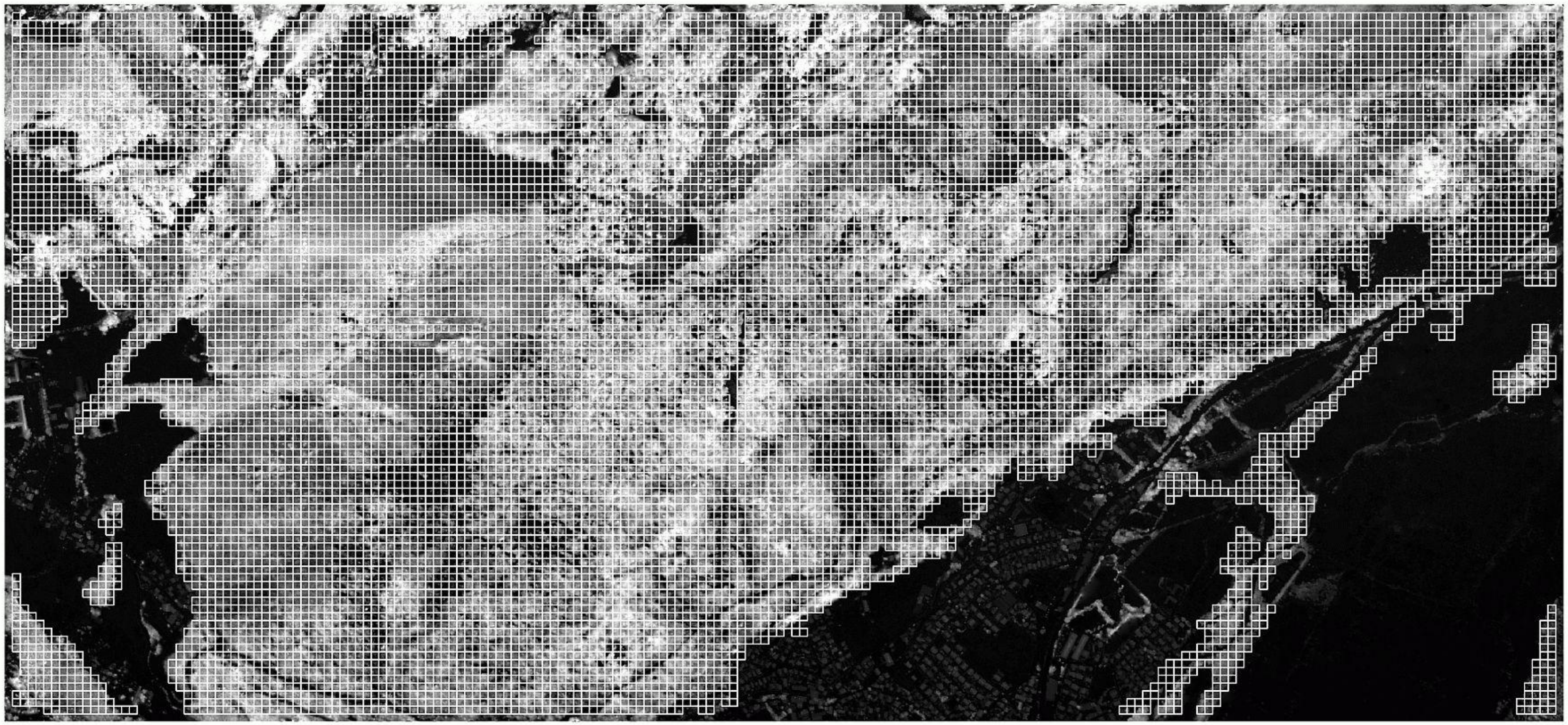
Exploring relationships at inventory plots:

$$Y = f(X_1, X_2, \ldots, X_n)$$

Y = e.g. timber volume in m³ ha^{-1}

$X_1, X_2, \ldots, X_n$ = Features derived from stereoscopic aerial photographs

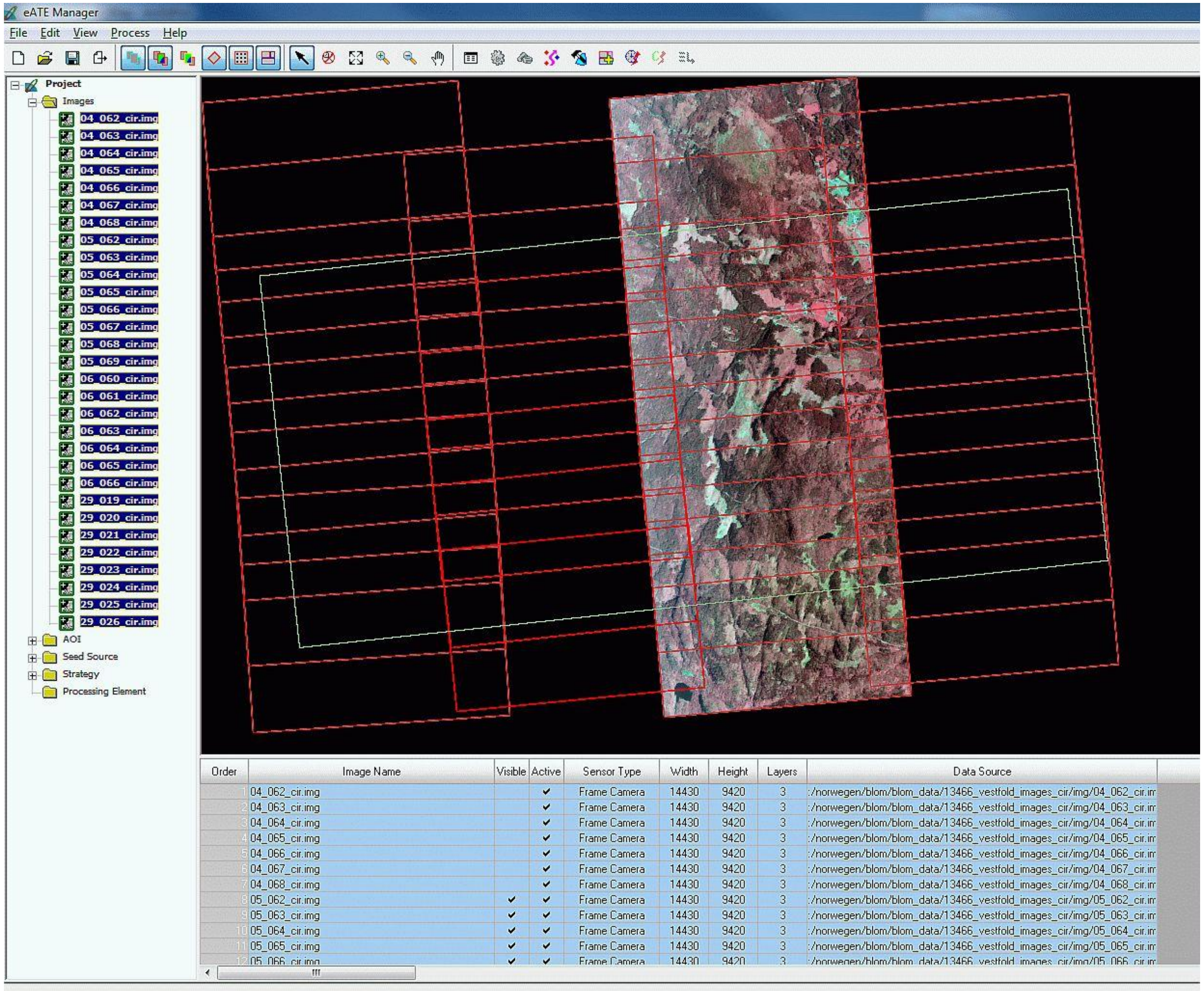
Outlook:



→ Regionalization of forest inventories

Results – Vestfold

Results – Vestfold



- 30 CIR images
- 8 bit
- Size ~ 37 km²

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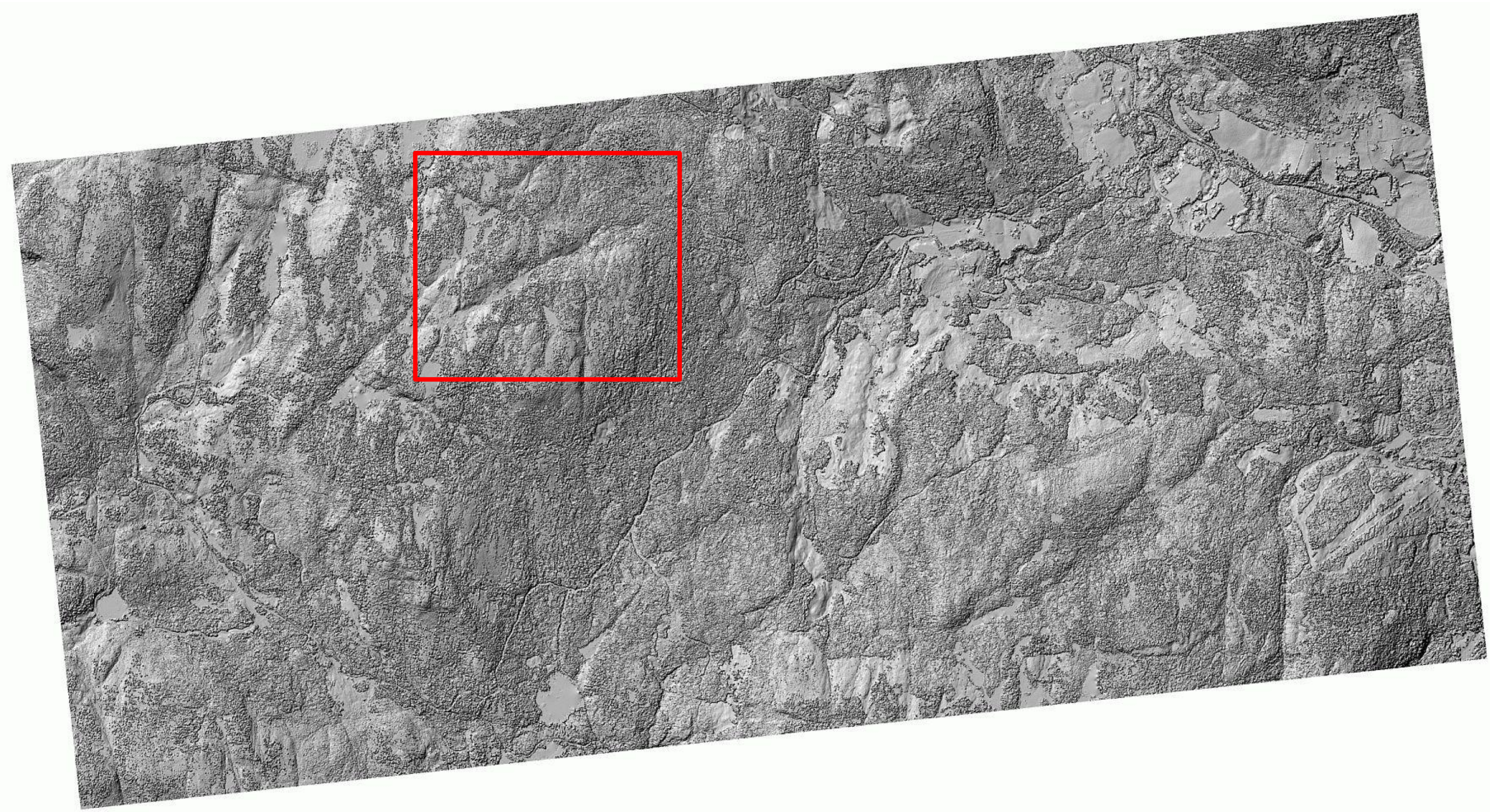
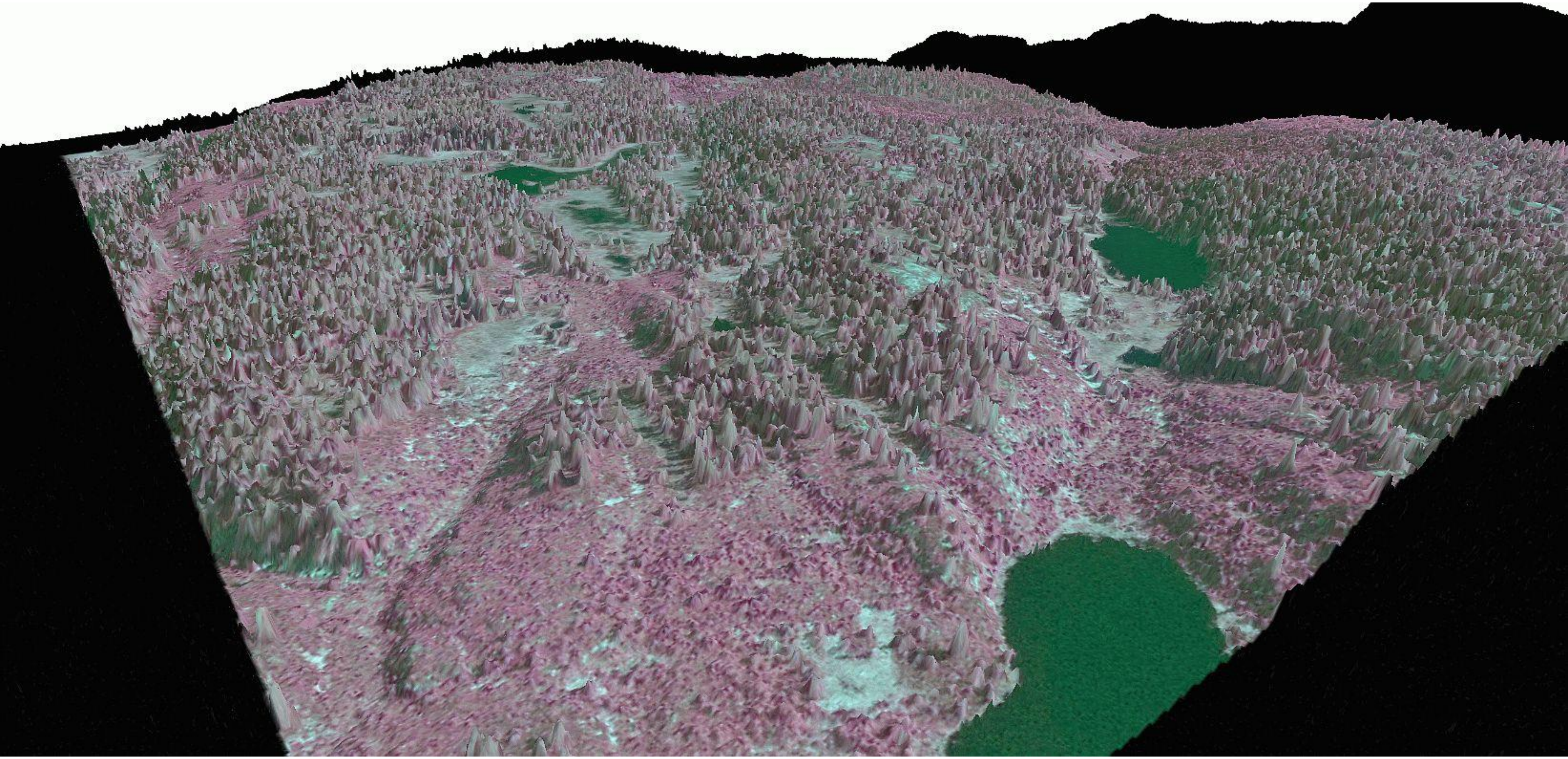
für Wald und Forstwirtschaft

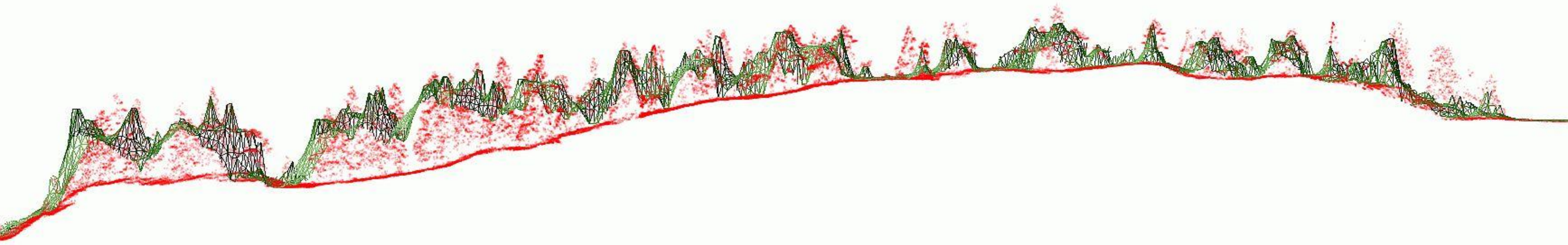
Results – Vestfold



Results – Vestfold

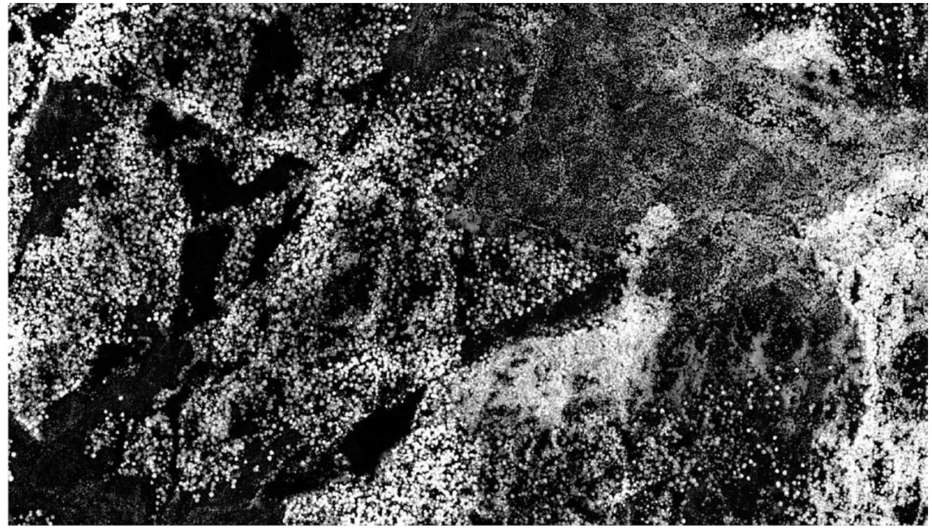


Results – Vestfold



Results – Vestfold

ALS-CHM

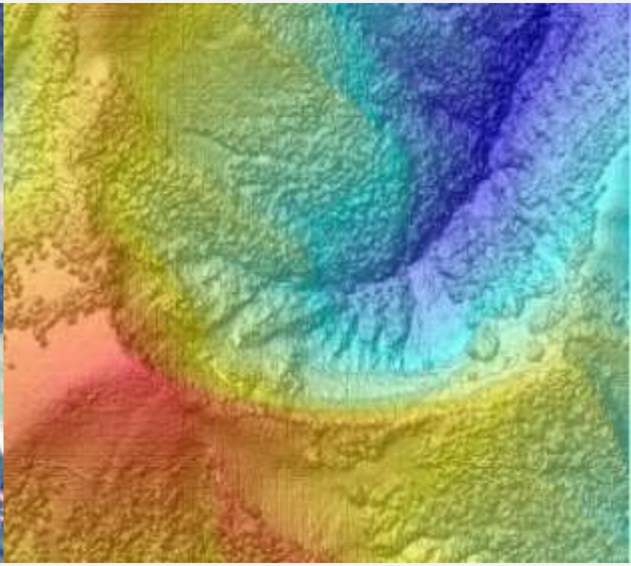


Photogrammetric CHM


Thank you very much for your attention!

Semi-automatic extraction of forest area, type and composition from ADS40/80 images and derived CHMs for the Swiss NFI





Lars T. Waser

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Swiss National Forest Inventory (LFI)

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www.lfi.ch www.wsl.ch

*M.Sc. in Geography / *E*nvironmental Science, @ WSL since 1999, project manager, PhD student since 2008

***1999-2004:** several national and EU-projects where remote sensing was involved, e.g. detection of storm losses, MODIS land cover products, prediction of biodiversity, TWW etc.

***Since 2005:** focus on derivation of **forest parameters** (area, species, structure etc.) from **airborne remote sensing** data for LFI, Biotop protection, other projects etc.

***Publications: ISI:** 12 (7 first author); **other:** 28

Content

Background

Data sets

Methods

Tree area

Tree species

Problems / restrictions

Recommendations / outlook

Motivation

- Need of spatial accurate forest information
- Demand of country-wide forest area and composition maps
- Support tasks of the Swiss National Forest Inventory (NFI)
- Protection and management tasks of monitoring programs

Background: Swiss National Forest Inventory

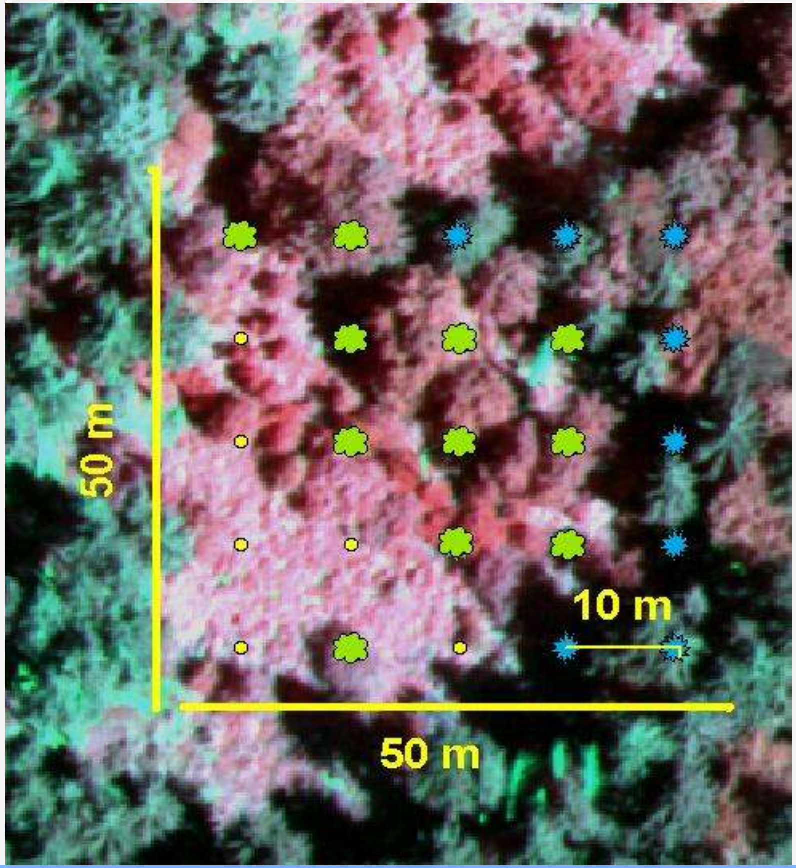
- <u>Combined inventory (2-phase)</u>

  - Stereo-interpretation of ADS40 images
  - Field surveys (about 6500 field plots / 700 per year)

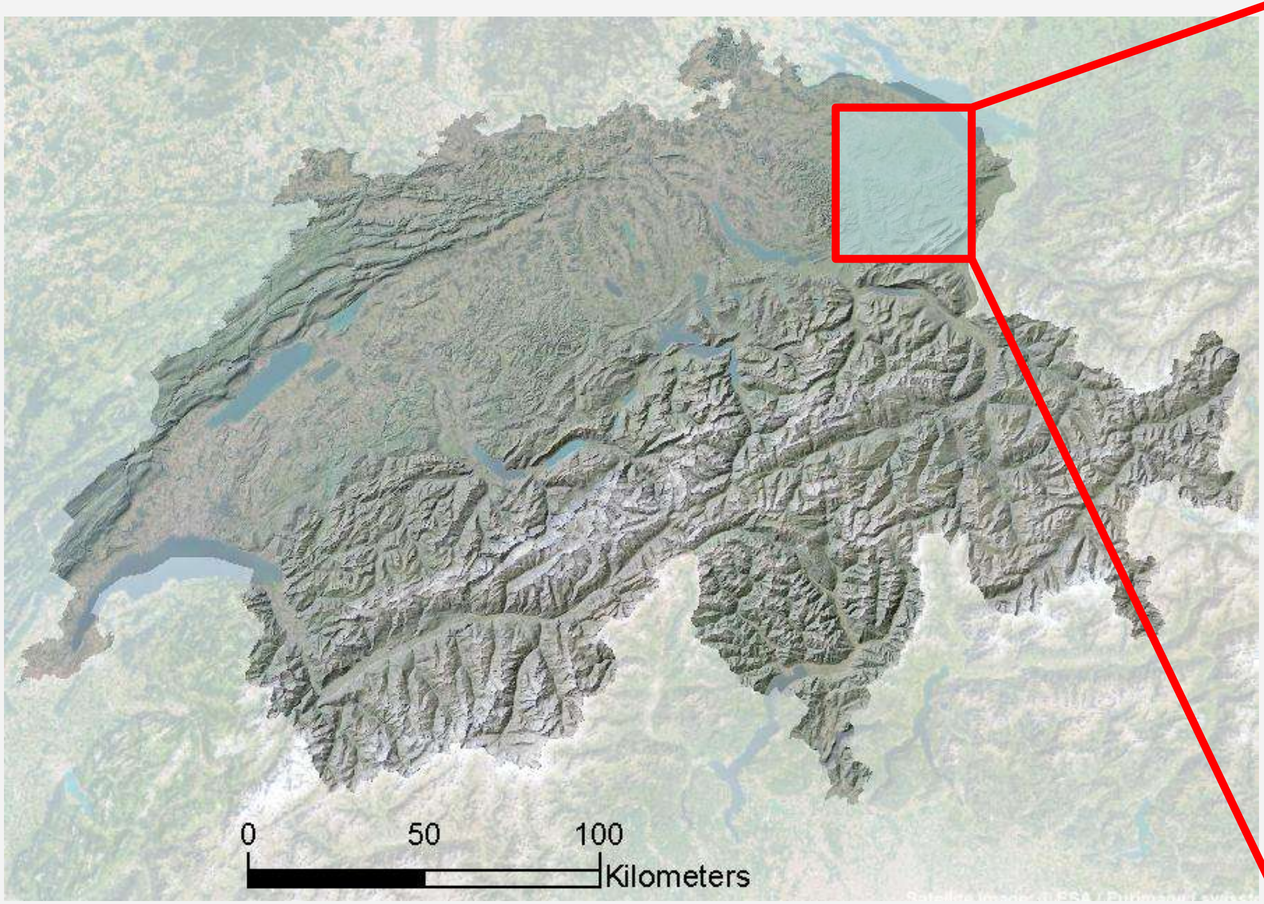
- <u>4 data surveys</u>

  NFI1: 1983 - 1985
  NFI2: 1993 - 1995
  NFI3: 2004 - 2007
  NFI4: 2009 - 2018

0,5 km grid +
1,0 km grid
1,4 km grid



Study area: NE part of Switzerland



- approx. 1500km^2, 500m – 2500m a.s.l.
- 47°22’ N / 8°28’ E
- **Open and close mixed forest; coniferous forests (>1300m a.s.l.)**

Content

Background

Data sets

Methods

Tree area

Tree species

Problems / restrictions

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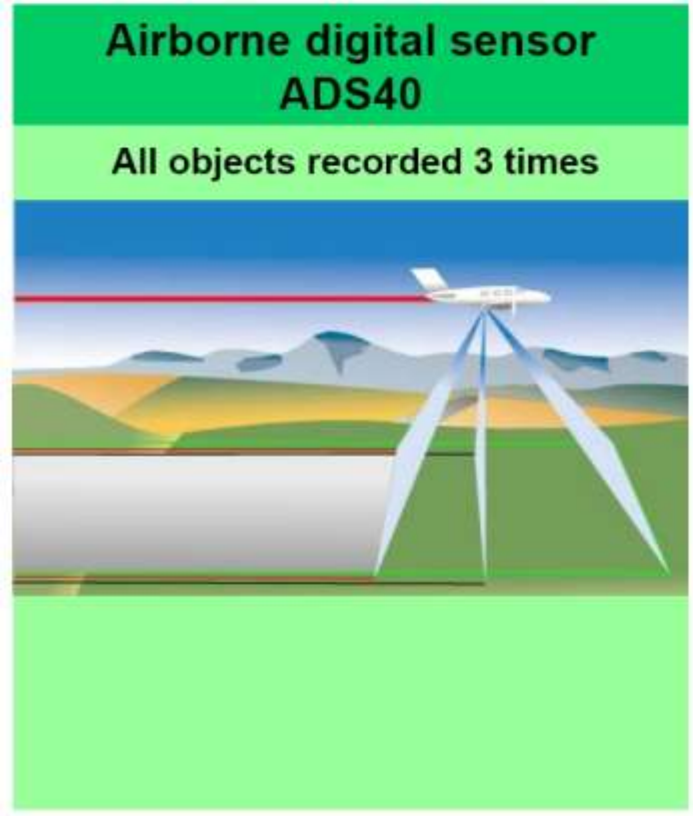
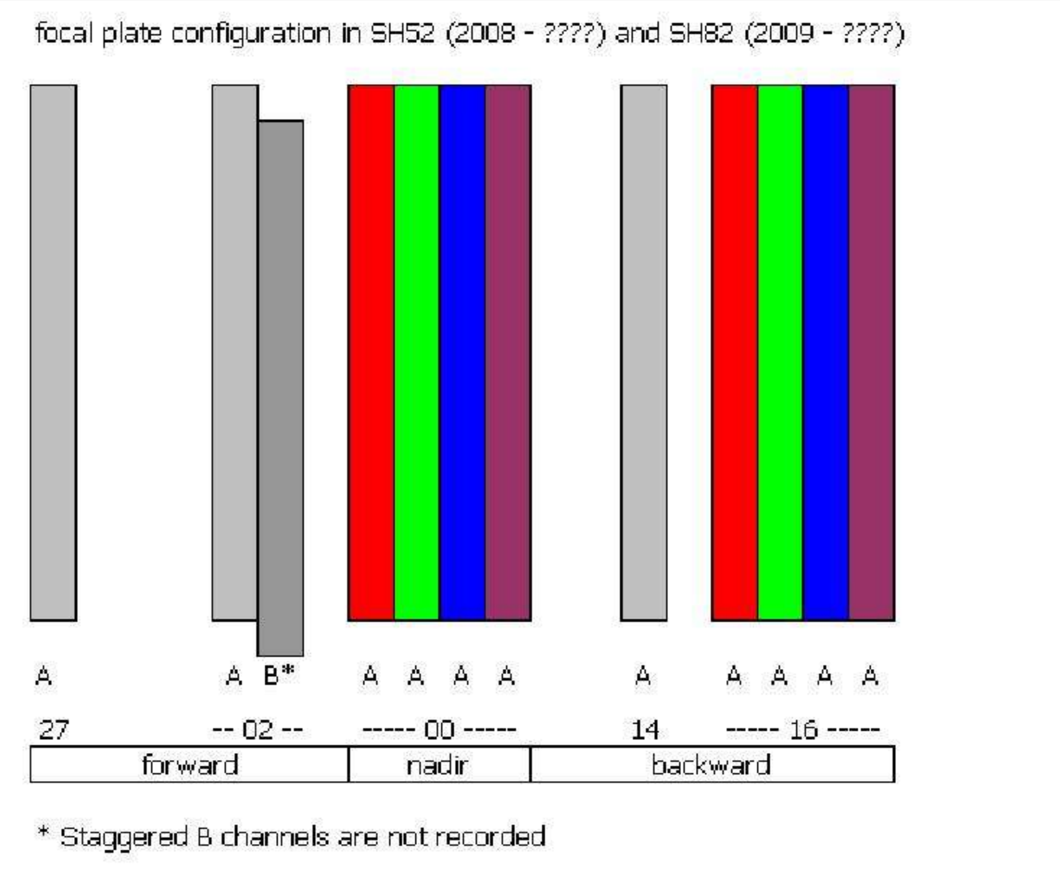
Input data 1: Remote sensing data

