Hyytiälä Forest Remote Sensing Experiment - Documentation

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1 Background

1.1 Purpose

This document lists different data and metadata, observations and activities that were considered worth storing for possible future use, given the noteworthy acquisition and processing costs. The documented data are collected in projects by Ilkka Korpela. They include

- Sample plot data, from seedling stands to old growth forests, 1995-
- Geometric reference data (GNSS, levelling), 2000-
- Aerial images, 1946-
- Airborne LiDAR, 2004-
- Terrestrial photogrammetry, 2007-
- Documentary photography, 2000-

1.2 Structure

The data are stored on a '\\Device\'.

1. \\DEVICE\HYDE_REF\ refers to hypertext-based (www) documentation with sub-directories.

2. Data that consumes lots of storage is not archived here but in other subdirectories of \\ DEVICE\.

The directory structure is referred to throughout this document.

1.3 About the data not stored here

What are not included here are activities by other research groups, e.g. by LAI detectives' group, and TLS activities by FGI etc. There possible exists spaceborne optical imagery (VTT research) and SAR (FMI), as well as airborne (even UAV) hyperspectral data (UH/Geography, Aalto University). Small samples of weather data are included here, to go with the remote sensing data acquisitions. Otherwise, SMEAR databases and those by the FMI can be used. Hyytiälä forest station probably has records of other activities in Hyytiälä. And, of course, if an article mentions "Hyytiälä".

1.4 Some history and purpose for the experiment

The field activities began in 1995 with the establishment of permanent forest plots and acquisition of aerial images. Plots are characterized by accurate local and global positioning of trees that are measured 1–6 times by Dec 2024. Activities have been targeted at establishing reference data for optical remote sensing. The remote sensing data are either airborne or close-range. There are many studies done based on the data.

Because most trees and other objects are positioned and identified accurately, the plots are 'permanent' at the tree-level. Most of the plots are 'selected', i.e. they have been subjectively delineated in the field for a particular reason (experiment). For example, some plots were selected because they represent a certain species mixture, or the presence of an understory, or a specific canopy structure.

The experiment focuses on a small area of about 700 ha, managed by Metsähallitus, enclosing the SMEAR II station. Some of the remote sensing data has coverage of Susimäki old growth and Lakkasuo mire complex. There is reasonable variability in the forests, however, and by no means, are the field plots highly representative of Finnish forests.

1.5 Acknowledgements

The investments are mostly by personal grants, but also by different consortia and by Hyytiälä research station. Field measurements have involved some 50 (total of 900!) students each summer (2007-2024), as well many research assistants 1995-. Particular help and/or financial support by the listed people is acknowledged

Pentti Räsänen, Jouko Laasasenaho, @ UH; field work 95-97
Timo Kuuluvainen; Simo Poso; @ UH; aerial imaging 97
Silja Pirttijärvi @ Hyytiälä; support 95-
Antti Uotila, Juho Aalto @ Hyytiälä; resources for field work 1995-
Jaakko Uusitalo; RTK/GPS 2000
Timo Tokola @ UH/UEF; ADS40-campaign 2008; LiDAR campaigns 2004-2007; Field campaigns 2003-04; 2009; Arranging different types funding & consortia 2002-2007
Markus Holopainen, Pauline Stenberg @UH; Field campaigns as a part of field courses 2007-2016
Arthur Rohrbach & Ron Roth @Leica geosystems; Aerial imaging using ADS40 2008; LiDAR 2010.
Ulrich Beisl @ Leica; Aerial imaging 2008, Spectroscopy
Eija Honkavaara et al. @ FGI; Aerial imaging 2009, Radiometric campaigns 2008, 2009, 2010
Juha Hyyppä @ FGI; LiDAR 2007, 2010, VRS-GNSS 2014
Pekka Savolainen @ Blom/Terractec; LiDAR 2006, 2016. Aerial images 2006, 2007, GNSS data 2008
Jonne Davidsson et al. @ Finnmap; LiDAR 2007, 2010, 2011a, 2011b, 2012, 2013, 2015; Aerial images 2010, 2012, 2013, 2015;
Maanmittauslaitos/ilmakuvatoimisto; Aerial imaging 2004 and 2009; Old film scans, 2018, 2022 images.
Topografikunta, Scans of old aerial films
Geotrim; Network GPS/GNSS equipment 2005-2019
SMEAR II Community; Weather & atmospheric data 1997-, LiDAR 2013 (Siikaneva & Hyytiälä combined), LiDAR of 2018 and 2020
Metsähallitus; LiDAR 2004, 06, 07, 10. Field work 1996-97
Stora Enso; LiDAR 2006, Field work 2010.
UPM; LiDAR 2006, 2007
UH/MMEKO/MMVAR; LiDAR 2006 (Lakkasuo), LiDAR and images of 2023.
Metla (Prof. Tomppo); LiDAR 2007
University of Joensuu/UEF (Prof. Maltamo, Jari Vauhkonen, Lauri Korhonen); LiDAR 2007; Field work 2008, 2009, 2011.
Arbonaut; Academy of Finland co-operation 2006-2008
Metsäteho; LiDAR 2006
Metsämannut; LiDAR 2007
Metsämiesten säätiö; aerial imaging 1997, 2002; field work 1996-97; 2002; aerial image scans 1946-2000; *Time-travelling in Hyytiälä 1946-2004* in 2006. Field campaign of 2013.
TEKES; Field activities 2006, 2010;
MATINE; Activities 2005-2006.
Academy of Finland; activities 2006-2008; 2011-2016; LiDAR 2012, LiDAR 2013, LiDAR 2015, LiDAR 2016
Suomen Luonnonvarain Tutkimussäätiö; activities 2008-2010, Field work 2010
Helsingin yliopiston rahastot 2009–2011; LiDAR 2010, 2011a, 2011b, Field work 2009-2011
MMM yhteistutkimusvarat 2002-2003; Development of KUVAMITT

Fig. 1. Summer of 2000. Jarno Kallonen and Jaakko Uusitalo carrying out RTK GPS measurements on recently established ground control points. These were marked with metal bolts.

Fig. 4. Forestry student taking an azimuth observation to position a tree using spatial resection. 2008, MARV1 course.

Fig. 2. Nina Rautjärvi and Sini Kokkonen; field workers in 2002. Some of the plots were already measured once and tree labels with a local map of stems and values of the previous measurements are being prepared.

Fig. 5. Dr. Ulrich Beisl from Leica Geosystems in August 2008. The weather was not favorable for the ADS40 campaign. The sensor was in Tallinn, and finally on August 23 it was flown to Hyytiälä by Estonian land board.

Fig. 3. At the SAHATIE plot, August 2006. The VRS GPS antenna with a 4-m pole is seen on the front. The VRS/Network GNSS has been used since 2005 to position points in low vegetation at cm-accuracy.

Fig. 6. Mapping understory trees at cm-level accuracy in Lapinkangas, July 2009. Pauliina Kulha and Aarne Hovi

1.6 List of publications

Peer reviewed (to be completed)

1. Fish, S., Haakana, M., Korpela, I. and Melkas, T. 1998. Spatial relationships in a forest stand. In: Spatial Statistics in GIS Applications. (Eds. Artimo, K. and Haggrén, H.) Cartography and Geoinformatics Publications 4. Helsinki University of Technology. pp. 7-39.

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Theses done utilizing the experiment

1. Antti Mäkinen, MSc, UH
2. Sini Kokkonen, MSc, UH
3. Aarne Hovi, MSc, UH
4. Liisi Koivisto, MSc, UH
5. Tuukka Tuomola, MSc, UH
6. Felix Rohrbach, MSc, ETH
7. Lauri Korhonen, PhD, UEF
8. Jari Vauhkonen, PhD, UEF
9. Ville Heikkinen, PhD, UEF
10. Perttu Anttila, PhD, UEF
11. Mikko Vastaranta, PhD, UH
12. Ants Vain, PhD, Estonia
13. Lauri Markelin, PhD, HUT
14. Aarne Hovi, PhD, UH
15. Markus Karppinen, MSc, UH
16. Antti Polvivaara, MSc, UH
17. Antti Polvivaara, PhD, UH (under preparation)

Data used in teaching
(to be completed)
UH courses in Forest Sciences – GIS/RS
ME-011B, ME-013C, ME-233, ME-234, FOR-254,
ME-232, FOR-25?
UEF Course in Remote sensing

1.7 Featured

Talks

1. *Fast and slow shutters, wide and narrow band-pass filters - Investigating the species issue for over a decade, the optical airborne way.* HyperBio seminar, Oslo November 30, 2015.

2. *Airborne optical remote sensing of the forests and mires of Hyytiälä 1997 - 2011*. Finnish Geodetic Institute's Research seminar, March 2011.

3. *Laserkokeiluja Hyytiälän metsissä ja soilla 2004-2010*. Maanmittauslaitoksen laserkeilaus- ja korkeusmalliseminaari 2010. Oct 8, 2010.

4. *Metsäalueen historian rekonstruointi ilmakuva-aikasarjoista. Reconstructing silvicultural history using a time-series of archived aerial photographs*. Surveying expo "Paikkatietomarkkinat". Helsinki, Sept 27, 2005.

Teaching activities

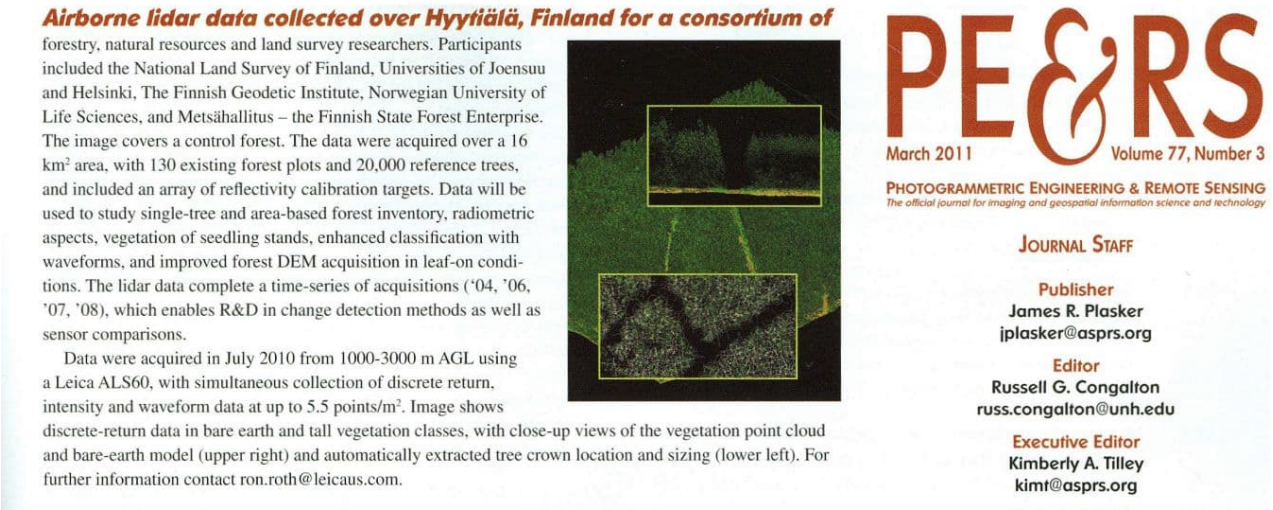
1. MMVAR37 / ME-234 (2011, 2012-2020) Basic course in programming
2. GIS201 GIS analysis and modeling, 2012
3. MARV104 forest inventory project 2012
4. MARV1 (FOR110b) Basic course in forest mensuration 1997-1999; 2007-2015, ME-013C 2016-2024
5. MARV4/FOR-254 Forest inventory project 2007, 2009, 2016, 2018, 2020, 2022, 2024
6. MINV12 PhD course in 3D remote sensing of forests, 2006
7. NOVA PhD-course in 3D remote sensing, Mekrijärvi 2009
8. LiDAR technology course for forest experts, Evo 2010
9. ME-233 Forest Inventory 2017, 19, 21, 23, 25

Supporting other activities

1. Surface type classification of Siikaneva Eddy-Covariance site, 2014-2015 (Prof. Timo Vesala, UH)
2. LAI estimation for surroundings of lake Kuivajärvi (Dr. J. Pumpanen UH)
3. Participating in the global LiDAR data activities at FLUXNET sites. D. Baldocchi, M. Beland. Berkely. 2012.
4. SMEAR 2010 campaign; C. Nichol, U of Edinborough
5. Wood-procurement in peatland forests, Prof. Uusitalo METLA; 2011.
6. Hyytiälä 100-yr anniversary. WWW-site “Time-traveling in Hyytiälä 1946-2006”; 2010.
7. SMEAR II intermediate fellings 2020, mapping of 40000 trees in the surroundings

Exposure in media

1. PERS 3/2011 front cover and three-page article by Dr. Ron Roth @ Leica Geosystems.
2. UH Web site, Science News, April 2012



Airborne lidar data collected over Hyytiälä, Finland for a consortium of forestry, natural resources and land survey researchers. Participants included the National Land Survey of Finland, Universities of Joensuu and Helsinki, The Finnish Geodetic Institute, Norwegian University of Life Sciences, and Metsähallitus – the Finnish State Forest Enterprise. The image covers a control forest. The data were acquired over a 16 km² area, with 130 existing forest plots and 20,000 reference trees, and included an array of reflectivity calibration targets. Data will be used to study single-tree and area-based forest inventory, radiometric aspects, vegetation of seedling stands, enhanced classification with waveforms, and improved forest DEM acquisition in leaf-on conditions. The lidar data complete a time-series of acquisitions ('04, '06, '07, '08), which enables R&D in change detection methods as well as sensor comparisons.

Data were acquired in July 2010 from 1000-3000 m AGL using a Leica ALS60, with simultaneous collection of discrete return, intensity and waveform data at up to 5.5 points/m². Image shows discrete-return data in bare earth and tall vegetation classes, with close-up views of the vegetation point cloud and bare-earth model (upper right) and automatically extracted tree crown location and sizing (lower left). For further information contact ron.roth@leicaus.com.

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1.8 Map of Hyytiälä

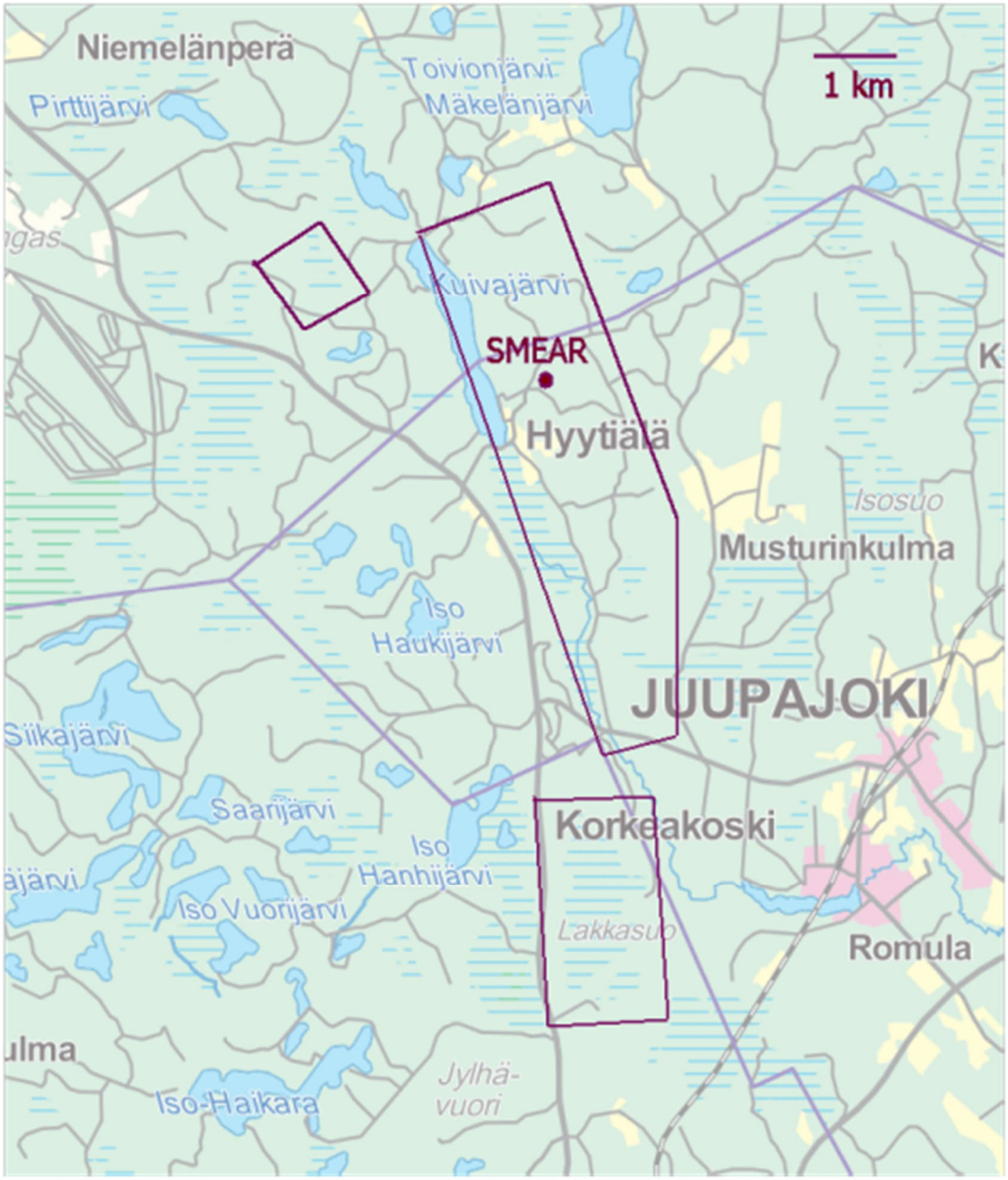


Fig. 7. Map showing the main area of interest with field activity near Hyytiälä, as well as the Lakkasuo and Susimäki areas

.

2 Aerial photography (Photogrammetry)

Essentially, there are aerial (and terrestrial) images since 1946, which are mostly oriented in a coordinate system that is "time-invariant". They are not re-sampled into orthoimages, but retained 'in the original form, at the time of exposure, on the focal plane'.ADS40 line-sensor data from 2008 exist in both raw and stereo-orientation.

2.1 Concepts and terminology

2.1.1 Frame sensor geometry

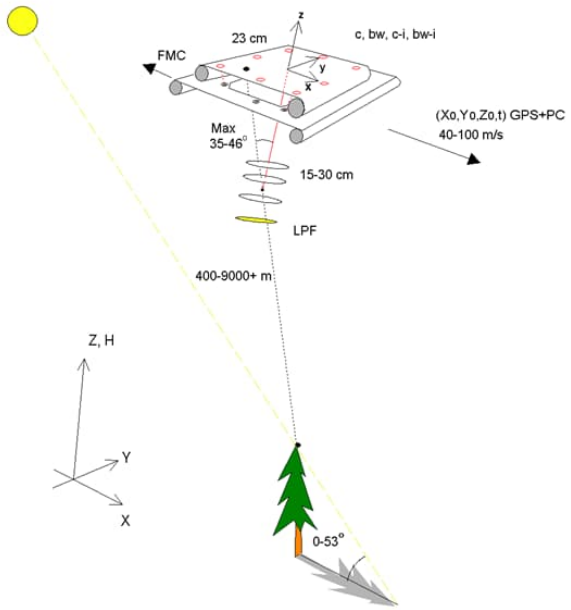


Fig. 8. Image capture with a film-based frame sensor. The image ray extends from the object to a point in the focal plane. Camera moves during exposure (shutter is released) but is motion compensated. Filters attenuate UV-light. Cartesian coordinate systems: one for the camera (xyz) and one for the object space (XYZ). All rays pass through a projection center and the camera is rotated about it. In Hyytiälä, the solar elevation is 30-50º, and typical field-of-view of the cameras is from ±25 to ±45 º. Film cameras produced square-shaped images, while those of digital cameras are rectangular.

2.1.2 Kuvamitt

The image and LiDAR data documented here are as such 'compatible' with an in-house digital photogrammetric workstation called KUVAMITT. It is written in Visual Basic 6 and C/C++, in the win32-environment. \\Device \Kuvamitt\ directory has different versions of KUVAMITT and related supporting software. A DEMO with training data is given in (Appendix 4. LABS in photogrammetry and LiDAR-based STRS with KUVAMITT).

2.1.3 Object coordinate system

A Cartesian XYZ system, meters, is required in photogrammetry (Fig. 8). This is the coordinate system for everything in the scene that is viewed by the images. In Hyytiälä this is approximated by the KKJ-2/N60 map projection. It is considered a right-handed system; KKJ-East = X, KKJ-North = Y, N60 = Z (exceptions exist). N60 values (Z) are ortometric heights, values above the mean sea level, in the 1960 epoch. The global GPS coordinate system is based on an ellipsoid (WGS84/ETRS89), and a geoid model tells the height difference between the orthometric elevations and those from the ellipsoid. This difference is ~18.67 m with respect to the N60 system in Hyytiälä. The "new" N2005 heights are 0.32 m above N60.

LiDAR data were originally delivered in the UTM35 projection with ellipsoidal heights but were always converted to KKJ-2/N60 that forms a common basis for the remote sensing and reference data.

2.1.4 Camera coordinate system – camera calibration and lens errors

This is a Cartesian xyz system, metric, inside the camera according to the perspective camera model. The origin is at projection center 'inside the lens' – an ideal point through which all image rays pass. The planar focal plane (where the image forms) is at some distance z = ± *c* (positive or negative image), from this point, and the plane normal intersects the projection center and forms the optical axis. *c* is called the camera constant. The intersection of the optical axis on the focal plane is called the principal point.

Image rays entering the aperture are mapped by optics to a point in the focal plane. This mapping is a straight line from the object, via the projection center, to a point in the focal plane. All points in the focal place have camera coordinates (x, y, c), where *c* is constant, and can be omitted leaving (x, y), in meters, in the focal plane. Camera coordinates (0, 0) are (in an ideal camera, pin-hole camera) for a point at the origin, which is in the middle of the focal plane, at the principal point. All points in the object space that are aligned with the optical axis map there. In real cameras, this point (x_0, y_0), defines the best symmetry for the perspective mapping, is physically at some location. This is defined in camera calibration along with the camera constant *c*, [m]. These three parameters are the minimal set of parameters that define the interior camera orientation.

Aerial (film) cameras are expensive instruments, and the lenses and focal plane are built such that the collinearity of image rays and the perspective mapping are reproduced in the images, down to an accuracy of a few micrometers. Such cameras are called metric. All aerial images in Hyytiälä were collected using metric sensors.

If the lens or the focal plane is not perfect, the deviations from the pinhole camera can be corrected for using equations that tell how wrongly the pixels in an image are with respect to a perfect camera. The deviations can be large in consumer-grade cameras, especially if the FOV is large (Fig. 9), up to tens of pixels. Terrestrial photo-grammetry images were collected using consumer-grade cameras.

Fig. 9. This image shows two superimposed images, the original one with lens distortions and an image that was re-sampled to represent an image in which the lens errors were removed, and the image follows the perspective mapping as closely as possible.

The correction equations are also called camera calibration models, and they model radial and tangential distortions, skewness of the focal plane etc. These parameters can be solved by using special arrangements (Fig. 10).

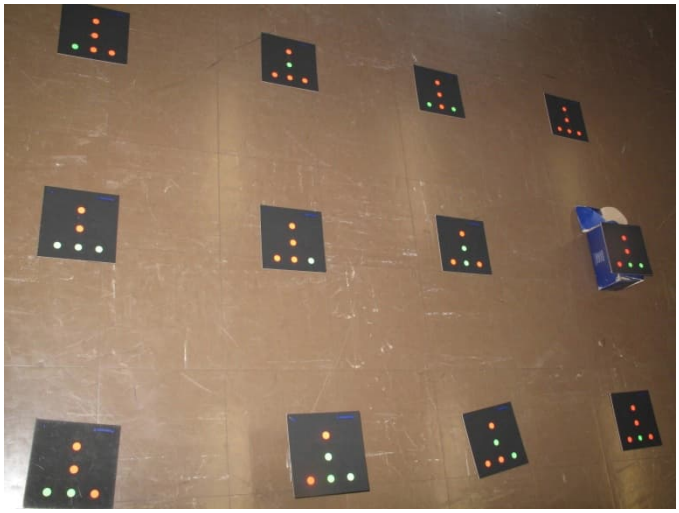


Fig. 10. Camera calibration targets. These are viewed from many directions with the camera that is calibrated, and a large bundle block is formed (of image rays that meet at the color-coded points), up to 15-20 rays per point from different directions, and the correction equations are solved with non-linear regression. The equations can be used to re-sample the image into a pinhole (undistorted) camera image, in which the deviations are minimized.

Kuvamitt uses only lens-corrected images. The calibration equations cannot be entered. Only focal length and position of the principal point are allowed.

2.1.5 Raster image coordinate system

Aerial images and raster elevation models have a width (W) and height (H), in pixels. Indexing starts from 0 and reaches to (W-1) or (H-1). The pixel in the up-left corner is the origin if the coordinate system is defined as left-handed, and the y-axis grows downwards. In a right-handed definition, the origin is in the low-left corner pixel, and the y-axis grows upwards. The coordinates system is continuous, and the mid-point of a pixel has the coordinates #.5 and #.5. Thus, the center of the pixel defining the origin has the column, row coordinates (0.5, 0.5). So, if a DEM has the origin at X = 6860000.00 and Y = 350000.00, and a grid size of 3 m, then the center of the pixel at the origin corresponds to (6860001.50, 350001.50).

KUVAMITT uses a right-handed system internally, and changes made in direction of the y-axis are seen throughout the code (y' =((height-1) - y). The same definition applies to other raster data, i.e. elevation models.

When an aerial image is scanned, each pixel in the digital image represents a point (area) in the focal plane that 'captured the image' (Fig. 8). The principal point, the origin of the camera coordinate system is at some (column, row) coordinate in the raster image. For photogrammetry a conversion to the camera coordinates (x,y) is needed. In Kuvamitt, and affine transformation is used for this task.

x' = ax + by + c
y' = dx + ey + f

If (x,y) are raster images coordinates, in meters, then c and f define the offset to the principal point, in column and row -values. If the raster image is perfectrly aligned with the camera coordinates system, and pixels are of equal size in both directions, 1/a == 1/e == size of the pixel in meters; and b == d == 0.

2.1.6 Exterior orientation - Frame sensors

Most aerial images are taken with a camera that follows the perspective camera model and are defined a point called the projection center. It is located at some (X0, Y0, Z0) world position, in the Cartesian object coordinate system (Fig. 8). The camera rotates about this point in 3D. This rotation defines 9 directional cosines between the axes of the two systems: camera and the object coordinate system (xX, xY, xZ, yX, yY, yZ, zX, zY, zZ). These cosines form an orthogonal 3x3 rotation matrix. The matrix is a function of three rotations: omega, phi, and kappa. There are many ways of arriving to the rotation matrix using different definitions for the rotations. Only the matrix is unambiguous. Because it is orthogonal, its inverse is simply the transposed matrix, and the direction of the mapping (scene – camera, camera – scene) is changed that way.

The set of six parameters {X0, Y0, Z0, omega, phi, and kappa} defines the exterior orientation – where the projection center (camera) was and how it was rotated about the projection center during exposure.

In Kuvamitt, the definition of the three rotations is such that the orthogonal R-matrix is given by the following nine equations.

R(1, 1) = Cos(phi)*Cos(kappa)
R(1, 2) = -Cos(phi)*Sin(kappa)
R(1, 3) = Sin(phi)
R(2, 1) = Cos(omega)*Sin(kappa)+Sin(omega)*Sin(phi)*Cos(kappa)
R(2, 2) = Cos(omega)*Cos(kappa)-Sin(omega)*Sin(phi)*Sin(kappa)
R(2, 3) = -Sin(omega)*Cos(phi)
R(3, 1) = Sin(omega)*Sin(kappa)-Cos(omega)*Sin(phi)*Cos(kappa)
R(3, 2) = Sin(omega)*Cos(kappa)+Cos(omega)*Sin(phi)*Sin(kappa)
R(3, 3) = Cos(omega)*Cos(phi)

If (X,Y,Z) is the point in the scene that is mapped to an image point in the focal plane (p_x, p_y), and the projection center is in point (X0, Y0, Z0), and c is the camera constant, the following subroutine yields the image points coordinates in the camera coordinate system:

```
Public Sub r_transform_3D(X, Y, Z, p_x, p_y, c, X0, Y0, Z0)
Dim k As Double
If (c <> 0#) Then
   k = (R(1,3)*(X-Xo) + R(2,3)*(Y-Yo) + R(3,3)*(z-Zo))
  Else
 k = 0#
End If
If (k <> 0) Then
  p_x = -c*(R(1,1) *(X-Xo)+R(2,1)*(Y-Yo)+R(3,1)*(z-Zo)) / k
  p_y = -c*(R(1,2) *(X-Xo)+R(2,2)*(Y-Yo)+R(3,2)*(z-Zo)) / k
Else
  p_x = p_y = 0#
End If
End Sub
```

Then, if this point is denoted (X, Y), its camera coordinates in meters are converted to an image position (column, row) using affine transformation. Parameters of it are a_, b_, c_, d_, e_, and f_:

```
Select Case direction
 Case 0 ' From camera coordinates to image coordinates (pixels)
  px = a_ * X + b_ * Y + c_
  py = d_ * X + e_ * Y + f_
 Case 1 'From image coordinates (pixels) to camera (m)
  px = (-e_*c_ + e_*X + f_*b_ - Y*b_) / (a_*e_ - b_*d_)
  py = -(a_*f_ - a_*Y - c_*d_ + X*d_) / (a_*e_ - b_*d_)
 End Select
End Sub
```

The code above can be used to check if an XYZ point maps to a particular image. The HDR-file of an image has the IO and EO orientation parameters. See (Appendix 1a – HDR-files, frame sensor).

2.1.7 Pushbroom sensors

A line-sensor has a focal plane as in any camera, but the photon detector is not a rectangular CCD array or a film frame. The image capture is done using a single or several line-shaped image detectors, such as 1xN pixel CCD row-detectors. Preferably, the lines are aligned in the direction of the x-axis in the camera, if the y-axis points to the direction of the flying. A sensor line in the middle of the focal plane views the scene right below the vertically mounted camera, to the left and right. A line at the back of the camera views the scene in front of the plane (Fig. 11).

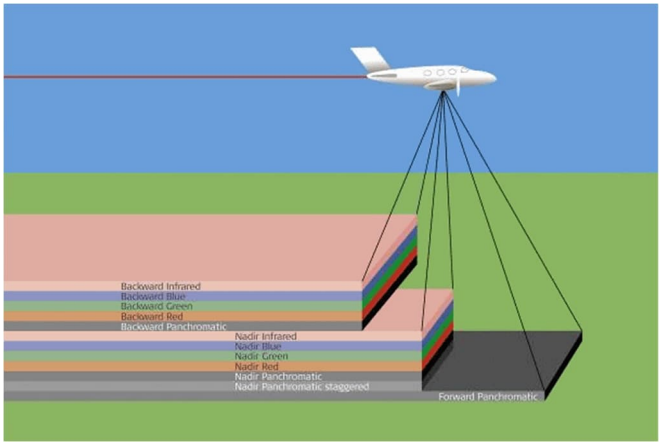


Fig. 11. A line sensor with 11 linear light sensing photodetectors on the focal plane, viewing the forward, nadir and backward directions.

A pushbroom sensor has similar optics to a frame camera, but there is no shutter, i.e. light is received on the focal plane through an aperture continuously. Typically, a beam splitter is used to deflect the different parts of the spectrum to the wanted detector lines (in multi- or hyperspectral sensors).

The photodetecting elements are allowed to integrate the signal for some milliseconds, and during this time the camera moves forward. Thus, the squared-shaped pixels capture a square-shaped area only if the ground speed and the integration time match.

The scene is flown over and as integration happens several hundred times per second, the consecutive lines form an 'image-mat' consisting of thousands of lines. The camera is mounted on a stabilizing platform, such that the movements of the aircraft do not show in the image (Fig. 12).

The perspective mapping, or the pinhole-camera principle, holds in push-broom (line) sensors as well. However, whereas in a frame sensor, where 'millions of image rays' map to the focal plane during the shutter release, when the camera is in a certain location and rotation, it is not possible to map an XYZ point to the push-broom image-mat in the simple way as depicted in Section (Exterior orientation - Frame sensors). A line sensors 'takes exposures' every few milliseconds and if the aircraft's nose turns quickly, the same point on the scene can map to several image lines, and some pixels may integrate light from an extended pixel as the camera rotates with the plane (the motion compensation is never perfect, Fig. 12).

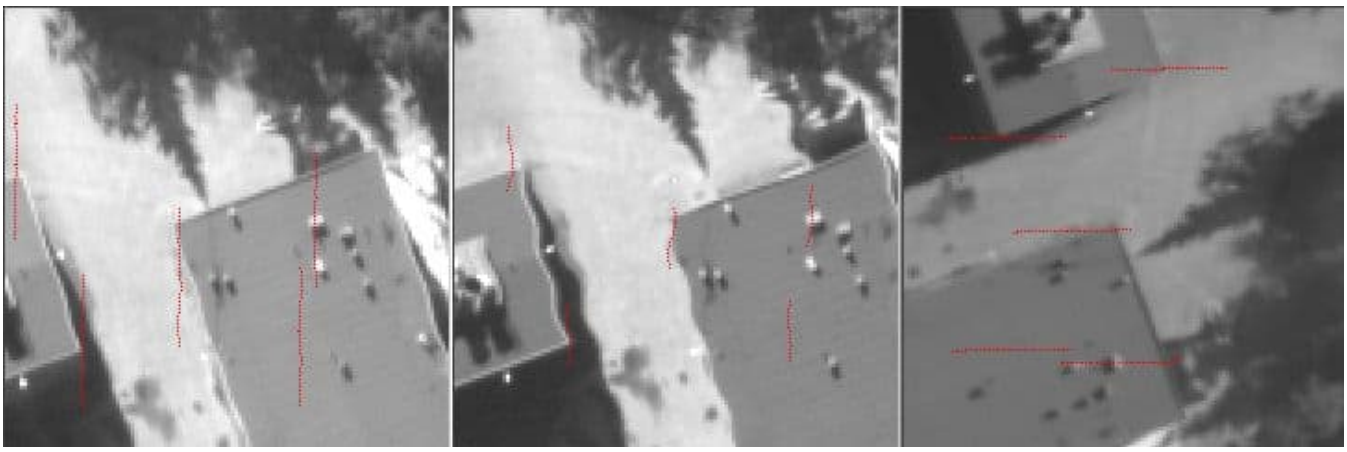


Fig. 12. Epipolar line segments in two ADS40 line-sensor Level-0 images (raw) and in one Level-1 (stereo-oriiented) image. The roof corners and chimneys were pointed in some fourth image, resulting in image rays (epipolar line segments) down towards to the scene. Segments of these lines over a Z-range of ± 5 m were drawn on the images. L0 images show the camera movement and epipolar lines become curved, while L1 image is projected to a plane and the epipolar line is nearly horizontal, enabling quick search along image rows and stereo viewing.

Because of the continuous collection of an image-mat, finding the right pixel for an XYZ point in the scene calls for iteration, and is computationally more expensive than the use of collinear equations for frame images that consist of some tens of operations. The iteration narrows down to the expected line and then finds the pixel in that line or interpolates between neighboring pixels on consecutive image lines.

The other direction is simpler. A pixel has certain camera coordinates (x,y) and was integrated during some time point t. The orientation information, set {X0, Y0, Z0, omega, phi, and kappa} is known for each time point, and the R-matrix is easily computed. The ray can be cast from the pixel via the projection center at position (X0, Y0, Z0) to the direction defined by the three angles towards the scene.

The experiment includes push-broom image data by ADS40 sensor.

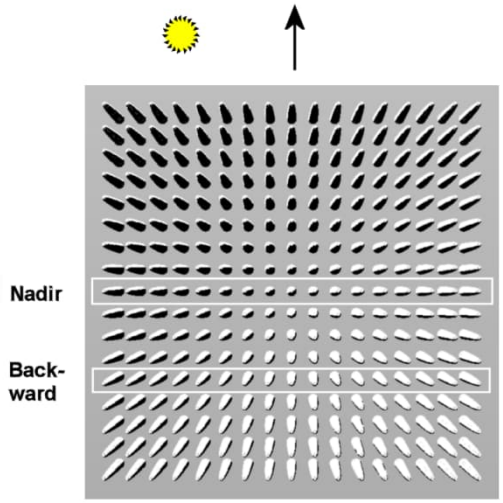


Fig. 13. The perspective distortion of trees is always the same in an image mat captured by a line. A linear sample in the polar coordinates of the BRDF (depends on the flying direction and solar azimuth.) is obtained.

2.1.8 Raw and projected images

An image was captured by the digital sensor array or film, which was scanned into a raw digital image. In multi-head cameras (pan-sharpening principle), the final image can consist of many sub-images, that exist as such, or that have been 'stitched together'. This fusion may involve correction for lens errors.

In film images, lens (and digitizer) errors are remnant in the raw images. In images taken with multi-head photogrammetric sensors, the errors are removed in post-processing. In terrestrial images, the lens errors remain but the correction functions are given to enable the re-projection into distortion-free 'metric' images.

Projected images can be images normalized to form stereo pairs (for stereo viewing), or orthoimages, or ADS40 line sensor images in which the camera movement is removed, and image is re-projected to some plane. Kuvamittt does not support extended camera models. The projected versions can be produced from the raw images using the lens error information, exterior and interior orientation information and appropriate software.

Fig. 14. A raw image scanned from the 18x18 cm aerial film (1946); north is 'to the left'. An orthoimage patch of the Kallenautio kestikievari. North is up, and each pixel corresponds to an XY location in a map projection.

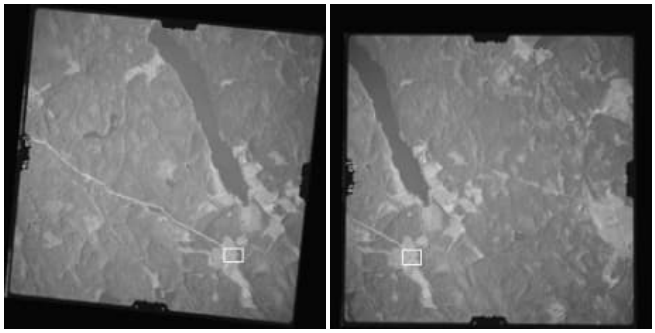


Fig. 15. Stereo normalized pair from 1946. The corresponding targets are on the same image lines (rows).

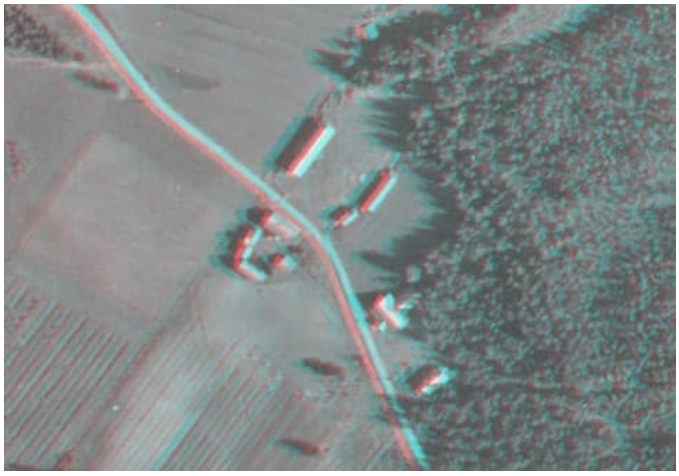


Fig. 16. Anaglyph stereo view. The left image and right image are superimposed with some offset in the column direction, and different colors are used for the left and right images (use red-blue glasses).

2.1.9 Campaign and frame/image ids

An image belongs to a campaign. For example, code FM97251 refers to the FM-Kartta company, year 1997 and their internal campaign number 251 comprising one strip of nine overlapping photographs on B&W film (Fig. 17). The exposures all have a unique code, numeric. It is essential to know the sensor and date of photography to have access to the right camera calibration certificate for information about focal length, position of the principal point, lens errors, lens MTF, radiometric features in digital sensors etc.

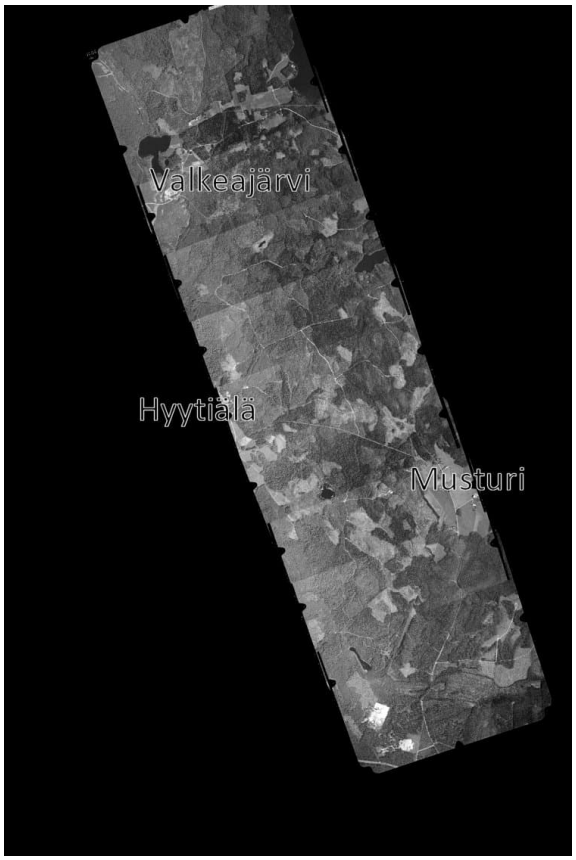


Fig. 17. The nine frame images of FM97251 (1:10000, B&W film) extend from Lapinkangas to Valkeajärvi

2.1.10 Solving the exterior orientation (EO) for frame images

The exterior orientation (EO), i.e. parameter set {X0, Y0, Z0, omega, phi, kappa} for each FRAME image has been established using bundle block adjustment, or aerial triangulation (AT).

AT uses redundancy, which is provided by image overlaps. Same scene points are seen in more than one image (Fig. 18). These are 'tie points'. Their XYZ coordinates are typically unknown.

Just by using tie points, it is possible to establish a bundle block that has the right relative geometry, but an arbitrary position (XYZ), scale and attitude (3 rotations).

Most tie points that 'tie together' 2–M images. In addition, there can be scene points for which X, Y and Z are observed (full control points), X and Y (planimetric), or just Z (height) is known. Using these observations, the bundle block is brought to the right position, attitude and scale. Alternatively, or as a complement, the unknown EO parameters per image {X0, Y0, Z0, omega, phi, kappa}, can be observed at some accuracy during the flight, by means of satellite positioning and inertial navigation systems. When such observations are available, AT is called GPS/IMU-assisted. Such systems have been on board since the early 2000s. The GNSS/IMU observations are available for many campaigns since 2002.

Weighted non-linear regression is used to solve the large system of linearized equations of AT. In it, weights are used to balance between different a priori error estimates. For example, the measurement accuracy of the control points may vary. It is possible to impose further 'observations' to the regression. For example, if three tie points (a, b, c) are known to be on a 3D line, or have the same Z (lake shoreline), such simple observation equations can be added to the system (Za – Zb = 0; Zb-Zc=0; Zc-Za=0).

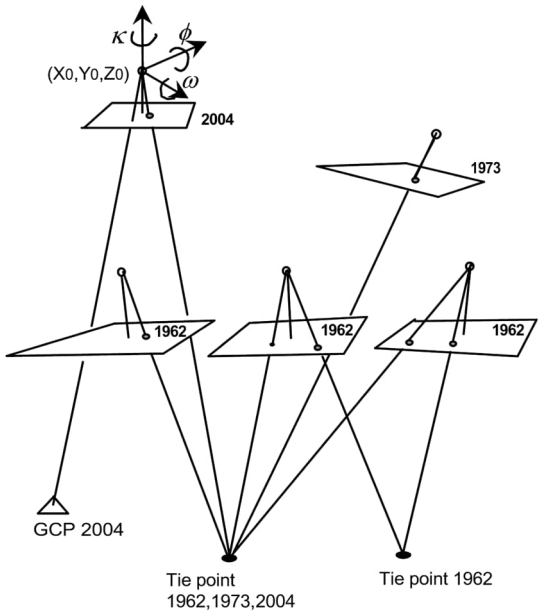


Fig. 18. Principle of multi-temporal aerial triangulation (AT) that combines ground control points (GCP), direct sensor observations and immobile points seen in multi-temporal images. The EO parameters are solved using AT.

AT of vertical aerial images is highly automated, and manual AT should be avoided, because it is a laborious task, but has been done in many cases in Hyytiälä as commercial software was lacking.

2.1.11 KUVAMITT HDR files

Each aerial image comes with a header file, *. HDR (Appendix 1a – HDR-files, frame sensor, Appendix 1b – HDR-files, line-sensor).

An HDR-file is ANSI-coded text, and shows the exterior and interior orientation parameters, image size, color model, mm.

Potential future improvements to the HDR-files (additional attributes, now lacking) include:

- Date and time of photography
- Camera model (string)
- Free notes (string)
- Coordinate system (string)
- Camera calibration (lens errors) parameters and/or distortion values, LUT-style

2.1.12 UTM – KKJ conversion, Geoid corrections

When activities in Hyytiälä began, KKJ-2/N60 system was well alive, and is therefore used still (2024).

Since about 2010, ETRS-TM35FIN coordinate system has been in use in Finland. A cm-accurate local conversion between KKJ-2/N60 and the UTM35 (x,y) / WGS84 ellipsoid heights (z) exists:

```
YKJ_Y = 1.000402868 * UTM_Y +
        -0.000006294037 * UTM_X + 116.5155

YKJ_X = 0.000007547778794 * UTM_Y +
        1.000404696 * UTM_X + 2999916.234

KKJ_x = -0.04613085453 * YKJ_Y +
        0.998685712 * YKJ_X - 521029.6315

KKJ_y = 0.04614063371 * YKJ_X +
        0.9986922807 * YKJ_Y - 148875.5398

N60 = WGS84_H - 18.67 // (Geoid FIN2000)
```

Here YKJ refers to the Gauss-Kruger projection along longitude 27 i.e. the KKJ-3 zone, while KKJ is KK2-2 zone (longitude 24).

18.67 m is the Geoid correction for N60 in Hyytiälä. It is the difference between WGS84 ellipsoidal heights and N60 orthometric heights. N2000 orthometric heights - add 0.32 m to N60 elevations in Hyytiälä.

Note, a new height system is introduced in Finland. The geoid models are kept-up-to date, and for example the model N2010 shows a different geoid correction to (mean sea level) because of 'land upthrust', some 4 mm/a.

See also EurefMuunnos.exe, and the FGI's website site for coordinate transformations.

N.B. It is not possible to redefine the exterior orientation of the images without careful consideration of the different coordinate systems. To convert the image EO to another system, it is advisable to first find conjugate points (X,Y,Z) and their image positions (x,y) on the images, then convert the XYZ to the new system XYZ_{new}, and carry out bundle block adjustment in the new XYZ system. This has been done in e.g. the 2020 RGB-imaging campaign.

There may be (advanced) ways of finding the 3D rotation + offset (for the six EO parameters) for each image that considers the exact rotations and offsets between the two XYZ systems in that very point. E.g. the direction Z-axis of KKJ/N60 changes continuously in space (the rotation between KKJ xyz and any other system). Such conversions might be found in some sophisticated photogrammetric systems.

2.2 Analogue film images 1946-2004

All large-scale images covering Hyytiälä have been looked for from the archives of the National Land Survey, Topografikunta and, Finn-map/Blom Finland, and the photographs were digitized using high-grade photogrammetric scanners at pixel sizes of 14, 15 and 21 micrometers, 8 bits per color per pixel. This work was mostly done in 2005–2006. The formats were variants of TIFF, but the stored raw images are in row order, [RGB] or grey-level, one byte per pixel (unsigned 8-bit char), band-interleaved-by-pixel –type (BIP). The HDR-files are needed to determine the W and H of the raw-images.

The camera calibration certificates were collected, and these include information on the calibrated camera constant, location of the fiducial marks in the camera coordinate system, position of the principal point with respect to the fiducial marks, information on the radial and tangential lens distortions etc., i.e. parameters for the interior orientation.

Older film frames were 18 x 18 cm in size (1940s), later a 23x23-cm size was used.

A fiducial mark transformation (affine) has been estimated for each frame. It can be used to convert the column-row image observations the metric x,y camera coordinates. See the HDR-files.

$$\begin{bmatrix} x_{new} \\ y_{new} \end{bmatrix} = \begin{bmatrix} a & b & c \\ d & e & f \end{bmatrix} \begin{bmatrix} x_{old} \\ y_{old} \\ 1 \end{bmatrix} \qquad \begin{aligned} x_{new} &= ax_{old} + by_{old} + c \\ y_{new} &= dx_{old} + ey_{old} + f \end{aligned}$$

The old images were oriented using tie points (Fig. 18) and control points (Fig. 19). See (Korpela, 2006) in Silva Fennica.

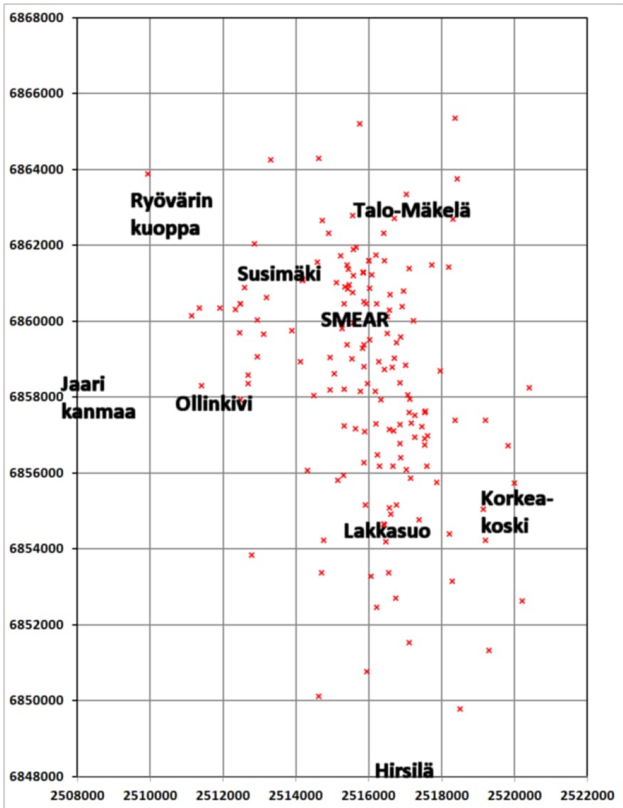


Fig. 19. Control points (XYZ, Z) used in the triangulation of 1946–2004 film images. Reliable EO information is available only for the area and images enclosed by the CPs. CPs were stones and man-made structures.

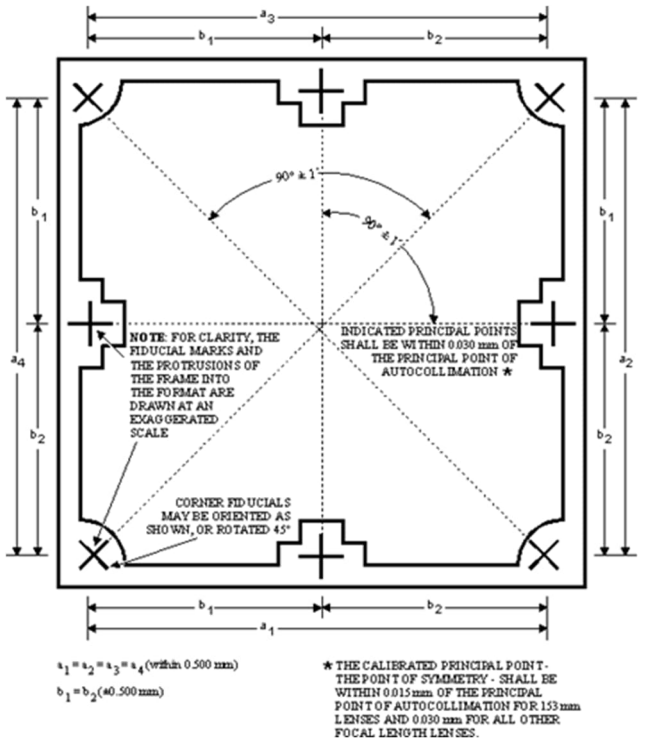


Fig. 20. USGS principle image of fiducials.

2.3 Digital frame-camera images 2006–

Since 2006 most (frame-type) aerial imaging has been done with multi-head digital sensors following the PAN-sharpening principle.

The term multi-head means that the device consists of multiple cameras each of which has its own lens, shutter and focal plane (Fig. 21). The shutter releases may be timed to compensate for camera forward movement during the few milliseconds of exposure.

PAN stands for panchromatic, i.e. wide spectral response in the visible-near-infrared spectrum, ~ B&W film. A high-resolution PAN image is a mosaic of several sub-images that are captured by several lenses. The mosaic is a perspective image, and in the mosaicking (stitching) process, interpolation is done, thus the very original image structure of the sub-images may not be entirely preserved.

Multispectral (MS) imaging is done with separate cameras for each band. They typically have a different focal length, thus larger pixels on the ground, but the field-of-view matches that of the mosaicked PAN image. Filters are used to get a narrower spectral response at blue, green, red, and near-infrared bands. These MS images have a different resolution, lower compared to PAN. The ratio of the pixel sizes is called the PAN-sharpening ratio.

The post processing software of the camera manufacturer is needed to output the different image products, and they differ between sensors.

- The very raw PAN sub-images are typically not available
- The stitched PAN image with high resolution is available (PAN level2 or PAN- Level3, and the IO and EO can be defined for this image. These images have PRNU-calibration.
- The raw MS images are available, but it may not be possible to define the IO and EO for these, to map XYZ scene points to a R/G/B/N band pixel. Level2 RGBN images have EO and PRNU calibration.
- PAN-sharpened image (color or color-infrared) is available. The method of PAN-sharpening s.b. known. In that process the MS information is used to 'color' the high-resolution PAN image and this process affects the radiometry of the final product.

2.3.1 UltraCAM-series

UltraCAM series (D and Xp) of cameras were used in 2006, 2007 2010, and 2012. Later UltraCam models in 2015, 2018, 2020, 2022 and 2023. The camera captures images with 4 PAN + 4 multispectral CCDs. These images have lens errors, and the PAN images have overlap. The four PAN images are called L1 images and processed into a single perspective PAN image with lens errors removed (the PAN images are stitched). There are five L2 images: PAN, BLU, GRN, RED, and NIR. PAN-sharpening is used to combine the grey-levels and details of the high-resolution PAN-image with the multispectral channels to produce Level-3 images that have as many pixels as the PAN image has. The radiometry of these is highly changed and these should be used for visualization only.

Fig. 21. Top: UltraCamX with four multispectral lenses and four PAN lenses. Bottom: Z/I imaging DMC II (Hyytiälä 2009).

2.3.2 DMC

In 2009, a z/I imaging DMC camera was used, which is also a multi-head device (Fig. 21). See Section (2009 DMC morning/noon flights). Like the UltraCam sensors, the user has access to post processed 'virtual' images. National land survey has since captured topographic images with the same sensor. The DMC at NLS was abandoned in 2016?

2.3.3 Hasselblad

In 2011, 2013 and 2015 a Haselblad camera was operated in the LiteMapper Waveform LiDAR sensor system that combines imaging

and laser scanning. The RGB sensor is metric as the lens errors are in the sub-pixel range (< 6 um).

2.3.4 Titan RGB camera

During the LiDAR of 2016 (Titan 3-band LiDAR), there was an RGB sensor capturing images. The lens errors were not entirely removed by the calibration.

2.3.5 Riegl 1550 RGB camera (2018, 2020,2023)

These LiDAR campaigns were done during the daytime and an RGB sensor captured images during the acquisition. The resolution of the sensor was the highest in the 2023 sensor system.

2.4 Additional data during campaigns

This section is incomplete (diary type). Since 2010 the vegetation is mostly documented by field photography when a LiDAR or imaging campaign took place.

* Sudenkytö road, i.e. 'Sudenkydön lenkki' got a layer of crushed stones in spring 2006 (LiDAR of 2006). This enabled its use for radiometric calibration of LiDAR in 2006/07.

* Fields of Ala-Hyytiälä had turnip mustard in 2007, oat in 2006 (LiDAR intensity calibration of 2007)

* Shape files of Lauri Korhonen (Canopy Cover, 2009)
hyde_ccplots_shp.zip

* Removal of gravel from roofs of buildings A/B/C – autumn 2007.

* Weather data, in-situ reflectance measurements, reflectance tarps BRDFs, camera calibration certificates etc. (to be completed)

* High-voltage power lines were dismantled in 2023

* Hyytiälä buildings (dormitories) from 1977 were dismantled in 2024 and their bitumen roofs or linear structures no longer serve as calibration taskets.

2.5 The aerial image campaigns

Table 1. Characteristics of imaging campaigns.

Campaign	Scale	Color model	Pixel, cm	Sensor	SMEAR	Susi-mäki	Lakka-suo	Siika-neva	Speciality
1946-S533	1:20000	BW	30	f=20 cm	1	0	1	0.5	
1946-S537	1:20000	BW	30	f=20 cm	0	1	0	0.5	
1946-S544	1:20000	BW	30	f=20 cm	1	0	1	0	includes series S550
1962-62121C	1:16000	BW	24	f=15 cm	1	1	0	0	Clouds
1963-6306	1:60000	BW	90	f=15 cm	1	1	1	1	Overview of the whole Hyytiälä area
1966-66163	1:20000	BW	30	f=15 cm	1	1	1	0.2	
1969-69113	1:13000	BW	19	f=15 cm	0	1	0	0	Along road 66, for road construction
1973-73166	1:21600	RGB	32	f=15 cm	1	1	1	0.2	
1973-73204	1:21600	CIR	32	f=15 cm	1	1	1	0.2	
1977-KT7736	1:17500	BW	25	f=15 cm	1	1	1	0	
1983-89193	1:12400	BW	19	f=15 cm	0	0	0	0	Along Väärinmaja-road, for road construction
1984-84128	1:16000	BW	24	f=21 cm	1	0	1	0	
1985-85151	1:15000	CIR	21	f=15 cm	0	1	0	0	Research (Poso et al.)
1985-85230	1:10000	CIR	14	f=15 cm	1	0	0.5	0	"
1985-85231	1:10000	BW-IR	14	f=15 cm	1	0	0.6	0	"
1985-85232	1:20000	CIR	28	f=15 cm	1	0	1	0	"
1985-85233	1:30000	CIR	42	f=15 cm	1	1	1	1	Orientation in Siikaneva is uncertain, lack of GCPs
1986-86100	1:30000	CIR	42	f=15 cm	1	0	0	0	SMEAR obstructed by a cloud
1986-86286	1:30000	CIR	42	f=15 cm	0	1	0	0	
1988-88086	1:30000	CIR	42	f=15 cm	1	1	1	0.5	
1989-89204	1:30000	CIR	42	f=15 cm	1	1	1	0.1	
1989-89254	1:5000	CIR	8	f=15 cm	1	0	0	0	SMEAR not in stereo
1991-91142	1:30000	CIR	42	f=15 cm	1	0	1	0	
1992-92064	1:30000	CIR	42	f=15 cm	1	1	0	1	
1992-92199	1:5000	CIR	8	f=15 cm	0	0	0	0	
1995-95267	1:5000	CIR	8	f=15 cm	0	0	0	0	Joensuu-Helsinki commaloration, ministry of agr.for.
1995-95268	1:20000	CIR	28	f=15 cm	1	0	0	0	"
1995-95269	1:30000	CIR	42	f=15 cm	1	1	1	1	"
1995-95270	1:50000	CIR	70	f=15 cm	1	1	1	1	"
1997-97248	1:5000	CIR	8	f=15 cm	1	1	0	0	ilkka korpela's licentiate thesis photography
1997-97249	1:16000	CIR	22	f=15 cm	1	0	0	0	"
1997-97250	1:5000	BW	8/10	f=15 cm	0	0	0	0	"
1997-97251	1:10000	BW	21	f=15 cm	1	0	0	0	"
1998-98110	1:16000	BW	24	f=21 cm	1	0	1	0	NLS-topographic
1999-99108	1:16000	BW	24	f=21 cm	1	0	1	0	
1999-99264	1:30000	CIR	42	f=15 cm	1	1	0	0.2	
2000-00106	1:16000	BW	24	f=15 cm	1	0	0	0	
2002-02204A	1:6000	RGB	9	f=15 cm	1	0	0	0	
2002-02204B	1:6000	CIR	9	f=15 cm	1	0	0	0	

Table 2. Continues

Campaign	Scale	Color model	Pixel, cm	Sensor	SMEAR	Susi-mäki	Lakka-suo	Siika-neva	Speciality
2002-02205	1:12000	CIR	18	f=15 cm	1	0	0	0	
2002-02206	1:16000	CIR	22	f=15 cm	1	0	0	0	
2002-02207	1:30000	CIR	42	f=15 cm	1	0	1	0	
2004-04402	1:14000	CIR	21	f=21 cm	1	0	0.5	0	
2004-04403	1:8000	CIR	12	f=21 cm	1	0	0.3	0	
DIGITAL IMAGING starts from 2006 - no more film photography									
2006-06205	5800 m	PAN-CIR	51	Ultracam-D	1	1	1	0.8	Only PAN-sharpened CIR (24 bit) images stored
2006-06214	1000 m	PAN, RGBN	8.5/27	Ultracam-D	1	0	0	0	L3 (PAN-CIR, 24 bit), L2 PAN (16 bit), L2 RGBN (64 bit)
2007-07015	2350 m	PAN, RGBN	20/64	Ultracam-D	1	0	1	0	L3 (PAN-CIR, 24 bit), L2 PAN (16 bit), L2 RGBN (64 bit)
2008-ADS40_1	1000 m	PAN, RGBN	10	ADS40-SH52	1	0	0.5	0	L0 raw, L1 ASR, ATM,
2008-ADS40_2	2000 m	PAN, RGBN	20	ADS40-SH52	1	0	1	0	L0 raw, L1 ASR, ATM, BRDF, FULL (corrections)
2008-ADS40_3	3000 m	PAN, RGBN x 2	30	ADS40-SH52	1	1	1	0	L0 raw, L1 ASR, ATM, BRDF, FULL (corrections)
2008-ADS40_4	4000 m	PAN, RGBN x 2	40	ADS40-SH52	1	1	1	0	L0 raw, L1 ASR, ATM, BRDF, FULL (corrections)
2009-DMC-1101	2000 m	PAN, RGBN	20/80	Z/I imaging DMC I	1	0	1	0	sun at 25 degrees; L3 32 bit RGBN-PAN, L2 16-bit PAN, L2 48 bit RGBN
2009-DMC-1102	3000 m	PAN, RGBN	30/120	Z/I imaging DMC I	1	0	1	0	sun at 25 degrees; L3 32 bit RGBN-PAN, L2 16-bit PAN, L2 48 bit RGBN
2009-DMC-1103	4000 m	PAN, RGBN	40/160	Z/I imaging DMC I	1	0	1	0	sun at 25 degrees; L3 32 bit RGBN-PAN, L2 16-bit PAN, L2 48 bit RGBN
2009-DMC-1104	2000 m	PAN, RGBN	20/80	Z/I imaging DMC I	1	0	1	0	sun at 45 degrees; L3 32 bit RGBN-PAN, L2 16-bit PAN, L2 48 bit RGBN
2009-DMC-1105	3000 m	PAN, RGBN	30/120	Z/I imaging DMC I	1	0	1	0	sun at 45 degrees; L3 32 bit RGBN-PAN, L2 16-bit PAN, L2 48 bit RGBN
2009-DMC-1106	4000 m	PAN, RGBN	40/160	Z/I imaging DMC I	1	0	1	0	sun at 45 degrees; L3 32 bit RGBN-PAN, L2 16-bit PAN, L2 48 bit RGBN
2010-UCXp	2500 m	PAN, RGBN	15/45	Ultracam-Xp	1	0	0	0	L3 (PAN-CIR, 24 bit), L2 PAN (16 bit), L2 RGBN (64 bit)
2011-Hasselblad	750 m	RGB	12	Hasselblad H4D-50	1	0	0	0	24-bit RGB; leaf-off November
2012-UCD	1500 m	PAN, RGBN	13/42	Ultracam-D	1	0	0	0	L3 (PAN-CIR, 24 bit), L2 PAN (16 bit), L2 RGBN (64 bit)
2013-Hasselblad	750 m	RGB	12	Hasselblad H4D-50	1	0	0	1	24-bit RGB; Early summer, separate blocks in Siikaneva
2015-UCXp	5000 m	RGBN 8bit	10	UltraCam SXp	1	1	1	0	By NLS, only 12 images were acquired in 2018 for FOR254
2015-Hasselblad	750 m	RGB	12	Hasselblad H4D-50	1	0	0	0	24-bit RGB; Late summer, overexposure.
2016-Titanf	1000 m	RGB	10	CS10000 integrated	1	0	1	0	24-bit RGB; June 14, manual relative orientation with iWitnessPro
2018-Riegl	1200 m	RGB	10	IXU-RS2001	1	0	0	0	24-bit RGB, automatic aerial triangulatoin.
2020-Riegl	1200 m	RGB	10	IXU	1	0	0	0	24-bit RGB, repeats 2018-Riegl imaging, June 3
2020-UCam	3300 m	PAN, RGBN	13/42	Ultracam	1	0	1	0	Vexcel ultracam, June 10, low solar elevation, LvL2 and Lvl3
2022-NLS	7000 m	RGBN 8bit	40	UltraCAM Eagle	1	1	1	?	May 25, not yet full leaf condx, low solar elevation, only LvL3 RGBN
2023-Riegl	1200 m	RGB	10		1	0	0	0	
2023-UCam	3300 m	PAN, RGBN	13/42	UltraCam	1	0	1	0	

2.5.1 1946 Black & White (BW) - old land use in Hyytiälä

In 1946 the first cartographic images were acquired in the Hyytiälä area by Maanmittaushallitus. A horizontal camera was used (developed by Nenonen), and the camera was mounted to a Blenheim WWII bomber. The film is nitrate based in safety stock at Topografikunta. The two horizon images are not always (see S537) included in the scans. Images were oriented as a part of the 1946–2004 block, see (Korpela, 2006).

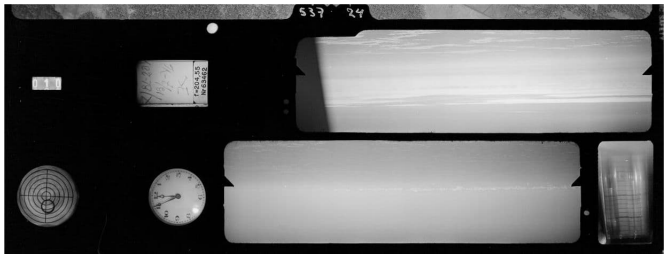


Fig. 22. S537 photo 24 was taken at 11:55, July 13, 1946.The horizon photos are shown.

S4728 is from Lyly and images were not oriented. The scans were acquired by a mistake done at Topografikunta who did the scanning in 2005.

S533

Due to wind, the coverage had suffered. Reaches from Korkeakoski in the East, to Lakkasuo in South, Siikakanges in West and N end of Kuivajärvi in the north.

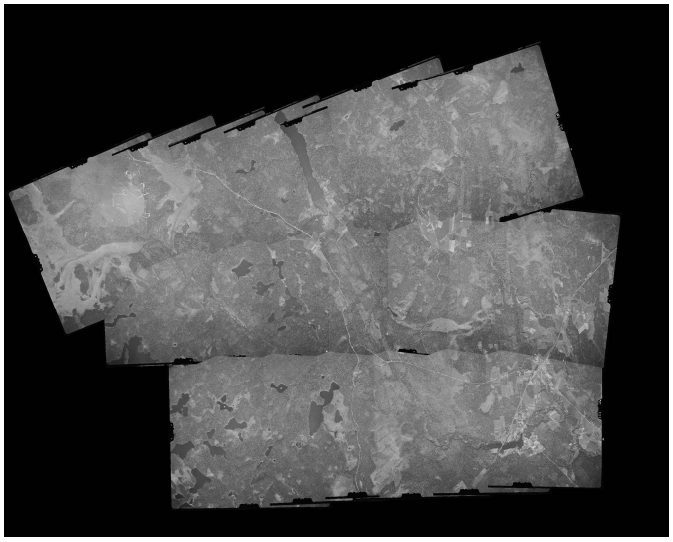


Fig. 23. Campaign 533. N=21 images, 06.06.1946, 10:27-12:00, BW, 1:20000, f=20cm/18x18 cm film, 15 microns.

Files stored (126 Files, 5 Folders, 6 349 916 028 actual bytes)

- Aerial_Images\533\Histogram
  Number of pixels by grey level
- Aerial_Images\533\Info
  Scanner parameters
- Aerial_Images\533\QuickView
  Decimated JPGs
- Aerial_Images\533\HDR
  Kuvamitt HDR files
- Aerial_Images\533\Images
  Image files in TIFF and RAW format

S537

Photography for the Map sheet north of Hyytiälä: Siikakangas – Talo-Mäkelä (6860000 North). Horizon camera parts of film scanned.

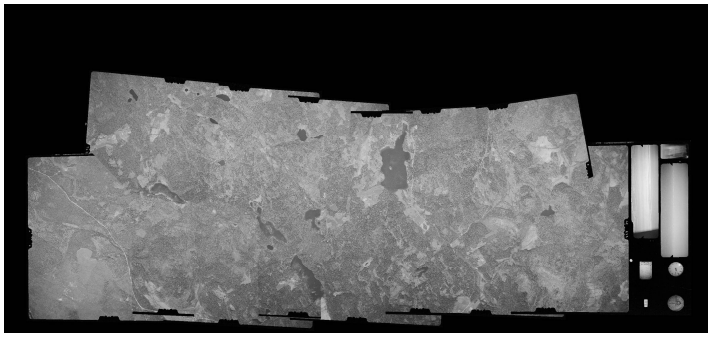


Fig. 24. Campaign S537. N=14 images, 13.07.1946, 12:45-15:30, BW, 1:20000, f = 20 cm/18x18 cm film, 15 microns

Files stored (84 Files, 5 Folders, 4 341 415 980 actual bytes)

- Aerial_Images\537\Histogram
  Number of pixels by grey level
- Aerial_Images\537\Info
  Scanner parameters
- Aerial_Images\537\QuickView
  Decimated JPGs
- Aerial_Images\533\HDR
  Kuvamitt HDR files
  - Aerial_Images\533\Images
    Image files in TIFF and RAW format

S544 & S550

Patch up campaigns. There were no GPS instruments those days to control the imaging locations. S544 is south of Hyytiälä: Lakkasuo-Huikonkangas. S550 has Hyytiälä in the middle.

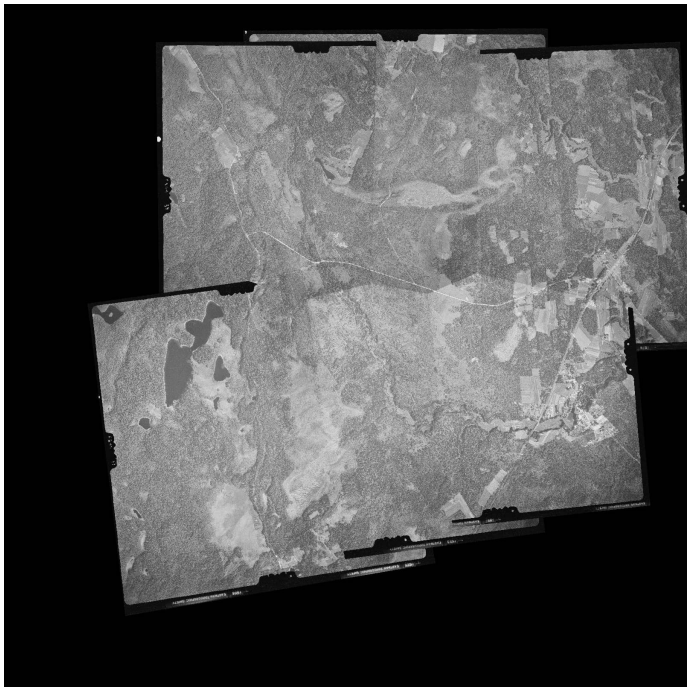


Fig. 25. Campaign S544, N=6 images, 17.07.1946 08:?? BW, 1:20000, f= 20 cm / 18 x 18 cm film, 15 um, Camera # 63462; A patch up?

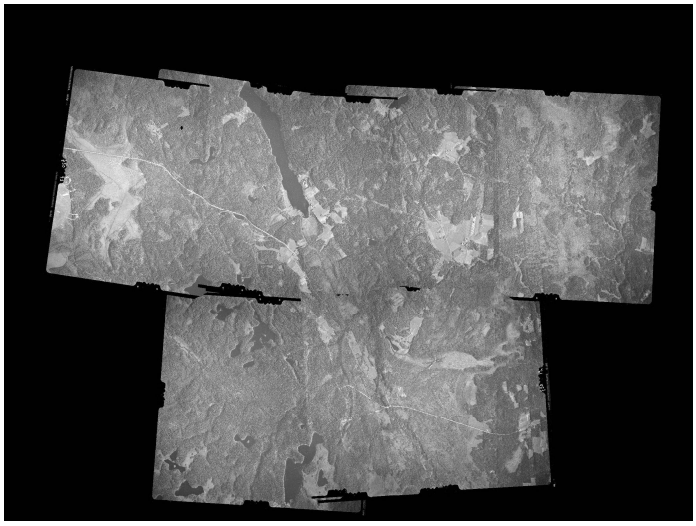


Fig. 26. Campaign S550. N=11 images, 20.08.1946 08:05-08:40, BW, 1:20000, 20/18, 15 um, Camera Mh N3; f=20.5 cm; Super XX film, A patch up.

Files stored (144 Files, 5 Folders, 3 383 043 366 actual bytes)

- Aerial_Images\544_550\Histogram
  Number of pixels by grey level
- Aerial_Images\544_550\Info
  Scanner parameters
- Aerial_Images\544_550\QuickView
  Decimated JPGs
- Aerial_Images\544_550\HDR
  Kuvamitt HDR files
- Aerial_Images\544_550\Images
  Image files and tiles in RAW format (see also the els file)

2.5.2 1962 BW - SMEAR stand clear-cut and burned

A small set of four scanned images that suffer from shadows cast by clouds. From Siikakangas to Mäkelänjärvi. Shows SMEAR stand right after prescribed burning in 1961!.

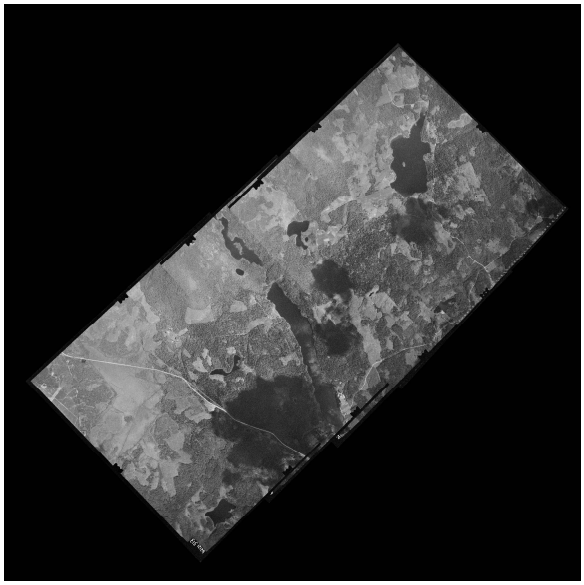


Fig. 27. campaign 62121C, N=4 images, 24.06.1962 09:23-09:26, BW, 1:16000, f=15/23x23 cm film, 15 um.

Files stored (8 Files, 2 Folders, (975 439 565 actual bytes)

- Aerial_Images\62121\HDR
  Kuvamitt HDR files
- Aerial_Images\62121\Images
  Image files in RAW format

2.5.3 1963 BW - Overview of the surrounding area to Hyytiälä

High-altitude 1:60000 photographs covering a large area around Hyytiälä. Acquisition date unknown. Orientation accuracy is lower far (> 5 km) away from Hyytiälä, from where there were few or no ground control points. 90-cm pixels (15 um).

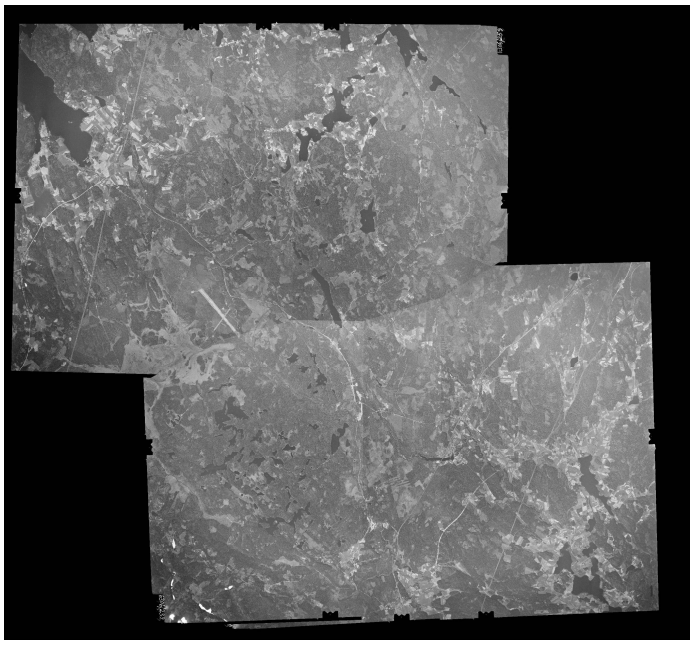


Fig. 28. Campaign 6306, N=6 images, dd.mm. 1963, hh:mm, BW, 1:60000, 15 cm/23x23 cm, 15um.

Files stored (36 Files, 5 Folders, 2 936 259 750 actual bytes)

- Aerial_Images\6306\Histogram
  Number of pixels by grey level
- Aerial_Images\6306\Info
  Scanner parameters
- Aerial_Images\6306\QuickView
  Decimated JPGs
- Aerial_Images\6306\HDR
  Kuvamitt HDR files
- Aerial_Images\6306\Images
  Image files in RAW and TIFF format

2.5.4 1966 BW - first forestry images

The first forestry campaign for Korkeakosken hoitoalue (forest district), head of which was the university's forester, and the office in Hyytiälä, in the Tapiola building.

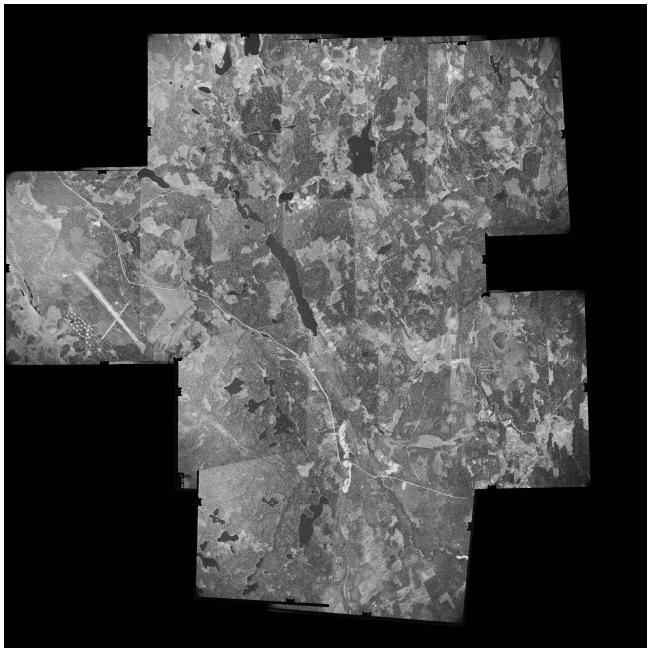


Fig. 29. Campaign 66163, N=15 images, 10.06.1966, 08:36-09:13, BW, 1:20000, f=15/23x23 cm film, 15 um.

Files stored (31 Files, 2 Folders, 3 611 865 449 actual bytes)

- Aerial_Images\66163\HDR
  Kuvamitt HDR files
- Aerial_Images\66163\Images
  Image files in RAW format

2.5.5 1969 BW - photography for construction of road 66

From Lapinkangas in SE to Siikakangas in NW. Ordered by Tie ja vesihallitus (TVH).

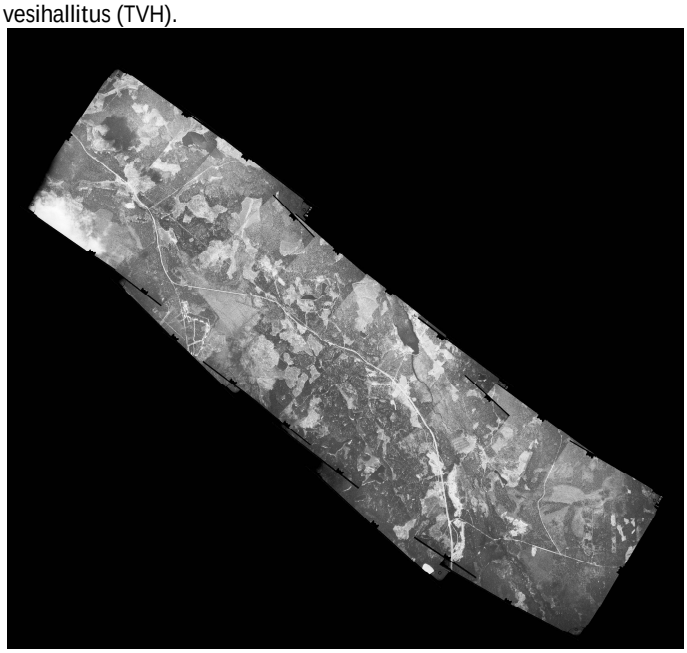


Fig. 30. Campaign 69113, N=9 images, 09.05.1969, 12:40-13:04, BW, 1:13000, f=15/23x23 cm, 15 um.

Files stored (29 Files, 2 Folders, 2 188 313 202 actual bytes)

- Aerial_Images\69113\HDR
  Kuvamitt HDR files
- Aerial_Images\69113\Images
  Image files and tiles in RAW format (see the els file)

2.5.6 1973 Color and CIR - Topographic mapping

73166

From Lauttakangas in S, Korkeakoski in W, Talo-Mäkelä in N to Siikakangas in NW.

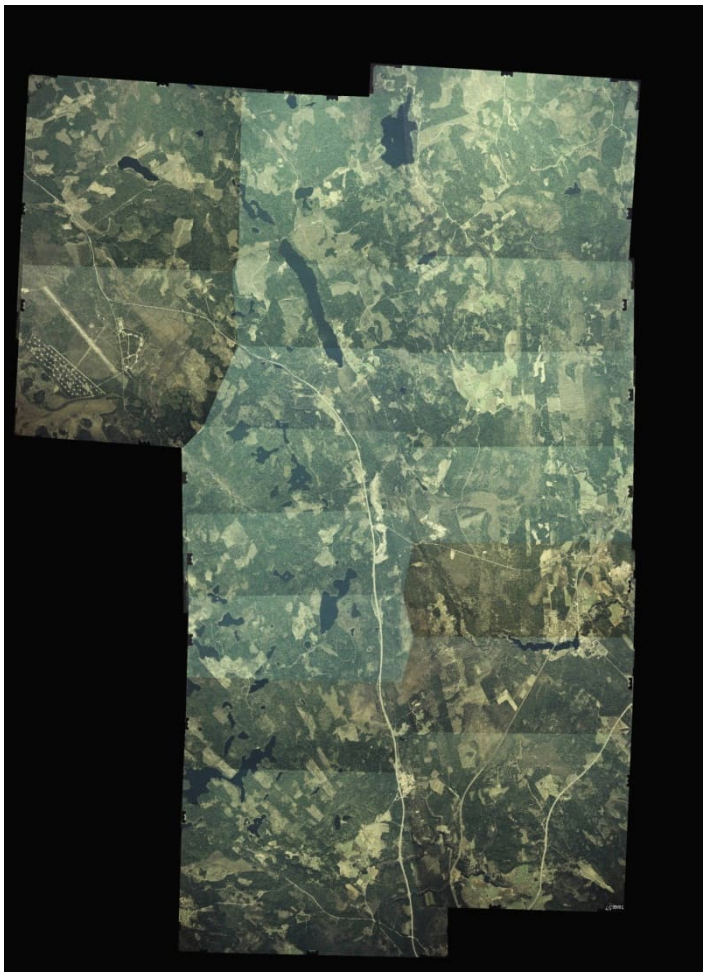


Fig. 31. Campaign 73166. N=17 images, 20.05.1973, 11:55-13:10, COL, 1:21600, f=15/23x23 cm, 15 um.

Files stored (35 Files, 2 Folders, 11 941 082 578 actual bytes)

- Aerial_Images\73166\HDR
  Kuvamitt HDR files
- Aerial_Images\73166\Images
  Image files in RAW format

73204

As 73166, but on CIR film. A bit of overexposure.

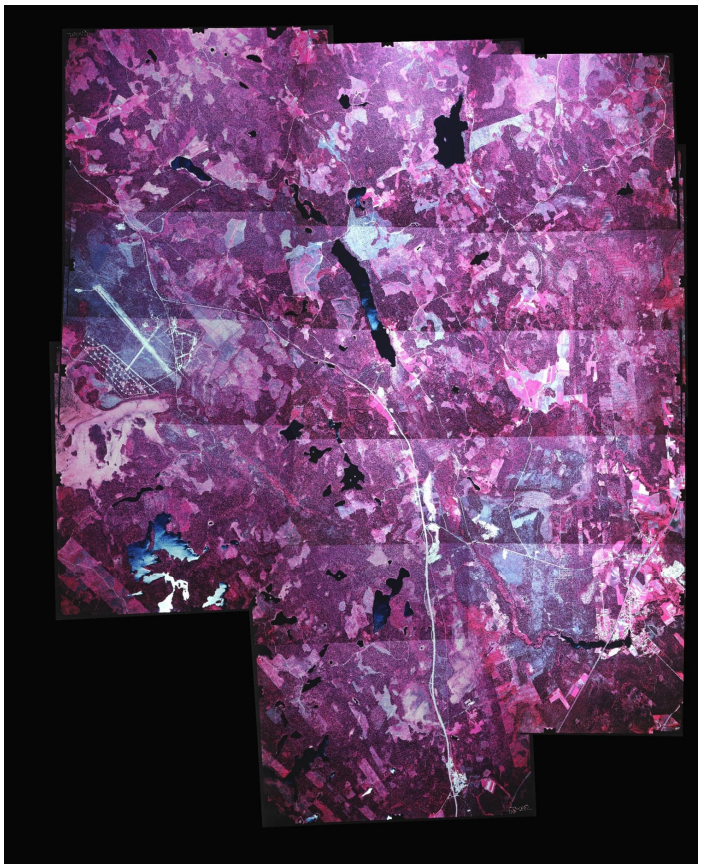


Fig. 32. N=17, 20.05.1973 11:55-13:10 COL, 1:21600, 15/23, 15 um

Files stored (47 Files, 2 Folders, 10 936 281 636 actual bytes)

- Aerial_Images\73204\HDR
  Kuvamitt HDR files
- Aerial_Images\73204\Images
  Image files and tiles in RAW/TIFF format (see the els file)

2.5.7 1977 BW - Orienteering; '77 buildings

KT7738 by Kunnallistekniikka company. Shows the Hyytiälä with the construction of many buildings in 1977.

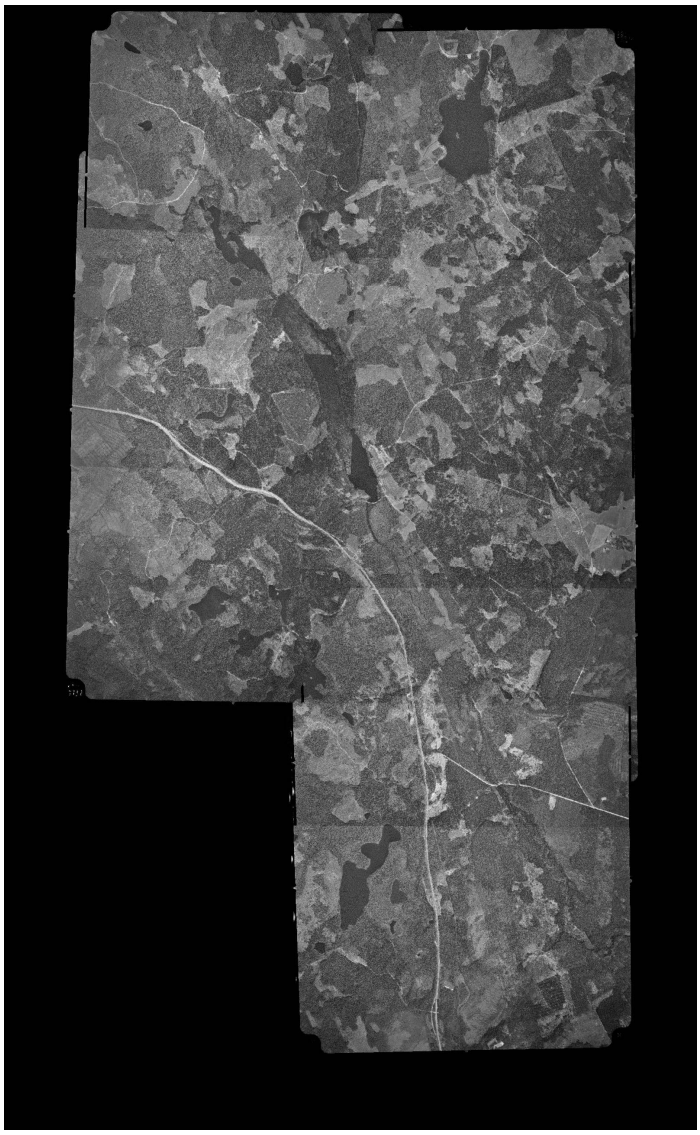


Fig. 33. N=11, 21.05.1977 09:30-09:40 BW, 1:17500, 15/23, 14 um.

Files stored (34 Files, 2 Folders, 3 038 395 309 actual bytes)

- Aerial_Images\7738\HDR Kuvamitt HDR files
- Aerial_Images\7738\Images RAW image files and TIFF tiles

2.5.8 1983 BW – Väärinmaja-road construction

83193

Along the Väärinmaja road from Lapinkangas to Toiviojärvi.

Fig. 34. Campaign 83193, N=11 images, 22.05.1983 10:56-11:04 BW, 1:12400, f= 15/23, 15 um.

Files stored (34 Files, 2 Folders, 2 636 982 657actual bytes)

- Aerial_Images\83193\HDR Kuvamitt HDR files
- Aerial_Images\83193\Images Image files and tiles in RAW format (see the els file)

2.5.9 1984 BW – Topographic mapping

84128

Narrow-angle camera images in leaf-off conditions. KKJ map sheet south of Hyytiälä.

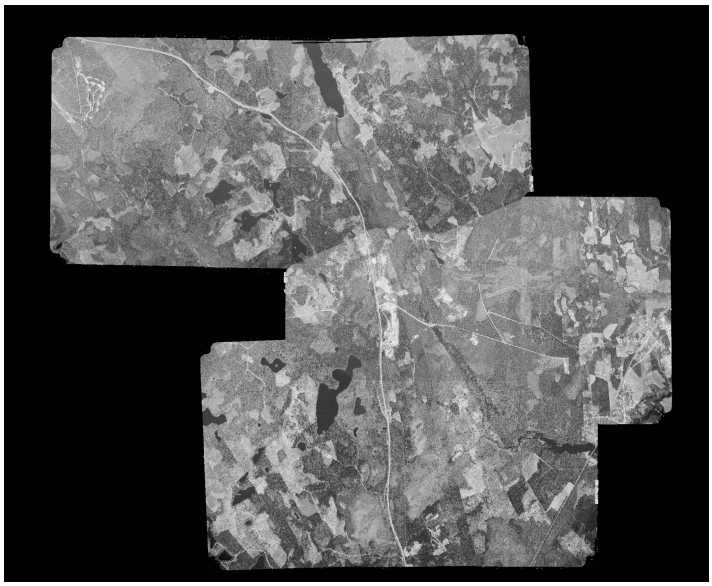


Fig. 35. Campaign 84128A, N=10 images, 13.05.1984, 09:55-11:36, BW , 1:16000, f=21/23x23 cm, 15 um.

Files stored (20 Files, 2 Folders, 2 421 522 046 actual bytes)

- Aerial_Images\84128\HDR Kuvamitt HDR files
- Aerial_Images\84128\Images Image files and tiles in RAW format (see the els file)

2.5.10 1985 CIR and BW-infrared for forestry/research

Images taken by Finnmap company (A company following Kunnallistekniikka, film archives possessed by FM-kartta, Blom Geomatics in 2013)

85151

CIR image triplet with Susimäki-Karhujärvi area in stereo.

Fig. 36. 85151; N=3, 26.06.1985, 12:05, CIR, 1:15000, 15/23, 14 um

Files stored (9 Files, 2 Folders, 2 485 925 184 actual bytes)

- Aerial_Images\85151\HDR
  Kuvamitt HDR files
- Aerial_Images\85151\Images
  Image files and tiles in TIF format

85230

Single strip with 8 CIR images taken for research by Keskusmetsälautakunta Tapio, Prof. Poso /UH, Metsähallitus. Large scale, 14 cm pixels.

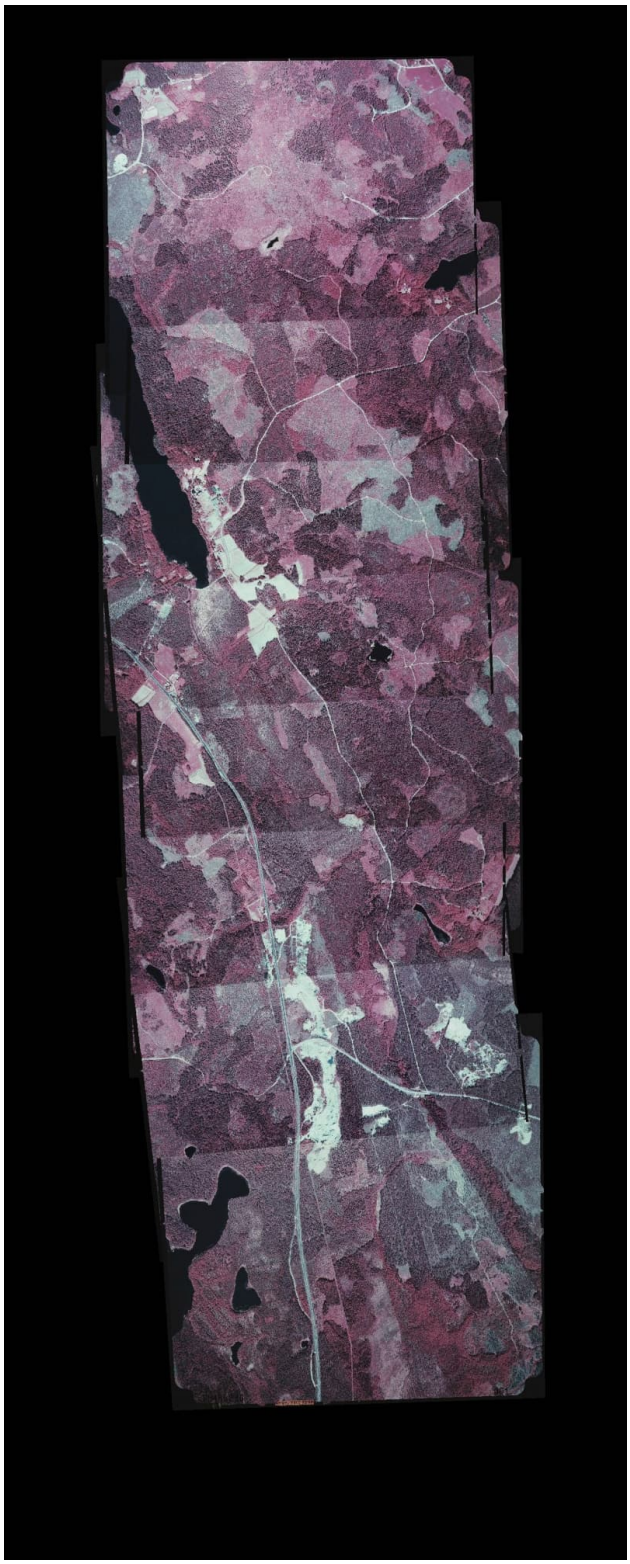


Fig. 37. 85230, N=8, 12.07.1985, 12:50, CIR, 1:10000, 15/23, 14 um.

Files stored (24 Files, 2 Folders, 6 629 133 791 actual bytes)

- Aerial_Images\85231\HDR
  Kuvamitt HDR files
- Aerial_Images\85231\Images
  Image files and tiles in TIF format

85231

Single strip with 11 images taken on rare BW-IR film, for research purposes by Keskusmetsälautakunta Tapio, Prof. Poso /UH, Metsähallitus. Large scale, 14 cm pixels. Shows Lakkasuo almost entirely.

Fig. 1. 85231. N=11, 12.07.1985, 13:00, BW-IR, 1:10000, 15/23, 14um

Files stored (32 Files, 2 Folders, 3 038 387 590 actual bytes)

- Aerial_Images\85231\HDR
  Kuvamitt HDR files
- Aerial_Images\85231\Images
  Image files and tiles in TIF format

85232

Single strip with 7 CIR images, for research by Keskusmetsä-lautakunta Tapio, Prof. Poso /UH, Metsähallitus. Medium scale, 28 cm pixels.

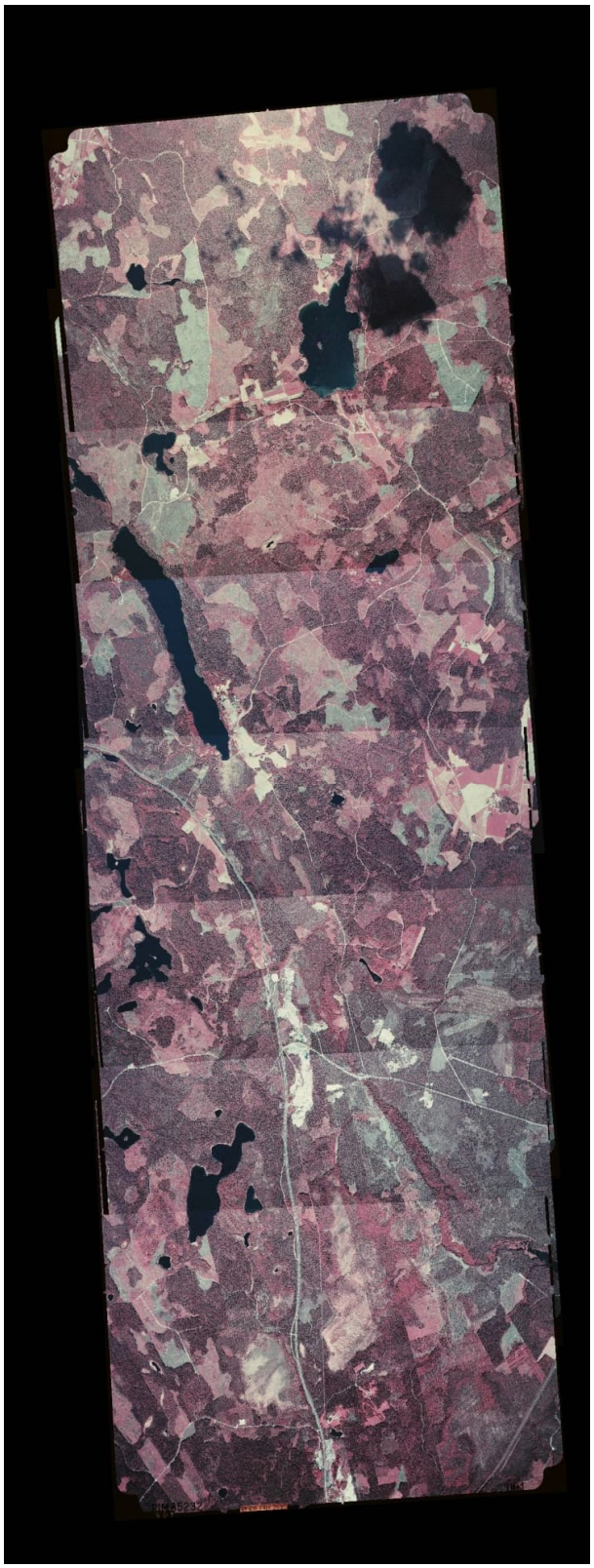


Fig. 38. 85232. N=7, 12.07.1985, 13:10, CIR, 1:20000, 15/23, 14um

Files stored (21 Files, 2 Folders, 5 774 877 925 actual bytes)

- Aerial_Images\85232\HDR
  Kuvamitt HDR files
- Aerial_Images\85232\Images
  Image files and tiles in TIF format

85233

Seven CIR images, with Siikaneva. N.B. The exterior orientation accuracy is poor further away from Hyytiälä (c.f. Fig. 19).

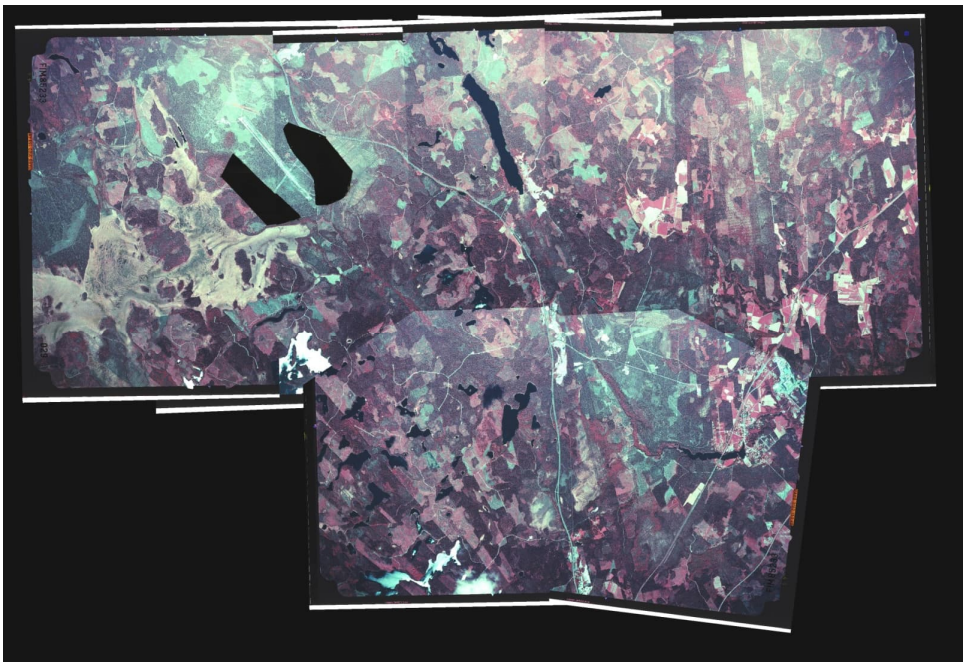


Fig. 39. 85233. N=14, 31.05.1986, 10:35, CIR, 1:30000, 15/23, 14 um. (Images 1-7 not triangulated, West of Siikaneva.)

