Field

Report

43000 - Waddenzee

LiDAR acquisition for 2024

Contents

1. General information

1.1. Customer

Name:	Nederlandse Aardolie Maatschappij B. V.
Adress:	Schepersmaat 2 9405 TA Assen PO BOX 28000 9400 HH Assen The Netherlands
Contact person:	Raoul Quadvlieg Geomatics Manager NAM

1.2. The project

Name:	Waddenzee – LiDAR acquisition for 2024
Number:	43000
Area:	Pinkegat and Zoutkamperlaag in the Wadden Sea, in the north of the Netherlands

1.3. Contractor

Name:	Field Geospatial AS
Address:	Drammensveien 260, 0283 Oslo Norway
Project number:	10456
Project manager:	Andreas Wiger

1.4. Coordinate system

Horizontal datum:	Amersfoort
Projection:	RD New (Oblique Stereographic)
Vertical datum:	Normaal Amsterdams Peil (NAP)

1.5. General project description

The Wadden Sea in the north of the Netherlands is the ultimate interface between land and sea and because of its mudflats and tidal shallows it is very sensitive to changes in dynamics such as erosion by sea level rise, marine sedimentation and surface subsidence due to gas production.

The objective of this survey is to acquire and process LiDAR data in order to monitor the dynamic process of the mudflat in Pinkegat and Zoutkamperlaag in the Wadden Sea using airborne LiDAR. Given the measured time-lapse topography over time change of morphological parameters such area, height and volume of the mudflat can be derived. The deviation of the morphological parameters is subject to an independent analysis which is out of scope of this project.

1.6. Project coverage

The figure below shows the location of coverage the 2 areas in the Waddenzee project:

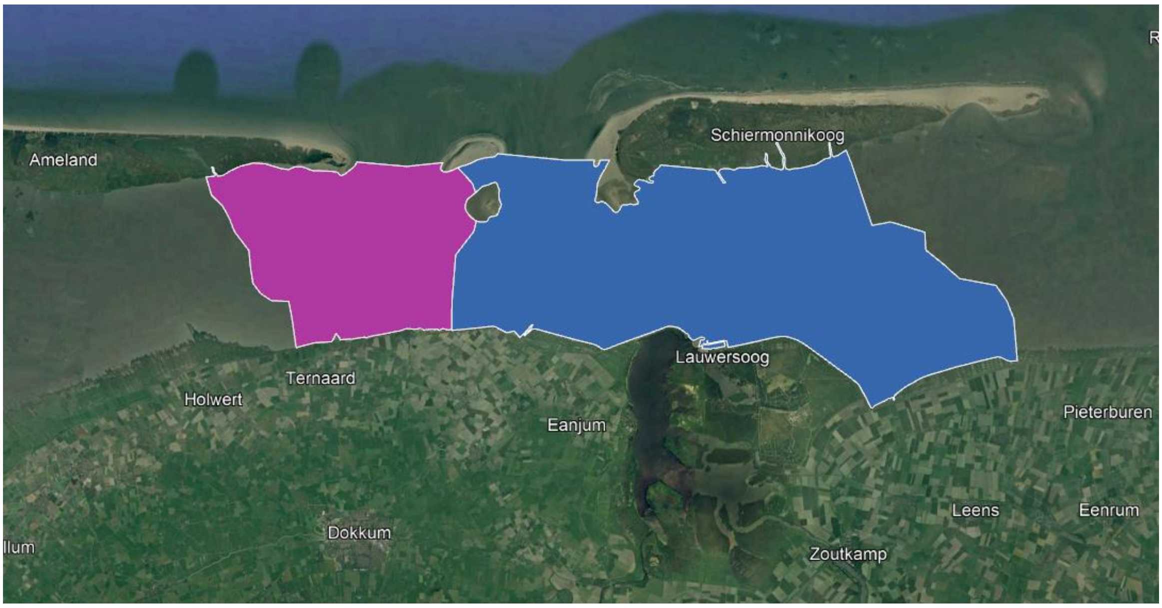

Figure 1: Project area Waddenzee.

1.7. Quality assurance

The project is executed according to Field's quality assurance system. On this project, the following aspects have been emphasized.

- Calibration of sensor system
- Crossing calibration lines
- Matching of flightlines
- Adjustment and control against measured points

2. Ground control points (GCP)

Ground control points are delivered by the customer. These points are high accuracy measurements of ground surfaces.

The CPs are grid measured on a flat area that are spread in the project as shown on the image below. The average difference between CP's and laser points in all areas are used for adjusting the dataset.

Figure 2: Location of collected GCP's marked in red.

