

Coastal Dune and Erosion Assessment of the North Coast of Puerto Rico

Final Report

**DOI-FEMA Natural and Cultural Resources
Recovery Support Function (NCR RSF)**



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Table of contents

Introduction.....	4-9
<u>Isabela</u>	
Barrio Bajuras (Pedro Albizu Campos St.).....	10-42
Barrio Bajuras (Monte de Oca St. 1).....	43-83
Golondrinas beach.....	84-104
Haudimar beach.....	105-124
Western part of Secret Spot Beach	
Before 2017 hurricane season.....	125-145
After 2017 hurricane season.....	146-166
Northeasterly swell 2018	167-186
Eastern part of Secret Spot Beach	
Before 2017 hurricane season.....	187-203
After 2017 hurricane season.....	204-219
Northeasterly swell 2018.....	220-239
Breach between Secret Spot and Middles.....	240-259
Middles Beach	
After 2017 hurricane season.....	260-276
Northeasterly swell 2018.....	277-294
Poza de Teodoro	
Before 2017 hurricane season.....	295-309
After 2017 hurricane season.....	310-323
Northeasterly swell 2018.....	324-340

Shore Island	359-378
Pozo Brujo	379-396
Camuy	
Villa Pesquera.....	397-418
Finca Nolla.....	419-438
Hatillo	
Costa Norte	439-458
Arecibo	
Jarealito	459-481
Maranto	
Before 2017 hurricane season.....	482-499
After 2017 hurricane season.....	500-514
Northeasterly swell 2018	515-531
 <u>Manatí</u>	
Poza de las mujeres.....	532-550
Mar Chiquita.....	551-569
 <u>Dorado</u>	
El Caracol.....	570-586
El Único.....	587-606
 Luquillo	
CEN.....	607-629

I. Introduction

Tropical storms and strong swells inflict a significant and social strain on coastal communities worldwide. In the United States alone, hurricane damage has totaled to roughly \$10 billion per year (normalized) over the last century (Pielke et al., 2008). More information is needed on the economic benefits of such services, particularly for coastal vegetated dune ecosystems. There are ways to use a novel geographic information system (GIS-based) technique for delineating, quantifying, and relating coastal dune volume vegetation area, and geographic and built environment covariates to sustained property damage (Pielke et al., 2008). There are ways to calculate the value of dune ecosystems using the principle of log-linear model semi-elasticity. That technique approximates the average per unit volume of dune ecosystem variables based on the derivative of the model's equation with respect to a dune variable (Wooldrige, 2000). That study presents evidence that coastal sand dune ecosystems have significant and meaningful economic value when it comes to storm protection.

There are ways to calculate the value of dune ecosystems using the principle of log-linear model semi-elasticity. That technique approximates the average per unit volume of dune ecosystem variables based on the derivative of the model's equation with respect to a dune variable (Wooldrige, 2000). That study presents evidence that coastal sand dune ecosystems have significant and meaningful economic value when it comes to storm protection.

We selected sites by conducting site visits along the north coast of the island and using NOAA imagery of the same areas. After identifying the sites we used an unmanned aerial vehicle (UAV) to create imagery of selected areas of coastal dunes on the north coast of Puerto Rico in order to assess the damage that the extreme weather events of the end of 2017 and early 2018 had on these systems. The project includes recommendations for the ecological restoration of the same areas to increase their resiliency, and that of the communities near them, to future extreme weather events.

II. General methodology

Selection of sites and data collected.

Study sites along the north coast of Puerto Rico were chosen based on the presence of sand dunes and their proximity to buildings and other property. These areas were given high priority. We chose sites in the following municipalities: Isabela, Camuy, Hatillo, Arecibo, Manatí, Dorado and Luquillo. We originally chose 37 sites and from those we identified 21 high priority sites for which we present the geographic coordinates, a brief description of the site, distance from structures and residential areas, percent vegetation cover, conservation threats and recommended ecological restoration courses of action.

Aerial imagery.

We also present aerial photo imagery captured with a **DJI Phantom 4** (off the shelf) UAV equipped with a 1/2.3" CMOS 12.4 M Effective pixels camera with an ISO range of 100-1600 for still pictures. The aerial imagery for each site included a contour map of the area with elevation intervals of 1 meter, RGB 3D imagery, orthomosaic models, digital surface models (DSM) with and without shading and thermal images. These images were analyzed for changes in the morphology of the dunes, creation of new breaches on the primary line of dunes, vegetation cover and patterns of sand accumulation. The images are also very useful in monitoring the progress of ecological restoration practices in the area.

Sand accumulation.

We identified areas of priority, on each of the project sites, for promoting the accumulation of sand. The initial volume of sand was calculated in these areas to be used as baseline data to monitor the progress of the ecological restoration techniques used. The same volumes can be calculated on future UAS imagery capture missions using the **Pix4D** photogrammetry software package. To calculate volume, we drew polygons in the Volumes view, Pix4Dmapper projects a grid with ground sampling distance (GSD) spacing on the base.

The images of each flight will be processed in separate projects, in which the volume of the area at this moment in time is computed. These computations will be used to calculate the differences of volume of an area over time.

For each cell i of the grid, its volume (V_i) is given by:

$$V_i = L_i * W_i * H_i$$

Where:

L_i = the length of the cell.

W_i = the width of the cell.

H_i = the height of the cell.

The Length (L_i) and Width (W_i) are equal to the project's GSD.

$$L_i = W_i = GSD$$

The Height (H_i) is given by:

$H_i = Z_{Ti} - Z_{Bi}$ Where: Z_{Bi} = the base altitude of each cell at the center of the cell.

Therefore, the volume V_i of cell i is given by:

$$V_i = GSD * GSD * (Z_{Ti} - Z_{Bi})$$

Pix4Dmapper calculates 2 volumes:

The **cut volume** V_C is the volume between the base and the 3D terrain, when the terrain is higher than the base.

$$\text{Cut volume} = V_C = V_{C1} + V_{C2} + \dots + V_{CN}$$

Where:

$$V_{C1..N} = \text{Cut volume for cell } i..N$$

The **fill volume** V_F is the volume between the base and the terrain when the terrain is lower than the base.

$$\text{Fill volume} = V_F = V_{F1} + V_{F2} + \dots + V_{FN}$$

Where:

$$V_{F1..N} = \text{Fill volume for cell } i..N.$$

The Total volume is given by:

$$\text{Total Volume} = V_T = V_C + V_F$$

Vegetation cover.

We used the **Sample Point** software to “point-classify” digital images in order to calculate percent vegetation cover for each site. A database of working images was created using the Database Wizard provided by this software package. This software provides the user a single-pixel sample point and the ability to view and identify the pixel context. This method allows an accuracy comparable with the most accurate field methods for ground vegetative cover measurements. This method will allow us to monitor changes in percent vegetation cover in areas where ecological restoration techniques will be applied.

Conservation threats

All of the sites we included in this assessment were significantly affected by the extreme weather events of the 2017 hurricane season and the March of 2018 strong northeasterly swell. The erosion, breaching and reduction of vegetation cover in these areas needs to be addressed in order to increase the resiliency of the coastal communities near them. Anthropogenic threats such as heavy foot and vehicular traffic on sensitive areas as well as illegal sand extraction also contribute to the degradation of these sites. Lack of an island wide or municipal sand relocation program is also missing therefore displaced sand is lost from the dune ecosystems.

Most of these locations are also an important habitat for protected species of sea turtles and other organisms.

Recommended ecological restoration courses of action (COA)

This report includes recommendations for the ecological restoration of the sites that were assessed. Most of these areas would benefit from effective **law enforcement** to reduce the illegal extraction of sand. Patrolling of these areas needs to be done randomly and formal law enforcement action plans need to be put in place.

The installation of **exclusion fencing** to block illegal all terrain vehicles and foot traffic from sensitive areas also needs to be installed in some sensitive areas. This can be combined with the installation of **wooden boardwalks** that are very effective in re-directing foot traffic away from sensitive areas of these sites. **Information signs** should also be installed close to the boardwalks to inform people about the benefits of dune restoration and about the beach accesses that need to be used. These signs can also identify important species of plants and animals living in the dune ecosystem.

A careful analysis of **patterns of foot and vehicular traffic**, are being conducted by our staff, using aerial imagery captured with a UAV. This study will help us identify the most effective locations to install these structures.

The installation of biomimicry setups (figure 2) to promote **sand accumulation** in sensitive areas should be used in most of the sites. The sand that accumulates should be stabilized with the planting of dune vegetation. The following species will be used in these areas: *Cocoloba uvifera* (beach grapes), *Scaveola plumieri* (Boborón), *Ipomea pes-caprae* (Beach Morning Glory), *Canavalia rosea* (Beach Bean), *Opuntia sp.* (Prickly Pear Cactus), *Conocarpus erectus* (Bottonwood Mangrove), *Suriana maritima* (Baycedar) and *Terminalia catappa* (Antillean almond) in dune areas. *Chrysopogon zizanioides* (Vetiver grass) for terrestrial areas subject to erosion from rain run-off that need to be stabilized.

Monitoring

Sand volume and percent vegetation cover will be monitored periodically and will be used as indicators of the progress of the ecological restoration process.



Figure 1. Wooden boardwalk in ecological restoration site on the Teodoro Beach in Isabela, Puerto Rico.



Figure 2. Biomimicry matrix in Teodoro Beach in Isabela.

III. Imagery

ISABELA

Barrio Bajuras (Pedro Albizu Campos Street), Isabela



A. Physical address:

Calle Pedro Albizu Campos, Barrio Bajuras, Isabela, Puerto Rico 00662.

B. Date of capture of imagery:

March 14, 2018

C. Coordinates:

18.5154 N -67.0929 W

D. Description of site:

This site is located at the end of the Pedro Albizu Campos Road in Barrio Bajuras of Isabela, Puerto Rico. This is a 372 m long asphalt paved street. The end of this street reaches a relatively well vegetated area of coastal dune. The segment of dune located at the end of this road completely collapsed as a result of the 2017 hurricane season and the northeasterly swell of March of 2018 leaving a breach on the dune and a wash-over fan of sand on the backdune and street. The breached area is flanked by a relatively well-stabilized line of primary dune.

Seawater also flooded the street after hurricane María and during the northeasterly swell. The accumulation of sand on the street and against the concrete fences of some houses located at the end of the street was as high as 1 m in some areas. Sand had to be pushed by heavy machinery back to the area where the breach on the dune formed (Figure 3). No consultation to our dune restoration program was made by the municipality or the Puerto Rico Department of Natural and Environmental Resources for the relocation of this sand.

The accumulated sand appears as a thin line on the middle part of the area being studied on the images below.

E. Distance from community:

This site is located at a distance of approximately 37 meters from the nearest house. This area is the end of a highly populated zone with a total of 27 (mainly concrete) houses on both sides of the street.

F. Aerial imagery

i. Contour map

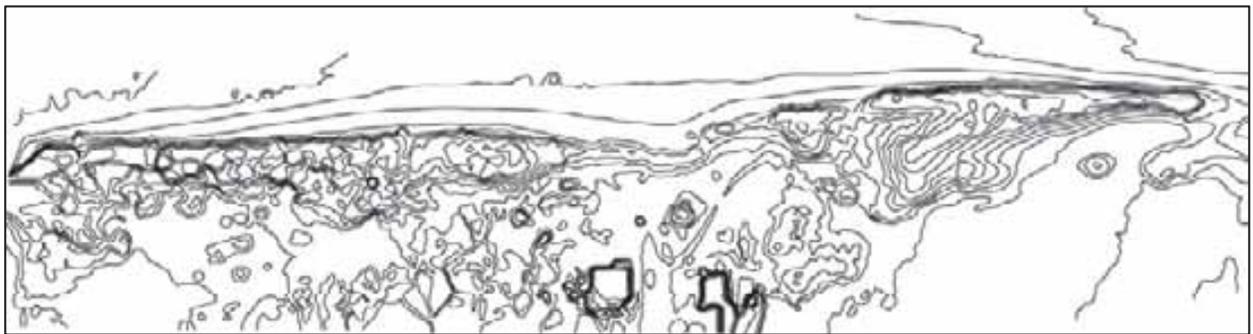


Figure 3. Contour map of Pedro Albizu street in Barrio Bajuras, Isabela Puerto Rico with elevation intervals of 1 meter.

ii. 3D imagery



Figure 4. Aerial 3D image of the area to the east of the end of Pedro Albizu Street in Barrio Bajuras, Isabela.



Figure 5. Aerial 3D image at the end of Pedro Albizu Street in Barrio Bajuras, Isabela. Note the heavy equipment tracks on the sand.

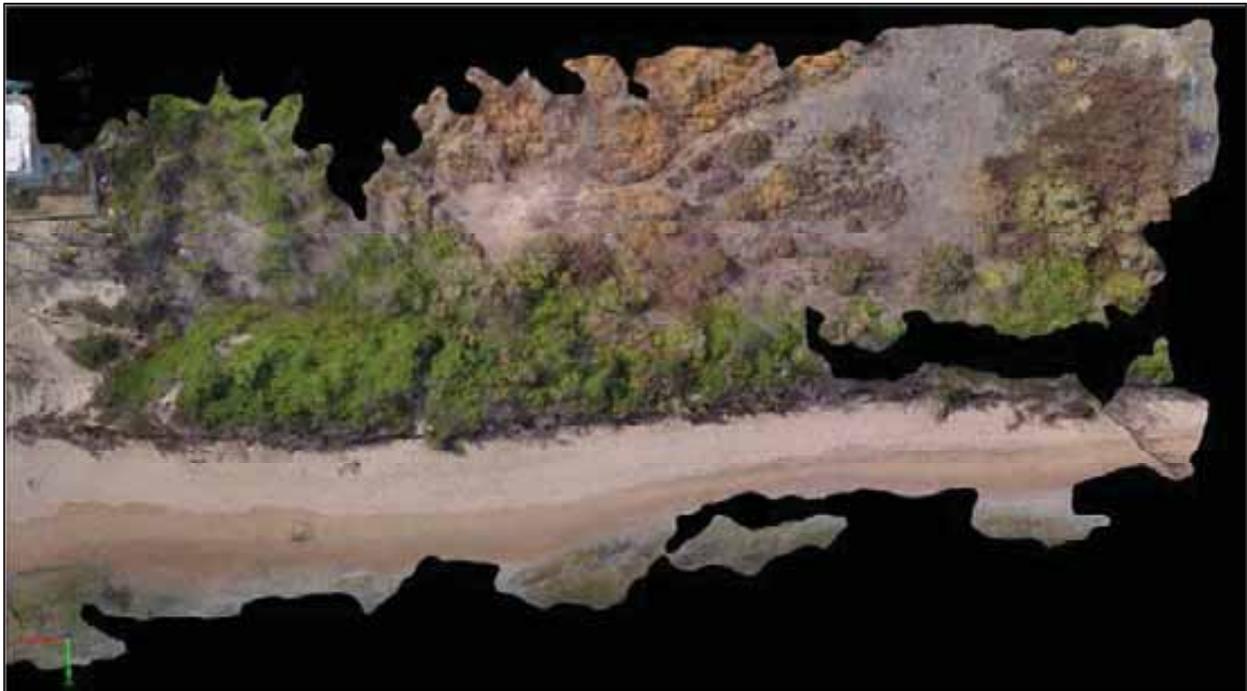


Figure 6. Aerial 3D image of the area to the west of the end of Pedro Albizu Street in Barrio Bajuras, Isabela

iii. Orthomosaic model



Figure 7. Orthomosaic image of the end of Pedro Albizu Campos St. in Barrio Bajuras in Isabela.

iv. Density Surface Models (DSM)

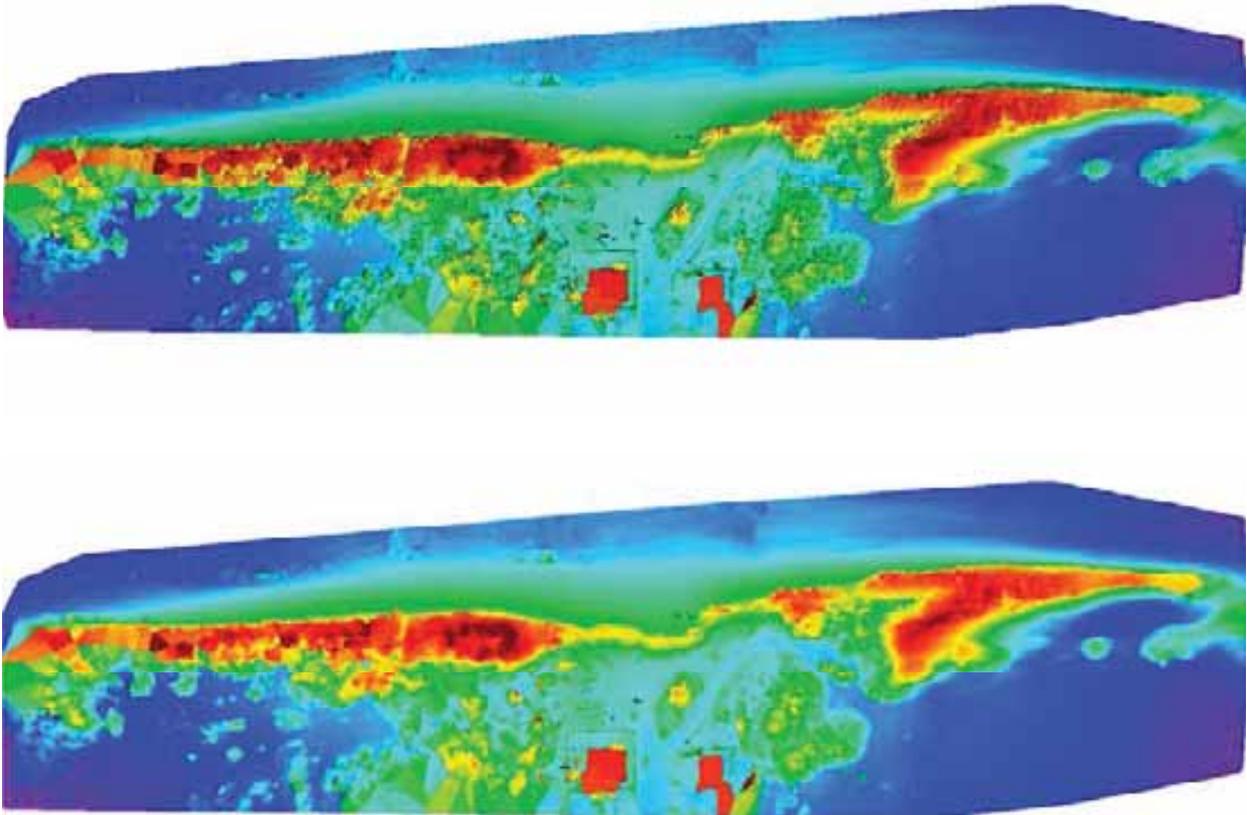


Figure 8. Density surface model spectral scale (with no-shading top and without shading bottom) images of the dune located at the end of Pedro Albizu Campos St. in Barrio Bajuras in Isabela.

