

Imaging Coastal Morphology at Rincon Public Beach using Data from Aerial Light Detection and Ranging (LiDAR) and Unmanned Aerial Vehicle Photogrammetry

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Introduction

Most of the planet Earth is covered by water, 71% of total planet surface to be exact, and most of these waters surround all the landmasses making up the rest of the surface (Martínez et al., 2007). This leads to a huge amount of coastline where these two meet. It is a very important ecosystem for many species of birds, crustaceans, turtles, and many others including humans. It is of the utmost importance to protect this environment, which when it is healthy is of such importance to humans (Figure 1). Humans have favored the coast for numerous reasons since time immemorial and studies have shown that they are the most favored location for humans to “...live permanently, for leisure, recreational activities, or tourism” (Martínez et al., 2007). This should justify the increasing studies on an area that is threatened by climate change and human activity (McGranahan et al., 2007). Some of these coastal communities rely principally on their surrounding coastal resources and these threats are a major concern. Rincón is a municipality in extreme western Puerto Rico with some of the most beautiful hills, ocean views, and beaches on the island, which fuel their primary economic driver tourism (Municipal website, <http://rincon.gov.pr/>, accessed November, 2019). The beaches of this municipality have suffered from severe erosion over the past 70 years (Thieler et al., 2007). The study site, Rincon Public Beach, is one of these severely eroded beaches whose shoreline has receded over 50m in the past 70 years, and whose rate of erosion has accelerated over the past 12 years to well over 1m per year of shoreline recession (Thieler et al., 2007). Being able to quickly and effectively study changes in beach morphology would be a great tool to have to monitor the beach on different time scales and before and after major events. Aerial and satellite light detection and ranging (LiDAR) images are very useful for producing digital elevation maps (DEMs) of the beach morphology that are used for coastal monitoring, but they have their weaknesses. Another useful tool that is being used lately is unmanned aerial vehicles (UAVs or drones) taking images that are then processed thru photogrammetry to make DEM maps, and these are very easily and cost-effectively deployed but also have their limitations. The purpose of this study is to compare these two tools and to analyze what their best and most effective use is for monitoring change of beach morphology.

Scientific Question

What are the benefits and disadvantages of using UAS photogrammetry and aerial LiDAR to evaluate beach morphology and change over time?

Objectives

- To compare the strengths and weaknesses of either method, and the possibility of their combined use for coastal studies
- To develop an efficient process to turn LiDAR data and orthomosaics into useful Digital Elevation Models (DEMs) that help the analysis of changing beach morphology in the short and medium-term (months-years)

Methodology

- Obtain high-resolution aerial LiDAR images of the study area collected by plane for the United States Geological Survey (USGS) using two long-range airborne LiDAR laser scanners (RIEGL LMS-Q680i, and RIEGL LMS-Q780) when they mapped the whole island in 2015 from a database created for these images (ftp://rockyftp.cr.usgs.gov/vdelivery/Datasets/Staged/Elevation/LPC/Projects/USGS_LPC_PR_PuertoRico_2015_LAS_2018/laz/)
- Unzip the images with a freeware program called laszip
- Fly a drone (DJI Mavic Pro with a 12.35 megapixel camera) over Rincón Public Beach taking over 500 images at 2 second intervals from different locations over the beach and different angles to the beach (Figure 2)
- Load randomly selected 164 images (164 because of time constraints) of the ones taken into a program called Agisoft
- In Agisoft one scrolls through each image and uses a tool that ‘masks’, or ‘tells’ the program to ignore a certain area of an image because things will move and that has a negative effect on its functioning when overlaying the images to produce a sparse pointcloud of the area using photogrammetry (Figure 3)

- This sparse pointcloud is then examined to eliminate points that have been produced that are in areas of non-interest or noticeably incorrect, then it is re-processed to create a dense pointcloud (Figure 4)
- This dense pointcloud is then re-processed to create a DEM map (Figure 5)
- The LiDAR images are uploaded into ArcMap where they are used to create a DEM elevation map
- The DEM from the drone images is also uploaded into ArcMap
- Using ArcMap tools both DEMs are compared (Figures 6, 7)

Results and Discussion

Both DEMs were very capable of mapping beach morphology. Due to time constraints of the semester, statistics were not produced but a qualitative comparison showed their clear capability for mapping with significant accuracy. Strengths and weaknesses of both methods were also clear. Photogrammetric quality is dependent on the lack of movement of the objects present in the image, which was the reason for the substantial masking that is necessary particularly at a public beach with people, animals, and vehicles. This limitation creates a very particular limitation when studying a beach with any amount of wave energy because it will cause significant error at the swash zone and seaward of the swash zone. LiDAR did not suffer from this limitation, although the clarity of the water might be a factor which in this case did not negatively affect observation of the swash zone but could at another time or place. The weakness of aerial LiDAR is the cost and the ease of deployment. Flying a plane over the area is very expensive and time consuming. That said, for large extents of coast airborne LiDAR from a plane is far more efficient than the large number of drone flights that would be necessary to cover the same area. The drone's strengths would be its very effective, easy and low-cost deployment which permits many more studies being possible at low cost and with short notice and/or regularity but of a limited area and not to study shoreline change.

