P-05-223

Oskarshamn site investigation

Aerial photography and airborne laser scanning Laxemar – Simpevarp

The 2005 campaign

Mats Nyborg, SwedPower AB

December 2005

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Abstract

This document reports the data gained by the 2005 aerial photography and airborne laser scanning campaign of the Laxemar – Simpevarp area, which is one of the activities performed within the site investigation at Oskarshamn.

The objective of the work was to

i) acquire aerial photographs from low flying altitude for the area in question,

ii) acquire extremely detailed data on terrain height using airborne laser scanning technique,

iii) using the aerial photographs to produce a digital mosaic of orthophotos of the area in question with a pixel size of 10 cm,

iv) using the ranging data from the laser to produce a high resolution continuous digital terrain model of the area in question.

In this report the methodology and processing together with quality assessments of aerial photography and LIDAR technique is presented.

Sammanfattning

SKB bedriver platsundersökning för ett framtida djupförvar för använt kärnbränsle i Oskarshamn. Undersökningarnas genomförande styrs i grunden av ett generellt program /SKB 2001a/ och platsspecifika program för Oskarshamn /SKB 2001b, 2004/. Mer detaljerad styrning av undersökningarnas genomförande och omfattning ges i projektplanen för platsundersökning i Oskarshamn. Föreliggande aktivitet tillhör WBS-nummer 1.1.2.10 i projektets operativa struktur.

Aktiviteten omfattar flygmätning med laserskanning (LIDAR) och flygfotografering över delområde Laxemar och delar av Simpevarp, se Figure 1-1. Aktiviteten har resulterat i en högupplöst terrängmodell baserad på laserdatat, orienterade flygbilder fotogrammetrisk bildtolkning och ortofoto i färg. Dessa resultat utgör tillsammans med markgeofysiska mätresultat ett detaljerat underlag för analys och beskrivning av bergmassans spröda strukturer mellan större deformationszoner. Materialet skall i ett första steg användas för fokusering i Laxemar (sommaren 2005) och därefter i den fortsatta platsmodelleringen. Det begränsade området över Simpevarp är också avsett för kommunens planarbete.

Contents

1 Introduction

This document reports the data gained by the 2005 aerial photography and airborne laser scanning campaign of the Laxemar – Simpevarp area, which is one of the activities performed within the site investigation at Oskarshamn. The work was carried out in accordance to activity plan SKB AP PS 400-05-035. In Table 1-1 are all controlling documents for performing this activity listed. Both activity plan and method descriptions are SKB's internal controlling documents.

All data acquisition and processing was carried out by Swedpower AB, Sweden and BlomInfo AB, Sweden, during the spring of 2005. SwedPower AB also performed project coordination and guidance.

The primary purpose of the work was to produce terrain information for detailed lineament detection to further enhance previous work on lineament analysis. The study area is shown in Figure 1-1.

The data produced comprise topographic data as airborne-borne LIDAR data, a terrain model at 0.25 m spatial resolution, and aerial photographs as orthoimagery at 0.1 m spatial resolution.

The work was carried out in different stages. First, raw data were acquired in April 2005. Following this, each data set was processed separately producing method-specific terrain information. The third stage, which involved SwedPower in reference to data processing, involved the compilation of the LIDAR data into a high-resolution terrain model. This stage in the procedure aimed specifically to produce data suitable for further lineament studies.

Table 1-1. Controlling documents for the performance of the activity.

Activity Plan	Number	Version
Flygmätningar med laserskanning och flygfotografering, 2005.	AP PS 400-05-035	1.0

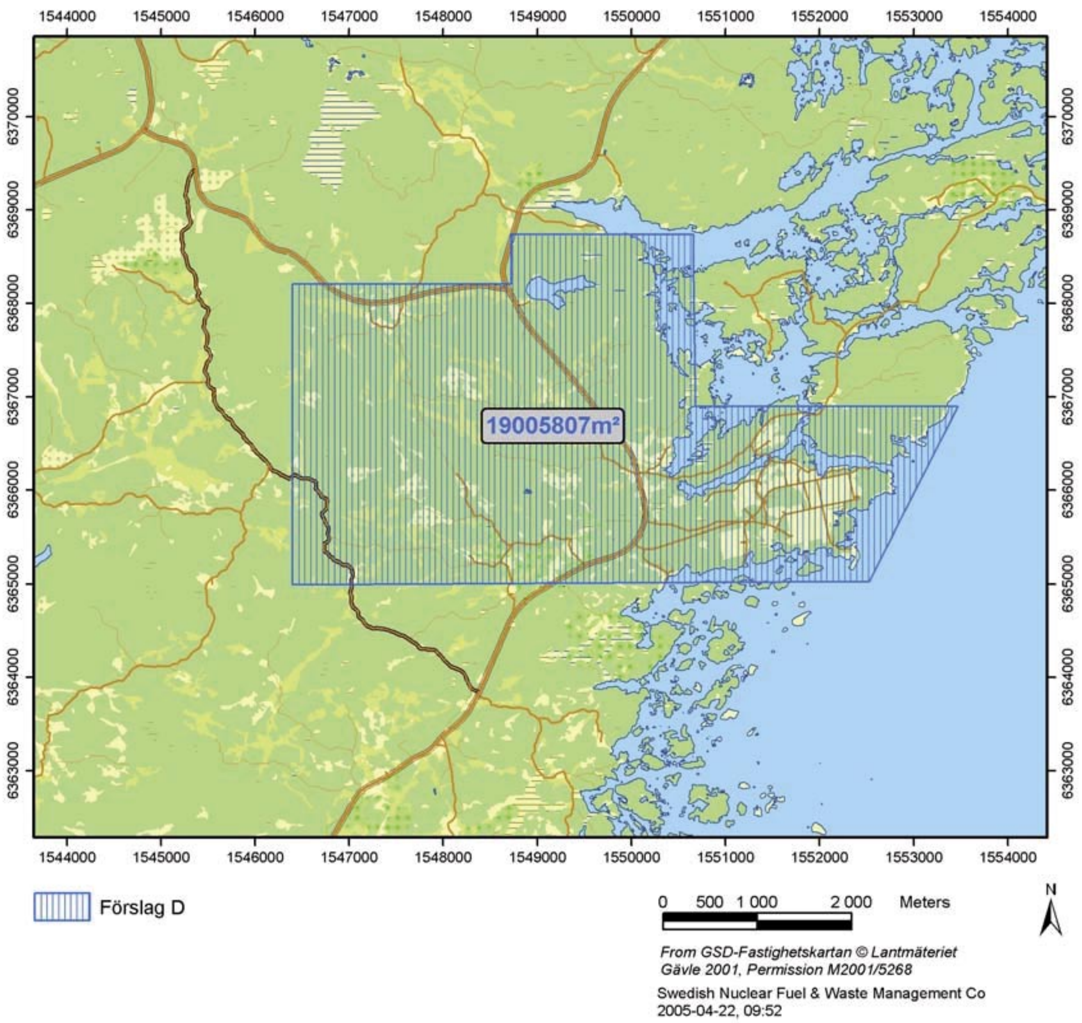

Figure 1-1. *Map showing the inventory area. The area comprises about 19 km².*

2 Objective and scope

Lineaments are line features or patterns on earth's surface that reflect geological structure. To detect and quantify properties regarding lineaments is an important part of the SKB site investigation program since they may trace deformation zones in the bedrock. Referring to SKB Method Description for Lineament Analysis /SKB 2001c/, two data sources may serve as major input for lineament detection and analysis as complement to other geological and geophysical data.

- Optical imagery (satellite imagery or aerial imagery) for visual interpretation and ground texturing.
- Terrain models for topographical interpretation and ground texturing.

Upcoming work on detailed lineament analysis within the Oskarshamn area will focus at a scale where already available terrain models and aerial imagery /Wiklund, 2002/ cannot meet requirements regarding resolution and accuracy. In order to meet these new requirements the objective of this present work was to

v) acquire aerial photographs from low flying altitude for the area in question,

vi) acquire extremely detailed data on terrain height using airborne laser scanning technique,

vii) using the aerial photographs to produce a digital mosaic of orthophotos of the area in question with a pixel size of 10 cm,

viii) using the ranging data from the laser to produce a high resolution continuous digital terrain model of the area in question.

In this report the methodology and processing together with quality assessments of aerial photography and LIDAR technique is presented.

2.1 Terminology

An orthophoto is an aerial photograph with constant scale all over the image area. In a perspective image i.e an uncorrected aerial photograph, objects closer to the camera are depicted with a larger scale than distant objects. These differences are eliminated in orthophotos by reprojecting the imagery, using a digital elevation model.

Light Detection and Ranging (LIDAR) is a scanning and ranging laser system that determines the range of the terrain from the instrument. The instrument is in this case mounted in a small airplane. This elevation data is generated at the rate of thousands of measurement points per second, with absolute vertical accuracies of up to 10 cm. After hitting the tree-canopy the laser beam finds a hole between the foliage and reaches the ground. The returns are registered and a dataset is created instantly.

3 Equipment

3.1 Description of equipment

All acquisition of data was performed under the supervision of SwedPower AB, Sweden, and BlomInfo AB, Sweden.

Blom Geomatics AS, Norway carried out the LIDAR capture including all sub processing of the laser data to discrete data points. FM-Kartta Oy, Finland, was subcontracted for the aerial photography mission and the processing of the uncorrected imagery to orthoimagery.

FM-Kartta Oy and Blom Geomatics AS both have permission to operate aerial photography and laserscanning in Sweden. The Swedish Civil Aviation Authority has issued relevant permissions valid for mapping purposes in Sweden.

The LIDAR flight was flown with a Piper Navajo PA 310 airplane (NL-AEY). The laser used was an Optech ALTM3100 (www.optech.ca). The Inertial Measurement Unit (IMU) used onboard the airplane was a Litton LN-200 A1 (www.ngnavsys.com). The GPS used was an Ashtech Z-Surveyor 2-frequency receiver (www.ashtech.com).

The aerial imagery was acquired with the same type of airplane as the LIDAR acquisition (NL-NAB). The camera used was a Leica RC30 equipped with a 153 mm lens (camera id#13311).

The aerial triangulation was made using the Match-AT software (INPHO GmbH – www.inpho.de). Orthorectification and mosaicing was performed using the OrthoBox software (INPHO GmbH – www.inpho.de).

Processing of LIDAR data was made using the TerraScan 2.20 software with support of Terrasolid/Terramodel/TerraMatch (Terrasolid Oy, Finland – www.terrasolid.fi).

Transformations related to projection parameters have been performed using the Gtrans 3.51 software package (www.lantmateriet.se).

4 Execution

Light Detection and Ranging (LIDAR) is a scanning and ranging laser system that basically determines the range of the terrain or the target from the instrument. Laser radar depends on knowing the speed of light, approximately 0.3 m per nanosecond. Using that, it is possible to calculate how far a returning light has travelled to and from an object. Airborne laser mapping use a combination of three technologies; a laser rangefinder (LIDAR), a highly accurate inertial reference systems (INS), and the global positioning satellite system (GPS). By integrating these subsystems in to a single instrument mounted in a small aeroplane, it is possible to rapidly produce accurate digital topographic maps of the terrain beneath the flight path of the aircraft.