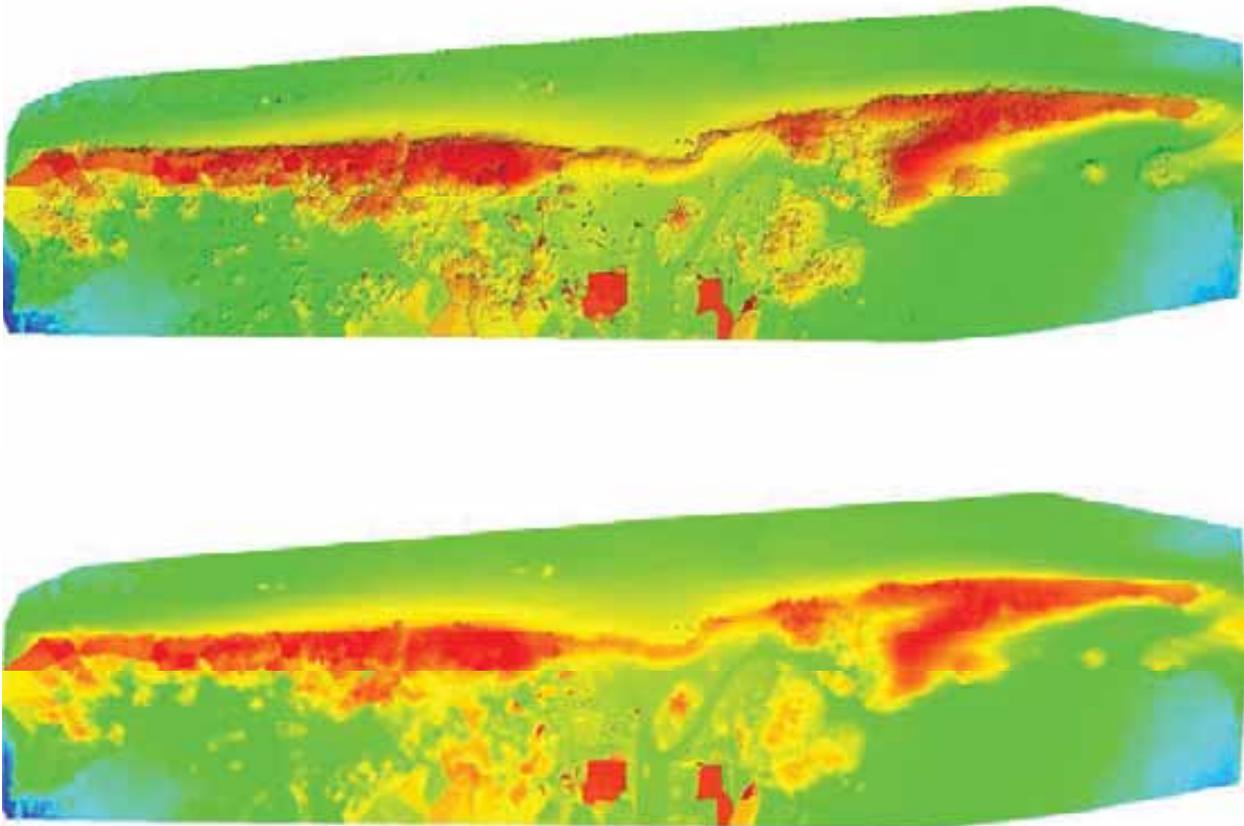


Figure 9. Density surface model (with no-shading on the top and without shading on the bottom) images of the dune located at the end of Pedro Albizu Campos St. in Barrio Bajuras in Isabela.

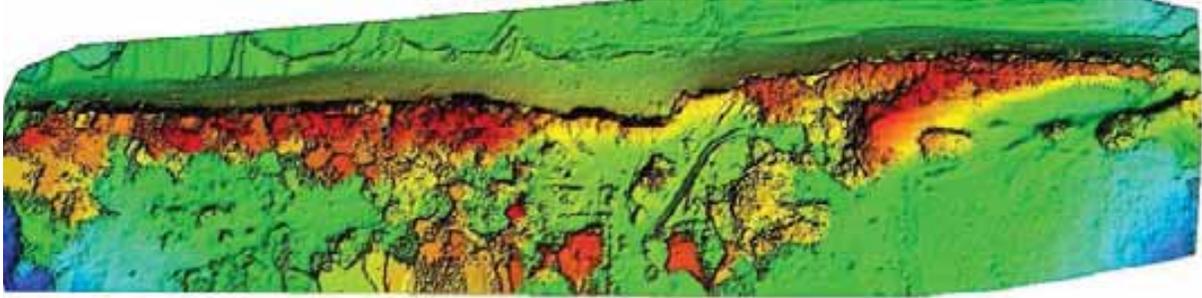


Figure 10. Density surface model before densification of the dune located at the end of Pedro Albizu Campos St. in Barrio Bajuras in Isabela.

v. Thermal images

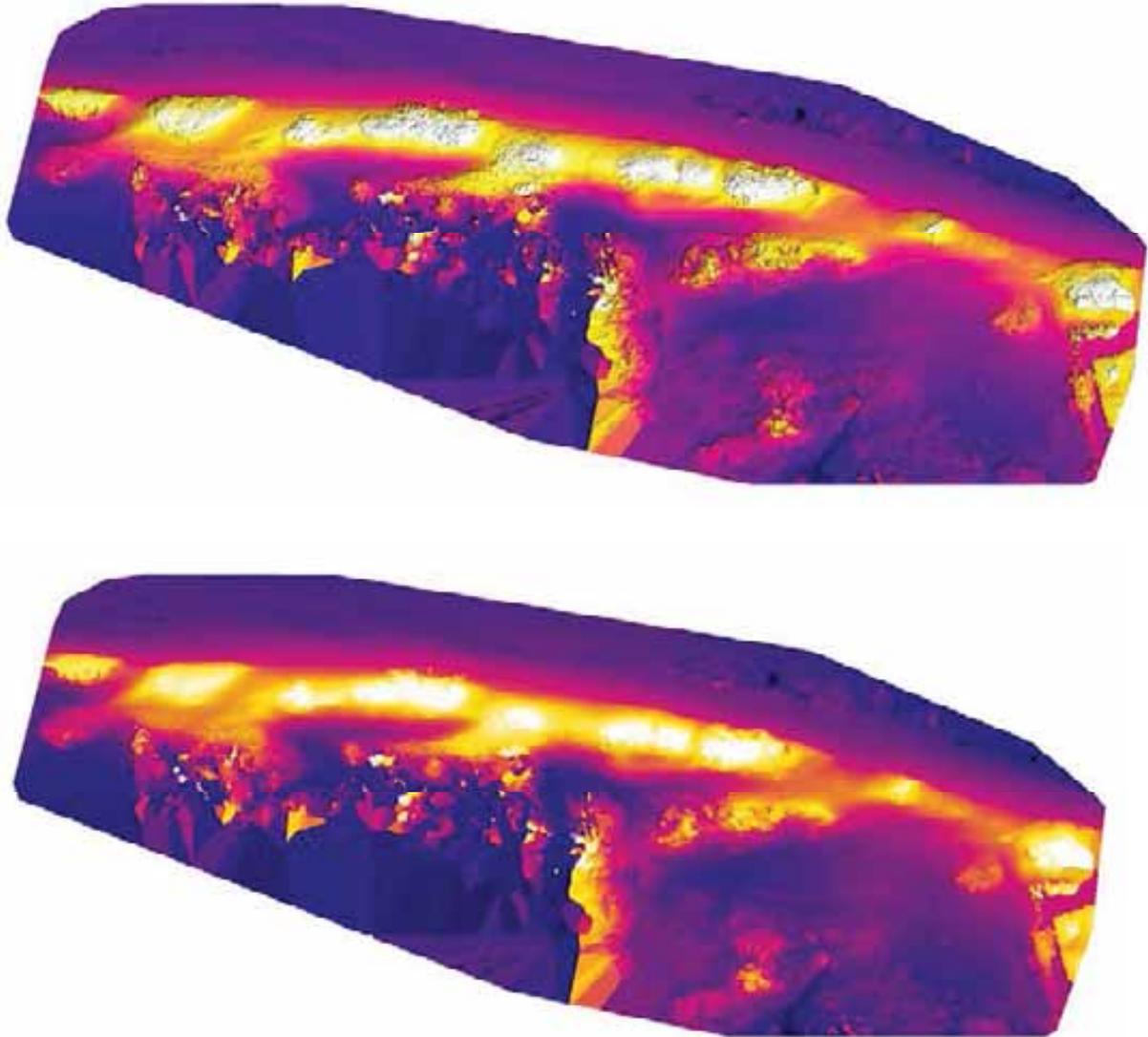


Figure 11. Thermal images (with no-shading on the top and without shading on the bottom) of the dune located at the end of Pedro Albizu Campos St. in Barrio Bajuras, Isabela.

vi. 3D altitude RGB North

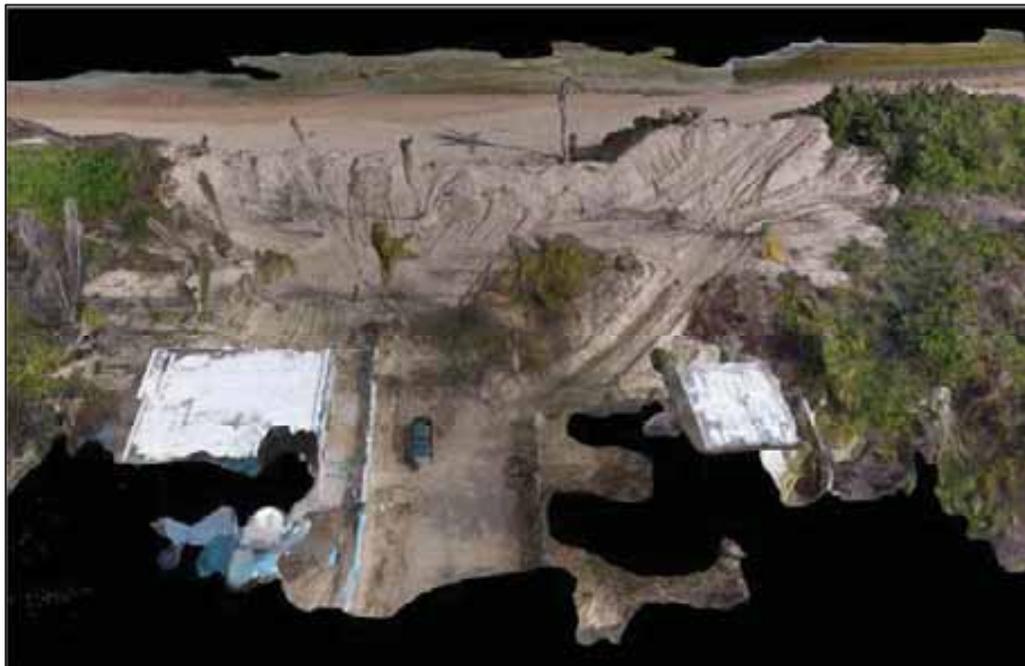


Figure 12. Three dimensional RGB images of the end of Pedro Albizu Campos St. in Barrio Bajuras, Isabela. View from the north (top) and from the south (bottom).



Figure 13. Three dimensional RGB images of the end of Pedro Albizu Campos St. in Barrio Bajuras, Isabela. View from the west (top) and from the east (bottom). Note the tracks of heavy equipment that was used to relocate sand that was displaced during the 2017 hurricane season and the strong northeasterly event of March of 2018.



Figure 14. Three dimensional RGB images of the dune to the east of the end of Pedro Albizu Campos St. in Barrio Bajuras, Isabela. View from the north (top) and from the west (bottom).



Figure 15. Three dimensional RGB images of the dune to the east of the end of Pedro Albizu Campos St. in Barrio Bajuras, Isabela.

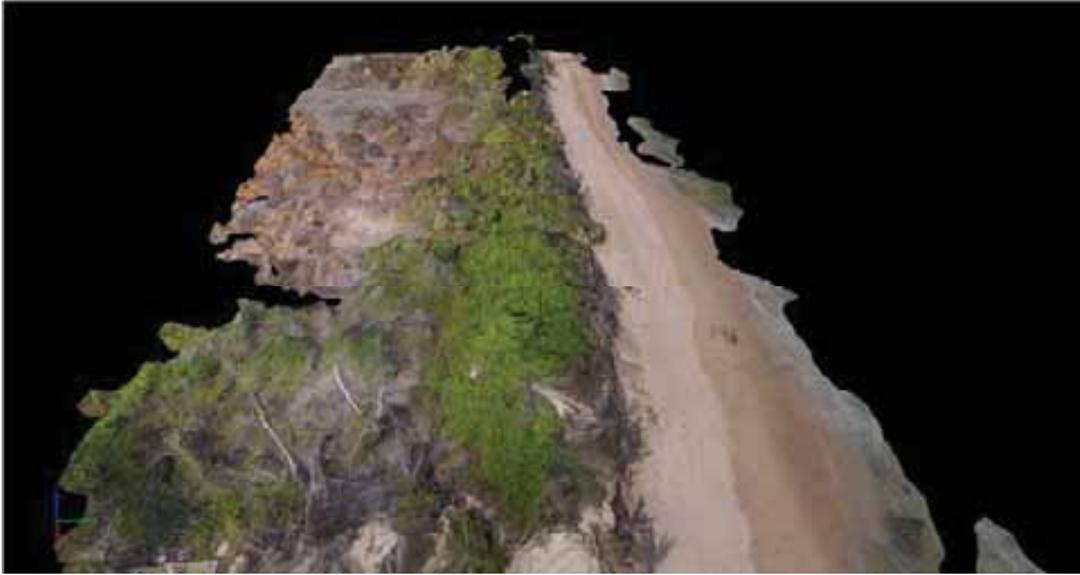


Figure 16. Three dimensional RGB image of the dune to the west of the end of Pedro Albizu Campos St. in Barrio Bajuras, Isabela.