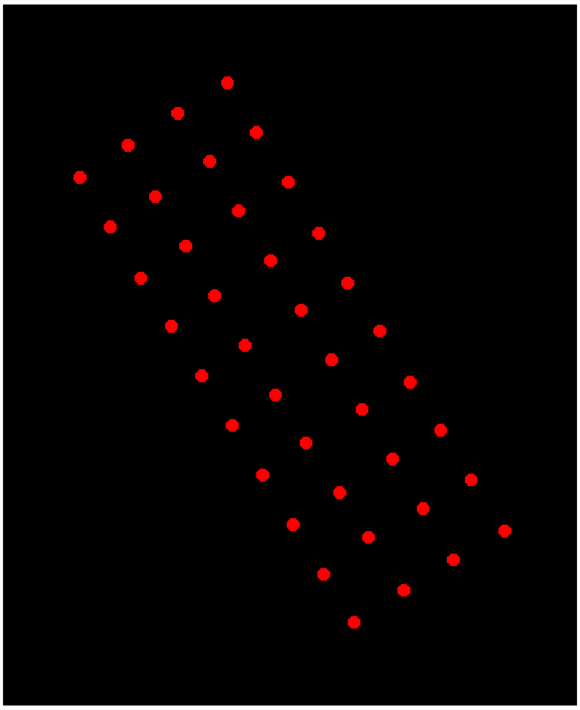

Figure 3: Top view of GCP-6 distribution.

3. Data capture

3.1. Survey platform specifications

The survey was performed with one LiDAR sensor - the Riegl VQ-1560 II-S - mounted in the aircraft LN-LOL-2, a Cessna 208B 5431. The same type of LiDAR scanner was used for the previous survey in 2023.

<table>
<tr><th colspan="2">Sensor</th><th colspan="6">Mount / navigation / LiDAR control</th></tr>
<tr><td>Manufacturer, type</td><td>Riegl, VQ-1560ii-S</td><td colspan="2">Gyro mount</td><td colspan="4">SOMAG GSM4000</td></tr>
<tr><td>Serial number</td><td>S2224893</td><td rowspan="6">Navigation system</td><td>Manufacturer, type</td><td colspan="4">Applanix PosTrack 610 V6 s/n 12298</td></tr>
<tr><td>Focal length (mm)</td><td>N/A</td><td>GNSS-receiver</td><td colspan="4">Trimble BD982 Rev nr. s/n 6102C01202</td></tr>
<tr><td>Rev nr.</td><td></td><td>GNSS-antenna</td><td colspan="4">Trimble AV39 (AERAT1675_180)</td></tr>
<tr><td>Last calibration</td><td>2021-05-12</td><td>IMU</td><td colspan="4">Applanix IMU-57 s/n 21501</td></tr>
<tr><td>FMC</td><td>N/A</td><td rowspan="2">Logging rate (Hz)</td><td rowspan="2">GNSS</td><td rowspan="2">5</td><td rowspan="2">IMU</td><td rowspan="2">200</td></tr>
<tr><td>Radiometric res.</td><td>N/A</td></tr>
<tr><th colspan="2">Aircraft</th><td colspan="2">LiDAR control system</td><td colspan="4">Riegl RiPROCESS</td></tr>
<tr><td>Manufacturer, type</td><td>Cessna 208B 5431</td><td colspan="2" rowspan="2">Boresight-calibration</td><td colspan="4" rowspan="2">2023-04-17
(ID: L505_2023_1)</td></tr>
<tr><td>Registration</td><td>LN-LOL-2</td></tr>
<tr><td>Pressurized</td><td>Yes</td><td colspan="2">IMU-initialization</td><td colspan="4">S-turn before first flight line / after last flight line</td></tr>
</table>

3.2. Acquisition parameters

The following acquisition parameters were used for all lines in the project:

LiDAR:	
Flying altitude:	1750m
Max ground speed:	155kts
Sensor:	Riegl VQ-1560 II-S
Total lines:	18
Total length:	239 nautical miles
FoV:	60 degrees
PRF per channel:	810 kHz
Total scan rate:	144 Hz
Laser power mode:	100%
Min. pt. density:	5,7 pts/m^2
Strip width:	1960 m
Lateral overlap:	55%

Out of the total of 18 flight lines, 5 of these are crossing lines used for matching purposes, and the remaining 13 are project flight lines. The customer requested a total surveying time of 3 hours. Based on this, a flying altitude of 1750 m above ground was chosen and other flight plan parameters have been adjusted to this.

3.3. Flightplan

Project lines are represented in blue, while crossing lines are drawn in green. Water level stations are marked with red crosses, see Appendix 1 for full flight plan:

