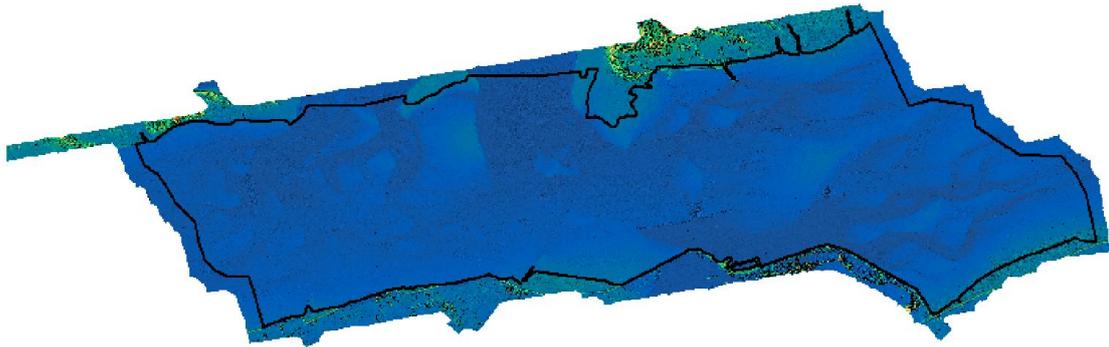


QUALITY REPORT WADDENZEE



Utrecht,
22-10-2016

Reference: QN16-0156/JLE
Author: Daisy Sparla

Version control and approval

Version control

Version	Date	Name/names contributor(s)	Remarks
1.0	22-10-2016	DEJ Sparla	
2.0	08-11-2015	DEJ Sparla	

Approval

	Function	Name	Date	Signature
Checked	Project leader	Jeroen Leusink		
Approved	Quality manager	Jeroen Leusink		

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Revision Report

22 oktober 2016

This is the first version of the report.

08-11-2016

This is the second version in the report. In this version the lines that has flown outside the tidal window are replaced with the lines from 15th of September. It concerns the lines 15,16,17 and 33. All necessary tables and pictures has been changed.

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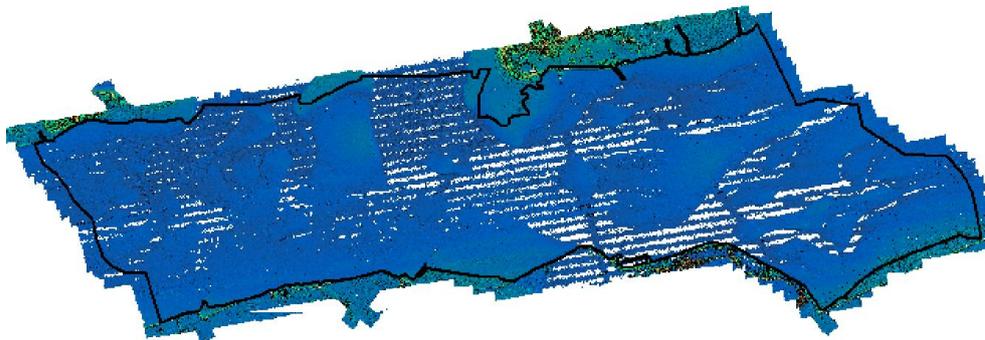
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1. Introduction

This document describes the quality concerning the delivery of the project T116018 Waddenzee. The project was flown in two flights, 14th of September, 16th of September and the replacement lines of 15th of September. The aircraft was G-OBSR of Ravenair, the scanner was the LM7800. The quality control of the flight was done on location in Groningen, while the aircraft was in the airport of Eelde.

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



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2. Flight specifications

The flight specifications are given in the table below.

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

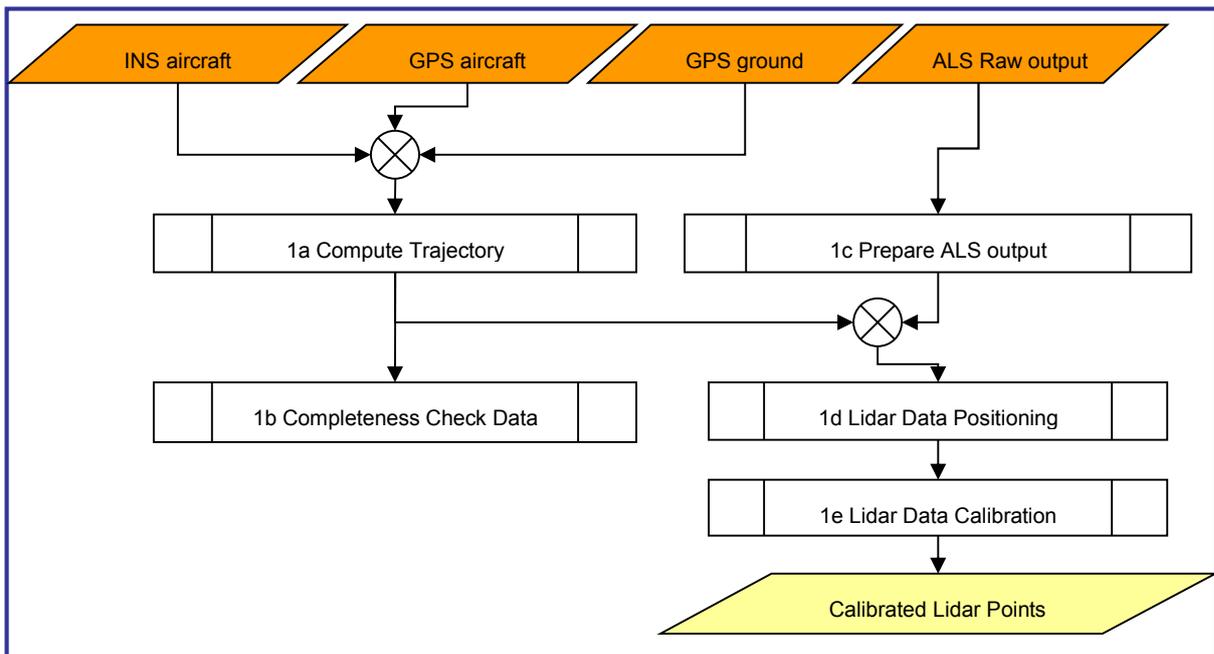
Flight specifications	
Flying height (nominal)	460 m AGL
Flying speed	130 kts
Side-lap (LIDAR)	36%
Minimum altitude	450 m AGL
Maximum altitude	500 m AGL

LiDAR	
Scan angle scanner (half)	30 degrees (60 degrees full)
Scanner pulse rate	400 kHz
Mirror frequency	184 lines/sec
Point density	4 pts/m ²

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.