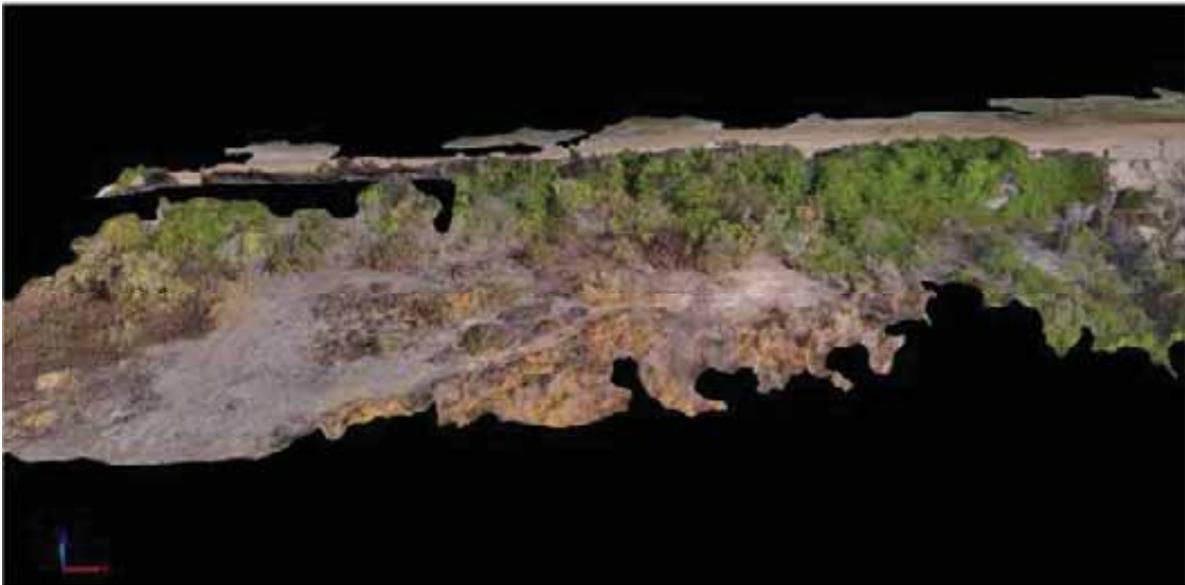
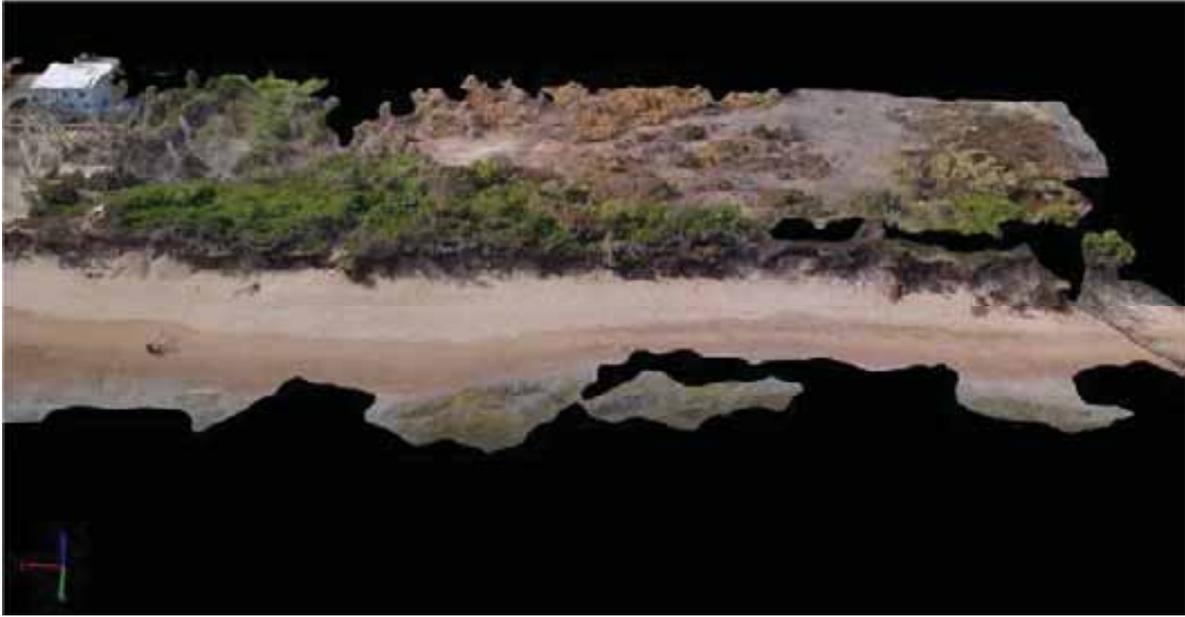


Figure 17. Three dimensional RGB image of the dune to the west of the end of Pedro Albizu Campos St. in Barrio Bajuras, Isabela. View from the north (top) and from the south.

vii. DSM grayscale

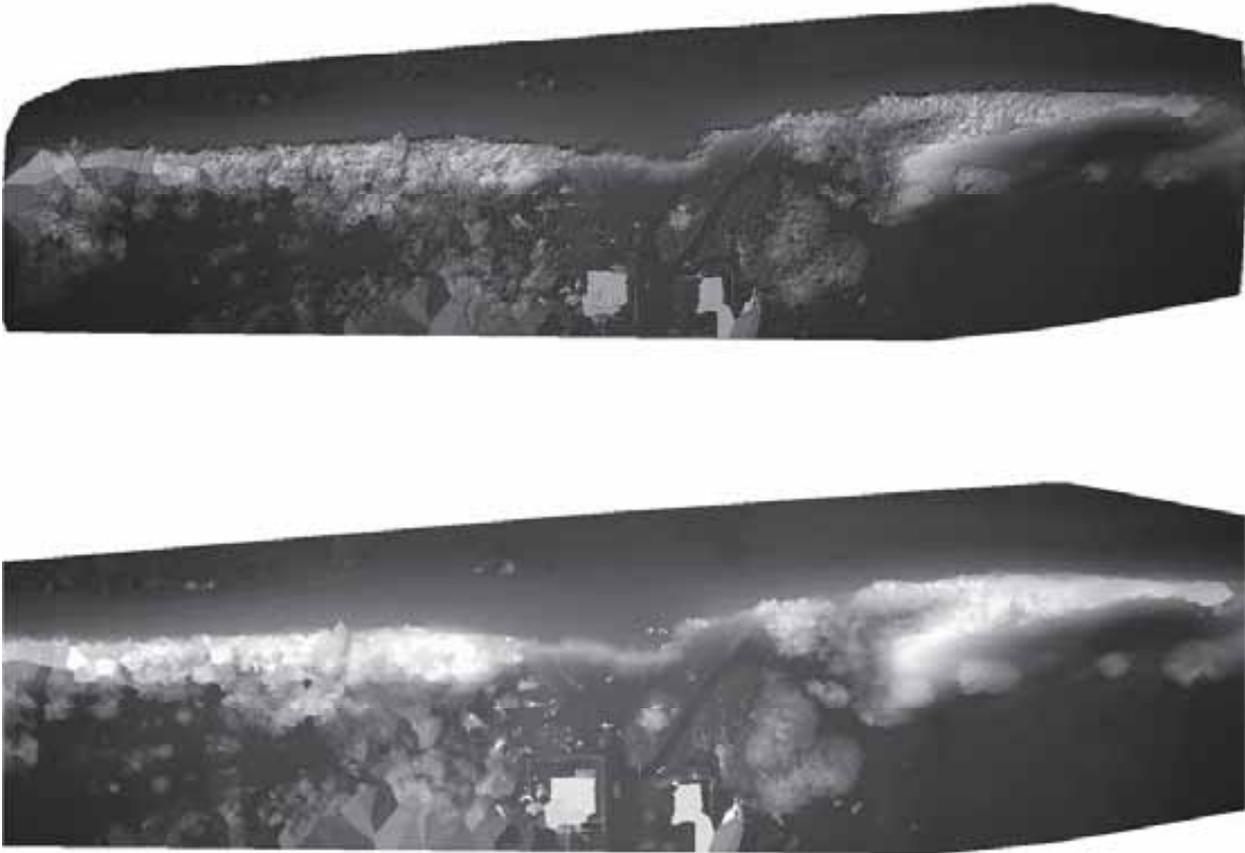


Figure 18. Grayscale DSM images of the dune to the west of the end of Pedro Albizu Campos St. in Barrio Bajuras, Isabela. The top image shows shades and the bottom is not shaded.

viii. On the ground pictures



Figure 19. Accumulation of sand and sea water displaced by hurricane María at the end of Pedro Albizu Campos Street. The picture was taken on September 21, 2018.



Figure 20. Accumulation of sand and sea water displaced by hurricane María at the end of Pedro Albizu Campos Street. The picture was taken on September 21, 2018.

Site report

H. Vegetation cover



Figure 21. Area of dunes at the end of Pedro Albizu Campos Street where the ecological restoration of this location will take place.

Vegetation covers 35.6% of the area at the end of Pedro Albizu Campos Street in Barrio Bajuras, Isabela on March 14, 2018. This area will be assessed every month after the ecological restoration activities have been started. This will allow us to monitor the progress of the re-vegetation efforts in this area.

I. Volume measurements of selected areas of the dunes

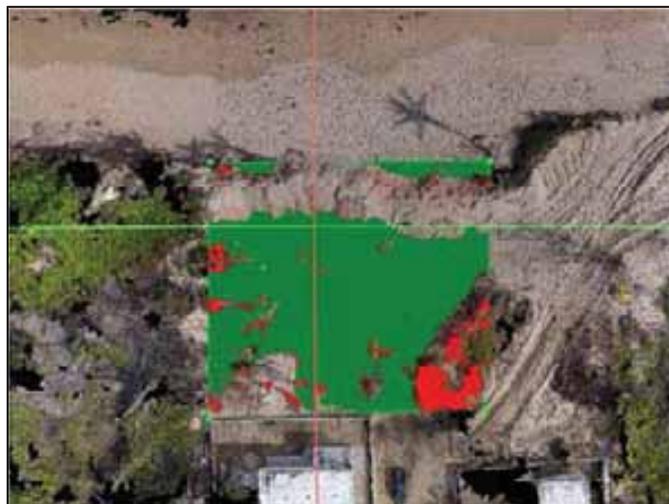


Figure 22. The polygon on the picture has a 3D area of $2,674.67 \text{ m}^2$ and a cut volume of $714.10 \pm 12.33 \text{ m}^3$, a fill volume of $-579.75 \pm 12.33 \text{ m}^3$ and a total volume of $116.35 \pm 31.09 \text{ m}^3$. This volume of this area will be monitored in subsequent months.

J. Conservation threats

The main conservation threats of this area are **foot and vehicular traffic**. The area of dunes at the end of the street did not resist the effects of the strong waves during the 2017 hurricane season and the northeasterly swell of March of 2018 while adjacent areas on the same dune did resist. This portion of the dune was breached and a wash-over fan was created probably because of the lack of vegetation caused by the heavy foot traffic of people walking from the end of the street to the road. There is not wooden boardwalk in this area and foot traffic is heavy especially during weekends and holidays.

There have been complaints made by local community members about **illegal sand extraction** in this area even though there have been no formal reports filed to the Department of Natural and Environmental Resources (DNER) law enforcement division.

There is no **relocation program** for displaced sand in this area. Sometimes sand is extracted from these areas by the municipal government to control voluntary motor oil spills on the roads especially during political rallies during election years.

K. Recommended ecological restoration courses of action (COA)

The installation of an “American Disability Act (ADA) compliant” **wooden boardwalk** of approximately 27 m in length and 1 m high (above the sand surface) will redirect foot traffic out of sensitive areas allowing plant growth and the accumulation of sand. The back and fore-dune area should be planted with **beach bean** (*Canavalia rosea*), **beach grape** (*Coccoloba uvifera*) and **beach morning glory** (*Ipomoea pes-caprae*).

Fencing in the form of bio-mimicry matrices made of segments of dismantled reclaimed shipping pallets should also be installed in the dune crest and fore-dune area in order to promote the accumulation of sand. An information sign on the importance of protecting sand dunes and laws regarding sand extraction should also be installed at the entrance of the site.

A program for the **relocation of displaced sand** needs to be created and put in effect as soon as possible in order to reduce the amount of sand lost from the beach during extreme weather events.

An effective **law enforcement plan** needs to be created in order to prevent the illegal extraction of sand from this area. It is very important to create a plan that is not predictable since most of the people that extract sand illegally do so during a time when no DNER law enforcement officers are patrolling the areas.



Figure 23. Area to be ecologically restored at the end of Pedro Albizu Campos St. in Barrio Bajuras, Isabela. Highlighted areas correspond to each technique that will be used in this area. Yellow represents the location of a wooden boardwalk, the red dot marks the location of an information sign, tan represents the area of the dune crest that where biomimicry matrices will be installed to promote the accumulation of sand. The areas shaded in light green represent locations for the planting of vegetation.

L. Pix4D quality report

Quality Report

Generated with Pix4Dmapper Pro version 4.2.25

Important: Click on the different icons for:

Help to analyze the results in the Quality Report

Additional information about the sections

Click [here](#) for additional tips to analyze the Quality Report

Summary

Project	New Entrada a la Inglesia Bajuras
Processed	2018-04-26 17:22:09
Camera Model Name(s)	FC330 3.6 4000x3000 (RGB)
Average Ground Sampling Distance (GSD)	1.29 cm / 0.51 in
Area Covered	0.047 km ² / 4.6625 ha / 0.02 sq. mi. / 11.5273 acres
Time for Initial Processing (without report)	03h:29m:23s

Quality Check

Images	median of 48810 keypoints per image	
Dataset	416 out of 427 images calibrated (97%), all images enabled	
Camera Optimization	4.93% relative difference between initial and optimized internal camera parameters	
Matching	median of 9078.5 matches per calibrated image	
Georeferencing	yes, no 3D GCP	

Preview

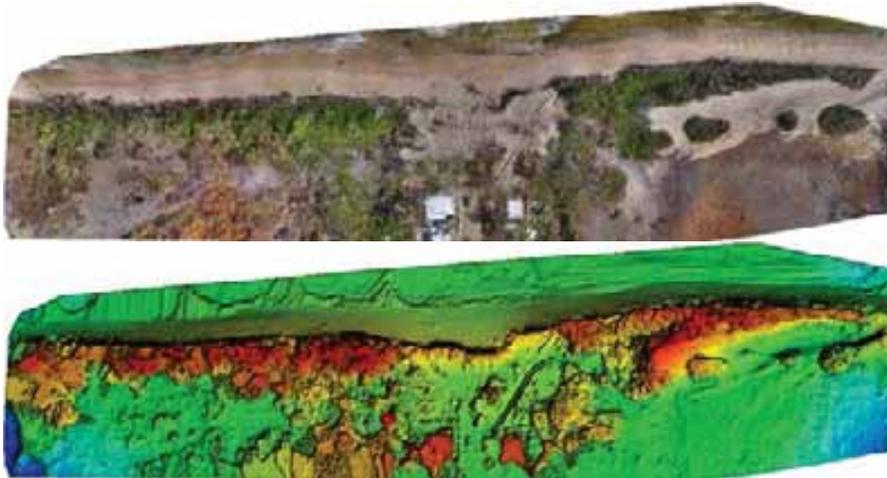


Figure 1: Orthomosaic and the corresponding sparse Digital Surface Model (DSM) before densification.

Calibration Details

Number of Calibrated Images	416 out of 427
Number of Geolocated Images	427 out of 427

Initial Image Positions

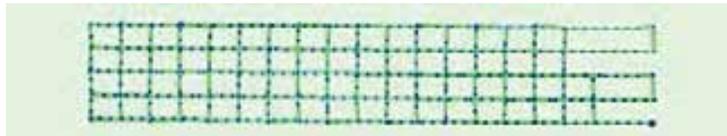
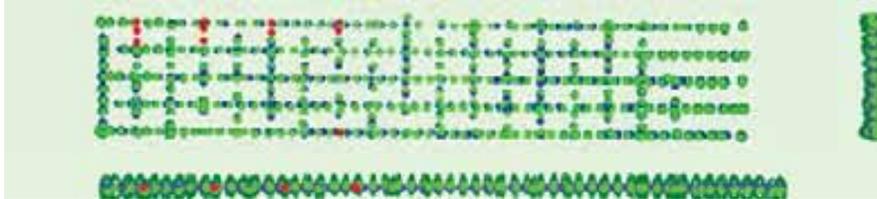


Figure 2: Top view of the initial image position. The green line follows the position of the images in time starting from the large blue dot.

Computed Image/GCPs/Manual Tie Points Positions



Uncertainty ellipses 10x magnified

Figure 3: Offset between initial (blue dots) and computed (green dots) image positions as well as the offset between the GCPs initial positions (blue crosses) and their computed positions (green crosses) in the top-view (XY plane), front-view (XZ plane), and side-view (YZ plane). Red dots indicate disabled or uncalibrated images. Dark green ellipses indicate the absolute position uncertainty of the bundle block adjustment result.

Absolute camera position and orientation uncertainties

	X [m]	Y [m]	Z [m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.195	0.195	0.477	0.721	0.149	0.097
Sigma	0.042	0.042	0.103	0.002	0.010	0.009

Overlap



Number of overlapping images: 1 2 3 4 5+

Figure 4: Number of overlapping images computed for each pixel of the orthomosaic. Red and yellow areas indicate low overlap for which poor results may be generated. Green areas indicate an overlap of over 5 images for every pixel. Good quality results will be generated as long as the number of keypoint matches is also sufficient for these areas (see Figure 5 for keypoint matches).

Bundle Block Adjustment Details

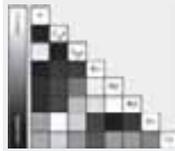
Number of 2D Keypoint Observations for Bundle Block Adjustment	4211004
Number of 3D Points for Bundle Block Adjustment	1561161
Mean Reprojection Error [pixels]	0.179

Internal Camera Parameters

FC330_3.6_4000x3000 (RGB). Sensor Dimensions: 6.317 [mm] x 4.738 [mm]

EXIF ID: FC330_3.6_4000x3000

	Focal Length	Principal Point x	Principal Point y	R1	R2	R3	T1	T2
Initial Values	2285.722 [pixel] 3.610 [mm]	2000.006 [pixel] 3.159 [mm]	1500.003 [pixel] 2.369 [mm]	-0.001	-0.002	0.000	-0.001	-0.001
Optimized Values	2398.556 [pixel] 3.788 [mm]	1963.350 [pixel] 3.101 [mm]	1460.197 [pixel] 2.306 [mm]	0.000	-0.005	0.003	0.000	-0.000
Uncertainties (Sigma)	0.261 [pixel] 0.000 [mm]	0.074 [pixel] 0.000 [mm]	0.190 [pixel] 0.000 [mm]	0.000	0.000	0.000	0.000	0.000



The correlation between camera internal parameters determined by the bundle adjustment. White indicates a full correlation between the parameters, ie. any change in one can be fully compensated by the other. Black indicates that the parameter is completely independent, and is not affected by other parameters.