- **ADS40**-SH52 / **ADS80**-SH82 images, level 1

(8 strips (5 km x 30 km); GSD: 25-50 cm; 2008-2010; RGB + NIR; 11Bit)

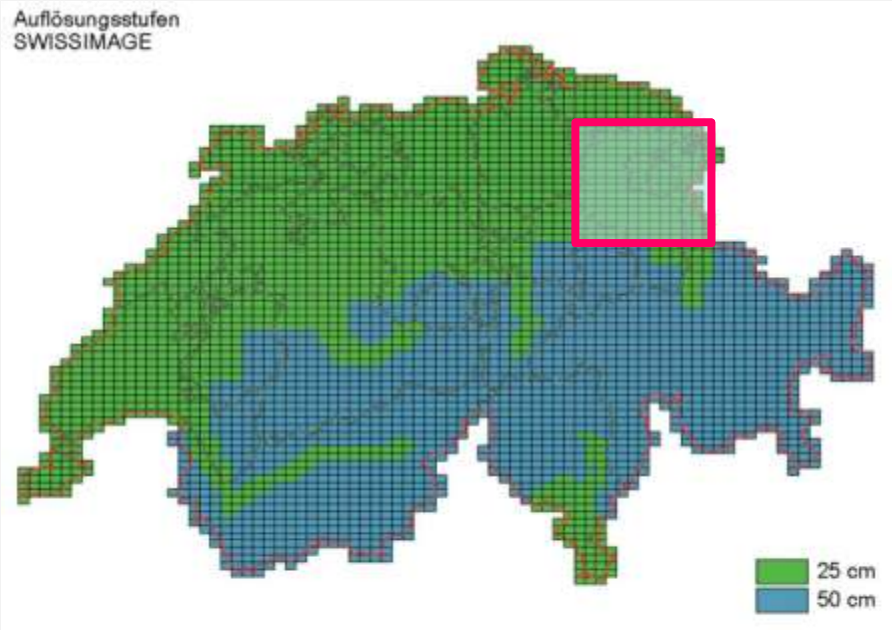


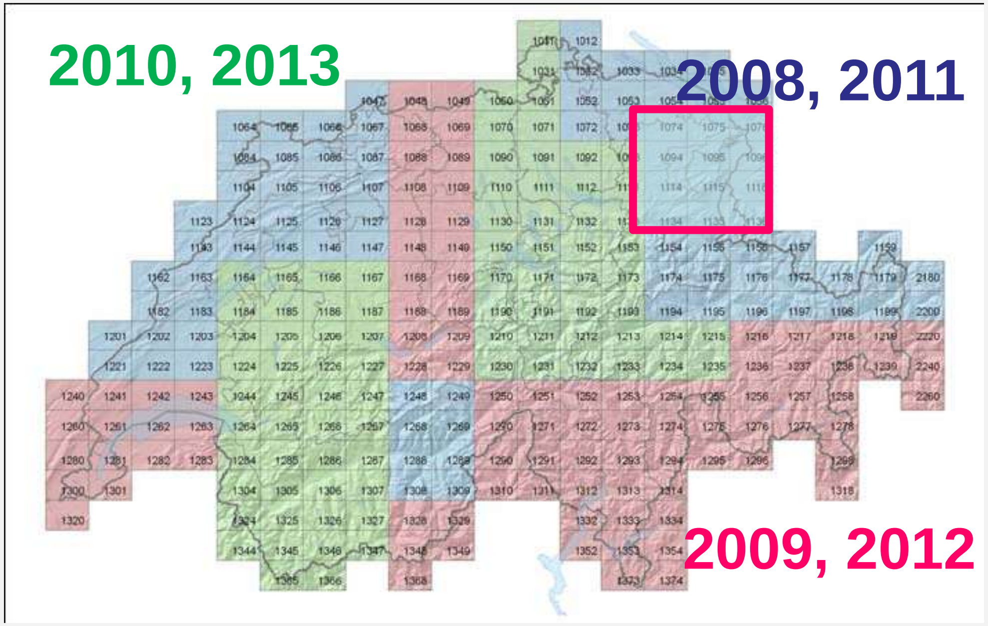


Input data 1: Remote sensing data

- **ADS40**-SH52 / **ADS80**-SH82 images, level 1

  (8 strips (5 km x 30 km); GSD: 25-50 cm; 2008-2010; RGB + NIR; 11Bit)



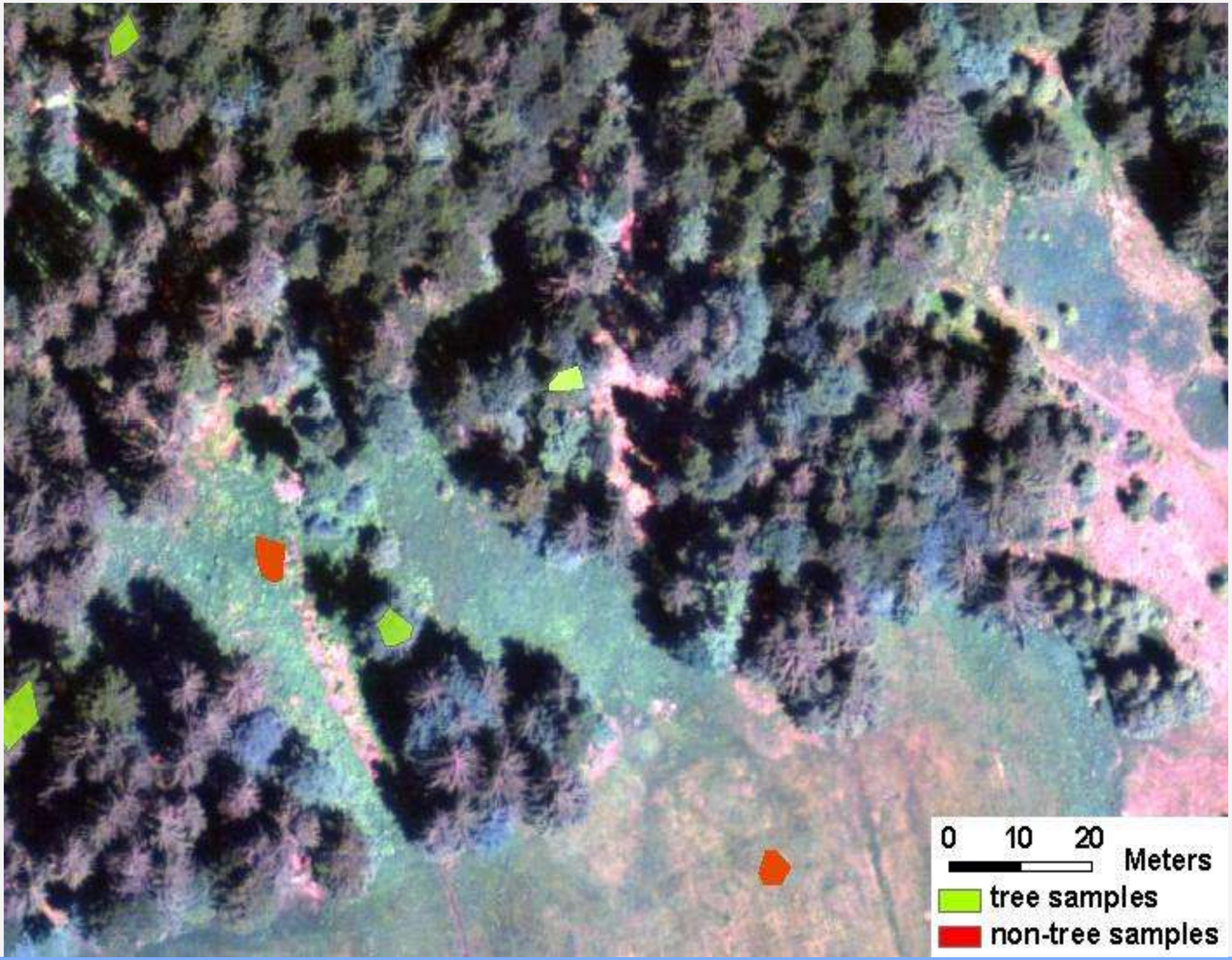


- LiDAR **D**igital **T**errain **M**odel (DTM-AV)

  (0.8 points / m^2; 2002 – 2003)

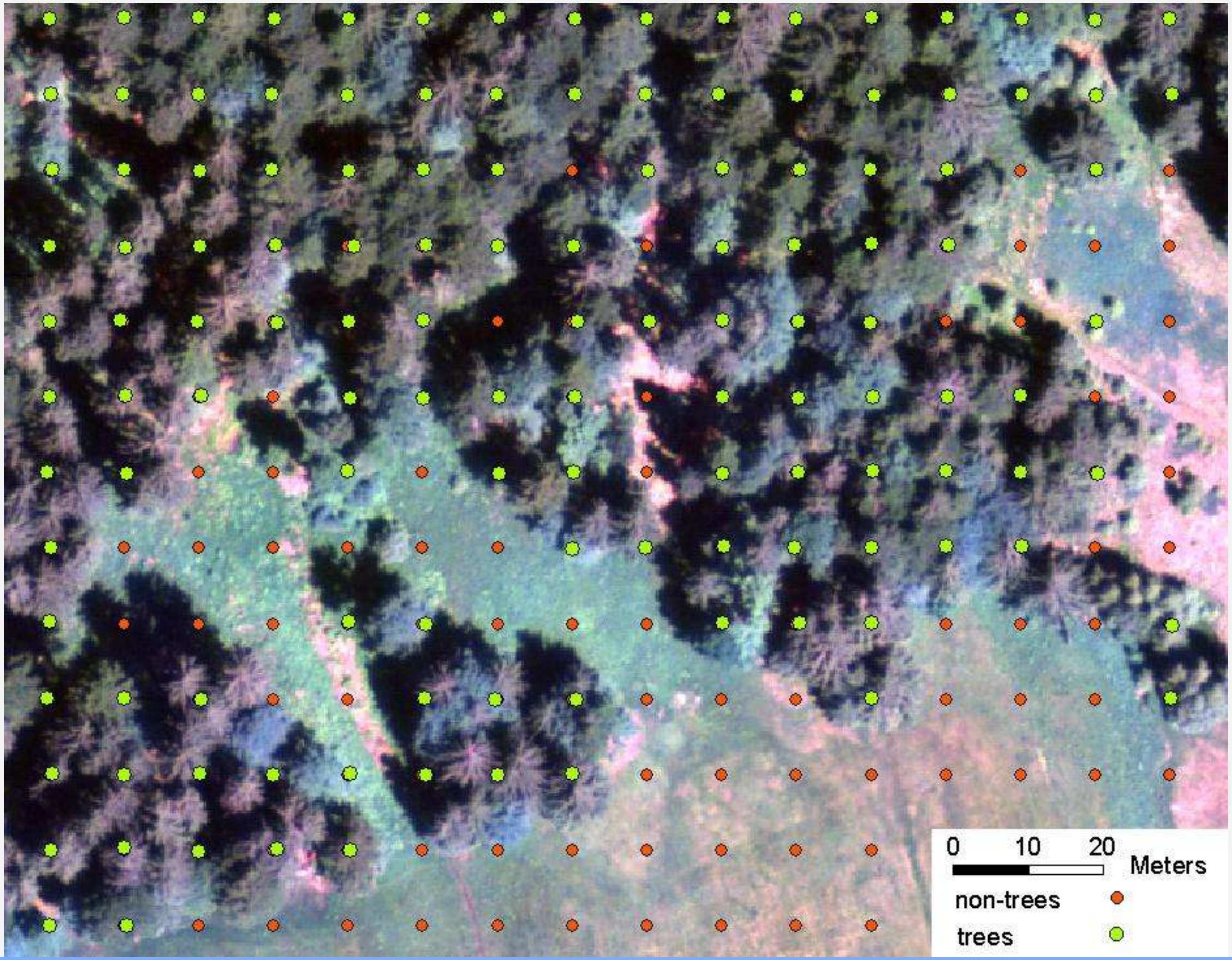
Input data 2: Reference data for tree area

- **Digitized tree / non-tree polygons (~ 600)**



Input data 2: Reference data for tree area

- **Photo-interpreted point raster (for selected areas)**



Input data 3: Reference data for tree species


- **Field surveys** (2008 – 2010; 6 days)

- Visits of **8** (main) tree species & digitized on the ADS40 orthoimages

=> *Ash, Beech, Birch, Larch, Maple, Norway spruce, Scots pine, White fir*

=> 300-500 samples / species for training and validation purposes

- **Coniferous / deciduous trees from NFI aerial image interpretation** (72 x 25 raster points)

Content

Background

Data sets

Methods

Tree area

Tree species

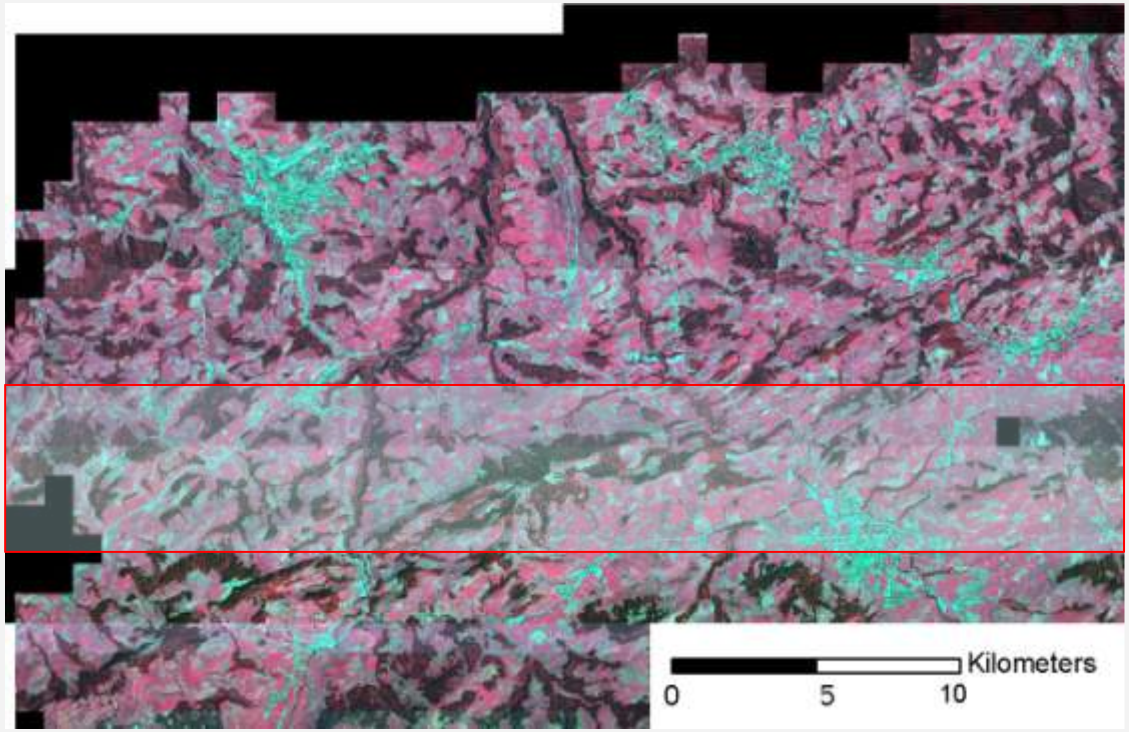
Problems / restrictions

Recommendations / outlook

Method: Data handling, processing

- Large datasets (1 strip ~ 2 x 12 GB RGB + CIR) => problems for classification, performance, handling etc.

=> Strip-wise processing and classifications



Strip Nr. 3 (August 2008)
ADS40-SH52 – CIR

Method: Modelling procedure

- Binomial logistic regression* using *R statistics*

=> two outcomes: tree / non-tree

- Multinomial logistic regression* in *R statistics*

=> more than two outcomes: 8 tree species

- Processing steps:

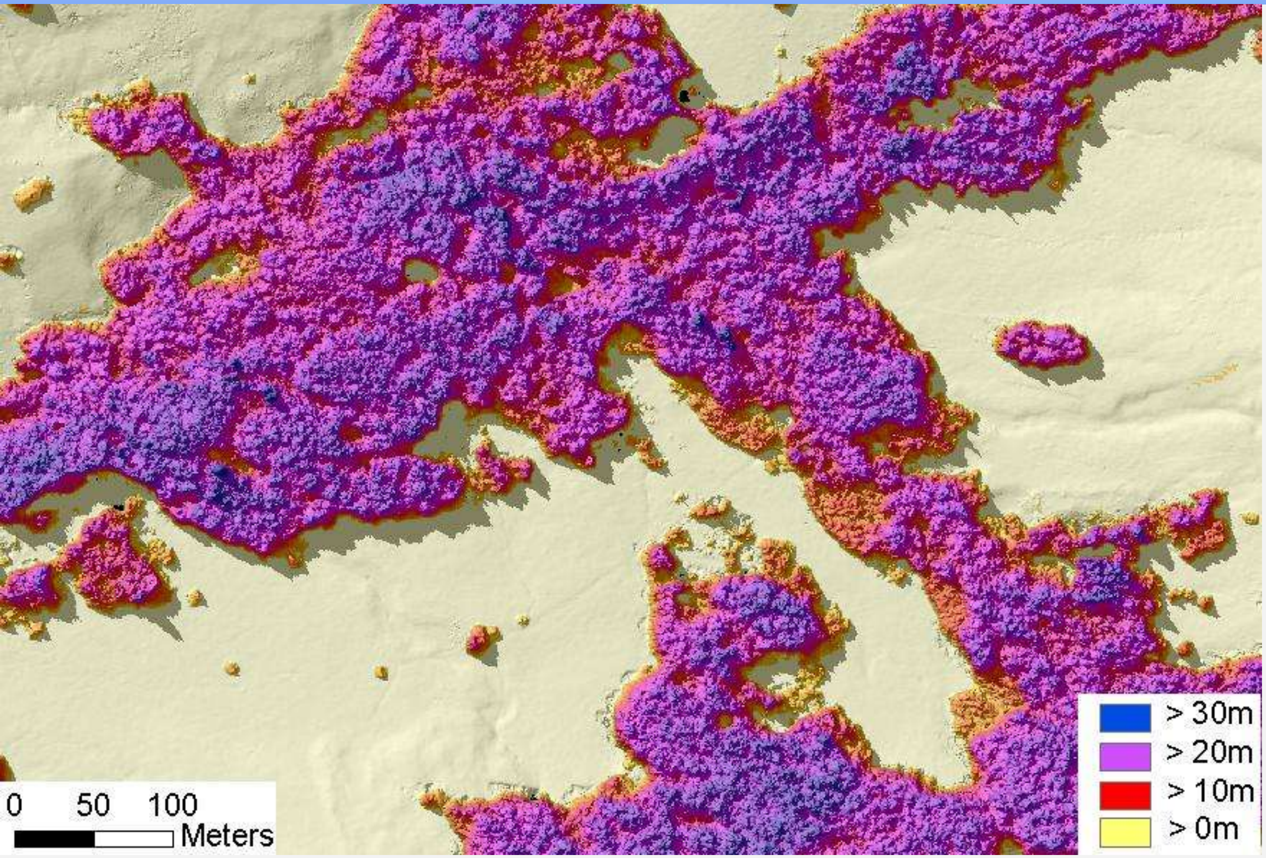
=> separately for each of the data sets (8 orthoimage strips)

=> derivation of explanatory variables (~ 30):

geometric & spectral signatures from ADS40 imagery

*Hosmer & Lemeshow 2000. *Applied logistic regression, 2nd ed., New York: Wiley, 373 p.*

Derivation of geometric variables



from: Waser *et al.* 2007. Environmental Modeling and Assessment 12: 315-328.

from: Waser *et al.* 2008. International Journal of Remote sensing 29 (5): 1261-1276

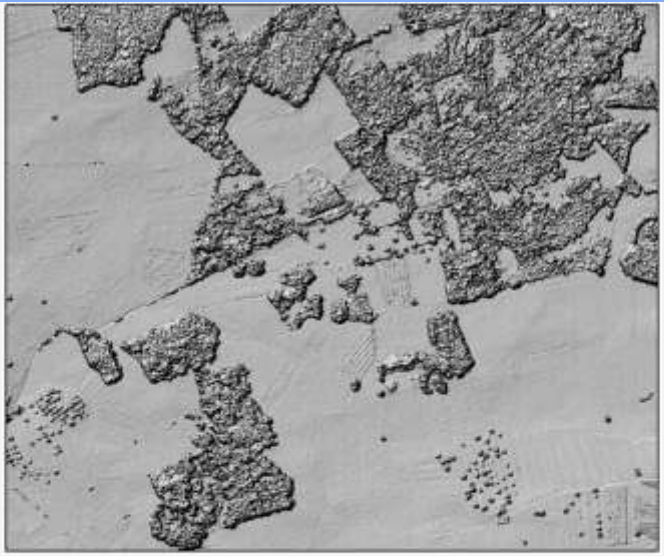
Strip Nr. 3 (August 2008)
ADS40-SH52 – CIR

- **n**ormalised **C**anopy **H**eight **M**odels (**nCHMs**):

(ADS40 CIR Digital surface models - LiDAR DTM; Ngate SocetSet)

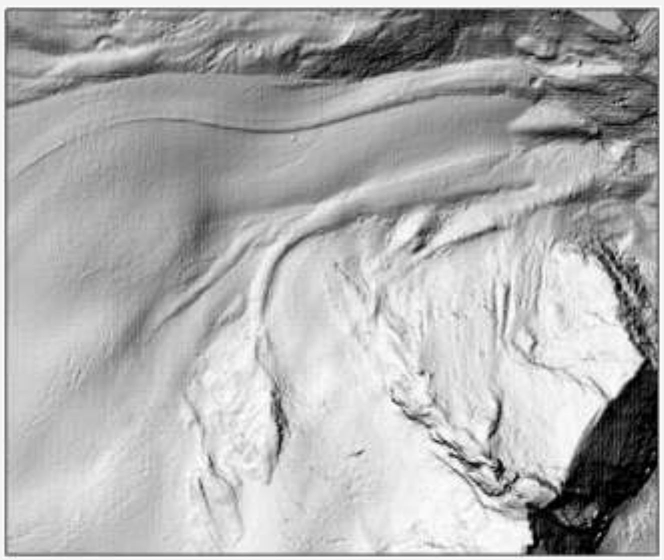
Ngate correlation strategies

‚forest‘



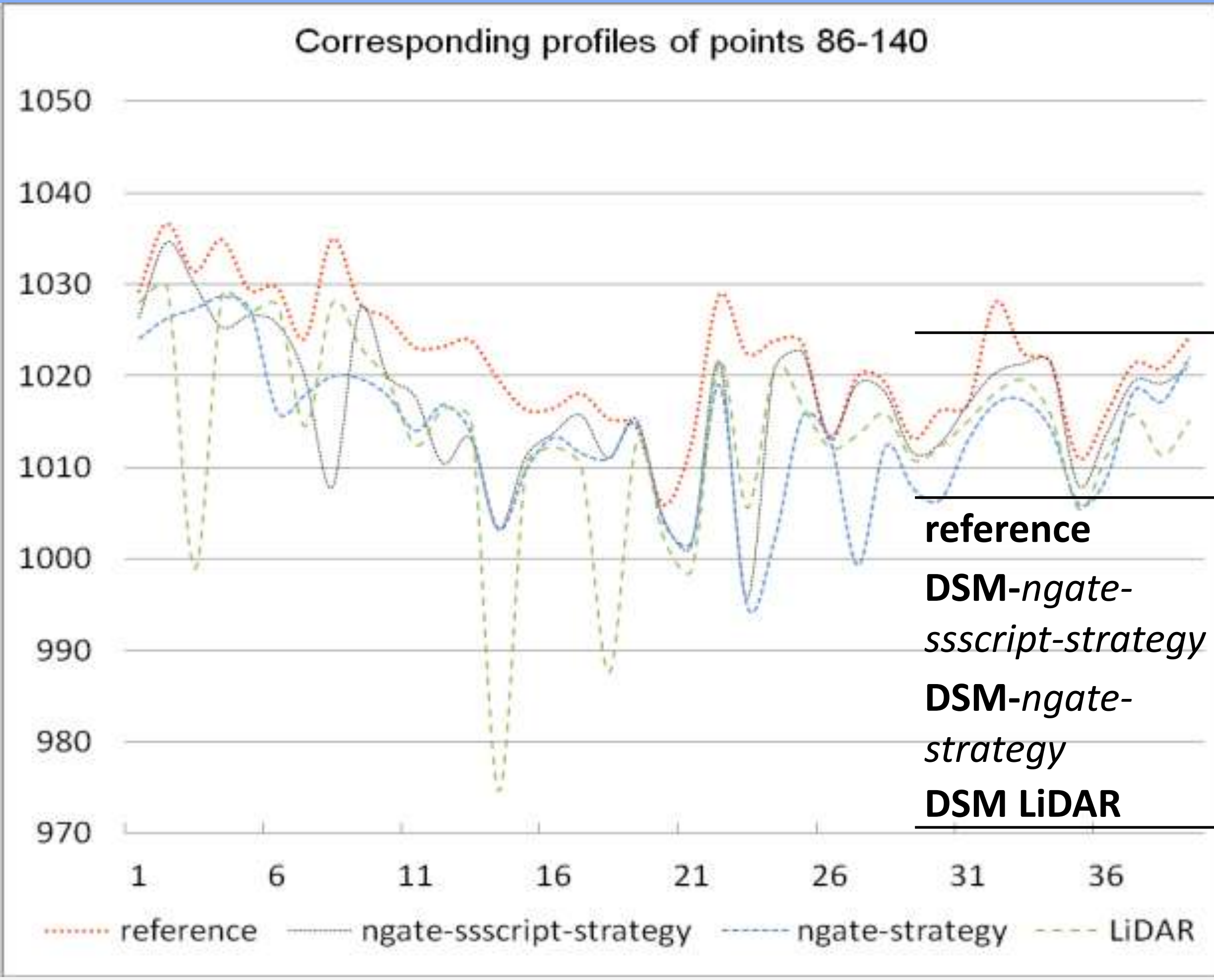
single features, e.g. trees

‚desert‘



flat areas, e.g. glaciers

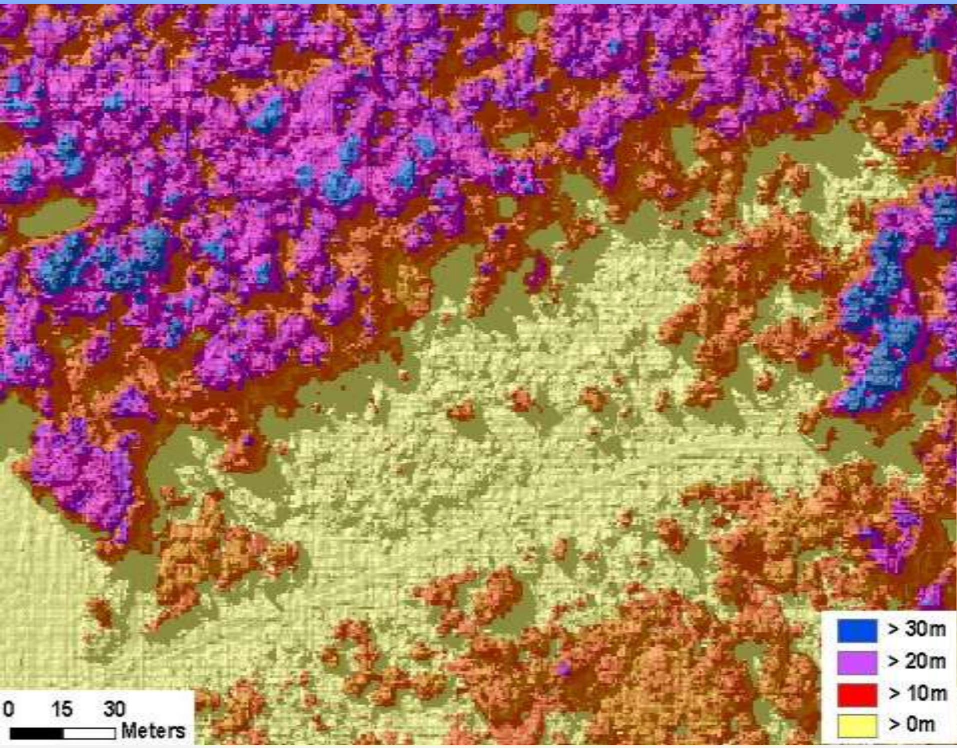
Accuracy assessment: DSMs

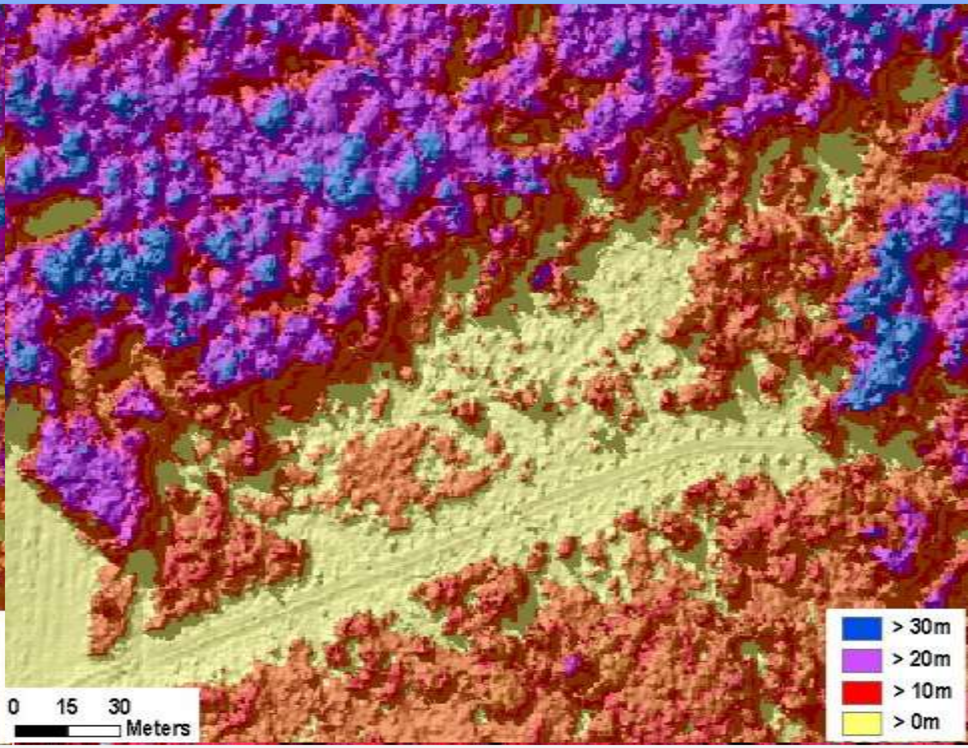


	Difference to reference (m)		
	Mean	Median	Standard deviation
reference	**1032.3**	1027.1	36.17
DSM-*ngate-ssscript-strategy*	-3.98	-4.98	-0.06
DSM-*ngate-strategy*	-6.83	-9.07	0.07
DSM LiDAR	-8.69	-6.82	1.90

