Report Lidar Survey

WADDENZEE

SPRING SURVEY 2016

Datum: 6th of June 2016

Client: Nederlandse Aardolie Maatschappij :

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Reviewer: F. de Boeck

Project number: N605

Version: v1

1 Introduction

Early May 2016, Eurosense carried out an airborne LiDAR survey for the Nederlandse Aardolie Maatschappij (NAM in this document).

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

This project was carried out for the 10th time; the previous surveys till May 2015 were executed by Fugro, from October 2015 Eurosense carried out the project.

- April 2010
- April 2011
- September 2011
- October 2012
- October 2013
- May 2014
- September 2014
- May 2015 Subcontract flight to Eurosense.
- October 2015

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 and 6 respectively. In Chapter 7 a summary of all conclusions is given.

2 Project specifications

2.1 Project area

The airborne survey covers the areas Pinkegat and Zoutkamperlaag. The survey area and flight lines are shown in Figure 1. The survey encompasses 879 kilometres of flight lines with an east-west orientation and five cross lines mostly perpendicular tot the flight lines.

Figure 1: Fligth plan overview.

2.2 Demands and conditions for survey

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 control grids on the edges of the project area (see Figure 8) to be able to check and enhance the absolute accuracy.

Simultaneously, aerial images are collected using an IGI Digicam 50MP camera. These images were used to attach an RGB value to the laser points. Due to this requirement, the surveys could only be executed during daytime.

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

Table 1: Survey platform.

Survey platform	Specificatie
Aircraft type and model	Cessna 404 (OO-GPS)
GPS/INS type and model	Novatel 512 + IGI IMU-IId
Scanner type and model	Riegl Q680i
Aerial camera type and model	IGI Digicam 50MP

Table 2: Flight parameters.

Parameters	Value
Height AGL	460 meter
Speed	130 kts
Line Spacing	338 meter
Theoretical overlap	180 meter
Number of lines	33
Number of cross lines	5

Table 3: Scan parameters.

Parameters	Value
Scan Angle	60 degrees
Frequency	240 KHz
Point density	4,3 points/m^2
MTA Zone	1

Table 4: Image Specifications.

Parameters	Value
Scan Angle	35 mm
Size of CCD matrix	817x 6132
CCD size	6 εm
Image GSD	7,9 cm

3 Missions

3.1 Flight overview

The survey was executed in two flights over target. In table 5 the responsible persons are listed who executed the survey. In table 6 overview is given of the executed flights.

Table 5: Overview project team.

Function	Person
Project Manager	Wout Velthoven
Captain	Douglas Strömberg
Co pilot	Dimitri Vandermeiden
Navigator	Donat Jackowski

Table 6: Overview flights (local time)

Date	Take off	Airport	Landing	Airport	Air time	
05-05-16	12:45	Deurne	18:25	Groningen	5:40	From North to South, than from South to North.
06-05-16	14:30	Groningen	20:12	Deurne	5:42	North to South