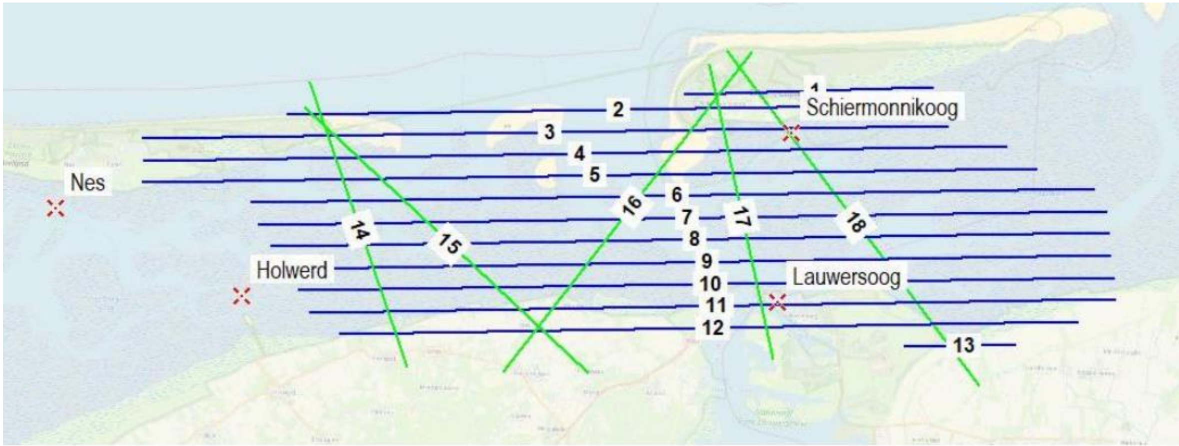

Figure 4: Flightplan and waterlevel stations

3.4. Execution of data capture

The survey, consisting of 13 project lines and 5 crossing lines, was completed in one single flight with take-off and landing at Groningen Airport, on the 5th of September 2024. The plane took off at 15:23 and landed at 18:17 UTC time. For the full flight report see appendix 2.

The predicted window was long enough to complete the capture of the entire flight plan in one flight. When analyzing actual tidal levels during the acquisition, it became clear that the measured water level at Holwerd deviated significantly from the forecasted values. This effect is normal for measurements at this station, and the remaining stations, (Lauwersoog, Schiermonnikoog and Nes) are more representative for the water coverage in the survey area. These stations have been emphasized when evaluating water levels in the table below:

Line number	Date	Time (GMT+2)	Schiermonnikoog (cm)	Lauwersoog (cm)	Nes (cm)	Holwerd (cm)	Highest (cm)	Lowest (cm)
1	05.09.2024	17:37:03	-84	-85	-88	-32	-84	-88
2	05.09.2024	17:41:45	-90	-90	-93	-34	-90	-93
3	05.09.2024	17:50:42	-101	-98	-102	-39	-98	-102
4	05.09.2024	18:00:51	-112	-107	-110	-45	-107	-112
14	05.09.2024	18:14:19	-124	-116	-119	-54	-116	-124
15	05.09.2024	18:19:03	-128	-118	-122	-58	-118	-128
16	05.09.2024	18:25:37	-132	-122	-126	-65	-122	-132
17	05.09.2024	18:31:55	-134	-126	-130	-71	-126	-134
18	05.09.2024	18:38:28	-137	-130	-134	-77	-130	-137
5	05.09.2024	18:48:20	-139	-135	-138	-89	-135	-139
6	05.09.2024	18:59:03	-144	-144	-141	-101	-141	-144
7	05.09.2024	19:08:07	-146	-145	-141	-111	-141	-146
8	05.09.2024	19:17:36	-151	-147	-139	-121	-139	-151
9	05.09.2024	19:26:26	-153	-147	-134	-129	-134	-153
10	05.09.2024	19:35:30	-152	-147	-127	-135	-127	-148
11	05.09.2024	19:44:24	-148	-146	-117	-141	-117	-145
12	05.09.2024	19:52:59	-145	-143	-106	-145	-106	-145
13	05.09.2024	20:05:07	-139	-136	-88	-151	-88	-139

- Flightlines are represented in the table above. Crossing lines are written in red font.
- Water levels are given in cm NAP (Normaal Amsterdams Peil) and are given at the start time for each flightline.

3.5. Survey risk assessment

See "Appendix_8_Risk_Assessment_Shell_(C208B)".

3.6. Reports on near-misses and incidents

No near-misses, accidents or any other events compromising the safety of the crew occurred during the project survey.

4. Navigation

4.1. Navigation processing

To form trajectories of position and orientation (angles), GNSS (Global Navigation Satellite Systems) and IMU (Inertial Measurement Unit) observations are post processed using one common Kalman filter, followed by a backwards filter recursion ("Rauch-Tung-Striebel-smoother"). This tightly coupled processing strategy ensures an optimal parameter estimation and error detection capability. The GNSS estimation integrated in this process follows the PPP (Precise Point Positioning) -processing strategy where linear combinations of code and phase observations from at least two frequencies, from at least GPS and GLONASS satellite systems are the main observables.

As part of the navigation processing, the (from calibration known) GNSS antennas phase center eccentricities and -variations, together with the observations (angles) from the sensor's gimbaled mount, are used to ensure high accuracy on the varying eccentricity between IMU mounted on the sensor, and the GNSS-antenna mounted on the outside of the aircraft.

The navigation post processing is performed using the software TerraPos, developed and maintained by Field Geospatial. For lidar data, the software version used is specified in the report from each processing result, while for image data, the version is specified in the header of the corresponding EO (Exterior Orientation) -file. Formal precision of position and attitude is also documented in the same documents.

