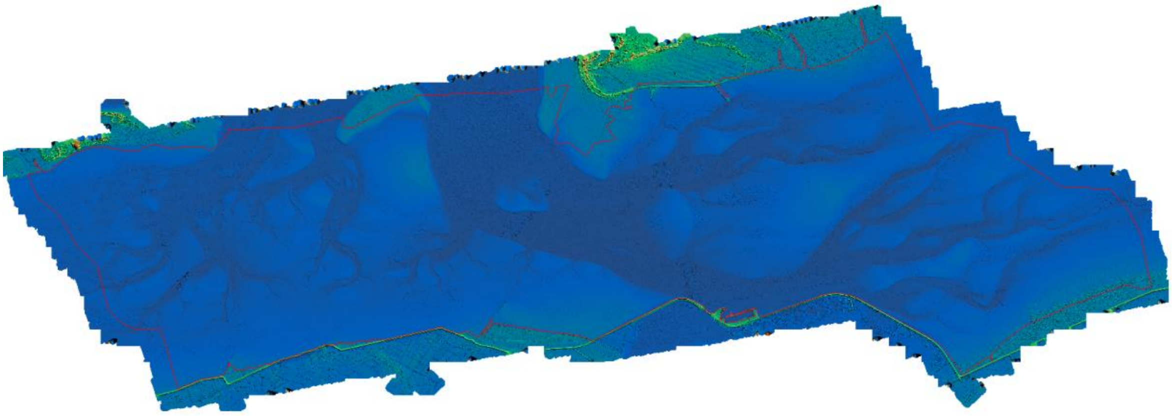
QUALITY REPORT
WADDENZEE



Utrecht,
06-02-2018

Reference: PN17-0030
Author: Tiago Silva

Version control and approval

Version control

Version	Date	Name/names contributor(s)	Remarks
1.0	19-12-17	Tiago Silva	
2.0	15-01-18	Tiago Silva	
3.0	06-02-18	Tiago Silva	

Approval

	Function	Name	Date	Signature
Checked	Project leader	Tiago Silva		
Approved	Quality manager	Tiago Silva		

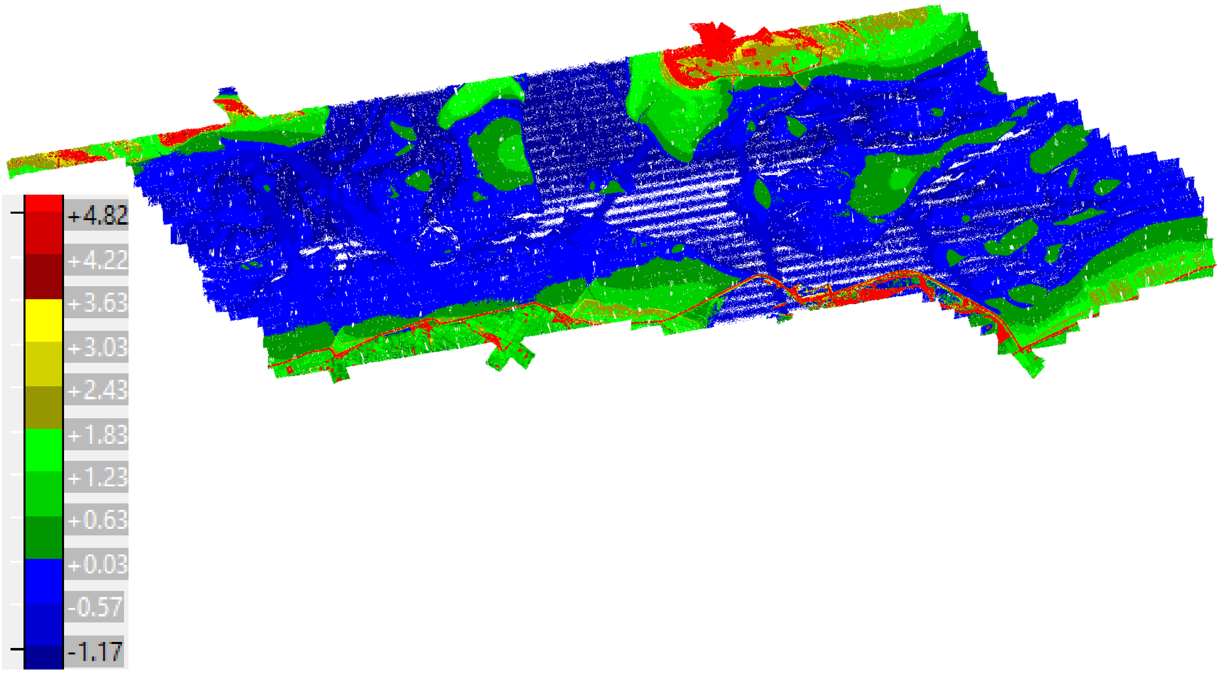
Contents

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. Chapter 11 we have the comparison between 2017 Spring with 2017 Autumn.
Finally chapter 12 gives an overview of all delivered products.

Figure 1.1 *Coverage of the project Waddenzee in elevation (m).*



2. Flight specifications

The flight specifications are given in the table below.

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

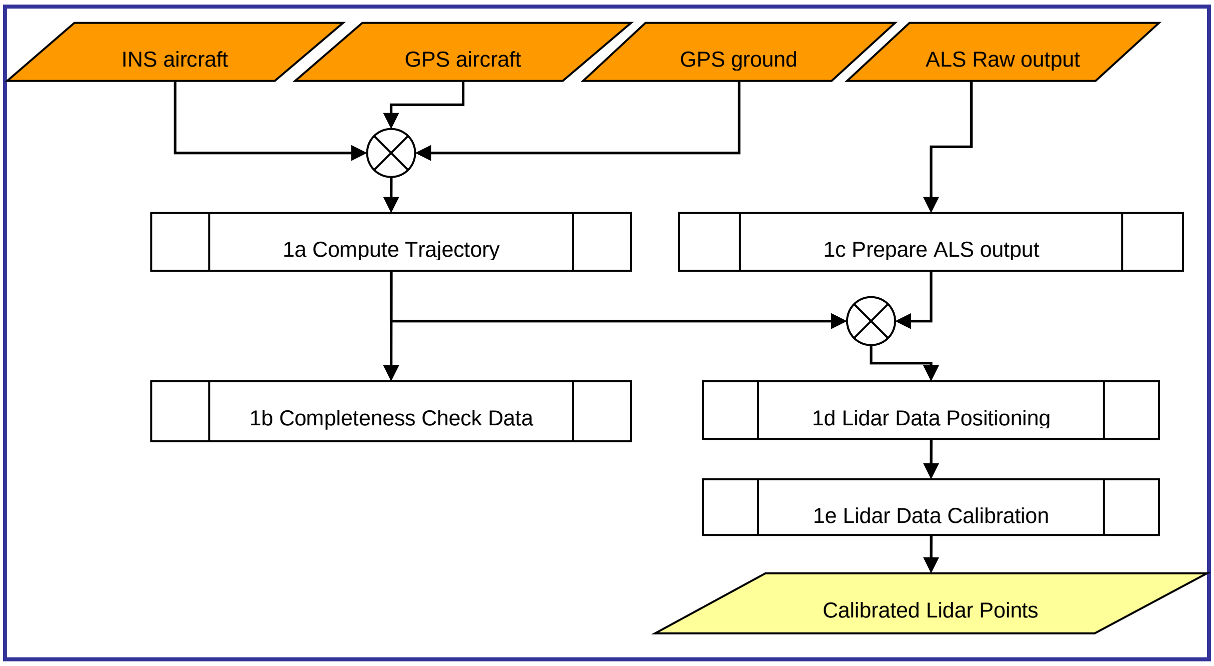
Flight specifications	
Flying height (nominal)	460 m AGL
Flying speed	130 kts
Side-lap (LIDAR)	36%
Minimum altitude	450 m AGL
Maximum altitude	500 m AGL

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 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
– Transforming 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 3.1 shows a graph of the intensity of the returned signal against time from emission. By fitting Gaussian distributions the individual reflection points are determined.

