Report

Coverages: 40958 / 25535

Project: Waddenzee – 1st LiDAR acquisition for 2018

terratec

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1. General information

1.1 Customer

Name:	Nederlandse Aardolie Maatschappij B. V.
Address:	Schepersmaat 2 9405 TA Assen PO BOX 28000 9400 HH Assen The Netherlands
Contact person:	Dhr. Shizhuo Liu

1.2 The project

Name:	Waddenzee – 1st LiDAR acquisition for 2018
Number:	40958 / 25535
Area:	Pinkegat and Zoutkamperlaag in the Wadden Sea, in the north of the Netherlands

1.3 Contractor

Name:	Terratec AS
Address:	Vækerøveien 3 0281 Oslo Norway
Project manager:	Andreas Velle Wiger
Project number:	8950

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.

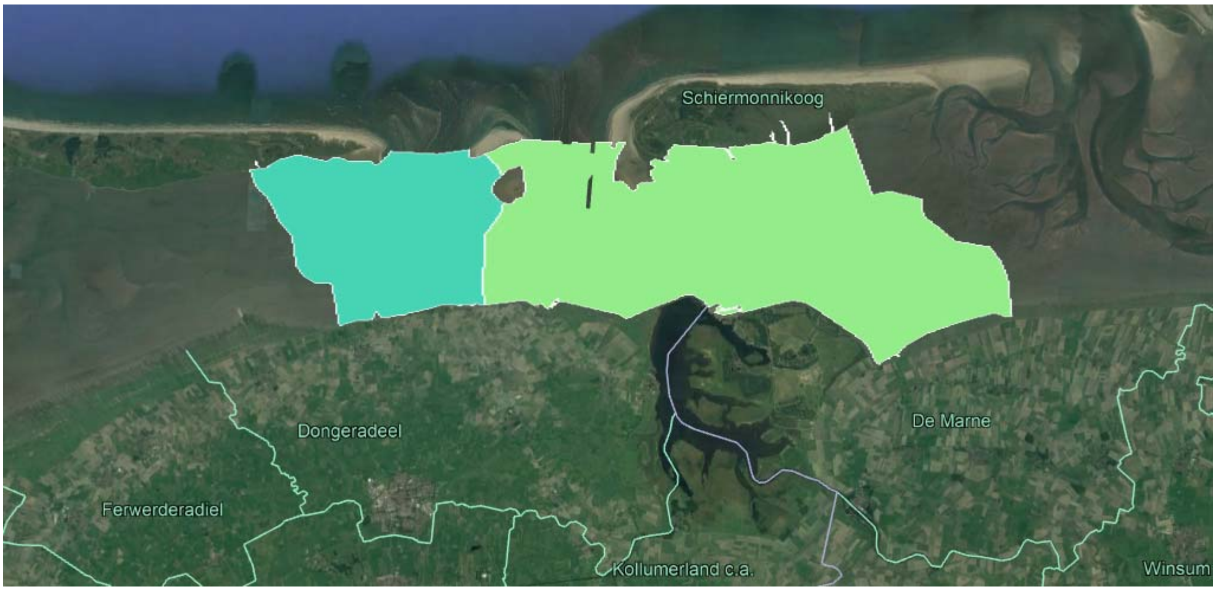


Figure 1: Project area Waddenzee

1.7 Quality assurance

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

- Calibration of sensor system
- Crossing calibration lines
- Matching of flight lines
- Adjustments and control by measured points

2. GROUND CONTROL POINTS (GCP)

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

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

Figure 2: Image shows location of collected GCP's

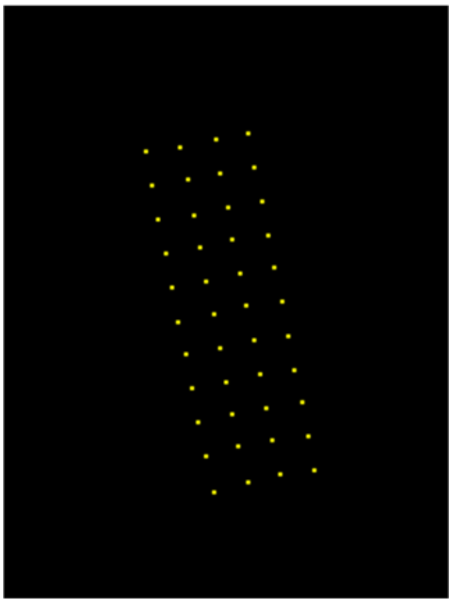


Figure 3: Top view of GCP-5 distribution

3. Data capture

3.1 Survey platform specifications

The survey was performed with two sensors mounted in the same aircraft. The Riegl VQ-1560i was chosen for the LiDAR acquisition, while the Leica DMC-III camera was chosen for the imagery. Both were mounted in the aircraft LN-LOL, a Cessna 208B with two camera hatches. Both LiDAR and photos were collected simultaneously. Each sensor was connected to their own separate GNSS antennas More details in the tables below:

3.1.1 Sensor system, LiDAR:

Sensor		Mount / navigation / LiDAR control		
Manufacturer,type	Riegl, VQ-1560i	**Gyromount**		SOMAG GSM4000
Serialnr.	S2222736	**Naviga-tion system**	**Manufacturer,type**	Applanix, POS-AV 610 ver 6
Focal length (mm)	N/A		**GNSS-reciever**	Trimble
Rev nr.				BD982
Last calibration	2017-06-08		**GNSS-antenna**	Trimble AV39 (AERAT1675_180)
FMC	N/A		**IMU**	Applanix IMU-57
Radiometric res.	N/A		**Logging rate (Hz)**	**GNSS** 5 **IMU** 200
Aircraft		**LiDAR control system**		Riegl RiACQUIRE
Manufacturer /type	Cessna 208B	**Boresight-calibration**		2018-07-19 (ID: L736_2018_01)
Registration	LN-LOL			
Pressurized	Yes	**IMU-initialization**		S-turn before first flightline/ after last flightline

3.1.2 Sensor system, Camera:

Sensor		Mount / navigation / camera control		
Manufacturer,type	Leica DMC III	**Gyromount**		Leica PAV100
Serialnr.	DMC 27521	**Naviga-tion system**	**Manufacturer,type**	Novatel SPAN
Focal length (mm)	92.0000		**GNSS-reciever**	Novatel
Rev nr.	V009			
Last calibration	2017-03-03		**GNSS-antenna**	Antcom G5Ant-42AT1 (ACGG5ANT-42AT1)
FMC	Yes		**IMU**	Litef LCI-100
Radiometric res.	PAN, R, G, B, IR. 14 bit		**Logging rate (Hz)**	**GNSS** 1 **IMU** 200
Aircraft		**Camera control system**		Leica FlightPro
Manufacturer /type	Cessna 208B	**Boresight-calibration**		2018-07-19 (ID: V521_2018_01)
Registration	LN-LOL			
Pressurized	Yes	**IMU-initialization**		S-turn before first flightline/ after last flightline

3.2 Acquisition parameters

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

LiDAR:		**Photo:**	
Flying altitude:	500 m AGL	Flying altitude:	500 m AGL
Max ground speed:	130 knots	Max ground speed:	130 knots
Sensor:	Riegl VQ-1560i	Sensor:	Leica DMC-III
Total lines:	40	Total lines:	40
Total length:	436,5 nautical miles	Total length:	436,5 nautical miles
FOV:	60 degrees	Total images:	4 062
PRF per channel:	1 000 kHz	GSD:	2 cm
Total scan rate:	550 Hz	Lateral overleap:	30 %
Laser Power Mode:	25%	Forward overlap:	30 %
Min. pt. density:	29,41 pts/m^2		
Strip width:	560 m		
Lateral overlap	36 %		

Out of the total of 40 flight lines, 6 of these are crossing lines used for matching purposes, and the remaining 34 were project flight lines. Customer requested maximum 500m flying height above ground other flight plan parameters have been adjusted to this.