Files stored (39 Files, 2 Folders, 11 400 920 792 actual bytes)

- Aerial_Images\85232\HDR — Kuvamitt HDR files
- Aerial_Images\85232\Images — Image files and tiles in RAW format; ESPA work-files

2.5.11 1986 CIR 1:30000 for forestry

86100

State-owned forests south of Hyytiälä in three stereo pairs.

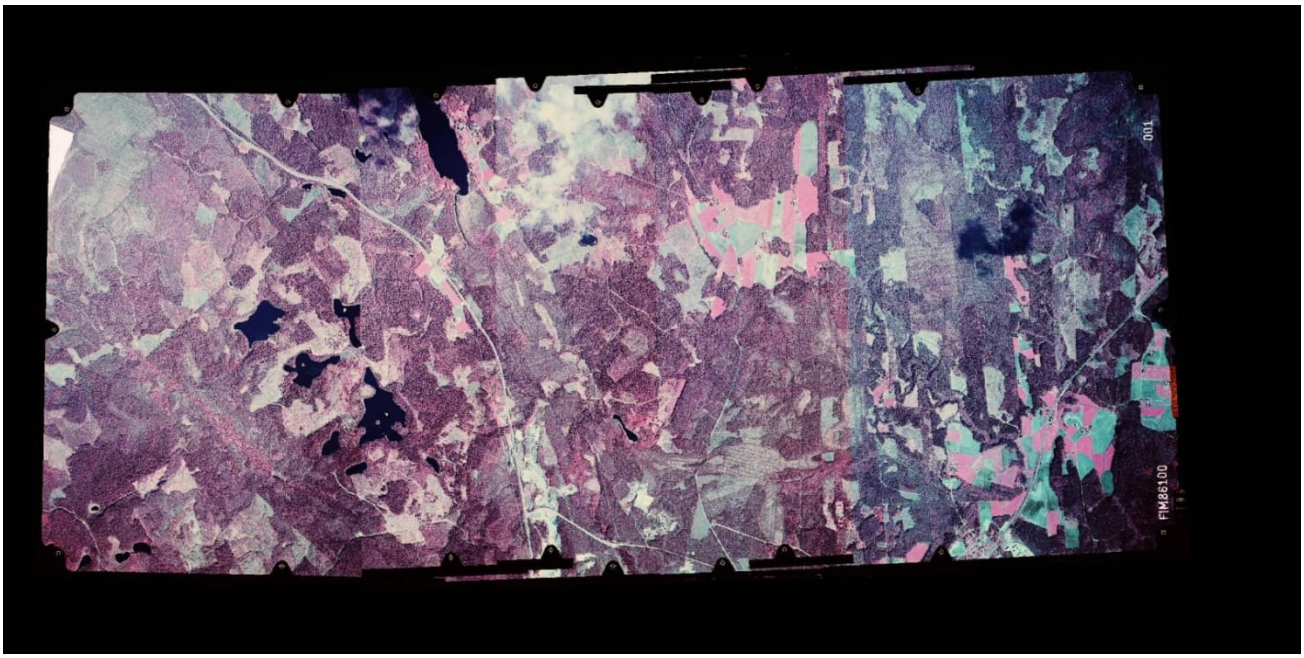


Fig. 40. N=4, 15.06.1986, 11:30-12:00, CIR, 1:30000, 15/23, 14 um.

Files stored (23 Files, 2 Folders, 5 247 924 741 actual bytes)

- Aerial_Images\86100\HDR — Kuvamitt HDR files
- Aerial_Images\86100\Images — Image files and tiles in RAW format; ESPA work-files

86286

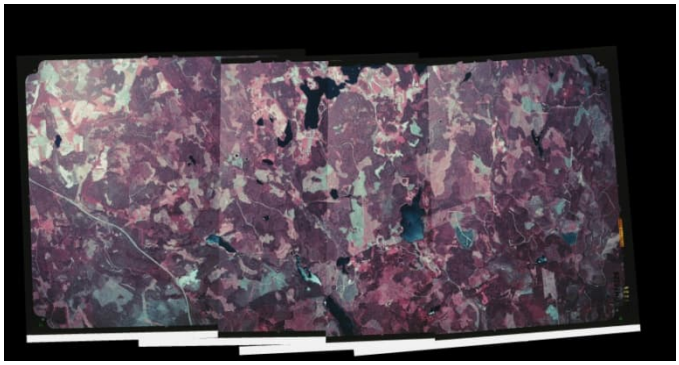


Fig. 41. N=4; Date ? Time ?, CIR, 1:30000, 15/23/14 um.

Files stored (20 Files, 2 Folders, 6 730 227 616 actual bytes)

- Aerial_Images\86286\HDR Kuvamitt HDR files
- Aerial_Images\86286\Images Image files and tiles in RAW format; ESPA work-files

2.5.12 1988 CIR 1:30000 for forestry

88086 – 1:30000

From Hirsilä in the south to Siikakangas.

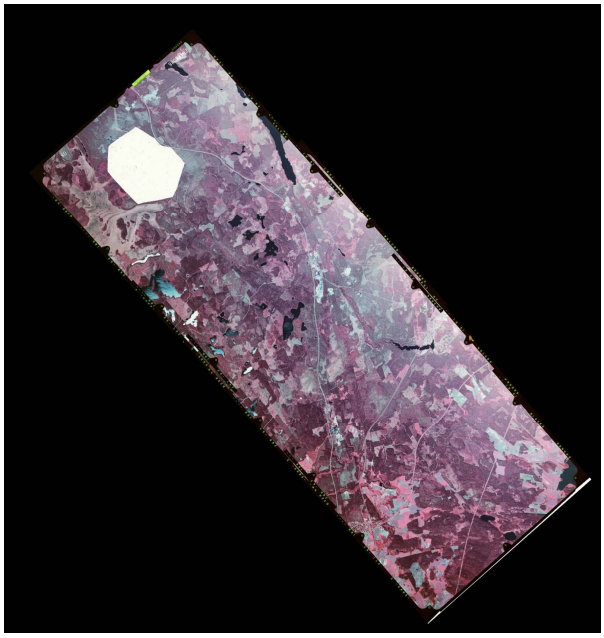


Fig. 42. N=9, 12.06.1988, 15:00, CIR, 1:30000, 15/23, 14um.

Files stored (26 Files, 2 Folders, 6 730 230 220 actual bytes)

- Aerial_Images\88086\HDR Kuvamitt HDR files
- Aerial_Images\88086\Images Image files and tiles in RAW format; ESPA work-files

2.5.13 1989 CIR 1:30000 forestry; 1:5000 for research

89204 – 1:30000

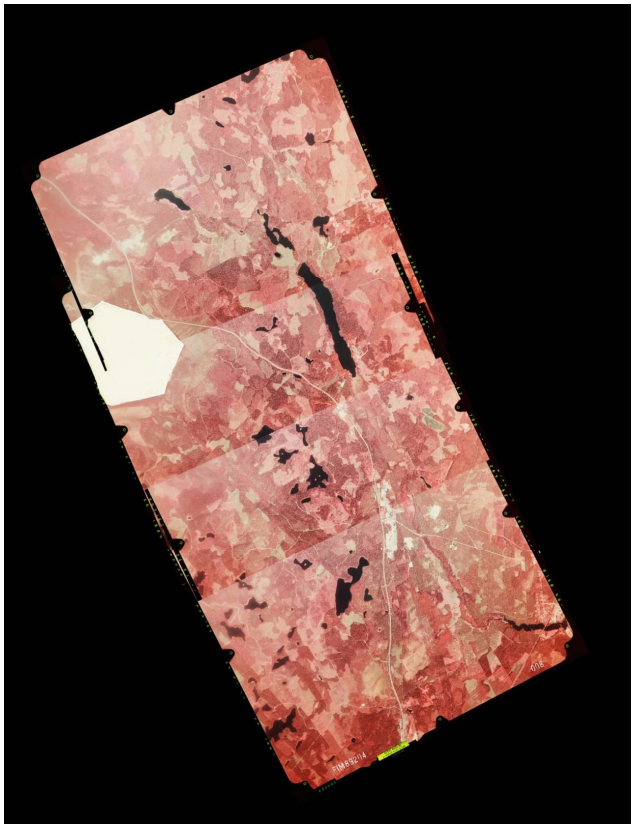


Fig. 43. N=4, 17.06.1989, 11:40, CIR, 1:30000, 15/23, 14um

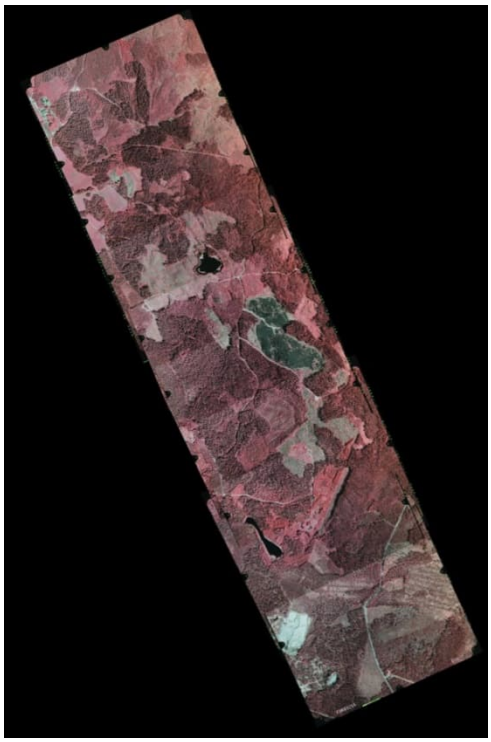
Files stored (16 Files, 2 Folders, 2 957 969 190 actual bytes)

- Aerial_Images\89204\HDR Kuvamitt HDR files
- Aerial_Images\89204\Images Image files and tiles in RAW format; ESPA work-files

89254 – 1:5000

Flight line from Ketunsuo to SMEAR II. 8 cm CIR pixels.

Fig. 44. N=9, 12.06.1989, 10:00, CIR, 1:5000, 15/23, 14.



Files stored (27 Files, 2 Folders, 7 384 656 831 actual bytes)

- Aerial_Images\89254\HDR Kuvamitt HDR files
- Aerial_Images\89254\Images Image files and tiles in RAW format; ESPA work-files

2.5.14 1991 CIR 1:30000 for forestry

91142

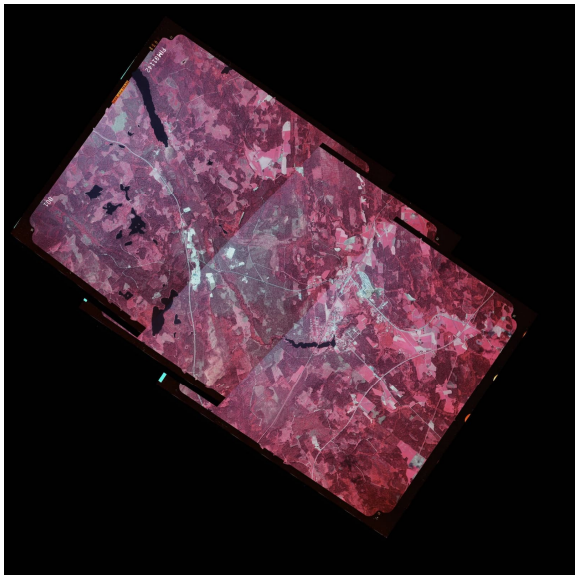


Fig. 45. N=3, 05.07.1991, 11:15, CIR, 1:30000, 15/23, 14.

Files stored (11 Files, 2 Folders, 2 391 333 394 actual bytes)

- Aerial_Images\91142\HDR Kuvamitt HDR files
- Aerial_Images\91142\Images Image files and tiles in RAW format; ESPA work-files

2.5.15 1992 CIR 1:30000 forestry, 1:5000 for research

92064, 1:30000

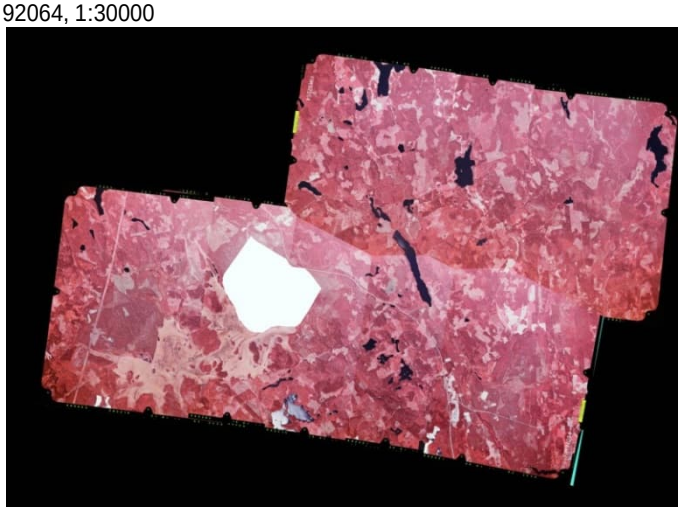


Fig. 46. N=8, 03.06.1992, 14:45, CIR, 1:30000, 15/23, 14.

Files stored (26 Files, 2 Folders, 6 044 192 760 actual bytes)

- Aerial_Images\92064\HDR Kuvamitt HDR files
- Aerial_Images\92964\Images Image files and tiles in RAW format; ESPA work-files

92199, 1:5000 Vuorijärvi SMI inventory area

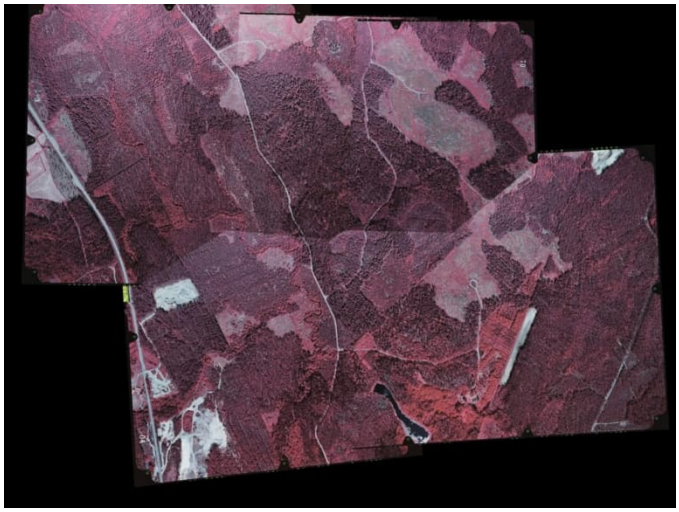


Fig. 47. N=6, 08.07.1992, 12:30, CIR, 1:5000, 15/23, 14

Files stored (18 Files, 2 Folders, 4 966 459 270 actual bytes)

- Aerial_Images\92199\HDR Kuvamitt HDR files
- Aerial_Images\92199\Images Image files and tiles in RAW format; ESPA work-files

2.5.16 1995 CIR 1:50000,30000, 20000, 5000 for research

95267A, 1:5000, SMI inventory area

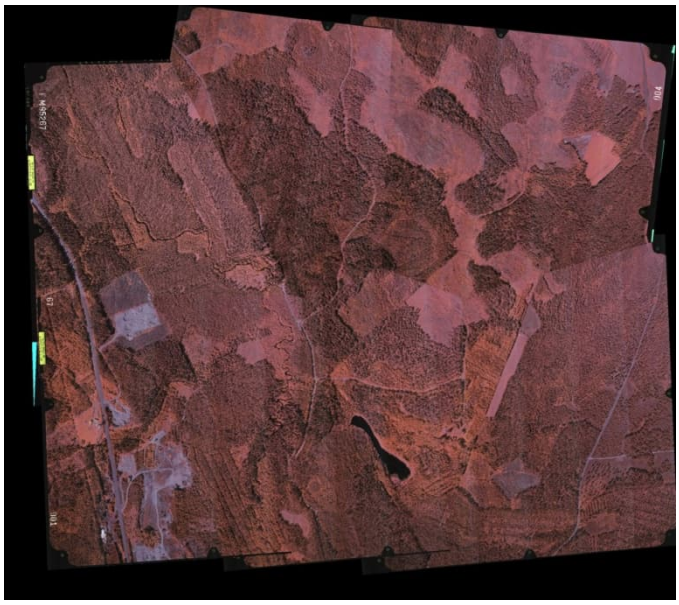


Fig. 48. N=6, 24.06.1995, 14.45, CIR, 1:5000, 15/23, 14

95267B, 1:5000

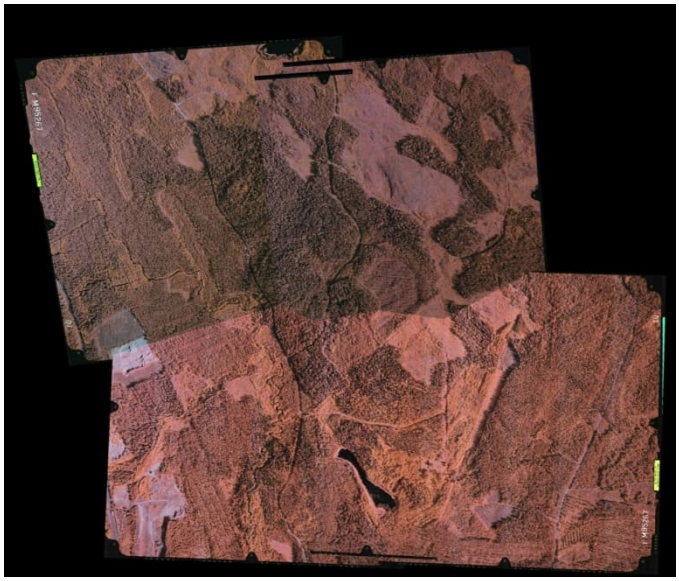


Fig. 49. N=6, 28.07.1995, 09:30, CIR, 1:5000, 15/23, 14/21

Files stored (39 Files, 2 Folders, 10 747 121 541 actual bytes)

- Aerial_Images\95267\HDR Kuvamitt HDR files
- Aerial_Images\95267\Images Image files and tiles in RAW format; three images rescanned at 14 um (TIFs)

95268, 1:20000

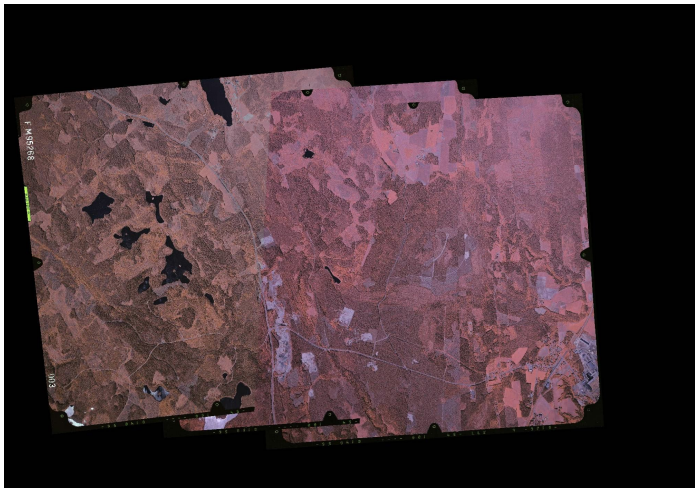


Fig. 50. N=3, 24.06.1995, 14:45, CIR, 1:20000, 15/23, 14

Files stored (9 Files, 2 Folders, 2 418 292 392 actual bytes)

- Aerial_Images\95268\HDR Kuvamitt HDR files
- Aerial_Images\95268\Images Image files in RAW format; TIFF tiles

95269, 1:30000

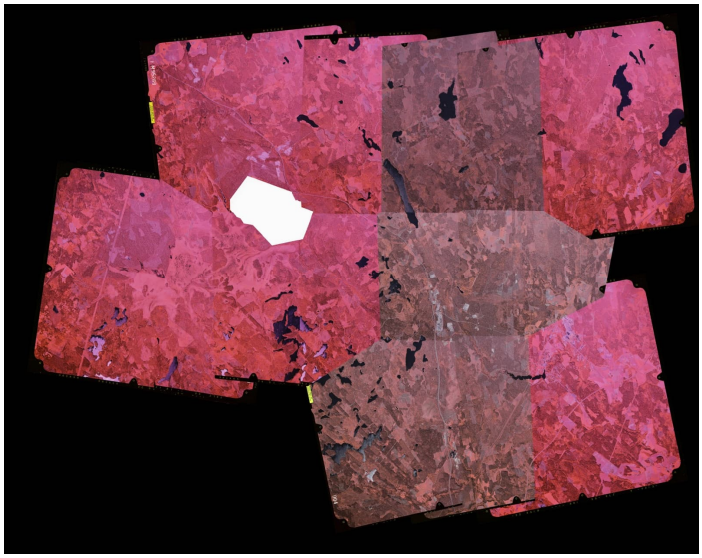


Fig. 51. N=14, 24.06.1995, 14:30, CIR, 1:30000, 15/23, 14

Files stored (46 Files, 2 Folders, 10 862 037 200 actual bytes)

- Aerial_Images\95269\HDR Kuvamitt HDR files
- Aerial_Images\95269\Images Image files in RAW format; RAW/TIFF tiles

95270, 1:50000

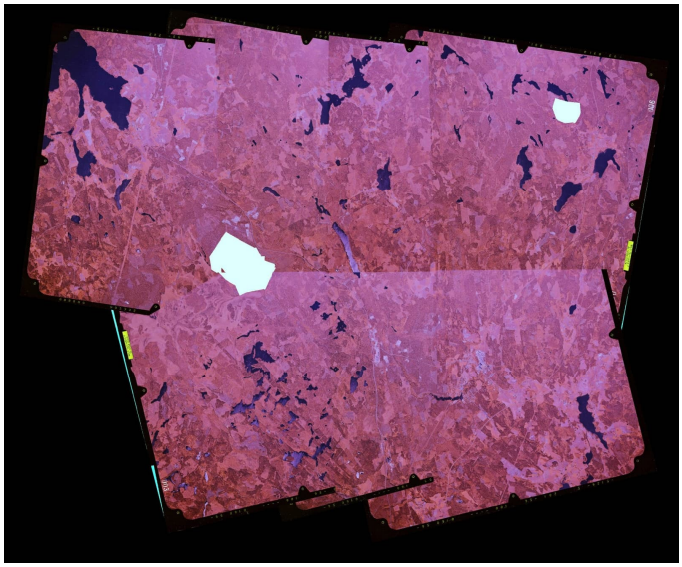


Fig. 52. N=7, 24.06.1995, 14:00, CIR, 1:50000, 15/23, 14

Files stored (23 Files, 2 Folders, 5 260 162 806 actual bytes)

- Aerial_Images\95270\HDR Kuvamitt HDR files
- Aerial_Images\95270\Images Image files in RAW format; RAW/TIFF tiles

2.5.17 1997 CIR 1:16000, 5000, BW 1:10000, 5000 research, Korpela

97248, 1:5000

Fig. 53. N=16, 19.06.1997, 10:15, CIR, 1:5000, 15/23, 14/21 um.

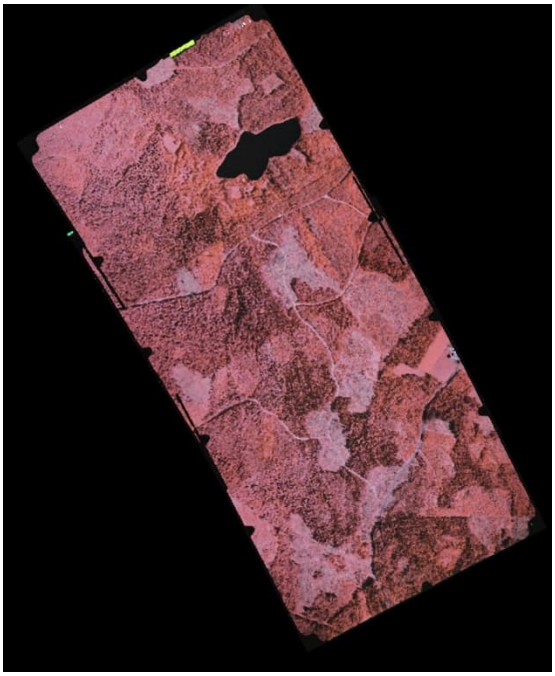


Fig. 54. 97248 image quadruplets from Lakua and Susimäki (Top).

Files stored (32 Files, 2 Folders, 9 578 254 110 actual bytes)

- Aerial_Images\97248\HDR Kuvamitt HDR files
- Aerial_Images\97248\Images Image files in RAW format; TIFF tiles

97249, 1:16000 Korpela

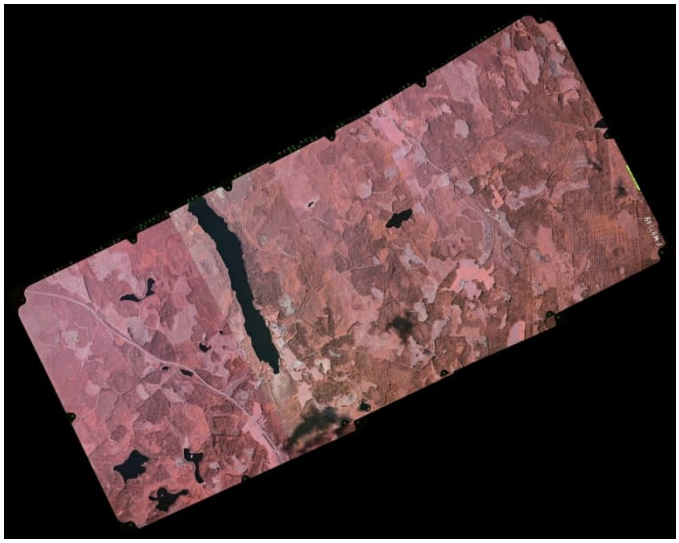


Fig. 55. N=4, 19.06.1997, 09:50, CIR, 1:16000, 15/23, 14 um

A few cloud shadows visible.

Files stored (12 Files, 2 Folders, 3 224 389 857actual bytes)

- Aerial_Images\97249\HDR Kuvamitt HDR files
- Aerial_Images\97249\Images Image files in RAW format; TIFF tiles

97250, 1:5000 Korpela

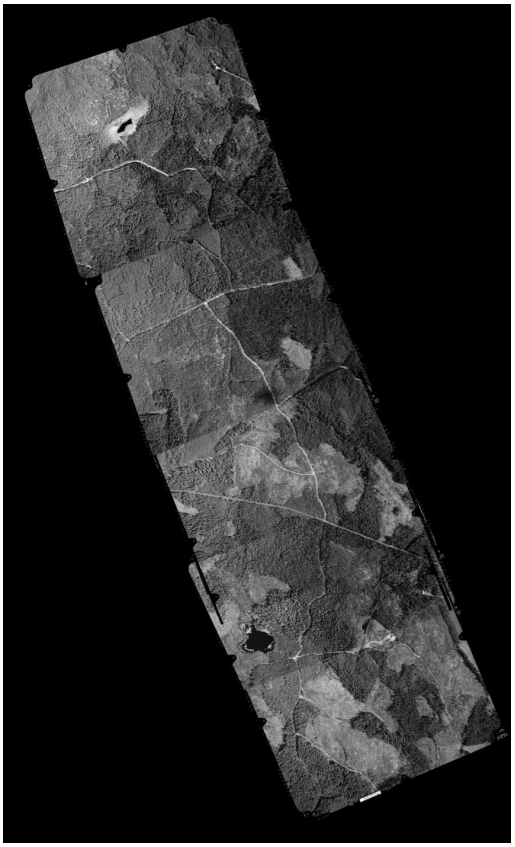


Fig. 56. N=6, 19.06.1997, 09:15, BW, 1:5000, 15/23, 21/14 um

Scanned both at 14 and 21 ums. HDR files are for the 21 um original scans (measurement of fiducials in 14 um images is needed)
Files stored (30 Files, 2 Folders, 2 073 488 176 actual bytes)

- Aerial_Images\97250\HDR Kuvamitt HDR files
- Aerial_Images\97250\Images Image files in RAW; TIFF tiles

97251 1:10000 Korpela

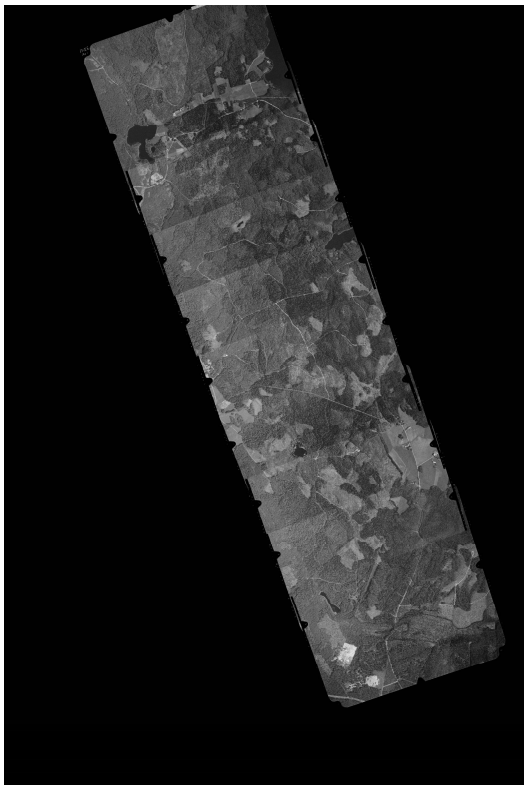


Fig. 57. N=9, 19.06.1997, 09:30, BW, 1:10000, 15/23, 21 um.

Files stored (27 Files, 2 Folders, 1,109,915,135 actual bytes)

- Aerial_Images\97251\HDR Kuvamitt HDR files
- Aerial_Images\97251\Images Image files in RAW; TIFF tiles

2.5.18 1998 BW 1:16000 topographic mapping

98110A

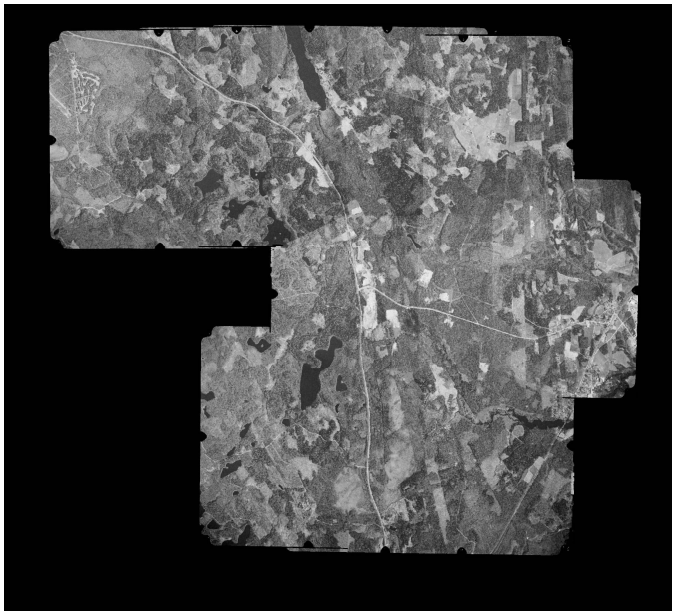


Fig. 58. N=12, 15.05.1998, 09:42-10:10, BW, 1:16000, 21/23, 15 um,

Files stored (35 Files, 2 Folders, 2,600,286,609 actual bytes)

- Aerial_Images\98110a\HDR Kuvamitt HDR files
- Aerial_Images\98110a\Images Image & tile files in RAW

2.5.19 1999 BW 1:16000 topography; CIR 1:30000 forestry 99108A

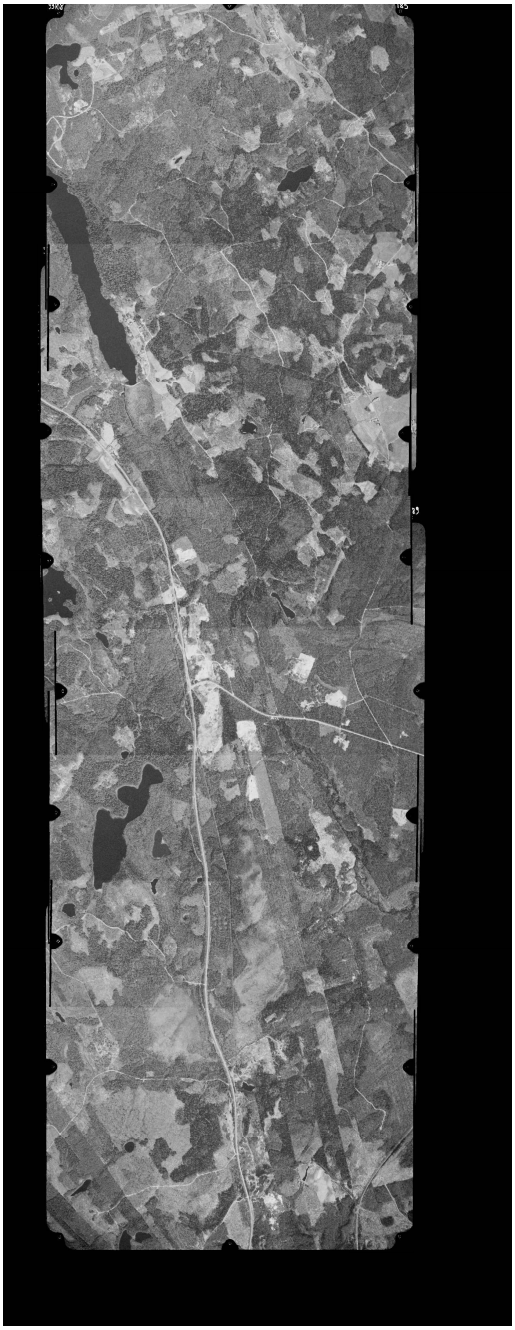


Fig. 59. N=8, 15.05.1999, 10:03-12:30, BW, 1:16000, 21/23, 15 um.

Files stored (26 Files, 2 Folders, 1,891,475,490 actual bytes)

- Aerial_Images\99108a\HDR Kuvamitt HDR files
- Aerial_Images\99108a\Images Images & tile files in RAW

99264

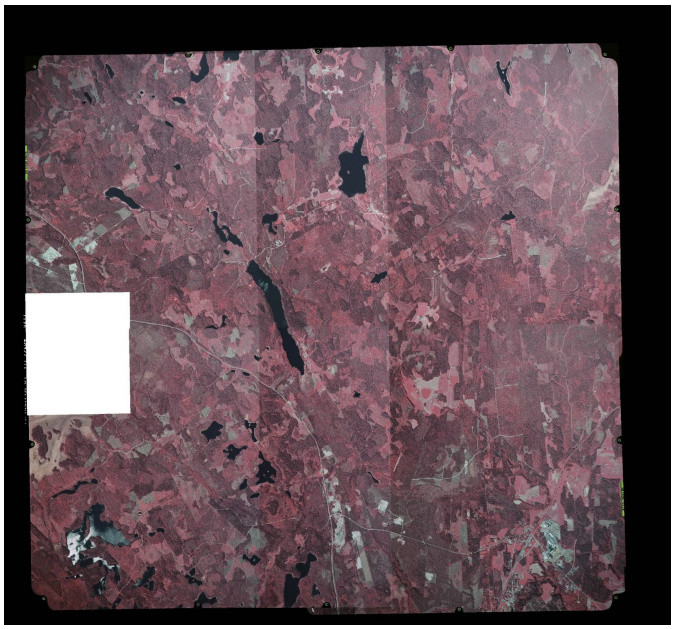


Fig. 60. N=6, 25.06.1999, 15:47, CIR, 1:30000, 21/23, 14 um

Files stored (29 Files, 2 Folders, 4,836,592,488 actual bytes)

- Aerial_Images\99264\HDR Kuvamitt HDR files
- Aerial_Images\99264\Images RAW & tiles in TIFF

2.5.20 2000 BW 1:16000 topographic mapping 00106

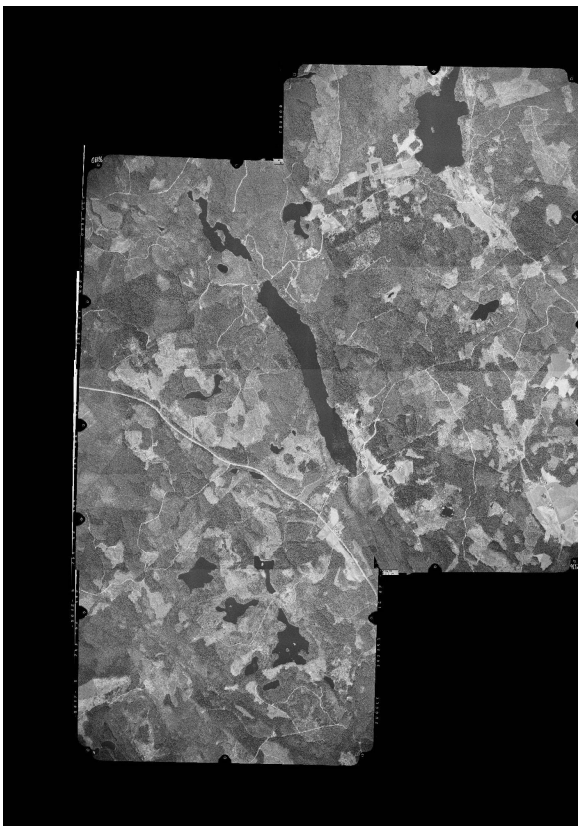


Fig. 61. N=7, 09.05.2000, 13:50, BW, 1:16000, 21/23, 15 um.

Files stored (22 Files, 2 Folders, 1,732,863,647 actual bytes)

- Aerial_Images\00106\HDR Kuvamitt HDR files
- Aerial_Images\00106\Images RAW & tiles in TIFF

2.5.21 2002 CIR/COL 1:5000, 10000, 16000, 30000 research

These images were acquired for the photogrammetric (3D) single-tree remote sensing studies (Korpela, 2004). Scanning of films was done at 14 ums resulting in about 16428 x 16428 pixel images. The color-images 02204A were acquired later in the summer.

02204A & B 1:5000

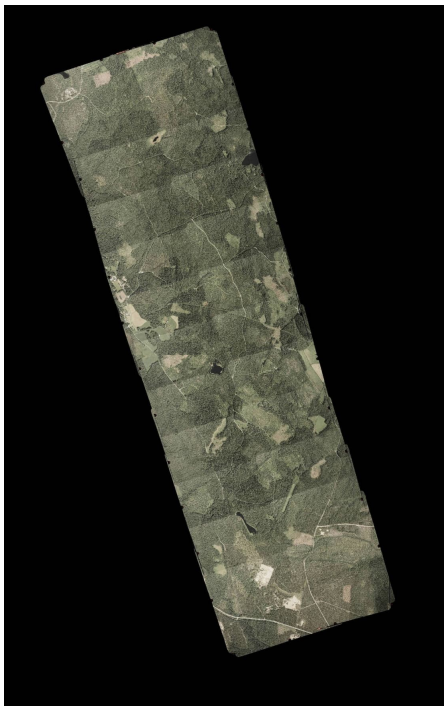


Fig. 62. N=22, 10.07.2002, 10:52-10:56, COL, 1:6000, 15/23, 14 um.

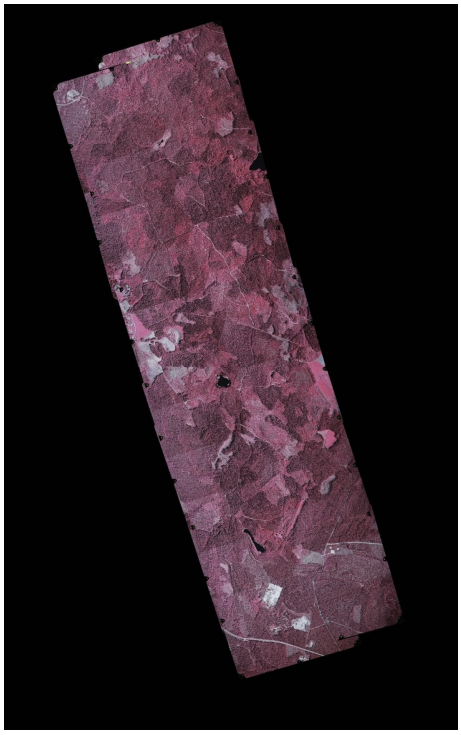


Fig. 63. N=22, 27.05.2002, 09:46, CIR, 1:6000, 15/23, 14 um.

Files stored (133 Files, 2 Folders, 35,676,490,631 actual bytes)

- Aerial_Images\02204\HDR Kuvamitt HDR files
- Aerial_Images\02204\Images RAW & tiles in TIFF

02205 1:12000

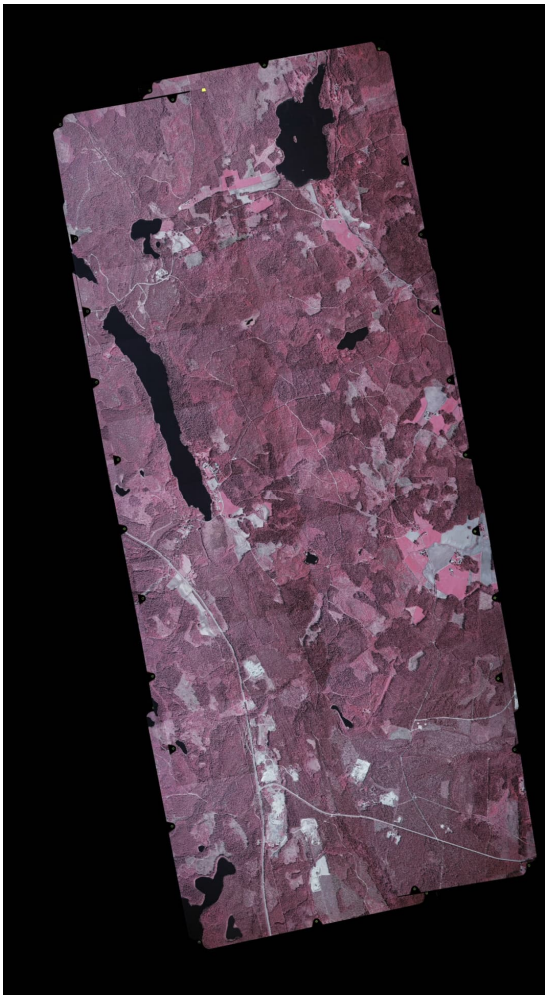


Fig. 64. N=18, 27.05.2002, 10:00, CIR, 1:12000, 15/23, 14 um.

Files stored (55 Files, 2 Folders, 14,565,624,679 actual bytes)

- Aerial_Images\02205\HDR Kuvamitt HDR files
- Aerial_Images\02205\Images RAW & tiles in TIFF

02206 1:16000

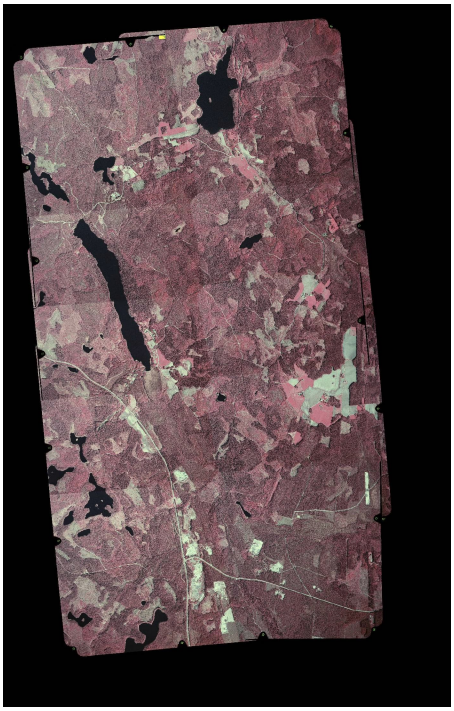


Fig. 65. N=10, 27.05.2002, 10:15, CIR, 1:16000, 15/23, 14 um.

Files stored (31 Files, 2 Folders, 8,179,008,365 actual bytes)

- Aerial_Images\02206\HDR Kuvamitt HDR files
- Aerial_Images\02206\Images RAW & tiles in TIFF

02207, 1:30000

Fig. 66. N=4, 27.05.2002, 10:34, CIR, 1:30000, 15/23, 14 um.

Files stored (12 Files, 2 Folders, 3,271,600,074 actual bytes)

- Aerial_Images\02207\HDR Kuvamitt HDR files
- Aerial_Images\02207\Images RAW & tiles in TIFF

2.5.22 2004 CIR 1:8000, 1:14000 normal angle; research

04402

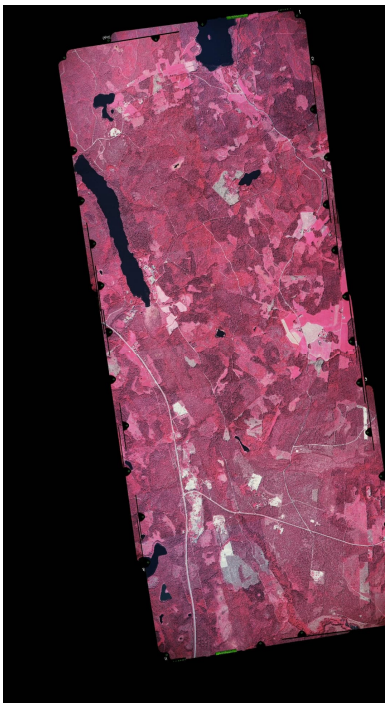


Fig. 67. N=20, 18.07.2004, 11:23-11:33, CIR, 1:14000, 21/23, 15

Files stored (12 Files, 2 Folders, 3,271,600,074 actual bytes)

- Aerial_Images\04402\HDR Kuvamitt HDR files
- Aerial_Images\04402\Images RAW & tiles in TIFF

04403

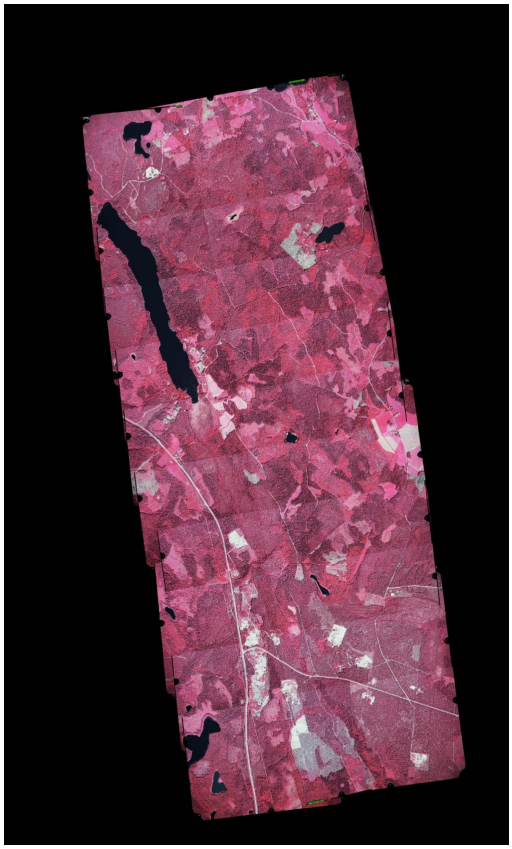


Fig. 68. N=30, 18.07.2004, 11:42-11:55, CIR, 1:8000, 21/23, 15 um.

Files stored (12 Files, 2 Folders, 3,271,600,074 actual bytes)

Aerial_Images\04402\HDR Kuvamitt HDR files

- Aerial_Images\04402\Images RAW & tiles in TIFF

2.5.23 2006 UltraCam-D 1:55000 & 1:10000

1:55000

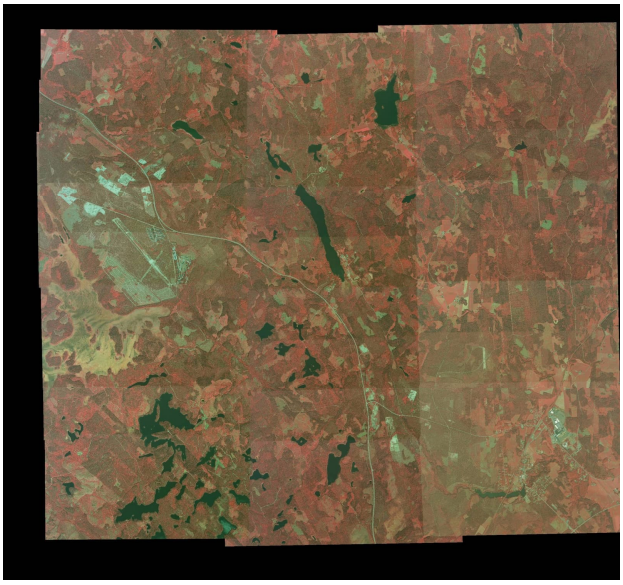


Fig. 69. N=24, 25.07.2006, 12:10-12:45, Vexcel UCD, 1:55000.

UltraCAM-D images from 6 km. Captured for an EU agriculture monitoring campaign. The GSD is 55 cm for the pan-sharpened images.

11500x7500 Pansharpened CIR, uint8 RGB-images.

Tiled TIF files, raw-files un-tiled.

The Direct georeferencing data were available. The AT was done manually. See the AT files for campaign **06214\AT\.**

Contents

\06025\

..\Images\

..\HDR\

06214, 1:10000

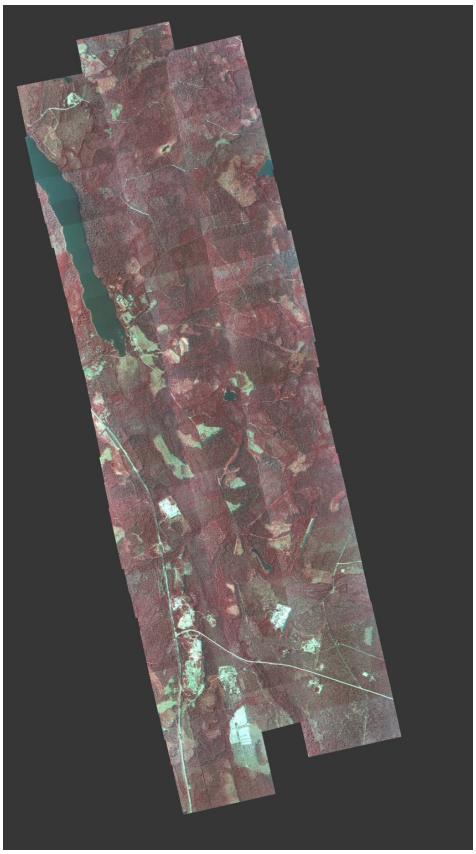


Fig. 70. N=82, 02.08.2006, 09:20-09:40, Vexcel UCD, 1:10000, 10/10, 9/28.5 cm.

This UCD campaign is from 1 km AGL, and the pixel GSDs are thus 9 cm for the PAN and 27 cm for the RGBN images.

Exposure settings were fixed at F8 & 1/175s.

The overlaps 67% / 25%.

The Lvl2 RGBN images are band-interlaced by line TIFFs with data starting after an 8-bit header section.

<u>Contents</u>

\06214\

..\Delivery\
The Lvl2 and Lvl3 images with Quickviews.
Results of the GPS/IMU.

..\AT\
The images were a part of a 568-image block that was manually triangulated. The block combines all 1946-2006 images from Hyytiälä. Since then, campaigns were oriented separately.

..\HDR\
Sample HDR files for the 8/16 bit versions

..\Images\
The raw image files.

2.5.24 2007 UltraCam-D 1:22000 research, 19/62 cm

07015

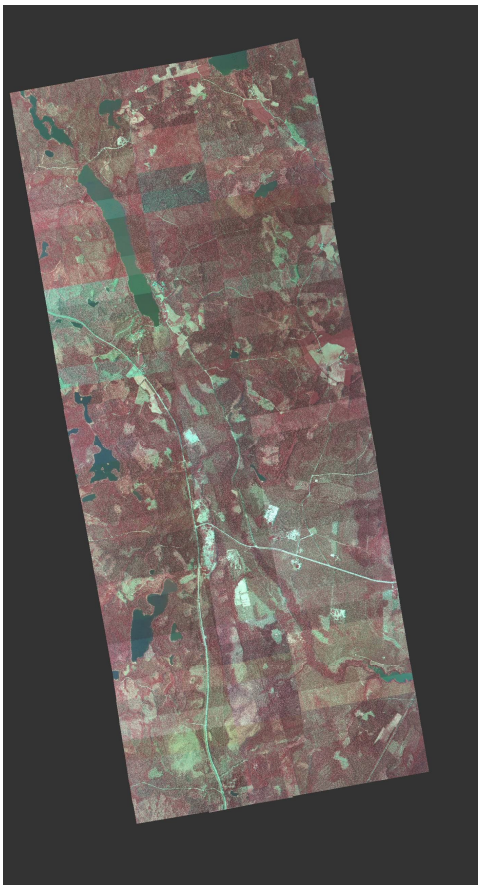


Fig. 71. campaign Blom 07015, N=102 images, 0.06.2007, 06:10-06:21 GMT, Vexcel UCD, 1:22000, f=10 cm, H = 2500 m

- \Aerial_Images\07015\RAW\
  RAW (BIP) versions, 510 files, 62 694 504 000 bytes.

  *_PAN_CIR_uint8.raw
  8-bit 'pan-sharpened' images (own C-code, non-optimal colors), 11500 x 7500 pixels

  *_PAN_uint16.raw
  Level 2 16-bit PAN image (stitched by the Vexcel software), 11500 x 7500 pixels

  *_PAN_uint8.raw
  Level 2 forced to 8-bit versions (own C-code, non-optimal conversion), 11500 x 7500 pixels

  *_RGBIR_uint16.raw
  Level 2 four-band images (3680 x 2400)

- \Aerial_Images\07015\qvCIR\
  CIR JPEGs of quick-view images N = 102 (By BlomKartta)

- \Aerial_Images\07015\HDR\
  Header files for KUVAMITT

- \Aerial_Images\07015\Metadata\...

  \Aerial_Triangulation\
  Aerial triangulation with Match-AT

  Direct Sensor Orientation observations
  Transformation from MATCH-At to KUVAMITT EO/IO
  GCPs with signals

  \CameraCalibration\
  Reports, short and long version

  \XMLs\
  Information regarding Level 2 image processing

NOTE; EO for image 1267 is missing from AAT-files (in the far north).

Times in TIFF headers are wrong, use GPS-times.

Notes

What we do during Lvl00 to Lvl02 processing is a registration of the color images to the panchromatic channel. In a first step the green channel is registered to the panchromatic channel and the red, blue and infrared channel is then registered to the green channel. In case we have detected defect pixels or row those are interpolated (you can check this in the calibration report, they shall be listed there). From which camera do you have the data? And which revision?

Another thing that I just thought of which is also interesting for you is the shutter jitter. As I reread your email, I read that you have UCD-data. Within the UltraCam-D the shutter variance when the shutter is closing. In the UltraCamX we have installed a light barrier to measure the exact exposure time. I have attached you a memo which we give to our customers concerning this issue. This probably helps you to understand this issue better.

Concerning the syntopic exposure you understand this small time difference correctly.

When you get first results in your research please let us know. We are always interested about other people work in this area, especially with UltraCam. And if you need further help just let me know.

Memo_Color_Stability.pdf

Spectral sensitivity curves (pdfs)

BFI07015: all images F8, 1/175 s.

Mid_exposure correction ei liity radiometriaan, paikannukseen eli laukaisun ajoitukseen. Mekaaninen suljin näet kestää tovin aueta ammolleen ja sitten taas sulkeutua. Tuo arvo kuvaa aikaeroa laukaisupulssin ja sulkimen aukiolon keskikohdan välillä.

Valotustiedot taitavat olla piilossa tiffin privaatitageissa. Mielestäni olen niitä joskus nähnyt selväkielisinäkin jossakin. Ainakin prosessointiohjelma (OPC) näyttää ne, mutta ei erikseen eri kameroille, vaan yhden yhteisen aukkolukeman. Kalibrointitodistuksesta löytyy sitten taulukot, miten eri nimellisaukot toteutuvat milläkin kameralla.

2.5.25 2008 ADS40-SH52 multispectral line-sensor, 1-4 km

2.5.25.1 The sensor test

This campaign was a demonstration of the ADS40 sensor in Finland. The sensor was flown to Tallinn, and installed in ES-MAA, the aircraft of the Estonian Land Board. Weather was poor, and imaging was carried out in sub-optimal conditions. There were four flying altitudes, to provide GSDs of 10, 20, 30 and 40 cm. An ALS50-ii LiDAR acquired data simultaneously.

The images were acquired on August 23, 2008 with a radiometrically calibrated ADS40 line-sensor. See Section Pushbroom sensors. The sensor flew above Hyytiälä starting at 0656 GMT at 1 km AGL. Data were acquired from 15 flight lines (strips), which were named according to the start time in GMT. 2-km acquisition started at 0745, 3-km at 0818, and 4-km at 0843 GMT. More image lines were active from 3 and 4 km than from 1 and 2 km, because of the constraints on data transfer in the sensor (*Table* 4).

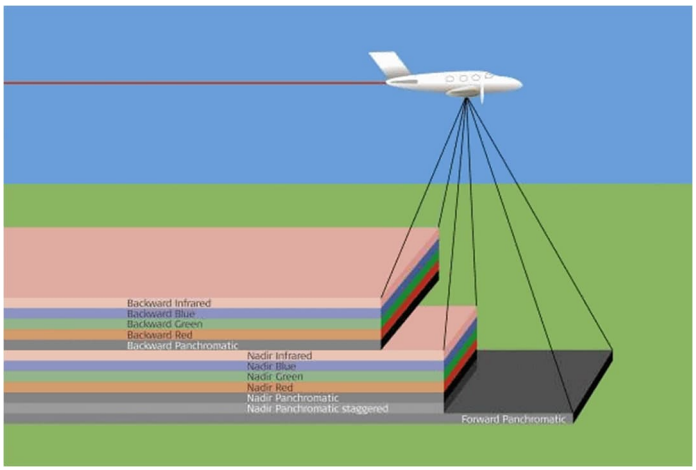


Fig. 72. The image lines range from Backward 16º to forward 27º geometry (ADS40-SH52).

2.5.25.2 IO and EO

The EO is defined for each scan line in an image, which was exposed for some milliseconds only. The IO is the same for each image line (focal length, xy position of each pixel on the focal plane). The sensor had eleven active lines on the focal plane (Fig. 72, Fig. 74).

Appendices 1B, 2A, 2B, 2C and 2D show the needed KUVAMITT files. A HDR-file has the tag "FRAME", "ADS L0" or "ADS L1", depending on the image type (See 2.5.24.3), and points to an ADS, CAM, ODF and SUP file. KUVAMITT has thus the ADS40 sensor model implemented to enable image-to-target and target-to-image photogrammetry.

The HDR file essentially shows the image type (L0 or L1), image size, and points to the single RAW image file. Thus, KUVAMITT does not allow the use of images blocks, i.e. several sub-images all below 2GB in size (the feature was not programmed as it was not needed for the research done with the data).

2.5.25.3 On image types

An image is in some band (PAN, BLU, GRN, RED, NIR), from a view direction (B16, B14, N00, F02A, F14). I.e. an image is always a 'grey-scale' one-band image (Fig. 73), collected by one of the 11 CCD-lines on the focal plane. The file is stored in the RAW format (BIP) using signed 16-bit integers ranging from -32,768 to 32,767. Only positive DNs exist.

The nomenclature is as follows

L0 Raw. Image DN-values are affected by the integration time. The L0 geometry shows the undulations of the sensor (Fig. 73). These images always have 12000 columns and as many rows as there were image lines exposed. Large images are split not to exceed the 2-Gbyte-limit.

L1 The undulations are removed by projecting the images in a strip to a plane at a fixed height. The image is 'turned 90-degrees counterclockwise', so that conjugate entities show on the same rows in the images of one strip.

These L1 images were converted into radiometrically calibrated versions, using the XPro software.

L2 Orthoimages. Some were calculated at Leica in Oct 2008, using the LiDAR DEM.

2.5.25.4 Radiometric corrections

The raw L0 images are comprised of uncalibrated DN-values. XPro software was used for rectifying the raw images to a reference plane, i.e. into L1 images. Simultaneously, different radiometric calibrations were applied. The corrections are explained in (Beisl et al. 2008)

- ASR, at-sensor radiance images (band-averaged)
- ATM, atmospherically corrected refl. product
- BRDF, brdf-corrected image product
- FULL, both atmospheric and brdf-corrected

The prefixes and L0/L1/L2 suffixes identify the four products. The raw L0 image does not have an L0 suffix. N.B., the conversion from raw to ASR is a simple linear operation, using laboratory calibration for offset and gain, as well as the integration time.

Table 3. The BLU-band backward-looking (B16) image versions from the strip flown at 0818 GMT, in August 23, 2008:

Image name	
08230818BLUB16A.raw	Raw, DN data
08230818BLUB16AL1.raw	At-sensor radiance
ATM_08230818BLUB16AL1.raw	Reflectance products
BRDF_08230818BLUB16AL1.raw	" "
FULL_08230818BLUB16AL1.raw	" "

The CAM file has the gain value c1. The (band-averaged at-sensor) radiance conversion is

$L = (c1 * DN) / t$

The integration times, t, are shown in Table 4. The values c1 are given in the CAM files in \Calibrations –folder (RADIOMETRIC_GAIN –variable).

In L1 reflectance images the pixel values 0…10000 correspond to reflectance values 0…1.

Table 4. Characteristics of the ADS40 data acquisition by strips.

Flying altitude [km]	Start time [GMT]	Flight path azi-muth [°]	Sun azi-muth [°]	Sun elevation [°]	Trees in image footprint	Trees occluded by cloud	Trees in cloud shadow	Trees lost [%]	Integrat-ion time [ms]	Active CCD lines
1	0656	349	119.3	27.1	55	0	0	0	1.94	N00
“	0703	169	121.0	27.8	6987	531	0	7.6	“	N00
“	0711	349	123.1	28.6	11955	2802	85	24.1	“	N00
“	0718	169	124.9	29.3	0	0	0	-	“	N00
“	0725	349	126.7	30.0	6997	0	0	0	“	N00
“	0733	169	128.8	30.7	7037	0	0	0	“	B16
2	0745	349	132.0	31.8	9599	308	0	3.2	2.77	N00
“	0753	169	134.2	32.5	13786	76	1019	7.9	“	N00
“	0800	349	136.1	33.1	9466	277	1306	16.7	“	B16
“	0808	169	138.3	33.7	13728	310	437	5.4	“	B16
3	0818	349	141.1	34.4	15626	146	117	1.7	4.16	N00
“	“	“	“	“	15626	0	48	0.3	“	B16
“	0825	169	143.1	35.0	15626	1683	772	15.7	“	N00
“	“	“	“	“	15626	895	366	8.1	“	B16
“	0833	260	145.4	35.5	13743	1983	1843	27.8	“	N00
“	“	“	“	“	13785	3933	912	35.1	“	B16
4	0843	169	148.3	36.1	15626	204	392	3.8	5.54	N00
“	“	“	“	“	15626	34	0	0.2	“	B16
“	0852	260	151.0	36.7	15110	283	601	5.9	“	N00
“	“	“	“	“	15110	1533	166	11.2	“	B16

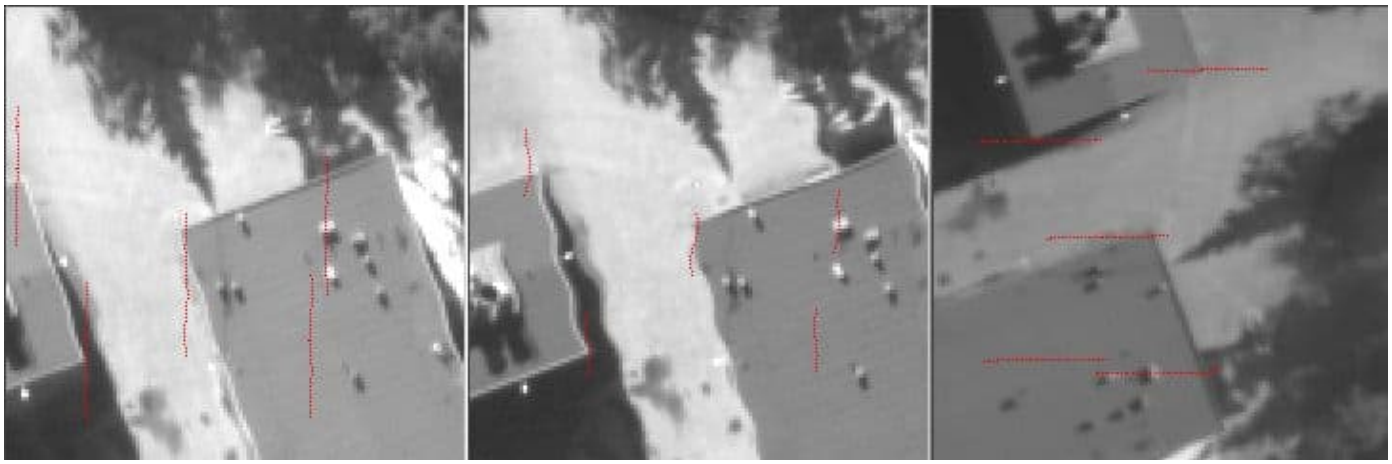


Fig. 73. Epipolar geometry of two ADS40 L0 images and one L1 image. The roof corner was pointed in some fourth image, resulting in an image ray down to the scene, which was defined for a segment with a Z-range ± 5 m. L0 images show the camera movement (undulations) and the epipolar lines become curved, while an L1 image is projected to a plane and the line is nearly horizontal.

2.5.25.5 Miscellaneous

For a flight line, there can be (Table 4),

- Four nadir image lines (N00), in BLU, GRN, RED and NIR;
- Four backward viewing image lines (B16), in BLU, GRN, RED and NIR; and
- Three panchromatic lines (F02A, B14, F27) (the staggered F02B sensor line was not used).

For some strips, the GRN N00 image replaced the PAN F02A in triangulation, and F02A files may be missing. In 1 km and 2 km strips only 4 multispectral lines were collecting data, because of the data flow exceeding the transfer and storage capacity.

The original files were stored in blocks, with file sizes not exceeding the 32-bit signed integer memory address (2 GB, limit in Visual Bassic 6.0), and the raw-files were made of the first (zero) blocks only. This is an issue only in the 1 km data, in which some 10% were left out at strip ends (exceeding 2GB). The original TIF-files are stored as well, for all image blocks. They contain Leica-specific TIFF tags and compression, use ADS40decompress.

L2 images (orthoimages, TIF) were produced at Leica Geosystems, using a DEM for which LiDAR data was collected simultaneously, in the UTM35 projection.

There are four types of additional files:

- *.HDR Header, see Appendix 1b.
- *.ADS Appendix 2a
- *.CAM Appendix 2b

- *.ODF.ADJ Appendix 2c
- *.SUP Appendix 2d

The needed functionality for i/o and photogrammetry with the ADS40 data resides for the most part in Module5.bas (ADS40_Module) in KUVAMITT.

The images were oriented at Leica, and data were delivered during autumn 2008. There were GCPs available (See Table 6).

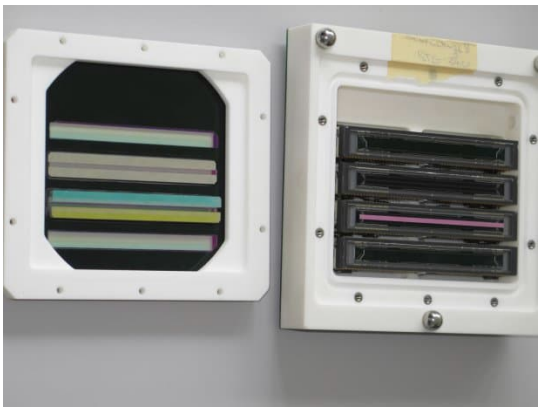
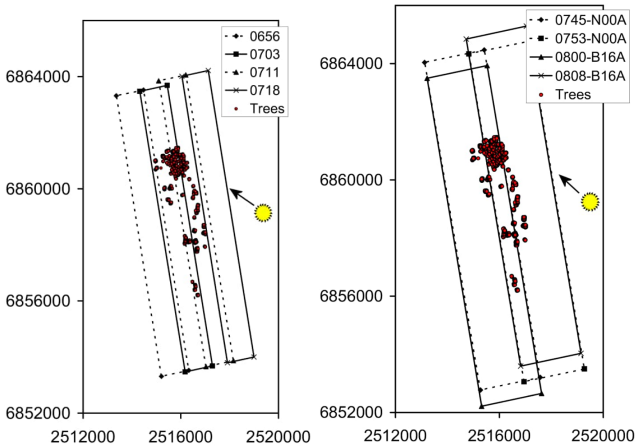


Fig. 74. ADS40-SH42 focal plane with the beamsplitters and CCD-arrays. ADS40-SH42 had less CCD-arrays than the ADS40-SH52 used in Hyytiälä 2008. ADS40 telecentric lens with a 6.3 cm focal length.



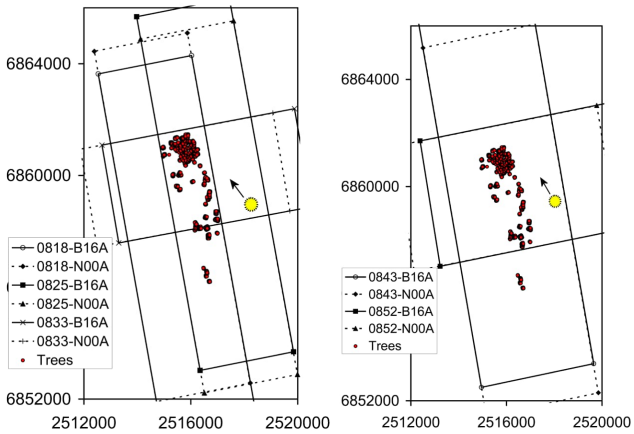


Fig. 75. Coverage of the strips, with Hyytiälä forest plots (2008).

2.5.25.6 Weather conditions and auxiliary data

During the acquisition, radiometric measurements were done on the field. These included installation of four reflectance tarps. Reflectance spectra of various targets were measured by FGI.

Fig. 76. The four tarps and the Siemens star on the football field. August 23, 2008.

- AOT was measured with the sun-photometer, horizontal visibility
- The weather data from SMEAR are available
- Ground nadir reflectance spectra were measured for tarps and other targets by FGI and U. Beisl
- The are pictures taken on the ground

2.5.25.7 Notes

Notes in Sept 2008

1. System correction

DSNU = 12000 additive constants
PRNU = 12000 multiplicative constants
- done on the sensor head
- for a uniform surface in the lab this gives you a uniform DN image

2. At-sensor radiance calibration
12 camera specific constants (one per CCD line)

3. Atmospheric correction
remove atmospheric haze, output is ground reflected radiance [W/m2/sr/um]

4. Reflectance calibration
divide by solar irradiance, output is ground reflectance (ratio of reflected to incoming light)

5. BRDF correction
One model for all pixels per flight line

The XPro workflow allows the following:

- L0 data = gray values DN, system corrected
- L1 data = epipolar rectification = remove aircraft movement, system corrected + radiance calibrated
- L2 data = Orthophoto, system corrected + radiance calibrated

L1 and L2 data have the following options:
- "simple dark pixel correction" or "modified Chavez method" robust empirical method of image enhancement (3), output is kind of ground reflected radiance
- "modified Song-Lu-Wesely method": atmospheric correction + reflectance calibration: superior for good weather conditions, one parameter per flight line: radiance of a dark pixel, output is ground reflectance
- "modified Song-Lu-Wesely method + BRDF correction": For seamless maps; output is ground reflectance

Notes Sept 19,2008

With newly supplied GPS base station data, we reprocess ALS data set.

Here is status update:

-Even new base station coordinate gave slight worse quality of GPS trajectory, but I understand this data is what we can do. ADS&ALS data processing has been proceeding with this input.
-Strip adjustment is done by manual verification, all lines match up reasonably.
-Control report against GCP shows slightly large STDEV=0.3m,usually we achieve 0.05m, Min/Max deviation was up to =/-0.7m,usually we achieve 0.1m.
-The poor result against GCP appears to come from input GPS for GrafNav a bit, and largely come from GCP location on the ground. GCPs are located side of the load, where there are bushes, grases or sloped surface that contributes to cause poor statistic.

Each flight line is relatively matches so we can proceed next step to prepare data set by following your preferred format. Another idea would be to re-measure GCP at the center of the load or flat surface area where has reasonable intensity (asphalt surface etc)to get better statistics.

Notes Nov 17, 2008

Yes, some lines have been recorded in compressed format in order to overcome data rate problems.

I would have expected that you get decompressed data, which however seem not to have happened. We'll send you a decompression utility, which converts these files. - - - We have however just detected a problem, we have to fix, so it may become tomorrow.

Opening compressed ADS40 images with LIBTIFF won't help you much. The resulting JPEG-de-compressed 8 bit images have still to be de-normalized to 16 bits. - LIBTIFF should however be able to do the decompression, but it will deliver unusable (striped) images. We are using LIBTIFF 3.8.2 inside our own code.

ADSDecompress.zip this is now the decompressor for tiff tiled jpeg images as a command line tool.

The usage is simple:

1. Unzip the archive into a directory.
2. ads40decompress <name>.ads

The uncompressed file will have the original name.
The original .ads and .tif files are moved to *_dcbak.*
Then you can do any further work with the uncompressed Pan-files.

Notes August 2008

The PAN lines were always flown uncompressed on low and high altitude lines. The low altitude lines (10cm and 20cm lines) were flown once with RGBN Nadir uncompressed and once with RGBN Backward uncompressed. This had to be done due to the limitation of the data throughput of the Control Unit CU40 and the Mass Memory MM40.

Notes June 2009

Sensor configurations used:

#1 10cm GSD: CT = IT =1.94ms
RGBNIR NADIR Raw + PANB compressed + PANF compressed
#2 10cm GSD: CT = IT =1.94ms
RGBNIR Backward Raw + PANN compressed + PANF compressed
#3 20cm GSD: CT = IT = 2.77ms
RGBNIR NADIR Raw + PANB compressed + PANF compressed
#4 20cm GSD: CT = IT = 2.77ms
RGBNIR Backward Raw + PANN compressed + PANF compressed
#5 30cm GSD: IT = 4.16ms
RGBNIR NADIR Raw + RGBNIR Backward Raw + PANB compressed + PANF compressed + PANN compressed
#6 40cm GSD: IT = 5.54ms
RGBNIR NADIR Raw + RGBNIR Backward Raw + PANB compressed + PANF compressed + PANN compressed

This means that for the 10 cm and 20 cm heights the Pan line, which included the active color CCD was switched off. Only the two other Pan lines were active. The triangulation could be made with the active green line of the color CCD. Probably the inactive Pan band was created as a dummy?

The heights 30 cm and 40 cm should have all Pan bands with images

I can confirm that all the flight lines delivered have in PANF02A, if existent, a file size that is half the size of the compressed PANF14A or PANF27A of that flight line. PANB14A_0_0, PANF02A_0_0, and PANF27A_0_0 of one flight line are all 16 bit, compress 7 type images of the same pixel size, but different file size.

The first minifications, e.g. PANF27A_2_0_0, are a 16 bit compress 1 type images of a quarter the pixel size and also a quarter of the file size of the uncompressed images, because all minification levels are uncompressed.

After decompression, files PANB14A_0_0, PANF02A_0_0, and PANF27A_0_0 of one flight line have the same file size, which equals the file size of the color bands of that flight line.

With a CU40 there is only one compression method (8 bit) but the jpg compression factor can be configured individually. So the different file size of the PANF02A is due to a different jpg compression setting during the flight. The compression was 4 times for PANF27 and PANB14 and 10 times for PANF02. If there was any necessity to do so, I couldn't find out. So the PANF02A images have slightly more jpg compression artifacts.

There are three comments for the flight lines 0703, 0718, and 0745 saying that the PAV was at limit in pitch. This may result in rectification errors. Usually the line is repeated then as with 0725. But in this case there was very few time left to complete the project.

2.5.25.8 Contents

Main folder \ADS40_2008\

..\Images\ADS_L0\

- L0 raw images

..\Images\ADS_L1\

..\10cm; ..\20cm; ..\30cm;..\40cm

- L1 raw images of type ASR, ATM, BRDF, and FULL and their HDR files, created in Dec 2009.

..\footprints

- The corner points of each image, 115 files

..Images\Blocks\

The L1 TIF images and their ads/odf/sup files from Dec 2009. These were converted into the L1-raw files in \ADS_L1\ folder.

..\Bins

The tree-level image features for the RSE study. ASR, ATM, BRF, and FULL version. One file per N00 or B16 images (combined RED,GRN,BLU,NIR)

..\Feature_extractor\

The VB-program for selecting subsets of trees/features from the BIN files.

..\Ground_measurements\

The various ground images, SMEAR measurements, AOT data, reflectance spectra etc.

..\Polygon_Check

..\Kuvamitt_Lite\

2.5.26 2009 DMC morning/noon flights, May 31, 2009

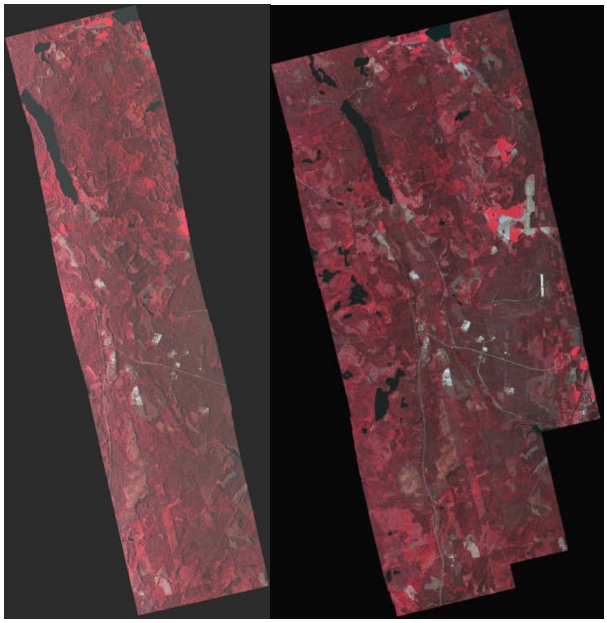


Fig. 77. The 2 km morning and noon images (1101 and 1104-SERIES) at 0515 and 0805–0830 GMT of May 31, 2009. One and three flight lines

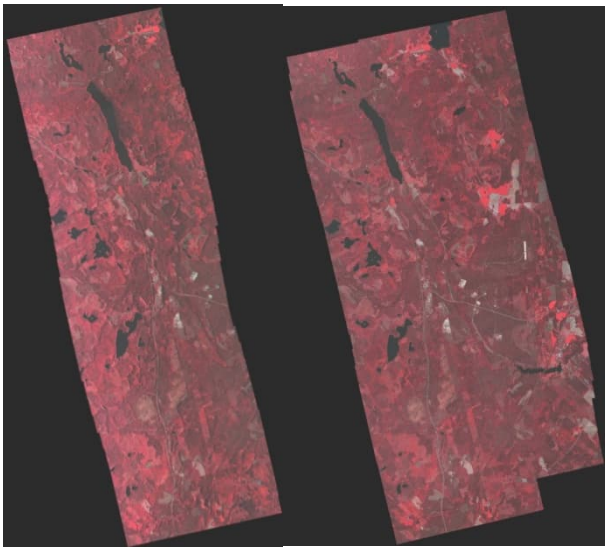


Fig. 78. The 3 km morning and noon images (1102 and 1105-SERIES) at 0520 and 0840 GMT. One and two flight lines.

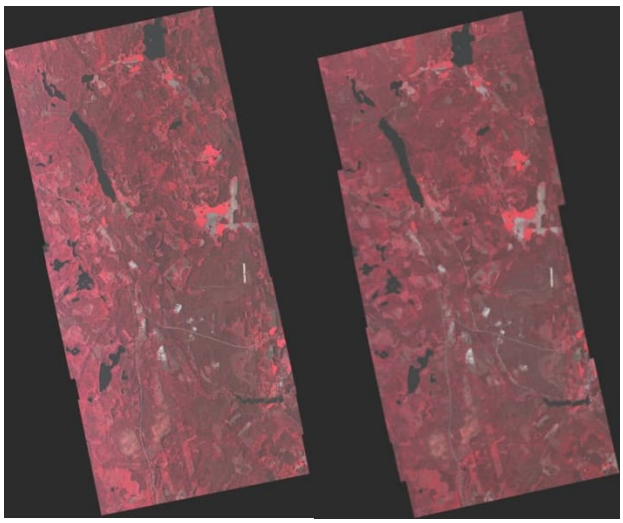


Fig. 79. The 4 km morning and noon images (1103 and 1106 SERIES) at 0530 and 0855 GMT. One flight line in both acquisitions.

Flight lines were repeated (not all, see Fig. 77) to study the effect from solar elevation (See Honkavaara et al.). The earliest time 0515 GMT corresponds to 0715 local time (0815 DST), which is when the sun elevation was 25 degrees. Morning of May 31, 2009. In total, 235 frames were captured.

Flight line, time, image codes, flying height

1 0515 GMT (1101_01_0001 – 36) 2 km
2 0520 GMT (1102_01_0001 – 26) 3 km
3 0530 GMT (1103_01_0001 – 11) 4 km
4 0805 GMT (1104_01_0001 – 38) 2 km
5 0815 GMT (1104_02_0039 – 74) 2 km
6 0825 GMT (1104_03_0075 – 101) 2 km
7 0840 GMT (1105_01_0001 – 24) 3 km
8 0850 GMT (1105_02_0025 – 50) 3 km
9 0855 GMT (1106_02_0001 – 11) 4 km

File adjext.0 has the AAT results for the camera EO parameters.

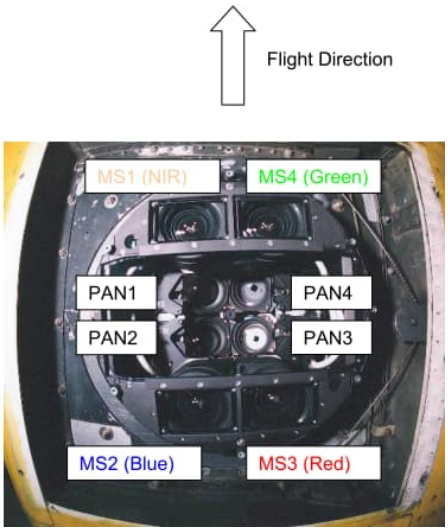


Fig. 80. The DMC I sensor with eight cameras. The images are wider in the perpendicular direction to the flight direction.

In the calibration certificate only, so-called virtual values are documented. All images are thus 'virtual images'. The projection center in the combined image is virtual as well.

The parameters for the high-resolution images:

- f = 0.12000 m
- H/W: 13824 x 7680
- pixel size 12 um
- ppa_x = 0.0, ppa_y = 0.0
- No distortion
- Pixel size, 2 km == 20 cm, 4 km == 40 cm

The virtual color images are smaller:

- f = 0.030 m
- H/W: 3456 x 1920
- pixel size 12 um
- ppa_x = 0.0, ppa_y = 0.0
- Pixel size, 2 km == 80 cm, 4 km == 160 cm

The delivery contains

Level-3 PAN-sharpened RGBN tiffs

- 8-bit per band, 32 bits per pixel
- No LUT for the 12 → 8-bit conversion applied
- 13824 x 7680
- Brovey pansharpening applied

Level 2 PAN tiffs

- 12 bits per pixel (stored with 16 bits)
- 13824 x 7680

Level-2 RGBN tiffs

- 12 bits per pixel (stored with 16 bits)
- 3456 x 1920

The delivery does not contain

So-called intermediate images

- These we do not have (available on request)
- 8 images; MS1-MS4, PAN1-PAN4
- No orientation is available for these
- No interpolation applied as in L2/L3

Defining the IO/EO for the L2 images (HDR)

The following parameters define the IO for the L2

```
1920, 3456 // image size
"r:\images\Ir4\20091101_01_0025_16_RGBN.raw"
0.03            // f
83333.3333      // affine col/x coefficient
 0              // row / x
 959.5          // offset to ppa_x
 0              // row / x
 83333.3333     // row/y coefficient
 1727           // offset to ppa_y
omega, phi, kappa, X0, Y0, Z0 as for the PAN image
```

Defining the IO/EO for the L3 images (HDR-file) and L2 PAN

```
7680, 13824
"I:\aerial_images\dmc2009\images\20091101_01_0029rgbn_uint8.raw"
0.12
83333.3333
0
3840
0
83333.3333
6911
omega, phi, kappa, X0, Y0, Z0 as for the PAN image
```

In the calibration certificate the order of MS bands is NIR, BLUE, RED, and GREEN. Is this the order of bands in the Level-2 TIFFs?

The adjusted real f's of the MS-cameras are 0.02501583, 0.02498438, 0.02497838 and 0.02485340 m. The calibration certificate shows the calibration parameters (Fraser, cf. iWitness calibration): ppa_x, ppa_y, f, k1, k2, k3, p1, p2, b1 and b2.

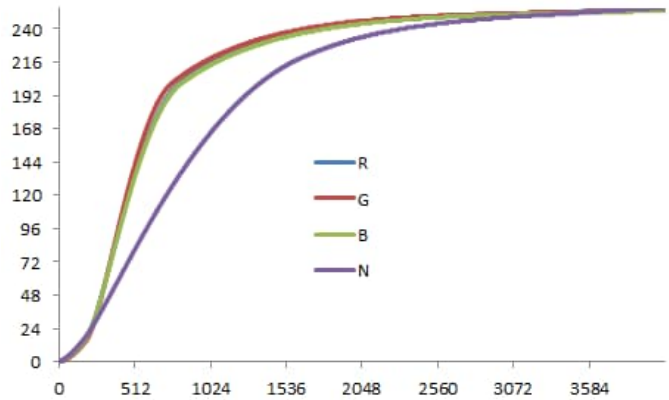


Fig. 81. The 8-bit LUT by NLS Finland for mapping between 4096 and 256 values that they apply normally. (Not used in the deliverables)

Contents

\DMC2009\

The exposure settings are given in file Kameratiedot_31052009(1).xlsx

\Delivery
L2 and L3 images by sub-campaign
Results of aerial triangulation
GPS-IMU observations

\Images
xlsx and cvs Files for making the HDR-files.

L2_PAN\	235 raw images
L2_RGBN\	235 raw images
L3_RGBN\	235 raw images

\TIF_TO_RAW\
c-code (visual studio 6) for the TIF-to-raw conversions

\HDR\
HDR-files

2.5.27 2010 UltraCam-XP; Winter '09- '10 snow-damage

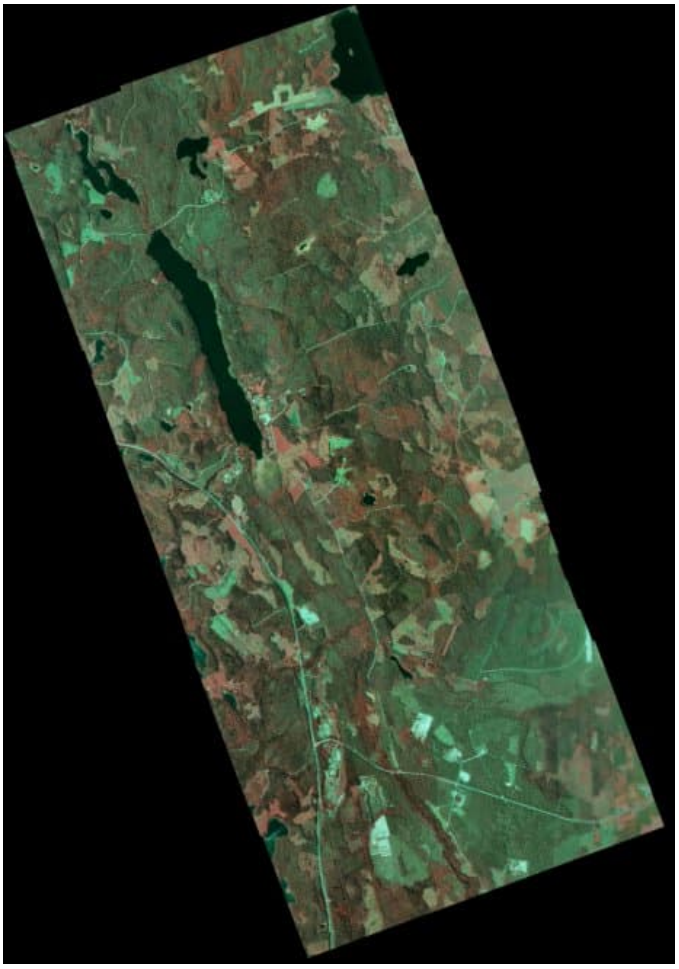


Fig. 82. Coverage of the 2010 photography (Haze in SE corner).

The photography was organized 'ad-hoc' to document the winter 2009-2010 snow-break phenomenon in Hyytiälä, at elevations above 160 m a.s.l. (See Vastaranta et al., 2011)

The weather requirements for photography were not strict, to reduce the weather risks and lower the price of photography. Somewhat hazy conditions prevailed during the acquisition.

- Vexcel UltraCam-X prime sensor, 2.5 km AGL
- 80/50% overlaps, two strips and 46 exposures.
- 1:3 PAN-sharpening ratio. 45 cm RGBN pixels. 15 cm PAN.
- 6 um and 18 um pixels, ppa_x and ppa_y = 0, f = 100.5 mm
- Lvl2 data:
  RGBN (####-Col.tif) TIFFs (5770 x 3770) 16 bit per band.
  PAN-TIFFs (17310 x 11310), 16-bit per pixel
- Lvl3 data:
  CIR-images, 17310 x 11310 pixels.
- XML-information files
- QuickView images in CIR, PAN and RGB.
- Match-AT statistics and AAT files (triangulation).
- HDR files

The L2 PAN-tiffs are tiled, while the L2 COL-tiffs are 'line interlaced' The pixel data starts at byte position 9, the reading is by lines of 5770 (x 2 bytes), first a row of red, then green, blue and nir. Then one reads again a row of red and so on.

The RAW versions now include the 8-bit CIR, and 16-bit PAN and RGBN images, i.e. the L3 and L2 images.

Lvl02-40802-Col.raw	RGBN uint 16
Lvl02-40802-Pan.raw	PAN uint16
40802.raw	CIR uint8

<u>Contents</u>

\2010\

xlsx and csv files for making the HDRs.

..\delivery\

The L2 and L3 TIF files,
results of the aerial triangulation,
Quickview-images

..\HDR\

Example HDR-files, for the 8-bit CIR, 16-bit PAN and 16-bit RGBN RAW images.

..\Images\

The RAW images, 138, 3 x 46 versions.

2.5.28 2011 Leaf-off Hasselblad RGB images Nov 15

Fig. 83. Coverage of the 8 parallel lines + 1 perpendicular line.

Images acquired with LiteMapper 6800 that combines WF-lidar and an RGB camera. The same sensor-combination was also used in 2013 and 2015. The interior orientation of the camera (lens distortions) is not perfectly known/solved as these images were only a by-product of laser scanning.

Hasselblad H4D-50 images

- 750 m AGL, 14 cm resolution
- f/6.8, 1/500 sec, (speed 40 m/s)
- ISO-800,
- 6132 x 8176-pixel images in TIFF format.
- 36.7 x 49.1 mm CCD Sensor,
- SLR digital camera, Diagonal FOV ± 41.2º.

The images (N=172) were oriented with MATCH-AT only in January 2013 by Finnmap company using GPS/IMU & GCP data. Lens distortion information is missing or needs to be solved from the data. The distortion coefficients are given for the 2015 images only. Self-calibration was tried too in 2013. Kuvamitt-images suffer from 1–2-pixel noise in epipolar geometry, which results in 10-30 cm offsets in the object space.

Calibrated f	0.0350683 m
Pixel size	0.006 mm
Principal point offset X	-15.5 pixels
Principal point offset Y	+10.5 pixels

Fig. 84. RGB image samples. Frost was present in open areas.

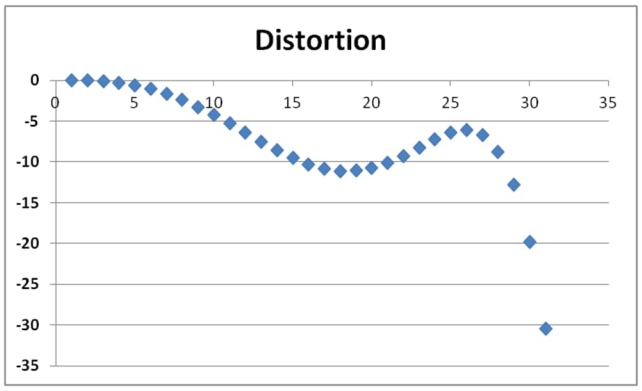


Fig. 85. Radial distortion (distance in mm) x (distortion in um). Coefficients or correction table missing for 2011 and 2013 Hasselblad campaigns. The distortion is less than 2 pixels but in the iamge corner.

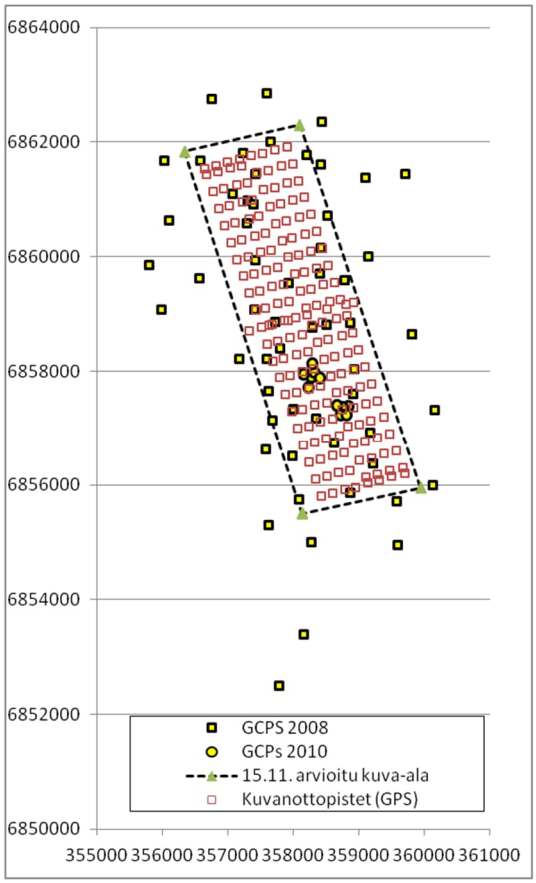


Fig. 86. The (X0,Y0), GCPs available and estimated AOI.

Table 5. GCPs established in 2010.

2010 established	KKJ2-X	Y	N60-Z
1075	2517028.101	6857411.642	157.861
1076	2516953.152	6857386.602	164.196
1077	2516855.963	6857418.36	167.833
1078	2516918.222	6857246.394	162.415
1079	2517012.977	6857255.065	157.355
1080	2516402.764	6857701.383	141.972
1085	2516447.796	6857886.496	158.612
1086	2516482.577	6857970.175	160.187
1087	2516443.304	6858123.127	149.333
1088	2516568.307	6857889.656	154.61
1033	2516321.089	6857943.825	147.575

Table 6. GCPs were established in summer 2008.

2008 perustettuja			
1001	2515540.89	6862805.67	142.587
1002	2514701.84	6862674.71	150.895
1004	2516393.1	6862347.33	173.783
1006	2515327.82	6860930.87	183.6
1007	2516419.3	6861606.31	171.097
1008	2516868.9	6859612.14	163.421
1009	2517940.44	6858704.41	136.287
1010	2517089.97	6857621.11	158.221
1012	2518347.86	6857404.14	145.797
1014	2516994.33	6858857.86	170.884
1016	2516420.83	6858753.14	174.925
1017	2516490.08	6859704.91	174.943
1020	2517209.24	6860029.82	152.908
1021	2515853.57	6858820.63	150.289
1022	2516632.59	6858809.19	178.132
1024	2515091.649	6861035.936	185.784
1025	2516565.19	6860725.57	171.046
1026	2516486.15	6860152.39	183.204
1028	2516547.034	6857174.103	145.167
1030	2517126.678	6855881.953	143.391
1031	2516221.508	6856496.677	140.688
1032	2516192.51	6857316.976	141.559
1033	2516321.067	6857943.827	147.533
1034	2515748.441	6858173.127	142.01
1035	2515943.44	6858367.63	143.763
1036	2515523.993	6859033.339	142.826
1037	2516018.421	6859523.081	173.297
1038	2516190.228	6861768.985	180.909
1039	2515634.313	6861961.73	187.634
1040	2515217.297	6861749.275	174.964
1041	2514580.198	6861582.616	152.799
1042	2515416.691	6860870.853	183.069
1045	2515883.108	6857110.091	146.24
1046	2516531.634	6853382.703	157.693
3743	2516208.9	6852470.26	168.27
4220	2514105.09	6858955.39	188.491
5040	2517851.62	6855766.72	147.55
5042	2517707.07	6861501.99	162.4
7627	2515429.58	6861396.75	198.528
1055	2517102.91	6861408.525	169.4942
1056	2518387.765	6856074.26	153.8538
1057	2517899.03	6855014.077	142.0002
1058	2517390.075	6856963.397	149.0726
1059	2515330.545	6860522.998	190.863
1060	2514028.063	6861560.729	148.2901
1061	2515908.162	6855258.078	164.9121
1062	2515333.491	6858152.131	153.7395
1063	2516579.97	6854991.942	148.3364
1064	2513880.105	6859737.327	177.8295
1065	2515803.38	6856585.121	162.4445
1066	2514153.749	6860521.976	170.484
1067	2515808.617	6857608.129	145.5813
1068	2516362.122	6855740.719	146.9316
1069	2514654.098	6859540.583	166.3937
1070	2515496.573	6859884.482	169.8306
1071	2517940.45	6858704.407	136.3298
1072	2517090.27	6858057.822	172.4008
1073	2517457.072	6856419.98	150.7234
1074	2516844.684	6856752.99	148.7866

Contents

\2011\

..Delivery\
The 175 TIF –files

..AT\
The results of the aerial triangulation

..Images\
The RAW images RGB

..\HDR\
The HDR-files

2.5.30 2012 UltraCamD; 90-minute repeated acquisition with fixed exposure settings

This campaign (July 12, 2012) was organized to have data for radiometric image normalization tests. The sensor was flown twice above the same area and along the same flight paths, using the same fixed exposure settings. Perpendicular lines were flown twice as well.

Fig. 87. AOI of the 2012 photography. Six N-S-oriented lines and one E-W line – all repeated twice/three times.

The campaign started at 06:35, and the lines were repeated after an interval of about 45 minutes. In total the campaign lasted 1h 30 min. The solar elevation increased almost 9 degrees from 34 to 42.5 degrees, while the azimuth increased from 107° to 130°. A manuscript (influence of Solar Zenith Angle) was prepared in 2020-23 using these images and the MSc thesis by Markus Karppinen.

Flight lines repeated by

	Images	Images	Images
Line 0	10064-10079	10272-10287	10480-10496
Line 1	10080-10111	10288-10319	
Line2	10112-10143	10320-10351	
Line3	10144-10175	10352-10383	
Line4	10176-10207	10384-10415	
Line5	10208-10239	10416-10447	
Line6	10240-10271	10448-10479	

Image times, GMT		Azim.	Elev
10064	06:35:19	107.1	34.0
10080	06:40:16		
10112	06:45:22		
10144	06:51:35		
10176	06:57:10		
10208	07:03:33		
10240	07:09:45		
10272	07:14:57	117.8	38.3
10288	07:20:37		
10320	07:26:28		
10352	07:32:39		
10384	07:38:38		
10416	07:44:52		
10448	07:51:11		
10480	07:56:41	129.4	42.4

- Vexcel UltraCam-D sensor; 9 um PAN; 28.125 um RGBN
- c = 101.4004 mm
- ppa_x 0.3757 mm (41.7 pixels)
- ppa_y 0.0029 mm (0.32 pixels)
- 1500 m AGL
- 14 cm PAN-pixels; 42-cm RGBN pixels.
- 67/80% overlaps. 432 exposures.

Rotation issues:
Lvl2 data, 16 bits per band:

RGBN (Col) TIFFs (3680 x 2400), Affine parameters
(0, 35555.55555, 1839.898, -35555.55555, 0, 1186.6432)
PAN-TIFFs (7500 x 11500), Affine parameters
(0, 111111.1111, 5749.7, -111111.1111, 0, 3708.26)

Lvl3 data: CIR-images, 7500 x 11500 pixels. Affine parameters.
(111111.1111, 0, 3791.74, 0, 111111.1111, 5750.32)

- XML-information files, QuickView JPEG images in CIR, PAN, RGB versions.
- Match-AT statistics and AAT files (triangulation).
- HDR files
- 1/250 s exposure, F8

Contents

\2012\
Files for making the HDR-files

..\Delivery\
TIFF L2 and L3 data, AT data.

..\Images\
1296 RAW images (3 x 432)

..\HDR\
The HDR-files

..\Preparations\

2.5.31 2013 Hasselblad RGB images, Hyytiälä & Siikaneva, May 28

Hyytiälä

Siikaneva

Images were acquired simultaneously with the Riegl LMS-Q680i LiDAR campaign on May 28, 2013; 09:30-12:20 GMT.

Hasselblad H4D-50, 50 Mpx camera, 6132 x 8176-pixel images in TIFF format. Focal length ###, PPA in X and Y.

Bell 206L (OH-HJL) helicopter.

Two separate image blocks: Hyytiälä and Siikaneva.

Hyytiälä

- Flying height 750 m AGL
- Flying speed 41 m/s
- F-stop f/6.8
- Exposure time 1/160 sec.

Aerial triangulation was done in April 2014 by IK. Tie points were measured with iWitness, and a rigid body transformation was done in iWitness using GCPs, followed by bundle block adjustment using IK's software. SD of residuals at 30 GCPs were 4, 7 and 9 cm for X, Y and Z, respectively. In iwitness the parameters were: f = 35.0617, xp = 0.036 mm, yp=0.006 mm. No distortions were considered in practice. The distortion parameters were not supplied, they are only available for the 2015 images with the same sensor. It might be advisable to try to estimate distortions using the Siikaneva images. The very high overlaps may give a wrong impression of low distortions. Estimation might still be weak.

