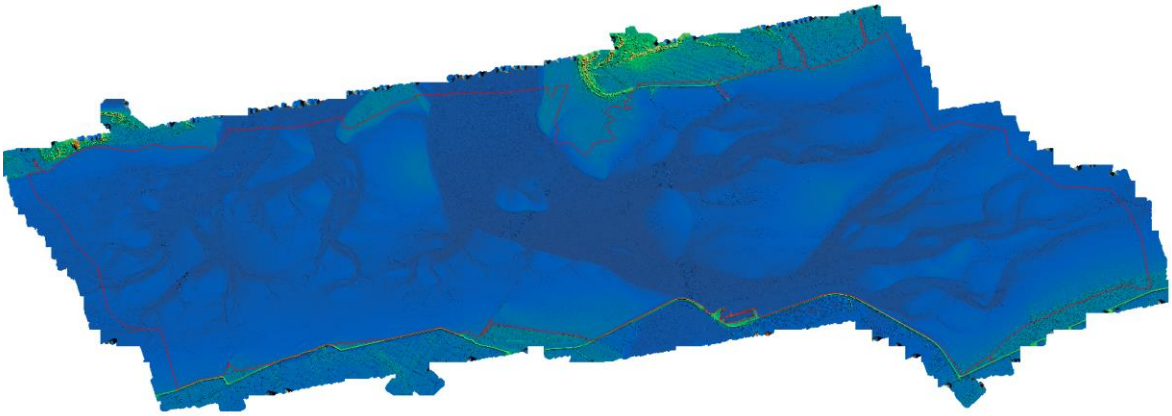
QUALITY REPORT WADDENZEE



Utrecht,
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Reference: PN17-0030
Author: Tiemco Nelissen

Version control and approval

Version control

Version	Date	Name/names contributor(s)	Remarks
1.0	19-06-17	Tiemco Nelissen	
2.0	28-07-17	Tiemco Nelissen	New CPG and flightplan

Approval

	Function	Name	Date	Signature
Checked	Project leader	Tiemco Nelissen		
Approved	Quality manager	Tiemco nelissen		

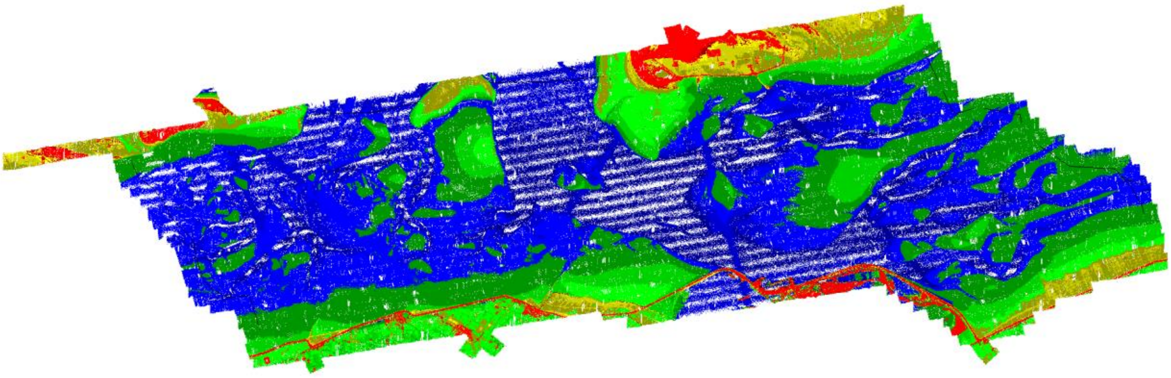
Contents

1. Introduction

This document describes the quality concerning the delivery of the project PN17-0030 Waddenzee.

The structure of this quality report is as follows. In chapter 2 the flight plan specifications are given. Chapter 3 Processing procedures, Chapter 4 shows the trajectory and GPS station accuracy, chapter 5 shows data completeness, chapter 6 shows the final relative height accuracy, chapter 7 gives the absolute height accuracy, chapter 8 describes the point density, chapter 9 describes the tidal stations and chapter 10 shows the orthophotos. Finally chapter 11 gives an overview of all delivered products.

Figure 1.1 *Coverage of the project Waddenzee*



2. Flight specifications

The flight specifications are given in the table below.

Equipment	
Airplane/heli	Fixed wing
Scanner	Riegl LMS-780
IMU	IGI Aerocontrol

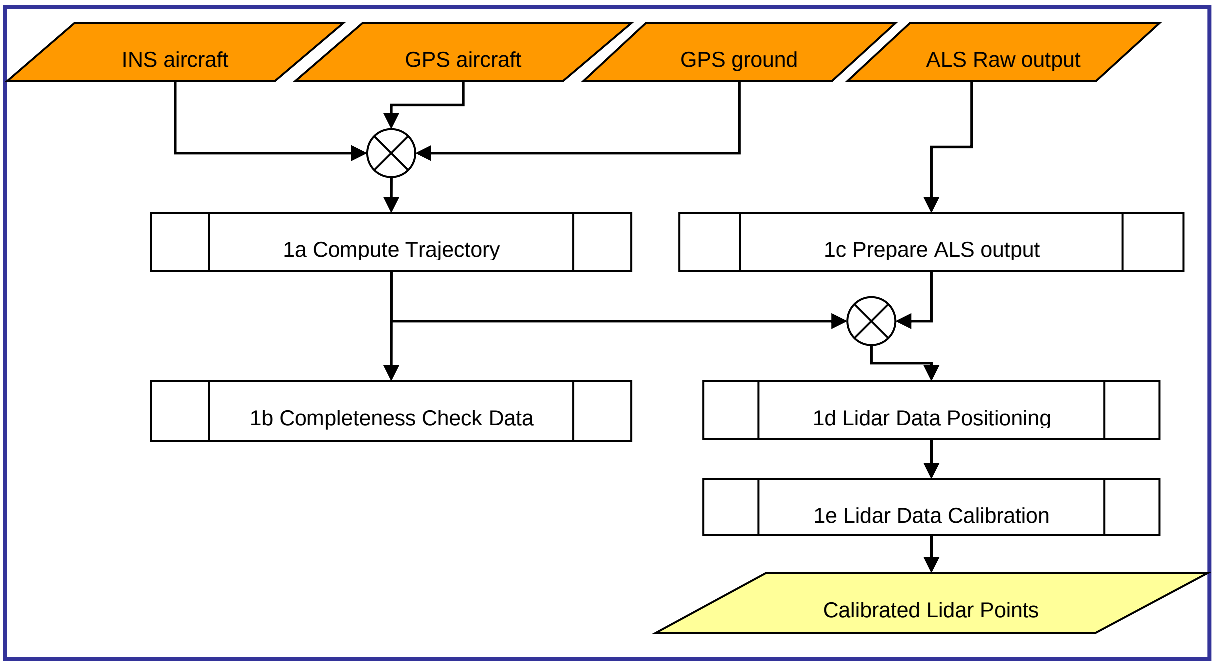
Flight specifications	
Flying height (nominal)	460 m AGL
Flying speed	130 kts
Side-lap (LIDAR)	36%
Minimum altitude	450 m AGL
Maximum altitude	500 m AGL

LiDAR	
Scan angle scanner (half)	30 degrees (60 degrees full)
Scanner pulse rate	400 kHz
Mirror frequency	184 lines/sec
Point density	4 pts/m2

GPS Base stations	
Permanent stations	Yes
Mobile stations	None

3. Processing procedures

3.1 Flight processing



Trajectory computation

Flight trajectories are the primary input for georeferencing LiDAR point clouds and orthophotos. The flight trajectories are calculated using a two-step approach:

1. Calculating the GPS trajectory;
2. Adding the inertial navigation system (INS) data.

The trajectory of each flight is computed according to a minimum of at least 1 GPS base station. The GPS recordings from the aircraft are used to compute the trajectory using each base station, resulting in multiple trajectories for each flight. These trajectories are combined into a final trajectory using a weighted average. The weight of each trajectory is based on fixed ambiguity. The resulting trajectory describes the flight path with a position per second (1 Hz).

