Waddenzee LiDAR Survey

Final Report

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Client: *Nederlandse Aardolie Maatschappij*
Author: *Fugro Geospatial B.V.*
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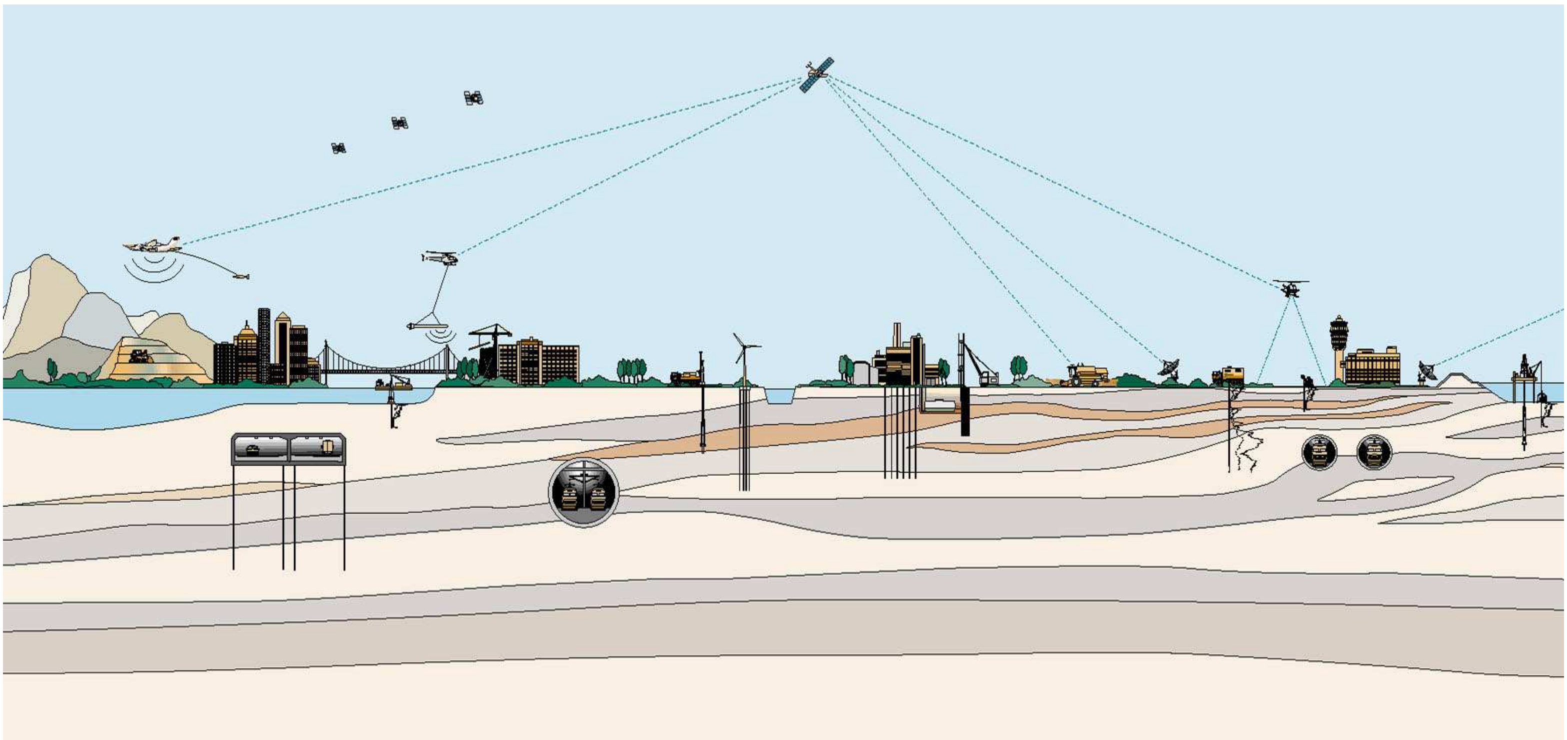

1. Introduction

In October 2013, Fugro Geospatial (Fugro in this document) carried out an airborne LiDAR survey for Nederlandse Aardolie Maatschappij (NAM in this document).

The aim of this survey is to monitor the mudflat areas in the Waddenzee Pinkegat and Zoutkamperlaag.

This project was carried out for the 5th time, the previous surveys were in spring of 2010, spring 2011, autumn 2011 autumn and autumn 2012. In the past, the surveys were carried out with the FLI-MAP 1000 scanner, this time it was carried out with a Riegl Q680i laserscanner, because it is assumed that using the Riegl scanner with lead to a higher point density and better reflectivity on these wet areas.

Besides this, the flightplan has changed, a number of cross lines has been introduced to increase the relative accuracy.

Further processing was directly started after finishing the survey. The end deliverables were delivered together with this report on a separate hard disk.

The final deliverables were delivered to Deltares (contracted analysis partner of NAM) and to NAM on a hard disk on the 5th of December 2013.

This report provides the relevant project information. After a short description of the project in Chapter 2, the data acquisition, data processing and data quality control are described in Chapters 3, 4 and 5 respectively. Chapter 6 consists of information about the creation of the end deliverables. In Chapter 7 a summary of all conclusions is given.

Appendices are digitally attached to the report.

2. Project specifications

2.1. Project Area

The airborne survey covers the areas Pinkegat and Zoutkamperlaag. The survey area and flightlines are shown in Figure 1. The survey encompasses 760 kilometres of flight lines with an east-west orientation (indicated in yellow) and five cross lines (indicated in pink). The area to be covered is indicated with the red line.

Figure 1: Project area and flightlines.

The digital boundary file is attached in Appendix A.

2.2. Demands and conditions for survey

The project has been executed according to the tender (our reference OF/13/279/ASM11085) as stated by Fugro.

The survey needs to be executed while the water level is below -0.70m NAP at Nes tidal station.

Opposed to the previous flights, this time the survey was executed with a Riegl Q680i scanner. Furthermore, five cross lines were flown to obtain a better relative accuracy (see Figure 1). The cross lines are situated over the six control grids on the edges of the project area (see Figure 3) to be able to check and enhance the absolute accuracy.

The Tables below show the specifications that were used during the survey.

Survey platform:

#	Surveying platform	
1	Aircraft type and model	Piper PA31 (9H-FMH)
2	GPS/INS type and model	IGI CCNS4 amd IGI IMU
3	Scanner type and model	LiteMapper 6800 *
4	Aerial camera type and model	DigiCAM

Flight parameters:

#	Parameters	Value	Unit
1	Height AGL	440	m
2	Speed	120	kts
3	Flight direction	E-W	
5	Line spacing	400	m
6	Number of lines	33	-
7	Number of cross lines	5	-

Scan parameters:

#	Parameters	Value	Unit
1	Scan Angle	(±)30	°
2	Frequency	200	kHz
3	Point density	4.3	pt/m²
4	MTA Zone	1	

Image specifications:

#	Specifications	Value	Unit
1	Focal length	50	mm
2	Size of CCD matrix	7216x5412	Pixel x Pixel
3	Pixel size	6.8	µm
4	Image GSD	5.2	cm

* The LiteMapper 6800 system is based on the Riegl Q680i laserscanner.

The flight parameters are a little bit different from the proposal:

- Flight speed has been increased from 100 to 120 kts. This is because the certified aircraft is a twin-engine and cannot fly slower than 120 kts;
- To compensate the higher speed, the flight altitude has been reduced to 440 m.

2.3. Client communication

In accordance to the clients requirement Fugro delivered a frequent processing update per e-mail accompanied by an up to date schedule for delivery and progress.

During the project in multiple instances the planning was slightly altered by Fugro in order to tune the route to end delivery. At no moment the schedule for the end delivery was jeopardized.