=> Based on 486 manually measured reference points

Accuracy assessment: nCHM

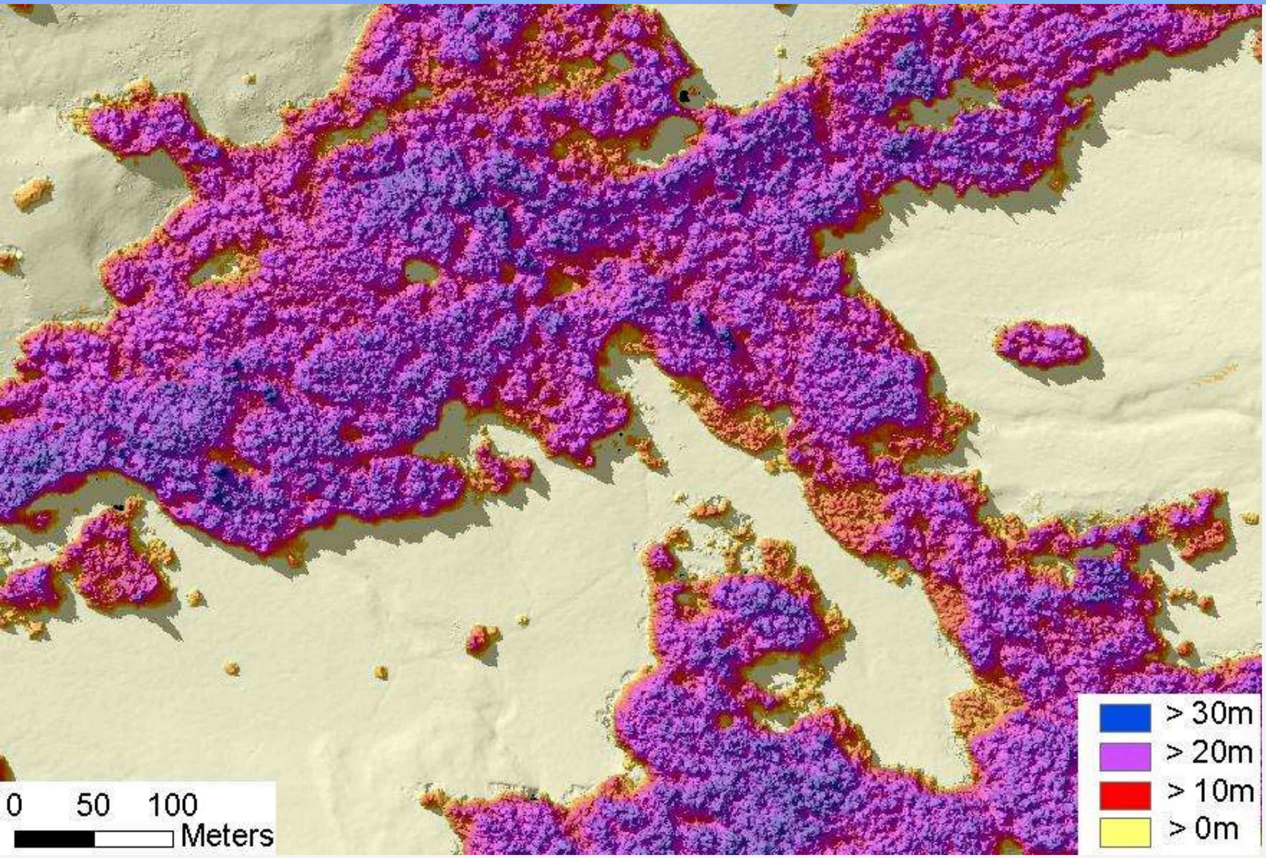




Standard forest strategy (© BAE Systems)

Modified forest strategy (© WSL)

Derivation of **geometric** variables



from: Waser *et al.* 2007. Environmental Modeling and Assessment 12: 315-328.

from: Waser *et al.* 2008. International Journal of Remote sensing 29 (5): 1261-1276

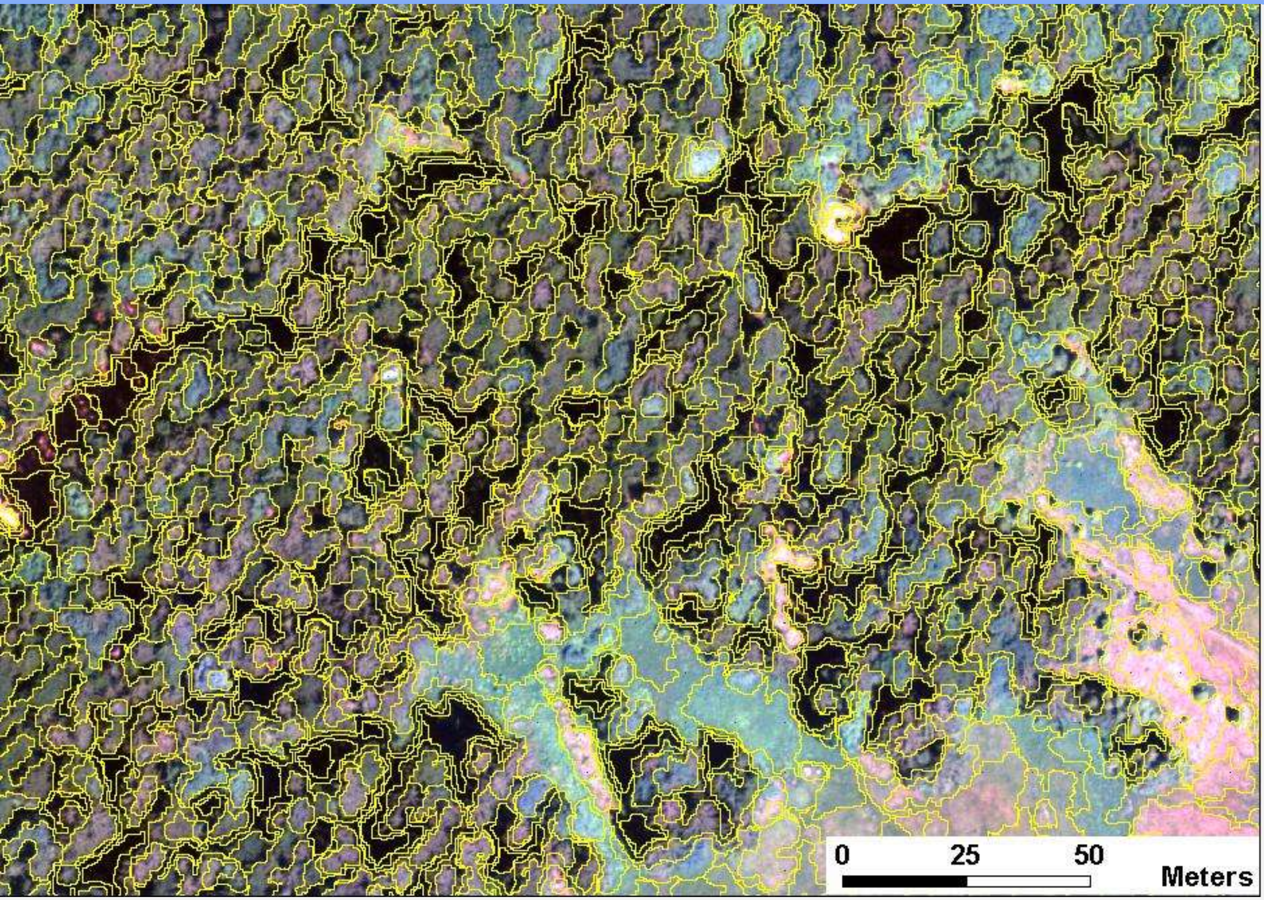
Strip Nr. 3 (August 2008)
ADS40-SH52 – CIR

- **n**ormalised **C**anopy **H**eight **M**odels (**nCHMs**):

(ADS40 CIR Digital surface models - LiDAR DTM-AV; Ngate SocetSet)

=> Geometric variables derived from nCHMs (height, curv, slope, etc.)

Derivation of spectral variables



from: Waser *et al.* 2007. Environmental Modeling & Assessment 12: 315-328

from: Waser et al. 2011. Remote Sensing of Environment 115: 76-85

Strip Nr. 3 (August 2008)
ADS40-SH52 – CIR

- Spectral variables derived from RGB and CIR bands:
  => original bands, ratio of bands, arithmetic combinations, IHS, PCA, LDA

=> Variables per square / segments (Definiens or mean-shift segmentation)

Content

Background

Data sets

Methods

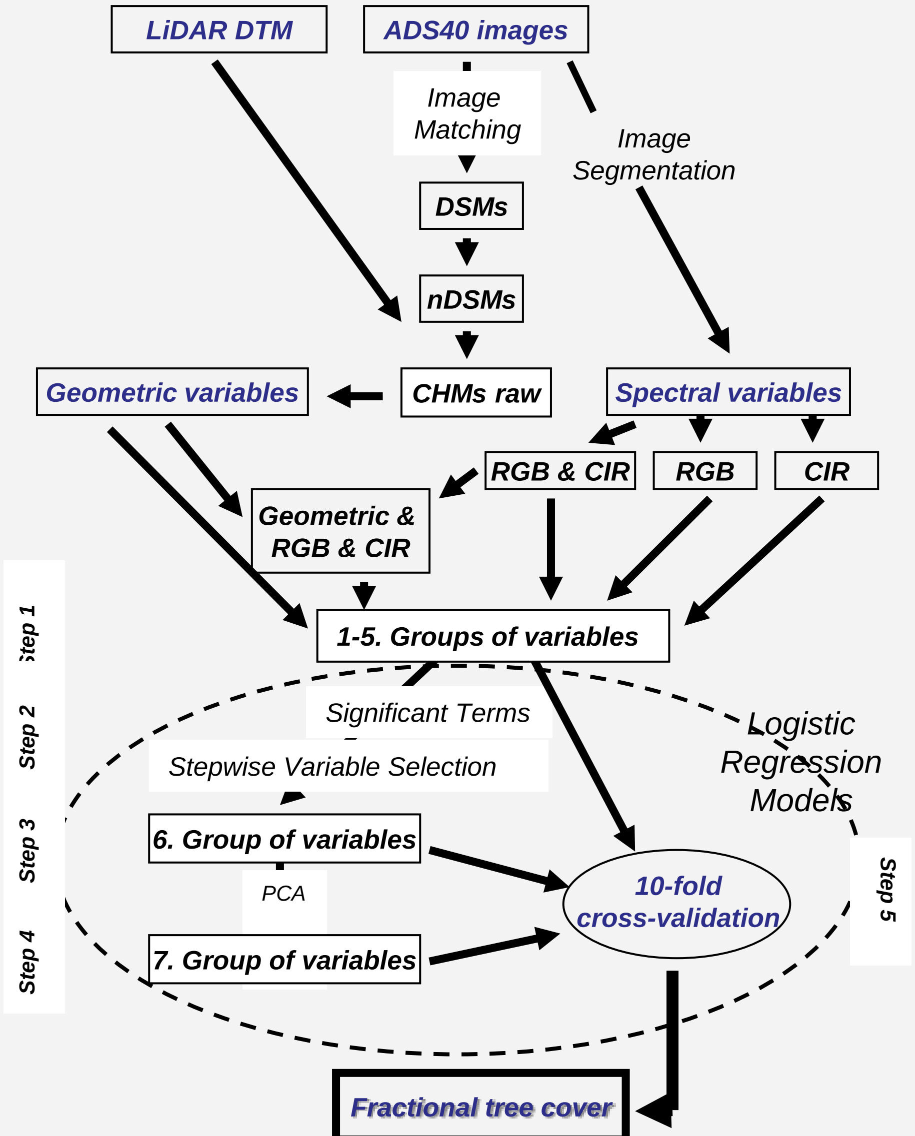
Tree area

Tree species

Problems / restrictions

Recommendations / outlook

Modelling Tree area

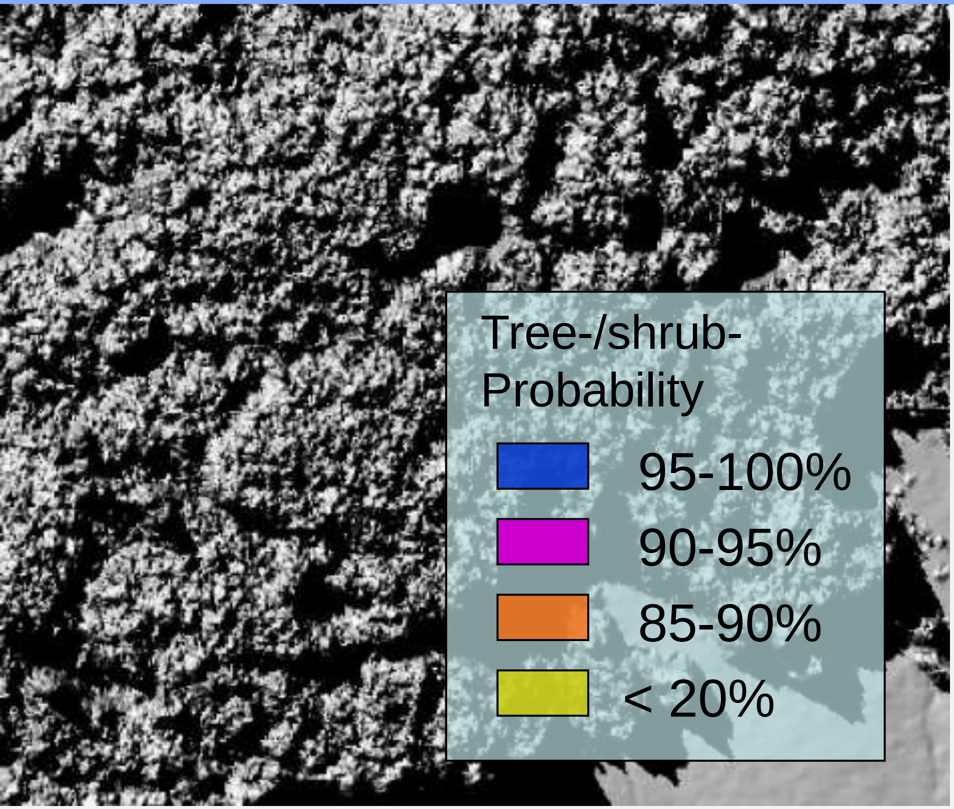


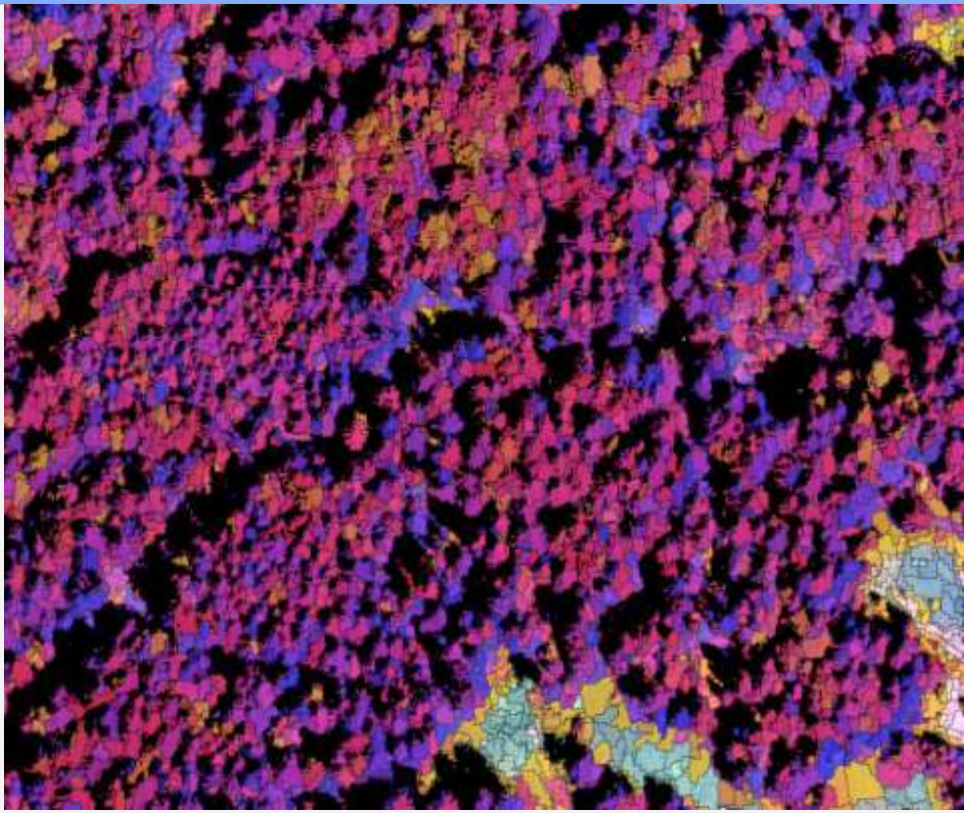
1) derivation of explanatory variables groups

2) step-wise variable selection

3) PCA of selected variables

Results: Tree area (fractional tree cover)





Fractional tree cover

- Logistic regression: pixel-wise prediction of tree probability
  ***CCR:* 0.99, *kappa:* 0.99 für P > 0.5)**

from: Waser *et al.* 2008. International Journal of Remote Sensing 29 (5): 1261 - 1276

from: Waser *et al.* 2008. Remote Sensing of Environment 112 (5): 1956 - 1968

Accuracy assessment: Tree area

- **Digitized tree / non-tree polygons (~ 600)**

Nr.	Variable groups	Strip 1		Strip 6	
		CCR	κ	*CCR*	κ
1	Geometric	**0.987**	**0.974**	0.916	0.832
2	RGB	0.864	0.742	0.815	0.723
3	CIR	0.791	0.561	0.774	0.532
4	RGB & CIR	0.844	0.687	0.880	0.759
5	Geometric & RGB & CIR	0.989	0.991	0.949	0.901
6	Variable selection	0.998	0.991	0.951	0.902
7	PCAs of variable selection	**0.999**	**0.998**	**0.962**	**0.924**

- **Photo-interpreted point raster (for selected areas)**

CCR: 0.98, κ: 0.91 für P > 0.5

Content

Background

Data sets

Methods

Tree area

Tree species

Problems / restrictions

Recommendations / outlook

Method: Classification procedure

- Multinomial logistic regression* in *R statistics*

=> more than two outcomes: 8 tree species

from: Waser et al. 2011. Remote Sensing of Environment 115: 76-85

- Processing steps:

=> separately for each of the data sets (8 orthoimage strips)

1) derivation of explanatory variables (~ 30):

geometric & spectral signatures from ADS40 imagery

2) step-wise variable selection (*AIC, both directions)*

3) significant variables grouped *(P < 0.05)*

4) 10-fold cross-validation suggests other variables

*Hosmer & Lemeshow 2000. *Applied logistic regression, 2nd ed., New York: Wiley, 373 p.*

Accuracy assessment I: 10-fold cross-validation

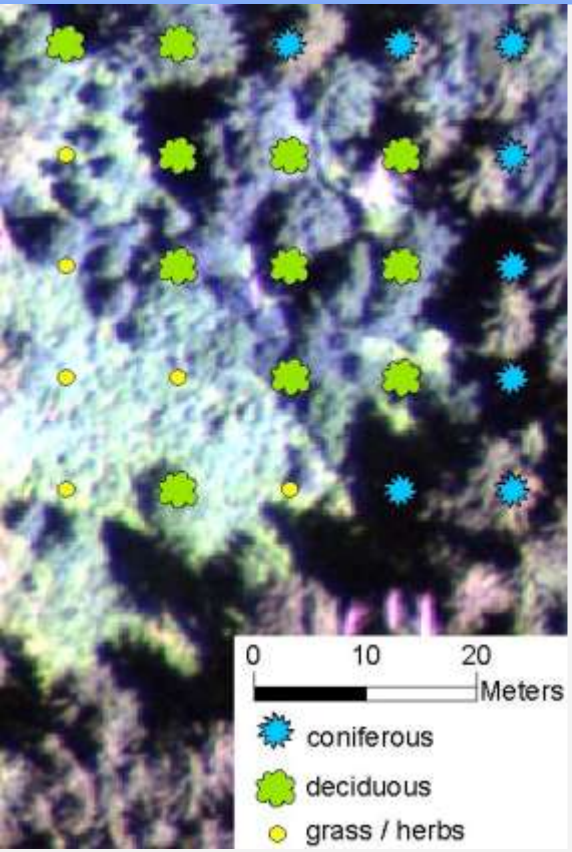
- Probability for tree species per square (5 x 5 m)

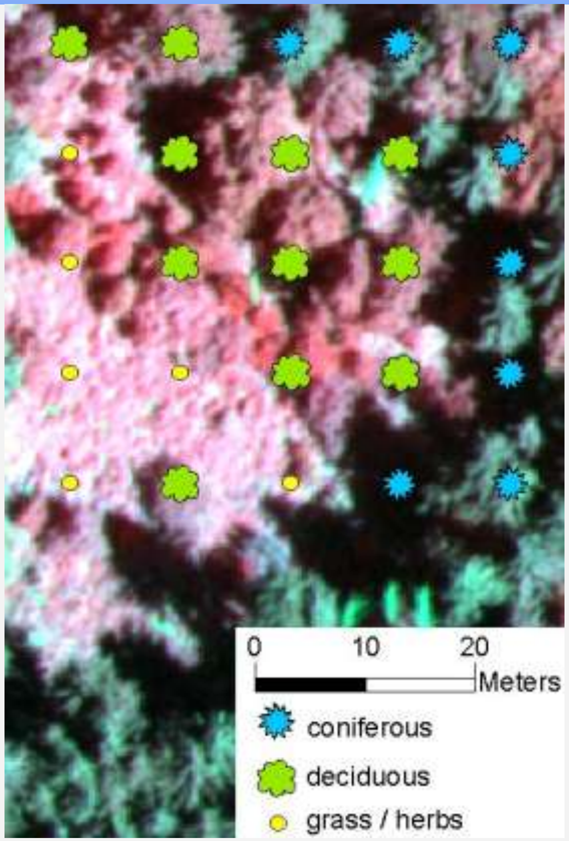
- Preliminary results: Species classification based on 5 models (~ 650 km^2; 5 image strips)

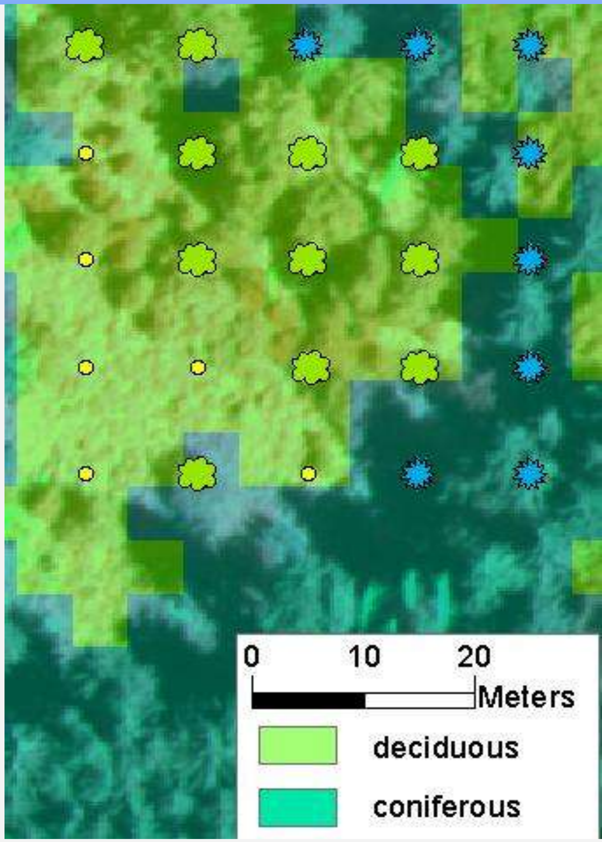
CCR	*White fir*	*Norway spruce*	*Scots pine*	*Larch*	*Ash*	*Beech*	*Maple*	κ
Strip 1+2 **Aug. 2008**	0.81	**0.92**	0.79	**0.55**	**0.86**	0.82	0.62	***0.72***
Strip 3 **May 2008**	0.65	**0.83**	0.59	**--**	**0.22**	**--**	**--**	***0.47***
Strip 4+5 **Aug. 2008**	0.82	**0.90**	0.72	**0.48**	**0.78**	0.76	**0.38**	***0.68***

from: Waser et al. 2011. Remote Sensing of Environment 115: 76-85.

Accuracy assessment II: photo-interpreted NFI-points







Classified deciduous / coniferous trees verified with 1800 NFI photo-points: **93% overall accuracy**

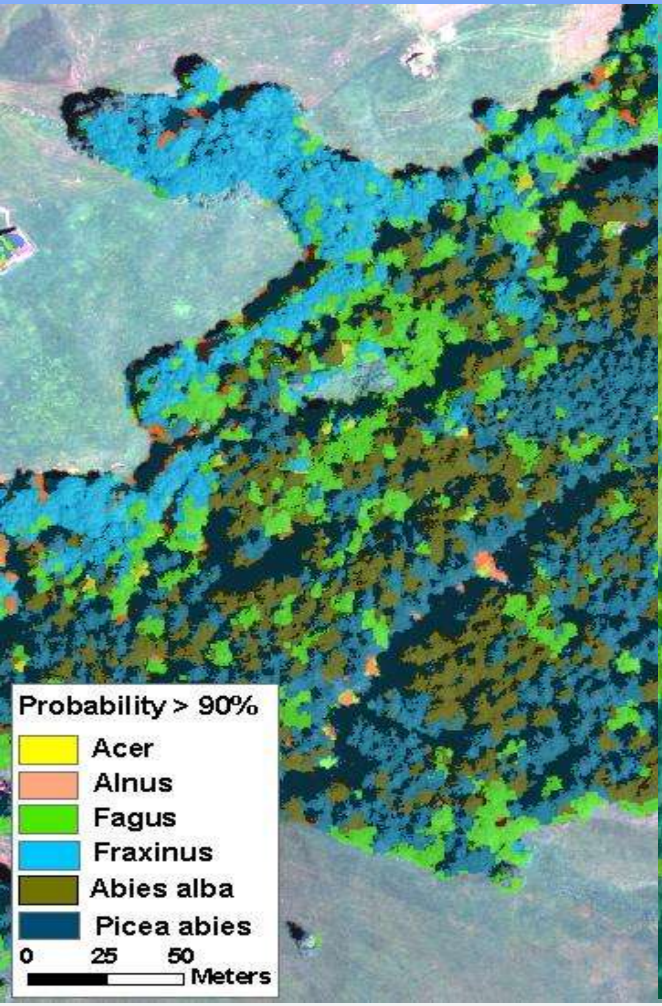
Comparison with other airborne sensors

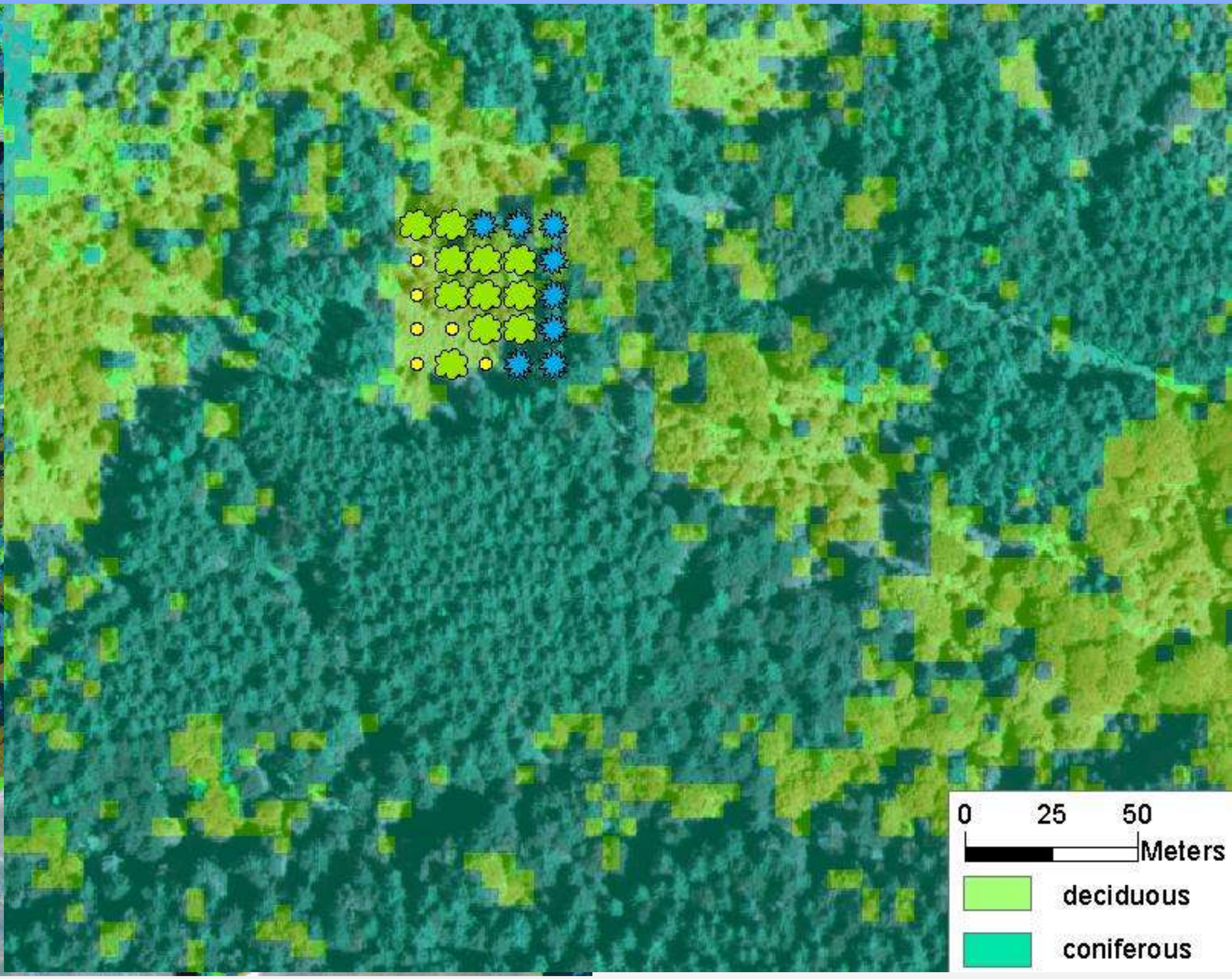
- Study area from DGPF – project 2009 @ Vaihingen, Germany
- 8 different tree species, 10-fold cross-validated

	DMC	ADS40	Jas150	Ultracam
CCR	**0.88**	0.85	0.80	0.74
Kappa	**0.86**	0.83	0.76	0.68
user	0.94	0.83	0.81	0.63
producer	0.72	0.81	0.74	0.55

from: Waser et al. 2010. PFG 10 (2): 132- 141.