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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 allow 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.

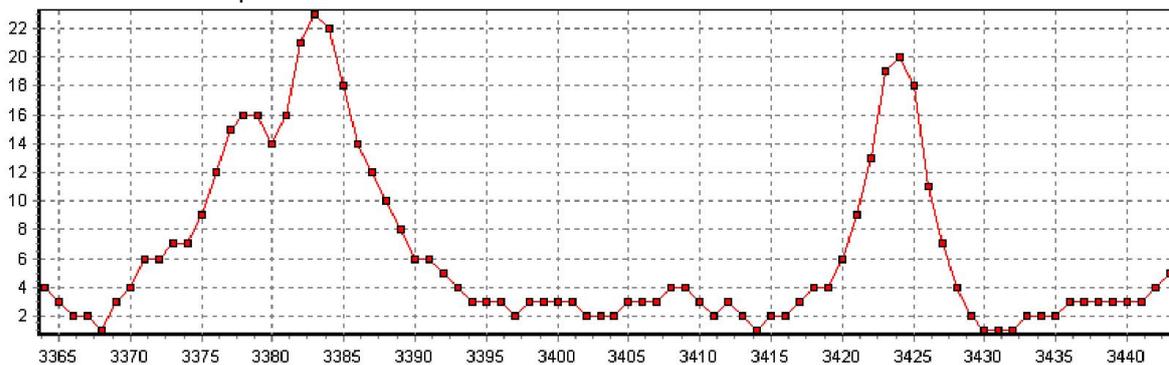


Figure 4.1 Discretized full waveform scanner output. On the x-axis the signal time is shown, on the y-axis the returning signal intensity is shown. The first peak represents the first pulse, the second peak shows the last pulse. In practice the first pulse will often represent vegetation and the last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

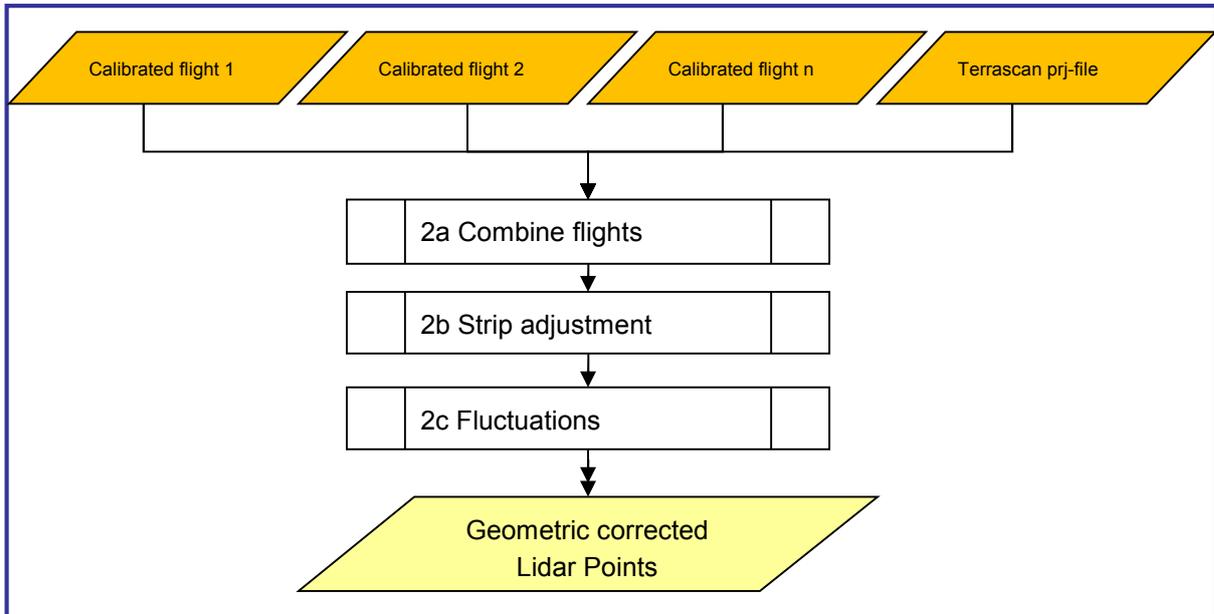
For the actual calculation of the laser point coordinates the flight trajectory and the recorded flight times of the laser pulse are combined. Using the RProcess software package the laser point coordinates are projected to the ETRS coordinate system. In the last step the point coordinates in the ETRS 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 misalignment angles between the laser scanner and the IMU. Although the misalignment 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.

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3.2 Block processing



The project AOI is divided in several processing blocks. Each block may consist of various flights that are combined into a single data set for the block. At this stage systematic height deviations between strips are determined in a 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)

The final 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.

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4. Trajectory and GPS station accuracy

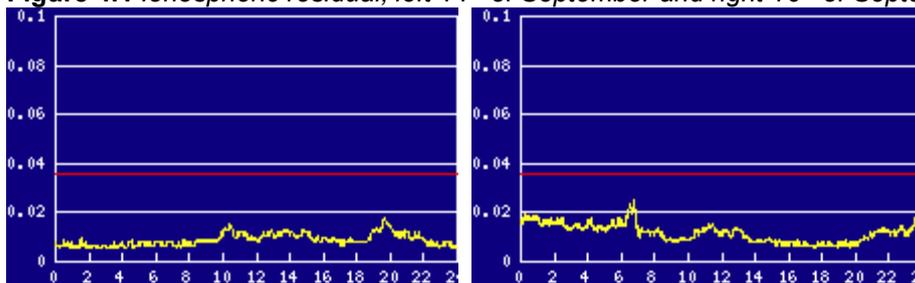
The GPS base stations used for the processing were part of the 06-GPS (Dutch network) network. The accuracy plots of the precise trajectory computation are given in Appendix A.

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 Northern part of the GPS network. As the figures show the residual is very low.