2.4. Quality, Health, Safety and Environment

The mission of Fugro Geospatial is to be one of the leading and most innovative companies in Aerial Survey and Mapping Services in Europe, Middle East and Africa, with healthy financial results and long term continuity of services. Fugro Geospatial is committed to be a reliable supplier for its clients, to provide a healthy and safe workplace for all its employees and partners and to protect the environment in accordance with applicable laws and the HSE Policy defined by the Fugro mother company.

Fugro is supported in this by the certification and adherence to OHSAS18001 and ISO9001.

Quality within Fugro is ruled by the slogan: “First time, on time, right”.

On base of the conditions stated by Shell Aircraft International (SAI) Fugro received approval after an aviation on-desk audit. Fugro was assessed as being acceptable on evidence of the overall standards observed during a desk-top assessment in the key areas of operations, engineering, safety management and the assurance of quality.

Fugro flew with a Piper PA31-350 Navajo aircraft, registration 9H-FMH, flown by Marc Rigutto. Both aircraft and commander have been approved for that survey by SAI.

Fugro executed and adhered to a comprehensive risk assessment for this project. None of the stated risks did happen. In appendix B the risk assessment is attached.

3. Data acquisition

3.1. Flight overview

The project has been coordinated from the field office at Teuge airfield. The survey was executed by a twin engine Piper Chieftain with call sign 9H-FMH. This plane has been approved by Shell Aircraft international before the survey started.

In Table 1 and Figure 2 a brief overview of the daily status of the project is given.

Date	Activity
11-10-2013	Mobilisation
12-10-2013	No tidal window
13-10-2013	Weather standby
14-10-2013	Weather standby
15-10-2013	Weather standby
16-10-2013	Weather standby
17-10-2013	Weather standby
18-10-2013	Survey
19-10-2013	Survey
20-10-2013	Survey
21-10-2013	Demobilisation

Table 1: Daily activity overview

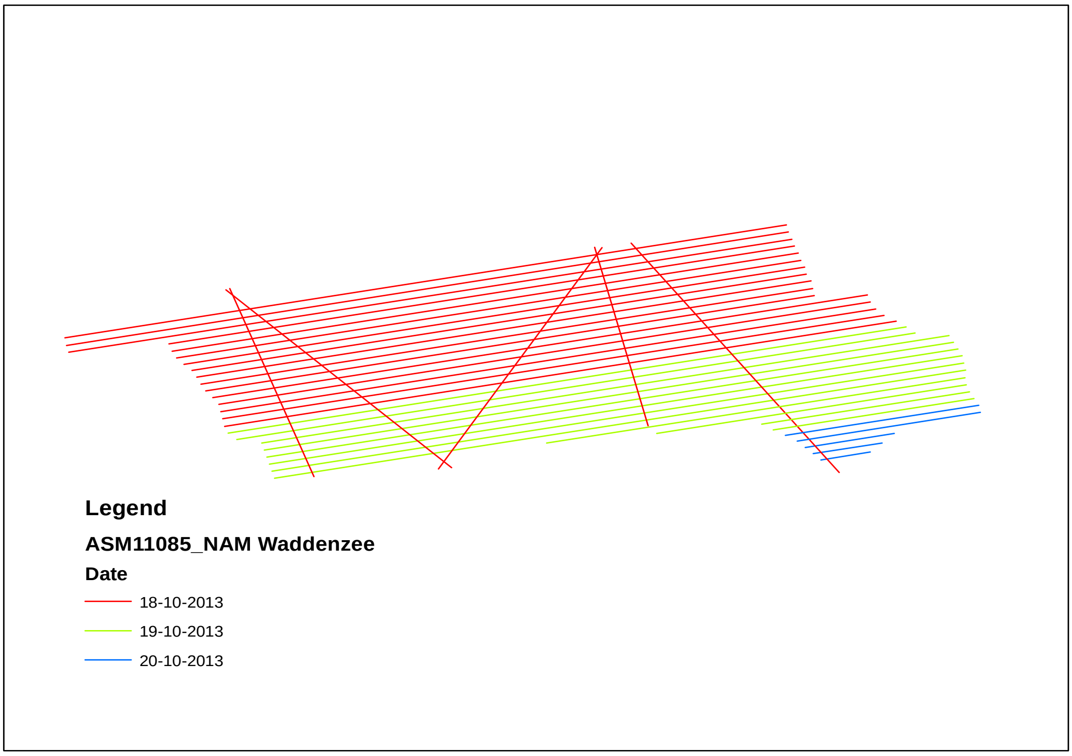

Figure 2: Overview of the 3 flights

3.2. Weather and tide

The weather was generally good, with clear skies. Only during the second day there were two short periods with light rain. However the lines that were affected are re-flown on the last day. The data acquisition was planned with tide level below the stated tide level -0.70m NAP, except for the cross lines. The only issue was that the suitable tidal windows where very late at the day, leaving only short time for the ferry back to the airport, before closure. Therefore, the cross lines have not been acquired twice per day.

Please see Appendix C for a more detailed overview of the weather and tide. Please note that there is a slight deviation on the first day, showing acquisition at water level -0.69 m. This is due to the fact that the tidal windows had to be used optimally and therefore the acquisition was timed as tight as possible, resulting in a (theoretically) to early start. However, it is only 1 cm difference, which is less than the accuracy of the survey so this is not an issue.

3.3. Cross lines

The five cross lines have each been flown at least twice. Originally it was planned that they would all be flown twice per survey day, however unfortunately the tidal windows were very short .on the survey days and also very late on the day, leaving less time for the ferry back to Teuge. Therefore, we have prioritised the normal (East-West) lines and could not fly all cross lines as often as planned:

- Cross line 34: flown twice, on 18-10 and 19-10
- Cross line 35: flown twice, on 18-10 and 19-10
- Cross line 36: flown twice, on 18-10 and 19-10
- Cross line 37: flown twice, on 18-10 and 19-10
- Cross line 38: flown three times, on 18-10, 19-10 and 20-10

However, still these cross lines connect the different flights and therefore contribute to a better relative matching over the project area.

3.4. Ground control

In the same period 13 control grids are surveyed, 9 on hard surfaces and 4 on the mud flats. In Figure 3 an overview of these locations is given. The locations indicated in green (GCP-1 to GCP-9) are the grids on hard surface, the others (in blue) are the grids on the mud flats. These areas are used to check the positioning of the flights. The cross lines are displayed as well, to show that these are planned over the hard surface GCP locations.

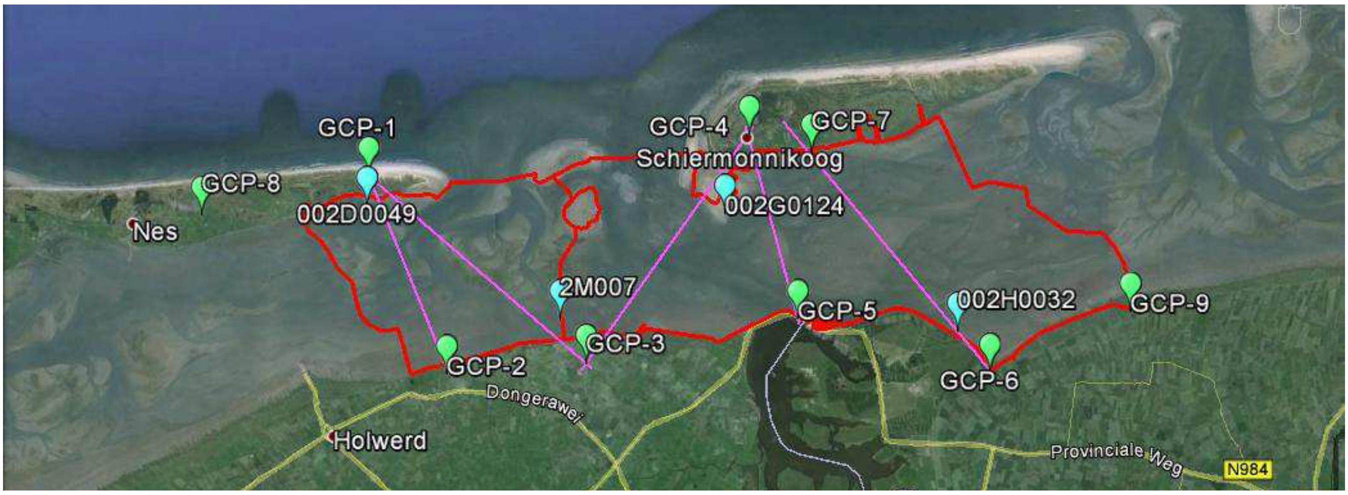

Figure 3: Overview of GCP locations

4. Data processing

4.1. Geodesy

4.1.1. Horizontal

The datum parameters used for this project are listed below:

Datum:	RD
Map projection:	Stereographic
Latitude of origin:	52º 09’ 22.178’’ N
Central meridian:	5º 23’ 15.500’’ E
False Easting:	155000
False Northing:	463000
Scale Factor:	0.9999079
EPSG Code:	28992

Ellipsoid:	Bessel 1841
Semi-major axis a:	6377397.155
1/f:	299.152812825

For the transformation between ETRS89 coordinates and RD the RDNAPTRANS 2008 correction grid is used.

4.1.2. Vertical

The NLGEO2004 geoid model is implemented in the RDNAPTRANS2008 transformation. This model is applied to transform the WGS-84 height to the orthometric NAP-heights.

4.2. Base Stations

Fugro makes use of loosely coupled GPS-processing. A network of actual base stations or virtual base stations closely surrounding the flight is selected. The acquired data is used to calculate a base line between the reference stations and the GPS antenna on the aircraft. The GPS RMS is calculated and checked with the specifications. The forward/reverse flight path is calculated to check the reliability of the solution.

In this case the data from the 06-GPS stations Drachten, Ballum and Borkum were used. The survey area is close to these three stations, leading to an optimal solution.

4.3. Field Processing

Most of the data processing that was done in the field relates to Quality Control and Data Management. Quality Control is discussed in Chapter 5. Data Management activities in the field include making back-ups on separate hard disks, putting the data with correct file names in the right directories and complete the right data management forms.

Processing was mainly done with Riegl software for data extraction and tools from Fugro Horizons for QC (coverage, density and noise).

4.3.1. GPS and INS Flight Trajectory Calculations

The software package AEROoffice from IGI and POSGNSS from Applanix are used for flight trajectory calculations. Loosely coupled solution was used to process the observables of the CORS stations combined with inertial navigation and the GPS antenna attached to the aircraft.

The locations of the CORS stations are in the vicinity of the flight path of the aircraft with an interval of no greater than approximately 60 km to insure a good calculation of the flight trajectory.

The processing workflow generally consists of four steps:

Step 1 – Processing the SBET
Step 2 – Extraction of LAS data and combining all of the LAS in a single project
Step 3 – Searching for corrections and adjusting of LAS data inside of the project.
Step 4 – Delivery.

So the corrections on the LiDAR data, based on overlaps between (cross)-strips and GCP's are determined in step 3. These corrections have been applied by adjusting the LAS data, using TerraMatch software, instead of adjusting the SBET, because this is a faster method.

5. Quality Control

In Figure 4, the processing and quality control procedure from acquiring the data to further end deliverables is shown. Every process needs a validation before the next step can be taken.

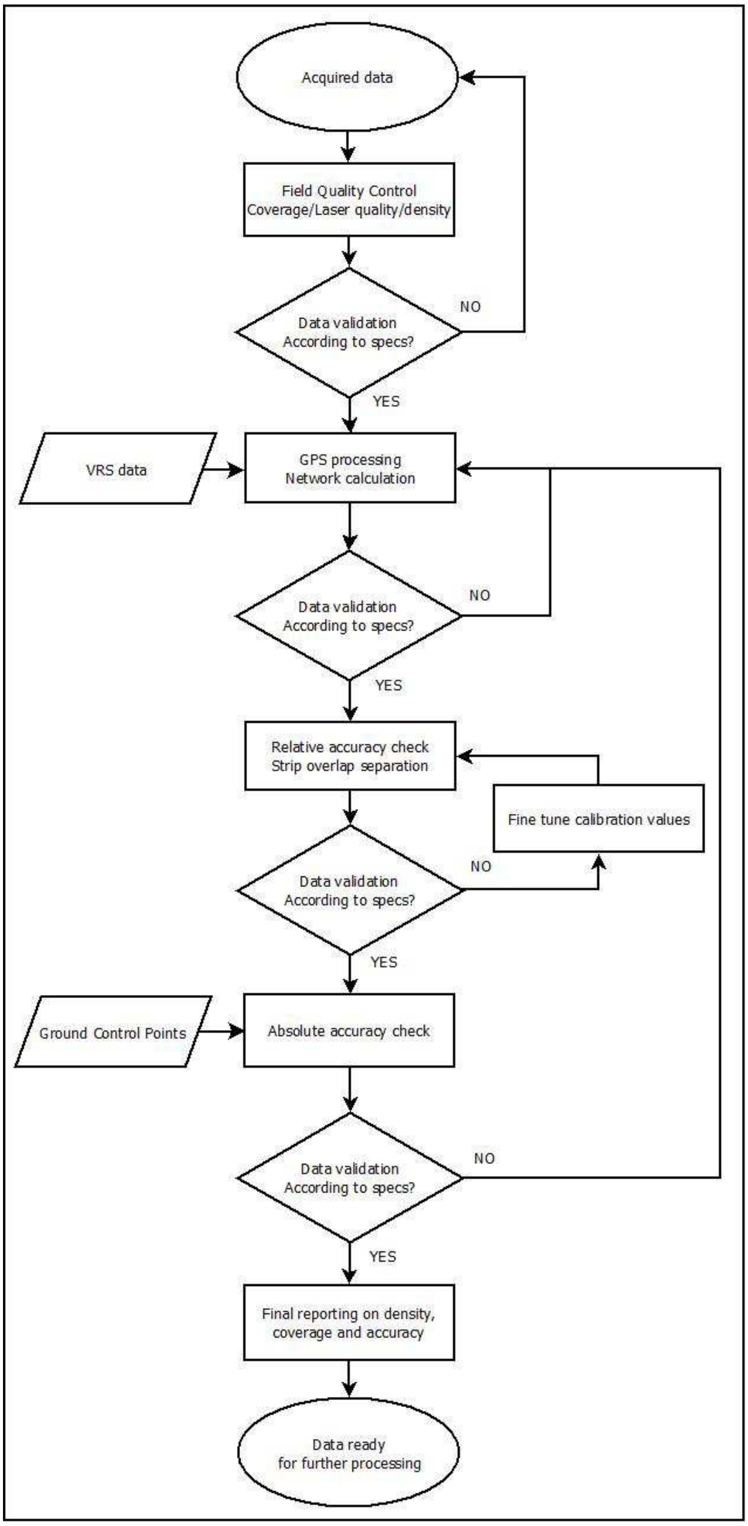

Figure 4: Processing flowchart

5.1. Laser quality

During and directly after the flight, some crucial checks are performed, to assure the data has been acquired up to the standards for further processing. The data is checked on:

- Reflection problems due to strongly absorbing material
- Lack of registered beams due to hardware glitches
- Excessive noise due to system failure

Analyzing the error messages and quick views of the data concluded that no anomalies were present.

Reflection problems on the wet area of mud flats are considered to be LiDAR technology limitation thus are not recognized as a peculiarity during QC process. The final QC on the data confirmed this statement in a later stage.