Conclusions

For a limited area and changes in beach morphology drone-based photogrammetry is very capable and very useful, but it is far less effective when studying large sections of coast or changes in the position of the shoreline. On the other hand, airborne LiDAR is also very effective and is a far better option to study changes in shoreline location and to study large sections of coast as long as there are enough monetary resources and availability to do so.

Recommendations

Given the availability at this moment of drone-based LiDAR surveying, the best possible method for studying coasts would be drone-based photogrammetry combined with drone-based LiDAR surveying as long as the extent of the coast is not too large. If there are no time constraints drones would probably always be more cost-effective than plane-based aerial LiDAR surveying, but for studies of large extents of coast within time constraints and with enough monetary resources plane-based airborne LiDAR surveying would probably be the best method.

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Figures

Coastal Ecosystem Services



Figure 1. Representation of Coastal Ecosystem Service (<http://nca2014.globalchange.gov/report/regions/coasts/graphics/coastal-ecosystem-services>)



Figure 2. Drone image from Rincon Public Beach with Dr. Stephen Hughes and Miguel Loubriel (red arrow) in the middle.



Figure 3. Cars and people who needed to be ‘masked’ to process images into pointclouds.

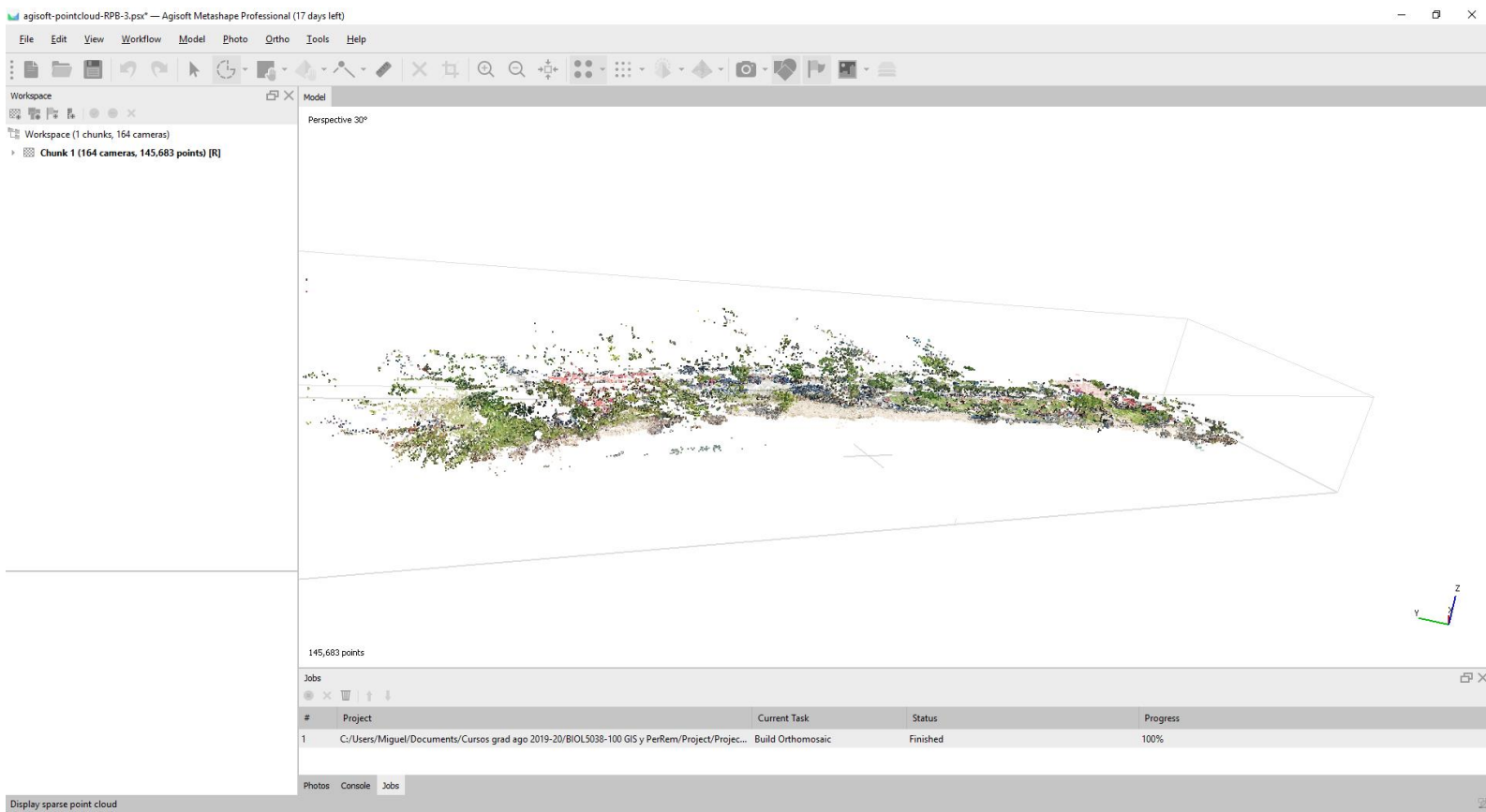


Figure 4. Sparse pointcloud created in Agisoft software.

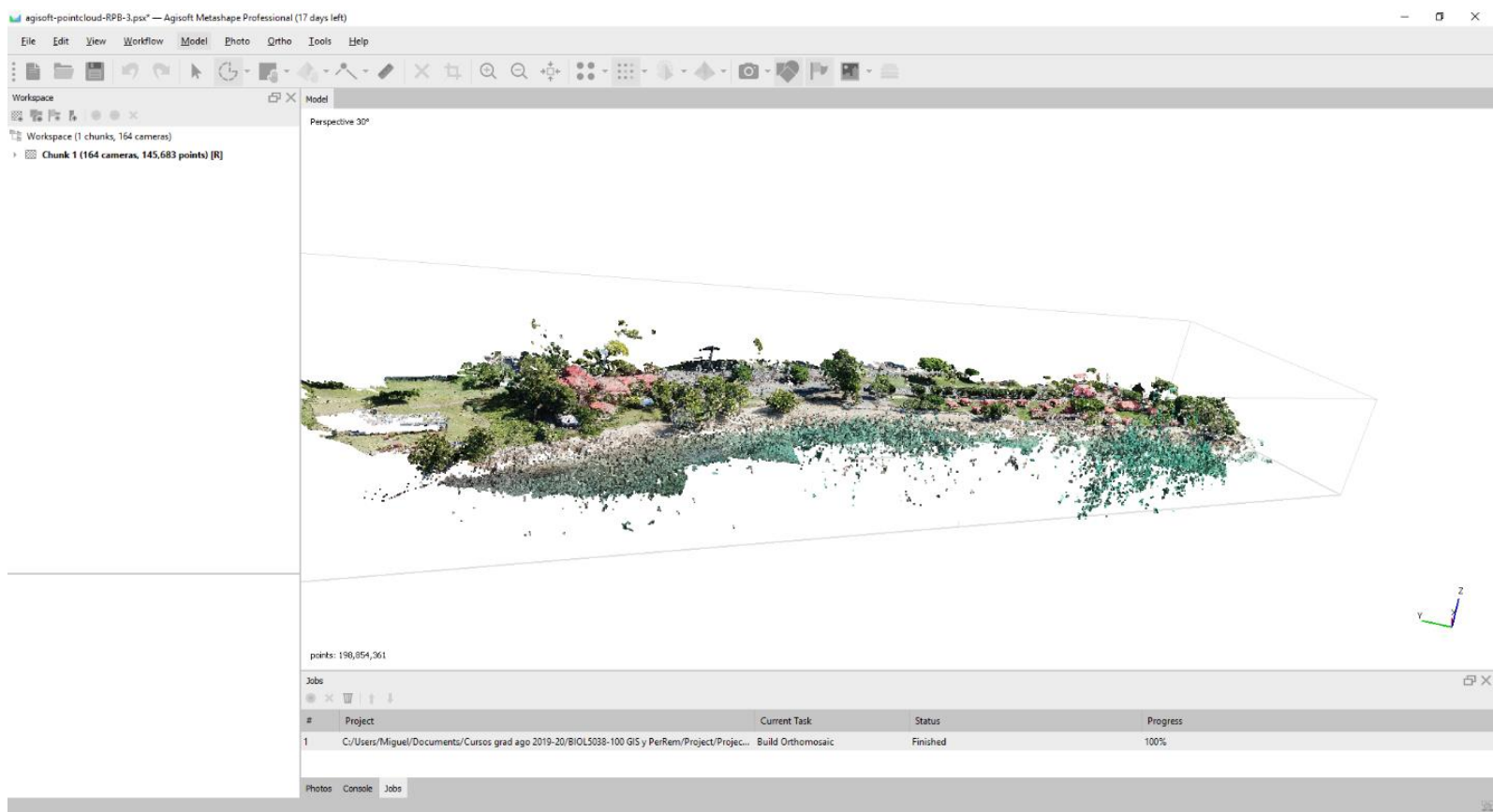


Figure 5. Dense pointcloud created with Agisoft software.