Results: Species / composition maps





=> Basis for timber volume, biomass estimations

Content

Background

Data sets

Methods

Tree area

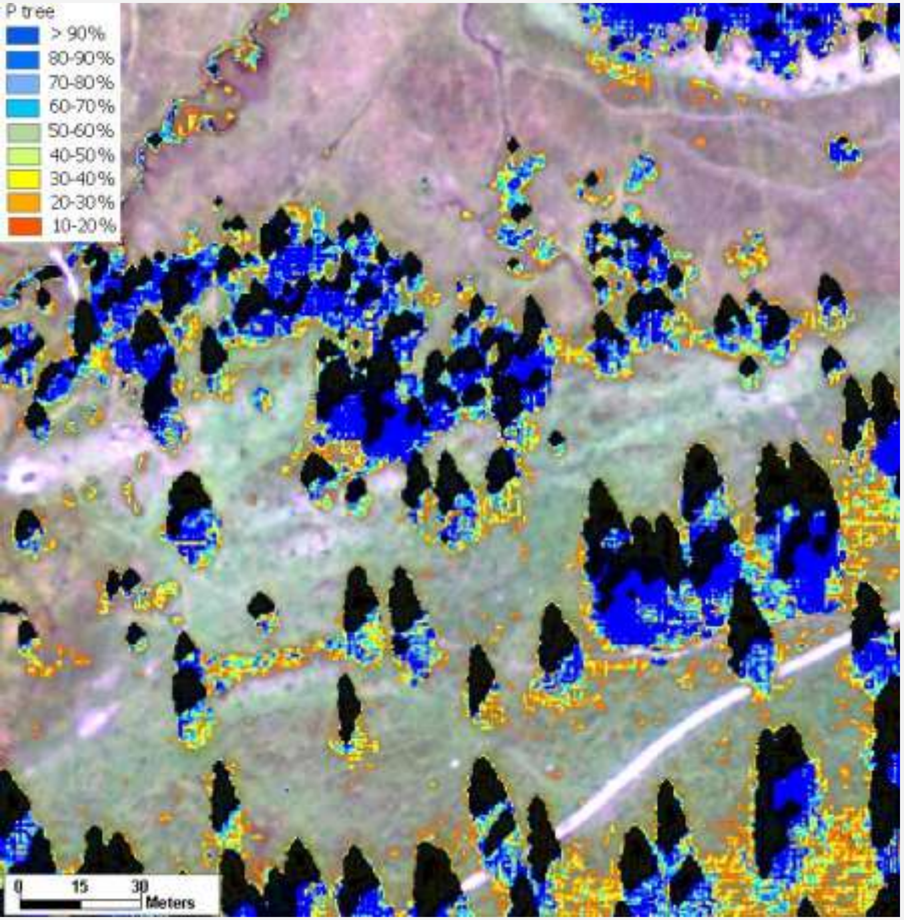
Tree species

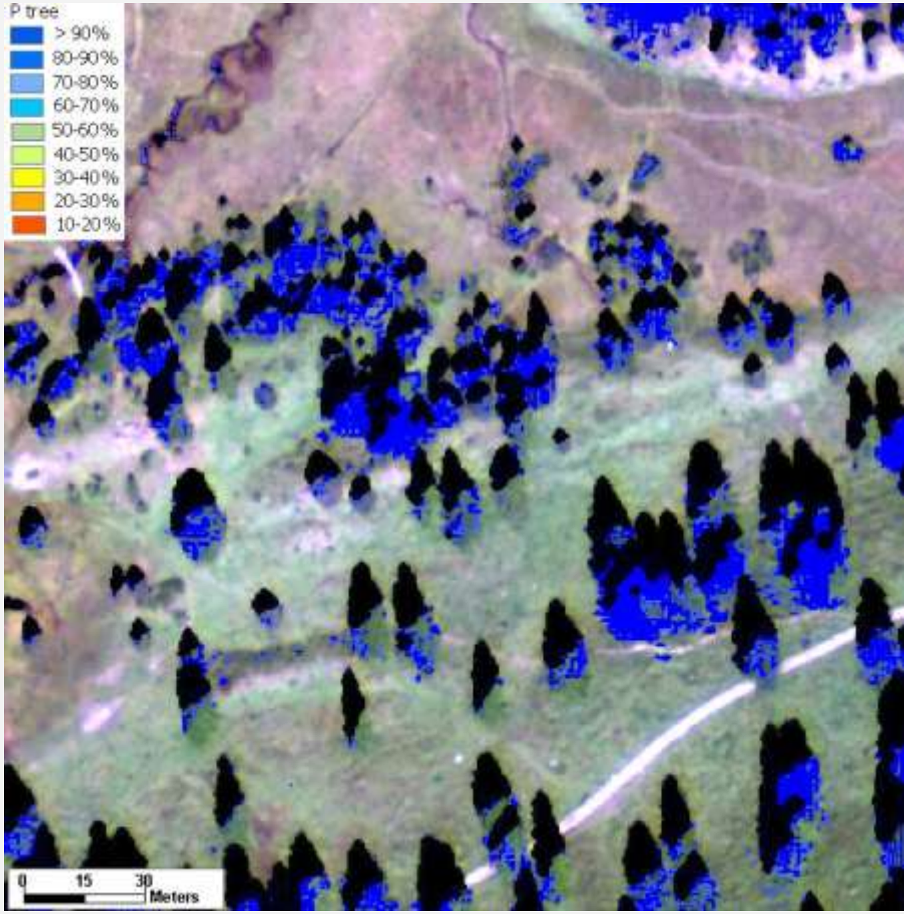
Problems / restrictions

Recommendations / outlook

Problems tree area: Tree probability threshold

- Under- /overestimation versus noise / artefacts



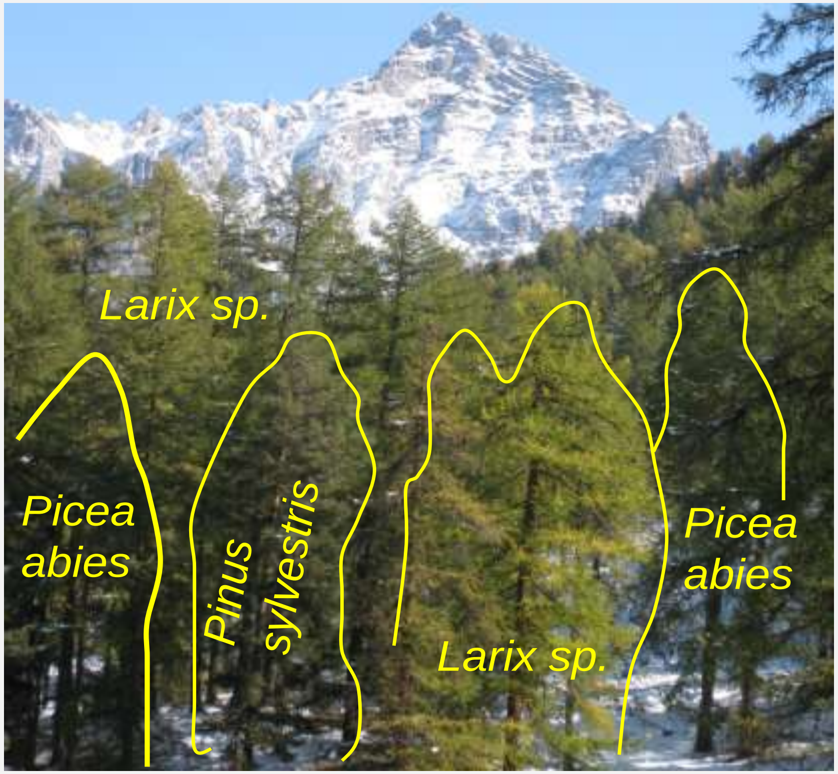


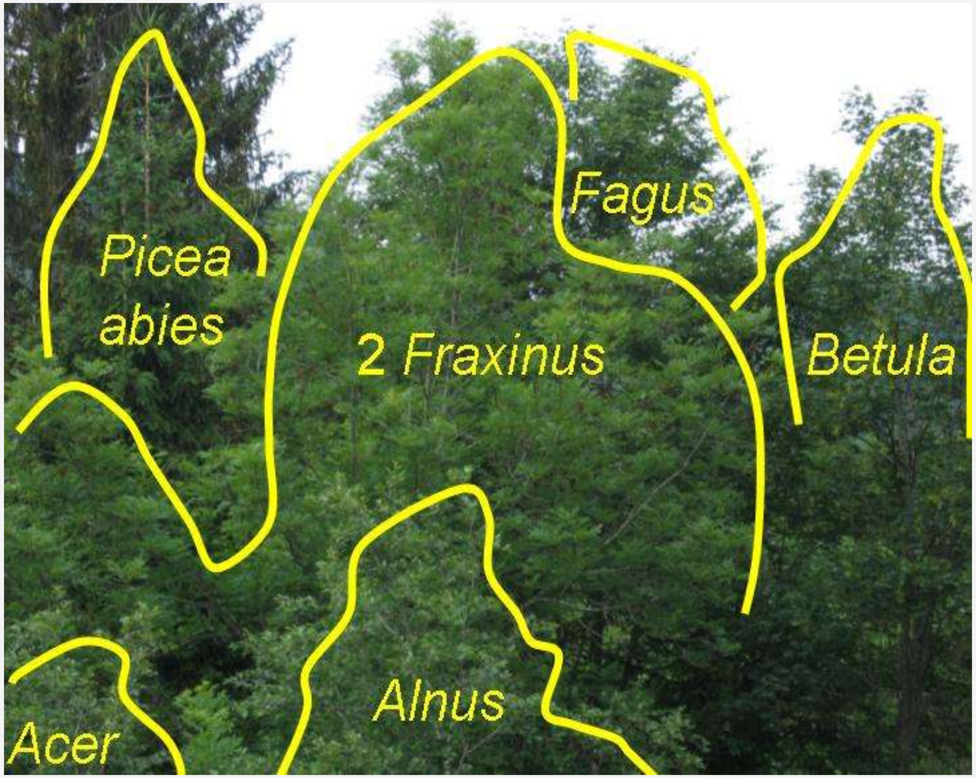
Fractional tree cover with P tree > 0.2 P tree > 0.8

Problems (I) tree species: Sample size, dominance

- Low accuracies for non-dominant tree species:

  => possible reasons: few samples, small crowns, vitality, shadows



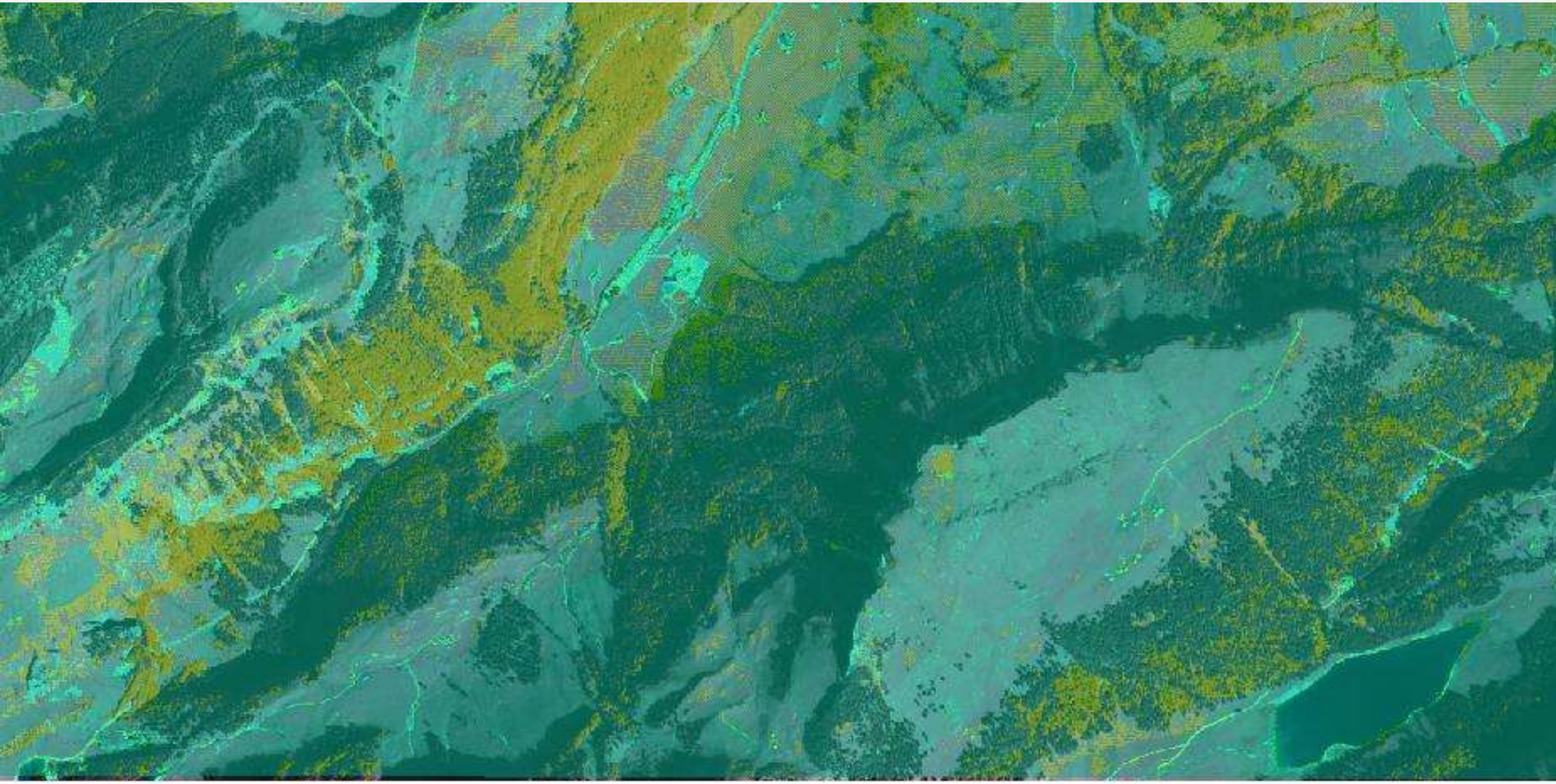


Problems (II) tree species: : Flight date, phenology

- Different date of image acquisition => not always ideal season

Problems (III) tree species: Topography, shadows

- Classification affected by topography (=> phenology), shadows etc.



Content

Background

Data sets

Methods

Tree area

Tree species

Problems / restrictions

Recommendations / outlook

Summary & outlook

- Tree area

  - High accuracy
  - Semi-automatically for large areas
  - Depending on quality of digital surface model

- Tree species

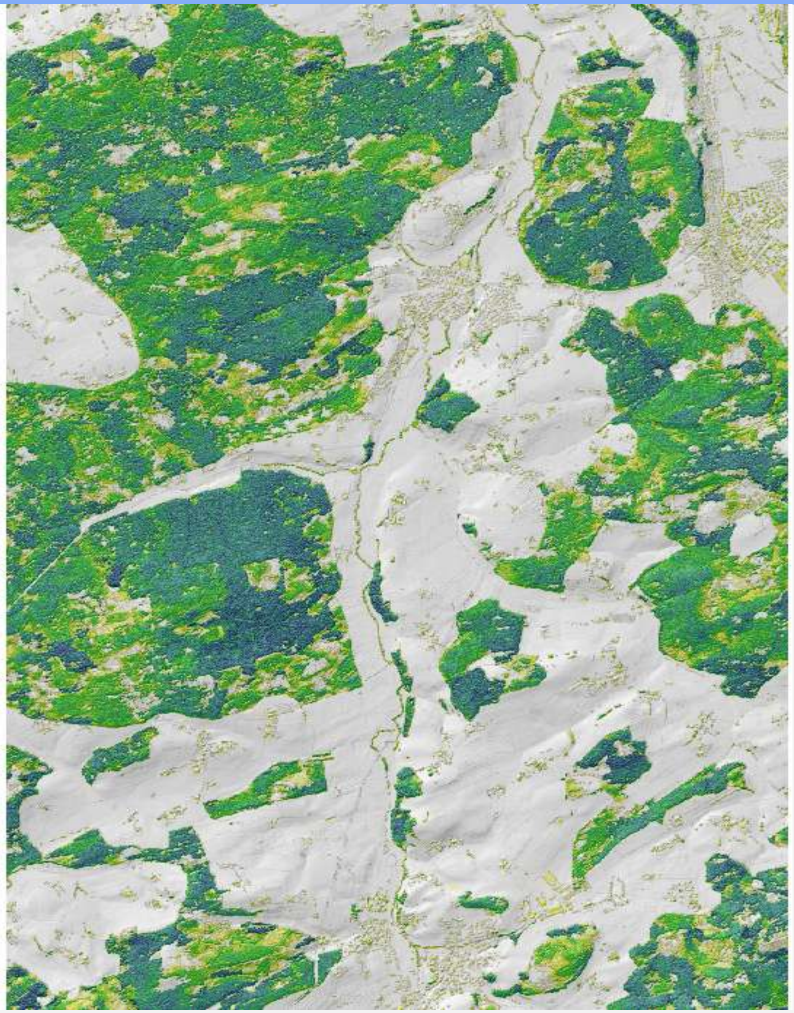
  - Focus on main tree species (high accuracy)
  - Semi-automatic approach, relatively few training data needed
  - Depending on quality of ADS40 images and less of DSMs
  - ADS40/80 data: reliable, continuity guaranteed

Summary & outlook

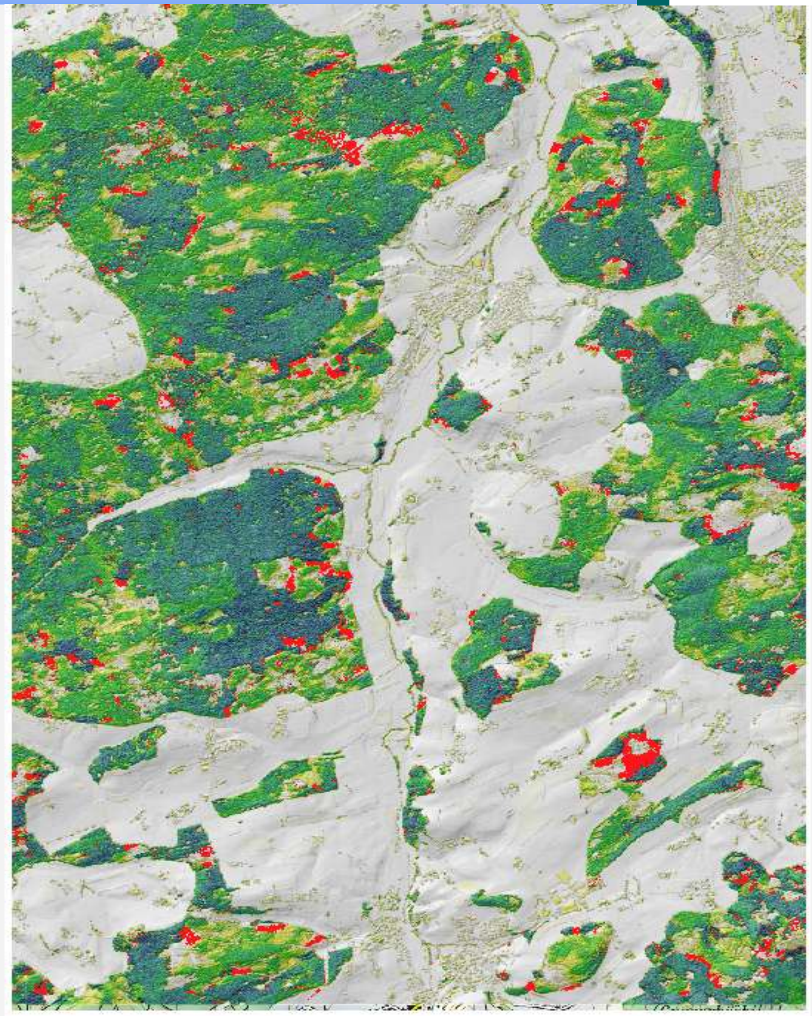
Outlook:

- Radiometric corrections (ATCOR 4 end of 2011)
- Application for entire area of Switzerland (42'000 km^2)
- Implementation of NFI field data
- High temporal availability (nation-wide every 3 years
- Swiss NFI applications (www.lfi.ch)

Application 1: Changes of stocked areas



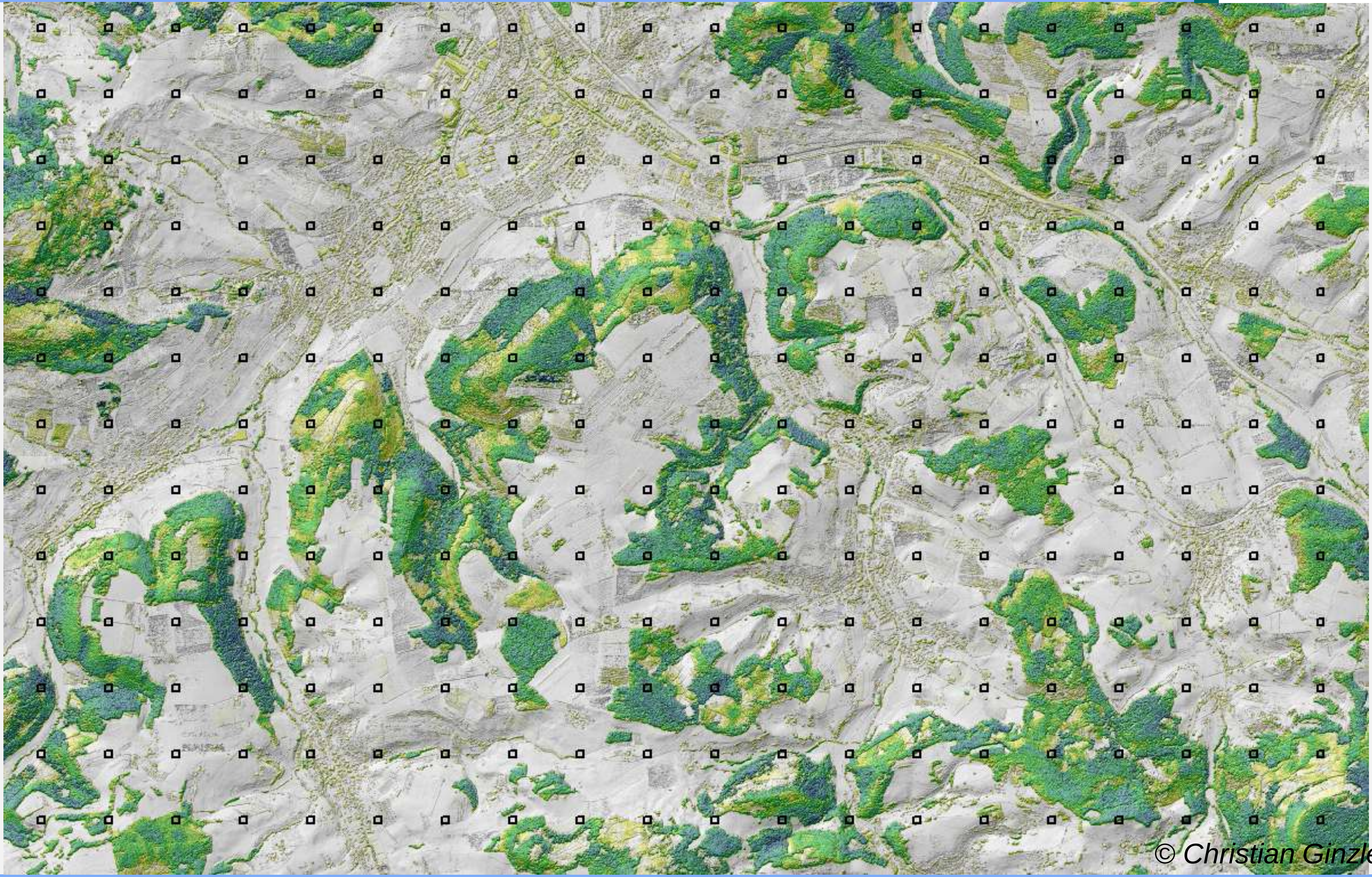
17.07.2006



06.08.2009

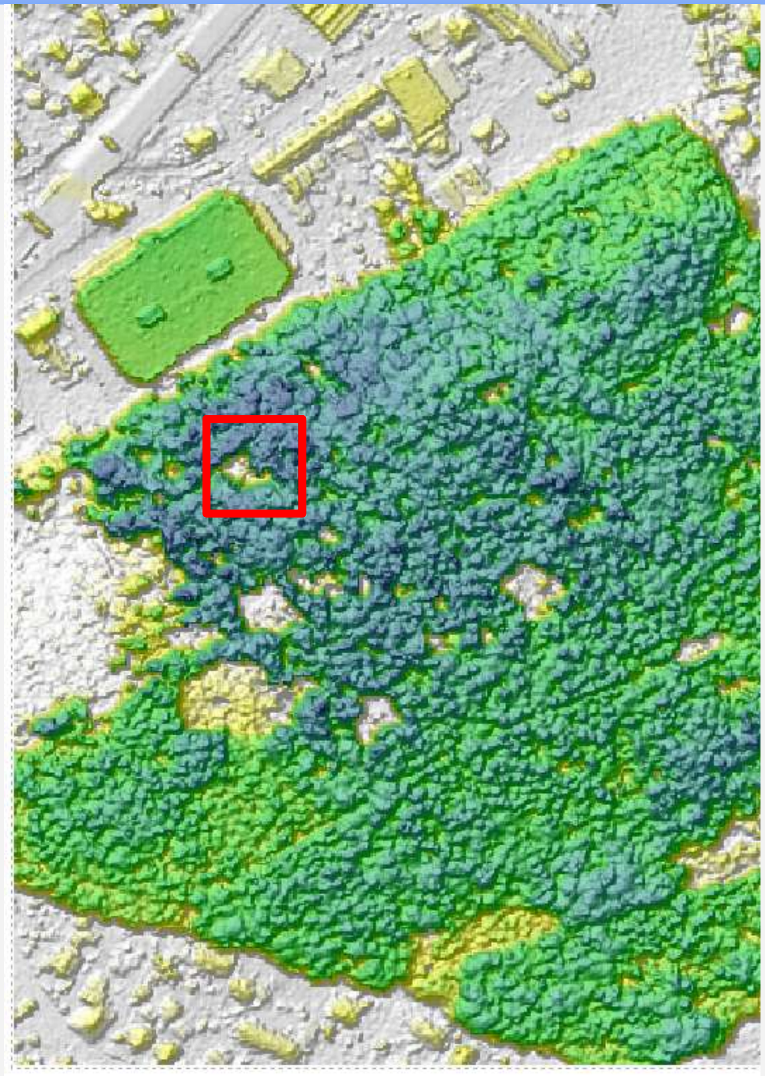
Application 2: NFI small area estimation

Landesforstinventar
Inventaire forestier national
Inventario forestale nazionale
Inventari forestal naziunal
National forest inventory