Siikaneva

- Flying height 300 m AGL
- Flying speed 36 m/s
- F-stop f/6.8
- Exposure time 1/160 sec

Automatic image matching was done (with Match AT) by the contractor. Direct georeferencing data was used w/o ground control. There potentially were small systematic errors in orientation, due to inaccuracy in focal length and/or the GNSS trajectories. There was no camera motion compensation, which affected the image matching. Comparison with ground reference points, measured with GNSS in a small area, indicated systematic Z-errors but these were not investigated further. There are further GNSS field data collected in the spring of 2014.

N.B. The orientation is in the UTM35/WGS84 ellipsoidal height system!

In November 2015, 35 images viewing the EC tower were triangulated using tie points that link overlapping strips, as there were clear issues in the AT results for between-strip match. The RMS went down from 10.9 um to 4 um. The adjustment was constrained by the earlier AT results, as the EO parameters were allowed set weights of 0.1 m and 0.005 radians, zero-mean, i.e. on average the block would not shift in XYZ. After AT, the match with LiDAR data was improved, as well as for the 800+ vegetation GNSS observations made in April 2014 in the area. These were used in the 2020 paper in Mires and Peat (Korpela et al.)!

The ground reference points were located in two separate, small areas, and are documented in:

- \HYDE_REF\Plots\2013_raspberryLAI_optical_GNSS\index.html

Contents

\2013\Hyytiala\
..\Tiff\
Tiff images (N = 208)
..\HDR\
Hdr-files
..\Hyytiala_KKJ2_N60.gps
Direct georeferencing data (XYZ, omega, phi, kappa) in KKJ2/N60

..\Triangulation\Hassel2013.iwp
iWitness project
..\Triangulation\###_####.icf
iWitness image observation files
..\Triangulation\Hassel2013_EOIO.txt
EOIO solution from iWitness
..\Triangulation\Control_2013_ilmakuvat.txt
Coordinates of the GCPs used in 2014 triangulation
..\Triangulation\solution2014.txt
Solution of the triangulation in 2014
..\Triangulation\Hasselblad_adjustment.zip
New triangulation from 2015

..\Triangulation\ICF_to_ima_obs.zip
Conversion program: .icf to image observation files
..\Triangulation\MINV12_triangulation_program_gcp_weights.zip
Triangulation program

\2013\Siikaneva\

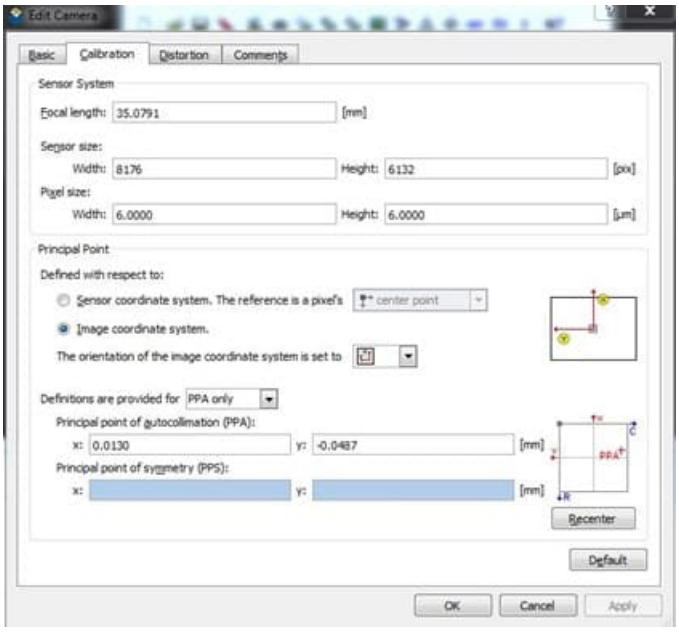
..\Tiff\
Tiff images (N = 98)
..\HDR\
Hdr-files
..\Ortho\
Orthoimages provided by the contractor
..\Siikaneva_TM35_ell.gps
Direct georeferencing data in ETRS-TM35FIN
..\Siikaneva_laserkeilaus_2013_at_raportti.txt
Match AT report

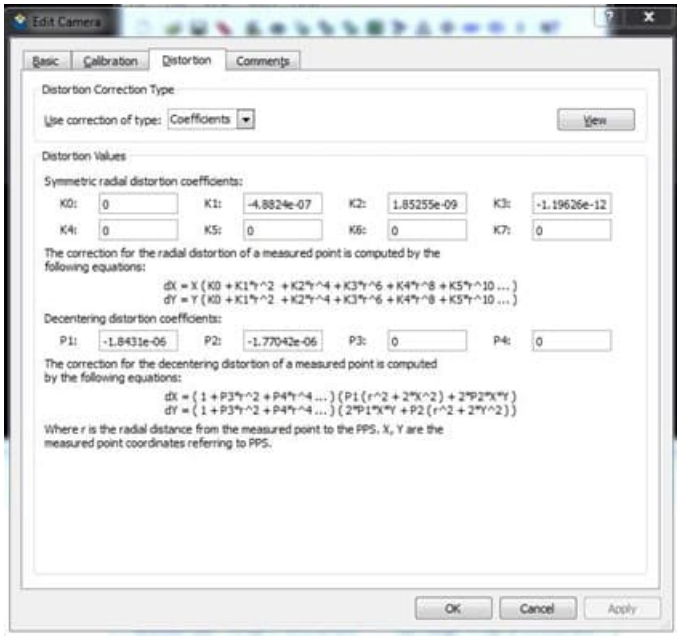
2.5.32 2015 Hasselblad RGB images, Aug 18

Images were acquired simultaneously with the Riegl LMS-Q680i LiDAR campaign on August 18, 2015; 07:43-10:19 GMT.

Slight overexposure. Delivery includes both exposure-corrected TIFFs and the original files from the camera as 7-zip compressed files.

The AT was done at Finnmap (utilizing the signals that were serviced in the spring of 2015), and, according to initial Q/C, geometry proved to be ok. The distortions (< 2 pixels) remain in the raw (pinhole) image for KUVAMITT.





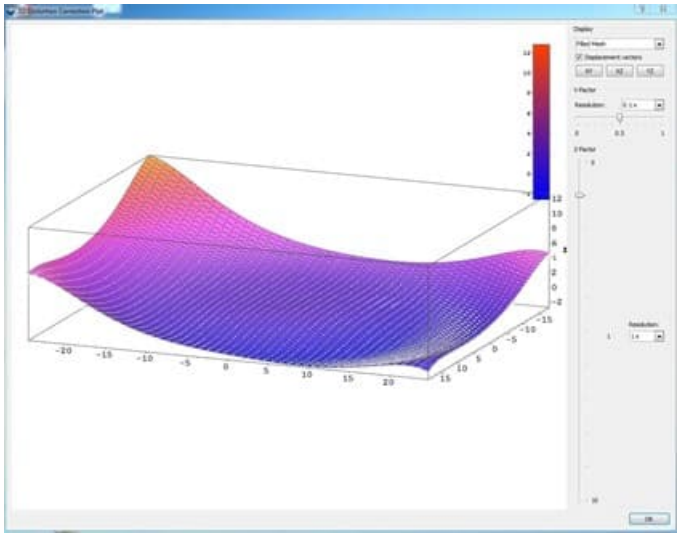


Fig. 88. Lens distortion illustration for the Hasselblad sensor in 2015 (unavailable for 2011, 2013).

Contents

2.5.33 2015 NLS 6 km imagery

Fig. 89. A set of images was obtained from NLS (via Olli Sirkiä). Triangulated by NLS in ETRS-TM35 (file 20151603A orientointitekijät.txt).

The images were asked from NLS for course ME-013C in 2018. EO in KKJ2/N60 was needed and images were oriented in KKJ2/N60 using iWitness and GCPs. AT results were refined by bundle-block adjustment using IK's software. The AOI is large with few GCPs far from Hyytiälä. 6 um pixels, 100.5 mm focal length. xp = -0.000000 mm, yp = 0.120000 mm. The images include RGBN-8-bit TIFFs. Matlab was used to create 3-band RGB-versions (RAW, BIP, kuvamitt-compatible).

Fig. 90, Information about the campaign. UltraCamX Prime with 11310x17310 PAN pixels. Time of exposure needs to be solved from the images or NLS databases.

The Matlab-code for extrating specific bands from the 4-band TIFF:

```
imgdata=imread('c:\data\aerial_NLS\20151603A_04_0096.tif');
A = imgdata(:,:,1:4);
B = rot90(A);
fileID = fopen('c:\temp\20151603A_04_0096_rgb.raw','w');
fwrite(fileID,flip(B(:,:,1:3)));
fclose(fileID);
close();
fileID = fopen('c:\temp\20151603A_04_0096_cir.raw','w');
fwrite(fileID,flip(B(:,:,[4,1,2])));
fclose(fileID);
close();
```

Contents

2.5.34 2016 Optech Titan camera images

RGB-images with the Optech CS10000 (Phase one, IQ180) camera in the Titan multispectral laser scanner. Exposure 1/125 secs (may vary between images?). ISO-50. 10328 x 7760 pixels, 5.2 um, 51.45 mm focal length. According to calibration from May 2015, the lens distortions are very large: up to 600 um (120 pixels).

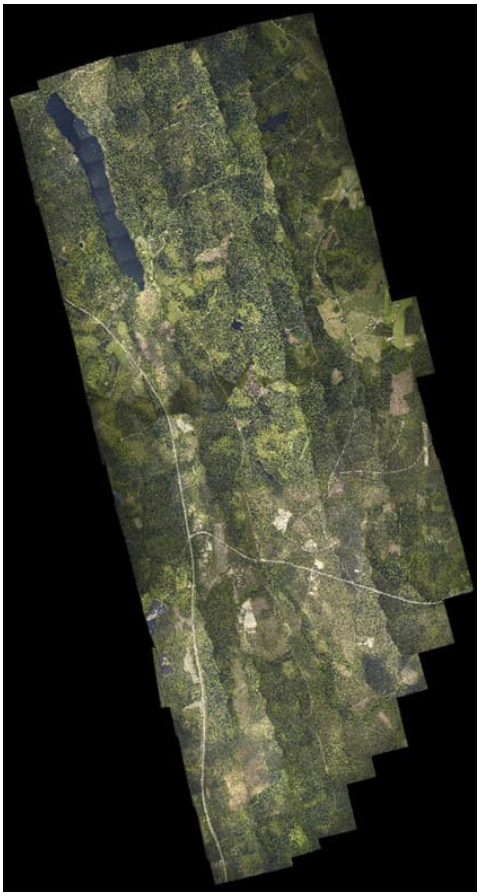


Fig. 91. AOI. Alltogether 226 images.

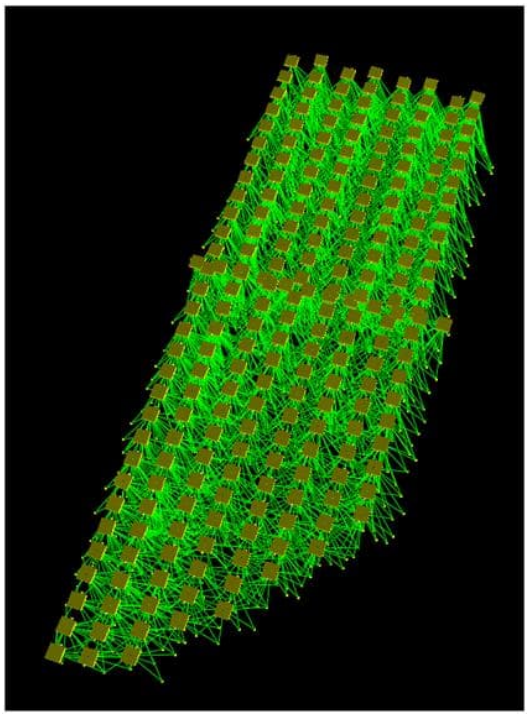


Fig. 92. AOI covers Lakkasuo in the south and the Syväniemi farm in the east - south-east. Alltogether 226 images.

AT was finally done manually using iWitness (by IK) followed by WLS-bundle block adjustment. iWitness was used to re-estimate the calibration parameters. The AT procedure uses the .icf -files from iWitness that contain the image coordinates (right-handed, centered at width/2, height/2) of all tie points (all points have 2 or more observations). Look at ..2016\AT\

At solution the RMS was 7.7 um, which suggests image observation errors and/or remnant distortions. Area-based image matching will therefore likely not be very accurate using these images and they are "documentary" in nature.

The RAW images are resampled to pinhole geometry using the VB-program in ..2016\AT\Rectify . These were initially tested with KUVAMITT, and while the epipolar geometry works, the few pairs (models) seem to be tilted some meters.

Contents

2.5.35 2018 Riegl 1560 RGB imagery

Phase one iXU-RS1000 camera. 100 MP with 11608 x 8708 RGB images. Acquired during LiDAR campaign May 24, 2018, at 06.33 GMT...06.55 GMT. Pixel size 4.6 um. Flying height 1330 m in N2000, i.e. about 1150 m AGL. The scale with 5-cm focal length was thus 1:22000 and one pixel corresponds to about 10 cm.

Fig. 93. Index of the Riegl 1560 images.

iXU-RS Technical Specifications

	iXU-RS 1000	iXU-RS 180	iXU-RS 160	iXU-RS 160 Achromatic
Resolution	**100 MP** 11608 x 8708	**80 MP** 10328 x 7760	**60.5 MP** 8984 x 6732	**60 MP** 8964 x 6716
Dynamic range	>84 db	>72 db		
Aspect ratio	4:3			
Pixel size	4.6 micron	5.2 micron	6.0 micron	
Sensor size effective	53.4 x 40.0 mm	53.7 x 40.4 mm	53.9 x 40.4 mm	53.8 x 40.3 mm
Lens factor	1.0			
Light sensitivity (ISO)	50-6400	35-800	50-800	200-3200
Camera type	Medium format camera for aerial photography			
Lens mount	Phase One RS dedicated mount			
Shutter speed	Leaf shutter; up to 1/2500 second			
Shutter control	1/3 f-stop increments			
Interfaces	USB 3.0; Secured power input (LEMO); Camera trigger; Mid-exposure pulse; Camera status; iX Link			
Live View/HDMI	• 1920 x 1080 25p/30p • 1280 x 720 50p/60p			
GPS/IMU support	Applanix, NovAtel, IGI, GGS, NMEA Devices			
Forward Motion Compensation	N/A	TDI controlled		
Data storage	• 1 TB SSD storage (optional iX Controller) • CompactFlash card Type I/II including UDMA 6 and 7			
Syncronization speed in multiple camera configuration	100 microseconds			
Capture rate — full resolution frame	0.6 s	1.25 sec	1.1 sec	1.1 sec
RAW File compression	IIQ large: 100 MB IIQ small: 65 MB	IIQ large: 80 MB IIQ small: 54 MB	IIQ large: 60 MB IIQ small: 40 MB	
Lens + technology optimizes	Color cast; Light falloff; Chromatic aberration; Fringing; Sharpness falloff; Lens distortion			
Output formats	Phase One RAW, TIF, JPG, CIR and NDVI			
Post processing	• iX Capture • Capture One Pro • Capture One Processing Engine			
IR cut-off filter	Available either with or without IR filter			
Connection to pod	Four M4 bolts			
Power input	12 - 30 V DC			
Maximum power consumption	10 W	12 W		
Weight iXU-RS (excluding lens)	.930 kg/2.05 lb			
Weight iXU-RS 50 mm	1.700 kg/3.7 lb			
Approvals	FCC (Class A), CE, RoHS			
Operating Conditions				
Temperature	-10° to 40°C (14° to 104°F)			
Humidity	15 to 80% (non-condensing)			

First 19 images have f/4, ISO 160 & 1/1250 sec exposure. Remaining images have f/4, ISO 125, 1/1250 sec exposure.

Calibrated values (10-parameter model) for the lens correction model were:

c	51.681 mm
xp	-0.073 mm
yp	-0.040 mm
Radial distortion	
K1	1.52902e-05
K2	-5.34204e-09
K3	8.63902e-13
Decentering distortion	
P1	-3.11216e-06
P2	3.22987e-06
Linear distortion	
B1	0.0
B2	0.0

The images were triangulated using MATCH-AT at Terratec. A set of signaled GCPs were delivered to the company to assist in Q/C, but the solution of AT was based only on direct georeferencing. This AT was done in UTM35 (ETRS-TM35FIN) with N2000 elevations USING gpsimu alone.

The match-at image observations and tie point XYZ-data were used to compute the orientation also in KKJ2/N60 system i.e. all values on the ground were transformed to KKJ-2 and N60 values and the orientation parameters (camera position and attitude, 6 per image) were re-estimated using bundle block adjustment. The residuals in signaled GCPs (N=14) were ca. 5 cm for X, Y and Z. The RMS of image errors was 1 um.

Table 7. The distorted images were rectified (re-sampled) to pinhole images using XY-rectify by Photometrix company by accounting for the lens distorted depicted by the parameters listed above. The EO parameters in KKJ-2/N60 are listed below in radians and meters.

Omega	Phi	Kappa	X0	Y0	Z0	Image #
-0.002310	0.000900	0.352667	2516883.511	6855394.285	1337.597	_1
-0.002380	0.002338	0.350512	2516753.118	6855752.828	1336.265	_2
-0.002091	0.002067	0.349562	2516622.829	6856113.574	1335.291	_3
-0.002585	0.000460	0.354048	2516491.189	6856474.547	1335.656	_4
-0.002057	0.000286	0.359686	2516358.194	6856834.697	1335.925	_5
-0.002055	0.001271	0.360792	2516222.538	6857194.591	1336.285	_6
-0.001967	0.001015	0.360691	2516087.939	6857552.894	1334.493	_7
-0.002751	0.002154	0.351571	2515954.558	6857914.622	1334.142	_8
-0.001933	0.001111	0.348138	2515824.663	6858275.408	1335.715	_9
-0.002180	0.001500	0.348123	2515695.999	6858637.703	1335.908	_10
-0.002023	0.000645	0.348735	2515566.204	6858998.683	1336.842	_11
-0.002249	0.001343	0.348199	2515435.732	6859359.643	1337.990	_12
-0.002514	0.002061	0.349067	2515305.587	6859721.919	1336.548	_13
-0.003049	0.001693	0.345705	2515177.245	6860082.919	1335.385	_14
-0.002305	0.002077	0.355403	2515046.526	6860445.861	1334.077	_15
-0.001910	0.000585	0.354588	2514914.116	6860804.766	1334.888	_16
-0.003219	0.000769	0.348863	2514782.055	6861166.184	1333.840	_17
-0.002582	0.002001	0.345121	2514652.718	6861527.307	1332.653	_18
0.002628	-0.002039	-2.799564	2515100.072	6861706.969	1337.625	_19
0.002511	-0.001739	-2.787837	2515227.491	6861345.659	1337.942	_20
0.001919	-0.000715	-2.774191	2515361.239	6860984.573	1339.035	_21
0.001529	-0.001072	-2.777093	2515500.813	6860627.515	1339.187	_22
0.002043	-0.001586	-2.787426	2515638.745	6860269.102	1338.099	_23
0.002226	-0.002789	-2.783857	2515772.454	6859908.270	1336.851	_24
0.002682	-0.002129	-2.786676	2515905.543	6859548.172	1338.778	_25
0.002858	-0.000753	-2.787334	2516037.755	6859188.286	1339.156	_26
0.001951	-0.001720	-2.795910	2516168.115	6858826.883	1338.685	_27
0.002139	-0.001642	-2.785787	2516298.109	6858465.526	1337.178	_28
0.002054	-0.001062	-2.793830	2516429.545	6858104.992	1337.234	_29
0.002227	-0.001634	-2.796295	2516558.938	6857742.472	1336.168	_30
0.002679	-0.001413	-2.786874	2516688.515	6857382.706	1338.977	_31
0.002117	-0.001909	-2.770880	2516823.485	6857021.650	1339.249	_32
0.001803	-0.000731	-2.792722	2516959.126	6856663.768	1336.969	_33
0.001550	-0.001792	-2.792609	2517219.059	6855939.604	1336.890	_34
0.001695	-0.001770	-2.795805	2517348.002	6855577.444	1337.264	_35
-0.002113	0.002383	0.350437	2517704.588	6856032.599	1344.134	_36
-0.002253	0.000921	0.357321	2517573.090	6856392.468	1343.717	_37
-0.002072	0.001275	0.355266	2517437.795	6856752.063	1344.739	_38
-0.002036	0.002188	0.354648	2517305.091	6857112.026	1344.129	_39

-0.002032	0.001650	0.358904	2517171.435	6857472.796	1342.967	_40
-0.001963	0.002258	0.352906	2517037.847	6857833.218	1345.669	_41
-0.002078	0.001712	0.350147	2516906.665	6858194.114	1343.991	_42
-0.001683	0.001322	0.344761	2516777.019	6858555.515	1342.726	_43
-0.001740	0.001819	0.337360	2516649.650	6858916.790	1342.107	_44
-0.002225	0.001600	0.349293	2516521.665	6859279.232	1341.814	_45
-0.002519	0.001068	0.351954	2516389.967	6859639.723	1342.100	_46
-0.002242	0.001698	0.350577	2516258.147	6860001.443	1343.329	_47
-0.001568	0.001052	0.348841	2516127.268	6860361.869	1344.079	_48
-0.002125	0.002290	0.350194	2515995.962	6860724.219	1344.459	_49
-0.002268	0.001182	0.354061	2515864.690	6861084.788	1344.050	_50
-0.002392	0.001891	0.352100	2515733.067	6861444.899	1344.277	_51
-0.002199	0.001362	0.348587	2515602.123	6861806.000	1342.822	_52
0.001646	-0.001462	-2.790483	2516017.379	6862077.717	1326.976	_53
0.002763	-0.001774	-2.786858	2516148.615	6861717.984	1327.214	_54
0.002259	-0.000611	-2.781693	2516281.997	6861357.564	1329.293	_55
0.002152	-0.001146	-2.788648	2516414.886	6860998.142	1329.374	_56
0.003081	-0.000838	-2.791557	2516545.704	6860637.130	1329.251	_57
0.001115	-0.001607	-2.792409	2516677.040	6860275.573	1327.373	_58
0.003039	-0.000681	-2.795770	2516807.214	6859913.567	1325.076	_59
0.002059	-0.000504	-2.789627	2516937.658	6859552.432	1328.456	_60
0.002048	-0.000384	-2.788005	2517069.409	6859192.052	1330.284	_61
0.002719	-0.001920	-2.784317	2517201.786	6858831.487	1328.682	_62
0.002309	-0.001039	-2.780136	2517335.913	6858471.180	1326.814	_63
0.002649	-0.001865	-2.782555	2517469.046	6858111.461	1328.606	_64
0.002371	-0.001202	-2.790451	2517601.672	6857750.298	1328.494	_65
0.001610	-0.000459	-2.793885	2517732.107	6857389.111	1326.532	_66
0.002282	-0.000916	-2.793303	2517862.451	6857028.418	1325.817	_67
0.001922	-0.000788	-2.787177	2517995.666	6856667.802	1327.089	_68
0.002175	-0.000760	-2.772958	2518131.185	6856308.543	1328.443	_69
-0.000983	-0.002571	1.911529	2517142.541	6860628.573	1340.365	_70
-0.001371	-0.002766	1.915499	2516778.715	6860500.803	1341.126	_71
-0.000925	-0.002459	1.915519	2516417.097	6860372.542	1341.871	_72
-0.001448	-0.002557	1.912020	2516055.037	6860243.694	1342.056	_73
-0.000977	-0.002497	1.905135	2515693.901	6860116.792	1340.511	_74
-0.000405	-0.002848	1.907739	2515330.361	6859991.350	1340.988	_75
-0.000598	-0.002290	1.907327	2514966.004	6859865.155	1342.266	_76
-0.001018	-0.003159	1.911633	2514603.751	6859739.193	1343.706	_77

2.5.36 2018 SMK 8 km imagery

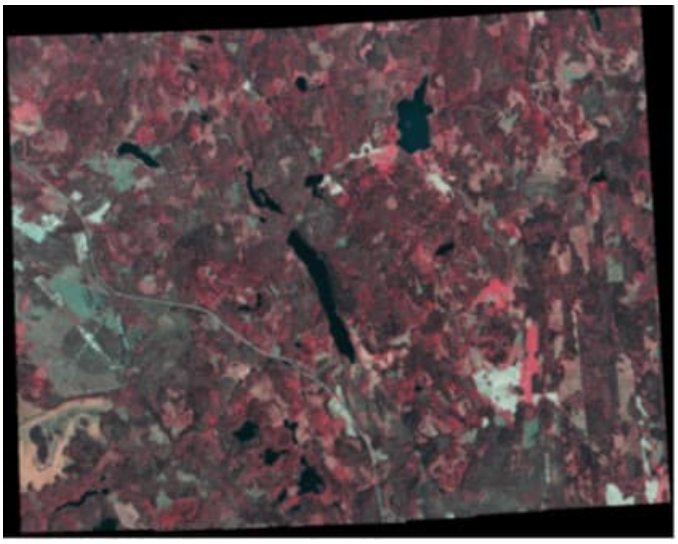


Fig. 94. Index of the six UltraCam Eagle images from 8 km.

Data was received from Terractec (for course ME-013C in 2019) and originally it is a taxpayer-financed campaign by SMK, Suomen Metsäkeskus.

C = 100.5 mm
PPAX = -0.080 mm
PPAY = 0.000 mm
17004 x 26460 pixels

See more information about the sensor in the 2020 3km imaging campaign Section.

The original EO was in UTM35 (Hyde_6_GPS_INS.txt).

The images were re-georeferenced (relative orientation) with iWitness (rigid tramnsformation) followed by WLS-bundle block adjustment with IK's adjustment software.

Data includes

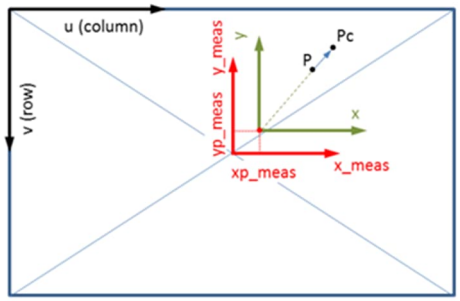
Level-2 TIFFs
Level-3 RGB & CIR TIFFs (turned into raw-files for KUVAMITT)
Camera calibration certificates.

2.5.37 2020 Riegl RGB imagery

Fig. 95. Index of the Riegl 2020 RGB-imagery. The flight repeats hte 2018 lidar/imaging campaign "1:1" with slight changes in both the lidar and camera sensors.

- Captured during Riegl laser scanning June 3, 2020, by Terratec Norway/Finland
- 1150 m AGL, apprx. 10 cm resolution, 67% f-overlap
- 14204 × 10652 pixels, 453,909,970 bytes per image
- Phase One - iXM-RS150F sensor, 54° × 42° FOV
- f/4, 1/800 seconds, ISO 100
- CMOS-sensor, no sensitivity curves, Bayer-filter??
- Calibration Nov 28, 2019:
  Pixel size 3.76 um,
  c = 51.5383 mm,
  xp = -0.0375 mm,
  yp = 0.1170 mm,
  k1=1.50518e-05,
  k2 = -4.76124e-09,
  k3=5.29874e13,
  p1=-1.78431e-06, p2=3.39647e-06
- 80 frames (TIFFs), 5 strips
- Match-At aerial triangulation with GPS/IMU data alone
- Consortium at UH (prof. Bäck, Puttonen, Holopainen, Vauhkonen & Korpela). Funding by courses utilizing these data + SMEAR.

Notes on the above calibration model:



1. Measurement data in the images are provided as pixel coordinates first. u_meas and v_meas values are columns and rows on the chip.
2. Transforming into metric coordinates is accomplished by:
   $x\_meas = ps \cdot (u\_meas - NC/2)$
   $y\_meas = -ps \cdot (v\_meas - NR/2)$
   with NC and NR the number of columns and rows, respectively. Pixel size is denoted by ps.
3. The coordinates of the principle point, xp_meas and yp_meas, in the x_meas/y_meas coordinate system allows the transformation in the camera coordinate system x, y, (z).
   $x = x\_meas - xp\_meas$
   $y = y\_meas - yp\_meas$
4. With
   $r = \sqrt{x^2 + y^2}$
   $dr = (K0 + K1 \cdot r^2 + K2 \cdot r^4 + K3 \cdot r^6 + K4 \cdot r^8 + K5 \cdot r^{10} + K6 \cdot r^{12} + K7 \cdot r^{14})$
   $dn = (1 + P3 \cdot r^2 + P4 \cdot r^4)$
   corrected coordinates (xc and yc) are calculated as
   $xc = x + x \cdot dr + dn \cdot (P1(r^2 + 2x^2) + 2P2 \cdot x \cdot y)$
   $yc = y + y \cdot dr + dn \cdot (P2(r^2 + 2y^2) + 2P1 \cdot x \cdot y)$.
5. These corrected coordinates of a measured point in the image is $P\_img(xc, yc, C)$ where C is the camera constant or focal length. Together with the front nodal point O (center of the camera coordinate system) this defines a ray towards the object,
   $O - P\_img = (-xc, -yc, -C)$

Fig. 96. Explanation of the camera parameters in the calibration pdf-file.

The aerial triangulation by Match AT was done using only GNSS-IMU data, i.e. without any ground control. The RMS-statistics below reflect thus accuracy of relative orientation and minor systematic errors may be present in any of the exterior orientation parameters. These can only be analysed by using the GCPs, some of which are visible in the images still.

<u>MATCH-AT-results (no ground control)</u>

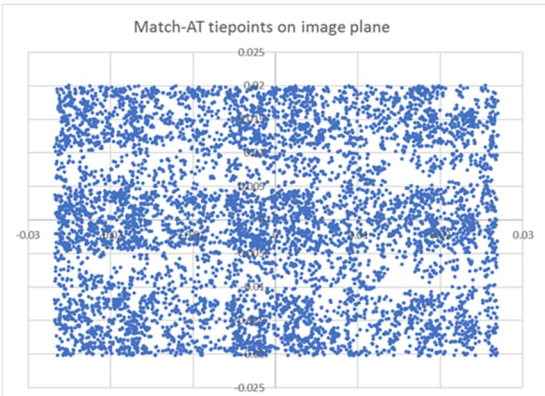
RMS IMU observations (number: 80)

omega	0.0029 [deg]
phi	0.0035 [deg]
kappa	0.0037 [deg]

RMS GNSS observations (number: 80)

x	0.054 [meter]
y	0.038 [meter]
z	0.040 [meter]

sigma naught 0.7 micron (16:16:53)



pix4D software (structure from motion) was briefly tested for solving the exterior orientation, it does however not consider the observatoins of image rotations (as observations), only the xyz-positions by GNSS.

The MATCH-AT triangulation was repeated by transforming the gnd-observations from UTM35/N2000 into KKJ-2/N60 coordinate system:

Table 8. Exterior orientation parameters in radians and degrees in the KKJ-2/N60 system.

IM	omega	phi	kappa	x0	y0	z0
657	0.008651	0.005487	0.352415	2516901.13	6855349.79	1339.27
658	0.009431	0.005418	0.349553	2516773.58	6855697.41	1340.26
659	0.008805	0.005174	0.342288	2516647.60	6856040.36	1340.08
660	0.008701	0.006271	0.360298	2516522.33	6856383.39	1340.17
661	0.008464	0.005714	0.350877	2516395.51	6856725.60	1340.43
662	0.009245	0.005765	0.352929	2516268.94	6857067.46	1340.42
663	0.008909	0.004777	0.356095	2516142.03	6857409.94	1340.37
664	0.009473	0.006001	0.346248	2516013.54	6857755.12	1340.52
665	0.008965	0.006049	0.346480	2515887.26	6858098.86	1339.93
666	0.008634	0.005044	0.334713	2515763.05	6858442.41	1339.23
667	0.009274	0.005349	0.353345	2515641.57	6858784.44	1339.59
668	0.007724	0.004088	0.352337	2515519.49	6859125.45	1339.97
669	0.008867	0.005236	0.357296	2515398.25	6859465.73	1339.43
670	0.008749	0.005648	0.360718	2515276.28	6859807.00	1339.54
671	0.009658	0.004839	0.355750	2515154.14	6860145.62	1339.16
672	0.009028	0.004953	0.334965	2515031.90	6860482.12	1339.31
673	0.008968	0.005733	0.348350	2514909.40	6860820.40	1340.50
674	0.008900	0.005099	0.373563	2514785.38	6861156.20	1339.91
675	0.009074	0.006417	0.359164	2514664.06	6861492.74	1339.27
621	-0.008782	-0.005433	-2.791684	2515138.33	6861590.23	1340.58
622	-0.008797	-0.005713	-2.798510	2515260.18	6861254.73	1340.90
623	-0.007991	-0.004659	-2.792065	2515381.71	6860918.96	1340.38
624	-0.009221	-0.006182	-2.787643	2515504.47	6860583.58	1340.16
625	-0.008671	-0.004893	-2.791228	2515627.91	6860248.69	1340.26
626	-0.009028	-0.006479	-2.791199	2515750.25	6859912.56	1340.58
627	-0.008623	-0.005591	-2.789350	2515874.67	6859574.09	1340.99
628	-0.009690	-0.005868	-2.796750	2516000.20	6859235.36	1340.29
629	-0.009252	-0.005688	-2.792903	2516125.68	6858894.81	1340.37
630	-0.008863	-0.006018	-2.789074	2516252.43	6858555.07	1341.11
631	-0.008483	-0.005438	-2.793821	2516375.87	6858215.66	1340.43
632	-0.008805	-0.004878	-2.786818	2516498.55	6857875.33	1340.10
633	-0.008955	-0.005715	-2.798806	2516622.20	6857531.53	1339.86
634	-0.008485	-0.006305	-2.785618	2516746.38	6857186.69	1340.21
635	-0.009347	-0.005850	-2.782225	2516873.35	6856844.64	1340.84
636	-0.009219	-0.006000	-2.789635	2517001.45	6856497.14	1340.85
637	-0.009656	-0.005265	-2.791717	2517130.08	6856151.86	1340.67
638	-0.009137	-0.005251	-2.784531	2517258.79	6855804.73	1340.88
639	0.008967	0.008054	0.354596	2517738.60	6855949.92	1346.64
640	0.008577	0.006216	0.356340	2517612.82	6856298.77	1346.76
641	0.008736	0.005537	0.356553	2517486.31	6856646.73	1346.84
642	0.009601	0.005296	0.356861	2517357.67	6856994.38	1346.94
643	0.008785	0.005150	0.358454	2517228.68	6857339.06	1347.27
644	0.009128	0.005750	0.346768	2517099.83	6857682.93	1346.95
645	0.008441	0.005849	0.339340	2516971.15	6858027.27	1345.55
646	0.009137	0.005334	0.339850	2516847.70	6858368.63	1344.99
647	0.009411	0.005795	0.344787	2516724.86	6858709.90	1345.21
648	0.008758	0.005330	0.358281	2516600.53	6859052.49	1345.83
649	0.009519	0.005497	0.358717	2516474.16	6859393.52	1345.97
650	0.008779	0.005901	0.345104	2516347.78	6859734.83	1345.43
651	0.009664	0.005483	0.349387	2516225.22	6860070.70	1345.14
652	0.009078	0.005473	0.346859	2516103.55	6860408.03	1345.61
653	0.008669	0.005100	0.347319	2515983.26	6860747.25	1345.80
654	0.009038	0.004850	0.352730	2515863.52	6861085.42	1345.74
655	0.009099	0.005186	0.364014	2515741.58	6861422.74	1345.77
656	0.008893	0.005121	0.349910	2515617.62	6861759.26	1346.11
676	-0.011187	-0.007197	-2.793250	2516070.14	6861930.50	1327.97
677	-0.009802	-0.005608	-2.790003	2516189.59	6861597.26	1327.93
678	-0.009216	-0.005644	-2.783156	2516311.30	6861266.38	1328.42
679	-0.010374	-0.005275	-2.800022	2516433.35	6860933.86	1328.44
680	-0.009984	-0.006612	-2.795458	2516553.13	6860600.67	1328.75
681	-0.009348	-0.006360	-2.782889	2516673.30	6860266.77	1328.95
682	-0.009495	-0.006338	-2.788987	2516793.93	6859933.61	1328.79
683	-0.009180	-0.005671	-2.789728	2516918.13	6859597.28	1328.61
684	-0.009448	-0.005277	-2.790411	2517038.77	6859259.78	1327.95
685	-0.010242	-0.006602	-2.786304	2517161.55	6858919.56	1328.13
686	-0.009802	-0.005579	-2.788387	2517286.66	6858585.33	1328.15
687	-0.008949	-0.005920	-2.788599	2517412.81	6858249.16	1328.11
688	-0.009298	-0.004596	-2.794802	2517540.72	6857910.22	1328.04
689	-0.009766	-0.005688	-2.789191	2517667.95	6857570.96	1327.59
690	-0.009821	-0.005440	-2.807992	2517791.35	6857229.75	1327.89
691	-0.009659	-0.005835	-2.800449	2517912.39	6856885.02	1328.80
692	-0.010003	-0.006328	-2.793754	2518035.40	6856539.49	1328.66
613	-0.006028	0.011510	1.901906	2516985.08	6860571.84	1343.29
614	-0.005245	0.009129	1.909518	2516646.35	6860453.36	1342.26
615	-0.006502	0.010068	1.908454	2516308.39	6860334.02	1341.84
616	-0.005450	0.009888	1.899643	2515971.28	6860216.44	1341.42
617	-0.005780	0.008732	1.908106	2515631.06	6860098.35	1341.19
618	-0.005066	0.009629	1.903497	2515291.52	6859979.33	1342.37
619	-0.005339	0.009311	1.912432	2514950.51	6859859.63	1343.44
620	-0.004527	0.009798	1.860798	2514607.18	6859739.37	1342.39

Following MATCH-AT recalculation in KKJ2/N60; the lens distortions were removed using iWitness (XYrectify) to create "pinhole versions" of the images (for kuvamitt). Bicubid interpolation was applied resulting in 14604 x 11052 images with xp, yp at column = 7311.97, row = 5557.11. Affine coefficients: [265957.4468, 0, 7311.97, 0, 265957.4468 , 5557.11}. The rectified images include 0-valued pixels in the margins but retain the original 3.76-micron pixel size. File names are 2020_1km_RGB_00###.raw. TIF-versions of these pinhole images were not stored, only the originals.
Epipolar geometry works well in these 2020 RGB images.

Files:

2.5.38 2020 UltraCam 3 km RGBN imagery

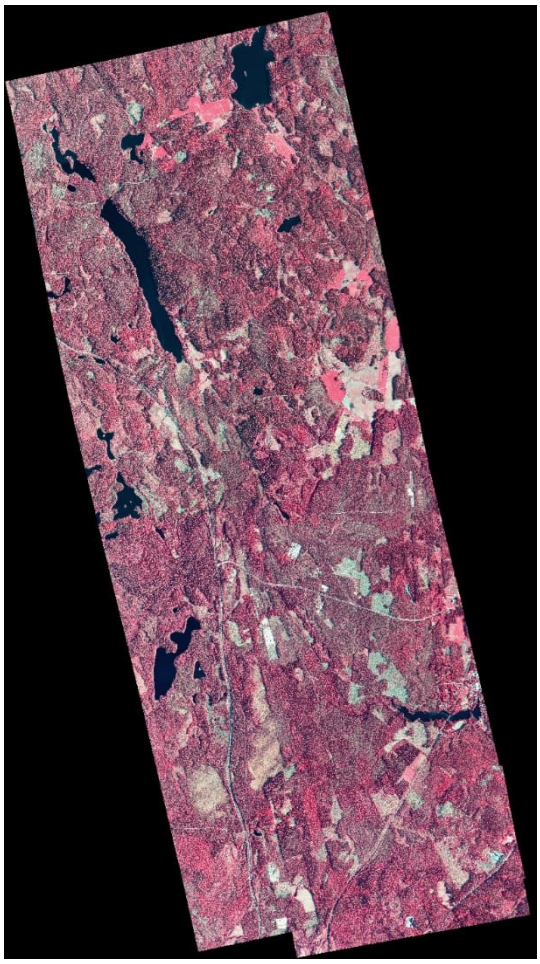


Fig. 97. Index of the 51 images in two strips. The flight was tuned in to cover Lakkasuo, which was however not covered by the LiDAR of 2020 due to budget constraints.

- Captured June 10, 2020, at 0520 GMT by Terratec
- Low solar elevation at 25-26°
- 3300 m AGL, apprx. 13 cm (PAN) resolution
- 80% forward-overlap
- Lvl2-PAN 26460 x 17004, 16 bits per pixel
  Lvl2-RGBN 8820 x 5668, RGBN, 16 bits per band
  Lvl3-RGBN 17004 × 26460 pixels, 8 bytes per band
  Lvl3-CIR-images (*.raw), 8 bytes per band
- PAN-sharpening ratio 1:3, i.e. multispectral pixels sample the ground at apprx. 40 cm resolutoin
- Ultracam Eagle M3, serial 431S71474X017018-f100
- 4 um pixels ("12 um" in RGBN (multispectral) using a focal length of 100.5 mm. All CCDs are the same.
- f/6.7, 1/250 seconds exposure settings, constant (verify)
- In total eight lenses and 9 (PAN) + 4 CCD-arrays: FTF9060-M Area CCD Sensor by DALSA
- Calibration Nov 28, 2019:
  Pixel size 4 um
  c = 100.500 mm, 33.3 mm in multispectral
  xp = 0.0 mm
  yp = 0.0 mm
  Remaining distortions < 2 um after applying a correction table from calibration.
- 51 frames, 2 strips
- Match-At aerial triangulation with GPS/IMU data alone
- Consortium at UH (prof. Bäck, Puttonen, Holopainen, Vauhkonen & Korpela). Funding by courses utilizing these data + SMEAR.

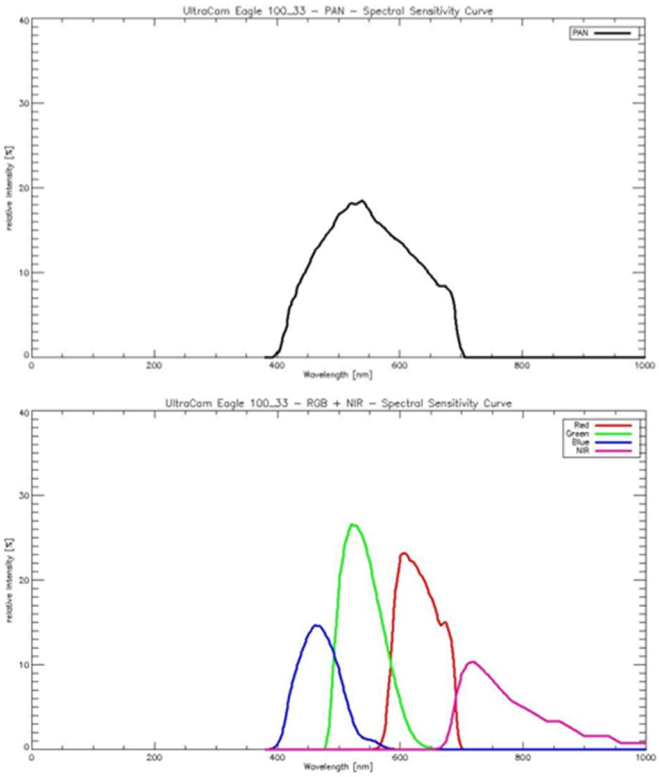


Fig. 98. Sensitivity curves from the calibration pdf.

The MATCH-AT triangulation by Terratec was utilized (tie points and their image observations) to transform the exterior orientation (by recalculating the bundle block adjustment) from UTM35/N2000 into KKJ-2/N60 coordinate system.

Table 9. Exterior orientation parameters in KKJ-2/N60 (radians and meters).

image	omega	phi	kappa	x0	y0	z0
_52	0.009057	-0.003245	1.782890	2516991.08	6852027.31	3478.121
_53	0.009842	-0.003437	1.787895	2516896.16	6852466.91	3478.203
_54	0.010751	-0.003647	1.791288	2516799.28	6852907.13	3477.846
_55	0.002271	-0.000391	1.797259	2516700.56	6853347.35	3477.185
_56	0.004156	-0.001000	1.797392	2516599.87	6853787.86	3477.121
_57	0.003975	-0.000542	1.801886	2516497.53	6854229.63	3476.871
_58	0.003525	-0.000672	1.805490	2516393.87	6854669.98	3476.739
_59	0.003686	-0.000247	1.808265	2516289.32	6855111.38	3476.792
_60	0.003060	-0.000374	1.810155	2516184.40	6855549.68	3477.374
_61	0.003230	-0.000345	1.810916	2516078.24	6855991.46	3477.686
_62	0.003357	-0.000868	1.811331	2515972.10	6856432.11	3477.579
_63	0.003056	-0.000731	1.807896	2515866.06	6856873.89	3477.408
_64	0.003498	-0.000328	1.805629	2515760.74	6857314.47	3476.996
_65	0.003471	-0.000172	1.804012	2515655.85	6857756.57	3476.631
_66	0.003138	-0.000548	1.800781	2515552.16	6858198.23	3476.402
_67	0.003191	-0.000358	1.794790	2515452.12	6858638.05	3476.692
_68	0.003054	0.000041	1.787748	2515355.05	6859078.47	3477.304
_69	0.003581	-0.000794	1.783623	2515260.06	6859521.50	3477.619
_70	0.002934	-0.000265	1.776435	2515166.72	6859966.76	3477.942
_71	0.002989	-0.000458	1.772625	2515076.32	6860410.25	3478.348
_72	0.002903	-0.000642	1.767529	2514988.29	6860853.43	3478.421
_73	0.002967	-0.000443	1.764789	2514901.51	6861298.28	3478.281
_74	0.003411	-0.000749	1.760855	2514816.77	6861742.53	3477.635
_75	0.003231	-0.001084	1.768330	2514731.49	6862188.35	3477.002
_76	0.003130	-0.000665	1.774269	2514642.07	6862635.46	3476.437
_77	-0.003330	0.000500	-1.348619	2515999.13	6862961.47	3476.636
_78	-0.003202	0.000729	-1.349197	2516097.33	6862522.40	3476.987
_79	-0.003325	0.000560	-1.348534	2516195.57	6862082.34	3477.093
_80	-0.003495	-0.000208	-1.348970	2516293.93	6861643.73	3477.314
_81	-0.003280	0.000625	-1.350387	2516392.32	6861203.94	3477.618
_82	-0.003154	0.000884	-1.350367	2516490.11	6860765.38	3477.566
_83	-0.002997	0.000200	-1.349106	2516588.33	6860323.52	3477.129
_84	-0.003236	0.000345	-1.350070	2516686.00	6859884.42	3476.761
_85	-0.003500	-0.000245	-1.352667	2516783.40	6859443.50	3477.106
_86	-0.003309	0.000510	-1.352553	2516879.72	6859003.17	3477.538
_87	-0.003511	0.000627	-1.353773	2516976.50	6858560.87	3477.385
_88	-0.003382	0.000486	-1.354784	2517072.71	6858120.27	3477.031
_89	-0.003176	0.000384	-1.355307	2517168.63	6857677.23	3477.248
_90	-0.003131	0.000658	-1.344470	2517267.35	6857235.29	3477.399
_91	-0.003181	0.000346	-1.339342	2517369.91	6856793.66	3478.057
_92	-0.003478	-0.000390	-1.337404	2517473.99	6856351.13	3478.777
_93	-0.003403	0.000673	-1.336447	2517577.49	6855910.60	3478.617
_94	-0.003254	0.000567	-1.339815	2517681.65	6855467.51	3477.948
_95	-0.003207	0.000205	-1.338981	2517784.48	6855027.15	3477.812
_96	-0.003277	0.000193	-1.338967	2517887.14	6854588.83	3477.553
_97	-0.003222	0.000332	-1.338027	2517990.54	6854148.43	3477.179
_98	-0.003430	0.000302	-1.338971	2518093.71	6853707.46	3477.521
_99	-0.003663	-0.000446	-1.341108	2518196.11	6853266.42	3477.318
_100	-0.003265	0.000411	-1.340688	2518298.26	6852826.27	3477.106
_101	-0.003039	0.000393	-1.341736	2518400.00	6852386.78	3477.041
_102	-0.003110	0.000637	-1.389003	2518502.19	6851943.47	3477.131

2.5.39 2022 UltraCam Eagle 7-km RGBN imagery

May 25, 2022 (08:23-09:42 DST) by National Land Survey (MML). Images were received for research and teaching at UH in September 2022 via Risto Ilves at NLS.

Camera and calibration UC-Eagle-2-413S71562X313019-f80_29.04.2021_A. (Certificate is with NLS).

The image set has Pan-sharpened Lvl3 images only, i.e., 8 bits per pixel RGBN (4 channel) TIFFs (1.3 GBytes each). Raw Lvl2-images (four bands and panchromatic) are in the NLS archives.

Focal length 0.0798000 m
Image size 14790 x 23010
Pixel size 4.6 microns
Principal point of autocollimation: column 7425, row 11504.5
Nominal pixel size on the ground is 40 cm.

At NLS, images were oriented in UTM35 with N2000 elevations using ESPA software. Espa's 3D rotation matrix (left-handed coordinate system) was solved for camera rotations (in a right-handed system) omega, phi, kappa using the iterative (manual) process in ESPA_TO_KUVAMITT.xls. Solving the orientation in KKJ2/N60 was done by creating ground points in a 400 m grid, which were converted from UTM35 to KKJ2 and "lowered 32 cm" (N2000->N60). These synthetic points were mapped to images and the image observations were applied in a bundle block adjustment. There exists no direct transformation method.

There are 22 exposures from two flight lines, which are numbered as 20221007A_01_0002...00013 and 221007A_02_0087...0096.

The images are from the start of the campaign (flight lines 1 and 2 of eight, 50-km-long). Exact exposure times were not in the delivery.

Solar elevation is ca. 27-30 degrees only. Solar Azimuth was 92-95 degrees. There are no special field images to show the phenology on May 25, 2022, as the imaging campaign was a standard mapping, and the timetable was not known in Hyytiälä. In some field images taken May 22-24 (IK visiting Hyytiälä) from Korkeakoski and Hyytiälä, only silver birch has (not fully developed) leaves. Aspens are leaf-off. Pubescent birch had almost no leaves.

The 4-band (BIL) TIFFs were broken into 1-band raw images with Matlab, and then re-sampled into 4-band raw BIP image files (*.raw) for the use KUVAMITT.

UTM35/N2000 orientation parameters

Image	X0	Y0	Z0	omega	phi	kappa
2	6851784.48	360752.60	7121.10	0.0130414	0.0107755	1.5798383
3	6852967.87	360743.09	7120.73	-0.0011860	-0.0027904	1.5760205
4	6854150.37	360739.36	7122.90	0.0014780	0.0006628	1.5743266
5	6855333.87	360741.83	7127.25	0.0010685	0.0000518	1.5668123
6	6856517.71	360757.13	7130.76	0.0001870	-0.0004510	1.5490580
7	6857701.51	360790.74	7132.23	0.0002016	-0.0002785	1.5356662
8	6858887.76	360821.91	7134.08	0.0002889	0.0004956	1.5579536
9	6860070.28	360830.56	7135.05	-0.0005204	0.0008871	1.5684786
10	6861254.05	360830.45	7135.56	0.0007408	0.0005801	1.5734054
11	6862436.51	360826.89	7135.13	0.0002244	0.0007446	1.5733838
12	6863618.22	360819.07	7135.58	0.0008152	0.0000532	1.5773076
13	6864802.85	360804.16	7136.40	0.0008109	-0.0000385	1.5857878
87	6863614.18	354297.50	7130.37	-0.0004916	-0.0005378	-1.5716632
88	6862431.20	354298.96	7129.98	-0.0006598	-0.0012033	-1.5698285
89	6861249.59	354304.53	7131.28	-0.0002208	0.0004018	-1.5673486
90	6860066.37	354309.89	7131.13	-0.0007240	-0.0023335	-1.5674167
91	6858883.95	354315.36	7130.98	-0.0010581	-0.0001094	-1.5673329
92	6857699.85	354323.46	7131.28	-0.0006203	-0.0018827	-1.5622166
93	6856517.02	354334.96	7131.81	-0.0001875	0.0006053	-1.5601995
94	6855334.97	354347.15	7132.61	-0.0005583	0.0002503	-1.5599423
95	6854152.57	354359.48	7133.30	-0.0004769	-0.0008066	-1.5605273
96	6852970.19	354371.25	7133.73	0.0000557	-0.0009758	-1.5636710

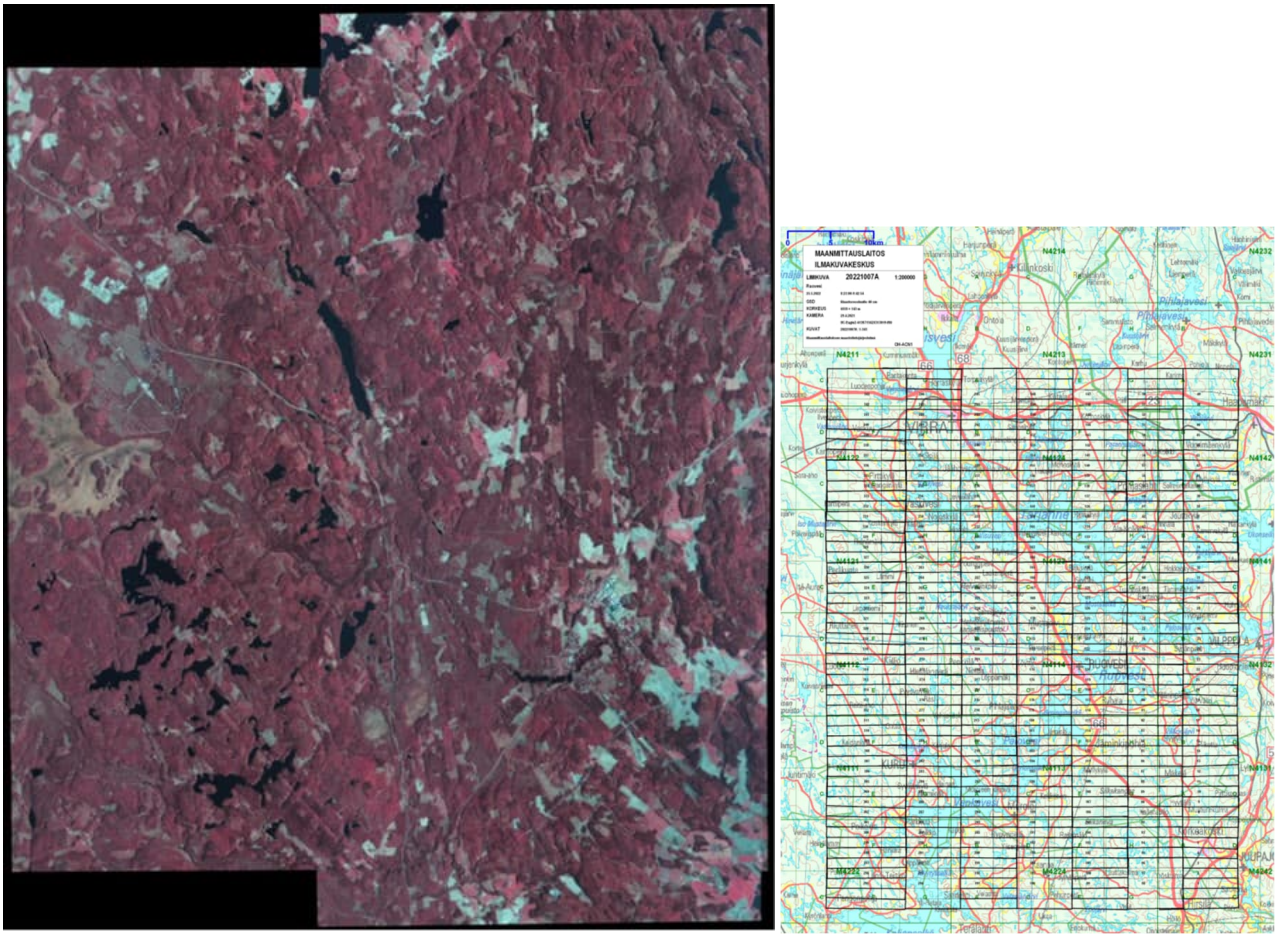


Fig. 99. Mosaic of the 22 images (May 25, 2022) added to the time-series. Images of the whole campaign.

KKJ2/N60 orientation parameters by bundle block adjustment with synthetic observations.

Omega	Phi	Kappa	X0	Y0	Z0
0.0125298	0.0113650	1.6259958	2519208.48	6851892.10	7121.87
-0.0010553	-0.0028419	1.6221791	2519144.38	6853073.97	7121.50
0.0014469	0.0007302	1.6204849	2519086.09	6854255.22	7123.67
0.0010661	0.0001011	1.6129705	2519033.95	6855437.76	7128.02
0.0002085	-0.0004416	1.5952163	2518994.61	6856621.24	7131.54
0.0002157	-0.0002690	1.5818244	2518973.57	6857805.51	7133.01
0.0002661	0.0005084	1.6041118	2518949.97	6858992.14	7134.86
-0.0005603	0.0008621	1.6146368	2518904.05	6860173.99	7135.83
0.0007138	0.0006135	1.6195638	2518849.32	6861356.68	7136.34
0.0001902	0.0007540	1.6195423	2518791.20	6862537.91	7135.91
0.0008124	0.0000904	1.6234662	2518728.86	6863718.18	7136.36
0.0008121	-0.0000010	1.6319463	2518659.30	6864901.06	7137.18
-0.0004671	-0.0005599	-1.5255044	2512213.41	6863413.17	7131.14
-0.0006041	-0.0012323	-1.5236697	2512269.46	6862231.33	7130.75
-0.0002397	0.0003914	-1.5211899	2512329.54	6861051.04	7132.05
-0.0006148	-0.0023640	-1.5212583	2512389.50	6859869.13	7131.91
-0.0010518	-0.0001583	-1.5211746	2512449.52	6858688.04	7131.75
-0.0005321	-0.0019088	-1.5160583	2512512.25	6857505.38	7132.06
-0.0002153	0.0005960	-1.5140411	2512578.32	6856324.16	7132.58
-0.0005691	0.0002248	-1.5137838	2512645.04	6855143.74	7133.39
-0.0004393	-0.0008274	-1.5143685	2512711.92	6853962.98	7134.08
0.0000993	-0.0009718	-1.5175121	2512778.24	6852782.22	7134.51

2.5.40 2023 June 15 3 km Ultracam Eagle RGBN-PAN imagery

This campaign repeats that of 2020. There are 51 images from two parallel flight lines.

Sensor	UC Eagle
PAN	17004 x 2640 pixels
RGBN	5568 x 8820 pixels
Height	3.5 km
Pixel size	13/40 cm
Focal length	100.5 mm (PAN)
PPA_X, PPA_Y	0.000, 0.000 mm
Pan-RGBN ratio	1:3
Time	11:35-11:44 GMT
Solar elevation	49.54 – 49.16 degrees
Solar azim.	206.2-208.6 degrees

Exterior orientation was solved without ground control points in UTM35/N2000 heights. EO was re-computed to KKJ2/N60 by IK.

XY-accuracy of forward ray-intersected targets was 20 cm.
Z-values are slightly biased (above true heights), perhaps 10-40 cm.

Exterior orientation ETRS-TM35FIN/N2000 (radians, meters):

Image	Omega	Phi	Kappa	X0	Y0	Z0
72426	0.0039711	0.0022118	1.7497853	360046.433	6851843.753	3498.158
72427	0.0089883	0.0047027	1.7505193	359964.439	6852289.328	3498.255
72428	0.0100066	0.0050297	1.7500207	359886.710	6852734.417	3496.350
72429	0.0085879	0.0055163	1.7494540	359811.636	6853180.217	3493.908
72430	0.0082424	0.0058757	1.7495431	359732.556	6853626.007	3493.935
72431	0.0067700	0.0040003	1.7494837	359649.276	6854070.297	3495.443
72432	0.0043330	0.0003541	1.7498567	359564.584	6854515.112	3495.425
72433	0.0053610	0.0022601	1.7494026	359482.855	6854959.634	3495.599
72434	0.0046715	0.0004808	1.7492854	359404.445	6855405.713	3494.274
72435	0.0045069	-0.0004761	1.7496188	359326.657	6855850.758	3493.703
72436	0.0054899	0.0011984	1.7491694	359249.039	6856296.908	3494.530
72437	0.0049367	0.0011984	1.7490977	359171.876	6856742.061	3494.828
72438	0.0046532	0.0013887	1.7491841	359094.462	6857188.287	3495.379
72439	0.0048293	0.0005155	1.7491254	359016.060	6857633.073	3494.747
72440	0.0047747	0.0005561	1.7506514	358936.095	6858078.912	3494.884
72441	0.0045192	0.0000614	1.7510006	358856.075	6858523.583	3495.724
72442	0.0046084	0.0005856	1.7487375	358779.909	6858969.885	3496.197
72443	0.0042270	0.0002364	1.7509381	358705.910	6859415.550	3494.367
72444	0.0047953	0.0005393	1.7508650	358631.210	6859862.228	3493.343
72445	0.0048889	0.0006000	1.7486321	358555.691	6860307.951	3494.254
72446	0.0044741	0.0007043	1.7504621	358480.228	6860754.186	3495.227
72447	0.0039837	0.0005338	1.7511638	358404.472	6861199.835	3495.218
72448	0.0042446	0.0002882	1.7494739	358326.383	6861645.641	3494.399
72449	0.0044177	0.0007288	1.7509032	358246.841	6862090.469	3494.876
72450	0.0051536	0.0005540	1.7505542	358167.817	6862536.243	3494.358
72451	0.0048698	0.0004530	1.7489985	358089.405	6862981.177	3494.686
72452	-0.0046681	-0.0013883	-1.3925640	356642.912	6862718.130	3494.974
72453	-0.0039685	-0.0004276	-1.3906865	356722.615	6862273.341	3494.828
72454	-0.0056198	-0.0010138	-1.3905350	356801.970	6861827.417	3494.627
72455	-0.0040822	-0.0004298	-1.3904414	356880.717	6861382.659	3495.628
72456	-0.0038497	-0.0003651	-1.3907229	356959.283	6860936.657	3495.911
72457	-0.0035275	-0.0008176	-1.3910562	357037.875	6860491.708	3494.451
72458	-0.0046348	-0.0006666	-1.3930780	357117.192	6860045.997	3494.317
72459	-0.0047215	-0.0001720	-1.3914265	357196.616	6859601.299	3496.116
72460	-0.0046329	-0.0002667	-1.3912628	357276.020	6859155.470	3498.610
72461	-0.0039391	-0.0003600	-1.3928732	357355.590	6858710.568	3498.142
72462	-0.0039747	-0.0009706	-1.3913256	357435.985	6858265.150	3496.891
72463	-0.0051255	-0.0008292	-1.3918316	357516.917	6857820.485	3497.531
72464	-0.0049680	-0.0005784	-1.3935312	357595.461	6857374.661	3498.571
72465	-0.0048497	-0.0006079	-1.3920958	357669.945	6856928.970	3498.416
72466	-0.0046197	-0.0005482	-1.3916503	357742.466	6856481.810	3497.094
72467	-0.0044502	-0.0007654	-1.3934182	357814.583	6856035.704	3496.962
72468	-0.0046307	0.0002320	-1.3918515	357887.978	6855588.734	3497.132
72469	-0.0044362	-0.0001133	-1.3908695	357962.727	6855143.191	3497.456
72470	-0.0042547	-0.0006327	-1.3940844	358039.302	6854696.671	3496.708
72471	-0.0043252	-0.0010870	-1.3917757	358116.241	6854251.790	3497.289
72472	-0.0052564	-0.0001756	-1.3919712	358192.886	6853806.487	3498.974
72473	-0.0036874	-0.0012734	-1.3932275	358270.945	6853360.450	3499.042
72474	-0.0043665	-0.0004137	-1.3911748	358352.074	6852916.016	3497.806
72475	-0.0052424	0.0000240	-1.3917337	358432.482	6852470.370	3497.811
72476	-0.0046810	-0.0006445	-1.3929874	358510.746	6852025.430	3498.146

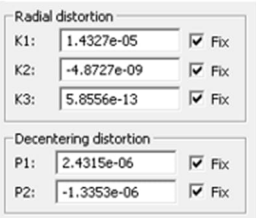
Exterior orientation KKJ2/N60 (radians, meters):

Image	Omega	Phi	Kappa	X0	Y0	Z0
72426	0.0038655	0.0023983	1.7959445	2514104.256	6851715.644	3498.361
72427	0.0087649	0.0051136	1.7966755	2514001.761	6852157.019	3498.448
72428	0.0097611	0.0054990	1.7961763	2513903.605	6852598.139	3496.552
72429	0.0083311	0.0059101	1.7956087	2513807.995	6853040.039	3494.102
72430	0.0079640	0.0062549	1.7956963	2513708.423	6853481.794	3494.142
72431	0.0065762	0.0043175	1.7956387	2513604.733	6853921.850	3495.651
72432	0.0043148	0.0005706	1.7960108	2513499.622	6854362.337	3495.631
72433	0.0052500	0.0025074	1.7955586	2513397.400	6854802.697	3495.799
72434	0.0046432	0.0006959	1.7954382	2513298.475	6855244.750	3494.482
72435	0.0045357	-0.0002545	1.7957725	2513200.267	6855685.763	3493.907
72436	0.0054284	0.0014570	1.7953234	2513102.108	6856127.966	3494.738
72437	0.0048777	0.0014251	1.7952517	2513004.453	6856569.149	3495.029
72438	0.0045889	0.0016076	1.7953381	2512906.541	6857011.388	3495.578
72439	0.0048041	0.0007391	1.7952789	2512807.671	6857452.153	3494.954
72440	0.0047419	0.0007851	1.7968076	2512707.236	6857893.919	3495.094
72441	0.0045156	0.0002766	1.7971566	2512606.758	6858334.475	3495.926
72442	0.0045751	0.0008043	1.7948928	2512510.069	6858776.878	3496.405
72443	0.0042109	0.0004417	1.7970952	2512415.588	6859218.718	3494.572
72444	0.0047604	0.0007721	1.7970178	2512320.351	6859661.561	3493.548
72445	0.0048474	0.0008260	1.7947871	2512224.293	6860103.410	3494.456
72446	0.0044388	0.0009129	1.7966173	2512128.318	6860545.719	3495.426
72447	0.0039438	0.0007207	1.7973185	2512032.069	6860987.515	3495.421
72448	0.0042322	0.0004897	1.7956305	2511933.488	6861429.256	3494.604
72449	0.0043830	0.0009347	1.7970593	2511833.479	6861870.015	3495.086
72450	0.0051291	0.0008006	1.7967096	2511733.982	6862311.728	3494.568
72451	0.0048440	0.0006792	1.7951526	2511635.085	6862752.664	3494.900
72452	-0.0046126	-0.0016020	-1.3464074	2510202.038	6862423.148	3495.182
72453	-0.0039496	-0.0006063	-1.3445292	2510302.205	6861982.412	3495.036
72454	-0.0055538	-0.0012645	-1.3443784	2510402.074	6861540.489	3494.841
72455	-0.0040595	-0.0006185	-1.3442876	2510501.246	6861099.821	3495.837
72456	-0.0038141	-0.0005384	-1.3445684	2510600.338	6860657.790	3496.118
72457	-0.0034830	-0.0009704	-1.3449021	2510699.409	6860216.913	3494.660
72458	-0.0045974	-0.0008828	-1.3469228	2510799.175	6859775.272	3494.522
72459	-0.0047191	-0.0003788	-1.3452715	2510899.095	6859334.683	3496.328
72460	-0.0046098	-0.0004684	-1.3451074	2510999.002	6858892.867	3498.818
72461	-0.0039269	-0.0005417	-1.3467172	2511098.986	6858452.089	3498.348
72462	-0.0039170	-0.0011434	-1.3451708	2511199.895	6858010.726	3497.103
72463	-0.0050888	-0.0010660	-1.3456763	2511301.229	6857570.252	3497.740
72464	-0.0049516	-0.0008083	-1.3473786	2511400.276	6857128.486	3498.774
72465	-0.0048114	-0.0008220	-1.3459416	2511495.295	6856686.567	3498.620
72466	-0.0045899	-0.0007583	-1.3454959	2511588.358	6856243.176	3497.298
72467	-0.0044062	-0.0009713	-1.3472636	2511680.979	6855800.788	3497.176
72468	-0.0046394	0.0000232	-1.3456948	2511774.959	6855357.633	3497.341
72469	-0.0044241	-0.0003050	-1.3447163	2511870.223	6854915.926	3497.671
72470	-0.0042221	-0.0008183	-1.3479293	2511967.322	6854473.357	3496.916
72471	-0.0042764	-0.0012745	-1.3456186	2512064.723	6854032.444	3497.503
72472	-0.0052422	-0.0004163	-1.3458163	2512161.810	6853591.059	3499.184
72473	-0.0036330	-0.0014355	-1.3470736	2512260.399	6853149.059	3499.246
72474	-0.0043377	-0.0006068	-1.3450200	2512361.967	6852708.725	3498.022
72475	-0.0052525	-0.0002089	-1.3455768	2512462.869	6852267.262	3498.022
72476	-0.0046545	-0.0008511	-1.3468300	2512561.595	6851826.317	3498.354

2.5.41 2023, Aug 18 1 km RGB imagery during LiDAR

These true-color images (n=86) are similar as those captured in 2020 during the LiDAR campaign.

Sensor	PhaseOne, RGB CCD array
Size	14204 x 10652 pixels (original)
Size	14604 x 11052 pixels (undistorted)
Height	1.2 km
Pixel size	8.5 cm, 3.76 um
Focal length	51.7710 mm
PPA_X, PPA_Y	-0.0076, -0.0717 mm



Time	06:28-06:45 GMT
Solar elevation	25.9 – 27.5 degrees
Solar azim.	111.7-115.33 degrees

These images were captured along the four pararallel flight lines of the LIDAR acquisition + perpendicular flight line #5. This line was not flown along the same path as in 2018 and 2020 (which had been requested). The original TIF images were resampled to undistorted versions in which the lens errors are largely removed, and the images are in “perfect” pinhole camera geometry.

The images from one flight line match well, but the epipolar geometry has a mismatch of about one pixel when using images of adjacent lines for 3D reconstruction. Also, it appears that the 3D reconstructed points float 10-30 cm above their true coordinates.

Omega	Phi	Kappa	X0	Y0	Z0	Image
-0.001345	0.000041	0.358735	2516937.95	6855209.49	1316.38	1
0.002700	-0.000020	0.359579	2516808.71	6855552.63	1321.57	2
0.002297	-0.000667	0.351325	2516678.38	6855895.40	1318.79	3
0.001173	-0.000558	0.352757	2516552.11	6856237.82	1317.39	4
0.001349	-0.001064	0.346121	2516426.26	6856579.27	1317.11	5
0.001515	-0.000998	0.349551	2516299.67	6856921.63	1316.86	6
0.001219	-0.000763	0.347874	2516174.37	6857265.21	1317.06	7
0.001601	-0.001166	0.343295	2516049.71	6857609.64	1317.60	8
0.001877	-0.000826	0.339567	2515925.96	6857955.21	1317.85	9
0.001464	-0.000545	0.340464	2515802.74	6858298.71	1317.89	10
0.001557	-0.001550	0.346086	2515680.44	6858639.49	1318.08	11
0.001305	-0.000543	0.349210	2515557.25	6858980.07	1318.14	12
0.001375	-0.000481	0.342700	2515434.29	6859320.90	1318.09	13
0.001163	-0.001377	0.339465	2515313.00	6859660.30	1318.29	14
0.001995	-0.000592	0.346552	2515191.07	6859999.56	1318.35	15
0.000974	-0.000950	0.358047	2515065.23	6860335.83	1318.64	16
0.001325	-0.000961	0.347968	2514940.02	6860672.91	1318.49	17
0.001937	-0.000490	0.348650	2514817.32	6861008.28	1318.46	18
0.001158	-0.001015	0.350957	2514693.38	6861345.71	1318.59	19
0.001499	-0.001155	0.347475	2514568.87	6861686.99	1318.54	20
0.010288	-0.002111	-2.787091	2515026.05	6861854.45	1321.67	21
0.014891	-0.004185	-2.797870	2515149.01	6861520.16	1321.61	22
0.016739	-0.004885	-2.790652	2515272.33	6861183.54	1321.44	23
0.014258	-0.003585	-2.788024	2515395.97	6860848.54	1321.32	24
0.002706	0.000017	-2.790494	2515519.11	6860513.74	1321.32	25
-0.002562	0.001247	-2.795856	2515641.35	6860178.09	1321.45	26
-0.002557	0.001843	-2.796050	2515762.95	6859843.45	1321.45	27
-0.001881	0.000951	-2.799139	2515886.52	6859502.93	1321.52	28
-0.000836	0.000941	-2.794731	2516010.96	6859162.11	1321.73	29
-0.001821	0.001490	-2.796953	2516134.28	6858823.20	1321.52	30
-0.002225	0.001675	-2.792519	2516259.08	6858481.55	1321.48	31
-0.001671	0.000793	-2.795844	2516383.06	6858143.11	1321.38	32
-0.001531	0.001076	-2.794832	2516507.70	6857802.77	1321.36	33
-0.002032	0.001471	-2.788880	2516633.63	6857460.56	1321.41	34
-0.001756	0.000952	-2.795115	2516760.07	6857116.33	1321.26	35
-0.000948	0.000991	-2.796767	2516884.32	6856773.03	1321.43	36
-0.001242	0.000654	-2.788937	2517011.57	6856425.61	1321.46	37
-0.001199	0.001175	-2.781773	2517141.18	6856079.90	1321.59	38
-0.001954	0.000668	-2.785818	2517271.33	6855734.41	1321.80	39
-0.001432	0.001242	-2.781722	2517401.56	6855388.04	1321.85	40
0.001666	-0.001118	0.356275	2517749.02	6855879.47	1327.74	41
0.001480	-0.001770	0.352582	2517619.54	6856226.30	1327.82	42
0.001590	-0.001286	0.346103	2517492.76	6856573.57	1327.57	43
0.001526	-0.000819	0.350342	2517364.97	6856922.98	1327.78	44
0.001517	-0.001637	0.349218	2517237.99	6857267.67	1327.84	45
0.001706	-0.000940	0.349289	2517111.50	6857612.63	1327.83	46
0.001849	-0.000843	0.354750	2516984.52	6857956.97	1327.90	47
0.001150	-0.001697	0.350278	2516858.49	6858295.87	1327.77	48
0.001245	-0.000229	0.353035	2516732.29	6858638.27	1327.45	49
0.001284	-0.001109	0.352551	2516605.21	6858978.30	1327.50	50
0.001835	-0.001056	0.342966	2516480.28	6859319.63	1327.44	51
0.001921	-0.001374	0.352390	2516355.61	6859661.47	1327.63	52
0.001375	-0.001775	0.353299	2516229.35	6860001.97	1327.72	53
0.001339	-0.001039	0.349927	2516105.51	6860338.19	1327.65	54
0.002117	-0.001074	0.351532	2515980.83	6860673.64	1327.77	55
0.001201	-0.001429	0.345000	2515855.82	6861010.56	1327.67	56
0.001163	-0.000742	0.338834	2515735.16	6861349.34	1327.35	57
0.001583	-0.000999	0.350706	2515612.90	6861686.82	1327.64	58
0.000557	-0.001381	0.347623	2515489.76	6862023.35	1327.73	59
-0.001809	0.001759	-2.803721	2515963.14	6862197.00	1317.33	60
-0.000090	0.002863	-2.797883	2516082.55	6861864.23	1318.23	61
-0.001173	0.002174	-2.798619	2516203.82	6861528.25	1318.51	62
-0.001605	0.001526	-2.802383	2516323.64	6861193.39	1318.60	63
-0.001952	0.001515	-2.799663	2516444.29	6860858.34	1318.49	64
-0.001596	0.001405	-2.800972	2516564.94	6860525.41	1318.46	65
-0.001137	0.001158	-2.788528	2516687.27	6860191.49	1318.42	66
-0.001426	0.001119	-2.792243	2516811.19	6859853.14	1318.39	67
-0.001648	0.001262	-2.795828	2516934.16	6859515.10	1318.27	68
-0.001447	0.001200	-2.798003	2517057.93	6859174.85	1318.36	69
-0.001049	0.001322	-2.790145	2517182.26	6858837.02	1318.44	70
-0.001729	0.001252	-2.796031	2517306.30	6858499.45	1318.51	71
-0.001417	0.001499	-2.792261	2517430.13	6858161.24	1318.63	72
-0.001039	0.001375	-2.790563	2517555.35	6857820.06	1318.88	73
-0.001486	0.000984	-2.794995	2517679.83	6857477.54	1318.79	74
-0.001301	0.001745	-2.796058	2517805.62	6857131.12	1318.61	75
-0.001589	0.001474	-2.796720	2517930.88	6856785.66	1318.64	76
-0.001276	0.000930	-2.788876	2518056.31	6856442.61	1318.83	77
-0.001014	-0.001129	-1.244091	2514275.58	6860375.83	1322.89	78
-0.001268	-0.001482	-1.245161	2514614.52	6860491.47	1322.63	79
-0.001502	-0.001286	-1.246506	2514954.34	6860606.48	1322.54	80
-0.001511	-0.001662	-1.243075	2515294.43	6860721.91	1322.41	81
-0.001127	-0.001646	-1.231205	2515633.09	6860840.25	1322.34	82
-0.001336	-0.001645	-1.235494	2515969.87	6860959.51	1322.26	83
-0.001481	-0.001340	-1.232305	2516306.85	6861078.45	1322.34	84
-0.001847	-0.001341	-1.228063	2516642.82	6861198.80	1322.36	85
-0.001897	-0.001180	-1.233604	2516982.68	6861319.79	1322.27	86

3 Airborne LiDAR data

3.1 General remarks

Fig. 100. First LiDAR acquisition in 2004. Geodetic point (88M5041) near Syväniemi farm in Musturinkulma, where the GPS reference station was put up after a fast translocation from Tikkakoski (EFJY).

3.1.1 Number of acquisitions

By Oct 2023, there have been 16 acquisitions/campaigns, of which one was done (2011b) in leaf-off conditions. Acquisition heights have varied from 300 m to 4 km. The same acquisition date can include several scanning heights or repeated strips of redundant data, called datasets (Table 10). AOIs include the 'Hyytiälä rectangle', Lakkasuo, Siikaneva and Susimäki, of which "Hyytiälä rectangle" is always included. It encloses SMEAR II and has been the focus of forest RS activities (Fig. 7). Lakkasuo is covered by data collected in 2006 and 2011.

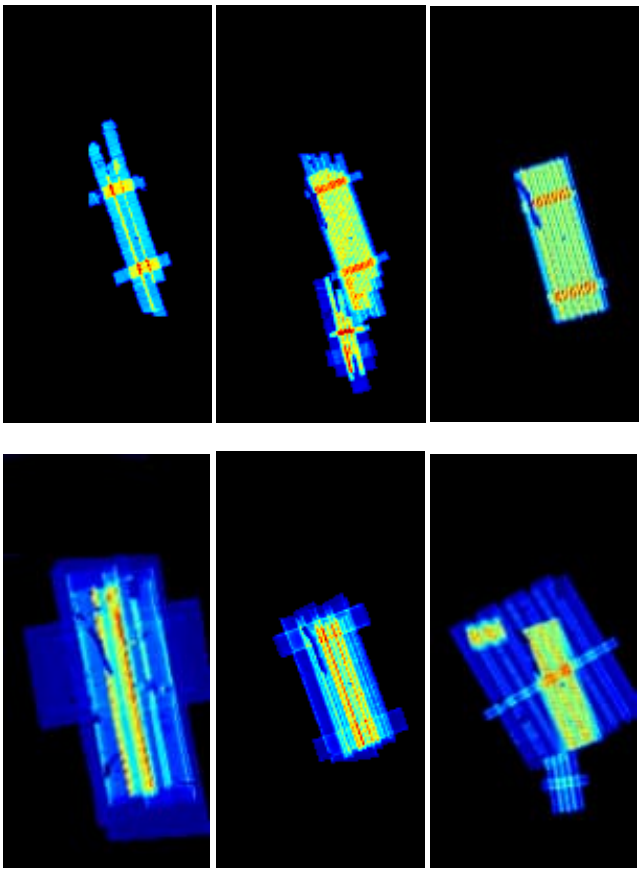


Fig. 101. Coverage of 2004, 2006, 2007 2008, 2010, & 2011 data. 10 x 20 km.

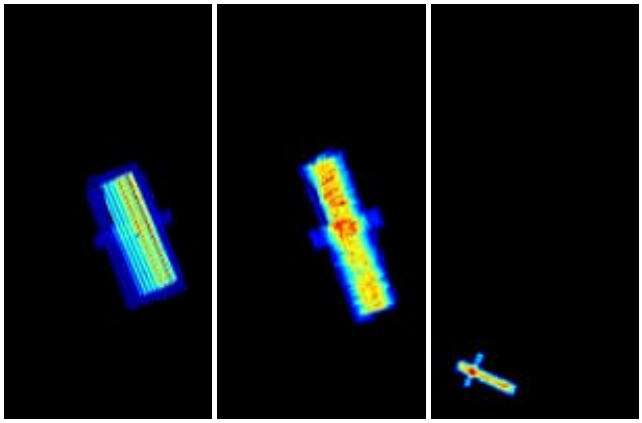


Fig. 102. Coverage of 2012, 2013 Riegl and 2013 Siikaneva LiDAR.

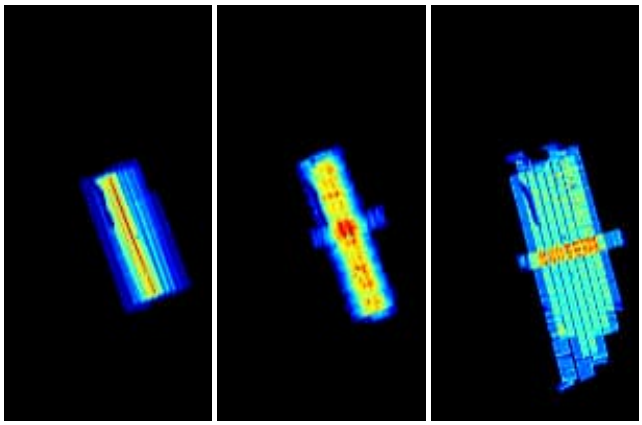


Fig. 103. Coverage of 2013 (ALS60), 2015 (Riegl) & 2016 (Optech) LiDAR. 10 x 20 km.

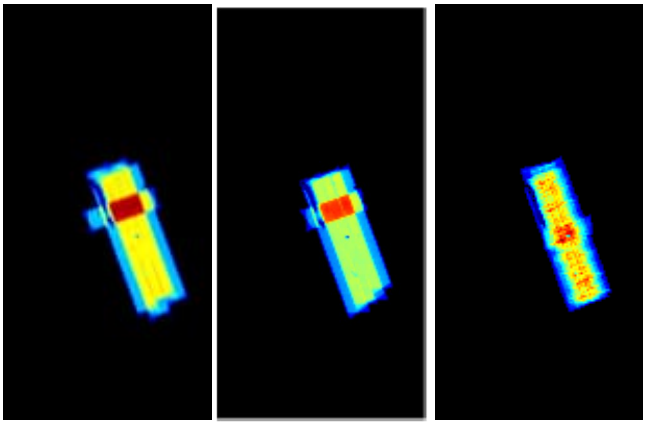


Fig. 104. Coverage of 2018, 2020 and leaf-off 2011 acquisitions. 10 x 20 km.

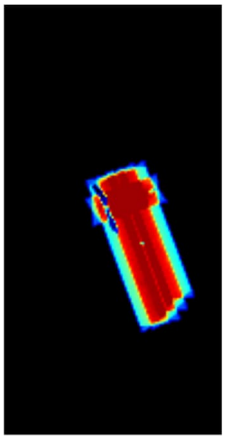


Fig. 105. Coverage of the 2023 acquisition. 10 x 20 km.

Table 10. LiDAR data sets in Hyytiälä

Year/set	Date	System	Sensor	Notes	Heights, km	Density	Coverage
2004	Aug, 5	DR	ALTM2033	One of first forest campaigns in Finland, DEM	0.9	1	Hyytiälä
2006-Hyytiälä	July 25	DR	ALTM3100	High-density for single-tree remote sensing	0.8	6	Hyytiälä
2006-Lakkasuo	July 25	DR	ALTM3100	Lakkasuo area, DEM	0.5, 1.2	2	Lakkasuo
2007	July 4	DR	ALS50-II	High-density, for single-tree remote sensing	0.8	6	Hyytiälä
2008-1km	Aug 23	DR	ALS50-II	Large FOV, during the ADS40 campaign	1	3	Hyytiälä, Lakkasuo
2008-2km	Aug 23	DR	ALS50-II	2km is the source data of DEM estim.	2	2	
2008-3km	Aug 23	DR	ALS50-II		3	0.5	
2008-4km	Aug 23	DR	ALS50-II		4	0.2	
2010-1km	July 19	DR+WF	ALS60+WDM65	First WF data, Leica test sensor	1	10/5 (all/WF)	Hyytiälä
2010-2km	July 19	DR+WF	ALS60+WDM65	1 and 2 ns sampling repeated strips, DEM	2	6/3 (all/WF)	Hyytiälä
2010-3km	July 19	DR+WF	ALS60+WDM65	1 and 2 ns sampling repeated strips	3	2/1 (all/WF)	Hyytiälä
2011a-1km-Hyytiälä	Aug 2	DR+WF	ALS60+WDM65		0.8	11	Hyytiälä
2011a-1km-Susimäki	Aug 2	DR+WF	ALS60+WDM65		0.8	?	Susimäki old growth
2011a-1km-Lakkasuo	Aug 2	DR+WF	ALS60+WDM65		0.9	?	Lakkasuo
2011a-2km-Hyytiälä	Aug 2	DR+WF	ALS60+WDM65		2	2	Hyytiälä
2011b	Nov 15	WF (DR)	LMS-Q680i	First leaf-off, in November	1	19	Hyytiälä
2012-05km	July5/6	DR+WF	ALS60+WDM65	Fixed SNR for flat targets	0.5	11/5 (all/WF)	Hyytiälä
2012-1km	July5/6	DR+WF	ALS60+WDM65	Multi-footprint data set	1	5	
2012-2km	July5/6	DR+WF	ALS60+WDM65		2	3	
2012-3km	July5/6	DR+WF	ALS60+WDM65		2.75	2	
2013a	May 28	WF (DR)	LMS-Q680i	Leaf-on, early summer	1	20	Hyytiälä + Siikaneva
2013b-07km	June 15/16	DR+WF	ALS60+WDM50	AGC on	0.7	10	Hyytiälä
2013c	??	DR	??	The national campaign by NLS (acquire)	?	1	All areas
2015	Aug 18	WF (DR)	LMS-Q680i	Echo detection thresholds low	1	20	Hyytiälä
2016	June 14	DR	Optech Titan	Three-band sensor	1	10	Hyytiälä, Lakkasuo
2018	May 24	DR	Riegl 1560	1064 nm early summer	1.2	15	Hyytiälä
2020	June 3	DR	”		1.2	15	Hyytiälä
2023	August 18	DR	”		1.2	15	Hyytiälä

3.1.2 Systems used

Less focus was put on (existed) understanding the systems in the beginning. Pulse density (p/m^2), or point density, was the main parameter that was looked at, in addition to the budget limits.

Since 2004, the campaigns have been carried out, using more and more sophisticated sensors, navigation systems, and data post processing solutions. Optech ALTM1033 was capable of 33 kHz pulse repetition frequency in 2004 (1-2 echoes), while Riegl LMS-Q680i delivered data at the rate of 267 kHz in 2011, and 1550i accelerated to 1 MHz per LiDAR, having twoinstalled in parallel.

All data are acquired with small-footprint systems, in which the beam divergence is ~0.3 milliradians, or below, at the 1/e point, where the intensity is down to 37% of the maximum in the center of the illuminated footprint.

Pure discrete-return (DR) recording systems were used 2004–2008. They receive the signal with a fast-response photodiode and process the analogue signal with specific circuits into range values, by measuring the 2-way travel time of the light pulse. ALS60 sensors that have both DR and waveform recording were used in 2010, 2011a, 2012, 2013b. 'Genuine' WF recording system (LMSQ680i) was used in 2011b, 2013a, and 2015. In 2016, three-band DR sensor Titan was tested and campaigns of 2018, 2020 and 2023 were done using a DR sensor capable of over 10 returns.

All sensors transmit short pulses, < 10 ns in length as measured by full-width-half-maximum (FWHM). The exact value of the FWHM of the transmitted pulse is known only for Leica ALS60. It is either 4 or 9 ns, depending on the pulse repetition frequency. FWHM of the 'system waveform' have been estimated for datasets containing waveform recordings. Pulses from well-defined targets were used.

The pulse densities vary and include "high-pulse-density" data (> 3 / m2) and "low-pulse-density" campaigns. Because of strip overlap, there is always considerable variation in pulse density.

The number of returns per pulse is 1–2, 1–4, 1–12 in the DR systems, but 1–10 in the WF acquisitions (Riegl LMS-Q680i). It should be noted that echo extraction from the WFs can result in almost any number of echoes if greedy parameterization is used.

Sensors have applied an oscillating mirror or a rotating polygonal mirror (2011b, 2013a, 2015, 2018, 2020, 2023). Pulse repetition frequency, PRF, is 30–400 kHz (up to 1MHz). The scan angles (perpendicular to the flying direction) are from ±15 to ±35º. The width of the area covered by a strip (flight line) depends on the flying height and the scan angle. Adjacent strips have some overlap (redundancy), and there usually are perpendicular strips that are needed for the control of the geometry of the data. Sometimes even the system calibration that established the position and attitude of the LiDAR sensor with respect to the GPS and inertial measurement unit is solely based on redundancy provided by the perpendicular strip. More common is that the (recently mounted) sensor is calibrated in an urban environment.

3.1.3 In situ measurements

There were radiometric measurements and/or reference targets in the field in datasets of 2008 and 2010.

Field photography right at the time of the campaign was made in 2011b, 2012, 2013a, 2013b, and 2015. In 2010, photographs of seedling/sampling stand vegetation were taken within 3 weeks after the campaign, as well as photographs of the calibration targets that were placed in the football field. Photographs of 2011a do not exist.

3.1.4 Campaign settings

In 2012, the signal-to-noise-ratio (SNR) of well-defined targets was kept constant from 500 m to 2.7 km acquisition heights to achieve varying footprint size, by accounting for the spherical 2-way losses. In other campaigns, the companies acquiring the data used 'good-known-settings' of the sensor, by accounting for the maximal eye-safety. The flying height, overlap, pulse density were features set by the researchers.

The waveform recordings are at sampling rates of 1 or 2 nano-seconds. Data of 2010, 2011a, 2012 and 2013b were acquired by Leica ALS60 that produced a single continuous sample of 256 or 128 amplitude values, while the 2011b (2013a, 2015) Riegl LMS-Q680i sensor could record several variable lengths (60/120/180, or 80/160/240) samples.

The data comprise the deliverables of the observations; usually strip-level data (LAS) files, trajectory data by strips, a project report, and metadata on the acquisition parameters as well as GNNS/IMU data. From these, binary pulse-records with specific record structure (Appendix 3) were processed and arranged in per-hectare binary files (Little Endian bit/byte order) to speed up file i/o. These are the files for analysis.

The wavelength is 1064 nm except in the Riegl LMS-Q680i (2011b, 2013a, 2015) data, where it was 1550 nm. In 2016, Titan by Optech used 1550, 1064 and 532 nm.

3.2 Data formats

Characteristic to all acquisitions is the use '*comprehensive data format*', which combines the trajectory information (position and attitude of the sensor) to each pulse transmitted, for which all information is stored in a 'pulse record'.

This means that the complete 3D path is retrievable (measurement of scatterer-free volume, even). Appendix 3 has the different formats used in the stored per-hectare binary file data of different acquisitions. The format was extended from fixed length records to variable length records as the potential number of DR echoes increased over time and storage issues became obvious.

The deliverables have included in-house/proprietary formats and those matching the LAS-standard by ASPRS. Again, these have been processed into per-pulse binary records that vary slightly between acquisitions, reflecting the changes/development in the sensors and recorded observations. These records are compiled into hectare-files, i.e. all pulses (their last echo) hitting a certain KKJ-2 hectare are in one file. However, all campaigns are separated (2004-2023), i.e. there are, several 'BIN-files' per hectare (e.g. 2004\080_056.bin, \2006\080_056.bin). The coordinate information of the deliverables has been changed from UTM35/WGS84-ellipsoidal heights to KKJ-2/N60 orthometric heights as a part of this process. The original files are stored also and documented here for future reference. Siikaneva 2013 bin-files are an exception and remained in the UTM35/WGS84 system.

The waveform data are in separate per-hectare binary files, and there is a file pointer from the pulse or the echo record to the start of the WF sequence that should be read and is associated with the pulse or its echo.

3.3 Digital elevation models (DEMs)

The data has been processed into DEMs that are defined in either the KKJ-2 (with N60 heights) or UTM35 map projections (ellipsoidal

heights). The estimation has never included manual editing of local errors, due to sharp break lines (cliffs, buildings, bridges etc.), but is based on visual assessment for parameter tuning. N.B. the DEMs can always be re-estimated using the original/filtered LiDAR data, even on-the-fly. Local small DEMs were filtered at times for specific needs, but these are not stored.

DEMs that cover the entire Hyytiälä rectangle were made from the 2004, 2008 and 2010 data. For Lakkasuo there is one made with the 2006 data.

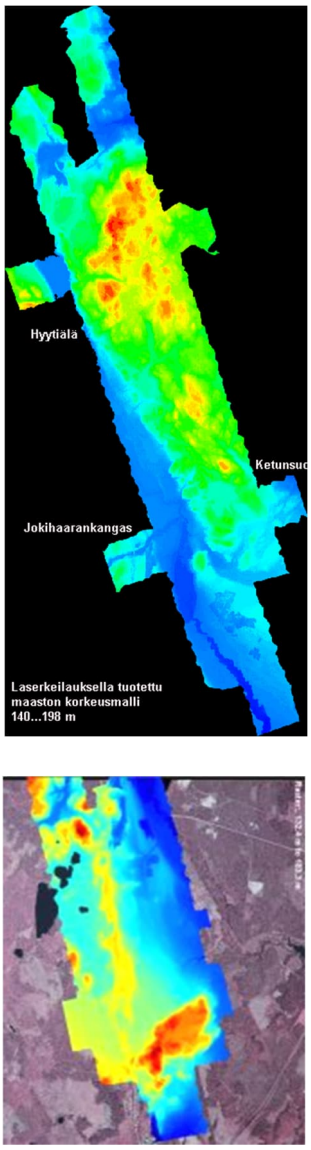


Fig. 106. Two DEMs estimated from the 2004 and 2006 data for Hyytiälä and Lakkasuo, respectively. (LiDARDTM.raw, Lakka.bil).

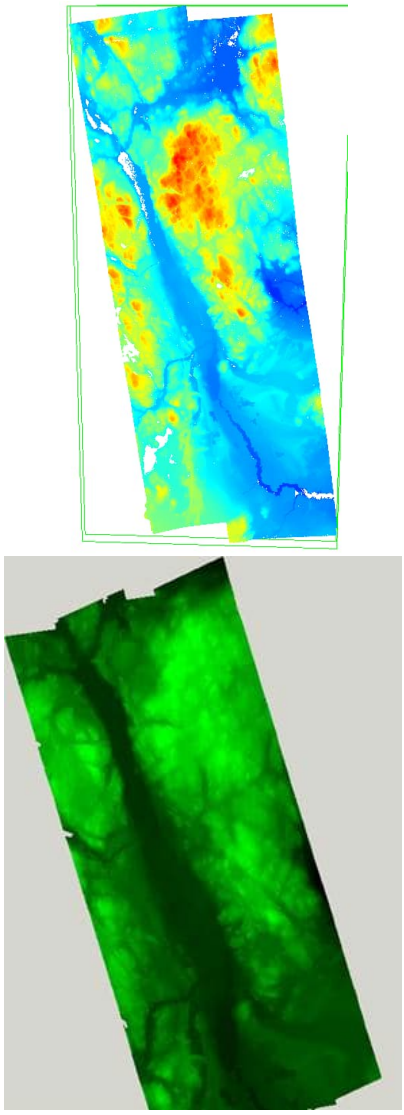


Fig. 107. Top 2 km 2008 DEM - filtered ground points (1900m_Gnd.las) as seen by Isenburg's LASVIEW.EXE. The DEM shows Lakkasuo only partially in the South. Missing data from water surfaces. Bottom: The 2010 DEM.

Table 11. LiDAR DEMs.

Campaign	Projection	low-left corner	Cell size, Width x Height	Notes on the format	Files
2004 Hyytiälä	KKJ-2/N60		1 m, 4054 x 9855	Low-left corner center: 2513971.5, 6854649.5 four-byte single	HydeLidarDEM.hdr, lidarDTM.raw
2006 Lakkasuo	KKJ-2/N60			Ground classification done at BLOM as. Raster model estimated with Isenburg's LAS to TIN (uint16, divide by 100). ground.zip (pwd gT67kp) has the points classified as ground.	lakka_.hdr, lakka_bil flipped

2008 Hyytiälä	UTM35/WGS84	1900-m data used; Terrascan; GND points in LAS. Other formats: 2 and 5 m grids (img/rrd)	1900m_Gnd.las
2010 Hyytiälä	UTM35/WGS84		grd.las hyytiala_DEM_2010.bin hyytiala_DEM_2010.hdr

3.4 Positional accuracy in 3D

Most comprehensive tests were carried out for possible Z-offsets, using accurate GNSS reference measurements made in well-defined man-made surfaces, such as roads.

Table 12. Z-offsets (LiDAR – ground truth).

Dataset	ΔZ, m	Ground truth
2004	-0.35	a
2006-Hyytiälä	0.05	a
2006-Lakkasuo	N/A	N/A
2007	-0.01	a
2008-1km	0.04	a
2008-2km	-0.02	a
2008-3km	0.12	a
2008-4km	0.10	a
2010-1km	-0.20	a
2010-2km (2010 DEM!)	-0.27	a
2010-3km	-0.16	a
2011a-1km-Hyytiälä	-0.01	a
2011a-1km-Susimäki	N/A	N/A
2011a-1km-Lakkasuo	N/A	N/A
2011a-2km-Hyytiälä	0.04	a
2011b	0.03	b
2012-05km	-0.02	b
2012-1km	0.05	b
2012-2km	0.00	b
2012-3km	0.08	b
2013a	0.04	c
2013b-07km	0.08	c
2013b-07km-AGCoff	0.02	c
2013b-08km-AGCoff	0.00	c
2013b-09km-AGCoff	-0.01	c
2013b-2km	0.00	c
2015	0.05	c

a VRS-GPS points in 2010: sand road (Forstitie), football field, asphalt road (from Hyytiälä towards route 66)
b VRS-GPS points in 2010 and 2012: asphalt road (from Hyytiälä towards route 66), sand road (Forstitie, Ala-Hyytiäläntie middle, Ala-Hyytiäläntie close to Lapinkangas)
c VRS-GPS points in 2013: Sand and asphalt roads over the entire Hyytiälä AOI

All datasets have been corrected for between-strip discrepancies by the companies delivering the data by applying what is called strip matching. In it, strip-level corrections are made to the attitude (rotation) parameters and Z of the GNSS so that adjacent overlapping LiDAR strips match well. Some of the project reports describe the processes used for achieving the best possible absolute and relative positioning accuracy.

The relative xy-match between strips is possible to monitor using breaklines in the scene. Examples of such are

- Shores of paludified ponds (Silmäpäänlammi, Vuorijärvi, Kaakkolammi)
- building roof without tangent vegetation (dormitories A, B, Impivaara)
- The SMEAR II tower
- 20 kV 3-cable power lines

These targets are measurable in 3D by means of photogrammetry, using aerial images, or by using terrestrial images of the Hyytiälä buildings.

Observed offsets are reported for each campaign separately.

The stored LiDAR data were not corrected for any geometric errors; corrections are to be applied by the users.

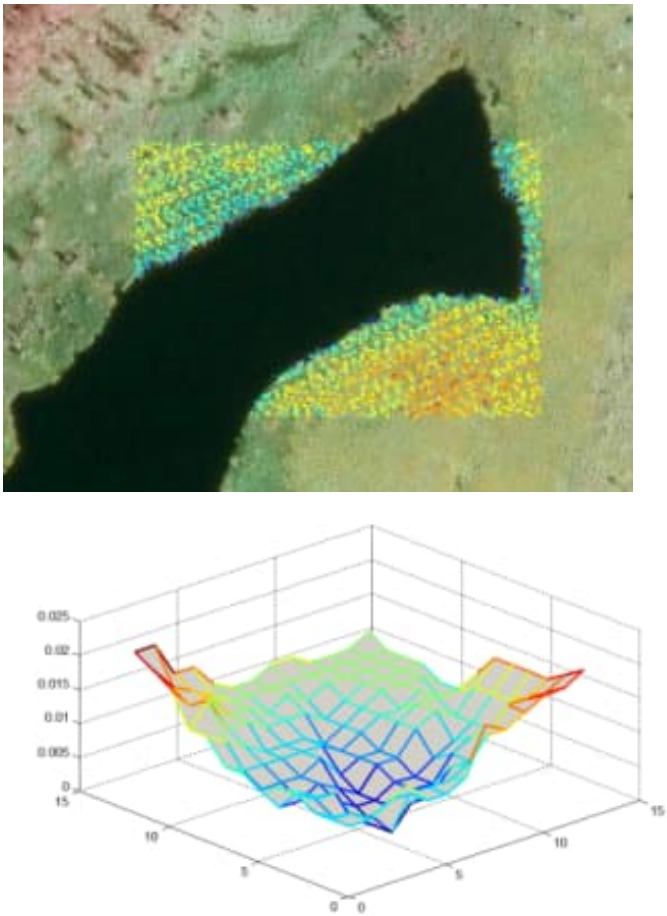


Fig. 108. Top: An example of 2 km LiDAR data from 2012 in Silmäpäänlammi. The shoreline is digitized from aerial images, constrained at constant elevation (here 182.2 m a.s.l) of the pond. The water absorbs the pulses, while the white moss triggers observations. The data are shifted in xy to minimize (Bottom) the number of LiDAR echoes from the water, inside the pond xy-polygon. This establishes a local xy-match of the data in a strip.

Absolute accuracy can only be controlled using monuments in the scene. Only in some special cases are there such (In 2010 corners of the reflectance tarps in the football field were mapped with Network GNSS).