4.1.1. Evaluation of the navigation processing result

All navigation processing results used in this project have been evaluated against a Quality Control check list. This evaluation includes (but is not limited to) verifying that the data set is suited for PPP processing, evaluating number of detected and repaired cycle slips, code and phase observation residuals, and fraction of observations detected as outliers.

All navigation solutions (trajectories) used in this project have passed the quality control without remarks.

See appendix 3 for navigation quality plots.

5. Laser scanning execution

5.1. Workflow

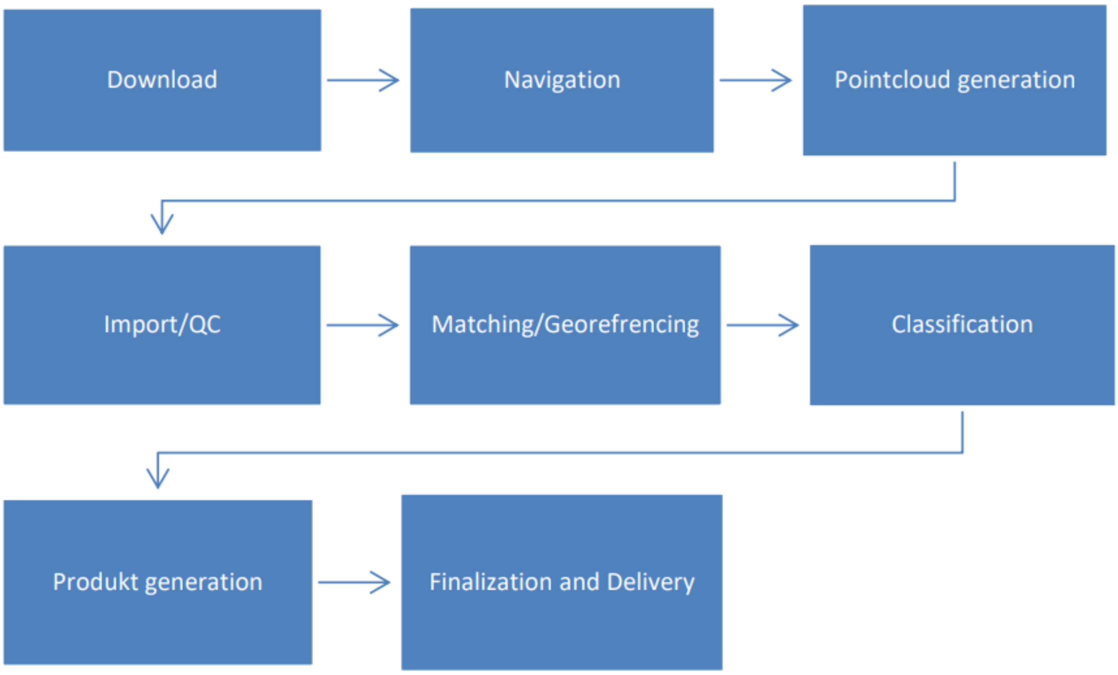

Figure 5: LiDAR production workflow.

5.2. Software

Navigation:

- Terrapos (Version 2.5.90)

Laser Processing:

- RiProcess (Version 1.9.4.1)
- Terrasolid (Version 24)
  - TerraMatch
  - TerraScan
  - TerraModel
  - TerraPhoto

5.3. Sensor calibration

Calibration of our sensors is performed by both the sensor manufacturer and Field Geospatial.

5.1.1. Factory calibration

The manufacturer performs sensor calibration. The calibration report and system parameter set are delivered along with the sensor. Factory calibration is also performed after repairs/upgrades and periodically according to service and maintenance plan.

See appendix 4 for factory calibration report.

5.1.2. Calibration of installed system

A calibration is performed at first installation in the aircraft, with changes in factory calibration or changes in the physical installation. In this calibration angle differences between components are solved and lever arms between GNSS antenna, IMU- and laser sensor are estimated. The lasers' range correction parameters are controlled against surveyed control points on ground.

5.1.3. System calibration

A system calibration is performed at a calibration field in Fredrikstad, Norway. This is to verify that the system is within specifications and to calibrate the sensor to ensure the best possible quality. Boresight angles and range correction values are the most important parameters to control in the project calibration.

There is also an estimation of boresight angles and performed on the actual project data. This is done to eliminate small residual errors locally.

5.4. Transformations

The navigation solution in TerraPOS is processed in WGS84. Transformation to Amerfoort/RD New with NAP heights is done with the software TerraScan from Terrasolid OY.

5.5. Point cloud processing

The point cloud is processed using the system manufacturers' software. Factory calibrated values and installation values are used to calculate point clouds for each flight line. The point clouds are output in WGS84 geocentric.

5.6. Project calibration

A calibration per flight session is performed. Correction values for Heading, Roll and Pitch are estimated and applied if they are found significant and reliable.

Evaluation of results:

No abnormal values have been found during this process. Results from the project calibration are shown in appendix 6.