3.3 Flight Plan

Project lines are represented in blue, while crossing lines are drawn in green. Water level stations are marked with red crosses:

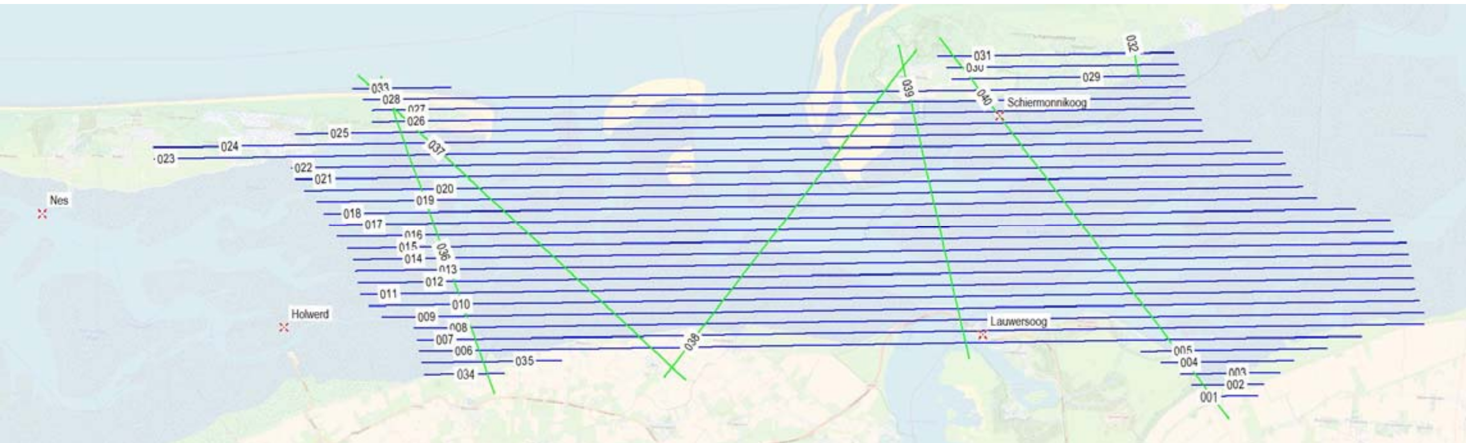


Figure 4: Flightplan and waterlevel stations

3.4 Execution of data capture

The survey area, consisting of 34 project lines and 6 crossing lines, were completed in 4 consecutive acquisition days. For each flight, all the 6 crossing lines were flown. To achieve the best result, the crossing lines were flown at the beginning and at the end of the tidal window, or in other words at the highest water levels. The goal was to capture the project lines at the lowest water levels. In addition to the project itself, 3 test lines were flown at higher altitudes to evaluate the result of a more efficient survey. These test lines are not included in this report. See appendix 1 for flight reports.

The total flying hours, including mobilization and de-mobilization can be seen in the table below:

Date:	**Take-off Airport / Time:**		**Landing Airport / Time:**		**Duration:**	**Purpose:**
2018-07-20	ENRK	07:55	EKVJ	09:55	02:00	Mobilization
2018-07-20	EKVJ	11:05	EHGG	12:30	01:25	Mobilization
2018-07-21	EHGG	07:40	EHGG	10:50	03:10	Datacapture
2018-07-22	EHGG	08:50	EHGG	12:10	03:20	Datacapture
2018-07-23	EHGG	10:00	EHGG	13:30	03:30	Datacapture
2018-07-24	EHGG	12:00	ENRK	15:30	03:50	Datacapture / de-mobilization
Total:					**17:15**	

All times UTC

ENRK = Rakkestad Airport Åstorp (NOR)
EKVJ = Stauning Vestjulland Airport (DEN)
EHGG = Groningen Airport Eelde (HOL)

3.4.1 All flown flight lines sorted by time

Line number:	Length (NM):	Date and time (UTC): (YYMMDD_HHMMSS)	Schiermonnikoog (cm):	Lauwersoog (cm):	Nes (cm):	Holwerd (cm):	Highest (cm):	Lowest (cm):
039	5.3	180721_075449	-62	-65	-71	-31	-62	-71
040	7.9	180721_080120	-67	-70	-75	-35	-67	-75
001	0.9	180721_080933	-74	-76	-81	-39	-74	-81
002	1.1	180721_081400	-77	-79	-84	-41	-77	-84
003	1.5	180721_081816	-81	-83	-87	-44	-81	-87
004	2.2	180721_082201	-84	-85	-89	-47	-84	-89
005	3.0	180721_082657	-89	-89	-93	-51	-89	-93
006	15.6	180721_083230	-94	-93	-96	-55	-93	-96
006	15.6	180721_084308	-101	-101	-102	-65	-101	-102
035	2.3	180721_085423	-110	-109	-108	-77	-108	-110
034	1.3	180721_085830	-113	-111	-109	-81	-109	-113
007	16.6	180721_090248	-115	-113	-111	-86	-111	-115
008	16.7	180721_091431	-119	-117	-113	-99	-113	-119
009	17.2	180721_092717	-122	-122	-115	-113	-115	-122
010	17.3	180721_093857	-125	-123	-114	-123	-114	-125
036	5.5	180721_095242	-125	-123	-109	-132	-109	-125
037	7.4	180721_095909	-123	-121	-106	-138	-106	-123
038	6.9	180721_100737	-121	-119	-101	-141	-101	-121
031	3.9	180721_101530	-117	-116	-96	-139	-96	-117
032	0.8	180721_102050	-115	-114	-91	-136	-91	-115
030	3.8	180721_102536	-112	-111	-88	-130	-88	-112
029	3.8	180721_103021	-110	-108	-85	-125	-85	-110
030	3.8	180721_103529	-106	-104	-79	-117	-79	-106
037	7.4	180722_090544	-64	-65	-71	-35	-64	-71
036	5.5	180722_091228	-69	-70	-75	-39	-69	-75
011	17.4	180722_091944	-74	-75	-80	-43	-74	-80
012	17.4	180722_093118	-83	-82	-87	-50	-82	-87
013	17.4	180722_094314	-90	-89	-92	-61	-89	-92
022	16.4	180722_095413	-96	-95	-97	-70	-95	-97
021	16.4	180722_100449	-102	-101	-100	-78	-100	-102
020	16.2	180722_101543	-107	-106	-103	-88	-103	-107
019	16.3	180722_102623	-110	-110	-105	-98	-105	-110
018	16.4	180722_103719	-113	-112	-104	-110	-104	-113
017	16.9	180722_104820	-114	-113	-102	-116	-102	-114
015	17.3	180722_105600	-112	-112	-99	-119	-99	-112
040	7.9	180722_110811	-109	-109	-93	-124	-93	-109
038	6.9	180722_111559	-106	-107	-88	-124	-88	-107
039	5.3	180722_112346	-102	-103	-83	-121	-83	-103
032	0.8	180722_112910	-100	-100	-80	-118	-80	-100
012	17.4	180722_113444	-97	-96	-75	-111	-75	-97
012	17.4	180722_114624	-89	-88	-64	-97	-64	-89

013	17.4	180722_115048	-85	-84	-60	-92	-60	-85
038	6.9	180723_101249	-63	-67	-72	-35	-63	-72
039	5.3	180723_101944	-69	-72	-77	-39	-69	-77
040	7.9	180723_102729	-75	-77	-81	-43	-75	-81
032	0.8	180723_103452	-80	-82	-86	-49	-80	-86
014	17.3	180723_104027	-84	-85	-89	-53	-84	-89
017	16.9	180723_105209	-93	-95	-95	-63	-93	-95
016	17.3	180723_110409	-100	-101	-101	-73	-100	-101
023	18.1	180723_111659	-107	-108	-106	-86	-106	-108
024	17.4	180723_112859	-112	-113	-108	-98	-108	-113
025	15.0	180723_114026	-117	-116	-108	-108	-108	-117
026	13.6	180723_115042	-119	-118	-107	-115	-107	-119
027	13.5	180723_120012	-119	-117	-104	-120	-104	-119
028	13.6	180723_120944	-116	-116	-101	-132	-101	-116
033	1.6	180723_121943	-112	-113	-95	-134	-95	-113
037	7.4	180723_122516	-109	-111	-92	-132	-92	-111
036	5.5	180723_123158	-106	-108	-88	-128	-88	-108
039	5.3	180724_121002	-96	-95	-93	-64	-93	-96
038	6.9	180724_121610	-100	-98	-96	-69	-96	-100
037	7.4	180724_122315	-103	-102	-99	-74	-99	-103
036	5.5	180724_122938	-106	-105	-102	-79	-102	-106
017	16.9	180724_123847	-110	-109	-102	-92	-102	-110
012	17.4	180724_125042	-113	-112	-102	-102	-102	-113
013	17.4	180724_130251	-115	-113	-101	-110	-101	-115
040	7.9	180724_131607	-114	-112	-97	-117	-97	-114
032	0.8	180724_132318	-112	-111	-93	-120	-93	-112