The number of Automatic Tie Points (ATPs) per pixel, averaged over all images of the camera model, is color coded between black and white. White indicates that, on average, more than 16 ATPs have been extracted at the pixel location. Black indicates that, on average, 0 ATPs have been extracted at the pixel location. Click on the image to see the average direction and magnitude of the re-projection error for each pixel. Note that the vectors are scaled for better visualization. The scale bar indicates the magnitude of 1 pixel error.

2D Keypoints Table

	Number of 2D Keypoints per Image	Number of Matched 2D Keypoints per Image
Median	48810	9078
Min	28506	339
Max	68089	27090
Mean	48876	10123

3D Points from 2D Keypoint Matches

	Number of 3D Points Observed
In 2 Images	1044478
In 3 Images	271418
In 4 Images	112706
In 5 Images	56130
In 6 Images	30990
In 7 Images	17473
In 8 Images	10675
In 9 Images	6740
In 10 Images	4112
In 11 Images	2472
In 12 Images	1583
In 13 Images	946
In 14 Images	554
In 15 Images	356
In 16 Images	204
In 17 Images	120
In 18 Images	85
In 19 Images	40
In 20 Images	29
In 21 Images	21
In 22 Images	10
In 23 Images	6
In 24 Images	3
In 25 Images	6
In 27 Images	1
In 28 Images	2
In 29 Images	1

2D Keypoint Matches

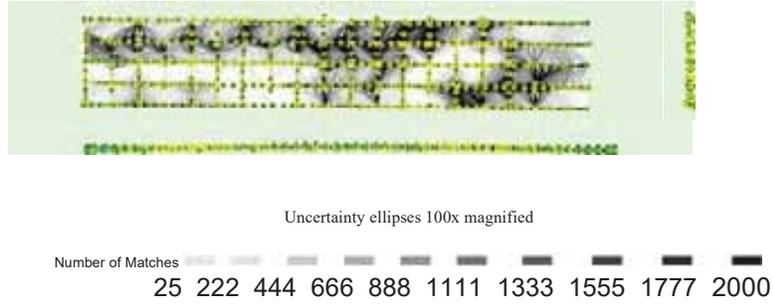


Figure 5: Computed image positions with links between matched images. The darkness of the links indicates the number of matched 2D keypoints between the images. Bright links indicate weak links and require manual tie points or more images. Dark green ellipses indicate the relative camera position uncertainty of the bundle block adjustment result.

Relative camera position and orientation uncertainties

	X [m]	Y [m]	Z [m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.007	0.006	0.013	0.010	0.017	0.009
Sigma	0.002	0.002	0.006	0.003	0.006	0.003

Geolocation Details

Absolute Geolocation Variance

Min Error [m]	Max Error [m]	Geolocation Error X [%]	Geolocation Error Y [%]	Geolocation Error Z [%]
-	-15.00	0.00	0.00	0.00
-15.00	-12.00	0.00	0.00	0.00
-12.00	-9.00	0.00	0.00	0.00
-9.00	-6.00	0.00	0.00	0.00
-6.00	-3.00	0.96	2.64	0.00
-3.00	0.00	64.18	31.73	51.20
0.00	3.00	33.17	65.62	48.80
3.00	6.00	1.68	0.00	0.00
6.00	9.00	0.00	0.00	0.00
9.00	12.00	0.00	0.00	0.00

12.00	15.00	0.00	0.00	0.00
15.00	-	0.00	0.00	0.00
Mean [m]		-0.091487	0.007206	-0.006555
Sigma [m]		1.315390	1.025356	0.813010
RMS Error [m]		1.318567	1.025381	0.813037

Min Error and Max Error represent geolocation error intervals between -1.5 and 1.5 times the maximum accuracy of all the images. Columns X, Y, Z show the percentage of images with geolocation errors within the predefined error intervals. The geolocation error is the difference between the initial and computed image positions. Note that the image geolocation errors do not correspond to the accuracy of the observed 3D points.

Relative Geolocation Variance

Relative Geolocation Error	Images X [%]	Images Y [%]	Images Z [%]
[-1.00, 1.00]	100.00	100.00	100.00
[-2.00, 2.00]	100.00	100.00	100.00
[-3.00, 3.00]	100.00	100.00	100.00
Mean of Geolocation Accuracy [m]	5.000000	5.000000	10.000000
Sigma of Geolocation Accuracy [m]	0.000000	0.000000	0.000000

Images X, Y, Z represent the percentage of images with a relative geolocation error in X, Y, Z.

Geolocation Orientational Variance	RMS [degree]
Omega	1.106
Phi	1.809
Kappa	2.394

Geolocation RMS error of the orientation angles given by the difference between the initial and computed image orientation angles.

Initial Processing Details

System Information

Hardware	CPU: Intel(R) Core(TM) i5-3330S CPU @ 2.70GHz RAM: 8GB GPU: Intel(R) HD Graphics (Driver: 10.18.10.4276), RDPDD Chained DD (Driver: unknown), RDP Encoder Mirror Driver (Driver: unknown), RDP Reflector Display Driver (Driver: unknown)
Operating System	Windows 7 Professional, 64-bit

Coordinate Systems

Image Coordinate System	WGS84 (egm96)
Output Coordinate System	WGS 84 / UTM zone 19N (egm96)

Processing Options

Detected Template	3D Maps
Keypoints Image Scale	Full, Image Scale: 1
Advanced: Matching Image Pairs	Aerial Grid or Corridor
Advanced: Matching Strategy	Use Geometrically Verified Matching: no
Advanced: Keypoint Extraction	Targeted Number of Keypoints: Automatic
Advanced: Calibration	Calibration Method: Standard Internal Parameters Optimization: All External Parameters Optimization: All Rematch: Auto, yes

Point Cloud Densification details

Processing Options

Image Scale	multiscale, 1/2 (Half image size, Default)
Point Density	Optimal
Minimum Number of Matches	3
3D Textured Mesh Generation	yes
3D Textured Mesh Settings:	Resolution: Medium Resolution (default) Color Balancing: no
LOD	Generated: no

Preview

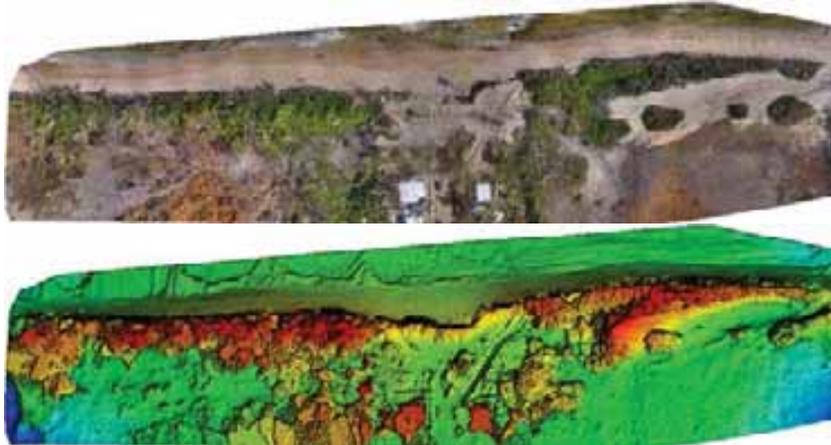


Figure 1: Orthomosaic and the corresponding sparse Digital Surface Model (DSM) before densification.

Calibration Details

Number of Calibrated Images	416 out of 427
Number of Geolocated Images	427 out of 427

Initial Image Positions

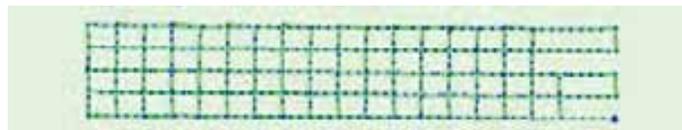
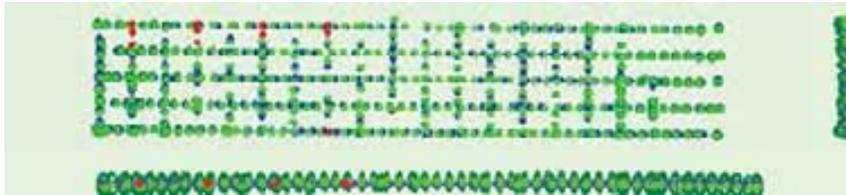


Figure 2: Top view of the initial image position. The green line follows the position of the images in time starting from the large blue dot.

Computed Image/GCPs/Manual Tie Points Positions



Uncertainty ellipses 10x magnified

Figure 3: Offset between initial (blue dots) and computed (green dots) image positions as well as the offset between the GCPs initial positions (blue crosses) and their computed positions (green crosses) in the top-view (XY plane), front-view (XZ plane), and side-view (YZ plane). Red dots indicate disabled or uncalibrated images. Dark green ellipses indicate the absolute position uncertainty of the bundle block adjustment result.

Absolute camera position and orientation uncertainties

	X [m]	Y [m]	Z [m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.195	0.195	0.477	0.721	0.149	0.097
Sigma	0.042	0.042	0.103	0.002	0.010	0.009

Overlap



Number of overlapping images: 1 2 3 4 5+

Figure 4: Number of overlapping images computed for each pixel of the orthomosaic.
 Red and yellow areas indicate low overlap for which poor results may be generated. Green areas indicate an overlap of over 5 images for every pixel. Good quality results will be generated as long as the number of keypoint matches is also sufficient for these areas (see Figure 5 for keypoint matches).

Bundle Block Adjustment Details

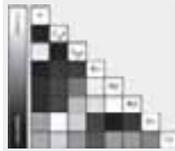
Number of 2D Keypoint Observations for Bundle Block Adjustment	4211004
Number of 3D Points for Bundle Block Adjustment	1561161
Mean Reprojection Error [pixels]	0.179

Internal Camera Parameters

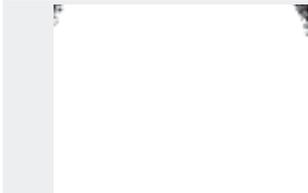
FC330_3.6_4000x3000 (RGB). Sensor Dimensions: 6.317 [mm] x 4.738 [mm]

EXIF ID: FC330_3.6_4000x3000

	Focal Length	Principal Point x	Principal Point y	R1	R2	R3	T1	T2
Initial Values	2285.722 [pixel] 3.610 [mm]	2000.006 [pixel] 3.159 [mm]	1500.003 [pixel] 2.369 [mm]	-0.001	-0.002	0.000	-0.001	-0.001
Optimized Values	2398.556 [pixel] 3.788 [mm]	1963.350 [pixel] 3.101 [mm]	1460.197 [pixel] 2.306 [mm]	0.000	-0.005	0.003	0.000	-0.000
Uncertainties (Sigma)	0.261 [pixel] 0.000 [mm]	0.074 [pixel] 0.000 [mm]	0.190 [pixel] 0.000 [mm]	0.000	0.000	0.000	0.000	0.000



The correlation between camera internal parameters determined by the bundle adjustment. White indicates a full correlation between the parameters, ie. any change in one can be fully compensated by the other. Black indicates that the parameter is completely independent, and is not affected by other parameters.



The number of Automatic Tie Points (ATPs) per pixel, averaged over all images of the camera model, is color coded between black and white. White indicates that, on average, more than 16 ATPs have been extracted at the pixel location. Black indicates that, on average, 0 ATPs have been extracted at the pixel location. Click on the image to see the average direction and magnitude of the re-projection error for each pixel. Note that the vectors are scaled for better visualization. The scale bar indicates the magnitude of 1 pixel error.

2D Keypoints Table

	Number of 2D Keypoints per Image	Number of Matched 2D Keypoints per Image
Median	48810	9078
Min	28506	339
Max	68089	27090
Mean	48876	10123

3D Points from 2D Keypoint Matches

	Number of 3D Points Observed
In 2 Images	1044478
In 3 Images	271418
In 4 Images	112706
In 5 Images	56130
In 6 Images	30990
In 7 Images	17473
In 8 Images	10675
In 9 Images	6740
In 10 Images	4112
In 11 Images	2472
In 12 Images	1583
In 13 Images	946
In 14 Images	554
In 15 Images	356
In 16 Images	204
In 17 Images	120
In 18 Images	85
In 19 Images	40
In 20 Images	29
In 21 Images	21
In 22 Images	10
In 23 Images	6
In 24 Images	3
In 25 Images	6
In 27 Images	1
In 28 Images	2
In 29 Images	1

Site name:

Barrio Bajuras (Monte de Oca St. 1), Isabela



A. Physical address:

Calle Monte de Oca, Barrio Bajuras, Isabela, Puerto Rico 00662

B. Date imagery was captured:

January 22, 2018

C. Description of site:

This is an area located at end of Monte de Oca street in Barrio Bajuras Isabela. It is a primary dune that has moderate levels of erosion and de-vegetation mainly due to anthropogenic activities. The area is adjacent to a guest house. This area is commonly know as “Sonia Rican” in this area. This site has 5 small patches of vegetation.

D. Distance from community:

66 m from the road and 65 m to houses

E. Coordinates:

18.5154660 N -67.08933729 W

F. Aerial imagery:

i. Contour map

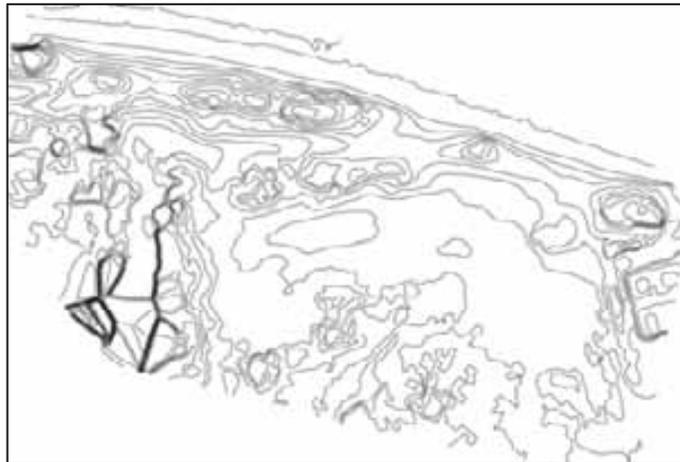


Figure 22. Contour map of Calle Monte de Oca, Barrio Bajuras, Isabela Puerto Rico with elevation intervals of 1 meter.

ii. 3D imagery



Figure 23. Aerial 3D image of the area at the end of Calle Monte de Oca, Barrio Bajuras, Isabela Puerto Rico

iv. Density Surface Models (DSM)

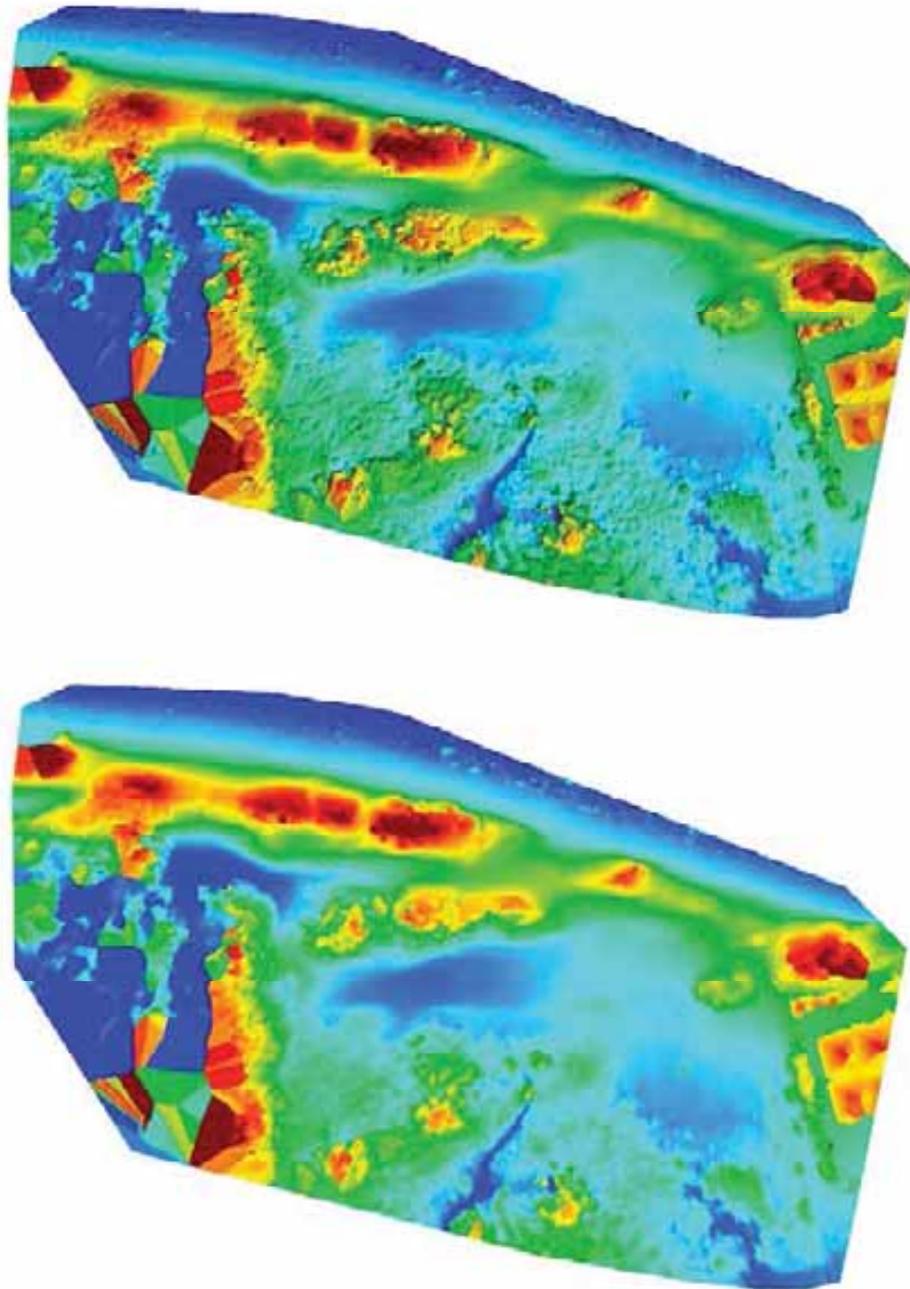


Figure 24. Density surface model spectral scale (with no-shading top and without shading bottom) images of the dune located at the end of Calle Monte de Oca, Barrio Bajuras, Isabela Puerto Rico