The laser scanner is mounted (in this case) in an aircraft and emits infrared laser beams at a high frequency. The scanner records the difference in time between the emission of the laser pulses and the reception of the reflected signal. A mirror is mounted in front of the laser. The mirror rotates and causes the laser pulses to sweep at an angle, back and forth along a line. The position and orientation of the aircraft is determined using a phase differenced kinematic GPS. A GPS is located in the aircraft and several ground stations (differential GPS) are located within the area to be mapped. The orientation of the aircraft is controlled and determined by the INS. The round trip travel times of the laser pulses, from the aircraft to the ground, are measured and recorded along with the position and orientation of the aircraft at the time of the transmission of each pulse. The GPS provides the coordinates of the laser system at the time the pulses are sent and the INS system basically determines the ω,Φ,κ i.e. the aircraft tilt. After the flight the vectors from the aircraft to the ground are combined with the aircraft position at the time of each measurement and the three dimensional X, Y, Z coordinates of each ground point are computed.

A very useful feature in LIDAR ranging is the availability of multiple returns. Because the frequency of the pulses the LIDAR sends out is often in the vicinity of 100,000 pulses per second, multiple returns from the same direction is possible. The laser spot sometimes hits more than one object on its trek to the ground. For example, it may pass through a vegetation canopy, touching leaves or branches before finding its way to the ground. LIDAR systems are typically capable of delivering just the “last return” when we only need data on the ground surface. When data about tree and/or vegetation heights is required, then we can simultaneously collect all “first returns.” Providing both sets of data, as in this case, allows users to view areas both with and without the existing vegetation, without having to fly projects twice.

Classification of laser data is an important processing step towards feature extraction, tree identification and 3D reconstruction. The last return is regarded to indicate ground level. In reference to present work, the laser data cloud has only been classified into ground points and non-ground points. The ground points constitute a basic class for which classification is straightforward when correctly interpreted. All points that are close to (i.e. within a given range) the surface given by the lowest terrain height are classified as ground points. Care need to be taken when analysing data related to local depressions such as trenches etc. The remaining data can be further classified as e.g. buildings, vegetation, power lines etc.

4.1 Data acquisition

4.1.1 The LIDAR acquistion

The LIDAR flight was flown on April 23, 2005, with a Piper Navajo PA 310 airplane. The weather conditions were very good. The flight altitude was approximately 900 m above ground (see table below). Flight lines were in both north-south and east-west directions and separated with a distance that resulted in a number of overlaps for the same area.

As with any LIDAR system, the accuracy of range measurements decline from nadir to the outside edge of the scan line. The greater the sensor's Field of View (FOV), the greater amount of error is present. To meet the requirements of a high accuracy, the sensor field of view have therefore been limited to 17-degrees (half angle). For dense ground cover, vegetation, the flying altitude is low with a smaller FOV and a higher scan frequency. This provides denser data, a smaller laser footprint for canopy penetration (more energy per unit area) while maximizing the likelihood of laser pulses reaching the ground.

The overall accuracy of the LIDAR data will generally be a function of the system calibration, flight parameters, atmospheric conditions, and GPS satellite constellation during the actual data acquisition.

Table 4-1. LIDAR acquisition parameters.

Altitude	900 m
Laser pulse frequency	100,000 Hz
Scanner frequency	58 Hz
Half scanning angle	17
Number of strips	52
Elevation accuracy	< 15 cm; 1 sigma
Speed	75 m/s

4.1.2 The aerial imagery acquisition

The aerial imagery was acquired on April 27, 2005, with a Piper Navajo PA 310 airplane (NL-NAB). The weather conditions were excellent. The flight altitude was approximately 1,000 m above ground (see table below). Approximate image scale was 1:6,700. Flying direction was east-west with an overlap between imagery in flying direction corresponding to 60% and a sidelap of 30%. Each photo has an approximate coverage of 1,500 m × 1,500 m.

Please find camera calibration protocol attached in Appendix 3.

Table 4-2. Aerial photography acquisition.

Altitude	1,000 m
Camera constant	0.153 m
Film	Colour
Number of strips	4
Number of horizontal GCP support	20
Number of vertical GCP support	20
Number of exposures	47

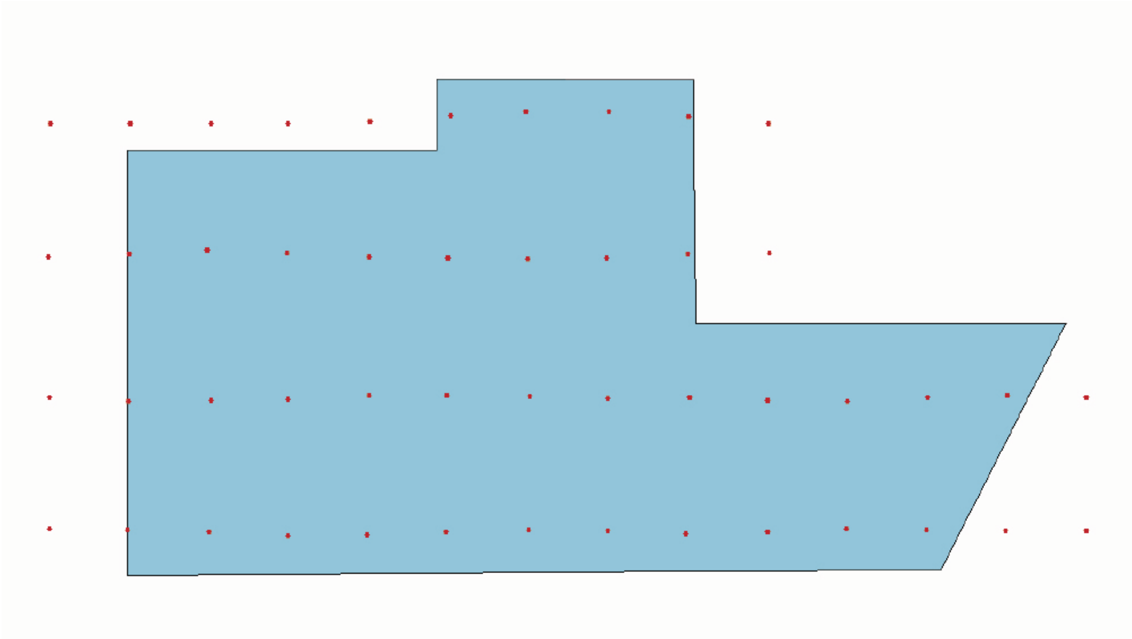

Figure 4-1. The position of each camera exposure as sampled by the in-flight GPS system.

Figure 4-2. The aerial photography photoindex.

4.2 Execution of field work

On April 25, 2005 ground control checkpoints was measured by the consultant company Geocon AB. Measurements was conducted both for the acquisition of aerial imagery and for the LIDAR data collection.

The distribution of control points (GCP) in reference to the aerial photography is visualised in Figure 4-3. Each GCP have been signalled using a 0.40-m wide wooden board painted in white colour.

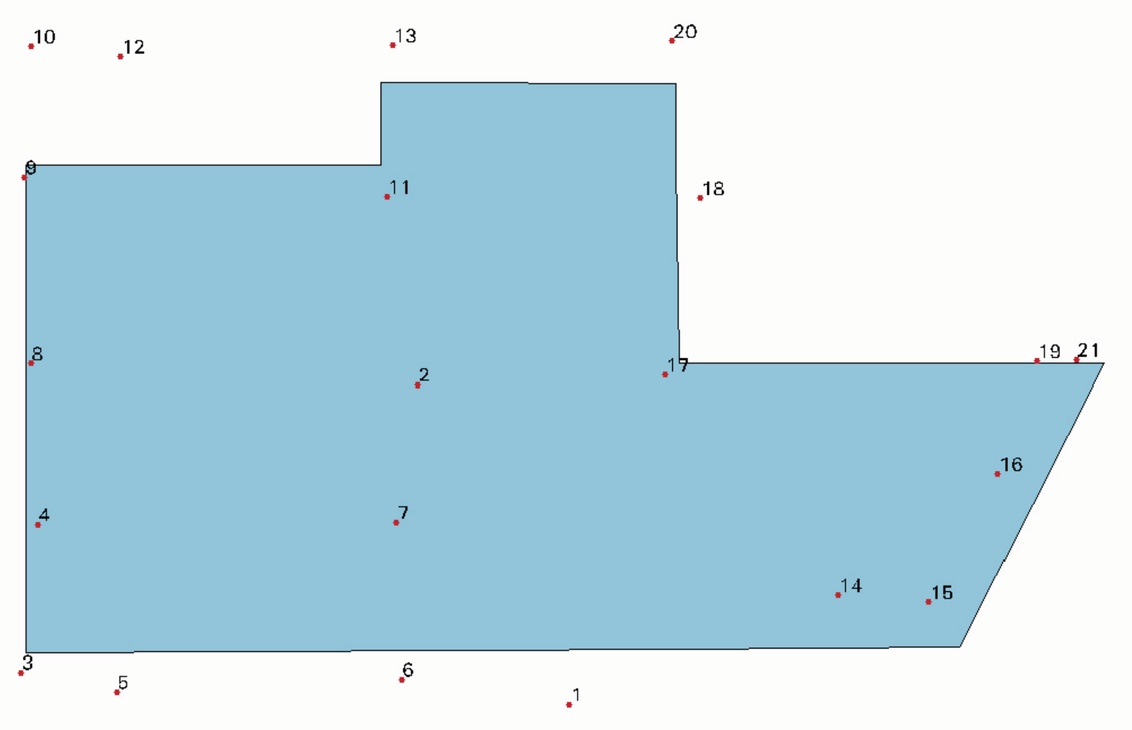

Figure 4-3. Position of signals for aerial photography. Red dot indicate position of signal. The numbering is in accordance to Table 4-3 below.

The distribution of calibration measurements regarding the LIDAR acquisition is presented in Figure 4-4.

Table 4-3. List of ground control points in reference to aerial photography.

Name	Northing	Easting	Elevation	Feature code
1	6364662.316	1549971.58	–0.183	GCP
2	6366755.794	1548977.278	13.531	GCP
3	6364871.714	1546374.419	17.197	GCP
4	6365839.996	1546484.744	7.03	GCP
5	6364744.044	1547003.499	9.287	GCP
6	6364826.278	1548871.874	6.509	GCP
7	6365854.828	1548839.134	13.919	GCP
8	6366891.118	1546438.885	24.873	GCP
9	6368120.567	1546397.22	16.668	GCP
10	6368975.868	1546439.444	11.65	GCP
11	6367992.463	1548774.67	9.322	GCP
12	6368907.975	1547030.378	16.834	GCP
13	6368980.596	1548811.658	3.336	GCP
14	6365374.894	1551728.038	0.75	GCP
15	6365326.026	1552329.168	2.015	GCP
16	6366172.658	1552779.373	1.399	GCP
17	6366817.532	1550597.553	0.587	GCP
18	6367980.752	1550830.287	0.432	GCP
19	6366908.324	1553031.654	5.954	GCP
20	6369008.005	1550648.622	3.981	GCP
21	6366917.409	1553290.883	4.187	GCP