5.7. Flightline matching

A relative matching is performed to solve for random deviations between flight lines. Best match in roll and Z between lines are calculated. All flight lines are involved in the calculations. The matching is evaluated by calculating elevation differences between flight lines in areas where they overlap. Results are shown in appendix 7.

5.8. LiDAR coverage control

A manual inspection is done to ensure that the whole area of interest is covered by the point cloud. Density plots are shown in figure 6 and 7 below:

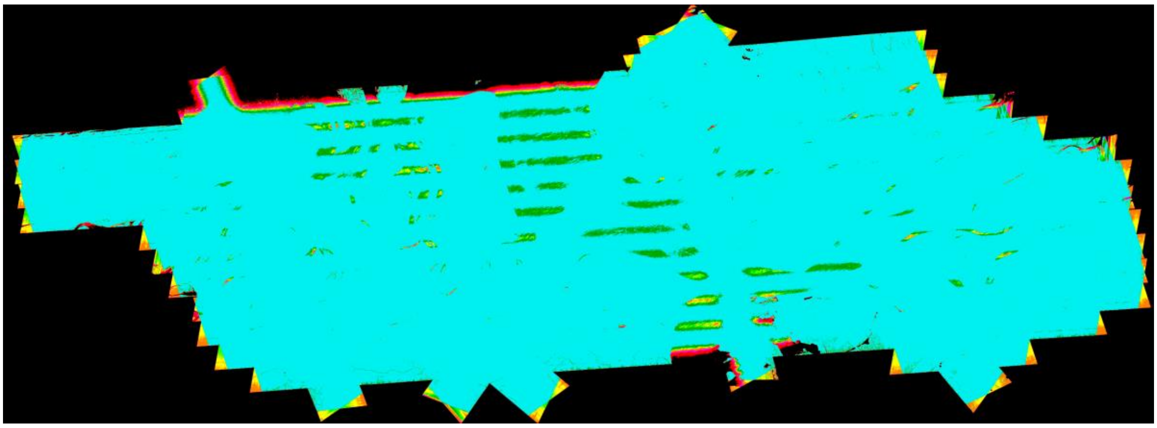

Figure 6: 4pts/m^2 on a 10m grid.

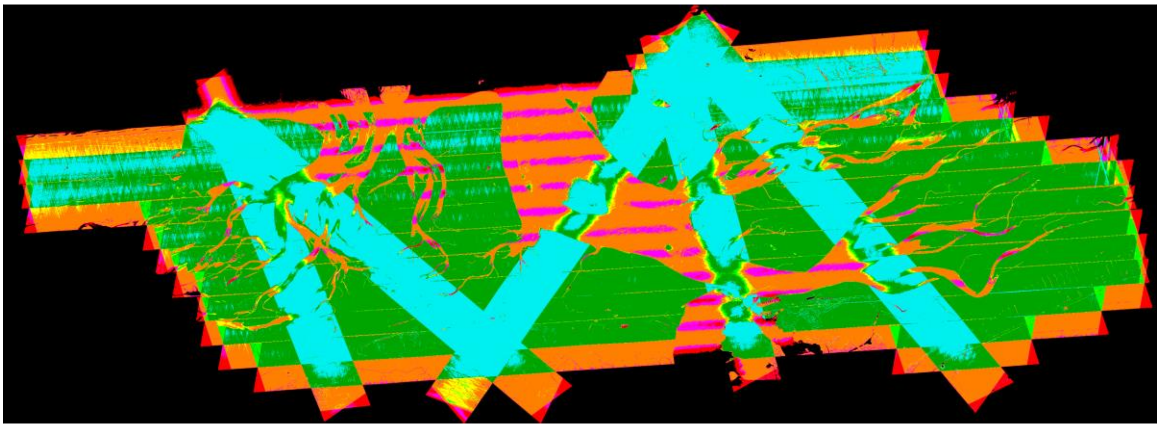

Figure 7: 10pts/m² on a 10m grid.

Color palette used in the density plots:

Point density	4			Point density	10		
From	To			From	To		
0.00	0.40	10%		0.00	1.00	10%	
0.40	1.60	40%		1.00	4.00	40%	
1.60	2.40	60%		4.00	6.00	60%	
2.40	3.40	85%		6.00	8.50	85%	
3.40	4.00	100%		8.50	10.00	100%	
4.00	4.60	115%		10.00	11.50	115%	
4.60	6.00	150%		11.50	15.00	150%	
6.00	100.00	> 150 %		15.00	100.00	> 150 %	

Figure 8: Point density palette used for 4 and 10 pts/m² respectively.