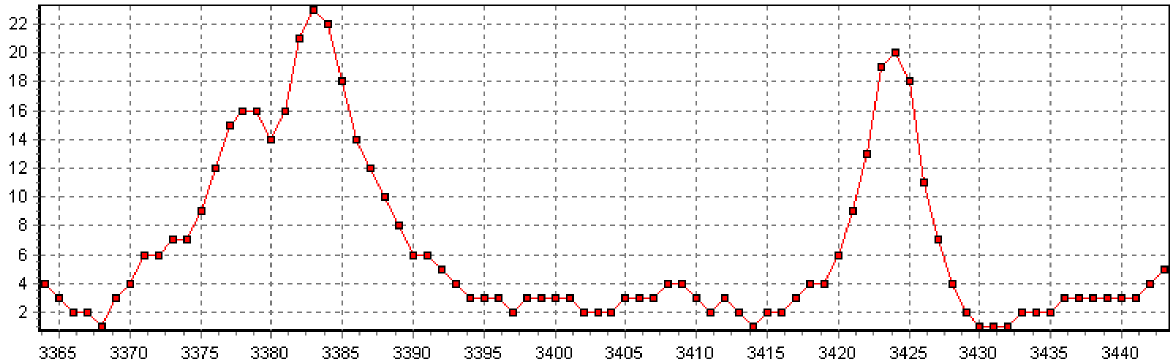


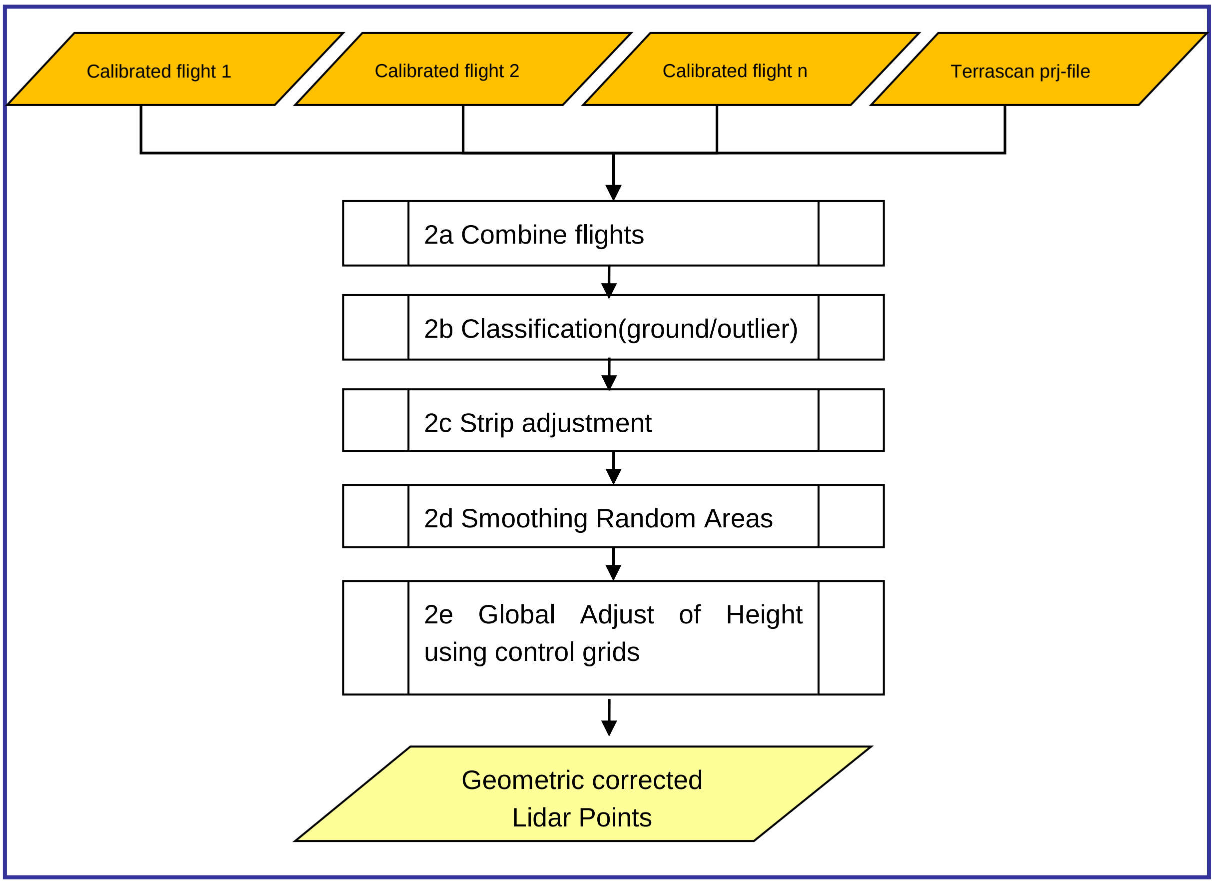
Figure 3.1 Discretized full waveform scanner output. On the x-axis the signal time is shown, on the y-axis the returning signal intensity is shown. The first peak represents the first pulse, the second peak shows the last pulse. In practice the first pulse will often represent vegetation and the last 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, laser point coordinates are projected to the ETRS coordinate system. In the last step the point coordinates in the ETRS coordinate system are transformed 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.

2b Classification:

In this step we use a classification macro that will allow us to perform a better strip adjustment. This macro classifies the data in the following classes:

1-unclassified
2-ground
5-vegetation
6-buildings
7-outliers

This classification is performed on each strip individually. The most important classes are ground and buildings, cause they are used as input for matching processes. Before defining tie lines, water areas are passed back to unclassified since they will not give accurate results in this areas.
Normally we also classify outliers (single points) to be sure that we don't have any outliers classified as ground, that could give us some erroneous areas for matching.
This outliers and other classes are calculated using our own macro, specificly built for strip adjustment.
Outliers classification (class 7) is done for single points or groups of points isolated (so laying above or below) from the rest of point cloud. Group of points (max 6) is classified as outliers if it exceeds of more than +/- 0.5m elevation of other points located in radius of 2 meters. Single points are classified as outliers if they exceed more than +/-0.3 m from other points in radius of 1m. At the end of this process after careful checks, class 7- outliers is deleted when its content doesn't show logical elevation values (it consists of isolated points located far below ground surface or far above high DSM objects).

2c 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 using tie lines, the following effects are removed or minimized:

- Errors in the lever arm between GPS and laser scanner
- 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)

Even though the system has been calibrated, we may still find some systematic errors in the project data.
Based on tie lines searched from ground and buildings classes, we can solve mismatches between laser data from different flight lines or between laser data and known points.
At some point within the correction workflow we must establish which parameters need to be corrected/improved (Heading,Roll,Pitch,dZ).

This strip adjustment will allow us to have data well relatively adjusted.

2d Smoothing Random Areas:

Ideally, relative matching of data should finish when all errors mentioned above are corrected by fixed translation and rotation applied per strip. Unfortunately reality is more complexed as quality of data is affected also by random errors that occur in the flight directions due to movement of the aircraft. Thus fluctuation correction model has to be applied to the dataset.
At this stage it is important to involve control measurements or crossstrips tightening data together as software computes guessed location for the tie line feature which corresponds to the average of the feature location between the laser data strips.
Process of finding fluctuations compares surface-to-surface short intervals of overlapping strips. As a result each short time interval of a strip gets its own correction value. Processing algorithm also takes into account estimates of positional accuracy for each line, which are then translated to weight factors while computing the average location. This results in lower accuracy strips getting a bigger correction and better accuracy paths getting a smaller correction.
Finally smoothing algorithm is applied to corrections curve, based on user defined factor, which determines, how fast corrections curve can change. A small smoothening factor results in a smoother curve. This is used for cases where tie lines are not so good and may contain outliers. A bigger factor results in a less smooth curve, where single tie line observations get more influence in the final solution, used for good tie lines.

2e Global Adjust of Height using control grids:

After strip adjustments, that allowed us to make a good relative adjustment using the overlap part, we passed to the final absolute geometric correction that is in height, using control points.
With a least- square method we can estimate a constant dz shift and apply it to the data, making our data with a good absolute accuracy.

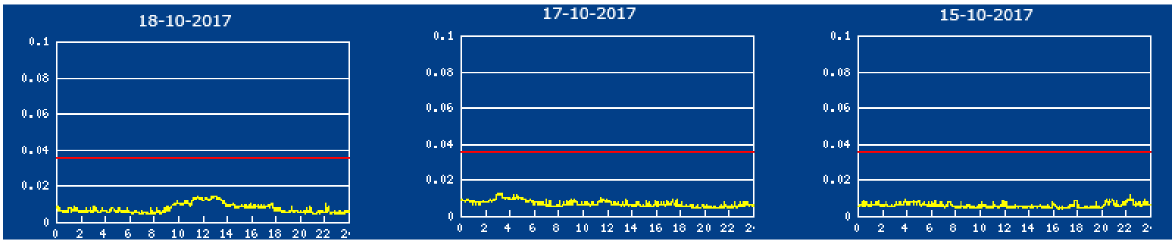
4. Trajectory and GPS station accuracy

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.

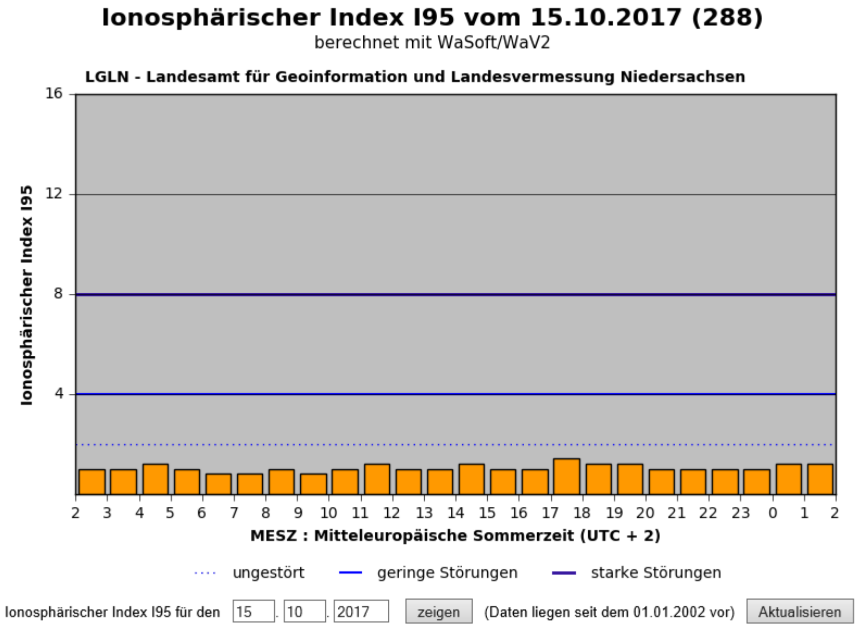
Another factor influencing the quality of the GPS base station is the ionospheric activity. For the Schiermonnikoog station, there is information about the ionospheric activity available. Figure 4.1 shows the ionospheric residual of the Northen part of the GPS network. As the figures show the residual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