5.2. Coverage

The coverage of the laser sensor is checked in the acquisition phase. The area covered by the sensor is compared with the boundary file supplied by the client (see Figure 1). Gaps are reported and re-flown.

The coverage is also compared with the data set of the previous year (2012), the results are shown in Figure 5 to Figure 8.

In Figure 5 and Figure 6 the 2013 data is projected over the 2012 data:

- Red is the 2012 data
- Blue is the 2013 data
- Data below -0.70 NAP is coloured dark red

Because the 2013 data is op top, the red areas indicate the locations that were covered in 2012, but showed no hits in 2013.

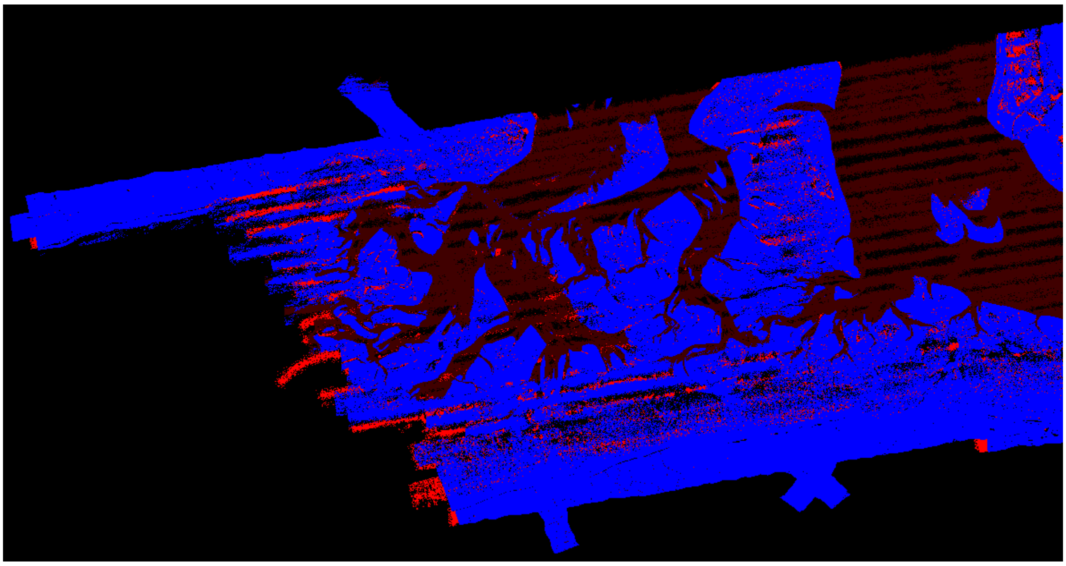

Figure 5: Coverage comparison, 2013 over 2012, western part

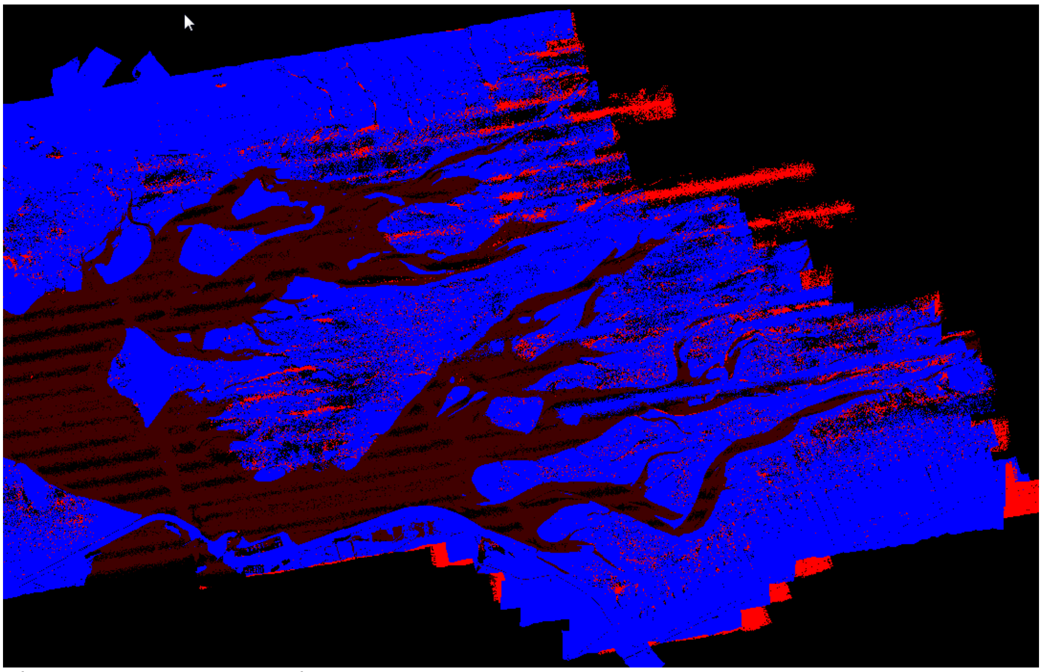

Figure 6: Coverage comparison, 2013 over 2012, eastern part

In Figure 7 and Figure 8 the data is projected the other way around, using the same colour coding. So in these images the blue areas indicate the locations that are covered in 2013 but showed no hits in 2012.