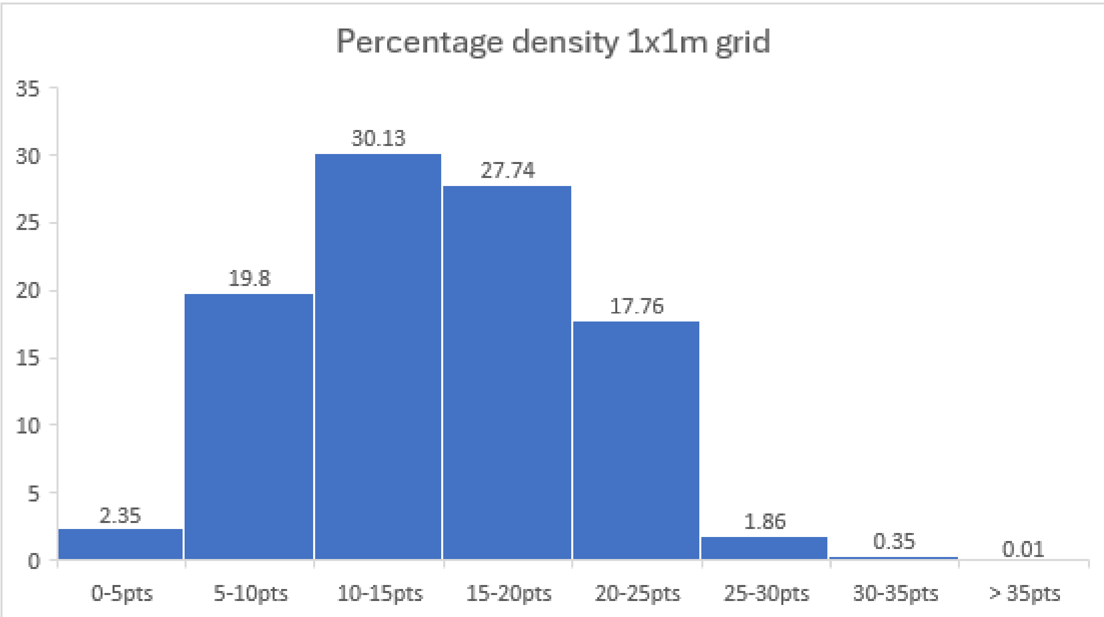

Figure 9: A histogram of the project point density within a 1x1m grid inside the AoI.

5.9. Height accuracy

The height quality of the point cloud has been controlled by comprehensive manual inspections against the GCPs. The overall manual inspections have shown average height deviations of no more than 2cm except for an outlier, GCP – 9, which has an average of 4,3 cm. The result is shown in the table below:

Control Surface	Average dZ (m)	Minimum dZ (m)	Maximum dZ (m)	Average magnitude (m)	RMS	Std. Dev
GCP - 1	-0.012	-0.029	0.002	0.012	0.015	0.008
GCP - 2	-0.003	-0.015	0.006	0.005	0.007	0.006
GCP - 3	-0.001	-0.036	0.033	0.008	0.012	0.012
GCP - 4	0.014	-0.020	0.055	0.020	0.024	0.020
GCP - 5	0.011	-0.010	0.039	0.013	0.016	0.012
GCP - 6	-0.011	-0.026	0.003	0.012	0.013	0.007
GCP - 7	-0.019	-0.044	-0.002	0.019	0.021	0.010
GCP - 8	0.020	-0.033	0.060	0.023	0.029	0.021
GCP - 9	0.043	0.009	0.072	0.043	0.046	0.016

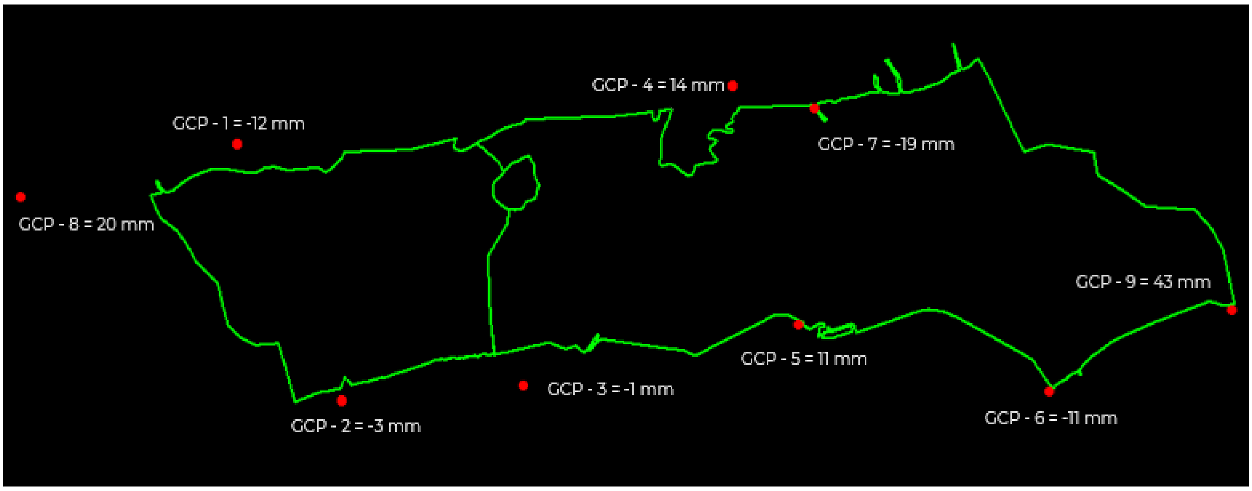

Figure 10: Overview of control surfaces after adjustment.