3.5 AGC correction in the Leica sensors

The Leica ALS50/ALS60 sensors apply a gain control loop. The stored intensity and WF amplitude data are affected by it. The observed values (S_{obs}) and the operation voltage of the AGC circuit ($AGC_{voltage}$) are stored as 1Byte unsigned integers (0…255).

Campaigns affected by AGC are 2007, 2008, 2010, 2011a, 2012, and 2013b.

Generally, the effects of AGC can be removed with normalization models. The model parameters are sought by finding radiometrically (reflectance) homogenous well-defined surfaces in the scene. In Hyytiälä these can be

old asphalt, ρ ~ 0.16 (at 1064 nm)
fine sand (volleyball field), ρ ~ 0.3
grass (football field), ρ ~ 0.45
gravel (old buildings), ρ ~ 0.25
bitumen (roofs of 1977 buildings, the gravel was cleared in the summer of 2008). ρ ~ 0.05
FGIs 4 x 4-m reflectance tarps 2008, 2010

The receiver gain is a function of $AGC_{voltage}$. This function has a sigmoid form, meaning that in the mid-range of $AGC_{voltage}$ values the gain increases linearly with the $AGC_{voltage}$. In the low-end of $AGC_{voltage}$ values the gain increases exponentially with $AGC_{voltage}$, and in the high-end it saturates. Various versions of normalization models have been used over years.

Model with additive correction term (RSE 112: 3891-3897). Used in studies made with 2007–2008 LiDAR data. Parameters?

$$S_{norm} = S_{obs} + (b \cdot S_{obs}) \cdot (127.5 - AGC_{voltage})$$

ii. Linear model (ISPRS JPRS 83: 81–93). If the $AGC_{voltage}$ values remain in the mid-range within the acquisition, a linear model is sufficient to remove the AGC effects. The linear model is of form

$$S_{norm} = \frac{1}{1 + (AGC_{voltage} - a) \cdot b} \cdot (S_{obs} - c)$$

iii. Non-linear model (Unpublished). This is better if the $AGC_{voltage}$ takes a wide range of values. The model is of form

$$S_{norm} = \frac{1}{a_3 + a_2 \cdot AGC_{voltage} + a_1 \cdot AGC_{voltage}^2} \cdot (S_{obs} - c)$$

Parameters of the linear model have been estimated for all Leica datasets. Pulses reflected from homogeneous calibration targets (natural and man-made) were used and the parameters were estimated separately for DR intensity and for WF amplitude data.

Parameters of the non-linear model have been estimated for 2012 data, using the same targets. The model was estimated simultaneously for four flying heights and included multiplicative "power correction" terms that made the observations from different flying heights comparable.

The model parameters and the estimation procedure for both linear and non-linear models are documented in

\HYDE_REF\LiDAR\LiDAR.html

The documentation includes polygons that delineate the calibration targets, and the data used in parameter estimation.

3.6 Additional remarks on sensors and data

3.6.1 Riegl LMS-Q680i: Output power, receiver linearity, and ringing

In Riegl LMS-Q680i, the transmitted pulse energy is determined by the pulse repetition frequency. We have asked the manufacturer, but they did not give the average power in watts.

The receiver has two non-linear channels: low-power (high-gain) and high-power (low-gain) channel. The lower end of the low-power channel, up to amplitude values of 130, is linear, with respect to power entering the aperture. Only the data from low power channel is exported to LAS1.3, which were used to generate the hectare BIN filess. In Siikaneva 300 m acquisition, the high power channel was in use, and Riegl's original sdf files have to be used to get access to these waveforms. See more detailed documentation in:

- LiDAR\2013a\Index.docx

N.B. In November 2015, the Siikaneva 2013 low-gain data were analyzed using MATLAB routines, because the FWHM that is computed from the overexposured low-power channel data were influenced by the peak power, i.e. the FWHM increases with signal strength.

Ringing-effect causes a false echo to occur after a strong echo (e.g. from ground surface). The false echoes occur in pulses that have maximum amplitude over approx. 100. See more detailed documentation in:

- LiDAR\2015\Riegl2015_QC.docx

3.6.2 Leica ALS60: Waveform samples in the prefix preceeding first DR echo

In all ALS60 datasets (2010-2013) there can be peaks in the waveform before the first DR echo, i.e. the DR circuit did not detect an echo although there was weak? backscattering preceding the first echo. These are found in <0.5% of the pulses.

3.7 Acquisitions

3.7.1 Structure of the Binary observation files

Appendix 3 shows code samples for reading the per-hectare tiles of binary LiDAR data. Each pulse is assigned to a hectare, and that file starts with an int32 (4 byte signed integer) that specifies the number of pulse records in that hectare file. The BIN files are separate for each campaign – but the data from several flight lines (acquisition heights) may be fused in the BIN file. Flight line (strip number) code, GPS-time and trajectory information can be used to distinguish between strips.

3.7.2 2004 DR, low-density, 1km, Optech, Hyytiälä

This is one of the first forest LiDAR campaigns in Finland. The modified Optech ALTM2033 sensor flew the next day in eastern Finland, in Matalansalo. The delivered data were first in the form of echoes, first and second echoes separated, but later data were obtained in comprehensive format (Appendix 3 – Formats of LiDAR pulse records 2004-201).

During acquisition, a GPS was at geodetic point 88M5040 (Fig. 100), with non-leveled N60 elevation of 136.1 m corresponding to ellipsoidal height of 154.787 m. There is an offset in elevation that remained in the stored LiDAR data. The N60 elevation was later in 2005 measured to be 136.28 m with a VRS GPS (Fin2000 geoid). The LiDAR Z-values need a correction of +0.18 m, and so does the DEM that was deduced from the data.

There are data from 1614 different hectares. The pulse density is 0.5-3 m^{-2}.

Original delivery, September 2004 was reprocessed in April 2005 to so-called comprehensive format.

Data stored includes also the GPS/IMU data. The intensity scale in ALTM1033 may include two gain/offset values; In addition to separate range detection circuits for the first (FR) and last return (LR) data. This must be examined.

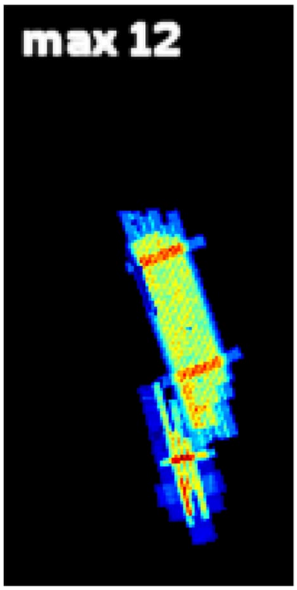
A GPS reference point: Lat: 61 50 5.18736; Long: 2420 13.73439; Ell height: 154.787

- August 5, 2004; GPS day 218; Day 4.4 of the GPS week; 11 GMT
- Pulse repetition frequency 33 kHz
- Scan Frequency 29 Hz
- Scan Angle ± 20 °
- Divergence 0.3 mrad
- Density 1.4 m2/pulse (0.7 per m2)
- Flying speed 75 m/s
- Trajectory in the post-processed comprehensive format files
- GPS/IMU yes, applanix files, raw/postp.
- Altitude 900 m AGL
- Strip adjustments ΔRoll, ΔPitch, ΔZ (Terramatch)

zip-password: juupajoki

\LiDAR\als2004\Original_Delivery
\LiDAR\als2004\Reprocessed
\LiDAR\als2004\BIN

3.7.3 2006 DR, high-density, 1km, Optech, Hyytiälä



This campaign consists of two acquisitions done during the same flight: Hyytiälä and Lakkasuo. Optech's ALTM3100 sensor was used. VRS-ground station in Orivesi was used for GPS. ALTM3100 recorded 1–4 discrete returns (points) for a pulse transmitted.

Hyytiälä 1 km - Blom project code: NO06735

- July 25, 2006; 15:41-16:57 GMT
- Pulse repetition frequency 100 kHz
- Scan Frequency 70 Hz
- Scan Angle ± 14°
- Divergence 0.3 mrad at 1/e?
- Density 6 per m2
- Flying speed 75 m/s
- Altitude 800 m AGL
- Trajectory in the cmp-files
- GPS/IMU system *******
- System calibration for ΔRoll, ΔPitch, ΔHeading, Δscale
- Strip adjustments ΔRoll, ΔPitch, ΔZ (Terramatch)

The data was delivered in Optech's comprehensive format, strip wise files *.cmp. (N=14). These were converted to ascii using BinToAsc.exe (README.txt), and further to per-hectare binary files (*.BIN). The data from Lakkasuo (500m, 1200m) are combined in the BIN files of 2006 with the Hyytiälä data.

zip-password: gT67kp

- \LiDAR\als2006\BIN\
  Per-hectare 207-byte pulse-records (Appendix 3) in BIN flies
- \LiDAR\als2006\CMP_files\
  Zipped per-strip cmp (comprehensive) files
- \LiDAR\als2006\Docs_Utilities\
  Reports, passwords, tenders
- \LiDAR\als2006\CMP_to_Bin\
  VB6 program calls a C++ dll-function CMP_to_BIN conversion
- \LiDAR\als2006\Lakkasuo_classified\
  Lakkasuo points divided between ground and non-ground

3.7.4 2006 DR, dense 500m, sparse 1200m; Lakkasuo-Vatiharju-Hanhisuo

Lakkasuo - Blom project code: NO06752

These Data are in the same 2006 BIN files, combined with the Hyytiälä campaign.

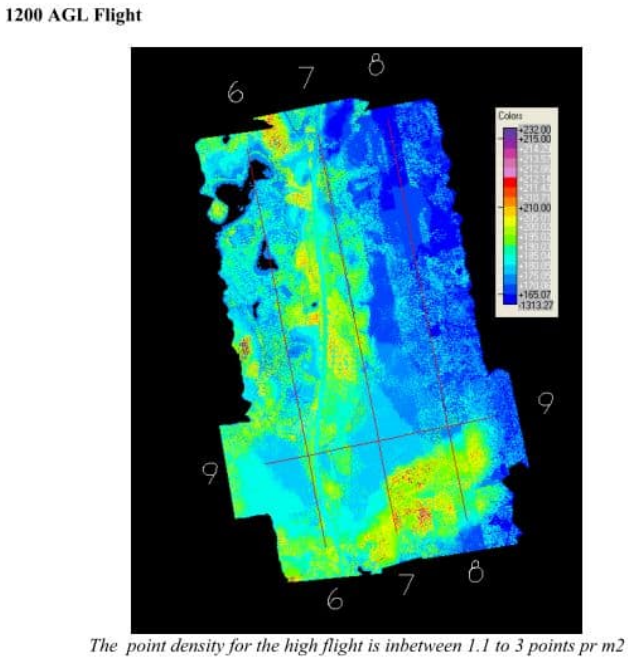


Fig. 109. Point elevation maps in the two acquisitions. 500 m AGL and 1200m AGL. Lakkasuo-Vatiharju-Hanhisuo

500 m (Vatiharju)

- July 25, 2006; 15:41-16:57 GMT
  (See the GPStime attribute of each pulse)
- Pulse repetition frequency 100 kHz
- Scan Frequency 31 Hz
- Scan Angle ± 14º
- Divergence 0.3 mrad at 1/e
- Density 5-18 per m2
- Flying speed 75 m/s
- Altitude 500 m AGL
- System calibration for ΔRoll, ΔPitch, ΔHeading, Δscale
- Strip adjustments ΔRoll, ΔPitch, ΔZ (Terramatch)

1200 m (Lakkasuo, Vatiharju, Hanhisuo)

- July 25, 2006; 15:41-16:57 GMT
  (See the GPStime attribute of each pulse)
- Pulse repetition frequency 70 kHz
- Scan Frequency 42 Hz
- Scan Angle ± 14º
-
- Divergence 0.3 mrad at 1/e
- Density 1-3 per m2
- Flying speed 75 m/s
- Altitude 1200 m AGL
- System calibration for ΔRoll, ΔPitch, ΔHeading, Δscale
- Strip adjustments ΔRoll, ΔPitch, ΔZ (Terramatch)

The data were delivered in comprehensive format, strip wise files *.cmp. (N = 5 + 4). Documentation is provided in a pdf. The *.cmp files were converted to ascii using BinToAsc.exe (README.txt), and further to per-hectare binary files (*.BIN). No GPS/IMU data are available.

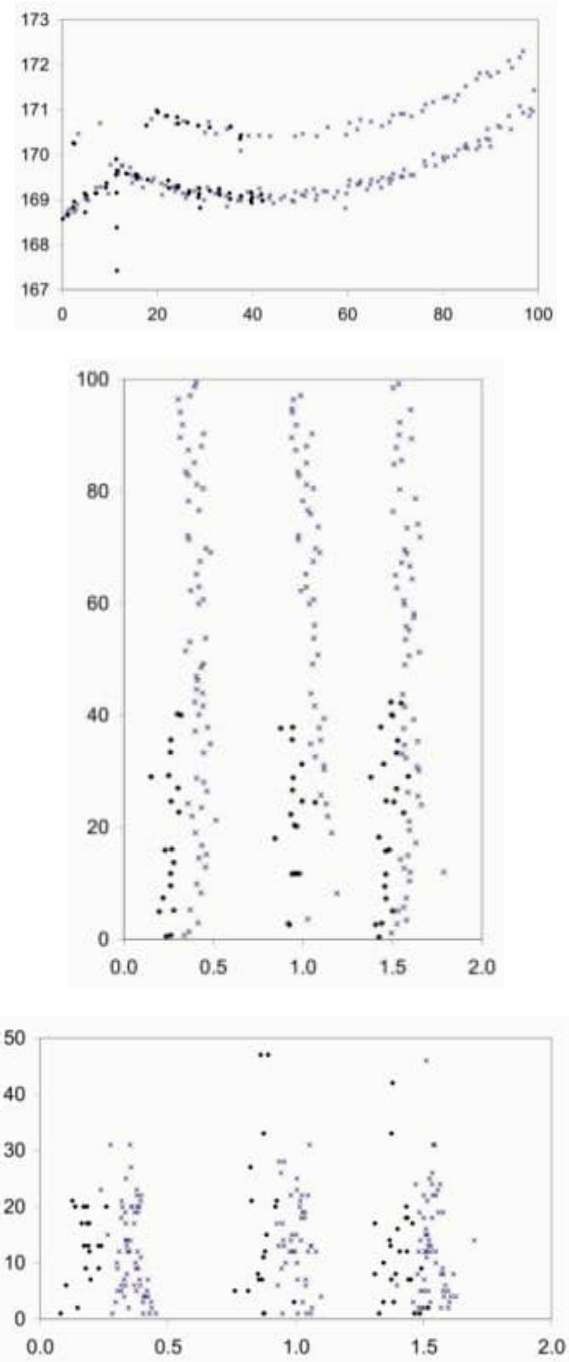
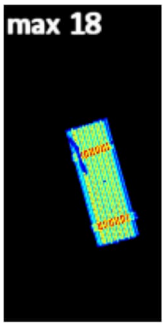


Fig. 110. In Vatiharju, a 3-cable 20 kV powerline. A 100-m-long segment of 500-m LiDAR data from two overlapping strips (a) shows the sideview with Z, (b) shows a bird-eye view, (c) intensity data 'as seen by a squirrel' with orthographic eyes viewing the cables in their direction. Minor xy offset between strips is seen, as well as dependence of the intensity on the intersection geometry (Gaussian PSF of the within-footprint irradiance, W/m2).

3.7.5 2007 DR, high-density, 1km, Leica ALS50, Hyytiälä



Leica ALS50-II sensor was flown by Finnmap FM-international. 1-4 discrete returns per pulse transmitted. Intensity recorded only for returns 1-3 (general feature of the ALS50/60-series sensors). AGC was effective, and the gain value is stored for each pulse.

- July 4, 2007; 15:40-17:25 GMT
- Pulse repetition frequency 115.8 kHz
- Scan Frequency 52 Hz
- Scan Angle ± 15º
- Divergence 0.15 mrad at 1/e
- Density 6 per m2
- Flying speed 72 m/s
- Altitude 800 m AGL
- Trajectory FILEs
- GPS/IMU system N/A
- System calibration for not reported
- Strip adjustments Terramatch

The first delivery was in LAS format; trajectory data was later combined to els-files. (using an in-house program by Jonne davidsson at Finnmap, eLAS.exe) eLAS considered (see run.bat), campaign-level ΔRoll, ΔPitch, ΔHeading, and strip-level ΔZs. The els files have point records and these were processed with a cpp-program (ALS2007_purku_v2.cpp) to per-hectare binary files with 207-byte pulse records (Appendix 3).

ALS2007\BIN
ALS2007\LAS_ELS
ALS2007\Docs
ALS2007\Utilities

Intensity based range correction, LUT N/A

AGC-correction?

Strip-files (power, temperature etc.) N/A

3.7.6 2008 Discrete-return low-pulse-density, 1, 2, 3, 4 km, Leica, Hyytiälä

During the ADS40 imaging campaign, August 23, 2008, ELB's ALS50-ii LiDAR sensor was making observations as well. The sensor-camera producing 1280x1024 RGB images was active, taking pictures at about every 100 m. From these the clouds at 700 m are seen (filenames are GMT + 2h). The campaign includes a repeated 1 km strip with and without the AGC. Kai Laemmert (Leica) was the navigator, and Yuji Kuwano (Leica) did the post processing. Estonian Land Board flew the campaign (ES-MAA).

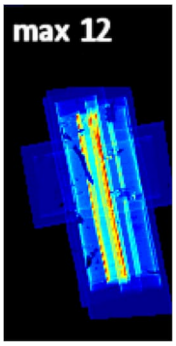


Fig. 111. 0845 GMT from (4 km).

The low flying speed made the PAV (gyro-stabilized mount) reach the 5-degree maximum in Pitch angle at times.

- August 23, 2008; 06:56-08:55 GMT
- Pulse repetition frequency 92.1,108.6, 77.6, 57.5 kHz
- Scan Frequency 35, 34, 23.4, 17.7 Hz
- Scan Angle ± 32.5º
- Divergence 0.15 mrad at 1/e
- Laser current 29%, 74%, 100%, 100%
  (in 4 km data there are less 2nd & 3rd returns)
- AGC Switch Up, Switch Dwn 12, 3 (1 km 0733 GMT AGC off)
- Density #, #, #, # per m2
- Flying speed 51 m/s (1km), 72 m/s (2-4 km)
- Altitude 1, 2, 3, 4 km AGL
- Trajectory hyytialaTrj_00001.asc
- System calibration for unknown (antenna vector ELB)
- Range-intensity calibr. SN080_IBRC_100kHz-071024.txt
- Strip adjustments Terramatch

The VRS base station data from Orivesi et al. was provided to Leica for GNSS calculations. Raw SCN-files are available – the reader?

Like LiDAR 2007, there are ELS-files that were converted to pulse-records that were written in the per-hectare

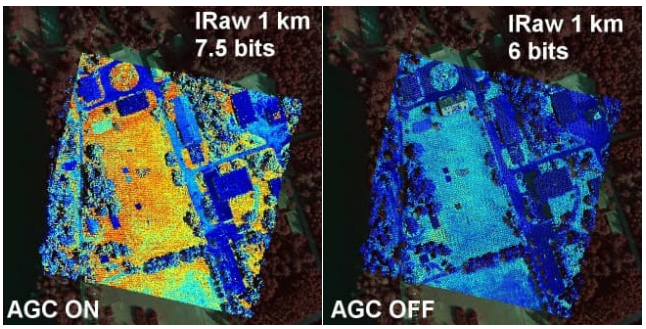


Fig. 112. The ALS2008 1 km data has a repeated strip with and without the AGC. Intensity dynamics are affected by it.

3.7.7 2010 Waveform/DR, varying-density, 1, 2, 3 km, Leica, Hyytiälä

The Hyytiälä area was flown

At 1 km, with 60% overlap, 1ns waveform sampling, 173.6 kHz
At 2 km, with 30% overlap, 2 ns, 119 kHz
At 2 km, with 30% overlap, 1 ns, 119 kHz
At 3 km, with 30% overlap, 2 ns, 83 kHz
At 3 km, with 30% overlap, 1 ns, 83 kHz

FOV was 30 degrees in all strips.

The campaign started at 15:30 GMT and the last strip was flown at 17:38 GMT.

ALS60 uses 2 different pulse widths based on selected Pulse Rate. 4 ns - higher than 115khz; 9 ns -lower than 115khz

Leica's ALS60 sensor with the WDM65 digitizer was relocated to Finland for July. See the flight_line_log files for more details.

3.7.8 2011a Waveform/DR, varying-pulse-density, 1, 2 km, Leica, Hyytiälä-Lakkasuo-Susimäki

This campaign provides data for area-based forest interpretation (2 km);

Lakkasuo LiDAR of 2006 was repeated (900 m);

Susimäki was scanned from 780 m as well as the 'Hyytiälä rectangle'.

Date August 2, 2011. Time 1653–19 GMT (times in strip filenames are GMT +3). Finnmap's ALS60 sensor with the new WDM65 module was used.

Campaign settings

(1km-Hyytiälä, 1km-Susimäki, 1km-Lakkasuo, 2km-Hyytiälä)

- Emitted pulse width — 4 ns
- FWHM of the system WF — 7.8 ns
- Beam divergence — 0.22 mrad at $1/e^2$
- WF sampling rate — 1 ns
- Number of samples in a WF — 256
- Scan angle — ± 15°
- Scan pattern — Sinusoidal
- Pulse repetition frequency — 118, 118, 105.9, 117.9 kHz
- Pulse max power/tot energy — #, #, #, #, J
- Pulse density — 10.7, ???, ???, 2.4 per m^2
- Strip overlap-% — 55, ???, ???, 30
- Flying speed — 62 m/s
- Altitude — 0.8, 0.8, 0.9, 2 km
- Trajectory — trj, and txt, @ 10 and 200 Hz
- System calibration — HRP, 3.8.2011 (place unknown)
- Strip adjustments — ΔRoll (global), ΔPitch (global), ΔHeading (global), ΔZ (strip-wise) (TerraMatch)

Data delivery and formats

The data was delivered to UH on several occasions because of some errors detected. The first delivery was in September 2011, and included DR + WF data (LAS1.3) and the trajectories. New LAS1.3 was requested in November 2011, because the WF data did not match with the DR echoes. New data was requested once more a year later in November 2012, as there had been a wrong parameter value entered to the ALS_PP software, which affected multi-echo pulses. Thus 2nd, 3rd, and 4th DR returns were missing. Strip adjustment was performed in conjunction with this 2012 delivery. Only the points, not the trajectories, were shifted in the adjustment. Strip adjusted points are in LAS1.2 format. They are exceptionally in 500x500m tiles, unlike in other campaigns where files were per strip.

The contractor sent to us also raw laser data (.scn) and a reader that converts the csn to csv files. We needed the raw data because we wanted to investigate if the DR returns were missing already in the raw data. This assumption proved to be wrong: The missing DR returns were due to problems in post-processing. The .csn files were also used for examining the erroneous intensity values: For 3–8% of the 2nd-3rd returns the DR intensity did not correlate with the WF peak amplitude. The problem was seen already in the raw data. It is thus a sensor issue, not a post-processing one. The same problem was seen in the 2012 data but not in the 2013 data, although the same sensor was used. Finally the examination of .csn revealed that there were pulses in which no echoes were triggered which was an interesting finding.

Processing into binary hectare files

We combined strip adjusted points (LAS1.2) with WF data (LAS1.3) based on GPS time stamp, and the data were written into per-hectare bin files. The format is the same as used in 2010 (Appendix 3). A Java program was used to do the task. The 10 Hz trajectories (files per strip) were used instead of 200 Hz to interpolate position of the LiDAR.

Further documentation

An html-document (in Finnish) was written in autumn 2012 when the data were delivered to us and were quality controlled. The reader is referred to that document for more details about the data, file formats, and problems/exceptions noticed during data processing:

- LiDAR\2011a\Hyytiala_ALS60_2011\index.html

Contents

\2011a\

..\bin\
Hectare binary data.
..\Weather\
Weather observations.
..\Hyytiala_ALS60_2011\
All the other data items and programs. See index.html.

3.7.9 2011b Waveform, leaf-off, high-density, 1 km, Riegl LMS-Q680i, Hyytiälä

A WF-recording sensor became available in the late autumn, and the first leaf-off dataset was ordered from Hyytiälä. Weather was not favorable, and the acquisition was as late as November 15, 2011.

Characteristics of the campaign

- November 15, 2011; 09:54-10:35 GMT
- Emitted pulse width ???
- FWHM of the system WF 4.3 ns
- Beam divergence 0.5 mrad at $1/e^2$
- WF sampling rate 1 ns
- Scan Angle ± 30°
- Scan pattern Rotating polygonal mirror
- System calibration for HRP, RiWorld, Hyytiälä 15.11.
- Strip adjustments Terramatch, ΔZ, ΔR, ΔP
- Pulse repetition frequency 240 kHz
- Pulse max power/tot energy # J
- Pulse density 19 per m2
- Strip overlap-% 75
- Flying speed 41 m/s Helicopter
- Altitude 750 m AGL
- DR data With RiAnalyze 5.2.2
- Trajectory trj, and txt, @ 256 Hz
- Range calibr. Tested, RMS 2.8 mm on roads

Notes on deliverables and processing (by AH)

The data QC was done multiple times 4-10/2012. The last version is from Oct 25, when data were processed into per-hectare BIN files. Original delivery was in April 2012. We noticed then that RiProcess, which outputs data in LAS1.3 format, left out some of the WF samples. The minor bug was fixed in Austria. Re-processing was done in early September 2012, and the delivery was in LAS1.3. However, it was then noticed in geometric Q/C that there were 10-30 cm offsets between strips. Only a campaign level HRP-estimation had been possible, as TerraMatch would not output LAS1.3 that is suitable for representing WF data. So, the strip matching was done on the point clouds, and delivered in point-wise LAS1.2 files. We then matched the WF data in the LAS1.3 files with the DR data in the strip-matched LAS1.2 files. Actually, the WF data of LAS1.3 were in WDP-files. GPS time stamps enabled the 1:1 matching. In addition to the LAS files, the delivery contains the Riegl's raw observation files (sdf) that can be viewed with WaveView.exe or RiWavelib dll library..

Fig. 113. Two hours after the scanning 17 photographs showing targets in Hyytiälä were taken by P. Kaitaniemi.

Format of the per-hectare BIN files

(See also Appendix 3) Echoes belonging to a pulse as well as the WF samples comprise a record. XY-coordinates of the last echo define the KKJ-2 hectare (BIN file) to which the pulse belongs.

There is one file for discrete return data (##1_##2.bin). Each echo has a file pointer to the waveform data file (##1_##2_wf.bin). Pointer indexing (unsigned 32bit integer) starts from file beginning that has the address 0. LMS-Q680i stores waveform data into 80-sample blocks. Echoes in a pulse can point to one or more waveform blocks. The blocks can be "connected" or "continuous", when exported to LAS1.3, if there is no gap between them. Thus, there can be waveform packets in the ##1_##2_wf.bin files that contain 80, 160 or 240 samples.

Structure of ###_###.bin, DR-data per hectare files

At file start, the number of pulses in the hectare (signed int32, bytes 0–3) are given. The first pulse record is at file position 4 (5th byte). Each record contains pulse-level attributes, and a variable number of echoes with the echo attributes.

<u>Pulse, variable length, depending on echo count</u>
* echoCount (signed 8-bit integer)
* gpsTime (64-bit float)
* byteLAS (signed 8-bit integer, NOTE: has errors in the case of more-than-7-return-pulses)
* echoes[] (36 bytes each, from last to first)
* scanAngle (signed 8-bit integer)
* poslidar.x (64-bit float)
* poslidar.y (64-bit float)
* poslidar.z (64-bit float)
* stripNum (trajectory number, signed 8-bit integer (not necessarily same as in original files))

<u>Echo, a 36-byte structure</u>
* pos.x (64-bit float)
* pos.y (64-bit float)
* pos.z (64-bit float)
* intensity (unsigned 16-bit integer)
* pointer (pointer to waveform data, signed 32-bit integer)
* waveformSampleSize (number of waveform samples, signed 16-bit integer)
* retPointWFLoc (distance of the DR echo from start of the waveform recording in picoseconds, 32-bit float)

Structure of ###_###_wf.bin WF data files

There is no header - WF data samples start from the beginning of the file. Waveforms are stored using unsigned 16-bit integers.

Aspects discovered during data processing

The retPointWFLoc (time from the echo to the start of the WF packet) is not accurate. It is rounded into the nearest nanosecond by RiProcess software. The more accurate value, if needed, can probably be calculated using original waveform data from the *.sdf -files.

There were small number of echoes that were missing the pointer to a waveform block. The reason for this was a bug in Riegl's RiProcess software. If the echo was located exactly in between two waveform blocks i.e. its distance from the start of waveform recording was rounded to 80 ns, it was left without pointer when exported to LAS1.3. If there was no subsequent echo after the one with missing pointer, the latter waveform block did not exist in the LAS - file. The bug was corrected, and final data do not contain echoes with

missing pointer to waveform data (except a small number of pulses at the end of some flight lines, reason for this remained unknown).

There is a problem considering return numbering when exporting to LAS1.3 using RiProcess. The return number and number of returns in a pulse are coded using 3-bit integers. If the pulse contains more than 7 returns, the return number for 8th, 9th etc. returns is always 7. Also the "number of returns" -flag is erroneous if pulse contains more than 7 returns. These pulses were corrected: the echoes were sorted by z-coordinate and relabeled. The number of pulses containing more than 7 echoes is extremely low. For example, in the first strip there were 23812840 pulses, of which 162 had more than 7 returns.

Some assessment of geometry/radiometry

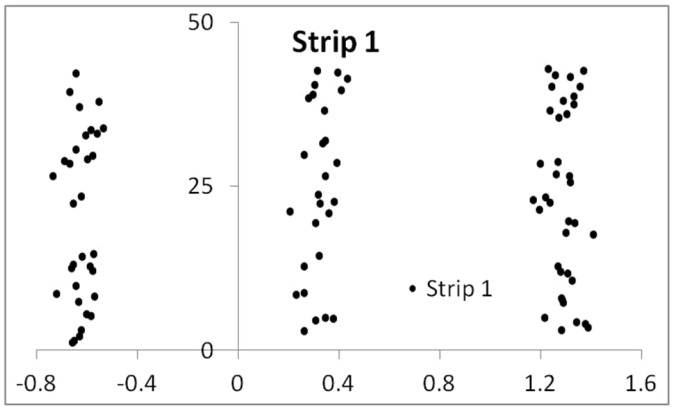


Fig. 114. A 20kV 3-cable powerline (500 m S of Hyytiälä, 40-m segment) had produced these DR returns for the 2011b data. The X-axis has the deviation in meters, perpendicular to the direction of the cables.

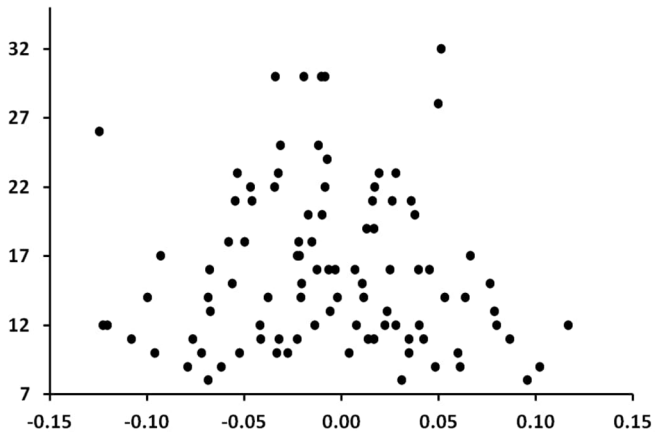


Fig. 115. DR intensities as a function distance from the cable.

Further documentation

An html-document (in Finnish) was written in autumn 2012 when the final data were delivered to us and were quality controlled. The reader is referred to that document for more details about the data, file formats, and problems/exceptions noticed during data processing. Note! Due to changes in folder structure some of the links in the document are broken.

- LiDAR\2011b\index.html

Images taken during the campaign:

- Terrestrial_Images\Other_Images\2011_LiteMapper_Keilaus\

Contents

\2011b\

..\Bin\
The per-hectare BIN files of Oct 25, 2012 processing
..\LAS1_2_strip_Matched\
Strip-matched DR data: LAS1.2 (*.las); Delivery of October 2012
..\LAS1_3_201209\
Campaign HRP matched DR + WF data in LAS1.3 format (*.las), WFs as *.wdp files, and TerraScan indexfiles (*.idx); Delivery of September 2012
..\Preparations\
Preparations of the campaign
..\Processing_1\
Java software used to process the data into binary hectare files. Test version and miscellaneous calculations.
..\Processing_2\
Java software used to process the data into binary hectare files. Final version from Oct 25 + processing log (Loki.txt).
..\RawLaserObs\
Raw WF data as *.sdf files
..\RiManuals\
Riegl's manuals: LiteMapper, RiAnalyze, RiProcess
..\riwavelib_sdf_1.3.51\
Riegl's dll's for reading .sdf files.
..\TerraMatch\
Z control report + other files
..\trj_256Hz_tm35fin\
Trajectories as .trj
..\trj_ascii_256Hz\
Trajectories as ascii
..\waveView\
Riegl's waveform viewer
..\Weather\
Weather data
..\Laserkeilausraportti_Hyytiala_LiteMapper_2011.pdf
Finnmap's original project report, 28.3.2012 (pdf)
..\index.html
Notes on data processing made by AH in autumn 2012 (in Finnish). Note! The links are broken.

3.7.10 2012 Waveform/DR, varying-pulse-density, 0.5, 1, 2, 3 km, Leica ALS60, Hyytiälä

The idea was to acquire pulses with varying footprint size at target. In addition, we wanted the irradiance (W/m^2) to be similar from all heights giving a constant signal-to-noise ratio (in well-defined surfaces).

There are 34 flight lines (Fig. 116). A single perpendicular line was flown only at 1 km, which was not optimal, considering the weights, i.e. sampling densities from various heights, and their influence on the system (misalignment) calibration.

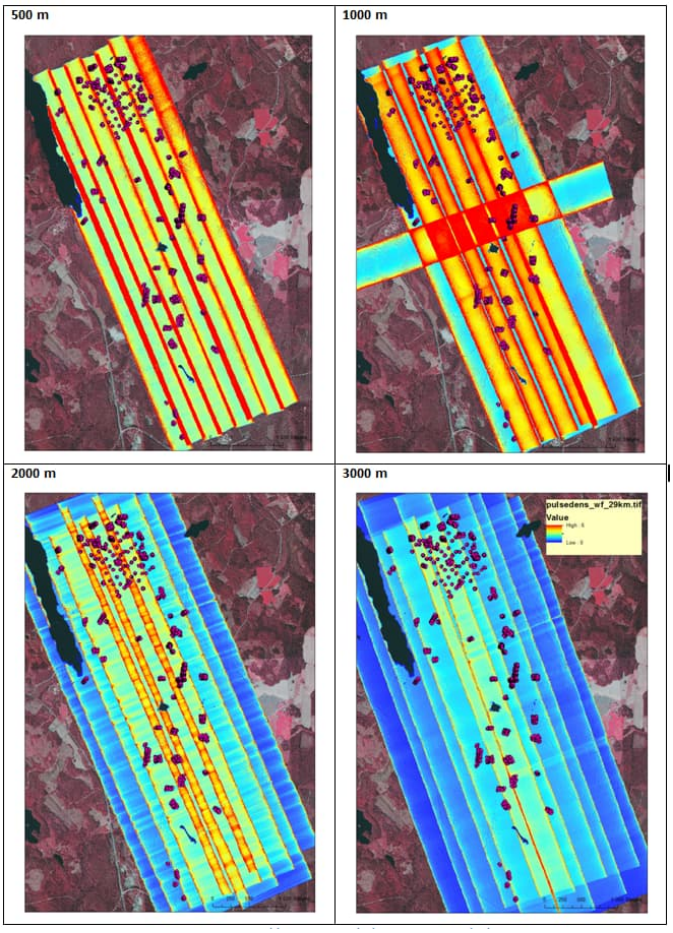


Fig. 116. The pulse densities (0-6) from 500 m, 1 km, 2 km, and 2.75 km AGL. Overlap-% increases with the height for keeping the densities high. July 5 data only.

Repeated lines

Flight lines 1–29 were flown July 5, and lines 30–34 were flown the following evening as it was suspected that the 500 m data had areas without sampling.

Differences in data recorded between pulses

At the start of each flight line, the data consists of DR data only, because the WF recording commenced with a delay. In addition, the 500 m data was acquired using high PRF, resulting in every second pulse pair being with / without the WF data. The repeated flight lines compensate this in part. The 500-m data has thus 2 x DR, 2 x (DR + WF), 2 X DR, ...

Intensity vs. WF amplitude data

We have understood that the receiver in the ALS60 used comprises a GAIN circuit followed by the WF digitizer and four separate (or eight) range detection circuits for the DR data. There may be separate ones (4 + 4) for the two pulse widths of the transmitted pulse. DR intensity is recorded for returns 1-3 and return 4 is always at value 1.

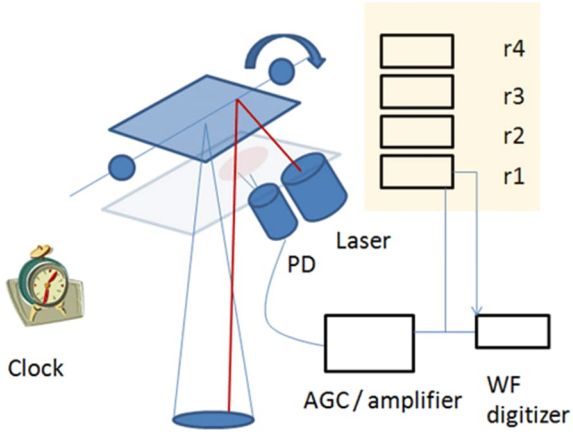


Fig. 117. Illustration of the ALS60 sensor as we understand it. The gain circuit affects the signal that is split between the WF recorder and the range detection circuits that all have their own geometric (time delays) and radiometric characteristics (offset and gain). The WF recording is triggered by r1 unit! Some 30 ns of WF is always stored in a buffer to be included in the recording.

Calibration and strip adjustments

The system calibration was first done with Hyytiälä data. Error in pitch angle was noticed: Coordinates of the echoes were shifted by 1 m in direction parallel to the strip, when flying from 2700 m altitude. The data were re-processed with HRP values used in Finnmap's earlier acquisitions (calibration place and date unknown). Strip adjustment was performed for the re-processed data.

Characteristics of the campaign

- July 5, 2012; 19.10 – 01.55 (departure - arrival)
- July 6, 2012; 14.35 – 16.05 (departure - arrival)
- Sensor — Leica ALS60 SN6125 Freebird
- Navigation — Leica FCMS
- Emitted pulse width — 4, 9, 9, 9 ns
- FWHM of the system WF — 7.8, 10.1, 10.3, 10.4 ns
- Beam divergence — 0.22 (1/e^2)
- WF sampling rate — 1 ns
- Number of sample in a WF — 256
- Scan Angle — ± 15°
- Scan pattern — Sinusoidal
- Scan Frequency — 68.4, 60.3, 33, 24.7 Hz
- Pulse repetition frequency — 152.6, 99.2, 58.9, 44.9 kHz
- Pulse max power/tot energy — # J
- Pulse density — 5.3/10.5 (WF/DR), 5.4, 3.2, 2.2 per m^2
- Strip overlap-% — 20, 45, 80, 85%
- Flying speed — 62 m/s
- Altitude — 500 m, 1, 2, 2.75 km AGL
- Trajectory — trj, and txt, @ 200 Hz
- System calibration for — HRP, time and place unknown
- Range calibration — Hyytiälä 5.7.
- Strip adjustments — ΔRoll, ΔZ, time-dependent ΔZ

N. B. The last (ID= 15) 1 km line had ± 20º Scan angles.

Further documentation

An html-document (in Finnish) was written in autumn 2012 when the data were received from Finnmap, quality controlled, and processed into per hectare bins. The reader is referred to that document for more details about the data, file formats etc.:

- LiDAR\2012\index.html

Images of vegetation and other targets nearby Hyytiälä station:

- Terrestrial_Images\Other_Images\2012_Hyytiala_ALS60\

3.7.11 2013a Waveform, high-density, 0.8, 0.3 km, Riegl LMS-Q680i, Hyytiälä-Siikaneva

Two areas were scanned in May 28: Hyytiälä and Siikaneva. The Hyytiälä flight was a repetition of the 2011 campaign. The same flying height and settings were applied. The Siikaneva flight was performed in order to map areas surrounding the two SMEAR towers with low-altitude, high pulse density data.

The data were acquired with a Bell 206L (OH-HJL) helicopter. The scanning system was IGI LiteMapper 6800 with Riegl ALS LMS-Q680i scanner. Both Hyytiälä and Siikaneva included also RGB aerial imagery acquired with a Hasselblad H4D-50 camera (documented elsewhere).

Because of the early summer acquisition, the leaves of birch had just reached their full size. Alder had still very small leaves, and aspen did not have full-grown leaves. Field photographs were taken in the Hyytiälä area after the campaign (29.5.):

- \HYDE_REF\LiteMapper_2013_valokuvat\index.html

Campaign settings

General

- May 28, 2013; 09:30-12:20 GMT
- Emitted pulse width ???
- FWHM of the system WF 4.5 ns
- Beam divergence 0.5 mrad at $1/e^2$
- WF sampling rate 1 ns
- Scan angle ± 30°
- Scan pattern Rotating polygonal mirror
- System calibration Sjökulla, April 27th, 2013
- Strip adjustments ΔRoll, ΔPitch, ΔHeading, ΔZ (TerraMatch)

Hyytiälä

- Pulse repetition frequency 240 kHz
- Pulse max power/tot energy # J
- Pulse density 19.5 per m^2
- Strip overlap-% 75
- Flying speed 41 m/s
- Altitude 750 m AGL

Siikaneva

- Pulse repetition frequency 400 kHz
- Pulse max power/tot energy # J
- Pulse density 50 per m^2
- Strip overlap-% 55
- Flying speed 36 m/s
- Altitude 300 m AGL

Data delivery and formats

The data provider extracted the DR points with RiAnalyze v5.4.3. The geoereferenced point cloud was generated with RiWorld v4.5.1, and data in LAS1.2 (DR point cloud) and LAS1.3 (DR point could + waveform data) were exported with RiProcess software. There were several problems with LAS export, and the data had to be processed several times. Finally, the LAS data was generated with new RiProcess v1.5.9 that preserved the time offset between DR echo and WF recording at pikosecond level (note that In the data from the 2011 Riegl campaign, this offset was rounded into nearest nanosecond). In addition to LAS format, the original WF data in Riegl's sdf format was provided if needed in further investigations.

Strip-adjustment was performed for the point cloud exported in LAS1.2 format. TerraMatch software was used. Global HRP-corrections, stripwise HRP-corrections, and stripwise Z corrections were applied.

Format of the per-hectare bin-files

We combined strip adjusted points (from LAS1.2) with WF data (from LAS1.3) into per-hectare bin files. The format is the same as used in 2011b (Appendix 3).

Note! Siikaneva data, unlike other LiDAR datasets in Hyytiälä, is in ETRS-TM35FIN coordinate system with ellipsoid heights. See Appendix 3.

Note! In Siikaneva, the received power was on average high. Therefore, large portion of waveform amplitude values were in the nonlinear part of the amplitude scale. Some of the waveforms were even recorded by both high- and low power channels of the receiver. The waveforms recorded by the high power channel were not exported in the LAS-format and are thus missing from the per-hectare bin files. For these data, the user is referred to the original sdf-files.

Contents

\2013a\
..\Raportti\
Reports by the contractor
..Index.docx
Documentation by Aarne Hovi. E.g. strip indexing, detailed documentation of issues occurred during data processing software etc., and related correspondence with Riegl.

Hyytiälä
Hyytiala\LAS_1.2\
Point data in LAS1.2 format, strip-adjusted and original
Hyytiala\LAS_1.3\
Non-strip adjusted point data + WF data in LAS1.3 format
Hyytiala\Raw_sdf\
Waveform data in Riegl's original format
Hyytiala\Trajectories_256Hz_TM35FIN_ellipH\
Trajectory data (ASCII and .trj formats)
Hyytiala\Lentolinjasovitus_korjaukset\
Calibration data and corrections due to strip adjustment. These apply to Siikaneva also.
Hyytiala\bin\
Data processed into binary hectare files
Hyytiala\HectareProcessing2013LiteMapper\
Java program used for processing into hectares. Runs in NetBeans environment.

Siikaneva
Siikaneva\LAS_1.2\
Point data in LAS1.2 format, strip-adjusted and original
Siikaneva\LAS_1.3\
Non-strip adjusted point data + WF data in LAS1.3 format
Siikaneva\Raw_sdf\
Waveform data in Riegl's original format
Siikaneva\Trajectories_256Hz_TM35FIN_ellipH\
Trajectory data (ASCII and .trj formats)
Siikaneva\DEM_20cm\
Raster DEM (tiff) in 20 cm resolution
Siikaneva\bin\
Data processed into binary hectare files
Siikaneva\HectareProcessing2013LiteMapperSiikaneva\
Java program used for processing into hectares. Runs in NetBeans environment.

3.7.12 2013b Waveform/DR, varying density, 0.7, 2, 0.7, 0.8, 0.9 km, Leica ALS60, Hyytiälä

Leica ALS60 sensor with WDM65 WF-digitization unit was used with fixed-wing aircraft (Piper Chieftain, OH-PNX). The sensor records 1–4 DR echoes per pulse, and the WF of each pulse was digitized at 1 ns.

The campaign includes five datasets. Data over the entire Hyytiälä rectangle were acquired from two flying heights:

- 2 × 6 km area, 13 strips, AGC on, ~700 m altitude
- 2 × 6 km area, 6 strips, AGC on, ~2000 m altitude

In addition, a smaller area was scanned with fixed receiver gain (AGC off) from three flying heights:

- 3 strips, AGC off, ~700 m altitude
- 3 strips, AGC off, ~800 m altitude
- 3 strips, AGC off, ~900 m altitude

Campaign settings

- June 15–16, 2013, 20:55 – 0:25 GMT
- Emitted pulse width 4 ns
- FWHM of the system WF 7.8 ns
- Beam divergence 0.22 mrad at $1/e^2$
- WF sampling rate 1 ns
- Number of samples in a WF 256
- Scan angle ± 15°
- Scan pattern Sinusoidal
- Pulse repetition frequency 105.9, 117.9, 105.9, 105.9, 105.9 kHz
- Pulse max power/tot energy #, #, #, #, # J
- Pulse density 10, 5, 5, 5, 5 per m^2
- Strip overlap-% 55, 67, 20, 30, 38
- Flying speed 62 m/s
- Altitude 0.7, 2, 0.7, 0.8, 0.9 km
- System calibration Turku, 15th June, 2015
- Strip adjustments ΔRoll, ΔPitch, ΔHeading, ΔZ (TerraMatch)

Data delivery and formats

Strip adjustment was performed by the contractor. Global heading roll, pitch, and Z corrections. Stripwise roll and Z corrections.

The contractor delivered flight- and post-processing reports, trajectory data (256 Hz trj and ascii), and the LiDAR records in LAS-format. The strip-adjusted DR point cloud was in LAS1.2. DR point cloud without strip adjustment and the WF data were in LAS1.3 format. We combined strip-adjusted DR points with WF data from LAS1.3 into binary hectare files.

Note! Small areas at the start/end of each strip were missing WF data. In addition, strip nr 29 (repeated) was missing WF data entirely.

Quality control and issues with the data

When acquiring the fixed-gain data, the gain was initially set too high. The first strip from 700 m (strip nr 14) was acquired with this too high gain. This strip was repeated (strip nr 15) and all the rest of the fixed-gain strips were acquired with the lower gain. However, the gain was still too high and the intensity data of the 700 m strips were saturated in highly reflective targets such as seedling stands and grass surfaces.

Status of vegetation and weather conditions

Photographs were taken during the campaign:

- HYDE_REF/LiDAR/LeicaALS_2013_kuvat/index.html

The flight was at night time, and there was near-ground fog on low-lying lands. Light dew was observed on low vegetation and grass.

Contents

\2013b\

Delivery:

..\Hyytiälä_laserkeilaus_als60_2013_raportti.pdf
Contractors report about data delivery
..\Hyytiälä_laserkeilaus_als60_2013_lentoraportti.pdf
Flight report
..\130615_210514_FlightLineLog.csv
Flight line log
...\LAS_original\
DR point data without strip adjustment (LAS1.2 and LAS1.3) + WF data (LAS1.3)
..\LAS_stripadjusted\
Strip adjusted DR point data (LAS1.2)
..\Trajectories\
Trajectory data in trj and ascii
..\Hyytiälä_laserkeilaus_als60_2013_lehtijako_TM35FIN.dgn
TerraScan project file

Processed hectare bins:

..\Index.docx
Notes on data processing by Aarne Hovi, includes strip indexing and pulse density maps
..\bin\
Binary hectare files
..\HectareProcessing2013Leica\
Java code for processing data into hectare files. Runs in NetBeans programming environment.
..\Leica2013_processing_log_AH_20130410.txt
Processing log file
..\leica_pulsedens.asc
Density of all pulses, all strips together (EsriGrid raster, 30 × 30 m resolution)
..\leica_pulsedens_missing_wf.asc
Density of pulses without waveform data, all strips together (EsriGrid raster, 30 × 30 m resolution)

AGC-compensation model for intensity and WF's Report here)

3.7.13 2013c DR (terrain modeling) data by NLS

These data were downloaded and turned into binary files following the per-hectare structure: ##1_##2.bin.

FN1 = Format$(Int((X - 2510000) / 100), "000")
FN2 = Format$(Int((Y - 6850000) / 100), "000")

There are data from 7147 hectares. Each file starts with an unsigned long that gives the number of 34-byte point-records.

```
Type NLS_POINT
 X As Double
 Y As Double
 z As Single
 Intensity As Byte
 EchoN As Byte
 NR As Byte
 Classification As Byte
 ScanAngle As Integer
 GpsTime As Double ' 34 bytes
End Type
```

The downloaded (from Paituli service)*.laz files represent 6 x 6 km areas. Each 6 x 6 km block comes with a CSV-file that has the metadata.

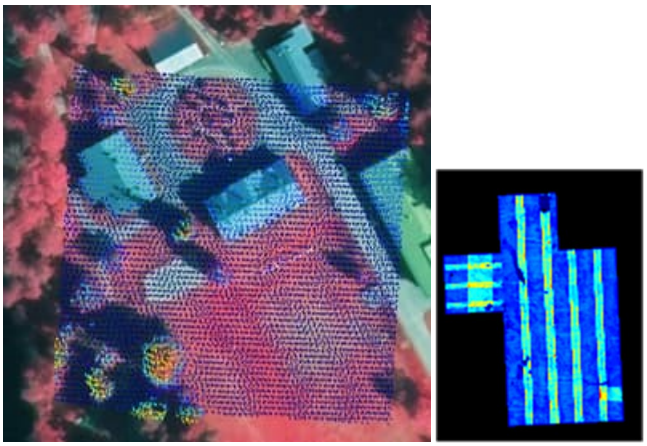


Fig. 118. The data are rather sparse, except for areas of overlapping strips.

3.7.14 2015 Waveform, high density, 0.8 km, Riegl LMS-Q680i, Hyytiälä

Repetition of 2011 and 2013 Riegl campaigns. Same flying height and settings applied. Used for a study that looked to the influence of phenology.

Data acquired with a Bell 206L (OH-HJL) helicopter. The scanning system was IGI LiteMapper 6800 with Riegl ALS LMS-Q680i scanner. RGB aerial imagery was acquired on the same flight, using Hasselblad H4D-50 camera.

The acquisition was first tried on 14th August but there were problems with the LiDAR sensor. The second trial was after re-assembling the LiDAR sensor on the platform (18th August). Field photogrammetry was performed during 14th-17th August to document the status of vegetation.

- Terrestrial_Images\Hyyt_kuvaus_Riegl2015\2015_LiteMapper_MaastoKuvaus.html

Campaign settings

- Aug 18, 2015; 07:43-10:19 GMT
- Emitted pulse width ???
- FWHM of the system WF 4.5 ns
- Beam divergence 0.5 mrad at $1/e^2$
- WF sampling rate 1 ns
- Scan angle ± 30°
- Scan pattern Rotating polygonal mirror
- System calibration HRP, Hyytiälä Aug 18th
- Strip adjustments ΔRoll, ΔZ (TerraMatch)
- Pulse repetition frequency 240 kHz
- Pulse max power/tot energy # J
- Pulse density 20 per m^2
- Strip overlap-% 75
- Flying speed 41 m/s
- Altitude 750 m AGL
- DR data With RiAnalyze 5.4.3
- Trajectory trj, and txt, @ 256 Hz

Data delivery and formats

The data provider extracted the DR points with RiAnalyze v5.4.3, and data in LAS1.2 (DR point cloud) and LAS1.3 (DR point could + waveform data) were exported with RiProcess v1.5.9. In addition to LAS files, the original WF data in Riegl's sdf format was provided.

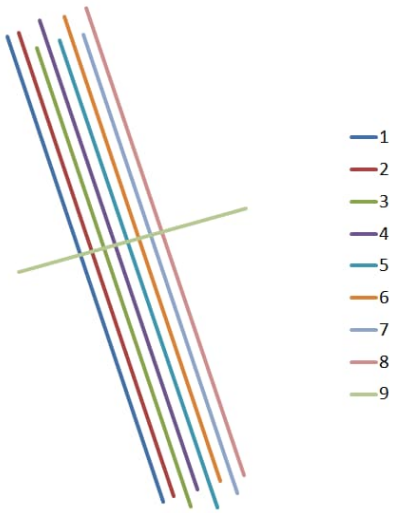
Originally, system calibration was made in Karjaa, but the system was re-assembled after Aug 14 trial. HRP calibration for the re-assembled system had to be performed with Hyytiälä data.

Strip-adjustment was performed for the point cloud exported in LAS1.2 format. TerraMatch software was used. Stripwise roll and Z corrections were applied. Only the point cloud was shifted in the adjustment, the trajectory data (ascii and trj files) was left untouched.

We combined strip adjusted points (from LAS1.2) with WF data (from LAS1.3) to form pulse records that were written into per-hectare bin files (Appendix 3).

Quality control and notes about the data

The strip numbers written in bin files equal those in 2011 and 2013. The strips were not flown in the same order. In 2015, strips #2 to #9 were flown first, and strip #1 last.



The XY accuracy was estimated by superimposing LiDAR returns on aerial images. No notable errors or mismatch between strips were detected.

The Z accuracy was evaluated by comparing against asphalt and sand road profiles measured with VRS-GPS. There was on average 0.05 m positive Z bias in the coordinates of the LiDAR echoes, i.e. the LiDAR Z was above the Z measured with GPS. The likely reason is that the Z calibration of LiDAR was perfomed using signaled GCPs (white crosses). It is likely that some of the LiDAR returns originated not from top of the signal but in between top of signal and ground. Consequently, some of the LiDAR echoes had Z below the signal's Z, and the echoes were therefore shifted upwards in the calibration.

Intensity and amplitude histograms over entire Hyytiälä were examined. There were hardly any pulses with amplitude values exceeding 200. Thus, only low power channel of the receiver was in use (high power channel is used if the peak amplitude exceeds approx. 220).

The parameters used in Gaussian decomposition (RiAnalyze) differed from 2011 and 2013 acquisitions that used the default values:

	2013	2015
"Threshold"	9	5
"Decay of trigger rise"	5.0	3.0

As a result, the proportion of multi-return pulses from all pulses was larger in 2015 (54–59 %) compared to 2013 (44–51 %). An error tag was assigned to each pulse to indicate the presence of ringing-induced echoes. The error tag replaced "byteLAS" variable in the bin files. See further explanations in Appendix 3 and in Riegl2015_QC.docx.

Contents

\2015\

Finnmap's delivery:

..\LAS1.2_sovitettu_500m_lehdet\
Strip adjusted echoes in LAS1.2 format, 500x500m tiles
..\LAS1.2_sovitettu_lentolinjoittain\
Strip adjusted echoes in LAS1.2, one file per flight line
..\LAS1.3\
Original (non-strip adjusted) echoes + WF data in LAS1.3
..\Raw_sdf\
Original unprocessed LiDAR data in .sdf format
..\report\
Finnmap's reports
..\trajectrory\
Trajectory data in ascii and .trj
..\RiAna_543.zip
Parameters used by FM in Gaussian decomposition

Data processed by UH:

..\bin\
Pulses in binary hectare format
..\DEM\
DEMs used for tagging the erroneous echoes
..\HectareProcessing2015LiteMapper\
Java program used for processing the data into hectare bins
..\hectare_processing_log.txt
Processing log file by AH
..\Riegl2015_QC.docx
Notes about the data made when processing into hectare bins
..\Aarnes_notes\
Miscellaneous calculations made for QC

3.7.15 2016 Discrete-return, 3-band, 1km, Optech Titan, Hyytiälä, Syväniemi, Lakkasuo

Nine overlapping flight lines. Channel numbering:

Ch1 = 1550 nm, Ch2 = 1064 nm, Ch3 = 532 nm.

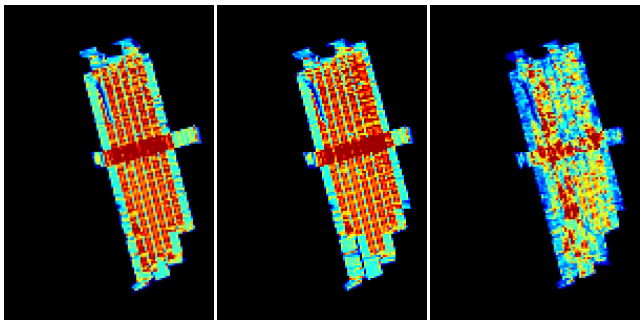
The scan patterns have a 3.5-degree (0, 3.5 and 7) offsets in flying direction, and nadir data are acquired by 1064 nm only.

The 207-byte pulse records consume disk space:

1550 nm	55,862,174,575 bytes
1064 nm	52,332,294,966
532 nm	41,349,348,178

There are most recorded pulses in SWIR and 20% of the GRN pulses never triggered a response.

The BASIC programs written for LAS-BIN conversion and data tiling are presented in Appendix 3.



Pulse density, CH1, Ch2 and Ch3.

Campaign settings (1550, 1064, 532)

- Date, time — June 14, 2016; 12:35-13:10 GMT
- Beam divergence — 0.35, 0.35, 0.7 mrad at 1/e
- Scan angle — ± 40° (3..22°, 0..22°, 7..23°)
- Scan pattern — Oscillating mirror
- System calibration — HRP & scale in Hyytiälä
- Strip adjustments — ΔHeading, ΔZ (all CHs combined)
- Pulse repetition frequency — 300, 300, 300 kHz
- Pulse max power/tot energy — # J
- Pulse density — <12 per m^2
- Strip overlap-% — ##
- Flying speed — ##
- Minimum echo separation — < 1 m
- Altitude — 1000 m AGL
- DR data — 0–4 echoes per pulse emitted
- Trajectory — txt, @ 200 Hz

The Z-values of the LAS-file echoes were subtracted 0.32 m from N2000 to N60.

3.7.16 2018 Discrete-return Riegl 1560, 1.15 km

Purpose

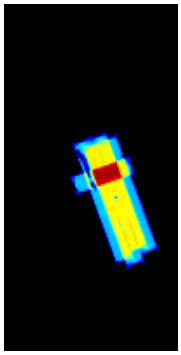
This campaign was initiated at 'last minute' and documents the status of the SMEAR II stations' vicinity prior to an intermediate felling of the nearby stands. Terratec (FIN/NOR) had their Riegl 1560i sensor in Finland and agreed to fly in Hyytiälä.

The campaign costs were covered by ICOS Suomi and the CoE at SMEAR (Bäck & Vesala). In return, students of course ME-013C measured a 4-ha forest plot surrounding the SMEAR station.

The campaign was repeated in 2020 using the same sensor model (different unit) and by striving for similar acquisition settings (same flight lines, same sensor, same settings).

Campaign settings

The data comprises 4 parallel strips and 1 perpendicular strip. RGB images were acquired simoultaneously.



Pulse density (0-40 /m2) per hectare (map size 10 x 15 km).

Date May 24, 2018

Acquisition time 0630-0654 GMT.

Ground photography at the site: kuvat24518.zip (by Pekka Kaitaniemi in Hyytiälä)

Delivered LAS1.2 data

Data were first delivered in LAS 1.2 (Point type 1) format in 500 x 500 m tiles and later in strip-files (N=5). After Q/C, it was recognized that data was duplicated, as each echo was twice in each LAS-file. A third delivery was needed.

Trajectory data (XYZ) is available at 1Hz resolution (70 m intrapoint distance) for computing the position of the sensor at a given point in time. Each LiDAR pulse has a time tag (GPS time, < 1 microsecond accuracy, 8-byte floating point representation), so it was possible to estimate the origin of the pulse vector and collect all return points per pulse transmitted into a single pulse-record (for kuvamitt-software). LAS 1.2 is point-format and points belonging to a pulse may no be in sequantial order in the file.

In rare cases, there could be upto 8-9 echoes per pulse transmitted. Echo number attribute in LAS 1.2 has a max of 7 (three-bit representation). Delivered LAS 1.2 file had all echoes, but the rare cases with 8 or 9 echoes per pulse transmitted may be corrupted in (8th and 9th return saved as 6th and 7th) the BIN-files created for KUVAMITT - simply because the echo number value of LAS1.2 is wrong, and it was not accounted for as these cases were very rare. LAS 1.4 files were never asked from Terratec. That format allows for more points per pulse (return number, number of returns attributes)

Kuvamitt-per-hectare bin files

Regular users would use LAS-files. All LiDAR data in Hyytiälä (2004-) is converted into "comprehensive format", in which pulses form the records, and each pulse has various attributes such as the position of the sensor, and all echoes belonging to it in sequantial order. A new binary format for kuvamitt-software was defined, because none of the previous (sensor specific) formats did not quite suit. Similar to Riegl-format used for the 2011, 2013 and 2015 , echoes of a pulse were stored in a variable length echo array as the number of echoes could range from 1 to 7.

Files realize a tiling into hectares in the KKJ2 coordinate system (as with all LiDAR from Hyytiälä), while the LAS files have UTM35/N2000 coordinates. The coordinates in the bin files are in KKJ2 Easting (x), Northing (y) and N60-orthometric elevatoin (z). Reduce .32 m from N2000 to get N60 orthometric heights.

First 4 bytes in the ha-file give the number of pulse records. These records start at fifth byte, which has the echocount (Byte, int8) attribute of the first pulse. Variables GPStime, ByteLAS, ScanAngle, PosLiDAR, Receiver and stripnum follow. See the visual basic type declaration below. Followed by these attributes are N x 23-byte EchoRiegl1560 echo-records, which have the xyz coordinates, intensity and classification as the attributes. The 2018 data is classified (ground, vegetation, tower), while the 2020 isn't.

```
Type PulseRIegl_1560          ' A whole pulse-record
  echocount As Byte           ' N of EchoRiegk_1560s
  GPStime As Double           ' Seconds
  ByteLAS As Byte             ' Byte copied from LAS-file
  ScanAngle As Byte           ' Scan Angle Rank in LAS
  PosLidar As Point_3d        ' XYZ of LiDAR
  Receiver As Byte            ' Which of the two scanners
  StripNum As Byte            ' Identifier for a strip
  Echoes() As EchoRiegl_1560
End Type

Type EchoRiegl_1560  ' A return, 1-10 in a pulse emitted
 pos As Point_3d              ' XYZ of the echo
 intensity As Integer         ' Intensity by RiProcess
 class As Byte                ' Classification
End Type
```

How was the conversion done: The LAS1.2 Point 1 data files comprises a header of 227 bytes followed by fixed-length echo records. A routine was written in C that splits these >2 GByte LAS-files into smaller chunks (< 2 GByte) that are readable with Visual Basic. (See Section Riegl 1560 processing, May 2018).

The 28-byte LAS 1.2 echo-record defined in Visual Basic:

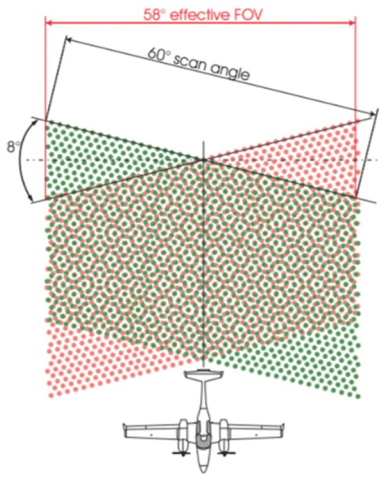
```
Type LasPoint1 ' point format 1 in las1.2
 X As Long
 Y As Long
 z As Long
 intensity As Integer
 PulseByte1 As Byte
 class As Byte
 ScanAngle As Byte
 UserData As Byte
 PointSourceID As Integer
 GPStime As Double
End Type
```

X values were stored as 32-bit integers, scaled by 0.001
Y values were also 32-bit integers, scaled by 0.001, offset by 6000000. Z values were as 32-bit longs, scaled by 0.001.
PulseByte1 has the structure "00111222", number of returns is in bits 3-5, while return number is in bits 6-8. Userdata has the sensor code 1 or 2 (1560i has two LiDAR scanners)!

About Riegl 1560i sensor

Runs two scanners (#1, #2) mounted in a known geometry. There is a tag for each pulse that tells the scanner. It is the Userdata attribute in the LAS-files. In the bin-files for kuvamitt, it is the Receiver attribute. Both are 1-byte entities although 1 bit would suffice.

FOV	58 degrees
Tilt angle (scan lines)	+/- 14 degrees
Forward/Backward Scan Angle in Non-Nadir Direction	+/- 8 (at the edges)



Notes on radiometry

Data were processed in “amplitude mode”, i.e. each intensity value is to be interpreted as gain in dB (power difference, power ratio) with respect to a minimum input power required to trigger an echo (interpretation is not verified by Riegl). It is unclear if intensity is affected by echo width, or if it corresponds to maximum amplitude of that echo. The latter is assumed to be the case.

$dB = 10 \log10(P_{out}/P_{in})$

Typical values on some surfaces were

	Intensity	Reflectance at 1064 nm
Bitumen	400-600	3-5%
Asphalt	1100	15%
Fine sand	1200	20%
Grass	1500	30-40%

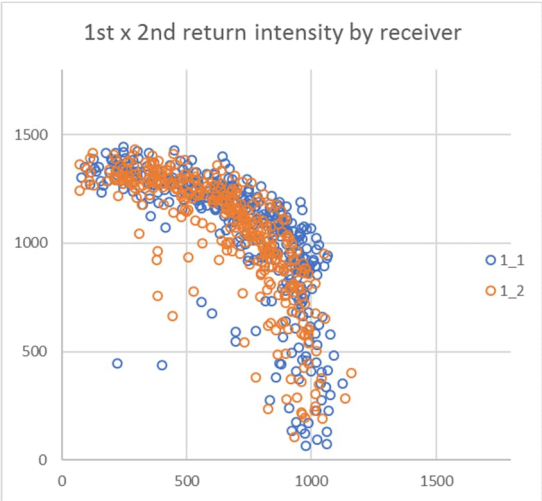
Very low values of 100-300 were observed for the instrument cottage roof at SMEAR, which normally has given rise to very few echoes owing to the absorbing paint.

$I_{grass} - I_{bitumen}$ => 1500-500 = 1000 is the gain between the two surfaces, which should be about 10 dB (3%->30% of relectance).

dB = Intensity/100 is a rough guess. If the minimal reflectance that triggers an echo is 0.01, then 1600 is 16dB stronger, 40 times more received power. The strongest intensity values were found in metal structures and wavy water.

Strong (Intensity>1800) echoes. The ditch has running water from a spring resulting in "corner reflections". Cars, roof, lake water and other metal structures constitute other strong reflectors.

As mentioned, it's not even known if intensity corresponds to peak amplitude or echo width/energy (integral).



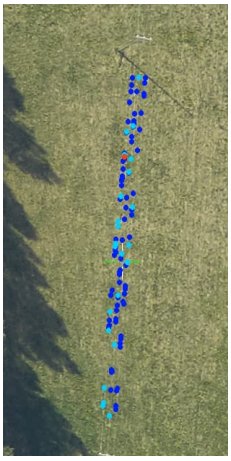
In a bog with sparse pine crowns, 3-6-m high, the joint distribution of (1st and 2nd) intensity data in 2-return pulses shows the logarithmic (dB) nature of the intensity data, and how receiver 1 intensity data are higher. Observations are given separately for scanners 1 and 2 in strip 1.

Assuming: intensity /100 = gain in dBs. Then, e.g. grass "corresponds to 15 dBs" and grass has a reflectance of 0.32, if the minimum (reference for received power Pin) in the data is 0.01. SMEAR-roof and branches gives as low intensity valuess as 50-100. So, the reflectances are 0.5 dB-1 dB above 0.01 reflectance, that is 0.0112...0.0126 in reflectance. The strongest values of intensity were above 2000 (100 power ratio if 2000=20dBs), so the reference cannot be 0.01 but lesser. The linearity of the sensor is unknown, so without field calibration, the interpretation of the intensity data remains speculative.

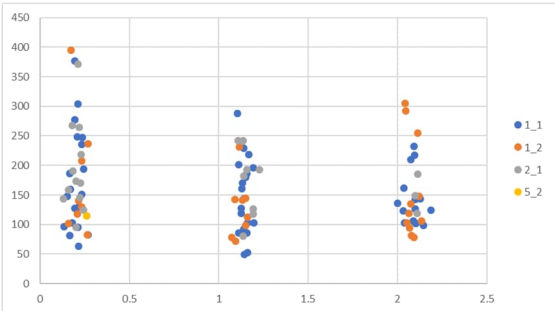
xyz-accuracy

The geometric accuracy has several aspects (and hierachic levels) to consider: A) Absolute accuracy in a coordinates system, B) between-strip errors (relative accuracy, strip matching, and C) between-scanner errors due to misalignment. Type C angular errors do not cause constant xyz shifts in the scene but can vary with scan zenith angle.

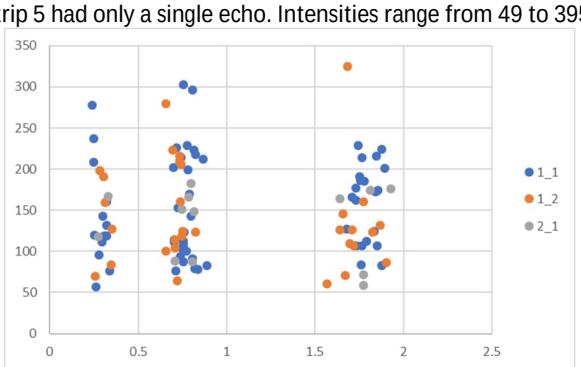
Linear targets were used to study Type B and C geometric accuracy. Type A accuracy was only indirectly assessed, since there are no accurate monuments in the scene, only features that can be measured using photogrammetric techniques (with limited accuracy). Large type A errors would show as discrepancies. Such errors were not observed. In all, no major errors of Type A, B or C were observed.



Powerline test site I with three parallel lines (90 cm separation) running S-N. Strip 1 (dark blue) produced most echoes (1190 m range), while Strip 2 (1264 m) fewer and strip 5 (perpendicular flight direction, 1285 m range, specular reflection?) produced only one echo in this segment that is 45 m long.

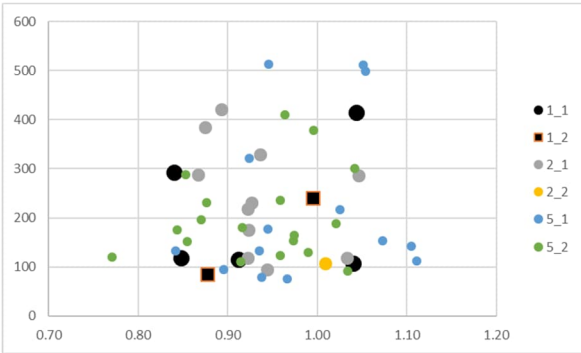


Powerline wires - squirrel's view. Strips 1, 2 and 5. No offsets between scanners or strips. Scanner 2 in strip 2 produced no echoes. Strip 5 had only a single echo. Intensities range from 49 to 395.

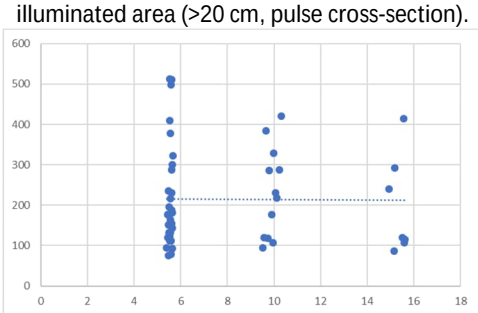


Powerline site II. Strips 1 and 2. No major offsets in the orthogonal direction (power lines parallalel to flying direction). Again, scanner 2 in strip 2 produced no echoes. Strip 5 did not cover this area.

SMEAR 380V cable: Strips 1, 2 and 5. Cable running towards SMEAR near the sawmill. Orientation of the cable is SW-NE.

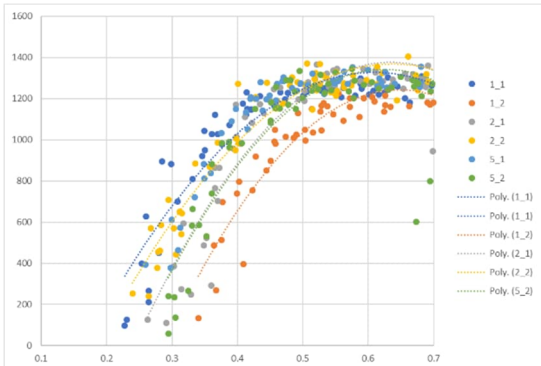


Overlapping strips 1, 2 and 5 produced echoes showing little (< 10 cm) systematic between-scanner offsets. X-axis shows distance from a parallel virtual cable, shifted by about 1 m. The cable "becomes 30 cm thick" owing to xyz inacccuracy and the size of the illuminated area (>20 cm, pulse cross-section).



Intensity and scan angle in the cable: Fewer echoes were observed the higher the scan angle is. (specular reflections, or just systematics in the point sampling as strip 5 with most echoes was flown in parallel direction).

Sawmill-roof site: Roof edge provides a perpendicular linear test feature for the cable.



Distance of echoes from a parallel line to the roof edges (at a distance of about 50 cm) x intensity shows that the between-scanner (type C) offsets are < 15 cm, while type B offsets are < 30 cm.

3.7.17 2020 Discrete-return Riegl Q1560, 1.15 km

'Repeated campaign' (2018) with minor changes due to sensor development. Purpose - to document the harvesting activities in winter 2019/20 by pairing these data with the 2018 campaign. The same flight paths were strived for as well any sensor settings. Again, make note that the 1560i sensor comprises too laser scanners, scanner #1 and #2.

As with 2018, data (LAS 1.2 files) were delivered four times by Terratec. First delivery had pulses filtered differently (allowed scan angle) from the 2018 acquisition. 2nd delivery fixed that problem, but the intensity data in these files are corrected for the range. Third delivery has the intensity data amplitude based in dBs as in 2018. The fourth delivery is in LAS1.4, because there were upto 10 echoes per pulse and LAS1.2 supports max. 7 pulses (return number and number of returns occupy three bits, 0-7). LAS 1.4 files gave no warnings with Lastools software. Aerial RGB photography in cloud-free conditions was carried out this time as well.

Date: June 3, 2020

Time: 05:43-05:57 GMT (5 strips)

Photography at the site

See photos in Korpela_fenologia2020.zip (by Pekka Kaitaniemi)

Splitting into per-hectare bin (kuvamitt) files

All this (except for discussion about LAS 1.4 format) is irrelevant to users of LAS-files. This tiling into 1 hecrate files was carried out only to turn the data readable with KUVAMITT-program. The format is explained in the documentation of the 2018 data.

In total, there are 5 LAS-files, one per strip. Since the files are large, they were first split by time into "LAS-files" (#.bin) smaller than 2GB (signed long integers in Visual Basic). The echoes in the bin-files were sorted by time and rearranged into per-hectare (kkj2) binary files, in which the LiDAR position is estimated from the 1Hz trajectory data. Importantly, all echoes belonging to a pulse are in sequental order in these per hectare binary files. However, the order in any 8-10-echo pulses cannot be trusted for the last echoes (8th, 9th, 10th), which are rare but exist. Why? LAS 1.2 files support 7 echoes per pulse and the echo order wasn't always correct despite attempts to sort by Z-coordinate. When using the bin-data or LAS 1.2 , this should be considered. Delivered LAS 1.4 files won't have this issue (recommended to be used).

Intensity data

The intensity data in the LAS-files were scaled 0-65000 (unsigned short) in deliveries #1 and #2, with range correction applied to the intensity values. Delivery #3 had the intensities in dB-scale, unccorrected amplitude-based and in LAS 1.2 format as requested - matching the format of the 2018 data. LAS 1.4 files should have the same content but are not verified (Oct 5, 2020). The two scanners inside 1560 called for Q/C for possible discrepancies. It was found that in hard surfaces, scanner #1 shows higher intensity values (in dB scale).

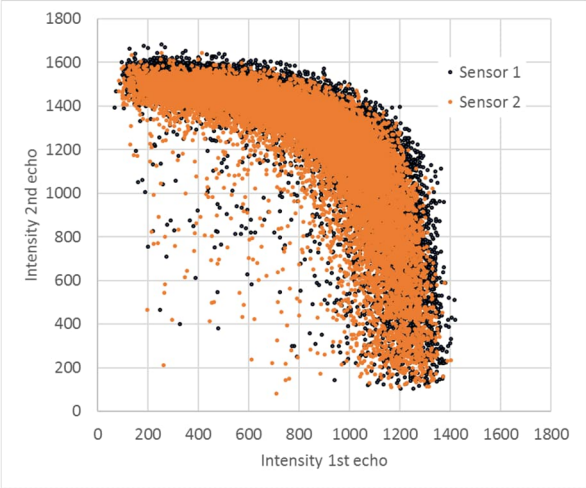


Fig. 119. Intensity of 2-return pulses in a pine bog. 1st return is from pine crows and the second from the bog surface. Pehkusuo, near Hyytiälä. Logarithmic nature of the intensity data shows clearly as does the difference between scanners 1 and 2. Sensor #1 giving rise to "stronger" echoes.

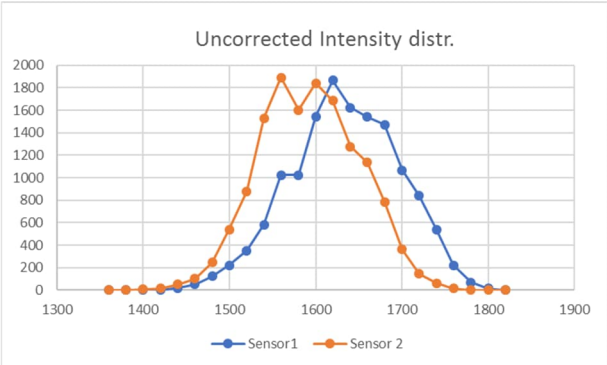


Fig. 120. Intensity histograms, Grass. N=14200. Scanner 1 shows higher values. Histograms combine observations from three overlapping strips.

Asphalt & dark bitumen echoes sampled for tests.

Assuming that the data really are in dB-scale, we could estimate the "voltage" that is in linear relationship with power entering the sensor's aperture, and then check if radar equation explains spherical losses due to varying range. There however is not enough range variation and repeated observations of suitable surfaces to do this.

Something was attempted, however. The CV of raw intensities (dB) in asphalt were 4.4% without range correction or correction for slant angle. The power term that miniimized the CV was 1, suggesting that the data are range corrected, if the linearity condition (dB-to-Power intensity data are ratio scale observation of received power) is met. In bitumen, CV was 12.5%. In dark bitumen, the power term that minimized CV was 5, suggesting that the linearity condition is not met. However, the estimation of the power term is highly ill-posed

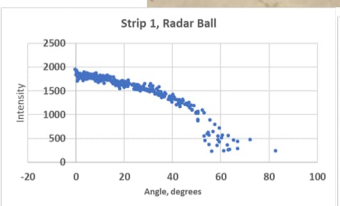
when range variation is lacking. It is highly unlikely that linearization with the simple equation is possible, so the corrected intensity values should not be treated as ratio-scale data as was the notion with 2018 data.

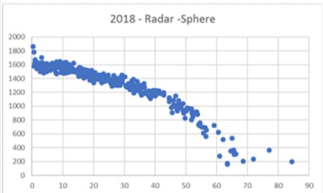
Table 13. Examples of targets of varying reflectance. Range is given in meters, I# refers to average of raw-dB-scaled-intensity in overlapping strips 1, 2 and 5. Dark bitumen has an intensity of about 600, while grass shows intensities above 1600.

Target	range1	range2	range5	I1	I2	I5
Bitumen1	1178	1238	1181	908	755	889
Bitumen2	1191	-	1217	625	-	589
Asphalt	1189	1277	1198	1322	1241	1292
Gravel	1189	1285	1194	1255	1182	1238
Fine Sand	1192	1305	1200	1477	1375	1448
Grass	1192	1299	1212	1669	1578	1637
Trees						
Sib. fir	1167	1277	1174	1120	1207	1090
Maple	1178	1285	1188	1260	1165	1213
N. spruce	1161	1233	1163	1020	1032	998
Pine, old	1161	1236	1165	1075	1072	1014
Other						
Power cable	1204	1178	1171	241	308	326
Wire	1186	1256	1276	246	234	213

The darkest bitumen has perhaps a reflectance of 2-3%, while that of grass is 50%. Lowest average intensity values were recorded for 20kV powerline wires, ca. 240. Lowest single intensity value was 90 in the power line wire. Range variation clearly explains the variation of average intensity in hard surfaces.

Now, if we assume that 1600 = 16 dB, then bitumen is 6dB, which is 10 dB less and that corresponds to a 10-fold difference. It does not explain the anticipated 12-13 dB difference in reflectance between bitumen and grass. Fine sand could have reflectance of about 20%, and it is down about 230 units, i.e. 2.3 dB, which is less than the expected ca. 3 dB. Maple and Siberian fir show the highest intensity values as expected. Next, the weather radar's sphere was used as a test target.



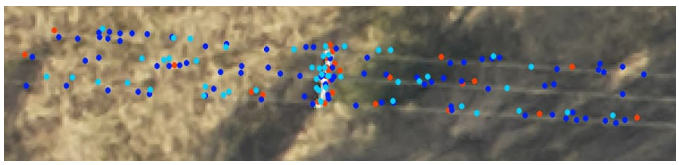


If the radar dome (sphere) has a radius of 2.7 m, the indidence angle could be computed for each pulse in strip 1, which has low scan zenith angle (< 1 degr) in both 2018 and 2020 data. At 45 degrees (surface normal off vertical), the (logarithmic) intensity falls from 1800 to 1200 in the 2020 data (6dB). The cosine is 0.7 at that angle, so the surface has high specular reflectance as 6dB implies that the intensity should reduce by a factor of 0.25. In all, we note that (nominal) intensity values are higher in the 2020 data compared to 2018.

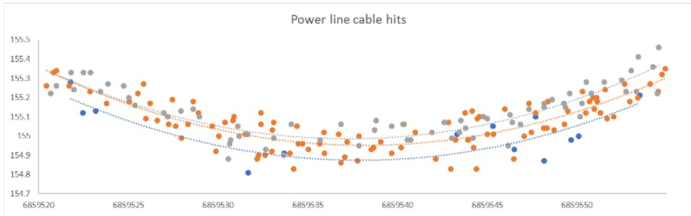
XYZ-accuracy analyses

The geometric accuracy has several aspects to consider: A) Absolute accuracy in a coordinates systenm, B) between-strip errors (relative accuracy, strip matching, and C) between-scanner errors due to misalignment.

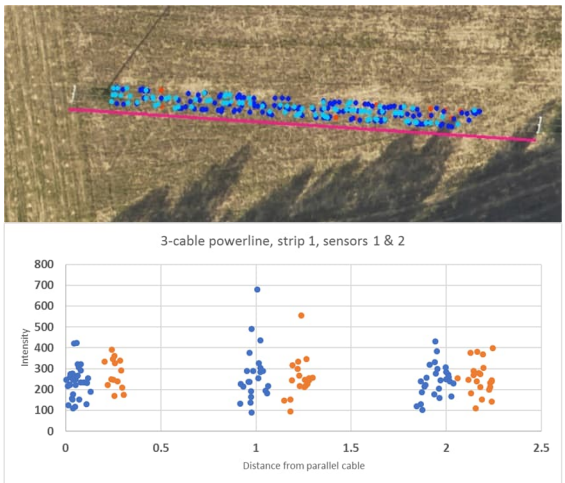
Linear targets were used to study type B and C geometric inaccuracy. Type A accuracy was only indirectly assessed, since there are no accurate 3D monuments in the scene, only features that can be measured using photogrammetric techniques. Large type A errors would show as discrepancies. Type C errors were observed and the vendor was asked to re-compute strip matching by correcting also the between-scannner misalignments (which they admitted not having done for this sensor unit, Nov 18, 2020).



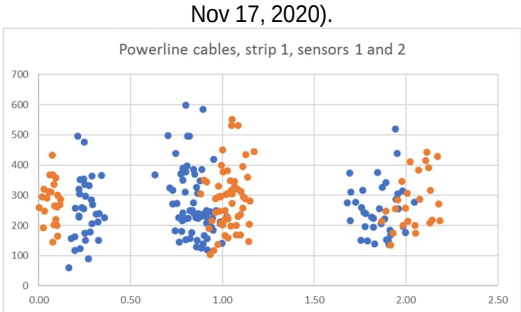
Power line wires (cables) .95 m apart. Color by strip (1, 2 and 5).



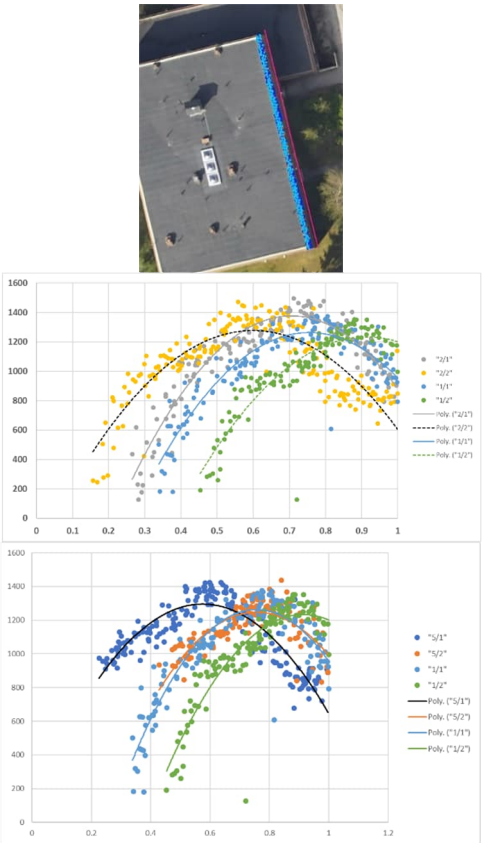
Sag in powerline cable, by strips. Noise (in Z, elevation) constitutes about 10 cm in these wire objects.



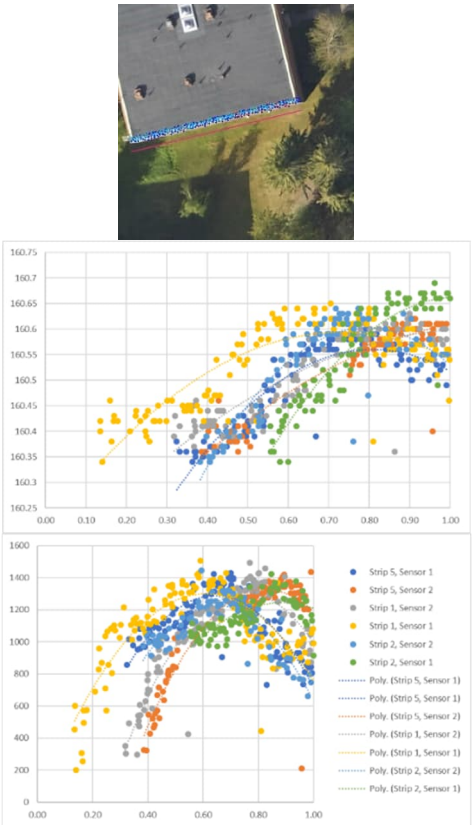
This powerline is aligned with the flying direction. Mismatch between scanners 1 and 2 within a single strip (#1) is ca. 20 cm. Correction for mismatch between sensors was not a part of the strip adjustment in deliveries 1-4. (information received from Terratec Nov 17, 2020).



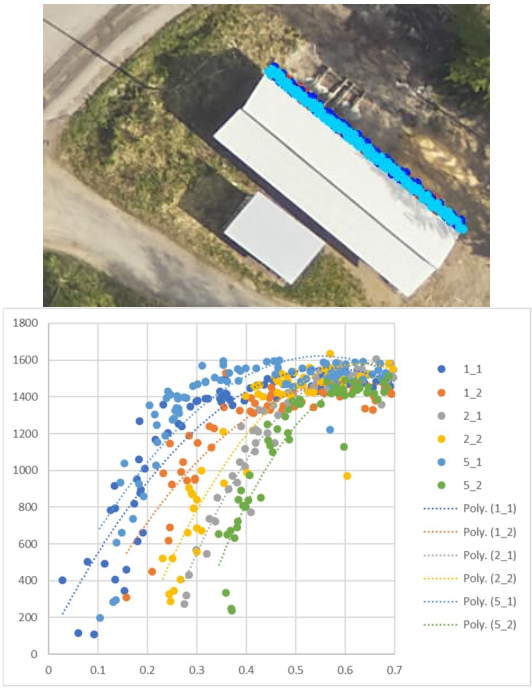
The offset between scanners is slightly lesser in cables running in the perpendicular direction to flight line. X-axis has distance, and blue dots on the left are "mirrored to the right".



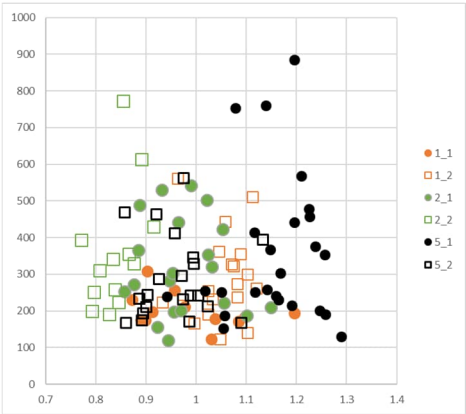
Analysis of XY-offsets using a sharp building edge aligned perpendicular to flight line direction. 3D line is set some 50 cm from the building running parallel with the "building's outer edge". Line-point distance is computed for each echo and points closer than 1 m /at the same elevation are outputted. X-axis has the distance (m) and y-axis show the intensity. Strips 1 and 2, sensors 1 and 2 separately. Offsets (Pitch angle) between scanners are 10 cm, between strips 30 cm.



The offsets in the perpendicular direction (building edge aligned with flying direction) are within 30 cm.



Sawmill's roof edge: Strip 5 - scanners 1 and 2 show large 25-30 cm offset in the SE-NE orientated roof edge, that runs perpendicular to that strip. Strip 5 shows lesser between-scanner offset.



Power cable: Again, in the perpendicular direction, strip 5 shows larger offset between scanners 1 and 2, about 25 cm.

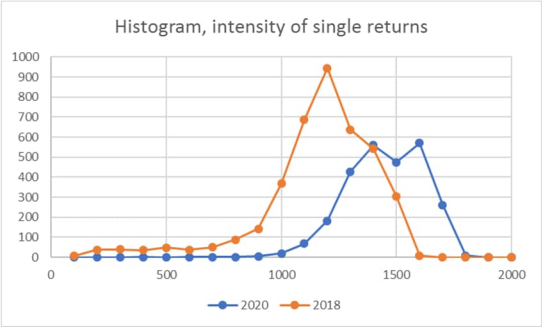
Comparison of the 2018 and 2020 data sets

This Section highlights the similarities and differences between the two acquisitoins and was done in November 2020.

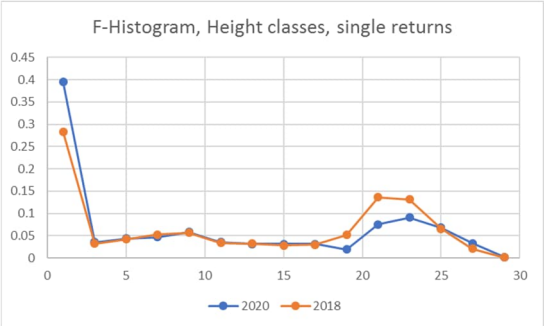
Test site 1, Ala-Hyytiälä old-growth forest. Circle with a radius of 10 m, 314 m2, all echoes analyzed

Data set 2020 has more echoes per pulse transmitted. There are more later echoes, 2nd, 3rd etc., while 2018 data has a maximum of 5 echoes per pulse. It is rather clear that the functioning of the receivers differs somewhat between 2018 and 2020 - in forest canopies (soft targets).

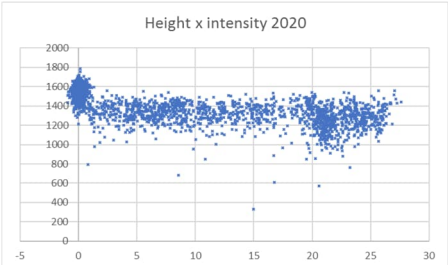
Nreturns	1st	2nd	3rd	4th	5th	6th	7	8	9
2020	13032	10448	6702	3137	1054	217	30	3	0
2018	12953	8976	4160	1197	74	0	0	0	0

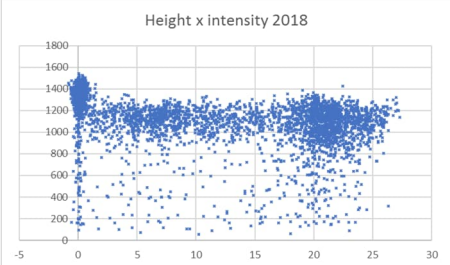


As a result (or because of it) - data set 2018 has more single-echo pulses, with a tail of cases with low intensity values, unexpected. This needs to be accounted for and it may be advisable to exclude those with intensity below a threshold (from the set of single returns).



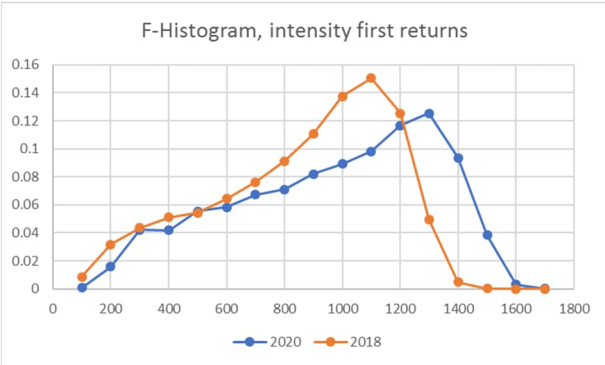
Fewer (%) single returns reached the forest floor in 2018 and more were observed in the upper canopy. X-axis shows height above ground in 2-m classes.





Single-return data intensity as a function of height above ground: The low intensities of single returns in 2018 spread across the whole height range. Unexpected, because single returns are by default strong reflections.

The mean intensities are 1145 (scanner 1) and 1085 (scanner 2) in the 2018 data and 1423 and 1377 in the 2020 data. Differences are not due to systematic differences in range or scan zenith angle. In the 2018 data, both scanners 1 and 2 share the phenomenon: "single returns include weak intensities". So, a malfunctioning of the other scanner does not explain why there are these (unexpected) weak single echoes in 2018 data. In analysing single-return data, this major difference needs to be accounted for. It may be advisable to filter out weak single returns (in 2018 data, intensity below 700) and (re-class) consider them as multi-return pulse echoes (first-of-many, intermediate or last-of-many).



In all first (single or first-of-many) return (canopy and ground) data, 2020 and 2018 data differ in intensity.

First-return intensities, h > 2 m. Average in by scanners #1 and #2

Year	#1	#2
2020	769	752
2018	691	660

First-return intensities, h < 2 m. Average in by scanners

Year	#1	#2
2020	1449	1431
2018	1241	1215

The difference of average intensity between 2018 and 2020 shows in the first-return data. Scanners 1 and 2 do not differ greatly, but scanner #1 shows somewhat higher intensity values in both 2018 and 2020.

In all echo types we note a difference in the range of intensities (min-max) canopy/ground data:

Intensities range 29-1541 in 2018
Intensities range 59-1786 in 2020

Test 2: Special hard and linear targets

Average intensity by year and scanner:

	20_1	20_2	18_1	18_2
Asphalt	1325	1288	1097	1044
Bitumen, dark	625	583	592	548
Bitumen, light	905	865	771	715
Grass	1670	1626	1477	1465
Fine sand	1452	1418	1230	1212
Gravel	1248	1211	1067	1008
Grass-moss	1581	1537	1445	1425
Wire 20 kV	234	240	154	138
Cable, 380 V	330	312	251	198
Roof, Institute	1129	1089	943	878

Grass produced the highest average intensity values in both datasets and both scanners. The abosulte difference (logarithmic!) between scanners is about 35 to 40 units in 2020 and 20 to 70 in 2018 data. In linear targets (wie, cable)that produced weak echoes, there were less observations and the results are less accurate.

Relative to Asphalt and Scanner 1:

Target	20_1	20_2	18_1	18_2
Asphalt	1.00	0.97	1.00	0.95
Bitumen	0.47	0.44	0.54	0.50
Bitumen	0.68	0.65	0.70	0.65
Grass	1.26	1.23	1.35	1.34
Fine sand	1.10	1.07	1.12	1.10
Gravel	0.94	0.91	0.97	0.92
Grass-moss	1.19	1.16	1.32	1.30
Wire	0.18	0.18	0.14	0.13
Cable	0.25	0.24	0.23	0.18
Roof	0.85	0.82	0.86	0.80
Spruce	0.80	0.78	0.85	0.82
Pine	0.74	0.72	0.81	0.77
Birch	0.76	0.75	0.80	0.75

The average intensity values relative to (normalized by) Asphalt and Scanner 1 show that dataset 2018 has a wider range, 0.13-1.35, while that of LiDAR 2020 is 0.18-1.23. Target grass-moss is likely unstable (2018-2020).

Scanner #2 is 0.02-0.04 units "weaker" than Scanner #1 in 2020 data, except for dark dargets (wire, cable). Scanner #2 is "weaker" in the 2018 sensor, about 0.04-0.05 units. Bright grass does not show any difference.

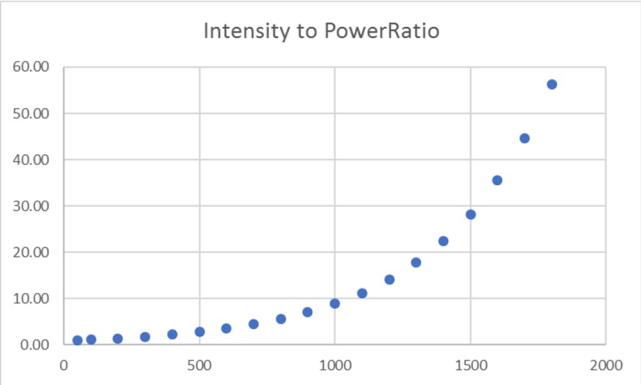
=> Logarithmic scale applies to both sensors, 2018 and 2020.
=> Scanner #2 shows lower intensity values
=> Sensor 2018 shows "wider intensity dynamics", nominal at least.

In trees, the relative differences do not hold for birch, which may be due to the early season and phenological diffrences between 2018 and 2020.

Target	20_1	20_2	18_1	18_2
Asphalt	1.00	0.97	0.83	0.79
Bitumen	1.00	0.93	0.95	0.88
Bitumen	1.00	0.96	0.85	0.79
Grass	1.00	0.97	0.88	0.88
Fine sand	1.00	0.98	0.85	0.83
Gravel	1.00	0.97	0.85	0.81
Grass-moss	1.00	0.97	0.91	0.90
Wire	1.00	1.03	0.66	0.59
Cable	1.00	0.95	0.76	0.60
Roof Inst	1.00	0.96	0.84	0.78
Spruce	1.00	0.98	0.88	0.84
Pine	1.00	0.97	0.90	0.85
Birch	1.00	0.98	0.86	0.81

When normalizing with target intensities by dataset 2020 - Scanner 1, the relative differences w.r.t. scanner 1 in 2018 are not constant (e.g. 0.85) across the range of targets. "Dark wire" is down to 66%, cable 76% and brighter targets show relative differences of 83% to 95%. Grass is at 90%. If intensity corresponds to peak amplitude or echo energy, remains unknown. Trees (soft targets) show 86-90% relative difference, while hard targets: fine sand, roof and gravel are at 85%.

On logarithmic nature of intensity data

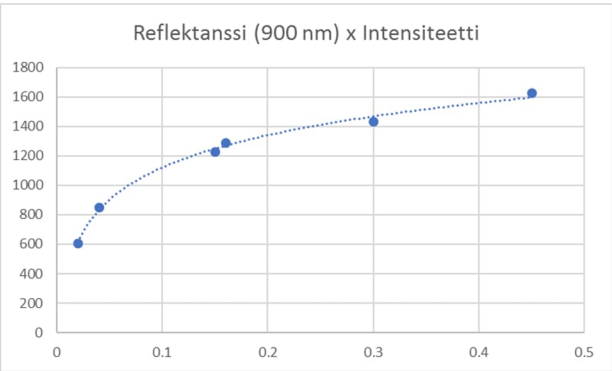


If the interpretation is that intensity is in dBs, and that represents power ratio (P_{out}/P_{in}), we can assume for example that intensity of 50 corresponds to the minimal recorded signal. Then, intensity of 1800 means 18 dBs above it. Power ratio of 56.

Now, the range of intensity values were

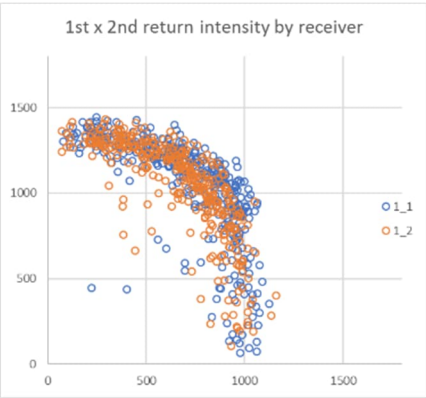
29-1541 in 2018 data
59-1786 in 2020 data

If these are interpreted as 0.3-15.4 dB and 0.6-17.8 dB, it would simply mean that the dynamic range in the 2018 data was larger. That, however, is unlikely and it is a matter of scaling and behaviours of two different instruments and four (2+2) different coarsely calibrated scanners.