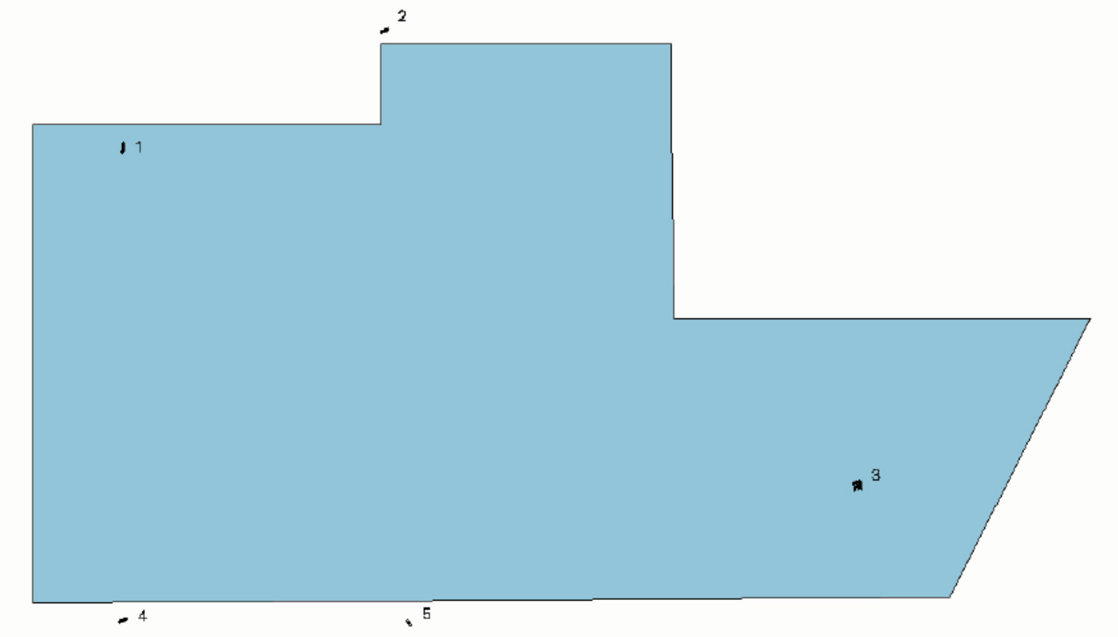

Figure 4-4. *Positions of calibration measurements during field work in reference to the LIDAR acquisitions. The locations 1, 2, 4 and 5 are measurements along profiles. The approximate length of each profile is 50 m. The number 3 location is located in a flat area where calibration measurements have been conducted on a grid basis. The size of the grid is 50 m × 50 m and contains 19 measurements.*

Mismatch between the survey data and LIDAR data can generally be attributed to either misalignments to either the inertial measurements or scanner offset or scale factors. Systematic error within the airborne GPS aircraft trajectory occasionally occurs and generally involves a vertical shift in the solution. In addition to an initial formal system calibration, field quality control measurements have been employed to verify the system pitch, roll, heading, scale, and offset calibration. Corrections for the IMU, pitch, roll, heading, and offset have been calculated and applied to the data to correct for the misalignments. By analyzing the flights over the open flat area, adjustments have been applied to the calibrated scale factor.

The ground control checkpoints were imported over the LIDAR flights to verify that the scanned data fits the terrain. After corrections the LIDAR data have been reprocessed and verified to be in calibration. For the final product, the mean difference between flight data and survey data is 0.001 m with an associated standard deviation of 0.068 m.

A detailed report regarding the LIDAR calibration results has been added in Appendix 2.

4.3 Data handling/post processing

4.3.1 The processing of aerial imagery to orthophoto

The workflow of aerial photography can be summarized in three steps; image acquisition, photogrammetric processing, and product output (HMK-FO).

The aerial film must be scanned to create a digital image. Once scanned, the digital image can be imported into a digital photogrammetric system. Obtaining the optimal pixel size (or scanning density) is often a trade-off between capturing maximum image information and the digital storage burden. Within this work the aerial film was scanned using 14 microns, which results in a file size with approx 16,400 rows and 16,400 columns (for each photograph). With 24 bits per pixel and no image compression, this file occupies about 800 megabytes. There were 47 exposures during flight, which gives total amount of scanned image data to approx 37.6 gigabyte. Triangulation establishes the geometry of the camera relative to objects on the ground. Figure 4-6 illustrates the triangulation workflow.

The interior orientation establishes the geometry inside the camera or sensor. For aerial photographs, fiducial marks are measured on the digital imagery and camera calibration information is entered. The final step is to calculate the exterior orientation, which establishes the location and attitude (rotation angles) of the camera during the time of image acquisition. Ground control points aid this process.

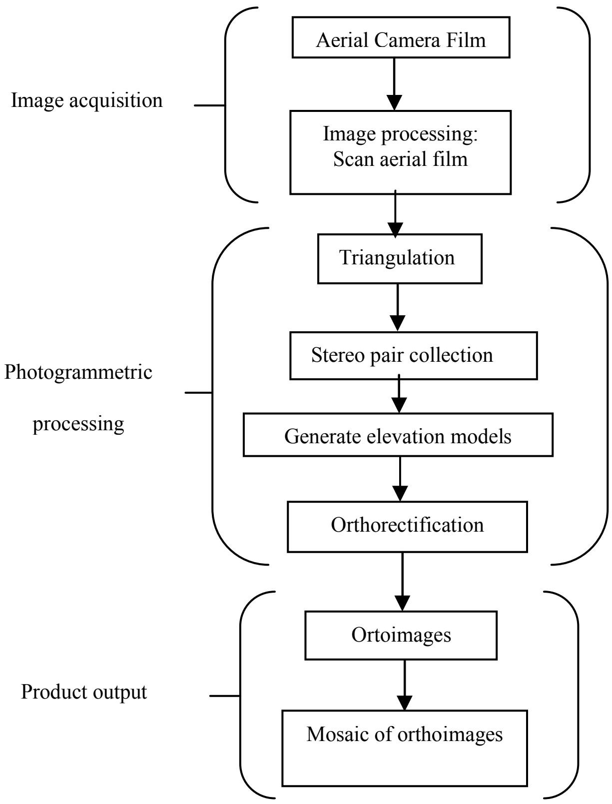

Figure 4-5. *The workflow of aerial photography.*

An image with an orthographic projection is one for which every point looks as if an observer were looking straight down at it, along a line of sight that is orthogonal (perpendicular) to the ground. Orthorectification takes the raw digital image and applies an elevation model (DTM) and triangulation results to create an orthoimage (Figure 4-7).

Once created the digital imagery are colour and contrasted balanced and finally mosaicked with adjacent orthoimages to form the final product output.

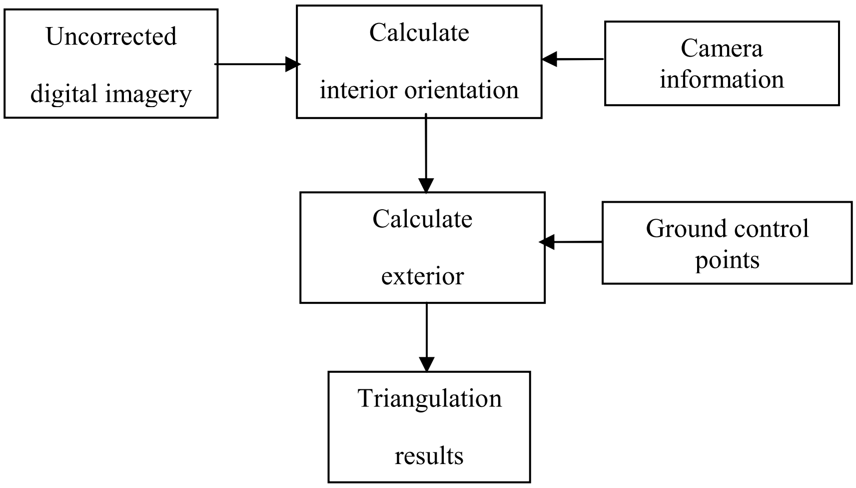

Figure 4-6. *The triangulation workflow.*

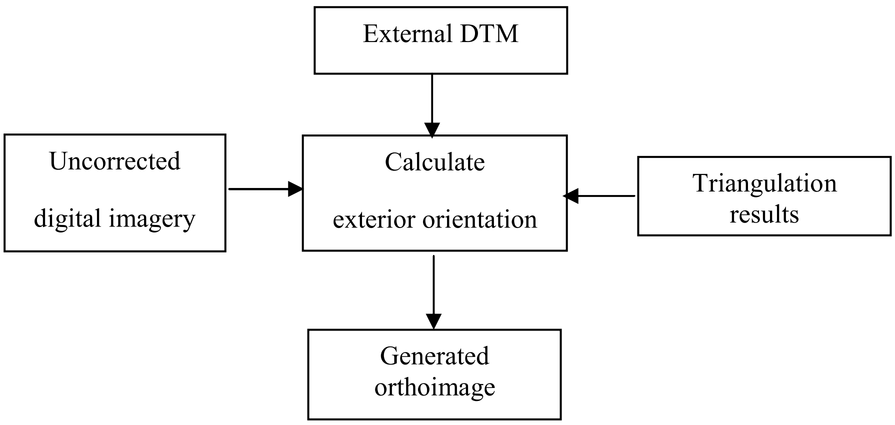

Figure 4-7. *Orthorectification work flow.*

4.3.2 The processing of LIDAR data to a terrain model

The derived LIDAR data are to be considered as discrete data points. Hence, not forming a continuous dataset. A digital elevation model (DEM) is a continuous dataset, a grid or raster in the northing/easting plane. To each raster point (pixel), there is a height attached.

Different types of grids or "images" can be produced depending on the selection of value for the cells. The nearest neighbour method is useful for converting regularly spaced, or almost regularly spaced X,Y,Z data to a grid file. Since the laser data cloud lie on a nearly complete grid with few missing holes, this method is useful for filling in the holes.

Resampling to a continuous terrain model have been done by direct insertion of laser data in the cells of a grid structure and post-process the grid in order to fill empty cells using a nearest neighbour technique. In nearest neighbour, essentially each grid cell of estimation becomes equal in value to its nearest neighbour. In this work we have used a grid with cell size of 0.25 m × 0.25 m. The 0.25 m resolution was chosen because it gave an expected frequency of at least one measurement per cell assuming that the laser measurements were evenly distributed over the field plot. Another reason the gridsize chosen was the diameter of the laser beam.

In addition to terrain elevation modern LIDAR systems usually also measure the "intensity" of the reflected laser pulse, see Figure 4-8. The intensity means the power density within the laser pulse. As the beam widens with distance and due to attenuation of the light in the atmosphere, power density decreases with distance. This information may be used to produce a monochromatic "intensity image" of the survey area. The intensity image will typically resemble a panchromatic aerial photograph. The intensity data constitute an excellent source of additional information that together with the elevation data provides good input to feature extraction and 3D reconstruction tasks.

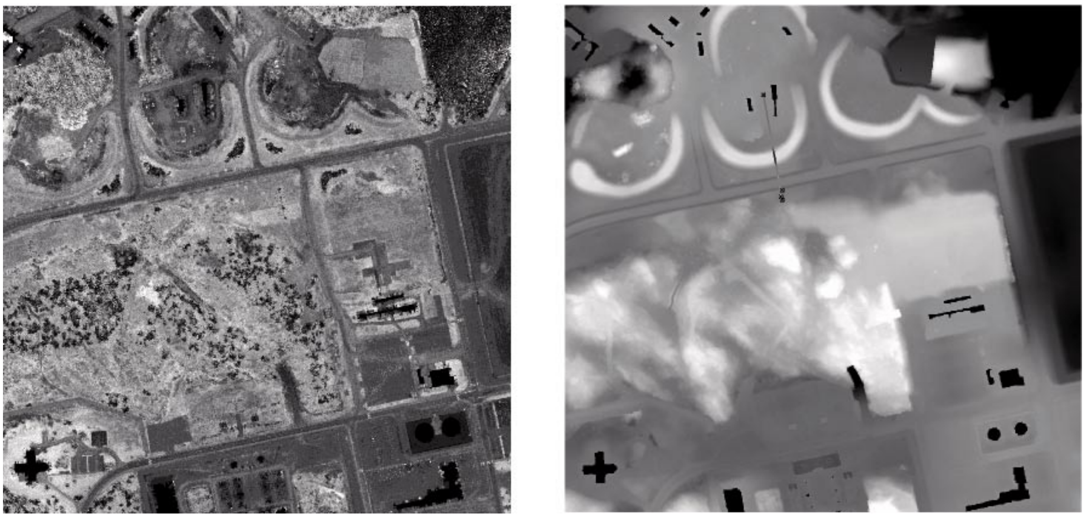

Figure 4-8. *To the left a LIDAR intensity image is viewed, the corresponding terrain model is viewed to the right.*

4.4 Analyses

4.4.1 LIDAR data

Point cloud density

One expectation of the LIDAR ranging measurements was the possibility to derive a continuous coverage of ground data not only for open areas but also in forested areas. The number of measurements per area unit to reach ground have therefore been analysed for different land cover conditions.