After the GPS trajectory is computed the higher frequency (256Hz) INS data is added using a Kalman filter. This results in an improved trajectory containing the position and orientation of the aircraft with a resolution of 256 times per second.

Raw data processing

For the Riegl scanner, conversion of the raw data to laser point measurements is performed in three steps:

– Full waveform analysis
– Exporting points
– Converting the point coordinates to the appropriate coordinate system

The full waveform analysis consists of the determination of echoes from the observed signal. The scanner records a so-called full waveform, which means that the entire returned signal is recorded. This will allows to collect data points underneath vegetation. Figure 4.1 shows a graph of the intensity of the returned signal against time from emission. By fitting Gaussian distributions the individual reflection points are determined.

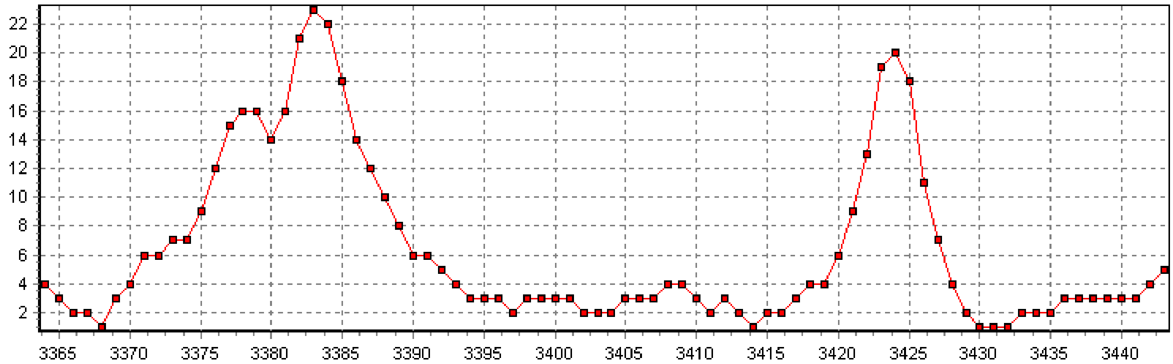


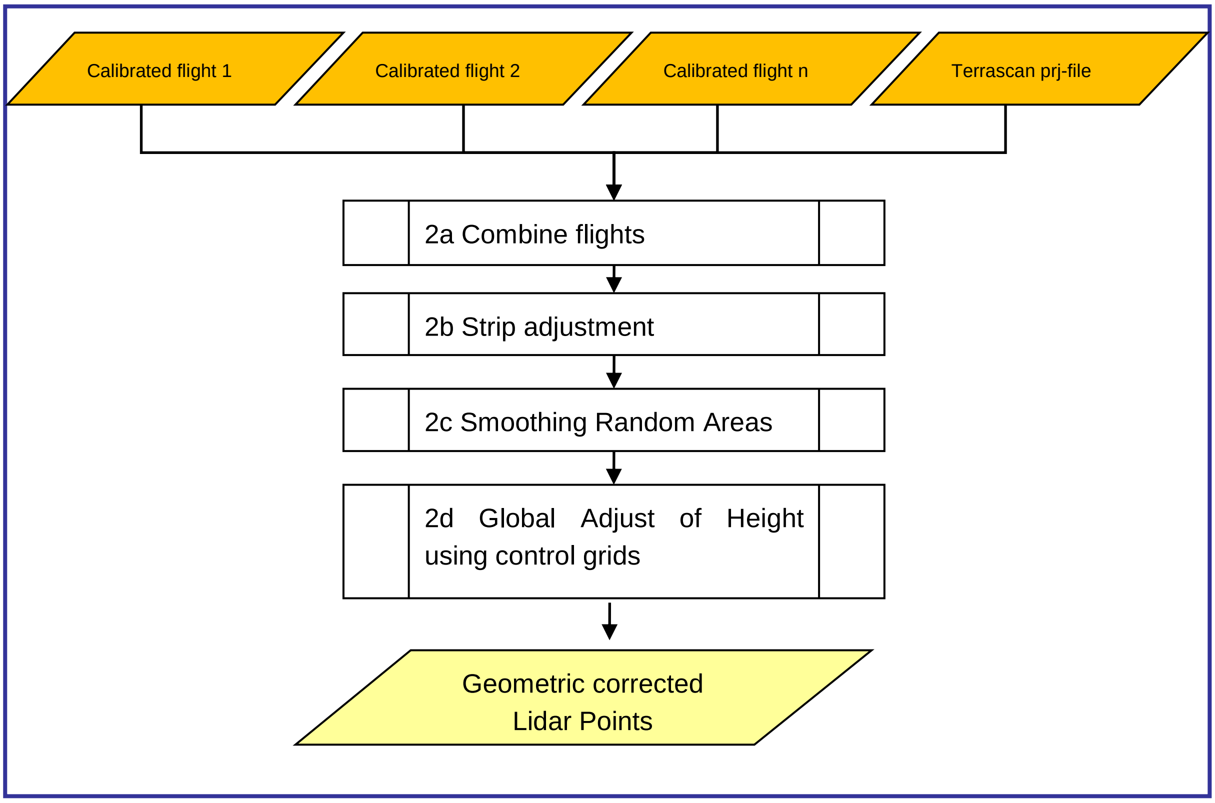
Figure 4.1 Discretized full waveform scanner output. On the x-axis the signal time is shown, on the y-axis the returning signal intensity is shown. The first peak represents the first pulse, the second peak shows the last pulse. In practice the first pulse will often represent vegetation and the last pulse the ground level.

For the actual calculation of the laser point coordinates the flight trajectory and the recorded flight times of the laser pulse are combined. Using the RIProcess software package the laser point coordinates are projected to the ETRS coordinate system. In the last step the point coordinates in the ETRS coordinate system are converted to the Dutch RD coordinate system and the data is partitioned into blocks of 500mx500m.

Boresight calibration

The data needs to be corrected for missallignment angles between the laser scanner and the IMU. Although the missalignment is constant, deviations in the three recorded angles (pitch, roll and yaw) will occur at every fresh boot of the INS-system. These errors are determined iteratively and applied to the LiDAR data, after which the results are checked by computing height difference grids within the strip overlaps.

3.2 Block processing



2a Combine flights:
The project AOI is devided in several processing blocks. Each block may consist of various flights (boresight calibration already done at this step) that are combined into a single data set for the block.

After this stage systematic height deviations between strips are determined in a strip adjustment.

2b Strip Adjustment:
All strip overlaps, cross strips and reference fields that area available for a block are used in the strip adjustment. By applying strip adjustment the following effects are removed or minimized:

- Errors in the lever arm between GPS and laserscanner
- Errors in the coordinates of base station receivers
- Errors due to atmospheric delay of GPS signals
- Errors due to atmospheric effects on the laser pulse (marginal effect)

2c Smoothing Random Areas:
The geometric corrections that are applied are height adjustments to correct for fluctuations in the

data that occur in the flight directions due to movement of the aircraft.
Finding fluctuations step compares short intervals of each strip against other overlapping strips. It computes elevation corrections for each strip based on a surface-to-surface comparison method. Each short time interval of a strip gets its own correction value. For the final correction file, the correction values can be averaged in order to get a smoother correction curve.

2d Global Adjust of Height using control grids:

The final geometric correction is in height, using control points.
An average dz is calculated and applied to the data.