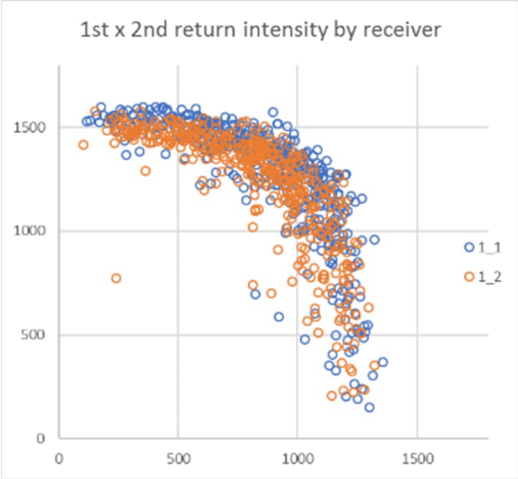


Some targets (bitumen, asphalt, fine sand, grass, gravel) in Hyytiälä were measured for nadir reflectance in 2008-2010. The change of reflectance per unit intensity (steepness of the curve) is the lowest when intensity is below 1000.

Test site 3: barren pine bog (Pehkusuo), 2-echo pulses

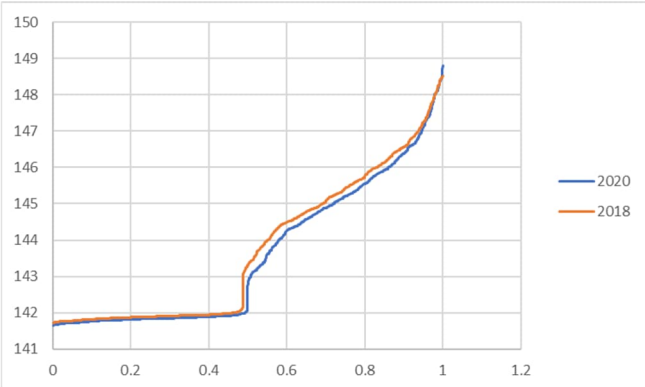


2018



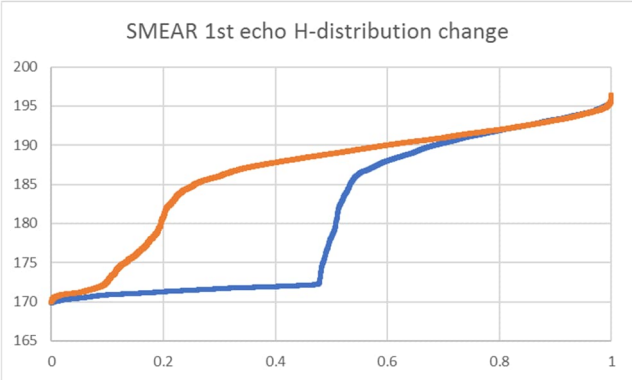
2020

Intensity of 1st (canopy) and 2nd return (ground) in barren pine-bog.



Height (z, elevation) distribution of points in 2-echo pulses in the pine bog. The shift is probably due to water level in the bog, or systematic ranging differences in the datasets. Height growth of the 3-6-m high trees is minimal, 2-5 cm/a.

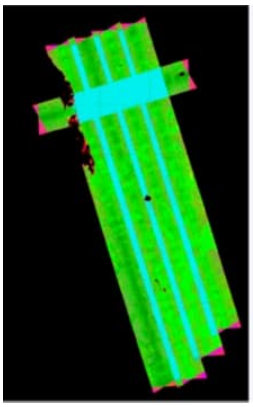
SMEAR-pine forest



At SMEAR, the thin-from-below logging and clearing of the understory shows in the height distributions. In 2018 10% of pulses found canopy gaps and produced a first only only at the ground, while it was nearly 50% in 2020.

3.7.18 2023 Discrete-return Riegl Q1560, 1.2 km

There is a separate 24-page document *Hyytiälä aerial photographs and LiDAR 2023.docx* that reports in more detail the campaign and compared it with the 2018 and 2020 "twins".

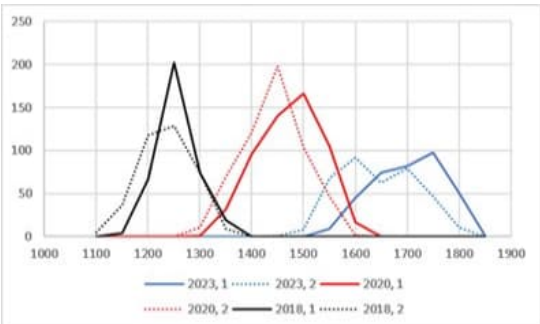


This campaign repeats those of 2018 and 2020 using the same five flight lines and sensor settings. Aerial images were captured during the acquisition.

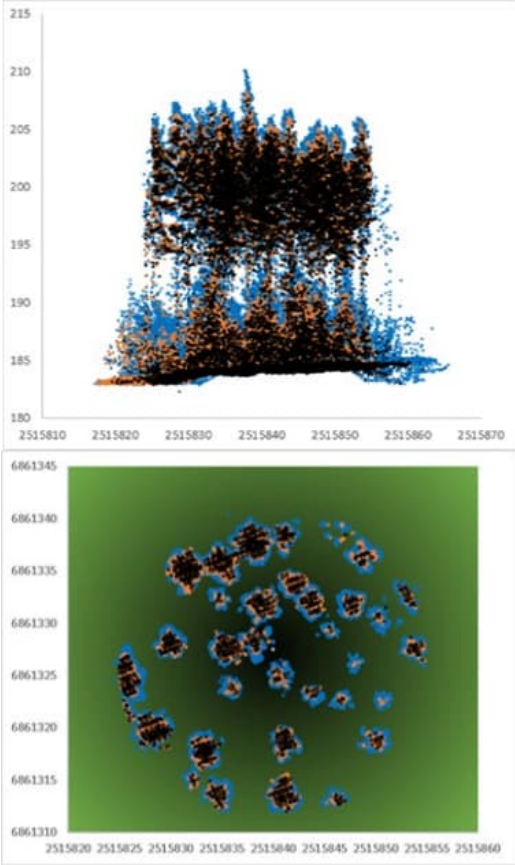
Date	August 18, 2023
Time, GMT	06:28-06:45
Project code	41847 (Terratec, now Field)
Flying	1310-1365 m AGL, 75 m/s
Scan angle	+/- 30 (28)
Sensor	Riegl 1560
Data	LAS 1.4 Point type 6
Coord. Syst	ETRS-TM35FIN + ellipsoidal heights
PRF	1MHz + 1 MHz (two scanners)

Data was processed by first sorting the LAS-files according to GPStime, echo number (1-11) and scanner number (1-2). This data was read echo by echo and trajectory file was analysed for the position of the sensor at the time of pulse transmission. This way all echoes belonging to the pulse were merged into pulse-records that also had the position of the sensor. There pulse data were converted to KKJ2/N60 geometry and stored in per hectare binary files (as is customary). The same binary format was used as was in 2018 and 2020.

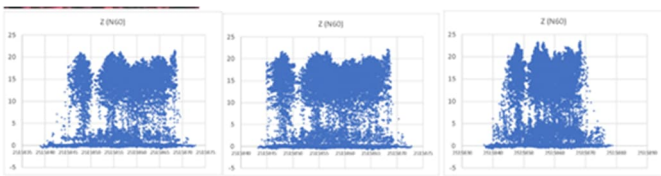
The geometry matched with reference targets at an accuracy of approximately 20 cm or better. Small offsets (+/- 8 cm) in elevation were observed between 2018, 2020 and 2023. Radiometry was evaluated in hard surfaces and canopies. The intensity data of the targets does not match (and is on logarithmic dB-scale), so intensity calibration is needed if they are used for change detection.



Intensity distributions in fine sand (Hyytiälä volleyball field). Scanners 1 and 2 are shown separately for each year, 2018, 2020, 2023.



Comparison of 2018, 2020 and 2023 in pine plot P1. The growth of trees is clearly visible in the side view and vertical slice atop the canopy.

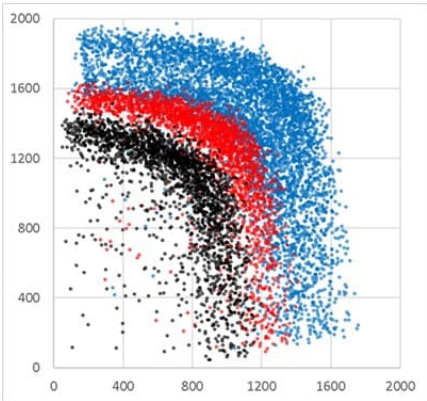


	Echoes	Pulses with N echoes	
1	17517	7483	42.72
2	10034	6221	35.51
3	3813	3101	17.70
4	712	694	3.96
5	18	17	0.10
6	1	1	0.01
7	0	0	0.00
8	0	0	0.00
Total		17517	

	Echoes	Pulses with N echoes	
1	17836	5861	32.86
2	11975	5580	31.29
3	6395	4350	24.39
4	2045	1700	9.53
5	345	307	1.72
6	38	32	0.18
7	6	5	0.03
8	1	1	0.01
Total		17836	

	Echoes	Pulses with N echoes	
1	18061	4730	26.19
2	13331	5142	28.47
3	8189	4643	25.71
4	3546	2525	13.98
5	1021	807	4.47
6	214	183	1.01
7	31	28	0.16
8	3	3	0.02
Total		18061	

In 2018 the scanners produced less echoes per pulse compared to 2020 and 2023.



Intensity data of two-echo pulses on a barren pine bog (Pehkusuo). X-axis has the 1st echo and y-axis shows the 2nd echo. Black = 2018, red = 2020, Blue = 2023. Scanners 1 and 2 blend.

4 Terrestrial images

Photogrammetric experiments. Camera EO and IO parameters were solved which enabled accurate orientation of the images. These are documented in more detail in the following sub-sections.

Other than photogrammetric images. The images do not have orientation information. These images include e.g., images taken during field and LiDAR campaigns, and are listed at the end of this section.

4.1 Lapinkangas forest floor 2007

A block of overlapping, oblique, down-looking, JPEG images (N=1053) of the bottom flora in a 30 x 32 m plot in Lapinkangas was acquired in August 2007. Data were used in (Korpela 2008) and reindeer lichens were then mapped from the images. A consumer-grade camera was used, and calibrated later.

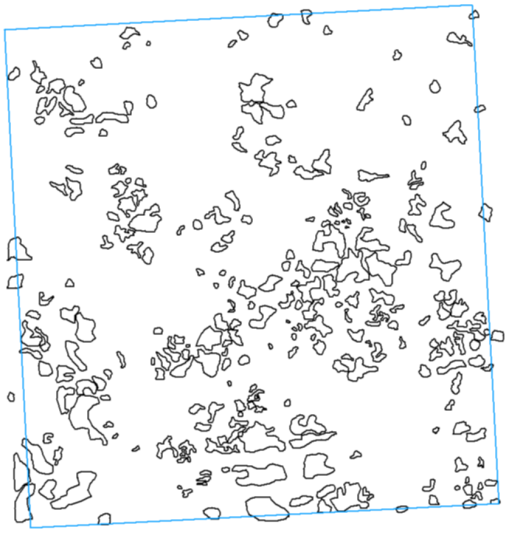


Fig. 121. The lichen patch map of the plot.

Camera	Canon Powershot G6
Focal length	7 mm (calibrated for this, shortest)

There were 27 lines (E–W oriented), with a 1.2-m spacing. Each line had 39 images with 0.8-m spacing. The camera-operator had a 1.55-m-high monopod and the camera was tilted down and pointing south when the photography was done.

Fig. 122. Line 1, image 2. Oblique view from a height of 1.5 m AGL. GCP #36 is seen. The xyz-coordinates were measured to the center point at the top.

Powershot G6 was calibrated using an indoor 3D test field (HUT) to solve the parameters: camera constant, c_{min}, principal point location (x_p, y_p), radial and tangential lens distortion (k_i, t_i), as well as the affinity and shearing (a, b) of the 3072×2304-pixel CCD. The parameters were solved in a bundle block adjustment of 21 convergent images with 1436 carefully measured image points of known XYZ. The pixel size was assumed to be 2.3 microns.

Table 14. Results of the calibration block adjustment for the camera parameters.

Parameter	Value	Standard error
x_p	1536.5	0.22
y_p	1151.7	0.26
c_{min}	7.35 mm	0.014 mm
k_1	–1.9399E-08	4.35E-10
k_2	1.1005E-15	2.88E-16
k_3	3.2917E-22	5.74E-23
t_1	2.4040E-07	1.57E-08
t_2	–4.8441E-07	2.03E-08
a	4.0370E-04	8.61E-05
b	3.1696E-04	1.17E-04
σ_0	0.53 pixels	df = 2672

2.1.2 Image observations. A common practice is to extend the collinearity equation with various parameters to acquire a model, which more accurately corresponds the imaging conditions (Brown (1976), Ebner (1976), Kilpelä (1981), Jacobsen (1982), Fraser (1997), Cramer *et al.* (2002), Jacobsen (2003)). Mathematical parameters used in this study were the well-known Ebner's parameters (Ebner 1976). The physical deformation model applied in this investigation was the following:

$$\Delta x = dx_0 - \frac{x}{c}dc + x(k_1 r^2 + k_2 r^4 + k_3 r^6) + p_1(r^2 + 2x^2) + 2p_2 xy + B_1 x + B_2 y \quad (1)$$

$$\Delta y = dy_0 - \frac{y}{c}dc + y(k_1 r^2 + k_2 r^4 + k_3 r^6) + 2p_1 xy + p_2(r^2 + 2y^2) \quad (2)$$

where $r^2 = x^2 + y^2$, k1, k2 and k3 model radial distortions, p1 and p2 model tangential distortions and B1 and B2 model affinity and shearing.

****

Conversion to camera model of iWitness

See iWitnes_solution_to_2007_calibration.xlsx

The iWitness equations are (Maple format)
fx:=-x*(k1*r^3+k2*r^5+k3*r^7)/r-p1*(r^2+2*x^2)-2*p2*x*y;
fy:=-y*(k1*r^3+k2*r^5+k3*r^7)/r-p2*(r^2+2*y^2)-2*p1*x*y;

, where
x = ($x_{measured}$ – xp)
y = ($y_{measured}$ – yp)
r^2 = x^2 + y^2
dr = k1*r^3+k2*r^5+k3*r7

Jan 2013: OLS estimation of k1, k2, k3, p1, and p2 by constraining B1, B2, xp and yp to zero.

The 2 x 5 differential quotients (5 parameters with respect to x and y) were computed, all units set to mm, corrections by the Ebner model (See above 2.1.2 from Honkavaara 2004) were the independent variables and the five parameters in iWitness model were solved using OLS estimation.

The 2007 calibration corresponds to :

k1	3.4530E-03
k2	-6.1517E-05
k3	-7.0916E-07
p1	-8.9787E-05
p2	1.9454E-04

Further, set c to 7.35 mm, pixel size to 2.3 um, B1 and B2 to zero, xp to zero and yp to zero.

Fig. 123. The same 2007 GCP seen in a 2007 image (top), and in a 2012 image. Immobility?

- Data for 1053 HDR-files were established in the KKJ-2/N60 system. Hdr_teko_LK.csv
- The JPEGs are ~5 Mbytes each (Fig. 122)
- 54 horizontal 'side views' covering the plot along y-axis, imaged towards the x-axis, 2 x 27, from each end of the horizontal image lines (Fig. 124).
- Espa image observations (row, col) for triangulation
- Triangulation files (observations, results)

Fig. 124. A 'side-view', one of 54, from the SW corner towards east. GCPs are seen, and it is possible to orientate the images, if needed.

* Distance – azimuth measurements of trees for positioning of the plot. These were from the four corners of the plot

In 2007 triangulation was carried out, using 36 GCPs. (wooden sticks). GCPs.xls, LK1.job.

The plot corners

See Plot_location.xls
The total station was set up at the SE corner, and aligned with the Y-axis of the plot. Corners were positioned using the total station, to the exact local positions of (0,0), (0,32), (30, 32), and (30,0).

From each corner point, trees with X and Y estimated in aerial images were observed for azimuth and distance. Locally, in a polar coordinate system:

x_local_i = distance * cos(azimuth+cv)
y_local_i = distance * cos(azimuth+cv)

where cv is the systematic deviation (compass variation) between the magnetic north and the north given by the compass (Bussoli, 0.5 degree nominal accuracy). Distance was corrected for the stem diameter. cv is an unknown. Index i is 1, 2, 3 or 4, for each corner.

Now, since the corners had exact local coordinates, it was possible to establish equations for mapping the local coordinates to global XY coordinates.

(From Korpela, 2008):

"The corner poles of the 960-m^2 plot and 36 control points inside the plot were positioned using a total station with a relative accuracy better than 1 cm. The LiDAR data and images were oriented in the national KKJ Gauss-Krüger map projection with elevations in the N60 system of orthometric heights (Z). The 3D plot coordinate system was tied to this object coordinate system, using trees as XY control points (Korpela et al., 2007). The interpoint distances (d) and azimuths (φ) were measured to nearby tree stems in each plot corner with a laser distance meter and a precision compass. The XYZ treetop positions were measured from a set of 6 aerial images. A total of 46 trees (i) were used as control points in a least-square adjustment of coordinates (Eq. 1) to solve the unknowns in Table 2. In the adjustment, the 4 corner poles ($Xc_{cp(j)}, Y_{cp(j)}$) formed a 30-m×32-m rectangle rotated about the plot origin.

$$\begin{cases} X_i = X_0 + \cos(\alpha)\cdot X_{cp(j)} - \sin(\alpha)\cdot Y_{cp(j)} + d_{ij}\cdot\cos(\varphi_{ij} + cv) + \varepsilon \\ Y_i = Y_0 + \sin(\alpha)\cdot X_{cp(j)} + \cos(\alpha)\cdot Y_{cp(j)} + d_{ij}\cdot\sin(\varphi_{ij} + cv) + \varepsilon \end{cases}$$

Orientation of the field plot:

Parameter	Value	Standard error
X_0, plot origin	2516587.218 m	0.068 m
Y_0, plot origin	6856270.139 m	0.065 m
α, rotation	3.01°	0.14°
cv, compass variation	8.15°	0.32°

The coordinates of all four corners:

X_local	Y_local	X	Y
0	0	2516587.22	6856270.14
0	32	2516585.54	6856302.10
30	32	2516615.50	6856303.67
30	0	2516617.18	6856271.71

The absolute position is accurate to 5-10 cm. See Section (Lapinkangas forest floor 2012).

Notes on the image orientation files

lines.obs has the col,row values in ascii (ESPA software), left-handed

ima_obs_UnCalib.txt observations computed from ESPA obs, right handed, half-pixel shift.

```
a = 427991
b = 1
c = 1536
d = 1
e = 427991
f = 1152
nrow = 2304
Loop
 colval = colval + 0.5
 rowval = (nrow - 1) - (rowval + 0.5)
 xp = (-e*c+e*x+f*b-y*b)/(a*e-b*d)
 yp = -(a*f-a*y-c*d+x*d)/(a*e-b*d)
End
```

ima_obs_calibFraser.txt Contains the metric image coordinates corrected for lens errors.

uk1053_5_Fraser_5_81.txt Solution vector (all unknowns with solutions) Final RMS of image residuals 5.81 um

Gnd_obs.txt has the GCP and tie point initial approx.

cam_obs_sol.txt has the initial apprx. for EO.

task.txt shows the number of images, XYZ GCPs, Z GCPs, tie points and image observations.

Note that f was set at 0.0073486 m in the final version, and pixel size is 2.3365E-06 m = (1/427991). These values are also used in Hdr_teko_LK.csv.

The plot elevation

The total station was 1.61 m above the ground, which is z == 0 in the local coordinate system.

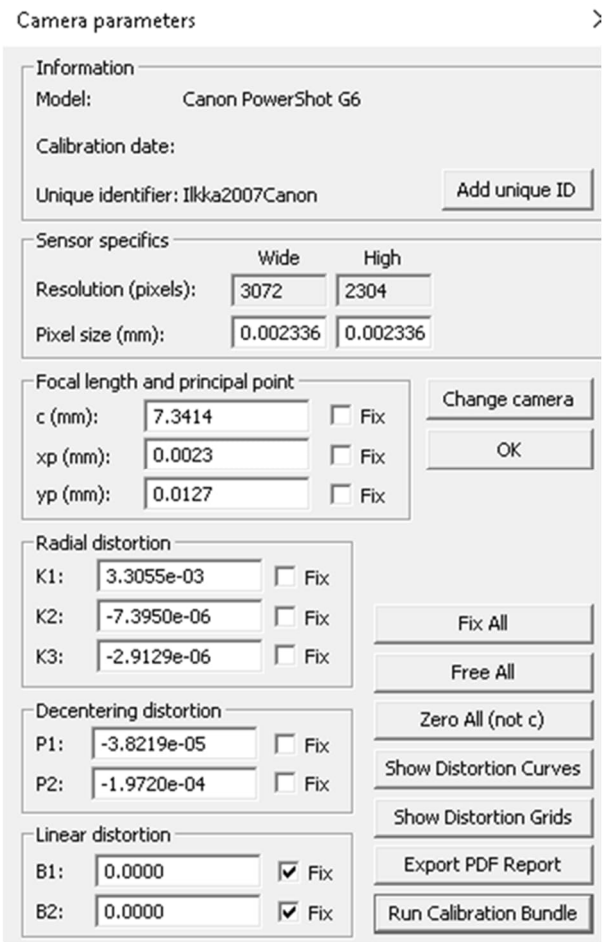
In 2007, the N60 elevation for the origin (P0) was set to 140.62 m in the triangulation. It was taken from leveling.

The elevation remains an issue because there was no permanent Z-monument between 2007-2012, or, more precisely, the elevation of P0 has not been measured in 2007, as it was in 2012.

=> Some Z constraints between conjugate points 2007-2012 may help here, but most likely there'll be a mismatch of 2-3 cm in Z too.

Calibration in Dec 2023

Using IWitness, the following parameter values were obtained



The values match reasonably well with those that were mathematically computed from the 2013 Ebner's model:

0.003453007	k1	3.4530E-03
-6.1517E-05	k2	-6.1517E-05
-7.09161E-07	k3	-7.0916E-07
-8.97873E-05	p1	-8.9787E-05
0.000194544	p2	1.9454E-04

Lens errors were removed using the new estimates in Dec 2023.

Filenames are 01_01_undistorted_bilinear.raw. The whole image set of 1053 images in raw format is 27.6 GB. Note! Image 23_20 is missing and replaced by a copy of image 23_19. It was searched in old CDs/DVDs without luck. Original JPEG-file is corrupted at 1 kB.

The lens error corrected images have 3472 x 2704 pixels but retain the pixel size of 2.336 microns.

The EO parameters from 2013 were used in making the image header-files for the lens error corrected images.

Image-#, omega, ohi, kappa, X0, Y0 and Z0, c=0.007341 mm.

01_01	-0.58838	-0.01354	3.22691	2516615.785	6856304.423	142.249
01_02	-0.58712	-0.01520	3.21462	2516614.985	6856304.259	142.255
01_03	-0.60411	-0.05932	3.18789	2516614.107	6856304.249	142.218
01_04	-0.57725	-0.08098	3.22391	2516613.298	6856304.218	142.177
01_05	-0.59756	-0.03642	3.17035	2516612.515	6856304.181	142.154
01_06	-0.54236	-0.05082	3.19848	2516611.724	6856304.136	142.211
01_07	-0.55721	-0.03809	3.17313	2516610.884	6856304.105	142.177
01_08	-0.57225	-0.00631	3.13847	2516610.132	6856304.111	142.212
01_09	-0.53881	-0.04974	3.18465	2516609.348	6856304.043	142.211
01_10	-0.58245	-0.04432	3.19502	2516608.536	6856304.026	142.207
01_11	-0.55785	-0.05062	3.20636	2516607.750	6856303.940	142.190
01_12	-0.52001	-0.02743	3.16504	2516606.966	6856303.833	142.209
01_13	-0.52552	-0.06738	3.17475	2516606.085	6856303.829	142.208
01_14	-0.51227	-0.07659	3.22027	2516605.348	6856303.755	142.177
01_15	-0.54644	-0.07523	3.21315	2516604.515	6856303.707	142.119
01_16	-0.55028	-0.04935	3.21209	2516603.788	6856303.649	142.132
01_17	-0.53997	-0.02146	3.19177	2516603.061	6856303.602	142.106
01_18	-0.55088	-0.03124	3.19783	2516602.234	6856303.620	142.081
01_19	-0.57964	-0.04220	3.19987	2516601.421	6856303.617	142.046
01_20	-0.57876	-0.03499	3.19255	2516600.621	6856303.550	142.028
01_21	-0.57524	-0.02595	3.21218	2516599.872	6856303.521	142.027
01_22	-0.56557	-0.06597	3.23489	2516599.011	6856303.351	142.095
01_23	-0.52396	-0.03358	3.17625	2516598.162	6856303.294	142.196
01_24	-0.48407	-0.10831	3.22561	2516597.270	6856303.236	142.305
01_25	-0.50622	0.00910	3.15228	2516596.601	6856303.196	142.201
01_26	-0.48598	-0.06968	3.19566	2516595.805	6856303.036	142.100
01_27	-0.47862	0.00874	3.15268	2516595.033	6856303.033	142.099
01_28	-0.50401	-0.00482	3.17774	2516594.234	6856303.058	142.082
01_29	-0.50119	-0.04796	3.22859	2516593.440	6856303.053	142.099
01_30	-0.48161	-0.00179	3.19779	2516592.670	6856302.969	142.057
01_31	-0.49193	-0.00043	3.18771	2516591.865	6856302.928	142.079
01_32	-0.49884	0.01533	3.16825	2516591.061	6856302.896	142.035
01_33	-0.49697	-0.01479	3.19725	2516590.262	6856302.804	142.037
01_34	-0.48443	-0.01226	3.17442	2516589.406	6856302.711	142.039
01_35	-0.55528	-0.05101	3.20877	2516588.577	6856302.739	141.926
01_36	-0.53942	0.04289	3.16180	2516587.909	6856302.667	141.956
01_37	-0.49046	0.01710	3.19310	2516587.072	6856302.541	142.057
01_38	-0.46059	0.02029	3.17272	2516586.209	6856302.472	142.091
01_39	-0.43622	0.19393	3.12118	2516585.614	6856302.388	142.189
02_01	-0.61053	-0.05160	3.22244	2516615.854	6856303.322	142.327
02_02	-0.58443	-0.02455	3.15529	2516615.090	6856303.207	142.312
02_03	-0.58565	-0.06554	3.20249	2516614.255	6856303.153	142.231
02_04	-0.56755	-0.01183	3.14637	2516613.475	6856303.141	142.194
02_05	-0.60088	-0.01639	3.17676	2516612.713	6856303.157	142.200
02_06	-0.58313	-0.00347	3.15601	2516611.905	6856303.107	142.244
02_07	-0.58345	-0.00810	3.17788	2516611.098	6856303.077	142.203
02_08	-0.56811	-0.06003	3.23608	2516610.322	6856303.031	142.300
02_09	-0.57243	0.00728	3.17231	2516609.554	6856302.958	142.234
02_10	-0.56890	-0.03459	3.21136	2516608.732	6856302.879	142.228
02_11	-0.50087	-0.00117	3.15398	2516607.926	6856302.783	142.200
02_12	-0.51125	-0.01896	3.16503	2516607.103	6856302.773	142.151
02_13	-0.53969	-0.00680	3.15496	2516606.310	6856302.741	142.190
02_14	-0.54391	-0.02723	3.16702	2516605.493	6856302.741	142.188
02_15	-0.54137	-0.02788	3.15724	2516604.696	6856302.696	142.237
02_16	-0.53763	-0.03437	3.20994	2516603.949	6856302.627	142.129
02_17	-0.54144	0.01327	3.16012	2516603.172	6856302.585	142.082
02_18	-0.52739	0.00817	3.16231	2516602.375	6856302.528	142.083
02_19	-0.52241	0.02503	3.13755	2516601.584	6856302.450	142.053
02_20	-0.50469	-0.00474	3.18742	2516600.786	6856302.401	142.091
02_21	-0.51020	-0.01723	3.20844	2516600.009	6856302.371	142.095
02_22	-0.50352	-0.02274	3.18408	2516599.167	6856302.290	142.068
02_23	-0.52217	-0.02602	3.15869	2516598.329	6856302.271	142.110
02_24	-0.54734	-0.04520	3.16981	2516597.500	6856302.293	142.146
02_25	-0.48116	-0.02303	3.17907	2516596.737	6856302.108	142.111
02_26	-0.50651	-0.01781	3.15336	2516595.952	6856302.045	142.091
02_27	-0.52259	0.00345	3.18356	2516595.165	6856302.044	142.023
02_28	-0.51583	-0.01013	3.17766	2516594.365	6856302.038	142.037
02_29	-0.50608	-0.00201	3.14926	2516593.574	6856301.969	142.043
02_30	-0.53198	-0.00470	3.19250	2516592.782	6856301.914	142.022
02_31	-0.44780	-0.01219	3.17020	2516591.982	6856301.744	141.981
02_32	-0.47634	-0.00612	3.16698	2516591.156	6856301.722	141.988
02_33	-0.46477	-0.00429	3.18790	2516590.384	6856301.722	141.975
02_34	-0.50258	-0.01266	3.19402	2516589.563	6856301.730	141.991
02_35	-0.46693	0.00628	3.18441	2516588.775	6856301.645	141.977
02_36	-0.50785	-0.00585	3.21717	2516587.995	6856301.658	141.986
02_37	-0.45729	-0.01927	3.25580	2516587.219	6856301.544	142.025
02_38	-0.46499	-0.02076	3.23688	2516586.357	6856301.473	141.989
02_39	-0.50541	-0.01052	3.19618	2516585.523	6856301.481	142.046
03_01	-0.48135	-0.10123	3.26744	2516615.896	6856301.865	142.495
03_02	-0.49059	-0.05461	3.17924	2516615.071	6856301.755	142.437
03_03	-0.46701	-0.03582	3.20088	2516614.320	6856301.672	142.322
03_04	-0.50181	-0.04326	3.20731	2516613.513	6856301.676	142.312
03_05	-0.48154	-0.02544	3.20148	2516612.738	6856301.637	142.290
03_06	-0.50409	-0.02604	3.21147	2516611.934	6856301.634	142.248
03_07	-0.45770	-0.04088	3.21812	2516611.178	6856301.513	142.294
03_08	-0.49897	-0.04819	3.20878	2516610.305	6856301.535	142.312
03_09	-0.50318	-0.04852	3.21809	2516609.517	6856301.486	142.243
03_10	-0.50111	-0.04501	3.24067	2516608.747	6856301.498	142.235
03_11	-0.50069	-0.03790	3.20803	2516607.937	6856301.464	142.216
03_12	-0.53462	-0.05772	3.20284	2516607.088	6856301.484	142.194
03_13	-0.50717	-0.04778	3.19487	2516606.309	6856301.422	142.160
03_14	-0.52502	-0.04435	3.17537	2516605.520	6856301.366	142.133
03_15	-0.50698	-0.03359	3.17819	2516604.722	6856301.332	142.077
03_16	-0.51970	-0.03242	3.19293	2516603.931	6856301.286	142.100
03_17	-0.51226	-0.03568	3.19183	2516603.136	6856301.212	142.081
03_18	-0.50009	-0.01066	3.17297	2516602.369	6856301.161	142.086
03_19	-0.49982	0.03642	3.13178	2516601.609	6856301.139	142.039
03_20	-0.48991	-0.02912	3.18041	2516600.780	6856301.113	142.082
03_21	-0.49572	-0.01243	3.17595	2516599.952	6856301.048	142.051
03_22	-0.49607	0.00141	3.17010	2516599.191	6856300.977	142.035
03_23	-0.46763	-0.03839	3.18455	2516598.337	6856300.911	142.055
03_24	-0.46780	-0.01554	3.18833	2516597.577	6856300.872	142.043
03_25	-0.51272	0.03805	3.16204	2516596.773	6856300.830	141.986
03_26	-0.47816	-0.02073	3.24481	2516596.031	6856300.883	142.078
03_27	-0.52184	0.01793	3.17464	2516595.211	6856300.889	142.025
03_28	-0.47301	-0.03799	3.23425	2516594.413	6856300.735	141.969
03_29	-0.49982	0.00831	3.17136	2516593.584	6856300.705	141.956
03_30	-0.50319	0.00885	3.16122	2516592.780	6856300.698	141.963
03_31	-0.52945	-0.03375	3.22498	2516592.003	6856300.680	141.973
03_32	-0.48391	0.00556	3.15395	2516591.179	6856300.610	141.943
03_33	-0.51599	-0.02105	3.13548	2516590.315	6856300.543	141.934
03_34	-0.51324	0.01154	3.15468	2516589.604	6856300.530	141.940
03_35	-0.52040	-0.00459	3.17266	2516588.757	6856300.488	141.887
03_36	-0.50932	-0.02774	3.20782	2516587.947	6856300.355	141.928
03_37	-0.55968	0.03355	3.14667	2516587.189	6856300.340	141.935
03_38	-0.52218	0.02670	3.17524	2516586.386	6856300.253	141.912
03_39	-0.49005	-0.04566	3.25614	2516585.595	6856300.124	141.897
04_01	-0.49767	-0.07738	3.23633	2516615.955	6856300.684	142.437
04_02	-0.51166	-0.09561	3.25307	2516615.140	6856300.618	142.515
04_03	-0.48591	-0.06130	3.24101	2516614.371	6856300.535	142.280
04_04	-0.51212	-0.01479	3.20349	2516613.593	6856300.517	142.263
04_05	-0.51272	0.01630	3.20009	2516612.832	6856300.467	142.300
04_06	-0.52865	-0.02711	3.18632	2516611.972	6856300.449	142.338
04_07	-0.50577	-0.02233	3.21403	2516611.166	6856300.381	142.302
04_08	-0.51932	0.06858	2.99966	2516610.332	6856300.350	142.466
04_09	-0.55843	-0.01613	3.18220	2516609.602	6856300.382	142.261
04_10	-0.57254	0.03528	3.14876	2516608.805	6856300.347	142.169
04_11	-0.56428	0.01344	3.16742	2516607.996	6856300.296	142.108
04_12	-0.56415	0.02284	3.17012	2516607.204	6856300.222	142.112
04_13	-0.54272	0.00711	3.18348	2516606.408	6856300.208	142.115
04_14	-0.53776	0.01210	3.17257	2516605.612	6856300.140	142.099
04_15	-0.56785	-0.03068	3.20207	2516604.791	6856300.138	142.042
04_16	-0.56802	-0.02838	3.18400	2516603.978	6856300.075	142.060
04_17	-0.60622	-0.01653	3.20617	2516603.234	6856300.061	141.992
04_18	-0.61508	0.00048	3.18069	2516602.431	6856300.072	141.970
04_19	-0.60240	-0.00144	3.17851	2516601.638	6856300.028	141.988
04_20	-0.60840	0.01717	3.16246	2516600.859	6856299.967	142.011
04_21	-0.57075	0.00435	3.17874	2516600.026	6856299.889	141.957
04_22	-0.57506	0.00098	3.17161	2516599.221	6856299.848	141.950
04_23	-0.58591	0.01927	3.17192	2516598.473	6856299.842	142.017
04_24	-0.62583	0.00155	3.20775	2516597.661	6856299.834	141.895
04_25	-0.59095	0.01501	3.17917	2516596.767	6856299.768	141.911
04_26	-0.57457	0.01134	3.20188	2516596.060	6856299.712	141.957
04_27	-0.57844	-0.00302	3.18516	2516595.240	6856299.626	141.914
04_28	-0.55386	0.00830	3.20131	2516594.452	6856299.584	141.953
04_29	-0.58627	0.00059	3.21350	2516593.653	6856299.570	141.934
04_30	-0.58177	0.02276	3.16413	2516592.844	6856299.529	141.948
04_31	-0.54283	0.03372	3.15487	2516592.065	6856299.416	141.963
04_32	-0.57523	-0.03033	3.20756	2516591.237	6856299.409	141.958
04_33	-0.54317	-0.03297	3.20669	2516590.419	6856299.322	141.914
04_34	-0.58287	0.02431	3.16979	2516589.653	6856299.335	141.983
04_35	-0.56414	0.00412	3.20283	2516588.847	6856299.237	141.926
04_36	-0.55997	0.00445	3.17411	2516588.040	6856299.178	141.935
04_37	-0.54643	0.00446	3.21370	2516587.269	6856299.162	141.912
04_38	-0.53377	0.00981	3.19586	2516586.463	6856299.097	141.926
04_39	-0.53534	0.00429	3.22935	2516585.676	6856299.018	141.910
05_01	-0.54092	-0.07105	3.26060	2516616.050	6856299.498	142.357
05_02	-0.52063	-0.08590	3.23559	2516615.317	6856299.408	142.325
05_03	-0.52937	-0.07009	3.19805	2516614.551	6856299.363	142.301
05_04	-0.56950	-0.06969	3.19576	2516613.726	6856299.329	142.242
05_05	-0.57561	-0.07611	3.18818	2516612.904	6856299.309	142.236
05_06	-0.55504	-0.03206	3.19723	2516612.177	6856299.216	142.231
05_07	-0.56632	-0.03114	3.19852	2516611.402	6856299.206	142.219
05_08	-0.52869	-0.05128	3.22281	2516610.569	6856299.125	142.212
05_09	-0.58335	-0.04918	3.19544	2516609.752	6856299.159	142.162
05_10	-0.55454	-0.05173	3.20368	2516608.963	6856299.101	142.139
05_11	-0.56598	-0.02843	3.18134	2516608.155	6856299.079	142.096
05_12	-0.57997	-0.04726	3.19308	2516607.363	6856299.069	142.158
05_13	-0.54738	-0.06143	3.19829	2516606.556	6856298.970	142.147
05_14	-0.52914	-0.06121	3.23692	2516605.793	6856298.887	142.066
05_15	-0.57364	-0.07694	3.24113	2516604.950	6856298.874	142.078
05_16	-0.57588	-0.05346	3.21360	2516604.166	6856298.829	142.034
05_17	-0.57696	-0.06591	3.21410	2516603.344	6856298.764	142.024
05_18	-0.56842	-0.03962	3.19116	2516602.597	6856298.745	142.025
05_19	-0.58446	-0.02619	3.15593	2516601.778	6856298.745	141.990
05_20	-0.59707	-0.04483	3.19362	2516600.990	6856298.722	142.006
05_21	-0.60993	-0.02402	3.17470	2516600.200	6856298.726	141.985
05_22	-0.53814	-0.06567	3.23366	2516599.409	6856298.634	141.980
05_23	-0.57246	-0.05083	3.21877	2516598.585	6856298.572	141.949
05_24	-0.63533	-0.01213	3.18311	2516597.794	6856298.586	141.947
05_25	-0.60491	-0.03953	3.20749	2516596.998	6856298.503	141.975
05_26	-0.59800	-0.02620	3.18260	2516596.233	6856298.451	141.985
05_27	-0.55870	-0.01892	3.16921	2516595.413	6856298.402	141.979
05_28	-0.55599	-0.07259	3.21683	2516594.561	6856298.315	141.989
05_29	-0.58876	-0.07360	3.20636	2516593.798	6856298.283	141.933
05_30	-0.57416	-0.07065	3.21840	2516592.961	6856298.206	141.945
05_31	-0.55982	-0.05656	3.19449	2516592.191	6856298.151	141.931
05_32	-0.57143	-0.03041	3.15390	2516591.385	6856298.163	141.924
05_33	-0.63164	-0.00866	3.16100	2516590.624	6856298.206	141.918
05_34	-0.55416	-0.04088	3.18073	2516589.789	6856298.046	141.930
05_35	-0.58147	-0.04964	3.17671	2516588.969	6856298.026	141.907
05_36	-0.54865	-0.04899	3.22135	2516588.208	6856297.977	141.933
05_37	-0.56754	-0.03228	3.20253	2516587.421	6856297.931	141.901
05_38	-0.56895	-0.01253	3.18474	2516586.581	6856297.888	141.942
05_39	-0.57735	0.02065	3.16637	2516585.814	6856297.851	141.949
06_01	-0.48308	-0.09242	3.23072	2516616.222	6856298.259	142.352
06_02	-0.47348	-0.11246	3.24337	2516615.388	6856298.093	142.359
06_03	-0.47558	-0.01688	3.14431	2516614.632	6856298.008	142.262
06_04	-0.51428	-0.04427	3.16388	2516613.799	6856298.039	142.277
06_05	-0.51108	-0.05468	3.22399	2516613.060	6856298.005	142.264
06_06	-0.51131	-0.01882	3.18751	2516612.248	6856297.958	142.245
06_07	-0.52082	-0.01229	3.18820	2516611.487	6856297.894	142.149
06_08	-0.52590	-0.03751	3.16796	2516610.652	6856297.920	142.208
06_09	-0.51758	0.01166	3.14939	2516609.879	6856297.830	142.181
06_10	-0.56421	-0.04940	3.17224	2516609.019	6856297.843	142.163
06_11	-0.54552	-0.01525	3.19781	2516608.277	6856297.804	142.150
06_12	-0.54758	-0.01494	3.18648	2516607.455	6856297.743	142.153
06_13	-0.53042	-0.04086	3.19377	2516606.655	6856297.719	142.138
06_14	-0.52848	-0.02396	3.19324	2516605.888	6856297.589	142.127
06_15	-0.50523	-0.03397	3.20326	2516605.078	6856297.536	142.121
06_16	-0.55768	-0.03321	3.18202	2516604.274	6856297.547	142.098
06_17	-0.51094	-0.02001	3.18012	2516603.483	6856297.443	142.078
06_18	-0.53962	-0.02155	3.17864	2516602.681	6856297.423	142.061
06_19	-0.50812	-0.01176	3.14042	2516601.886	6856297.388	142.043
06_20	-0.55462	-0.01128	3.17789	2516601.096	6856297.398	142.032
06_21	-0.55763	-0.01935	3.19226	2516600.291	6856297.359	142.043
06_22	-0.54016	-0.01472	3.19280	2516599.509	6856297.277	142.066
06_23	-0.52279	-0.03266	3.22249	2516598.730	6856297.251	142.062
06_24	-0.54210	-0.01997	3.18046	2516597.876	6856297.208	142.028
06_25	-0.54922	-0.04464	3.19014	2516597.086	6856297.190	142.030
06_26	-0.58346	-0.04322	3.17961	2516596.272	6856297.203	142.019
06_27	-0.54691	-0.03322	3.14856	2516595.461	6856297.090	142.058
06_28	-0.49619	-0.07066	3.21626	2516594.652	6856297.003	142.041
06_29	-0.55423	0.01702	3.11373	2516593.865	6856297.020	142.089
06_30	-0.55101	0.07837	3.12013	2516593.333	6856297.093	142.183
06_31	-0.56970	-0.03313	3.19840	2516592.294	6856297.008	141.989
06_32	-0.55055	-0.01725	3.19329	2516591.522	6856296.883	141.942
06_33	-0.58110	-0.01389	3.18515	2516590.738	6856296.889	141.932
06_34	-0.49592	-0.01872	3.19644	2516589.916	6856296.735	141.940
06_35	-0.56371	-0.01456	3.20620	2516589.118	6856296.784	141.945
06_36	-0.54886	-0.03703	3.19928	2516588.293	6856296.727	141.930
06_37	-0.55414	0.00543	3.15568	2516587.515	6856296.696	141.906
06_38	-0.55320	0.00615	3.17664	2516586.726	6856296.661	141.968
06_39	-0.58559	-0.00442	3.11283	2516585.829	6856296.653	141.962
07_01	-0.48008	-0.07293	3.19726	2516616.207	6856297.019	142.400
07_02	-0.53388	-0.05699	3.19737	2516615.486	6856296.958	142.382
07_03	-0.49917	-0.06835	3.23376	2516614.705	6856296.847	142.297
07_04	-0.49489	-0.04608	3.20206	2516613.874	6856296.820	142.213
07_05	-0.48354	-0.01569	3.19289	2516613.143	6856296.741	142.189
07_06	-0.47099	-0.01564	3.21862	2516612.337	6856296.693	142.218
07_07	-0.48401	-0.06155	3.21256	2516611.490	6856296.666	142.204
07_08	-0.50560	-0.02994	3.18276	2516610.695	6856296.676	142.227
07_09	-0.49240	-0.01388	3.16890	2516609.904	6856296.619	142.153
07_10	-0.51418	-0.03974	3.19264	2516609.105	6856296.602	142.152
07_11	-0.54723	-0.04120	3.19555	2516608.300	6856296.614	142.148
07_12	-0.54022	-0.01223	3.18330	2516607.540	6856296.585	142.145

07_13	-0.53090	-0.03663	3.19490	2516606.747	6856296.565	142.216	10_21	-0.50415	-0.05768	3.19621	2516600.565	6856292.603	142.123
07_14	-0.52755	-0.02430	3.19009	2516605.935	6856296.486	142.165	10_22	-0.48618	-0.07564	3.20238	2516599.779	6856292.587	142.093
07_15	-0.54833	-0.02896	3.17364	2516605.073	6856296.467	142.167	10_23	-0.55142	-0.05555	3.19166	2516598.959	6856292.644	142.168
07_16	-0.51876	-0.01575	3.20928	2516604.151	6856296.348	142.190	10_24	-0.48519	-0.06996	3.21404	2516598.173	6856292.512	142.070
07_17	-0.50145	-0.00134	3.16817	2516603.539	6856296.286	142.105	10_25	-0.53088	-0.06333	3.22417	2516597.405	6856292.549	142.048
07_18	-0.50150	-0.01350	3.17442	2516602.749	6856296.274	142.096	10_26	-0.56197	-0.04621	3.19438	2516596.575	6856292.543	142.001
07_19	-0.51710	-0.00569	3.17792	2516601.960	6856296.260	142.079	10_27	-0.52471	-0.06854	3.18265	2516595.747	6856292.457	142.000
07_20	-0.54244	-0.01191	3.17331	2516601.140	6856296.223	142.057	10_28	-0.52576	-0.05738	3.18959	2516594.907	6856292.373	141.978
07_21	-0.55343	-0.02513	3.19227	2516600.356	6856296.188	142.056	10_29	-0.52647	-0.05684	3.18754	2516594.181	6856292.328	141.974
07_22	-0.51041	-0.05162	3.22498	2516599.534	6856296.109	142.083	10_30	-0.54792	-0.03770	3.17398	2516593.290	6856292.307	141.978
07_23	-0.53490	0.01297	3.15068	2516598.892	6856296.146	142.144	10_31	-0.53584	-0.05656	3.20558	2516592.562	6856292.249	141.952
07_24	-0.54245	-0.04112	3.21572	2516597.959	6856296.021	142.073	10_32	-0.51916	-0.04025	3.16777	2516591.781	6856292.219	142.038
07_25	-0.55046	-0.03579	3.20986	2516597.154	6856295.986	142.066	10_33	-0.52972	-0.06048	3.19660	2516590.974	6856292.222	141.934
07_26	-0.52516	-0.04220	3.20856	2516596.378	6856295.921	142.018	10_34	-0.51025	-0.03796	3.20350	2516590.185	6856292.108	141.985
07_27	-0.55761	-0.04785	3.21449	2516595.545	6856295.890	142.044	10_35	-0.51071	-0.04281	3.19939	2516589.389	6856292.094	141.959
07_28	-0.52304	-0.02223	3.19395	2516594.760	6856295.820	142.038	10_36	-0.53602	-0.03715	3.20965	2516588.590	6856292.076	141.980
07_29	-0.51574	-0.08296	3.24607	2516593.952	6856295.787	142.043	10_37	-0.53691	-0.01290	3.17719	2516587.823	6856292.056	142.046
07_30	-0.52921	-0.03816	3.20193	2516593.120	6856295.751	141.998	10_38	-0.53468	-0.03293	3.18933	2516587.018	6856291.968	142.141
07_31	-0.52295	-0.02452	3.20096	2516592.341	6856295.702	142.005	10_39	-0.49471	-0.03855	3.17749	2516586.216	6856291.878	141.991
07_32	-0.50272	-0.03227	3.19327	2516591.557	6856295.638	141.997	11_01	-0.53310	-0.09892	3.17210	2516616.253	6856292.299	142.306
07_33	-0.53336	-0.03119	3.20598	2516590.767	6856295.579	141.997	11_02	-0.51267	-0.06464	3.17595	2516615.513	6856292.176	142.270
07_34	-0.52518	-0.02811	3.20942	2516589.990	6856295.538	141.972	11_03	-0.48449	-0.03355	3.16908	2516614.762	6856292.083	142.212
07_35	-0.54790	-0.01223	3.17097	2516589.140	6856295.477	141.974	11_04	-0.52518	-0.02107	3.19025	2516613.963	6856292.088	142.201
07_36	-0.55301	-0.01292	3.14329	2516588.345	6856295.456	141.980	11_05	-0.51404	-0.04409	3.18187	2516613.124	6856292.088	142.177
07_37	-0.50635	0.02245	3.11907	2516587.551	6856295.340	142.038	11_06	-0.52090	-0.05434	3.20304	2516612.346	6856292.011	142.175
07_38	-0.50915	-0.01899	3.16388	2516586.698	6856295.344	142.088	11_07	-0.49252	-0.02630	3.18730	2516611.569	6856291.955	142.131
07_39	-0.44297	-0.04644	3.22200	2516586.037	6856295.274	142.050	11_08	-0.49948	-0.02216	3.19561	2516610.803	6856291.933	142.130
08_01	-0.60387	-0.13187	3.22313	2516616.226	6856295.999	142.290	11_09	-0.50689	-0.00757	3.17598	2516610.044	6856291.909	142.124
08_02	-0.53246	-0.03576	3.14804	2516615.480	6856295.777	142.225	11_10	-0.50577	-0.02862	3.21173	2516609.206	6856291.907	142.115
08_03	-0.55883	-0.03989	3.17210	2516614.711	6856295.774	142.215	11_11	-0.50103	-0.01813	3.19124	2516608.490	6856291.840	142.170
08_04	-0.53719	-0.05131	3.19887	2516613.933	6856295.703	142.195	11_12	-0.49175	0.00452	3.18567	2516607.641	6856291.760	142.117
08_05	-0.55369	-0.05134	3.18479	2516613.114	6856295.658	142.189	11_13	-0.49253	-0.01246	3.20595	2516606.847	6856291.753	142.190
08_06	-0.57039	-0.04386	3.19675	2516612.338	6856295.615	142.160	11_14	-0.53373	-0.04353	3.18888	2516605.949	6856291.799	142.120
08_07	-0.51446	-0.04347	3.21582	2516611.567	6856295.533	142.167	11_15	-0.55161	-0.00523	3.19192	2516605.246	6856291.746	142.105
08_08	-0.52199	-0.03257	3.20484	2516610.773	6856295.470	142.206	11_16	-0.53238	0.01056	3.18683	2516604.458	6856291.697	142.098
08_09	-0.51768	-0.02154	3.17499	2516609.904	6856295.410	142.077	11_17	-0.54557	0.00252	3.20079	2516603.674	6856291.672	142.084
08_10	-0.51057	-0.01359	3.16911	2516609.150	6856295.399	142.089	11_18	-0.56648	-0.00355	3.18119	2516602.858	6856291.646	142.072
08_11	-0.55418	-0.09514	3.24695	2516608.335	6856295.449	142.129	11_19	-0.50465	-0.01999	3.19191	2516602.028	6856291.543	142.064
08_12	-0.53328	-0.05236	3.21652	2516607.564	6856295.372	142.117	11_20	-0.51932	0.00041	3.15226	2516601.229	6856291.536	142.064
08_13	-0.52818	-0.01092	3.18517	2516606.789	6856295.335	142.138	11_21	-0.56041	0.00712	3.14855	2516600.437	6856291.551	142.033
08_14	-0.53876	-0.07558	3.26226	2516605.967	6856295.265	142.119	11_22	-0.54174	-0.02884	3.16020	2516599.609	6856291.473	142.045
08_15	-0.54147	-0.04826	3.16105	2516605.133	6856295.218	142.126	11_23	-0.52759	0.00940	3.15466	2516598.821	6856291.366	142.016
08_16	-0.50941	-0.06677	3.18287	2516604.302	6856295.164	142.113	11_24	-0.50417	-0.02587	3.17715	2516597.993	6856291.329	141.994
08_17	-0.54978	-0.05000	3.18477	2516603.561	6856295.116	142.111	11_25	-0.53197	-0.05047	3.21464	2516597.199	6856291.332	142.004
08_18	-0.52775	-0.00734	3.18444	2516602.811	6856295.050	142.084	11_26	-0.54649	-0.03261	3.19351	2516596.437	6856291.293	141.991
08_19	-0.54283	-0.03438	3.18528	2516601.961	6856295.032	142.069	11_27	-0.56182	-0.02236	3.16509	2516595.592	6856291.284	141.981
08_20	-0.52224	-0.04049	3.17438	2516601.110	6856294.975	142.045	11_28	-0.54401	0.04311	3.15106	2516594.884	6856291.225	141.991
08_21	-0.52978	-0.05222	3.18286	2516600.353	6856294.940	142.080	11_29	-0.55549	-0.01715	3.17766	2516594.028	6856291.207	142.005
08_22	-0.53079	-0.05777	3.20793	2516599.539	6856294.907	142.063	11_30	-0.57011	-0.03029	3.21232	2516593.209	6856291.203	141.979
08_23	-0.52522	-0.06668	3.25003	2516598.767	6856294.813	142.068	11_31	-0.53857	0.00870	3.17247	2516592.450	6856291.116	141.965
08_24	-0.51393	-0.07800	3.24368	2516597.970	6856294.770	142.027	11_32	-0.55168	-0.05993	3.21819	2516591.607	6856291.080	141.944
08_25	-0.49281	-0.05403	3.20809	2516597.159	6856294.689	142.016	11_33	-0.52863	0.00954	3.17680	2516590.858	6856291.036	141.966
08_26	-0.54702	-0.06049	3.17481	2516596.352	6856294.702	142.046	11_34	-0.53112	-0.01695	3.19293	2516590.028	6856290.983	141.940
08_27	-0.50240	-0.03984	3.19103	2516595.591	6856294.646	142.041	11_35	-0.56380	-0.01672	3.19769	2516589.239	6856290.950	141.900
08_28	-0.51341	-0.04030	3.18917	2516594.788	6856294.587	142.011	11_36	-0.55720	-0.01895	3.17833	2516588.427	6856290.907	141.954
08_29	-0.52277	-0.01467	3.17415	2516593.970	6856294.632	142.006	11_37	-0.56664	-0.04260	3.17784	2516587.584	6856290.893	142.019
08_30	-0.52727	-0.07823	3.19534	2516593.125	6856294.571	142.002	11_38	-0.51787	-0.03978	3.22561	2516586.844	6856290.768	141.938
08_31	-0.52662	-0.08360	3.21738	2516592.358	6856294.475	142.002	11_39	-0.58365	-0.02238	3.26317	2516586.124	6856290.799	141.936
08_32	-0.56165	-0.04229	3.18912	2516591.598	6856294.503	142.118	12_01	-0.52561	-0.07411	3.19663	2516616.429	6856291.077	142.258
08_33	-0.53041	-0.04049	3.16987	2516590.745	6856294.435	142.013	12_02	-0.54225	-0.06907	3.20303	2516615.521	6856290.986	142.207
08_34	-0.52419	-0.03217	3.19729	2516590.025	6856294.369	141.989	12_03	-0.54083	-0.05780	3.21187	2516614.739	6856290.954	142.177
08_35	-0.50084	-0.02189	3.19896	2516589.233	6856294.297	142.015	12_04	-0.51837	-0.06357	3.22143	2516613.967	6856290.906	142.190
08_36	-0.51167	-0.05710	3.21349	2516588.418	6856294.262	141.992	12_05	-0.55177	-0.03085	3.19380	2516613.149	6856290.878	142.169
08_37	-0.53765	-0.02433	3.19595	2516587.610	6856294.265	141.986	12_06	-0.53097	-0.02358	3.17899	2516612.337	6856290.801	142.121
08_38	-0.51347	-0.00083	3.18715	2516586.858	6856294.236	142.059	12_07	-0.54256	-0.04556	3.18397	2516611.571	6856290.821	142.128
08_39	-0.53020	-0.09161	3.22978	2516585.979	6856294.145	142.040	12_08	-0.55672	-0.01440	3.17292	2516610.761	6856290.773	142.092
09_01	-0.53622	-0.04489	3.14845	2516616.358	6856294.732	142.303	12_09	-0.57566	-0.00598	3.16018	2516609.966	6856290.771	142.106
09_02	-0.54248	-0.02979	3.14268	2516615.553	6856294.624	142.284	12_10	-0.52234	-0.04748	3.21369	2516609.137	6856290.648	142.080
09_03	-0.53160	-0.01734	3.15256	2516614.746	6856294.592	142.261	12_11	-0.52393	-0.02414	3.19650	2516608.386	6856290.690	142.069
09_04	-0.54838	-0.00988	3.14807	2516613.957	6856294.566	142.244	12_12	-0.55891	-0.02005	3.17952	2516607.561	6856290.695	142.090
09_05	-0.56339	-0.03262	3.16442	2516613.165	6856294.513	142.246	12_13	-0.59563	-0.00598	3.19690	2516606.811	6856290.675	142.064
09_06	-0.55894	-0.06257	3.17946	2516612.324	6856294.502	142.199	12_14	-0.57283	-0.02251	3.20198	2516606.017	6856290.629	142.059
09_07	-0.49376	-0.04555	3.18360	2516611.530	6856294.449	142.144	12_15	-0.55963	-0.00218	3.17838	2516605.197	6856290.587	142.041
09_08	-0.58972	-0.07242	3.20451	2516610.746	6856294.443	142.136	12_16	-0.61014	-0.00492	3.18263	2516604.410	6856290.613	142.064
09_09	-0.54526	-0.05434	3.20097	2516609.999	6856294.367	142.139	12_17	-0.55782	-0.03414	3.18916	2516603.577	6856290.519	142.052
09_10	-0.54496	-0.05399	3.20721	2516609.176	6856294.355	142.144	12_18	-0.60370	-0.07459	3.21957	2516602.765	6856290.553	142.072
09_11	-0.52702	-0.01802	3.17866	2516608.369	6856294.304	142.140	12_19	-0.50831	-0.06774	3.18911	2516601.916	6856290.420	142.341
09_12	-0.55628	-0.04582	3.21722	2516607.609	6856294.332	142.162	12_20	-0.51148	-0.09452	3.19861	2516601.145	6856290.405	142.064
09_13	-0.55338	-0.03603	3.16553	2516606.756	6856294.279	142.103	12_21	-0.52184	-0.05141	3.15864	2516600.311	6856290.377	142.086
09_14	-0.56350	-0.03764	3.18955	2516605.966	6856294.275	142.138	12_22	-0.53739	-0.07259	3.19274	2516599.553	6856290.325	142.041
09_15	-0.53383	-0.06159	3.20939	2516605.169	6856294.215	142.113	12_23	-0.53165	-0.04362	3.17351	2516598.761	6856290.258	142.035
09_16	-0.56985	-0.04184	3.20902	2516604.434	6856294.226	142.096	12_24	-0.54970	-0.04789	3.22381	2516597.988	6856290.201	142.043
09_17	-0.51177	-0.07322	3.22810	2516603.598	6856294.076	142.074	12_25	-0.51257	-0.09185	3.24208	2516597.153	6856290.116	142.037
09_18	-0.56700	-0.06239	3.19181	2516602.790	6856294.089	142.112	12_26	-0.56564	-0.06236	3.22698	2516596.381	6856290.104	142.013
09_19	-0.54837	-0.06616	3.20822	2516601.993	6856294.022	142.099	12_27	-0.57268	-0.05537	3.22324	2516595.603	6856290.081	141.979
09_20	-0.52009	-0.04529	3.21157	2516601.213	6856293.914	142.047	12_28	-0.56170	-0.05102	3.20126	2516594.770	6856290.028	141.943
09_21	-0.55564	-0.04482	3.19448	2516600.427	6856293.907	142.015	12_29	-0.56018	-0.05270	3.22277	2516593.972	6856290.009	141.994
09_22	-0.55228	-0.04991	3.22468	2516599.657	6856293.885	142.020	12_30	-0.55546	-0.08135	3.23243	2516593.164	6856289.927	141.990
09_23	-0.52138	-0.06426	3.23027	2516598.822	6856293.841	142.069	12_31	-0.55381	-0.05601	3.19342	2516592.328	6856289.879	142.039
09_24	-0.54807	-0.06113	3.20746	2516597.997	6856293.676	142.016	12_32	-0.54681	-0.07558	3.21722	2516591.544	6856289.821	142.001
09_25	-0.53010	-0.05848	3.22124	2516597.208	6856293.672	141.998	12_33	-0.53818	-0.07273	3.22020	2516590.788	6856289.734	141.959
09_26	-0.52160	-0.03489	3.20671	2516596.458	6856293.543	142.009	12_34	-0.51805	-0.06802	3.22121	2516589.976	6856289.664	141.938
09_27	-0.51872	-0.04818	3.21819	2516595.636	6856293.507	142.024	12_35	-0.54548	-0.05126	3.17747	2516589.138	6856289.625	141.971
09_28	-0.51189	-0.03762	3.19697	2516594.834	6856293.491	142.036	12_36	-0.54067	-0.05536	3.17318	2516588.358	6856289.578	141.973
09_29	-0.50143	-0.05128	3.21425	2516594.030	6856293.435	141.952	12_37	-0.55111	-0.06405	3.22347	2516587.621	6856289.518	141.990
09_30	-0.51262	-0.07892	3.23981	2516593.218	6856293.393	141.987	12_38	-0.56063	-0.05388	3.19989	2516586.774	6856289.490	141.984
09_31	-0.54347	-0.06217	3.22563	2516592.434	6856293.400	141.945	12_39	-0.59396	0.00992	3.19380	2516586.058	6856289.508	142.132
09_32	-0.53171	-0.03702	3.20085	2516591.630	6856293.331	141.988	13_01	-0.55326	-0.06132	3.18118	2516616.616	6856289.944	142.248
09_33	-0.51540	-0.07251	3.23327	2516590.839	6856293.208	141.948	13_02	-0.53806	-0.04538	3.16193	2516615.809	6856289.864	142.233
09_34	-0.52285	-0.02964	3.19018	2516590.040	6856293.161	141.981	13_03	-0.56603	-0.04983	3.17531	2516615.013	6856289.896	142.177
09_35	-0.52324	-0.03106	3.19406	2516589.246	6856293.118	141.992	13_04	-0.54376	-0.00346	3.15327	2516614.267	6856289.817	142.200
09_36	-0.52332	-0.03408	3.21161	2516588.442	6856293.090	141.961	13_05	-0.56439	-0.10038	3.19751	2516613.372	6856289.772	142.206
09_37	-0.48806	-0.03968	3.24700	2516587.649	6856293.052	141.983	13_06	-0.52690	-0.02692	3.13407	2516612.632	6856289.691	142.127
09_38	-0.50523	-0.01885	3.18239	2516586.866	6856292.994	141.991	13_07	-0.58142	-0.03981	3.16555	2516611.836	6856289.673	142.146
09_39	-0.53760	-0.00929	3.16529	2516586.014	6856293.016	142.005	13_08	-0.54294	-0.01594	3.16508	2516611.073	6856289.575	142.140
10_01	-0.52845	-0.05634	3.16848	2516616.430	6856293.530	142.311	13_09	-0.53736	-0.00846	3.17699	2516610.262	6856289.550	142.125
10_02	-0.50703	-0.04163	3.18869	2516615.751	6856293.448	142.273	13_10	-0.54410	-0.07612	3.21508	2516609.404	6856289.540	142.111
10_03	-0.51662	-0.05487	3.19114	2516614.911	6856293.402	142.267	13_11	-0.51824	-0.09454	3.22665	2516608.639	6856289.462	142.108
10_04	-0.50578	-0.01322	3.15891	2516614.142	6856293.408	142.229	13_12	-0.52270	-0.05603	3.19442	2516607.867	6856289.424	142.103
10_05	-0.49041	-0.06134	3.20755	2516613.316	6856293.335	142.204	13_13	-0.59047	-0.07598	3.22180	2516607.050	6856289.490	142.091
10_06	-0.49153	-0.04383	3.17887	2516612.532	6856293.257	142.214	13_14	-0.51467	-0.03818	3.16547	2516606.260	6856289.333	142.077
10_07	-0.54121	-0.06647	3.19105	2516611.720	6856293.279	142.195	13_15	-0.53567	-0.05351	3.18878	2516605.430	6856289.364	142.072
10_08	-0.53745	-0.06107	3.20565	2516610.973	6856293.206	142.145	13_16	-0.56432	-0.04979	3.20607	2516604.664	6856289.361	142.082
10_09	-0.53668	-0.04682	3.19368	2516610.370	6856293.166	142.121	13_17	-0.53148	-0.07375	3.21318	2516603.865	6856289.287	142.116
10_10	-0.51123	-0.01352	3.17633	2516609.465	6856293.063	142.111	13_18	-0.54491	-0.03035	3.17244	2516603.120	6856289.254	142.101
10_11	-0.53980	-0.03915	3.20281	2516608.600	6856293.090	142.140	13_19	-0.52608	-0.03143	3.17373	2516602.295	6856289.284	142.104
10_12	-0.55241	-0.05100	3.20469	2516607.757	6856293.064	142.158	13_20	-0.52019	-0.04936	3.19389	2516601.493	6856289.205	142.112
10_13	-0.51638	-0.03582	3.18102	2516606.956	6856293.000	142.110	13_21	-0.53670	-0.07326	3.19797	2516600.699	6856289.149	142.141
10_14	-0.52186	-0.06177	3.20451	2516606.135	6856292.960	142.099	13_22	-0.53141	-0.09328	3.20241	2516599.811	6856289.052	142.069
10_15	-0.52094	-0.07292	3.21496	2516605.346	6856292.940	142.101	13_23	-0.52978	-0.09374	3.19995	2516598.962	6856289.023	142.019
10_16	-0.51787	-0.07183	3.18351	2516604.493	6856292.855	142.091	13_24	-0.54117	-0.08449	3.19150	2516598.204	6856289.038	142.000
10_17	-0.51390	-0.08675	3.19852	2516603.701	6856292.808	142.037	13_25	-0.56188	-0.09476	3.22395	2516597.434	6856289.002	141.994
10_18	-0.49781	-0.04820	3.18175	2516602.965	6856292.729	142.028	13_26	-0.58040	-0.06633	3.18733	2516596.647	6856288.973	142.032
10_19	-0.52650	-0.02084	3.17017	2516602.216	6856292.661	142.088	13_27	-0.54168	-0.07994	3.22389	2516595.846	6856288.879	142.035
10_20	-0.52823	-0.05990	3.19416	2516601.378	6856292.605	142.001	13_28	-0.57737	-0.05770	3.20384	2516595.063	6856288.854	142.018

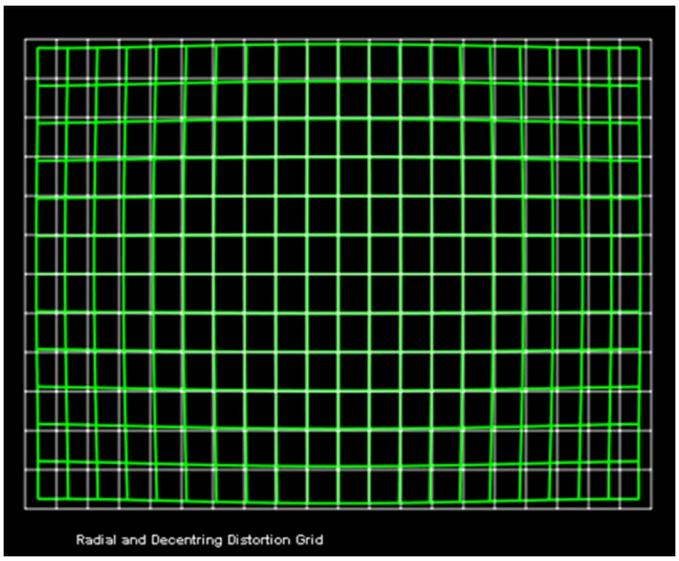
13_29	-0.55207	-0.05025	3.21991	2516594.296	6856288.802	142.027
13_30	-0.56058	-0.07178	3.21170	2516593.456	6856288.788	142.013
13_31	-0.54448	-0.07745	3.20962	2516592.635	6856288.717	141.997
13_32	-0.51501	-0.09146	3.23992	2516591.879	6856288.519	141.945
13_33	-0.52162	-0.07247	3.21909	2516591.063	6856288.503	142.057
13_34	-0.56350	-0.04898	3.20127	2516590.258	6856288.485	141.966
13_35	-0.51045	-0.12342	3.26812	2516589.492	6856288.380	141.969
13_36	-0.56591	-0.02110	3.18738	2516588.753	6856288.371	141.962
13_37	-0.57565	-0.04217	3.20165	2516587.929	6856288.441	141.953
13_38	-0.55804	-0.04452	3.19819	2516587.094	6856288.508	142.009
13_39	-0.55181	-0.01341	3.15657	2516586.247	6856288.340	142.046
14_01	-0.54215	-0.07899	3.21936	2516616.520	6856288.724	142.218
14_02	-0.56034	-0.03469	3.18007	2516615.727	6856288.668	142.188
14_03	-0.53480	-0.07477	3.21580	2516614.904	6856288.603	142.212
14_04	-0.52210	-0.04703	3.18944	2516614.077	6856288.550	142.174
14_05	-0.54666	-0.02551	3.14601	2516613.236	6856288.549	142.175
14_06	-0.54456	-0.03775	3.17611	2516612.471	6856288.509	142.130
14_07	-0.51964	-0.03581	3.19151	2516611.685	6856288.476	142.121
14_08	-0.55720	-0.02924	3.16348	2516610.872	6856288.458	142.127
14_09	-0.50457	-0.04616	3.19269	2516610.060	6856288.367	142.120
14_10	-0.57442	-0.03291	3.16058	2516609.335	6856288.487	142.242
14_11	-0.53868	-0.04635	3.17246	2516608.452	6856288.321	142.107
14_12	-0.52871	-0.05088	3.17467	2516607.662	6856288.310	142.184
14_13	-0.53541	-0.04917	3.20970	2516606.894	6856288.262	142.144
14_14	-0.52487	-0.04133	3.18654	2516606.086	6856288.220	142.103
14_15	-0.54500	-0.04905	3.20512	2516605.310	6856288.196	142.099
14_16	-0.52785	-0.01852	3.17654	2516604.500	6856288.185	142.095
14_17	-0.52242	-0.02870	3.17799	2516603.701	6856288.146	142.096
14_18	-0.54209	-0.03638	3.18435	2516602.923	6856288.200	142.134
14_19	-0.54309	-0.02435	3.18252	2516602.149	6856288.115	142.078
14_20	-0.53215	-0.06312	3.20758	2516601.299	6856288.017	142.122
14_21	-0.52223	-0.03949	3.17596	2516600.477	6856287.916	142.131
14_22	-0.55095	-0.06051	3.20796	2516599.684	6856287.924	142.080
14_23	-0.55049	-0.08175	3.20762	2516598.839	6856287.894	142.051
14_24	-0.55860	-0.10028	3.23307	2516598.045	6856287.856	142.036
14_25	-0.53327	-0.09239	3.20956	2516597.240	6856287.783	142.018
14_26	-0.54186	-0.07328	3.23402	2516596.478	6856287.726	142.052
14_27	-0.53404	-0.03340	3.18430	2516595.685	6856287.644	142.049
14_28	-0.54246	-0.03998	3.19073	2516594.882	6856287.609	142.048
14_29	-0.54259	-0.04734	3.19957	2516594.105	6856287.561	142.056
14_30	-0.53917	-0.06172	3.20061	2516593.272	6856287.518	142.000
14_31	-0.56100	-0.10133	3.21807	2516592.453	6856287.516	142.025
14_32	-0.51390	-0.07110	3.20395	2516591.656	6856287.445	142.035
14_33	-0.54021	-0.04278	3.20863	2516590.899	6856287.340	142.014
14_34	-0.54545	-0.03690	3.18997	2516590.097	6856287.288	142.020
14_35	-0.52613	-0.05678	3.20963	2516589.274	6856287.228	142.040
14_36	-0.52393	-0.07751	3.21632	2516588.457	6856287.162	142.035
14_37	-0.53655	-0.07761	3.22438	2516587.693	6856287.121	142.072
14_38	-0.52493	-0.06279	3.22791	2516586.925	6856287.041	142.019
14_39	-0.54310	0.00198	3.16604	2516586.150	6856287.034	142.014
15_01	-0.56816	-0.03008	3.12779	2516616.741	6856287.634	142.236
15_02	-0.51706	-0.02675	3.13920	2516615.952	6856287.441	142.165
15_03	-0.52561	-0.03914	3.15268	2516615.076	6856287.439	142.226
15_04	-0.56065	-0.02050	3.16534	2516614.377	6856287.449	142.294
15_05	-0.52923	-0.05305	3.17856	2516613.550	6856287.393	142.242
15_06	-0.54418	-0.07150	3.18666	2516612.741	6856287.348	142.187
15_07	-0.54126	-0.02057	3.14788	2516611.960	6856287.305	142.145
15_08	-0.56578	-0.03742	3.20101	2516611.164	6856287.361	142.216
15_09	-0.50059	-0.04712	3.19456	2516610.361	6856287.196	142.121
15_10	-0.52516	-0.02164	3.17692	2516609.596	6856287.186	142.144
15_11	-0.53674	-0.01412	3.17731	2516608.821	6856287.160	142.144
15_12	-0.52583	-0.03583	3.21461	2516608.002	6856287.128	142.128
15_13	-0.54752	-0.05262	3.19169	2516607.143	6856287.102	142.128
15_14	-0.52655	-0.02645	3.17563	2516606.386	6856287.045	142.152
15_15	-0.53536	-0.02008	3.17856	2516605.606	6856287.003	142.075
15_16	-0.56187	-0.02438	3.17933	2516604.823	6856286.992	142.085
15_17	-0.52696	-0.03455	3.18676	2516603.965	6856286.921	142.097
15_18	-0.50344	-0.04706	3.20759	2516603.218	6856286.866	142.089
15_19	-0.55460	-0.03948	3.19969	2516602.443	6856286.881	142.129
15_20	-0.49952	-0.00213	3.18205	2516601.672	6856286.784	142.140
15_21	-0.51150	-0.03457	3.19553	2516600.834	6856286.757	142.137
15_22	-0.48699	-0.05356	3.19884	2516600.013	6856286.683	142.121
15_23	-0.50688	-0.00946	3.19578	2516599.253	6856286.705	142.108
15_24	-0.50390	-0.06263	3.19989	2516598.380	6856286.650	142.064
15_25	-0.49872	-0.01684	3.16963	2516597.574	6856286.593	142.068
15_26	-0.57210	-0.07651	3.22127	2516596.775	6856286.614	142.034
15_27	-0.52259	-0.06507	3.21038	2516595.945	6856286.456	142.020
15_28	-0.48901	-0.06015	3.20169	2516595.175	6856286.417	142.026
15_29	-0.52560	-0.05264	3.20652	2516594.371	6856286.407	142.038
15_30	-0.52131	-0.05281	3.20473	2516593.571	6856286.360	142.038
15_31	-0.54316	-0.09254	3.21302	2516592.772	6856286.346	142.055
15_32	-0.53096	-0.06397	3.19272	2516591.973	6856286.264	142.041
15_33	-0.55707	-0.06123	3.19066	2516591.177	6856286.237	142.018
15_34	-0.53723	-0.03894	3.19338	2516590.413	6856286.128	142.013
15_35	-0.56367	-0.04882	3.17521	2516589.575	6856286.095	142.026
15_36	-0.53099	-0.06034	3.20129	2516588.775	6856286.020	142.001
15_37	-0.49156	-0.03102	3.18505	2516587.958	6856285.928	142.026
15_38	-0.54592	-0.09457	3.25637	2516587.233	6856285.952	142.030
15_39	-0.50349	-0.05594	3.22414	2516586.443	6856285.806	141.994
16_01	-0.51910	-0.06822	3.21520	2516616.747	6856286.272	142.280
16_02	-0.50118	-0.07172	3.20753	2516615.872	6856286.187	142.277
16_03	-0.50186	-0.05344	3.17580	2516615.084	6856286.137	142.209
16_04	-0.51620	-0.04668	3.17796	2516614.285	6856286.130	142.236
16_05	-0.47972	-0.05442	3.19191	2516613.497	6856286.071	142.185
16_06	-0.52135	-0.01127	3.13791	2516612.704	6856286.083	142.132
16_07	-0.51768	-0.05850	3.20132	2516611.909	6856286.079	142.133
16_08	-0.52498	-0.04348	3.19748	2516611.123	6856286.045	142.107
16_09	-0.54856	-0.02653	3.18312	2516610.319	6856285.989	142.119
16_10	-0.50300	-0.03595	3.21377	2516609.465	6856285.946	142.084
16_11	-0.55375	-0.05562	3.23184	2516608.725	6856285.938	142.104
16_12	-0.50960	-0.04733	3.22330	2516607.937	6856285.846	142.090
16_13	-0.49910	-0.06971	3.21983	2516607.106	6856285.773	142.092
16_14	-0.51455	-0.05114	3.21023	2516606.312	6856285.760	142.093
16_15	-0.51480	-0.04459	3.21847	2516605.535	6856285.677	142.072
16_16	-0.52805	-0.07757	3.22897	2516604.729	6856285.660	142.068
16_17	-0.49054	-0.06214	3.25000	2516603.954	6856285.578	142.050
16_18	-0.50558	-0.05893	3.22490	2516603.125	6856285.569	142.060
16_19	-0.49257	-0.06054	3.23820	2516602.330	6856285.509	142.080
16_20	-0.50739	-0.03423	3.19965	2516601.556	6856285.483	142.080
16_21	-0.51564	-0.05255	3.17486	2516600.700	6856285.461	142.064
16_22	-0.52981	-0.01772	3.16503	2516599.934	6856285.435	142.057
16_23	-0.52793	-0.02837	3.16834	2516599.136	6856285.401	142.074
16_24	-0.50439	-0.04783	3.17112	2516598.316	6856285.326	142.060
16_25	-0.46897	-0.03177	3.18755	2516597.508	6856285.305	142.069
16_26	-0.53016	-0.01192	3.13641	2516596.680	6856285.298	142.052
16_27	-0.52450	-0.05383	3.18355	2516595.915	6856285.261	142.045
16_28	-0.53898	-0.02514	3.17927	2516595.128	6856285.231	142.058
16_29	-0.55670	-0.02983	3.18785	2516594.336	6856285.219	141.983
16_30	-0.57261	-0.05499	3.19784	2516593.513	6856285.173	142.014
16_31	-0.54593	-0.08407	3.23335	2516592.699	6856285.141	142.033
16_32	-0.55800	-0.04513	3.21627	2516591.949	6856285.098	141.990
16_33	-0.53756	-0.06781	3.23345	2516591.140	6856284.980	142.033
16_34	-0.52417	-0.05762	3.17190	2516590.300	6856284.902	141.989
16_35	-0.50797	-0.02978	3.12543	2516589.509	6856284.848	141.995
16_36	-0.52281	-0.05459	3.18892	2516588.738	6856284.841	141.956

16_37	-0.53631	-0.04094	3.19553	2516587.953	6856284.797	141.998
16_38	-0.52989	-0.08832	3.24565	2516587.137	6856284.776	141.976
16_39	-0.51922	-0.12007	3.29658	2516586.349	6856284.685	141.957
17_01	-0.49298	-0.08501	3.20460	2516616.707	6856285.027	142.262
17_02	-0.53161	-0.01193	3.15457	2516615.921	6856284.993	142.263
17_03	-0.52520	-0.07693	3.21310	2516615.087	6856284.965	142.231
17_04	-0.50787	-0.03785	3.16848	2516614.339	6856284.907	142.201
17_05	-0.53282	-0.06566	3.18456	2516613.498	6856284.885	142.193
17_06	-0.51344	-0.06840	3.20588	2516612.721	6856284.752	142.129
17_07	-0.53690	-0.05171	3.17640	2516611.901	6856284.745	142.144
17_08	-0.50475	-0.05415	3.19450	2516611.124	6856284.685	142.091
17_09	-0.52069	-0.05663	3.19246	2516610.332	6856284.638	142.110
17_10	-0.52553	-0.05871	3.19705	2516609.532	6856284.654	142.102
17_11	-0.51609	-0.04606	3.19453	2516608.753	6856284.616	142.113
17_12	-0.59182	-0.03991	3.20313	2516607.986	6856284.664	142.242
17_13	-0.53357	-0.04906	3.20419	2516607.183	6856284.506	142.115
17_14	-0.53695	-0.05708	3.18325	2516606.270	6856284.472	142.045
17_15	-0.53550	-0.05480	3.18365	2516605.558	6856284.423	142.065
17_16	-0.54787	-0.05654	3.19972	2516604.746	6856284.393	142.066
17_17	-0.54033	-0.04777	3.17926	2516603.968	6856284.365	142.087
17_18	-0.51179	-0.04822	3.19105	2516603.183	6856284.291	142.118
17_19	-0.51954	-0.06183	3.19092	2516602.353	6856284.284	142.075
17_20	-0.54467	-0.08244	3.19464	2516601.523	6856284.268	142.096
17_21	-0.56158	-0.06249	3.20337	2516600.787	6856284.254	142.038
17_22	-0.55255	-0.06984	3.20455	2516599.959	6856284.172	142.028
17_23	-0.51800	-0.02431	3.16758	2516599.191	6856284.094	142.149
17_24	-0.56021	-0.09577	3.22339	2516598.338	6856284.126	142.083
17_25	-0.52908	-0.09595	3.21968	2516597.514	6856284.069	142.028
17_26	-0.50893	-0.07144	3.19143	2516596.735	6856283.988	142.058
17_27	-0.52100	-0.08515	3.21147	2516595.905	6856283.980	142.006
17_28	-0.57953	-0.06200	3.20334	2516595.168	6856284.006	141.983
17_29	-0.51198	-0.07745	3.22127	2516594.357	6856283.849	142.000
17_30	-0.53709	-0.05691	3.20346	2516593.555	6856283.824	141.995
17_31	-0.51159	-0.09001	3.23244	2516592.766	6856283.752	141.976
17_32	-0.54445	-0.07949	3.23168	2516591.945	6856283.770	142.003
17_33	-0.55351	-0.08382	3.16236	2516591.209	6856283.796	142.181
17_34	-0.53053	-0.05967	3.18718	2516590.373	6856283.675	142.033
17_35	-0.49870	-0.05215	3.18402	2516589.581	6856283.600	142.021
17_36	-0.53226	-0.08006	3.20000	2516588.751	6856283.621	141.948
17_37	-0.55970	-0.04255	3.18542	2516587.973	6856283.621	141.962
17_38	-0.52450	0.00352	3.17194	2516587.223	6856283.521	142.004
17_39	-0.54857	-0.03108	3.18350	2516586.515	6856283.490	141.976
18_01	-0.50138	-0.09658	3.19030	2516616.936	6856283.887	142.194
18_02	-0.52307	-0.06131	3.15584	2516616.217	6856283.830	142.210
18_03	-0.52333	-0.08097	3.21953	2516615.417	6856283.795	142.173
18_04	-0.51619	-0.06009	3.21476	2516614.645	6856283.729	142.121
18_05	-0.51658	-0.05126	3.19425	2516613.856	6856283.681	142.144
18_06	-0.52520	-0.06244	3.21435	2516613.058	6856283.690	142.121
18_07	-0.54460	-0.05321	3.20714	2516612.273	6856283.665	142.175
18_08	-0.53694	-0.04053	3.16292	2516611.460	6856283.605	142.107
18_09	-0.52572	-0.05656	3.17844	2516610.589	6856283.589	142.114
18_10	-0.55717	-0.07502	3.19613	2516609.854	6856283.576	142.092
18_11	-0.53605	-0.03406	3.17516	2516609.075	6856283.510	142.094
18_12	-0.49274	-0.06301	3.19070	2516608.254	6856283.453	142.119
18_13	-0.55123	-0.06014	3.19915	2516607.455	6856283.468	142.123
18_14	-0.50985	-0.04886	3.19107	2516606.694	6856283.377	142.078
18_15	-0.53676	-0.06283	3.19612	2516605.857	6856283.363	142.064
18_16	-0.52017	-0.06192	3.20897	2516605.082	6856283.315	142.038
18_17	-0.54160	-0.08250	3.23451	2516604.282	6856283.282	142.070
18_18	-0.53366	-0.08022	3.23547	2516603.486	6856283.219	142.003
18_19	-0.53961	-0.06463	3.18834	2516602.680	6856283.204	142.048
18_20	-0.55392	-0.06768	3.17989	2516601.852	6856283.170	142.053
18_21	-0.52174	-0.06050	3.18343	2516601.074	6856283.113	141.983
18_22	-0.55981	-0.03718	3.15859	2516600.270	6856283.092	142.016
18_23	-0.53154	-0.02740	3.17721	2516599.512	6856283.034	142.054
18_24	-0.52496	-0.03528	3.19816	2516598.731	6856282.988	142.120
18_25	-0.52585	-0.06732	3.19042	2516597.858	6856282.981	142.121
18_26	-0.53129	-0.07256	3.21669	2516597.067	6856282.943	142.034
18_27	-0.51330	-0.06695	3.22367	2516596.326	6856282.866	141.993
18_28	-0.54793	-0.05329	3.18746	2516595.475	6856282.834	141.984
18_29	-0.52282	-0.07115	3.22824	2516594.680	6856282.775	141.944
18_30	-0.51505	-0.04935	3.20240	2516593.899	6856282.689	141.971
18_31	-0.51807	-0.05713	3.20272	2516593.102	6856282.670	141.961
18_32	-0.55450	-0.05368	3.20507	2516592.300	6856282.677	141.961
18_33	-0.51939	-0.04841	3.20928	2516591.534	6856282.562	141.957
18_34	-0.49338	-0.06676	3.23866	2516590.718	6856282.492	141.972
18_35	-0.49462	-0.07821	3.22493	2516589.899	6856282.444	141.985
18_36	-0.51200	-0.07364	3.25306	2516589.126	6856282.376	141.960
18_37	-0.52224	-0.01683	3.16925	2516588.317	6856282.318	141.937
18_38	-0.54113	-0.00899	3.12304	2516587.516	6856282.289	141.978
18_39	-0.51672	0.04697	3.06375	2516586.735	6856282.238	142.018
19_01	-0.54503	-0.05940	3.18781	2516617.006	6856282.784	142.147
19_02	-0.53797	-0.07374	3.22095	2516616.248	6856282.642	142.133
19_03	-0.53591	-0.06706	3.18329	2516615.405	6856282.592	142.133
19_04	-0.55896	-0.08056	3.19753	2516614.637	6856282.568	142.132
19_05	-0.53395	-0.03879	3.16493	2516613.846	6856282.497	142.062
19_06	-0.56830	-0.02854	3.15737	2516613.052	6856282.524	142.109
19_07	-0.54249	0.00318	3.14379	2516612.305	6856282.519	142.192
19_08	-0.54586	-0.04642	3.15592	2516611.440	6856282.460	142.149
19_09	-0.54149	-0.06651	3.17051	2516610.620	6856282.393	142.101
19_10	-0.55525	-0.04427	3.16349	2516609.849	6856282.334	142.091
19_11	-0.53094	-0.03707	3.16095	2516609.061	6856282.283	142.096
19_12	-0.53253	-0.05219	3.20270	2516608.294	6856282.242	142.102
19_13	-0.55360	-0.02644	3.16673	2516607.492	6856282.198	142.067
19_14	-0.54073	-0.07506	3.20487	2516606.657	6856282.168	142.081
19_15	-0.53345	-0.04185	3.18844	2516605.873	6856282.103	142.075
19_16	-0.51886	-0.04448	3.19390	2516605.083	6856282.076	142.049
19_17	-0.54228	-0.06282	3.21456	2516604.252	6856282.041	142.028
19_18	-0.51214	-0.06321	3.21718	2516603.469	6856281.971	142.034
19_19	-0.50300	-0.04145	3.19224	2516602.683	6856281.878	142.040
19_20	-0.49566	-0.06887	3.21952	2516601.887	6856281.842	142.032
19_21	-0.51960	-0.06628	3.21919	2516601.070	6856281.824	142.007
19_22	-0.52007	-0.06799	3.20137	2516600.211	6856281.776	142.001
19_23	-0.52255	-0.06000	3.21134	2516599.504	6856281.736	142.009
19_24	-0.54235	-0.06589	3.20742	2516598.674	6856281.685	142.029
19_25	-0.53017	-0.07526	3.21834	2516597.847	6856281.630	142.021
19_26	-0.52155	-0.06956	3.21468	2516597.095	6856281.566	142.006
19_27	-0.52365	-0.06641	3.20660	2516596.272	6856281.570	142.004
19_28	-0.53834	-0.04100	3.19223	2516595.514	6856281.541	141.978
19_29	-0.52359	-0.07582	3.22989	2516594.681	6856281.492	141.947
19_30	-0.54463	-0.07279	3.22616	2516593.889	6856281.461	141.970
19_31	-0.54468	-0.05324	3.18458	2516593.050	6856281.437	141.949
19_32	-0.57256	-0.05439	3.18802	2516592.276	6856281.430	141.970
19_33	-0.58008	-0.06163	3.20586	2516591.463	6856281.435	141.978
19_34	-0.53972	-0.08315	3.21970	2516590.645	6856281.295	141.954
19_35	-0.53345	-0.08898	3.21353	2516589.853	6856281.171	141.981
19_36	-0.53137	-0.07509	3.19789	2516589.096	6856281.206	141.939
19_37	-0.57919	-0.10691	3.25684	2516588.280	6856281.208	141.950
19_38	-0.57253	-0.05414	3.17929	2516587.489	6856281.159	141.959
19_39	-0.55147	-0.00269	3.13051	2516586.733	6856281.123	141.944
20_01	-0.49678	-0.08380	3.23460	2516616.925	6856281.484	142.212
20_02	-0.53302	-0.13360	3.27225	2516616.105	6856281.414	142.190
20_03	-0.48701	-0.04493	3.20415	2516615.325	6856281.372	142.096
20_04	-0.53878	-0.03632	3.18792	2516614.539	6856281.422	142.135
20_05	-0.53334	-0.03599	3.20455	2516613.748	6856281.355	142.138

20_06	-0.50603	0.00093	3.18740	2516612.988	6856281.357	142.102
20_07	-0.50578	0.00459	3.18439	2516612.174	6856281.257	142.113
20_08	-0.53965	-0.03363	3.19897	2516611.449	6856281.261	142.122
20_09	-0.55134	-0.04604	3.19628	2516610.613	6856281.243	142.128
20_10	-0.56484	-0.03946	3.18377	2516609.736	6856281.271	142.084
20_11	-0.53380	-0.02969	3.17494	2516608.948	6856281.187	142.105
20_12	-0.56638	-0.01347	3.16548	2516608.139	6856281.172	142.137
20_13	-0.53254	-0.05081	3.20420	2516607.169	6856281.130	142.107
20_14	-0.52638	-0.05978	3.21550	2516606.559	6856281.022	142.066
20_15	-0.56352	-0.01574	3.18379	2516605.760	6856280.958	142.056
20_16	-0.57084	-0.02763	3.17226	2516604.925	6856280.920	142.052
20_17	-0.54032	-0.02066	3.14429	2516604.112	6856280.872	142.064
20_18	-0.53930	-0.09131	3.20215	2516603.310	6856280.832	142.034
20_19	-0.55384	-0.06735	3.22047	2516602.561	6856280.833	142.017
20_20	-0.54462	-0.04137	3.18793	2516601.780	6856280.692	142.025
20_21	-0.54602	-0.01430	3.18307	2516600.984	6856280.676	142.000
20_22	-0.55306	-0.04100	3.20401	2516600.178	6856280.643	141.986
20_23	-0.56712	-0.00189	3.18348	2516599.431	6856280.527	142.003
20_24	-0.54155	-0.00663	3.19366	2516598.593	6856280.509	142.017
20_25	-0.55661	-0.05390	3.24787	2516597.812	6856280.500	142.010
20_26	-0.53457	-0.01922	3.20601	2516597.011	6856280.407	141.973
20_27	-0.53940	-0.01407	3.15838	2516596.197	6856280.325	141.974
20_28	-0.53471	-0.01175	3.17518	2516595.398	6856280.286	141.996
20_29	-0.54531	-0.02216	3.19360	2516594.589	6856280.274	142.007
20_30	-0.53126	-0.04607	3.20321	2516593.803	6856280.209	142.034
20_31	-0.53725	0.00619	3.15092	2516593.012	6856280.134	142.022
20_32	-0.57145	-0.01944	3.19824	2516592.224	6856280.169	142.115
20_33	-0.51298	-0.04539	3.20529	2516591.389	6856280.065	142.000
20_34	-0.50098	-0.00641	3.16036	2516590.609	6856279.989	141.991
20_35	-0.51964	0.01510	3.12637	2516589.816	6856279.938	142.035
20_36	-0.51848	0.01089	3.14280	2516588.991	6856279.979	141.995
20_37	-0.50855	-0.03654	3.19209	2516588.165	6856279.962	142.141
20_38	-0.52982	-0.05388	3.21158	2516587.396	6856279.916	142.029
20_39	-0.54770	-0.01091	3.16860	2516586.553	6856279.844	142.011
21_01	-0.52551	-0.09119	3.22019	2516616.889	6856280.397	142.212
21_02	-0.57129	-0.07200	3.20153	2516616.089	6856280.376	142.181
21_03	-0.55603	-0.04748	3.17348	2516615.315	6856280.265	142.157
21_04	-0.56773	-0.03519	3.18705	2516614.533	6856280.223	142.110
21_05	-0.56184	-0.05059	3.19618	2516613.730	6856280.210	142.114
21_06	-0.57935	-0.05240	3.19770	2516612.902	6856280.180	142.099
21_07	-0.52363	-0.06656	3.22971	2516612.103	6856280.144	142.117
21_08	-0.55038	-0.04309	3.19201	2516611.328	6856280.104	142.067
21_09	-0.53781	-0.04846	3.18828	2516610.502	6856280.027	142.108
21_10	-0.56360	-0.07136	3.19561	2516609.729	6856280.004	142.133
21_11	-0.51666	-0.05065	3.17189	2516608.917	6856279.937	142.088
21_12	-0.54816	-0.03739	3.19569	2516608.143	6856279.901	142.088
21_13	-0.60660	-0.02106	3.18733	2516607.165	6856279.849	142.065
21_14	-0.53601	-0.06275	3.19725	2516606.527	6856279.815	142.067
21_15	-0.55425	-0.03851	3.17850	2516605.738	6856279.751	142.069
21_16	-0.54741	-0.03434	3.17659	2516604.949	6856279.711	142.064
21_17	-0.54233	-0.02673	3.16907	2516604.143	6856279.634	142.046
21_18	-0.55384	-0.06590	3.20483	2516603.330	6856279.640	141.998
21_19	-0.56211	-0.02589	3.17753	2516602.543	6856279.589	142.005
21_20	-0.55050	-0.05644	3.20637	2516601.736	6856279.521	142.009
21_21	-0.53494	-0.04237	3.19359	2516600.936	6856279.448	141.970
21_22	-0.55566	-0.04965	3.19803	2516600.166	6856279.444	141.985
21_23	-0.56512	-0.03799	3.20402	2516599.332	6856279.412	141.990
21_24	-0.54161	-0.05471	3.20837	2516598.536	6856279.380	142.013
21_25	-0.57367	-0.05294	3.19396	2516597.768	6856279.336	141.984
21_26	-0.56378	-0.08458	3.21957	2516596.940	6856279.268	141.989
21_27	-0.53210	-0.04168	3.19368	2516596.176	6856279.184	141.973
21_28	-0.52293	-0.06790	3.21488	2516595.331	6856279.167	141.996
21_29	-0.55514	-0.06000	3.21541	2516594.546	6856279.062	141.967
21_30	-0.53779	-0.04167	3.21494	2516593.769	6856279.002	142.011
21_31	-0.56277	-0.07996	3.22169	2516592.944	6856278.953	142.034
21_32	-0.52498	-0.05874	3.20112	2516592.170	6856278.850	142.029
21_33	-0.51186	-0.01643	3.18389	2516591.381	6856278.833	142.138
21_34	-0.58782	-0.11065	3.20532	2516590.512	6856278.831	142.108
21_35	-0.56895	-0.01899	3.17132	2516589.779	6856278.826	141.999
21_36	-0.55984	-0.03731	3.18229	2516588.966	6856278.778	141.948
21_37	-0.57571	-0.03543	3.20146	2516588.189	6856278.741	141.979
21_38	-0.52856	0.00034	3.18016	2516587.438	6856278.633	142.022
21_39	-0.54712	-0.01229	3.14807	2516586.544	6856278.639	142.014
22_01	-0.49026	-0.06407	3.18147	2516616.987	6856279.070	142.156
22_02	-0.51428	-0.05609	3.16480	2516616.171	6856278.934	142.183
22_03	-0.52786	-0.03603	3.15009	2516615.392	6856278.918	142.175
22_04	-0.55962	-0.04792	3.17223	2516614.610	6856278.967	142.214
22_05	-0.53117	-0.07349	3.17702	2516613.779	6856278.886	142.105
22_06	-0.53299	-0.03762	3.18473	2516613.034	6856278.857	142.073
22_07	-0.51988	-0.04294	3.20492	2516612.252	6856278.796	142.082
22_08	-0.52370	-0.03664	3.20113	2516611.464	6856278.725	142.115
22_09	-0.53577	-0.02326	3.17818	2516610.647	6856278.705	142.092
22_10	-0.48849	0.00399	3.14227	2516609.849	6856278.606	142.061
22_11	-0.49253	-0.01706	3.15776	2516609.047	6856278.603	142.116
22_12	-0.53913	-0.02668	3.16312	2516608.224	6856278.600	142.169
22_13	-0.48286	-0.02972	3.15775	2516607.426	6856278.453	142.083
22_14	-0.47698	-0.00940	3.13453	2516606.648	6856278.376	142.089
22_15	-0.50419	-0.03744	3.17902	2516605.839	6856278.414	142.067
22_16	-0.49041	-0.02233	3.18616	2516605.067	6856278.363	142.060
22_17	-0.48331	-0.03711	3.16584	2516604.237	6856278.302	142.023
22_18	-0.53708	-0.06392	3.20234	2516603.424	6856278.319	142.051
22_19	-0.49008	-0.04941	3.17479	2516602.622	6856278.258	142.016
22_20	-0.51265	-0.03432	3.16426	2516601.831	6856278.267	142.025
22_21	-0.49897	-0.03679	3.18575	2516601.060	6856278.191	141.998
22_22	-0.51972	-0.02198	3.16471	2516600.244	6856278.179	142.008
22_23	-0.50895	-0.04027	3.20225	2516599.456	6856278.142	141.987
22_24	-0.50531	-0.04335	3.21820	2516598.678	6856278.060	141.995
22_25	-0.48013	-0.00079	3.21806	2516597.931	6856278.024	142.019
22_26	-0.49884	-0.10879	3.21317	2516596.967	6856278.022	142.022
22_27	-0.50711	-0.02603	3.15878	2516596.245	6856277.961	141.953
22_28	-0.55387	-0.03608	3.16016	2516595.456	6856277.928	141.997
22_29	-0.54708	-0.04239	3.20821	2516594.689	6856277.909	141.989
22_30	-0.53131	-0.05795	3.21524	2516593.865	6856277.866	141.988
22_31	-0.49864	-0.03927	3.19043	2516593.031	6856277.787	142.011
22_32	-0.50327	-0.06411	3.22682	2516592.260	6856277.736	141.983
22_33	-0.51248	-0.03508	3.18652	2516591.450	6856277.698	141.953
22_34	-0.48990	-0.02555	3.18287	2516590.685	6856277.629	141.995
22_35	-0.53039	-0.06187	3.21375	2516589.861	6856277.647	142.035
22_36	-0.50298	-0.04114	3.20129	2516589.087	6856277.561	141.970
22_37	-0.55204	-0.02527	3.22145	2516588.337	6856277.563	141.996
22_38	-0.56966	-0.02961	3.23562	2516587.498	6856277.540	142.033
22_39	-0.52457	-0.01583	3.20488	2516586.596	6856277.438	141.993
23_01	-0.50105	-0.08731	3.18991	2516617.031	6856277.921	142.170
23_02	-0.51243	-0.08651	3.20297	2516616.255	6856277.864	142.125
23_03	-0.56088	-0.05938	3.19328	2516615.479	6856277.860	142.127
23_04	-0.55237	-0.06749	3.19649	2516614.676	6856277.811	142.096
23_05	-0.53676	-0.03133	3.18524	2516613.913	6856277.742	142.043
23_06	-0.50492	-0.05048	3.19541	2516613.111	6856277.692	142.084
23_07	-0.54879	-0.02989	3.19723	2516612.335	6856277.646	142.033
23_08	-0.51535	-0.00210	3.18934	2516611.541	6856277.590	142.100
23_09	-0.51755	-0.01718	3.16655	2516610.694	6856277.538	142.082
23_10	-0.51991	-0.02464	3.16756	2516609.892	6856277.513	142.003
23_11	-0.54621	0.01268	3.15432	2516609.139	6856277.503	142.041
23_12	-0.52833	-0.04242	3.17965	2516608.298	6856277.464	142.056
23_13	-0.53818	-0.02440	3.16075	2516607.507	6856277.407	142.023

23_14	-0.54537	-0.05319	3.17823	2516606.672	6856277.399	142.046
23_15	-0.55700	-0.02283	3.15533	2516605.880	6856277.367	142.051
23_16	-0.51482	-0.02851	3.17452	2516605.083	6856277.224	142.093
23_17	-0.55432	-0.05497	3.19080	2516604.272	6856277.192	142.040
23_18	-0.52363	-0.06329	3.19203	2516603.491	6856277.160	142.006
23_19	-0.51782	-0.06437	3.20613	2516602.691	6856277.124	141.983
23_20	-0.50943	-0.03388	3.19831	2516601.923	6856277.041	141.967
23_21	-0.54590	-0.02344	3.18337	2516601.114	6856277.019	142.040
23_22	-0.51650	-0.06015	3.21149	2516600.313	6856276.939	142.024
23_23	-0.54288	-0.05240	3.22051	2516599.525	6856276.914	141.963
23_24	-0.53643	-0.04859	3.22971	2516598.739	6856276.892	141.955
23_25	-0.57929	-0.05295	3.21893	2516597.934	6856276.874	141.996
23_26	-0.55385	-0.00758	3.15655	2516597.119	6856276.820	141.994
23_27	-0.52708	-0.00394	3.15283	2516596.307	6856276.775	141.956
23_28	-0.55182	-0.05876	3.17664	2516595.485	6856276.779	142.008
23_29	-0.52086	-0.01558	3.14920	2516594.703	6856276.728	141.977
23_30	-0.52298	-0.02154	3.15568	2516593.935	6856276.676	141.972
23_31	-0.51141	-0.03234	3.15300	2516593.108	6856276.630	141.988
23_32	-0.52114	-0.04057	3.18725	2516592.324	6856276.613	142.029
23_33	-0.53549	-0.01273	3.17619	2516591.513	6856276.587	141.988
23_34	-0.53101	-0.04581	3.20953	2516590.717	6856276.505	141.971
23_35	-0.56600	-0.04692	3.20339	2516589.928	6856276.502	141.967
23_36	-0.53757	-0.03847	3.21009	2516589.166	6856276.451	141.963
23_37	-0.58671	-0.04340	3.22008	2516588.269	6856276.466	142.026
23_38	-0.50347	-0.04062	3.24247	2516587.827	6856276.300	142.036
23_39	-0.49891	0.00543	3.18639	2516587.007	6856276.272	142.035
24_01	-0.51111	-0.08275	3.19564	2516617.062	6856276.740	142.163
24_02	-0.55469	-0.10302	3.24322	2516616.335	6856276.663	142.110
24_03	-0.51912	-0.04840	3.21783	2516615.585	6856276.560	142.147
24_04	-0.55620	-0.05407	3.19576	2516614.736	6856276.579	142.115
24_05	-0.55678	-0.03448	3.17406	2516613.956	6856276.566	142.073
24_06	-0.54547	-0.03132	3.18841	2516613.166	6856276.541	142.019
24_07	-0.56579	-0.03059	3.18351	2516612.362	6856276.576	141.995
24_08	-0.58166	-0.02705	3.18768	2516611.567	6856276.580	142.013
24_09	-0.58606	-0.01818	3.19665	2516610.764	6856276.478	141.960
24_10	-0.56046	-0.05264	3.19780	2516609.948	6856276.425	141.932
24_11	-0.58112	0.00496	3.15029	2516609.173	6856276.388	141.957
24_12	-0.54000	-0.03687	3.16759	2516608.344	6856276.300	141.987
24_13	-0.53875	-0.01519	3.15380	2516607.582	6856276.270	141.974
24_14	-0.51581	-0.00759	3.14839	2516606.777	6856276.212	141.987
24_15	-0.56177	-0.05204	3.17588	2516605.946	6856276.250	141.997
24_16	-0.50405	-0.01087	3.17733	2516605.184	6856276.160	142.087
24_17	-0.56189	-0.04806	3.18256	2516604.344	6856276.139	142.004
24_18	-0.56504	-0.03473	3.16741	2516603.574	6856276.113	141.998
24_19	-0.58609	-0.03312	3.17248	2516602.771	6856276.113	141.975
24_20	-0.55070	-0.00207	3.17144	2516602.007	6856276.049	142.138
24_21	-0.51751	-0.03725	3.18518	2516601.169	6856275.995	142.041
24_22	-0.54488	-0.04371	3.19564	2516600.396	6856276.002	141.995
24_23	-0.52292	-0.03726	3.18988	2516599.571	6856275.945	141.956
24_24	-0.53118	-0.02987	3.21147	2516598.799	6856275.910	141.971
24_25	-0.56412	-0.06944	3.23569	2516597.981	6856275.841	141.941
24_26	-0.56893	-0.02475	3.22101	2516597.200	6856275.707	141.968
24_27	-0.57367	-0.00341	3.20348	2516596.405	6856275.714	141.956
24_28	-0.54296	-0.01112	3.20802	2516595.629	6856275.642	141.998
24_29	-0.52840	-0.03384	3.18782	2516594.795	6856275.591	142.020
24_30	-0.55457	-0.02542	3.16959	2516593.996	6856275.635	142.131
24_31	-0.54904	-0.06023	3.21593	2516593.179	6856275.539	141.986
24_32	-0.55011	-0.05393	3.20500	2516592.370	6856275.539	142.030
24_33	-0.53588	-0.01935	3.18236	2516591.595	6856275.466	142.013
24_34	-0.53446	-0.03038	3.17716	2516590.776	6856275.435	141.952
24_35	-0.53695	-0.01143	3.16249	2516590.001	6856275.385	141.995
24_36	-0.54276	0.02780	3.10827	2516589.195	6856275.332	142.000
24_37	-0.54225	0.00054	3.11165	2516588.382	6856275.250	141.990
24_38	-0.50286	0.03252	3.12643	2516587.669	6856275.148	142.016
24_39	-0.55320	-0.02957	3.16538	2516586.808	6856275.178	142.013
25_01	-0.52542	-0.07277	3.23018	2516617.209	6856275.633	142.121
25_02	-0.53015	-0.07088	3.24562	2516616.454	6856275.538	142.086
25_03	-0.51825	-0.10233	3.27571	2516615.647	6856275.459	142.091
25_04	-0.53626	-0.12532	3.27721	2516614.834	6856275.420	142.098
25_05	-0.52956	-0.08376	3.24072	2516614.020	6856275.275	142.127
25_06	-0.55292	-0.05203	3.21439	2516613.237	6856275.193	142.152
25_07	-0.53413	-0.04213	3.17277	2516612.429	6856275.210	142.155
25_08	-0.53919	-0.05405	3.18820	2516611.662	6856275.163	142.049
25_09	-0.54219	-0.04583	3.16922	2516611.022	6856275.137	142.037
25_10	-0.52218	-0.05276	3.17360	2516610.145	6856275.083	142.026
25_11	-0.52584	-0.03683	3.15326	2516609.313	6856275.086	141.992
25_12	-0.54941	-0.04013	3.15960	2516608.439	6856275.038	142.042
25_13	-0.51138	-0.04893	3.16488	2516607.625	6856274.988	141.979
25_14	-0.52271	-0.04624	3.17030	2516606.842	6856274.987	141.937
25_15	-0.50903	-0.05110	3.19251	2516606.026	6856274.942	141.947
25_16	-0.53877	-0.06349	3.20272	2516605.238	6856274.924	141.951
25_17	-0.49686	-0.05730	3.18613	2516604.437	6856274.833	141.916
25_18	-0.49471	-0.05113	3.18208	2516603.636	6856274.796	141.909
25_19	-0.53514	-0.07061	3.21193	2516602.848	6856274.774	141.907
25_20	-0.50879	-0.03499	3.19560	2516602.084	6856274.706	141.933
25_21	-0.49453	-0.07623	3.21690	2516601.241	6856274.678	141.925
25_22	-0.50271	-0.07062	3.21518	2516600.462	6856274.640	141.893
25_23	-0.52966	-0.07307	3.22221	2516599.631	6856274.608	141.883
25_24	-0.51353	-0.06573	3.22072	2516598.856	6856274.562	141.874
25_25	-0.52179	-0.07765	3.23887	2516598.054	6856274.519	141.880
25_26	-0.52675	-0.05525	3.21460	2516597.279	6856274.458	141.911
25_27	-0.55199	-0.03933	3.20720	2516596.484	6856274.448	141.907
25_28	-0.51608	-0.08711	3.25414	2516595.659	6856274.423	141.944
25_29	-0.50718	-0.07607	3.23633	2516594.866	6856274.368	141.953
25_30	-0.50263	-0.06630	3.23469	2516594.059	6856274.274	141.998
25_31	-0.49554	-0.04250	3.18910	2516593.290	6856274.176	141.966
25_32	-0.51475	-0.06381	3.19929	2516592.462	6856274.177	141.998
25_33	-0.52152	-0.03074	3.17207	2516591.687	6856274.140	142.014
25_34	-0.49912	-0.03102	3.16799	2516590.883	6856274.107	142.001
25_35	-0.51579	-0.01720	3.16150	2516590.106	6856274.128	142.040
25_36	-0.49540	-0.00652	3.16499	2516589.314	6856274.014	142.008
25_37	-0.51493	-0.02985	3.17216	2516588.507	6856274.016	141.947
25_38	-0.49228	-0.01383	3.18763	2516587.756	6856274.003	141.960
25_39	-0.50559	0.00240	3.15793	2516586.861	6856273.986	141.967
26_01	-0.49604	-0.04222	3.22297	2516617.215	6856274.414	142.159
26_02	-0.49368	-0.05469	3.23421	2516616.535	6856274.304	142.139
26_03	-0.54292	-0.00170	3.17568	2516615.766	6856274.280	142.160
26_04	-0.55767	-0.03468	3.20551	2516614.929	6856274.254	142.154
26_05	-0.60950	-0.01810	3.19434	2516614.160	6856274.205	142.193
26_06	-0.53886	-0.05832	3.21974	2516613.342	6856274.081	142.111
26_07	-0.55592	-0.04003	3.18622	2516612.527	6856274.059	142.074
26_08	-0.55382	-0.03383	3.20141	2516611.725	6856274.066	142.121
26_09	-0.53223	-0.03960	3.19674	2516610.928	6856274.010	142.064
26_10	-0.59246	-0.04301	3.16548	2516610.101	6856274.023	141.998
26_11	-0.59497	-0.03022	3.16528	2516609.321	6856274.074	141.943
26_12	-0.57675	-0.02022	3.14918	2516608.524	6856274.013	141.935
26_13	-0.57714	-0.02163	3.17052	2516607.755	6856273.959	141.944
26_14	-0.59815	-0.02518	3.17981	2516606.949	6856273.948	141.944
26_15	-0.56960	-0.04148	3.18861	2516606.140	6856273.869	141.991
26_16	-0.54446	-0.04945	3.18678	2516605.319	6856273.808	142.010
26_17	-0.55867	-0.05063	3.16995	2516604.498	6856273.798	142.007
26_18	-0.54063	-0.04707	3.16652	2516603.699	6856273.735	141.952
26_19	-0.54615	-0.05206	3.19322	2516602.921	6856273.758	141.974
26_20	-0.51556	-0.04939	3.20376	2516602.141	6856273.643	141.989
26_21	-0.54755	-0.06555	3.21881	2516601.335	6856273.576	141.970

26_22	-0.52216	-0.04300	3.20337	2516600.546	6856273.499	141.936
26_23	-0.55362	-0.03427	3.20514	2516599.766	6856273.478	141.942
26_24	-0.53706	-0.05380	3.23700	2516598.924	6856273.428	141.934
26_25	-0.54076	-0.04726	3.22563	2516598.144	6856273.428	141.977
26_26	-0.55911	-0.05115	3.23324	2516597.384	6856273.434	141.970
26_27	-0.58637	-0.05978	3.25737	2516596.563	6856273.438	141.971
26_28	-0.57413	-0.02404	3.23808	2516595.783	6856273.295	141.951
26_29	-0.59781	-0.08093	3.19032	2516594.884	6856273.273	141.948
26_30	-0.56180	-0.05405	3.20242	2516594.130	6856273.173	142.002
26_31	-0.53034	-0.03400	3.17383	2516593.341	6856273.168	141.952
26_32	-0.54782	-0.02057	3.16690	2516592.542	6856273.125	141.946
26_33	-0.54860	-0.04585	3.19030	2516591.733	6856273.083	141.942
26_34	-0.51067	-0.02679	3.19656	2516590.979	6856272.977	141.986
26_35	-0.49901	-0.04805	3.21222	2516590.164	6856272.908	142.000
26_36	-0.54125	-0.04886	3.19141	2516589.351	6856272.885	141.979
26_37	-0.53242	-0.00202	3.13899	2516588.585	6856272.815	141.966
26_38	-0.54978	0.00851	3.14630	2516587.793	6856272.822	141.949
26_39	-0.53097	-0.03385	3.14245	2516586.914	6856272.766	141.986
27_01	-0.56158	-0.04450	3.22294	2516617.337	6856273.212	142.055
27_02	-0.55666	-0.02518	3.20479	2516616.522	6856273.215	142.149
27_03	-0.57023	-0.04375	3.21756	2516615.726	6856273.165	142.126
27_04	-0.55018	-0.02028	3.19862	2516614.977	6856273.095	142.157
27_05	-0.56166	-0.05617	3.20281	2516614.167	6856272.993	142.155
27_06	-0.56000	-0.02112	3.16016	2516613.353	6856272.988	142.154
27_07	-0.54884	-0.03187	3.17436	2516612.539	6856272.989	142.111
27_08	-0.56350	-0.03201	3.18195	2516611.737	6856272.942	142.096
27_09	-0.56954	-0.04935	3.20057	2516610.965	6856272.904	142.071
27_10	-0.57068	-0.04399	3.18268	2516610.134	6856272.868	142.040
27_11	-0.53943	-0.04749	3.18388	2516609.340	6856272.818	142.032
27_12	-0.56692	-0.05528	3.19124	2516608.555	6856272.811	142.036
27_13	-0.55768	-0.06801	3.20516	2516607.735	6856272.719	142.014
27_14	-0.54185	-0.04930	3.20613	2516606.976	6856272.669	142.026
27_15	-0.52290	-0.07550	3.20890	2516606.112	6856272.599	142.019
27_16	-0.54778	-0.07501	3.21939	2516605.360	6856272.605	141.973
27_17	-0.56144	-0.06217	3.19823	2516604.541	6856272.547	141.946
27_18	-0.56188	-0.04208	3.18553	2516603.741	6856272.532	141.945
27_19	-0.56254	-0.03673	3.18405	2516602.970	6856272.469	141.928
27_20	-0.56712	-0.03756	3.19852	2516602.185	6856272.446	141.900
27_21	-0.58712	-0.07621	3.21632	2516601.362	6856272.379	141.897
27_22	-0.57986	-0.07198	3.23931	2516600.565	6856272.353	141.920
27_23	-0.53662	-0.04550	3.22386	2516599.796	6856272.333	141.932
27_24	-0.58426	-0.05599	3.21346	2516598.972	6856272.318	141.896
27_25	-0.55052	-0.03904	3.20757	2516598.177	6856272.273	141.921
27_26	-0.53037	-0.00889	3.18468	2516597.373	6856272.205	141.928
27_27	-0.58050	-0.05418	3.20683	2516596.541	6856272.183	141.951
27_28	-0.60228	-0.17667	3.19596	2516595.585	6856272.146	141.855
27_29	-0.54706	-0.13583	3.19476	2516594.876	6856272.054	141.850
27_30	-0.53771	-0.00278	3.18713	2516594.255	6856272.047	141.978
27_31	-0.54386	-0.05908	3.22355	2516593.391	6856271.997	142.061
27_32	-0.50689	-0.04474	3.20311	2516592.601	6856271.998	141.996
27_33	-0.56990	-0.04635	3.17259	2516591.764	6856271.986	141.916
27_34	-0.56940	-0.06852	3.16435	2516590.954	6856271.883	141.889
27_35	-0.55906	-0.06143	3.17223	2516590.167	6856271.823	141.899
27_36	-0.50524	-0.00119	3.15702	2516589.436	6856271.733	141.925
27_37	-0.54325	-0.01143	3.17269	2516588.677	6856271.699	141.897
27_38	-0.54172	-0.05243	3.20304	2516587.890	6856271.604	141.900
27_39	-0.53320	-0.01493	3.13695	2516587.075	6856271.525	141.914



Radial distortion is up to 74 pixels, decentring 4.