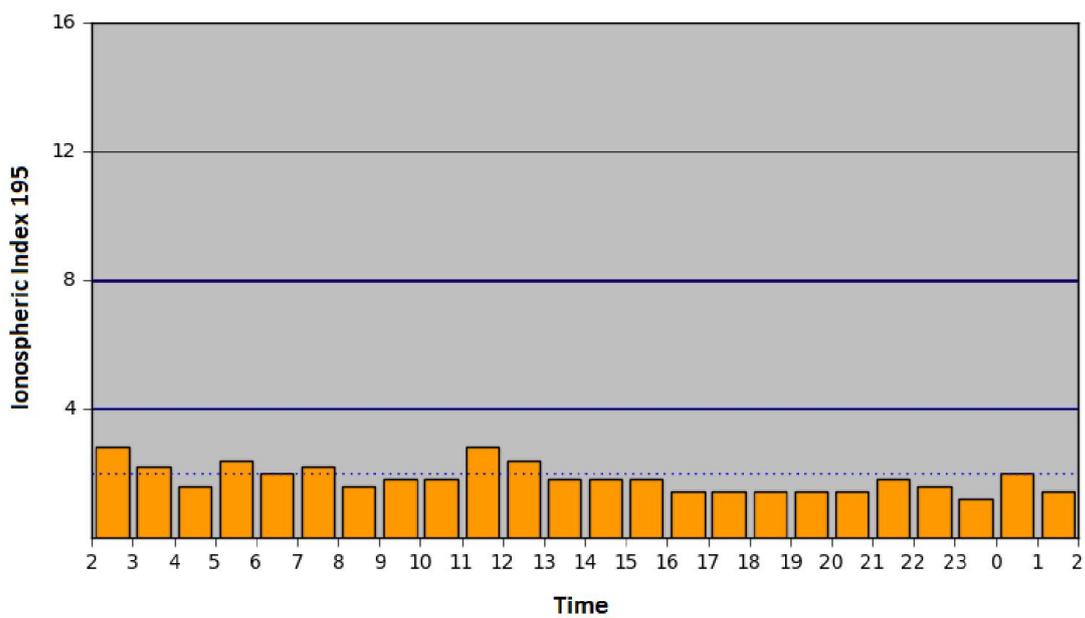
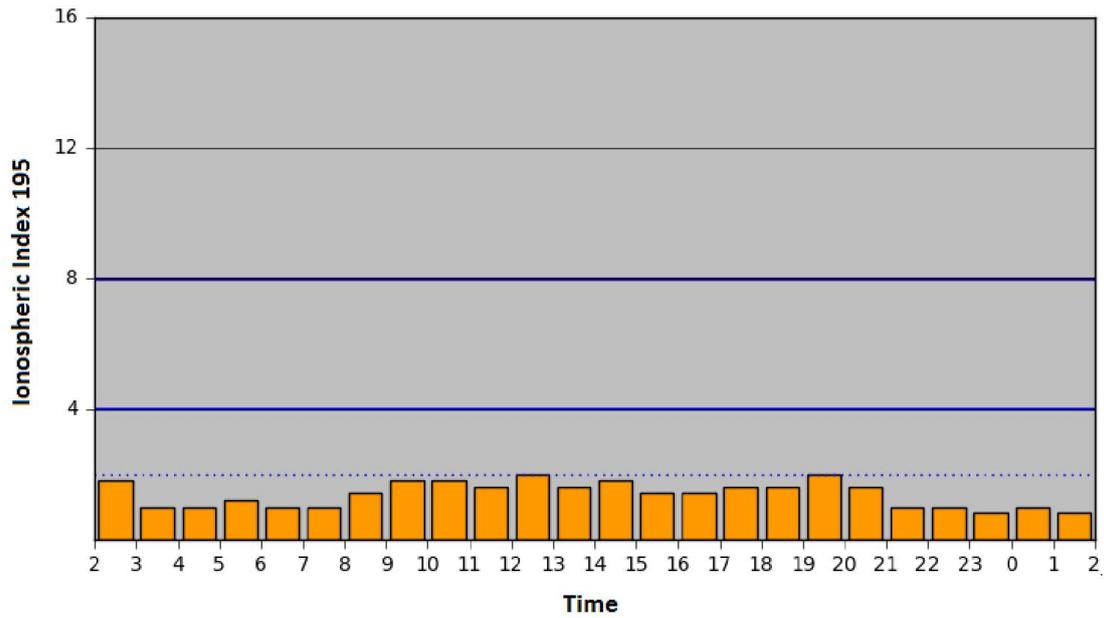
Figure 4.1 Ionospheric residual, left 14th of September and right 16th of September.



The ionospheric activity can also be expressed with the ionospheric noise index 195. The 195 values compute all corrections for the satellites 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.

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Figure 4.2 Ionospheric noise 195 index, first 14th of September; second 16th of September. 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.



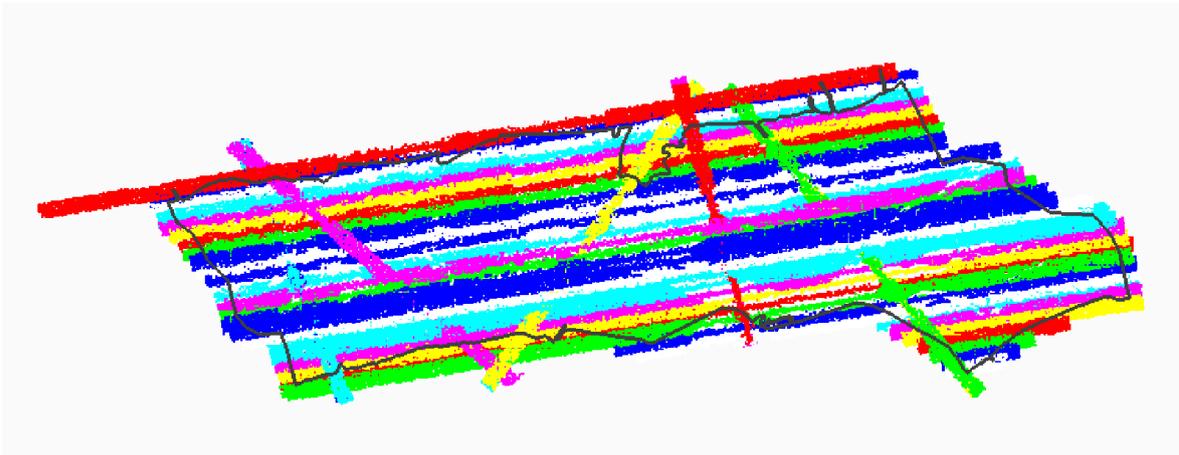
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5. Completeness check

The data acquisition was done in 2 flights: on September 14th and 16th, 2016. Because there were a few lines out of the tidal window, a replacement was done of those lines with the flight of 15th of September. 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.*