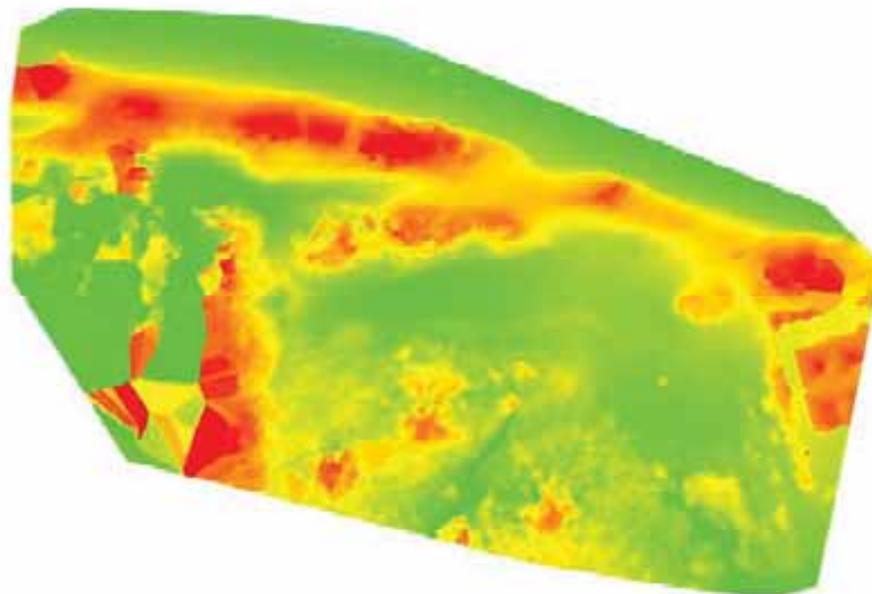
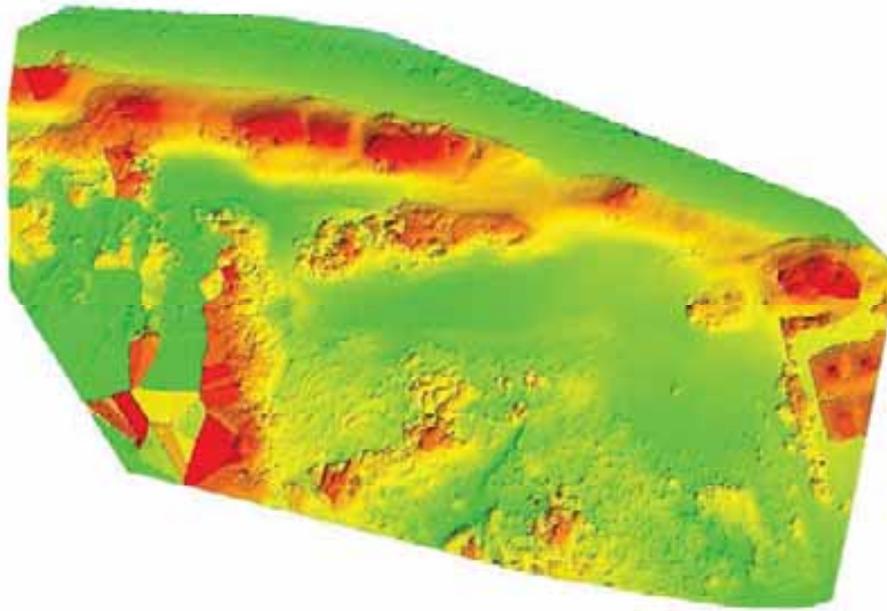


Figure 25. Density surface model (with no-shading top and without shading bottom) images of the dune located at the end of Calle Monte de Oca, Barrio Bajuras, Isabela.

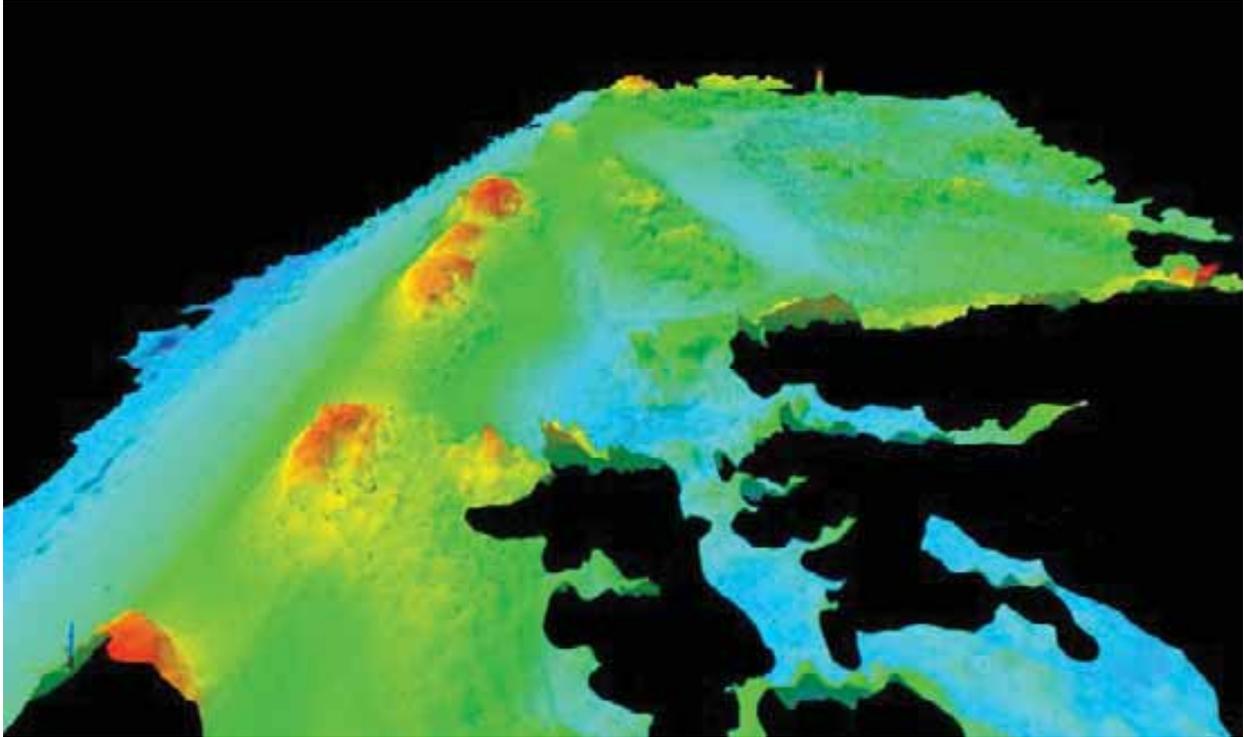


Figure 26. Three dimensional density surface model images of the dune located at the end of Calle Monte de Oca, Barrio Bajuras, Isabela.

v. Thermal images

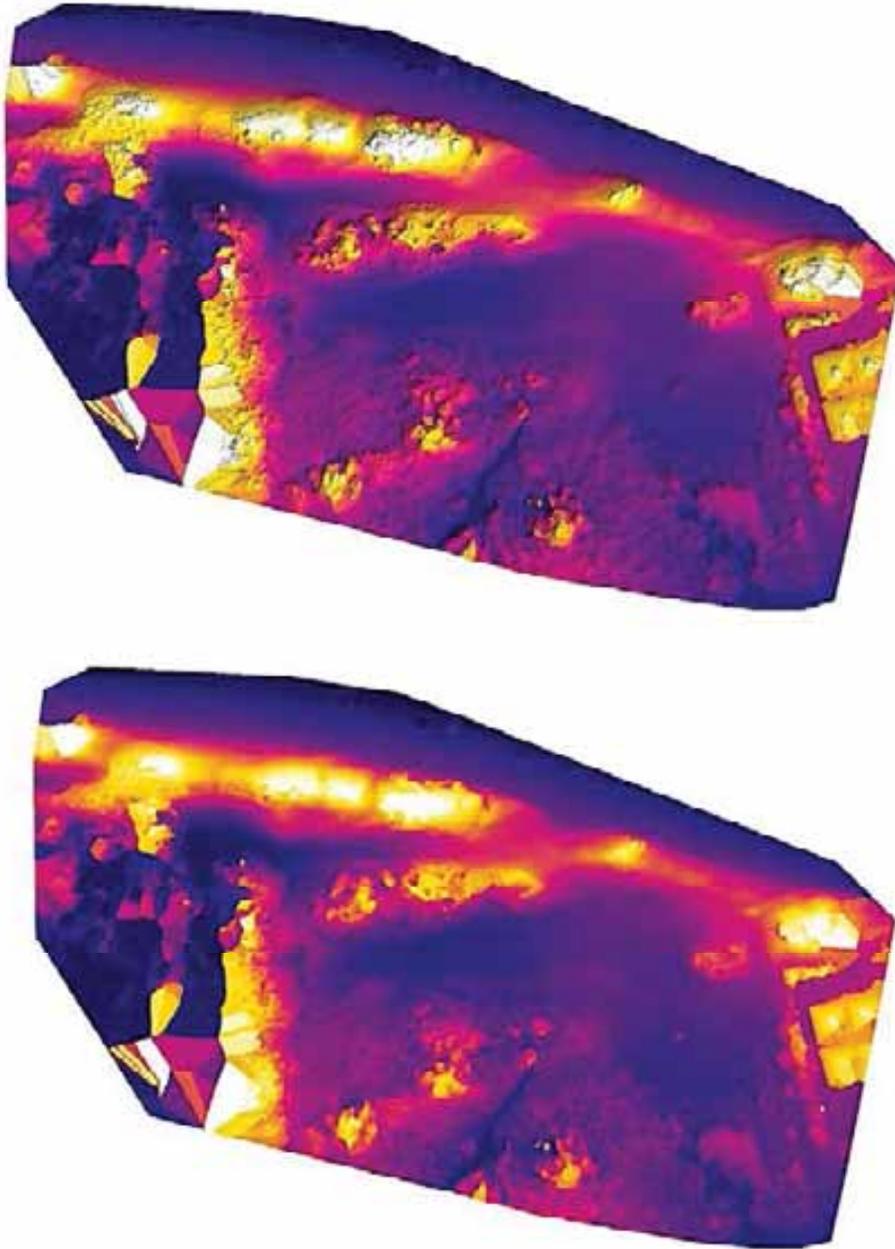


Figure 27. Thermal images (with no-shading top and without shading bottom) of the dune located at the end of Calle Monte de Oca, Barrio Bajuras, Isabela.

vi. 3D altitude RGB



Figure 28. Three dimensional RGB images of the dune located at the end of Calle Monte de Oca, Barrio Bajuras, Isabela. The top image is a view from the north and the bottom is a view from the east.



Figure 29. Three dimensional RGB image of a view from the west of the dune located at the end of Calle Monte de Oca, Barrio Bajuras, Isabela.

vii. DSM grayscale

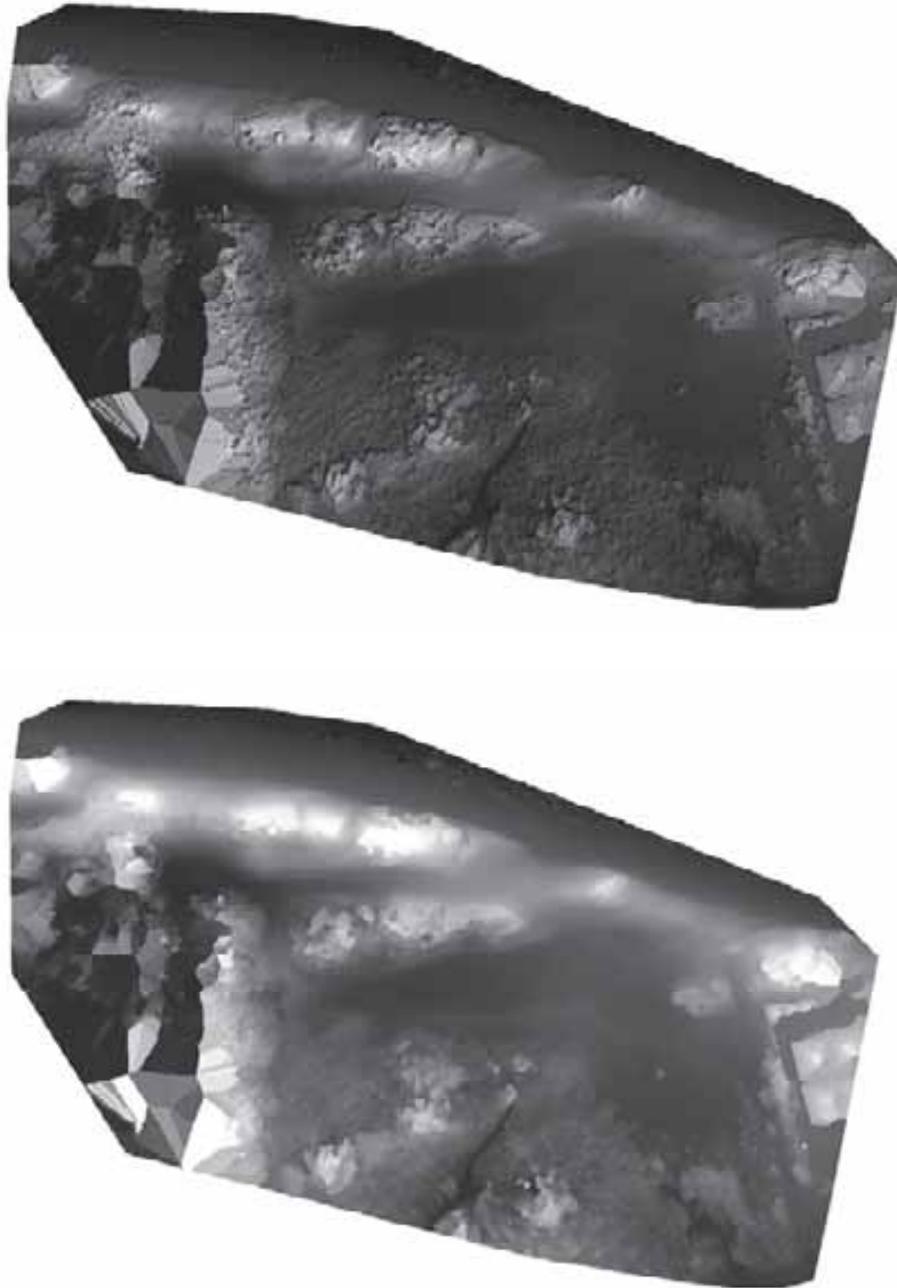


Figure 30. Grayscale DSM images of the dune at the end of Calle Monte de Oca, Barrio Bajuras, Isabela. The top image shows shades and the bottom is not shaded.

Site report

G. Vegetation cover



Figure 31. Area in which the percent vegetation cover is being calculated in Calle Monte de Oca, Barrio Bajuras, Isabela, Puerto Rico. The vegetation cover in this area was calculated to be 31.1% on January 22, 2018.