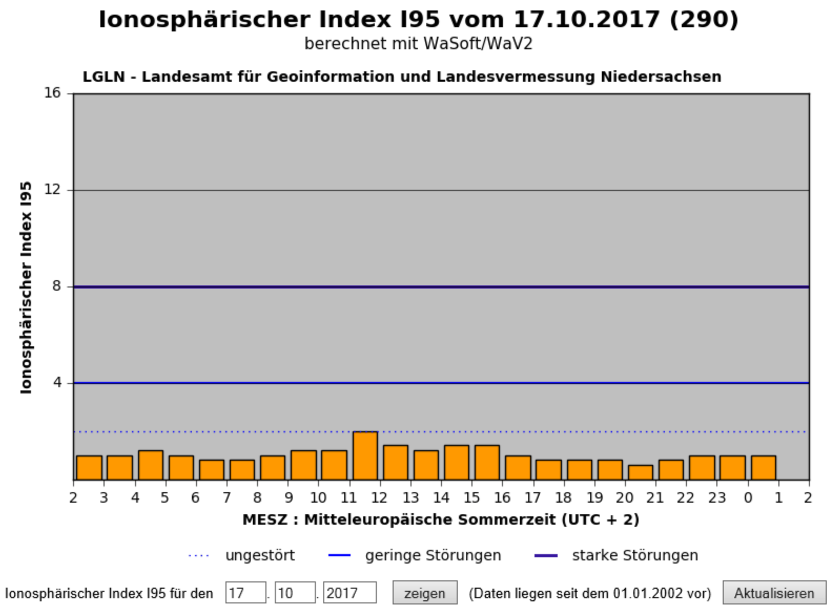
Figure 4.1 *Ionospheric residual, left 15th , 17th and 18th of May. On the x-axis the signal time is shown in hours, on the y-axis the ionospheric residual is shown.*

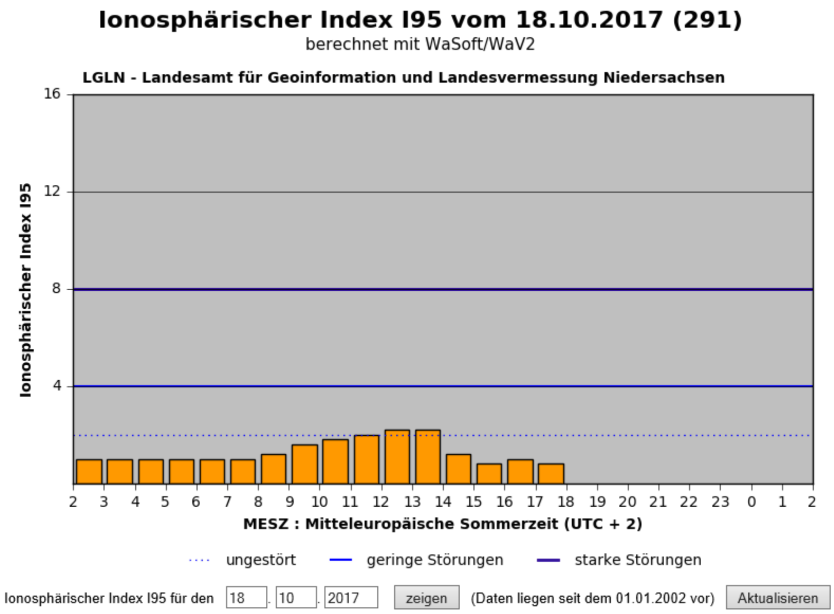


The ionospheric activity can also be expressed with the ionospheric noise index 195. The 195 values compute all corrections for the sattelites of all the station of the network with a timewindow of 1 hour. What happened is that the worst 5 % is rejected and the highest values left will be displayed in the graph. Figure 4.2 shows the 195 values for the 15th, 17th 18th of October, indicating a non-disturbed base station.

Figure 4.2 *Ionispheric noise 195 index, first 15th of October; second 17th of October and third 18th of October . 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.*



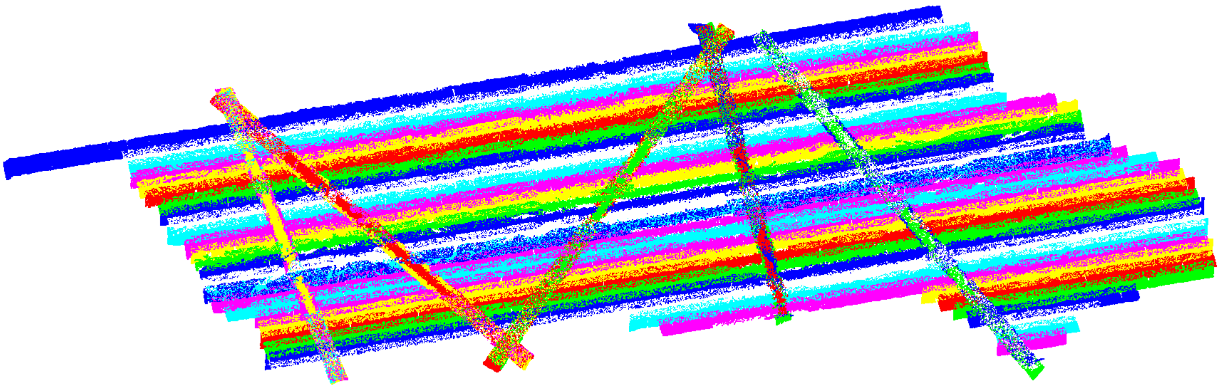



Ionosphärischer Index I95 vom 18.10.2017 (291)
berechnet mit WaSoft/WaV2
LGLN - Landesamt für Geoinformation und Landesvermessung Niedersachsen
Ionosphärischer Index I95
16
12
8
4
2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 0 1 2
MESZ : Mitteleuropäische Sommerzeit (UTC + 2)
ungestört
geringe Störungen
starke Störungen
Ionosphärischer Index I95 für den 18 . 10 . 2017
zeigen
(Daten liegen seit dem 01.01.2002 vor)
Aktualisieren

5. Completeness check

The data acquisition was done in 3 flights: on October 15th, 17th and 18th, 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 1,5 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.*