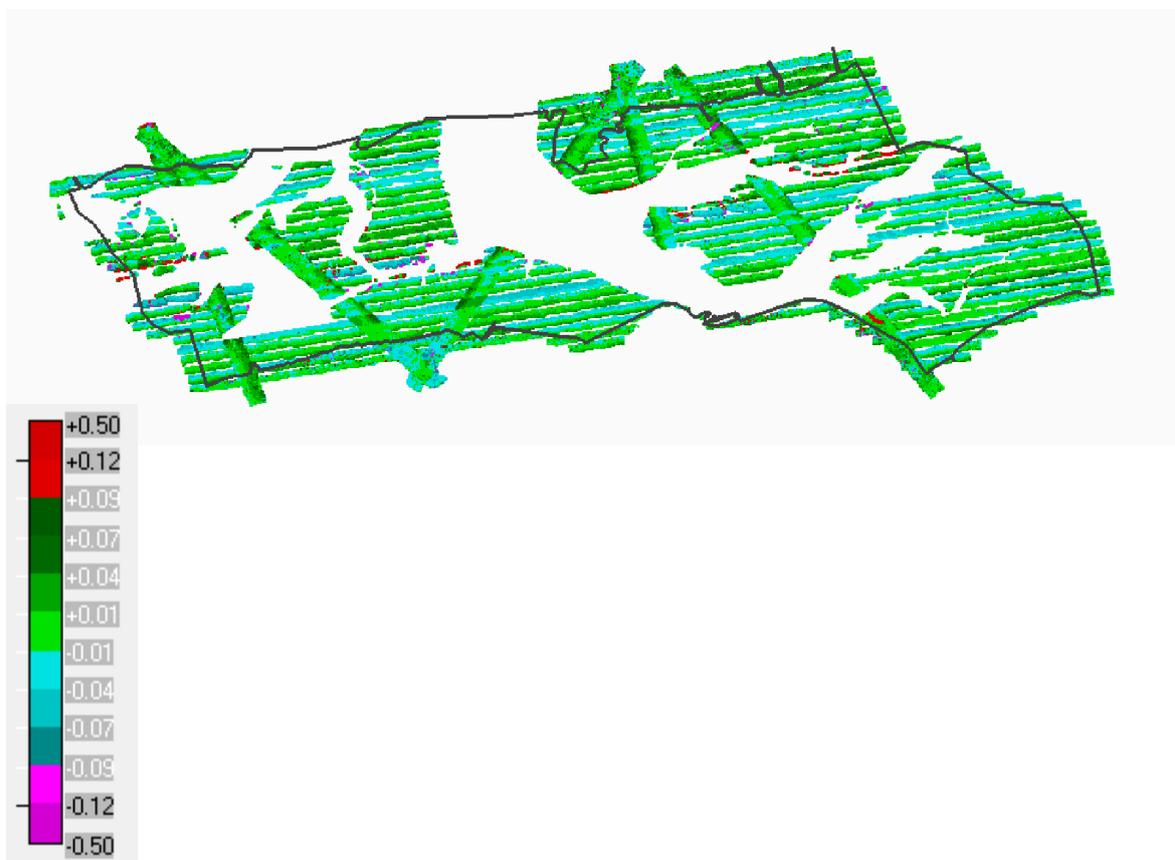
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6. Final relative height accuracy

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).

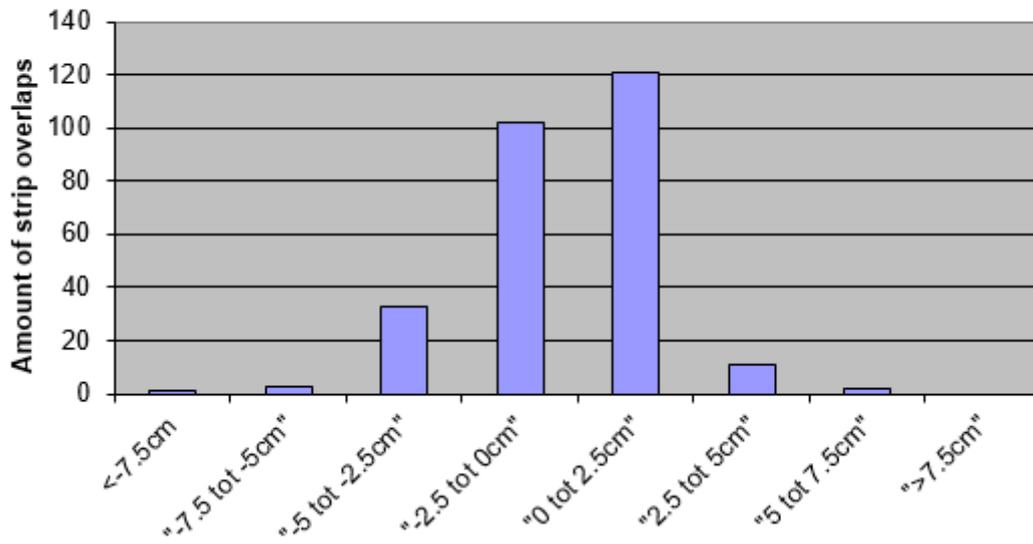
A visual display of the differences between overlapping strips is given in the figure below. The average difference for all strip overlaps is 2 mm, the average standard deviation is 3.0 cm. Big water areas are cut out of the data to give an accurated overview of the relative height accuracy. There are 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.

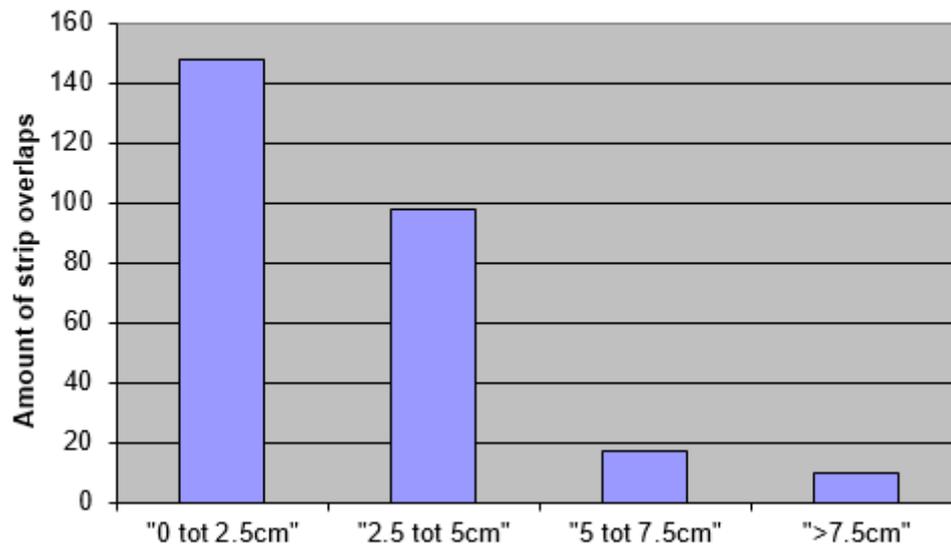


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Figure 6.2 Histograms of the average mis-match and the standard deviation
Histogram average mis-match



Histogram standard deviation



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7. Absolute height accuracy

The absolute height 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 area and the height of the LiDAR data. For the reference field there are more than one flightline to determine the average. The result is shown in the table below.