H x. Pix4D quality report

Quality Report

Generated with Pix4Dmapper Pro version 4.1.22

Important: Click on the different icons for:

- Help to analyze the results in the Quality Report
- Additional information about the sections

Click [here](#) for additional tips to analyze the Quality Report

Summary

Project	Mision Sonia Rican
Processed	2018-01-22 14:30:57
Camera Model Name(s)	FC330_3.6_4000x3000 (RGB)
Average Ground Sampling Distance (GSD)	2.82 cm / 1.11 in
Area Covered	0.033 km ² / 3.2663 ha / 0.01 sq. mi. / 8.0753 acres
Time for Initial Processing (without report)	10m:55s

Quality Check

Images	median of 37785 keypoints per image	✓
Dataset	49 out of 49 images calibrated (100%), all images enabled	✓
Camera Optimization	5.13% relative difference between initial and optimized internal camera parameters	⚠
Matching	median of 7911.92 matches per calibrated image	✓
Georeferencing	yes, no 3D GCP	⚠

Preview

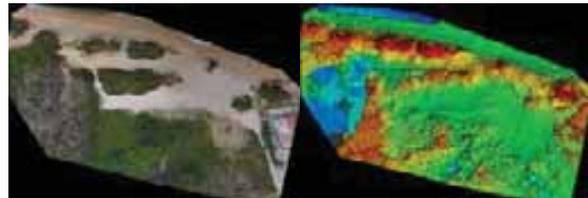


Figure 1: Orthomosaic and the corresponding sparse Digital Surface Model (DSM) before densification.

Calibration Details

Number of Calibrated Images	49 out of 49
Number of Geolocated Images	49 out of 49

Initial Image Positions

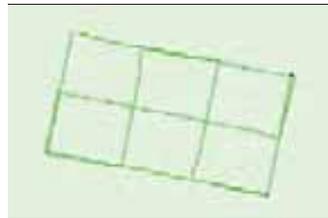


Figure 2: Top view of the initial image position. The green line follows the position of the images in time starting from the large blue dot.

Computed Image/GCPs/Manual Tie Points Positions

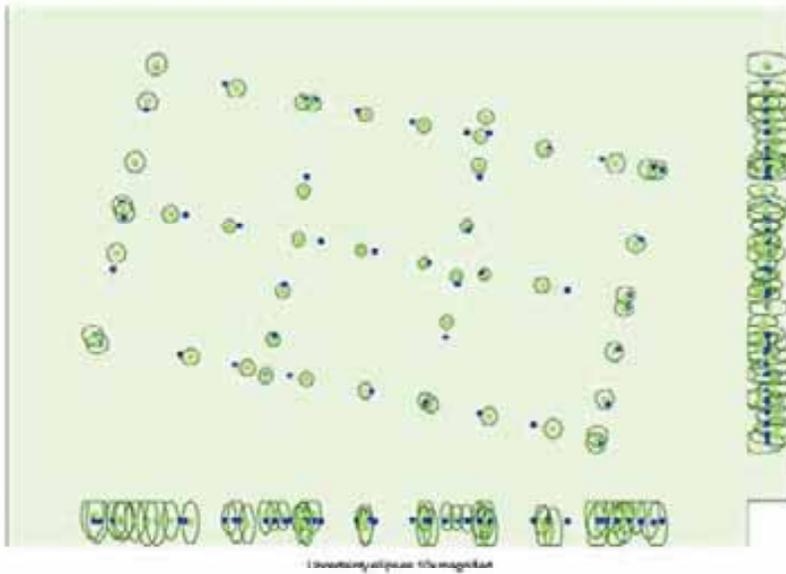


Figure 3. Offset between initial (blue dots) and computed (green dots) image positions as well as the offset between the GCPs initial positions (blue crosses) and their computed positions (green crosses) in the top-view (XY plane), front-view (XZ plane), and side-view (YZ plane). Dark green ellipses indicate the absolute position uncertainty of the bundle block adjustment result.

Absolute camera position and orientation uncertainties

	X[m]	Y[m]	Z[m]	Omega (degree)	Psi (degree)	Kappa (degree)
Mean	0.203	0.203	0.493	0.826	0.381	0.226
Stdev	0.004	0.004	0.000	0.007	0.014	0.010

Overlap

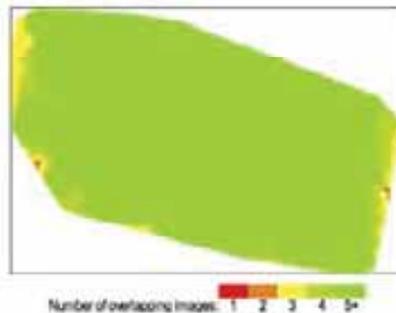


Figure 4. Number of overlapping images computed for each pixel of the orthomosaic. Red and yellow areas indicate low overlap for which poor results may be generated. Green areas indicate an overlap of over 3 images for every pixel. Good quality results will be generated as long as the number of overlap matches is also sufficient for these areas (see Figure 5 for subplot matrices).

Bundle Block Adjustment Details

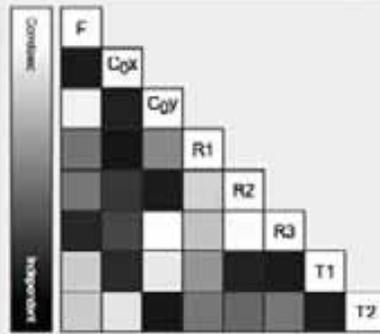
Number of 2D Keypoint Observations for Bundle Block Adjustment	436244
Number of 3D Points for Bundle Block Adjustment	132117
Mean Reprojection Error (pixels)	0.170

Internal Camera Parameters

PG330_3.6_4000x3000 (RGB), Sensor Dimensions: 6.317 [mm] x 4.736 [mm]

Exam 03 - 4/2012 - 3 - 4/2012-10/2012

	Final Length	Principal Point x	Principal Point y	R1	R2	R3	T1	T2
Initial Values	2075.722 [pixel] 3.810 [mm]	2833.030 [pixel] 3.199 [mm]	1533.033 [pixel] 2.269 [mm]	-0.001	-0.003	0.000	-0.001	-0.001
Optimized Values	2465.142 [pixel] 3.798 [mm]	1961.697 [pixel] 3.096 [mm]	1465.030 [pixel] 2.305 [mm]	0.002	-0.007	0.004	0.000	0.000
Uncertainty (Sigma)	0.028 [pixel] 0.001 [mm]	0.114 [pixel] 0.000 [mm]	0.300 [pixel] 0.001 [mm]	0.000	0.000	0.000	0.000	0.000



The correlation between camera internal parameters determined by the bundle adjustment. White indicates a full correlation between the parameters, so any change in one can be fully compensated by the other. Black indicates that the parameter is completely independent, and is not affected by other parameters.



The number of Automatic Tie Points (ATPs) per pixel, averaged over all images of the camera model, is color coded between black and white. White indicates that, on average, more than 16 ATPs have been extracted at the pixel location. Black indicates that, on average, 0 ATPs have been extracted at the pixel location. Click on the image to see the average direction and magnitude of the re-projection error for each pixel. Note that the vectors are scaled for better visualization. The scale bar indicates the magnitude of 1 pixel error.

2D Keypoints Table

	Number of 2D Keypoints per Image	Number of Matched 2D Keypoints per Image
Median	37780	7912
Min	26216	618
Max	64560	21052
Mean	37932	8993

3D Points from 2D Keypoint Matches

	Number of 3D Points Observed
In 2 Images	101012
In 3 Images	24017
In 4 Images	10200
In 5 Images	5005
In 6 Images	3488
In 7 Images	2344
In 8 Images	1091
In 9 Images	1145
In 10 Images	809
In 11 Images	629
In 12 Images	399
In 13 Images	306
In 14 Images	174
In 15 Images	109
In 16 Images	74
In 17 Images	40
In 18 Images	45
In 19 Images	32
In 20 Images	29
In 21 Images	4
In 23 Images	2

2D Keypoint Matches

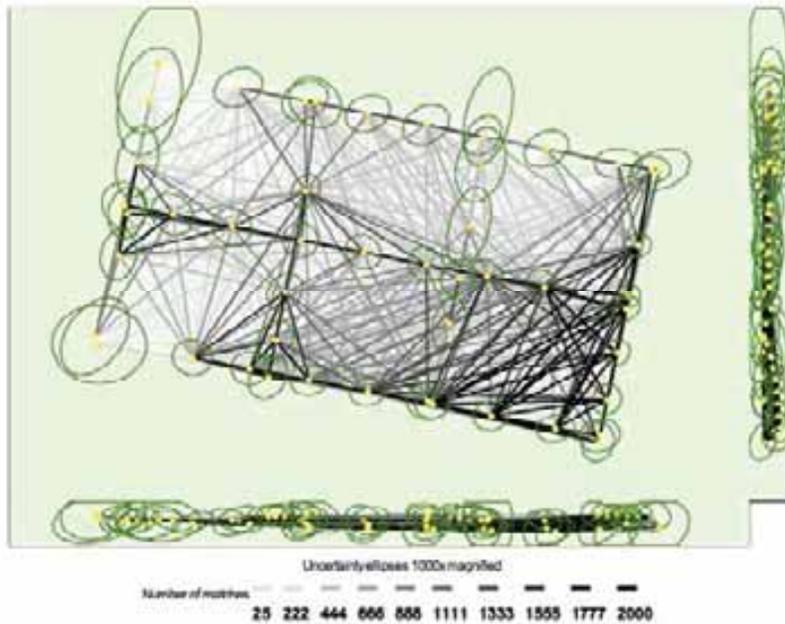


Figure 8: Computed image position with links between matched images. The thickness of the links indicates the number of matched 2D keypoints between the images. Bright links indicate weak links and require manual fix points or more images. Dark green ellipses indicate the relative camera position uncertainty of the bundle block adjustment result.

Relative camera position and orientation uncertainties

	X [m]	Y [m]	Z [m]	Omega (degree)	Phi (degree)	Theta (degree)
Mean	0.006	0.006	0.004	0.007	0.007	0.004
Sigma	0.002	0.003	0.001	0.003	0.002	0.001

Geolocation Details

Absolute Geolocation Variance

Min Error [m]	Max Error [m]	Geolocation Error X [%]	Geolocation Error Y [%]	Geolocation Error Z [%]
16.00	-15.00	0.00	0.00	0.00
-15.00	-12.00	0.00	0.00	0.00
-12.00	-9.00	0.00	0.00	0.00
0.00	-6.00	0.00	0.00	0.00
-6.00	-3.00	12.24	6.12	0.00
-3.00	0.00	24.49	30.61	61.22
0.00	3.00	66.10	61.22	36.78
3.00	6.00	6.12	2.04	0.00
6.00	9.00	2.04	0.00	0.00
9.00	12.00	0.00	0.00	0.00
12.00	15.00	0.00	0.00	0.00
15.00	-	0.00	0.00	0.00
Mean [m]		0.000010	0.002802	-0.000110
Sigma [m]		2.145754	1.373357	1.318024
RMS Error [m]		2.145754	1.373357	1.318024

Min Error and Max Error represent geolocation error intervals between -1.5 and 1.5 times the maximum accuracy of all the images. Columns X, Y, Z show the percentage of images with geolocation errors within the production error intervals. The geolocation error is the difference between the error and computed image positions. Note that the image geolocation errors do not correspond to the accuracy of the observed 3D points.

Relative Geolocation Variance

Relative Geolocation Error	Images X [%]	Images Y [%]	Images Z [%]
>1.00, 1.00]	90.92	100.00	100.00
>2.00, 2.00]	100.00	100.00	100.00

[3.00, 3.00]	100.00	100.00	100.00
Mean of Geolocation Accuracy [%]	0.000000	0.000000	10.000000
Signs of Geolocation Accuracy [%]	0.000000	0.000000	0.000000

Images X, Y, Z represent the percentage of images with a relative geolocation error in X, Y, Z.

Geolocation Orientation Variance	RMS (degree)
Omega	2.040
Psi	1.638
Kappa	2.700

Geolocation RMS error of the orientation angles given by the difference between the initial and computed image orientation angles.

Initial Processing Details

System Information

Hardware	CPU: Intel(R) Core(TM) i5-3330S CPU @ 3.70GHz RAM: 8GB GPU: Intel(R) HD Graphics (Driver: 10.18.10.3412), PDPD00 Chained DD (Driver: unknown), PDP Encoder Minor Driver (Driver: unknown), PDP Reflector Overlay User (Driver: unknown)
Operating System	Windows 7 Professional, 64-bit

Coordinate Systems

Image Coordinate System	WGS84 (epsg:31466)
Output Coordinate System	WGS 84 / UTM Zone 18N (epsg:31466)

Processing Options

Default Template	3D Mesh
Keypoints Image Scale	Full Image Scale: 1
Advanced: Matching Image Pairs	Aerial Grid or Contour
Advanced: Matching Strategy	Use Geometrically Verified Matching: no
Advanced: Keypoint Extraction	Targeted Number of Keypoints: Automatic
Advanced: Calibration	Calibration Method: Standard Internal Parameters Optimization: All External Parameters Optimization: All Rematch: Auto: yes

Point Cloud Densification details

Processing Options

Image Scale	multiscale, 1/2 (Half Image size Default)
Point Density	Optimal
Minimum Number of Matches	3
3D Textured Mesh Generation	yes
3D Textured Mesh Settings:	Resolution: Medium Resolution (default) Color Balancing: no
LCD	Generated: no
Advanced: 3D Textured Mesh Settings:	Sample Density: Chained: 1
Advanced: Image Groups	group1
Advanced: Use Processing Area	yes
Advanced: Use Annotations	yes
Time for Point Cloud Densification	05m:19s
Time for Point Cloud Classification	NA
Time for 3D Textured Mesh Generation	02m:44s

Results

Number of Generated Tiles	1
Number of 3D Densified Points	2792900
Average Density (per m ²)	115.44

DSM, Orthomosaic and Index Details

Processing Options



Output Orthorectified Resolution	1 x1000 (2.00 m/pixel)
LDM/Flats	Noise Filtering <input checked="" type="checkbox"/> Surface Smoothing <input checked="" type="checkbox"/> Yes/None
Raster DSM	Generated <input checked="" type="checkbox"/> Method: Intersect Diagonal Weighting Merge Tiles <input checked="" type="checkbox"/>
Orthomosaic	Generated <input checked="" type="checkbox"/> Merge Tiles <input checked="" type="checkbox"/> Geo-TIFF without transparency <input checked="" type="checkbox"/> Strip Size: Tiles and RGB: No
Time for DSM Generation	07m:04s
Time for Orthomosaic Generation	08m:20s
Time for DSM Generation	50s
Time for Contour Lines Generation	50s
Time for Bathymetry Map Generation	01s
Time for Index Map Generation	01s

Barrio Bajuras (Monte de Oca St. 2)

A. Physical address –

Calle Monte de Oca, Barrio Bajuras, Isabela, Puerto Rico 00662

B. Date imagery was captured:

March 14, 2018

C. Aerial imagery:

Contour



Figure 32. Contour map of Pedro Albizu street in Barrio Bajuras, Isabela Puerto Rico with elevation intervals of 1 meter.