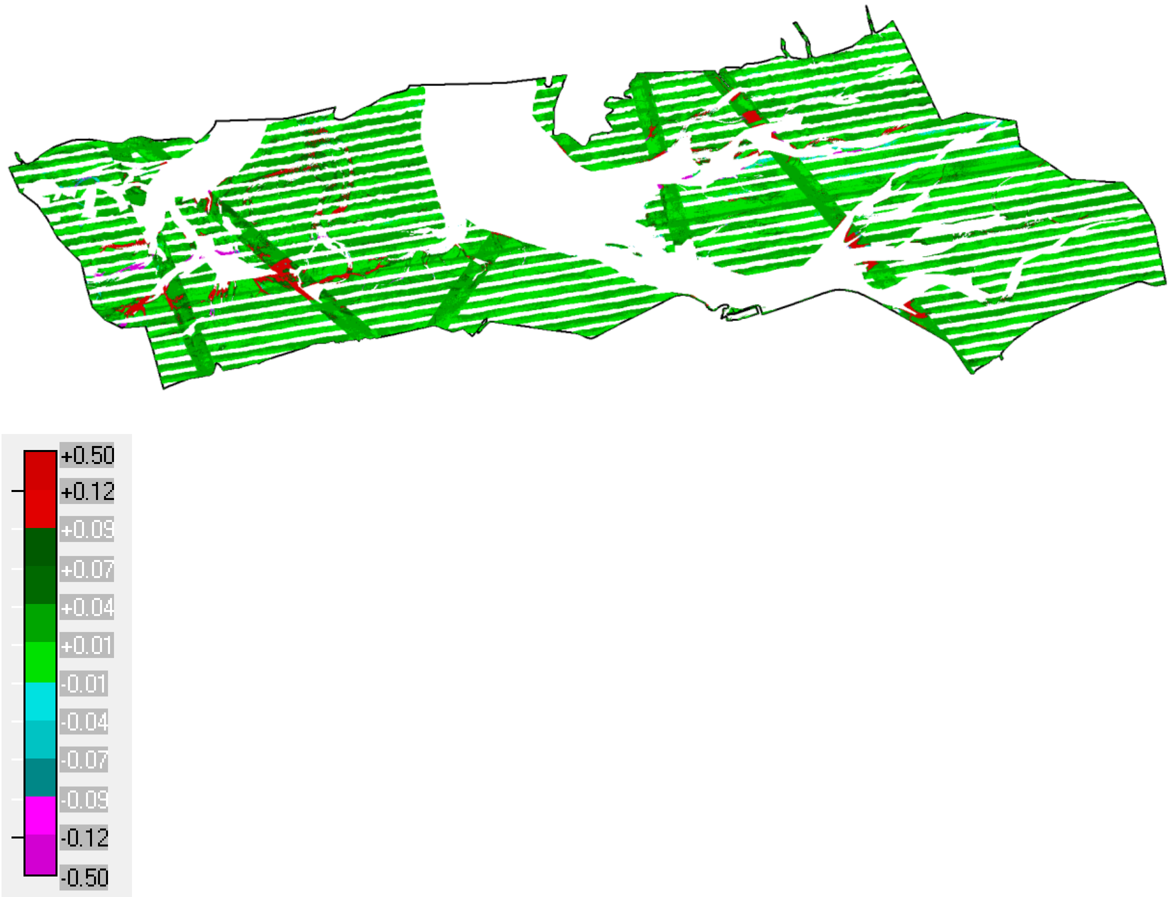
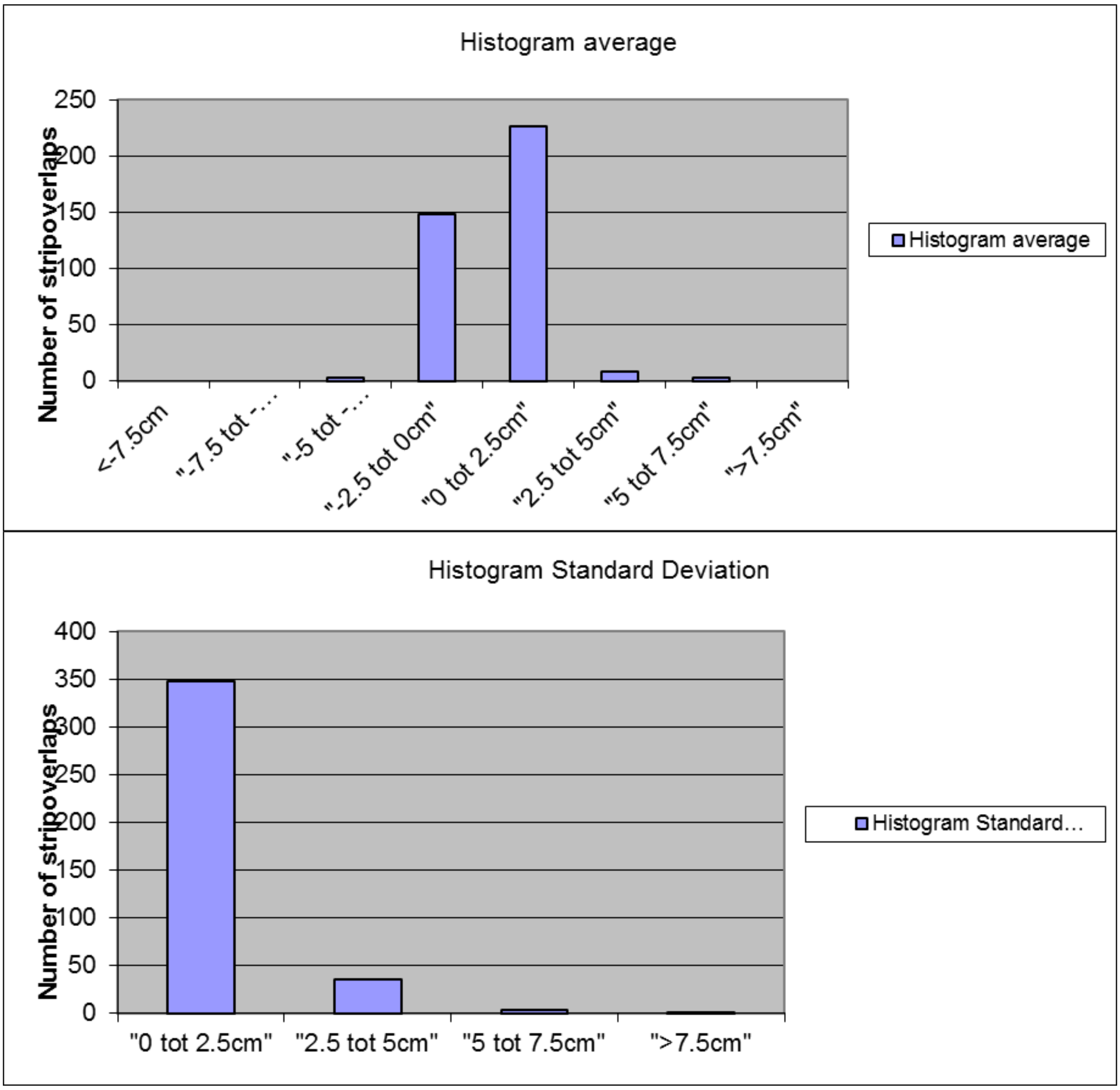


Figure 6.2 *Histograms of the average mis-match and the standard deviation*



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 and the height of the LiDAR data.
The result is shown in the table below.

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

Reference field	Average difference (mm)	Standard deviation (mm)
GCP 2: Ternaard	1	9
GCP 3: Nes_Dongeradeel	-4	4
GCP 4: Schiermonningoog_dorp	-17	7
GCP 5: Lauwersoog	4	12
GCP 6: Vijfhuizen	10	7
GCP 7: Schiermonnikoog_Veerweg	-9	7
GCP 8: Ameland_Kooiweg	-25	8
GCP 9: Kleine_Huisjes	-8	5

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 96.37% 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 8.57 pts/m2.

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

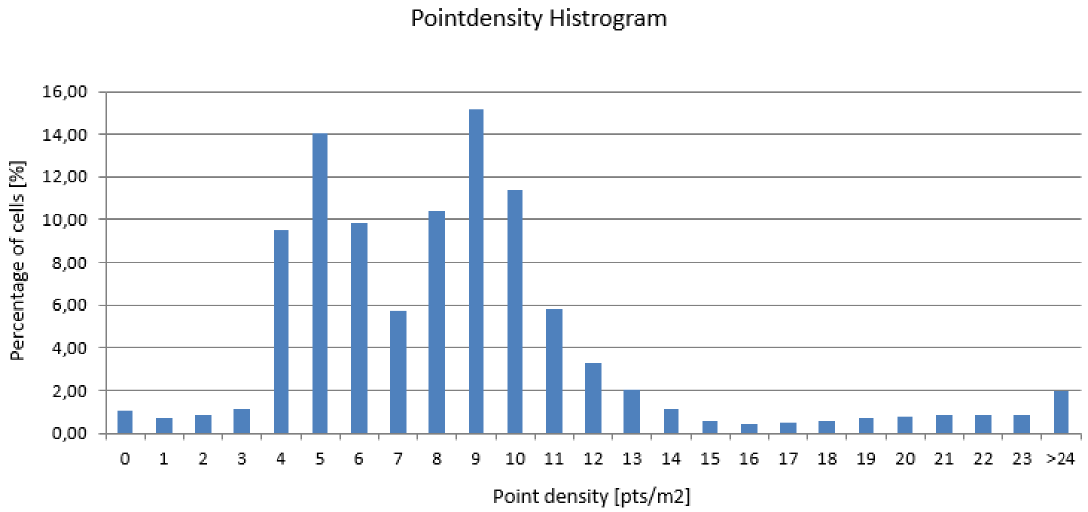


Figure 8.2 *Overview of the point density without big water areas.*

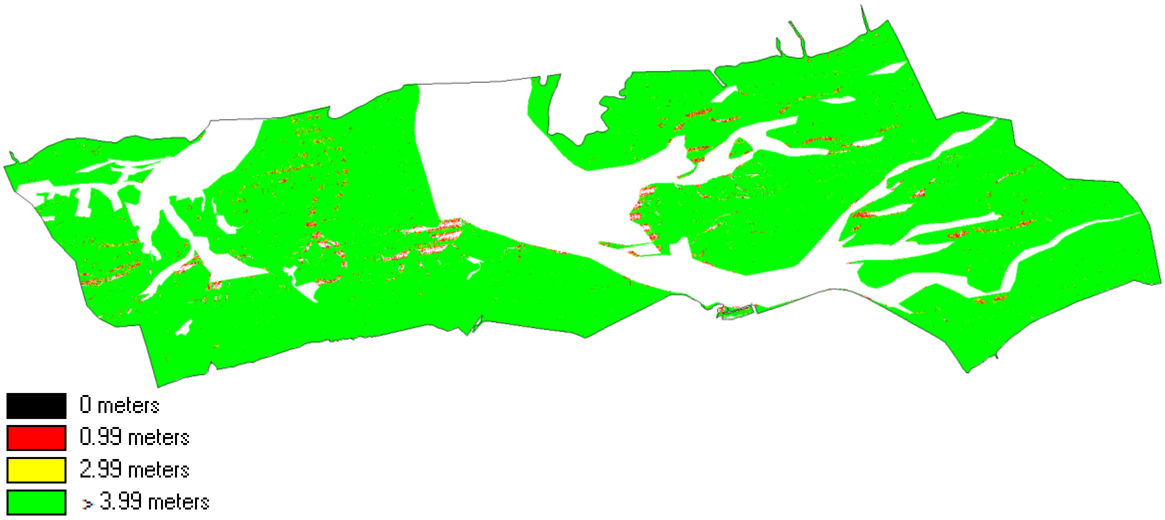


Figure 8.3 and 8.4 *are giving the same overview, only including big water areas this time. Average pointdensity including big water areas is 7,76 pts/m2 and within the area 88.70% of the cells have a pointdenisty of 4 pst/m2 or higher.*