- *Crossing lines are represented in grey font. Project lines in black.*
- *Water levels are given in cm NAP (Normaal Amsterdams Peil) and are given for the start time of each flight line.*
- *The tidal station "Holwerd" is not considered in the calculations of "Highest" and "Lowest".*
- *The UTC timestamp of lines who are rejected due to weather conditions or sensor errors are highlighted in red.*
- *The values for "Highest" and "Lowest" water level of flight lines captured outside of the allowed water level of -70 cm NAP are highlighted in red.*
- *The only project lines flown above the required minimum water level are lines 012 and 013 from the 22nd of July. These are re-flown on the 24th of July.*
- *Weather conditions were good throughout the project period, with exception of the 22nd of July where a few clouds resulted in clouds on lines 012 and 013. These were re-flown later the same day. A small cloud also on line 017 appeared on the 23rd of July.*
- *Line 017 flown on the 22nd of July was rejected due to a camera error. It was re-flown on the 23rd of July but rejected due to a small cloud. It was flown again and accepted on the 24th of July.*

3.4.2 All flown flight lines sorted by line number

	21st of July 2018		22nd of July 2018		23rd of July 2018		24th of July 2018	
Line number:	Date / Time (UTC)	NAP (Highest)	Date / Time (UTC)	NAP (Highest)	Date / Time (UTC)	NAP (Highest)	Date / Time (UTC)	NAP (Highest)
001	180721_080933	-74						
002	180721_081400	-77						
003	180721_081816	-81						
004	180721_082201	-84						
005	180721_082657	-89						
006	180721_084308	-101						
007	180721_090248	-111						
008	180721_091431	-113						
009	180721_092717	-115						
010	180721_093857	-114						
011			180722_091944	-74				
012			180722_114624	-64			180724_125042	-102
013			180722_115048	-60			180724_130251	-101
014					180723_104027	-84		
015			180722_105600	-99				
016					180723_110409	-100		
017			180722_104820	-102	180723_105209	-93	180724_123847	-102
018			180722_103719	-104				
019			180722_102623	-105				
020			180722_101543	-103				
021			180722_100449	-100				
022			180722_095413	-95				
023					180723_111659	-106		
024					180723_112859	-108		
025					180723_114026	-108		
026					180723_115042	-107		
027					180723_120012	-104		
028					180723_120944	-101		
029	180721_103021	-85						
030	180721_103529	-79						
031	180721_101530	-96						
033					180723_121943	-95		
034	180721_085830	-109						
035	180721_085423	-108						
032	180721_102050	-91	180722_112910	-80	180723_103452	-80	180724_132318	-93
036	180721_095242	-109	180722_091228	-69	180723_123158	-88	180724_122938	-102
037	180721_095909	-106	180722_090544	-64	180723_122516	-92	180724_122315	-99
038	180721_100737	-101	180722_111559	-88	180723_101249	-63	180724_121610	-96
039	180721_075449	-62	180722_112346	-83	180723_101944	-69	180724_121002	-93
040	180721_080120	-67	180722_110811	-93	180723_102729	-75	180724_131607	-97

	21st of July	22nd of July	23rd of July	24th of July	Totals:
Session length w/o crossing lines (NM):	107.2	116.4	127.4	51.7	**402.7**
Session number of lines w/o crossing lines:	15	7	9	3	**34**
Session progress (line lenght):	27 %	29 %	32 %	13 %	**100 %**
Session progress (number of lines):	44 %	21 %	26 %	9 %	**100 %**
Total session hours w/o crossing lines:	1.57	1.25	1.43	0.55	**4.80**
Session progress (per session):	32.8 %	26.0 %	29.8 %	11.4 %	**100 %**

3.5 Survey risk assessment

See "Appendix 2 – Survey Risk Assessment"

3.6 Reports of near-miss 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 follow 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 Terratec AS. 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

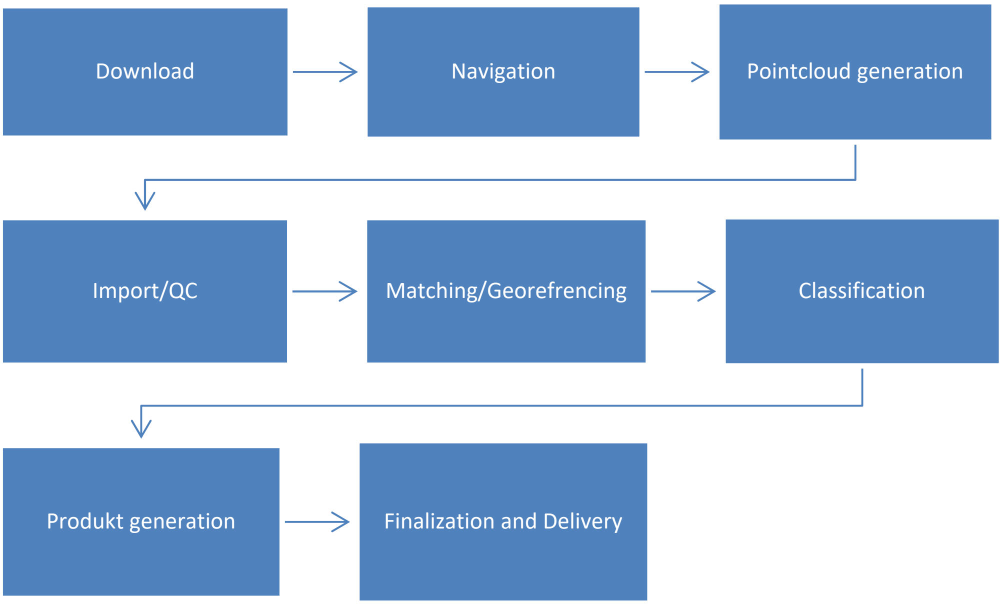
All navigation processing results used in this project has been evaluated against a Quality Control check list. This evaluation includes (but are not limited to) verifying that the data set is suited for PPP processing, evaluating number of detected and repaired cycle slips, code and phase observation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

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

See appendix 3 for navigation quality plots.

5. Laser scanning execution

5.1 Workflow



5.2 Software

Navigation:

- Terrapos (vers 2.5.90)

Laser Processing:

- RiProcess (vers 1.8.5)
- Terrasolid (vers 18)
  - TerraMatch
  - TerraScan
  - TerraPhoto
  - TerraModel

5.3 Sensor calibration

Calibration of our sensors are performed by both the sensor manufacturer and Terratec.

5.3.1 Factory calibration

The manufacturer performs a sensor calibration. The calibration report and system parameter set is 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

5.3.2 Calibration of installed system

A calibration is performed at first time installation in 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.

5.3.3 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 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 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 outputted in WGS84 geocentric.

5.6 Project calibration

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

Evaluation of results:

No abnormal values have been found during this process.

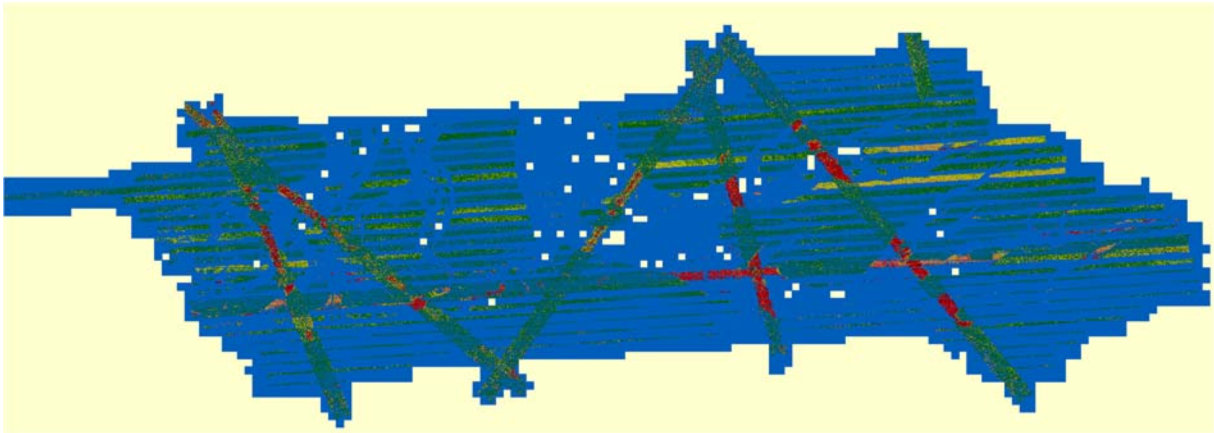
Results from the project calibration is shown in appendix 5.

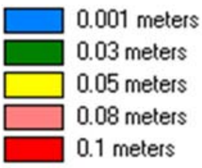
5.7 Flight line matching

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.

Evaluation of results:

No abnormal values have been found during this process. Results from the flight line matching is shown in appendix 6.





Homogenity plot shows dz between lines after matching is applied. Red areas are over water with different water heights, green shows dz lower than 3cm. White squares are blocks with few to no laser hits on water.