Table 7.1 Differences between the LiDAR data and the reference areas.

Reference field	Average difference (mm)	Standard deviation (mm)
GCP 1: Kleine huisjes	3	5
GCP 2: Ameland kooiweg	3	11
GCP 3: Schiermonningoog	6	23
GCP 4: Vijfhuizen	10	11
GCP 5: Lauwersoog	4	30
GCP 6: Schiermonnikoog_corrected	9	27
GCP 7: Nes	7	7
GCP 8: Ternaat	-8	11

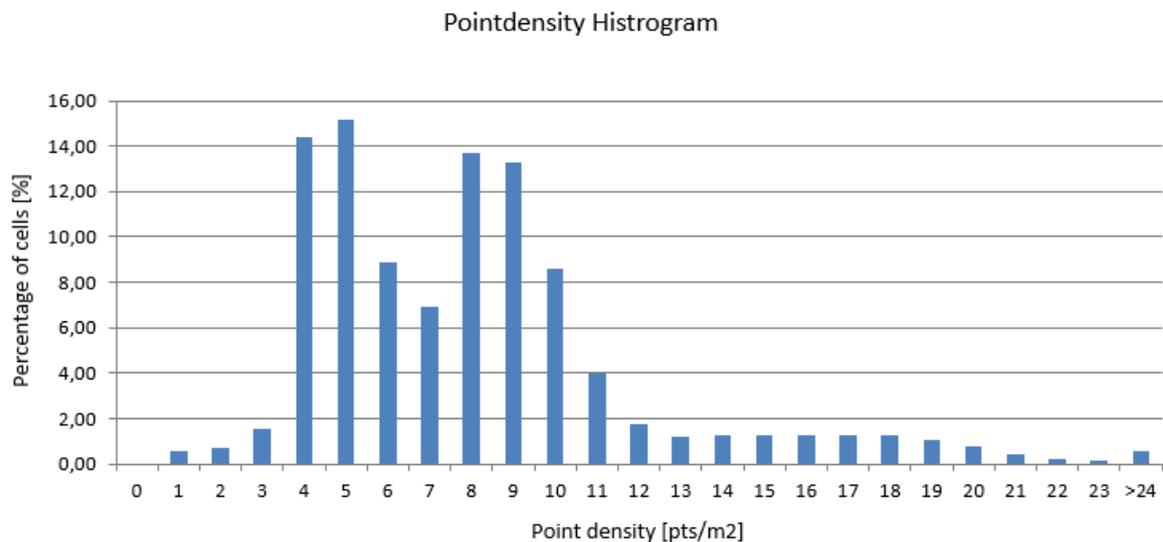
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8. Point density

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 overview of the point density is shown in figure 8.2. Within the area 97% 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 point density histogram. There are some red and black spots visible in figure 8.2 indicating the small water areas. The average point density is 7.0 pts/m².

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



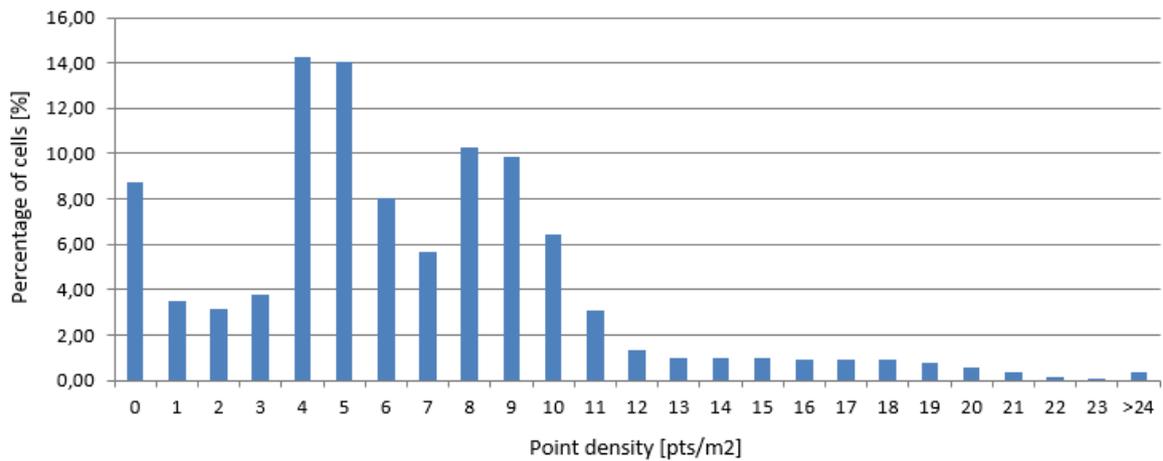
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Figure 8.2 Overview of the point density without big water areas.



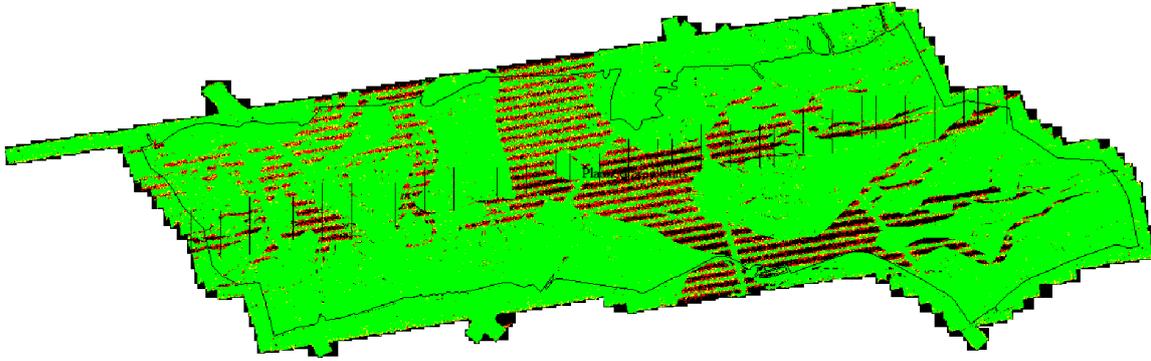
Figure 8.3 and 8.4 are giving the same overview, only including big water areas this time. Average pointdensity including big water areas is 6.5 pts/m² and within the area 80.85% of the cells have a pointdensity of 4 pst/m² or higher.

Pointdensity Histogram



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Figure 8.4 Overview of the point density with big water areas.



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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. The first two lines of the 14th of September and the last three lines of 16th of September are not flown in the tidal window of -0.70 NAP, this is approved by the customer. After discussed with the customer to replace the lines 1033, 3015, 3016, 3017 with the lines 2033, 2015, 2016, 2017 of the second flight 15th of September. Figure 9.1 shows the project area with the tidal stations.