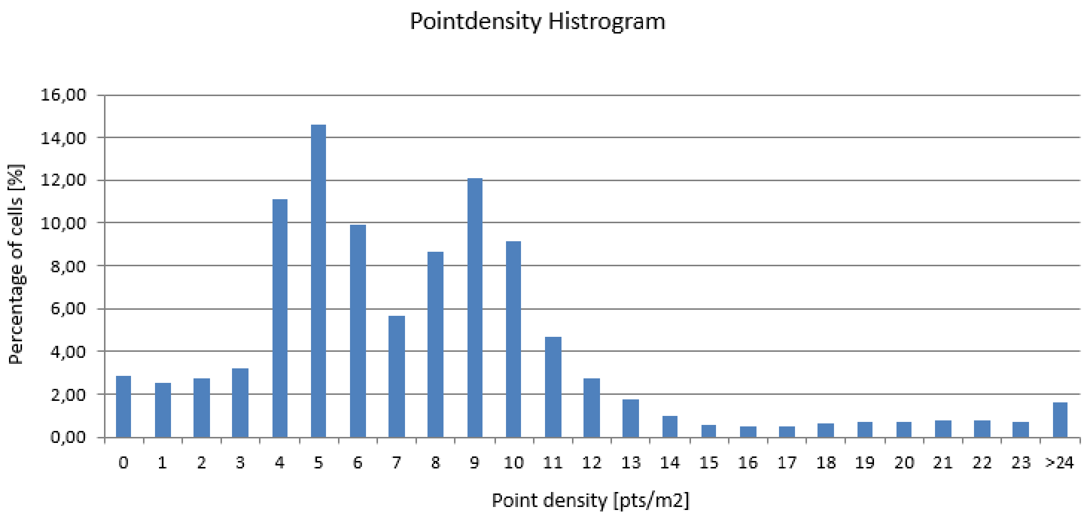
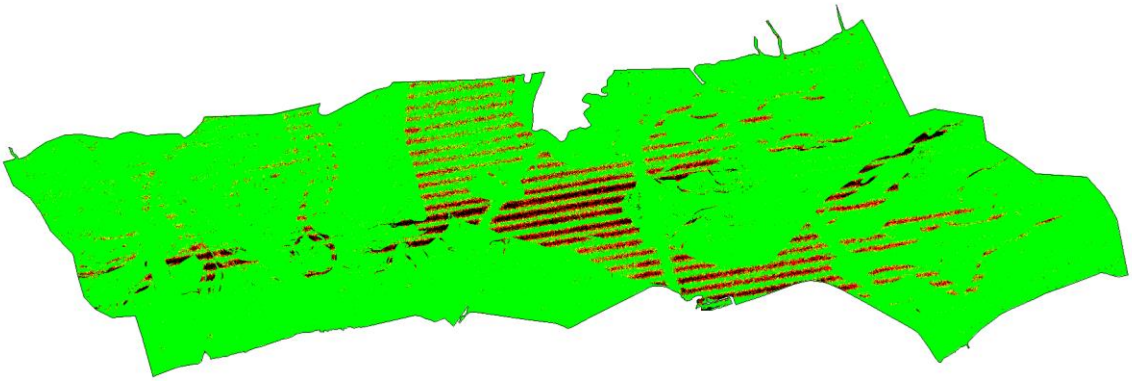


Figure 8.4 *Overview of the point density with big water areas.*



9. Water levels

The Waddenzee project needed to be flown with a maximum tidal height of -0.70m 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 first number in the table). Days flown 15_Oct, 17_Oct, 18_Oct, 15_17_18_OCT.*

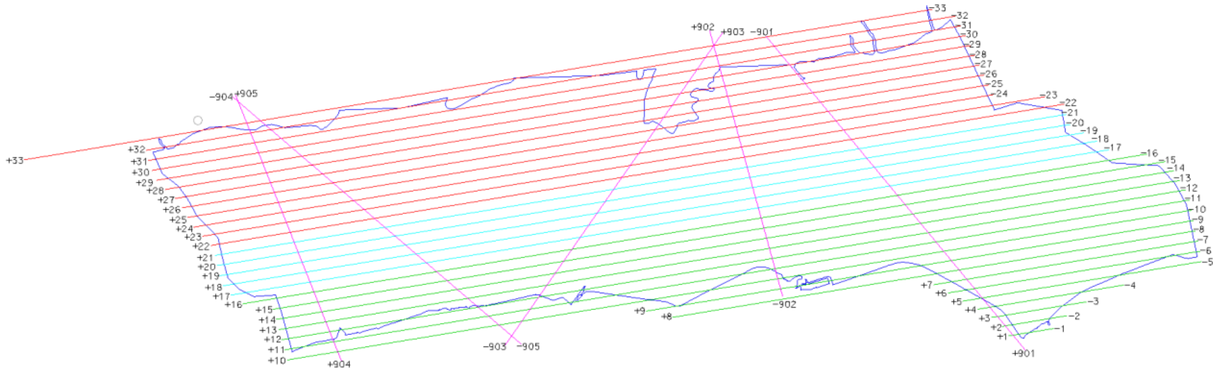


Table 9.1 *The begin and end time (local time GMT+2) of acquisition with the Tidal (max -70cm water level) window times.*

Line number	Date	Begin time	End time
3901	15-Oct	11:52	11:55
3902	15-Oct	11:58	12:01
3001	15-Oct	12:04	12:04
3002	15-Oct	12:06	12:07
3003	15-Oct	12:09	12:10
3004	15-Oct	12:13	12:14
3005	15-Oct	12:17	12:19
3006	15-Oct	12:22	12:24
3007	15-Oct	12:26	12:29
3008	15-Oct	12:32	12:37
3009	15-Oct	12:39	12:44
3010	15-Oct	12:47	12:55
3011	15-Oct	12:57	13:05
3012	15-Oct	13:07	13:16
3013	15-Oct	13:18	13:26
3014	15-Oct	13:28	13:37
3015	15-Oct	13:39	13:47
3016	15-Oct	13:49	13:58
3905	15-Oct	14:01	14:04
3904	15-Oct	14:06	14:09
3903	15-Oct	14:12	14:15

Sunday 15th October						
AM	PREDICTED TIMES			REAL TIMES		
Station	Start	Stop	TT	Start	Stop	TT
SHIER	12:00	14:30	02:30	11:30	15:15	03:45
LAU	12:00	14:30	02:30	11:30	15:15	03:45
NES	11:50	14:00	02:10	11:30	14:40	03:10
HOL*			00:00			00:00
Acquisition			00:00	**11:30**	**14:50**	**03:20**

Line number	Date	Begin time	End time
4904	17-Oct	14:06	14:09
4905	17-Oct	14:12	14:14
4903	17-Oct	14:16	14:20
4901	17-Oct	14:22	14:26
4902	17-Oct	14:29	14:32
4033	17-Oct	14:36	14:45
4032	17-Oct	14:47	14:54
4031	17-Oct	14:57	15:05
4030	17-Oct	15:07	15:14
4029	17-Oct	15:18	15:26
4028	17-Oct	15:28	15:35
4027	17-Oct	15:38	15:46
4026	17-Oct	15:48	15:55
4025	17-Oct	15:57	16:05
4024	17-Oct	16:07	16:14
4023	17-Oct	16:17	16:25
4022	17-Oct	16:27	16:35

Tuesday 17th of October						
PM	PREDICTED TIMES			REAL TIMES		
Station	Start	Stop	TT	Start	Stop	TT
SHIER	14:00	17:10	03:10	13:40	17:10	03:30
LAU	14:00	17:10	03:10	13:30	17:30	04:00
NES	13:50	16:40	02:50	13:40	17:00	03:20
HOL*			00:00			00:00
Acquisition	**14:00**	**17:00**	03:00	**13:40**	**17:10**	**03:30**

Line number	Date	Begin time	End time
5904	18-Oct	15:16	15:19
5905	18-Oct	15:21	15:24
5903	18-Oct	15:26	15:29
5901	18-Oct	15:31	15:35
5902	18-Oct	15:38	15:40
5021	18-Oct	15:45	15:52
5020	18-Oct	15:55	16:02
5019	18-Oct	16:04	16:11
5018	18-Oct	16:13	16:21
5017	18-Oct	16:23	16:30
5018	18-Oct	16:32	16:39

Wednesday 18th of October						
PM	PREDICTED TIMES			REAL TIMES		
Station	Start	Stop	TT	Start	Stop	TT
SHIER	15:00	18:00	03:00	15:15	18:00	02:45
LAU	14:50	18:00	03:10	15:15	18:00	02:45
NES	14:50	17:20	02:30	15:20	17:30	02:10
HOL*			00:00			00:00
Acquisition	**14:55**	**17:40**	**02:45**	**15:15**	**17:45**	**02:30**

HOL was only used in the first season. Uses a different system than the other 3, that makes the numbers there less accurate. It was agreed that we will not consider it anymore.*

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 (Ground Sample Distance) 7cm were retiled. This led to slight shifts in x and y tiling (1 pixel in Y and 5 pixel in X) for the LiDAR and the orthophoto tiles. Nevertheless, this doesn't influence on the main purpose of the orthophoto to interpret the LiDAR data.

The camera used in this survey was a Hasselblad H4D-50 (serial number DH43046309) with Lens HC35.