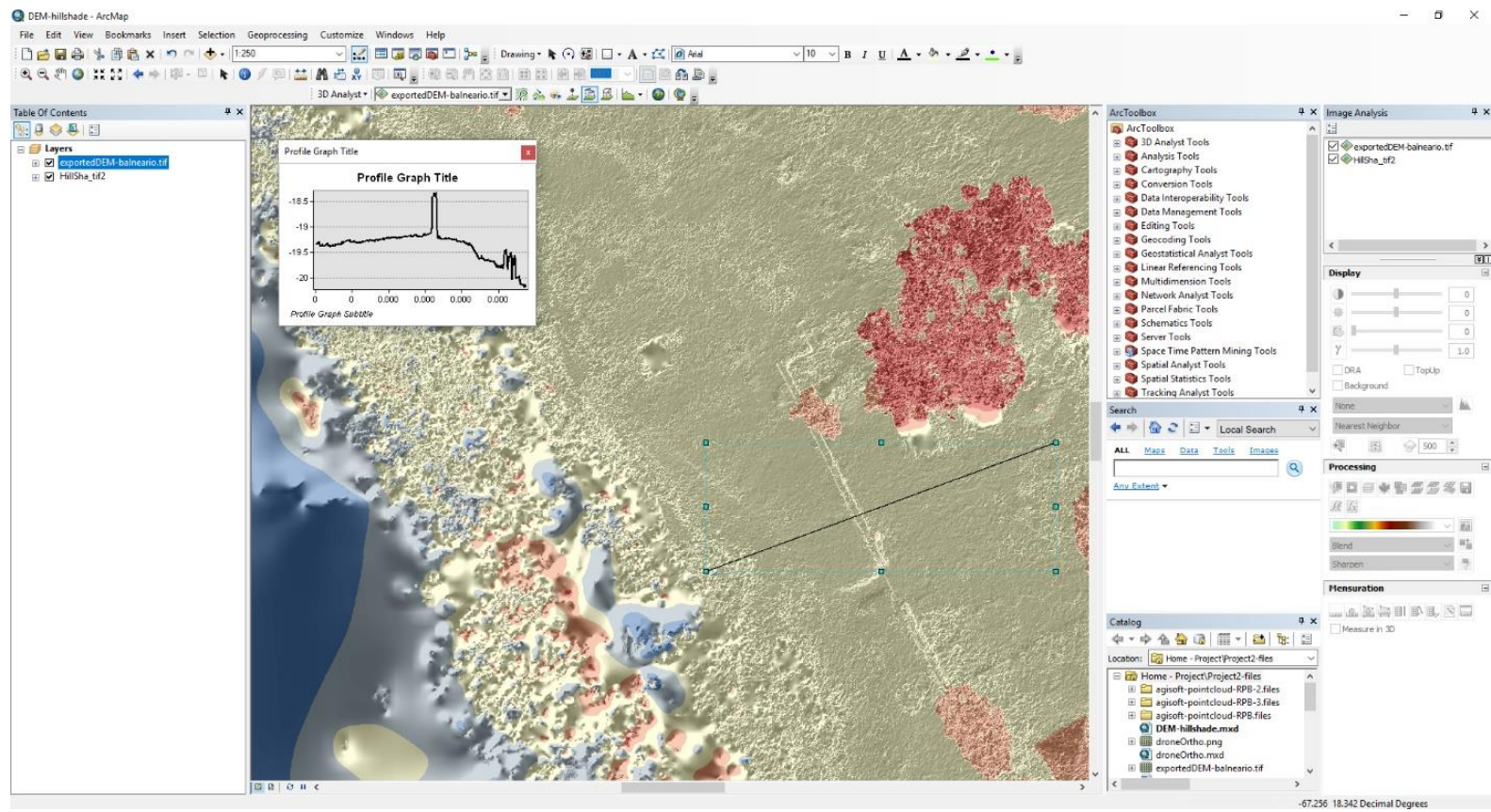


Figure 6. DEM of Rincon Public Beach from drone photogrammetry showing profile line and elevation graph.