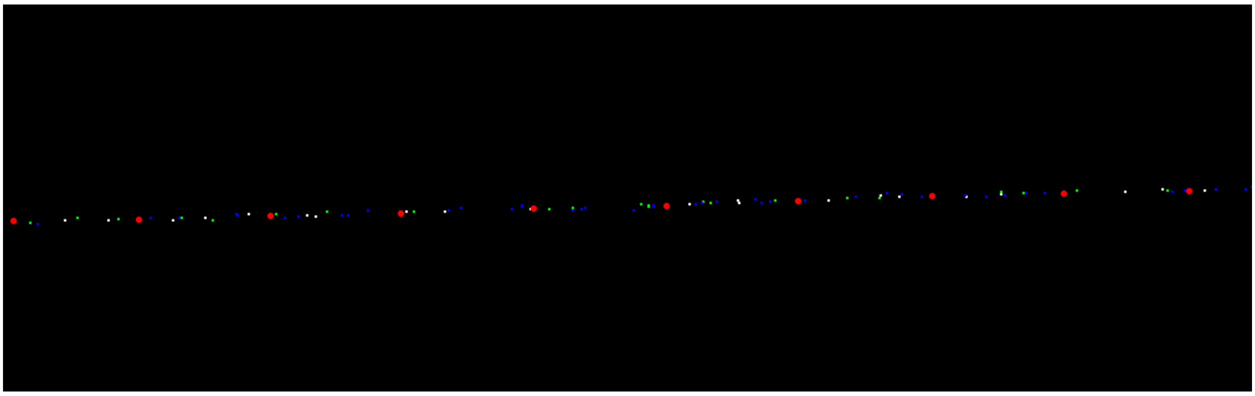

Figure 11: Control surface points in red from GCP - 4 after adjusting the LiDAR point cloud. The different colors represent different flightlines.

Evaluation of result:

The delivered CP-points delivered from the customer are well distributed at the edges of the project, with adjustment results within specs. Giving good CP adjustment as seen in images above. The deviations shown in the table are within expectations. The CP adjustment has been a direct linear height adjustment, which is identical in the entire project.

5.10. Conclusion georeferencing

The results from calibration, matching and control against known points show that the data is of good quality and within the expected values.

5.11. Reflectance

The data has been produced with reflectance. Reflectance is amplitude corrected for range – i.e., the effect of amplitude reducing with range of intensity spectrum. This gives intensity values for the same object homogeneous values no matter scan angle returns.

Amplitude – The raw measurement of the power strength of the return echo. It is the value of the power of the light that we receive back from the target. Later, during real-time post processing, we receive amplitude which is defined as the ratio of the actual detected optical amplitude of the echo pulse versus detection threshold of the instrument. Thus, the value of the amplitude reading is a ratio, given in the units of decibel (dB). By introducing amplitude readings in this way, we can use them to improve object classification. Amplitude depends on the distance, further away the scanner is from the target the less power it receives.

Reflectance – A target property that refers to the optical power that is reflected by that target at a certain wavelength. RIEGL's V-Line instruments provide a reflectance reading for each detected target as an additional attribute. The reflectance provided is a ratio of the actual, optical amplitude of that target to the amplitude of a diffuse white flat target at the same range reading is given in decibel (dB). Negative values indicate diffusely reflecting targets, whereas positive values are usually retro-reflecting targets. Reflectance is distance independent, thus is a perfect attribute for many different classifications and further processing.