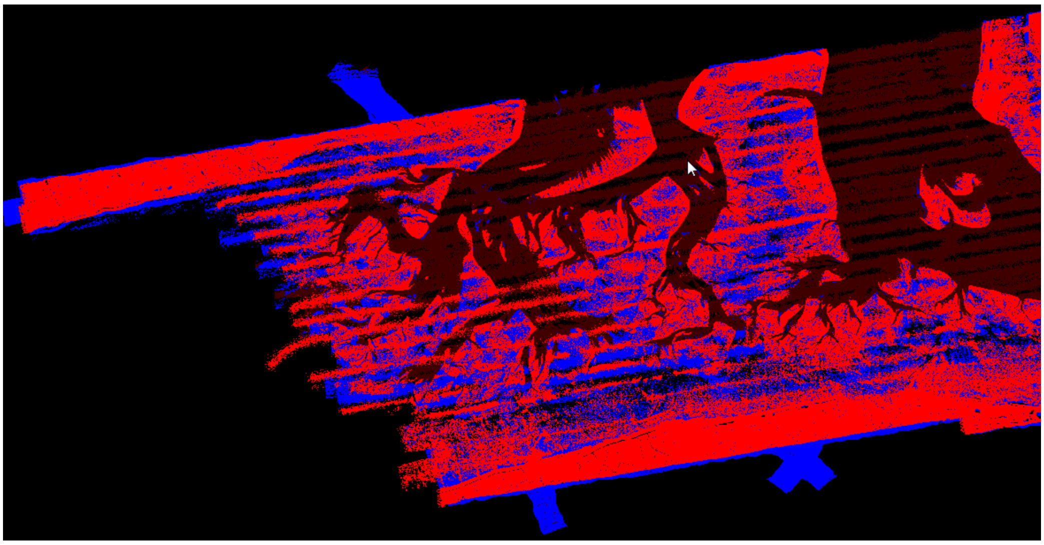

Figure 7: Coverage comparison, 2012 over 2013, eastern part

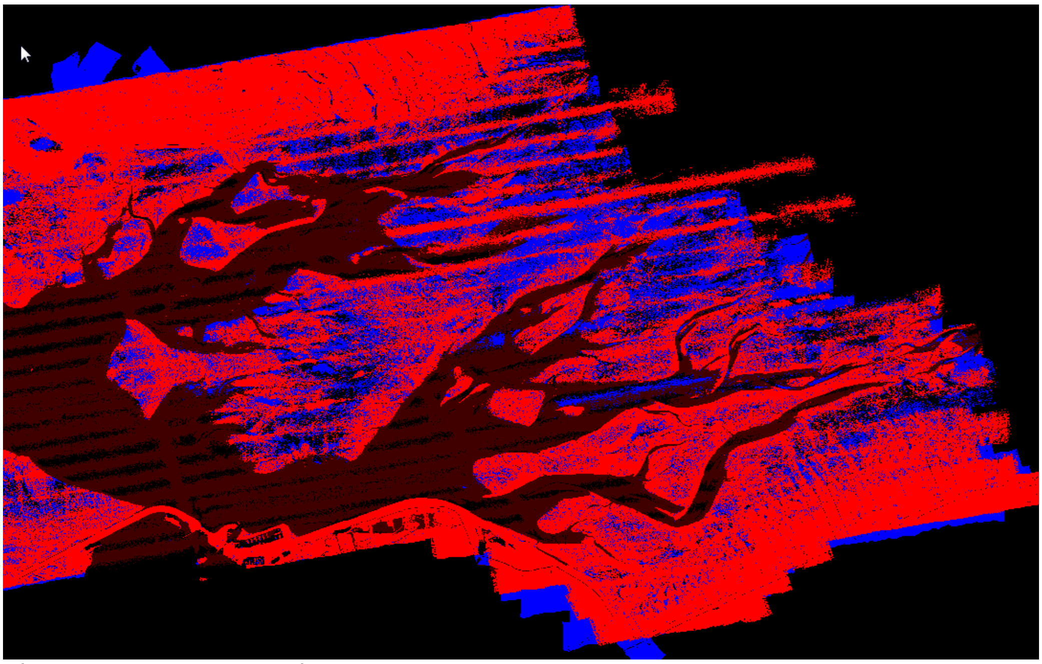

Figure 8: Coverage comparison, 2012 over 2013, western part

From these images, it can be seen that generally the coverage in 2013 is better than in the previous years. Besides some larger locations at edges of the area, caused by a difference in the flight plan, it can be seen that the coverage on the mud flats in mud flats is better in 2013. Due to the wet nature of the mud flats, there are more hits right below the aircraft and less to the side causing this striped pattern. Due to the fact that the flightlines of 2013 do not exactly overlap the flightlines in 2012, there are differences in the coverage between the two years. Some locations area that wre right below the aircraft, and therefore show good coverage, in one year may be on the side of a strip in the other year, where less hits are. The line spacing however is the same for both years.

5.3. Point Density

After the data acquisition a preliminary density check can be executed. The check on the point density requirements is executed in the post-processing phase. The amount of points per m^2 is calculated and according to a colour scheme visually checked on deviations from the expected point density. Point density reduction could take place in the following situations:

- Flight dynamics could cause local deviations in point density
- Lower reflection due to high absorbing material
- Terrain circumstances, like wet area's or steep terrain

Last two situations are considered to be LiDAR technology limitation thus the consequences (low density) of such are not mitigated or avoided during the acquisition phase.

In Figure 9 an overview of the point density over the project area is given. The legend of this overview is as follows:

- Green: 4 or more points per m^2
- Yellow: 3 points per m^2
- Grey: < 2 points per m^2
- Red: Below -0.70 m NAP (so deep water areas)
- Black: No data

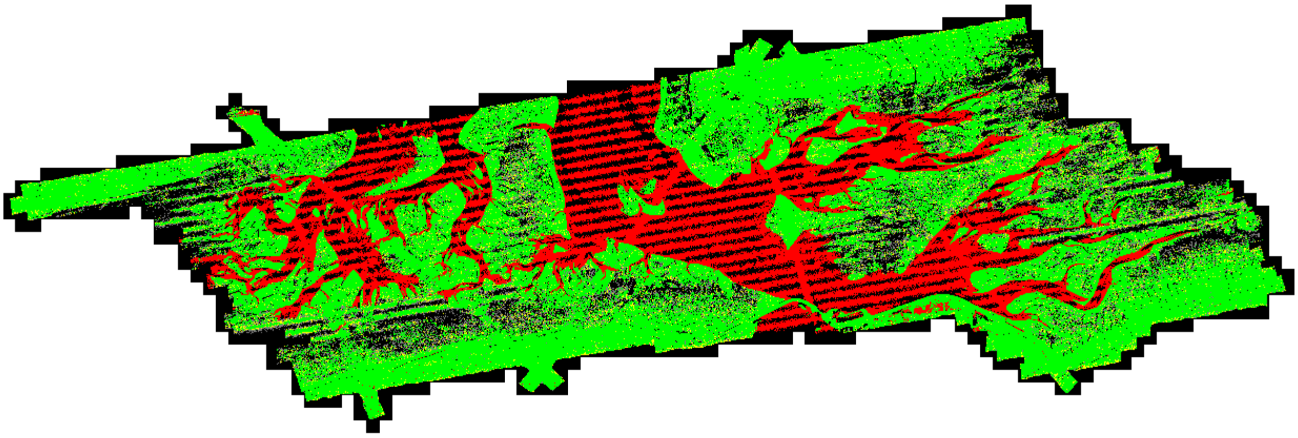

Figure 9: Point density overview

It is clearly visible that on the mainland and the islands the point density is always more than 4 points per m^2. On the mudflats the point density is generally also m ore than 4 points per m^2, however due to the lower reflections on wet areas there are some areas with a lower point density.

In deeper water only a few point just below the aircraft are collected, resulting in the striped pattern.

In Figure 10 a detail of the point density plot is given.

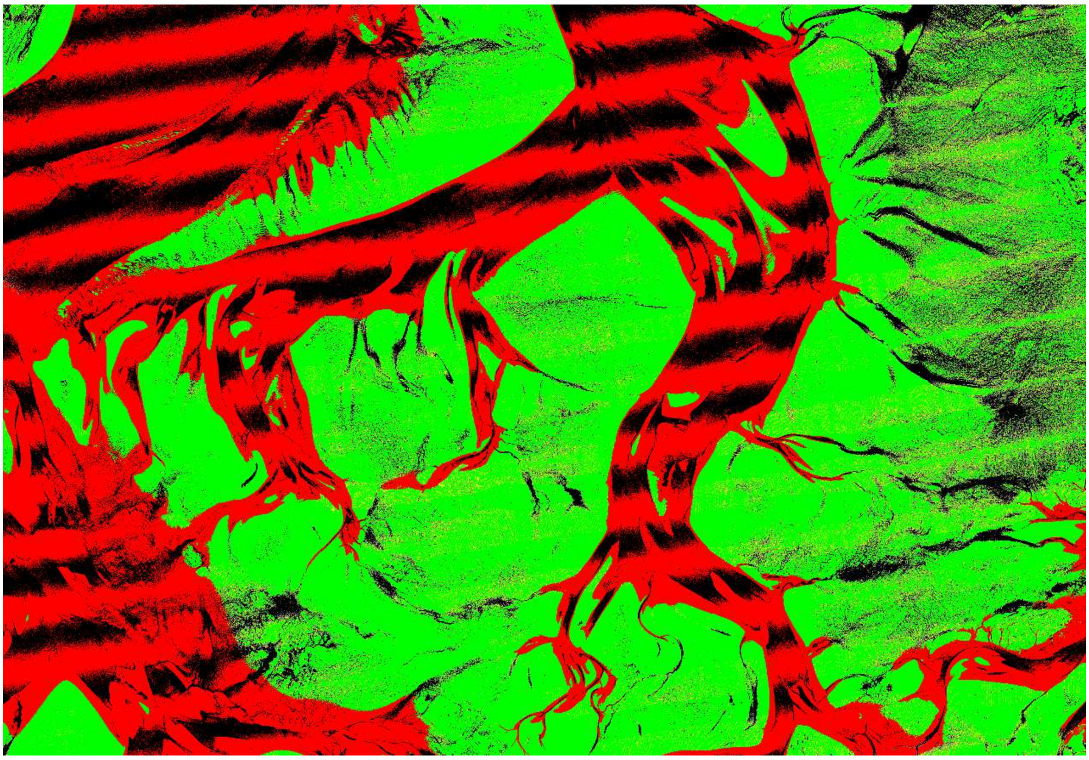

Figure 10: Detail of the point density plot

5.4. Theoretical accuracy

Flying at an altitude of 440 m with a speed of 120 kts and laser frequency of 200 kHz the following theoretical accuracies were expected.