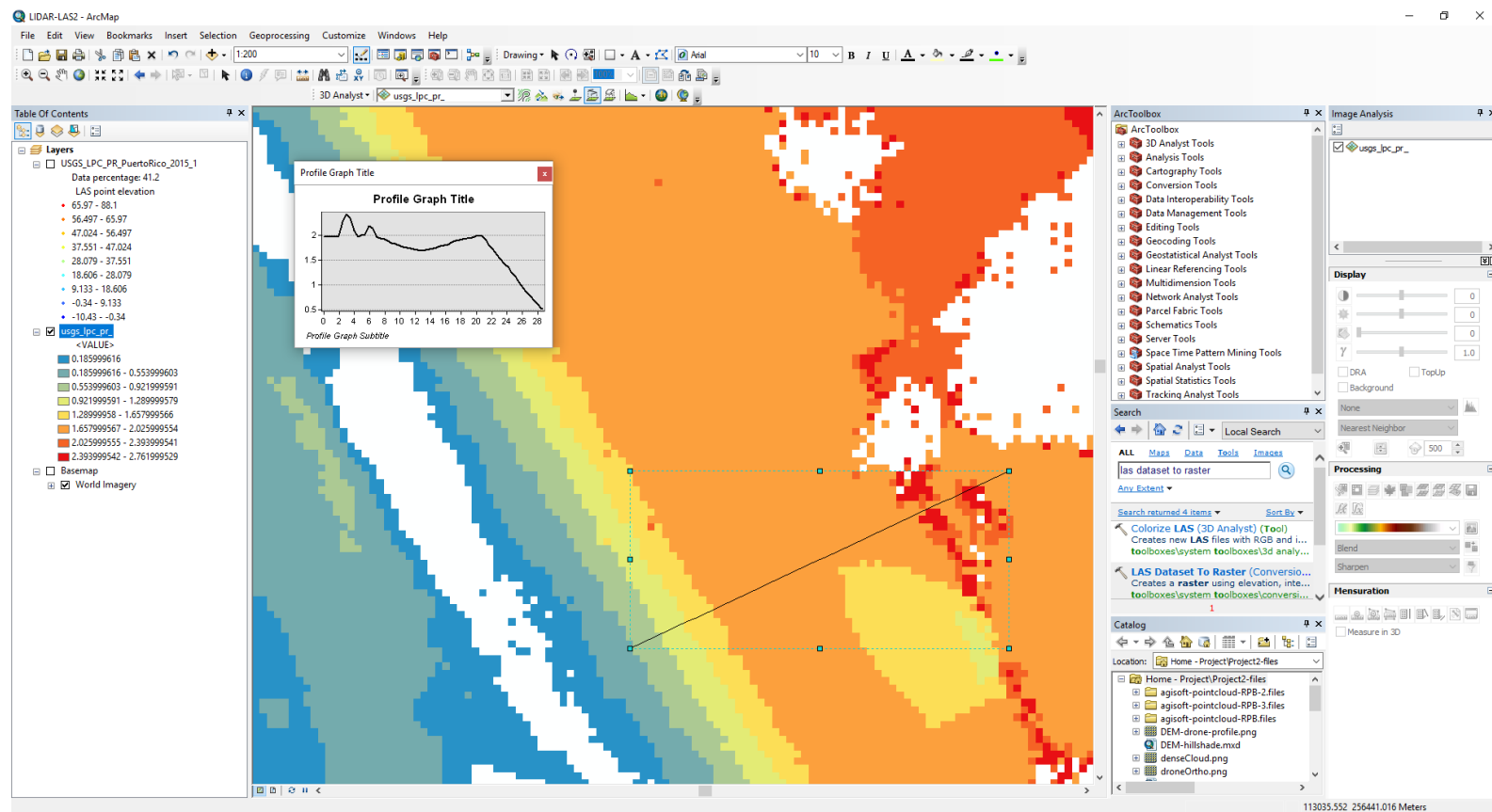


Figure 7. DEM of Rincon Public Beach from airborne LiDAR showing profile line and elevation graph.