Figure 9.1 Tidal stations with project area



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

Line number	Date	Begin time	End time	Start Low Water	End Low Water	Water level mm				explanation
						Schiermonnikoog	Lauwersoog	NES	Holwerd	
01033	14-09	13:42	13:50	14.00	17.10	-56	-61	-61	N/A	Started to early
01020	14-09	13:54	14:01	14.00	17.10	-64	-66	-65	N/A	Started to early
01022	14-09	14:05	14:12	14.00	17.10	-70	-74	-72	N/A	
01021	14-09	14:16	14:23	14.00	17.10	-79	-81	-80	N/A	
01905	14-09	14:28	14:31	14.00	17.10	-87	-89	-86	N/A	
01904	14-09	14:34	14:38	14.00	17.10	-96	-95	-93	N/A	
01903	14-09	14:41	14:44	14.00	17.10	-104	-100	-98	-63	
01902	14-09	14:48	14:50	14.00	17.10	-104	-100	-98	-63	
01007	14-09	14:52	14:55	14.00	17.10	-112	-105	-104	-73	
01008	14-09	14:58	15:03	14.00	17.10	-112	-105	-104	-73	
01009	14-09	15:12	15:17	14.00	17.10	-120	-114	-111	-97	
01010	14-09	15:20	15:28	14.00	17.10	-122	-118	-112	-109	
01011	14-09	15:31	15:39	14.00	17.10	-122	-120	-112	-116	

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01012	14-09	15:42	15:50	14.00	17.10	-123	-120	-110	-128	
01013	14-09	15:53	16:01	14.00	17.10	-124	-121	-106	-136	
01014	14-09	16:04	16:12	14.00	17.10	-122	-118	-99	-137	
01023	14-09	16:15	16:23	14.00	17.10	-117	-117	-92	-137	
01901	14-09	16:28	16:31	14.00	17.10	-112	-114	-83	-129	
01006	14-09	16:35	16:37	14.00	17.10	-106	-106	-73	-117	
01005	14-09	16:41	16:43	14.00	17.10	-102	-99	-63	-102	
01004	14-09	16:46	16:47	14.00	17.10	-102	-99	-63	-102	
01003	14-09	16:50	16:51	14.00	17.10	-95	-91	-34	-89	
01002	14-09	16:54	16:54	14.00	17.10	-95	-91	-34	-89	
01001	14-09	16:57	16:57	14.00	17.10	-95	-91	-34	-89	
02017	15-09	16:19	16:26	14:40	18:10	-150	-149	-137	-134	
02016	15-09	16:30	16:37	14:40	18:10	-155	-153	-135	-155	
02015	15-09	16:41	16:48	14:40	18:10	-155	-153	-130	-160	
02033	15-09	17:16	17:24	14:40	18:10	-141	-141	-101	-155	
03905	16-09	15:55	15:57	15.30	18.45	-86	-92	-91	N/A	
03032	16-09	16:02	16:09	15.30	18.45	-97	-100	-99	N/A	
03031	16-09	16:12	16:19	15.30	18.45	-107	-106	-108	N/A	
03030	16-09	16:21	16:28	15.30	18.45	-117	-113	-113	-63	
03029	16-09	16:31	16:39	15.30	18.45	-125	-121	-118	-75	
03028	16-09	16:41	16:48	15.30	18.45	-128	-127	-121	-92	
03027	16-09	16:51	16:58	15.30	18.45	-132	-132	-125	-106	
03026	16-09	17:01	17:08	15.30	18.45	-136	-135	-126	-131	
03024	16-09	17:11	17:18	15.30	18.45	-137	-137	-125	-141	
03025	16-09	17:39	17:45	15.30	18.45	-134	-140	-114	-148	
03904	16-09	17:49	17:52	15.30	18.45	-134	-140	-105	-150	
03903	16-09	17:55	17:56	15.30	18.45	-132	-136	-94	-148	
03903	16-09	18:00	18:03	15.30	18.45	-128	-130	-81	-137	
03902	16-09	18:06	18:09	15.30	18.45	-128	-130	-81	-137	
03901	16-09	18:13	18:16	15.30	18.45	-119	-121	-68	-122	
03019	16-09	18:22	18:29	15.30	18.45	-108	-110	-46	-103	
03018	16-09	18:32	18:39	15.30	18.45	-94	-96	-33	-87	
03017	16-09	18:42	18:50	15.30	18.45	-78	-79	-20	-74	Started to late
03016	16-09	18:52	19:00	15.30	18.45	-64	-61	-9	-65	Started to late
03015	16-09	19:03	19:11	15.30	18.45	-54	-36	0	N/A	Started to late

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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.

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11. 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.

11.1 Georeferenced points per line

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

11.2 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.

11.3 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.

11.4 Two lines per flight flown in the same direction

There was a request to deliver the two lines flown in the same direction from each flight as unshifted LAZ per line. The data is similar to the georeferenced points per line except for the fact that no shift and fluctuation has been applied to this data. Naming is the flightlinenumber.

11.5 Til index in shape

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

11.6 Flightline in shape

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

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11.7 Orthophotos

Format tif and one ECW. GSP is 7cm.

11.8 Present Report

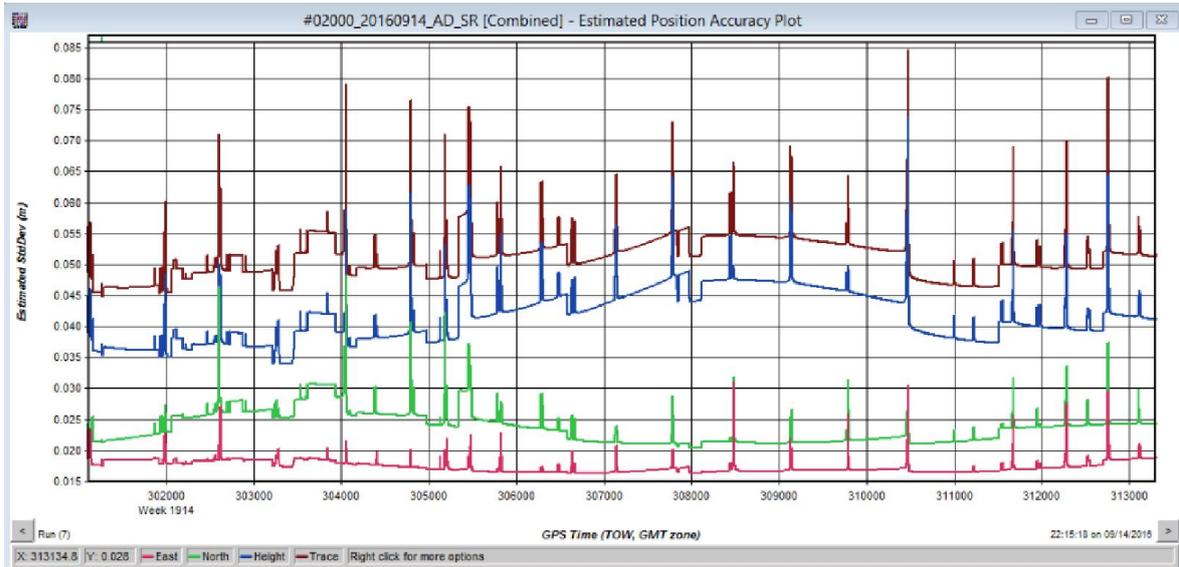
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Appendix A Flight accuracies