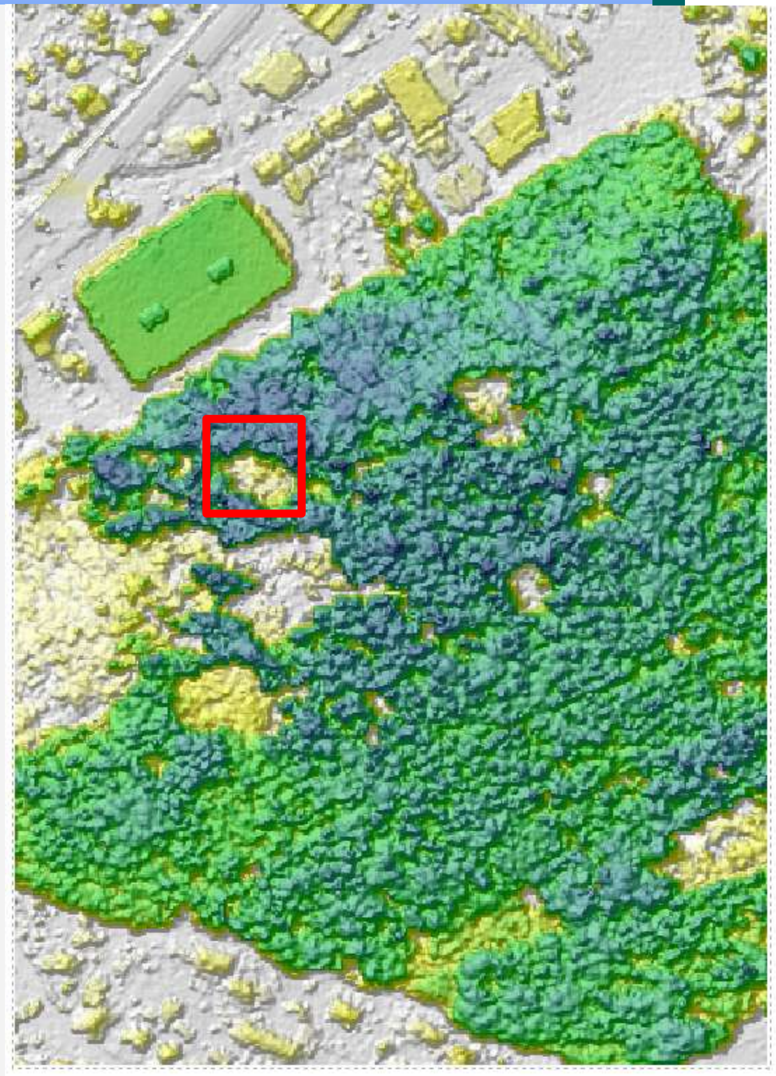


© Christian Ginzler

Application 3: NFI updating of sample plots



17.07.2006



06.08.2009

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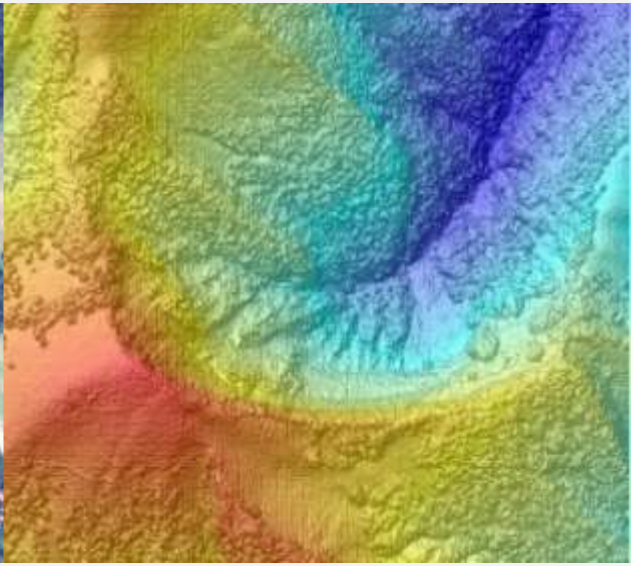
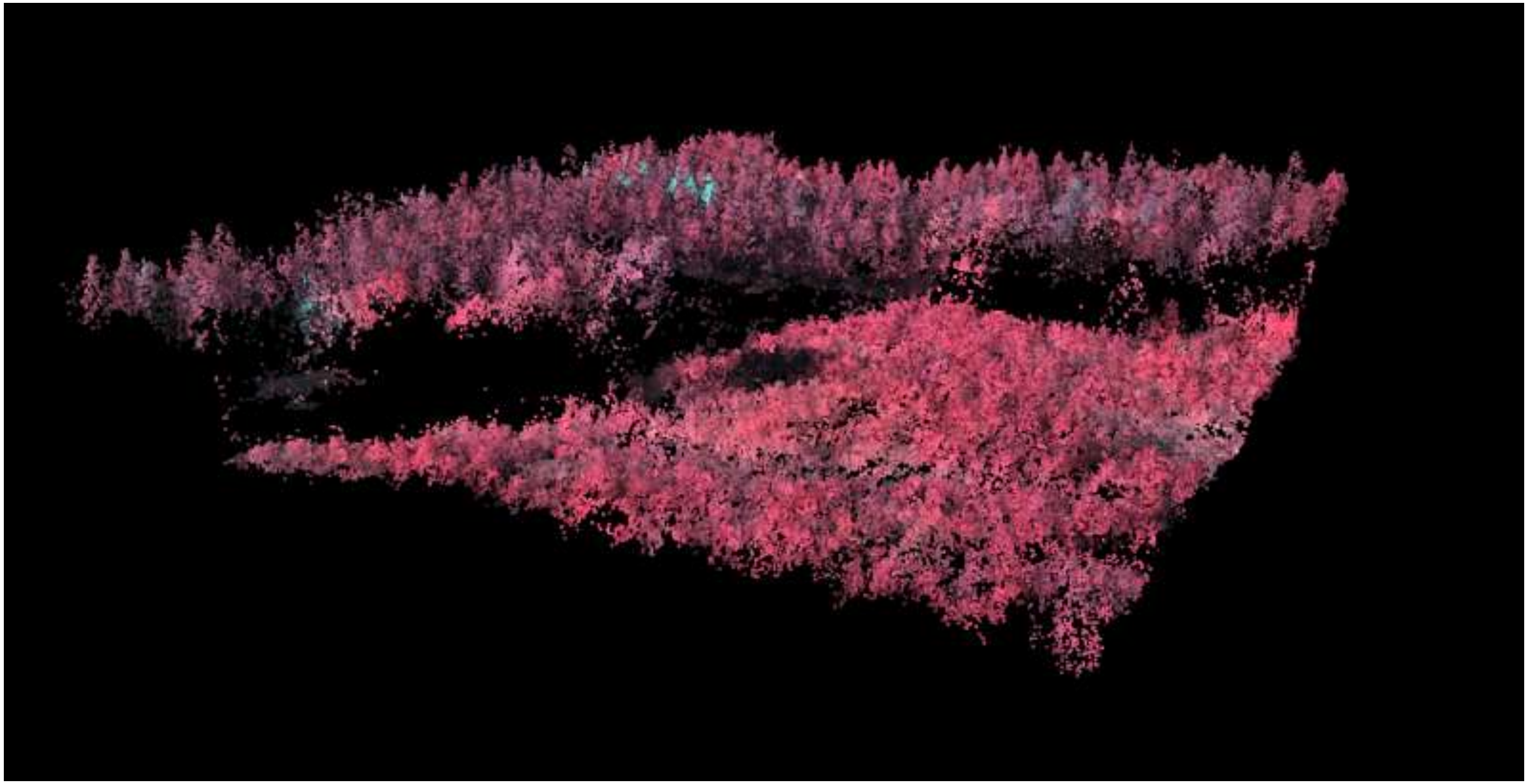
Semi-automatic extraction of forest area, type and composition from ADS40/80 images and derived CHMs for the Swiss NFI



Lars T. Waser

Swiss Federal Research Institute (WSL) waser@wsl.ch
Swiss National Forest Inventory (LFI) www.lfi.ch www.wsl.ch

Estimation of forest variables using 3D data from aerial imagery



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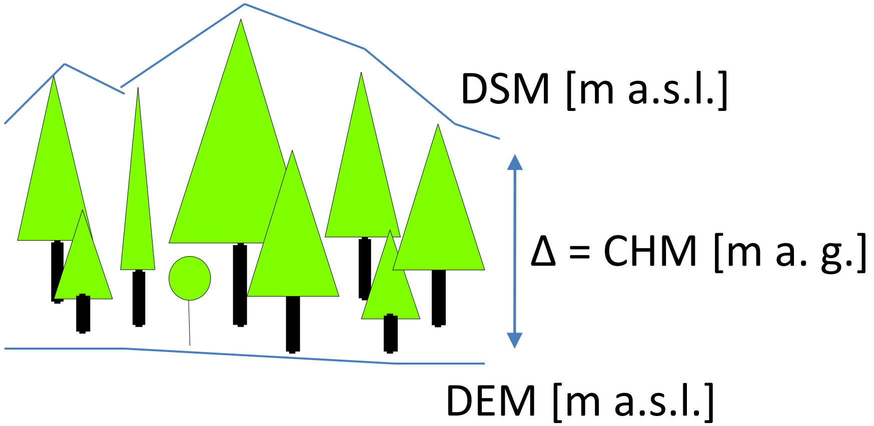
Content

- Background
- Two studies:
  - High resulution canopy height model from SAAB dynamics
  - 3D-data from Lantäteriet's aerial imagery.
- Observations

Background

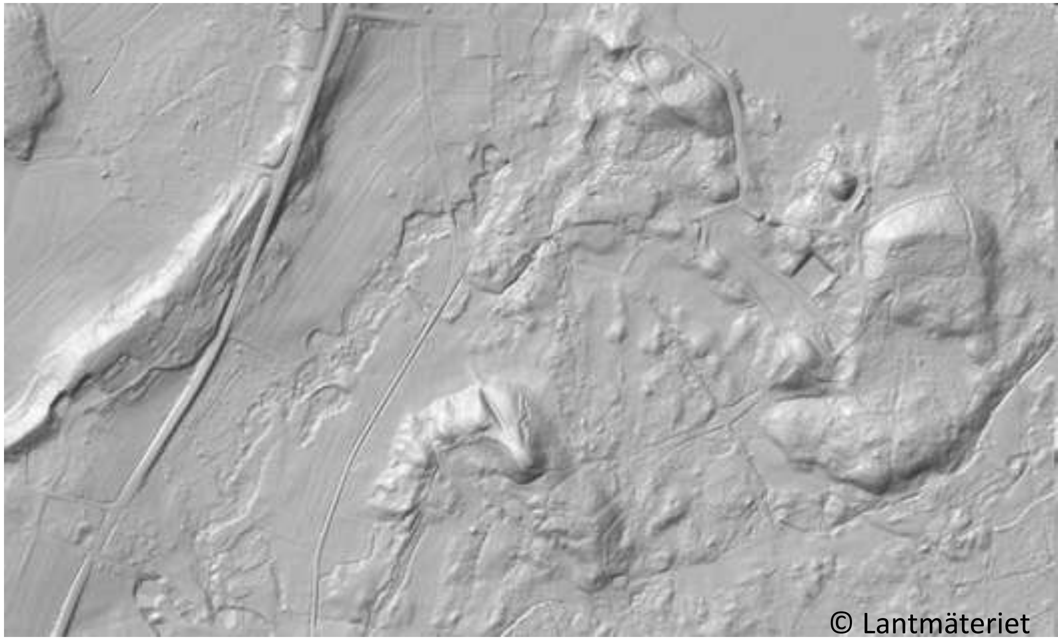
- New, accurate national DEM is produced for Sweden.
- Possibly enables usage of DSM data to map vegetation height above ground.
- Cost-efficient way to improve spectral-based mapping with new information.

Digital height models



New national DEM of Sweden

- Produced by Swedish National Land Survey 2009-2013
- Using ALS, 1-2 p/m^2
- 2,5 m raster grid
- RMS < 0.5 m
- Approx. 20 M Euro production costs



Forest Data Capture Using Optical 3D Surface Models from C3 Technologies System

Wallerman J., Bohlin J., Fransson J.E.S and Lundberg K.

ASPRS/MAPPS 2009 Specialty Conference, DIGITAL MAPPING - From Elevation to Information, San Antonio, Texas, USA, 16-19 November, 2009.

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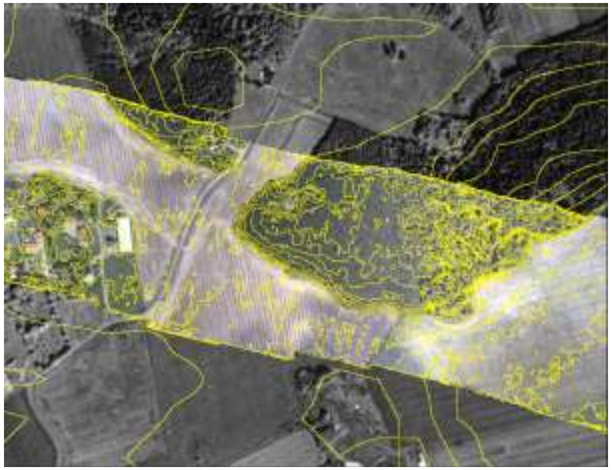
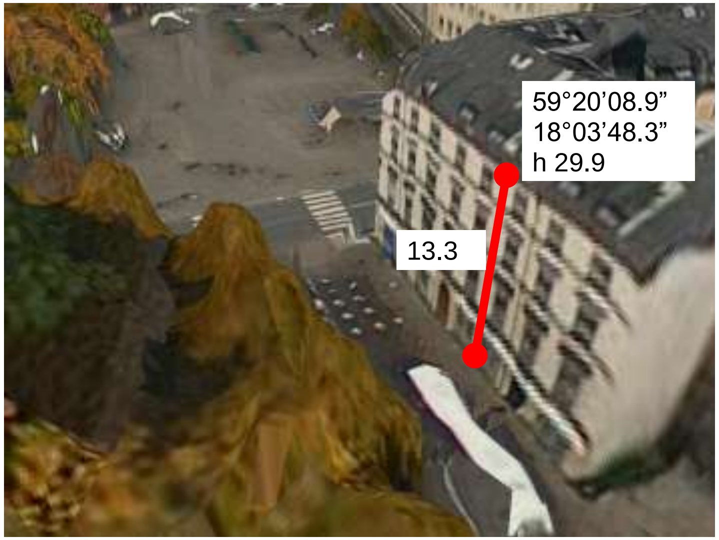
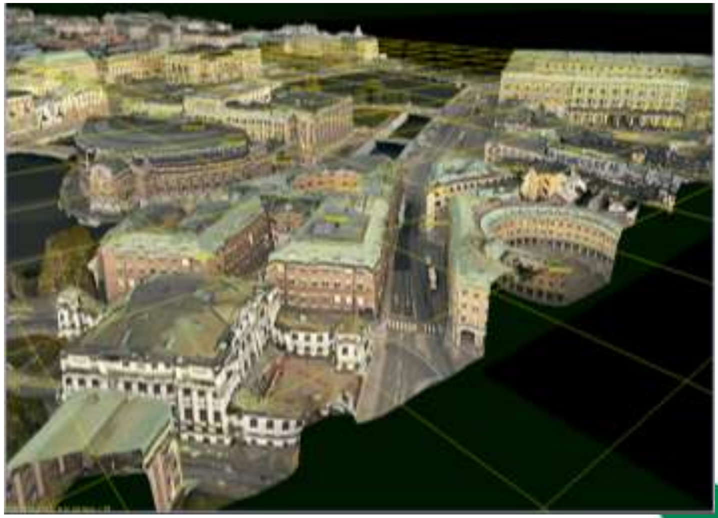
Output from Rapid 3D Mapping™







SAAB

C3 TECHNOLOGIES

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Dept. of Forest Resource Management
SLU

Aim

- Pilot study assessment of the potential for forest mapping using RM DSM data, using:

- Single tree detection,
- Model height, diameter and volume of single trees using RM data,
- Evaluate mapping (prediction) performance, in terms of RMSE

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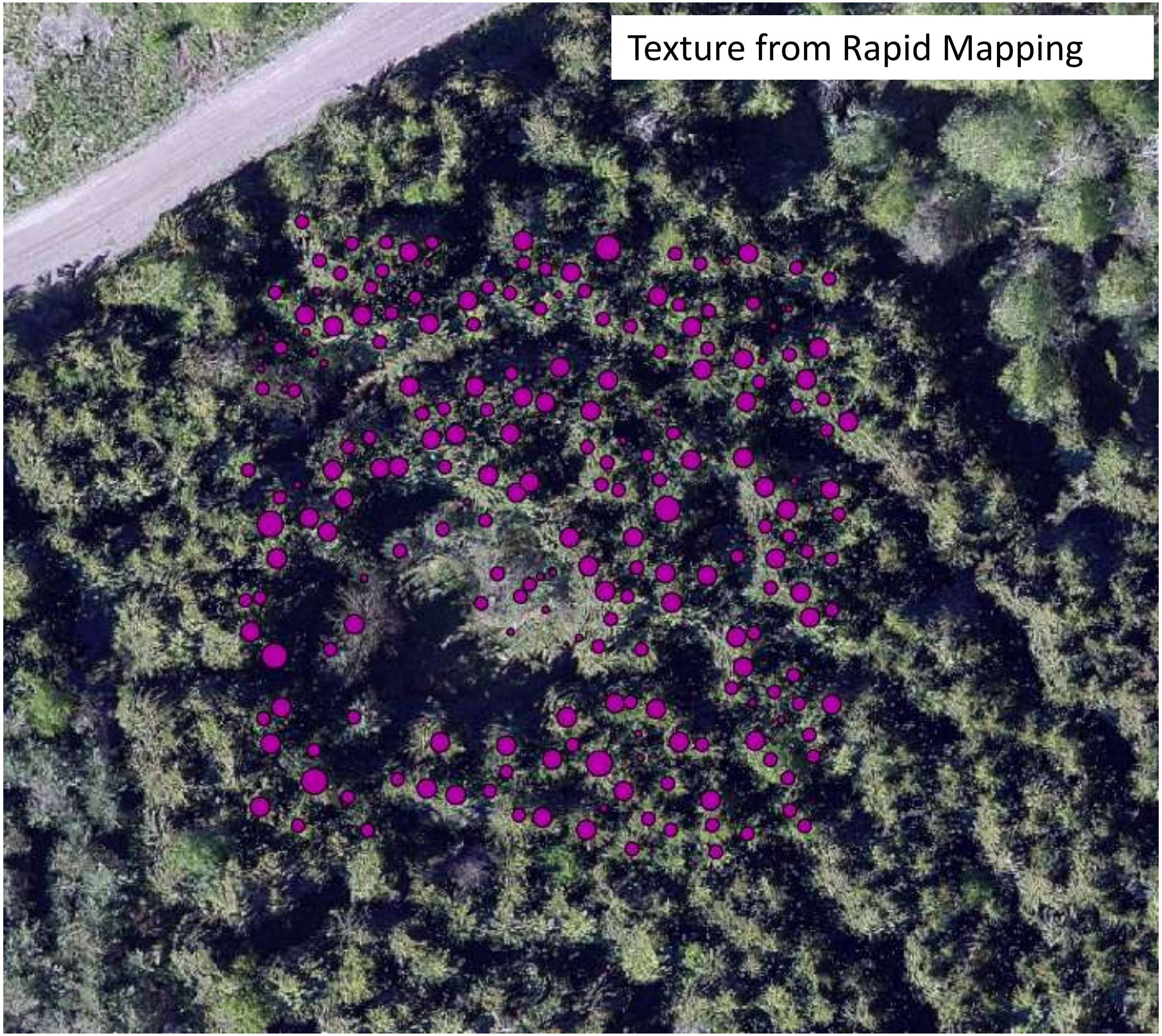
Analysis

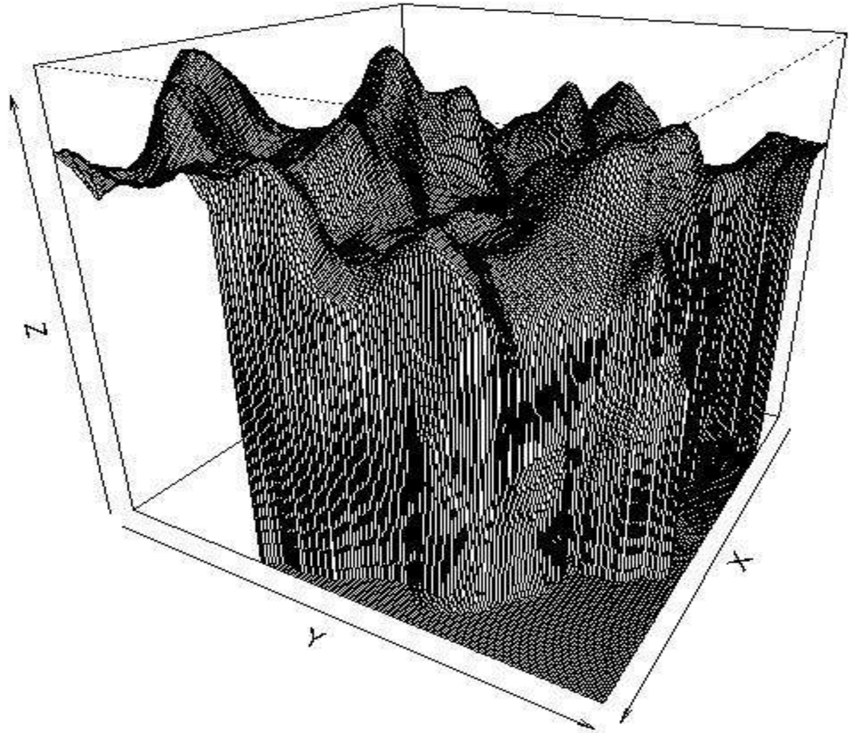
1. Individual tree detection
2. Segmentation of the DSM,
3. Relating each field measured tree to a corresponding segment,
4. Modeling tree height, stem diameter, and stem volume from field measurements and DSM data,
5. Evaluation of tree parameter estimation accuracy
   1. Prediction accuracy of single trees (cross-validation)
   2. Prediction accuracy of area averages (plot averages)



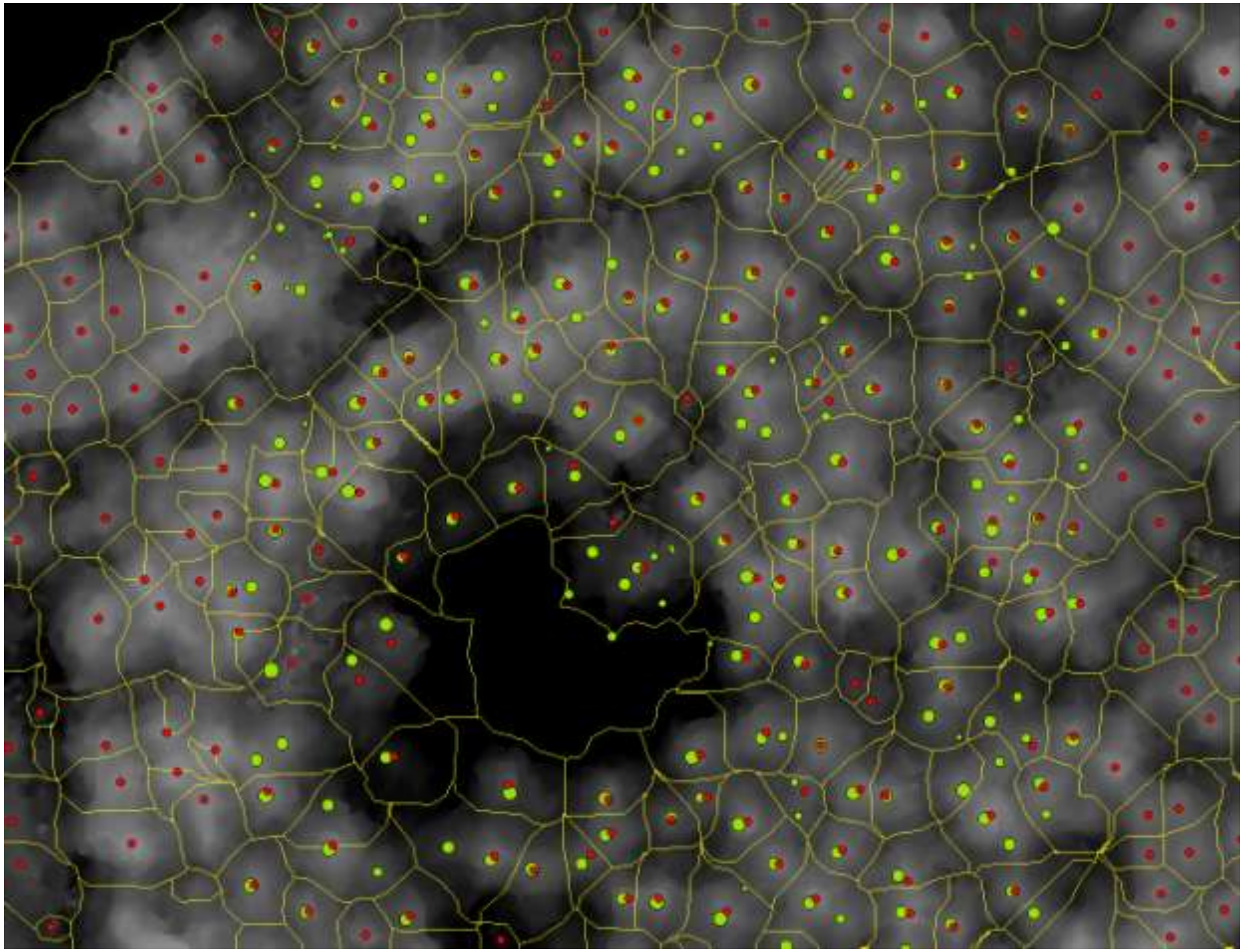
MSS Kvarn
Plot 2

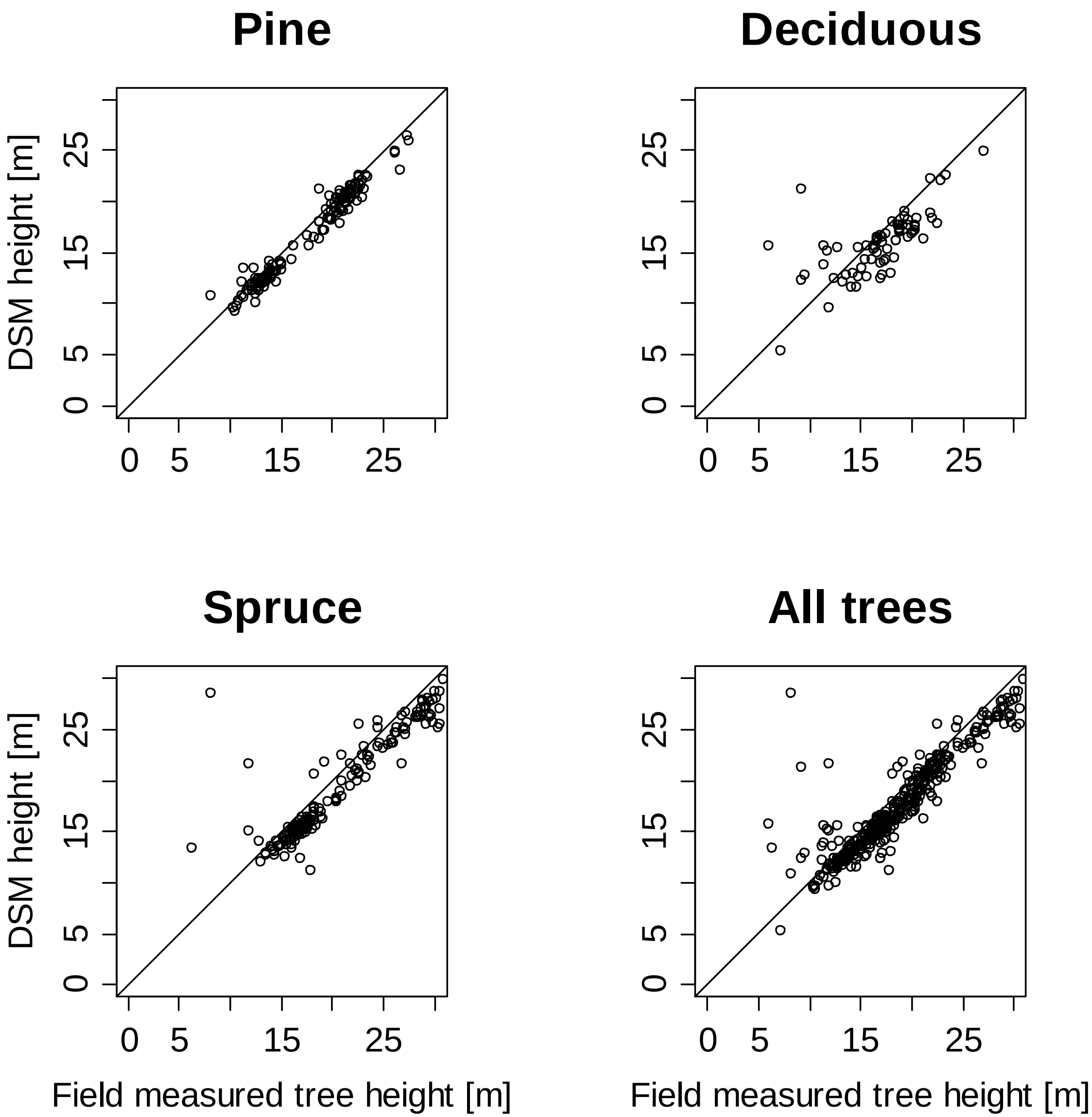
High accuracy positions of trees. (cm)

Rapid Mapping (C3)



Individual tree detection





ASPRS/MAPPS 2009 Specialty Conference, DIGITAL MAPPING - From Elevation to Information, San Antonio, Texas, USA, 16-19 November, 2009.

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Plot level

Plot	Portion detected trees	Detected stem volume
1	60%	85%
2	68%	82%
3	65%	84%
4	62%	67%
5	65%	74%
Totalt:	64%	79%

Results

Plot	Basal area weighted mean tree height [m]	Basal area weighted mean stem diameter [cm]	Mean stem volume/ha [m^3/ha]
1	-2.1	-6.6	95
2	0.1	0.30	-18
3	-0.47	-2.3	12
4	0.37	-1.5	-20
5	0.45	-0.6	-44
RMSE	0.96 (4.7%)	3.2 (11%)	48 (18%)

ESTIMATING FOREST STAND VARIABLES USING 3D DATA FROM THE Z/I DMC SYSTEM

Jonas Bohlin, Jörgen Wallerman, Johan E.S. Fransson,

Swedish University of Agricultural Sciences,
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Jonas.Bohlin@srh.slu.se

Goals

Target: Estimating forest stand variables for forest management planning, using high resolution optical 3D data.

Study goal:

- Evaluate mapping performance by canopy height data acquired Z/I DMC and airborne laser scanner DEM.
- Assess standwise prediction accuracy (tree height, basal area, and stem volume).

Sensor for 3D-data
Z/I DMC

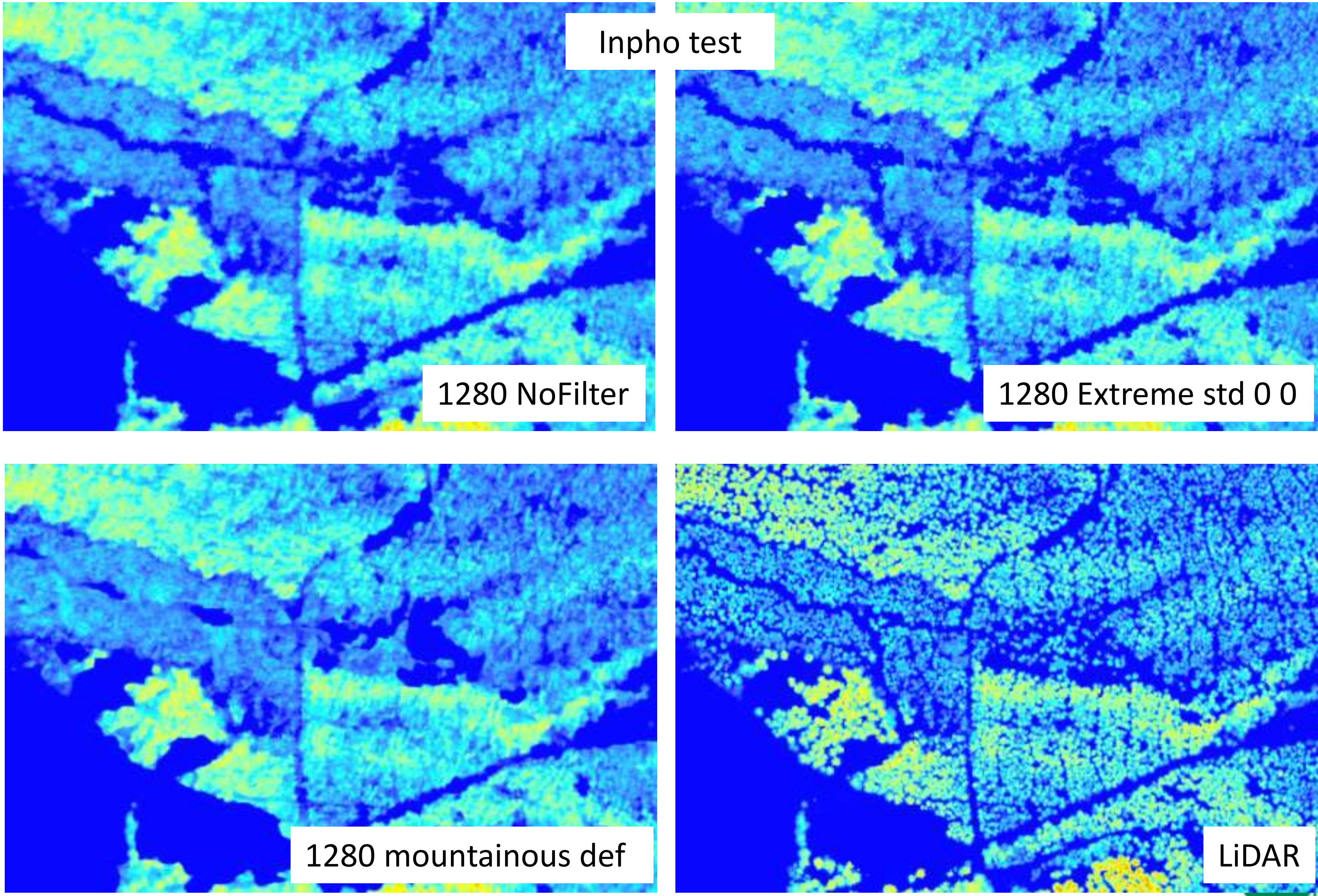
- Zeiss/intergraph Digital Mapping Camera.
- Airborne.
- Multispectral and panchromatic sensors.
- Operated by Swedish Land Survey for standard photography – 4800 m flight altitude, 60/30% stereo overlap.
- DSM available using automatic matching of stereo imagery, such as MatchT (Inpho).