5.8 Lidar coverage control

A manual inspection is done to ensure that the whole area of interest is covered by the point cloud.

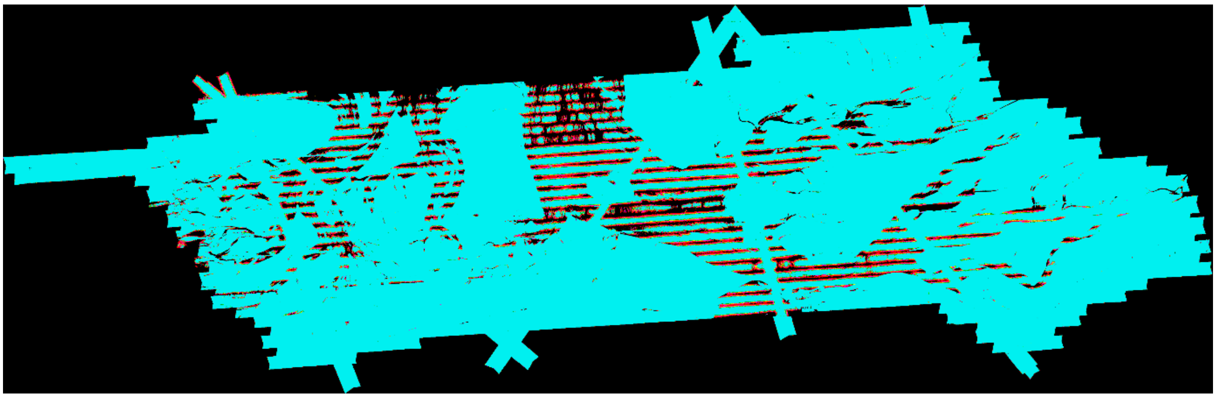


Figure 5: 4pkt/m2 on a 10m grid

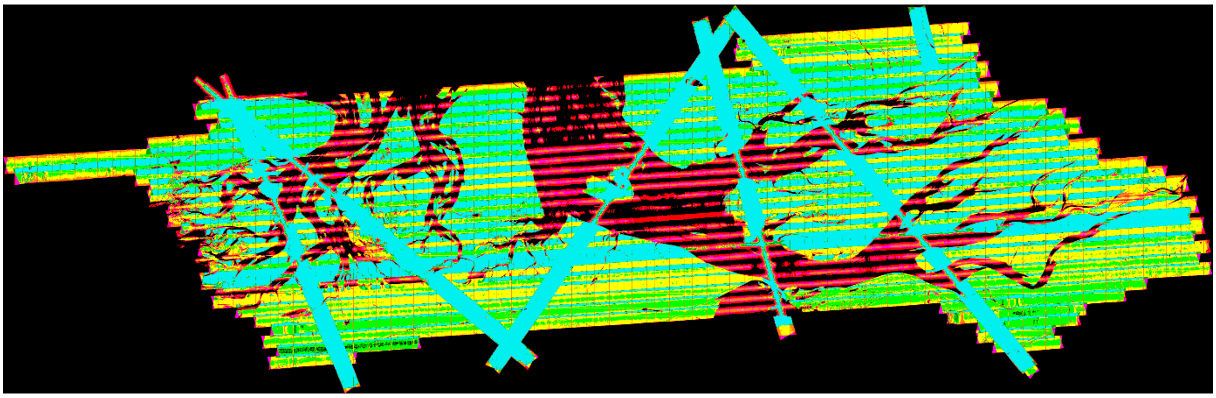


Figure 6: 40pkt/m2 on a 10m grid

Palette used in images:

4pkt/m2 pallet

0	0,4	10 %	black
0,4	1,6	40 %	red
1,6	2,4	60 %	magenta
2,4	3,4	85 %	orange
3,4	4	100 %	yellow
4	4,6	115 %	green
4,6	6	150 %	dark green
6	100	> 150 %	cyan

40pkt/m2 pallet

0	4	10 %	black
4	16	40 %	red
16	24	60 %	magenta
24	34	85 %	orange
34	40	100 %	yellow
40	46	115 %	green
46	60	150 %	dark green
60	100	> 150 %	cyan

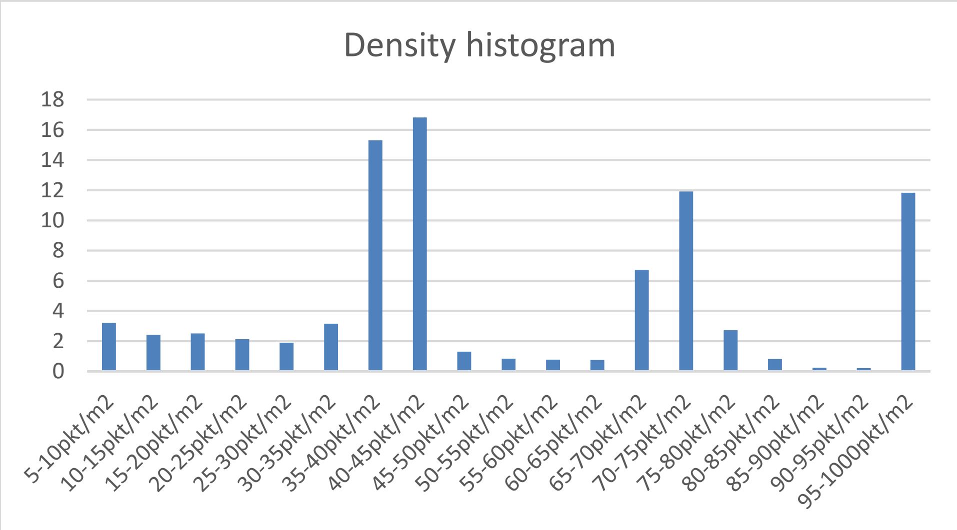


Figure 7: Project density histogram. Y-axis shows percentages of 1x1m tiles with specific density.

The average density for a single flight line is between 35-45points/m2 – Where the density spikes at 65-75points/m2 are because of multiple crosslines used in the dataset. Where 2 separate sets of crossing lines cross each other and regular line on hard surface the density jumps to above 100pkt/m2

5.9 Height accuracy

Control against ground control points:

The height quality of the point cloud has been controlled by comprehensive manual inspections against the GCPs. The overall manual inspections have shown height deviations of no more than 3-4cm. 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 - 2	0.009	-0.0100	0.030	0.010	0.013	0.010
GCP – 3	-0.030	-0.040	-0.020	0.030	0.031	0.007
GCP – 4	-0.007	-0.020	0.010	0.009	0.011	0.008
GCP – 5	-0.005	-0.030	0.010	0.007	0.010	0.009
GCP – 6	0.019	0.010	0.030	0.019	0.020	0.006
GCP – 7	-0.026	-0.050	-0.010	0.026	0.027	0.008
GCP – 8	0.011	0.000	0.020	0.011	0.013	0.006
GCP – 9	0.038	0.020	0.050	0.038	0.039	0.007