Appendix

Sensors – UAV – DJI Mavic Pro 1



CAMERA –

1/2.3" (CMOS), Effective pixels: 12.35 M (Total Pixels: 12.71 M)

LENS – FOV 78.8° 26mm (35mm format equivalent) f/2.2, Distortion < 1.5%, Focus from 0.5 m to ∞

ISO Range – Video: 100 – 3200, Photo: 100 – 1600

Shutter Speed – 8s – 1/8000s

Image Size – 4000 x 3000

Max Video Bitrate – 60Mbps

Still Photography Modes: Still Shot, Burst

Shooting: 3/5/7 frames, Auto Exposure

Bracketing (AEB): 3/5 bracketed frames at 0.7, EV Bias, Interval

Video Recording Modes: C4K: 4096x2160 24p,

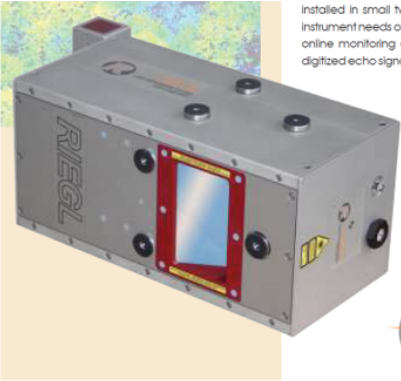
4K: 3840x2160 24/25/30p, 2.7K: 2720x1530

24/25/30p, FHD: 1920x1080

24/25/30/48/50/60/96p, HD: 1280x720

24/25/30/48/50/60/120p

Sensors – Airborne LiDAR



Installed in small twin- or single-engine planes, helicopters or UAVs. The instrument needs only one power supply and GPS timing signals to provide online monitoring data while logging the precisely time-stamped and digitized echo signal data to the rugged RIEGL Data Recorder.

- Topography & Mining
- Corridor Mapping
- City Modeling
- Mapping of Lakesides & River Banks
- Agriculture & Forestry
- Target Classification
- Glacier & Snowfield Mapping
- Power Lines

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Applications:

Full Laser Power:

- Wide Area / High Altitude Mapping
- Topography & Mining
- Glacier & Snowfield Mapping

Reduced Laser Power:

- City Modeling
- Mapping of Lakesides & River Banks
- Agriculture & Forestry
- Corridor Mapping



RIEGL LMS-Q680i – long-range airborne laser scanner

- Minimum Range – 30m
- Accuracy – 20mm
- Precision – 20mm
- Laser Pulse Repetition Rate – up to 400 kHz
- Effective Measurement Rate – up to 266 kHz at 60° scan angle
- Laser Wavelength – Near Infrared
- Scanning Mechanism – Rotating Polygon Mirror
- Scan Pattern – Parallel Scan Lines
- Scan Angle Range - +/- 30° = 60° total
- Scan Speed – 10 - 200 lines/sec
- Angle Measurement Resolution – 0.001°

RIEGL LMS-Q780 – long-range airborne laser scanner

- Minimum Range – 50m
- Accuracy – 20mm
- Precision – 20mm
- Laser Pulse Repetition Rate – up to 400 kHz
- Effective Measurement Rate – up to 266 kHz at 60° scan angle
- Laser Wavelength – Near Infrared
- Scanning Mechanism – Rotating Polygon Mirror
- Scan Pattern – Parallel Scan Lines
- Scan Angle Range - +/- 30° = 60° total
- Scan Speed – 14 - 200 lines/sec
- Angle Measurement Resolution – 0.001°

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Agisoft Metashape

Processing Report
02 December 2019



Survey Data

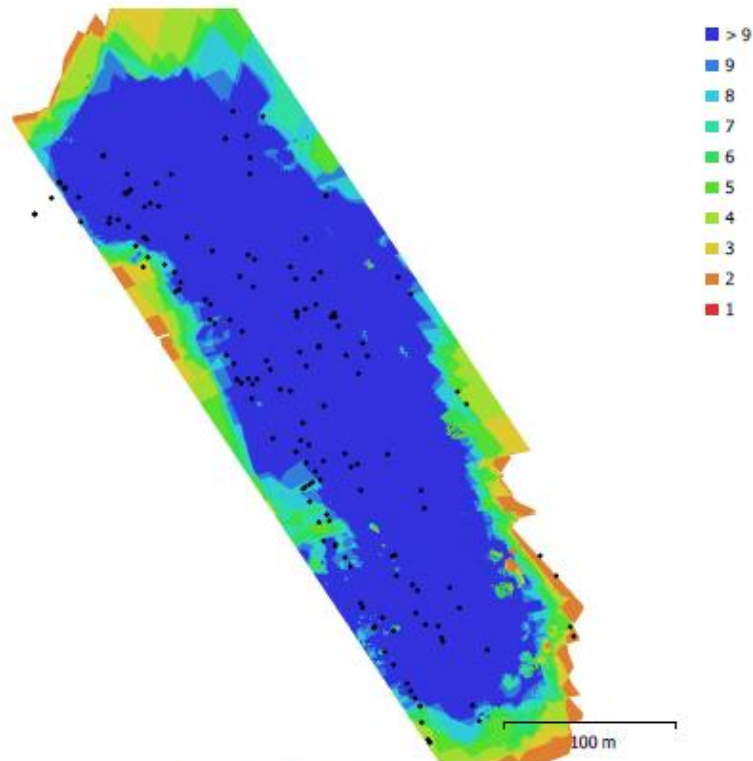


Fig. 1. Camera locations and image overlap.