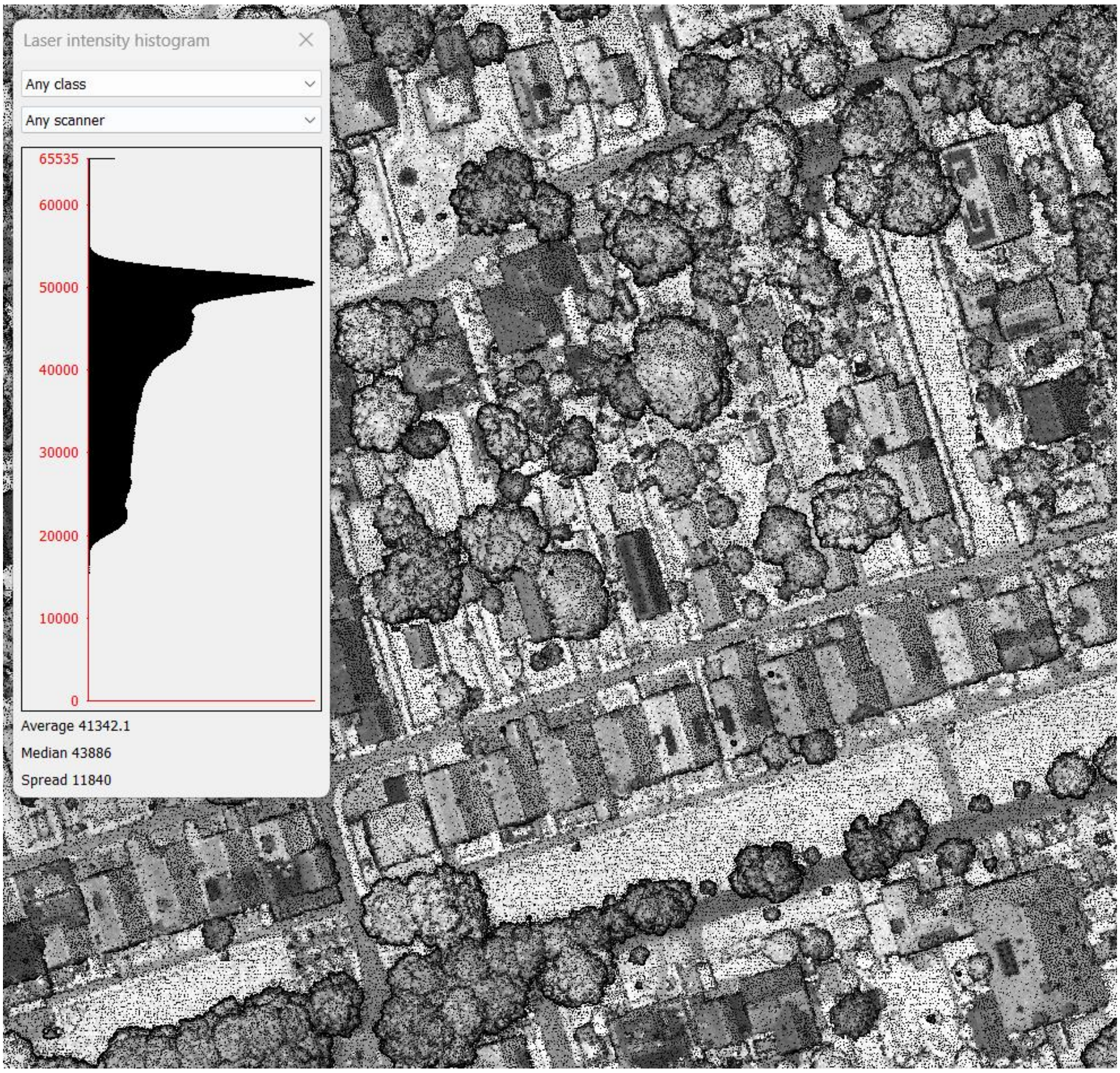

Figure 12: Image shows intensity values in top view with histogram.

Figure 13: Image shows intensity in cross section / 3D view.

6. Point cloud classification

Automatic methods are used to classify the point cloud. In this project the laser data is divided into the following classes:

1) Unclassified
2) Ground
7) Noise

6.1. Ground classification

Terrain surface points are classified as class 2. This class also contains points on water surfaces where these have reflected the LIDAR beam.

Classification of ground points is the most time-consuming part of classification. In this process automatic filtering through defined algorithms is performed. The challenge with this filtering is to find the parameters that are best at picking out points that are describing details in the terrain surface not adding vegetation or other features that are not considered ground. Factors that influence the choice of parameters are point density, topography, and the density of vegetation coverage.

In this project, only the automated ground classification has been done, there has been no manual editing of the data.

6.2. «Noise» filtering

Noise points are filtered out. These are erroneous registered points caused by multipath reflections, airborne particles (e.g. water, dust) or objects like, for example, birds. Most of these points are filtered out by automated classification routines.

6.3. Classification «unclassified»

Points that are not considered to be ground or noise are classified as class 1.

6.4. Evaluation of classification

This project has been automatically classified using TerraScan. Classification is good considering that there has not been any manual editing.

7. Delivery of point cloud

7.1. Overview of files in the delivery

- Lidardata
  - Tiled in 250x250m blocks.
  - Full coverage for each individual flight line.
- Navigation
  - SBET; full navigation for the LiDAR data capture.
  - Trajectories; Trajectories for each flight line.

7.2. Folder structure

- 10456 Waddenzee 2024
  - 01_Report
  - 02_Lidar
    - 01_LiDAR_Block_Tiles
      - Lidar_Block_Tiles_Laz.zip
    - 02_LiDAR_Per_Flight_Line
      - Flight_Lines_Laz.zip
    - 03_Navigation
      - 01_SBET
      - 02_Trajectories

8. APPENDICES

Appendix 1: “Appendix_1_FlightPlan_43000_01_01_Waddenzee_L510”
Appendix 2: “Appendix_2_LiDAR_flightreport_LN-LOL-2_20240905”
Appendix 3: “Appendix_3_GNSS-INS”
Appendix 4: “Appendix_4_L505_2021.05.10_Factory Calibration VQ-1560II-S S2224893”
Appendix 5: “Appendix_5_System_Calibration_VQ-1560II-S S2224893_L505”
Appendix 6: “Appendix_6_HRP_Correction”
Appendix 7: “Appendix_7_dZdR_Correction”
Appendix 8: “Appendix_8_Risk_Assessment_Shell_(C208B)”