A simple land cover classification has been performed using the derived orthophotos, delineating the study area into two main classes (1) areas dominated by open conditions (2) areas dominated by forest conditions. A third class was also produced, because of shadowing effects within the imagery. The shadows normally indicate open conditions, ie. it may be regarded as an extension of the open land cover class. An example of this classification is shown in Figure 4-9.

The density of LIDAR measurements has been calculated on basis of number of data point per square meter.

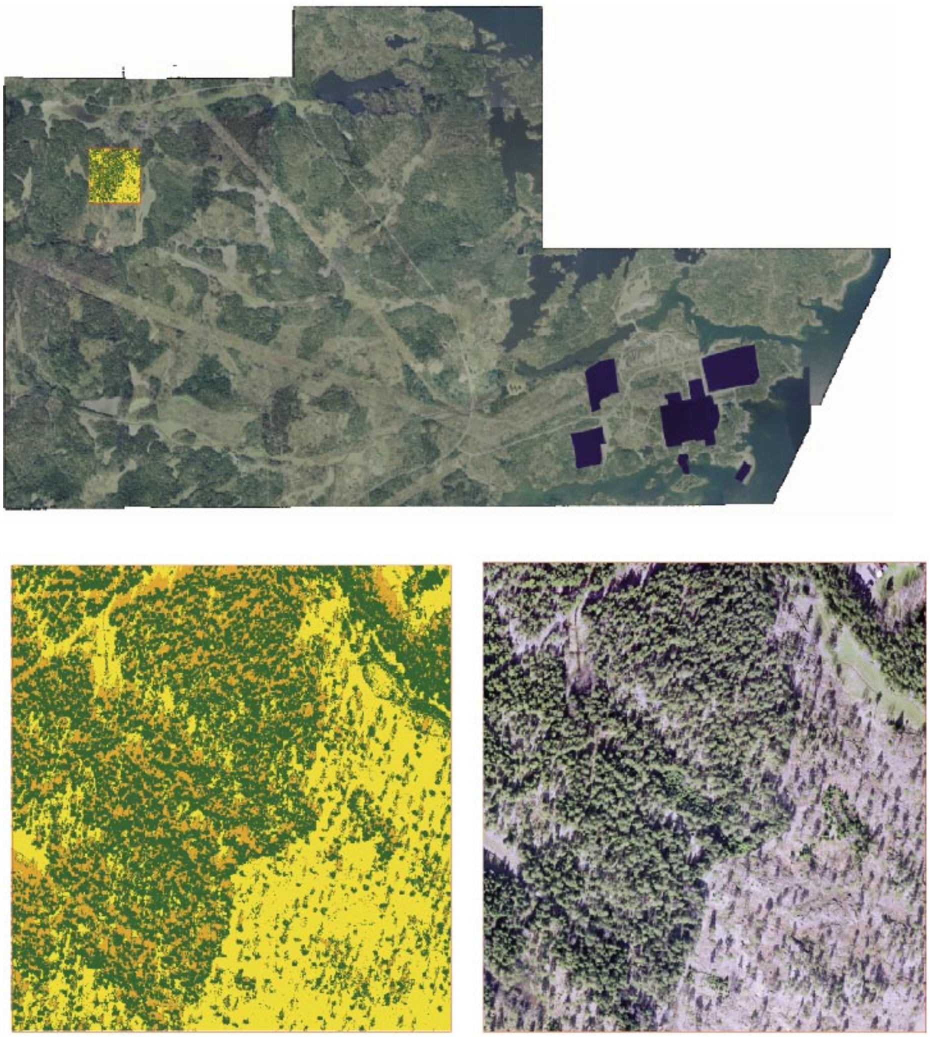

Figure 4-9. *A classified orthophoto is shown to the lower left. The greenish colour indicates areas mainly forested. Yellow colour indicate open conditions, while brownish colour indicate shadowed areas considered as mostly open. The image in the lower right is the true-colour orthoimage of the same area.*

Table 4-4. Number of data point per square meter.

Open conditions	5.8 points per m^2
Forested conditions	2.9 points per m^2

In Figure 4-11 a plot of the distance of separation between each sample to its closest neighbour sample is viewed. All pairs of sample measurements have been counted and classified into groups dependent on the distance between the samples. Please note that already at distances less than 0.5 m an extreme amount of data pairs are present. This indicates the very high density of data points within the LIDAR data cloud.

Point terrain height representativity

Two important questions regarding the data needs to be answered as part of a quality check,

- Does the acquired height data resolve major elements of the terrain i.e. from a statistical point of view; is there a remaining variability at a scale smaller than that of the sampling distance?
- Does the data show a reasonable spatial continuity?

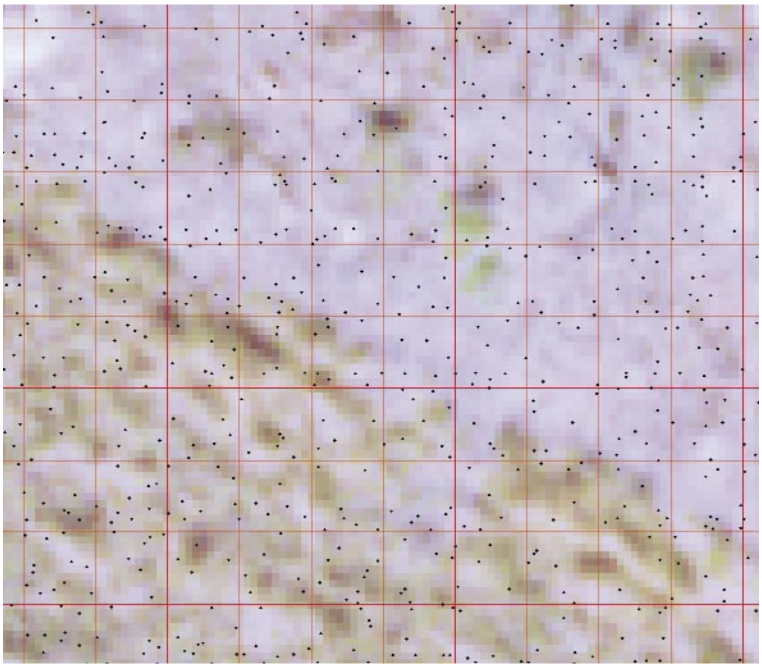

Figure 4-10. *The LIDAR data cloud for an open area. The small black dots represents measurements classified as ground hits. The superimposed grid (in red) has a size of 1 m × 1 m. The number of measurements per square meter may directly be appreciated. The image in the background is a part of the produced 10 cm orthophoto.*

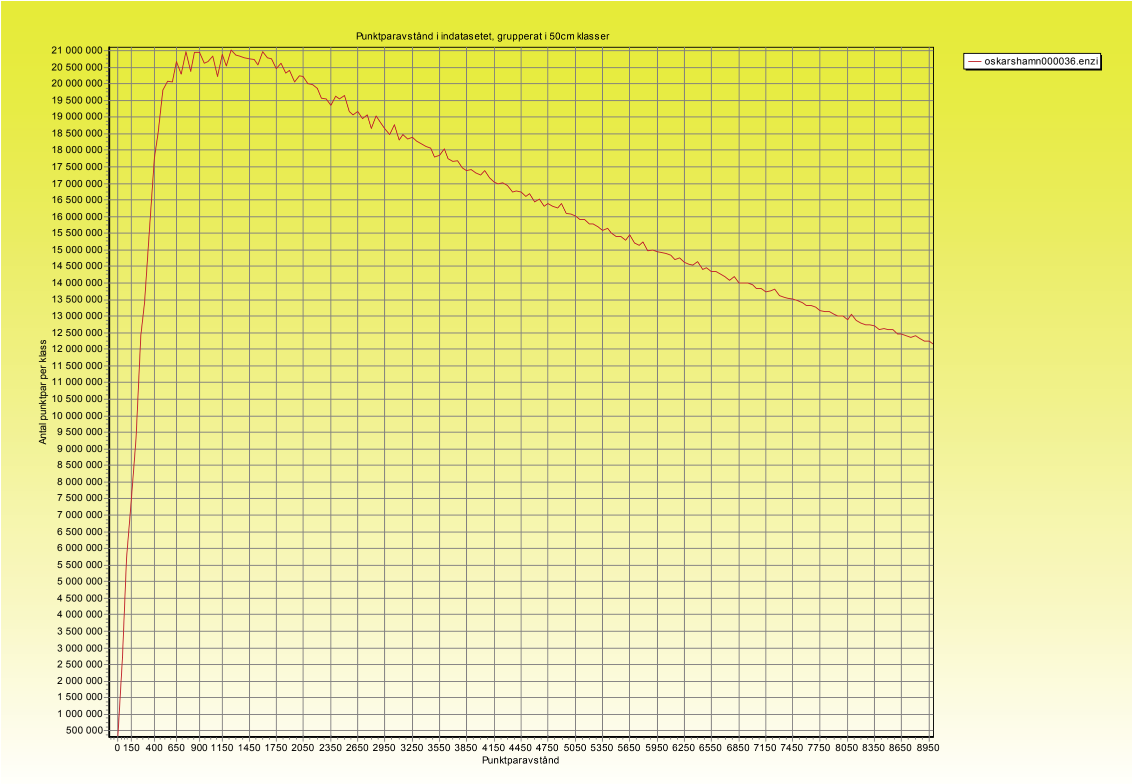

Figure 4-11. *In the drawing above the number of pairs of data have been plotted against the distance of separation between points. Y-axis represents the number of pairs found within a specific distance interval and the X-axis represents distance in centimetres. The input data to this plot represents a sub sample of the complete dataset and comprise 2,013,768 data points.*

First we need to emphasize some additional practical matters about laserscanning. The size of projection of the laser beam on the ground is important when discussing the spatial resolution of the data. The laser pulse is defined by three parameters; length, width (or diameter) and intensity. The width of the laser pulse (ie. the diameter of the laser beam) depends on the beam divergence and the distance from the sensor. The size of objects that is supposed to be resolved need to be in parity to this on-the-ground width. It should be noted that the diameter of the beam and the grid size of the terrain model is of the same order; 0.25 m.

Spatial patterns are very important characteristics of geographic measurements. It is the salient property for texture recognition. Spatial continuity of the terrain height observations therefore plays a key role in studying the representatives of LIDAR point observations.

Geostatistics is a collection of statistical methods for the analysis of spatially separated data. The spatial relationship between observations at the various locations can be explored by variogram analysis.

A variogram summarises the relationship between differences in pairs of measurements and the distance of the corresponding points from each other. Variogram relates variability to spatial separation and provides a concise and unbiased description of the scale (operational scale) and the pattern of spatial variability. To estimate average differences in terrain height as a function of the distance separating points, we group pairs of points by their separation distances. At very close distances variability is low, and as the separation distance increases, so does variability.