Error source	Remark	Effect on XY or Z	Order of magnitude	Unit	Effect on XY (in meters)		Effect on Z (in meters)	
					Nadir	Edge	Nadir	Edge
Location Survey system	GPS	XY	0.02	Meter	0.020	0.020	-	-
		Z	0.03	Meter	-	-	0.030	0.030
Position Survey system	Heading Pitch Roll	XY XY & Z XY & Z	0.0100 0.0075 0.0075	Degree Degree Degree	0 0.058 0.058	0.045 0.058 0.077	0 0 0	0 0.007 0.038
Range noise		XY & Z	0.020	Meter	0	0.010	0.020	0.017
Angle measurement Laser beam	Noise	XY & Z	0.0000001	Second	0.009	0.010	10e-7	0.005
Rotation axis alignment		XY	0.025	Mrad	0.006	0.006	-	-
Footprint	Beam divergence	XY	0.012 0.50	Meter mrad	0.039	0.044	-	-
Time registration			0.00010	Second	0.006	0.006	-	-
Total error				**Systematic** **Stochastic**	**0.068** **0.061**	**0.100** **0.075**	**0.015** **0.025**	**0.038** **0.030**

Table 2: Theoretical accuracies

The accuracy for each dimension (X, Z and Z) consists of various error sources (as shown above). For this project the height accuracy is very important, for which the following theoretical accuracies are calculated:

- Maximum systematic height error of 3.8 cm
- Maximum stochastic height error of 3.0 cm

	Z accuracy between laser and ground control points
1 sigma	68% < 6.8 cm (1*3.0 cm+3.8 cm)
2 sigma	95% < 9.8 cm (2*3.0 cm+3.8 cm)
3 sigma	99,6% < 12.8 cm (3*3.0 cm + 3.8 cm)

Between two overlaps there are √2x stochastic error and a double systematic error. With the following formula it is possible to check the overlaps between two laser files:
(Sigma x √2 x stochastic error) + (2x systematic error) =

	Z accuracy between two passes
1 sigma	68% < 11.8 cm
2 sigma	90% < 16.1 cm
3 sigma	99,6% < 20.3 cm

All mentioned above are the maximum theoretical errors; the real errors can be less because errors can cancel each other out. Besides, these values of based on the maximum errors, which occur at the edge of a beam. In nadir (centre of the beam) the errors are less, as can be seen in Table 2.

5.5. Relative Accuracy Check

The relative accuracy is checked by comparing the overlaps between flights.

Overlaps are typically planned for the following reasons:

- parallel flight lines where two adjacent flight lines will show a lateral overlap (to cover a larger area that cannot be recorded in a single pass)
- crossing flight lines where an area is covered by more than one laser file with different flight direction
- At the borders of sections, to avoid data gaps flights are planned in such a way that subsequent sections will have a slight overlap with earlier recorded data.

Strip overlap separation calculation is a method for estimating the relative accuracy of laser data, a decreased accuracy can be caused by:
- Calibration issues, often manifested as separations on roof tops and lateral to the flight line.
- GPS/INS processing, often manifested as separations along the flight line.

The relative height offsets are obtained by measuring the height separation between overlapping regions from adjacent strips. Height separation can be computed between totally overlapped footprints from the two strips. For these purposes two different grid data sets are constructed, one for each strip, and then the cell values of these surfaces are compared.

By applying a colour scheme to the separation values, a clear analysis can be made of the relative accuracy of the laser data. In Figure 11 an overview of the strip overlaps is given. The overlaps are indicated with the following colour coding:

	Overlap magnitude
(dark grey)	0 - 3 cm
(light grey)	3- 6 cm
(yellow)	6- 10 cm
(red)	> 10 cm

The overlaps were checked using the following criteria:

- Height difference of 0 cm to 6 cm: good
- Height difference of 6 cm to 10 cm: research is required, if it is structural.
- Height difference bigger than 10cm: research is required

Note that these values do not match the maximum theoretical error values as mentioned in Paragraph 5.4. As stated, the values from Paragraph 5.4 are the maximum statistically allowed errors, whereas from practical experience the errors are usually less. Therefore different test values, based on experience, are generally used in this test.

A conclusion of this method could be to revise the INS/GPS processing or fine tune the calibration values.

It can be seen that in general most of the overlaps are grey, indicating the relative accuracy is good. However still some yellow and red areas are visible. However this can mainly be explained by the method of work (gridding two data sets before analyzing the difference). Therefore, a few general notes have to be made:

- Vegetated and built-up areas do not give a reliable view on the accuracy. This is due to the fact that the laser pulse does not always reflect on exactly the same spot. In case of vegetation for example, the laser pulse will likely reflect on different branches resulting in poor overlap differences. A similar issue occurs with buildings, when the laser pulse may either hit the roof top or the ground (or half-half), also resulting in poor overlap differences. Therefore these areas are not reliable for this test, only large flat areas such as fields or roads are suitable.

- If flights are far apart in time, circumstances could have changed, resulting in strip overlap differences. However, in this specific project the time span between the flights is rather short, so this should not be the case.
- Moving circumstances (e.g. water) or objects (e.g. cars) are not suitable for this method.

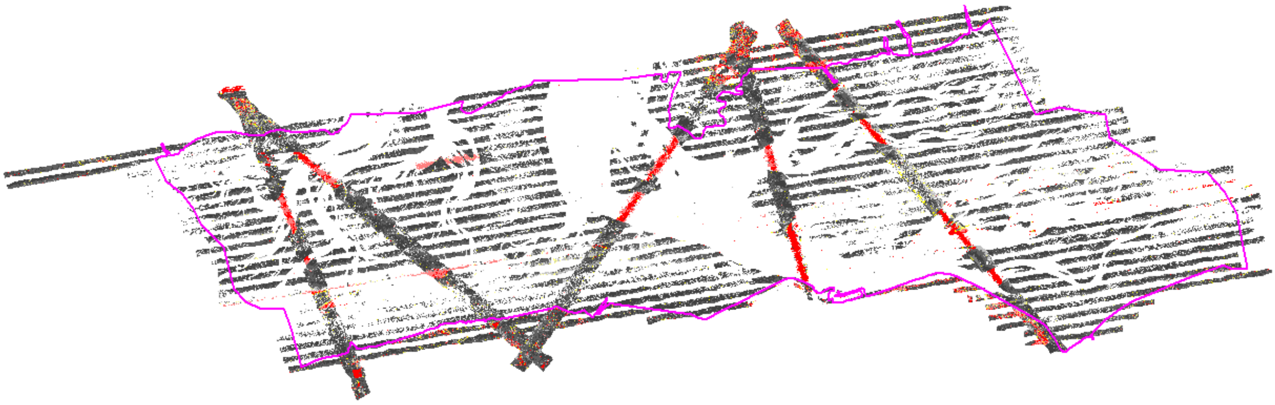

Figure 11: Overview of the overlaps

This becomes more clear when the overview is viewed in more detail, see for example Figure 12. Onshore, it can be seen that the overlap differences are generally very good at flat areas (fields). The red and yellow areas are either vegetated or built-up areas. In the upper left, some yellow colour can be seen. However, this is mixed with grey colours, indicating that the overlap differences are just spread around the 6 cm, resulting in grey and yellow tints mixed.