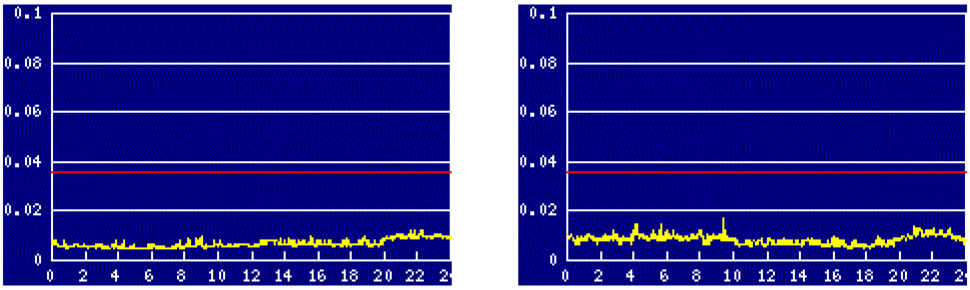
4. Trajectory and GPS station accuracy

The GPS base stations used for the processing were part of the 06-GPS (Dutch network) network. The accuracy plots of the precise trajectory computation are given in Appendix A.

The GPS station that has been used is located at Schiermonnikoog. All GPS stations of the Dutch network are certificated by the Kadaster. This is a company what registers real estate and geographic information. The procedure to get the GPS station certified, is to use three full days of logged data within a period of two weeks availability the GPS station is available. If the result of those three days separately have an accuracy of 1 cm (XY) and 3cm (Z), the average will be taken for the certification. This means that the standard deviation of the used coordinates are 3mm (XY) and 10mm (Z).
The Schiermonnikoog basestation is therefore determined with a adequate accuracy to calculate the trajectories with a standard deviation of 2.7cm (XY) and 4cm (Z). If there is a deviation in the GPS station it will result in a systematic deviation in the LiDAR data. This systematic deviation discovered and removed when checking the data against the available reference data.

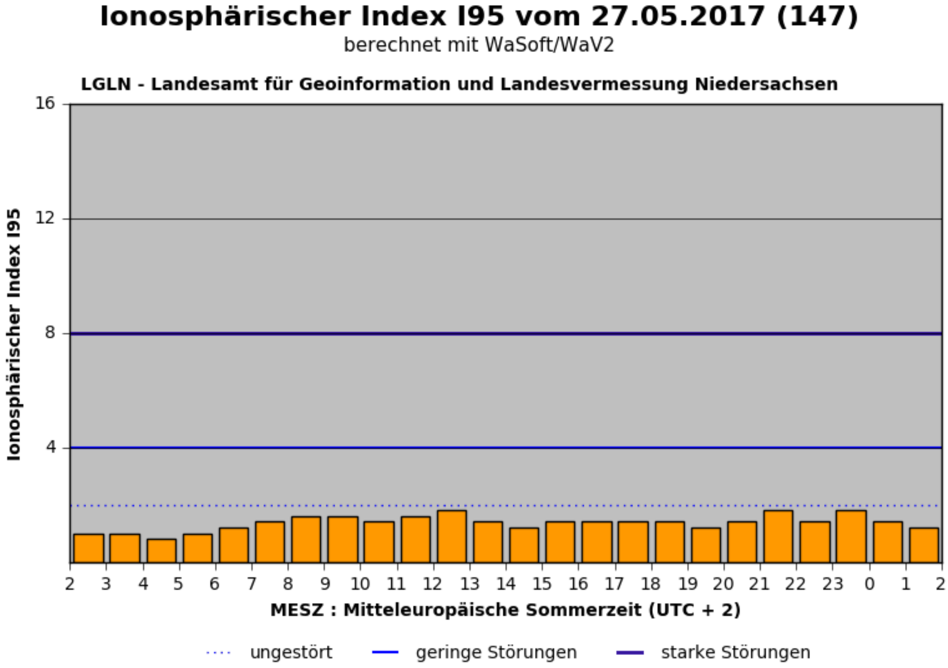
Another factor influencing the quality of the GPS base station is the ionospheric activity. For the Schiermonnikoog station, there is information about the ionospheric activity available. Figure 4.1 shows the ionospheric residual of the Northen part of the GPS network. As the figures show the residual is very low.

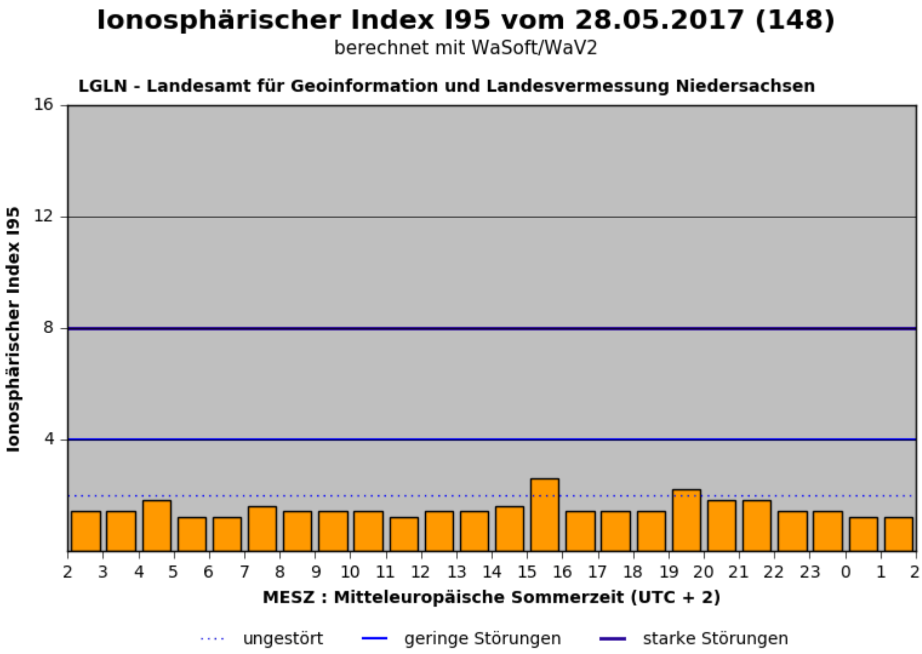
Figure 4.1 *Ionospheric residual, left 27th and 28th of May.*



The ionospheric activity can also be expressed with the ionospheric noise index 195. The 195 values compute all corrections for the sattelites of all the station of the network with a timewindow of 1 hour. What happened is that the worst 5 % is rejected and the highest values left will be displayed in the graph. Figure 4.2 shows the 195 values for the 14th an 16th of September, indicating a non-disturbed base station.

Figure 4.2 *Ionispheric noise 195 index, first 27th of May; second 28th of May. The line with the dots (2) means undisturbed, blue line (4) means a light disturbance and the dark blue line (8) means a high disturbance.*

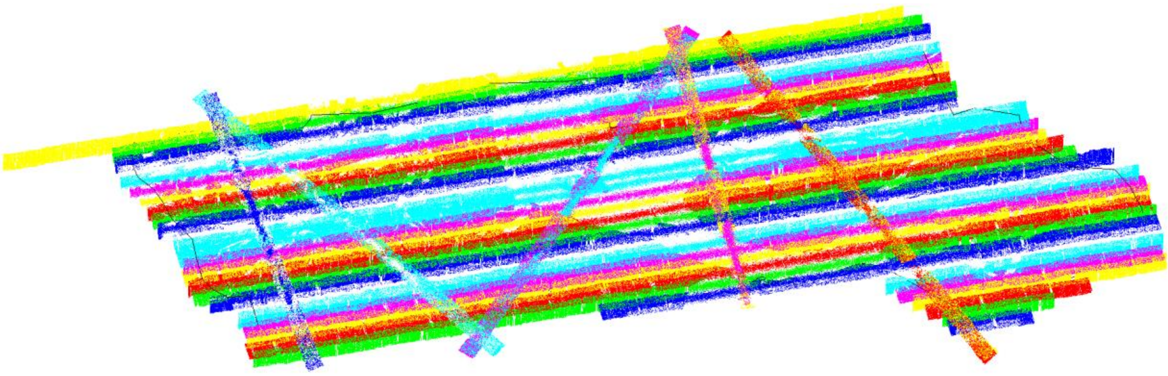




5. Completeness check

The data acquisition was done in 2 flights: on May 27th and 28th, 2017. A first quality control was performed directly after flights which assured data completeness for the project area. Figure 5.1 shows the LiDAR data colored by flightline. The black line indicate the project area. The project area is fully covered by LiDAR data.