Remningstorp study area

- 1600 ha of boreal forest in southern Sweden (58° N).
- Consisting of mainly Norwegian spruce, Scotts pine and Birch.
- Field data: 344 circular plots (10 m radius), georeferenced by DGPS.
- 23 forest stands. Stand delineation made in aerial stereo images.

Data

- Digital Elevation Model from the Topeye ALS
- 3D data from Z/I DMC
  - 4800m 60/30 0,5m standard altitude and stereo overlap.
  - 4800m 80/30 0,5m standard altitude but denser stereo overlap along track.
  - 1200m 80/60 0,2m special photo mission.



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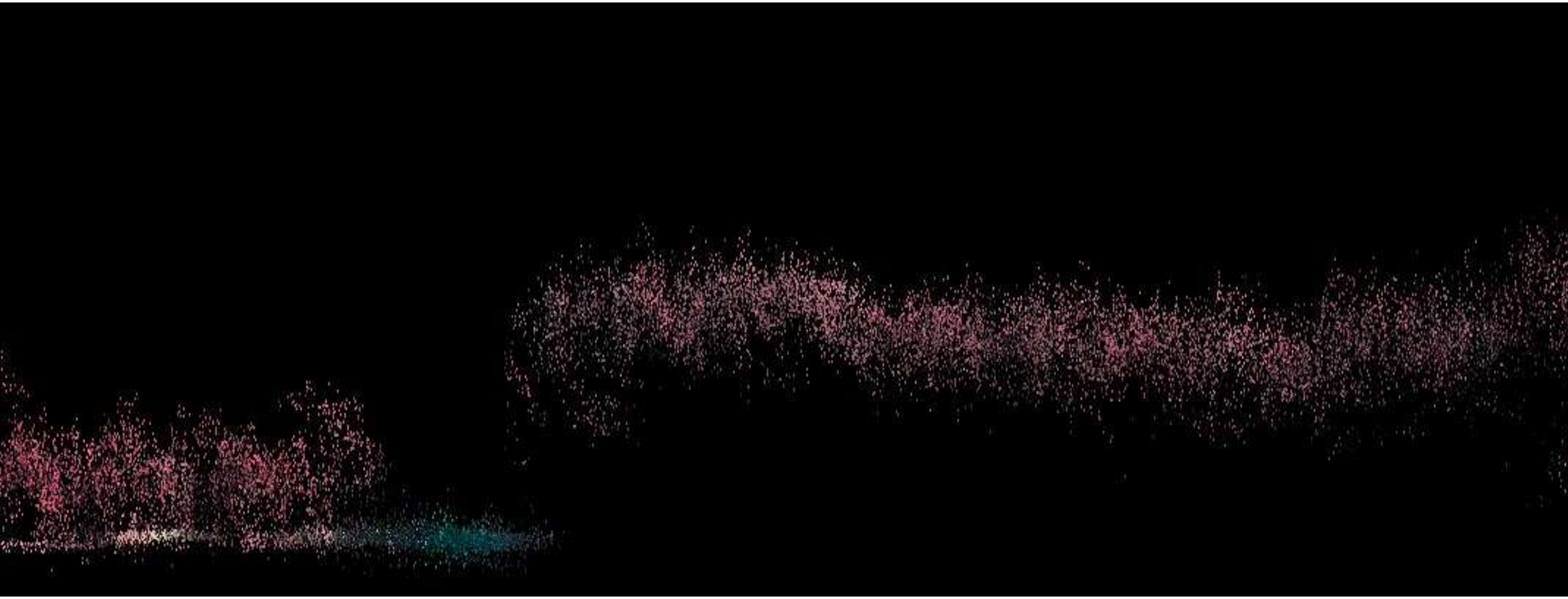
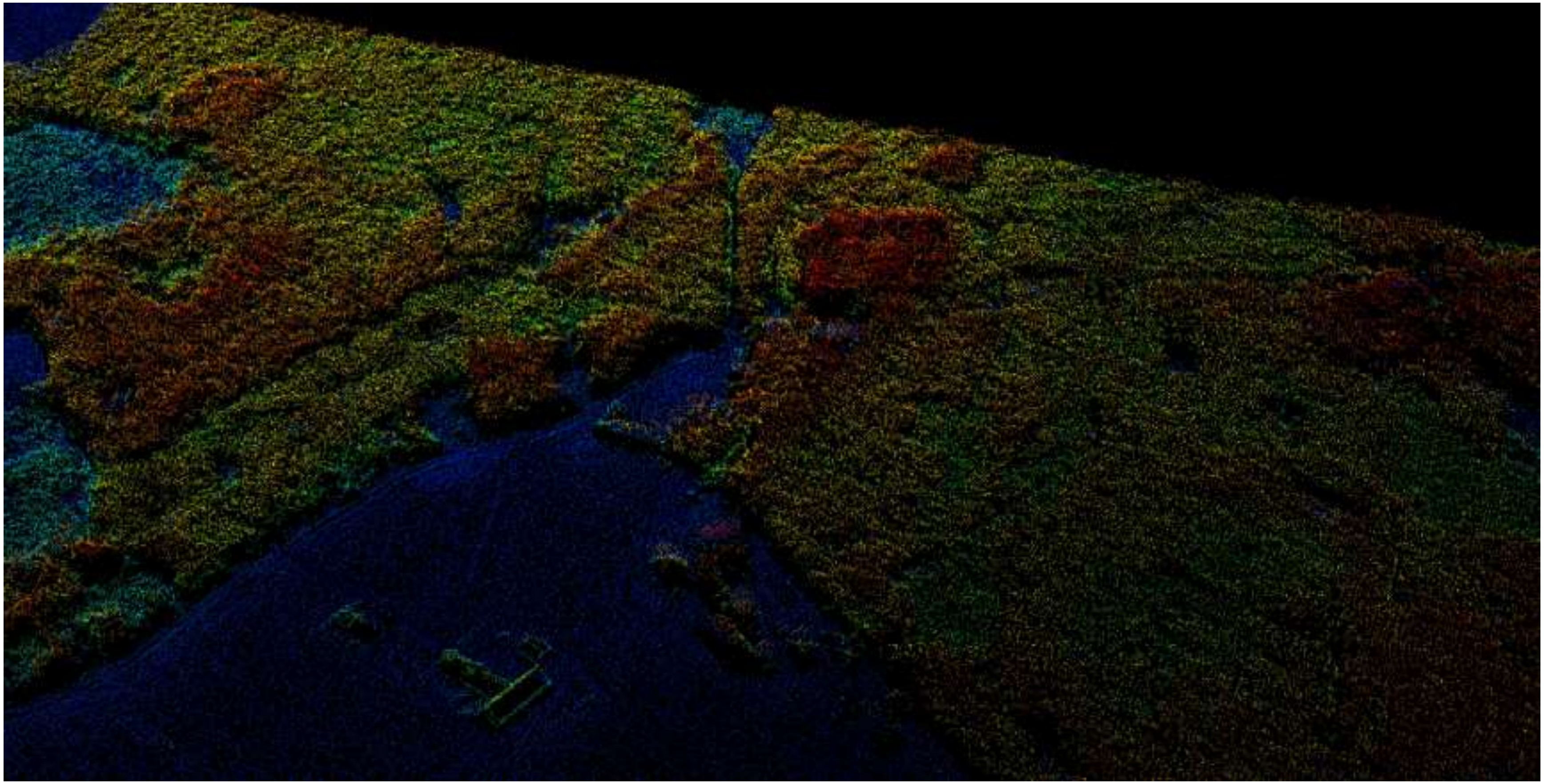
Photogrametric point cloud (PPC)



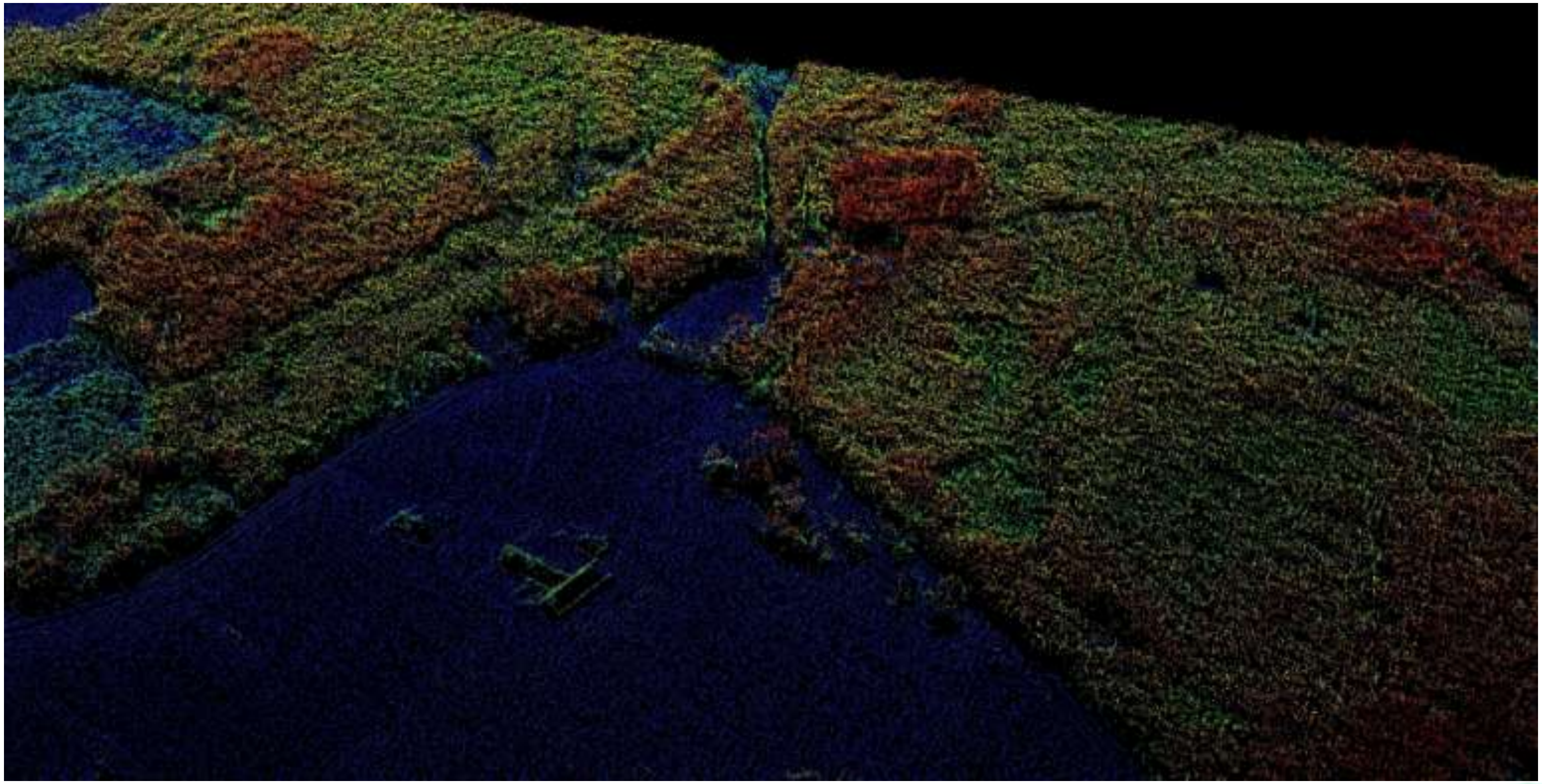
Area method

- Subtract groundelevation from point cloud (nPPC)
- Aggregte point cloud to plot level, 18 m raster
  - Create metrics Maximum (p100), vegetation index, variance, texture metrics…..
- Link metrics to field plots
- Create regression models
- Predict forest variables; volume, basal area, height
- Test model at stand level

4800m 60/30 0,26 p/m^2



4800m 80/30 0,40 p/m^2



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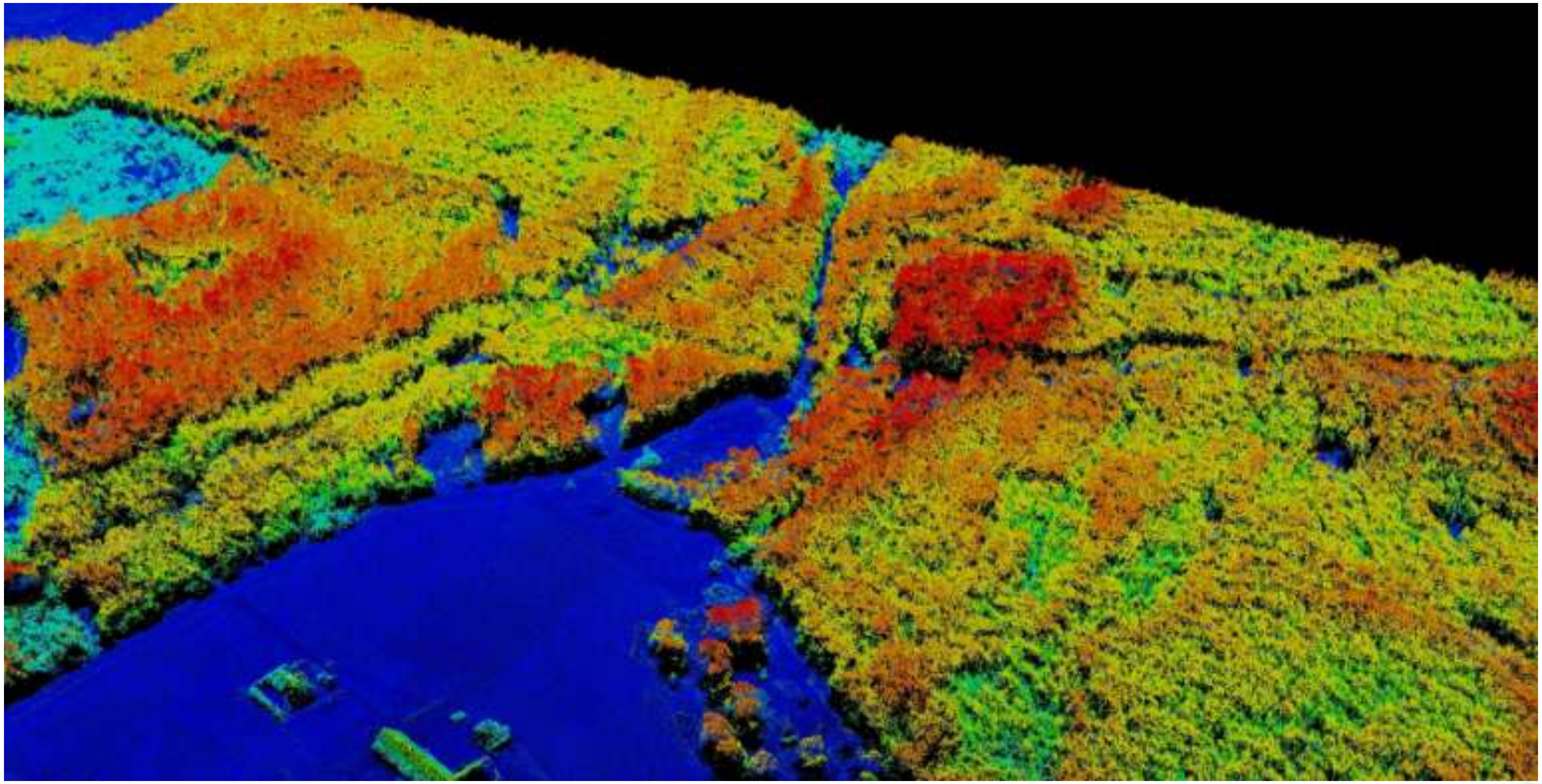
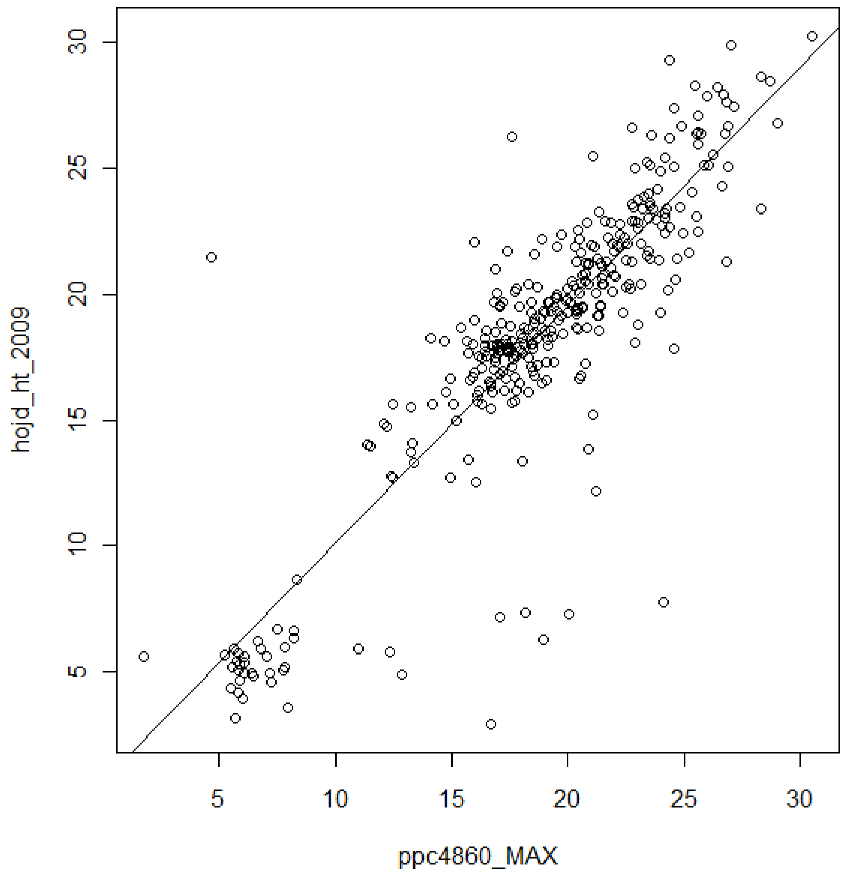
1200m 80/60 6,25 p/m^2

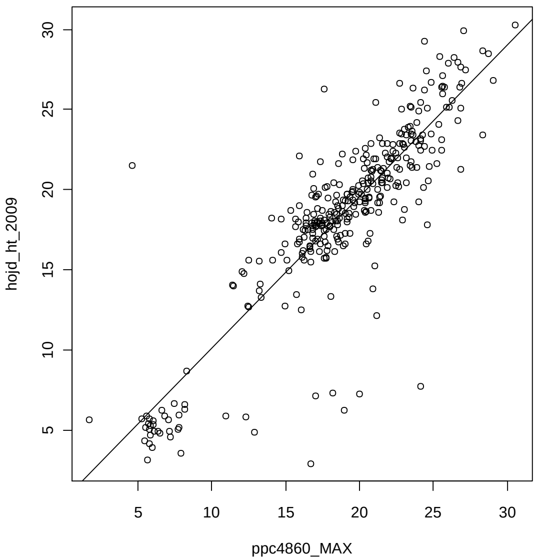


Mean Height

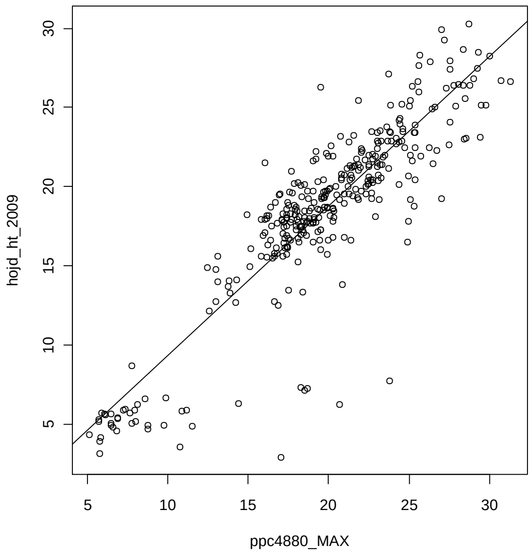



```
> ###################  Modeling Height  ########################
> plot(ppc4860_MAX~hojd_ht_2009, plotdata)
>
> modelH <- lm(hojd_ht_2009~ppc4860_MAX, plotdata)
> summary(modelH)

Call:
lm(formula = hojd_ht_2009 ~ ppc4860_MAX, data = plotdata)

Residuals:
    Min      1Q  Median      3Q     Max
-15.703  -1.024   0.256   1.244  16.529

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  0.60020    0.55867   1.074    0.283
ppc4860_MAX  0.94767    0.02866  33.068   <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 2.804 on 342 degrees of freedom
Multiple R-squared: 0.7618,     Adjusted R-squared: 0.7611
F-statistic:  1094 on 1 and 342 DF,  p-value: < 2.2e-16

> |
```

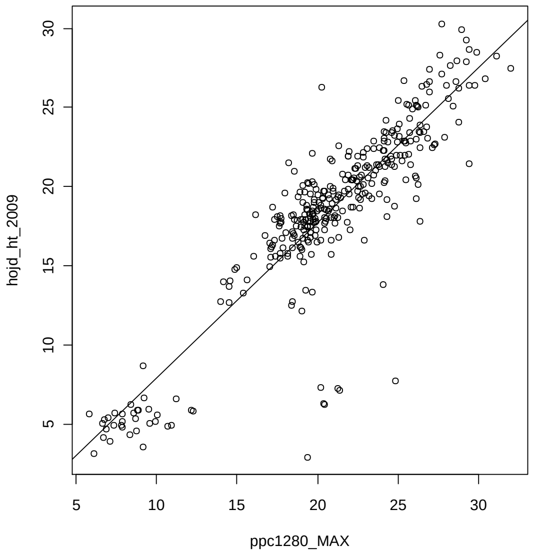
Mean Height



hojd_ht_2009
ppc4860_MAX
5
10
15
20
25
30



hojd_ht_2009
ppc4880_MAX
5
10
15
20
25
30



hojd_ht_2009
ppc1280_MAX
5
10
15
20
25
30

Stem volume

```
> modelV13 <- lm(log(vol_ht_2009+0.001)~I(ppc4860_MAX^0.01) + I(ppc4860_VEG^2), plotdata)
> summary(modelV13)

Call:
lm(formula = log(vol_ht_2009 + 0.001) ~ I(ppc4860_MAX^0.01) +
    I(ppc4860_VEG^2), data = plotdata)

Residuals:
    Min      1Q  Median      3Q     Max
-9.5176 -0.1511  0.0809  0.2386  3.1450

Coefficients:
                      Estimate Std. Error t value Pr(>|t|)
(Intercept)         -1.634e+02  1.213e+01 -13.472  < 2e-16 ***
I(ppc4860_MAX^0.01)  1.618e+02  1.192e+01  13.576  < 2e-16 ***
I(ppc4860_VEG^2)     2.210e-04  2.678e-05   8.251 3.46e-15 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.7254 on 341 degrees of freedom
Multiple R-squared: 0.6213,     Adjusted R-squared: 0.6191
F-statistic: 279.8 on 2 and 341 DF,  p-value: < 2.2e-16

>
```

Basal area

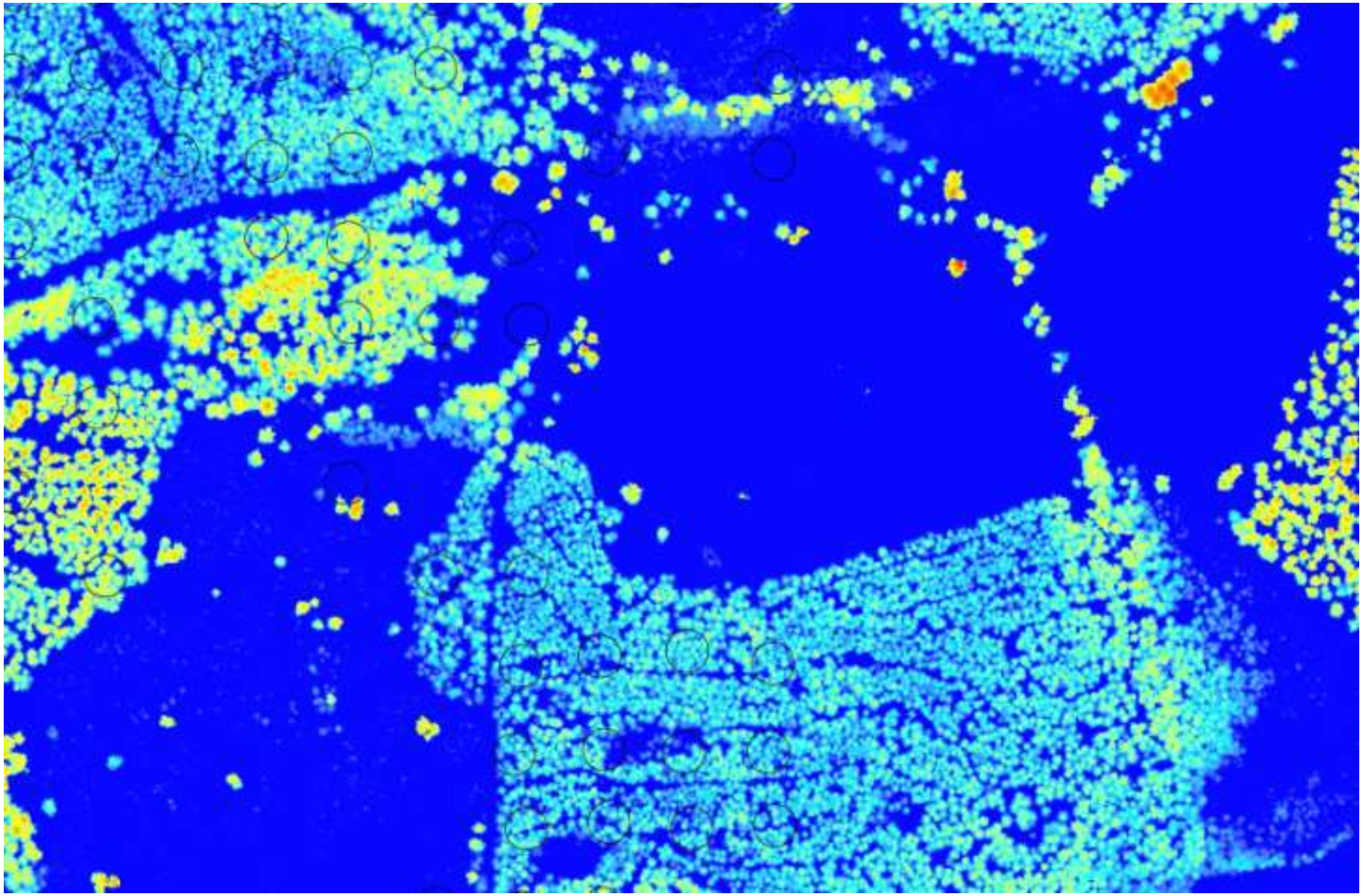
```
> modelG15 <- lm(log(gyta_ht_2009+0.001)~I(ppc4860_MAX^0.01) + I(ppc4860_VEG^2), plotdata)
> summary(modelG15)

Call:
lm(formula = log(gyta_ht_2009 + 0.001) ~ I(ppc4860_MAX^0.01) +
    I(ppc4860_VEG^2), data = plotdata)

Residuals:
    Min      1Q  Median      3Q     Max
-3.6705 -0.1121  0.0355  0.1817  1.7467

Coefficients:
                      Estimate Std. Error t value Pr(>|t|)
(Intercept)         -8.415e+01  7.192e+00  -11.70   <2e-16 ***
I(ppc4860_MAX^0.01)  8.314e+01  7.070e+00   11.76   <2e-16 ***
I(ppc4860_VEG^2)     1.877e-04  1.589e-05   11.81   <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.4303 on 341 degrees of freedom
Multiple R-squared: 0.6531,     Adjusted R-squared: 0.6511
F-statistic:   321 on 2 and 341 DF,  p-value: < 2.2e-16

>
```