11. Comparison between surveys

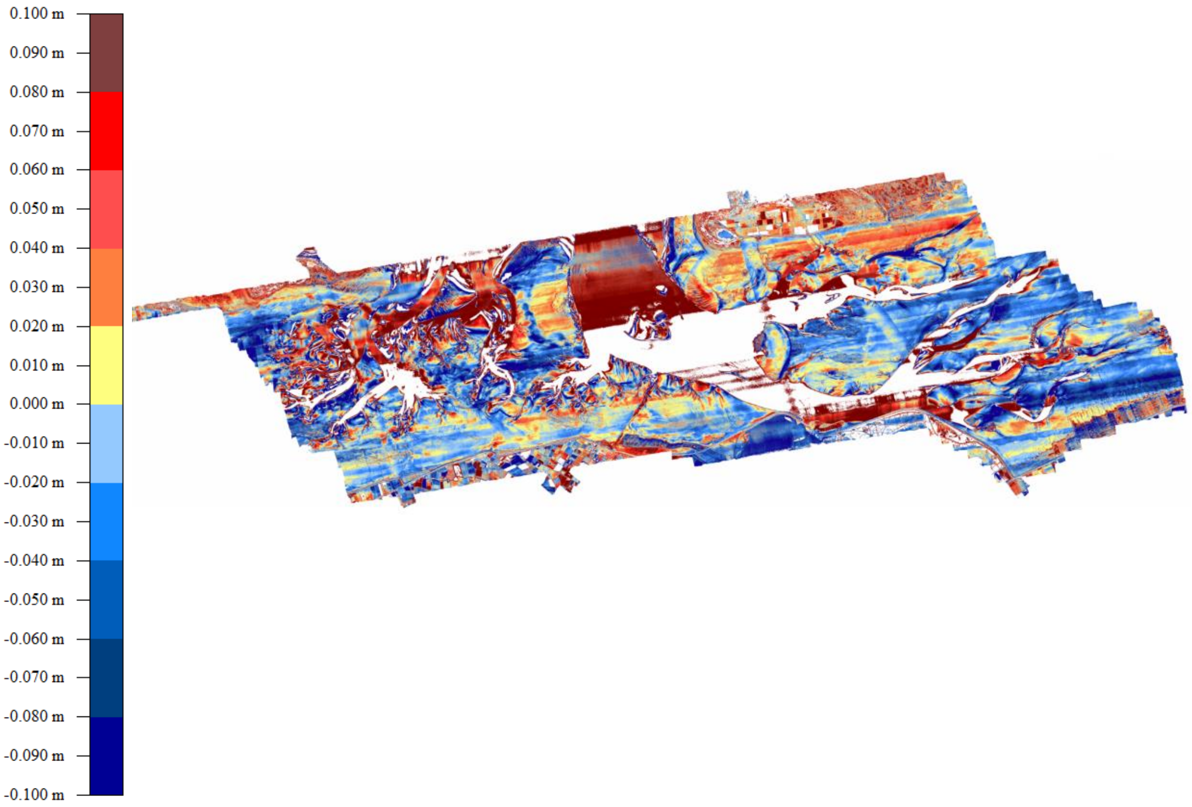


Figure 11.1 Comparison 2016 Autumn vs 2017 Spring surveys (2016 Autumn minus 2017 Spring).

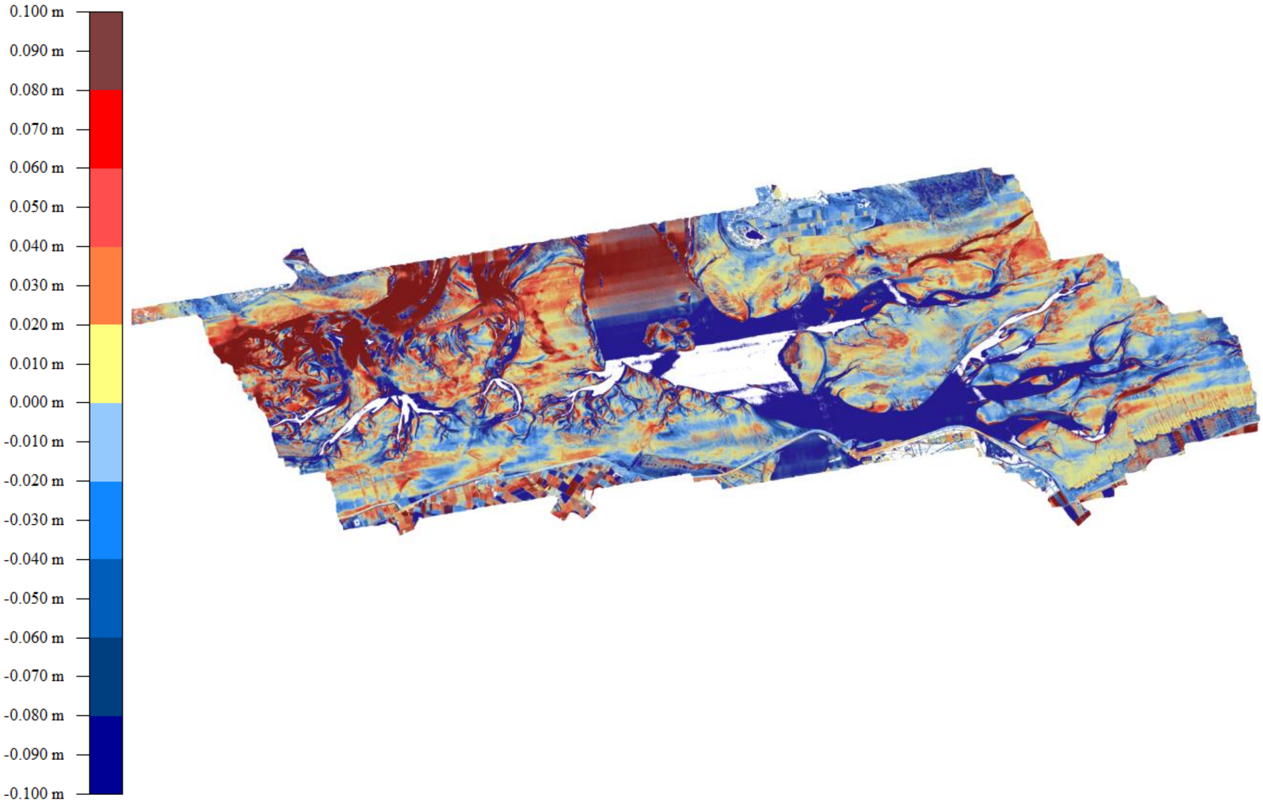


Figure 11.2 Comparison 2017 Autumn vs 2017 Spring surveys (2017 Spring minus 2017 Autumn).

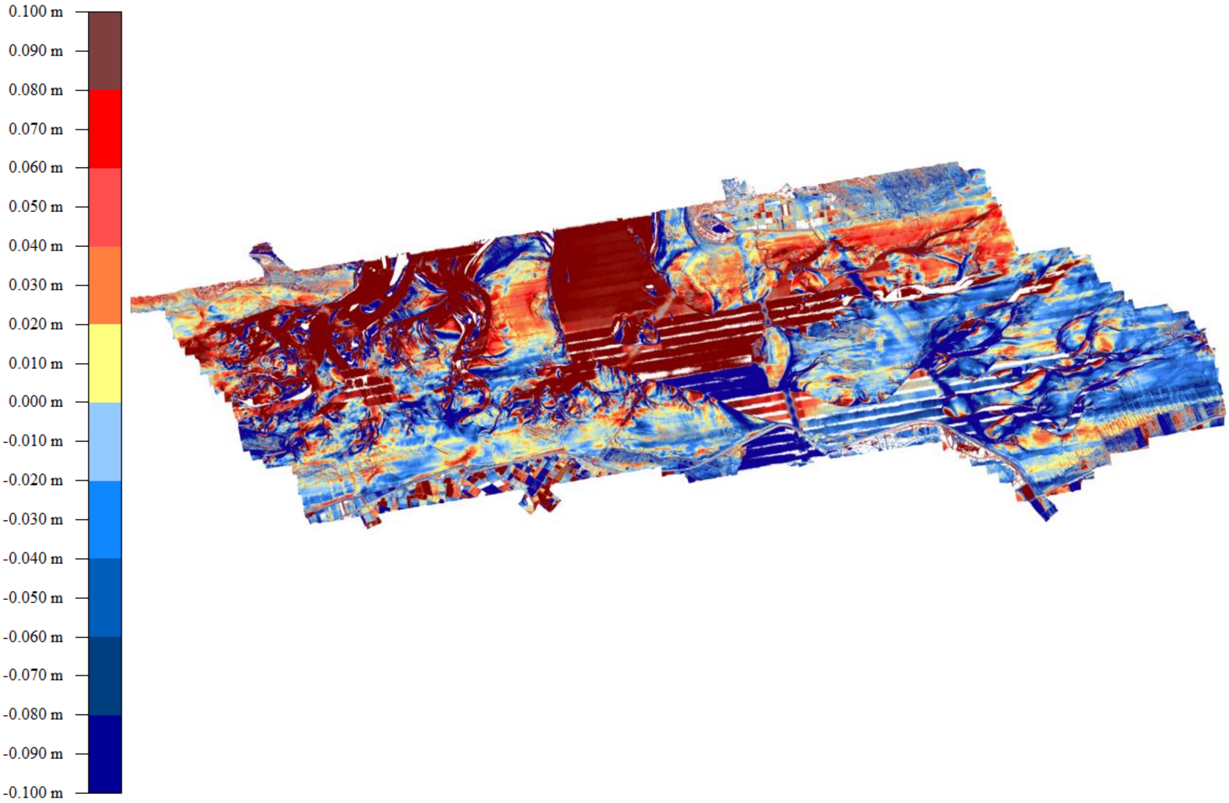


Figure 11.3 Comparison 2017 Autumn vs 2016 Autumn surveys (2016 Autumn minus 2017 Autumn).