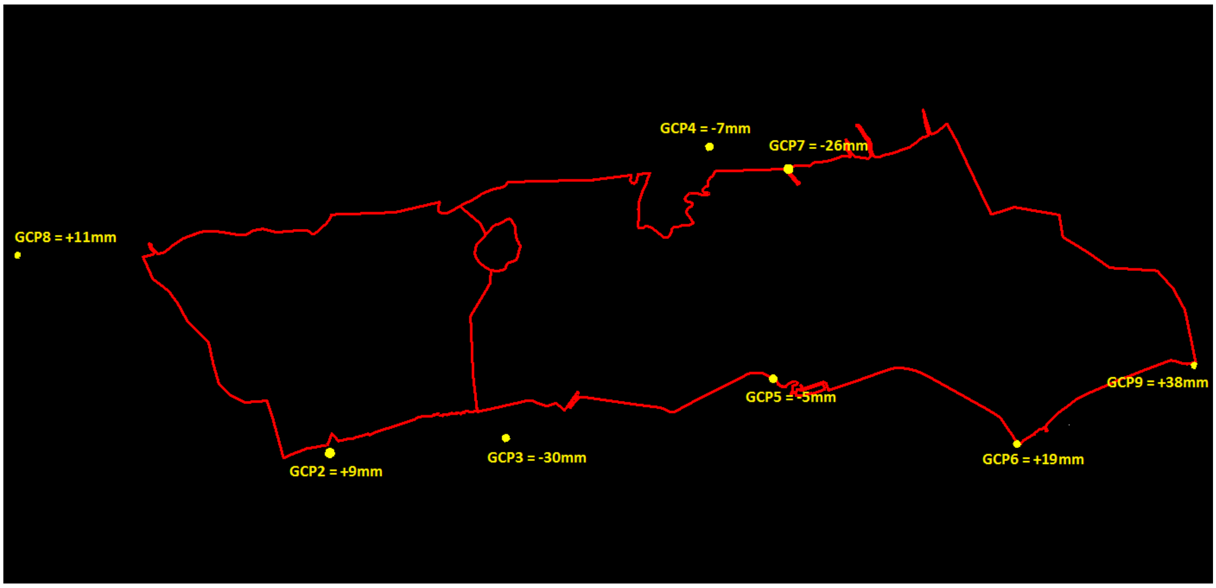


Figure 8: Overview of Control surfaces after adjustment

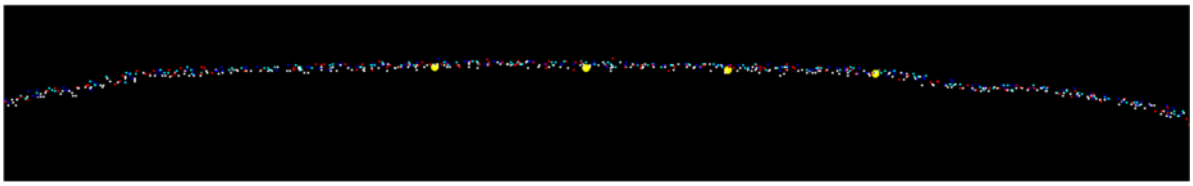


Figure 9: Control surfaces (yellow) after adjusting laserdat +10 mm. The different colors represent different flightlines

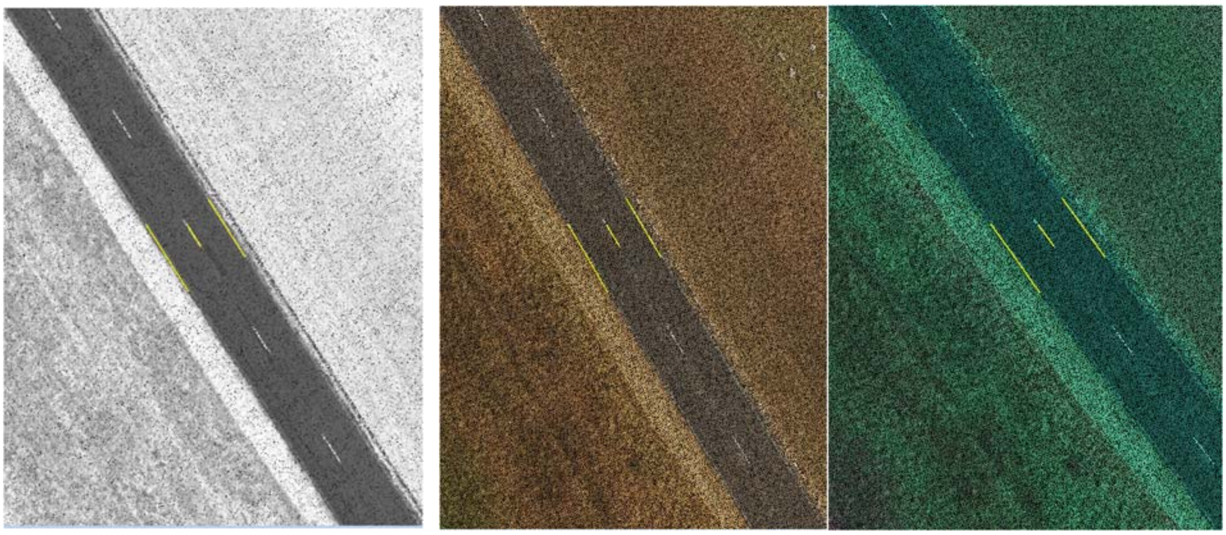
Evaluation of result:

The delivered CP points delivered from 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 done has been a direct linear height adjustment, which is identical in the entire project.

5.10 Horizontal accuracy

The laser point cloud was manually controlled and inspected between laserdata intensity and RGB and CIR coloring. White stripes and edges of road and roofs were found to be suited to check horizontal accuracy. The images below show comparison of white stripes and edge of road between laser intensity, RGB and CIR coloring. Manual stripes are drawn to show the variance between the color sets. The provided control points are from flat areas and could therefore not be used for xy verification.

Laser Intensity **RGB** **CIR**



Evaluation of horizontal accuracy:
The control shows that the horizontal accuracy is good.

5.11 Conclusion georeferencing

The results from calibrations, matching and control against known points shows that the data is of very good quality and well within the expected values.

5.12 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 on, 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 it to improve the object classification. Amplitude depends on the distance, further away the scanner is from the target the less power it receives.

Reflectance – A target property. 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 10: Image shows intensity values in top view with histogram

Figure 11: Image shows intensity in cross section / 3D view

5.13 Test Flights

There has been flown 3 Test lines at 3 different flight heights.

800m	1200m	1730m
18-22pkt/m2	10-15pk/m2	5-7pkt/m2

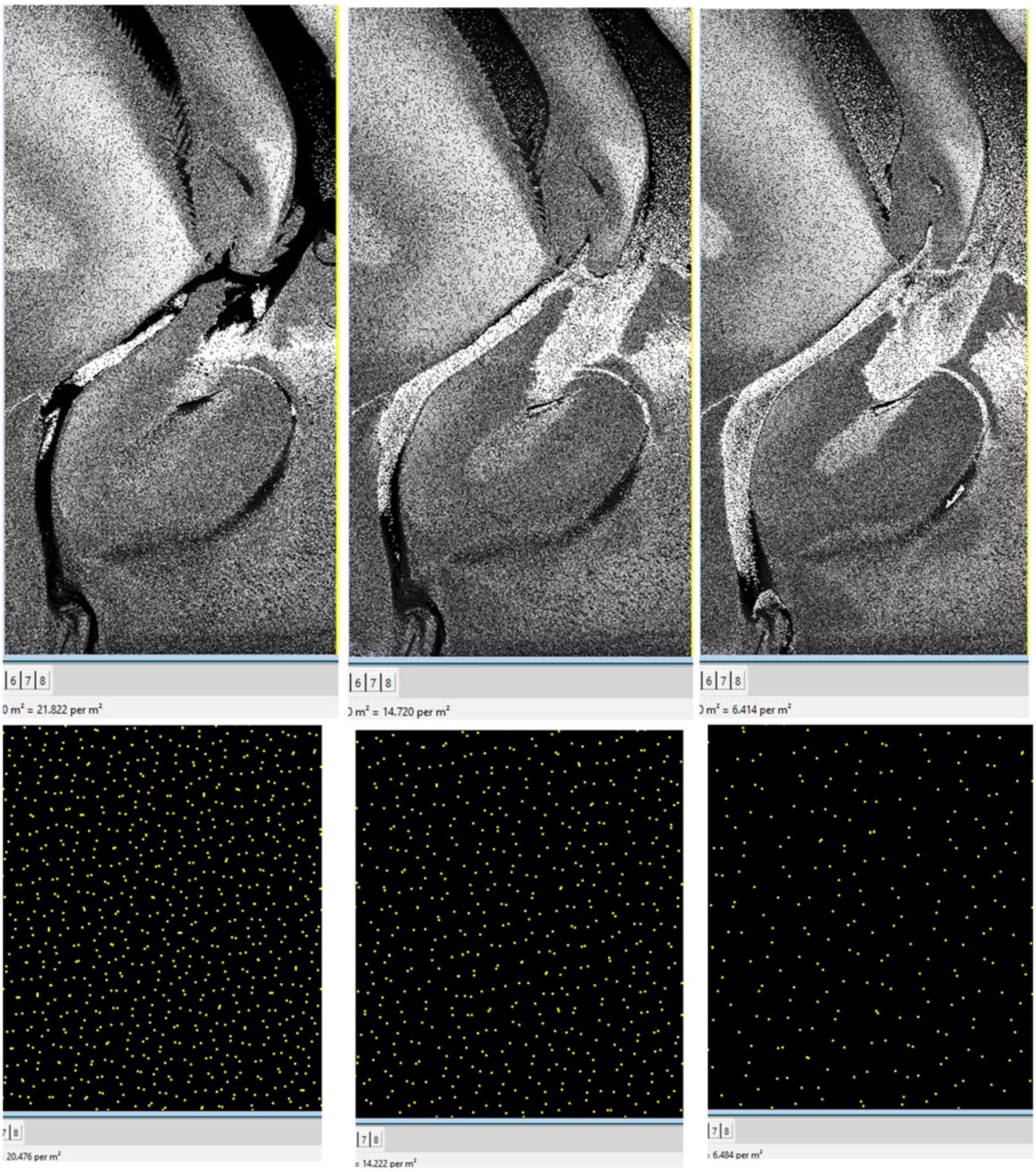


Figure 12: Images on the top shows how the terrain attributes are kept with increasing flight height and lower density The lower images shows an even distribution of laser points with decreasing density due to higher flight height

The test lines were flown over an area with no roads, and therefore no control points. To do height adjustment for the test lines, ground points at 4 different areas from full dataset delivery was used as “known points”. Test line at 800m was adjusted 0cm. Test line at 1200m was adjusted -5cm and test line at 1730m was adjusted -5cm based on the full dataset.