Number of images:	164	Camera stations:	164
Flying altitude:	63.8 m	Tie points:	145,683
Ground resolution:	1.95 cm/pix	Projections:	338,883
Coverage area:	0.064 km ²	Reprojection error:	0.813 pix

Camera Model	Resolution	Focal Length	Pixel Size	Precalibrated
FC220 (4.73mm)	4000 x 3000	4.73 mm	1.57 x 1.57 μ m	No

Table 1. Cameras.

Camera Calibration

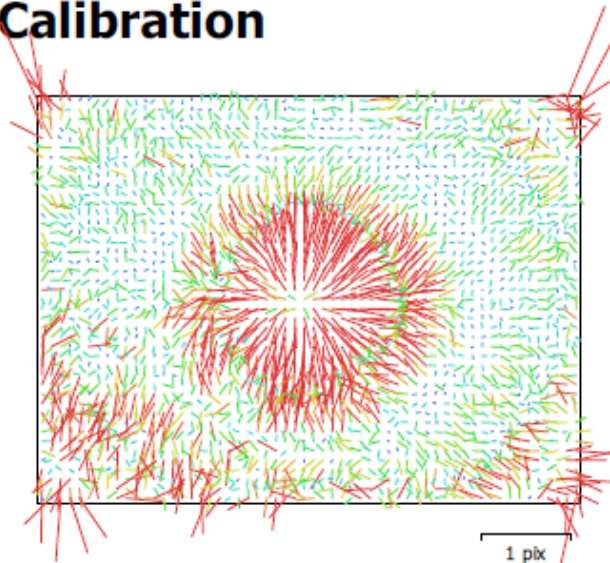


Fig. 2. Image residuals for FC220 (4.73mm).

FC220 (4.73mm)

164 images

Type	Resolution	Focal Length	Pixel Size
Frame	4000 x 3000	4.73 mm	1.57 x 1.57 μm

	Value	Error	F	Cx	Cy	K1	K2	K3	P1	P2
F	3071.48	0.53	1.00	-0.09	-0.42	0.11	-0.02	0.06	-0.08	-0.15
Cx	-26.248	0.27		1.00	0.27	-0.09	0.00	0.01	0.86	0.40
Cy	23.2619	0.31			1.00	-0.13	0.03	-0.04	0.29	0.74
K1	0.0369516	0.0002				1.00	-0.91	0.86	-0.10	-0.15
K2	-0.0925626	0.0007					1.00	-0.98	0.00	-0.01
K3	0.0981965	0.0008						1.00	0.00	-0.01
P1	0.00050861	2.7e-005							1.00	0.40
P2	0.000464383	2.5e-005								1.00

Table 2. Calibration coefficients and correlation matrix.

Camera Locations

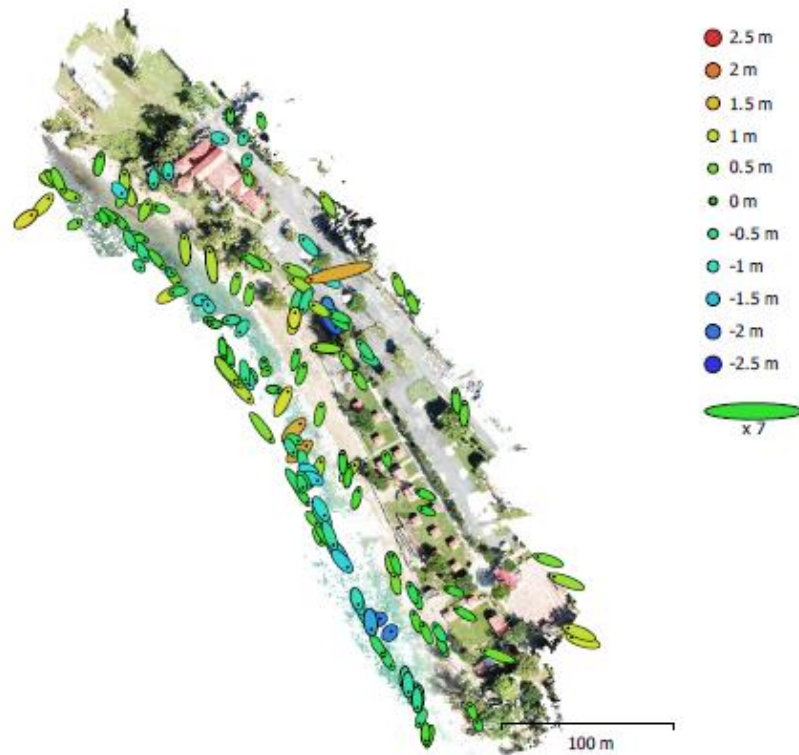


Fig. 3. Camera locations and error estimates.