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 (12.2) 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 swath (area covered) of each line.

12.6 Orthophotos

Format tif and one ECW. GSD is 7cm.

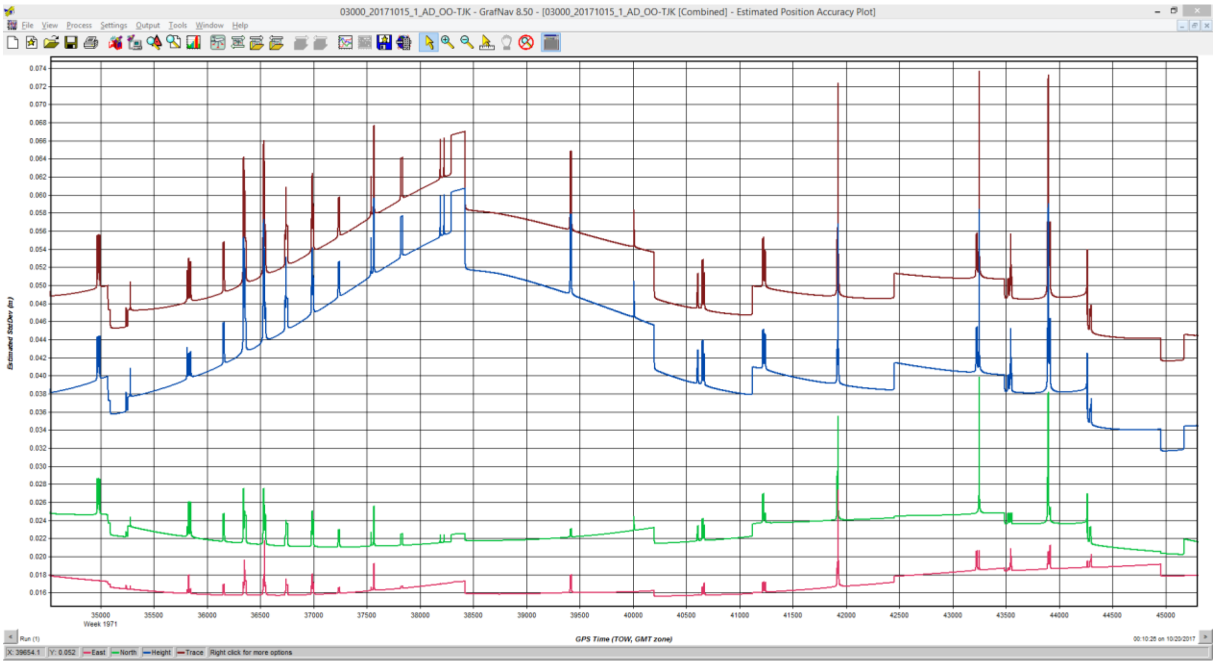
12.7 Report

Include comparison with previous data, profiles…

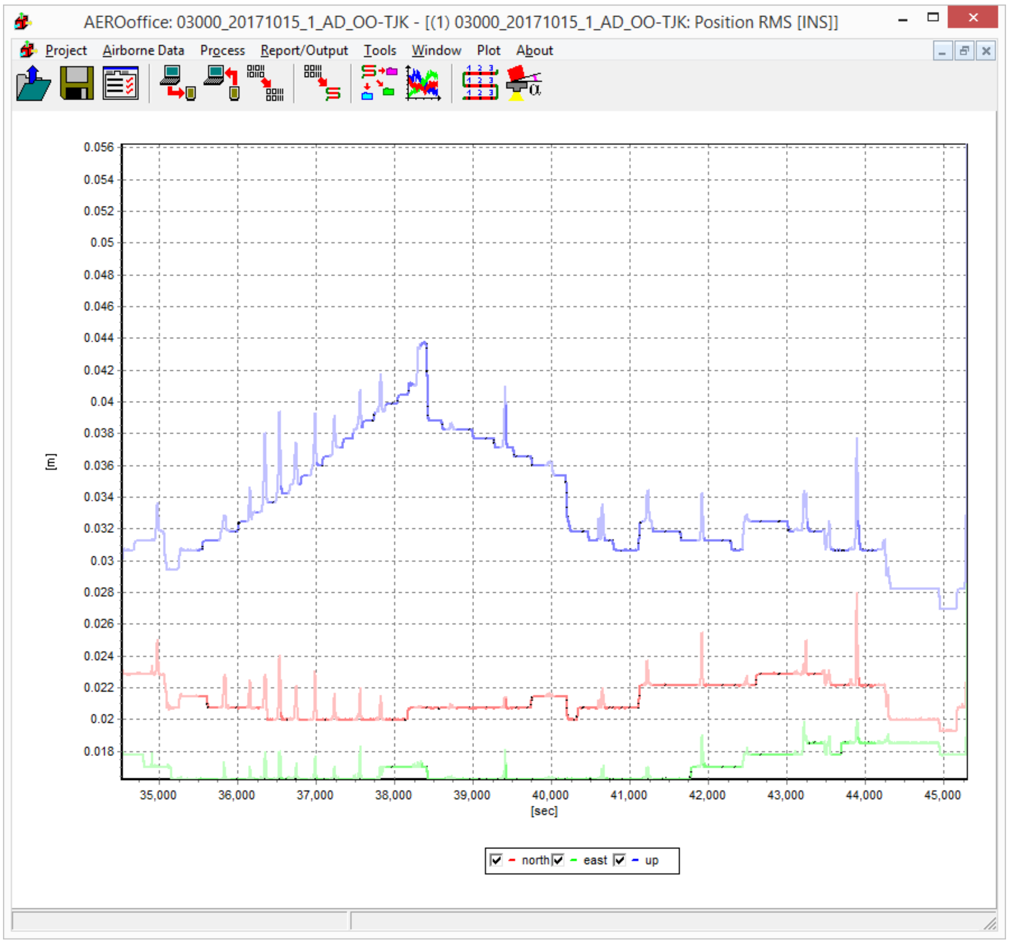
Appendix A Flight accuracies

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 – 2017-10-15



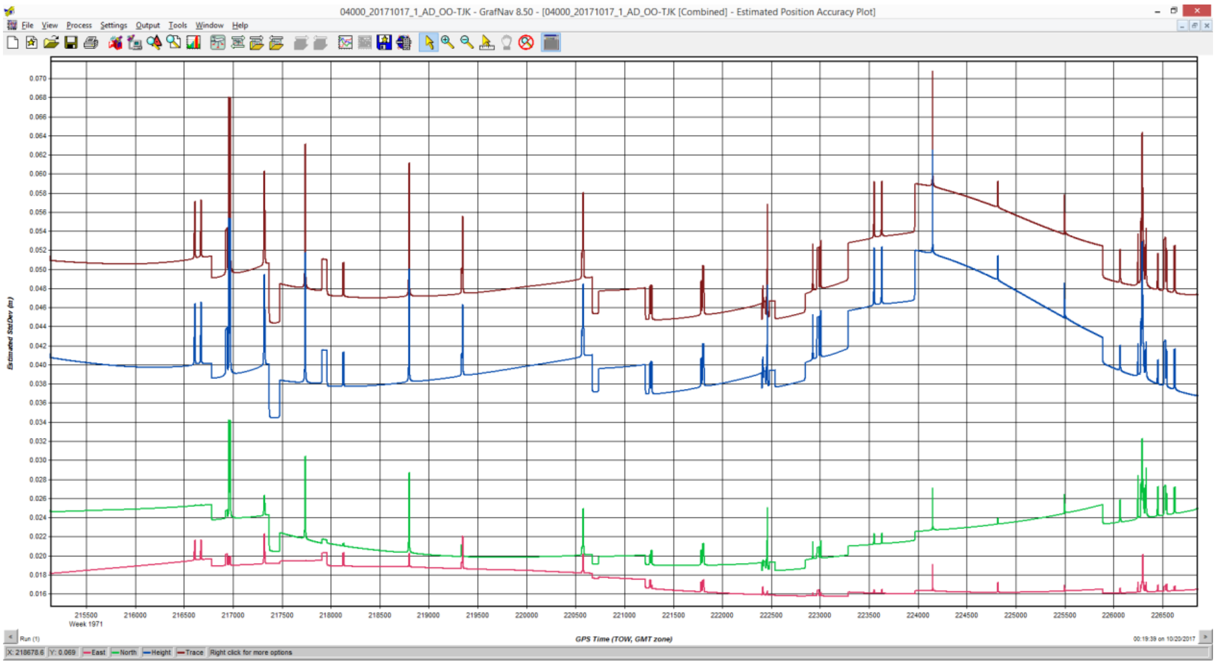
Estimated accuracy of the solution