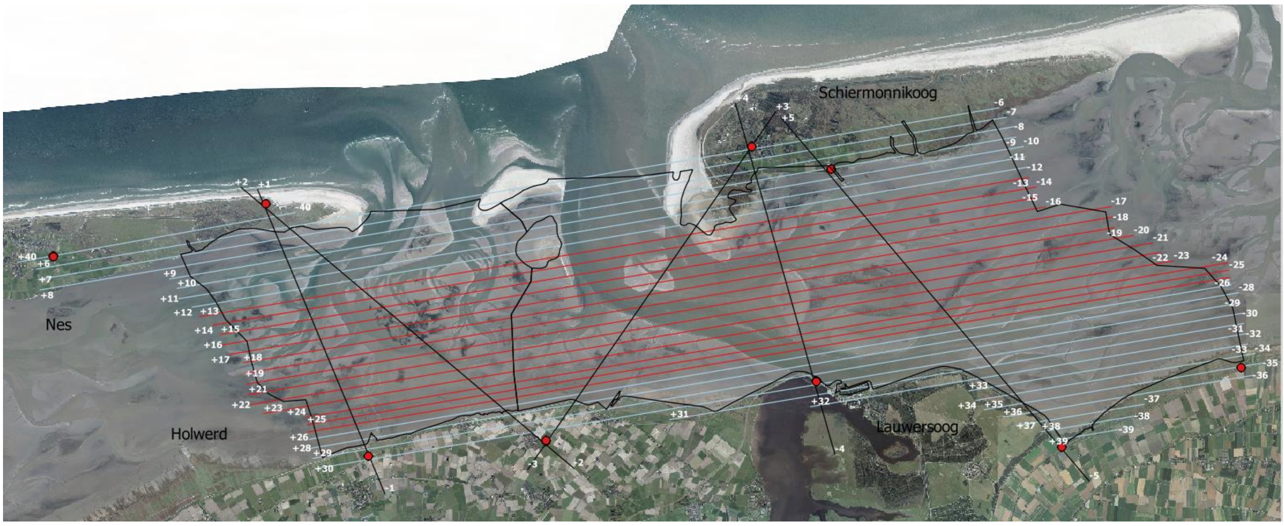

Figure 2: Fligth plan overview. Blue lines flown on 5-5-2016, Red lines flown on 6-5-2016. Cross lines (Black) are flown avery mission.

3.2 Tidal planning.

In order to achieve the requirements lower than -0,70 m NAP, two main actions were implemented:

- Survey windows were first planned using the astronomical tide table, and then refined on the morning of the flight using the expected tide provided by the Rijkswaterstaat http://www.rijkswaterstaat.nl/apps/geoservices/rwsnl/awd.php?mode=html&projecttype=waterstanden.

- Water level for this campaign has been assessed by 4 stations (Nes, Holwerd, Lauwersoog and Schiermonnikoog (see location on Figure 1 Page 3). Survey Lines have been flown when the entire lines were below -0.70 m NAP (according to expected tide tables)

On Thursday 5-5-2016 and Friday 6-5-2016 the weather was stable, good visibility and clear blue sky. In tale 7 the tidal levels are given for 5 and 6 May 2016

Table 7: Used tidal stations (local time) when water level is lower than -0,70 m NAP

Location	Day	Astronomical		Expected		Observed	
		start	end	start	end	start	end
Holwerd*	05-05-16	15:00	17:40	15:00	17:50	15:00	18:00
Lauwersoog	05-05-16	14:10	17:40	14:00	17:50	14:10	18:00
Nes	05-05-16	14:10	17:10	13:50	17:20	14:00	17:20
Schiermonnikoog	05-05-16	14:20	17:40	14:00	17:50	14:10	17:50
Holwerd*	06-05-16	15:50	18:40	15:40	18:40	15:50	18:40
Lauwersoog	06-05-16	15:00	18:40	15:00	18:40	15:10	18:40
Nes	06-05-16	15:00	18:00	15:00	18:10	15:00	18:00
Schiermonnikoog	06-05-16	15:10	18:00	15:00	18:40	15:20	18:40

*Station Holwerd is interpolated since this station does not excist.

The cross lines have been flown avery mission. Crossline 1,3,5 are flown before the survey. Cross line 2,3 and 4 have been flown after the survey. Crossline 3 has been flown the second time in opposite direction.

4 Date 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 09ô22.178ôôN
Central meridian:	5º 23ô15.500ôôE
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. This is applied for both the LiDAR survey as the terrestrial surveys.

4.1.2 Base Stations

For trajectory processing, we made use of tightly coupled GPS-processing. A network of actual base stations and virtual base stations closely surrounding the flight is selected. The used base stations are Schiermonnikoog, Ameland en Leewarden from Netpos. 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 against specifications. The forward/reverse flight path is calculated to check the reliability of the solution.

4.1.3 Field processing

Most of the data processing that was done in the field relates to Quality Control and Data Management. Quality Control is provided 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.

4.1.4 GPS and INS Flight Trajectory Calculations

The software package GrafNav from Novatel and AeroOffice from IGI were used for flight trajectory calculations. Tightly coupled solution was used to process the observables of the CORS stations and the GPS an-tenna attached to the aircraft in GrafNav; this GPS-only solution was then combined with inertial navigation in AeroOffice.