Figure 5.1 *Data completeness, data colored by flightline.*



6. Final relative height accuracy

After applying the calibration, shift and fluctuations to the data the final height accuracy can be computed. The final height accuracy has two components: the relative height accuracy as shown in figure 6.1 and the absolute height accuracy as explained in chapter 7. The relative accuracy is determined based on the height differences between strips. For each grid cell the difference between z-values of overlapping strips is computed. An accurate relative positioning of the strips is obtained by applying bore-sight corrections (roll, pitch and heading).

A visual display of the differences between overlapping strips is given in the figure below. The average difference for all strip overlaps is -2 mm, the average standard deviation is 1,8 cm. Big water areas are cut out of the data to give an accurated overview of the relative height accuracy. There are some red/purple spots in the figure below, these are mainly small water areas.

Figure 6.1 *Height difference grids of the strip overlaps; color bar is in meters.*

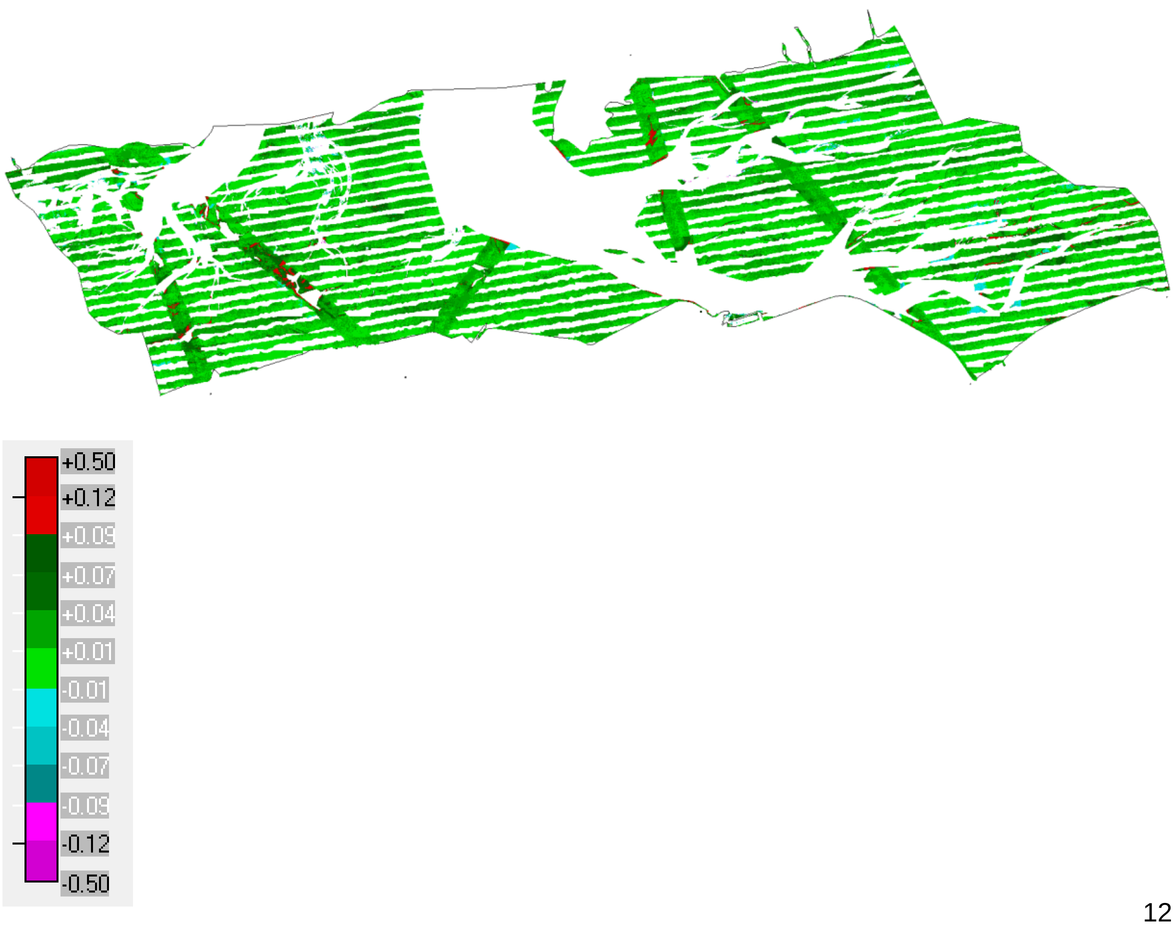
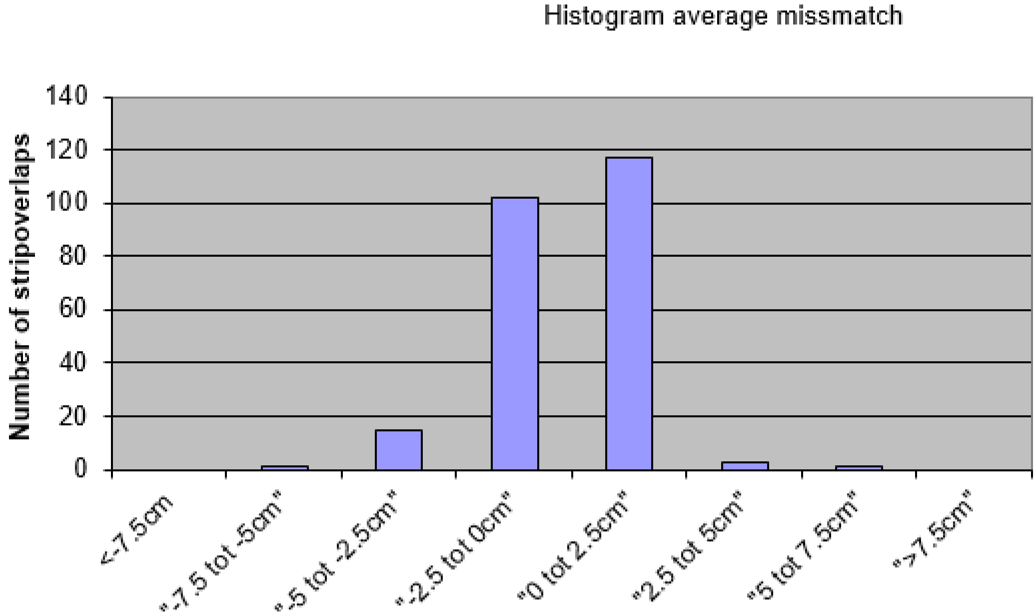
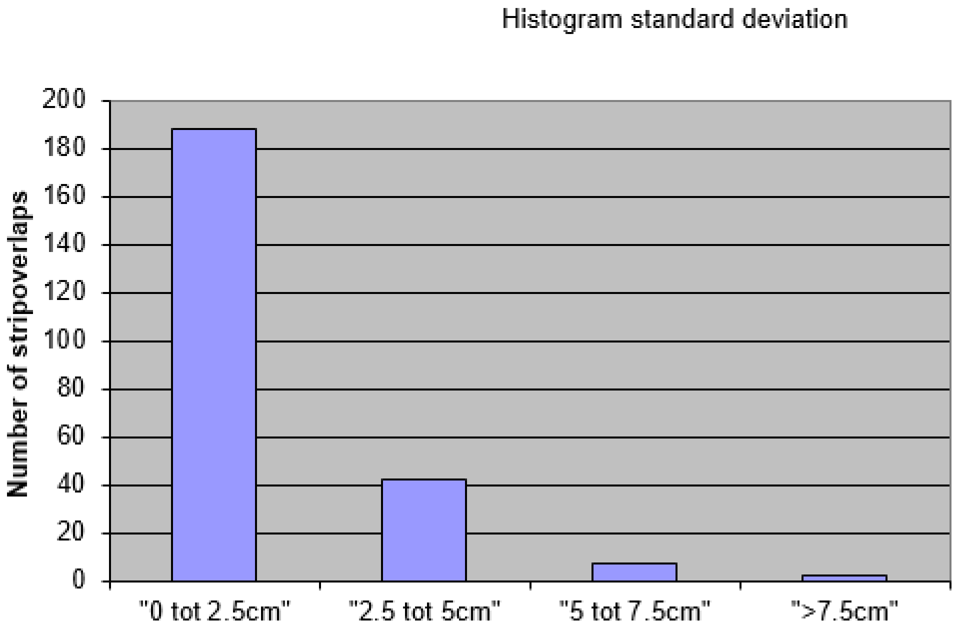


Figure 6.2 *Histograms of the average mis-match and the standard deviation*





7. Absolute height accuracy

The absolute heigth accuracy of the strips is checked using 8 height reference areas. For every reference area, the average difference and the standard deviation is computed between the height of the reference a and the height of the LiDAR data. For the reference field there are more then one flightline to dertemine the average. The result is shown in the table below.