A characteristic feature of the variogram is the typical rise of variability towards some constant value, the sill. The sill is the total variability level at which the variogram value becomes constant. The range is the distance at which we reach the total amount of variability. If it appears that the variogram does not reach zero variance at zero distance, we may talk of the apparent intercept as the nugget variance. The nugget is a representation of error or variability at separations smaller than the sample distance. Further, the nugget variance of variograms may be used to estimate the uncertainty of the measurements (e.g. caused by remaining signal fluctuation not present within the data). If the nugget value approaches the sill, there is no redundancy between any of the samples, and none of the samples is any closer to the point being estimated than any other, in terms of statistical distance. The result would be a simple average of the available data with a complete lack of spatial correlation.

An example of a typical variogram showing spatial correlation has the shape shown in Figure 4-12.

From the resolution point of view the most interesting behaviour of the variogram is at short distances between data points. However, the sample variogram cannot provide direct information on distances shorter than the minimum spacing between the sample data. Of practical reasons we therefore talk about the *apparent* intercept to the ordinate, when extrapolated back to zero distance, which then indicates the variance remaining at lags smaller than that of the sampling distance. This in turn depends on variance associated to a small-scale variability not measured during data sampling.

In Figure 4-12 the spatial continuity of the LIDAR data has been plotted. The left diagram shows the overall continuity for distances up to 1,000 m of separation. The beforehand expected overall variance of the whole sample equals 21.83 m^2 (Table 4-5), and represents the variability expected if all samples were independent, showing spatial correlation. The observed variability lies below the overall variance until about 600 m, thus indicating a strong spatial continuity. In Figure 4-13 the variogram to the right shows spatial continuity at close range, distance of separation less than 5 m. When extrapolated back to zero distance, the variogram clearly approach zero variance indicating that almost no variability exists at distances less than minimum sampling distance. However, this conclusion need to be related to that the footprint of the laser beam (the diameter of the laser beam on the ground) is of the same order as the gridsize of 0.25 m.

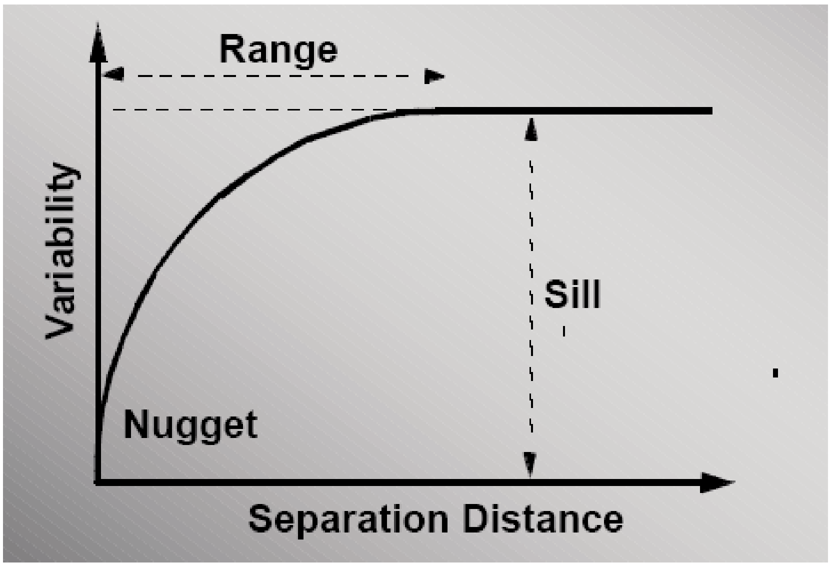

Figure 4-12. *The variogram.*

Table 4-5. Summary statistics of sample data.

Summary statistics	
Number of observations	48,384
Range	27.25
Midrange	18.635
Minimum	5.01
25%-tile	14.42
Median	18.04
75%-tile	21.2
Maximum	32.26
Average	17.8008
Standard Deviation	4.67228
Variance	21.8302
Coef. Of Variation	0.262475
Coef. Of Skewness	0.0962951

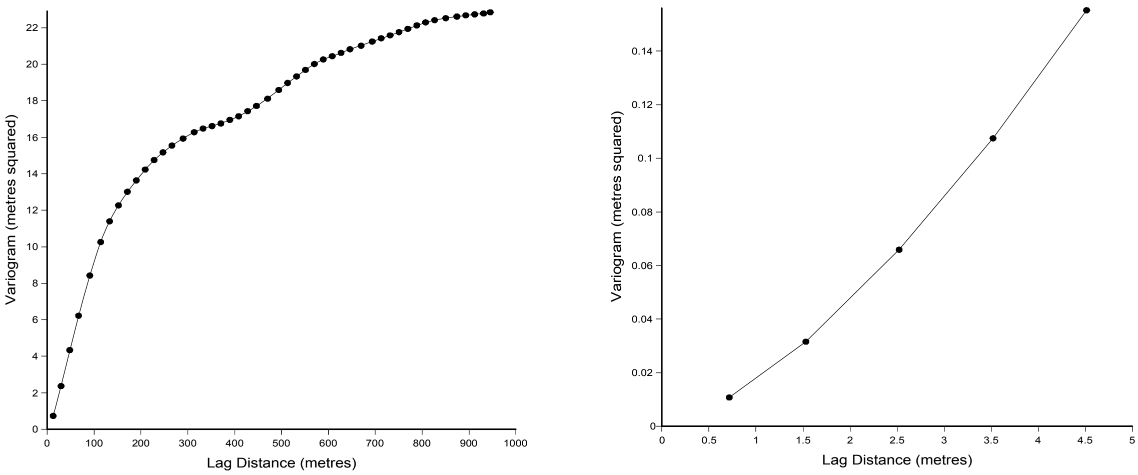

Figure 4-13. *The spatial continuity of the LIDAR data described using variograms. The variogram has been calculated using a total of 48,384 measurement points subsampled from the complete dataset.*

5 Results

5.1 Overall quality of product

The acquisition of aerial photographs and following processing are in accordance to the recommendations stated in the notifications given by the National Land Survey of Sweden, HMK-FO, in all relevant parts.

FM-kartta Oy, Finland, who performed the actual aerial photography mission and the processing of the uncorrected imagery to orthoimagery, is certified according to ISO 9001:2000 (certificate number 161094A).

5.2 Aerial imagery – orthophoto

5.2.1 Aerial imagery and orthophoto deliverables

The deliverables in reference to aerial photographs and produced orthophoto mosaic comprise the following

Table 5-1. Aerial photography deliverables.

Type	Format	Software
Camera calibration certificate	Paper hard copy	
Photoindex	Paper hard copy	
GPS-data	Digital ASCII	Desktop publishing format
Contact copies	Paper hard-copy	
Aerial photographs scanned	Digital TIFF uncompressed 24-bit colour	Desktop publishing format
Aerial triangulation results	Digital PAT-B	MATCH-AT compatible – INPHO GmbH
Orthophoto	Digital TIFF uncompressed 24-bit colour – ESRI tfw	Desktop publishing format/GIS format georeferenced

The orthophoto mosaic of the complete area have, of practical reasons related to the size of the digital output, been subdivided according to Figure 5-1. After subsectioning the mosaic consist of 91 datasets, each with coverage of 800 m × 800 m.

The naming convention of all subsectioned datasets is based on the geographical position. The name of the dataset 6364850n1551850e.tif refers to the centre coordinate of the pixel situated in the southwest corner of the image, ie. a northing coordinate of 6364850 m and an easting coordinate of 1551850 m (RT90 2.5gV 0;-15).

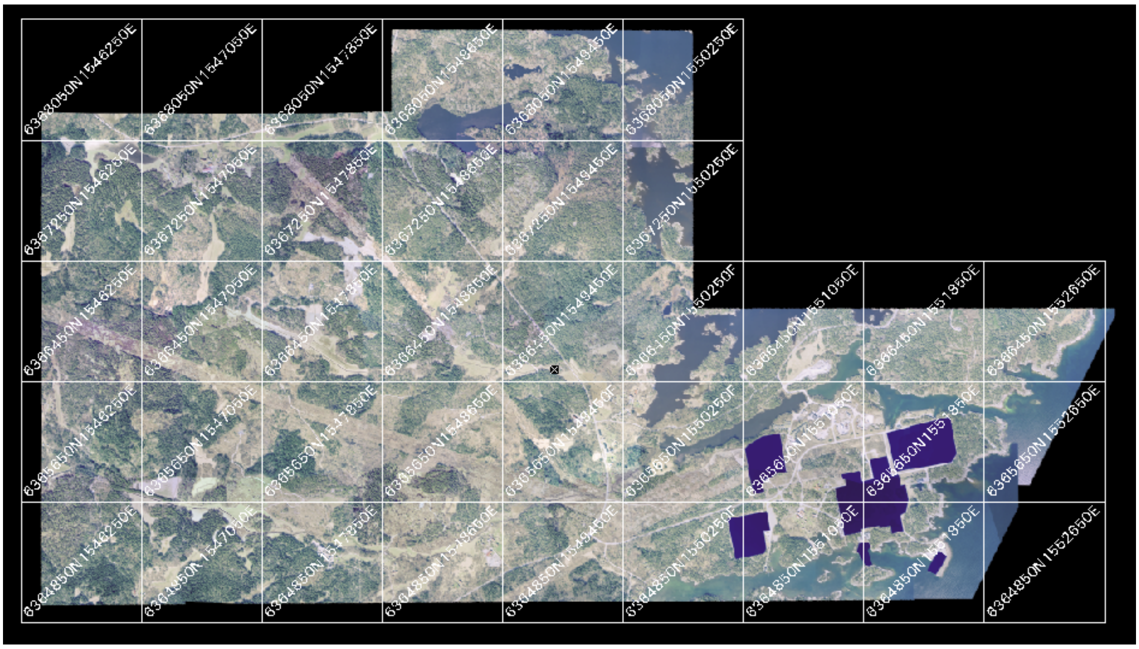

Figure 5-1. *The subdivision of the orthophotomosaic superimposedon the derived mosaic.*

5.3 LIDAR data

5.3.1 LIDAR deliverables

The complete scanning results have been stored in Terramodel internal format.

Because LIDAR produces extremely dense data that requires a tremendous amount of storage and processing power, the data is usually reduced. However, in this present work no reduction of data has occurred.

The raw LIDAR point cloud data is derived in the SWEREF99 UTM 33 reference system using the GRS 1980 ellipsoidal model. All subsequent processing have been carried out in this projection to avoid introducing errors. Finally the data have been translated into the target map projection (RT90/RH 70 2.5 gV 0:-15) through the Gtrans software package.

The LIDAR deliverables specifically include data formatted in a space separated ASCII file column format in which all aboveground features have been removed. The complete scanning results including aboveground objects are delivered in Terramodel format (Terrasolid Oy, Finland).

The ASCII datasets delivered consist of a height reading per each measured point together with an intensity reading. Each line refers to one measurement, without any header. An example of a dataset is shown in Table 5-1. First column is the easting coordinate, second column is the northing coordinate, third column the height measurement in the Swedish RH70 height system and the fourth column is the signal strength.

Table 5-1. An example of a LIDAR ASCII data set.