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 ensure a good calculation of the flight trajectory.

The processing workflow generally consists of four steps:

Step 1 – Processing the SBET (Smoothed Best Estimated Trajectory)

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.

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. The differences are translated into corrections values for the system orientation – east, north, elevation, roll, pitch and heading.

The Tie line approach was used. This approach is using feature to feature matching, looking for section lines on flat ground, section lines on surface, roof intersection line. The different tie lines types are searched for in different laser point classes. For tie lines on flat ground and surfaces, ground class is used, and for roof intersection, building class is used. After automatic search of tie lines, some manual filter of the worst tie line with the largest mismatch is checked. On water surfaces, different levels of water are present and big mismatches are detected. All the tie lines from water surfaces where removed to not influence the final correction. After cleaning the tie lines, corrections for roll pitch and heading for all dataset is calculated and applied to the tie lines. After corrections XYZ per strip are calculated and applied to the tie lines. If the output result from tie lines is satisfying we apply the same correction to the laser dataset. After output control report using, the reference field check is done on the LiDAR dataset

4.1.5 RGB assignment

In order to make the Lidar point cloud easier to interpret, natural RGB colours were assigned to the laser points. The Riegl laser scanner does however not capture these colours, therefore a different approach is followed where the aerial images are used.

After the data capture, the images are georeferenced using the same trajectory as the Lidar data, to make sure these two data sets match well. By using specialized software for every laser point the nearest pixel in the aerial image is determined and the RGB value of that pixel is copied and assigned to the laser points.

5 Workflow

In the figure below, the general processing and quality control procedure from acquiring the data to deliverables is shown.