Table 7.1 *Differences between the LiDAR data and the reference areas before global height adjustment.*

Reference field	Average difference (mm)	Standard deviation (mm)
GCP 2: Ternaard	19	8
GCP 3: Nes_Dongeradeel	-2	6
GCP 4: Schiermonningoog_dorp	-16	7
GCP 5: Lauwersoog	-3	9
GCP 6: Vijfhuizen	-2	5
GCP 7: Schiermonnikoog_Veerweg	2	5
GCP 8: Ameland_Kooiweg	29	7
GCP 9: Kleine_Huisjes	0	6

Table 7.2 *Differences between the LiDAR data and the reference areas after global height adjustment.*

Reference field	Average difference (mm)	Standard deviation (mm)
GCP 2: Ternaard	16	8
GCP 3: Nes_Dongeradeel	-5	6
GCP 4: Schiermonningoog_dorp	-19	7
GCP 5: Lauwersoog	-5	9
GCP 6: Vijfhuizen	-5	5
GCP 7: Schiermonnikoog_Veerweg	-1	5
GCP 8: Ameland_Kooiweg	26	7
GCP 9: Kleine_Huisjes	-3	6

8. Point density

The point density is checked for the whole project area by computing point density grids with a cell spacing of 1 by 1 meter.

The histogram of the point density is given in figure 8.1, an overviews of the point density is shown in figure 8.2. Within the area 95% of the cells have a point density of 4 pts/m2 or more. It should be noted however that the statistics have not been corrected for small water areas, where point density drops significantly. Big water areas have been excluded while making a pointdenisty histogram. There are some red and black spots visible in figure 8.2 indicating the small water areas. The average point density is 8.0 pts/m2.

Figure 8.1 *Histogram of the point density without big water areas.*

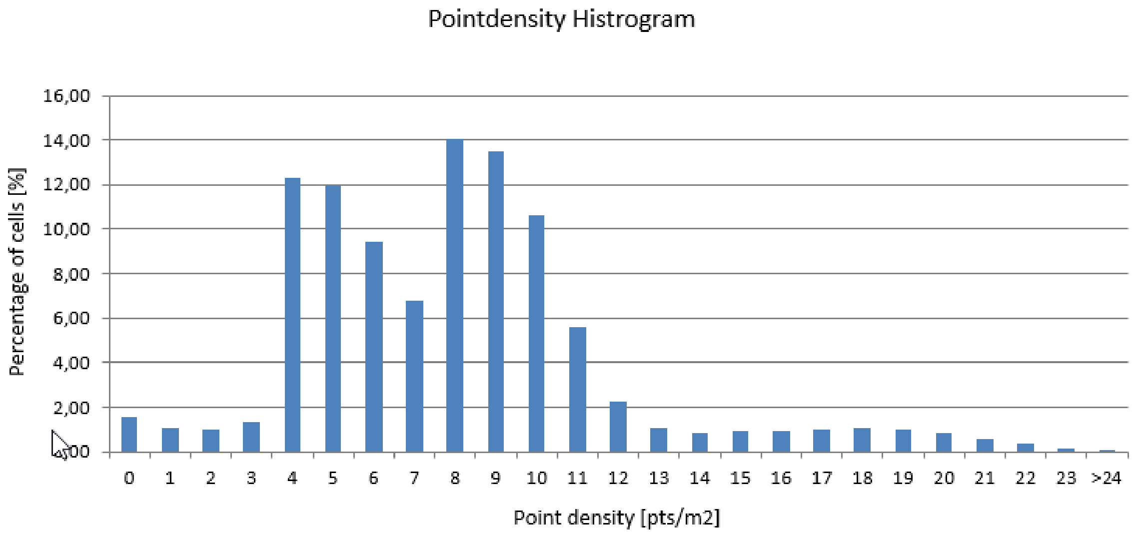


Figure 8.2 *Overview of the point density without big water areas.*

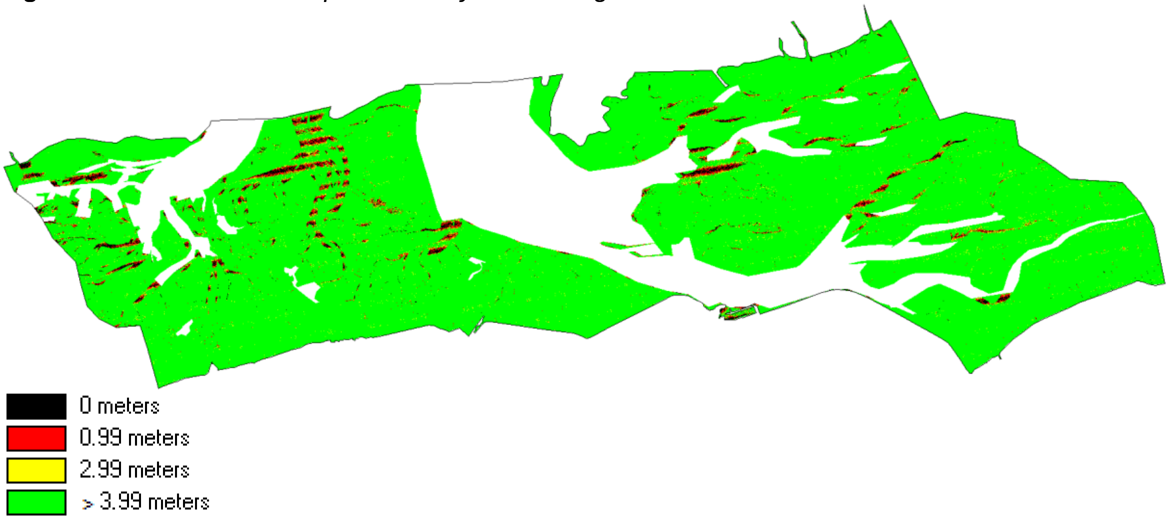


Figure 8.3 and 8.4 *are giving the same overview, only including big water areas this time. Average pointdensity including big water areas is 7,2 pts/m2 and within the area 85% of the cells have a pointdenisty of 4 pst/m2 or higher.*