4.2 Lapinkangas forest floor 2012

The same 30x32-m plot was visited again July 5, 2012. The 2007 corners were found, and total station was set up in a location with good view across the plot. Imaging lines with 2-m spacing, E-W-oriented, as in 2007, were established. Distance between photo positions was 1.5 m. This gave 17 x 21 = 357 images. This time, a total of 54 GCPs were positioned in the area (wooden poles). Their numare 10-63. The corner poles P0...P3 from 2007 were measured coordinates with interpoint distances of 31.986, 29.988, 31.983, and 30.042 m. The poles P1..P3 were sticks that had not been entirely immobile as they were only some 5-10 cm into the humus/sand.

The leveled total station was oriented (X0, Y0, rotation) with the help of trees that were measured for XY coordinates in aerial images of 2012, and they numbered 64. The solution for total station was: 99.65º, 2516605.898 m, 6856269.563 m. The sdevs of X0 and Y0 were 0.03 m. When the corner poles P0-P3 were solved for XY using the total station orientation result and observations, the coordinates were:

Corner	X	Y	ΔX	ΔY
P0	2516617.35	6856271.73	-0.12	-0.11
P1	2516615.74	6856303.67	-0.25	-0.10
P2	2516585.79	6856302.20	-0.24	0.00
P3	2516587.34	6856270.25	0.17	-0.02

ΔX, ΔY are the deviations to coordinates of 2007 (See Section Lapinkangas forest floor 2007).

These results clearly indicate that there were systematic differences in the fotogrammetric coordinates of trees.

Another solution was obtained by minimizing the RMS-error between 2007 and 2012, for the eight X and Y coordinates of the corner poles P0-P3. The 28 common (2007 & 2012) trees were used, with the fotogrammetric XY coordinates of 2007. While minimizing the RMS (of 2007 vs. 2012 differences) at the four corners, the SDEV of the X and Y residuals were 0.33 m for the 28 common trees. SE is 0.33/sqrt(28) ~ 0.06 m. The mean deviations were -0.031 m, and -0.017 m, suggesting quite good fit between the azimuth/distance field observations of 2007 and 2012.

Solution of plot corner coordinates utilizing the tree coordinates of 2007 for 28 trees observed for azimuth and distance with the total station in 2012. RMS of ΔX, ΔY was minimized here:

Corner	X	Y	ΔX	ΔY
P0	2516617.17	6856271.70	0.05	-0.03
P1	2516615.51	6856303.64	-0.02	-0.02
P2	2516585.56	6856302.12	-0.01	0.03
P3	2516587.17	6856270.17	-0.01	0.01

In this solution, the total station orientation became 99.56º, 2516605.720 m, 6856269.513 m, showing an offset of 18 cm in X and 5 cm in Y to the solution applying 64 trees observed in aerial images of 2012.

What needs to be done (written in 2013), clearly, is a local triangulation from accurate GNSS points. The current absolute solution can be off 5–15 cm because of the fotogrammetric observations of tree positions might be affected by aerial image orientation offsets and effects by the solar azimuth on trees seen in the images. Such offsets were observed in Korpela (2008) between LiDAR and the positioned lichen mats (and in Korpela, Hovi. Morsdorf 2012, for the neighboring LK3 plot).

Another option is to find corresponding targets in the 2007 and 2012 image blocks, and compute the offset from these data (Fig. 127). This might however be difficult, because so few immobile and unchanged details will be available. (tried in Dec 2023).

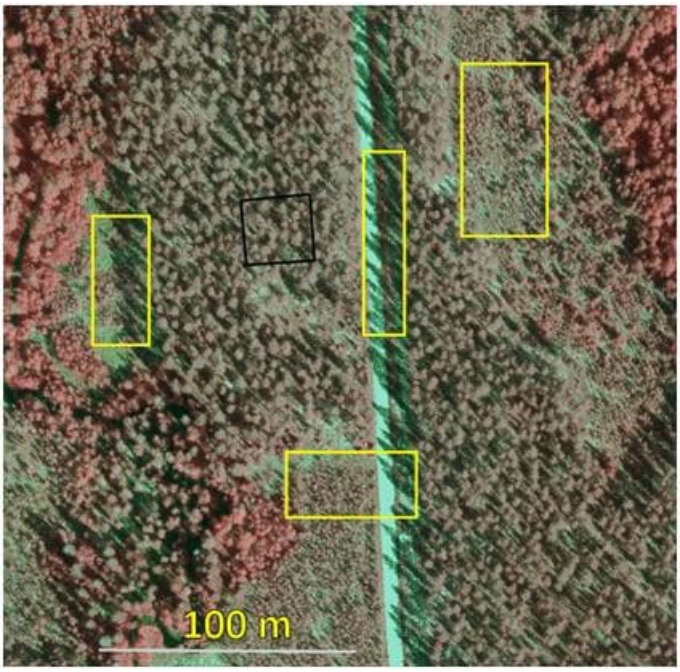


Fig. 125. The aerial image of 2012 shows potential openings from where a Network GNSS solution is available.

Imaging July 5, 2012

A 3.76-m high (height of the ball-joint in the camera head) pole was used. Nikon D300 with f=18 mm was used. The optical axis pointed south and down, zenith angle was ~70º. The camera often rotated about the pole as seen in Fig. 126. The f-number was fixed at f/8. ISO-400. Shutter speed varied (automatic). Time tags are from 14:36 to 18:45 (4 hours).

Fig. 126. An image where the camera has rotated some 10 degrees and the optical axis is not exactly towards south. The pole with the leveling bubble is seen.

Photography started from the plot's NE corner, and the first line was traversed E->W, and the next by returning W->E, and so on. DSC9383.jpg ... DSC9746.jpg. There are some gaps in the numbering of the DSC#### (images re-taken).

Orientation - interior

The iWitness camera calibration was done the next day:

```
Camera number: 1, name: NIKON CORPORATION
NIKON D300, ID: Cala_20120706_2
Calibration Date: 06/07/2012 13:42pm
Resolution: 4288 x 2848 pixels, Pixel Size =
0.0055 mm
 c =   18.686582 mm
xp =    0.018544 mm
yp =    0.041191 mm
K1 = 4.5472e-004
K2 = -2.1406e-007
K3 = -3.5513e-009
P1 = 3.9502e-005
P2 = 9.6460e-006
B1 = 0.0000e+000
B2 = 0.0000e+000
```

Orientation – exterior

Triangulation has not been done (2013). The coordinates systems of 2007 and 2012 were shown to match with a precision of 2-3 cm.

If triangulation of 2012 imagery is tried, it would be preferable to try to find conjugate points seen in both 2007 and 2012, but this may be very challenging. Details of tree bark may perhaps be used, or stems of small understory spruces and pines (XY constraints), but in all probability the mismatch will be in the order of 2-3 cm. In 2007, there were only 36 GCPs, with an average spacing of 6 m, and the images covered smaller areas, giving a higher number of images between GCPs, which may skew locally the coordinates.

The absolute orientation of the GCPs of 2012 needs to be established as explained before. It is a less demanding task than the orientation of the 357 images, which may take 30-40 hours.

Files

Plot_positioning_using_64_trees_with_2012_photo_coords.xlsx
Solution of total station orientation by fitting to the 64 trees positioned in 2012 images. (updates in Dec 2023)

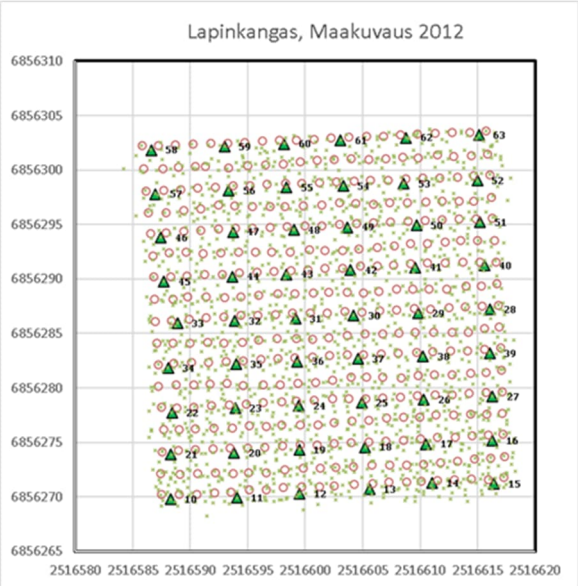
Plot_positioning_using_28_trees_with_2007_photo_coords.xlsx
Solution of total station orientation by fitting the plot corners of 2007 and 2012, using 28 common trees observed in both time points and the fotogrammetric tree coordinates of 2007.

JPEGs\

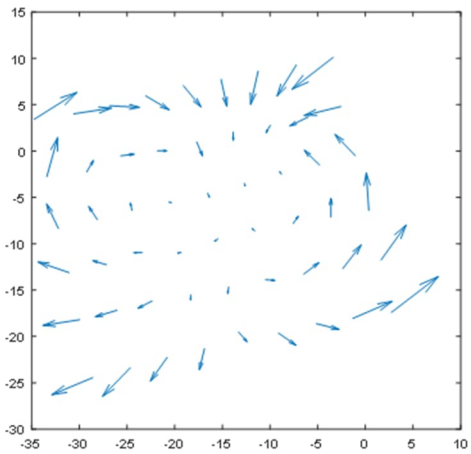
Fig. 127. Example image pair with an almost similar view geometry.

Orientation in Dec 2023

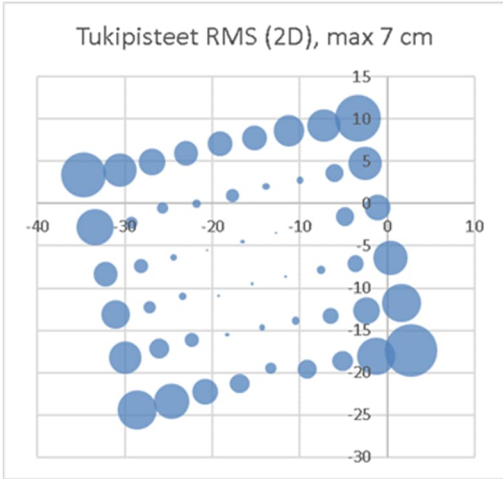
The images were triangulated with iWitness (manually) by positioning tie points (n=1649) between images. Of these, 54 were GCPs that had been measured with the tacheometer in July 2012. iWitness does relative orientation (bundle block adjustment), and the resulting 3D point cloud of tie points was transformed using a rigid 3D transformation to the network of the 54 GCPs. The errors in these 54 points had SDEVs of 20, 26 and 12 mm. GCPs were not used in triangulation to "force geometry to comply" to these observations.



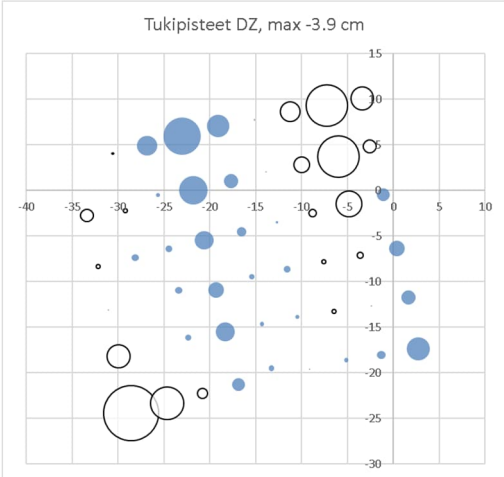
Map of camera positions, GCPs (treated as tie points) and tiepoints in the KKJ2 coordinate system.



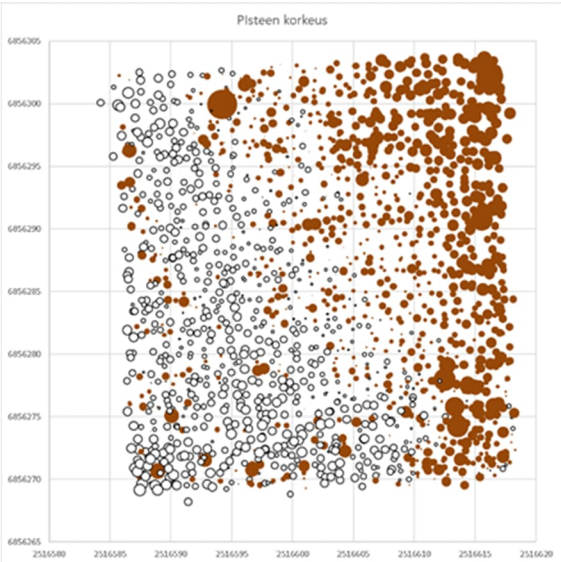
The XY error vectors in XY in the 54 control points (Matlab quiver plot).



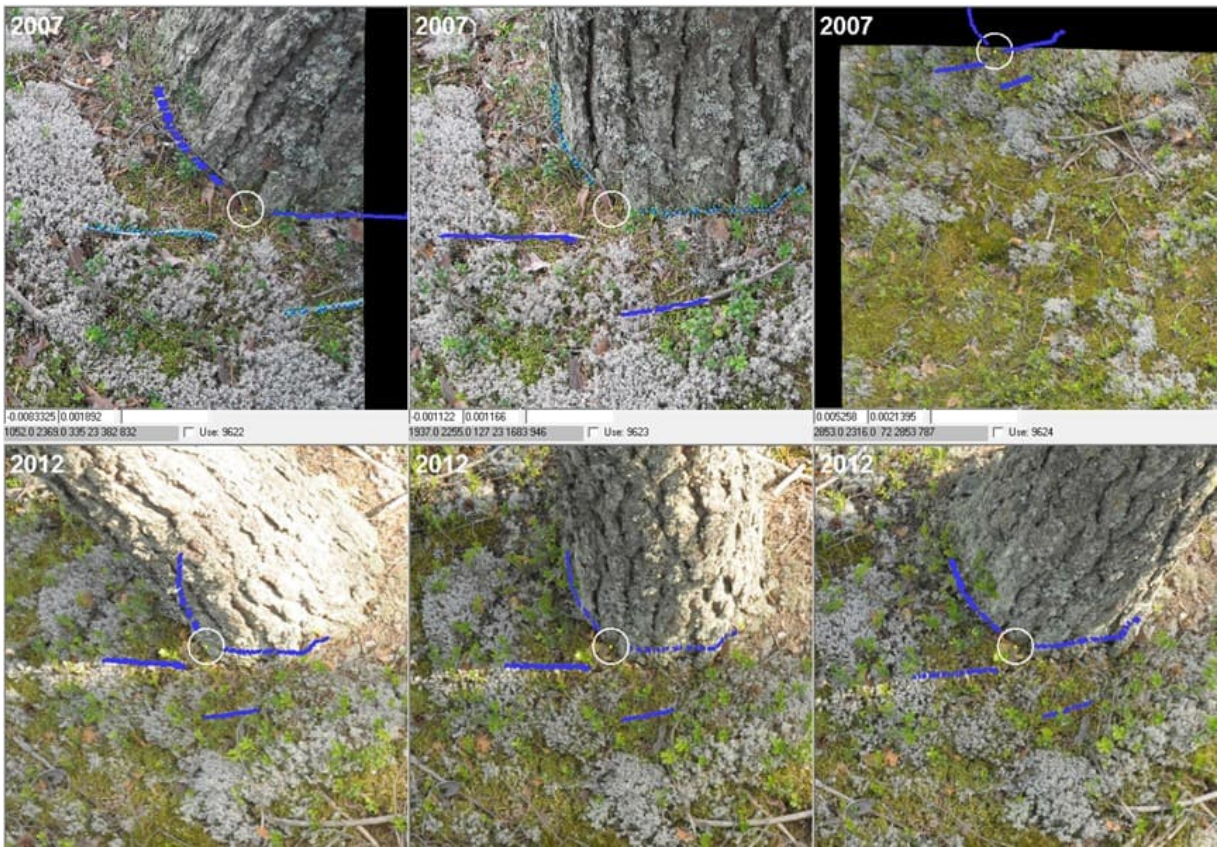
Norm of the XY error vectors in the 54 control points (Excel). Norm varies 0..70 mm.



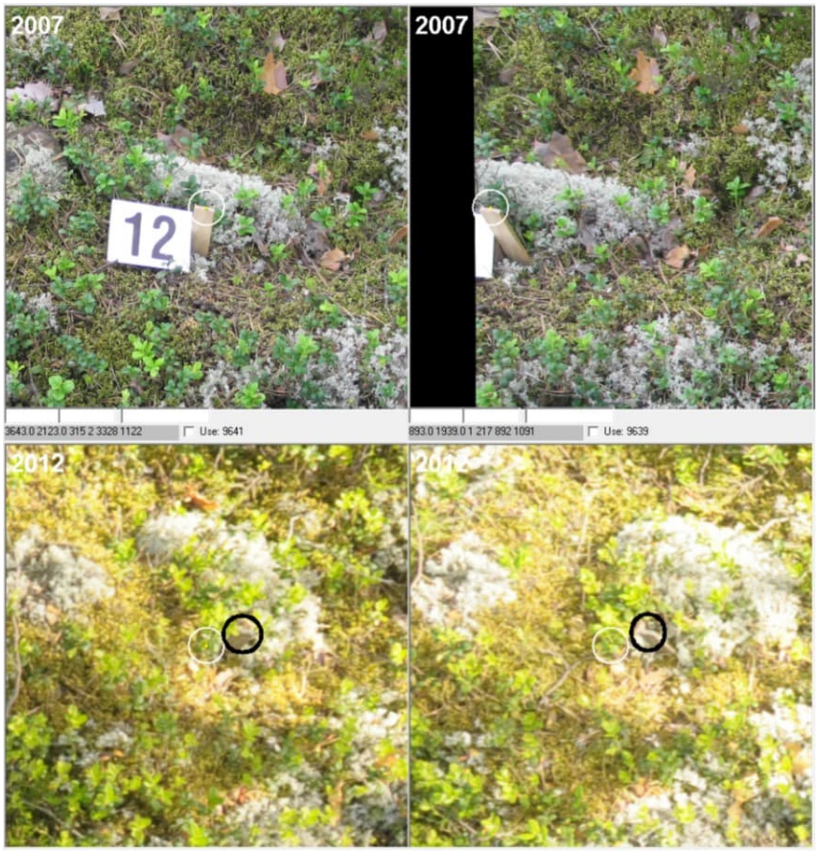
Z-errors in the control points (-39...+26 mm).



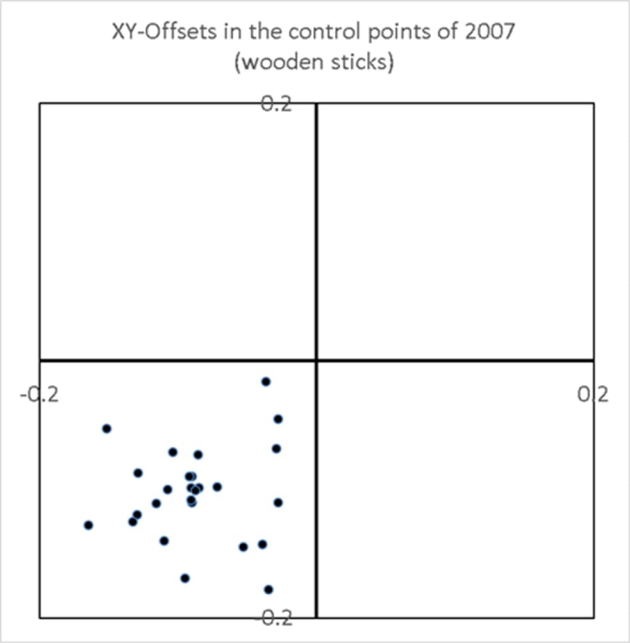
Elevation variation of tie points 140.39-142.31 m (N60 system of heights). Ground varies from 140.4...140.9, points above are tiepoints in trunks of trees, stumps, understory trees.



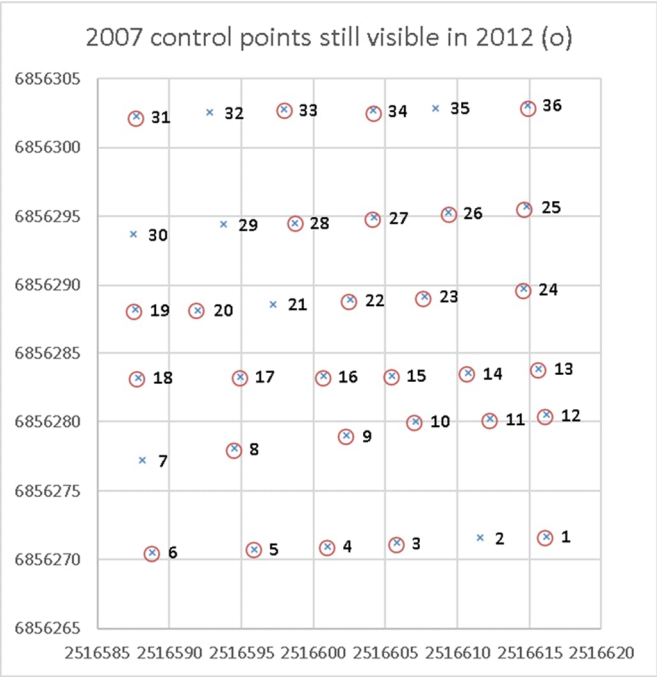
In the centre of the plot the geometry of the 2007 and 2012 image blocks has just 1-3 cm offsets. Image pair of 2007 and four images of 2012. A twig was positioned in 2007 images (circled) and using the Z values, objecs were pointed in the 2007 images (blue dots are short epipolar lines at that Z). All litter has changed in 5 years, lichen mats are tracable.



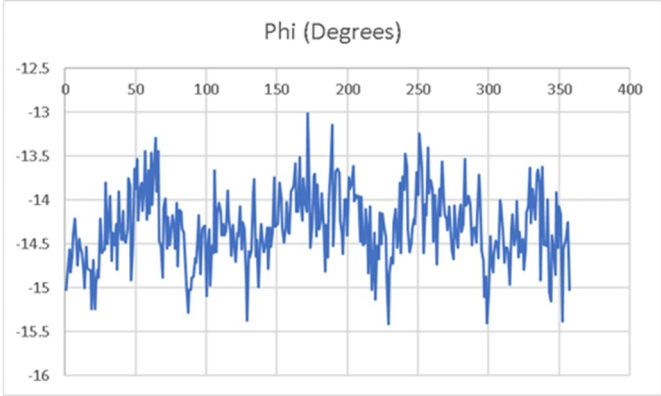
GCP #12 of 2007 was one of the 27 control points of 2007, where the wooden stick was still visible in the 2012 images (in many cases the stick had bent or broken). In image scale, the offset was 4.6 cm with 3D photogrammetric coordinates 2516616.17, 6856280.51, 140.85 and 2516616.12, 6856280.49, 140.86, i.e. showing offsets of 5 cm, 2 cm and 1 cm in X, Y and Z.



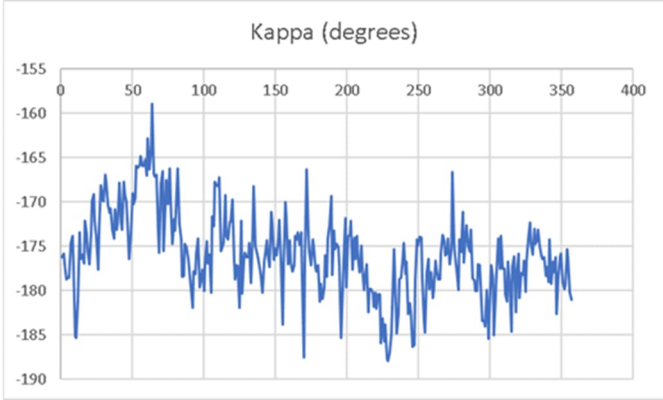
XY-offsets between the GCPs of 2007 and their photogrammetric coordinates in the 2012 images (includes all broken / bent cases). The average offsets of 88 and 101 mm were applied to the 54 GCPs of 2012 to have the image blocks of 2007 and 2012 match better. The SDEV of deviations were 37 and 35 mm in X and Y. The SDEV of Z coordinate differences was 27 mm.



Circled GCPs still had remnants of the wooden stick seen in the 2012 images. The numbering of points is from 2007.



The camera tilt was 14-15 degrees in images 1-357.



The camera rotated about the 4 m pole +/- 10 degrees (the pole rotated in the hands of the photographer), but the overlaps were high enough such that each point is seen in stereo.

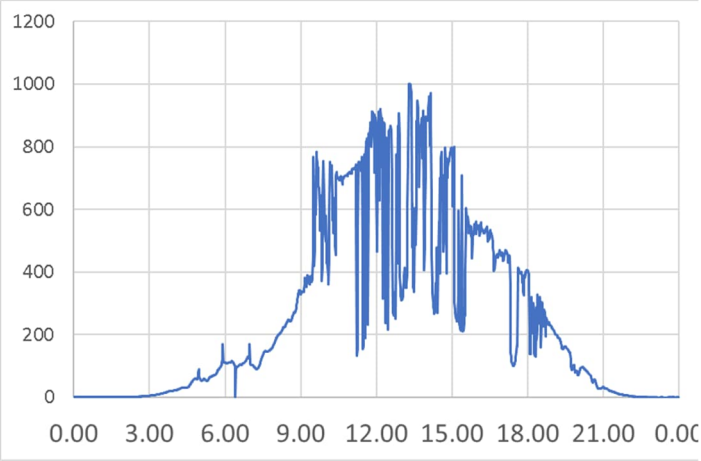
The EO-parameters following shift to match 2007 block are given below.

Image-#, omega, phi, kappa, X0, Y0, Z0 of the images:

9383	-0.26218	-0.03581	-3.07509	2516615.834	6856303.665	144.506
9384	-0.25808	-0.01823	-3.06960	2516614.392	6856303.567	144.461
9385	-0.25409	-0.02246	-3.09031	2516612.867	6856303.511	144.389
9386	-0.25866	-0.01552	-3.11906	2516611.365	6856303.444	144.374
9387	-0.25559	-0.02355	-3.11689	2516609.857	6856303.370	144.409
9388	-0.25116	-0.01714	-3.11663	2516608.369	6856303.302	144.401
9389	-0.24801	-0.03479	-3.04828	2516606.897	6856303.203	144.353
9390	-0.25389	-0.03454	-3.03357	2516605.394	6856303.186	144.374
9391	-0.25725	-0.02593	-3.09089	2516603.878	6856303.110	144.369
9392	-0.25204	0.01217	3.05199	2516602.361	6856303.029	144.320
9393	-0.25355	0.01274	3.04778	2516600.849	6856302.939	144.326
9394	-0.25491	-0.01922	3.12190	2516599.302	6856302.867	144.299
9395	-0.25866	-0.03784	-3.02778	2516597.873	6856302.867	144.290
9396	-0.26181	-0.02273	-3.07858	2516596.370	6856302.742	144.452
9397	-0.25372	-0.03725	-3.07003	2516594.842	6856302.634	144.252
9398	-0.25777	-0.02382	-3.08834	2516593.378	6856302.585	144.254
9399	-0.25820	-0.05648	-3.00492	2516591.849	6856302.553	144.204
9400	-0.25843	-0.03742	-3.03034	2516590.360	6856302.495	144.197
9401	-0.26613	-0.03795	-3.06421	2516588.815	6856302.437	144.153
9402	-0.25632	-0.02635	-3.08987	2516587.336	6856302.367	144.127
9403	-0.26603	-0.04001	-3.02920	2516585.866	6856302.343	144.105
9404	-0.26092	-0.05777	-2.96606	2516586.039	6856300.203	144.132
9405	-0.25816	-0.05992	-2.95182	2516587.689	6856300.210	144.159
9406	-0.25968	-0.04981	-3.00493	2516589.064	6856300.345	144.162
9407	-0.24807	-0.03096	-3.04068	2516590.534	6856300.416	144.210
9408	-0.25492	-0.01996	-3.10045	2516591.426	6856300.391	144.245
9409	-0.25435	-0.04339	-3.01917	2516593.410	6856300.308	144.236
9410	-0.25422	-0.06815	-2.93357	2516595.109	6856300.528	144.260
9411	-0.24084	-0.05315	-2.96165	2516596.655	6856300.579	144.265
9412	-0.25313	-0.04844	-2.96517	2516598.178	6856300.643	144.278
9413	-0.24689	-0.06660	-2.91429	2516599.630	6856300.847	144.295
9414	-0.24360	-0.06219	-2.92806	2516601.116	6856300.971	144.302
9415	-0.25637	-0.04897	-2.97242	2516602.626	6856301.080	144.335
9416	-0.25079	-0.04886	-2.98868	2516604.063	6856301.138	144.328
9417	-0.25333	-0.05121	-2.97905	2516605.623	6856301.085	144.453
9418	-0.24907	-0.03934	-3.02252	2516607.108	6856301.139	144.339
9419	-0.25825	-0.03583	-3.04005	2516608.603	6856301.276	144.450
9420	-0.24262	-0.04598	-2.98157	2516609.937	6856301.226	144.447
9421	-0.24881	-0.04378	-3.02089	2516611.615	6856301.501	144.428
9422	-0.25228	-0.04570	-3.00861	2516612.999	6856301.376	144.423
9423	-0.24656	-0.06487	-2.93005	2516614.539	6856301.426	144.398
9424	-0.25217	-0.05307	-3.00964	2516615.952	6856301.564	144.503
9425	-0.25285	-0.05314	-3.02182	2516616.178	6856299.628	144.438
9426	-0.24991	-0.07905	-2.92684	2516614.759	6856299.589	144.414
9427	-0.24011	-0.06360	-2.95047	2516613.307	6856299.430	144.380
9428	-0.24169	-0.06407	-2.96763	2516611.771	6856299.356	144.316
9429	-0.26037	-0.04045	-3.03929	2516610.301	6856299.366	144.414
9430	-0.25335	-0.02190	-3.07941	2516608.814	6856299.281	144.335
9431	-0.23810	-0.03563	-3.03103	2516607.332	6856299.170	144.351
9432	-0.24209	-0.06598	-2.95096	2516605.790	6856299.146	144.343
9433	-0.23624	-0.05537	-2.97166	2516604.318	6856299.060	144.295
9434	-0.24839	-0.06881	-2.95886	2516602.797	6856299.016	144.294
9435	-0.24210	-0.08322	-2.89628	2516601.324	6856298.939	144.296
9436	-0.24082	-0.07526	-2.89996	2516599.808	6856298.858	144.283
9437	-0.24655	-0.07154	-2.89353	2516598.370	6856298.850	144.257
9438	-0.24100	-0.08067	-2.87616	2516596.781	6856298.790	144.262
9439	-0.23463	-0.07938	-2.89615	2516595.296	6856298.688	144.259
9440	-0.24830	-0.07577	-2.89565	2516593.796	6856298.633	144.251
9441	-0.23844	-0.08512	-2.88337	2516592.266	6856298.495	144.214

9442	-0.24698	-0.07947	-2.91579	2516590.742	6856298.445	144.193
9443	-0.23494	-0.09134	-2.84142	2516589.255	6856298.330	144.142
9444	-0.24530	-0.07584	-2.90230	2516587.750	6856298.257	144.166
9445	-0.23799	-0.08723	-2.86105	2516586.258	6856298.160	144.124
9446	-0.23192	-0.10978	-2.77333	2516586.414	6856296.190	144.159
9447	-0.24266	-0.06517	-2.91143	2516587.992	6856296.204	144.165
9448	-0.23471	-0.06819	-2.91713	2516589.537	6856296.375	144.172
9449	-0.25247	-0.06440	-2.91284	2516590.983	6856296.564	144.197
9450	-0.25373	-0.05085	-3.02640	2516592.539	6856296.872	144.268
9451	-0.25975	-0.03788	-3.06640	2516593.966	6856296.828	144.240
9452	-0.24583	-0.07096	-2.93144	2516595.506	6856296.765	144.237
9453	-0.24410	-0.07746	-2.90572	2516597.029	6856296.771	144.283
9454	-0.25405	-0.02098	-3.06327	2516598.338	6856296.738	144.315
9455	-0.24775	-0.06190	-2.97241	2516599.931	6856296.793	144.280
9456	-0.25331	-0.06728	-2.92400	2516601.531	6856296.861	144.282
9457	-0.25180	-0.06561	-2.97174	2516603.062	6856297.114	144.287
9458	-0.24734	-0.06390	-2.90125	2516604.478	6856297.017	144.319
9459	-0.24992	-0.06344	-2.96400	2516606.057	6856296.985	144.318
9460	-0.25400	-0.04031	-3.04989	2516607.461	6856297.089	144.352
9461	-0.24489	-0.04709	-3.00149	2516608.950	6856297.082	144.336
9462	-0.25742	-0.05133	-3.02419	2516610.561	6856297.155	144.394
9463	-0.24630	-0.06928	-2.94092	2516612.021	6856297.232	144.415
9464	-0.24661	-0.07936	-2.90106	2516613.473	6856297.218	144.413
9465	-0.25001	-0.03493	-3.01099	2516614.719	6856297.272	144.438
9466	-0.25092	-0.03866	-3.04090	2516616.282	6856297.617	144.464
9467	-0.25429	-0.02362	-3.11398	2516616.390	6856295.682	144.429
9468	-0.26128	-0.03001	-3.11214	2516614.971	6856295.642	144.431
9469	-0.26672	-0.04543	-3.04899	2516613.498	6856295.580	144.431
9470	-0.26229	-0.04155	-3.05748	2516612.018	6856295.537	144.398
9471	-0.26230	-0.03784	-3.07947	2516610.540	6856295.471	144.372
9472	-0.25969	-0.02588	-3.09821	2516609.044	6856295.415	144.340
9473	-0.25954	-0.02831	-3.13638	2516607.518	6856295.361	144.307
9474	-0.25598	-0.01461	3.10774	2516606.030	6856295.255	144.345
9475	-0.25674	-0.02561	-3.10373	2516604.578	6856295.199	144.336
9476	-0.25127	-0.03001	-3.10840	2516603.064	6856295.124	144.314
9477	-0.24740	-0.04128	-3.06934	2516601.561	6856295.007	144.247
9478	-0.25913	-0.05426	-3.03916	2516600.027	6856294.938	144.284
9479	-0.25018	-0.02385	-3.13501	2516598.515	6856294.900	144.247
9480	-0.24981	-0.01670	-3.12355	2516597.060	6856294.852	144.291
9481	-0.24954	-0.03410	-3.10042	2516595.526	6856294.791	144.238
9482	-0.26340	-0.02476	-3.14157	2516594.000	6856294.766	144.199
9483	-0.25431	-0.03359	-3.08691	2516592.520	6856294.722	144.231
9484	-0.25016	-0.05619	-3.04442	2516590.973	6856294.571	144.246
9485	-0.26142	-0.02880	-3.08884	2516589.514	6856294.497	144.173
9486	-0.25342	-0.04979	-3.06987	2516587.970	6856294.344	144.165
9487	-0.25484	-0.01640	3.13681	2516586.607	6856294.245	144.214
9488	-0.23841	-0.04600	-2.99549	2516586.819	6856292.219	144.235
9489	-0.25466	-0.04994	-3.01533	2516588.238	6856292.470	144.205
9490	-0.24726	-0.07329	-2.92788	2516589.744	6856292.557	144.232
9491	-0.24484	-0.07153	-2.93496	2516591.215	6856292.431	144.199
9492	-0.24672	-0.07390	-2.93600	2516592.725	6856292.492	144.192
9493	-0.25135	-0.08474	-2.91846	2516594.267	6856292.566	144.226
9494	-0.24904	-0.03804	-3.06359	2516595.772	6856292.543	144.233
9495	-0.25147	-0.04516	-3.05253	2516597.159	6856292.593	144.255
9496	-0.25057	-0.03080	-3.04547	2516598.755	6856292.541	144.466
9497	-0.24241	-0.06321	-2.95416	2516600.441	6856292.788	144.269
9498	-0.24776	-0.03944	-3.03380	2516601.824	6856292.701	144.225
9499	-0.25062	-0.04169	-3.04102	2516603.369	6856292.687	144.232
9500	-0.25545	-0.05264	-3.00636	2516604.737	6856292.874	144.285
9501	-0.24923	-0.04773	-3.00566	2516606.371	6856292.989	144.297
9502	-0.25478	-0.06866	-2.96271	2516607.832	6856293.129	144.328
9503	-0.25658	-0.03867	-3.08248	2516609.239	6856293.338	144.314
9504	-0.25077	-0.03081	-3.11868	2516610.702	6856293.361	144.349
9505	-0.25161	-0.03341	-3.09116	2516612.271	6856293.452	144.417
9506	-0.24570	-0.02829	-3.09340	2516613.614	6856293.594	144.480
9507	-0.25420	-0.01865	3.10846	2516615.074	6856293.636	144.437
9508	-0.24876	-0.04512	-3.00470	2516616.585	6856293.645	144.441
9509	-0.25021	0.02761	3.13580	2516616.710	6856291.666	144.479
9510	-0.26005	-0.00554	-3.07853	2516615.278	6856291.661	144.409
9511	-0.26833	-0.01943	-3.06747	2516613.775	6856291.651	144.395
9512	-0.25452	-0.01135	-3.07626	2516612.269	6856291.565	144.358
9513	-0.25568	-0.02186	-3.07506	2516610.752	6856291.579	144.343
9514	-0.25429	-0.02501	-3.04730	2516609.254	6856291.522	144.342
9515	-0.24292	-0.00738	-3.12702	2516607.800	6856291.389	144.317
9516	-0.24022	-0.03032	-3.02519	2516606.332	6856291.283	144.335
9517	-0.25564	-0.04496	-2.93566	2516604.860	6856291.294	144.281
9518	-0.25220	-0.03103	-3.05469	2516603.316	6856291.105	144.339
9519	-0.26168	-0.02736	-3.06251	2516601.774	6856291.097	144.263
9520	-0.25185	-0.01067	-3.07750	2516600.346	6856290.958	144.242
9521	-0.24920	-0.01334	-3.09817	2516598.851	6856290.866	144.247
9522	-0.25310	-0.00776	-3.11137	2516597.368	6856290.793	144.262
9523	-0.25462	0.00861	3.13765	2516595.868	6856290.704	144.196
9524	-0.25309	-0.01701	-3.08410	2516594.359	6856290.628	144.210
9525	-0.24986	-0.01955	-3.07008	2516592.843	6856290.532	144.254
9526	-0.25802	-0.02066	-3.04353	2516591.348	6856290.504	144.198
9527	-0.24986	-0.02189	-3.07040	2516589.797	6856290.386	144.186
9528	-0.25370	-0.00773	-3.09559	2516588.353	6856290.293	144.250
9529	-0.25083	-0.04704	-2.98707	2516586.873	6856290.274	144.197
9530	-0.23978	-0.03276	-3.00814	2516586.959	6856288.220	144.201
9531	-0.24956	-0.01381	-3.08096	2516588.573	6856288.266	144.175
9532	-0.24936	-0.02008	-3.05840	2516589.856	6856288.442	144.164
9533	-0.24918	-0.02790	-3.07221	2516591.445	6856288.440	144.234
9534	-0.24091	-0.02700	-3.03768	2516593.049	6856288.357	144.187
9535	-0.24407	-0.03534	-3.00235	2516594.496	6856288.443	144.244
9536	-0.24976	-0.01758	-3.08642	2516596.037	6856288.616	144.242
9537	-0.25278	0.02116	3.07481	2516597.675	6856288.757	144.226
9538	-0.24957	-0.01460	-3.09100	2516599.157	6856288.764	144.236
9539	-0.24469	-0.03954	-2.96843	2516600.769	6856288.834	144.256
9540	-0.25077	-0.02721	-2.99681	2516602.121	6856288.856	144.263
9541	-0.25103	-0.00096	-3.08950	2516603.713	6856288.868	144.272
9542	-0.24269	-0.02136	-3.04203	2516605.136	6856288.819	144.297
9543	-0.24203	-0.01465	-3.08654	2516606.503	6856288.973	144.296
9544	-0.24145	-0.00432	-3.10325	2516608.071	6856289.145	144.317
9545	-0.23704	-0.01600	-3.09090	2516609.424	6856289.155	144.335
9546	-0.24671	-0.02543	-3.03364	2516610.859	6856289.168	144.323
9547	-0.24661	-0.02638	-3.04104	2516612.432	6856289.151	144.319
9548	-0.23578	-0.01923	-3.02739	2516614.091	6856289.429	144.409
9549	-0.24476	-0.03189	-3.05177	2516615.407	6856289.421	144.377
9550	-0.24834	-0.02077	-3.02662	2516616.792	6856289.638	144.412
9551	-0.24010	-0.03200	-3.12320	2516616.880	6856287.678	144.371
9552	-0.24471	-0.00814	3.01076	2516615.462	6856287.592	144.310
9553	-0.24659	-0.05597	-3.08392	2516614.038	6856287.526	144.360
9554	-0.22704	-0.09554	-2.90354	2516612.575	6856287.433	144.349
9555	-0.24246	-0.07507	-3.02978	2516611.011	6856287.353	144.324
9556	-0.25383	-0.05402	-3.06589	2516609.550	6856287.394	144.306
9557	-0.24986	-0.05646	-3.09216	2516608.019	6856287.274	144.306
9558	-0.23956	-0.06638	-3.04041	2516606.547	6856287.213	144.335
9559	-0.23910	-0.06420	-3.05509	2516605.028	6856287.062	144.268
9560	-0.25149	-0.04984	-3.09597	2516603.512	6856287.128	144.251
9561	-0.24124	-0.05611	-3.10448	2516602.023	6856286.967	144.204
9562	-0.25009	-0.05423	-3.09118	2516600.513	6856286.975	144.233
9563	-0.24818	-0.05152	3.12030	2516598.957	6856286.938	144.239
9564	-0.24299	-0.05410	-3.12779	2516597.508	6856286.816	144.226
9565	-0.24881	-0.04525	3.12527	2516595.940	6856286.757	144.191
9566	-0.25846	-0.04953	-3.13452	2516594.488	6856286.732	144.217
9567	-0.24928	-0.06052	-3.07293	2516592.986	6856286.627	144.242
9568	-0.25571	-0.05386	-3.11506	2516591.457	6856286.574	144.198
9569	-0.24460	-0.06013	-3.03945	2516590.011	6856286.410	144.193
9570	-0.23813	-0.08669	-3.01148	2516588.429	6856286.295	144.192
9571	-0.22937	-0.08709	-2.95478	2516587.055	6856286.210	144.213
9572	-0.25346	-0.04443	-3.11005	2516587.168	6856284.232	144.252
9573	-0.24446	-0.06426	-3.02275	2516588.613	6856284.193	144.178
9574	-0.23865	-0.06480	-3.06083	2516590.034	6856284.239	144.263
9575	-0.23816	-0.06501	-3.04884	2516591.588	6856284.262	144.243
9576	-0.23891	-0.06326	-3.05665	2516593.005	6856284.200	144.186
9577	-0.24845	-0.05196	-3.08926	2516594.588	6856284.250	144.205
9578	-0.25105	-0.02364	3.04865	2516596.039	6856284.473	144.215
9579	-0.25509	-0.03128	-3.13506	2516597.660	6856284.604	144.187
9580	-0.24417	-0.05722	-3.08027	2516599.301	6856284.639	144.274
9581	-0.24429	-0.07091	-2.99976	2516600.715	6856284.573	144.166
9582	-0.25141	-0.04139	-3.13583	2516602.113	6856284.669	144.255
9583	-0.23992	-0.07019	-3.03638	2516603.730	6856284.938	144.281
9584	-0.24206	-0.06822	-3.03059	2516605.271	6856285.049	144.268
9585	-0.24110	-0.06797	-3.00470	2516606.801	6856285.055	144.262
9586	-0.23752	-0.05209	-3.09946	2516608.234	6856285.141	144.308
9587	-0.24465	-0.07124	-3.03794	2516609.663	6856285.166	144.286
9588	-0.24341	-0.05342	-3.07865	2516611.250	6856285.208	144.294
9589	-0.24382	-0.06591	-3.03423	2516612.864	6856285.231	144.351
9590	-0.24350	-0.04928	-3.07666	2516614.289	6856285.184	144.398
9591	-0.25259	-0.04248	-3.10549	2516615.701	6856285.570	144.585
9592	-0.24370	-0.06198	-3.05356	2516616.968	6856285.694	144.394
9593	-0.25332	-0.01522	-3.09454	2516617.105	6856283.773	144.364
9594	-0.25301	-0.00895	-3.14117	2516615.673	6856283.619	144.384
9596	-0.24623	-0.02344	-3.12035	2516614.179	6856283.514	144.298
9597	-0.25080	-0.02321	-3.08999	2516612.712	6856283.485	144.314
9598	-0.25891	0.00000	3.09873	2516611.224	6856283.409	144.324
9605	-0.24556	-0.08895	-3.13878	2516609.749	6856283.341	144.294
9606	-0.26225	-0.09750	-3.13867	2516608.194	6856283.285	144.287
9607	-0.25946	-0.10016	3.13698	2516606.674	6856283.237	144.269
9608	-0.25079	-0.09124	3.11035	2516605.176	6856283.129	144.239
9609	-0.26416	-0.08602	3.13727	2516603.725	6856283.118	144.249
9610	-0.25353	-0.09217	3.10624	2516602.208	6856283.039	144.275
9611	-0.25611	-0.09590	3.13336	2516600.725	6856282.937	144.188
9612	-0.24681	-0.10258	3.13474	2516599.205	6856282.830	144.279
9613	-0.25315	-0.08124	3.03878	2516597.696	6856282.762	144.307
9614	-0.24711	-0.08565	3.08616	2516596.209	6856282.685	144.189
9615	-0.24974	-0.07669	3.04060	2516594.693	6856282.591	144.184
9616	-0.25182	-0.08013	3.07395	2516593.211	6856282.505	144.205
9617	-0.26014	-0.06427	3.00826	2516591.674	6856282.456	144.198
9618	-0.26906	-0.04855	3.00304	2516590.224	6856282.419	144.213
9619	-0.25906	-0.06999	3.01881	2516588.657	6856282.333	144.173
9620	-0.25574	-0.07308	3.05647	2516587.311	6856282.231	144.206
9621	-0.25703	-0.03365	3.11010	2516587.298	6856280.223	144.225
9622	-0.24871	-0.08180	-3.06085	2516588.874	6856280.358	144.190
9623	-0.24608	-0.06405	-3.11253	2516590.425	6856280.358	144.207
9624	-0.25374	-0.03714	3.05771	2516591.819	6856280.465	144.235
9625	-0.25195	-0.04421	3.09629	2516593.276	6856280.491	144.199
9626	-0.24084	-0.06412	-3.11988	2516594.698	6856280.297	144.170
9627	-0.25482	-0.07057	-3.11524	2516596.409	6856280.409	144.166
9628	-0.23961	-0.07965	-3.07612	2516597.919	6856280.389	144.199
9629	-0.24223	-0.08561	-3.04777	2516599.482	6856280.531	144.202
9630	-0.23508	-0.07356	-3.10901	2516600.965	6856280.589	144.192
9631	-0.23777	-0.07317	-3.08401	2516602.502	6856280.794	144.210
9632	-0.25008	-0.05376	3.09598	2516604.083	6856281.110	144.271
9633	-0.25462	-0.04259	3.11690	2516605.437	6856281.085	144.254
9634	-0.25289	-0.04929	3.09973	2516606.856	6856281.066	144.283
9635	-0.24998	-0.03168	3.03078	2516608.450	6856281.025	144.285
9636	-0.24801	-0.02665	3.03367	2516609.899	6856281.228	144.287
9637	-0.24913	-0.05844	-3.12190	2516611.308	6856281.335	144.290
9638	-0.23874	-0.08756	-3.04033	2516612.837	6856281.292	144.282
9639	-0.24330	-0.08479	-3.05333	2516614.479	6856281.427	144.322
9640	-0.23107	-0.08234	-3.03642	2516615.835	6856281.484	144.295
9641	-0.23566	-0.08247	-3.03695	2516617.142	6856281.705	144.372
9642	-0.23804	-0.01791	-3.12035	2516617.214	6856279.714	144.373
9643	-0.25495	-0.00127	3.08222	2516615.826	6856279.685	144.371
9644	-0.24506	0.00298	3.05972	2516614.324	6856279.622	144.330
9645	-0.24739	-0.02275	-3.10523	2516612.851	6856279.496	144.283
9646	-0.23388	-0.03242	-3.07965	2516611.387	6856279.429	144.258
9647	-0.24300	-0.01958	-3.13893	2516609.862	6856279.389	144.257
9648	-0.24031	-0.03385	-3.10591	2516608.371	6856279.273	144.247
9649	-0.24221	-0.01931	3.12784	2516606.864	6856279.206	144.266
9650	-0.25255	-0.02512	-3.14128	2516605.364	6856279.140	144.235
9651	-0.24336	-0.03856	-3.08364	2516603.881	6856279.082	144.209
9652	-0.25709	-0.02484	-3.09800	2516602.467	6856279.084	144.171
9653	-0.24891	-0.02394	-3.11923	2516600.892	6856278.981	144.215
9654	-0.24217	-0.03585	-3.11952	2516599.338	6856278.878	144.199
9655	-0.24752	-0.02520	-3.06838	2516598.018	6856278.838	144.305
9656	-0.23668	-0.04781	-3.03193	2516596.433	6856278.726	144.163
9657	-0.24457	-0.04624	-3.04457	2516594.938	6856278.614	144.189
9658	-0.24739	-0.03398	-3.07236	2516593.449	6856278.508	144.213
9659	-0.24806	-0.03336	-3.06694	2516591.927	6856278.465	144.250
9660	-0.25030	-0.04703	-3.03857	2516590.409	6856278.358	144.280
9661	-0.24555	-0.02685	-3.09005	2516588.912	6856278.282	144.177
9662	-0.25145	-0.03261	-3.05963	2516587.575	6856278.295	144.211
9663	-0.25423	-0.07091	-2.90900	2516587.762	6856276.303	144.226
9664	-0.25609	-0.04037	-3.04611	2516589.105	6856276.285	144.185
9665	-0.24538	-0.03523	-3.07279	2516590.546	6856276.341	144.188
9666	-0.25130	-0.02728	-3.10401	2516592.131	6856276.406	144.215
9667	-0.25374	-0.01705	-3.13964	2516593.723	6856276.439	144.168
9668	-0.24799	-0.04143	-3.04153	2516595.236	6856276.614	144.188
9669	-0.24530	-0.02978	-3.06494	2516596.707	6856276.578	144.174
9670	-0.25064	-0.05815	-2.98762	2516598.062	6856276.666	144.200
9671	-0.24920	-0.03978	-3.08598	2516599.631	6856276.677	144.148
9672	-0.23625	-0.04254	-3.03544	2516601.185	6856276.721	144.226
9673	-0.24552	-0.05454	-3.01307	2516602.587	6856276.937	144.204
9674	-0.24493	-0.04270	-3.05430	2516604.116	6856277.075	144.237
9675	-0.24361	-0.03868	-3.06558	2516605.612	6856277.132	144.235
9676	-0.24518	-0.04548	-3.02162	2516607.142	6856277.364	144.207
9677	-0.25336	-0.02031	-3.11733	2516608.619	6856277.397	144.186
9678	-0.25013	-0.02539	-3.12190	2516610.040	6856277.417	144.188
9679	-0.24974	-0.02178	3.14096	2516611.473	6856277.589	144.245
9680	-0.25276	-0.02063	-3.14139	2516613.012	6856277.607	144.222
9681	-0.24727	-0.03512	-3.08934	2516614.507	6856277.660	144.212
9682	-0.23940	-0.03317	-3.09084	2516615.877	6856277.714	144.242
9683	-0.24261	-0.01868	3.11876	2516617.217	6856277.751	144.263
9684	-0.25433	-0.03343	3.08169	2516617.306	6856275.813	144.263
9685	-0.25650	-0.03334	3.08090	2516616.048	6856275.772	144.258
9686	-0.26369	-0.02279	3.07156	2516614.590	6856275.706	144.243
9687	-0.25961	-0.04550	-3.14119	2516613.104	6856275.587	144.240
9688	-0.26883	-0.02205	3.04596	2516611.594	6856275.535	144.257
9689	-0.26315	-0.02952	3.09869	2516610.120	6856275.437	144.228
9690	-0.25152	-0.05459	-3.09201	2516608.621	6856275.305	144.197
9691	-0.25618	-0.05681	-3.11383	2516607.098	6856275.227	144.152
9692	-0.25871	-0.01914	3.05299	2516605.617	6856275.118	144.128
9693	-0.25482	-0.04215	3.13288	2516604.092	6856275.066	144.122
9694	-0.25242	-0.05496	-3.10740	2516602.623	6856274.981	144.109
9695	-0.25341	-0.07322	-3.03956	2516601.130	6856274.881	144.181
9696	-0.25587	-0.04971	-3.09873	2516599.628	6856274.882	144.130
9697	-0.24444	-0.07061	-3.03455	2516598.116	6856274.792	144.124
9698	-0.24569	-0.06957	-3.09777	2516596.541	6856274.657	144.131
9699	-0.25014	-0.05497	-3.09852	2516595.094	6856274.607	144.155
9700	-0.25678	-0.04536	3.13393	2516593.535	6856274.577	144.155
9701	-0.25391	-0.04796	3.11924	2516592.052	6856274.488	144.189
9702	-0.25384	-0.05880	-3.08543	2516590.559	6856274.403	144.214
9703	-0.25481	-0.04827	-3.12939	2516589.057	6856274.335	144.193
9704	-0.26119	-0.02161	3.05984	2516587.638	6856274.250	144.156
9705	-0.24981	-0.06002	-3.09395	2516587.536	6856272.214	144.115
9706	-0.24711	-0.05700	-3.07428	2516589.180	6856272.196	144.122
9707	-0.25327	-0.02910	3.09871	2516590.697	6856272.214	144.155
9708	-0.25115	-0.05692	-3.11037	2516592.305	6856272.285	144.134
9709	-0.24459	-0.06677	-3.06869	2516593.807	6856272.219	144.200
9710	-0.25570	-0.04789	3.12723	2516595.155	6856272.314	144.147
9711	-0.25068	-0.05105	-3.10766	2516596.731	6856272.285	144.160
9712	-0.25462	-0.05033	-3.11144	2516598.310	6856272.574	144.132
9713	-0.25205	-0.05940	-3.08341	2516599.895	6856272.708	144.115
9714	-0.25818	-0.04609	3.13922	2516601.368	6856272.738	144.080
9715	-0.25415	-0.06235	-3.08423	2516602.737	6856272.822	144.134
9716	-0.24681	-0.07742	-3.03959	2516604.262	6856272.861	144.116
9717	-0.24560	-0.07476	-3.00691	2516605.915	6856273.023	144.147
9718	-0.23796	-0.06901	-3.04924	2516607.418	6856272.990	144.193

9719	-0.24897	-0.06555	-3.07077	2516608.903	6856273.029	144.230
9720	-0.24205	-0.08253	-3.01932	2516610.401	6856273.107	144.234
9721	-0.24402	-0.07034	-3.04901	2516611.872	6856273.241	144.285
9722	-0.24819	-0.06988	-3.04217	2516613.329	6856273.339	144.299
9723	-0.23911	-0.07558	-3.02129	2516614.832	6856273.561	144.422
9724	-0.23832	-0.06485	-3.05443	2516616.253	6856273.664	144.340
9725	-0.24095	-0.06550	-3.07455	2516617.400	6856273.776	144.279
9726	-0.26030	-0.06676	-3.07919	2516617.352	6856271.894	144.289
9727	-0.23776	-0.05920	-3.07502	2516616.004	6856271.703	144.335
9728	-0.25337	-0.05003	-3.11266	2516614.553	6856271.728	144.274
9729	-0.25318	-0.05958	-3.09582	2516613.045	6856271.685	144.287
9730	-0.25340	-0.05265	-3.12447	2516611.574	6856271.588	144.303
9731	-0.24427	-0.06892	-3.04100	2516610.183	6856271.500	144.232
9732	-0.26271	-0.04341	-3.12815	2516608.908	6856271.478	144.170
9733	-0.26443	-0.07203	-3.08391	2516607.341	6856271.428	144.221
9734	-0.25131	-0.04394	-3.10531	2516605.973	6856271.284	144.165
9735	-0.25448	-0.06357	-3.07589	2516604.381	6856271.215	144.110
9736	-0.25922	-0.04113	3.09608	2516602.625	6856271.099	144.169
9737	-0.24278	-0.05301	-3.11489	2516601.311	6856271.011	144.230
9738	-0.25388	-0.06984	-3.07345	2516599.815	6856271.028	144.202
9739	-0.24569	-0.06757	-3.06859	2516598.191	6856270.932	144.169
9740	-0.24724	-0.05378	-3.12462	2516596.715	6856270.784	144.195
9741	-0.26852	-0.06415	-3.13852	2516595.201	6856270.714	144.197
9742	-0.25398	-0.05484	-3.12920	2516593.634	6856270.559	144.108
9743	-0.25270	-0.06709	-3.05949	2516592.174	6856270.488	144.179
9744	-0.25195	-0.06547	-3.08006	2516590.693	6856270.355	144.143
9745	-0.24873	-0.05206	3.13660	2516589.119	6856270.316	144.120
9746	-0.26228	-0.02991	3.12299	2516587.544	6856270.289	144.075

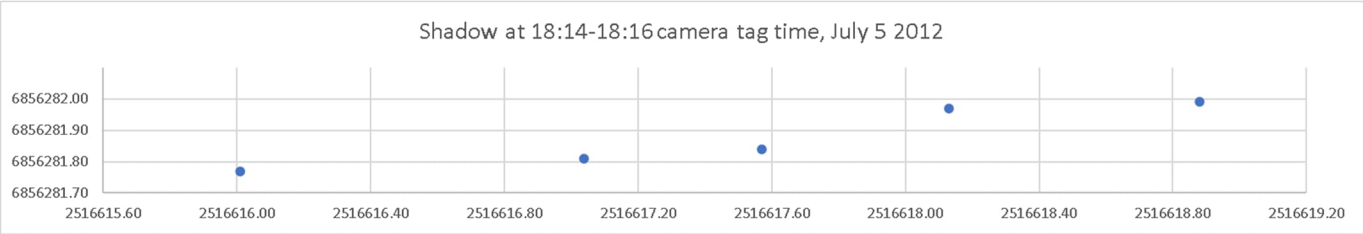


Global radiation at SMEAR II on July 5, 2012. Field imaging took place in the afternoon.

In image # 9641, the shadow direction of a trunk implied a solar azimuth of approximately 265 degrees. Time tag in that images was 18:15. According to suncalc.org, at UTC+3 (18:17), the azimuth was 266 degrees. The camera times are UTC+3 times and can be trusted.

Tree trunk-shadow points:

x	y
2516618.13	6856281.97
2516616.01	6856281.77
2516617.04	6856281.81
2516617.57	6856281.84
2516618.88	6856281.99



4.3 Canopy imaging at Lapinkangas 3 (LK3) plot June 2011

Fig. 128. This is an example photo that shows pine and spruce crowns.

Date of field work and photography June 7-10, 2011.

Fig. 129.

The idea was to take zenith-looking and oblique images at locations where a LiDAR pulse had traversed and of tree crowns.

Tacheometer was used to establish a network (set) of imaging points that were marked with a small wooden pole. The local xyz coordinates were established in the tacheometer coordinate system at a precision of well better than 10 mm.

Four of the points were positioned in the KKJ2/N60 system by observing interpoint (N = 13-17) azimuths and distances, and LS adjustment of these observations (triangulation and trilateration). The RMSE of the 8 solved xy coordinates (df = 5) was 0.07 m.

D = 150 mm polystyrene spheres were hauled to the canopy to serve the purpose of control points (CPs). The coordinates were measured at 4-cm local accuracy, using the tacheometer as theodolite.

A monopod with a h of 1.53 m and a ball-joint mount was used. The radius from the turning point to the projection center was assessed to be 7 cm. The two rotations of the camera (azimuth, elevation) were accounted for in computing the observed projection center position during the photography. The monopod was leveled vertical.

June 10, the photography took place in five sessions between 0845 and 2300 local time.

Canon Powershot G6 was used. It was calibrated only in September, and the calibration was compared against that of 2007. Considering the different definitions for the pixel size (2.33 vs. 2.3 um), there was a 0.1% difference in the f/pixel ratio. The lens deformations are of the same order acknowledging the fact that the ppa-coords were set to zero (they were within one pixel, in 2007), when they were solved from the coefficients of 2007 to match those of the iWitness.

Table 15. iWitness calibration parameters. Value (2007) shows the parameters solved from the Ebner model parameters that were estimated in 2007.

Parameter	Value (2007)	Value 2012
f	7.350 mm	7.228 mm
xp	0.000 mm	0.0329 mm
yp	0.000 mm	0.0342 mm
k1	3.4530E-03	3.7909e-003
k2	-6.1517E-05	-5.0964e-005
k3	-7.0916E-07	-1.5227e-006
p1	-8.9787E-05	-4.3770e-005
p2	1.9454E-04	-2.3405e-004

Calibration Date: 20/09/2011 14:43pm
Resolution: 3072 x 2304 pixels, Pixel Size = 0.0023 mm

c = 7.227937 mm
xp = 0.032902 mm
yp = 0.034274 mm
K1 = 3.7909e-003
K2 = -5.0964e-005
K3 = -1.5227e-006
P1 = -4.3770e-005
P2 = -2.3405e-004
B1 = 0.0000e+000
B2 = 0.0000e+000

The exterior orientation was solved, using WLS adjustment of image observations, projection center coordinates and CP coordinates.

1.5 pixel RMSE was obtained.

There were a total of 284 images.

Data

Photogrammetric_Images\LK3_Canopy_Photos2011\
hdr_teko_LK3_2011.csv file for making HDRs
LK3_cam_data.csv file with EO

HDR\
Header files for kuvamitt

Hyde_latvuskuvien_orientointi\
Folder with contents from the orientation in 2011

Images\
Lens-error corrected JPGs and RAWs

Images_orig\
Original images – note date is wrong by one day

4.4 Hyytiälä buildings and urban trees May 2012

Fig. 130. DR LiDAR data superimposed on an image pair from the site #4.

Date of photography and field work, May 2-4; 2012.

Reference data to be used in conjunction with the November 2011 Riegl WF-LiDAR.

4.4.1 Sites of photography

There were six sites, from where convergent photography were taken, all in the vicinity of the forest station. The camera-target distances vary between sites as does the imaging geometry (angles of rays meeting).

1. Aspens between the Machine hall and Institute building
Nikon images DSC7327-DSC 7338
RMSE 10.7 um, (0.06, 0.15, 0.05) a posteriori sdevs of sphere CPs

2. Engelmannii spruce and a dry A. sibirica next to Impilinna
Canon images IMG7360-IMG7370
RMSE 5.37 um, (0.09, 0.11, 0.16) a posteriori sdevs of sphere CPs

3. Memorial spruce stand
Nikon images DSC7429-DSC7437
RMSE 10.8 um, (0.09, 0.15, 0.04) sdevs of sphere CPs

4. Large birch trees and a pine next to Pikku Sauna
Nikon images DSC7353-DSC7369
RMSE 16.5 um, (0.13, 0.14, 0.12) sdevs of sphere CPs

5. Large accommodation building A
Nikon images DSC7387-7396
RMSE 8.2 um, (0.15, 0.17, 0.14) sdevs of photogrammetric CPs

6. The buildings around the football field
Nikon images DSC7397-DSC7423
RMSE 12 um, (0.28, 0.23, 0.31) sdevs of photogrammetric CPs

4.4.2 Description of activities – sites 1-4 with trees

Cameras were the Canon Powershot G6 and Nikon D300 with zoom lenses used at the minimal focal length. Camera calibrations done with iWitness are given below.

A monopod with a ball-joint (at h of 1.533 m), total length 1.587 m, was used. The radius from the ball-joint to the estimated position of the projection center was 7 cm and 9 cm, for Canon and Nikon, respectively. The projection center was assumed to be collinear with the line thru the ball-joint and the point of attachment to the camera body.

A tacheometer was used to establish camera positions (points P1-P39) on the ground, which were marked using a 5x5-cm plywood plate, with a 6” nail anchoring the plate to the ground. This local xyz position was transformed to the KKJ2/N60 XYZ system by orientating the leveled tacheometer with XY control points (CPs), which were measured in large-scale aerial images (man-made targets in buildings etc.). The Z was taken from LiDAR data, and has an uncertainty of about 3-5 cm and the XY positions (points K1-K7) of the tacheometer were obtained at about 0.1 m accuracy, using 4-8 CPs. All camera positions were positioned from two tacheometer station positions, which were oriented, using different sets of CPs to provide redundancy.

There were polystyrene spheres in the canopy as additional CPs, which were positioned, using the tacheometer as a theodolite.

The image blocks were first oriented with iWitness, using a relative orientation. Rigid 3D transformation (offset, rotation, scale) was applied to the ray bundle by supplying the camera coordinates and coordinates of the spheres. The approximate camera rotations were then used in refining the coordinates of the projection centers (the use of the ball-joint camera head – the xyz-offset with respect to the measured point at the base of the monopod changed with the rotation of the camera), and the orientation was re-established, using weighted least-square bundle block adjustment. In it, the a priori measurement accuracies of 0.1 m for the sphere (XYZ) and 0.025 m for the projection center coordinates.

4.4.3 Description of activities – sites 5-6 with buildings

These images were taken from free positions and the EO was established using the CPs seen in the images (man-made targets positioned in aerial images)

4.4.4 Calibrations, Canon

Calibration Date: 02/05/2012 14:54pm
Resolution: 3072 x 2304 pixels, Pixel Size = 0.0023 mm

c = 7.233562 mm
xp = 0.024801 mm
yp = 0.046810 mm
K1 = 3.7848e-003
K2 = -5.8565e-005
K3 = -1.0617e-006
P1 = -3.1726e-005
P2 = -2.7222e-004
B1 = 0.0000e+000
B2 = 0.0000e+000

Calibration Date: 04/05/2012 15:32pm
Resolution: 3072 x 2304 pixels, Pixel Size = 0.0023 mm

c = 7.232394 mm
xp = 0.022468 mm
yp = 0.056819 mm
K1 = 3.7189e-003
K2 = -4.3547e-005
K3 = -1.7692e-006
P1 = -2.4074e-005
P2 = -3.6359e-004
B1 = 0.0000e+000
B2 = 0.0000e+000

4.4.5 Calibration, Nikon

Calibration Date: 03/05/2012 8:24am
Resolution: 4288 x 2848 pixels, Pixel Size = 0.0055 mm

c = 18.696734 mm
xp = 0.049724 mm
yp = 0.076118 mm
K1 = 4.6007e-004
K2 = 5.5803e-008
K3 = -4.8944e-009
P1 = 2.5894e-005
P2 = -9.8620e-006
B1 = 0.0000e+000
B2 = 0.0000e+000

4.4.6 Data

Photogrammetric_Images\Hyytiala_May2012\

\Images_and_EO\
The original JPEG images, and folder for each site with the files for the weighted least square adjustment, iWitness files. Folder ...\Panorama\MINV12_triangulation_program_gcp_weights\ has the VB6 code for the WLS adjustment.

\1_Aspens ...\6_Building_panoramic folders have the lens error corrected images and the HDR files for KUVAMITT.

\Cameracalibration folder has the iWitness projects for the lens calibration.

\FieldWork\

areafile.txt // area file of the geodimeter
Calibration_EOIO_CanonPSG6_1.txt
Calibration_EOIO_CanonPSG6_2.txt
Calibration_EOIO_NikonD300.txt
HaavikkoPointData.txt // positions of CPs in aerial images
hdr_teko_touko2012.csv // file for producing HDR files
Hyytiala_03052012.xlsx // computation of P-points
Hyytiala_03052012_kuvaustiedot.xlsx // info on photography
jobifile.txt // the job-file of the Geodimeter
Maastofotogrammetriaa.htm // coordinate solutions
Teodoliitti_2.xls // file for theodolite positioning, two obs
Teodoliitti_3.xls // file for theodolite psotioning, three obs
Touko2012TakymFiles.zip // The raw Geodimeter files

4.5 Systematic canopy imaging at SMEAR 60-yr-old pine plot June 2012

Fig. 131. This is an example photo from the pine stand that shows two CPs – polystyrene spheres.

4.5.1 Description of activities

An area of 12 x 10 m was delineated in a pine stand, for the purpose of establishing a 1-m grid of camera positions (N=143) for vertical, zenith-looking imaging. The positions were marked with 5x5-cm plywood plates, anchored to the ground. A total of 42+6 (K1-K48) of these were positioned locally, using a tacheometer. Eight additional oblique views are included from photo locations K43-K48 (and from two non-mapped points).

The tacheometer was oriented in the KKJ2/N60 system, using intrapoint distance and azimuth observations to N = 29 trees (positioned in aerial images). The average L2 norm of the XY residuals was 31 cm, thus, for 29 trees, the SDEV of the tacheometer position was apprx. 5 cm in X and Y. The tacheometer position estimate was 2515592.675, 6860098.042, 179.0 and the rotation 43.88 degrees with respect to the KKJ-North. LiDAR points were used for deriving the Z. Tacheometer was on flat rock in a canopy opening.

Seven polystyrene spheres (CPs) were hauled to the canopy and measured for local xyz at an accuracy of better than 5 cm in 3D (theodolite principle).

The images were taken June 21, at 6 am. There were 143 zenith looking and 9 oblique images.

The exterior orientation was established with iWitness, and adjusted using WLS bundle block adjustment. In it, the XYZ coordinates of the spheres were used (a priori SD of 0.1 m for X, Y and Z), the camera positions (0.025 m for X0, Y0 and Z0), as well as stem XY positions (a priori SD of 0.1 m). The latter were observed with the tacheometer, and as tie points (vertical objects) in the images. The camera positions were adjusted for the rotation of the camera head (and projection center) - causing an xyz offset. See EO_analyses.xlsx. The gnd_obs.txt and cam_obs.txt files show the used observations with the corresponding a priori weights. The average a posteriori sdev of the projection center coordinates was 23 mm, and RMS of image residuals was 3.1 pixels.

The oblique images were omitted apart from two in the lens-corrected image set (the EO exists for these). I.e. there are 145 lens-corrected #_corr.jpg images.

4.5.2 Data

Photogrammetric_Images\Canopy_Photos_2012\Pine\
Calibration.txt The used iWittness calibration coefficients
EO\
WLS-adjustment files
EO\ iWitness_Files\
Image observations (*.icf), observation files (iwp), iwitness EO results based on rigid 3D transformation
HDR\
HDR files and CSV files for producing HDR-files.
Images\
The original from July 21 and lens-error corrected JPG and RAW images.

4.6 Systematic canopy imaging at Silmäpäänlammi 60-yr-old spruce plot - July 2012

Fig. 132. This is an example photo from the spruce stand, showing spruce crowns and some pine crowns on the low-right corner.

This site was similar to the pine stand, except that there were no CPs in the canopy, but 42 camera positions marked on the ground, and 60-mm spheres (attached on ropes) as tie points some 5-6 m above the ground. Photography was in the morning of July 6, 2012.

The tacheometer orientation was established with 31 trees. The SDEVs were 0.043 m for X and Y. The position estimate was 2515675.908, 6861266.421, 188.2 and the tacheometer wads rotated 45.17 degrees with respect to the KKJ-North. LiDAR points were used for the Z. The tacheometer was on flat terrain lacking low vegetation.

iWitness was used for orientation – with X0, Y0 and Z0 corrected for the xyz-offset due to camera rotation about the ball-joint camera head. RMS of image residuals was 2.8 pixels. The results of the rigid 3D transformation were used as such, because the residuals at the 42 known points were small, with SDEVs of 18, 11 and 22 mm, for x, y and z. Mean sdevs of tie point coordinates were at 4, 4 and 13 mm. The solution was not changed in WLS bundle block adjustment.

4.6.1 Data

Photogrammetric_Images\Canopy_Photos_2012\Spruce\

EO\
Iwitness – image coordinates of tie-points
HDR\
HDR-files of the 143 zenith-looking images
Images\
The original and lens-corrected JPEGs, lens-corrected RAWs

4.7 2010 TEKES images

Photogrammetric_Images\Tekes2010\

TEKES photogrammetric experiment. Dokumentointi keskeneräinen. Sites, images, which were oriented, which not. Powershot G6?

Other_Images\2010_Kuvia_Hyytialasta_AH

Some images taken by Aarne Hovi during the field activities.

4.8 Canopy imaging at Lapinkangas Lichen plot, July 2012

Photogrammetric_Images\Lk_pysty\

Convergent images of trees were taken. Ilkka lisää dokumentaatio!!!

4.9 Sahatie 20-yr-old mixed stand imaging 2007

Photogrammetric_Images\2007_Sahatie\

Miscellaneous 22 documentation images of the plot taken in August 2007 with f = 7 mm, views show the tree labels. The trees on the plot were mapped with a total station/GNSS prior to photography. Images can be oriented only roughly as the GCPs (labels) are positioned in XY, and labels are at 1.3 m height above gnd, which has z-accuracy of 5-10 cm. Use the calibration of the G6 from the Lapinkangas 2007 image data.

Inventory data / tree measurements – See Hyde_Ref plot data

4.10 Leaf angle distributions, July 2013

Photogrammetric_Images\LAD_2013\

A test was done to see if leaf-angle distributions could be measured by means of photogrammetry, using a 3D structure of known dimension and attitude in the scene. See html-documentation:

- LAD\LAD_photogrammetry_2013.html

4.11 Riegl 2015 campaign, August 2015

Photogrammetric_Images\Hyyt_kuvaus_Riegl2015\

Images at various locations were taken to document the status of vegetation during the LiDAR campaign. See html-documentation:

- 2015_LiteMapper_MaastoKuvaus.html

4.12 Other than photogrammetric images

Other_Images\
Contains all other than photogrammetric images. The names of the sub-folders have the year and a description of what was imaged:

2000_RTK_GPS\
2004_ALTM1033_laserkeilaus\
2004_HuppionLetto\
2005_MetsaekologianKurssi\
2006_Aikasarja_Patsainmaki\
2006_Taimikot\
2007_KuviaHydenKoealoilta\
2007_Taimikot\
2008_ADS40\
2009_Alikasvosmittaukset\
2009_DMC_Kuvaus\
2009_FGI_Leica_Tapaaminen\
2009_Kaukokartoituspaivat\
2010_ALS60_Leica_Finnmap\
2010_Antti_Makinen_Vaitos\
2010_Evo_Laserseminaari\
2010_Harvennukset\
2010_Joensuu\
2010_Kuvia_Hyytialasta_AH\
2010_Lumituhoja\
2010_Vierailu_Leica_Heerbrugg\
2011_Abi_Vierailu_Viikki\
2011_AlumniJuhla_Viikki\
2011_A_Hovi_Seminaari\
2011_GL_seminaari\
2011_Joensuun_Reissu\
2011_Kevatretki_Hyytialaan\
2011_Lapinkangas_Latvuskuvaukset\
2011_Lauri_Korhonen_Vaitos\
2011_LiteMapper_Keilaus\
2011_MARV1_koealoja_AH\
2011_Minna_Raty_vaitos\
2011_Prof_Pfeifer_TKK\
2011_UMB_Matka\
2012_Heinakuu_6_Pihapiiri_ALS60\
2012_Hyytiala\
2012_Hyytiala_ALS60\
2012_Kohteiden_Etsinta_Retki\
2012_Kyle_Eyvindson_Vaitos\
2012_Markus_Holopainen_Virkaanastujaiset\
2012_Mekrijarven_Matka\
2012_Mikko_Vastaranta_Vaitos\
2012_Taimikot_AH\
2012_Teppo_Hujalan_DosenttiLuento\
2013_Awuar_Baffour_Vaitos\
2013_Hyytialan_Tyontekijoita\
2013_Hyytiala_ALS60_dokumentointikuvat_AH\
2013_Kuvia_Finnmapin_ALS50\
2013_LAI_LAD_mittaukset\
2013_LiteMapper_dokumentointikuvat_AH\
2013_LiteMapper_Pihakuvia\
2013_Metsalaitoksen_Tilaisuuksista\
2013_Vatukot_LAI_ja_optiset_omin_AH\
2014_Automatka_Palkane_Hyytiala\
2014_ForestSAT\
2014_Harvennukset_AH\
2014_Jarkko_Saarimaki\
2014_KIT\
2014_Kuvia_Hyytialasta\
2014_Metsalaitokselta\
2014_NorUt_UAV\
2014_SekalKoealoja_Norut_AH\
2014_Siikaneva\
2014_Taksaattori_Kokous\
2014_Zurich\
2015_GCP_tarkistus_AH\
2015_Hyytialasta\
2015_Kulotus\
2015_Metsalaitokselta\
Marv1_2007\
Marv1_2008\
Marv1_2009\
Marv1_2010\
Marv1_2011\
Marv1_2013\
Marv1_2014\
Marv1_2015\

5 UAV images

All data are in folder
\UAV\

5.1 2010 TEKES

Two 14–23 ha areas were imaged on 5.8.2010 for TEKES Social Forest campaign.

Six areas were prepared in the field before the campaign. Suitable areas were selected that had enough landing space and contained field reference plots. GCP signals were established and positioned with GNSS. There are up to 5 signals per area. These are white crosses made of 10 cm wide wooden board. GCPs are documented under “ground reference data”.

Only two areas (#1 and #2) were finally imaged. Photogrammetric DSMs of both areas were delivered to UH. Original RGB images exist only for area #1. Area #2 images were never requested from EnsoMosaic.

Contents

\2010_TEKES_UAV\

UAV_plan_20100723.pdf
Document of the prepared areas

Images\
Images for area #1:
8-bit RGB images in JPG (N=81)
Tiff images, converted from JPG?

mosaics\
Image mosaic of area #1

Blocks\
Ilkka, what is this?

DSM\
DSMs delivered to UH for evaluation, see the README.txt for details

Meeting_20110523.pptx
Report_20110606.pdf
Reports on evaluation of the DSMs by UH

5.2 2014 Norut

UAV imagery acquired by Northern Research Institute (Norway). Images were acquired over AH1 plot and nearby fields, 1.7.2014 in the morning. Small quadcopter?. Canon PowerShot SX230 HS camera. False colour images. The UAV was broken in the midst of the campaign.

\2014_UAV\

Images in tiff format (N = 314)

..\MaxMax.txt
Camera IO parameters

The block was densified with Pix4D in May 2020. The block is small, and the value of the imagery is marginal. Camera parameters and EO parameters were solved using a small number of GCPs.

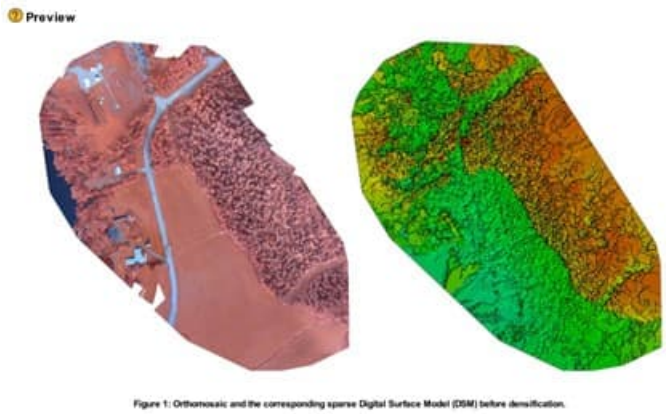


Fig. 133. Area covered near Ala-Hyytiälä farm (Muistokoivikko stand shows in the North)

5.3 2018 Henri Riihimäki (Vuorijärvensuo)

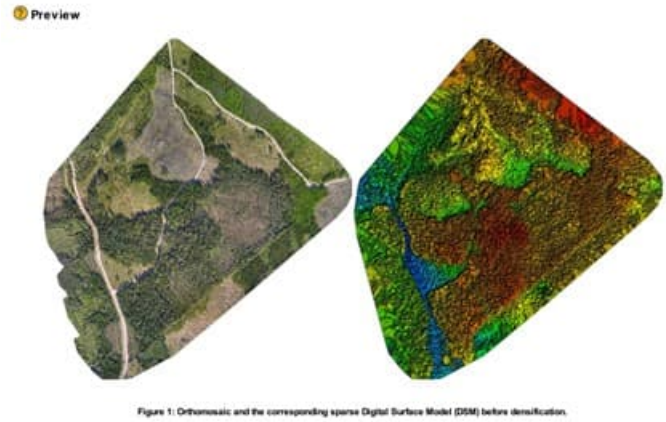


Fig. 134. N=603 images. 75 ha covering Vuorijärvensuo-area. Images were oriened with Pix4D and normalized to pinhole-cameras images for KUVAMITT. EO was solved in UTM35/N2000. HDR-files for kuvamitt and a CSV with the IO/EO information were created.

DATA (c) Henri Riihimäki

METADATA
Kuvattu 15.05.2018
Pilvet: 0/8
Lennokki: Phantom 4
Autopilotti: Map pilot
Frontal overlap: 90%
Side overlap: 70%
Lentokorkeus: 150 m (noin)

Fenologia:
Lehdet: Leaf-on (ei kuitenkaan täydessä lehdessä)
Aluskasvillisuus: Vähän tämän vuotisia ruohoja, heinää. Pääosin laostunutta, viime vuotista ruskeaa kasvillisuutta. Saniaiset ei puhjenneet.

Käyttöehdot:
-Saa käyttää vapaasti vapaasti opetukseen, lähde mainittava
-Ei levitystä edelleen
-Muu käyttö sovittava erikseen, yhteystiedot:
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6 Field reference data

The document below gives an overview of what is measured in the field. Links to detailed description and data are given. The links refer to subfolders of \Field_data\. Terrestrial photographs are excluded here because they were documented elsewhere.

The field reference data are divided into

i) Permanent forest plots that are continuously kept up to date.
ii) Geometric ground control, e.g. signaled GCPs used in aerial triangulation, or elevation data for estimating Z accuracy of LiDAR data.
iii) Other ground reference measurements.

6.1 Permanent forest plots with mapped trees (over 20-year-old forests)

Mapping methods – planimetric coordinates, orthometric heights

The first mapped plots were established in 1995 using a total station (mapping into a local XYZ-system). The use of total stations for tree mapping lasted from 1995 to 2005. A mirror was placed in front of the stem and the XYZ-coordinates were calculated by extending the 3D vector using the DBH observation. Alternatively, occluded trees were measured using a 2-4-m-long vector with end points visible the the total station (to reduce the need for the tedious relocating the apparatus during mapping). These (local) stem maps are approximately 10-cm accurate.

The estimation of the XY-offset and rotation (2D) of the plot's local coordinate system (corners, center point) in the national coordinate system KKJ2 has been establed in most cases using photogrammetric measurements of trees, or by direct measurements with an accurate GNSS (2005-) in seedling stands, where the antenna could be placed at 1-4-m height. The absolute positioning accuracy of the plots has not been tested but is likely better than 30 cm in the photogrammetric estimation and better than 5 cm when using RTK-GNSS in seedling stands (RTK-GNSS does not worl under a canopy).

In 2000, field levelling was done to obtain orthometric heights to some of the plots as the terrain models (map contour lines) at the time had low accuracy. An accurate DEM was obtained only in 2004 following the first LiDAR campaign (1 m resolution, 0.25 m RMS accuracy) and levelling was no longer needed except in very accurate work. The height system was N60 and since 2005 the national system has been N2005, which shows 32 cm higher values in Hyytiälä. The ellipsoidal height of N60 (geoid correction) was 18.67 m, i.e., all WGS-84 ellipsoidal heights should be added 18.67 m to get N60 and 18.67 + 0.32 to obtain N2000 elevations.

Since 2005, the xy-mapping of trees has been based on the photogrammetric-geodetic method by Korpela et al. (2007), which was published in Silva fennica. In it, large trees (their treetops) are positioned in remote sensing data (images, point clouds) and these trees are used as control points in the field for the XY-positioning of small or occluded trees and other targets such as plot corner poles. Using this method, the trees are directly mapped into the national map coordinate system, and, hence, the size of the plots was no longer limited by line-of-sight in the field. The accuracy of the positions is 0.1-0.5 m and depends on the number of trees used as control points, and their geometry.

Selection of forest plots, types of plots

Table below shows the plots by year of establishment.

Table 16. Permamnent plots in over 20-year-old stands - year of establishment. Plot codes in red are abandoned in May 2023.

Year	Plot Code
1995	MMM1, MMM2
1996	S1, S2, S3, S4, S5, S6
1997	B1, B2, B3, B4, P1, P2, P3, P4, P6
1998-2001	No new plots
2002	FT_2002, KM, MKuusi, LK1, LK2,
2003	L15, L88
2004	No new plots
2005	LiisiK, MAKU, TELE
2006	AH1, AH2, FT_2006, PTS
2007	Sahatie, Marv31, Marv37, Marv 41, Marv 50, Marv60, Marv62, Marv78, MARV81, MARV84, MARV94, MARV96, MARV103, MARV107, MARV108, MARV114, MARV122, MARV131, MARV132, MARV133
2007	59 MARV4_# circular plots
2008	MARV08_1ABCD, MARV08_2ABCD, MARV08_3_ABCD, MARV_08_4ABCD, ME185, ME186, ME187, ME188
2009	MARV09_1ABCD, MARV09_2ABCD, MARV09_7ABCD, MARV09_8ABCD, MARV09_9ABCD, MKoivu
2010	MARV10_1AB, MARV10_2AB, MARV10_3ABC, MARV10_4AB, MARV10_5AB, MARV10_6AB
2011	MARV11_1ABCD, MARV11_2CD, MARV11_3AB, MARV11_4ABC, MARV11_5, MARV11_7ABC
2012-2014	- (no new established plots)
2015	MARV15_5ABC, MARV15_6, MARV15_7AB, MARV15_8AB, MARV15_9, MARV15_10, MARV15_11
2016	MARV16_1ABC, MARV16_2AB, MARV16_3ABC, MARV16_4AB, MARV16_5ABCD
2017	TEXAS, VJSUO, ASEMA
2018	SMEAR, TAPIOLA
2019	No new plots
2020	No new plots
2021	No new plots
2022	No new plots
2023	No new plots
2024	No new plots

The plot locations have been mostly subjectively selected to include some specific forest structure or site type. Exception to this rule are the 59 permanent (inventory, MARV4_#) circular plots with measurements done in 2007, 2013, 2019 and 2024.

Trees are identified by numbers. The plot size varies between 0.04–4 ha. There are three shapes: rectangular, circular, and free-shaped. Rectangular plots are the most common. Some of them have subplots to divide the workload. The free-shaped plots do not have strictly defined boundaries. The trees are mapped from an arbitrarily shaped area (plots SAHATIE, TELE, PTS, FT_2006).

The tree positioning method prior to 2006 was tacheometer. Later, photogrammetric-geodetic method has been applied. In it, trees visible to high-resolution aerial image and/or LiDAR data are first mapped by manual measurements. These trees are identified in the field,and form a network of control points in triangulation or

trilateration that is performed to position the omission trees. In addition to tacheometer and the photogrammetric-geodetic method, GNSS was used to position the trees if tree height is below approx. 5 m (seedling stands).

The minimum size of trees that are mapped and measured is determined by plot-specific minimum diameter at breast height (DBH) (tree height in some plots). If the photogrammetric-geodetic method was applied for mapping, the inclusion of trees is a bit more complicated. First, all trees discernible in the RS data are mapped. The discernibility is dependent e.g., on tree height, stand density, and resolution of the RS data. Second, all the omission trees exceeding the minimum diameter (or height) are mapped.