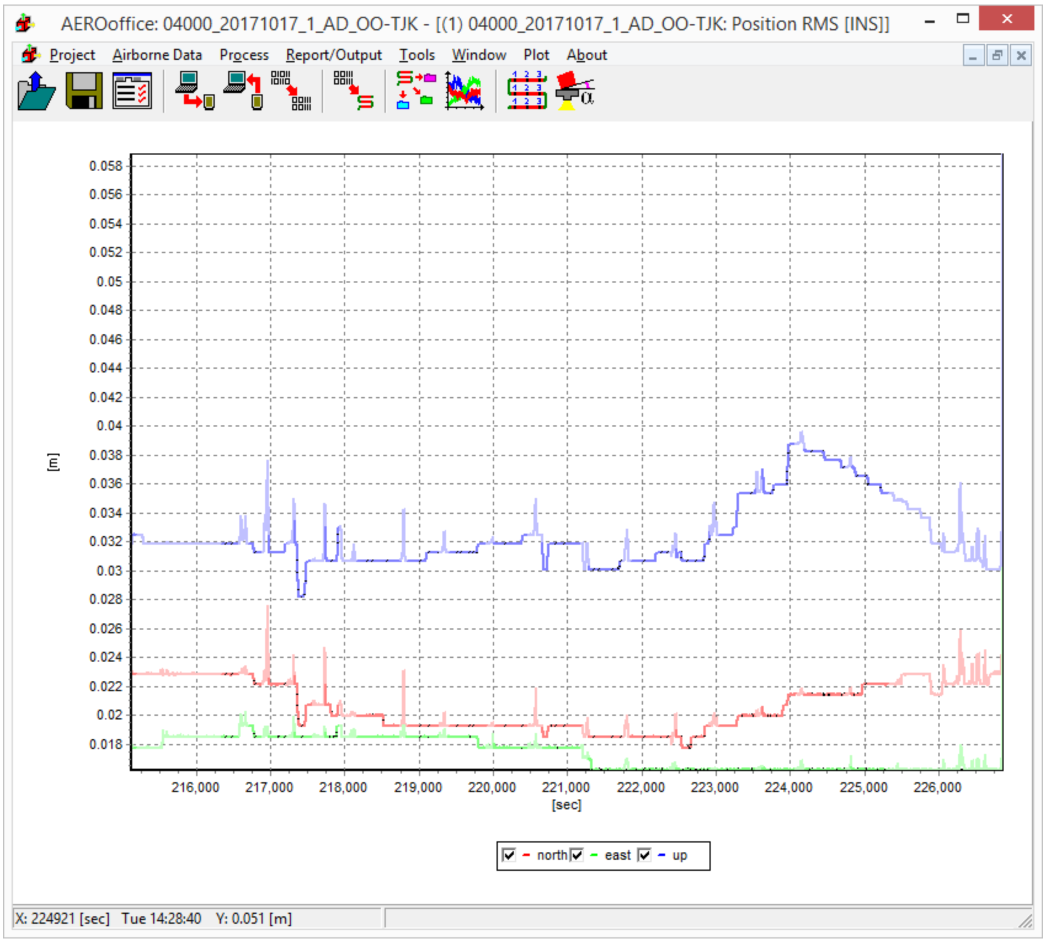
Estimated accuracy of the trajectory after combining the GPS solution with INS.

***Report*:**	**Quality report Waddenzee**
***Date*:**	06-02-2018

Flight 02 – 2017-10-17

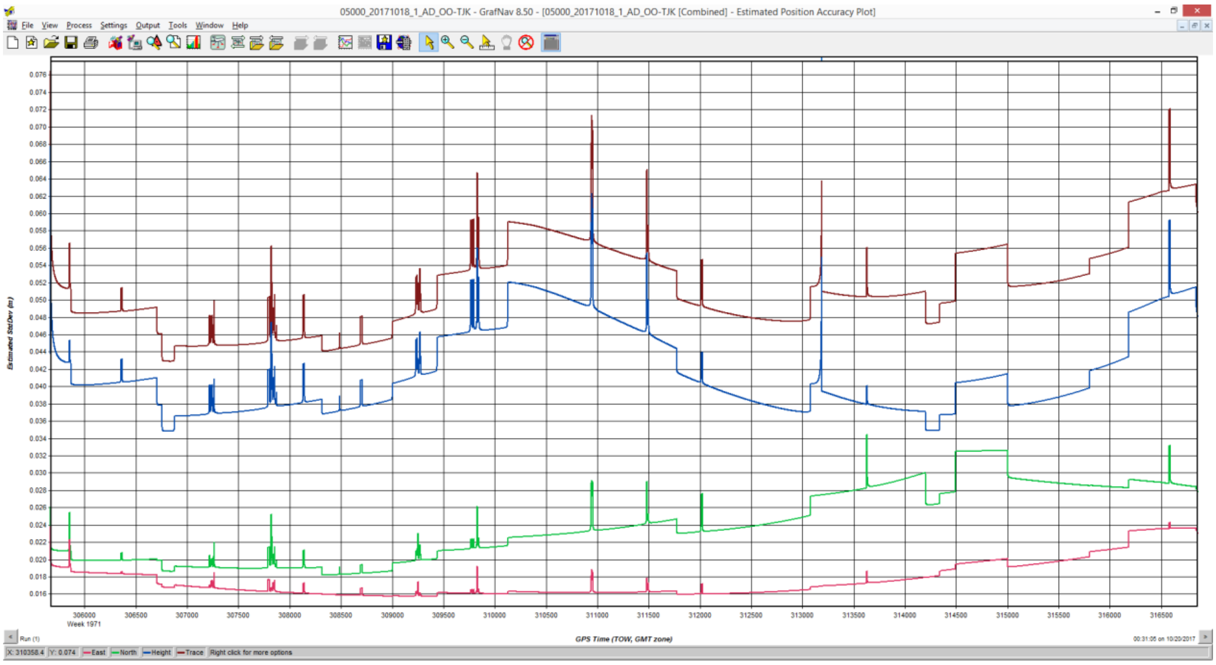


Estimated accuracy of the solution

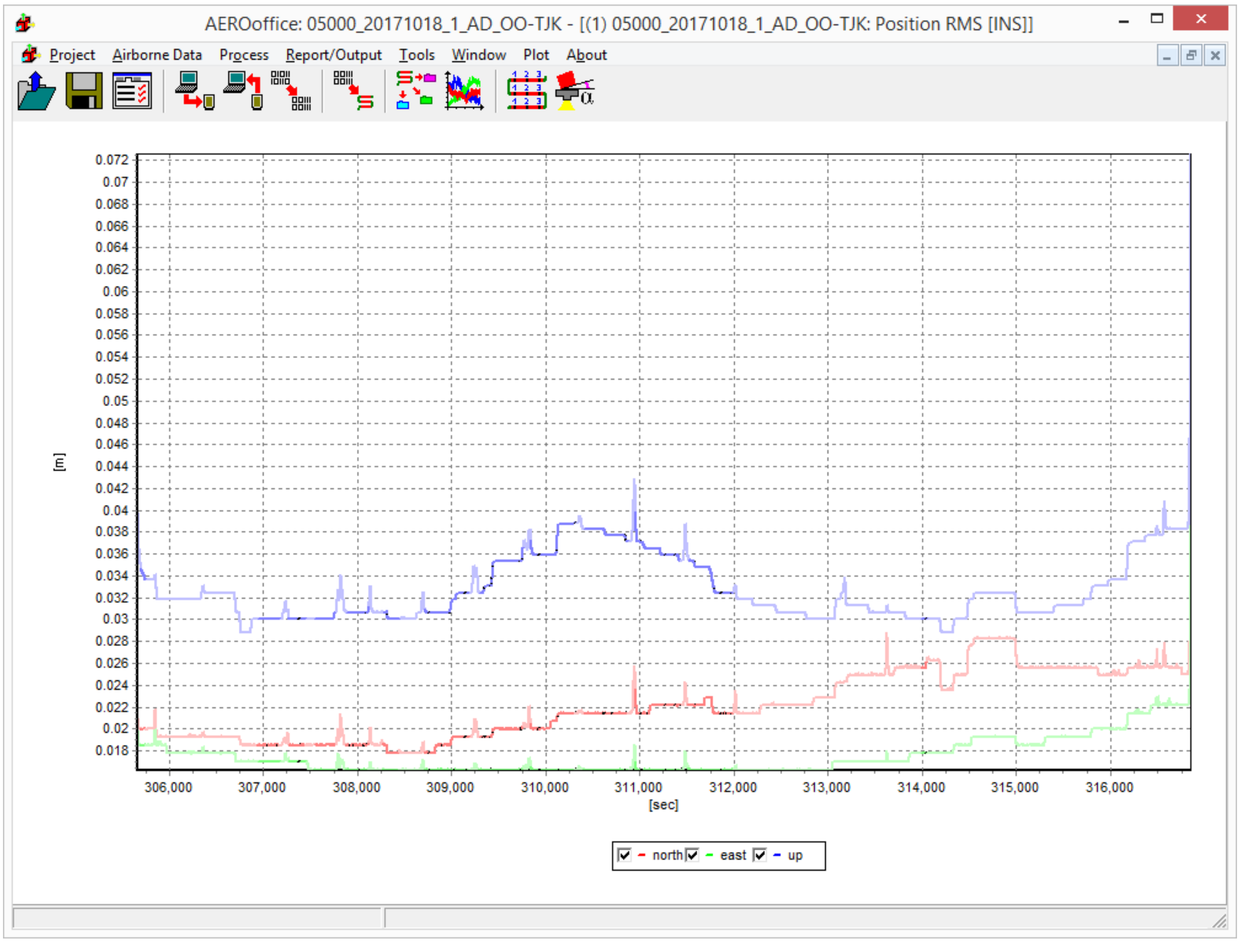


Estimated accuracy of the trajectory after combining the GPS solution with INS.

Flight 03 – 2017-10-18



Estimated accuracy of the solution



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