1546679.300	**6364989.590**	**13.510**	**10.7**
1546679.460	6364987.530	13.130	8.9
1546679.510	6364986.840	12.940	0.3
1546680.080	6364987.140	13.040	1.7
1546680.010	6364987.830	13.310	8.8
1546679.970	6364988.510	13.350	8.2
1546679.920	6364989.190	13.490	6.2
1546679.870	6364989.870	13.640	8.3
1546679.820	6364990.550	13.780	8.3
1546679.770	6364991.230	13.630	9.3
1546679.720	6364991.910	13.680	9.2
1546679.680	6364992.590	13.620	9.0
1546679.620	6364993.270	13.980	6.9
1546679.570	6364993.970	14.170	7.5
1546679.520	6364994.650	14.240	7.9
1546679.470	6364995.330	14.290	7.0
1546679.470	6365005.600	14.810	0.2
1546680.360	6364993.350	13.910	9.3
1546680.410	6364992.670	13.740	9.9
1546680.490	6364991.300	14.060	6.0
1546681.600	6364985.180	11.990	2.7
1546681.560	6364985.860	11.940	6.2
1546681.240	6364989.290	13.760	3.0
1546681.010	6364992.690	13.820	10.1
1546680.970	6364993.370	13.810	9.4
1546680.810	6364995.420	14.180	0.5

The subdivision of the ASCII-datasets follows a system shown in Figure 5-2. Each data tile is numbered from west to east starting in the lower left corner of the study area. The file type is *.enzi (enzi stands for Easting, Northing, Z terrain heght, and Intensity). The dataset naming convention used, is based on this simple numbering with the prefix oskarshamn added (example oskarshamn000042.enzi). In Appendix 1, summary statistics for each image tile is listed.

Terrain model

The gridded terrain model is delivered in the same subsectioning system as the ortophoto mosaic. The terrain model together with the associated subdivion system is viewed in Figure 5-2. The naming convention of delivered datasets is identical to the delivery of the orthomosaic.

To enhance and further illustrate the very detailed texture of the terraain model derived, a shaded relief visualization have been produced.

A shaded relief image provides an illustration of variations in terrain elevation. Based on a specified position of the sun, areas that would be in sunlight are highlighted and areas that would be in shadow are shaded.

Resampling of laser data in regular grids has its pros and cons. The main pros are memory and computation efficiency. Storing rectangular grids requires only storage of cell values, information of grid dimension and position for one corner whereas storing sets of irregular points requires that the coordinates and possible optional values are stored explicitly for all points. Algorithms working on rectangular grids are in general much easier to implement and they usually also run faster then algorithms working on data structures of free points. Furthermore, using regular grids also makes it possible to utilize the vast amount of experience, methods and already existing software for analysis of data stored in regular grids. The cons are the introduction of position uncertainties and the potential loss of information. Both effects depend on the selected cell size. Position uncertainty arises since the exact position (easting, northing) of a laser point is lost when it is placed in a cell. The maximum error introduced is equal to half the cell diagonal. It arises for laser points having an exact position corresponding to cell corners. The problem of loss of information arises when there is more than one laser point in a cell and only the value from one point is used. Hence, keeping the cell size down is important in order to reduce the position uncertainties and the loss of information. On the other hand, it should be noted that the cell size should not be too small since it causes unnecessary large grids that consume memory and computational power and also give rise to lots of empty cells that complicates interpolation. It is important that the cell size is adapted to the laser point density in the raw data.

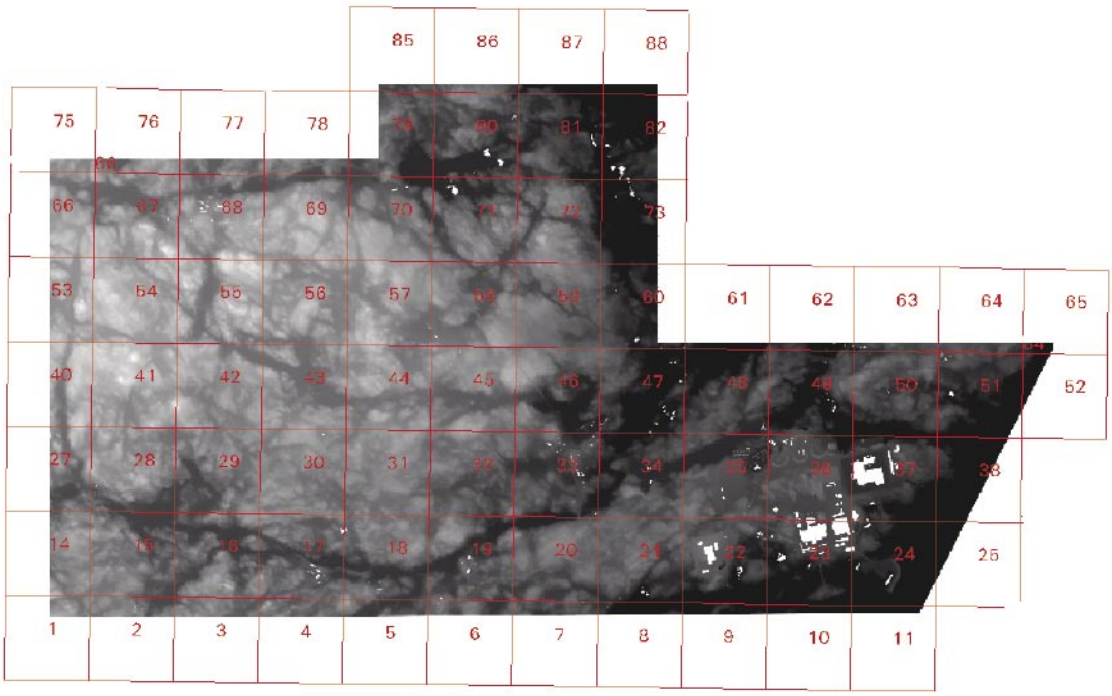

Figure 5-2. *The subdivision of the LIDAR point measurements into ASCII datasets superimposed the gridded terrainmodel. The number indicated is the file-number of each image tile.*

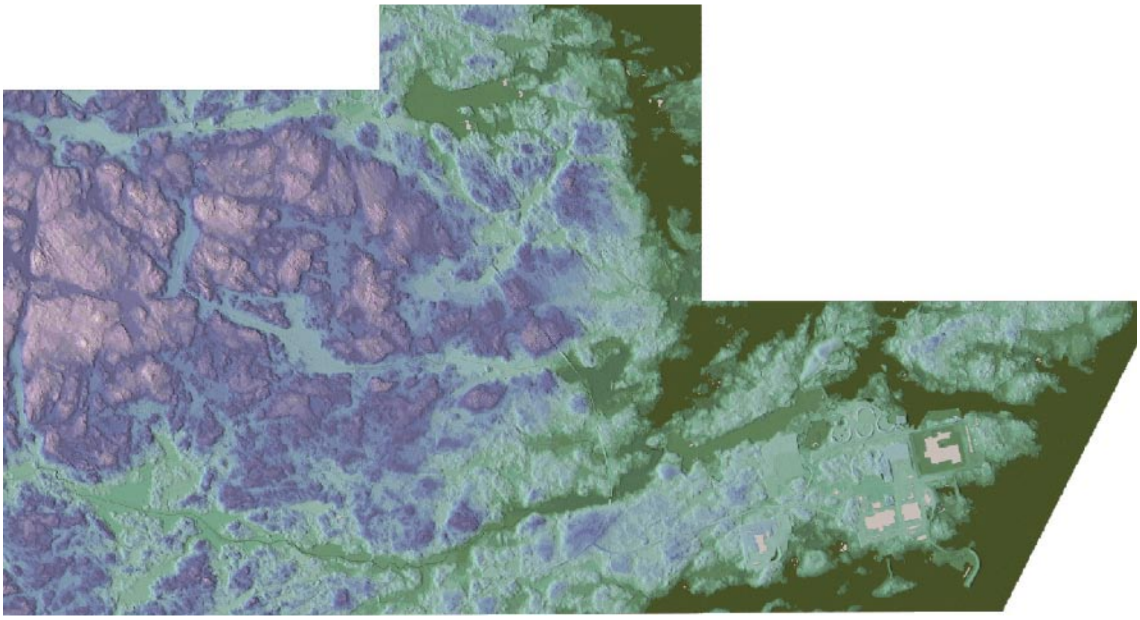

Figure 5-3. *Shaded relief of the derived terrain model. Light direction is 270 degrees (ie. sunlight from west).*

6 References

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SKB 2001a. Platsundersökningar, undersökningsmetodet och generellt genomförande-program. SKB R-01-10, Svensk Kärnbränlsehantering AB.

SKB 2001b. Platsundersökning vid Simpevarp. SKB R-01-44. Svensk Kärnbränlsehantering AB.

SKB 2001c. Metodbeskrivning för lineamentstolkning baserad på topografiska data. SKB MD 120.001, Svensk Kärnbränlsehantering AB.

Wiklund S, 2003. Digitala ortofoton och höjdmodeller. SKB P-02-02, Svensk Kärnbränslehantering AB.

Appendix 1

LIDAR data

Summary statistics for all delivered ASCII files. Z1 is the terrain height and Z2 is the recorded intensity.

Fil	XMin	Xmax	YMin	Ymax	Z1Min	Z1Max	Z2Min	Z2Max	Antal p
oskarshamn000088.enzi	1550324.500	1550698.000	6368682.000	6368757.500	-0.830	0.020	0.000	162.000	76362
oskarshamn000003.enzi	1547279.625	1547881.125	6364988.000	6365121.000	6.170	18.940	0.000	17.000	215001
oskarshamn000004.enzi	1547879.750	1548481.250	6364991.500	6365114.000	7.390	21.620	0.000	340.000	228062
oskarshamn000005.enzi	1548480.000	1549081.375	6364995.500	6365106.500	2.900	19.930	0.000	17.000	291163
oskarshamn000006.enzi	1549080.375	1549681.625	6364999.000	6365099.500	2.790	14.250	0.000	54.000	210850
oskarshamn000007.enzi	1549680.625	1550281.625	6365002.500	6365092.500	2.190	12.310	0.000	340.000	151483
oskarshamn000008.enzi	1550280.875	1550881.750	6365006.000	6365085.500	-0.870	6.110	0.000	338.000	123998
oskarshamn000009.enzi	1550881.125	1551482.000	6365010.000	6365078.000	-0.870	4.970	0.000	510.000	105492
oskarshamn000010.enzi	1551481.500	1552082.250	6365013.500	6365071.000	-0.850	2.340	0.000	132.000	90490
oskarshamn000011.enzi	1552081.750	1552571.875	6365017.000	6365064.000	-0.940	0.060	0.000	38.000	47686
oskarshamn000014.enzi	1546393.250	1546687.875	6365128.000	6365731.500	7.390	24.770	0.000	100.000	591183
oskarshamn000015.enzi	1546680.875	1547288.000	6365121.000	6365728.000	3.580	21.270	0.000	340.000	1221482
oskarshamn000016.enzi	1547281.000	1547888.250	6365114.000	6365721.000	2.900	25.430	0.000	420.000	1267847
oskarshamn000017.enzi	1547881.125	1548488.375	6365107.000	6365714.000	2.150	19.940	0.000	272.000	1458029
oskarshamn000018.enzi	1548481.375	1549088.500	6365100.000	6365707.000	1.500	19.440	0.000	62.000	1605597
oskarshamn000019.enzi	1549081.500	1549688.625	6365092.500	6365700.000	0.440	19.030	0.000	340.000	1819395
oskarshamn000020.enzi	1549681.750	1550288.750	6365085.500	6365692.500	0.430	17.700	0.000	486.000	1642793
oskarshamn000021.enzi	1550281.750	1550889.000	6365078.500	6365685.500	-0.920	15.570	0.000	510.000	1570166
oskarshamn000022.enzi	1550882.000	1551489.125	6365071.500	6365678.500	-2.830	12.360	0.000	510.000	1530233
oskarshamn000023.enzi	1551482.125	1552089.250	6365064.000	6365671.500	-0.990	11.810	0.000	396.000	1338087
oskarshamn000024.enzi	1552082.250	1552689.375	6365058.500	6365664.000	-1.020	7.920	0.000	370.000	1126913
oskarshamn000025.enzi	1552685.000	1552874.625	6365282.000	6365657.000	-0.920	0.060	0.000	48.000	96988
oskarshamn000027.enzi	1546393.125	1546695.000	6365728.500	6366332.000	5.060	26.970	0.000	56.000	778023
oskarshamn000028.enzi	1546688.000	1547295.125	6365721.000	6366328.500	4.070	25.240	0.000	110.000	1344994
oskarshamn000029.enzi	1547288.125	1547895.375	6365714.000	6366321.500	4.360	21.100	0.000	22.000	1519893
oskarshamn000030.enzi	1547888.375	1548495.375	6365707.000	6366314.000	9.630	22.960	0.000	510.000	1573888
oskarshamn000031.enzi	1548488.500	1549095.625	6365700.000	6366307.000	8.120	21.410	0.000	17.000	1660261
oskarshamn000032.enzi	1549088.625	1549695.750	6365693.000	6366300.000	2.390	20.650	0.000	17.000	1698629
oskarshamn000033.enzi	1549688.750	1550295.875	6365686.000	6366293.000	-0.150	15.280	0.000	204.000	1688593
oskarshamn000034.enzi	1550288.875	1550896.125	6365678.500	6366286.000	-0.860	15.330	0.000	510.000	1620642
oskarshamn000035.enzi	1550889.125	1551496.250	6365671.500	6366278.500	0.600	14.620	0.000	510.000	1759393
oskarshamn000036.enzi	1551489.125	1552096.375	6365664.500	6366271.500	-1.010	13.970	0.000	348.000	2013678
oskarshamn000037.enzi	1552089.375	1552696.625	6365657.500	6366264.500	-1.120	10.500	0.000	268.000	1509090
oskarshamn000038.enzi	1552689.500	1553176.750	6365655.000	6366257.000	-1.000	6.270	0.000	166.000	598574
oskarshamn000040.enzi	1546393.125	1546702.250	6366328.500	6366932.000	10.770	28.480	0.000	112.000	830991
oskarshamn000041.enzi	1546695.125	1547302.250	6366321.500	6366928.500	13.010	32.360	0.000	17.000	1408642
oskarshamn000042.enzi	1547295.250	1547902.500	6366314.500	6366921.500	10.570	29.070	0.000	56.000	1559540
oskarshamn000043.enzi	1547895.500	1548502.625	6366307.000	6366914.500	9.840	23.710	0.000	510.000	1742410