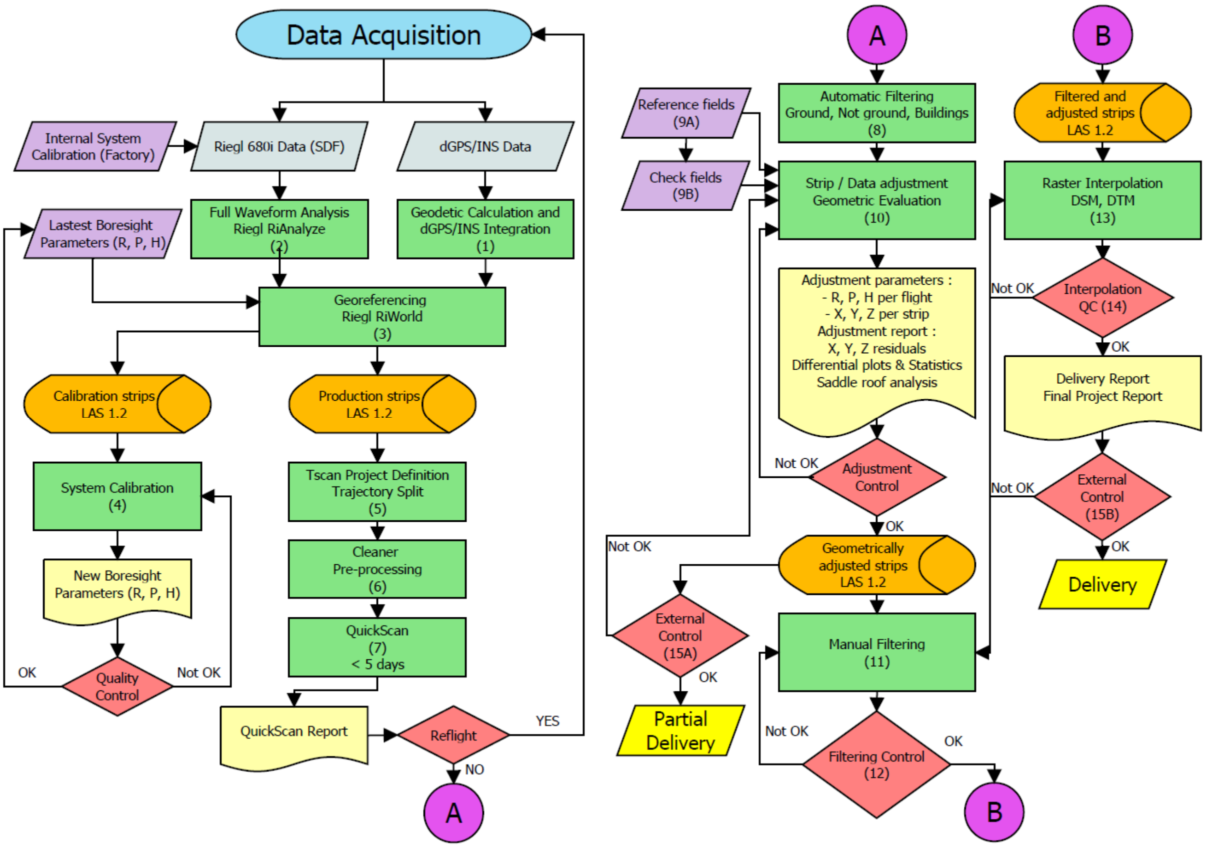

Figure 3: Workflow processing lidar data.

5.1 Coverage

The area is checked if gaps related to the flight acquisition are present in the dataset. This check is done visually on the reached overlap between the runs. No gaps have been found. All flown runs have overlap with neighbouring runs.