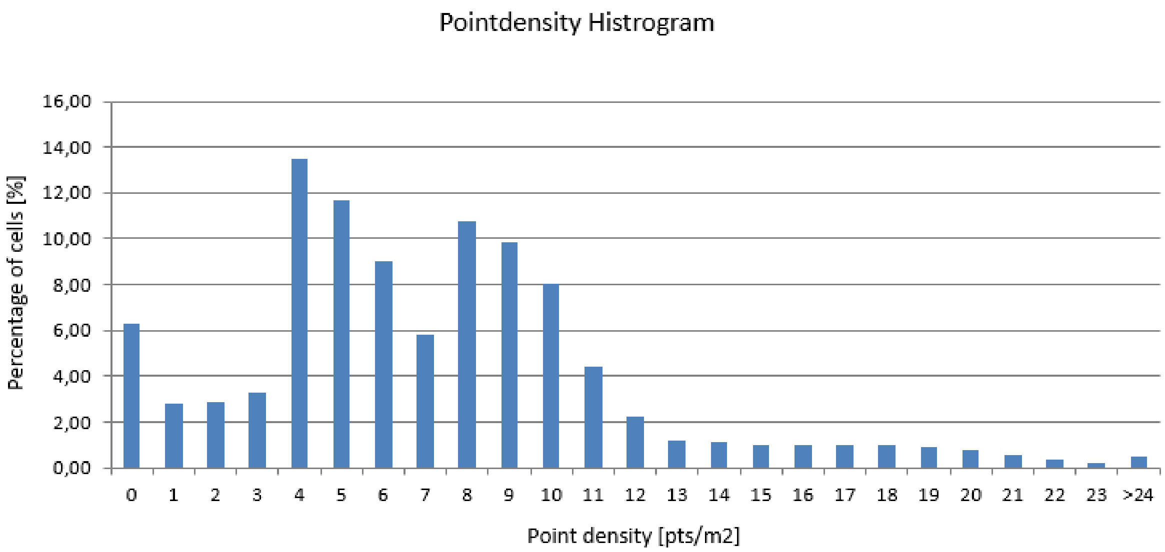
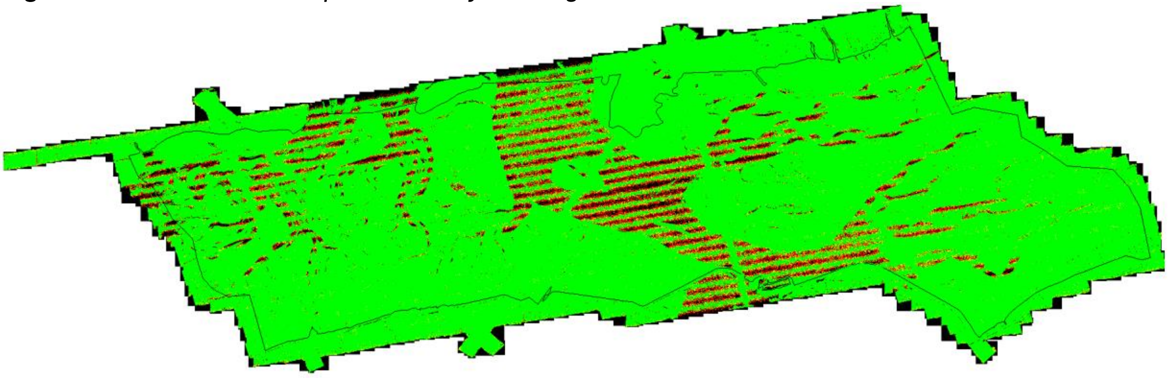


Figure 8.4 *Overview of the proint density with big water areas.*



9. Tidal station

The Waddenzee project needed to be flown with a maximum tidal height of -0.70 NAP. In the table below the date and time for each line is visible.

Figure 9.1 *Flight plan (flight numbers correspond to number in Line Number table without the orange number).*

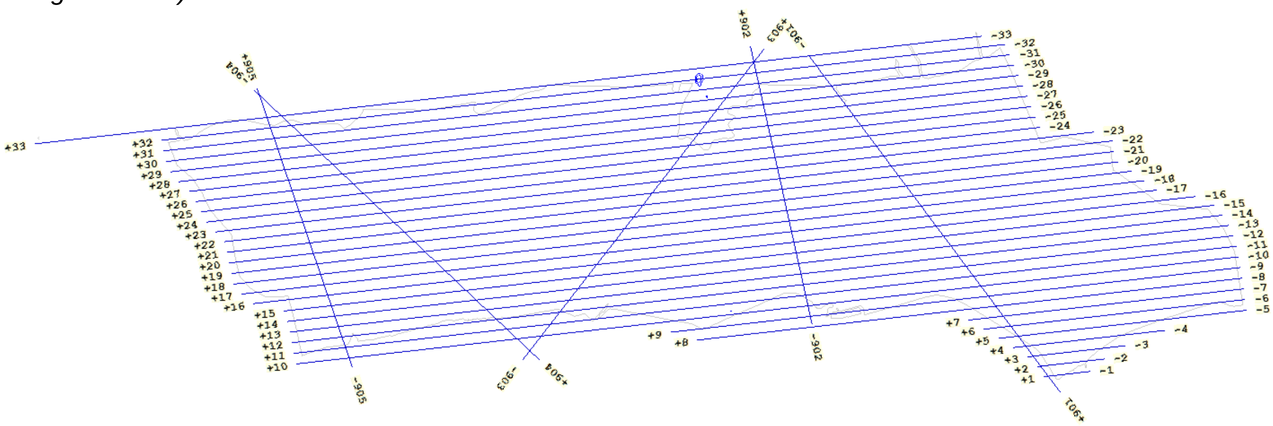


Table 9.1 *The begin and end time of acquisition with the Tidal window times*

						Water level mm				
Line number	Date	Begin time	End time	Start Low Water	End Low Water	Schier-monnik-oog	Lauwers-oog	NES	Hol-werd	explanation
1001	27-05	16:27	16:27	16.15	20.15	-75	-83	-78	-45	
1902	27-05	16:31	16:34	16.15	20.15	-75	-83	-89	-45	
1903	27-05	16:37	16:40	16.15	20.15	-88	-93	-100	-50	
1904	27-05	16:43	16:47	16.15	20.15	-88	-93	-100	-55	
1905	27-05	16:49	16:52	16.15	20.15	-101	-116	-111	-65	
1010	27-05	16:56	17:04	16.15	20.15	-101	-116	-120	-70	
1009	27-05	17:07	17:12	16.15	20.15	-128	-127	-120	-70	
1008	27-05	17:14	17:19	16.15	20.15	-128	-137	-130	-85	
1011	27-05	17:22	17:29	16.15	20.15	-139	-148	-130	-85	
1012	27-05	17:32	17:40	16.15	20.15	-148	-157	-139	-101	
1013	27-05	17:42	17:50	16.15	20.15	-157	-164	-156	-134	
1014	27-05	17:52	18:00	16.15	20.15	-157	-169	-162	-154	
1015	27-05	18:04	18:12	16.15	20.15	-169	-174	-168	-165	
1016	27-05	18:14	18:22	16.15	20.15	-173	-177	-172	-176	
1017	27-05	18:25	18:33	16.15	20.15	-173	-179	-175	-182	
1018	27-05	18:35	18:43	16.15	20.15	-178	-179	-175	-188	

1019	27-05	18:46	18:53	16.15	20.15	-178	-179	-172	-195	
1020	27-05	18:56	19:03	16.15	20.15	-178	-178	-172	-200	
1021	27-05	19:05	19:13	16.15	20.15	-178	-177	-164	-194	
1033	27-05	19:20	19:27	16.15	20.15	-175	-169	-124	-186	
1901	27-05	19:33	19:37	16.15	20.15	-162	-161	-106	-167	
1007	27-05	19:40	19:42	16.15	20.15	-154	-154	-89	-143	
1006	27-05	19:45	19:47	16.15	20.15	-140	-154	-89	-143	
1005	27-05	19:50	19:52	16.15	20.15	-140	-140	-73	-121	
1004	27-05	19:55	19:56	16.15	20.15	-140	-140	-73	-101	
1003	27-05	19:58	19:59	16.15	20.15	-122	-122	-57	-101	
1002	27-05	20:02	20:02	16.15	20.15	-122	-122	-57	-101	
2032	28-05	17:39	17:47	15.20	19.00	-76	-80	-89	-30	
2031	28-05	17:49	17:56	15.20	19.00	-88	-91	-100	-34	
2030	28-05	18:00	18:08	15.20	19.00	-100	-101	-110	-40	
2029	28-05	18:10	18:17	15.20	19.00	-112	-108	-119	-49	
2028	28-05	18:20	18:28	15.20	19.00	-123	-116	-127	-60	
2027	28-05	18:31	18:37	15.20	19.00	-132	-127	-135	-73	
2026	28-05	18:40	18:47	15.20	19.00	-139	-138	-141	-92	
2025	28-05	18:50	18:56	15.20	19.00	-144	-145	-146	-108	
2024	28-05	18:59	18:06	15.20	19.00	-149	-145	-146	-124	
2023	28-05	19:09	19:18	15.20	19.00	-156	-154	-150	-139	
2022	28-05	19:18	19:26	15.20	19.00	-157	-157	-152	-153	
2905	28-05	19:30	19:33	15.20	19.00	-158	-159	-149	-163	
2904	28-05	19:35	19:38	15.20	19.00	-158	-159	-149	-163	
2903	28-05	19:41	19:45	15.20	19.00	-159	-159	-145	-166	
2902	28-05	19:47	19:50	15.20	19.00	-159	-157	-137	-175	
2001	28-05	19:52	19:52	15.20	19.00	-159	-157	-137	-175	
2901	28-05	19:55	19:58	15.20	19.00	-154	-155	-128	-176	