oskarshamn000044.enzi	1548495.625	1549102.750	6366300.000	6366907.000	9.190	25.210	0.000	510.000	1478634
oskarshamn000045.enzi	1549095.750	1549702.875	6366293.000	6366900.000	6.570	23.010	0.000	140.000	1600851
oskarshamn000046.enzi	1549695.875	1550303.000	6366286.000	6366893.000	-0.070	21.490	0.000	36.000	1560018
oskarshamn000047.enzi	1550296.000	1550903.125	6366278.500	6366886.000	-1.020	12.920	0.000	510.000	1346641
oskarshamn000048.enzi	1550896.250	1551503.375	6366271.500	6366878.500	-0.840	13.230	0.000	510.000	1464512
oskarshamn000049.enzi	1551496.375	1552103.500	6366264.500	6366871.500	-4.960	13.350	0.000	510.000	1611718
oskarshamn000050.enzi	1552096.375	1552703.625	6366257.500	6366864.500	-0.820	15.030	0.000	510.000	1573410
oskarshamn000051.enzi	1552696.500	1553303.750	6366251.500	6366857.500	-0.980	11.280	0.000	354.000	1279644
oskarshamn000052.enzi	1553299.750	1553479.875	6366494.000	6366850.000	-0.870	6.140	0.000	124.000	96392
oskarshamn000053.enzi	1546393.125	1546709.250	6366928.500	6367532.500	15.970	31.180	0.000	17.000	724741
oskarshamn000054.enzi	1546702.250	1547309.375	6366922.000	6367529.000	15.190	29.090	0.000	24.000	1561094
oskarshamn000055.enzi	1547302.375	1547909.500	6366914.500	6367521.500	10.420	30.410	0.000	216.000	1574427
oskarshamn000056.enzi	1547902.500	1548509.625	6366907.500	6367514.500	10.830	27.390	0.000	72.000	1775451
oskarshamn000057.enzi	1548502.750	1549109.875	6366900.500	6367507.500	10.060	26.810	0.000	18.000	1599277
oskarshamn000058.enzi	1549102.875	1549710.000	6366893.000	6367500.500	5.830	21.300	0.000	70.000	1745966
oskarshamn000059.enzi	1549703.125	1550310.250	6366886.000	6367493.000	4.500	19.320	0.000	94.000	1425338
oskarshamn000060.enzi	1550303.125	1550903.625	6366879.000	6367486.000	-1.010	11.270	0.000	510.000	956236
oskarshamn000061.enzi	1550903.250	1551503.875	6366871.500	6366921.000	-0.800	7.000	0.000	372.000	87430
oskarshamn000062.enzi	1551503.375	1552104.125	6366864.500	6366921.000	-0.890	7.440	0.000	174.000	125676
oskarshamn000063.enzi	1552103.625	1552704.375	6366857.500	6366921.000	0.140	11.610	0.000	18.000	167693
oskarshamn000064.enzi	1552703.750	1553304.625	6366850.500	6366921.000	1.800	10.860	0.000	17.000	166153
oskarshamn000065.enzi	1553303.875	1553516.250	6366848.500	6366921.000	-0.810	4.360	0.000	246.000	48100
oskarshamn000066.enzi	1546393.125	1546716.375	6367529.000	6368132.500	9.760	26.350	0.000	48.000	620210
oskarshamn000067.enzi	1546709.375	1547316.375	6367522.000	6368129.000	8.630	32.370	0.000	34.000	1555607
oskarshamn000068.enzi	1547309.500	1547916.625	6367514.500	6368121.500	5.960	31.060	0.000	34.000	1731480
oskarshamn000069.enzi	1547909.625	1548516.750	6367507.500	6368114.500	4.710	26.930	0.000	308.000	1638190
oskarshamn000070.enzi	1548509.875	1549117.000	6367500.500	6368107.500	1.270	24.830	0.000	510.000	1539341
oskarshamn000071.enzi	1549110.000	1549717.125	6367493.500	6368100.500	1.290	18.940	0.000	510.000	1430706
oskarshamn000072.enzi	1549710.125	1550317.250	6367486.000	6368093.500	-0.970	22.940	0.000	316.000	1481303
oskarshamn000073.enzi	1550310.250	1550698.500	6367481.500	6368086.000	-0.960	7.040	0.000	510.000	733044
oskarshamn000075.enzi	1546393.125	1546717.500	6368129.000	6368222.500	14.080	22.920	0.000	17.000	120549
oskarshamn000076.enzi	1546716.500	1547317.750	6368122.000	6368223.000	9.040	22.300	0.000	17.000	265360
oskarshamn000077.enzi	1547316.625	1547917.875	6368114.500	6368223.000	8.540	19.220	0.000	17.000	291978
oskarshamn000078.enzi	1547916.750	1548518.125	6368107.500	6368223.000	4.680	18.900	0.000	104.000	308234
oskarshamn000079.enzi	1548517.000	1549124.125	6368100.500	6368705.500	1.080	17.550	0.000	336.000	1100289
oskarshamn000080.enzi	1549117.125	1549724.250	6368093.500	6368700.500	0.240	16.680	0.000	510.000	1455741
oskarshamn000081.enzi	1549717.250	1550324.375	6368086.500	6368693.500	-0.920	13.720	0.000	510.000	1222509
oskarshamn000082.enzi	1550317.375	1550698.250	6368082.000	6368686.500	-0.990	7.080	0.000	262.000	690456
oskarshamn000085.enzi	1548719.625	1549124.750	6368700.500	6368761.500	3.660	13.830	0.000	36.000	102567
oskarshamn000086.enzi	1549124.125	1549725.000	6368693.500	6368760.500	0.370	16.160	0.000	84.000	150105
oskarshamn000087.enzi	1549724.375	1550325.250	6368686.500	6368759.000	-0.860	8.250	0.000	488.000	141987
oskarshamn000002.enzi	1546679.250	1547281.000	6364984.500	6365128.000	5.670	20.360	0.000	510.000	284671

Appendix 2

Report

NO05722

Oskarshamn

BLOM GEOMATICS

SUBSIDIARY OF THE BLOM GROUP

CONTENTS

Appendix:

1. *Flight plan,* ***Appendix_1_Flight_plan_ NO05722.pdf****.*

1. INTRODUCTION

This document summarizes the Lidar flight and the data processing of the "Oskarshamn" project. Blom Geomatics internal reference number for this project is NO05722.

2. FLIGHT MISSIONS

The project was flown in one flight. The LIDAR flight was flown with a Piper Navajo PA 31 airplane (LN-AEY). Pilot was Jon Wold and operator was John Frøybu.

2.1. LIDAR flights

The LIDAR survey was executed on 23th April 2005 (DOY 113).

Project	Oskarshamn
Altitude	900 m
PRF	100000 Hz
Scanner freq	58 Hz
Half angle	17
Speed	75 m/s

3. FIELD SURVEYING OF CONTROL SURFACES

102 control points were supplied by BlomInfo AB.

4. LIDAR - DATA COLLECTION AND PROCESSING

4.1. LIDAR data collection

4.1.1. Flight – LIDAR 23.04.05, flight 11305a

Flight name:	11305a
Date:	23.04.2005
Period (UTC):	08:58 – 13:02
Weather conditions:	OK

Solutions using ground stations

Ground station:	Blankaholm	Coordinate	SWEREF 99
GPS antenna:	ASH700936D_M	North	57 34 49.31868
ARP- L1	0.1089	East	16 30 54.76777
ARP - L2	0.1274	Height el.	70.504
Vertical Ant. H	0.0710	**Ellipsoid**	GRS 1980

Ground station:	Pauliström	Coordinate	SWEREF 99
GPS antenna:	AOAD/M_T	North	57 27 59.06423
ARP- L1	0.110	East	15 30 38.03375
ARP - L2	0.128	Height el.	200.103
Vertical Ant. H	0.0710	**Ellipsoid**	GRS 1980

Ground station:	Böda	Coordinate	SWEREF 99
GPS antenna:	ASH701946.3	North	57 14 49.01530
ARP- L1	0.110	East	17 03 31.13783
ARP - L2	0.128	Height el.	45.440
Vertical Ant. H	0.0710	**Ellipsoid**	GRS 1980

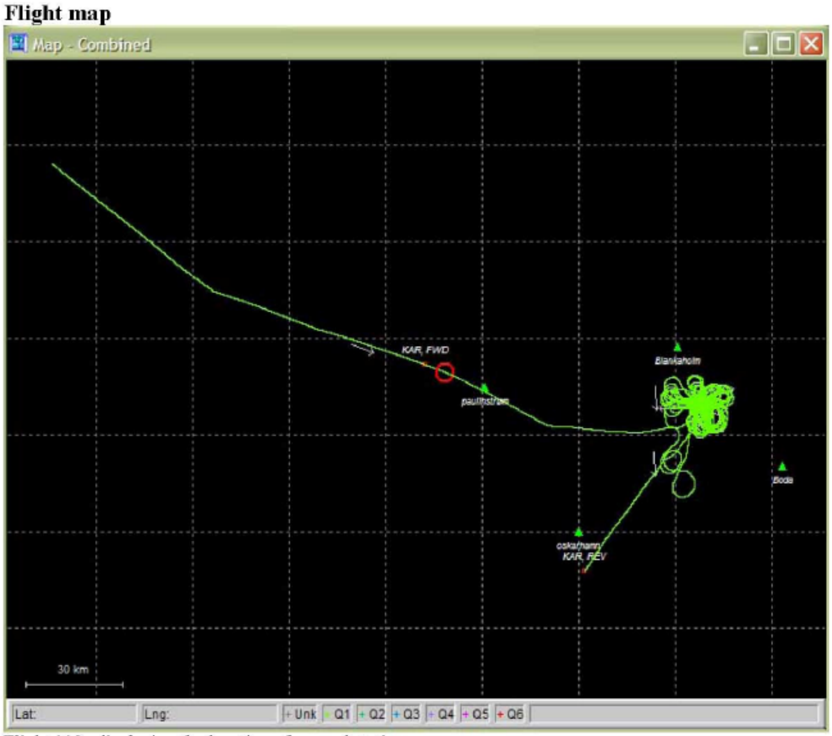
Ground station:	Oskarshamn	Coordinate	SWEREF 99
GPS antenna:	ASH700936D_M	North	57 03 56.29169
ARP- L1	0.110	East	15 59 48.50146
ARP - L2	0.128	Height el.	149.753
Vertical Ant. H	0.0710	**Ellipsoid**	GRS 1980

Solutions using all ground stations

The solutions where made with a Multi-base technique. Two separate solutions with different kinematic ambiguity resolution were made. The "separation plot" on page 6, shows the difference between the solutions.