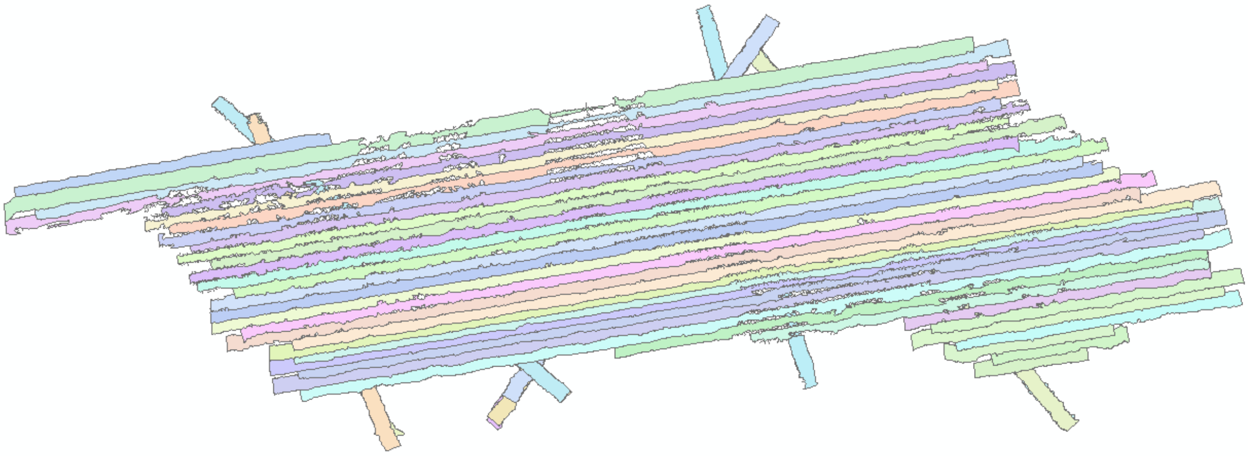

Figure 4: Runs footprints - Check for gaps

5.2 Height difference between strips

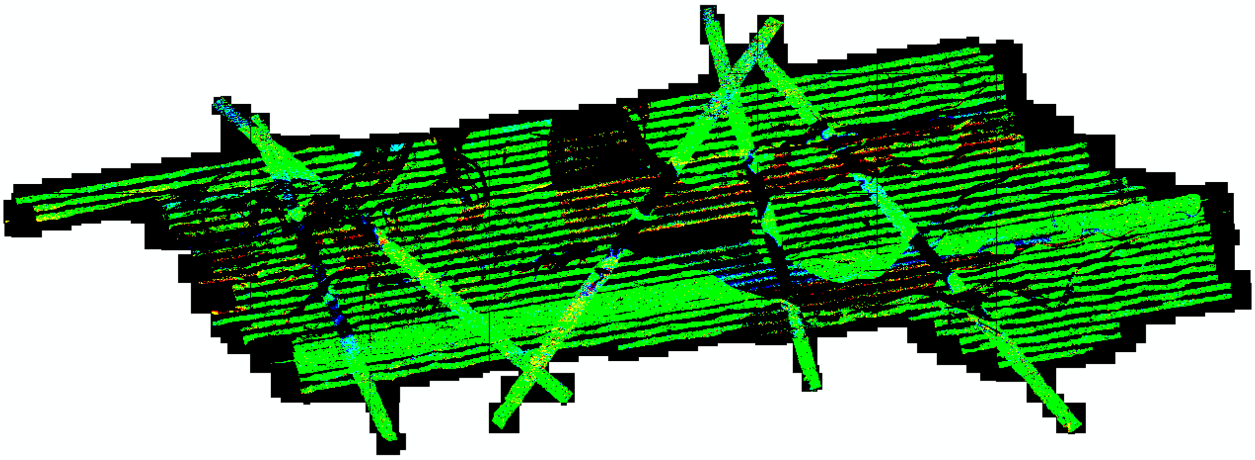

Figure 5: Height difference between strips: green <0-5cm; red 5-10cm; blue >10cm

All blue and red areas were checked in the LiDAR data. These high values are present because of the different water levels between the survey lines.

5.3 Density plot

The check on the point density requirements is executed in the post-processing phase. The amount of points per m² 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 areaô 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 6 an overview is given of the point density over the project area. Itô s clearly visible that the point density is reached on normal terrain circumstances (dry land). In figure 7 a detailed view is given showing that the point density is lower caused by lower reflection due to high absorbing material.

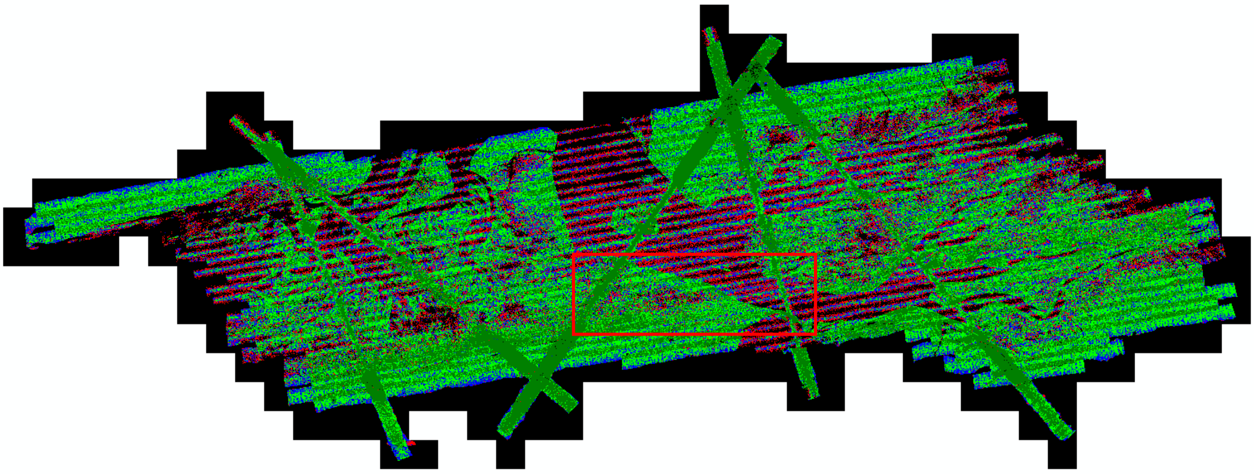

Figure 6: Point density [pts/m²] red (1), blue (2-3), ligth green (4-8), dark green (>8)