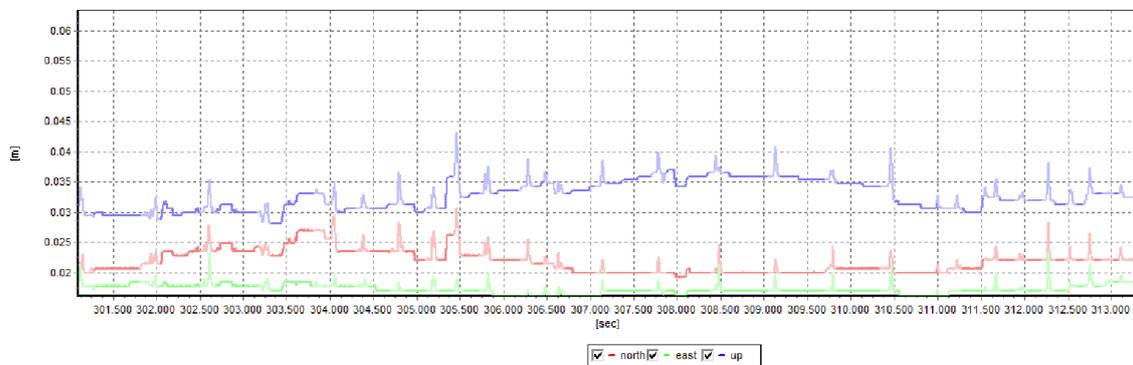
In this appendix the accuracy of the flight trajectory is shown by figures of the accuracy of the trajectory after combination of the GPS-solution with INS. Each flight has two figures, the top one gives the accuracy of the GPS solution. The second figure gives the accuracy after combining the GPS solution 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.

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Flight 01 - 20160914



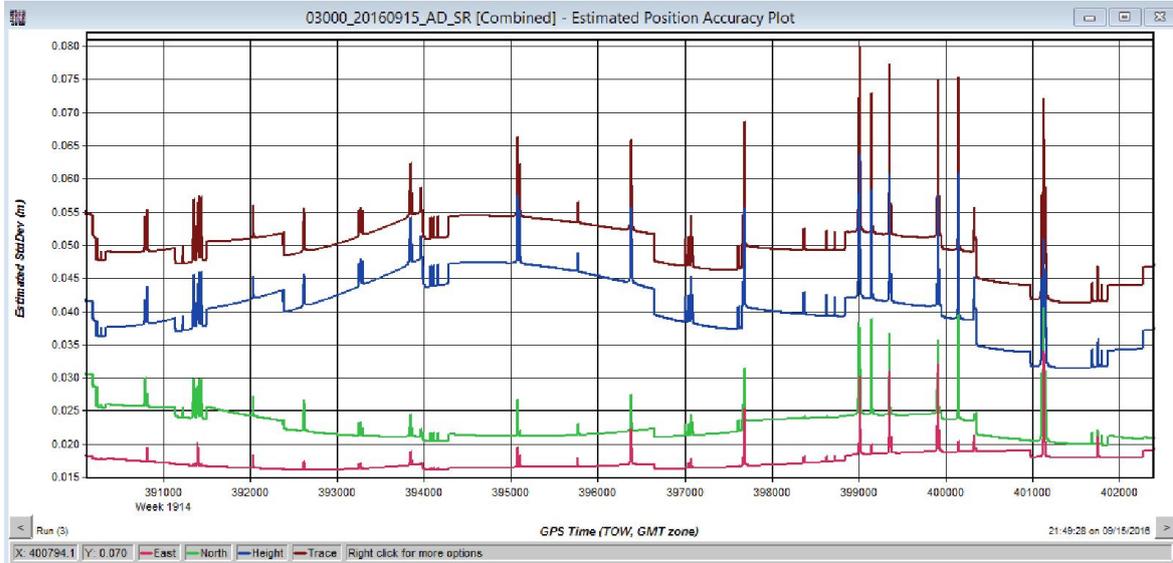
Estimated accuracy of the solution



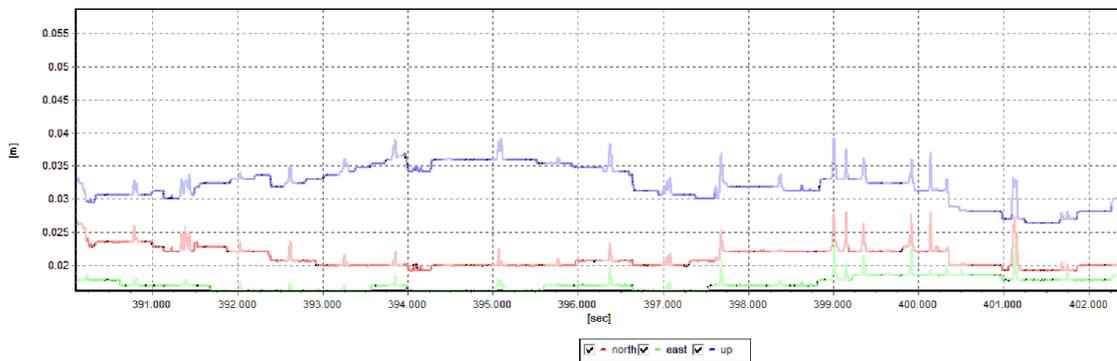
Estimated accuracy of the trajectory after combining the GPS solution with INS.