The measurements vary between plots. Normally, diameter at breast height and a visual estimate on tree status are recorded. Other data, e.g. height measurements on sample trees, are measured when needed. Tree heights are not usually necessary because they can be obtained from the RS data or predicted with models. The measurements are kept up to date by regular re-visits in the field, typically at 5 to 8 years interval. By Jan 2025, the plots had been measured 1–6 times.
Most of the plots are located on state-owned land that is managed according to common silvicultural practices. Thinnings and clear-cuts can be performed, and the status of the plot changes. Because the field measurements are difficult to perform all at the same timepoint, manual aerial image and LiDAR data interpretation is also used to update the status of the all the trees at a certain timepoint. These updates have been performed in 2008, 2011, and 2015.

Measurement data for the permanent plots are available in the wwww database (in Finnish):

- http://www.helsinki.fi/~korpela/HYDE_REF/Plots/Koealat_Hyytialassa.html

The copy of the data is kept on this device:

- \HYDE_REF\Plots\

Koeala	Kuvaus1	Kuvaus	Koko	Rajatiedosto	Tilanne 12/2024	Seuranta	Viimeisin
MMM1	MÄ-Ku-Ko	Kallionen, sekam.	120 x 60 jälj.	MMM1.csv	Etelä kaistalehakattu	tien N-puoli	1995,2002,2013
MMM2	Ku-Mä	Vanha kuusivalt. 150 v	150 x 70	MMM2.csv	Ei käsittelyjä	ok	1995, 2002, 2013
S1	Ku	Kuusen kasvatus	50 x 50	S1.csv	Ei käsittelyjä	ok	1996, 2002, 2006, 2009, 2013, 2022
S2	Ku	Kuusen kasvatus	50 x 50	S2.csv	Ei käsittelyjä	ok	1996, 2002, 2006, 2009, 2013, 2022
S3	Ku	Kuusen kasvatus, luonnonnormaa	50 x 50	S3.csv	Ei käsittelyjä	ok	1996, 2002, 2006, 2009, 2013, 2022
S4	Ku	Kuusen kasvatus	50 x 50	S4.csv	Ei käsittelyjä	ok	1996, 2002, 2006, 2009, 2013, 2022
S5	Ku	Kuusen kasvatus	50 x 50	S5.csv	Ei käsittelyjä	ok	1996, 2002, 2006, 2009, 2013, 2022
S6	Ku	Kuusen kasvatus	50 x 50	S6.csv	Ei käsittelyjä	ok	1996, 2002, 2006, 2009, 2013, 2022
P1	Mä	Männyn kasvatus	50 x 50	P1.csv	Ei käsittelyjä	ok	1997, 2992, 2006, 2009, 2010, 2013, 2022
P2	Mä	Männyn kasvatus	50 x 50	P2.csv	Ei käsittelyjä	ok	1997, 2992, 2006, 2009, 2010, 2013, 2023
P3	Mä	Männyn kasvatus	50 x 50	P3.csv	Ei käsittelyjä	ok	1997, 2992, 2006, 2009, 2010, 2013, 2023
P4	Mä	Männyn kasvatus, luonnonnormaa	50 x 50	P4.csv	Ei käsittelyjä	ok	1997, 2992, 2006, 2009, 2010, 2013, 2023
P6	Mä	Männyn kasvatus	50 x 50	P6.csv	Ei käsittelyjä	ok	1997, 2992, 2006, 2009, 2010, 2013, 2023
B1	Ko	Koivun kasvatus	40 x 40	B1.csv	Harvennettu 2017?	ok (harvennus)	1997, 2002, 2010, 2014, 2023
B2	Ko	Koivun kasvatus, luonnonnormaal	40 x 40	B2.csv	Ei käs.	ok	1997, 2002, 2010, 2014, 2022
B3	Ko	Koivun kasvatus	40 x 40	B3.csv	Ei käs.	ok	1997, 2002, 2010, 2014, 2023
B4	Ko	Koivun kasvatus	40 x 40	B4.csv	Ei käs.	ok	1997, 2002, 2010, 2014, 2023
FT_2002	Ku-Mä-Ko	Sekametsä-ympyrä	r=21 m	FT_2002.csv	Ei käs.?	ok	2002, 2009, 2013, 2022
KM	MÄ-Ku-Ko	Koppimännikkö ympyrä	r=21 m	KM.csv	Harvennus 2020, osin SM	ok	2002, 2010, 2014, (jäi SMEAR sisään)
MK	Ku	Muistokuusikko	100 x 50	MK.csv	Ei käs.	ok	2002, 2007, 2009, 2010,..2024
AH1	Ku-Mä-Ku	Ala-Hyytiälä talonpoik	60 x 80	AH1.csv	Korvattu aseman koealal	**Hylätty**	2006, 2013
AH2	Ku-Mä-Ko	Ala-Hyytiälä sekam.	60 x 60	AH2.csv	Avohakattu 2021	**Hylätty**	2006, 2013
FT_2006	Ku-Mä	Ku-mä varttunut	130 x 60	FT_2006.csv	Onko käsitelty?	ok	2006, 2013
LiiSiK	Ku	Maapuita mitattu (Kiisi Koivisto)		LiiSiK.csv	Ei seurattu Liisin jälkeen	**Hylätty**	2005,
LK1	Mä	VT mä 100 v	50 x 50	LK1.csv	Ei käs.	ok	2002, 2007, 2009 (kairauksia), 2023
LK2	Mä	VT mä 100 v	50 x 50	LK2.csv	Ei käs.	ok	2002, 2007, 2009 (kairauksia), 2022
LK3	MÄ-Ku	VT mä-ku 100 v	30 x 100	LK3.csv	Ei käs.	ok	2009, 2014
MAKU	1955 ist	Mä-Ku varttunut	100 x 40	MAKU.csv	Osa hakattu 2014? Analy	**Hylätty**	2005, 2009, 2010, 2014
TELE	1960 ist	Tervaleppä, LhK	60 x 60	TELE.csv	Ei käs.	ok	2005, 2009, 2013, 2022
PTS	1955 ist	Sekametsää mäellä	100 x 50	PTS.csv	Ei käs.	ok	2006, 2010, 2014, 2023
ME185	1973 ist Mä	Laatuharvennus		ME185.csv	Mittaukset epäluotettavi	**Hylätty**	2008,
ME186	1973 ist Mä	Laatuharvennus		ME186.csv	Mittaukset epäluotettavi	**Hylätty**	2008,
ME187	1973 ist Mä	Laatuharvennus		ME187.csv	Mittaukset epäluotettavi	**Hylätty**	2008,
ME188	1973 ist Mä	Laatuharvennus		ME188.csv	Mittaukset epäluotettavi	**Hylätty**	2008,
Sahatie	Mä-Ku	T2/02 sekataimikko 1985	60 x 50	Sahatie.csv	Harvennettu 2019? Bulkk	Kannattaako?	2007, 2014
marv1_31	MÄ-Ku-Ko	135-v. lh.metsässä	40 x 40	marv1_31.csv	Ei käs	ok!	2007, 2013, 2022
marv1_37	Vatkg	uud.kypsää	40 x 40	marv1_37.csv	Kaistalehakattu 2017?	? Hyl	2008, 2012
marv1_41	MT Leku	Kaksijaksoinen	40 x 40	marv1_41.csv	Ei käs.	ok	2007, 2013
marv1_50	MT Ku	Varttunutta	30 x 30	marv1_50.csv	Ei käs. 75% TEXAS alan sisällä		2007, 2013
marv1_60	TR Mä	Pieni luonnontil.	20 x 40	marv1_60.csv	Ei käs. (metsään rajalla	ok	2007, 2013, 2022
marv1_62	MT Ku	uud.kypsä (2007)	30 x 40	marv1_62.csv	Ei käs.	ok	2007, 2012, 2023
marv1_78	MT KU-KO	varttunutta (2007)	30 x 30	marv1_78.csv	Ei käs.	ok	2007, 2013
marv1_81	MT KU-MÄ	vanhaa, Kalelan kuusikko	30 x 40	marv1_81.csv	Ei käs.	ok	2007, 2012
marv1_84	MT KU	varttunut tiheä	30 x 30	marv1_84.csv	Ei käs.	TEXASin sisällä	2007, 2012
marv1_94	Mtkg Mä-Ko	Kaksijaksoinen	30 x 50	marv1_94.csv	Ei käs. vai onko hakattu?	hakattu?	2007, 2013
marv1_96	Ptkg KU-MÄ	Kaksijaksoinen, varttunutta	30 x 40	marv1_96.csv	Ei käs.	ok	2007, 2013
marv1_103	MTs Ku-Ko	uud.kypsää	30 x 30	marv1_103.csv	Hakattu vuosi 2012-13	**Hylätty**	2007, 2013
marv1_107	MT Ku	Järeää	30 x 40	marv1_107.csv	Tuhoja (vähän puita enää	Kannattaako?	2007, 2013
marv1_108	Ptkg MÄ	uud.kypsää	25 x 40	marv1_108.csv	Ei käs.	ok	2007, 2013

marv1_114	CT/VT mä vart	varttunutta	50 x 45	marv1_114.csv	LK1 korvannut		2007,
marv1_122	MT Omorika	Kaksityvisiä, jaettu kahteen ruutu	30 x 40	marv1_122.csv	Ei käs.	ok	2007, 2012
marv1_131	MT Ku	Tiheä, kasvatus	30 x 40	marv1_131.csv	Osa koealaa menetetty l	Hylätty?	2007, 2012
marv1_132	MT Ko	Ensiharventamaton (2007)	30 x 40	marv1_132.csv	Harvennettu 2014?	ok, jos viim. dat	2007, 2012, 2014
marv1_133	MT Mä	Ensiharventamaton (2007)	30 x 40	marv1_133.csv	Viimeinen mittaus?		2007, 2010, 2024
MARV1_08_1A	Mä	Varttunut mä, lann?	30 x 30	MARV1_08_1A.csv	Ei käs. Lumituho 09/10	ok	2008, 2010
MARV1_08_1B	Mä	Varttunut mä, lann?	30 x 30	MARV1_08_1B.csv	Ei käs. Lumituho 09/10	ok	2008, 2010
MARV1_08_1C	Mä	Varttunut mä, lann?	30 x 30	MARV1_08_1C.csv	Ei käs. Lumituho 09/10	ok	2008, 2010
MARV1_08_1D	Mä	Varttunut mä, lann?	30 x 30	MARV1_08_1D.csv	Ei käs. Lumituho 09/10	ok	2008, 2010
MARV1_08_2A	Mä-Ku	Uud.kypsä ku-mä	35 x 35	MARV1_08_2A.csv	Avohakkuu 2013	Hylätty	2008, 2012
MARV1_08_2B	Mä-Ku	Uud.kypsä ku-mä	35 x 35	MARV1_08_2B.csv	Avohakkuu 2013	Hylätty	2008, 2012
MARV1_08_2C	Mä-Ku	Uud.kypsä ku-mä	35 x 35	MARV1_08_2C.csv	Avohakkuu 2013	Hylätty	2008, 2012
MARV1_08_2D	Mä-Ku	Uud.kypsä ku-mä	35 x 35	MARV1_08_2D.csv	Avohakkuu 2013	Hylätty	2008, 2012
MARV1_08_3A	Ku	Vanha kuusivalt	50 x 50	MARV1_08_3A.csv	Avohakattu 2014	Hylätty	2008, 2013
MARV1_08_3B	Ku	Vanha kuusivalt	50 x 50	MARV1_08_3B.csv	Avohakattu 2014	Hylätty	2008, 2013
MARV1_08_3C	Ku	Vanha kuusivalt	50 x 50	MARV1_08_3C.csv	Avohakattu 2014	Hylätty	2008, 2013
MARV1_08_3D	Ku	Vanha kuusivalt	50 x 50	MARV1_08_3D.csv	Avohakattu 2014	Hylätty	2008, 2013
MARV1_08_4A	Mä-Ku-Ko	varttunut sekam.	30 x 50	MARV1_08_4A.csv	Ei käs. (MTAITO)	ok	2008, 2013, 2021, 2024
MARV1_08_4B	Mä-Ku-Ko	varttunut sekam.	30 x 50	MARV1_08_4B.csv	Ei käs. (MTAITO)	ok	2008, 2013, 2021, 2023, 2024
MARV1_08_4C	Mä-Ku-Ko	varttunut sekam.	30 x 50	MARV1_08_4C.csv	Ei käs. (MTAITO)	ok	2008, 2013, 2021, 2023, 2024
MARV1_08_4D	Mä-Ku-Ko	varttunut sekam.	30 x 50	MARV1_08_4D.csv	Ei käs. (MTAITO)	ok	2008, 2013, 2021, 2024
MARV1_09_1A	Ku-Mä	Sekametsää 50 v	35 x 35	MARV1_09_1A.csv	Ei käs. 2013-	ok - 2022	2009, 2013, 2023
MARV1_09_1B	Ku-Mä	Sekametsää 50 v	35 x 35	MARV1_09_1B.csv	Ei käs. 2013-	ok - 2022	2009, 2013, 2023
MARV1_09_1C	Ku-Mä	Sekametsää 50 v	35 x 35	MARV1_09_1C.csv	Ei käs. 2013-	ok - 2022	2009, 2013, 2023
MARV1_09_1D	Ku-Mä	Sekametsää 50 v	35 x 35	MARV1_09_1D.csv	Ei käs. 2013-	ok - 2022	2009, 2013, 2023
MARV1_09_2A	Ku-Mä	SEKAMETSÄÄ 100 v	45 x 45	MARV1_09_2A.csv	Ei käs. 2013-	ok	2009, 2013, 2023
MARV1_09_2B	Ku-Mä	SEKAMETSÄÄ 100 v	45 x 45	MARV1_09_2B.csv	Ei käs. 2013-	ok	2009, 2013, 2023
MARV1_09_2C	Ku-Mä	SEKAMETSÄÄ 100 v	45 x 45	MARV1_09_2C.csv	Ei käs. 2013-	ok	2009, 2013, 2023
MARV1_09_2D	Ku-Mä	SEKAMETSÄÄ 100 v	45 x 45	MARV1_09_2D.csv	Ei käs. 2013-	ok	2009, 2013, 2023
MARV1_09_7A	Mä	Koppimä-pohj	35 x 40	MARV1_09_7A.csv	Harv 2020	ok, d13 merkit	2009, 2023
MARV1_09_7B	Mä	Koppimä-pohj	35 x 40	MARV1_09_7B.csv	Harv 2020	ok, d13 merkit	2009, 2023
MARV1_09_7C	Mä	Koppimä-pohj	35 x 40	MARV1_09_7C.csv	Harv 2020	ok, d13 merkit	2009, 2023
MARV1_09_7D	Mä	Koppimä-pohj	35 x 40	MARV1_09_7D.csv	Harv 2020	ok, d13 merkit	2009, 2023
MARV1_09_8A		60v Mä-Ku	40 x 40	MARV1_09_8A.csv	Ei käs.	ok	2009, 2010, 2014, 2022
MARV1_09_8B		60v Mä-Ku	40 x 40	MARV1_09_8B.csv	Ei käs.	ok	2009, 2010, 2014, 2022
MARV1_09_8C		60v Mä-Ku	40 x 40	MARV1_09_8C.csv	Ei käs.	ok	2009, 2010, 2014, 2022
MARV1_09_8D		60v Mä-Ku	40 x 40	MARV1_09_8D.csv	Ei käs.	ok	2009, 2010, 2014, 2022
MARV1_09_9A		ylitiheä ku	15 x 30	MARV1_09_9A.csv	Ei käs.	ok	2009, 2014, 2022
MARV1_09_9B		ylitiheä ku	16 x 30	MARV1_09_9B.csv	Ei käs.	ok	2009, 2014, 2022
MARV1_09_9C		ylitiheä ku	17 x 30	MARV1_09_9C.csv	Ei käs.	ok	2009, 2014, 2022
MARV1_09_9D		ylitiheä ku	18 x 30	MARV1_09_9D.csv	Ei käs.	ok	2009, 2014, 2022
MARV1_10_1A		Mä-Ko pellolla	50 x 50	MARV1_10_1A.csv	Ei käs	ok	2010, 2013, 2022
MARV1_10_1B		Mä-Ko pellolla	50 x 50	MARV1_10_1B.csv	Ei käs.	ok	2010, 2013, 2022
MARV1_10_2A		Koivu-kuusi vartt	40 x 40	MARV1_10_2A.csv	voim. harv 2018?	80 x 40 m alana	2010, 2013
MARV1_10_2B		Koivu-kuusi vartt	40 x 40	MARV1_10_2B.csv	voim. harv 2018?	80 x 40 m alana	2010, 2013
MARV1_10_3A		Mä-Ko	30 x 70	MARV1_10_3A.csv	Harv 2021	Harv	2010, 2013, 2024
MARV1_10_3B		Mä-Ko	30 x 70	MARV1_10_3B.csv	Harv 2021	Harv	2010, 2013, 2024
MARV1_10_3C		Mä-Ko	30 x 70	MARV1_10_3C.csv	Harv 2021	Harventamaton	2010, 2013, 2024
MARV1_10_4A		Sekametsä	45 x 45	MARV1_10_4A.csv	ei käs.	ok	2010, 2013, 2023
MARV1_10_4B		Sekametsä	45 x 45	MARV1_10_4B.csv	ei käs.	ok	2010, 2013, 2023

MARV1_10_5A		Vanha sekam.	50 x 50	MARV1_10_5A.csv	ei käs.	ok	2010, 2013
MARV1_10_5B		Vanha sekam.	50 x 50	MARV1_10_5B.csv	ei käs.	ok	2010, 2013
MARV1_10_6A		RaR mä	30 x 45	MARV1_10_6A.csv	ei käs	ok	2010, 2013, 2023
MARV1_10_6B		RaR mä	30 x 45	MARV1_10_6B.csv	ei käs	ok	2010, 2013, 2023
MARV1_11_1A		Männikkö-kumpare-kasvup	50 x 50	MARV1_11_1A.csv	Ei käs.	ok	2011, 2023
MARV1_11_1B		Männikkö-kumpare-kasvup	50 x 50	MARV1_11_1B.csv	Ei käs.	ok	2011, 2023
MARV1_11_1C		Männikkö-kumpare-kasvup	50 x 50	MARV1_11_1C.csv	Ei käs.	ok	2011, 2023
MARV1_11_1D		Männikkö-kumpare-kasvup	50 x 50	MARV1_11_1D.csv	Ei käs.	ok	2011, 2023
MARV1_11_2A		Sekametsä, ei mitatu	40 x 30	MARV1_11_2A.csv	Ei käs.	Ei ole mitattu kertaakaan (puulajit)	
MARV1_11_2B		Sekametsä, ei mitattu	40 x 30	MARV1_11_2B.csv	Ei käs.	Ei ole mitattu kertaakaan	
MARV1_11_2C		Sekametsä	40 x 30	MARV1_11_2C.csv	Ei käs.	ok	2011, 2014
MARV1_11_2D		Sekametsä	40 x 30	MARV1_11_2D.csv	Ei käs.	ok	2011, 2014
MARV1_11_3A		VT kuusikko 40 v	30 x 30	MARV1_11_3A.csv	Ei käs	ok (maalattu)	2011, 2022
MARV1_11_3B		VT kuusikko 40 v	30 x 30	MARV1_11_3B.csv	Ei käs	ok (maalattu)	2011, 2022
MARV1_11_4A		Kuusikko yläharv	50 x 50	MARV1_11_4A.csv	Ei käs.	mittaus 2019? M	2011, 2014
MARV1_11_4B		Kuusikko yläharv	50 x 50	MARV1_11_4B.csv	Ei käs.	mittaus 2019? M	2011, 2014
MARV1_11_4C		Kuusikko yläharv	50 x 50	MARV1_11_4C.csv	Ei käs.	mittaus 2019? M	2011, 2014
MARV1_11_5A		Ensiharventamaton mä	20 x 40	MARV1_11_5A.csv	Harvennettu 2019?	Jatkossa yksi ko	, 2011
MARV1_11_5B		Ensiharventamaton mä	20 x 40	MARV1_11_5B.csv	Harvennettu 2019?	Jatkossa yksi ko	, 2011
MARV1_11_7A		Vanha ku-mä	60 x 40	MARV1_11_7A.csv	ei käs.	ok	2011, 2014
MARV1_11_7B		Vanha kuusivalt	60 x 40	MARV1_11_7B.csv	ei käs.	ok	2011, 2014
MARV1_11_7C		Vanha kuusivalt	60 x 40	MARV1_11_7C.csv	ei käs.	ok	2011, 2014
MARV1_15_1A		Mä kallioinen kasvupaikka	45 x 55	MARV1_15_1A.csv	Ei käs.	ok	2015,
MARV1_15_1B		Mä ku vanhaa lh.	40 x 75	MARV1_15_1B.csv	Ei käs	ok	2015,
MARV1_15_2A		Sekametsää lh. metsä	40 x 70	MARV1_15_2A.csv	Ei käs.	ok	2015, 2024
MARV1_15_2B		Sekametsää lh. metsä	40 x 70	MARV1_15_2B.csv	Ei käs.	ok	2015, 2024
MARV1_15_2C		Sekametsää lh. metsä	40 x 70	MARV1_15_2C.csv	Ei käs.	ok	2015, 2024
MARV1_15_3		Korpi lh. metsä	30 x 80	MARV1_15_3.csv	Ei käs.	ok	2015,
MARV1_15_4		Korpi lh. metsä	35 x 80	MARV1_15_4.csv	Ei käs.	ok	2015, 2022
MARV1_15_5A		Vanha kuusivalt.	45 x 80	MARV1_15_5A.csv	Ei käs.	ok	2015, 2023
MARV1_15_5B		Vanha kuusivalt.	45 x 80	MARV1_15_5B.csv	Ei käs.	ok	2015, 2023
MARV1_15_5C		Vanha kuusivalt.	45 x 80	MARV1_15_5C.csv	Ei käs.	ok	2015, 2023
MARV1_15_6		mänty ensiharv. Vinometsä	30 x 30	MARV1_15_6.csv	Ei käs.	ok	2015, 2021, 2022, 2024
MARV1_15_7A		40 V SEKAMETSÄ	30 X 40	MARV1_15_7A.csv	Harvennettu 2019?	Jos mitataan nii	2015,
MARV1_15_7B		40 V SEKAMETSÄ	30 X 40	MARV1_15_7B.csv	Harvennettu 2019?	Jos mitataan nii	2015,
MARV1_15_8A		Varttunut ku-ko	40 x 70	MARV1_15_8A.csv	Ei käs.	ok	2015, 2021
MARV1_15_8B		Varttunut ku-ko	40 x 70	MARV1_15_8B.csv	Ei käs.	ok	2015, 2021, 2022, 2024
MARV1_15_9		Lehtikuusi 1980	55 x 55	MARV1_15_9.csv	Ei käs.	ok	2015, 2021
MARV1_15_10		Kontorta 1980	50 x 50	MARV1_15_10.csv	Ei käs.	ok	2015, 2021
MARV1_15_11		ensiharventamaton VT-kuusi	25 x 30	MARV1_15_11.csv	Ei käs.	ok	2015, 2021, 2022, 2024
MARV1_16_1A		Vanha kuusivalt.	50 x 70	MARV1_16_1A.csv	Ei käs.	ok	2016,
MARV1_16_1B		Vanha sekam.	50 x 70	MARV1_16_1B.csv	Ei käs.	ok	2016,
MARV1_16_1C		Vanha sekam.	50 x 70	MARV1_16_1C.csv	Ei käs.	ok	2016,
MARV1_16_2A		Vanha Kuusivalt.	60 x 60	MARV1_16_2A.csv	Ei käs.	ok	2016,
MARV1_16_2B		Vanha Kuusivalt.	60 x 60	MARV1_16_2B.csv	Ei käs.	ok	2016,
MARV1_16_3A		Vanha Kuusivalt.	45 x 90	MARV1_16_3A.csv	Ei käs.	ok	2016,
MARV1_16_3B		Vanha Kuusivalt.	45 x 90	MARV1_16_3B.csv	Ei käs.	ok	2016,
MARV1_16_3C		Vanha Kuusivalt.	45 x 90	MARV1_16_3C.csv	Ei käs.	ok	2016,
MARV1_16_4A		Vanha sekam.	45 x 60	MARV1_16_4A.csv	Ei käs.	ok	2016,
MARV1_16_4B		Vanha sekam.	45 x 60	MARV1_16_4B.csv	Ei käs.	ok	2016,

MARV1_16_5A		45 v sekametsä	50 x 50	MARV1_16_5A.csv	Harv. ennen mitt.	ok	2016,
MARV1_16_5B		45 v sekametsä	50 x 50	MARV1_16_5B.csv	Harv. ennen mitt.	ok	2016,
MARV1_16_5C		45 v sekametsä	50 x 50	MARV1_16_5C.csv	Harv. ennen mitt.	ok	2016,
MARV1_16_5D		45 v sekametsä	50 x 50	MARV1_16_5D.csv	Harv. ennen mitt.	ok	2016,
marv4_2		4 aarin pysyvä inv.ala	r=11.28	marv4_2.csv	Harv. 2020	ok	2007, 2013, 2019, 2024
marv4_6		4 aarin pysyvä inv.ala	r=11.28	marv4_6.csv	Osin lanssip. 2020?	ok	2007, 2013, 2019, 2024
marv4_11		4 aarin pysyvä inv.ala	r=11.28	marv4_11.csv		ok	2007, 2013, 2019, 2024
marv4_12		4 aarin pysyvä inv.ala	r=11.28	marv4_12.csv		ok	2007, 2013, 2019, 2024
marv4_15		4 aarin pysyvä inv.ala	r=11.28	marv4_15.csv	Harv. 2020	ok	2007, 2013, 2019, 2024
marv4_19		4 aarin pysyvä inv.ala	r=11.28	marv4_19.csv		ok	2007, 2013, 2019, 2024
marv4_21		4 aarin pysyvä inv.ala	r=11.28	marv4_21.csv	Harv. 2020	ok	2007, 2013, 2019, 2024
marv4_25		4 aarin pysyvä inv.ala	r=11.28	marv4_25.csv		ok	2007, 2013, 2019, 2024
marv4_29		4 aarin pysyvä inv.ala	r=11.28	marv4_29.csv	Harv. 2020	ok	2007, 2013, 2019, 2024
marv4_31		4 aarin pysyvä inv.ala	r=11.28	marv4_31.csv		ok	2007, 2013, 2019, 2024
marv4_35		4 aarin pysyvä inv.ala	r=11.28	marv4_35.csv		ok	2007, 2013, 2019, 2024
marv4_37		4 aarin pysyvä inv.ala	r=11.28	marv4_37.csv	Harv. 2020	ok	2007, 2013, 2019, 2024
marv4_41		4 aarin pysyvä inv.ala	r=11.28	marv4_41.csv		ok	2007, 2013, 2019, 2024
marv4_45		4 aarin pysyvä inv.ala	r=11.28	marv4_45.csv		ok	2007, 2013, 2019, 2024
marv4_49		4 aarin pysyvä inv.ala	r=11.28	marv4_49.csv		ok	2007, 2013, 2019, 2024
marv4_53		4 aarin pysyvä inv.ala	r=11.28	marv4_53.csv		ok	2007, 2013, 2019, 2024
marv4_57		4 aarin pysyvä inv.ala	r=11.28	marv4_57.csv	Lanssipaikka 2018 vai 20?	ok	2007, 2013, 2019, 2024
marv4_61		4 aarin pysyvä inv.ala	r=11.28	marv4_61.csv		ok	2007, 2013, 2019, 2024
marv4_65		4 aarin pysyvä inv.ala	r=11.28	marv4_65.csv		ok	2007, 2013, 2019, 2024
marv4_69		4 aarin pysyvä inv.ala	r=11.28	marv4_69.csv		ok	2007, 2013, 2019, 2024
marv4_73		4 aarin pysyvä inv.ala	r=11.28	marv4_73.csv		ok	2007, 2013, 2019, 2024
marv4_77		4 aarin pysyvä inv.ala	r=11.28	marv4_77.csv		ok	2007, 2013, 2019, 2024
marv4_81		4 aarin pysyvä inv.ala	r=11.28	marv4_81.csv		ok	2007, 2013, 2019, 2024
marv4_85		4 aarin pysyvä inv.ala	r=11.28	marv4_85.csv		ok	2007, 2013, 2019, 2024
marv4_89		4 aarin pysyvä inv.ala	r=11.28	marv4_89.csv		ok	2007, 2013, 2019, 2024
marv4_93		4 aarin pysyvä inv.ala	r=11.28	marv4_93.csv		ok	2007, 2013, 2019, 2024
marv4_97		4 aarin pysyvä inv.ala	r=11.28	marv4_97.csv	Taimikko 2014	ok	2007, 2013, 2019, 2024
marv4_101		4 aarin pysyvä inv.ala	r=11.28	marv4_101.csv	Harv. 2017?	ok	2007, 2013, 2019, 2024
marv4_105		4 aarin pysyvä inv.ala	r=11.28	marv4_105.csv		ok	2007, 2013, 2019, 2024
marv4_109		4 aarin pysyvä inv.ala	r=11.28	marv4_109.csv		ok	2007, 2013, 2019, 2024
marv4_113		4 aarin pysyvä inv.ala	r=11.28	marv4_113.csv		ok	2007, 2013, 2019, 2024
marv4_117		4 aarin pysyvä inv.ala	r=11.28	marv4_117.csv		ok	2007, 2013, 2019, 2024
marv4_121		4 aarin pysyvä inv.ala	r=11.28	marv4_121.csv	Harv 2014/15?	ok	2007, 2013, 2019, 2024
marv4_125		4 aarin pysyvä inv.ala	r=11.28	marv4_125.csv		ok	2007, 2013, 2019, 2024
marv4_129		4 aarin pysyvä inv.ala	r=11.28	marv4_129.csv		ok	2007, 2013, 2019, 2024
marv4_131		4 aarin pysyvä inv.ala	r=11.28	marv4_131.csv		ok	2007, 2013, 2019, 2024
marv4_135		4 aarin pysyvä inv.ala	r=11.28	marv4_135.csv		ok	2007, 2013, 2019, 2024
marv4_139		4 aarin pysyvä inv.ala	r=11.28	marv4_139.csv		ok	2007, 2013, 2019, 2024
marv4_143		4 aarin pysyvä inv.ala	r=11.28	marv4_143.csv		ok	2007, 2013, 2019, 2024
marv4_147		4 aarin pysyvä inv.ala	r=11.28	marv4_147.csv		ok	2007, 2013, 2019, 2024
marv4_151		4 aarin pysyvä inv.ala	r=11.28	marv4_151.csv		ok	2007, 2013, 2019, 2024
marv4_155		4 aarin pysyvä inv.ala	r=11.28	marv4_155.csv	Noin 2016 tulva?	ok	2007, 2013, 2019, 2024
marv4_159		4 aarin pysyvä inv.ala	r=11.28	marv4_159.csv		ok	2007, 2013, 2019, 2024
marv4_163		4 aarin pysyvä inv.ala	r=11.28	marv4_163.csv		ok	2007, 2013, 2019, 2024
marv4_167		4 aarin pysyvä inv.ala	r=11.28	marv4_167.csv		ok	2007, 2013, 2019, 2024
marv4_171		4 aarin pysyvä inv.ala	r=11.28	marv4_171.csv	Lanssipaikka 2010?	ok	2007, 2013, 2019, 2024
marv4_175		4 aarin pysyvä inv.ala	r=11.28	marv4_175.csv		ok	2007, 2013, 2019, 2024
marv4_179		4 aarin pysyvä inv.ala	r=11.28	marv4_179.csv		ok	2007, 2013, 2019, 2024
marv4_183		4 aarin pysyvä inv.ala	r=11.28	marv4_183.csv		ok	2007, 2013, 2019, 2024
marv4_187		4 aarin pysyvä inv.ala	r=11.28	marv4_187.csv	Harv. 2020	ok	2007, 2013, 2019, 2024
marv4_191		4 aarin pysyvä inv.ala	r=11.28	marv4_191.csv		ok	2007, 2013, 2019, 2024
marv4_195		4 aarin pysyvä inv.ala	r=11.28	marv4_195.csv	Osin 2012 aukolla	ok	2007, 2013, 2019, 2024
marv4_199		4 aarin pysyvä inv.ala	r=11.28	marv4_199.csv		ok	2007, 2013, 2019, 2024
marv4_203		4 aarin pysyvä inv.ala	r=11.28	marv4_203.csv		ok	2007, 2013, 2019, 2024
marv4_207		4 aarin pysyvä inv.ala	r=11.28	marv4_207.csv		ok	2007, 2013, 2019, 2024
marv4_211		4 aarin pysyvä inv.ala	r=11.28	marv4_211.csv	Osin 2012 aukolla	ok	2007, 2013, 2019, 2024
marv4_215		4 aarin pysyvä inv.ala	r=11.28	marv4_215.csv		ok	2007, 2013, 2019, 2024
marv4_219		4 aarin pysyvä inv.ala	r=11.28	marv4_219.csv		ok	2007, 2013, 2019, 2024
marv4_223		4 aarin pysyvä inv.ala	r=11.28	marv4_223.csv		ok	2007, 2013, 2019, 2024
TEXAS	3.8 ha	Suurkoeala, kuusikko	160 x 240 m	TEXAS.csv		ok	2017, 2020
Vjsuo	2.14 ha	Suurkoeala, suomännikkö	130 x 165	Vjsuo.csv		ok	2017, 2020
SMEAR	4.2 ha	Suurkoeala, männikkö	150 x 280 m	SMEAR.csv		ok	2018, 2021
Tapiola	2.25 ha	Suurkoeala, vanhametsä	150 x 150	Tapiola.csv		ok	2018,
Asema	1.02 ha	Asmean hehtaari talonp.metsää	85 x 120	Asema.csv		ok	2017, 2019, 2021, 2023
Mkoivu	0.24 ha	Muiskokoivikko 2009-	30 x 80	Mkoivu.csv		ok	2009, 2010,..,24
2003_leimikko88		Rasinmäen ala GPS ScandJFR			Avohak. 2003 mittaukser	Hylätty	2003, hakkuukonedata
2003_leimikko15		Rasinmäen ala GPS ScandJFR			Avohak. 2003 mittaukser	Hylätty	2003, hakkuukonedata

LISÄKSI 42 MARV4-2007 kertakoealaa, yht. 1.7 ha					p99 (2023), m	p2h (2023), osuus alle 2m		Mitattu
marv4_3	2515325	6860925		r=11.28	14.4	0.326	ok	2019, 2024
marv4_4	2515325	6860975		r=11.28	15.1	0.408	ok	2019, 2024
marv4_9	2515375	6860975		r=11.28	16.5	0.283	ok	2019, 2024
marv4_10	2515375	6861025		r=11.28	18.0	0.305	ok	2019, 2024
marv4_14	2515425	6860875		r=11.28	16.6	0.491	ok	2019, 2024
marv4_16	2515425	6860975		r=11.28	17.5	0.284	ok	2019, 2024
marv4_18	2515425	6861075		r=11.28	18.2	0.136	ok	2019, 2024
marv4_33	2515525	6861075		r=11.28	22.2	0.198	ok	2019, 2024
marv4_36	2515575	6860775		r=11.28	20.1	0.119	ok	2019, 2024
marv4_38	2515575	6860875		r=11.28	23.8	0.246	ok	2019, 2024
marv4_42	2515575	6861075		r=11.28	18.4	0.088	ok	2019, 2024
marv4_52	2515625	6861025		r=11.28	22.4	0.130	ok	2019, 2024
marv4_56	2515625	6861225		r=11.28	22.4	0.298	ok	2019, 2024
marv4_60	2515675	6860725		r=11.28	25.2	0.238	ok	2019, 2024
marv4_67	2515675	6861075		r=11.28	20.7	0.250	ok	2019, 2024
marv4_74	2515725	6860575		r=11.28	21.4	0.066	ok	2019, 2024
marv4_104	2515775	6861175		r=11.28	22.1	0.126	ok	2019, 2024
marv4_110	2515825	6860575		r=11.28	22.1	0.360	ok	2019, 2024
marv4_111	2515825	6860625		r=11.28	22.9	0.307	ok	2019, 2024
marv4_114	2515825	6860775		r=11.28	3.0	0.964	ok	2019, 2024
marv4_118	2515825	6860975		r=11.28	19.6	0.183	ok	2019, 2024
marv4_123	2515825	6861225		r=11.28	22.8	0.505	ok	2019, 2024
marv4_127	2515875	6860575		r=11.28	22.8	0.266	ok	2019, 2024
marv4_130	2515875	6860725		r=11.28	23.3	0.272	ok	2019, 2024
marv4_142	2515925	6860525		r=11.28	26.3	0.087	ok	2019, 2024
marv4_148	2515925	6860825		r=11.28	19.1	0.243	ok	2019, 2024
marv4_158	2515975	6860575		r=11.28	26.8	0.076	ok	2019, 2024
marv4_166	2515975	6860975		r=11.28	26.3	0.129	ok	2019, 2024
marv4_168	2515975	6861075		r=11.28	21.7	0.272	ok	2019, 2024
marv4_170	2515975	6861175		r=11.28	21.5	0.513	ok	2019, 2024
marv4_176	2516025	6860725		r=11.28	26.4	0.246	ok	2019, 2024
marv4_178	2516025	6860825		r=11.28	25.0	0.154	ok	2019, 2024
marv4_180	2516025	6860925		r=11.28	20.0	0.240	ok	2019, 2024
marv4_184	2516025	6861125		r=11.28	18.9	0.551	ok	2019, 2024
marv4_198	2516075	6861125		r=11.28	21.9	0.367	ok	2019, 2024
marv4_200	2516075	6861225		r=11.28	26.3	0.379	ok	2019, 2024
marv4_206	2516125	6860825		r=11.28	22.6	0.253	ok	2019, 2024
marv4_213	2516125	6861175		r=11.28	26.6	0.038	ok	2019, 2024
marv4_214	2516175	6860625		r=11.28	28.5	0.174	ok	2019, 2024
marv4_216	2516175	6860725		r=11.28	29.8	0.063	ok	2019, 2024
marv4_218	2516175	6860825		r=11.28	23.6	0.251	ok	2019, 2024
marv4_220	2516175	6860925		r=11.29	21.0	0.151	ok	2019, 2024

6.2 Geometric ground control

6.2.1 2000 GCPs, signaled

Established signaled GCPs (N = 16) for aerial triangulation. White crosses, 30x(100-150) cm.

- \HYDE_REF\Misc\Muut.html

6.2.2 2002 Levelling (vaaitus)

Plots MMM1, MMM2, S1-S6, P1-P4, P6, B1-B4. Determining Z-coordinate of the plot origin by bringing the Z from known control points.

- \HYDE_REF\Misc\Muut.html

6.2.3 2005 Levelling (vaaitus)

MML ground control points. Determining Z-coordinate of the plot origin by bringing the Z from known control points.

- \HYDE_REF\Misc\Muut.html

6.2.4 2005 GCPs, natural and man-made

Positioning of natural and man-made targets with VRS-GPS. Used for triangulating the aerial image time series in Hyytiälä.

- \HYDE_REF\Misc\Muut.html

6.2.5 2006 Z profiles

VRS-GPS Z profiles in seedling/sapling stands.

- \HYDE_REF\Misc\Muut.html

6.2.6 2006 GCPs, natural and man-made

VRS-GPS measurements. Measurement of natural and man-made GCPs to be used for 2006 aerial image triangulation. Measurement of z control points for leveling. (Ilkka tarkista että kuvaus on oikein!)

- \HYDE_REF\Misc\Muut.html

6.2.7 2006 Levelling (vaaitus)

Plots TELE, MK, KM, FT, LK1, LK2, MMM2, TEXAS. Determining Z-coordinate of the plot origin by bringing the Z from known control points.

- \HYDE_REF\Misc\Muut.html

6.2.8 2007 Z profiles

VRS-GPS measurement of road profiles for evaluating accuracy of the 2007 LiDAR data.

- \HYDE_REF\Misc\Muut.html

6.2.9 2008 GCPs, signaled

Checking, repairing and painting old signaled GCPs from 2000. Establishment of new (N = 20). Positioned with VRS-GPS.

- \HYDE_REF\Misc\Muut.html

6.2.10 2010 GCPs, signaled

Established new signaled GCPs in six 500×500 m areas for TEKES UAV campaign. In each area there were up to 5 GCPs established. GCPs are white crosses made of 15x100 cm wood (Note! they are smaller than the other signaled GCPs in Hyytiälä). Positioned with VRS-GPS.

- \HYDE_REF\Misc\Muut.html

6.2.11 2010 Z profiles

Points positioned with VRS-GPS (N = 290). Sand road, football field, asphalt road, *Trifolium* field.

- \HYDE_REF\Misc\Muut.html

6.2.12 2012 Z profiles

Points positioned with VRS-GPS (N = 204). Sand road, oat field.

- \HYDE_REF\Misc\Muut.html

6.2.13 2013 Z profiles

Points positioned with VRS-GPS (N = 896). Sand and asphalt roads. Cover quite well the entire Hyytiälä AOI.

- \HYDE_REF\Misc\Muut.html

6.2.14 2015 GCPs, signaled

Checked the status of signaled GCPs. Painted and repaired 38 and re-built 2 signals. Discarded those that had moved from their place. Also discarded majority of those that were completely broken and would have needed re-building.

- \HYDE_REF\Misc\Muut.html

6.3 Other ground reference

6.3.1 2003 Clear-felled stands #15 and #88

Growth measurements of clear-felled trees. Ilkka has to check the documentation. Data are in:

- \HYDE_REF_2015\Misc\Muut.html

6.3.2 2006 Seedling/sapling stand vegetation

Samples of vegetation and abiotic material in six stands, positioned with VRS-GPS. Small plots (N = 6) containing trees, and subjectively selected point samples (N = 947) of trees and other vegetation.

- \HYDE_REF\Plots\TaimikkoData2006\Taimikot_2006.html

6.3.3 2006 Mire surface vegetation

Mire surface vegetation sampled for For.Eco.Manag. (2009) study.

- \HYDE_REF\Misc\Muut.html

6.3.4 2007 Exotic tree species nearby Hyytiälä

Photogrammetric-geodetic mapping and field reference measurements of exotic trees (N = 577).

- \HYDE_REF_2015\Misc\Muut.html

6.3.5 2007 Seedling/sapling stand vegetation

Samples of vegetation and abiotic material in seven stands, positioned with VRS-GPS. Small plots (N = 6) containing trees, and subjectively selected point samples (N = 1085) of trees and other vegetation.

- \HYDE_REF\Plots\TaimikkoData2007\Taimikot_2007.html

6.3.6 2010 TEKES mobile phone plots

Selected 30 permanent forest plots, in which 54 image locations were established. The image locations were marked in the field, and positioned with triangulation/trilateration, using trees as control points. The markings were removed after the imaging but the coordinates of the locations are known.

- \2010_Social_Forest\
  See README.txt

6.3.7 2010 Seedling/sapling stand vegetation

Samples of vegetation and abiotic material in 14 stands, positioned with VRS-GPS.

i. Small plots in which every tree was measured for species and height. (14 new plots, 3 plots from 2006/2007 re-measured: 6908 trees in total)

ii. Subjectively selected point samples of trees and other vegetation. Species and height measured. (2357 samples)

iii. Subjectively selected samples of low vegetation. Height measured, and percentage canopy cover estimated visually. (945 samples)

- \HYDE_REF\Plots\TaimikkoData2010\Taimikot_2010.html

6.3.8 2012 Systematic search of one-species stands

Jan-Feb 2012. Circular plots (N = 479) of 10 m radius searched systematically over Hyytiälä area, by visual interpretation of 2010 aerial images. Used in reference for AISA hypespectral data in 2010 (Paras Pant, UEF). Some of the broadleaved plots checked in the field by Antti Uotila.

- \HYDE_REF\Misc\Muut.html

6.3.9 2012 Seedling/sapling stand vegetation

Vegetation and abiotic material measured and positioned with VRS-GPS.

i. Point samples of young trees, low vegetation and abiotic material, in seedling and sapling stands (N = 1550).
ii. Circular plots in seedling and sapling stands (N = 72). Height of trees measured and treatment need evaluated.

- \HYDE_REF\Plots\TaimikkoData2012\index.html

6.3.10 2012 Shoot and leaf geometry, fireweed and raspberry

Shoot geometry measured for LiDAR simulation study. Geometry of 10 sample shoots of fireweed and 10 of raspberry measured. In addition leaf shapes digitized.

- \HYDE_REF\Misc\Muut.html

Measurement data

- \2012_raspberry_fireweed_birch_leaves_scanned\

Scanned images of leaves, tiff-format

6.3.11 2012 Search of radiometrically interesting targets under forest

Field trip, searching for interesting targets, positioned with differential GNSS, 1-4 m XY accuracy.

- \HYDE_REF\Plots\Alikasvos_2012\elokuu_2012_ilkka.html
- \HYDE_REF\Plots\Alikasvos_2012\elokuu2012_aarne.html

6.3.12 2013 LAI of raspberry canopies

1-4 m^2 sample plots (N = 50) of raspberry canopies in two recently regenerated stands. To be used for developing LiDAR simulator. The LAI was determined and the plots positioned with VRS-GPS.

Following measurements were performed for determining LAI:

i. Specific leaf area was determined by scanning, drying, and weighing leaf samples (N = 50).

ii. Leaf area variation between shoots was estimated by measuring leaf area of sample shoots (N = 40). The variation was used to determine sampling ratio i.e. how large proportion of the shoots should be sampled when determining the LAI of the plots, see below.

iii. Determinging LAI of sample plots (N = 50). For 21 plots, a randomly selected subset of shoots was taken, and the leaves of shoots were dried and weighed. The LAI was estimated based on specific leaf area and the sampling ratio applied when selecting the sample shoots. For the remaining 29 plots, the LAI was predicted based on fresh biomass. The biomass models were based on the 21 plots that had more accurate measurements.

- \HYDE_REF\Plots\2013_raspberryLAI_optical_GNSS\index.html
  In the html-page, see:
  '1. Specific leaf area measurements'
  '2. Sample shoots for determining intershoot leaf area variation'
  '3. LAI measurements from sample areas'
- \2013_raspberryLAI_optical_GNSS\index.html
  Same data as in HYDE_REF but includes images

6.3.13 2013 Optical properties of fireweed and raspberry leaves

Directional-hemispherical reflectance and transmittance spectra were measured for sample leaves (N = 22) of raspberry and fireweed, using field spectroradiometer and integrating sphere. To be used for developing LiDAR simulator. The samples were taken from seven locations in one newly regenerated forest stand. The specific leaf area of the leaves was also measured.

- \HYDE_REF\Plots\2013_raspberryLAI_optical_GNSS\index.html
  In the html-page, see:
  '4. Leaf optical properties measurements'
- \2013_raspberryLAI_optical_GNSS\index.html
  Same data as in HYDE_REF but includes images

6.3.14 2013 Seedling/sapling stand vegetation

Point samples of fireweed and birch (N = 300) in seedling and sapling stands, measured and positioned with VRS-GPS. Collected in order to complement the raspberry LAI measurements, so that the LiDAR simulator could be tested against 2013 LiDAR data.

- \HYDE_REF\Plots\2013_raspberryLAI_optical_GNSS\index.html
  In the html-page, see:
  '5. Other GNSS observations from Hyytiälä'
- \2013_raspberryLAI_optical_GNSS\index.html
  Same data as in HYDE_REF but includes images

6.3.15 2013 Photogrammetric-geodetic mapping of trees around SMEAR station

Maps and files prepared for photogrammetric-geodetic mapping of trees around the SMEAR station.

- \HYDE_REF\Misc\Muut.html

6.3.16 2014 Mire surface vegetation

Samples of mire surface vegetation (N = 844) in Siikaneva. Positioned with VRS-GPS. Data in HYDE_REF, Ilkka has to check that everything is documented.

- \HYDE_REF\Misc\Muut.html

7 Notes on DPW software KUVAMITT

7.1 Technical implementation and central limitations

The data formats of LiDAR and imagery are closely linked with the digital photogrammetric software KUVAMITT, developed and maintained since 1999 by Ilkka Korpela.

Technically, KUVAMITT is a VB6 program, developed with Microsoft Visual studio 6 from 1998. It uses the win32 libraries and has thus many limits. One central is the 2GB limit. A file pointer cannot be set at value larger than 2^{31}-1, which hinders read/write of large files. Internally, VB6 sets limits for the size of individual data structures, which are restricted at below 300 Mbytes. Thus, a normal RGB aerial image cannot be read in memory completely.

The 4- and 2-byte integers in VB6 are signed (as signed int & signed short in C), and only an unsigned 1-byte integer data type is available (unsigned # in C). The floating-point double and single types are the same as in standard C.

VB supports variable length arrays as a part of Types (structs in C). Types are used as data collections with attributes. An example of a Type is Point3D.

```
Type Point3D
  x As double
  y As double
  z as double
End type

Dim MyPoint as Point3D
MyPoint.x = 2.0
```

VB6 comes with many build-in objects that have attributes (properties) and methods.
An example is a PictureBox, instances of which are used to display raster images in KUVAMITT.

There are build-in functions, and deficiencies are replaced sometimes by API functions, such as for the missing atan2() function.

Variables can have local (function, subroutine) scope, but there are also variables with global score. They are called Public variables. Some are used by KUVAMITT, for example the three variables X_sol, Y_sol, Z_sol are central as they define the current 3D point solution.

There are Forms which correspond to program windows. That can be loaded, made visible, invisible or unloaded. Form1.frm is the main program window. A form is an object with methods and attributes.

Variable, Type, Array, dll-function etc. declarations and written functions and subroutines are in code modules (*.bas). Arguments may be passed by reference (ByRef) or by value (ByVal). For example, an array is passed to an external dll-function by reference to the very first element, e.g. “Byref MyArray(0,0)”.

The menus are created in VS6 menu editor. It creates a Form-level (Private) subroutine with suffix “_Click()”.

Binary file i/o in VB starts from pointer == 1 (not file position 0 as in C).

KUVAMITT relies on many files (icons, mouse pointers, dll-files, ascii parameter files) that must be in C:\DATA\ directory.

VB6 is compiled on the fly, allowing for easy debugging but slow execution.

Because of being win32 compatible, functions in the win32-API or in external DLLs can be called from VB6 as external functions. The size of the passed arguments (data) is limited. KUVAMITT uses many API DLLs and two DLLs compiled with the VC6 compiler.

Support for VB6 is promised until 2018 in the windows operating systems.

7.2 Some main principles

There can be nine images loaded and displayed. Loading means that the interior and exterior orientation data are read. These data are in the *.HDR files (Appendices 1a and 1b).

The raw image file is read for a N x N part (pixels), which is to be displayed on the screen in a PictureBox-object. Here N is always a multiple of 4, because the displayed NxN image file (N x N pixels) is a BMP file that can easily be loaded for display in a PictureBox object. C:\DATA\ has files Pic0.bmp…Pic8.bmp.

Fig. 135. An example (Pic2.bmp) found in the C:\DATA\ folder.

The partial image displayed is always a “cut” of a larger image, and has an origin defined in the image coordinate system of the large (main) image. Thus it is possible to compute the (col, row) values, and using affine transformation, derive the metric position in the camera coordinate system.

There is always a solution (X_sol, Y_sol, Z_sol), and the images displayed can be centered on the positions to which this point maps in the images.

The photogrammetry is simpler for the frame-images (2D sensor array, one exposure), than it is for the ADS40 line sensor images (continuous integration of image lines for an image mat, continuum of line images with perspective mapping in one direction only).

Appendix 4 has a 10-page document about KUVAMITT from 2009.

8 Missing optical data

Satellite images?

In 2011, a hyperspectral campaign was carried out by a consortium led by Prof. Petri Pellikka (UH Geography).

Appendix 1a – HDR-files, frame sensor

An example of a HDR-file for a frame sensor. Scanned (frame-sensor) film image from summer 2004 (2004_440220.hdr). The part following "/" is a comment, that should not be included in a HDR-file. The structure of the HDR file has evolved since 1999, when the development of KUVAMITT-software started.

```
FRAME                              / "FRAME", "ADS L0" or "ADS L1"
 440220                            / integer image code
 15376                             / width in pixels, N columns
 15346                             / height in pixels, N rows
"d:\04402\04402_0020_cp.raw"       / reference to image file
 1                                 / color model, 1 == RGB, 8 bits per color
 7650                              / image centered at this column at start
 7650                              / " " " " row " "
 0                                 / Upper left corner column value (if sub-image)
 0                                 / Upper left corner row value (cut sub-image)
 15376                             / Size of the sub-image, width in pixels
 15346                             / size of the sub-image, height in pixels
 0.21407                           / focal length, meters
 0                                 / ppa_x coordinates on focal plane, m
 0                                 / ppa_y coordinates on focal plane, m
 0                                 / Helmert transformation, scale
 0                                 / Helmert transformation, rotation
 0                                 / Helmert transformation, x offset camera crds
 0                                 / Helmert transformation, y offset camera crds
 0                                 / Helmert transformation, x offset columns
 0                                 / Helmert transformation, y offset rows
 66651.86199                       / Affine x' = a*x + b*y + c
 77.422884                         / Affine x' = a*x + b*y + c
 7689.1583                         / Affine x' = a*x + b*y + c
-72.835259                         / Affine y' = d*x + e*y + f
 66652.35792                       / Affine y' = d*x + e*y + f
 7670.856393                       / Affine y' = d*x + e*y + f
-0.00774701                        / omega, radians
-0.00604603                        / phi, radians
-1.41541515                        / kappa, radians
 2515620.549                       / X0, meters
 6861977.347                       / Y0, meters
 3136.447821                       / Z0, meters
 2.426481061                       / solar azimuth, radians
 0.769680053                       / solar elevation, radians
AdditionalExposures                /
 0                                 / How many additional images associated
 0                                 / type of i'th (see color model)
 0                                 / filepointer (path to raw file)
 0                                 / width in pixels
 0                                 / height in pixels
 0                                 / type of (i+1)'th and so on..
 0
 0
 0
```

The AdditionaleExposures part is used with UltraCAM L2 images, which have the same EO as the Pan-sharpened L3 image that is viewed (screen i/o). This part likely changes in the future, because many parameters are missing and assumed by the KUVAMITT-code.

Appendix 1b – HDR-files, line-sensor

An example of a HDR-file for an ADS40 image. (08230656BLUN00A.hdr). August 23, 0656 GMT, BLUE band viewed by nadir (N00) image line comprising 12000 pixels. The part following "/" is a comment, that should not be included in a HDR-file.

```
ADS L0                                      / Raw image, L1 projected to plane
d:\10cm\cam\BLUN00A.cam                     / interior orientation file
d:\10cm\odf\08230656BLUN00A.odf.adj         / EO for each image line (row)
d:\10cm\sup\08230656BLUN00AL0.sup           / Info photogr. Cartesian system
d:\10cm\ads\08230656BLUN00A.ads             / Calibration parameters etc.
 8230656                                    / Image code
 12000                                      / width, always 12000 in L0 data
 97424                                      / height, number of captured lines
"d:\10cm\raw\08230656BLUN00A_0_0.raw"       / image file
 2                                          / 2 == 16 bit mono
 6000                                       / center column, start value for i/o
 48712                                      / center line, "
 0                                          / if a cut sub-image, UpLeft col
 0                                          / " " " ", " row
 12000                                      / width of sub-image
 97424                                      / height of sub-image
 0.0627                                     / focal length
 0
 0
 0
 0
 0
 0
 0
 0
 153846.1538                                / reciprocal of pixel size, 6.5 um
 0
 48712                                      / middle row
 0
 153846.1538
 6000                                       / middle col
 0                                          / EO is defined in adj/sup files
 0                                          / for each image line, here 97424
 0                                          / lines in total
 2516000                                    / Nonsense
 6858500                                    / Nonsense
 3000                                       / Nonsense
 0                                          / solar azimuth, not defined here
 0                                          / solar elevation
AdditionalExposures                         / Not used with ADS40
 0
 0
 0
 0
 0
 0
 0
 0
 0
```

Appendix 2a – ADS40 specific information - *.ADS files

Public integer MAXIMA = 9 ‘ there can be 9 images in the KUVAMITT screen, max

```
Type BlockData
 L0 As Long
 L1 As Long
 FileName As String
End Type

Type ADSHDR ' data in the *.ads file
 HEADER As Byte
 BANDS As Byte
 DEPTH As Byte
 BITS As Byte
 LINES As Long
 SAMPLES As Long
 TILE_X As Long
 TILE_Y As Long
 HARDWARE_COMPRESSED As Byte
 LINES_PER_BLOCK As Long
 SAMPLES_PER_BLOCK As Long
 BLOCK_DATA(0 To MAXIMA - 1, 1 To 3) As BlockData
 NUMBER_OF_SUBIMAGES As Long
End Type
```

An example of an ADS-file (Nadir BLUE, at 0656 GMT), N.B. RAW-files are untiled, and reference is in the HDR-file

```
ADS_HEADER          1
BANDS               1
DEPTH               2
BITS                16
LINES               97424
SAMPLES             12000
TILE_Y              256
TILE_X              256
HARDWARE_COMPRESSED 0
LINES_PER_BLOCK     89088
SAMPLES_PER_BLOCK   12000
BLOCK_DATA          0 0 08230656BLUN00A_0_0.tif
BLOCK_DATA          1 0 08230656BLUN00A_1_0.tif
```

Appendix 2b – ADS40 specific information - *.CAM files

I/O data and information on how to convert the pixel values into at-sensor radiance (integration time is the time difference between GPSTIME of subsequent image lines, see ODF-files). xy focal plane coordinates are given to all 12,000 pixels in this image line.

An example file, the IO of nadir blue line, BLUN00A.cam

```
ADS_CALIBRATION_FILE 1
CALIBRATION_SOURCE    "ORIMA"
CAMERA_NAME           "30120"
SENSOR_LINE           "BLUN00A"
CALIBRATION_DATE      "Tue Sep 30 12:45:55 2008"
FOCAL_LENGTH_MM       62.70000
NUM_PIXELS            12000
PIXEL_SIZE            0.00650
RADIOMETRIC_GAIN      0.00005
IRRADIANCE_GAIN       1.00000
LEFTSIDE_GAIN         1
PAV_Z_OFFSET          0.17100
START_XY
-0.01165  -39.01087
-0.01166  -39.00412
-0.01166  -38.99737
-0.01166  -38.99061
-0.01167  -38.98385
```

... all 12000 pixels...continues

Appendix 2c – ADS40 specific information - *.ODF files

It is a binary file, an example file 08230656BLUN00A.odf.adj
Notepad sees it like this

ODF 1.2 "ORIMA" 30120_20080823065636_ADS40_Demo_Finnland_V5
30120_20080823065636_ADS40_Demo_Finnland_V5_1 97424 0 1000 3 1000000 0 283651200
1.0791782857 0.4237346719 543505 10000 1 100000 -2 10000000 1099 ö–ñÿÍÎ
³˜³ÿP™ !ùÿÿÈ©¸

VB-code for reading an ODF file, * N is the number of characters or Bytes,

```
Dim cFileId As String * 16
Dim cDataSource As String * 32
Dim cProjectID As String * 64
Dim cStripNameID As String * 64
Dim cNumberOfDataSets As String * 16
Dim cNumOfODFs As Long
Dim cUnitsPosition As String * 2
Dim cPrecisionPosition As String * 14
Dim cUnitsAngles As String * 2
Dim cPrecisionAngles As String * 14
Dim cRotationSequence As String * 16
Dim cAbsoluteTime As String * 16
Dim cComments As String * 96
Dim cAnchorLatitude As String * 16
Dim cAnchorLongitude As String * 16
Dim cBaseTime As String * 12
Dim cPrecisionTime As String * 20
Dim cBaseX As String * 12
Dim cPrecisionStdDevPosition As String * 20
Dim cBaseY As String * 12
Dim cPrecisionStdDevAngles As String * 20
Dim cBaseZ As String * 32
```

The reading is in binary mode, read head (file pointer) is moved between variables.
After reading the strings, the conversion to meaningful numeric variables follows:

```
NumOfODFs = Int(Val(Trim(cNumberOfDataSets)))
BaseTime = Int(Val(Trim(cBaseTime)))
PrecisionTime = Int(Val(Trim(cPrecisionTime)))
PrecisionPosition = Int(Val(Trim(cPrecisionPosition)))
BaseX = Int(Val(Trim(cBaseX)))
BaseY = Int(Val(Trim(cBaseY)))
BaseZ = Int(Val(Trim(cBaseZ)))
PrecisionAngles = Int(Val(Trim(cPrecisionAngles)))
PrecisionStdDevPosition = Int(Val(Trim(cPrecisionStdDevPosition)))
PrecisionStdDevAngles = Int(Val(Trim(cPrecisionStdDevAngles)))
```

The number of image lines for which there is orientation data is numOfODFs
This information comes in binary (44 Byte) records, and here is the (struct) or Type definition for reading:

```
Type ODFReadstruct
  GPStime As Long
  X As Long
  Y As Long
  z As Long
  omega As Long
  phi As Long
  kappa As Long
  StdDevX As Integer
  StdDevY As Integer
  StdDevZ As Integer
  StdDevOmega As Integer
  StdDevPhi As Integer
  StdDevKappa As Integer
End Type
```

What then is stored is in a different struct with decimal representation:

```
Type ODFStruct
  GPStime As Double
  X As Double
  Y As Double
  z As Double
  omega As Double
  phi As Double
  kappa As Double
  a00 As Double
  a01 As Double
```

```
  a02 As Double
  a10 As Double
  a11 As Double
  a12 As Double
  a20 As Double
  a21 As Double
  a22 As Double
  StdDevX As Single
  StdDevY As Single
  StdDevZ As Single
  StdDevOmega As Single
  StdDevPhi As Single
  StdDevKappa As Single
End Type
```

The conversions are (with errors in the sdevs due to VB integer being signed 16)

```
ODFarray(k).GPStime = (ODF.GPStime / PrecisionTime + CDbl(BaseTime))
ODFarray(k).X = ODF.X / CDbl(PrecisionPosition) + CDbl(BaseX)
ODFarray(k).Y = ODF.Y / CDbl(PrecisionPosition) + CDbl(BaseY)
ODFarray(k).z = ODF.z / CDbl(PrecisionPosition) + CDbl(BaseZ)
ODFarray(k).omega = ODF.omega / CDbl(PrecisionAngles)
ODFarray(k).phi = ODF.phi / CDbl(PrecisionAngles)
ODFarray(k).kappa = ODF.kappa / CDbl(PrecisionAngles)
Rem the reading of unsigned short -values fails and the STDDEV-values are incorrect
ODFarray(k).StdDevX = ODF.StdDevX / CDbl(PrecisionStdDevPosition)
ODFarray(k).StdDevY = ODF.StdDevY / CDbl(PrecisionStdDevPosition)
ODFarray(k).StdDevZ = ODF.StdDevZ / CDbl(PrecisionStdDevPosition)
ODFarray(k).StdDevOmega = ODF.StdDevOmega / CDbl(PrecisionStdDevAngles)
ODFarray(k).StdDevPhi = ODF.StdDevPhi / CDbl(PrecisionStdDevAngles)
ODFarray(k).StdDevKappa = ODF.StdDevKappa / CDbl(PrecisionStdDevAngles)
```

The values a00…a22 are the elements of the 3x3 rotation matrix, calculated from omega, phi and kappa, as explained in Section “Concepts and terms”.

Appendix 2d – ADS40 specific information - *.SUP files (support)

This file tells many things and is an output of the processing software.
For example, the photogrammetric coordinate system in ADS40 is local, and Cartesian, and the SUP-file has information on how to convert the XYZ data in this local system to the WGS84-XYZ. Back and forth. From and to WGS84-XYZ, KUVAMITT has implementations of UTM and KKJ-2.

All photogrammetry is done in the LOCAL system, and results are converted to KKJ where all field data is:
1. Photogrammetry to get the XYZ-local
2. XYZ-local ⇒ WGS84_XYZ (sup-file)
3. WGS84_XYZ ⇒ UTM
4. UTM ⇒ KKJ

Or the other way around, to see where the field data maps
1. KKJ ⇒ UTM
2. UTM ⇒ WGS84_XYZ
3. WGS84_XYZ ⇒ XYZ-local (sup-file data)
4. Photogrammetry for image line, column on the line

An example, 08230656BLUN00AL0.sup

```
--------------------
support_file d
IMAGE_ID "08230656BLUN00A"
IMAGE_FILE_NAME 1 "R:\ADS40_Demo_Finnland_V5\Flight_10cm\images\08230656BLUN00A.ads"
LINES 97424
SAMPLES 12000
RECTIFICATION_TERMS
             0.00000000000000e+000 0.00000000000000e+000 1.00000000000000e+000
             0.00000000000000e+000 1.00000000000000e+000 0.00000000000000e+000
GRND_BIAS 0.00000000000000e+000 0.00000000000000e+000 0.00000000000000e+000
BIAS 0.000000 GAIN 1.000000
GROUND_ZERO 2.00182669506973e+002 3.14943395819402e+001 1.85000000000000e+002
LOAD_PT 2.00182669506973e+002 3.14943395819402e+001 1.85000000000000e+002
COORD_SYSTEM 0
UNITS 1
USE_FAST_MATH 0
MAX_AND_MIN_ELEVATION 140.0 230.0
IMAGE_MOTION 0
INITIALIZED 2
STATUS 0
PHOTO_DATE "Fri Sep 26 10:34:15 2008"
QUALITY 53
SENSOR_TYPE ADS
IMAGE_LEVEL 0
MEAN_TERRAIN_HEIGHT 185.000000
ANCHOR_LATITUDE 1.079178285671
ANCHOR_LONGITUDE 0.423734671902
LINE_STAGGERED FALSE
VIEW_OF_LINE NADIR
RADIOMETRIC_PROPERTY BLUE
IMAGE_DATE Fri Sep 26 10:34:15 2008
NUMBER_SCAN_LINES 97424
SENSOR_ROTATION FALSE
CORRECTION NO_CORRECTION
LEVEL_0_GSD 0.09475279
ORIGINAL_ORIENTATION R:\ADS40_Demo_Finnland_V5\Project_10cm\odf\08230656BLUN00A.odf
ADJUSTED_ORIENTATION R:\ADS40_Demo_Finnland_V5\Project_10cm\odf\08230656BLUN00A.odf.adj
ORIGINAL_CALIBRATION R:\ADS40_Demo_Finnland_V5\Project_10cm\cam\ADS40_30120\v001\BLUN00A.cam
ADJUSTED_CALIBRATION R:\ADS40_Demo_Finnland_V5\Project_10cm\cam\ADS40_30120\v002\BLUN00A.cam
LOCAL_ORIGIN 2.75170803241219e+006 1.24118409598441e+006 5.59972026370906e+006
BASIS  -4.11167689069547e-001 9.11559724573880e-001 0.00000000000000e+000 -8.03603899554576e-001
-3.62473186780590e-001 4.72052922335835e-001 4.30304431868749e-001 1.94092909195352e-001
8.81570211902715e-001
```

The Type declaration for the SUP-file attributes is

```
Rem Data in the support file
Type ADS40Support
  IMAGE_ID As String * 30
  IMAGE_FILE_NAME As String * 100
  LINES As Long
  SAMPLES As Long
  RECTIFICATION_TERMS(1 To 6) As Double
  GRND_BIAS(1 To 3) As Double
  BIAS As Double
  GAIN As Double
  GROUND_ZERO As Point3d
  LOAD_PT As Point3d
  COORD_SYSTEM As Byte
  UNITS As Byte
  USE_FAST_MATH As Byte
  MIN_AND_MAX_ELEVATION As Point2D
  IMAGE_MOTION As Byte
  INITIALIZED  As Byte
  Status As Byte
  PHOTO_DATE As String * 30
  QUALITY As Byte
  SENSOR_TYPE As String * 10
  IMAGE_LEVEL As Byte
  MEAN_TERRAIN_HEIGHT As Double
  ANCHOR_LATITUDE As Double
  ANCHOR_LONGITUDE As Double
  LINE_STAGGERED As Boolean
  VIEW_OF_LINE As String * 12
  RADIOMETRIC_PROPERTY As String * 20
  IMAGE_DATE As String * 30
  NUMBER_SCAN_LINES As Long
  SENSOR_ROTATION As Boolean
  CORRECTION As String * 20
  LEVEL_0_GSD As Double
  ORIGINAL_ORIENTATION As String * 160
  ADJUSTED_ORIENTATION As String * 160
  ORIGINAL_CALIBRATION As String * 160
  ADJUSTED_CALIBRATION As String * 160
  LEVEL_0_NAME As String * 80
  RECT_SCALE As Double
  RECT_ROTATION As Double
  RECT_XOFFSET As Double
  RECT_YOFFSET As Double
  RECT_HEIGHT As Double
  RECT_USE_CALIBRATION As Boolean
  LOCAL_ORIGIN As Point3d ‘ WGS84-XYZ
  BASIS(1 To 3, 1 To 3) As Double ‘ Rotation at that point between local and WGS84-XYZ
End Type
```

For example, going from KKJ to Local is

```
Public Sub KKJ_to_LSR(i As Long, kkj_x As Double, kkj_y As Double, kkj_z As Double, Xl As
Double, yl As Double, zl As Double)

Dim Lat As Double, Lon As Double, H As Double, UTM_E As Double, UTM_N As Double
Rem First KKJ to UTM
Call KKJ_to_UTM(kkj_x, kkj_y, kkj_z, UTM_E, UTM_N, H)
Rem UTM to WGS84
Dim apu As Long, Zone As Long
Zone = 35
Dim xn As Double, yn As Double, Zn As Double
apu = UTM_TO_WGS84XYZ(xn, yn, Zn, Lat, Lon, H, UTM_E, UTM_N, Zone)
Rem Perform LSR (local cartesian) to WGS84-XYZ conversion
Xl = ADSSUP(i).BASIS(1, 1) * (xn - ADSSUP(i).LOCAL_ORIGIN.X) + ADSSUP(i).BASIS(1, 2) * (yn -
ADSSUP(i).LOCAL_ORIGIN.Y) + ADSSUP(i).BASIS(1, 3) * (Zn - ADSSUP(i).LOCAL_ORIGIN.z)
yl = ADSSUP(i).BASIS(2, 1) * (xn - ADSSUP(i).LOCAL_ORIGIN.X) + ADSSUP(i).BASIS(2, 2) * (yn -
ADSSUP(i).LOCAL_ORIGIN.Y) + ADSSUP(i).BASIS(2, 3) * (Zn - ADSSUP(i).LOCAL_ORIGIN.z)
zl = ADSSUP(i).BASIS(3, 1) * (xn - ADSSUP(i).LOCAL_ORIGIN.X) + ADSSUP(i).BASIS(3, 2) * (yn -
ADSSUP(i).LOCAL_ORIGIN.Y) + ADSSUP(i).BASIS(3, 3) * (Zn - ADSSUP(i).LOCAL_ORIGIN.z)
End Sub
```

Appendix 3 – Formats of LiDAR pulse records 2004-2013

A BIN file always starts with a 4byte signed long, which tells how many pulse-records there are stored. The first record starts right after the signed long.

Optech modified ALTM1033, 2004

```
Rem ALTM2033 type of LiDAR records
Type ALS_Point
 GPS_time As Double  ' 8 bytes
 Xl As Double        ' 8 LiDAR position
 yl As Double        ' 8
 zl As Single        ' 4
 omega As Single     ' 4 LIDAR attitude, what system, UTM?
 phi As Single       ' 4
 kappa As Single     ' 4
 Scan_angle As Single ' 4
 Xf As Double         ' 8 first return
 Yf As Double         ' 8
 Zf As Single         ' 4
 Intf As Single       ' 4 intensity
 Rangef As Single     ' 4
 Xs As Double         ' 8 second return
 Ys As Double         ' 8
 Zs As Single         ' 4
 Ints As Single       ' 4 intensity
 Rangel As Single     ' 4
End Type ' 100 bytes per pulse
```

FN1_FN2.bin hectare file. FN1 is the easting, FN2 in the northing, three digit strings:
FN1 = Format$(Int((Xc - 2514000) / 100), "000")
FN2 = Format$(Int((Yc - 6855000) / 100), "000")
The origin is thus at X == 2514000, Y == 6855000.

Optech ALTM3100, 2006

Conversion programs \ALS2006\CMP_To_BIN\

```
Type Point3d
 X As Double
 Y As Double
 z As Double
End Type

Rem 2006 ALTM 3100 pulse data, 207 bytes per record
Type LidarRecord
 GPStime As Double
 PulseCount As Byte
 Returns(1 To 4) As Point3d
 intensity(1 To 4) As Integer
 range(1 To 4) As Double
 angle As Double
 Roll As Double
 pitch As Double
 heading As Double
 PosLiDAR As Point3d
 StripNum As Integer
 SyncBit As Byte
 Res1 As Byte
 Res2 As Byte
 Res3 As Byte
End Type
```

The first encountered return has (in VB6, first index is 1, not zero-based) index (4), the last is (1). The last is always a copy, unless it is a 4-echo pulse. Second return is (3) and third is (2). If (2) exists and is not same (1), then it is a 4-echo pulse.

Computing the hectare coordinates is

```
FN1 = Format$(Int((Xs - 2510000) / 100), "000")
FN2 = Format$(Int((Ys - 6850000) / 100), "000")
```

Leica ALS50-ii, 2007 and 2008

Quite similar to ALTM3100 in 2006; processed from els-files to per hectare BIN files with “LiDarRecord” 207-byte structures (see below).

ALS2007_purku_v2.cpp

```
// els-files per point records
struct ELASpoint {
  double x;
  double y;
  double z;
  unsigned short intensity;
  unsigned char return_number : 3;
  unsigned char number_of_returns_of_given_pulse : 3;
  unsigned char scan_direction_flag : 1;
  unsigned char edge_of_flight_line : 1;
  unsigned char classification;
  char scan_angle_rank;
  unsigned char user_data;
  unsigned short point_source_ID;
  double gps_time;
  double x_lidar;
  double y_lidar;
  double z_lidar;
  double roll;
  double pitch;
  double heading;
  unsigned short agc;
  int dummy;
  short dummy2;
} LiDR2007;

// Per-pulse records in the BIN-files

struct Point3d {
     double x;
     double y;
     double z; };

struct LidarRecord {
   double GPSTime;
   char PulseCount;
   struct Point3d LastPulse; // 0 last, 1 third, 2 = second, 3 = first
   struct Point3d SecondPulse; // 0 last, 1 third, 2 = second, 3 = first
   struct Point3d ThirdPulse; // 0 last, 1 third, 2 = second, 3 = first
   struct Point3d FirstPulse; // 0 last, 1 third, 2 = second, 3 = first
   short  Intensity[4];
   double Range[4];
   double Angle;
   double Roll;
   double Pitch;
   double Heading;
   struct Point3d Poslidar;
   short StripNum;
   char SyncBit;
   unsigned char Res1;
   unsigned char Res2;
   unsigned char Res3;
 } LiDR;

LiDR.Res1 = unsigned char(LiDR2007A[l].agc);
LiDR.Res2 = LiDR2007A[l].edge_of_flight_line;
LiDR.Res3 = LiDR2007A[l].classification;
LiDR.SyncBit = LiDR2007A[l].scan_direction_flag;
```

VB6

```
Rem Coordinates of the 1-ha BIN file for point Xs, Ys
FN1 = Format$(Int((Xs - 2510000) / 100), "000")
FN2 = Format$(Int((Ys - 6850000) / 100), "000")
```

Leica ALS60 2010, 2011a, 2012, and 2013b

These data include recorded waveforms. The discrete return data is in BIN files and the structure is given below. One attribute gives the read position (in VB file starts at Byte 1, in C/C++ it is position 0, VB-style used here) to the WF data file. I.e. WF data are also split to hectare files. ALS60 records one continuous 128 or 256 sample WF record. At sampling rate of 1 ns, 256 amplitude values (8-bit) are recorded.

FN1 and FN2 are three-digit coordinates of the KKJ-2 hectare.

```
FN1 = Format$(Int((Xs - 2510000) / 100), "000")
FN2 = Format$(Int((Ys - 6850000) / 100), "000")
```

FN1_FN2.bin	/ The discrete return file, first 4-byte Long tells the number of records
FN1_FN2_128.bin	/ The WF of 2 ns sampling (a part of the flight lines)
FN1_FN2_256.bin.	/ The WF of 1 ns sampling

```
Type LidarRecord2010
 GPStime As Double
 PulseCount As Byte
 Returns(1 To 4) As Point3d   ‘ first index (4), second (3), third (2), last/fourth (1)
 intensity(1 To 4) As Integer
 range(1 To 4) As Double
 angle As Double
 Roll As Single
 Fileoffset As Long           ' The fileoffset to WF record starting from address 1
 pitch As Double
 heading As Double
 PosLiDAR As Point3d
 StripNum As Integer
 SyncBit As Byte
 Res1 As Byte                 ‘ AGC
 Res2 As Byte
 wavetype As Byte             ‘ 0 == no WF, 127 = 128, 255 = 256 samples
End Type
```

Riegl 2011b, 2013a, 2015

The initial observations are in proprietary format (Riegl). The contractor used RiProcess software to compute DR data from the recorded waveform samples. Noteworthy, the sensor could record several from one pulse emitted. Sampling was at 1 nanosecond, and the outputted LAS format had 80, 160 or 240 sample long waveform sample sequences.

In 2011b, the attribute `RetPointWFLoc` that tells in picoseconds, the start time for the sample (from the detected echo, along the pulse path), is only at nanosecond accuracy, which is ± 500 ps. In 2013a this bug in RiProcess was fixed, and 2013a data has `RetPointWFLoc` that has at pikosecond-level accuracy.

The data are in per hectare BIN-files. FN1 and FN2 are three-digit coordinates of the KKJ-2 hectare.

```
FN1 = Format$(Int((Xs - 2510000) / 100), "000")
FN2 = Format$(Int((Ys - 6850000) / 100), "000")
```

FN1_FN2.bin / The discrete return file, first 4-byte Long tells the number of records
FN1_FN2_wf.bin / The WF at 1 ns (80, 160 or 240 sample sequences, 2-byte integers)

For 2013a Siikaneva data the coordinates are exceptionally in ETRS-TM35FIN system and the FN1 and FN2 are computed:

```
FN1 = Format$(Int((Xs - 349000) / 100), "000")
FN2 = Format$(Int((Ys - 6857000) / 100), "000")
```

The Type declarations in VB6 are

```
Type EchoRiegl                  ‘ A discrete-return, there can be 1-10 in a pulse emitted
 pos As Point3d                 ‘ XYZ of the echo
 intensity As Integer           ‘ Intensity by RiProcess
 Pointer As Long                ‘ File pointer to the waveform sample, starts at 0
 WaveSampleSize As Integer      ‘ 80, 160 or 240
 RetPointWFLoc As Single        ‘ picoseconds, to the start of the WF sample
End Type

Type PulseRIegl                 ‘ A whole pulse-record
  echocount As Byte             ‘ Tells how many echoes RiProcess extracted (EchoRiegls)
  GPStime As Double             ‘ Seconds
  ByteLAS As Byte               ‘ Byte copied from LAS-file, contains: return number, overall
                                      number of returns, scan direction flag, and edge of flight
                                      line tag (replaced with echo error tag in 2015 data, see
                                      footnote *)
  Echoes() As EchoRiegl         ‘ variable-length array that holds the EchoRiegl DR echoes
  ScanAngle As Byte             ‘ “Scan Angle Rank” –field copied from LAS
  PosLiDAR As Point3d           ‘ XYZ of LiDAR
  StripNum As Byte              ‘ Identifier for a strip
End Type
```

VB6 Sample code for reading pulses, echoes and waveforms

```
LiDARBinPath = "g:\Riegl2011_bin\"
Open LiDARBinPath & FN1 & "_" & FN2 & ".bin" For Binary As 100
Get #100, , Nha
ReDim LiDRiegl(1 To Nha) As PulseRIegl
Pointer = 5
For k = 1 To Nha
 Get #100, Pointer, LiDRiegl(k).echocount  ' Read  record by record
 Get #100, , LiDRiegl(k).GPStime
 Get #100, , LiDRiegl(k).ByteLAS
 ReDim LiDRiegl(k).Echoes(1 To LiDRiegl(k).echocount) As EchoRiegl
 Get #100, , LiDRiegl(k).Echoes            ' Read all echoes
 Get #100, , LiDRiegl(k).ScanAngle
 Get #100, , LiDRiegl(k).PosLiDAR
 Get #100, , LiDRiegl(k).StripNum
 Pointer = Pointer + 1 + 8 + 1 + CLng(LiDRiegl(k).echocount * 36) + 1 + 24 + 1
 For j = 1 to LiDRiegl(k).echocount          ' Loop echoes for WF samples
  ReDim wave(1 To LiDRiegl(k).Echoes(j).WaveSampleSize) As Integer
  Open LiDARBinPath & FN1 & "_" & FN2 & "_wf.bin" For Binary As 101
  Get #101, LiDRiegl(k).Echoes(j).Pointer + 1, wave
  Close (101)
 Next j
Next k
```

*) In the 2015 data, “byteLAS” was replaced with an error tag that tells if there are erroneous echoes in the pulse. Errors can be caused by reflections from the sky or there can be false echoes caused by ringing, because the detection threshold was set low in WF decomposition.

Finnmap had detected erroneous echoes based on pure geometric criteria: echo height from ground and distance to nearest neighbor echoes. We calculated a probability measure (P_r) for each echo. It tells how likely an echo is false echo induced by ringing. We also calculated the echo height from ground (H) to detect the sky-echoes. H was based on 2010 DEM (2008 DEM was used on the edges of the AOI where 2010 DEM was not available).

The error tag is composed of three parts: 0-5 + 0-30 + 0-200. It can thus take values between 0-235.

Part 1. Last-of-many echo

0	No detected error in the last-of-many echo
1	Error based on FM’s classification && low probability (P_r < 0.25) that the echo is a false echo
2	Error based on FM’s classification && high probability (P_r >= 0.75) that the echo is a false echo
3	Error based on FM’s classification && medium probability (P_r >= 0.25) that the echo is a false echo
4	No error based on FM’s classification && high probability (P_r >= 0.75) that the echo is a false echo
5	No error based on FM’s classification && medium probability (P_r >= 0.25) that the echo is a false echo

Part 2. First-or-only echo

+0	No detected error in the first-or-only echo
+10	Error in the first-or-only echo, because it is too high (H > 42.5 m)
+20	Error in the first-or-only echo based on FM’s classification && no error based on H (-2.5 m < H < 42.5 m)
+30	First-or-only echo notably below the ground (H < -2.5 m). This indicates that there is an error in the DEM.

Part 3. Other than first-or-only or last-of-many echo

+50	Medium probability that 2nd echo is a false echo (P_r >= 0.25)
+100	No detected error in the 2nd echo, but medium probability (P_r >= 0.25) that 3rd echo is a false echo

+150 No detected error in the 2nd-3rd echo, but medium probability (P_r >= 0.25) that 4th echo is a false echo
+200 No detected error in 2nd-4th echo, but medium probability (P_r >= 0.25) that 5th or higher echo is a false echo

Example of use:

Error tag is 161 (= 1 + 10 + 150) → 1: FM has detected an error in the last-of-many echo.
10: the first echo is over 42.5 m above ground
150: the 4th echo is a false echo with a medium probability

Calculation of P_r:

$$P_r = \exp\left(\frac{-(\Delta R - b_1)^2}{2 \cdot b_2^{\,2}}\right)$$

If $I_{m+1} > b_3 I_m^{\,b_4}$, $P_r = P_r \cdot \exp\left(\frac{-\left(I_{m+1} - b_3 I_m^{\,b_4}\right)^2}{2 \cdot b_5^{\,2}}\right)$

If $I_m > b_6$, $P_r = P_r \cdot \exp\left(\frac{-(I_m - b_6)^2}{2 \cdot b_7^{\,2}}\right)$

Parameter values:

b1 = 1.63
b2 = 0.254796545
b3 = 0.3974
b4 = 0.5651
b5 = 4.246609083
b6 = 100
b7 = 16.98643633

High-probability threshold 0.75 was chosen so that 99% of ringing-induced echoes from flat surfaces were found by this criteria.

Optech Titan, 2016

The three-band data were delivered in stripwise LAS1.2 files that comprised, 30-bytes per echo, with ASCII trajectory files. Channel 1 = 1550 nm, Ch2 = 1064 nm and Ch3 = 532 nm. The GPS-times were sorted and the echoes belonging to the same transmitted pulse were combined in the 207-byte per pulse format, each band separated (files). The per-hectare BIN files again have the number of records as int32 at the file start and the 207-byte records start from there.

```
Type LidarRecord
 GPStime As Double                  // Standard GPS time, missing 1E9 seconds
 PulseCount As Byte                 // Number of echoes
 Returns(1 To 4) As point3D         // The XYZ-coords of the echoes, 4=first, 1= last or fourth
 intensity(1 To 4) As Integer       // Intensity values
 Range(1 To 4) As Double            // Not assigned (!)
 angle As Double                    // Scan zenith angle
 Roll As Double                     // From the TRJ file, unit?
 pitch As Double                    //  "
 heading As Double                  //  "
 PosLiDAR As point3D                // Transformed from UTM+N2000 to KKJ+N60
 StripNum As Integer                // 1-9
 SyncBit As Byte                    // Scanner channel bits of LAS1.2
 Res1 As Byte                       // Userdata byte in LAS 1.2
 Res2 As Byte                       // Edge of flight line flag bit og LAS1.2
 Res3 As Byte                       // Scandir bit in LAS1.2
End Type
```

PROGRAMS/ROUTINES FOR CONVERTING LAS and TRJ-files into the 207-byte per pulse format, per hectare tiling (in the KKJ2 system).

```
Private Sub Command2_Click()
' Sorting of LAS-files, by acquiring a list of integers indicating the sort order of LAS records
For N = 1 To 9
 Open "C:\TEMP\LiDAR\Kanava" & Text6.Text & "\Jonottain\0000" & CStr(N) & ".las" For Binary As 1
 Get #1, 1, Hdr
 Dim LpointLast As LasPoint
 Dim LpointFirst As LasPoint
 ReDim Times(1 To Hdr.NumOfPointRec1) As Double
 ReDim indx(1 To Hdr.NumOfPointRec1) As Long
 Get #1, 1 + Hdr.OffsetToData + (1 - 1) * 30, LpointFirst
 Get #1, 1 + Hdr.OffsetToData + (Hdr.NumOfPointRec1 - 1) * 30, LpointLast
```

```
 For j = 1 To Hdr.NumOfPointRec1
   Get #1, 1 + Hdr.OffsetToData + (j - 1) * 30, LpointFirst
   If j Mod 10000 = 0 Then Form1.Caption = Format$(j / Hdr.NumOfPointRec1 * 100, "0.0")
   Times(j) = LpointFirst.GPStime
   If j Mod 1000 = 0 Then
    Form1.Caption = N & "," & j
   End If
 Next j
 Form1.Caption = "Sorting"
 Call indexx(UBound(Times), Times, indx)
 Form1.Caption = "Printing"
 Open "C:\TEMP\LiDAR\Kanava" & Text6.Text & "\Jonottain\000" & CStr(N) & "_times_sorted_long.bin" For Binary As 5
 Put #5, , indx
 Close (5): Close (1): Close (3): Close (4)
Next N
Form1.Caption = "Done"
End Sub

Private Sub Command1_Click()
' reading the LAS file in the sort-order and writing 207-byte records in per hectare files
Open Form1.Text2.Text For Input As 1 ' name of the trj.file
Form1.Caption = "Reading TRJ"
ReDim Trj(1 To 100000) As Trajectory
i = 0
 Do Until EOF(1)
  i = i + 1
  Input #1, Trj(i).GPStime, Trj(i).X, Trj(i).Y, Trj(i).z, _
            Trj(i).Roll, Trj(i).pitch, Trj(i).heading
 Loop
ReDim Preserve Trj(1 To i) As Trajectory
Dim interval As Double
interval = 0.005 ' Seconds, 200 Hz
Close (1)
Dim iTRJ As Long
iTRJ = 1 ' index to trajectory
Dim LiDR As LidarRecord
Open Form1.Text3.Text For Binary As 1  ' LAS file name
Get #1, 1, Hdr
Open Form1.Text4.Text For Binary As 3  ' sorted list of longs, read order
ReDim indx(1 To Hdr.NumOfPointRec1) As Long
Get #3, , indx
Close (3)
Dim Retnum As Byte, NR As Byte, Lpoint As LasPoint
Form1.Caption = "Reading..."
Get #1, 1 + Hdr.OffsetToData + (indx(1) - 1) * 30, Lpoint
Form1.Caption = "Done..."
CurTime = Lpoint.GPStime
ik = 0
Do Until (ik = Hdr.NumOfPointRec1)
   Npoints = 0 'points in a pulse
   ik = ik + 1 ' case
   Dim outByte(1 To 6) As Byte
   Call ZeroLiDR(LiDR) ' just puts zeroes to the struct
ReadPoint:
   j = indx(ik)
   Get #1, 1 + Hdr.OffsetToData + (j - 1) * 30, Lpoint
   If CurTime = Lpoint.GPStime Then
      Npoints = Npoints + 1
      ik = ik + 1
      apu = MYFUNC_MASKING(Lpoint.PulseByte1, CByte(15), outByte(1)) ' return number
      apu = MYFUNC_MASKING(Lpoint.PulseByte1, CByte(240), outByte(2)) ' number of returns
      Retnum = outByte(1)
      NR = outByte(2) / 16
      apu = MYFUNC_MASKING(Lpoint.PulseByte2, CByte(15), outByte(3)) ' classification flags
      apu = MYFUNC_MASKING(Lpoint.PulseByte2, CByte(48), outByte(4)) ' scanner channel
      apu = MYFUNC_MASKING(Lpoint.PulseByte2, CByte(64), outByte(5)) ' scandir flag
      apu = MYFUNC_MASKING(Lpoint.PulseByte2, CByte(128), outByte(6)) ' edge of flight line
      LiDR.Res1 = Lpoint.UserData
      LiDR.Res2 = outByte(6) / 128    ' edge flag
      LiDR.Res3 = outByte(6)          ' scandir
      LiDR.SyncBit = outByte(4) / 48  ' scanner channel
      LiDR.GPStime = Lpoint.GPStime
      LiDR.intensity(5 - Retnum) = Lpoint.intensity
      LiDR.Returns(5 - Retnum).X = -0.04614190132 * (Lpoint.Y * Hdr.YScaleFactor + Hdr.YOffset) _
      + 0.9990901664 * (Lpoint.X * Hdr.XScaleFactor + Hdr.XOffset) + 2474938.474
      LiDR.Returns(5 - Retnum).Y = 0.9990949702 * (Lpoint.Y * Hdr.YScaleFactor + Hdr.YOffset) _
      + 0.04615302083 * (Lpoint.X * Hdr.XScaleFactor + Hdr.XOffset) - 10341.1406
      LiDR.Returns(5 - Retnum).z = (Lpoint.z * Hdr.ZScaleFactor + Hdr.ZOffset) '
      GoTo ReadPoint
   End If

   If NR <> Npoints Then MsgBox ("?")
   ik = ik - 1
   CurTime = Lpoint.GPStime
   LiDR.PulseCount = Npoints
   LiDR.intensity(1) = LiDR.intensity(5 - NR)
   LiDR.Returns(1).X = LiDR.Returns(5 - NR).X
   LiDR.Returns(1).Y = LiDR.Returns(5 - NR).Y
   LiDR.Returns(1).z = LiDR.Returns(5 - NR).z

   If Abs(LiDR.GPStime - Trj(iTRJ).GPStime) > 0.02 Then
     Call Get_iTrj(Lpoint, iTRJ, interval)
   End If

   Call UTM_to_KKJ(LiDR.PosLiDAR.X, LiDR.PosLiDAR.Y, LiDR.PosLiDAR.z, Trj(iTRJ).Y, Trj(iTRJ).X, Trj(iTRJ).z)
   LiDR.Roll = Trj(iTRJ).Roll: LiDR.pitch = Trj(iTRJ).pitch: LiDR.heading = Trj(iTRJ).heading

   Dim v1 As Vector3D, v2 As Vector3D
   v1.X = LiDR.PosLiDAR.X - 2510000: v1.Y = LiDR.PosLiDAR.Y - 6850000: v1.z = LiDR.PosLiDAR.z
   v2.X = LiDR.Returns(1).X - 2510000: v2.Y = LiDR.Returns(1).Y - 6850000: v2.z = LiDR.Returns(1).z
   v1.X = v1.X - v2.X: v1.Y = v1.Y - v2.Y: v1.z = v1.z - v2.z
   v2.X = 0: v2.Y = 0: v2.z = v1.z
   LiDR.angle = vector_angle(v1, v2) * 57.2957795130823
   LiDR.StripNum = Int(Text7.Text)
   RecordNum = RecordNum + 1
   FN1 = Format$(Int((LiDR.Returns(1).X - 2510000) / 100), "000")
   FN2 = Format$(Int((LiDR.Returns(1).Y - 6850000) / 100), "000")
   Dim Npulses As Long
    Open Form1.Text5.Text & FN1 & "_" & FN2 & ".bin" For Binary As 100
```

```
    Get #100, 1, Npulses
    If Npulses = 0 Then Put #100, CLng(3000) * 207, CLng(Npulses)
    Rem Move pointer to start
    Put #100, 1, CLng(Npulses + 1)
    Put #100, 5 + Npulses * 207, LiDR
    Close (100)
    SaveNow = False
    Np = 0

    If ik Mod 1000 = 0 Then
      DoEvents
      Form1.Caption = ik & "," & RecordNum & "," & Format$((ik / Hdr.NumOfPointRec1) * 100, "0.0") & "%"
      Open Form1.Text1.Text For Append As 5
      Print #5, ik
      Close (5)
    End If

nextpoint: Loop
Close (1)
Close (5)
End Sub

Private Sub Command3_Click()
' Sets the names of the filenames according to Ch and strip# choices
Form1.Text1.Text = "c:\temp\Lidar\Kanava" & Text6.Text & "\Jonottain\log" & Text7.Text & ".txt"
Form1.Text2.Text = "c:\temp\trajectory0000" & Text7.Text & ".txt"
Form1.Text3.Text = "c:\temp\LiDAR\Kanava" & Text6.Text & "\Jonottain\0000" & Text7.Text & ".las"
Form1.Text4.Text = "c:\temp\LiDAR\Kanava" & Text6.Text & "\Jonottain\000" & Text7.Text & "_times_sorted_long.bin"
Form1.Text5.Text = "c:\temp\LiDAR\Kanava" & Text6.Text & "\"
End Sub

Declare Function MYFUNC_ACOS Lib "c:\data\pascaldll.dll" (ByVal v1 As Double) As Double

Type HdrBlock
 FileSign As String * 4
 FileSource As Integer
 GlobalEncoding As Integer
 ID1 As Long
 ID2 As Integer
 ID3 As Integer
 ID4 As String * 8
 VersionMajor As Byte
 VersionMinor As Byte
 SystemID As String * 32
 Software As String * 32
 c_Day As Integer
 c_Year As Integer
 HdrSize As Integer
 OffsetToData As Long
 NofVarLenRec As Long
 PointDataFormatId As Byte
 PointDataRecLen As Integer
 NumOfPointRec As Long
 NumOfPointSByReturn(1 To 5) As Long
 XScaleFactor As Double
 YScaleFactor As Double
 ZScaleFactor As Double
 XOffset As Double
 YOffset As Double
 ZOffset As Double
 MaxX As Double
 MinX As Double
 MaxY As Double
 MinY As Double
 MaxZ As Double
 MinZ As Double
 StartofWaveformDataPacketRec1 As Long ' it is a long long NEED TO SPLIT
 StartofWaveformDataPacketRec2 As Long
 StartofNumOfExtVarLRec1 As Long ' it is a long long
 StartofNumOfExtVarLRec2 As Long
 NumOfExtVarLenRec As Long
 NumOfPointRec1 As Long ' it is a long long
 NumOfPointRec2 As Long
 NumofPointsByReturn1(1 To 15) As Long ' it is a long long
 NumofPointsByReturn2(1 To 15) As Long
End Type

Type VarLenRecHdr
 Reserved As Integer
 UserID As String * 16
 RecordID As Integer
 RecLenAfterHdr As Integer
 Descriptio As String * 32
End Type

Type LasPoint ' point format 6 in las1.4
 X As Long
 Y As Long
 z As Long
 intensity As Integer
 PulseByte1 As Byte
 PulseByte2 As Byte
 class As Byte
 UserData As Byte
 ScanAngle As Integer
 PointSourceID As Integer
 GPStime As Double
End Type

Type Vector3D
 X As Double
 Y As Double
 z As Double
End Type
Type point3D
 X As Double
 Y As Double
 z As Double
End Type
```

```
Rem 2006 ALTM 3100 pulse data, 207 bytes per record
Type LidarRecord
 GPStime As Double
 PulseCount As Byte
 Returns(1 To 4) As point3D
 intensity(1 To 4) As Integer
 Range(1 To 4) As Double
 angle As Double
 Roll As Double
 pitch As Double
 heading As Double
 PosLiDAR As point3D
 StripNum As Integer
 SyncBit As Byte
 Res1 As Byte
 Res2 As Byte
 Res3 As Byte
End Type

Type Trajectory
 GPStime As Double
 X As Double
 Y As Double
 z As Double
 Roll As Double
 pitch As Double
 heading As Double
End Type

Public LiDR As LidarRecord
Public Trj() As Trajectory
Public Lpoint() As LasPoint

Public Hdr As HdrBlock

Type LASFile
  LASFileName As String
  TRJFilename As String
  NofPoints As Long
End Type

Declare Function MYFUNC_MASKING Lib "c:\data\pascaldll.dll" (ByRef Inp As Byte, ByRef Mask As Byte, ByRef Out As Byte) As
Long

Public Sub Get_iTrj(ByRef Lpoint As LasPoint, ByRef iTRJ As Long, interval As Double)

  Tdiff = Lpoint.GPStime - Trj(iTRJ).GPStime
  Hop = Int(Tdiff / interval)
  Do Until Abs(Tdiff) < 0.01
    iTRJ = iTRJ + Hop
    Tdiff = Lpoint.GPStime - Trj(iTRJ).GPStime
    Hop = Int(Tdiff / interval) / 2
  Loop
End Sub

Public Sub ZeroLiDR(LiDR As LidarRecord)

 LiDR.GPStime = 0
 LiDR.PulseCount = 0
 For i = 1 To 4
  LiDR.Returns(i).X = 0
  LiDR.Returns(i).Y = 0
  LiDR.Returns(i).z = 0
  LiDR.intensity(i) = 0
  LiDR.Range(i) = 0
 Next i
 LiDR.angle = 0
 LiDR.Roll = 0
 LiDR.pitch = 0
 LiDR.heading = 0
 LiDR.PosLiDAR.X = 0
 LiDR.PosLiDAR.Y = 0
 LiDR.PosLiDAR.z = 0
 LiDR.StripNum = 0
 LiDR.SyncBit = 0
 LiDR.Res1 = 0
 LiDR.Res2 = 0
 LiDR.Res3 = 0

End Sub

Public Sub indexx(ByVal N As Long, ra() As Double, indx() As Long)

Rem Heapsort from Numerical recipes
Rem indx(1 to N) is an index table, returned
Rem ra(1 to N) is the data to be sorted, left as is.

Dim i As Long, j As Long, l As Long, IR As Long, indxt As Long
Dim q As Double
On Error GoTo virhe_sort
For j = 1 To N
 indx(j) = j
Next j

l = N / 2 + 1
IR = N

10:
 If (l > 1) Then
  l = l - 1
  indxt = indx(l)
  q = ra(indxt)
 Else
  indxt = indx(IR)
  q = ra(indxt)
  indx(IR) = indx(1)
  IR = IR - 1
   If (IR = 1) Then
```

```
    indx(1) = indxt
   Exit Sub
   End If
 End If
i = l
j = l + l
20: If j <= IR Then
     If j < IR Then
      If (ra(indx(j)) < ra(indx(j + 1))) Then j = j + 1
     End If
     If (q < ra(indx(j))) Then
      indx(i) = indx(j)
      i = j
      j = j + j
     Else
     j = IR + 1
     End If
     GoTo 20
    End If
   indx(i) = indxt
   GoTo 10
virhe_sort:
MsgBox ("Error in Heapsort, l is " & l)
End Sub

Public Sub UTM_to_KKJ(kkj_x As Double, kkj_y As Double, kkj_z As Double, UTM_E As Double, UTM_N As Double, H As Double)
Rem Local, Hyytiälä spesific set of eqns, based on a triangle of geodetic points +- 5 cm accuracy
kkj_x = -0.04614190132 * UTM_N + 0.9990901664 * UTM_E + 2474938.474
kkj_y = 0.9990949702 * UTM_N + 0.04615302083 * UTM_E - 10341.1406
kkj_z = H - 18.67 - 0.32 ' FIN2000 geoid model difference in the area needs the 32 cm for N60
End Sub

Public Function vector_length(ByRef vector As Vector3D) As Double
 vector_length = (vector.X ^ 2 + vector.Y ^ 2 + vector.z ^ 2) ^ 0.5
End Function
Public Function vector_angle(vec1 As Vector3D, vec2 As Vector3D) As Double
 vector_angle = MYFUNC_ACOS((vec1.X * vec2.X + vec1.Y * vec2.Y + vec1.z * vec2.z) / (vector_length(vec1) *
vector_length(vec2)))
End Function
```

Riegl 1560 processing, May 2018

Final (3rd) delivery consisted of 5 LAS-files with LAS1.2 Point type 1 data. The objective of Q/C and postprocessing was to merge data into per-pulse records that hold the position of the sensor and all observations (echoes) that originated from the pulse transmitted.

Because the files had file-sizes of above 2 Gbytes, the LAS data were "sliced by time". The previous deliberables (1st and 2nd) had the Lidar records all twice (duplicates acroos the files), thus a 3rd one. ☹

The C-function MyFuncOutputTimes receives the name of the LAS-file to be sliced and outputs at max 6 files, which have 4-byte long at the start giving the number of 28-byte LAS-points that follow. (#.bin). The time-interval is given in the source code (slicing).

Next routine in VB reads the sliced LAS-files (#.bin) and stores the GPSTimes and sorts them to an index file.

This means that 0.bin is associated with 0_times_sorted_long.bin and reading 0.bin with the order depicted by the sorted-file results in reading in timewise sorted manner.

The third routine takes the "LAS-file" #.bin and the sorted list #_times_sorted_long.bin. Looks for echoes at a given time point, fills two pulse structures (receiver 1 and receiver 2) that can co-exist. There can be upto 6? echoes per pulse. The trajectory is interpolated for the position of LiDAR at the given time point with TRJ data at 1 Hz (about 70 m of lying in a second). All coordinates are transformed into KKJ-2/N60 and data were stored in per-ha bin files (tiling).