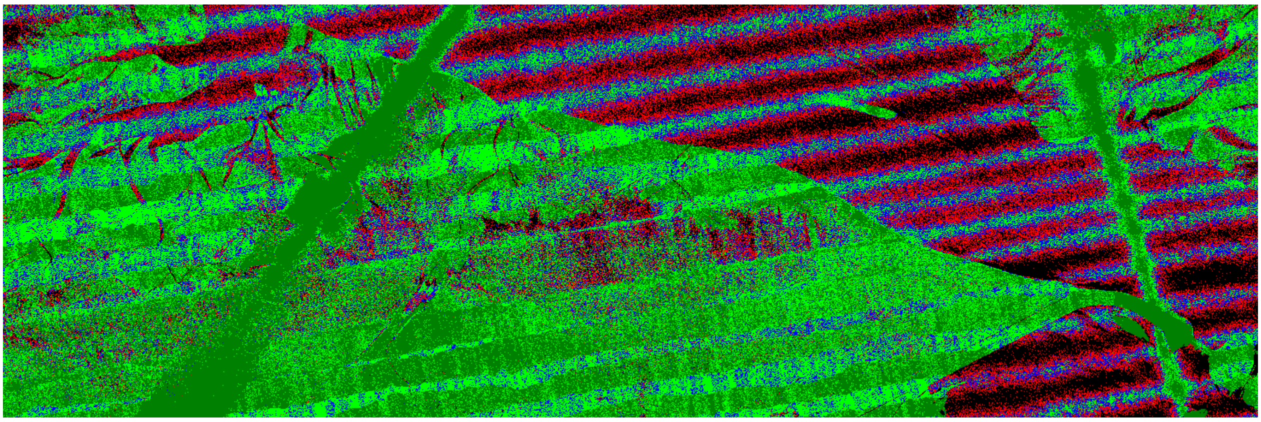

Figure 7: Zoom on point density [pts/m²] red (1), blue (2-3), ligth green (4-8), dark green (>8).

Any visible inprovement is visible with the close axes.

5.4 Ground control

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). 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. Points in these grids were extracted and compared to one another to perform accuracy assessments.

	Control Grid	dZ max	dZmin	dZ average	St. Dev. dZ
before adjustment	GCP-1	-0.034	-0.067	-0.048	0.009
	GCP-2	-0.057	-0.100	-0.077	0.011
	GCP-3	-0.005	-0.066	-0.034	0.016
	GCP-4	0.032	-0.042	-0.001	0.019
	GCP-5	0.017	-0.003	0.010	0.005
	GCP-6	0.053	0.004	0.028	0.013
	GCP-7	0.009	-0.011	-0.001	0.005
	GCP-8	0.159	0.046	0.098	0.035
	GCP-9	0.033	0.018	0.026	0.003
after adjustment	GCP-1	-0.023	-0.045	-0.034	0.005
	GCP-2	-0.037	-0.068	-0.052	0.007
	GCP-3	-0.007	-0.043	-0.024	0.010
	GCP-4	0.020	-0.020	0.003	0.010
	GCP-5	0.028	0.010	0.020	0.005
	GCP-6	0.044	0.025	0.036	0.005
	GCP-7	0.030	0.001	0.013	0.006
	GCP-8	/	/	/	/
	GCP-9	0.056	0.039	0.049	0.003

Table 8: Height difference reference fields and LiDAR data in meters before and after adjustment

The average height difference is 0,010 m with a standard deviation of 0,034 m.

GCP8 data could not be used, because GCP8 area has been re-worked since its survey in 2013.

Figure 9: GCP8 during the survey in 2013 (left) and after 2014 (right).

An overview of Control Grids location is provided in Figure 4. 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 Control Grids locations.