Z error is represented by ellipse color. X,Y errors are represented by ellipse shape.
Estimated camera locations are marked with a black dot.

X error (m)	Y error (m)	Z error (m)	XY error (m)	Total error (m)
0.853708	0.97152	0.763019	1.29332	1.50162

Table 3. Average camera location error.

X - Longitude, Y - Latitude, Z - Altitude.

Digital Elevation Model

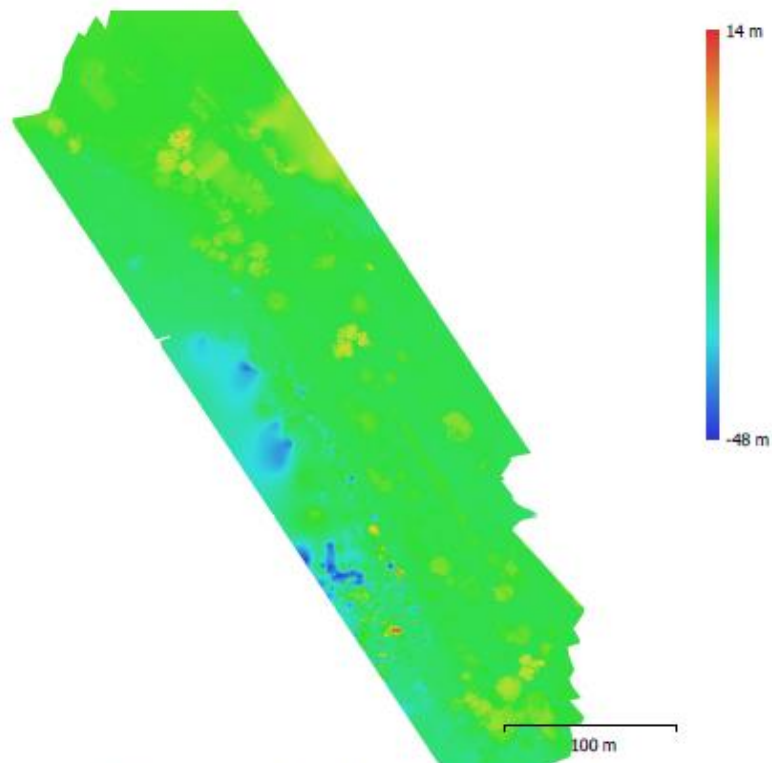


Fig. 4. Reconstructed digital elevation model.

Resolution: 1.95 cm/pix
Point density: 0.263 points/cm²

Processing Parameters

General

Cameras	164
Aligned cameras	164
Coordinate system	WGS 84 (EPSG::4326)
Rotation angles	Yaw, Pitch, Roll

Point Cloud

Points	145,683 of 169,670
RMS reprojection error	0.306836 (0.813154 pix)
Max reprojection error	0.971061 (29.9412 pix)
Mean key point size	2.64354 pix
Point colors	3 bands, uint8
Key points	No
Average tie point multiplicity	2.52696

Alignment parameters

Accuracy	Highest
Generic preselection	Yes
Reference preselection	Yes
Key point limit	40,000
Tie point limit	4,000
Filter points by mask	No
Mask tie points	No
Adaptive camera model fitting	No
Matching time	9 minutes 54 seconds
Alignment time	1 minutes 47 seconds
Software version	1.5.5.9097

Depth Maps

Count	161
Depth maps generation parameters	
Quality	Ultra High
Filtering mode	Mild
Processing time	2 hours 43 minutes
Software version	1.5.5.9097

Dense Point Cloud

Points	198,854,361
Point colors	3 bands, uint8
Depth maps generation parameters	
Quality	Ultra High
Filtering mode	Mild
Processing time	2 hours 43 minutes
Dense cloud generation parameters	
Processing time	1 hours 32 minutes
Software version	1.5.5.9097

DEM

Size	23,012 x 29,399
Coordinate system	WGS 84 (EPSG::4326)
Reconstruction parameters	
Source data	Dense cloud
Interpolation	Enabled
Processing time	2 minutes 36 seconds
Software version	1.5.5.9097

**General
Software**

Version
Platform

1.5.5 build 9097
Windows 64