10. Orthophotos.

For processing the orthophotos the same trajectory was used as the one for LiDAR. Using the LiDAR DTM and the processed GPS/IMU data, the coordinates of the principal point and the focal length of the sensor system were calibrated. Applying this camera calibration file, the bore-sight parameters per flight were calculated. In consideration of keeping the original colors of the CIR imagery as true as possible, the final mosaic was processed with minimum color balancing.

In order to use the LiDAR 500x500m tileoverview, the orthophoto tiles with GSD 7cm were retiled. This led to slight shifts in x and y for the LiDAR and the orthophoto tiles. Nevertheless, this doesn't influence on the main purpose of the orthophoto - to interpret the LiDAR data.

11. Comparison 2016 Autumn vs 2017 Spring

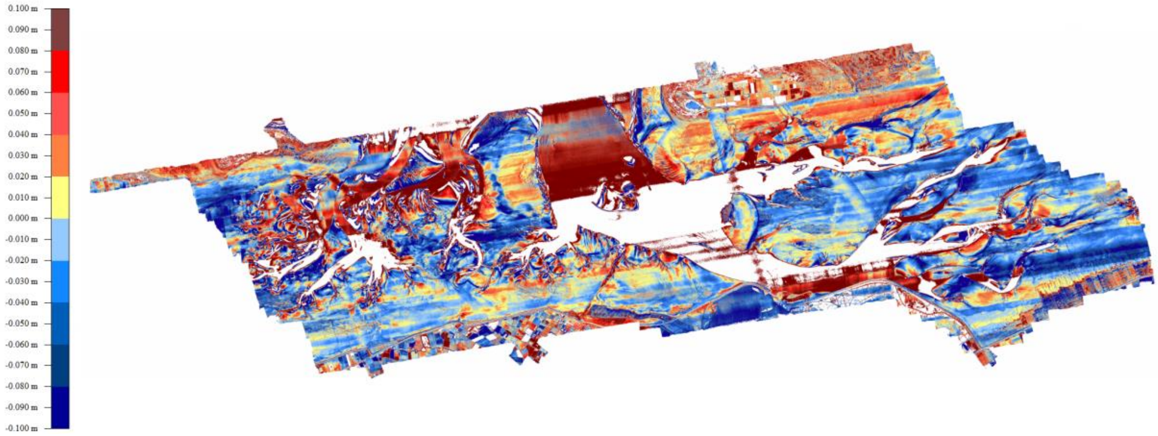


Figure 11.1 Comparison 2016 Autumn vs 2017 Spring surveys.

12. Products

This chapter gives an overview of the delivered products. All LiDAR data has been delivered in the projection Dutch RD with NAP height. The transformation used is RDNAPTRANS2008. The data partitioned in blocks of 500m by 500m. Naming of the files refers to the block minimum easting and northing coordinate.

12.1 Georeferenced points per line

Each flightline as LAZ. The data is classified as class 1. Outliers (noise) are excluded. Naming is the flightlinenumber.

12.2 Georeferenced points per tile

Each 500m by 500m tile in LAZ, included more than one flightline. The data is classified as class 1. Outliers are excluded. Naming is in easting and northing coordinates of the lower left corner of each tile.

12.3 DEM

From each tile (11.3) an DEM is exported in 1m grid ASCII format. Cells contains the average value of the data in that tile. Outliers are excluded. Naming is in easting and northing coordinates of the lower left corner of each tile.

12.4 Til index in shape

Shape of all the tiles included the easting and northing coordinates of the lower left corner of each tile.

12.5 Flightline in shape

For each flight there is a shape which contains the theoretical information of each line.

12.6 Orthophotos

Format tif and one ECW. GSP is 7cm.