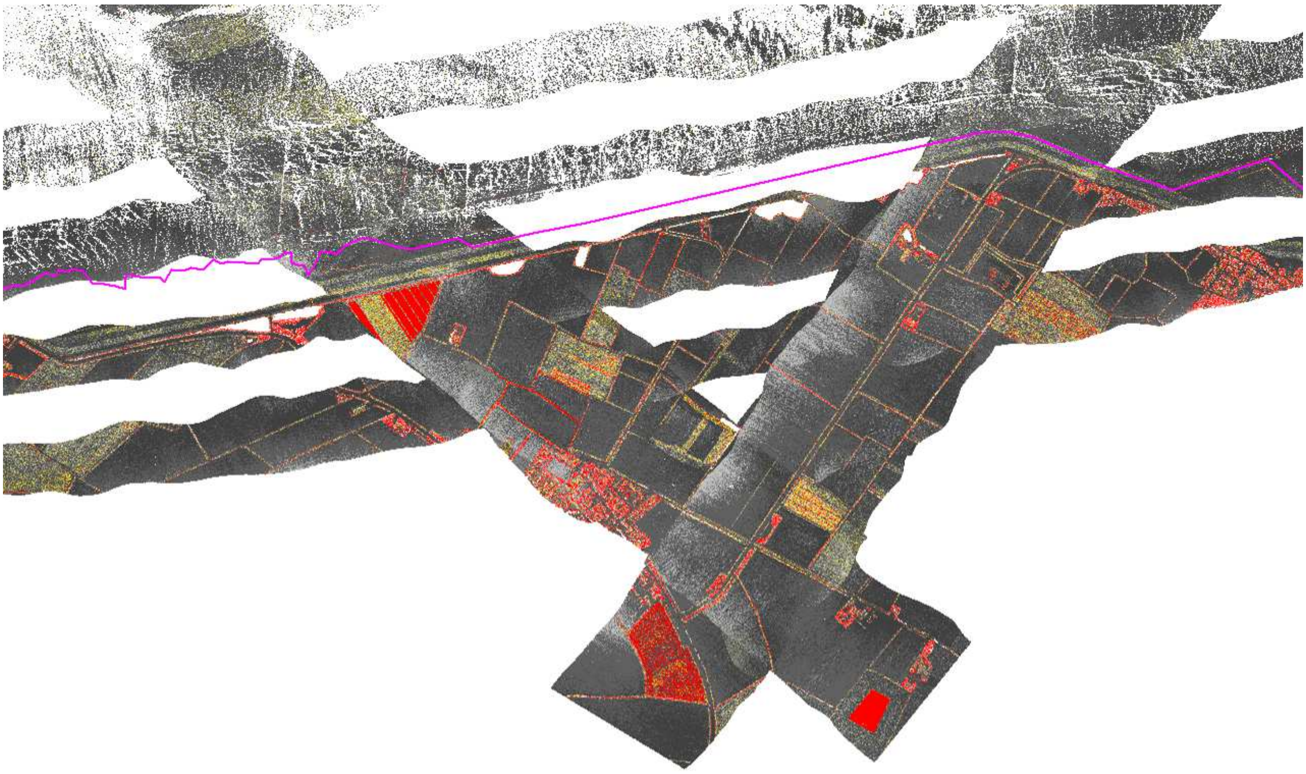

Figure 12: Detail of the overlap overview

So although the relative accuracy cannot be quantified exactly an analysis of these overlap figures prove that the relative accuracy is within expectations.

5.6. Absolute Accuracy

To evaluate the accuracy of a dataset, a comparison must be performed between the coordinates of several points, which are locatable easily in all the dataset(s), and an independent dataset of higher accuracy. For this research, LIDAR data were compared to Ground Control Points collected separately with RTK GPS and levelling equipment. Those points were used as a ground truth to estimate the absolute accuracy of the Z of the laser. A Grid Comparison method was used to develop grids of various resolutions. Points in these grids were extracted and compared to one another to perform accuracy assessments.

As already shown in Figure 3, for this survey 9 control grids on hard surface and 4 control grids on the mudflats were surveyed. All land surveys have been performed by Fugro GeoServices B.V.

In Figure 13 an example of one of the control grids on hard surface is given.

Figure 13: Example of one of the GCP's uses for this project

The flights were first matched in a relative way, see Paragraph 5.5. After that, the complete data set is checked with the ground control points to check if for any systematic errors and adjust the entire dataset to match the ground control points. After this, the final check is done on the same Ground control points.

All grid checks were checked using the following criteria:

Maximum systematic error (Average dz)	Maximum stochastic error (standard deviation)
100% < 3.8 cm	68.3% < 3.0 cm
	95.4% < 6.0 cm
	99,7% < 9.0 cm

The complete results of the checks are included in Appendix D, a summary is given in Table 3.

Parameter	Grid 1	Grid 2	Grid 3	Grid 4	Grid 5	Grid 6
Nr of points	40	40	40	40	28	40
Average dz	-0.022	0.003	-0.007	0.006	0.020	-0.001
Minimum dz	-0.034	-0.010	-0.025	-0.012	0.002	-0.015
Maximum dz	-0.013	0.013	0.005	0.027	0.029	0.006
Root mean square	0.022	0.006	0.009	0.010	0.020	0.004
Std deviation	0.004	0.006	0.007	0.008	0.005	0.004

Parameter	Grid 7	Grid 8
Nr of points	40	40
Average dz	-0.006	-0.023
Minimum dz	-0.024	-0.031
Maximum dz	0.017	-0.014
Root mean square	0.010	0.022
Std deviation	0.008	0.003

Table 3: Absolute accuracy check for grids on hard surface. Dz is calculated as laser Z minus known Z

Grid 9 is removed from this Table, as this grid shows a large systematic error of 4.7 cm. This grid has been investigated by comparing the grid measurements with surveys from previous years but this grid does not match the old data as well. Therefore it is assumed that this grid is not reliable, probably this is due to an unreliable NAP bolt. Besides this, part of grid 5 was surveyed incorrectly, resulting in less points for that grid.

When the grids from all point together are analyzed, this results in the values shown in Table 4.

Parameter	Average of all points
Nr of points	308
Average dz	-0.005
Minimum dz	-0.034
Maximum dz	0.029
Root mean square	0.014
Std deviation	0.014

Table 4: Absolute accuracy check, results on all points

These results show that the systematic error as well as the stochastic error is well within the expected maximum errors.

Apart from the 9 control grids on hard surface, four grids on the mudflats were measured. These grids have been measured by GPS-RTK, using a base station of our own that was placed on the land. The base station was levelled relative to an official NAP benchmark. See Figure 14 for an example of such a grid.

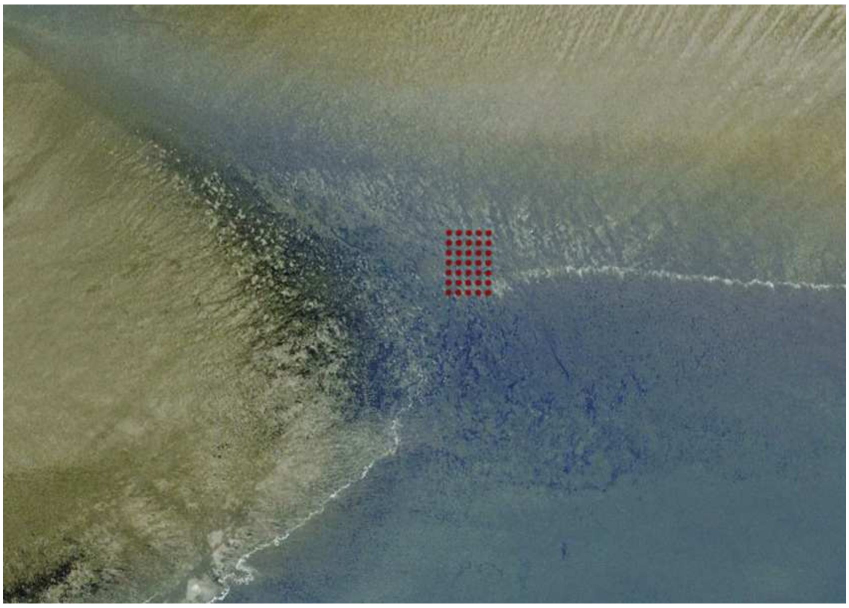

Figure 14: Example of a grid on mudflats

As these grids are located on the mudflats, which may vary over time and per season, they should ideally have been surveyed at the same time as the LiDAR acquisition (18 until 20 October 2013). However, for several reasons, such as weather, tidal conditions and LiDAR equipment problems, this was not possible.