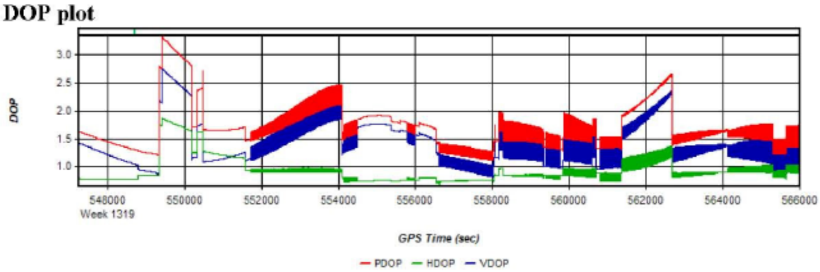
The solutions are combined weighted on distance and standard deviation.

Flight map



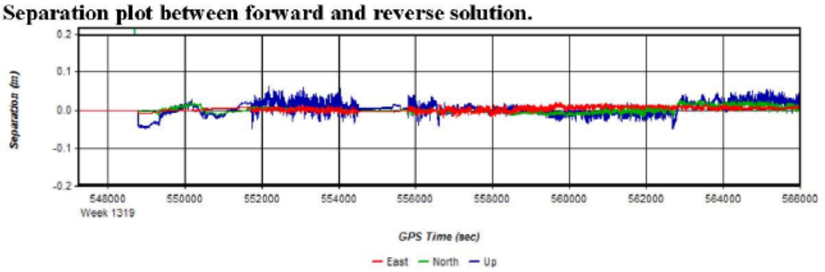
Flight 113a displaying the location of ground station

DOP plot



Number of satellites

Separation plot between forward and reverse solution.



Conclusion

The solutions are calculated in GrafNav from Waypoint Consulting inc. The separation plot combined with the Pdop plot indicates that the GPS solution is very good.

GPS/INS Calculation

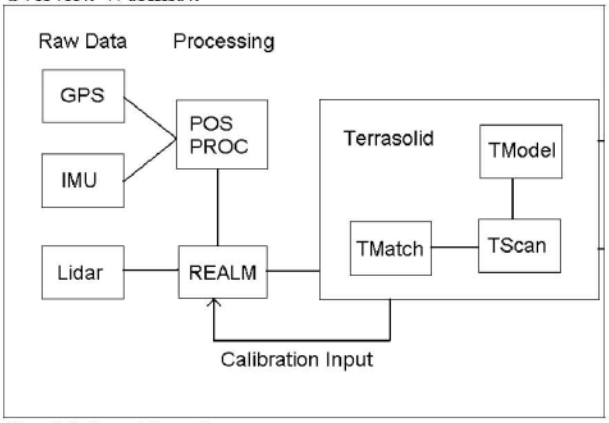
The calculation was done with PosProc from Applanix.

IMU report:	Start	end
Time intervall	08:59	13:02
Nr. of interpolation	0	
Nr. of gaps	0	
Correct time types	yes	

The result is within specification of the instrument.

4.2. LIDAR XYZ calculation and control

Overview Workflow



Simplified workflow diagram

The following software has been used:

Name	Product by	Tasks
REALM	Optech	Tape decoding, XYZ processing
POSPAC	Applanix	GPS/INS processing
TerraScan	TerraSolid	Point data management, QC
TerraMatch	TerraSolid	System calibration, QC

Calibration

Systematic errors were found using TerraSolid utilities, such as dRoll, dPitch, dHeading and mirror scale factor. The result was reset to the final XYZ process in Realm, according to the plot above.

Parameter	Estimated value
dRoll	0.0047°
dPitch	-0.0207°
dHeading	0.104°
Scale	-0.0002

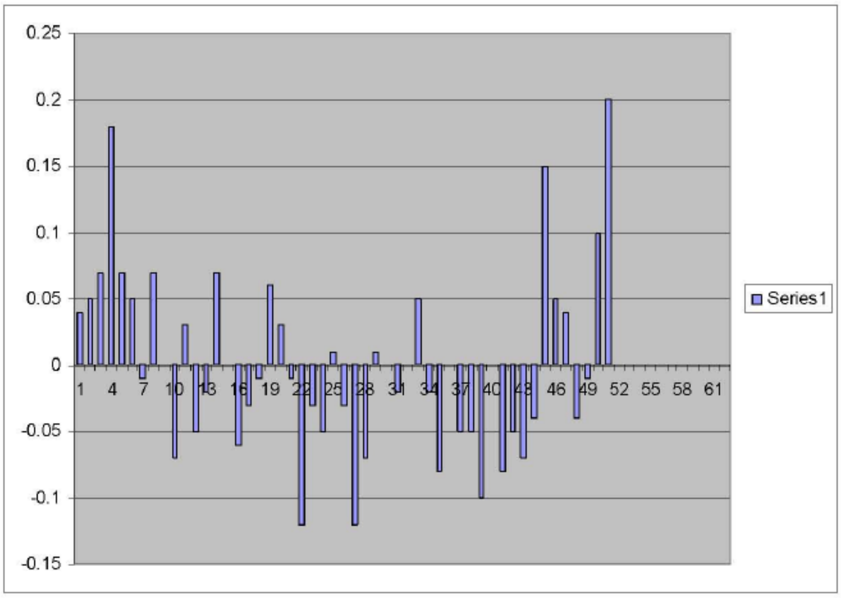
Model offset

102 control points were delivered from BlomInfo AB. These points were collected at different locations and in different types of terrain. To find a good estimate of the model offset, 52 points in areas with low angel of inclination and hard surfaces were chosen.

Height deviations Z shift analysis:

Control area no.	Average dHeight (m)	St. deviation (m)
52 points	0.234	0.068

It was decided to shift the Lidar data with a constant Z shift of 0.234 meters.



The plot above shows the difference between the lidar data and the control points after Z adjustment.

5. PRODUCTS

The following products are being delivered:

5.1. Point cloud

Classified points are delivered as space separated ASCII (East, North, Height, Intensity). The classes are delivered in separate files. There are 3 classes:

1. Non ground
2. Ground
3. Low single points

Comments: The class "Low single points" contains point lying under our defined ground. The reasons for the "low single points" can be; multi path, weak return signal, water reflection irregularities and depressions in the ground.

5.2. Coordinate System

All points are delivered in Sweref 99 UTM 33, ellipsoidal height GRS1980.

Appendix 3

CAMERA CALIBRATION CERTIFICATE

CAMERA TYPE :	RC30
LENS TYPE :	15/4 UAG-S
LENS NO. :	13311

Calibration date: 15.02.2005 LEICA AG, HEERBRUGG

swissoptic
SwissOptic AG
Heinrich-Wild-Strasse
CH-9435 Heerbrugg
Schweiz

RC30 15/4 UAG-S No. 13311 15.02.2005

Aperture: 4.0
Filter on goniometer: VIS (400 - 700 NM)
Filter on camera: --
C.F.L. : 153.46 mm

Radial distortion (micrometers) referred to principal point of symmetry (PPS)
(Positive values denote image displacement away from center)

Radius	Half - Sides				Mean
mm	1	3	2	4	
10	0.1	-0.4	-0.1	-0.2	-0.1
20	-0.3	-0.8	-0.2	-0.5	-0.4
30	-0.6	-0.8	-0.2	-0.9	-0.6
40	-0.7	-0.5	-0.4	-0.5	-0.5
50	-0.7	-0.6	-0.4	-0.5	-0.5
60	-1.4	-1.3	0.2	-0.4	-0.7
70	-0.9	-0.5	-0.2	0.1	-0.3
80	-1.2	0.1	0.3	0.6	0.0
90	0.1	0.2	1.2	0.9	0.6
100	0.5	0.5	2.2	1.5	1.1
110	1.1	0.7	2.9	2.4	1.7
120	1.4	1.3	2.5	1.9	1.7
130	0.4	0.2	2.4	1.4	1.1
140	-1.3	-1.6	0.1	1.1	-0.4
148	-3.5	-3.4	-1.9	-0.6	-2.3

Photographic resolution (line pairs per millimeter)

International 3-line test-chart, contrast (log) : 2.0
Aperture: 4.0
Filter: VIS (400-700 NM)
Film: KODAK PANATOMIC X 2412
Developer: KODAK HC110

Angle (deg)	0	5	10	15	20	25	30	35	40	45
Radial:	147	147	145	127	139	134	128	121	101	83
Tangential:	147	146	127	123	116	108	99	99	77	59

AWAR (Area weighted average resolution) in lp/mm: 113

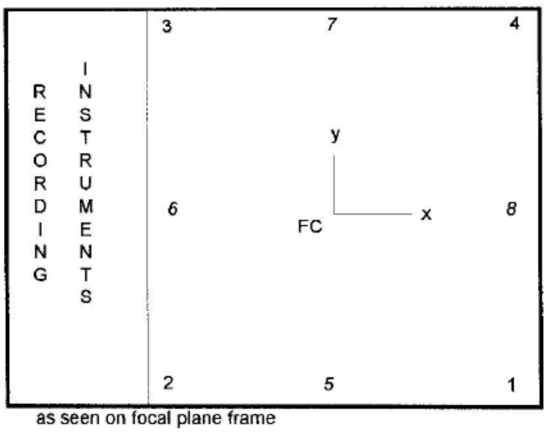
RC30 15/4 UAG-S No. 13311 15.02.2005

Principal point of autocollimation (PPA) and principal point of symmetry (PPS)
referred to central cross (FC), see diagram

	x (mm)	y (mm)
PPA	0.003	-0.002
PPS	0.003	-0.004

Fiducial marks, referred to central cross (FC)

	x (mm)	y (mm)		x (mm)	y (mm)
1	105.997	-105.998	**5**	-0.002	-112.002
2	-106.001	-106.001	**6**	-112.000	0.001
3	-106.001	106.002	**7**	-0.005	111.997
4	106.001	106.001	**8**	111.995	-0.001



as seen on focal plane frame

RC30 15/4 UAG-S No. 13311 15.02.2005

Aperture: 4.0
Filter on goniometer: VIS (400 - 700 NM)
Filter on camera: --
C.F.L. : 153.46 mm