Yet another format is applied for a per-ha bin-file (In VBasic):

```
Type Point_3d
 X As Double
 Y As Double
 Z As Single
End Type

Type EchoRiegl_1560    ' A discrete-return echo
 pos As Point_3d              ' XYZ of the echo
 intensity As Integer        ' Intensity
 class As Byte                    ' classification as in
LAS 1.2
End Type

Type PulseRIegl_1560    ' A whole pulse-record
  echocount As Byte       '  extracted (EchoRiegl_1560s)
  GPStime As Double      ' Seconds
  ByteLAS As Byte            ' Byte from LAS-file
  ScanAngle As Byte        ' "Scan Angle Rank" -field
copied from LAS
  PosLidar As Point_3d   ' XYZ of LiDAR
  Receiver As Byte           ' Which of the two
  StripNum As Byte         ' Identifier for a strip
  Echoes() As EchoRiegl_1560 ‘ variable length part
End Type
```

Reading in VB

```
Get #100, , NHA
If NHA = 0 Then Exit Sub
ReDim Lidr1560(1 To NHA) As PulseRIegl_1560
Pointer = 5
Get #100, Pointer, Lidr1560(1).echocount
 For k = 1 To NHA Step 1
  If k <> 1 Then Get #100, , Lidr1560(k).echocount
  Get #100, , Lidr1560(k).GPStime
  Get #100, , Lidr1560(k).ByteLAS
  Get #100, , Lidr1560(k).ScanAngle
  Get #100, , Lidr1560(k).PosLidar
  Get #100, , Lidr1560(k).Receiver
  Get #100, , Lidr1560(k).StripNum
  ReDim Lidr1560(k).Echoes(1 To Lidr1560(k).echocount) As
EchoRiegl_1560
  Get #100, , Lidr1560(k).Echoes
```

```
int __stdcall MyFuncOutputTimes(char *infilename, int NumofRecs, char *outfilename)
{
// READ A HUGE LAS-file and output timewise sliced files with simple long header
 struct LasRecord
 {  int X;
    int Y;
    int z;
    short Intensity;
    unsigned char PulseByte1;
    unsigned char Clasification;
    unsigned char UserData;
               unsigned char ScanAngle;
    short PointSourceID;
               double GPStime;
 } LasPoint;

   FILE *fin, *fout;
   __int64 i; __int64 offset;
   char *buffer;
   buffer = (char *) malloc(200 * sizeof(char));
   int j, l, k;
   unsigned char Hdr[228];
   double timet;
   fin = fopen(infilename,"rb");
   if (fin==NULL)
   {
       l  = sprintf(buffer,"Tiedoston in avaus ei onnistunut \n");
       MessageBox ( NULL, buffer,"MyFuncMatlabCall",MB_OK);
       return 0;
   }
   fout = fopen(outfilename,"wb");
   if (fout==NULL)
   {
               l  = sprintf(buffer,"Tiedoston out avaus ei onnistunut \n");
               MessageBox ( NULL, buffer,"MyFuncMatlabCall",MB_OK);
               fclose(fin);
               return 0;
   }
   int m = 0;
   double mintime, maxtime;
   mintime = 10E90;
   maxtime = 0;
   l = _fseeki64(fin,1,SEEK_SET);
   i = _ftelli64(fin);
   k = fread(&Hdr[0],sizeof(Hdr),1,fin); // Read the public header block of 227 bytes
   for (l = 1; l <= (NumofRecs);l++) //     read the 28 -byte records, gps-time is always at Byte position, 20 within
   {
               m++;
               k = fread(&LasPoint,sizeof(LasRecord),1,fin); // Read the 8-byte information, GPS-time
               timet = LasPoint.GPStime;
               if (timet < mintime) {mintime = timet;}
               if (timet > maxtime) {maxtime = timet;}
   }
    k = fseek(fout,1,SEEK_SET);
    k = fwrite(&mintime,sizeof(double),1,fout); // Write the 28-byte information
    k = fwrite(&maxtime,sizeof(double),1,fout); // Write the 28-byte information
    fclose(fout);
   double timediff;
   timediff = maxtime-mintime;
   m = 0; // counter
   l = _fseeki64(fin,1,SEEK_SET);
   i = _ftelli64(fin);
   k = fread(&Hdr[0],sizeof(Hdr),1,fin); // Read the public header block of 227 bytes
   FILE *finput[6];
   int NEchoes[6];
   for (l = 0; l < 6; l++){NEchoes[l]=0;}
   finput[0]=fopen("c:\\temp\\1\\LiDAR\\0.bin", "wb");
   finput[1]=fopen("c:\\temp\\1\\LiDAR\\1.bin", "wb");
   finput[2]=fopen("c:\\temp\\1\\LiDAR\\2.bin", "wb");
   finput[3]=fopen("c:\\temp\\1\\LiDAR\\3.bin", "wb");
   finput[4]=fopen("c:\\temp\\1\\LiDAR\\4.bin", "wb");
   finput[5]=fopen("c:\\temp\\1\\LiDAR\\5.bin", "wb");
   double bin = 20.0;
   l = _fseeki64(fin,0,SEEK_SET);
   k = fread(&Hdr[0],sizeof(Hdr),1,fin); // Read the public header block of 227 bytes
   offset = __int64(sizeof(Hdr)) + __int64(0) * __int64(28) +1;
   k = _fseeki64(fin,offset,SEEK_SET);
   for (l = 1; l <= (NumofRecs);l++) //     read the 28 -byte records, gps-time is always at Byte position, 20 within
   {
               m++;
```

```
            int icase;
            k = fread(&LasPoint,28,1,fin); // Read t    he 28-byte information
            timet = LasPoint.GPStime;
            if (timet < mintime + bin){icase = 0;NEchoes[0]++;}
            if (timet >= mintime + bin && timet < mintime + 2.0*bin){icase = 1;NEchoes[1]++;}
            if (timet >= mintime + 2.0*bin && timet < mintime + 3.0*bin){icase = 2;NEchoes[2]++;}
            if (timet >= mintime + 3.0*bin && timet < mintime + 4.0*bin){icase = 3;NEchoes[3]++;}
            if (timet >= mintime + 4.0*bin && timet < mintime + 5.0*bin){icase = 4;NEchoes[4]++;}
            if (timet >= mintime + 5.0*bin){icase = 5;NEchoes[5]++;}
            fseek(finput[icase],0,SEEK_SET);
            fwrite(&NEchoes[icase],sizeof(int),1,finput[icase]);
            fseek(finput[icase],(NEchoes[icase]-1)*sizeof(LasRecord)+4,SEEK_SET);
            fwrite(&LasPoint,sizeof(LasRecord),1,finput[icase]);
   }
   free (buffer);
   for (l = 0; l < 6; l++) {fclose(finput[l]);}
   return 0; }
```

```
Private Sub Command2_Click()
' Sorting of LAS-files, by acquiring a list of integers indicating the sort order of LAS records
Dim Npoints As Long
For N = 0 To 4
 Open "C:\TEMP\1\LiDAR\" & CStr(N) & ".bin" For Binary As 1
 Get #1, 1, Npoints
 Dim Lpoint As LasPoint1
 ReDim Times(1 To Npoints) As Double
 ReDim indx(1 To Npoints) As Long
 For j = 1 To Npoints
   Get #1, 5 + (j - 1) * 28, Lpoint
   If j Mod 10000 = 0 Then Form1.Caption = Format$(j / Npoints * 100, "0.0")
   Times(j) = Lpoint.GPStime
 Next j
 Close (1)
 Form1.Caption = "Sorting"
 Call indexx(UBound(Times), Times, indx)
 Form1.Caption = "Printing"
 Open "C:\TEMP\1\LiDAR\" & CStr(N) & "_times_sorted_long.bin" For Binary As 5
 Put #5, , indx
 Close (5): Close (1): Close (3): Close (4)
Next N
Form1.Caption = "Done"
End Sub
```

```
Private sub command1_click()
' reading the LAS file in the sort-order and writing 207-byte records in per hectare files
Open "c:\temp\1\LiDAR\20180524_063330.txt" For Input As 1 ' name of the trj.file
Form1.Caption = "Reading TRJ"
ReDim Trj(1 To 100000) As Trajectory
i = 0
 Do Until EOF(1)
  i = i + 1
  Input #1, Trj(i).GPStime, Trj(i).Y, Trj(i).X, Trj(i).z, _
            Trj(i).Roll, Trj(i).pitch, Trj(i).heading
 Loop
ReDim Preserve Trj(1 To i) As Trajectory
Dim interval As Double
interval = 1 ' Seconds,1 Hz
Close (1)
Dim iTRJ_start As Long, iTRJ_end As Long, Nps As Long
iTRJ_start = 1 ' index to trajectory


Open "c:\temp\1\LiDAR\0.bin" For Binary As 1  ' LAS file name
Get #1, 1, Nps
Open "c:\temp\1\LiDAR\0_times_sorted_long.bin" For Binary As 3  ' sorted list of longs, read order
ReDim indx(1 To Nps) As Long
Get #3, , indx
Close (3)
strip = 1

Dim Retnum(1 To 2) As Byte, NR(1 To 2) As Byte, Lpoint As LasPoint1
Dim Sensor1 As Boolean, Sensor2 As Boolean
Dim Npts(1 To 2) As Long

Rem read the first
Get #1, 5 + (indx(1) - 1) * 28, Lpoint
Curtime = 0
Open "c:\temp\0_errors.txt" For Output As 6
ik = 1
Dim outByte(1 To 6) As Byte
' Here we read the first echo to get a time stamp
Get #1, 5 + (1 - 1) * 28, Lpoint
Curtime = Lpoint.GPStime

Dim PosLidar As point3D, Npulses As Long
case1 = False: case2 = False  ' have we declared the LiDR-pulse records of receiver 1 / 2

Do Until (ik = Nps)
  Sensor1 = False: Sensor2 = False
  PointsAdded1 = 0: PointsAdded2 = 0:
  PointsRead = 0: NR(1) = 0: NR(2) = 0
  iTRJ_start = 1
```

```
  case1 = False: case2 = False
  If ik Mod 10000 = 0 Then
   Form1.Caption = ik / Nps * 100
   DoEvents
  End If

  Do Until (NewTime = True)
   Get #1, 5 + (indx(ik) - 1) * 28, Lpoint
   If Lpoint.GPStime <> Curtime Then GoTo EchoesRead
   apu = MYFUNC_MASKING(Lpoint.PulseByte1, CByte(7), outByte(1))   ' return number 0-3 bits
   apu = MYFUNC_MASKING(Lpoint.PulseByte1, CByte(56), outByte(2))  ' number of returns 4-7 bits
   apu = MYFUNC_MASKING(Lpoint.PulseByte1, CByte(64), outByte(5))  ' scan dir
   apu = MYFUNC_MASKING(Lpoint.PulseByte1, CByte(128), outByte(6)) ' edge
   Retnum(Lpoint.UserData) = outByte(1)
   NR((Lpoint.UserData)) = outByte(2) / 8
   Npts(Lpoint.UserData) = Npts(Lpoint.UserData) + 1
   Curtime = Lpoint.GPStime       ' the Curtime is set at the value of the first echo, first sensor
   If Lpoint.UserData = 1 And Npts(Lpoint.UserData) = 1 Then ' assign the Pulserecord with NR points to hold
    Dim LiDR1 As PulseRIegl_1560
    ReDim Echoes1(1 To NR(Lpoint.UserData)) As EchoRiegl_1560
    Call Get_iTrj(Lpoint, iTRJ_start, interval, PosLidar)
    LiDR1.ByteLAS = Lpoint.PulseByte1:
    LiDR1.ScanAngle = Lpoint.ScanAngle
    LiDR1.echocount = NR(1):        LiDR1.GPStime = Lpoint.GPStime
    LiDR1.Receiver = 1:             LiDR1.PosLidar.X = PosLidar.X
    LiDR1.PosLidar.Y = PosLidar.Y:  LiDR1.PosLidar.z = PosLidar.z
    LiDR1.StripNum = strip
    Sensor1 = True
    case1 = True
   End If

   If Lpoint.UserData = 2 And Npts(Lpoint.UserData) = 1 Then
    Dim LiDR2 As PulseRIegl_1560
    ReDim Echoes2(1 To NR(Lpoint.UserData)) As EchoRiegl_1560
    LiDR2.ByteLAS = Lpoint.PulseByte1:
    LiDR2.ScanAngle = Lpoint.ScanAngle
    LiDR2.echocount = NR(2):        LiDR2.GPStime = Lpoint.GPStime
    LiDR2.Receiver = 2:             LiDR2.PosLidar.X = PosLidar.X
    LiDR2.PosLidar.Y = PosLidar.Y:  LiDR2.PosLidar.z = PosLidar.z
    LiDR2.StripNum = strip
    Sensor2 = True
    case2 = True
   End If
    ' ASSIGN VALUES
   If Lpoint.UserData = 1 Then ' we have an echo for this sensor
    If Echoes1(Retnum(Lpoint.UserData)).intensity > 0 Then Print #6, "Allready data here 1" & ","; ik
    Echoes1(Retnum(Lpoint.UserData)).intensity = Lpoint.intensity
    Echoes1(Retnum(Lpoint.UserData)).class = Lpoint.class
    Echoes1(Retnum(Lpoint.UserData)).pos.X = Lpoint.X
    Echoes1(Retnum(Lpoint.UserData)).pos.Y = Lpoint.Y
    Echoes1(Retnum(Lpoint.UserData)).pos.z = Lpoint.z
    PointsAdded1 = PointsAdded1 + 1
    case1 = True
   End If
   If Lpoint.UserData = 2 Then ' we have an echo for this sensor 2
    If Echoes2(Retnum(Lpoint.UserData)).intensity > 0 Then Print #6, "Allready data here 2" & ","; ik
    Echoes2(Retnum(Lpoint.UserData)).intensity = Lpoint.intensity
    Echoes2(Retnum(Lpoint.UserData)).class = Lpoint.class
    Echoes2(Retnum(Lpoint.UserData)).pos.X = Lpoint.X
    Echoes2(Retnum(Lpoint.UserData)).pos.Y = Lpoint.Y
    Echoes2(Retnum(Lpoint.UserData)).pos.z = Lpoint.z
    PointsAdded2 = PointsAdded2 + 1
   End If
   ik = ik + 1
   PointsRead = PointsRead + 1
  Loop

EchoesRead:

  ' We end up here, when all echoes for this timnepoint (two sensors may co-exist) are read, perform error
analyses

  If NR(1) = 0 And LiDR1.echocount <> 0 Then Call ZeroLiDR(LiDR1, Echoes1)    ' just zeroes to the struct
  If NR(2) = 0 And LiDR2.echocount <> 0 Then Call ZeroLiDR(LiDR2, Echoes2)    ' just zeroes to the struct,
if there are no data
  If NR(1) <> PointsAdded1 Then Print #6, "Error 1" & "," & ik
  If NR(2) <> PointsAdded2 Then Print #6, "Error 2" & "," & ik
  If (NR(1) + NR(2)) <> (LiDR1.echocount + LiDR2.echocount) Then Print #6, "Error 4" & "," & ik
  ' Lets outbut the data
  If NR(1) > 0 Then
    For j = 1 To NR(1) ' loop echoes
      LX = Echoes1(j).pos.X: LY = Echoes1(j).pos.Y: LZ = Echoes1(j).pos.z
    ' Apply scaling and offsets
      Echoes1(j).pos.X = -0.04614190132 * (CDbl(LY) * 0.001 + 6000000#) + 0.9990901664 * (CDbl(LX) * 0.001 +
0#) + 2474938.474
      Echoes1(j).pos.Y = 0.9990949702 * (CDbl(LY) * 0.001 + 6000000#) + 0.04615302083 * (CDbl(LX) * 0.001 +
0#) - 10341.1406
      Echoes1(j).pos.z = (CDbl(LZ) * 0.001 + 0#) - 0.32  ' We go to N60 from N2000
    Next j
    FN1 = Format$(Int((Echoes1(NR(1)).pos.X - 2510000) / 100), "000")
    FN2 = Format$(Int((Echoes1(NR(1)).pos.Y - 6850000) / 100), "000")
    Open "c:\temp\1\LiDAR\bin\" & FN1 & "_" & FN2 & ".bin" For Binary As 100
    Nbytes = FileLen("c:\temp\1\LiDAR\bin\" & FN1 & "_" & FN2 & ".bin")
    Get #100, 1, Npulses
    If Nbytes = 0 Then
```

```
      Npulses = 0
      Nbytes = 4
    End If
    Put #100, 1, CLng(Npulses + 1)
    Put #100, Nbytes + 1, LiDR1
    Put #100, , Echoes1
    Close (100)

  End If
  If NR(2) > 0 Then
    For j = 1 To NR(2) ' loop echoes
      LX = Echoes2(j).pos.X: LY = Echoes2(j).pos.Y: LZ = Echoes2(j).pos.z
    ' Apply scaling and offsets
      Echoes2(j).pos.X = -0.04614190132 * (CDbl(LY) * 0.001 + 6000000#) + 0.9990901664 * (CDbl(LX) * 0.001 +
0#) + 2474938.474
      Echoes2(j).pos.Y = 0.9990949702 * (CDbl(LY) * 0.001 + 6000000#) + 0.04615302083 * (CDbl(LX) * 0.001 +
0#) - 10341.1406
      Echoes2(j).pos.z = (CDbl(LZ) * 0.001 + 0#) - 0.32  ' We go to N60 from N2000
    Next j
    FN1 = Format$(Int((Echoes2(NR(2)).pos.X - 2510000) / 100), "000")
    FN2 = Format$(Int((Echoes2(NR(2)).pos.Y - 6850000) / 100), "000")
    Open "c:\temp\1\LiDAR\bin\" & FN1 & "_" & FN2 & ".bin" For Binary As 100
    Nbytes = FileLen("c:\temp\1\LiDAR\bin\" & FN1 & "_" & FN2 & ".bin")
    Get #100, 1, Npulses
    If Nbytes = 0 Then
      Npulses = 0
      Nbytes = 4
    End If
    Put #100, 1, CLng(Npulses + 1)
    Put #100, Nbytes + 1, LiDR2
    Put #100, , Echoes2
    Close (100)

  End If


  Curtime = Lpoint.GPStime
  Sensor1 = False
  Sensor2 = False
  Call ZeroLiDR(LiDR1, Echoes1)    ' just puts zeroes to the struct
  Call ZeroLiDR(LiDR2, Echoes2)   ' just puts zeroes to the struct

Loop
Exit Sub
```

Appendix 4. LABS in photogrammetry and LiDAR-based STRS with KUVAMITT

NOVA-Mekrijärvi
Fri June 12, 2009
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Contents

1 Purpose of the exercises

The lectures and labs will expose you to **IMAGES**

Simple FRAME camera model (~pin-hole, ~perspective) and exterior orientation
- scanned film images, digital cameras, multi-lens systems

PUSHBROOM camera/sensor model, exterior orientation
- ADS40-(SH52) camera

Getting 3D data using images
- single image
- solving the correspondence problem
- a pair of images
- multiple images
- trying the impossible, mixing XYZ-systems in adjustment
- Automatic 2-image and 3-image matching (area-based correlation)
- Monoplotting helped by LiDAR

Superimposing 3D data in images
- frame images vs. ads40
- Measuring tree top position / 3D data capture in images
- visibility/discernibility of trees of different relative height
- manual ray intersection
- manual template matching
- manual LiDAR monoplotting
- semi-automatic, template matching

Measuring tree crown diameter / dimensions in images
- manual, xy-vector in images
- manual, template matching
- semi-automatic crown silhouette modeling

Classification of the species (RADIOMETRY)
- Effects of the scale and BRF
- Visual interpretation
- Numerical – getting the pixel samples

Model chain in STRS – computing the single tree DBH
- Role of sampling, measurement and model errors
- Regression estimation OR
- Non-parametric estimation
- How to avoid excess costs?

Image chain & imaging issues
- The image chain is a good concept!
- Weather and medium, the light sources
- Phenology, time-of-day
- Post-processing, to interpolate or not?
- PAN-sharpening, what goes on behind the scenes?
- What does it cost to fly? Implications on method / camera / vendor selection?

Labs will expose you to LiDAR, which is compared to images and examples of co-use are given in (some of the themes):

- Evaluating the XY-matches, relative and absolute
- Evaluating the Z-accuracy of LiDAR
- Effective resolution of images and LiDAR?
- FW, discrete-return or mixed systems?
- Different systems: als50 and altm3100
- Different altitudes: 1, 2, 3 and 4-km data
- LiDAR intensity; comparable between sensors?
- Backscatter amplitude, factors affecting it?

2 Description of the demo data in C:\DATA\

21 About the data and examples

The LiDAR, Image and reference tree data is from Hyytiälä, (62°N, 24°E) in southern Finland (see http://www.helsinki.fi/~korpela/HYDE_REF/). Use of the data and KUVAMITT source code is hereby limited to this NOVA-course. If you are interested in doing research with the Hyytiälä remote sensing experiment, please contact Ilkka.korpela@helsinki.fi. Joint research efforts utilizing the experiment have been launched recently involving forest, remote sensing and photogrammetry researchers in Finland, Norway, Austria and the UK.

22 Frame images 1946–2009

KUVAMITT supports 8/16-bit, non-tiled, 1- 3-, or 4-channel raw/BIP-images (C/C++ arrays of unsigned char or unsigned short data).

UltraCAM/DMC images can have the 16-bit 1-channel PAN and the 4-channel R, G, B, NIR image versions in non-tiled, raw BIP format.

Image files are always named *.raw. Each image has an ASCII *.hdr -file, which contains the interior and exterior orientation parameters in [m] and radians. KUVAMITT assumes that the images are free from lens errors or that the medium does not affect the path of the image rays. The simple collinear equations are used. Extensions are easily made, when needed, e.g. when working with consumer grade cameras.

The XYZ system is always assumed to be Cartesian; thus no Earth curvature corrections are made.

For film images with fiducial marks, a Helmert or an Affine transformation is used to convert between the *row,col* -system of the image and the metric *xy*-system of the film/focal plane in the camera. Oldest images are from 1946 and newest from 2007 (Z/I DMC images from May 31, 2009 are not processed yet).

23 ADS40-pushbroom images from 2008

The set includes some pushbroom images taken in August 2008. In-situ radiometric measurements were carried out simultaneously that allow the testing of atmospheric correction models.

The sensor model is basically the same as in Frame images, however, the orientation parameters (camera position and attitude) are given for each scan line with 2–8-ms integration time and a direct solution of the *XYZ_in_object_spa-*

ce_to_pixel_pos routine cannot be found, but it is solved iteratively.

In a strip, alternatively 6 or 11 CCD-lines were "exposured" using integrations times between 2.3 to 8 milliseconds. Each strip yielded 6 or 11 images, or image mats, consisting of several 2GB TIFF-files. Handling of ADS40 data requires thus some additional bookkeeping because of the huge image sizes.

The *.hdr-file points to four ads40-spesific files with the needed metadata: *.ads, *.odf, *.cam, *.sup. The ads-file has metadata on the number of scan lines and image files. An *.odf file has the orientation data for each scan line. *.cam file contains the calibrated focal-plane xy-position of each pixel in the 12000-pixel line-CCDs. *.sup has the needed data for conversions between coordinate systems - there is a local Cartesian XYZ system where all photogrammetric computations are made. This is anchored to a local UTM35/WGS84 point, which is the system where the GPS/IMU observations were made during flight. Finally, these coordinates can be converted into any national system.

The images are coded per sensor line (11). "REDN00A", for example, stand for the nadir view in the red band. There are RED, GRN, BLU, NIR and PAN images looking in **B**ack, **N**adir or **F**orward direction at -16 to +27 degree angles.

Flying heights in August 23, 2008 were 1, 2, 3, or 4 km corresponding to GSDs of 10, 20, 30 and 40 cm. ADS40 has 6.5 micron pixels, with an effective resolution of ~6.4 um. The DN-values convert to at-sensor irradiances using calibration coefficients provided by the sensor manufacturer.

/ ADS40 radiometry; look for papers by Ulrich Biesl
/ ADS40 geometry: Udo Templemann

24 LiDAR data 2004, 2006-2008

Folders ***c:\data\als2004\, c:\data\als2006\, c:\data\als2007***, and ***c:\data\als2008*** have LiDAR pulse records in binary 100- and 207-byte records in files **##1_##2.bin**.

Altm1233-Blom, altm3100-Blom, als50-FinnMap and als50-Maa-Amet were the used sensors. Each pulse record has the following variables

- GPStime, secs from the beginning of the GPS-week
- Position and attitude of the LiDAR, in XYZ and 3 angles
- Scan angle
- 1-4 echoes with XYZ, intensity, range
- AGC & other miscellaneous parameters, depending on the sensor

The LiDAR data is processed into 1-ha binary files.

25 DEMs (DTMs) and CHMs

KUVAMITT supports raster and TIN DEMs/CHMs. In our sample files, the heights are meters above sea level in the Finnish orthometric N60 system. The data consists of 4-byte decimal number (float, single) arrays.

26 KUVAMITT- digital photogrammetric software

C:\data\kuvamitt_nova\project2.vbp starts the old Visual Basic 6.0 programming environment and opens the KUVAMITT source code project.

KUVAMITT consists of several Windows, in *Form#.frm* files plus supporting Visual Basic code modules in *Module#.bas* files. CTRL-R opens a project window, where these files (components) are listed. In addition, KUVAMITT uses two C/C++ DLLs of its own and several other 3rd-party DLL's, e.g. by Mathworks.

In each demo, there are instructions on how to change the source code to learn about the algorithms that are included.

3 LAB-1 Geometric properties of LiDAR and images

Demo – 1 Learning about KUVAMITT and our data

a. Start C:\data\kuvamitt_nova\project2.vbp

b. Press "F5" to Run the VB code, the program starts. Be sure that the regional settings in the PC have comma as list separator and point for the decimal symbol.

c. Press "F2" to read aerial images, go to the folder c:\data\imafiles\demo1\ and select the images, one at a time by repeating the F2 read process. Read order of images: 3913, 3914, 3915, 440304! These FRAME images are centered to some buildings at the Hyytiälä forest station, University of Helsinki.

In KUVAMITT, there can be 1-9 images displayed in the main window, Form1. The F2-routine opens the images and centeres then to an XYZ-solution (using the CTRL-M command).

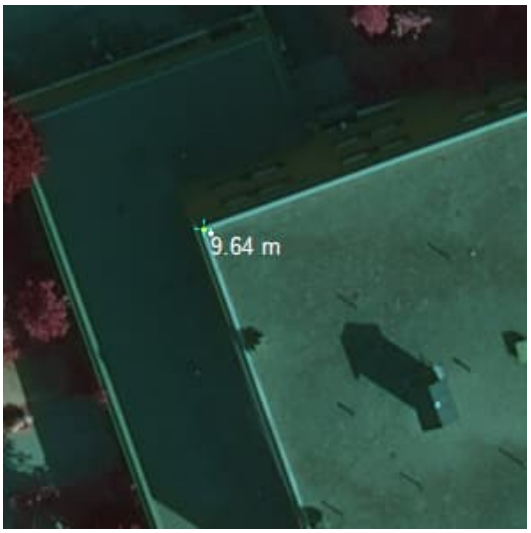
d. Read a raster DEM of the area: "File | Add tin or raster height models | Add raster elevation (DEM) model (*.hdr)", select the file c:\data\HydeLiDARDEM.hdr and introduce a 0.20-m offset to the Z-data, when prompted.

All data are in KKJ-2/N60 XYZ-system, which is a Gauss-Kruger map projection for XY and orthometric heights for Z, i.e. meters a.s.l.

Now, there should be 4 images displaying a roof corner. Some image codes are imposed in white text, as well as the scale in 1:####. There is one film images (CIR, 21/23 RC20, 1.9 km) an three pan-sharpened digital CIR images (Ultracam D, 1 km).

e. Try clicking the corner of the roof in all images. You are making image observations of the corner. The text boxes above the images show the xy and (col,row) – images coordinates for the observations that you made.

Use **CTRL-C to clear any graphics** that hinders you from seeing the corner.



"**9.64 m**" is the height of some LiDAR echoes above the DTM, but let us first concentrate in the basic photogrammetric / geometric issues.

f. Pay attention to the row: "Space intersection results": when clicking the corner in images. It shows the current XYZ-solution that KUVAMITT uses.

g. Try zooming, panning and centering images.

Keep CTRL pressed down when clicking – ZOOM OUT
Keep SHIFT pressed down when clicking – ZOOM IN
Keep ALT pressed down when clicking – PAN MODE
Try CTRL-M, it centers everything to XYZ-solution

Zooming out becomes slow after 25%; this is because KUVAMITT does not support tiled images or does not use static image (resolution) pyramids, which are used by many DPW-software.

h. Clearing images and observations. Try CTRL-A, it clears graphics and empties the text boxes.

Demo – 2 Getting XYZ-coordinates manually

1. Monoplotting or monoscopic analysis
Click the corner of the flat roof in image 3913. The select from the menu: (3D | Intersection of rays… | Point intersection, ONE image…)

When prompted for the Z of the target, give 158 m, which is our current best guess.

The solution now is

X:

Y:

Z: 158.00 m

This is what one image (two observations) can give.
2. Least square ray intersection.
Now continue by clicking the same corner in all four images. Then perform least square ray intersection (4 images = 8 observations – 3 unknowns; redundancy of 5), Press CTRL-I.

The space intersection results are:

X:

Y:

Z:

And the reliability measures are

RMSE: micrometers

SD(X): m

SD(Y): m

SD(Z): m

3. LS-ray intersection in image pairs

Let's look at the Z solution by selecting different image pairs for the LS-ray intersection. Activate / disable images by selecting the check-box above the image. Make notes of the Z-values.

440304 – 3913, Z:

3913 – 3914, Z:

3914 – 3915, Z:

3913 – 3915, Z:

The Z-accuracy is mainly affected by the geometry of the meeting rays. Base-height ratio is a key indicator.

4. Pushbroom images ADS40, NIR-band

Using CTRL-D command (add image), open the image header file c:\data\ads40\hdr\08230703NIRN00A.hdr.

It is a NADIR-looking NIR-band view with a 10-cm nominal resolution.

The image is so-called L0 raw data where all camera movements (leftovers from the gyro stabilized movements) are seen. ADS40 images are normally rectified to plane, where corresponding entities sit on the same row (epipolar resampling of images).

5. Epipolar geometry, search lines.

Open the options window, CTRLO. Increase the Z-depth of the epipolar search from 5 to 50 m, and press "apply changes".

Now, when you click on any target in any image, that image ray is displayed in the other images in XYZ points that are ± 50 m from the Z-value of the current solution. The Z-parameter is looped at 0.25 m steps and the XY-points along the image ray are computed and the points are displayed in the images.

If the geometry, i.e. the exterior and (camera) interior orientations are well established, the corresponding point in the other images are found along the epipolar search lines, unless their Z deviates more than 50 m.

Demo – 3 Getting XYZ-coordinates semi-automatically

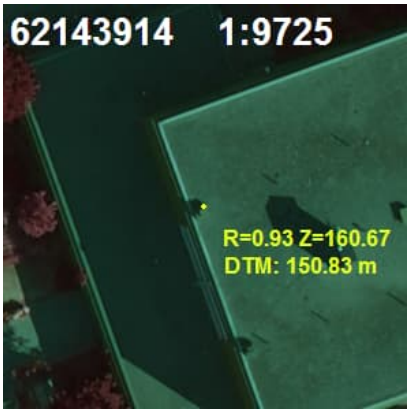
1. Using the confined search line; area-based image matching in an image pair.

Next we will do automatic search of the corresponding image point, in two images.

The image in the upper left corner s.b. 3913, and next to it, 3914 in the middle and 3915 as rightmost. 3913 is our master image (index 0). 3914 is the slave (index 1).

From the menu, select (State | Measure surface points (pair)).

Click something in the master image, on the roof.



The area –based matching looks, along the epipolar line, the corresponding features in the images, and based on cross-correlation (other measures exist too), decides the solution.

2. Epipolar geometry, area-based image matching in an image triplet.

Next we will do automatic search of the corresponding image point, supported by three images.

The image in the upper left corner s.b. 3913, and next to it, 3914 in the middle and 3915 as rightmost. Now 3914 is our master image (index 1). 3913 and 3915 are the slaves (indeces 0, 2).

From the menu, select (State | Measure surface points (triplet)).

Click something in the master image, in the middle of the upper row, on the roof. Use CTRL-M to center the images to the solution.

Compare pair matching and triplet matching by using the left and the middle images as master image. You should notice that the coordinates for the “same objects” differ.

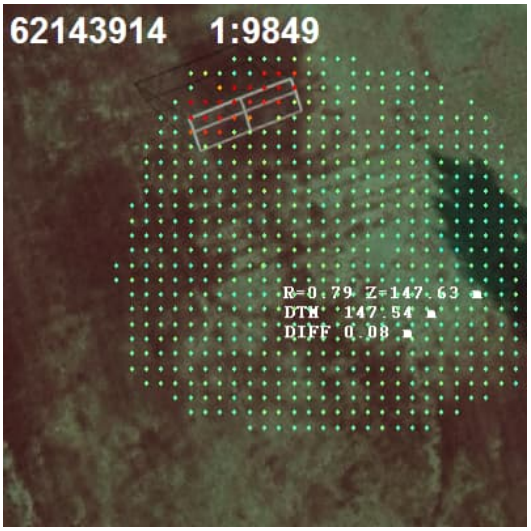
Demo – 4 Getting XYZ-coordinates almost automatically

3. Automatic matching inside an image polygon

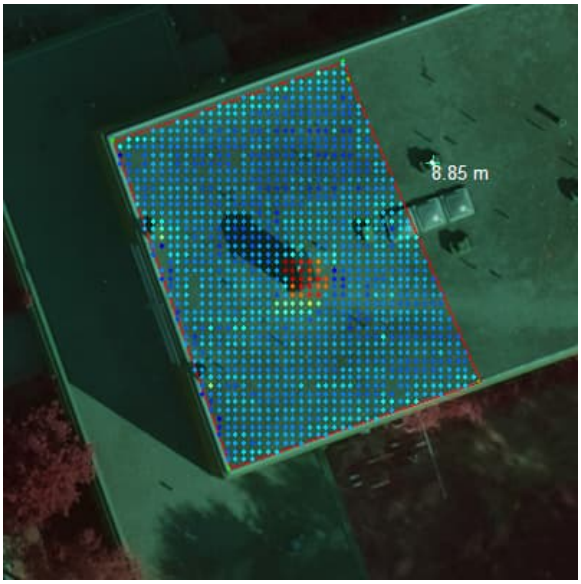
When you are done with item 15, pan (ALT-click) the image 3913 “to the left”, until you reach a football field, where you can click the image to get the solution there and centre all images (CTRL-M).

Then using menu commands (State | Draw Polygon) and (State | Draw XY-polyline given Z), delineate a polyline in the middle image (3914), by starting with the right-mouse-click, then digitize with the left-button, and finish by clicking SHIFT-right-click.

Deactivate “draw mode” using menu commands (State | Draw Polygon) and (State | Draw XY-polyline given Z). Then click a point in the field and start image matching (Surface matching | Triple image matching).



The matching is carried out in an image grid of image 3914, grid density is parameter as well as the size of the correlation window (see CTRL-O, options).



Here, the triplet matching was done in a +-3 m deep search space, and 0.5-m grid on the roof delineated by a polyline.

4. Anaglyph stereo – epipolar rectification (Optional)

If you have 3913 in the up left image position, and 3914 to the right of it; these two make a stereo pair.

(File | Create an anaglyph Stereo pair)

Set pixel size to 28 um, the rest you can just “OK”

Computing the stereo pair takes a while.

(File | Open the anaglyph Stereo Window)

(File | Open stereo pair file) – c:\data\pair.txt

Double-click the image to PAN.

“U”, “D” brings the solution up/down 1 meter.

In epipolar-resampled images the corresponding entities are on the same rows which greatly simplifies the implementation of search algorithms.

Image matching fails easily if the correspondence problem is difficult to resolve (occlusion, repeated texture). Image contains a small greenhouse.

Demo – 5 LiDAR data

Remove all images by pressing F3. Then open using F2 command c:\data\imafiles\demo1\2006_6214**3914**.txt and c:\data\imafiles\demo1\2006_6214**3915**.txt files. Try CTRL-Z (read DTM value) command. The ground should be at 151.09 m a.s.l. Use (File | Add TIN or Raster… | Add raster elevation model), if the ground was at -99 m.

1. Plot altm2033 data in images

First we break the control of the program (pause), by pressing CTRL-break.

CTRL-R opens the Project window. Select Form1.frm, in the code window, select the plot_als_bin_file routine. There, find the following code sequence:

```
Rem ********** Parameters *************
MaxDTM = 50
MinDTM = 0
DistA = 25
PlotIntensity = True
UseZNotH = False
```

MaxDTM and MinDTM set the range of values that is visualized in the HSV-colors. DistA is the XY radius of a plot in which the the data is superimposed. If PlotIntenity is set to False, height above ground is the theme, and if UseZNotH is true, absolute z-values are used for the theme (set range 155–162 m a.s.l.).

"F5" runs the code, then select (3D | Plot… | Plot 2004 LiDAR).

Try setting the values.

What can you say about the altm2033 intensity?

How about the XY-accuracy?
(Zoom in near the straight border of the roof)

2. Plot altm3100 data in images

Form1.frm routine **Print_ALS_near_solution_Click()** reads the altm3100 LiDAR data in 207 byte records and superimposes in the images. (3D | Plot | Plot 2006 LiDAR).

List 1. Struct / Type declaration of Optech's comprehensive format (altm3100).

```
Rem 2006 ALTM 3100 pulse data, 207 bytes per record
Type LidarRecord
 GPStime As Double
 PulseCount As Byte
 Returns(1 To 4) As point3D
 Intensity(1 To 4) As Integer
 Range(1 To 4) As Double
 angle As Double
 Roll As Double
 Pitch As Double
 Heading As Double
 Poslidar As point3D
 StripNum As Integer
 SyncBit As Byte
 Res1 As Byte
 Res2 As Byte
 Res3 As Byte
End Type
```

3. LiDAR; pulses or points?

Having the pulse geometry stored allows for using LiDAR for the measurement of scatterer-free volume. It also allows for checking the XY-accuracy of the data, if suitable linear features exist.

Click one corner of the roof, to get the XYZ-solution there.

(3D | Plot | Plot 2006-2007 LiDAR) plots the LiDAR pulses at 160.4 m a.s.l. Those that produced an echo above the elevation are drawn in red. "altm3100 points" are in dark yellow, and als50 "echoes" in light blue.

There are data from 4 overlapping strips and two sensors. The pulses are projected to the plane, Z = 160.4 and colored according to sensor and penetration of plane Z = 160.4 m.

Demo – 6 Tree measurements

1. Treetop positioning and tree height estimation with LiDAR monoplotting

You can start by removing all images (F3) and reading the image pair 3913 and 3914 with the F2-command.

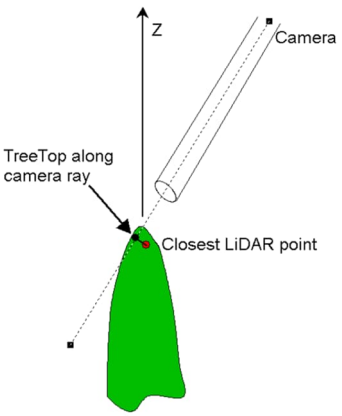
PAN (Alt-click) in the images to the right to see a spruce tree (see below).

Click the top of the tree in the image, until you get ~22.50 m as the tree height.

This is the height estimate using "LiDAR-monoplotting"; where you sent a "1-m thick ray/tube" down to the scene by clicking in the image, and the first LiDAR point (2006-2008 data sets, plot by using Shift-Ins command) encountered inside the tube, was forced to intersect the ray keeping the camera-echo distance the same.

The RED dot is this solution. If you see a white dot, that is the first LiDAR echo in the “camera-ray-tube”.

If you press F12, the DTM is displayed in the screen. Tree height is simply the difference in Z.



2. Treetop position using LS ray intersection

Click the treetop (CTRL-C clears the graphics) in both images. Then CTRL-I to get the LS ray intersection solution. CTRL-Z gives the ground elevation, is the height still 22.50 m (or similar to the LiDAR-monoplotting value)?

3. Tree crown shape using non-linear regression

With the XYZ-position of the treetop, press “2” in the keyboard. That starts an iterative process where the point cloud is used for modeling the radius of the tree crown. Initial approximation is given by tree height and sp, which we assume to be P. abies, thus “2”.

The estimated crown diameter is given (Dcr: #.# m) as well as height estimates and a DBH estimate at the top of the Form1.frm window, in green text.

If you press “1”, you assume it is a pine.

Similarly, “3” is for birch / broad-leaved trees.

The DBH is estimated using species-spesific regression equations (Kallivirta and Tokola 2005),:

SQRT(DBH) = a*SQRT(H)+b*SQRT(CW)+epsilon

4. Tree crown width in image; semi-automatic template matching.

Remove all images, using the F3-command.

Read images 3913, 3914, 440303, 440304 using F2-command from c:\data\imafiles\MK\

Click in the treetop near the solution, in all images.

Press CTRL-I to solve the ray intersection.

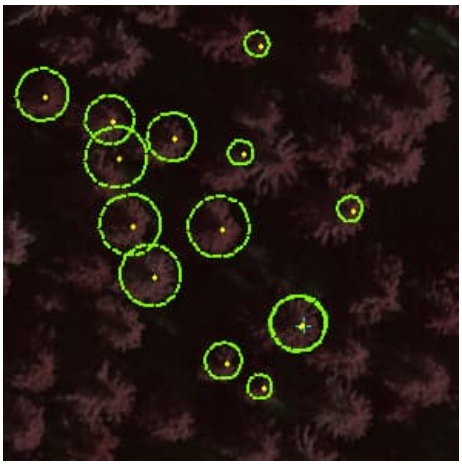
Capture templates in images, using the CTRL-X command.

Make a series of templates over 7 scales, menu command (Image matching | Resize templates).

Activate check-Box “Multi-scale TM” on the main form.

Deactivate the epipolar lines in images (Options window, CTRL-O, Draw epipolar line…).

Click tree tops in any image to measure the Treetop position and Crown width using Template matching.



Template matching is used for 3D treetop positioning and the “best scale” gives an estimate of crown width, relative to the model tree.

/ISPRS Hannover Workshop 2007 /

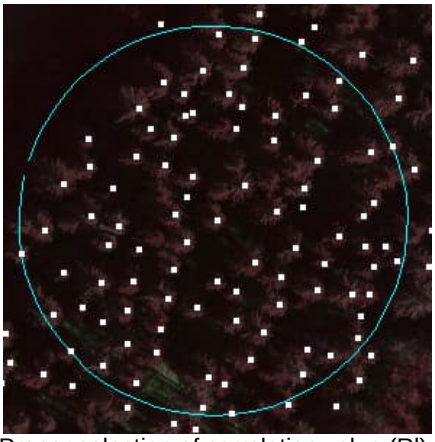
5. Treetop positioning – almost automatic

Click the model tree used at the start to get the solution to get the “photo-plot” centered at that tree.

Set the plot-radius to 10 m (box with 23 as default)

Image matching | Read data for plotcenter
| Capture templates (not needed, done)
| Compute correlation images (CTRL-Y)
| Create XYZ point set (CTRL-N)
| Find Clusters (CTRL-W)

Adjust parameters XY (1.5) and RI (0.3), and re-run the clustering step (CTRL-W).



Proper selection of correlation value (RI) and minimum distance between treetops (XY) resulted in a reasonable treetop detection results.

/Silva Fennica monographs 3, 2004/

4 Lab 2 – RADIOMETRIC ISSUES

Demo 1 – the image data for XYZ point

The 3D point could be for example e.g. a LiDAR return or a point on the surface of a crown model.

We need a mapping from the XYZ object space to the xyz-space of the camera. In camera, z = ± c, i.e. the focal length, and xy-plane corresponds to the film/focal/ccd plane. The

origin is in the center, and KUVAMITT assumes that the xy-system is right-handed.

In a film-image the extent of the xy-plane is typically 23x23 cm.

UltraCAM D has a virtual “3.3 x 5.2-cm film-plane”, actually there are 8 CCDs. Some are 24 mm x 36 mm, in size.

ADS40 has CCD-lines with 12000, 6.5-um pixels, which constitutes a 7.8-cm line of pixels; all 11 lines are on the same focal plane.

First we solve the xy-coordinates of the point.

Look for MODULE1.BAS and routine
Public Sub r_transform_ground_to_pixel

Inside it, find the routine Call a_transform_affine
Click the marginal to the left, to activate this line, it turns red.
The debugger will now stop on this line.

Then start Visual Basic, F5, and read an image using the F2 (Take c:\data\imafiles\demo1\2006_62143914.txt)

When the debugger stops at the line, place the cursor on top of variables camera_x and camera_y. The values are meters, in the xy-system.

Then, click on the marginal to activate debugger on the next line that has the End Sub –statement.

Continue the execution with F5-command (Continue).

Then look at the values of variables p_x and p_y by placing the cursor on top of them. These values correspond to column, row position in the image. They are decimal values, that need to be converted into a pixel, or the pixels in the vicinity are interpolated.

NOTE: In KUVAMITT, the origin (0,0) of the image coordinate system is in the low left corner of the image, and in the center of the pixel, the value is always (#.5, #.5). There exists no standards on the definition of the origin.

Demo 2 – the 16-bit R, G, B, NIR -values

The monoplotting procedure has some code for the retrieval of the pixel data for the XYZ-point that has been solved (Demo 6/1).

Pause the program (CTRL-break) and look at Module1.bas, and routine Cast_Image_ray_and_Find_Closest_LiDAR;

Find the code segment (use CTRL-F)
```
Rem RGBNIR-VALUES
GoTo PassBy
```

Write “Rem” or “’” in front of the GOTO statement.

Then run the code F5 and click targets in the image 3914.

The R G B NIR Pan_Mean and PAN_SD values are printed in the image.

Try different targets.

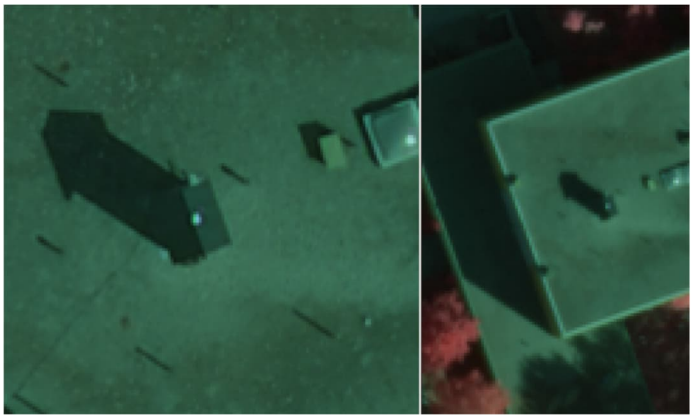
Demo 3 – PAN-sharpened vs. original

Remove all images (F3).

Open using F2 command:
c:\data\imafiles\demo1\2006_62143914.txt

Open using CTRL-D command:
c:\data\hdr\62143914_uint8.hdr

This image has the 28.125 um (actually 9 um) pixels in NIR R and G bands; transformed from 16 to 8 bits.


The PAN-sharpening ratio of UCD is 1:3.2.

Try getiing the 16-bit pixel values, at times they are not the same, because of minor orientation differences and interpolation errors.

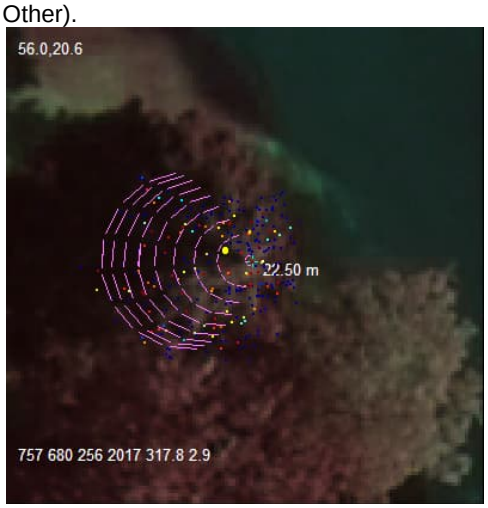
Demo 4 – Collecting LiDAR intensities

Pause the project using CTRL-Break. Look for procedure Match_Local_Crown() in Form1.frm.

Look for the code below:
```
GoTo PassBy
Form1.Picture1(0).CurrentX = 10
Form1.Picture1(0).CurrentY = 10
```

Make the GOTO statement into a remark by adding Rem at the start.

Run the code (F5), find a tree top and measure it using the LiDAR monoplotting technique. Then model the crown envelope by pressing either “1”, “2”, or “3” (Pine, Spruce, Other).



Mean intensity and SD of intensity are given in the upper left corner. Only first-return data is used.

C:\data\intensities.txt has all the observations. Given are distance down the top (m) and intensity (DN). Two sensors, als50 and altm3100 are used together.

5 Some KUVAMITT commands:

EDITING OBSERVATIONS

CTRL-A
Deletes all image observations and clears images
CTRL-C
Clears the images

MOVING AROUND

CTRL-M
Centers images to XYZ solution (variables X_sol, Y_sol, Z_sol)
Alt-Click
PAN an image
Ctrl-Click
Zoom out an image
Shift-Click
Zoom in an image
Click
Sets the image, xy-observation for an image (displayed in text boxes)

3D POSITIONING

CTRL-I
Computes least square ray intersection based on the image observations
CTRL-Z
Check the raster DEM elevation (Z) for the current XYZ-solution
F12
Plots the DEM in the images over certain area, in HSV-colors.

READING IMAGES

F2
Inserts an image to a specified XYZ-position.
F3
Removes one or all images from the display
F8
Compute images in which the XYZ-solution is visible.
CTRL-D
Reading an image (HDR-file)

PLOTTING LIDAR

Shift-ins
Plots 3 sets of LiDAR points (altm3100, 2006, 1km) (als50, 2007, 1km) (als50, 2008, 1, 2, 3 4km) in the images

Appendix 5. EO of the frame images

#		f	omega	phi	kappa	x0	y0	z0	id	path	year
1	0	0.20453	-0.071348	0.020872	-2.998308	2516042.847	6854295.962	4095.455	54439	c:\data\hdr\1946_54439.hdr	1946
2	0	0.20453	-0.023050	0.014195	-3.018826	2517401.434	6854493.971	4094.275	54440	c:\data\hdr\1946_54440.hdr	1946
3	0	0.20453	0.019864	0.031785	-3.049979	2518784.087	6854640.144	4089.347	54441	c:\data\hdr\1946_54441.hdr	1946
4	0	0.20453	-0.027764	0.050020	0.019042	2516832.415	6856917.878	4081.684	54452	c:\data\hdr\1946_54452.hdr	1946
5	0	0.20453	0.006187	0.039931	0.017454	2517830.342	6856897.374	4081.373	54453	c:\data\hdr\1946_54453.hdr	1946
6	0	0.20453	-0.033651	0.003238	0.035773	2519280.408	6856872.482	4081.258	54454	c:\data\hdr\1946_54454.hdr	1946
7	0	0.20453	-0.008020	-0.019865	1.637701	2517268.157	6856327.703	4277.923	55012	c:\data\hdr\1946_55012.hdr	1946
8	0	0.20453	-0.004778	-0.013577	1.631486	2517537.896	6856358.081	4280.518	55013	c:\data\hdr\1946_55013.hdr	1946
9	0	0.20453	-0.006573	0.018829	1.629559	2516084.936	6856239.735	4282.015	55014	c:\data\hdr\1946_55014.hdr	1946
10	0	0.20453	0.008069	0.013886	1.626831	2515816.831	6856226.041	4286.746	55015	c:\data\hdr\1946_55015.hdr	1946
11	0	0.20453	-0.019642	0.006252	1.506057	2514538.801	6856156.049	4260.925	55016	c:\data\hdr\1946_55016.hdr	1946
12	0	0.20453	0.001869	-0.017833	-1.714644	2512689.164	6859833.362	4278.198	55045	c:\data\hdr\1946_55045.hdr	1946
13	0	0.20453	0.016102	-0.006795	-1.717275	2514223.847	6859746.516	4285.951	55046	c:\data\hdr\1946_55046.hdr	1946
14	0	0.20453	0.002584	-0.007551	-1.714569	2514517.285	6859723.958	4285.222	55047	c:\data\hdr\1946_55047.hdr	1946
15	0	0.20453	-0.019702	-0.002170	-1.621963	2516072.663	6859664.583	4276.453	55048	c:\data\hdr\1946_55048.hdr	1946
16	0	0.20453	0.000161	0.001703	-1.616746	2517694.467	6859703.878	4284.627	55049	c:\data\hdr\1946_55049.hdr	1946
17	0	0.20453	-0.012120	-0.006253	-1.622418	2519523.924	6859740.558	4284.384	55050	c:\data\hdr\1946_55050.hdr	1946
18	0	0.20453	0.013339	-0.044108	-0.001784	2519522.848	6854837.338	4146.399	533106	c:\data\hdr\1946_533106.hdr	1946
19	0	0.20453	-0.014293	-0.048238	0.031720	2518250.440	6854818.225	4144.984	533107	c:\data\hdr\1946_533107.hdr	1946
20	0	0.20453	-0.023906	-0.028955	0.036591	2517010.755	6854767.622	4151.832	533108	c:\data\hdr\1946_533108.hdr	1946
21	0	0.20453	-0.006268	-0.032229	0.046651	2515762.445	6854709.814	4150.375	533109	c:\data\hdr\1946_533109.hdr	1946
22	0	0.20453	-0.020037	-0.031467	0.051377	2514517.302	6854634.511	4149.620	533110	c:\data\hdr\1946_533110.hdr	1946
23	0	0.20453	-0.031524	-0.047104	0.033411	2513280.609	6854567.539	4149.090	533111	c:\data\hdr\1946_533111.hdr	1946
24	0	0.20453	0.042690	0.023089	-3.113004	2512099.225	6857523.226	4157.570	533118	c:\data\hdr\1946_533118.hdr	1946
25	0	0.20453	0.041733	0.032718	-3.140783	2513386.013	6857587.587	4151.915	533119	c:\data\hdr\1946_533119.hdr	1946
26	0	0.20453	0.040000	0.039196	-3.153059	2514693.426	6857615.313	4144.877	533120	c:\data\hdr\1946_533120.hdr	1946
27	0	0.20453	0.003865	0.063544	-3.194823	2515999.747	6857612.708	4139.747	533121	c:\data\hdr\1946_533121.hdr	1946
28	0	0.20453	0.070051	0.034898	-3.198681	2517336.515	6857595.021	4137.378	533122	c:\data\hdr\1946_533122.hdr	1946
29	0	0.20453	0.048086	0.026643	-3.216271	2518649.964	6857537.291	4150.112	533123	c:\data\hdr\1946_533123.hdr	1946
30	0	0.20453	0.050068	-0.000829	-3.231845	2519969.391	6857456.052	4140.099	533124	c:\data\hdr\1946_533124.hdr	1946
31	0	0.20453	0.027924	-0.017809	0.299474	2518811.661	6860750.357	4155.755	533200	c:\data\hdr\1946_533200.hdr	1946
32	0	0.20453	-0.011650	-0.012078	0.290750	2517568.938	6860548.923	4174.198	533201	c:\data\hdr\1946_533201.hdr	1946
33	0	0.20453	0.041297	-0.076041	0.326394	2516342.812	6860323.079	4143.259	533202	c:\data\hdr\1946_533202.hdr	1946
34	0	0.20453	-0.069015	-0.001703	0.354372	2515106.566	6860046.705	4170.023	533203	c:\data\hdr\1946_533203.hdr	1946
35	0	0.20453	-0.018984	-0.046328	0.371448	2513902.256	6859767.774	4153.260	533204	c:\data\hdr\1946_533204.hdr	1946
36	0	0.20453	-0.023316	-0.039313	0.357888	2512675.977	6859476.697	4144.373	533205	c:\data\hdr\1946_533205.hdr	1946
37	0	0.20453	0.009370	-0.050655	0.361450	2511448.850	6859183.627	4140.427	533206	c:\data\hdr\1946_533206.hdr	1946
38	0	0.20453	-0.006168	-0.029166	0.395392	2510224.535	6858873.250	4139.185	533207	c:\data\hdr\1946_533207.hdr	1946
39	0	0.20453	0.005504	-0.031909	0.006980	2519407.773	6862166.933	4136.814	537024	c:\data\hdr\1946_537024.hdr	1946
40	0	0.20453	0.007960	-0.031131	-0.022880	2518084.682	6862111.439	4141.388	537025	c:\data\hdr\1946_537025.hdr	1946
41	0	0.20453	0.022532	-0.033818	-0.008714	2516749.154	6862073.498	4136.549	537026	c:\data\hdr\1946_537026.hdr	1946
42	0	0.20453	-0.009716	-0.041643	-0.033264	2515413.208	6862034.197	4135.411	537027	c:\data\hdr\1946_537027.hdr	1946
43	0	0.20453	0.018722	-0.057577	-0.017448	2514069.476	6862018.927	4137.740	537028	c:\data\hdr\1946_537028.hdr	1946
44	0	0.20453	-0.011232	-0.031868	-0.040004	2512730.852	6861995.210	4138.596	537029	c:\data\hdr\1946_537029.hdr	1946
45	0	0.20453	0.032613	-0.037513	-0.025865	2511389.197	6862011.853	4134.176	537030	c:\data\hdr\1946_537030.hdr	1946
46	0	0.20453	0.003865	-0.044686	0.005180	2510052.701	6861997.220	4134.048	537031	c:\data\hdr\1946_537031.hdr	1946
47	0	0.20453	0.015023	0.042818	-3.218507	2511683.741	6863591.289	4137.380	537050	c:\data\hdr\1946_537050.hdr	1946
48	0	0.20453	0.012099	0.049036	-3.191770	2513125.741	6863437.699	4130.199	537051	c:\data\hdr\1946_537051.hdr	1946
49	0	0.20453	-0.010525	0.039982	-3.193848	2514568.358	6863292.337	4144.038	537052	c:\data\hdr\1946_537052.hdr	1946
50	0	0.20453	-0.056108	0.037954	-3.127557	2516005.378	6863186.495	4142.638	537053	c:\data\hdr\1946_537053.hdr	1946
51	0	0.20453	-0.036138	0.055444	-3.058191	2517457.141	6863181.427	4134.660	537054	c:\data\hdr\1946_537054.hdr	1946
52	0	0.20453	-0.039435	0.026944	-2.976594	2518916.311	6863304.236	4133.242	537055	c:\data\hdr\1946_537055.hdr	1946
53	0	0.15236	-0.006291	0.021381	-2.381357	2513204.785	6860056.672	2662.571	62121313	c:\data\hdr\1962_62121313.hdr	1962
54	0	0.15236	-0.009528	0.016664	-2.376385	2514241.738	6860984.158	2654.511	62121314	c:\data\hdr\1962_62121314.hdr	1962
55	0	0.15236	-0.023630	0.009414	-2.373706	2515270.306	6861920.178	2649.688	62121315	c:\data\hdr\1962_62121315.hdr	1962
56	0	0.15236	-0.029160	0.023100	-2.347033	2516240.641	6862851.912	2636.442	62121316	c:\data\hdr\1962_62121316.hdr	1962
57	0	0.15245	0.008789	0.004172	-3.106597	2514646.039	6854722.534	9403.538	6306239	c:\data\hdr\1963_6306239.hdr	1963
58	0	0.15245	0.001941	0.031685	-3.108668	2517730.297	6854698.325	9384.372	6306240	c:\data\hdr\1963_6306240.hdr	1963
59	0	0.15245	0.008471	0.013090	-3.107656	2520871.709	6854682.509	9347.328	6306241	c:\data\hdr\1963_6306241.hdr	1963
60	0	0.15245	-0.008775	-0.005229	-0.010683	2514777.826	6864434.645	9379.987	6306259	c:\data\hdr\1963_6306259.hdr	1963
61	0	0.15245	-0.009983	-0.020318	-0.010636	2511970.556	6864473.054	9367.432	6306260	c:\data\hdr\1963_6306260.hdr	1963
62	0	0.15245	-0.013638	-0.016283	-0.011509	2509147.499	6864513.731	9360.856	6306261	c:\data\hdr\1963_6306261.hdr	1963
63	0	0.15292	0.015658	0.001512	-0.080048	2516643.654	6854922.075	3178.600	6616304	c:\data\hdr\1966_6616304.hdr	1966
64	0	0.15292	0.052821	0.009726	-0.064262	2514853.630	6855064.059	3178.768	6616305	c:\data\hdr\1966_6616305.hdr	1966
65	0	0.15292	-0.009709	-0.016016	-3.138171	2514260.564	6857989.269	3173.325	6616315	c:\data\hdr\1966_6616315.hdr	1966
66	0	0.15292	-0.002051	0.001399	-3.109191	2515902.656	6857958.260	3172.754	6616316	c:\data\hdr\1966_6616316.hdr	1966
67	0	0.15292	-0.006932	-0.014767	-3.085554	2517540.360	6857958.690	3178.971	6616317	c:\data\hdr\1966_6616317.hdr	1966
68	0	0.15292	0.002449	0.011143	0.031763	2517021.818	6860976.225	3175.445	6616326	c:\data\hdr\1966_6616326.hdr	1966
69	0	0.15292	0.002244	0.000737	0.039013	2515363.607	6860956.414	3180.293	6616327	c:\data\hdr\1966_6616327.hdr	1966
70	0	0.15292	0.014839	0.019770	0.023966	2513694.032	6860934.375	3181.018	6616328	c:\data\hdr\1966_6616328.hdr	1966
71	0	0.15292	0.001085	-0.013761	-3.108659	2519271.229	6857970.552	3185.176	6616318	c:\data\hdr\1966_6616318.hdr	1966
72	0	0.15292	0.008512	0.001930	0.020785	2512016.259	6860911.369	3181.309	6616329	c:\data\hdr\1966_6616329.hdr	1966
73	0	0.15292	-0.014963	-0.002926	0.010256	2510308.456	6860919.586	3176.354	6616330	c:\data\hdr\1966_6616330.hdr	1966
74	0	0.15292	0.002809	-0.002219	-3.142703	2513615.522	6864040.649	3180.601	6616339	c:\data\hdr\1966_6616339.hdr	1966
75	0	0.15292	-0.010550	0.001126	-3.102114	2515310.507	6863977.660	3180.276	6616340	c:\data\hdr\1966_6616340.hdr	1966
76	0	0.15292	-0.001905	-0.013542	-3.129021	2516949.622	6863971.414	3187.116	6616341	c:\data\hdr\1966_6616341.hdr	1966
77	0	0.15292	-0.013880	-0.012574	-3.096503	2518752.380	6863928.506	3188.788	6616342	c:\data\hdr\1966_6616342.hdr	1966
78	0	0.15298	0.038555	-0.010600	-0.513635	2517567.008	6856073.778	2148.968	6911301	c:\data\hdr\1969_6911301.hdr	1969
79	0	0.15298	0.056351	-0.008531	-0.596462	2516586.842	6856744.792	2150.782	6911302	c:\data\hdr\1969_6911302.hdr	1969
80	0	0.15298	-0.040851	0.040318	-0.732776	2515646.571	6857484.506	2169.638	6911303	c:\data\hdr\1969_6911303.hdr	1969
81	0	0.15298	0.006050	-0.022452	-0.643619	2514735.283	6858342.104	2162.966	6911304	c:\data\hdr\1969_6911304.hdr	1969
82	0	0.15298	0.012759	-0.024891	-0.662284	2513795.171	6859139.509	2143.300	6911305	c:\data\hdr\1969_6911305.hdr	1969
83	0	0.15298	0.031451	0.021931	-0.671141	2512958.552	6859844.910	2142.497	6911306	c:\data\hdr\1969_6911306.hdr	1969
84	0	0.15298	-0.002907	0.023891	-0.779711	2512081.757	6860632.326	2163.244	6911307	c:\data\hdr\1969_6911307.hdr	1969
85	0	0.15298	0.026133	-0.025415	-0.646039	2511252.966	6861468.006	2154.042	6911308	c:\data\hdr\1969_6911308.hdr	1969
86	0	0.15298	0.017131	0.003913	-0.599250	2510333.158	6862221.811	2139.601	6911309	c:\data\hdr\1969_6911309.hdr	1969
87	0	0.15286	-0.021110	-0.016740	1.521965	2514935.768	6861931.572	3469.934	7316622	c:\data\hdr\1973_7316622.hdr	1973
88	0	0.15286	-0.021607	-0.004991	1.569122	2514845.197	6860413.642	3467.162	7316623	c:\data\hdr\1973_7316623.hdr	1973
89	0	0.15286	-0.019766	-0.020951	1.552021	2514809.875	6858873.288	3475.756	7316624	c:\data\hdr\1973_7316624.hdr	1973
90	0	0.15286	-0.019321	-0.009952	1.599774	2514764.803	6857334.182	3476.460	7316625	c:\data\hdr\1973_7316625.hdr	1973
91	0	0.15286	-0.009780	-0.021743	1.603580	2514801.837	6855795.663	3474.236	7316626	c:\data\hdr\1973_7316626.hdr	1973
92	0	0.15286	-0.021408	-0.020621	1.563281	2514815.788	6854235.007	3473.507	7316627	c:\data\hdr\1973_7316627.hdr	1973
93	0	0.15286	0.020620	0.001308	-1.574788	2518213.936	6856889.448	3469.295	7316660	c:\data\hdr\1973_7316660.hdr	1973
94	0	0.15286	0.019222	-0.002840	-1.561942	2518205.717	6858663.611	3470.874	7316661	c:\data\hdr\1973_7316661.hdr	1973
95	0	0.15286	0.018370	0.015495	-1.595741	2518188.551	6860421.736	3470.083	7316662	c:\data\hdr\1973_7316662.hdr	1973
96	0	0.15286	0.014632	0.008718	-1.627201	2518247.715	6862211.763	3458.132	7316663	c:\data\hdr\1973_7316663.hdr	1973
97	0	0.15286	-0.019532	0.022218	1.593351	2518146.073	6862694.663	3478.725	7320456	c:\data\hdr\1973_7320456.hdr	1973
98	0	0.15286	-0.006233	-0.000920	1.576599	2518181.878	6860870.643	3476.341	7320457	c:\data\hdr\1973_7320457.hdr	1973
99	0	0.15286	0.000014	0.014455	1.588954	2518190.159	6858976.163	3470.611	7320458	c:\data\hdr\1973_7320458.hdr	1973
100	0	0.15286	-0.022895	0.003971	1.555947	2518217.019	6856986.173	3481.275	7320459	c:\data\hdr\1973_7320459.hdr	1973

101 0 0.15286 0.000077 0.003430 1.563600 2518206.758 6854934.201 3475.629 7320460 c:\data\hdr\1973_7320460.hdr 1973
102 0 0.15286 0.010012 -0.012930 -1.514122 2515089.743 6856925.702 3480.763 7320491 c:\data\hdr\1973_7320491.hdr 1973
103 0 0.15286 0.002208 0.005959 -1.570402 2515084.019 6858925.616 3475.151 7320492 c:\data\hdr\1973_7320492.hdr 1973
104 0 0.15286 0.000297 -0.025472 -1.553039 2515137.404 6860937.094 3477.338 7320493 c:\data\hdr\1973_7320493.hdr 1973
105 0 0.15286 0.004527 -0.009369 -1.554916 2515163.491 6862787.989 3484.787 7320494 c:\data\hdr\1973_7320494.hdr 1973
106 0 0.15286 0.021322 -0.003954 -1.638366 2511757.764 6860175.620 3468.909 7316619 c:\data\hdr\1973_7316619.hdr 1973
107 0 0.15286 0.018965 0.004219 -1.632502 2511816.100 6861995.515 3472.487 7316620 c:\data\hdr\1973_7316620.hdr 1973
108 0 0.15286 -0.018292 -0.012682 1.538911 2514773.024 6852603.049 3469.040 7316628 c:\data\hdr\1973_7316628.hdr 1973
109 0 0.15286 -0.025317 -0.010072 1.558624 2514733.473 6850937.146 3480.145 7316629 c:\data\hdr\1973_7316629.hdr 1973
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1685 0 0.035062 -0.035455 -0.021285 -2.563105 2515641.179 6861446.785 926.095 006_2029 c:\data\hdr\2013_RGB_006_2029.hdr 2013
1686 0 0.035062 -0.041524 0.015273 -2.700064 2515751.671 6861152.156 933.899 006_2030 c:\data\hdr\2013_RGB_006_2030.hdr 2013
1687 0 0.035062 -0.048199 0.006247 -2.637580 2515848.217 6860854.305 938.850 006_2031 c:\data\hdr\2013_RGB_006_2031.hdr 2013
1688 0 0.035062 -0.026172 0.008800 -2.581301 2515960.561 6860556.016 946.465 006_2032 c:\data\hdr\2013_RGB_006_2032.hdr 2013
1689 0 0.035062 0.008936 -0.012649 -2.646511 2516072.863 6860262.852 939.614 006_2033 c:\data\hdr\2013_RGB_006_2033.hdr 2013
1690 0 0.035062 -0.013009 -0.023696 -2.580799 2516172.876 6859963.824 937.031 006_2034 c:\data\hdr\2013_RGB_006_2034.hdr 2013
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1693 0 0.035062 0.018398 -0.062980 -2.574933 2516502.599 6859078.450 945.270 006_2037 c:\data\hdr\2013_RGB_006_2037.hdr 2013
1694 0 0.035062 -0.010579 0.000774 -2.639336 2516605.511 6858777.670 947.387 006_2038 c:\data\hdr\2013_RGB_006_2038.hdr 2013
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1716 0 0.035062 0.029519 0.011768 0.157944 2516887.068 6858550.315 917.205 007_2060 c:\data\hdr\2013_RGB_007_2060.hdr 2013
1717 0 0.035062 0.015680 0.027340 0.192728 2516782.727 6858845.695 926.192 007_2061 c:\data\hdr\2013_RGB_007_2061.hdr 2013
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1763 0 0.035062 -0.033363 0.018106 2.032439 2514813.603 6858709.942 922.352 009_2107 c:\data\hdr\2013_RGB_009_2107.hdr 2013

Appendix 6. IO of the frame images (2015 are missing)

path	id	width	height	a	b	c	d	e	f (affine)
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c:\data\hdr\2002_22041229.hdr	22041229	16432	16432	71432.804	-193.814	8202.276	195.436	71434.042	8240.972
c:\data\hdr\2002_22041230.hdr	22041230	16432	16432	71432.125	-107.608	8189.464	108.550	71432.134	8251.887
c:\data\hdr\2002_22041231.hdr	22041231	16432	16432	71431.750	-166.527	8160.472	165.843	71432.687	8267.089
c:\data\hdr\2002_22041232.hdr	22041232	16432	16432	71432.041	-180.516	8011.237	182.503	71432.897	8262.441
c:\data\hdr\2002_22041233.hdr	22041233	16432	16432	71433.702	-247.424	8030.917	248.387	71433.267	8270.690
c:\data\hdr\2002_22041234.hdr	22041234	16432	16432	71435.865	-247.053	8037.590	248.219	71433.693	8263.430
c:\data\hdr\2002_22041235.hdr	22041235	16432	16432	71436.575	-174.813	8212.518	175.207	71436.689	8239.652
c:\data\hdr\2002_22041236.hdr	22041236	16432	16432	71437.153	-119.141	8268.932	119.912	71436.199	8226.785
c:\data\hdr\2002_22041237.hdr	22041237	16432	16432	71436.680	-47.020	8166.893	49.227	71436.859	8222.614
c:\data\hdr\2002_22041238.hdr	22041238	16432	16432	71438.763	-66.746	8219.040	67.155	71437.654	8227.202
c:\data\hdr\2002_22041239.hdr	22041239	16432	16432	71443.087	-113.477	8191.375	116.695	71439.703	8233.016
c:\data\hdr\2002_22041240.hdr	22041240	16432	16432	71441.873	-224.067	8173.144	226.908	71440.530	8253.122
c:\data\hdr\2002_22041241.hdr	22041241	16432	16432	71440.246	-283.470	8204.079	284.575	71437.942	8244.883
c:\data\hdr\2002_22041242.hdr	22041242	16432	16432	71437.350	-311.515	8175.787	312.839	71435.914	8246.648
c:\data\hdr\2002_22041243.hdr	22041243	16432	16432	71441.218	-207.200	8258.695	208.586	71440.812	8228.588
c:\data\hdr\2002_22041244.hdr	22041244	16432	16432	71437.011	-150.044	8154.255	150.955	71436.876	8214.541
c:\data\hdr\2002_22041245.hdr	22041245	16432	16432	71439.531	-130.165	8093.877	132.179	71436.927	8214.219
c:\data\hdr\2002_22041246.hdr	22041246	16432	16432	71437.621	-144.434	8021.671	146.831	71437.702	8216.651
c:\data\hdr\2002_22041247.hdr	22041247	16432	16432	71437.918	-167.624	8189.970	169.766	71436.925	8222.221
c:\data\hdr\2002_22041248.hdr	22041248	16432	16432	71437.223	-201.350	8177.205	201.379	71436.761	8229.074
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c:\data\hdr\2002_22044575.hdr	22044575	16432	16432	71424.013	-136.059	8194.103	140.266	71426.478	8267.141
c:\data\hdr\2002_22044576.hdr	22044576	16432	16432	71423.495	-103.589	8146.090	108.117	71425.511	8276.377
c:\data\hdr\2002_22044577.hdr	22044577	16432	16432	71422.598	-74.245	8188.124	77.424	71424.405	8248.746
c:\data\hdr\2002_22044578.hdr	22044578	16432	16432	71420.857	-126.711	8122.863	130.147	71423.564	8266.733
c:\data\hdr\2002_22044579.hdr	22044579	16432	16432	71422.689	-99.844	8207.776	102.512	71424.614	8254.433
c:\data\hdr\2002_22044580.hdr	22044580	16432	16432	71421.711	-99.296	8176.558	101.207	71425.355	8262.986
c:\data\hdr\2002_22044581.hdr	22044581	16432	16432	71424.146	-70.239	8220.046	73.966	71424.681	8263.321
c:\data\hdr\2002_22044582.hdr	22044582	16432	16432	71423.472	-90.458	8156.751	93.000	71424.272	8260.825
c:\data\hdr\2002_22044583.hdr	22044583	16432	16432	71423.224	-80.395	8149.367	83.159	71426.081	8266.380
c:\data\hdr\2002_22044584.hdr	22044584	16432	16432	71430.737	-95.324	8113.624	98.270	71430.638	8258.027
c:\data\hdr\2002_22044585.hdr	22044585	16432	16432	71427.192	-79.236	8165.496	81.819	71430.064	8249.014
c:\data\hdr\2002_22044586.hdr	22044586	16432	16432	71421.768	-114.636	8164.612	120.818	71424.532	8267.306
c:\data\hdr\2002_22044587.hdr	22044587	16432	16432	71425.125	-114.501	8215.693	118.168	71425.604	8276.387
c:\data\hdr\2002_22044588.hdr	22044588	16432	16432	71424.280	-99.253	8156.573	103.816	71425.599	8263.419
c:\data\hdr\2002_22044589.hdr	22044589	16432	16432	71424.400	-165.849	8174.733	168.920	71425.547	8270.981
c:\data\hdr\2002_22044590.hdr	22044590	16432	16432	71419.277	-146.052	8177.475	151.660	71421.275	8281.653
c:\data\hdr\2002_22044591.hdr	22044591	16432	16432	71406.843	-185.559	8018.316	191.623	71410.904	8272.387
c:\data\hdr\2002_22044592.hdr	22044592	16432	16432	71408.491	-178.101	8073.097	182.896	71412.562	8279.466
c:\data\hdr\2002_22044593.hdr	22044593	16432	16432	71412.532	-178.062	8039.653	183.082	71415.440	8277.481
c:\data\hdr\2002_22044594.hdr	22044594	16432	16432	71415.251	-155.365	8057.492	161.267	71417.278	8261.207
c:\data\hdr\2002_22044595.hdr	22044595	16432	16432	71429.279	-107.786	8069.071	113.388	71426.676	8250.926
c:\data\hdr\2002_22054596.hdr	22054596	16400	16431	71431.877	-111.430	8182.340	116.810	71430.497	8257.012
c:\data\hdr\2002_22054597.hdr	22054597	16400	16431	71422.976	-61.794	8182.453	66.875	71421.576	8260.768
c:\data\hdr\2002_22054598.hdr	22054598	16400	16431	71420.250	-126.255	8140.367	132.796	71419.914	8262.343
c:\data\hdr\2002_22054599.hdr	22054599	16400	16431	71421.092	-130.539	8179.256	136.637	71421.100	8274.965
c:\data\hdr\2002_22054600.hdr	22054600	16400	16431	71421.578	-129.276	8181.563	135.706	71421.369	8274.696
c:\data\hdr\2002_22054601.hdr	22054601	16400	16431	71416.976	-106.233	8144.492	109.816	71419.804	8254.663
c:\data\hdr\2002_22054602.hdr	22054602	16400	16431	71418.666	-137.656	8164.963	141.949	71419.326	8263.244
c:\data\hdr\2002_22054603.hdr	22054603	16400	16431	71419.247	-121.325	8096.034	126.325	71419.638	8268.121
c:\data\hdr\2002_22054604.hdr	22054604	16400	16431	71420.170	-109.842	8101.981	114.987	71418.408	8272.893
c:\data\hdr\2002_22054605.hdr	22054605	16400	16431	71434.072	-153.154	8150.021	157.067	71431.418	8279.666
c:\data\hdr\2002_22054606.hdr	22054606	16400	16431	71416.030	-120.632	8094.754	120.486	71421.506	8244.799
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c:\data\hdr\2013_RGB_008_2077.hdr	008_2077	8176	6132	0.000	-166666.667	4089.000	166666.667	0.000	3085.700
c:\data\hdr\2013_RGB_008_2078.hdr	008_2078	8176	6132	0.000	-166666.667	4089.000	166666.667	0.000	3085.700
c:\data\hdr\2013_RGB_008_2079.hdr	008_2079	8176	6132	0.000	-166666.667	4089.000	166666.667	0.000	3085.700
c:\data\hdr\2013_RGB_008_2080.hdr	008_2080	8176	6132	0.000	-166666.667	4089.000	166666.667	0.000	3085.700
c:\data\hdr\2013_RGB_008_2081.hdr	008_2081	8176	6132	0.000	-166666.667	4089.000	166666.667	0.000	3085.700
c:\data\hdr\2013_RGB_008_2082.hdr	008_2082	8176	6132	0.000	-166666.667	4089.000	166666.667	0.000	3085.700
c:\data\hdr\2013_RGB_008_2083.hdr	008_2083	8176	6132	0.000	-166666.667	4089.000	166666.667	0.000	3085.700
c:\data\hdr\2013_RGB_008_2084.hdr	008_2084	8176	6132	0.000	-166666.667	4089.000	166666.667	0.000	3085.700
c:\data\hdr\2013_RGB_008_2085.hdr	008_2085	8176	6132	0.000	-166666.667	4089.000	166666.667	0.000	3085.700
c:\data\hdr\2013_RGB_008_2086.hdr	008_2086	8176	6132	0.000	-166666.667	4089.000	166666.667	0.000	3085.700
c:\data\hdr\2013_RGB_008_2087.hdr	008_2087	8176	6132	0.000	-166666.667	4089.000	166666.667	0.000	3085.700
c:\data\hdr\2013_RGB_008_2088.hdr	008_2088	8176	6132	0.000	-166666.667	4089.000	166666.667	0.000	3085.700
c:\data\hdr\2013_RGB_008_2089.hdr	008_2089	8176	6132	0.000	-166666.667	4089.000	166666.667	0.000	3085.700
c:\data\hdr\2013_RGB_008_2090.hdr	008_2090	8176	6132	0.000	-166666.667	4089.000	166666.667	0.000	3085.700
c:\data\hdr\2013_RGB_008_2091.hdr	008_2091	8176	6132	0.000	-166666.667	4089.000	166666.667	0.000	3085.700
c:\data\hdr\2013_RGB_008_2092.hdr	008_2092	8176	6132	0.000	-166666.667	4089.000	166666.667	0.000	3085.700
c:\data\hdr\2013_RGB_008_2093.hdr	008_2093	8176	6132	0.000	-166666.667	4089.000	166666.667	0.000	3085.700
c:\data\hdr\2013_RGB_008_2094.hdr	008_2094	8176	6132	0.000	-166666.667	4089.000	166666.667	0.000	3085.700
c:\data\hdr\2013_RGB_008_2095.hdr	008_2095	8176	6132	0.000	-166666.667	4089.000	166666.667	0.000	3085.700
c:\data\hdr\2013_RGB_008_2096.hdr	008_2096	8176	6132	0.000	-166666.667	4089.000	166666.667	0.000	3085.700
c:\data\hdr\2013_RGB_008_2097.hdr	008_2097	8176	6132	0.000	-166666.667	4089.000	166666.667	0.000	3085.700
c:\data\hdr\2013_RGB_009_2098.hdr	009_2098	8176	6132	0.000	-166666.667	4089.000	166666.667	0.000	3085.700
c:\data\hdr\2013_RGB_009_2099.hdr	009_2099	8176	6132	0.000	-166666.667	4089.000	166666.667	0.000	3085.700
c:\data\hdr\2013_RGB_009_2100.hdr	009_2100	8176	6132	0.000	-166666.667	4089.000	166666.667	0.000	3085.700
c:\data\hdr\2013_RGB_009_2101.hdr	009_2101	8176	6132	0.000	-166666.667	4089.000	166666.667	0.000	3085.700
c:\data\hdr\2013_RGB_009_2102.hdr	009_2102	8176	6132	0.000	-166666.667	4089.000	166666.667	0.000	3085.700
c:\data\hdr\2013_RGB_009_2103.hdr	009_2103	8176	6132	0.000	-166666.667	4089.000	166666.667	0.000	3085.700
c:\data\hdr\2013_RGB_009_2104.hdr	009_2104	8176	6132	0.000	-166666.667	4089.000	166666.667	0.000	3085.700
c:\data\hdr\2013_RGB_009_2105.hdr	009_2105	8176	6132	0.000	-166666.667	4089.000	166666.667	0.000	3085.700
c:\data\hdr\2013_RGB_009_2106.hdr	009_2106	8176	6132	0.000	-166666.667	4089.000	166666.667	0.000	3085.700
c:\data\hdr\2013_RGB_009_2107.hdr	009_2107	8176	6132	0.000	-166666.667	4089.000	166666.667	0.000	3085.700

Appendix 7. Programs and used by Aarne Hovi 2009–2015

Programs\AarneHovi\

I have used mainly Java, Matlab, and R. Java was used for computationally intensive tasks and IO of binary files. Matlab was mainly for waveform processing and data analysis. R was for statistical analyses.

The Matlab and R codes should run on any system. The Java codes need NetBeans IDE and Java to be installed. Information on configuring your computer and running the Java programs are given in the next Section.

About Java programs

General

The Java programs are all source code, i.e. they are not compiled into .jar files. They were written in NetBeans programming environment. Each program is thus a NetBeans project stored in a project folder that can be opened and the code run through NetBeans. In addition, the user must have Java development kit (JDK) installed.

All the programs documented in the following Sections were tested in a 64-bit Windows7, with NetBeans 8.0.2, and JDK 1.7u79. Some of the programs use external Java packages in addition to JDK. The external packages are always included in the project folder and the NetBeans project is configured to include the external packages in its runtime libraries. Thus the programs should run correctly without any modifications. Programs that have high memory requirements need 64-bit Java. The LiDAR simulator needs 32-bit Java because it uses some external Java packages that are 32-bit.

32-bit Java needed:

- LiDAR simulator

64-bit Java needed:

- Processing raw LiDAR data into hectare files
- Waveform processing for noise-exceeding amplitude sequences and their attributes

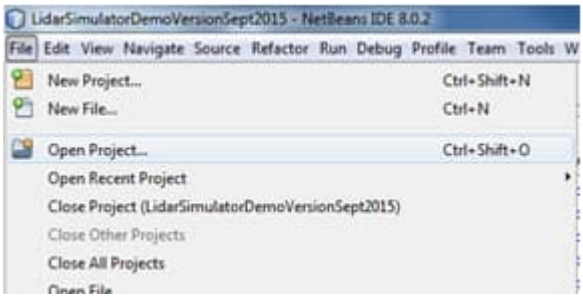
NetBeans 8.0.2 and JDK 1.7u79 (32 and 64-bit) installation packages (standalone installation) are found in:

Java_NetBeans_installation_packages\

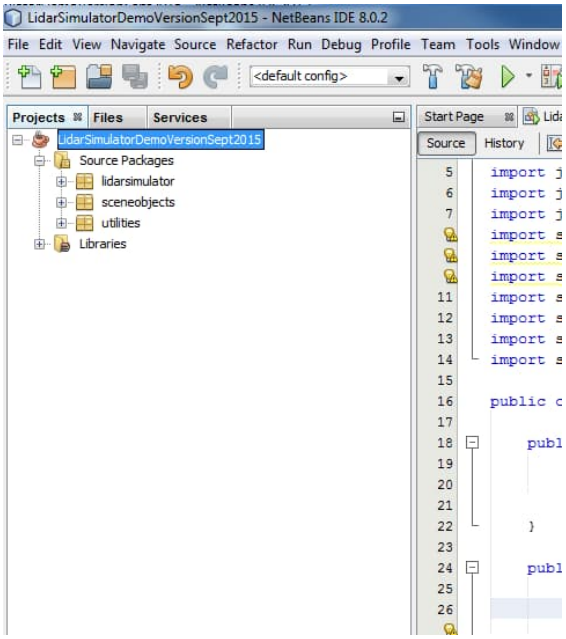
Install first JDK, then NetBeans. NetBeans installation will not succeed if you do not have appropriate version of JDK installed.

Running NetBeans projects

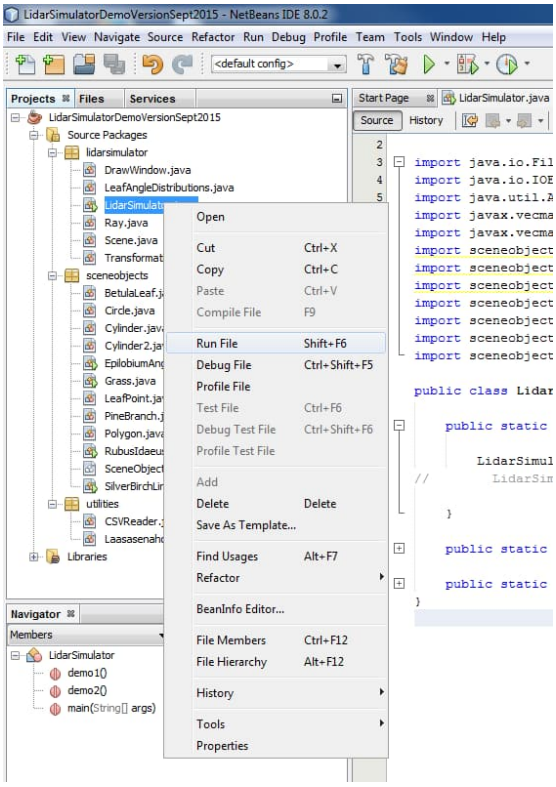
Opening NetBeans project: Choose “File” → “Open project”, navigate to the project folder and choose “Open project”.



The project folder structure is shown on the left hand side panel. It lists all the Java packages and classes included in the project:



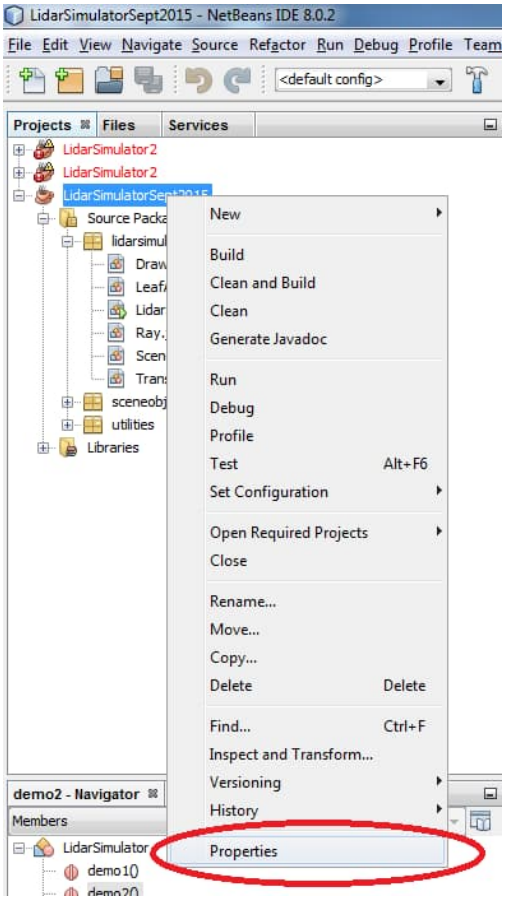
Code can be run by right-clicking the Java class you want to run, and selecting “Run File”:

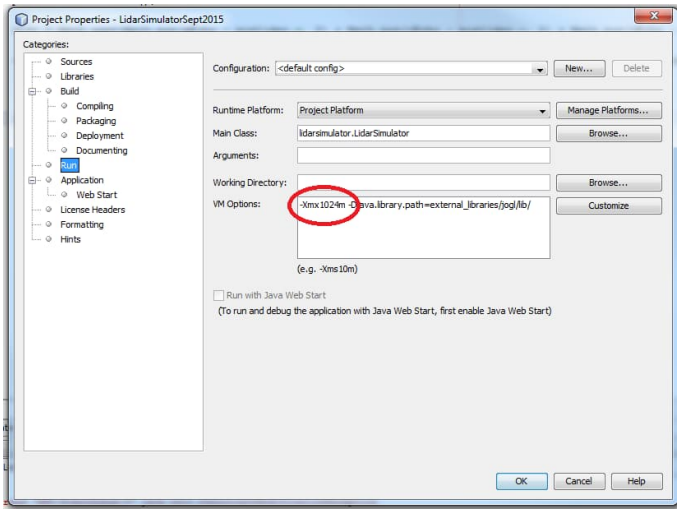


Configuring NetBeans projects

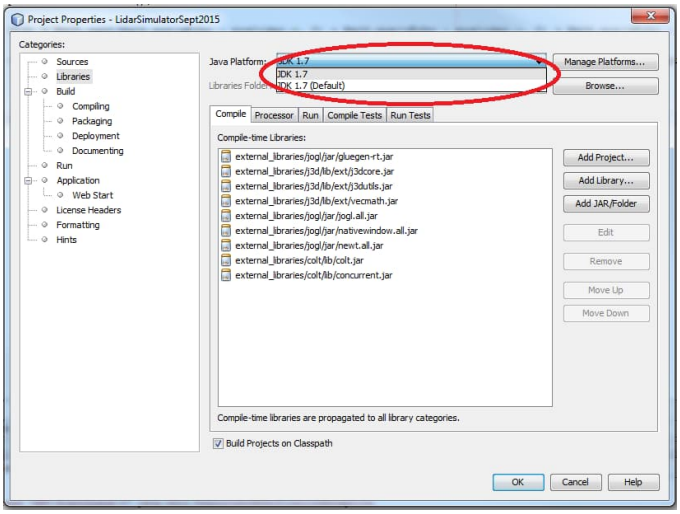
Setting maximum heap size: When the default settings are applied the maximum heap size is limited. For most of the programs to run, particularly those handling large amounts of data in the memory, the maximum heap size must be set higher.

Right-click the project name on the left hand side panel. Choose “Properties” → “Run”. In the “VM Options” panel, add a text “-J-Xmx16000m”, for example. This means that the maximum permitted memory allocated is 16 GB.





Selecting the JDK version to use (32- or 64-bit): Right-click the project name on the left hand side panel. Choose “Properties” → “Libraries”. Select the JDK from the list. If you cannot find the appropriate version, go to “Manage platforms” → “Add platform”.


Project Properties - LidarSimulatorSept2015
Categories:
Sources
Libraries
Build
Compiling
Packaging
Deployment
Documenting
Run
Application
Web Start
License Headers
Formatting
Hints
Java Platform:
JDK 1.7
JDK 1.7
JDK 1.7 (Default)
Manage Platforms...
Browse...
Compile
Processor
Run
Compile Tests
Run Tests
Compile-time Libraries:
external_libraries/jogl/jar/gluegen-rt.jar
external_libraries/j3d/lib/ext/j3dcore.jar
external_libraries/j3d/lib/ext/j3dutils.jar
external_libraries/j3d/lib/ext/vecmath.jar
external_libraries/jogl/jar/jogl.all.jar
external_libraries/jogl/jar/nativewindow.all.jar
external_libraries/jogl/jar/newt.all.jar
external_libraries/colt/lib/colt.jar
external_libraries/colt/lib/concurrent.jar
Add Project...
Add Library...
Add JAR/Folder
Edit
Remove
Move Up
Move Down
Compile-time libraries are propagated to all library categories.
Build Projects on Classpath
OK
Cancel
Help

Program 1 - Processing raw LiDAR data into binary hectare files

This Java program was used to process LiDAR data delivered by FInnmap. The program reads in LiDAR echoes, waveforms, and trajectory data, and constructs LiDAR records which are then written into binary hectare files. A separate version exists for each LiDAR dataset, from 2011a to 2015, because there were small differences in structure of the data (tiled vs. one file per flight line), file format (one big LAS1.3 file vs. separate wdp files to store WF data), etc.. Program versions are found See the LiDAR folders: 2011a\, 2011b,etc.

Common to all datasets was that the data were always delivered both in LAS1.2 (strip-adjusted echoes) and in LAS1.3 (echoes without strip adjustment + waveform data). Trajectory data was also always available. The trajectories were not changed in the strip-adjustment, thus they can be some centimeters off.

TerraMatch that was used in strip adjustment was not able to output LAS1.3, but LAS1.3 is needed to output waveform data. Therefore two separate file formats. The program reads discrete echoes from LAS1.2, one at a time. It then finds the same echo from LAS1.3 file, based on the GPS time. The echo in LAS1.3 has pointer to waveform data, which is also read in. The final product (LiDAR records in the binary hectare file) has DR echoes from LAS1.2, waveform data from LAS1.3, and position of the LiDAR interpolated from trajectory data.

Program 2 - LiDAR simulator

Programs\AarneHovi\Lidar_simulator\

This is the LiDAR simulator written for *Remote Sensing of Environment 140*: 665-678. The theoretical foundations of the simulator are described in that paper.

NetBeans project folder “LidarSimulator” contains all the required code and input files. Open the project in NetBeans and navigate to file “LidarSimulator.java”. LidarSimulator.demo() contains code for running a small demo.

The demo runs in sequential order and calls all the Java classes and methods needed in simulation. The code does following:

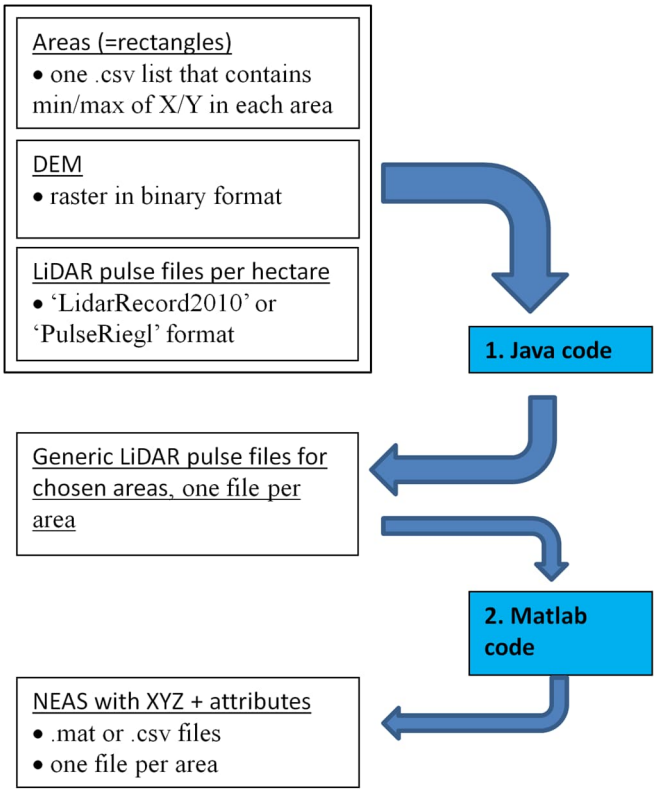
- Initializes a scene in which to place vegetation models. The size of the scene is determined, the scene is partitioned into voxels to speed up calculations, and the position and view direction of the eye (needed in visualizations) are given.
- Reads LiDAR system waveform from a csv file. The csv file can be modified to allow simulation of varying system waveforms.
- Sets the parameters of the constant fraction discriminator that is used to detect discrete echoes from the simulated waveform.
- Sets noise parameters (mean and standard deviation of noise in the waveform).
- Constructs scene objects (two 3-m-high birches and a ground surface) and places them into the scene. The birches are constructed of geometric primitives (cylinders, polygons, truncated cones) that have reflectance and transmittance.
- Performs an OpenGL visualization of the scene. This is optional and can be commented out if not needed.
- Sets the position of the LiDAR sensor and the direction of the LiDAR pulse to be fired into the scene. The pulse direction is determined by giving an approximate estimate of 3D point at which you expect the first LiDAR echo to occur.
- Simulates a LiDAR measurement. This is all done by the method scene.simulatePontLightSource() that doies following:
    - Simulates the target differential scattering cross-section by means of ray tracing. The number of rays per pulse, number of scattering orders simulated, and the beam divergence of the pulse are given in the parameters.
    - Convolves the differential scattering cross-section with the system waveform of the LiDAR.
    - Detects first DR echo from the waveform, using constant fraction discriminator.
    - Prints the position of the LiDAR, the first DR echo, and the waveform into a csv file. Optionally, the target differential scattering cross-section can be outputted into another csv, separately for 1st order scatterinng, 2nd order scattering, 3rd order scattering, etc.
- Makes an animation of the rays fired into the scene. This can be commented out if you do not want to display the animation.

Program 3 - Waveform processing for noise-exceeding amplitude sequences and their attributes

Programs\AarneHovi\WF_feature_extraction\

General workflow

The processing is done for rectangular areas that can be of any size. The data for the area are first read from per hectare BIN files and written into binary files in which the pulses are in a so called 'generic pulse format' i.e. the format is the same independent of the sensor (Leica or Riegl waveform data). Reading of per hectare binaries and writing into generic format is done with Java code. The files in generic format are then read into Matlab and processed to noise-exceeding amplitude sequences (NEAS) with XYZ and other attributes.



Step 1. Java code: Extracting LiDAR pulses for the areas

The program is in NetBeans project LidarProcessingJava/.

The following Java function contains the main calculation routine in sequential order:

- LidarProcessingJava/SourcePackages/main/Main lidarDataExtractionForRectangularAreas()

The function does the following:

- Reads .csv file that contains the extent (min/max X and Y) of the rectangles and the maximum tree height within the area. Note that in the code the areas are called "plot clusters" or "clusters"
- Reads in LiDAR pulses for the areas from the per hectare binary files. A buffer is added around each area. It accounts for the maximum tree height and maximum scan angle and ensures that all the pulses are included that had intersected the trees at the edge of the area. N.B. Every dataset has its own code for processing. It is done in a large IF-block, which is inside a loop that runs through all areas.
- Prints out binary files (one per each area and per each LiDAR dataset) that contain pulses in generic format. Alternatively, csv files containing DR echoes only can be outputted. Too high echoes (H>45 m) are filtered out in the process. N.B. output in generic pulse format is possible for 2010 and newer LiDAR data, and output in csv is possible for all LiDAR datasets starting from 2004.

Step 2. Matlab code: Processing WF data

Matlab codes are located in folder NEAS_extraction_Matlab\

There is one main routine "standwise_processing.m" that runs in sequential order and calls the necessary functions. It does the following:

- Reads in raster DEM in EstriGrid ascii format (https://en.wikipedia.org/wiki/Esri_grid). Optionally you can read also a raster containing tree segments. This is needed if you want to label NEASs with segment ID.
- Reads in filenames of the input files containing LiDAR pulses (binary generic pulse format), and of the outputfiles containing NEASs (.mat and/or .csv). The working directory is set in the beginning and all the files are assumed to be located in the working directory.
- Loops through all the input files (per area). For each file
    - Calls function "genericWfRead3.m" that reads the file
    - Calls either dunction "wfProcessEntireFile.m" or "wfProcessEntireFile2".m" that does the waveform processing and outputs NEASs in different formats.
    - Searches height from ground for each NEAS. Optionally searches also the tree segment ID for each NEAS.
    - Outputs NEASs in .mat or .csv

Description of generic pulse format

Pulse format is designed to handle waveform LiDAR data. The format is designed so that there can be pulses with arbitrary many DR echoes and waveform sample blocks. Also the size of the waveform sample block can be variable. The idea was that the file format is the same for both Riegl and Leica waveform data.

In the beginning of the file there are four attributes:

int64	(file pointer index 0) number of pulses in the file
int8	(file pointer index 8) maximum number of echoes in a pulse
int8	(file pointer index 9) maximum number of waveform blocks in a pulse
int8	(file pointer index 10) maximum number of waveform blocks in a pulse

The rest of the file, starting from file pointer index 11, contains LiDAR pulses. Each pulse has following attributes:

GenericWFPulse

poslidar.x	float64	X of the LiDAR sensor
poslidar.y	float64	Y of the LiDAR sensor
poslidar.z	float64	Z of the LiDAR sensor
agc	uint8	AGC recording (for Leica ALS50-ii/ALS60 only)
drEchoCount	int8	Number of DR echoes in the pulse
Echoes (1 to drEchoCount)	EchoXYZI	DR echoes
wfSampletype	int8	1 = Unsigned byte, 2 = Unsigned short
wfSamplerate	int8	Waveform sample rate in nanoseconds
wfBlockCount	int8	Number of waveform blocks in the pulse
wfBlockSize (1 to wfBlockCount)	int16	Number of samples in each waveform block
wfBlockRange (1 to wfBlockCount)	float64	Range [m] where each waveform block starts
Waveform blocks (1 to wfBlockCount)	uint8[]/uint16[]	Waveform sample blocks, they are written sequentially, from first to last. The waveform samples are stored either as uint8 or uint16, depending on whether the data is from Leica or Riegl sensor.

EchoXYZI

x	float64
y	float64
z	float64
intensity	float64

Program 4 - Random forest classification

Programs\AarneHovi\RF_classifications\

This is a sample R code for running Random Forest classification. The R code is commented. Follow the instructions in the code. The folder contains a sample tree set that has LiDAR waveform features ('MD trees' used in Hovi et al. RSE 2015, LiDAR features computed from 2011 800m LiDAR data).