6. POINT CLOUD CLASSIFICATION

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

1) Unclassified
2) Ground
7) Noise

6.1 Ground classification

Terrain surface points are classified as class 2. This class also contain 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 is 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 multi path 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 «non-ground»

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 performed any manual editing.

7. Image processing execution

7.1 Image capture

IMAGE CAPTURE					
Nr. runs	Nr. images	GSD (cm)	Date of capture	Date of clearance	Note
40	5013	2	2018-07-21 2018-07-22 2018-07-23 2018-07-24	2018-07-20	

Quality assurance of image capture				
Check	Method	Result	Approved	Note
Completeness(%)	Count nr. Images vs. flightplan	100	Yes	
	Check coverage vs. aoi	100	Yes	
Lowest sun angle (°)	Check angle first/last image	36,0	Yes	
Clouds, incl. haze, smoke(%)	Visual check	<1	Yes	Haze in fligtline 11 images 136-137
Cloud shadow (%)	Visual check	7	Yes	Flightline 21 images 119-120, 147-149, flightline 20 images 148-149, flightline 22 images 102-104, 138-153, flightline 11 images 12, 66-79, 106, 109,141-159, flightline 30 images 1-36, flightline 29 images 35-36, flightline 32 images 1-8, flightline 31 images 1-37, flightline 15 images 1-21, 25-26, 158, flightline 18 images 1-8, 138-139, , flightline 19 images 142-144, , flightline 13 images 7-24, 48-53, flightline 12 images 7-26, 32-55,69-75, 136-145, 155-159, flightline 12 images 155-159, flightline 17 images 5-19, 49-62, 146-150, flightline images Ther are cloud shadows in all crosslines but these iamges will not be used in color coding of pointclouds (flightlines 32, 36-40).
Snow cover (%)	Visual check	0	Yes	

Stereo coverage outside project area (%)	Visual check, sampling	Average lateral	47.7	Yes	
		Average forward	28.6	Yes	
Latral overlap (%)	Visual check, sampling	Average	30.5	Yes	
		Minimum	26.4	Yes	
Forward overlap (%)	Visual check, sampling	Average	48.2	Yes	
		Minimum	47.4	Yes	

EVALUTAION OF RESULT
The aerial image acquisition was performed according to relevant procedures from TerraTec's quality assurance system. The results are evaluated with respect to customer requirements and expectations. The results are found to be in accordance with project requirements.

7.2 Image processing DMC

Figure 13 gives and overview of image processing from raw data download to final data delivery. The first step is to download image data received from operations on Leica DMC III sensor system disks to servers in the processing center. The software Z/I Copy is used for doing the download and for checking consistency and verifying downloaded data.

After download we do a double backup of raw data to magnetic tapes, which are stored for four years. The two tape sets are stored at different locations.

The next step is preprocessing data to an intermediate level. The images are geometrically adjusted based on the camera calibration and the different color bands are co-registered. The software HxMap 2.2.3 is used for processing and for the all the following steps of image processing. An automatic color balancing which is described more thoroughly in the next chapter is also done.

After image processing all images are checked for image quality, project area coverage, overlap etc. The images are also checked for clouds, cloud shadows, smoke etc. to meet the customer requirements.

After the quality assessment we perform radiometric adjustments as described in the next chapter.

When the radiometric adjustments are done, images are exported in the images format required by the customer. We also produce and geographic overview of image footprints in shape and pdf file formats to accompany the reports. Before delivery a QC of is performed.

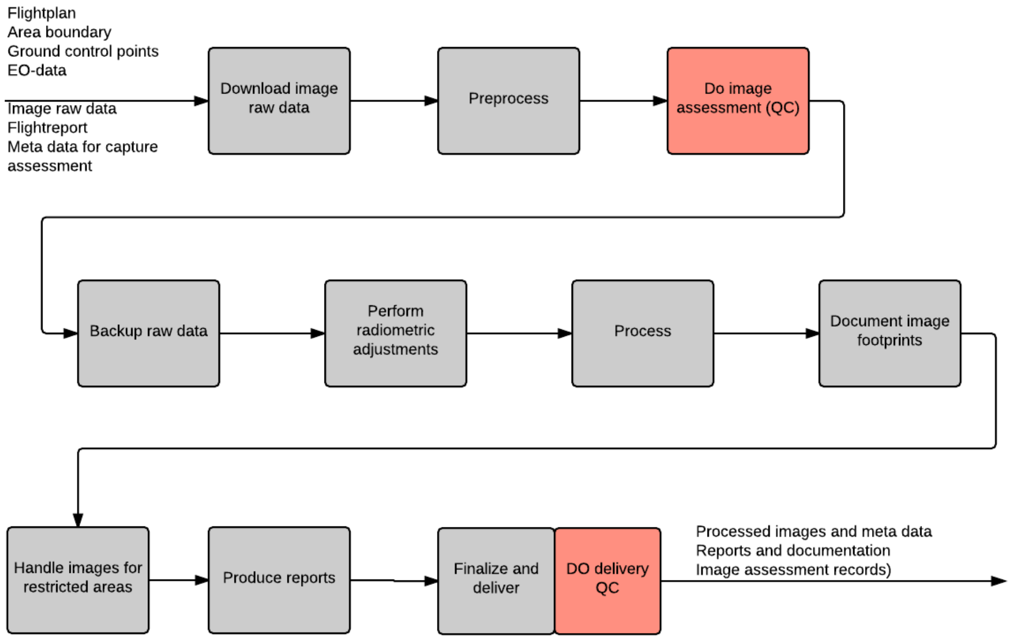


Figure 13: Image processing from raw data download to data delivery

REPORT FROM AERIAL IMAGE DATA CAPTURE PROCESSING	
Finalization processing	2018-09-07
Date of report	2018-09-06

SOFTWARE AND METHODS USED	
Software	HxMap 2.0.1
Geometric processing	The camera consists of a high resolution panchromatic image and 4 color images at a lower resolution. Each of the cameras / images have known corrections and known relative positions determined by lab-calibration. During processing corrections are applied automatically by means of a set of unique calibration files, as well as corrections based on temperature measurements in the camera. While preparing of final Level 3 images, the images are rotated 270° The resulting images are ready for use when all known corrections are applied during processing. Inner orientation elements are documented in the attached camera calibration report.
Radiometric processing	The radiometric properties of each of the camera lenses and CMOS and CCDs are known from lab-calibration and associated corrections are applied automatically when preparing the panchromatic level 2 images. Calibration is performed for various apertures, hence an optimal correction for the current exposure setting is used. In this process information from overlapping areas between frames are utilized, thereby achieving homogeneous data sets. When preparing final level 3 images color information from the color frames are added to the high-resolution panchromatic images using "pansharpening".

	Level 3 images are corrected globally or in groups with user-controlled histogram parameters. Differences between individual images appear due to different exposure, lighting and surface conditions. These are minimized by means of color balancing based on automatically measured points in image overlap. Remaining differences in color, contrast and brightness are minimized "manually" by means. a set interactive histogram functions.
Compressions	All processing mentioned above takes place in 16-bit radiometric resolution and without data compression. Depending on the ordered delivery format, conversion of radiometric resolution (usually 16 to 8 bit) and data compression as the last step before delivery. For both these processes standardized algorithms are used to reduce data loss to a minimum.
Miscellaneous	Original image raw data are store for 4 years

QUALITY ASSURANCE

Check	Methods	Approved	Note
Unsharp images	Visual checks are performed for a number of images.	Yes	
Contrast/color/brightness; individual images	Visual checks Histogram check	Yes Yes	There are reflection spots in individual images in flighline 6,7,8,9,10, 11,12 and 13, and also the crosslines 38 and 39.
Contrast/color/brightness; complete coverage	Visual checks Histogram check	Yes Yes	
Loss of important image content	Check of under/over-exposure Histogram check (saturation)	Yes Yes	Some roofs and facades with overexposed pixels due to incident angle and high reflectance material.
Stereo coverage flight line breaks	Visual checks	-	No broken flight lines

EVALUATION FOR RESULT

Image processing is conducted according to TerraTec's quality assurance system.