These four grids were surveyed on the following days:

- 2M007: 24-10-2013
- 002H0032: 25-10-2013
- 002D0049: 29-10-2013
- 002G0124: 31-10-2013

These grids have been checked with the LiDAR data as well, in the same way as the grids on hard surface. However, the grids on the mudflats are less accurate, because the points can not be idealized as good as points on a hard surface and can therefore not be surveyed as accurate. Besides that, the grids may show a difference due to variation in time. Therefore these grids have only been used to check the data and not to fit the data.

The results from the RMSE analysis for the four locations using the derived control planar features are listed in Table 5.

Parameter	**Grid 002D0049**	**Grid002G0124**	**Grid 002H0032**	**Grid 2M007**
Nr of points	35	35	34	35
Average dz	-0.088	0.041	0.020	-0.018
Minimum dz	-0.157	0.022	-0.008	-0.049
Maximum dz	-0.025	0.061	0.053	0.019
Root mean square	0.091	0.042	0.024	0.024
Std deviation	0.026	0.009	0.014	0.016

Table 5: Absolute accuracy check for grids on mudflats

5.7. DTM

From the point cloud average grids are produced, with a cell size of 1 x 1 metre. The DTM is checked on coverage and whether it is a correct representation of the terrain.

The results of the coverage check are given in Figure 15. From the figure can be seen that the entire project area (between the red boundary) is covered.

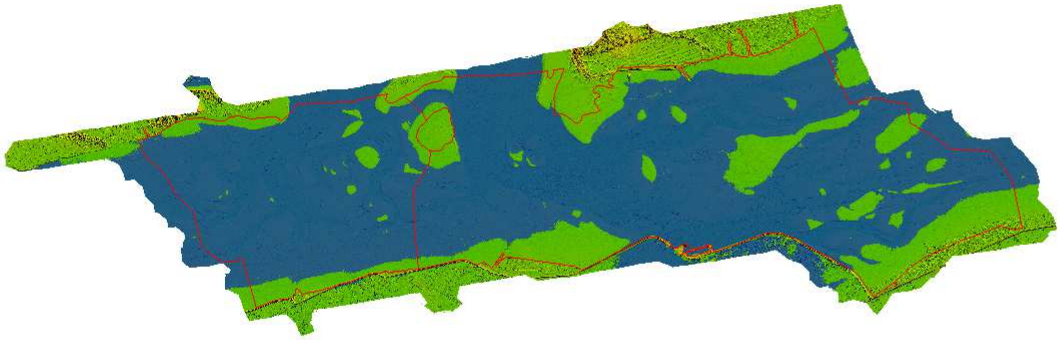

Figure 15: DTM of the project area

Several spot-checks have been done to visually determine if the grids are representative. The check is specifically aimed to determine locations with unexpected big height differences. No anomalies were found in this test. Only at the edges of the area, outside the boundary, some errors due to the interpolation were found. In Figure 16 some examples of these errors are shown. This is however inevitable as there are no data points at the edges of the area.

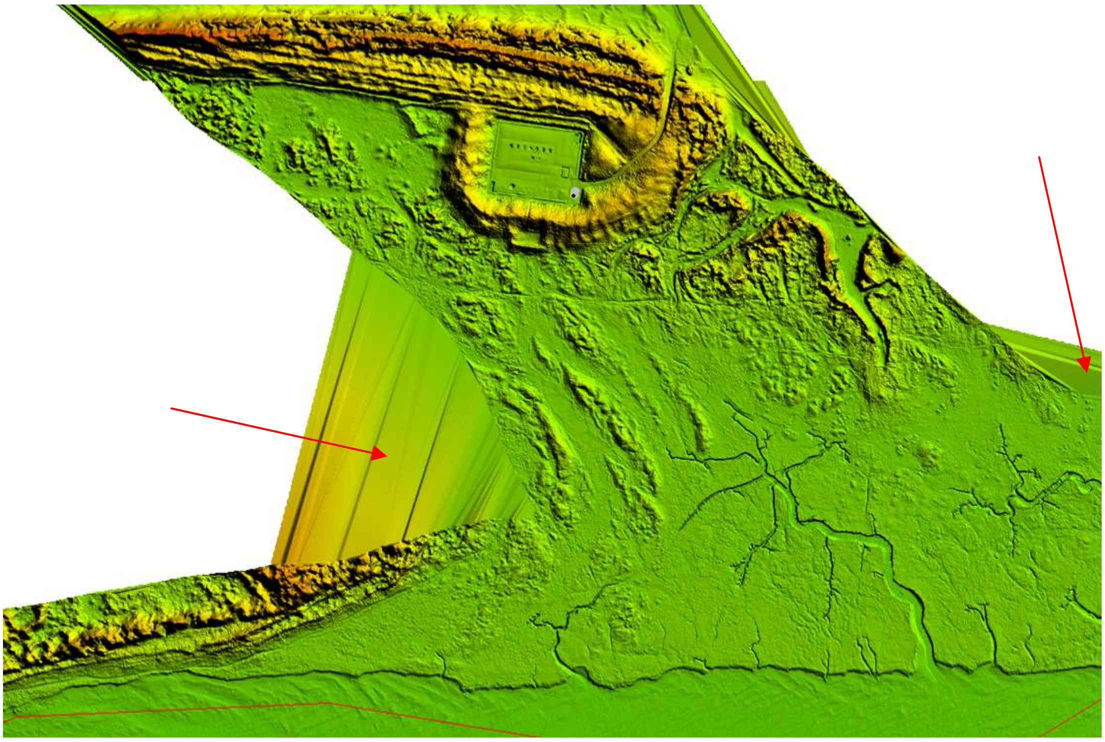

Figure 16: Examples of interpolation errors

6. Deliverables

The following data has been delivered to Deltares and NAM on the 5th of December:

- LAS Files with outliers removed
- DTM as 1m average grids in ASC and XYZ format

The data has a tile dimension of 1000x1250m.

Fugro can supply further products like differential grids and imagery for identification at request.

7. Conclusion

Below a summary is given of the conclusions and approvals made in the quality report.

Specification	Condition or requirement	Conclusion	Approved
Absolute accuracy	9 Ground control grids to check the absolute z- accuracy < 62 mm	Average dz (cm) 0.0 SD dz (cm) 0.1	Approved
Relative accuracy	Allowed difference between overlapping flights	Quality checked	Approved
Classification ground/non-ground	Should be of sufficient quality to create reliable ground model	Quality check	Approved
Laser quality	Check on anomalies in laser quality	No anomalies found	Approved
Laser coverage	The entire area inside the boundary must be covered	With exception of deep waters the entire area is covered with laser points	Approved
Point density	Point density should be more than 4 points per m^2 on dry areas	Point density on representative locations is more than 4 points per m^2.	Approved
DTM	Check on coverage	Entire project area covered.	Approved
DTM	Check on correct representation	Inside project boundary no anomalies were found. Only at the edges some anomalies were found due to interpolation issues	Approved