Aerial 3D

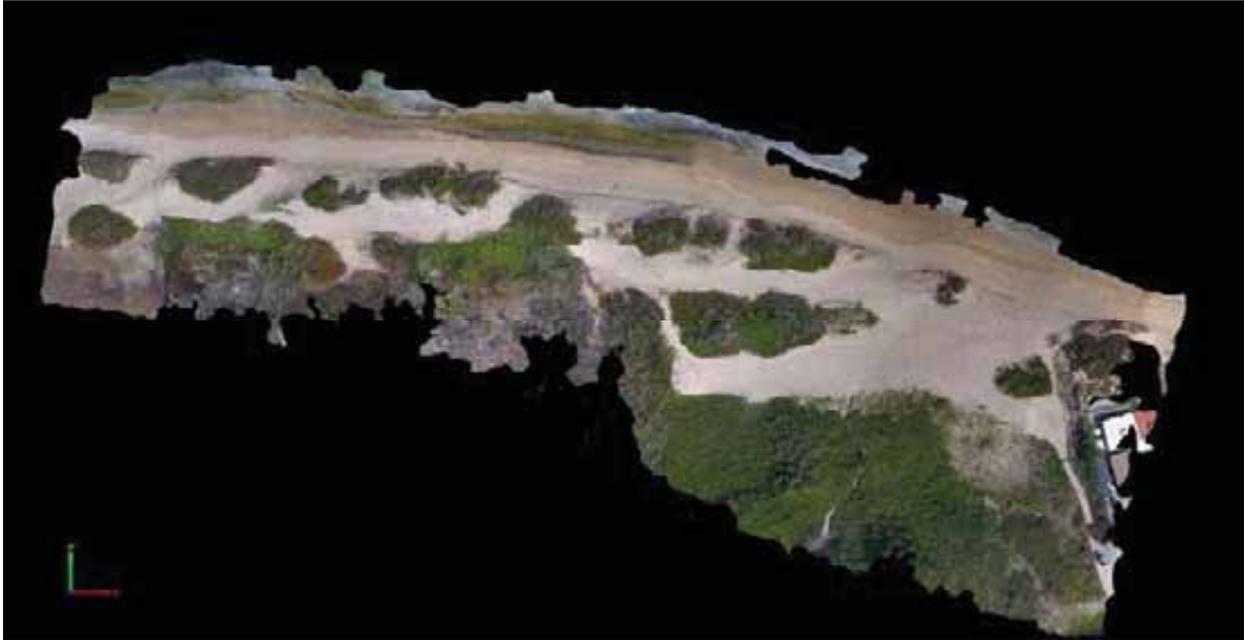


Figure 33. Aerial 3D image of the area at the end of Calle Monte de Oca, Barrio Bajuras, Isabela Puerto Rico

Orthomosaic



Figure 34. Orthomosaic image of the end of Calle Monte de Oca, Barrio Bajuras, Isabela Puerto Rico

Density Surface Models (DSM)

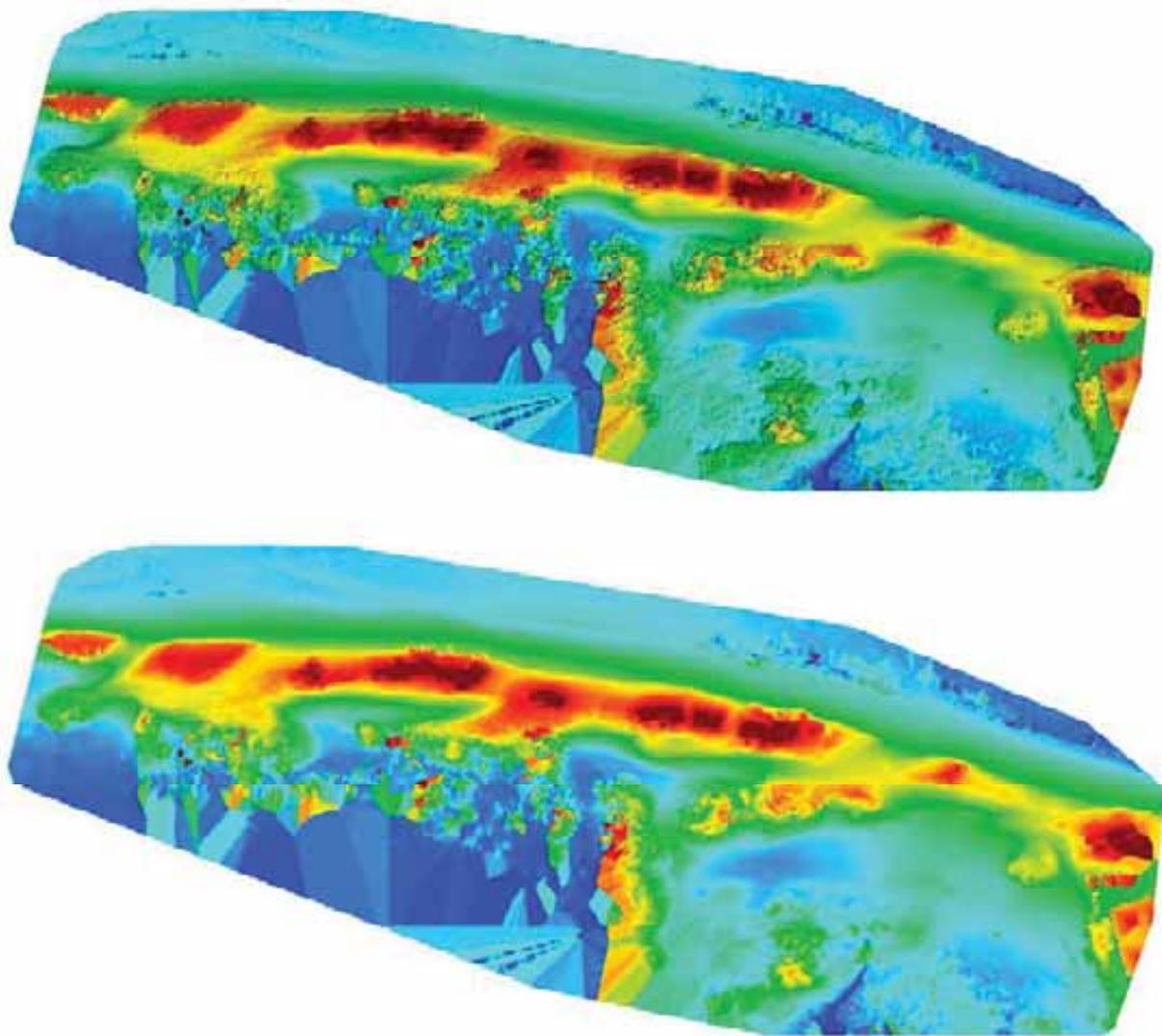


Figure 35. Density surface model spectral scale (with no-shading top and without shading bottom) images of the dune located at the end of Calle Monte de Oca, Barrio Bajuras, Isabela Puerto Rico

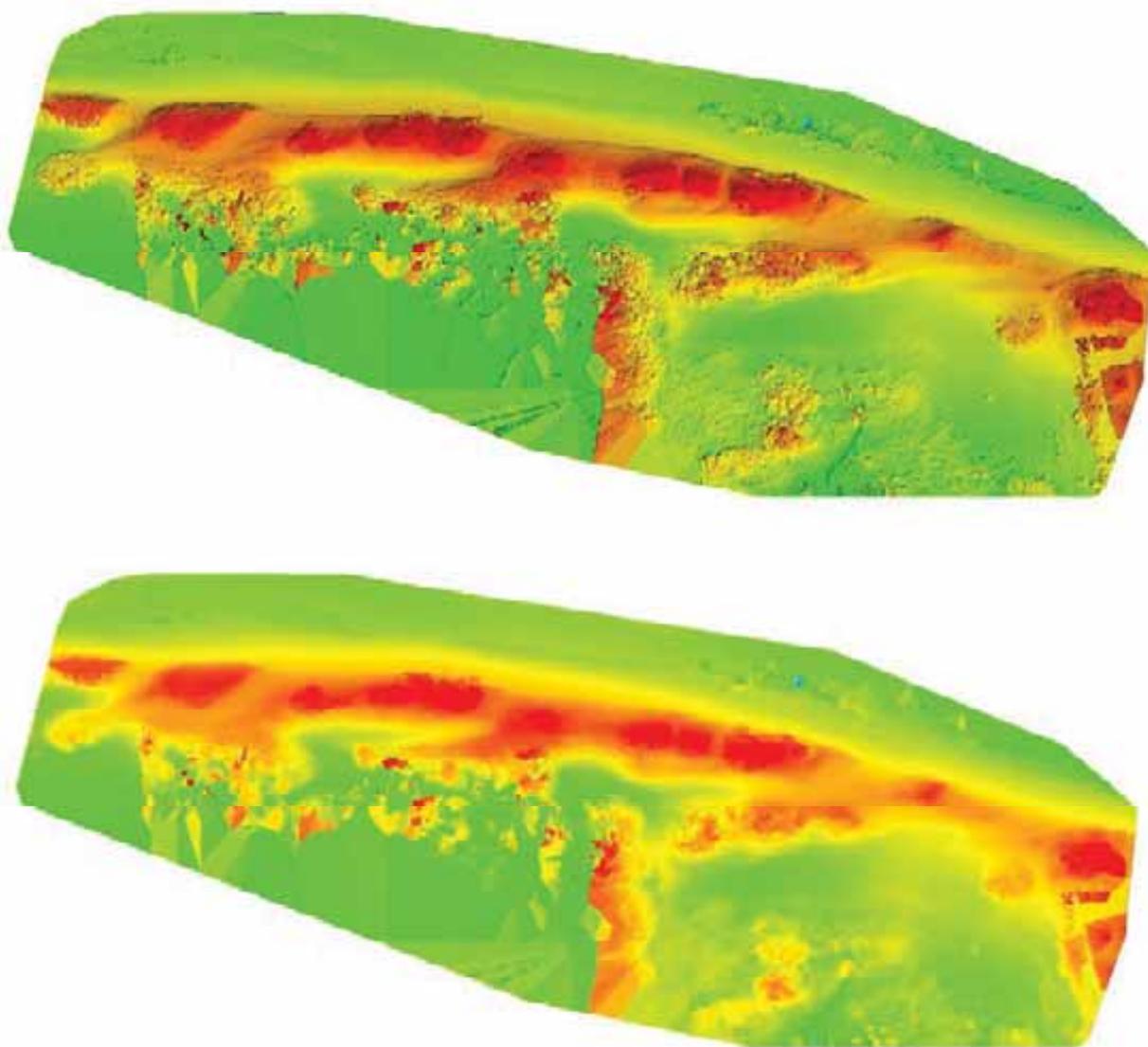


Figure 36. Density surface model (with no-shading top and without shading bottom) images of the dune located at the end of Calle Monte de Oca, Barrio Bajuras, Isabela.

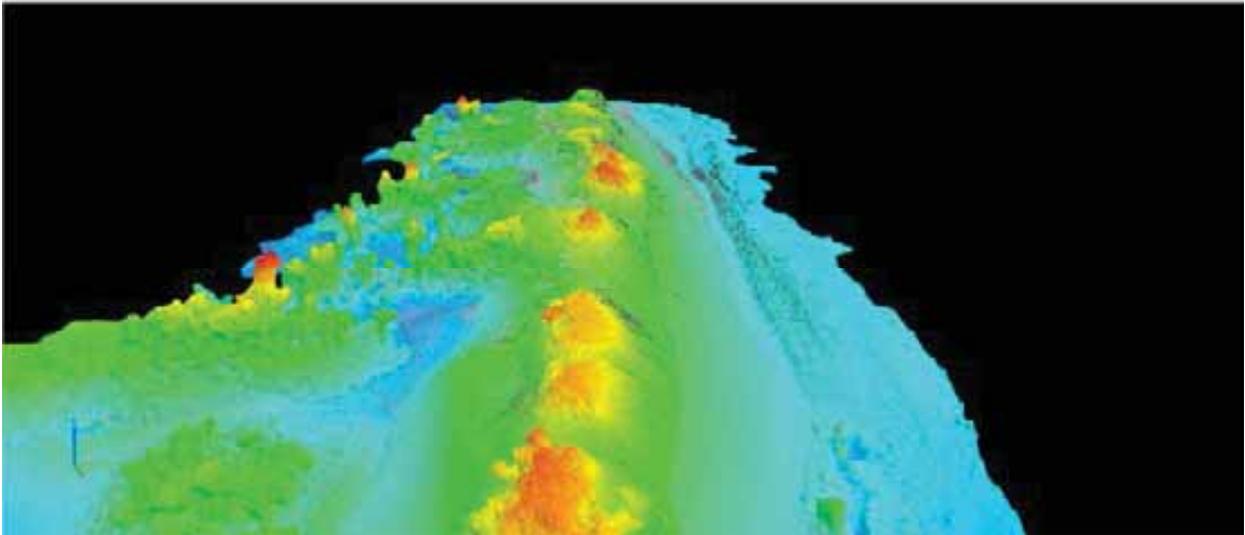
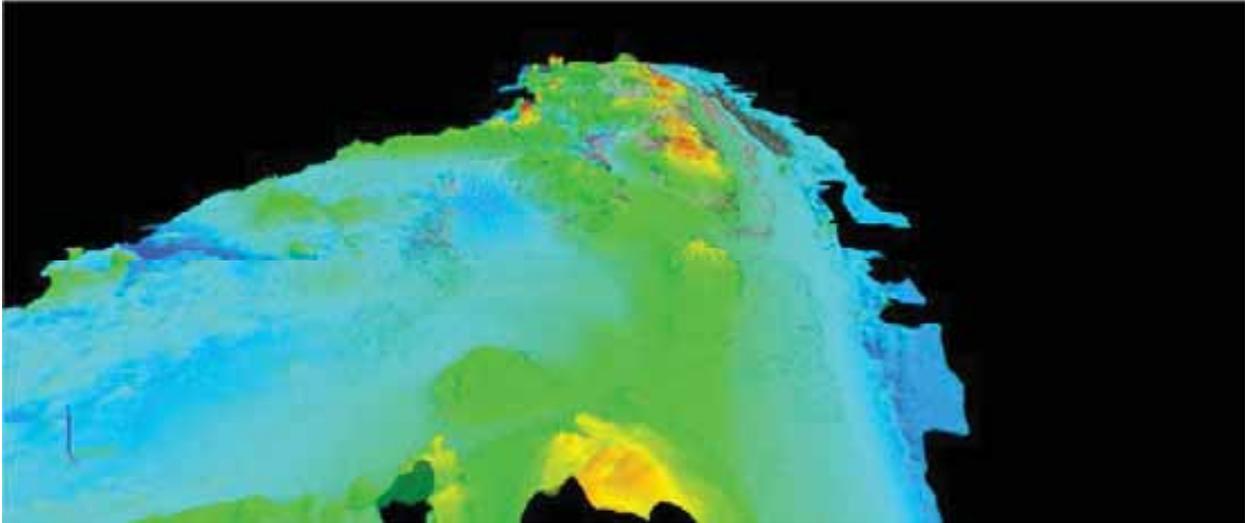


Figure 37. Three dimensional density surface model images of the dune located at the end of Calle Monte de Oca, Barrio Bajuras, Isabela. View from the east.

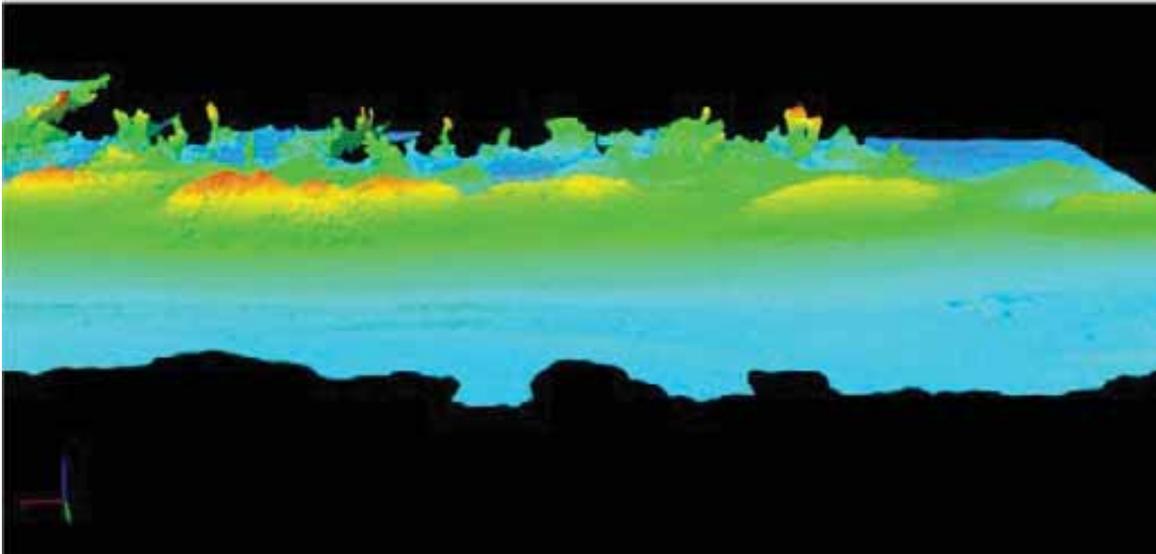
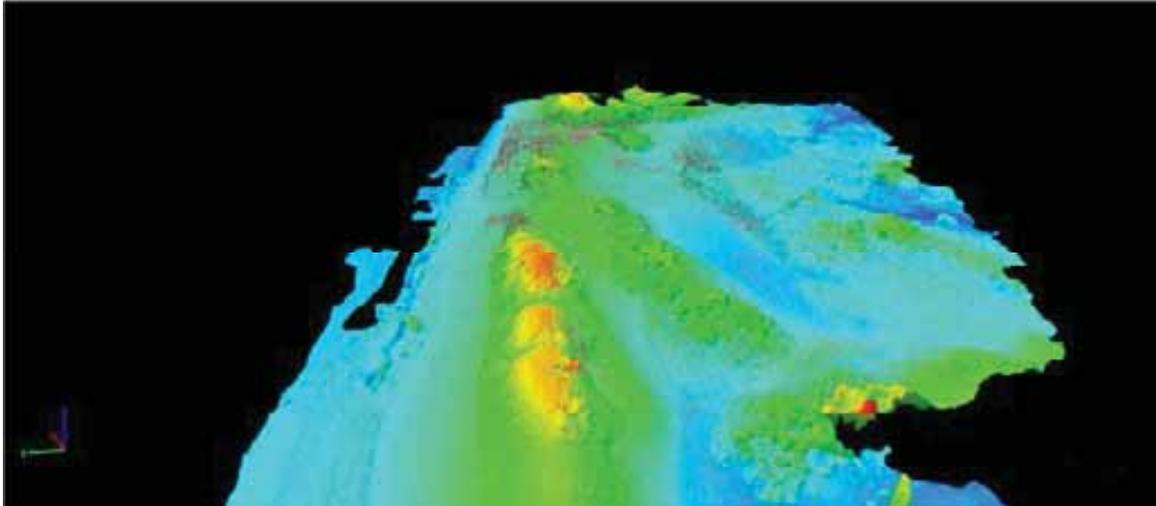


Figure 37. Three dimensional density surface model images of the dune located at the end of Calle Monte de Oca, Barrio Bajuras, Isabela. View from the west (top) and from the north (bottom).