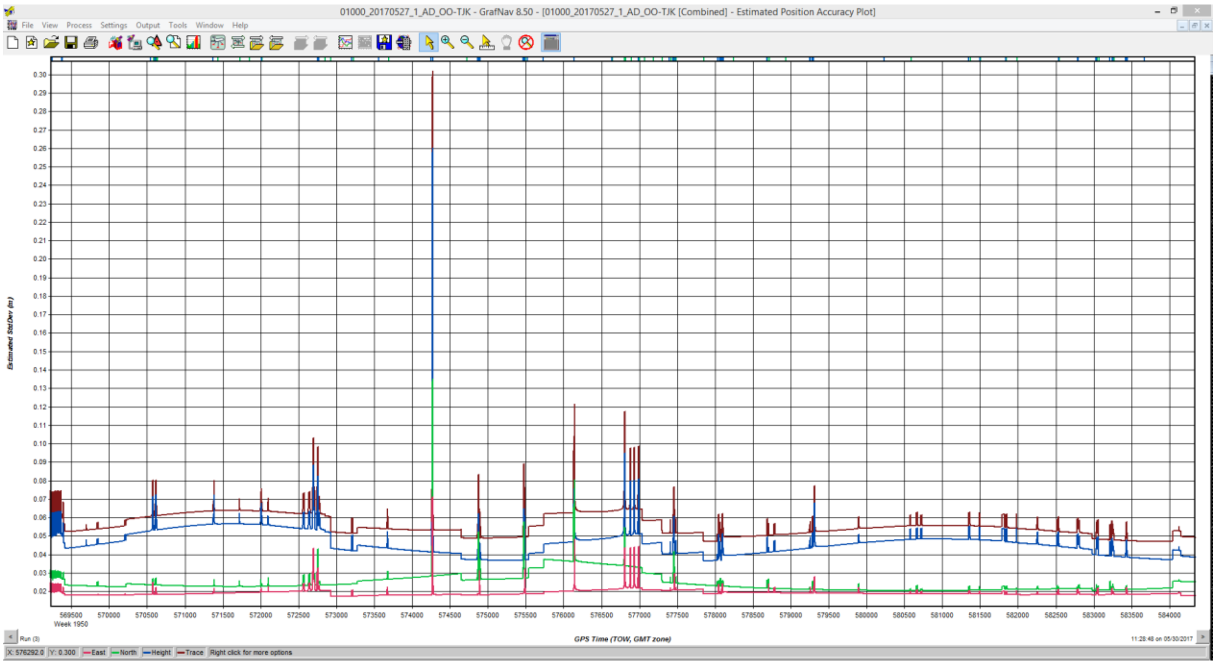
12.7 Report

Include comparation with previous data, profiles…

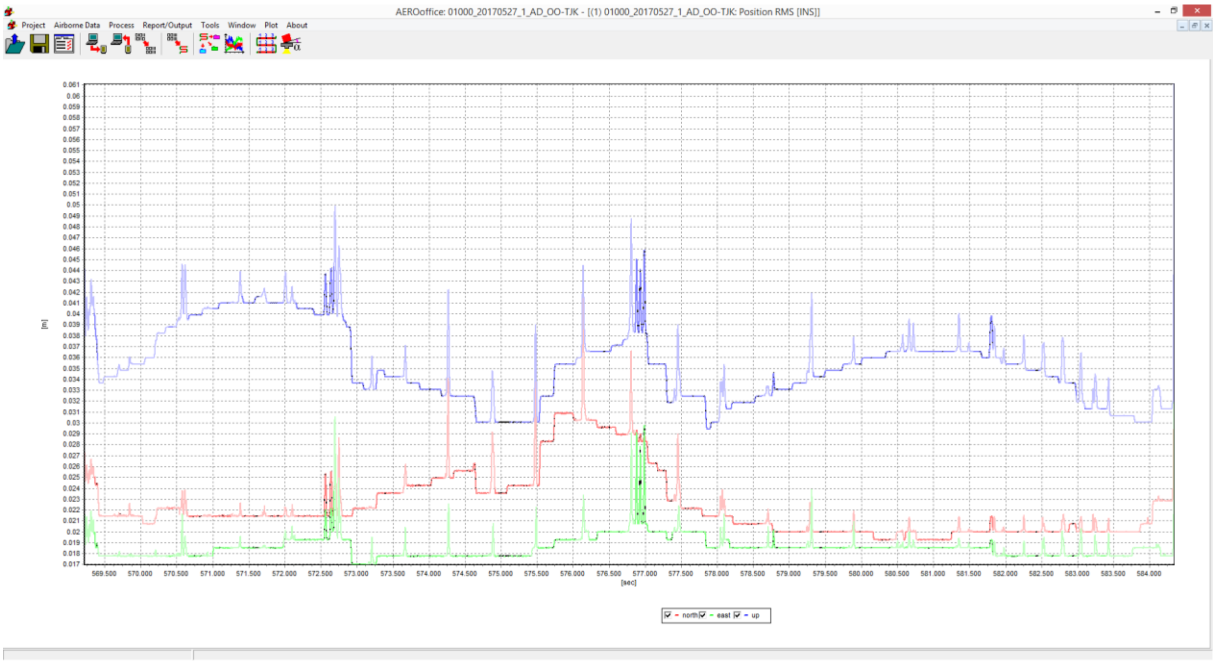
Appendix A Flight accuracies

In this appendix the accuracy of the flight trajectory is shown by figures of the accuracy of the trajectory after combination of the GPS-solution with INS. Each flight has two figures, the top one gives the accuracy of the GPS solution. The second figure gives the accuracy after combining the GPS solution with the INS data. For the first figure, blue shows the height, green shows the north, red shows the east solution and brown shows the trace of the flight. For the second figure, blue shows the height, green shows the east and red shows the north solution.

Flight 01 – 2017-05-27

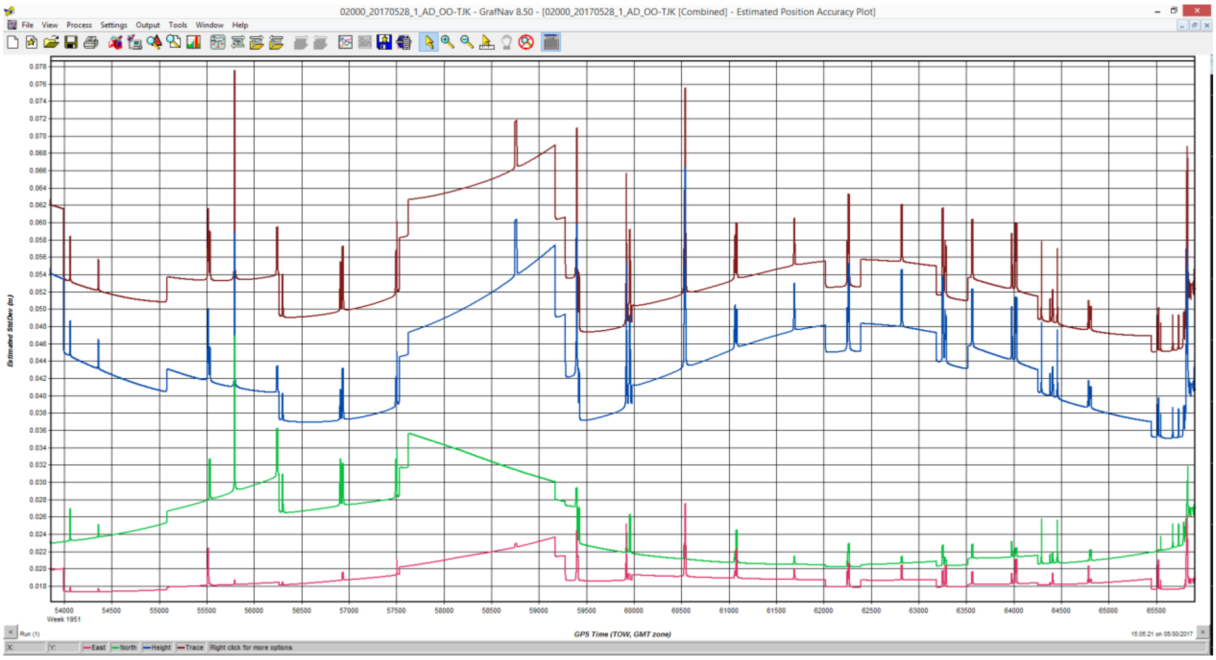


Estimated accuracy of the solution

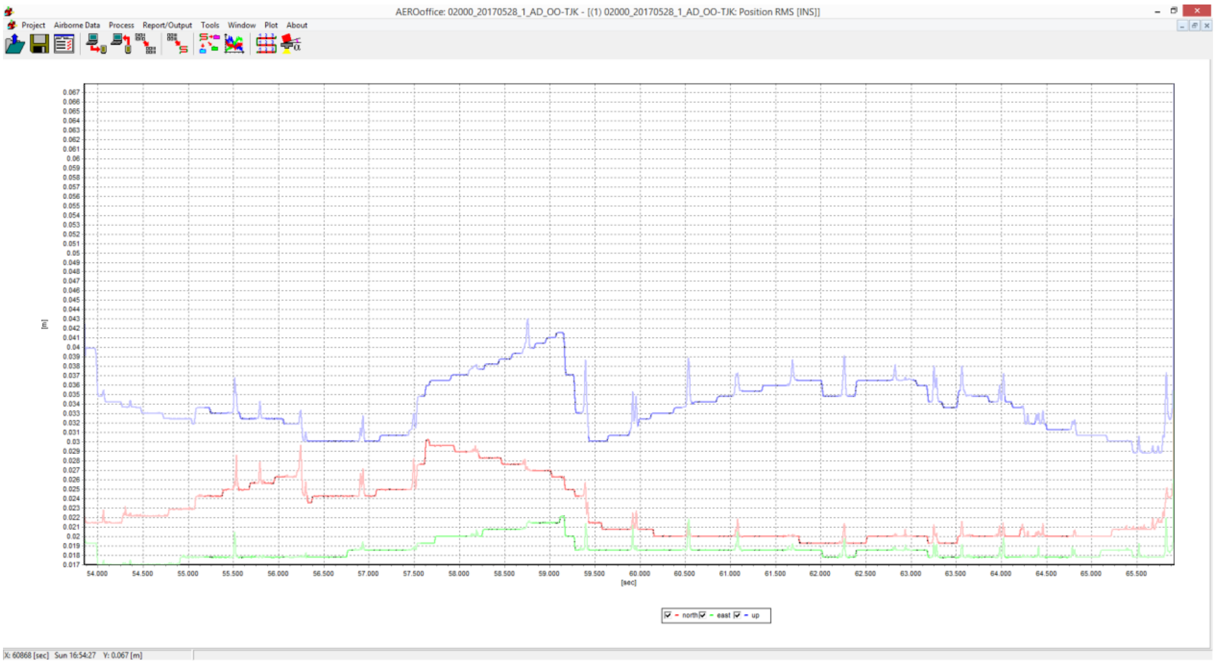


Estimated accuracy of the trajectory after combining the GPS solution with INS.

Flight 02 – 2017-05-28



Estimated accuracy of the solution



Estimated accuracy of the trajectory after combining the GPS solution with INS.