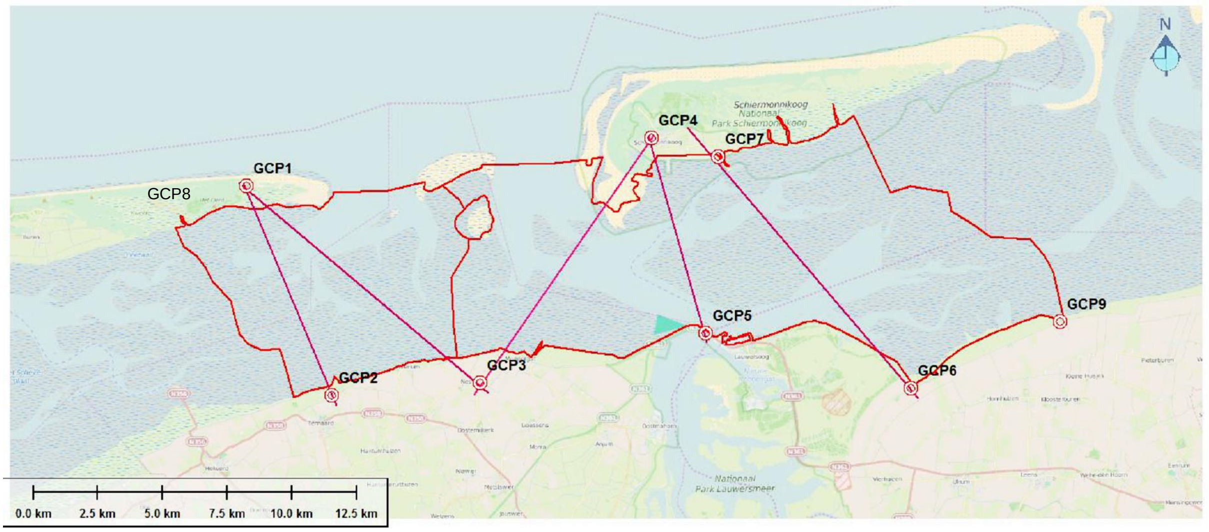

Figure 10: Overview location GCP's.