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Flight 02 – 20160915



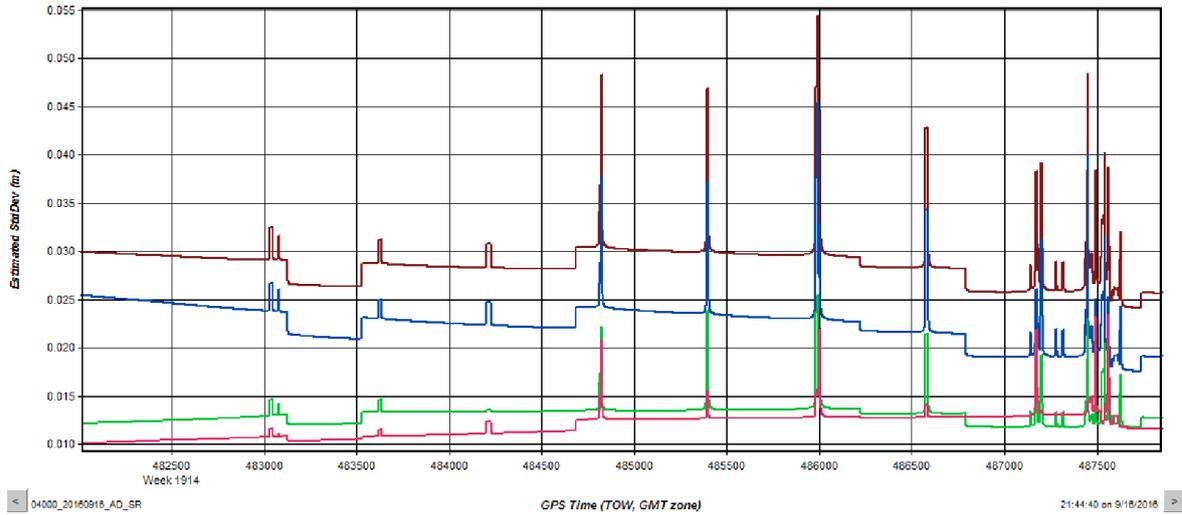
Estimated accuracy of the solution



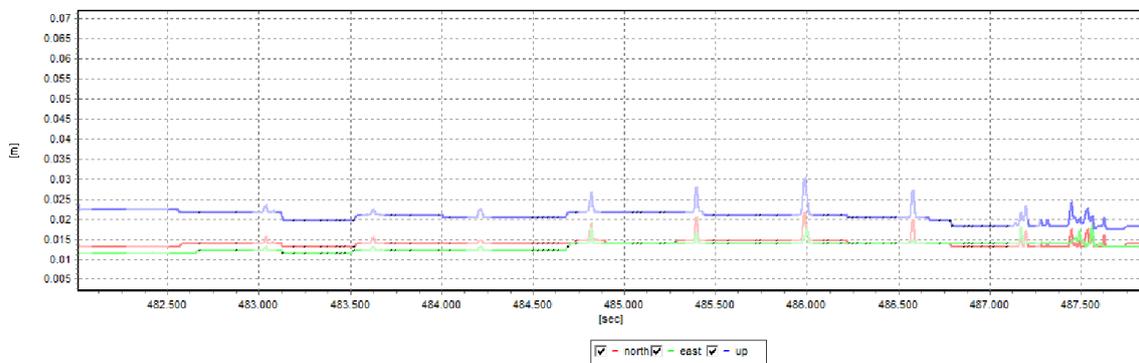
Estimated accuracy of the trajectory after combining the GPS solution with INS.

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Flight 03 Part1 - 20160916



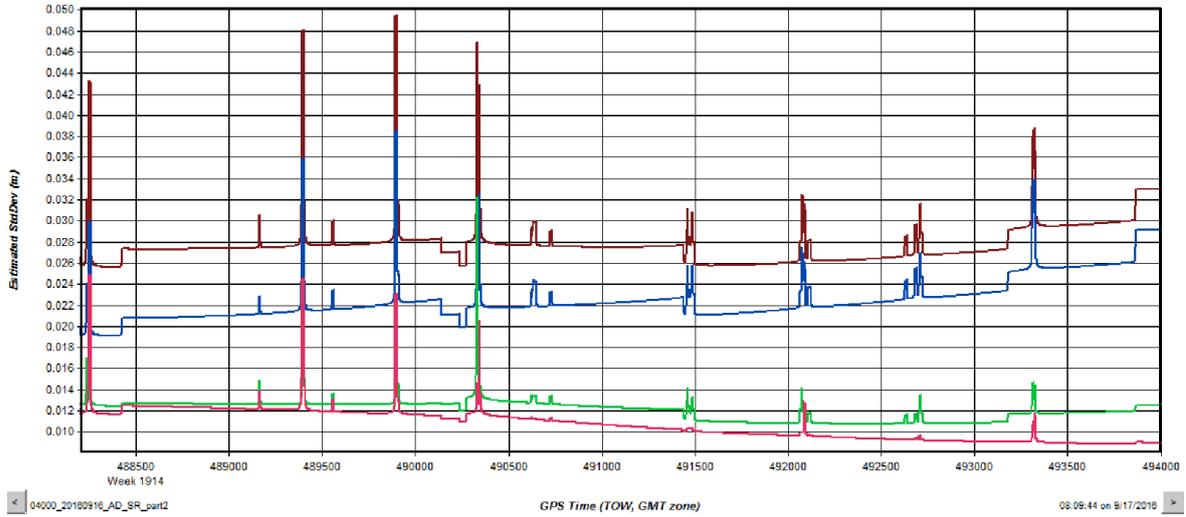
Estimated accuracy of the solution



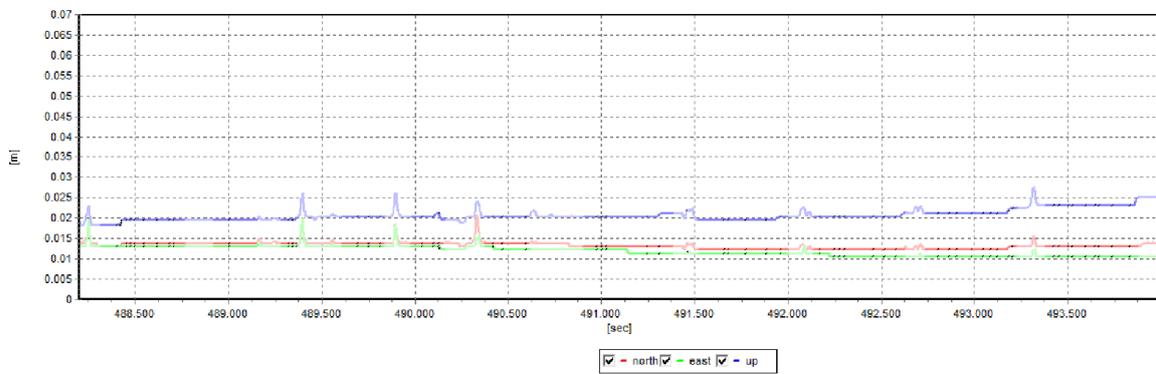
Estimated accuracy of the trajectory after combining the GPS solution with INS.

Report: Quality report Waddenzee
Date: 22-10-2016

Flight 03 Part2 - 20160916



Estimated accuracy of the solution



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