The results are evaluated with respect to customer requirements and expectations. The results are found to be in accordance with project requirements.

Deliveries		
Delivery	**File format**	**Medium**
Images RGB, CIR	3x8 bit TIFF Tiled, JPEG compression Q5 with full image pyramid	HDD
Footprint, graphical	PDF	HDD
Footprint, vector format	SHP	HDD
Camera calibration report	PDF	HDD

Check of delivery		
Check	**Performed**	**Note**
Meta data of correct reference system	Yes	
Completeness, ordered products	Yes	
Completeness, number of images (all typs/formats)	Yes	
Completeness, meta data (all types/formats)	Yes	
Dataformat, all deliveries	Yes	
Folderstructure and consistent naming	Yes	
Classified images removed from delivery	-	

7.3 Image radiometry workflow

The software HxMap is used for processing Leica DMC III images. The first processing step is called Ingest and resulting in one panchromatic image and one 4-channel color image with one red, blue, green and infrared channel per frame. The panchromatic image data has 3 times higher resolution than the color and infrared image data.

Processing steps during Ingest (preprocessing):

- Geometrically co-registration of image data from the different image sensors
- Geometric correction and radiometric correction based on factory camera calibration
- Removal of optical lens effects
- Removal of atmospheric effects
- White balance adjustment
- Color balancing between different flightlines in one flight session (“Multiframe”)

During the Ingest processing step the images from the 5 different sensors are geometrically co-registered and single bands of each image is geometrically and radiometrically corrected based on the factory camera calibration. An atmospheric correction is also applied using a terrain model and information on the sun position relative to the image frame to remove differences in the scene caused by sun-terrain geometry. The effect of haze is also removed during this step. Haze is most prominent in imagery taken from great elevation reaching GSDs of 15-30cm. The white balance is automatically adjusted for each image and flightlines are colorbalanced during the "Multiframe"-step to obtain a homogenous appearance of all images from one flight session. For some cases the multiframe-step does not handle radiometric differences correctly, and a calibrated version can be exported. Atmospheric correction is applied, but not colorbalancing for images during calibrated export. As shown in figure 14 and figure15, multiframe colorbalancing did not enhance the homogeneity in this project since colorbalancing using HxMap usually will fail in areas with large waterbodies. Due to of this, the calibrated approach was chosen for the final image export. The imagery shown in figure 2 is enhanced further before RGB point cloud color coding using tools descried in the following section

Figure 14: Mosaic of project after corrections including atmospheric correction and Multiframe color balancing

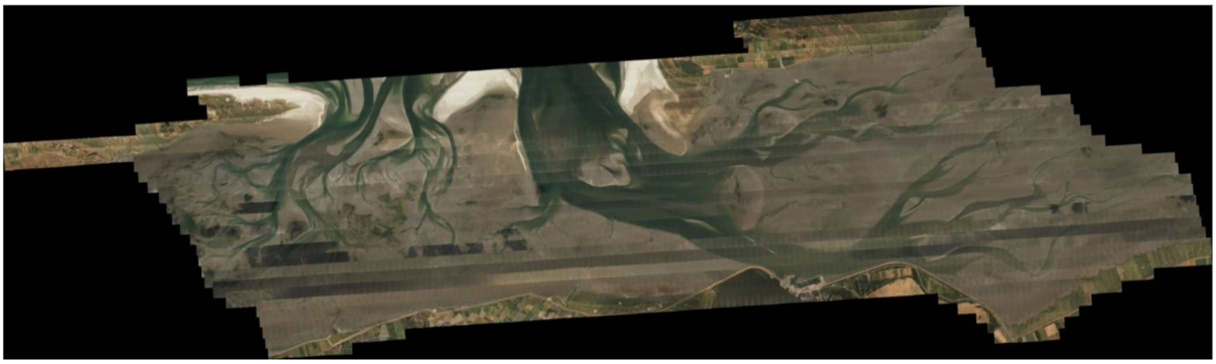


Figure 15: Mosaic of project after all corrections except Multiframe color balancing

After the Ingest processing step manual adjustment is applied to the imagery using radiometric profiles. DMC III imagery is captured using a 14 bit sensor. Standard image products are delivered in either 8 or 16-bit radiometric resolution. The radiometric profiles are curves used for altering the pixel values and transforming from 14-bit resolution to either 8 or 16-bit resolution. When applying the radiometric profiles, the intensity (brightness) for all bands are altered. The goal is to visualize all information in the image, to achieve good visibility in shadow areas, not to overexposed in bright areas and to achieve sufficient contrast. For RGB products the white balanced achieved through the automatic Ingest processing step is sufficient, meaning that the same radiometric profile can be used for all RGB-channels. When producing CIR-imagery, consisting of near infrared, red and green color information, the curve used for the near infrared band usually differs from the curve used for the red and green bands. The reason for this is to take down the color saturation cause by the infrared band to improve the contrast and making it easier to differentiate for example different three species.

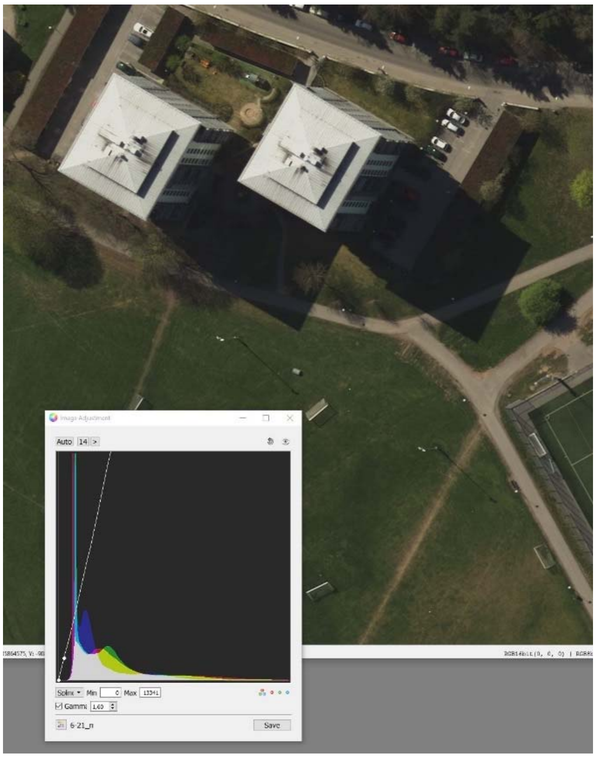


Figure 16: Screenshot of adjusting radiometric profile in HxMap

If a project consists of several flight sessions the automatic color balancing explained for the Ingest-step will usually result in slightly different radiometry for different sessions. When applying color profiles, the goal is to minimize the effects of these differences on the overall radiometry. Further color balancing between different flight sessions can also be adjusted during orthophoto production.

The radiometric profile is used as an input when exporting final products like RGB and CIR images. During the export images are pansharpened to increase the geometric resolution. Since the geometric resolution of the panchromatic image is three times higher, color information from the closes pixel in the color images is “added” to the panchromatic pixels resulting in a color image appearing to have the same geometric resolution as the original panchromatic image.

It is worth noting that different radiometric profiles are used when producing RGB and CIR imagery, resulting in the red and green band in the RGB image having different pixel values from the red and green band in the CIR image. If exporting 4-band RGBI images it is possible to deduct both CIR and RGB from the same dataset. For these images the red and green band will be identical since only one radiometric profile is applied.

8. RGB AND CIR-COLORING

8.1 Point cloud coloring

The points in the classified point cloud have been assigned color values from the generated orthophoto of the simultaneously captured vertical images of the area. In order to match the point density in the LIDAR-data, image data has been downsampled from original GSD 2cm (2500 pixels per m^{2}) to GSD 10cm (100 pixels per m^2).

Point color is taken from the enhanced orthophoto explained in next section.