5.5 Differential map

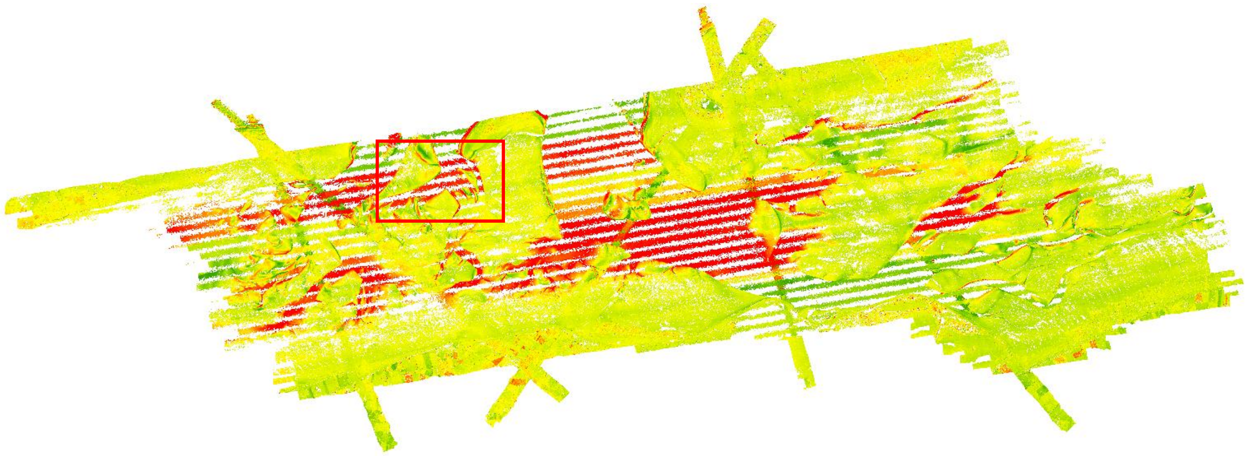

Figure 11: Differential plot 09/2015 – 05/2016

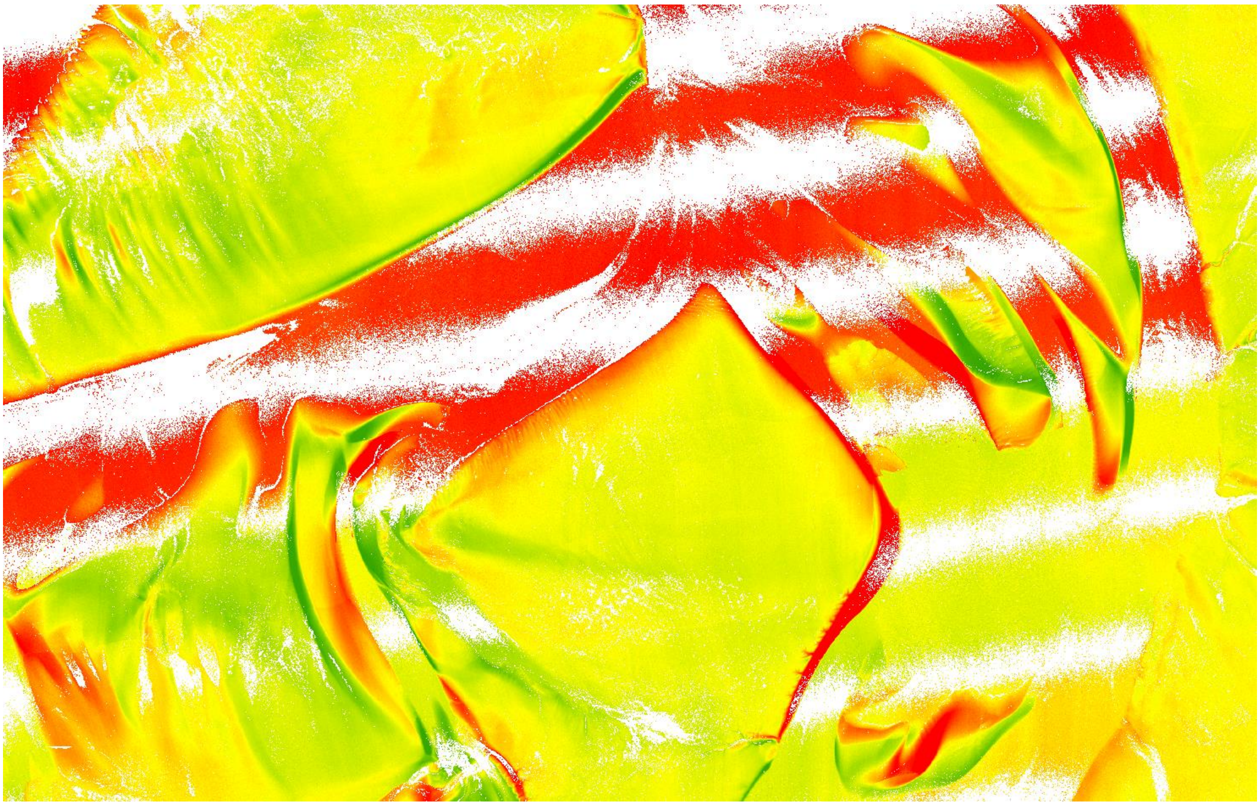

Figure 12: Zoom on the differential plot 09/2015 ï 05/2016

Red: $Z_{2015} > Z_{2016}$

Yellow: $Z_{2015} = Z_{2016}$

Green: $Z_{2015} < Z_{2016}$

6 Theoretical errors of a single strip

In LiDAR surveys, usually a stochastic and a systematic error can be discriminated. The stochastic error indicates the high frequent noise of the LiDAR measurement system. Most of this noise will disappear when the data is gridded to a larger cell size. The systematic error indicates the low frequent navigational error. This error will remain constant over short periods of a couple of seconds, when GPS constellation and flight circumstances do not change. However, within a flight strip, and even more between two flight strips, this will change significantly. In fact, this error has a stochastic character, but due to the long wavelength it can locally considered to be constant.

Table 5: Error distribution in Lidar system.

Error Source	Remark	Effect on X,Y,Z	Order of magnitude	Unit	Effect on XY (in meters)		Effect on Z (in meters)	
					Nadir	**Edge**	**Nadir**	**Edge**
Location Survey	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	0.008 0.005 0.005	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	0,010	0,02	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	-	Rotation axis alignment
Footprint	Beam divergence	XY	0.012 0.50	Meter mrad	0,039	0,044	-	-
Time registration			0.00010	Second	0.006	0.006	0.0001 0	Second
Total error				**Systematic** **Stochastic**	0,068 0.061	0,100 0.075	0,015 0.025	0,038 0.030

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	8 Ground control grids to check the absolute z-accuracy < 68 mm	Average dz: 1.0 cm StdDev dz: 1.2 cm	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 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