Results

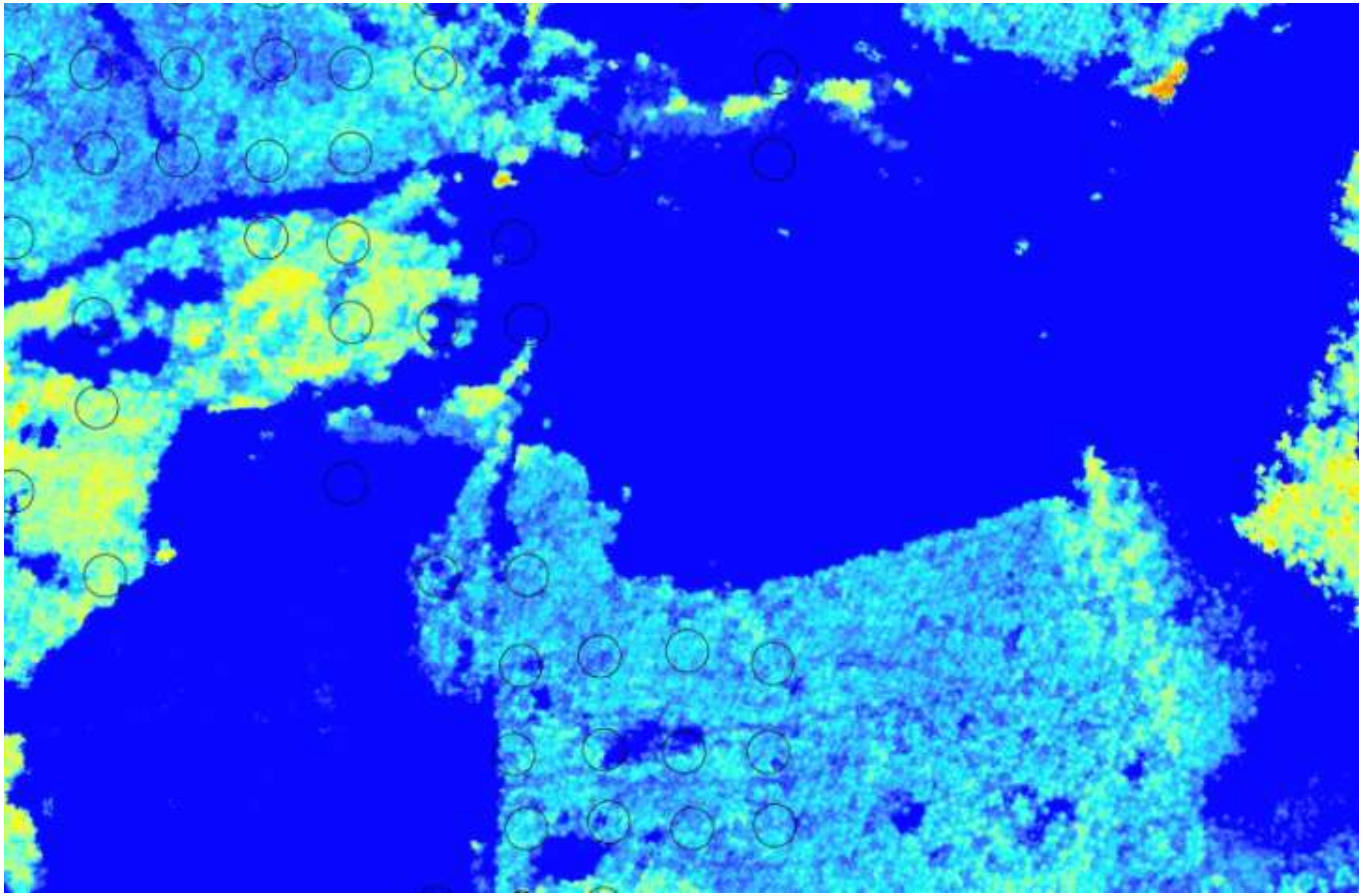
	4860			4880			1280		
	Height (m)	Volume (m3)	Basal area (m2)	Height (m)	Volume (m3)	Basal area (m2)	Height (m)	Volume (m3)	Basal area (m2)
RMSE	1.9	43.2	4.6	2.0	45.1	4.5	1.7	45.8	4.6
RSME%	10.7	16.9	16.9	11.2	17.6	16.7	9.7	17.9	16.9
Bias	0.32	-5.89	-0.78	0.40	-3.34	-0.65	0.29	-8.4	-1.10

To be published

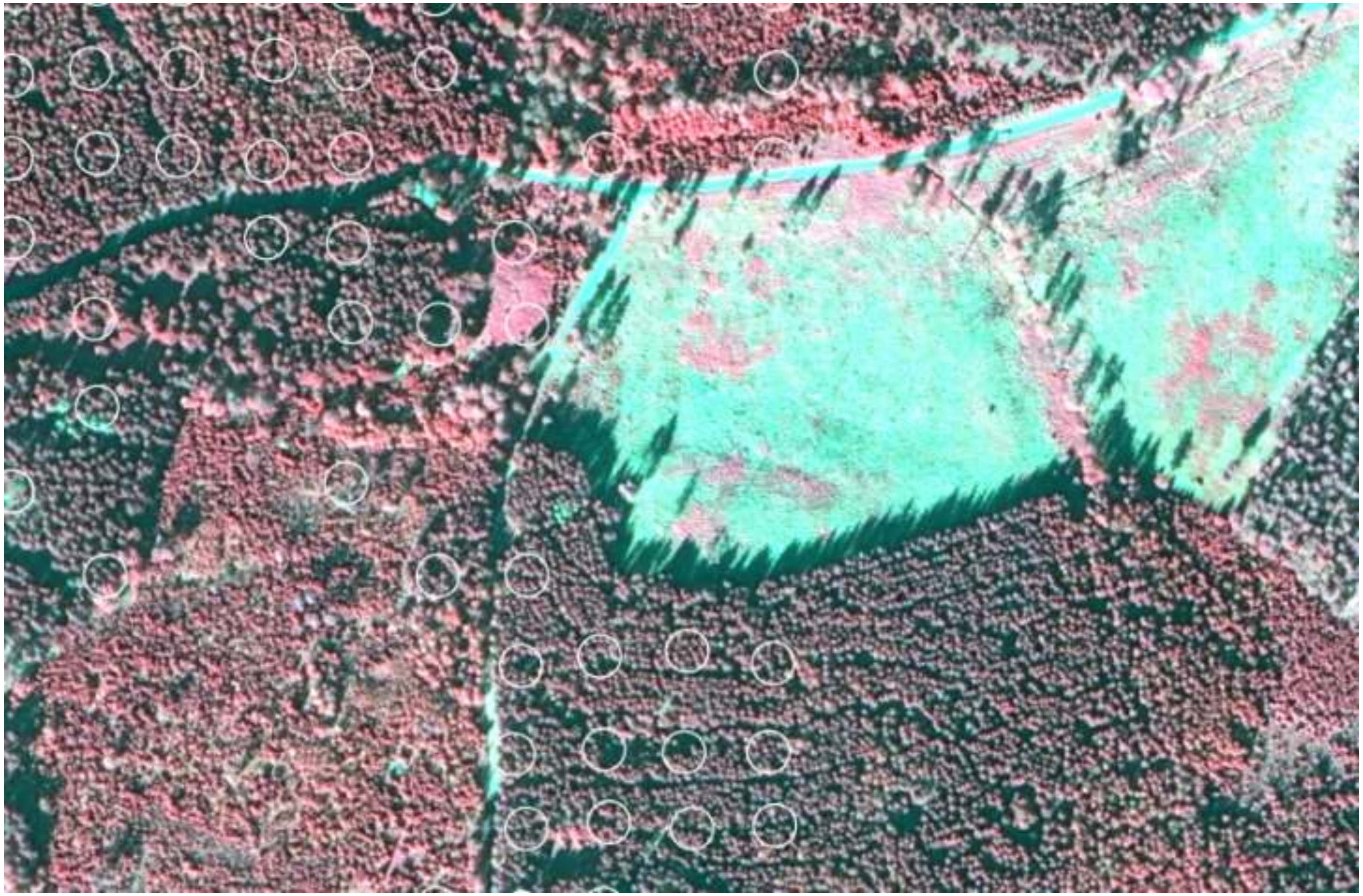
Lidar DSM



Stereo matched DSM



Orthophoto

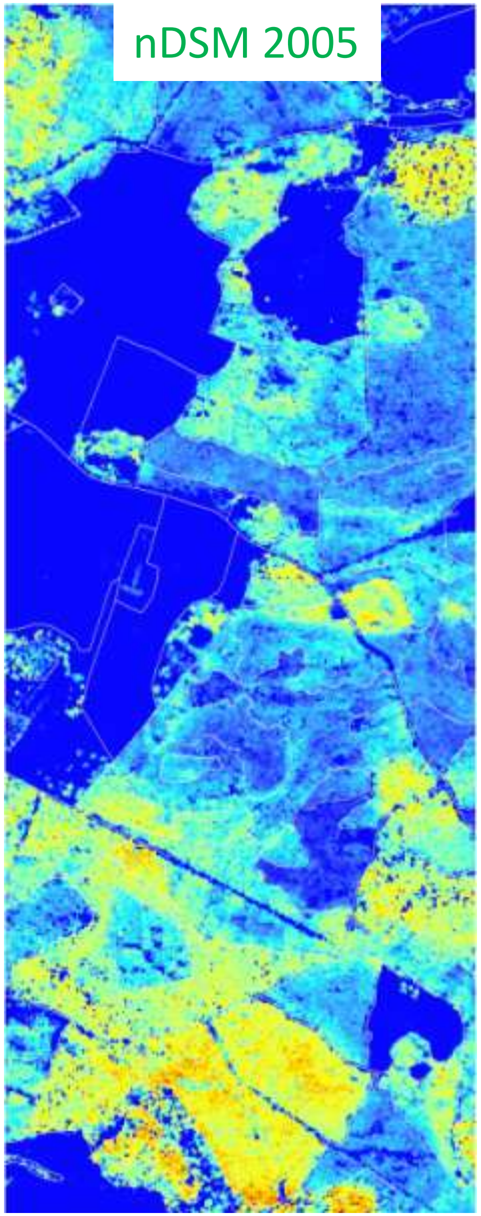


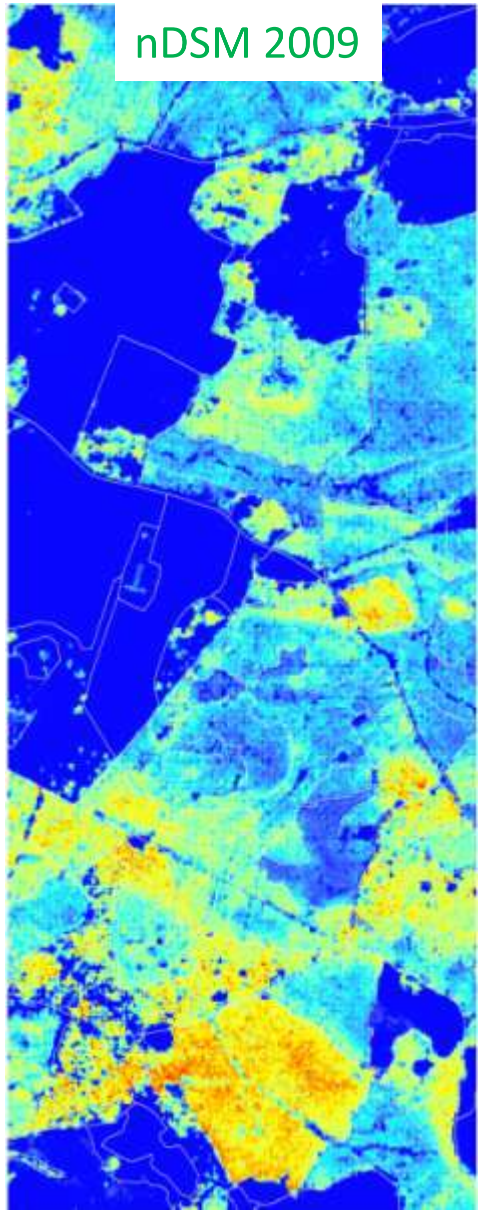
Different band combinations

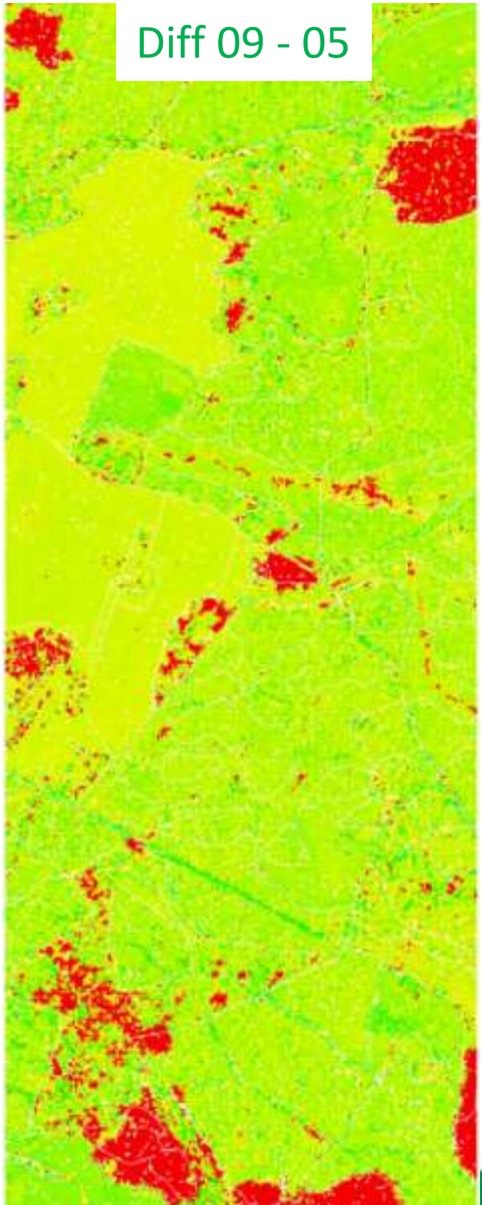
Pan sharpened CIR

Pan sharpened NIR

Panchromatic


nDSM 2005


nDSM 2009


Diff 09 - 05

The End

Questions?

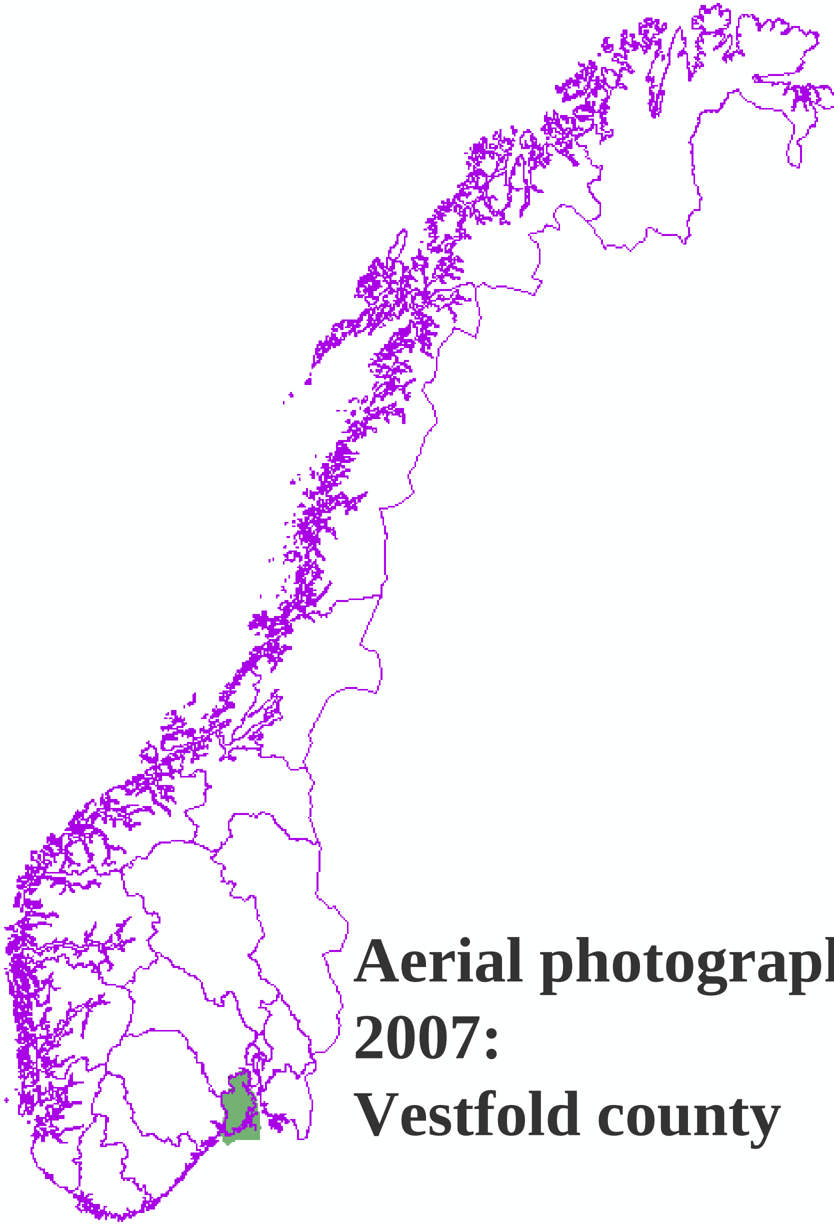
Extracting data for single trees

Svein Solberg

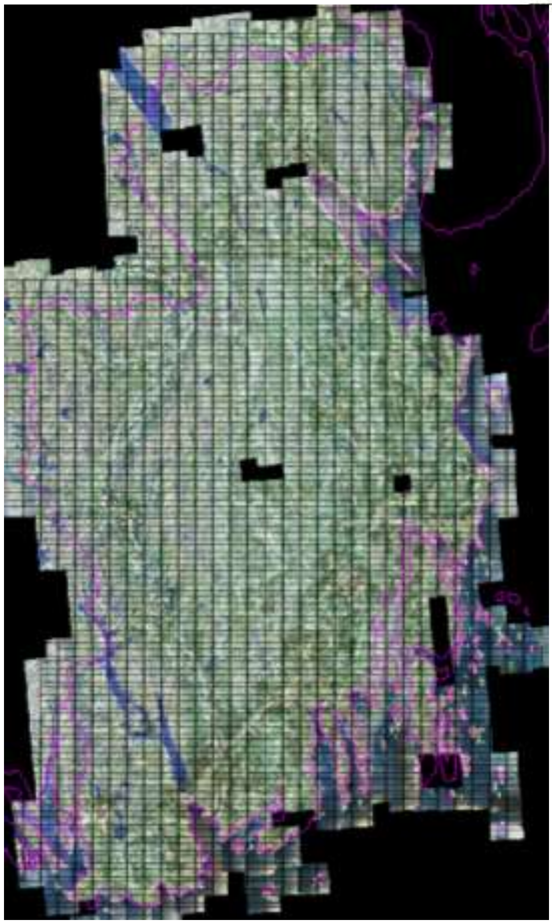
Skog og landskap

Grammetry Workshop
Ås, 9. June 2011

The problem



Aerial photography 2007: Vestfold county



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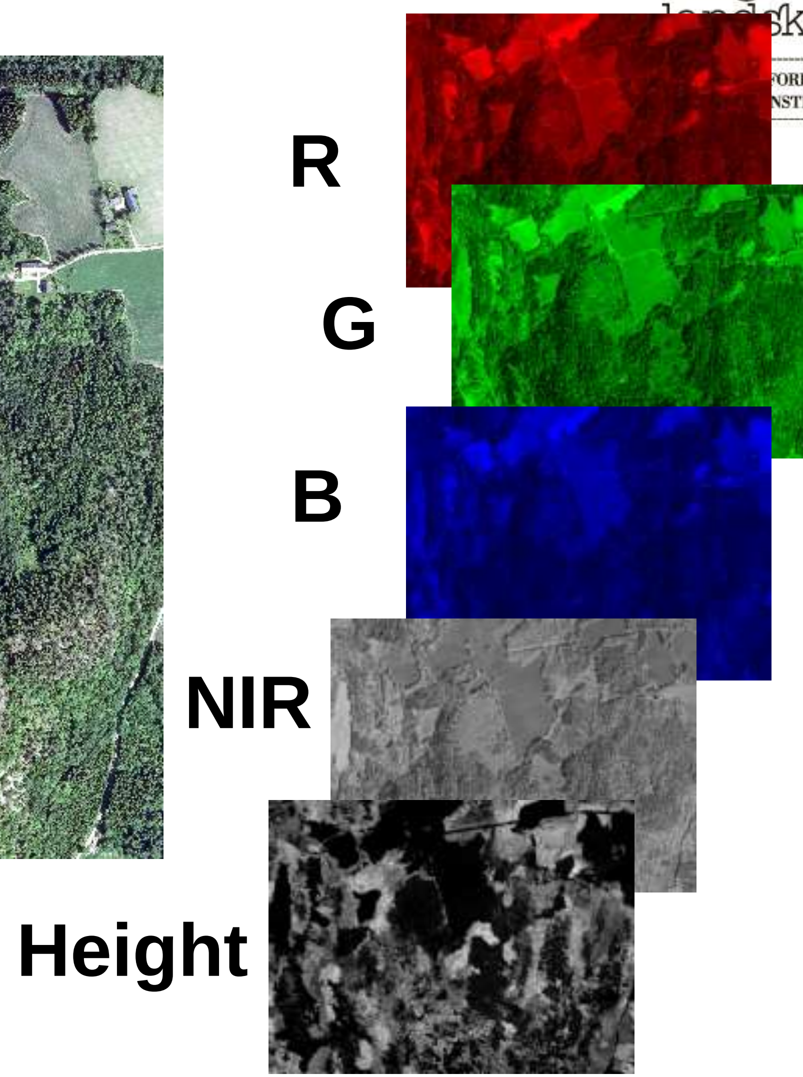
1400 tiles true ortophoto 1200 x 1600 m, 5 bands, spatial resolution 20 cm



Main idea: detect and classify single trees

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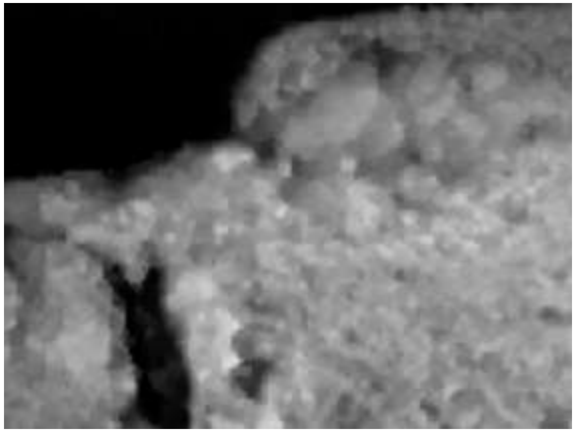
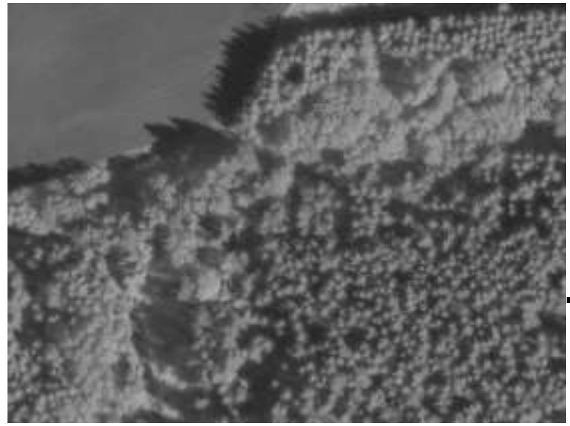
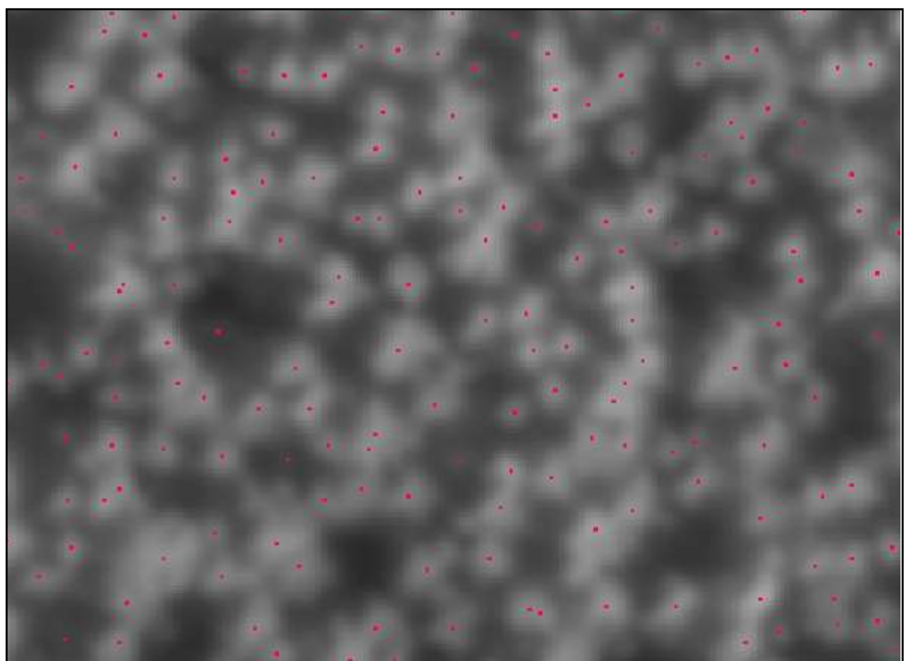


X

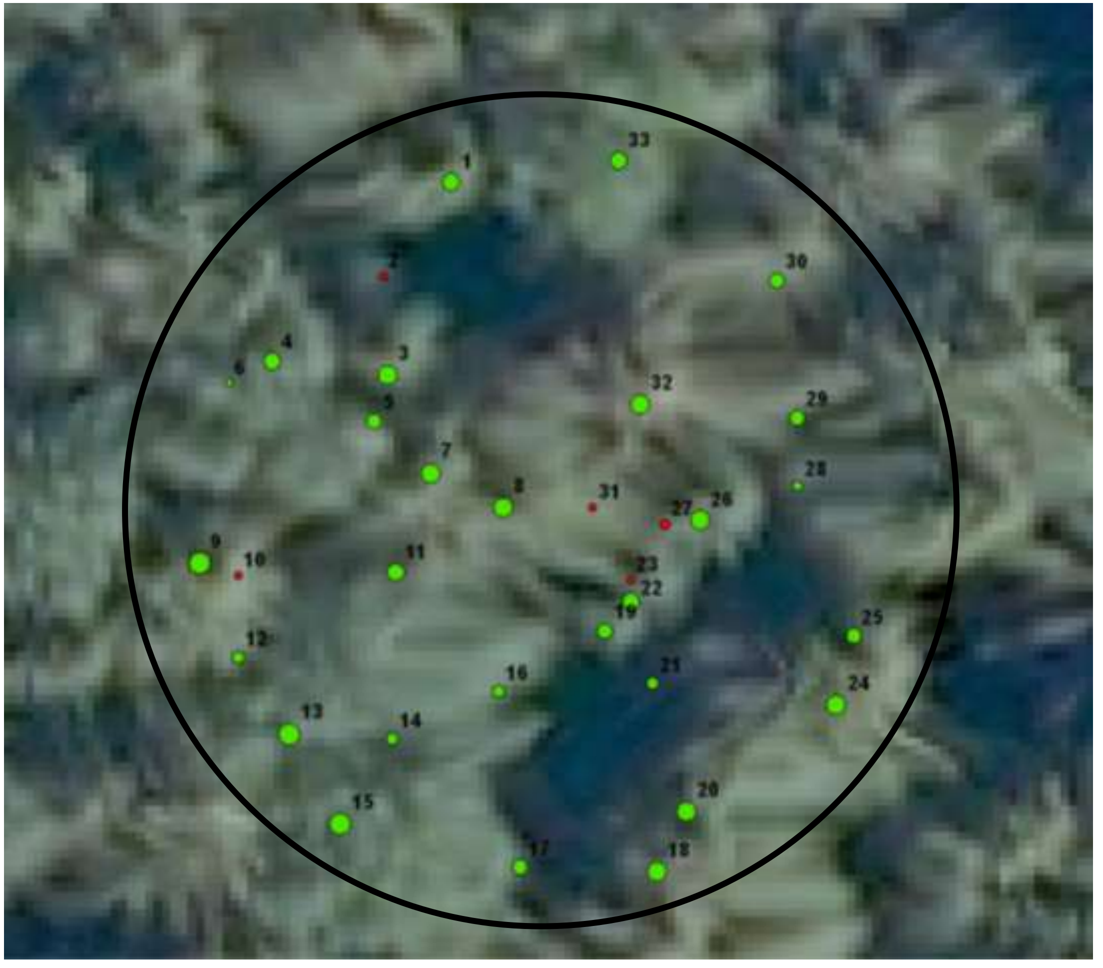


→ Smoothing
N * 3x3



Local
maxima

Using NFI plots as ground truth and training data



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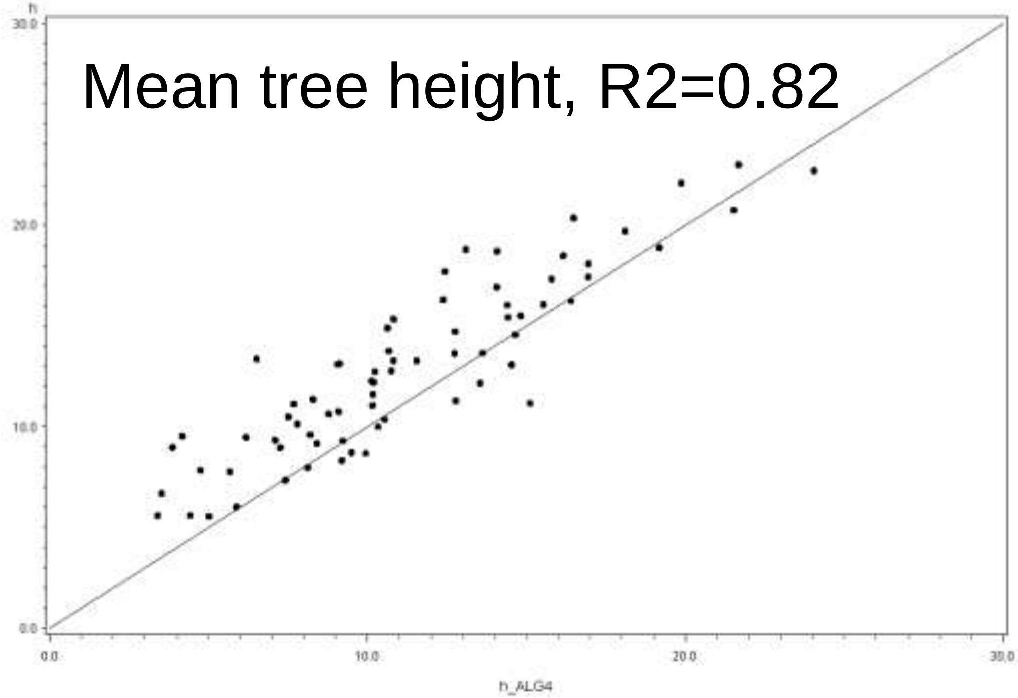