Figure 17: RGB colored pointcloud

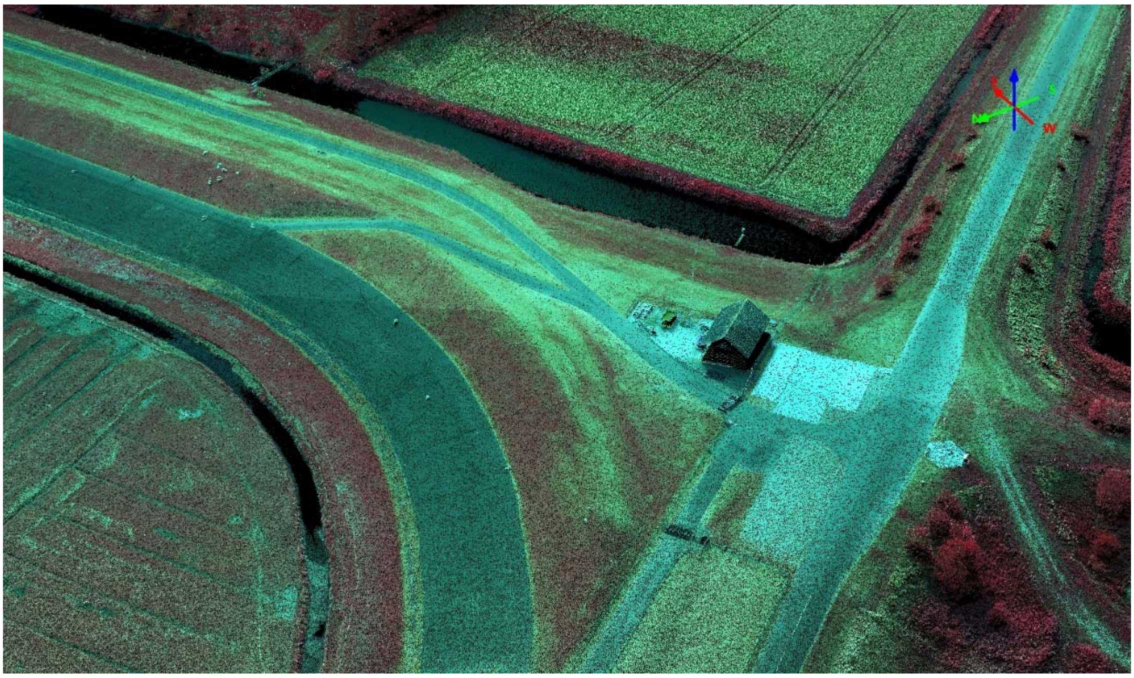


Figure 18: CIR colored pointcloud

The imagery used for producing the colored point cloud was 8-bit. According to ASPRS las 1.4 specification the color value is stored as a 16-bit value. This means the color value is scaled up to 16-bit but keeps its relative value.

8.2 Enhancing image radiometry and orthophoto processing in OrthoVista (Inpho)

Prior to orthophoto processing a photo adjustment was performed in OrthoVista RadiometrixEditor.
The RadiometrixEditor allows changing interactively the histogram, color, saturation, intensity, contrast of a single image or group of images.

To achieve the best possible contrast and color in single images and homogeneity between images the function Manual Gradation and Intensity were used to modify gradation and intensity curves of selected images.

The Gradation correction is preferred for RGB images, as also slight color casts can be corrected. The Intensity correction is preferred for IR (infrared) imagery, as here, color changes are not wanted.

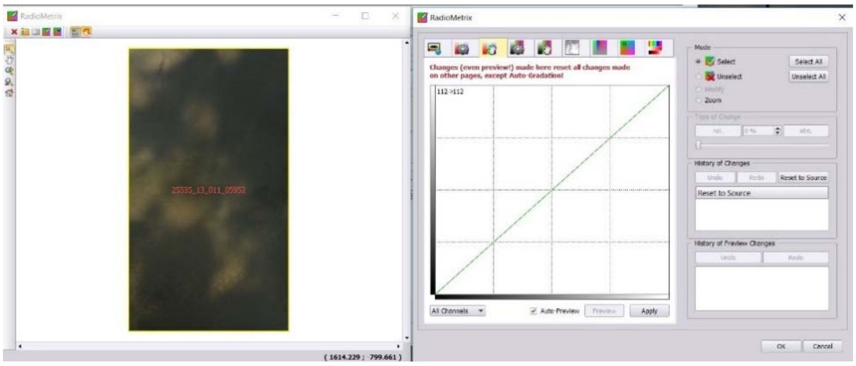


Figure 19a: Screenshot of a raw RGB image produced in HxMap

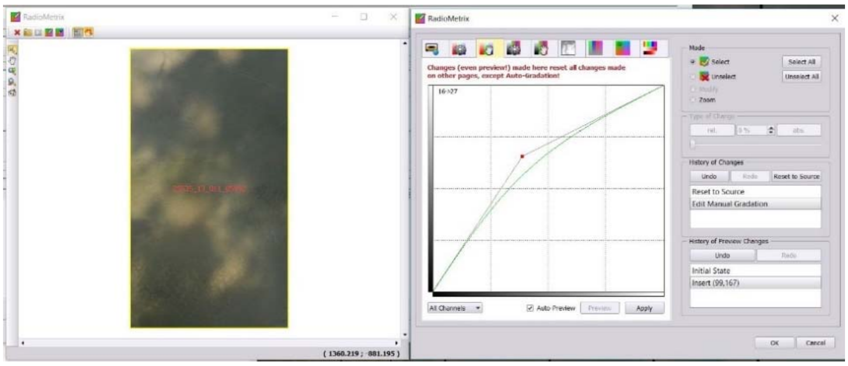


Figure 19b Screenshot of the RGB image adjusted in RadiometrixEditor - Manual Gradiation

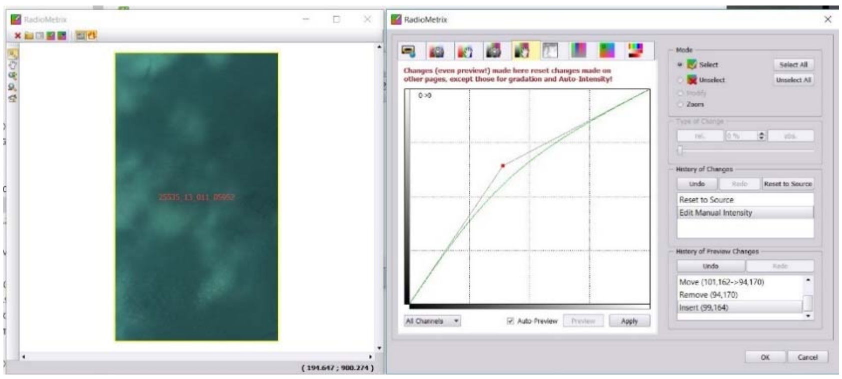


Figure 19c Screenshot of the CIR image adjusted in RadiometrixEditor - Manual Intensity

Further radiometric adjustment between overlapping images was performed in connection with the mosaic processing in OrthoVista with the feature "Global tilting adjustment" option. This feature observes differences in intensity, contrast and color between overlapping images / flightlines and calculates relative corrections that compensate for the differences.

Figure 20: Orthomosaic – images after GlobalTilting adjustment

9. DELIVERY OF POINT CLOUD

9.1 Overview of files in the delivery

- Laserdata RGB colored
  - Tiled in 250x250 blocks
  - Per flightline
- Laserdata CIR colored
  - Tiled in 250x250 blocks
  - Per flightline
- Image
  - RGB, .tif Q5 compressed with overviews
  - CIR, .tif Q5 compressed with overviews
- Navigation
  - EO for images
  - SBET, full navigation for laser
  - TRJ – files per laserline

9.2 Folder structure

- 8950 Waddenzee (25535 & 40958)
    - 01_Report
    - 02_Lidar
        - 01_LASDATA-RGB
            - 01_TILED
            - 02_PER_FLIGHTLINE
        - 02_LASDATA-CIR
            - 01_TILED
            - 02_PER_FLIGHTLINE
        - 03_NAVIGATION
            - 01_SBET
            - 02_TRJ
        - 03_TEST_AREA
            - 01_800m
            - 02_1200m
            - 03_1730m
    - 03_Images
        - 01_RGB
        - 02_QUICKVIEWS-RGB
        - 03_CIR
        - 04_QUICKVIEWS-CIR
        - 05_EO
        - 06_SHP
        - 07_TEST_AREA
            - 01_800m
                - 01_RGB
                - 02_QUICKVIEWS-RGB
                - 03_CIR
                - 04_QUICKVIEWS-CIR
                - 05_EO
            - 02_1200m
                - 01_RGB
                - 02_QUICKVIEWS-RGB
                - 03_CIR
                - 04_QUICKVIEWS-CIR
                - 05_EO
            - 03_1730m
                - 01_RGB
                - 02_QUICKVIEWS-RGB
                - 03_CIR
                - 04_QUICKVIEWS-CIR
                - 05_EO

10. APPENDIXES

Appendix 1: LiDAR flight report
Appendix 2: Risk Assessment Shell
Appendix 3: GNSS-INS
Appendix 4: System Calibration VQ-1560i
Appendix 5: HPR Correction
Appendix 6: dZdR correction
Appendix 7: CalibProtocol_DMCIII
Appendix 8: Image_plot_25535