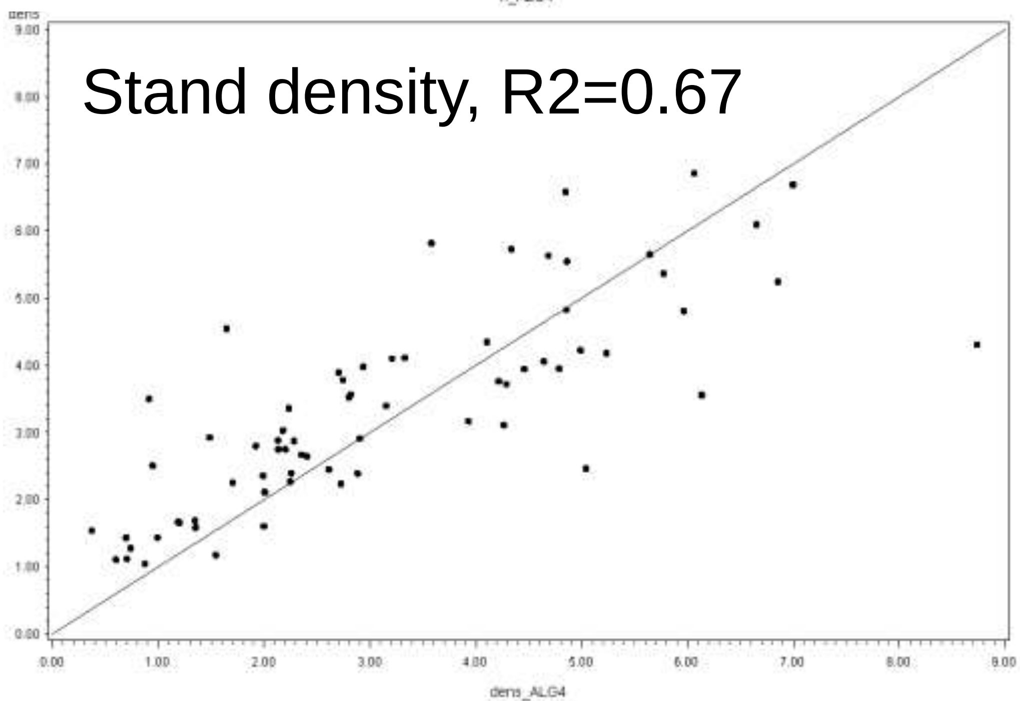

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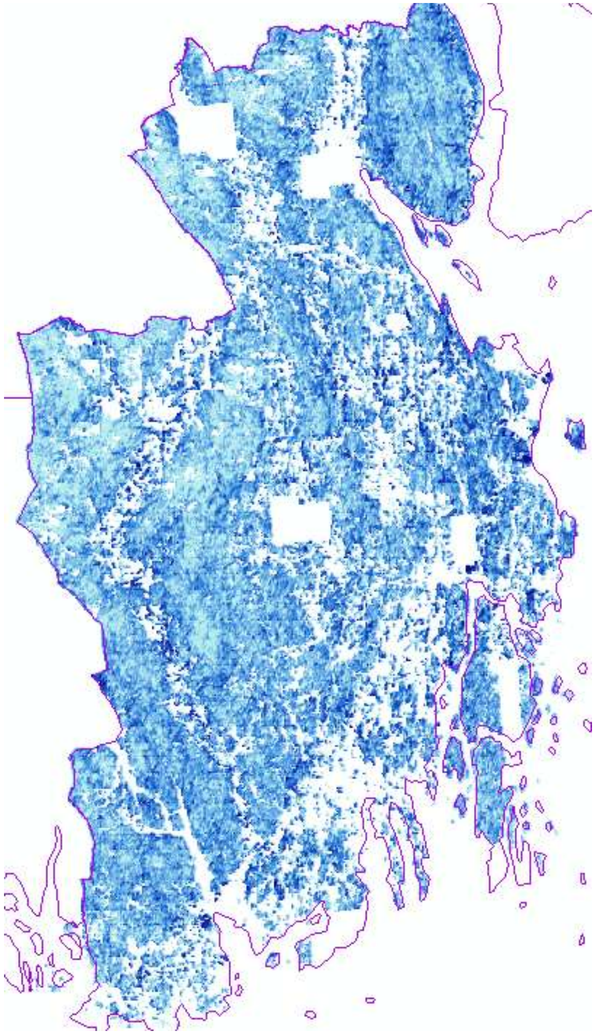
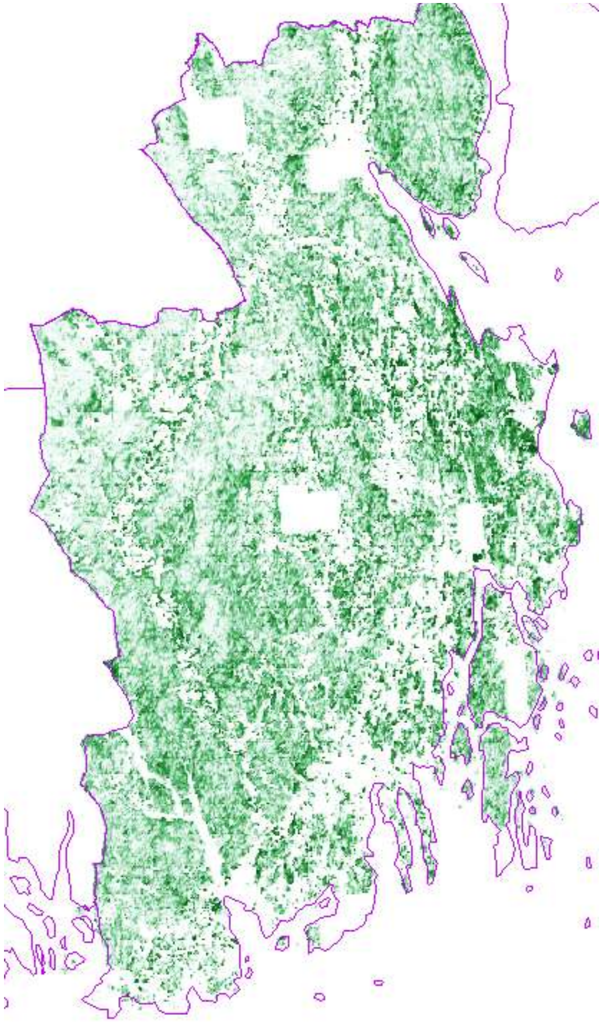
Results for NFI plots: Extracting stand properties

36 million trees found with extracted heights

Mean tree height 0-39 m Stand density (1/S%) 0-4





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Classification of tree species and dead trees

1. Extract signatures from NFI plots + additional plots with dead trees
2. Classification
3. Derive %spruce and %pine per stand
4. Generate a-priori probability for dead trees per stand
5. Re-classify

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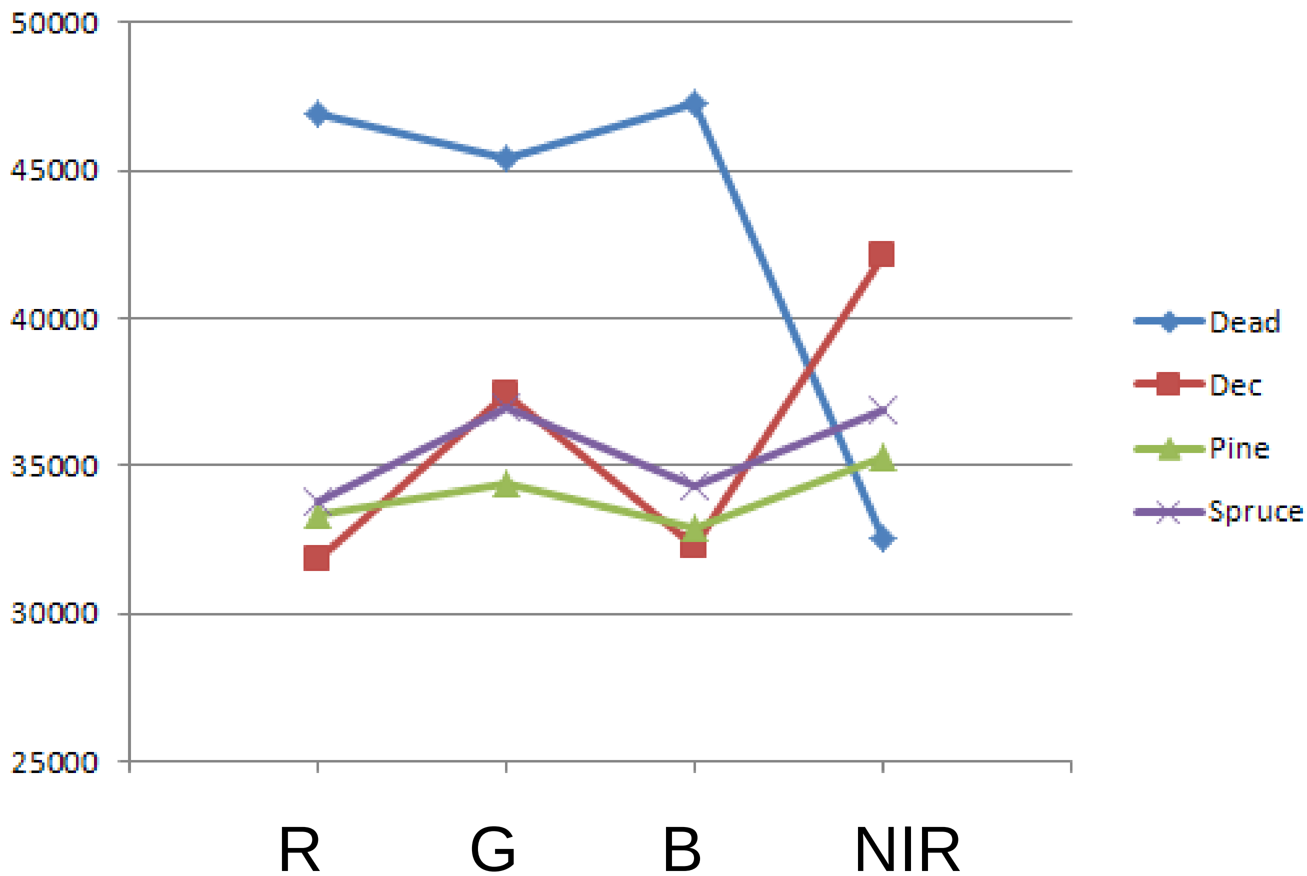
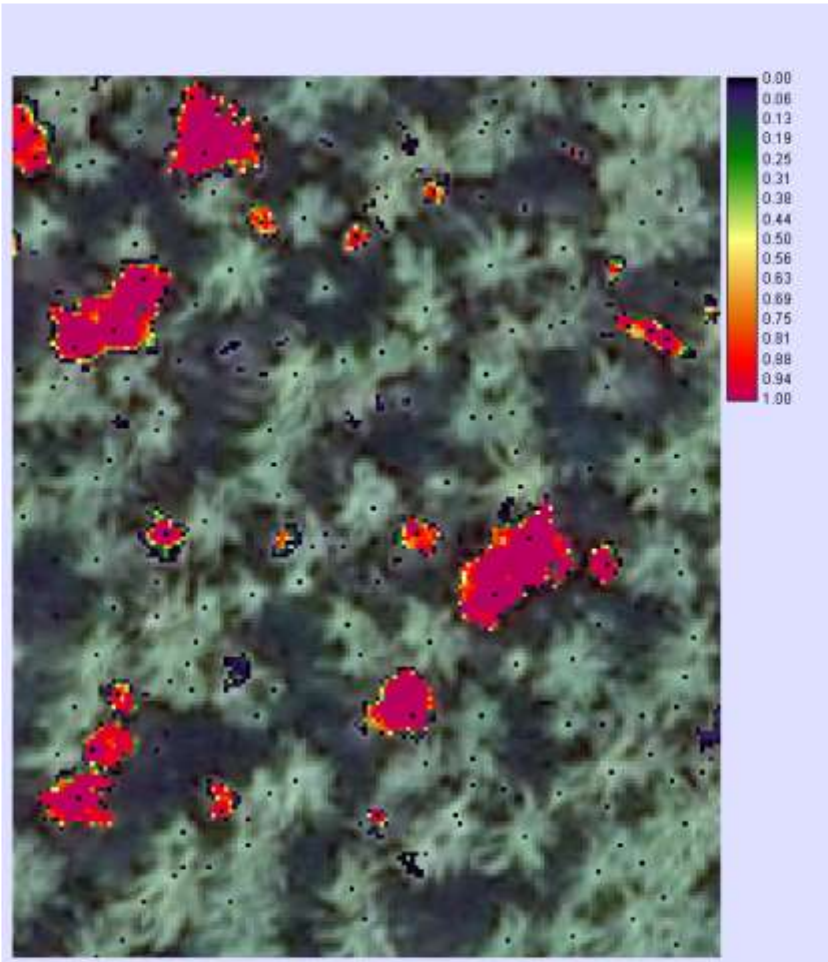
Signatures

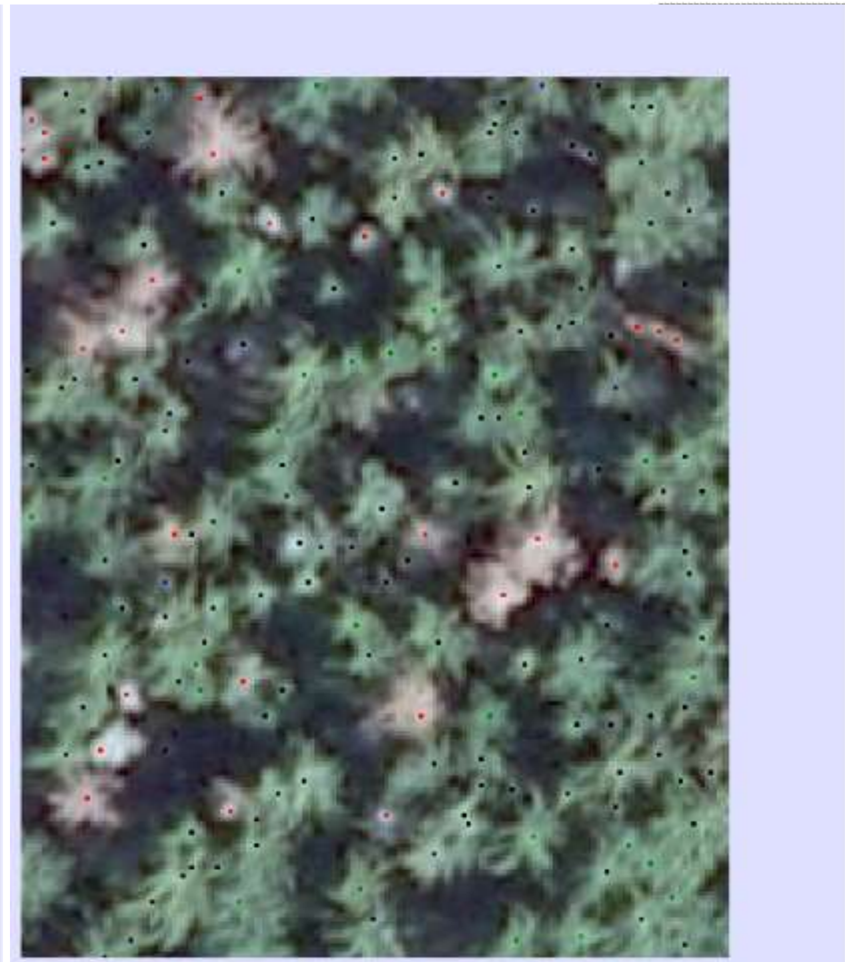


50000
45000
40000
35000
30000
25000
R
G
B
NIR
Dead
Dec
Pine
Spruce

Probability for dead trees



Final classification



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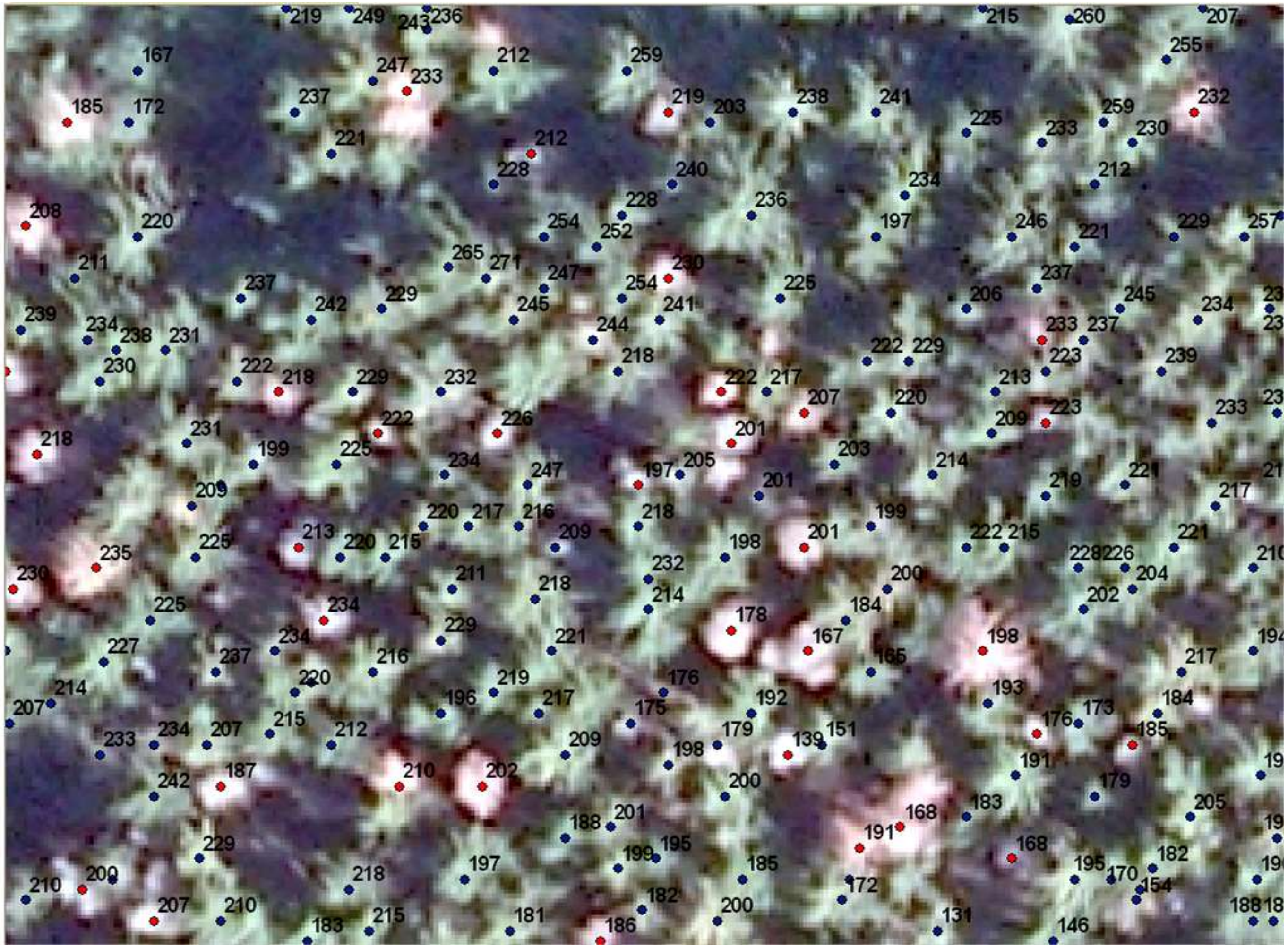
Classified trees with height (dm)



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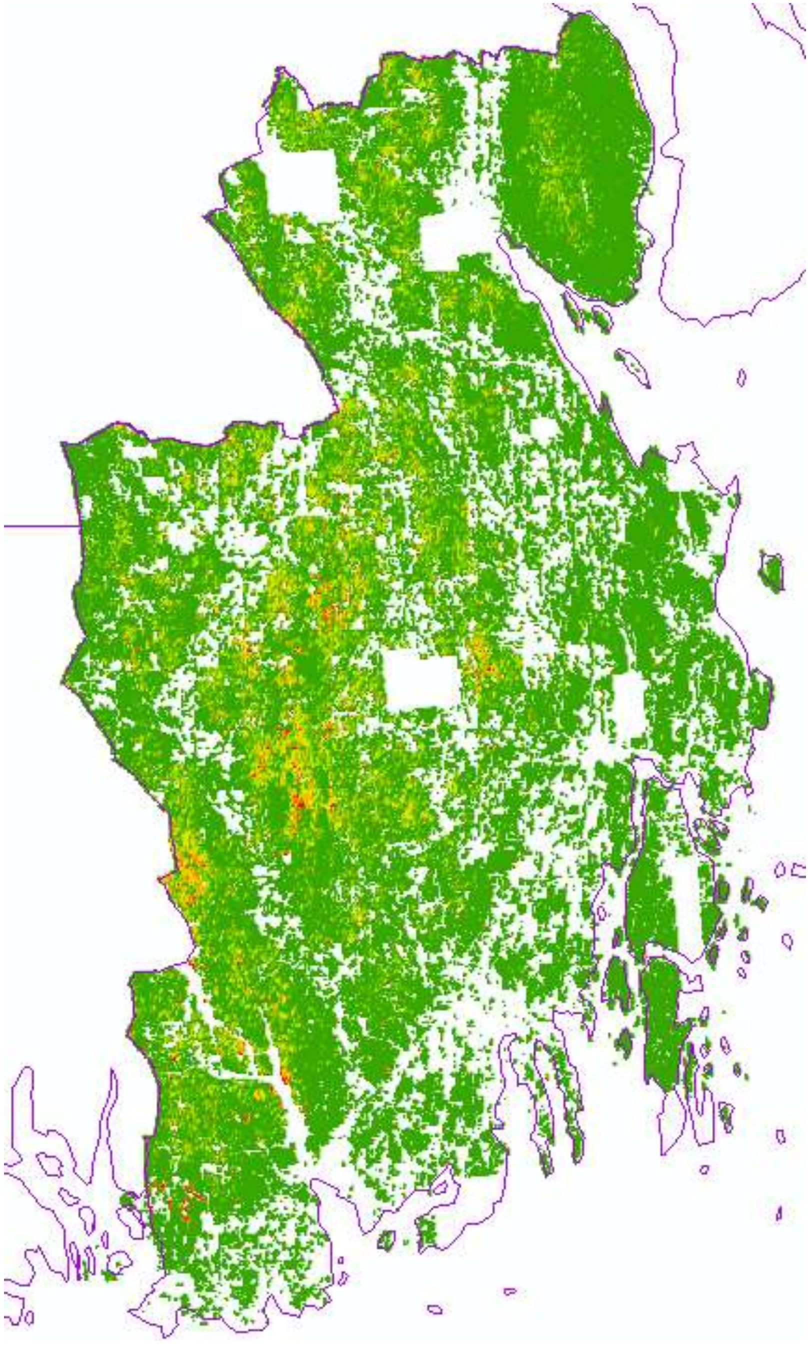
Classification «leave-1-out»

		classified				
		spruce	pine	deciduous	dead	Total
real	spruce	39	13	10	0	62
	pine	24	98	3	0	125
	deciduous	30	25	268	0	323
	dead	0	53	0	111	164
	Total	93	189	281	111	674

Kappa 4 cl	Acc. % 4 cl	Kappa Live-Dead	Acc. % Live-Dead	Omission% Dead	Commission% Dead
0.66	75	0.76	92	32	0

Preliominary: Frequency of dead trees



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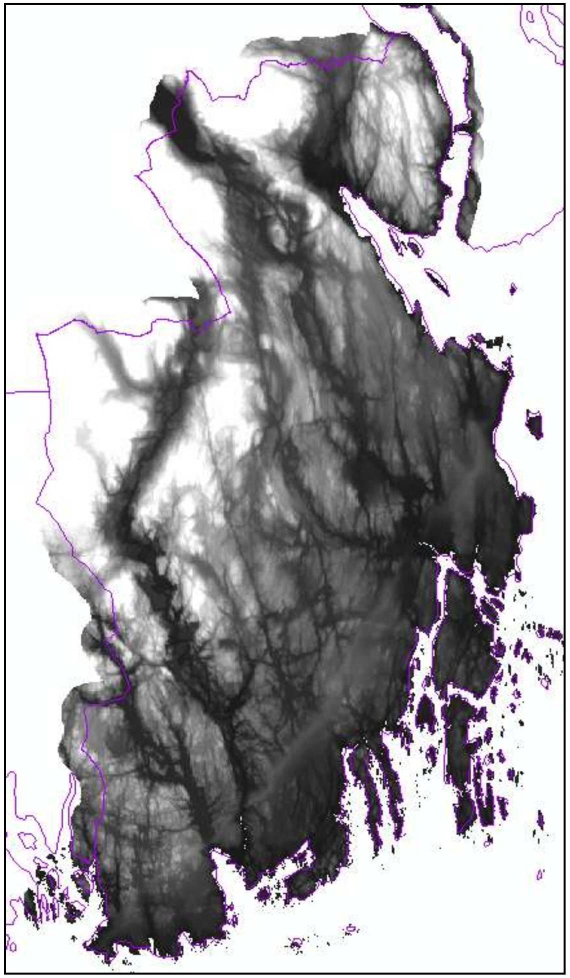
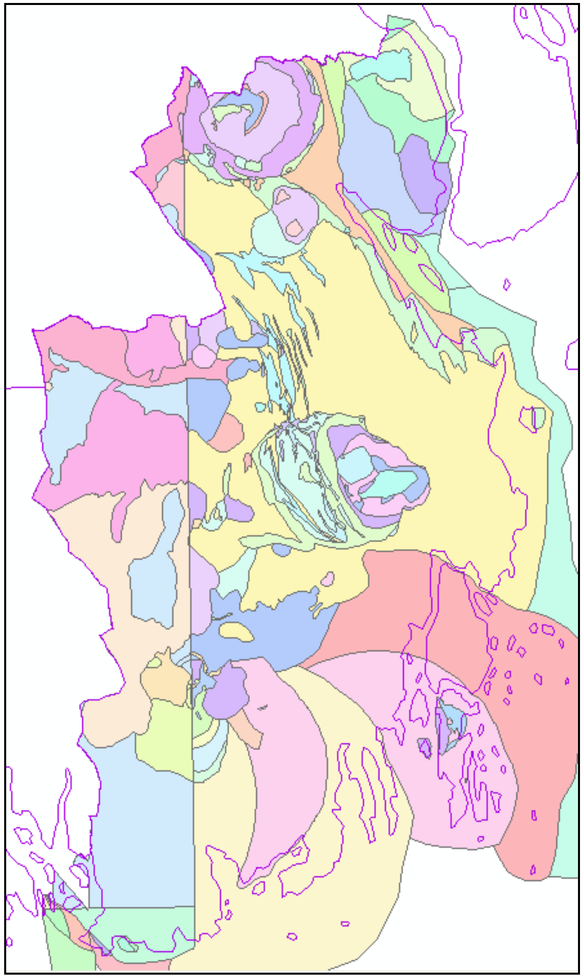
Andre GIS data:

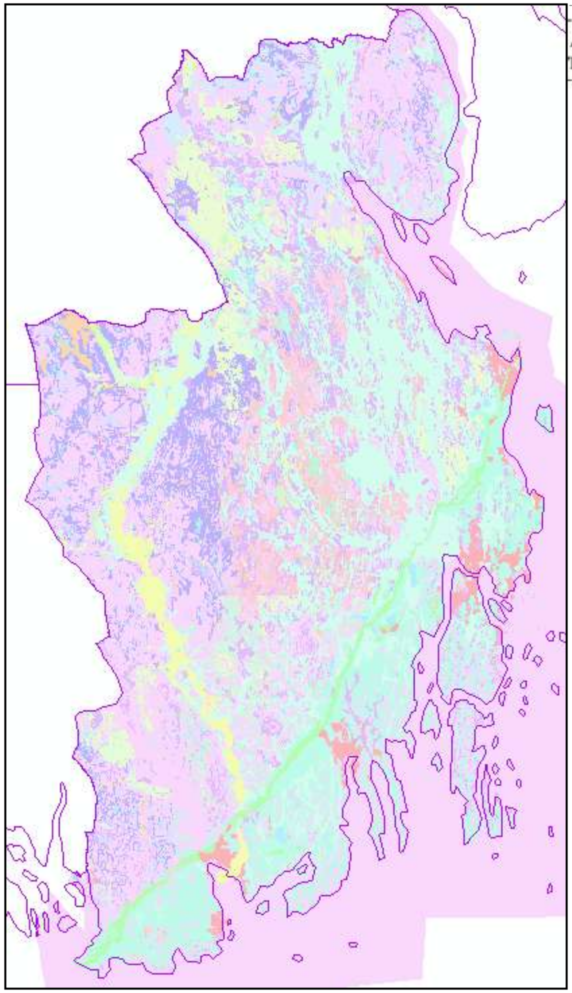
Høyde over havet og terreng



Berggrunn



Løsmasser



Project aims

- **Map the distribution of dead trees**

- **Identify risk factors**

- **Clarify causal factors**

- **Make scenarios for spruce drought under climate change**

- **Indicate possible silvicultural adaptions**

The Norwegian Forest and Landscape Institute cordially invites to the seminar

Creation of digital elevation models from aerial images for forest monitoring purposes

on 9 June 2011, 9:00-14:00h
in the large meeting room at the Norwegian Forest and Landscape Institute (Skog og Landskap), Høgskoleveien 8, 1431 Ås.

Background
Vegetation height information is one of the most important parameters for predicting forest attributes such as timber volume and biomass. Although airborne laser scanning (ALS) data are operationally used in forest planning inventories in Norway, a regularly repeated acquisition of ALS data for large regions still appears to be unfeasible. Therefore, several research groups analyze the use of other data sources to retrieve vegetation height information. One very promising approach is the stereogrammetric derivation of vegetation heights from overlapping digital aerial images. Aerial images are acquired over almost all European countries on a regular basis making image data for stereogrammetry readily available. This seminar wants to bring together researchers and practitioners that produce and utilize stereogrammetric data to share their experiences.

Preliminary program

9:00h	Welcome note (Rasmus Astrup, Skog og Landskap)
9:10h	DSM generation using Single Pixel Correlation in Vestfold (Inge Myklebust, BLOM ASA)
9:50h	Using vegetation heights derived from aerial images for small domain estimation in the Norwegian Forest Inventory (Johannes Breidenbach, Skog og Landskap)
10:20h	Coffee break
10:40h	Derivation of digital surface models from areal images in Bavaria (Christoph Straub, Bavarian Forest Research Institute)
11:20h	Semi-automatic extraction of forest area, type and composition from ADS40/80 images and derived CHMs for the Swiss NFI (Lars Waser, Swiss Federal Institute for Forest, Snow and Landscape Research)
12:00h	Lunch (see below)
13:00h	Estimation of forest variables using 3D data from aerial imagery (Jonas Bohlin, Swedish University of Agriculture Science)
13:30h	Single tree detection in true ortho photos (Svein Solberg, Skog og Landskap)
13:50h	Final discussion

The participation is free of charge. All guests are welcome to have lunch at the local cantina for a contribution of 150 NOK. Please send a short notice upon your participation and the interest in having lunch at the cantina until 1 June 2011 to Severin.Woxholtt@skogoglandskap.no. For questions regarding the program, please contact Johannes.Breidenbach@skogoglandskap.no.