Thermal images

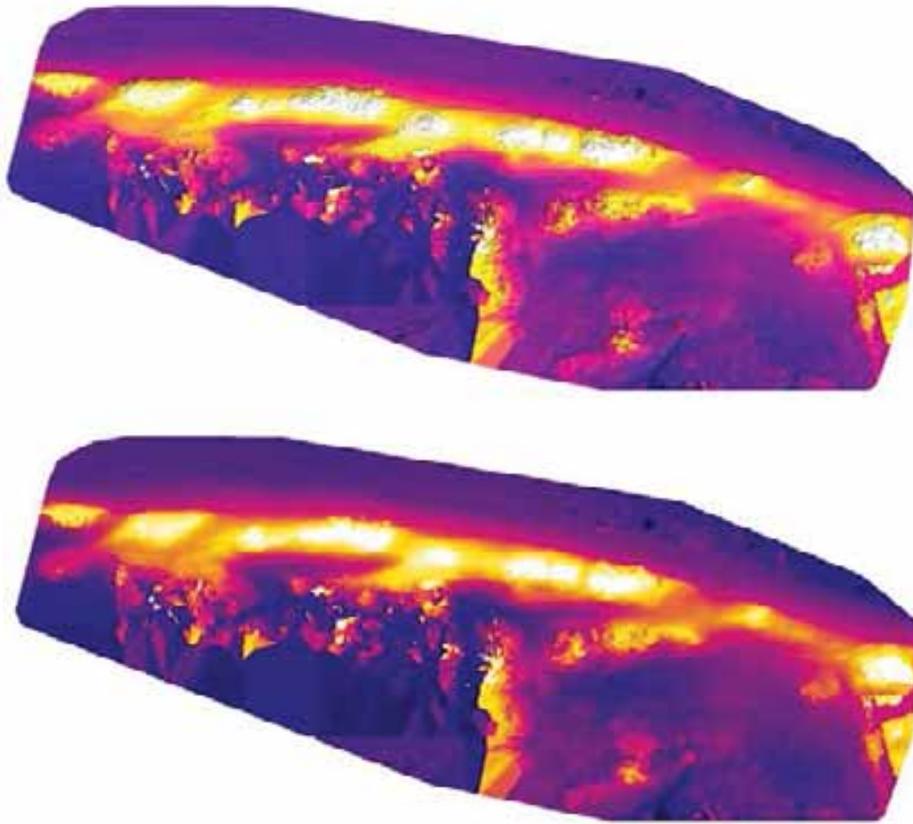


Figure 38. Thermal images (with no-shading top and without shading bottom) of the dune located at the end of Calle Monte de Oca, Barrio Bajuras, Isabela.

3D altitude RGB North

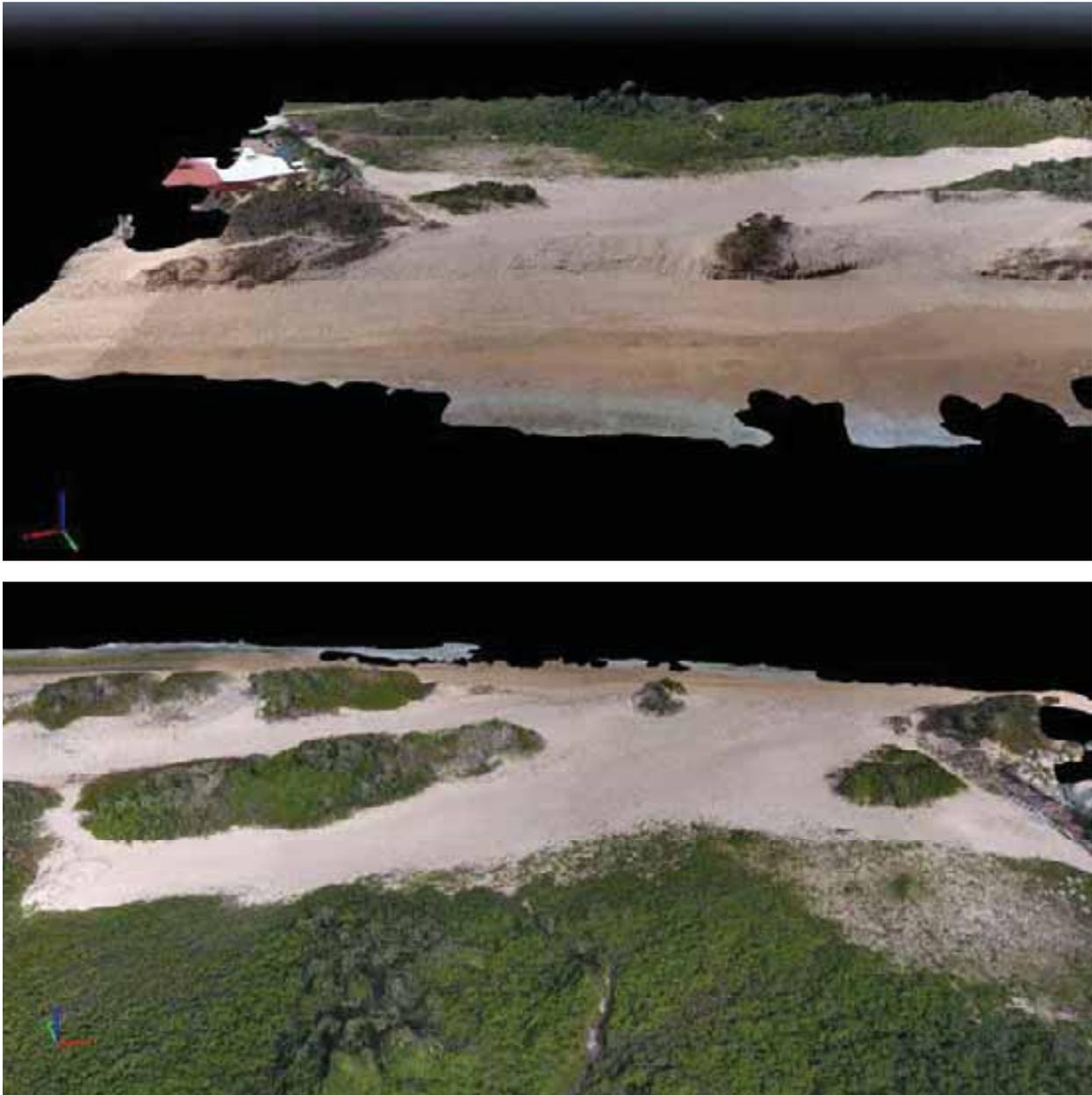


Figure 39. Three dimensional RGB images of the dune located at the end of Calle Monte de Oca, Barrio Bajuras, Isabela. The top image is a view from the north and the bottom is a view from the south.

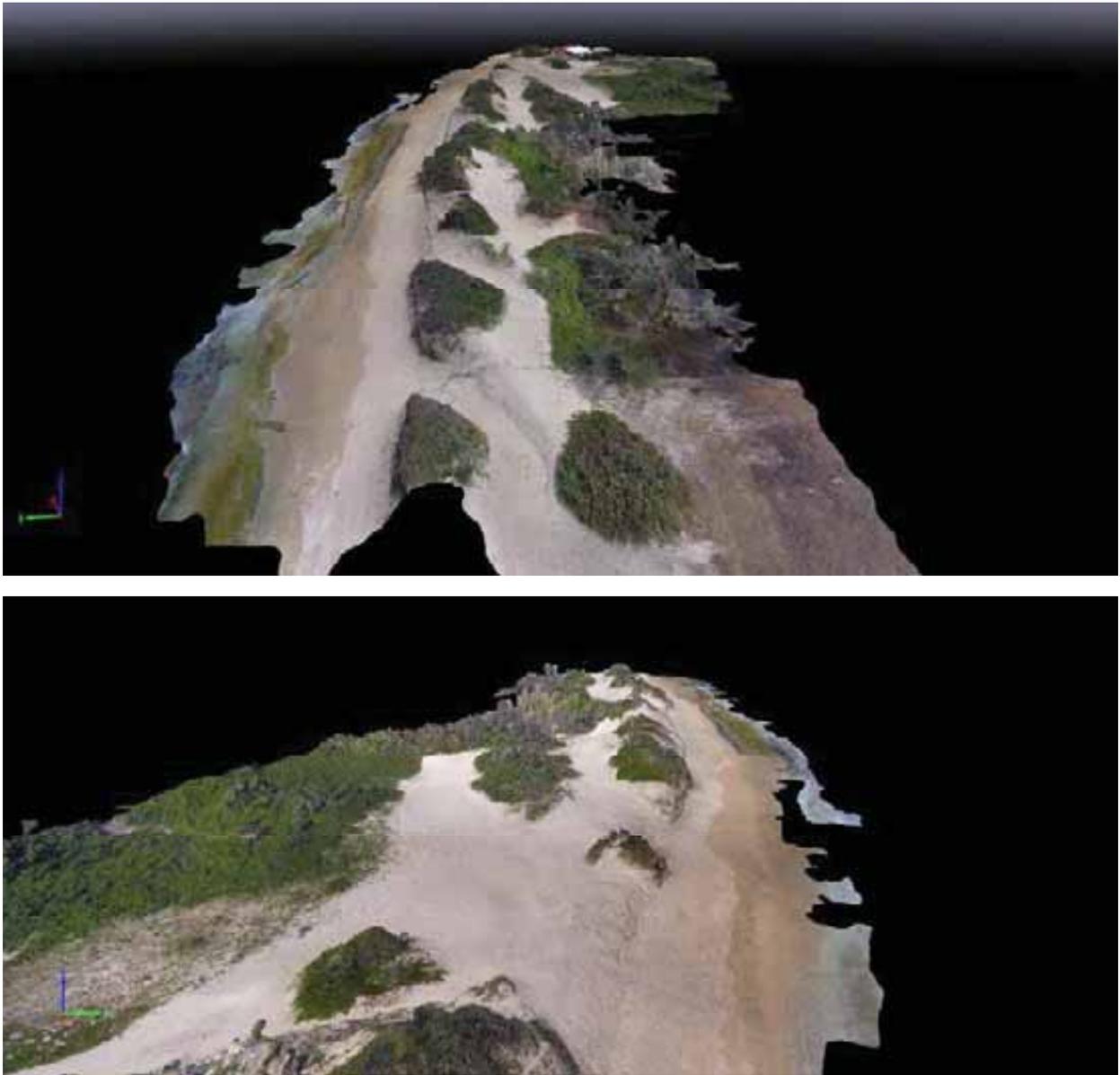


Figure 40. Three dimensional RGB images of the dune located at the end of Calle Monte de Oca, Barrio Bajuras, Isabela. The top image is a view from the west and the bottom is a view from the east.

DSM grayscale

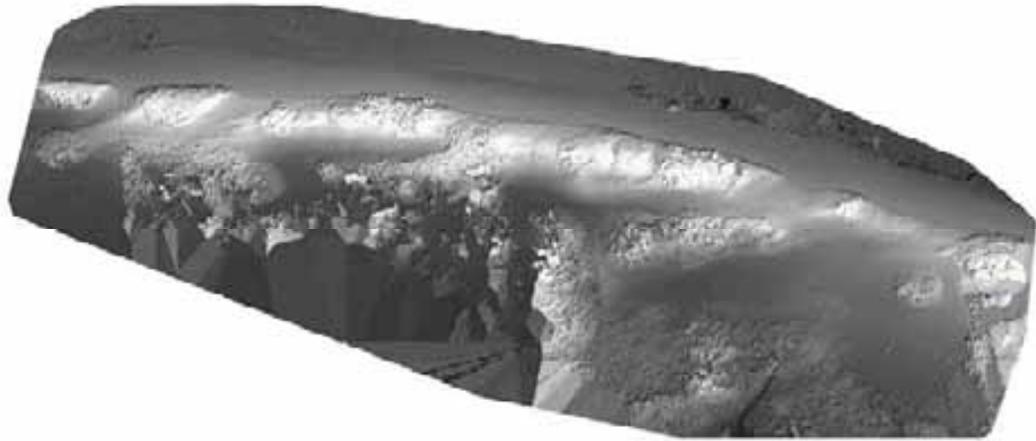


Figure 41. Grayscale DSM images of the dune at the end of Calle Monte de Oca, Barrio Bajuras, Isabela. The top image shows shades and the bottom is not shaded.

H. Site repor

I. Vegetation cover



Figure 42. Area for which percent vegetation cover is being monitored in Calle Monte de Oca, Barrio Bajuras, Isabela, Puerto Rico after northeasterly event in March 14, 2018. The vegetation cover in this area was calculated to be 29.3%.

J. Volume measurements of selected areas of the dunes

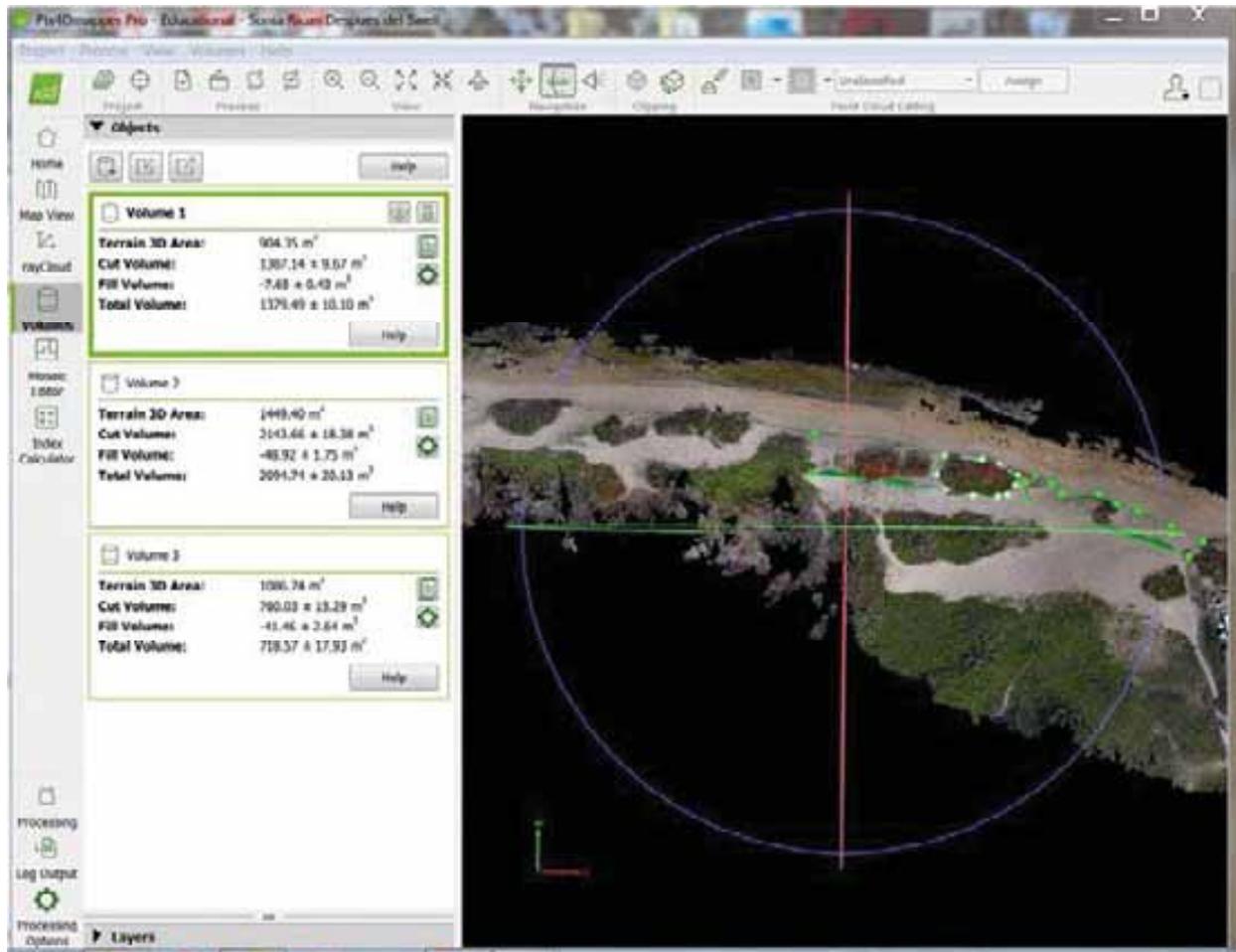


Figure 43. The polygons marked within green points are three areas of sand volume monitoring. The sand volume will be calculated repetitively every two months, on the same areas, as part of the implementation phase of this project. The initial cut volume of the first polygon on the left is $1,387.14 \pm 9.67 \text{ m}^3$, that of the polygon in the middle is $2,143.66 \pm 18.38 \text{ m}^3$ and $760.03 \pm 15.29 \text{ m}^3$. This data will be used in spatio-temporal modeling and monitoring the progress of restoration practices implemented in this area..

K. Conservation threats

The main threats in this area are: illegal traffic of all terrain-vehicles and foot traffic and significant sand extraction. We have evidence from hidden wild-life cameras of the high incidence of this activity. There are formal reports of this activity during 2015-2016 in the Puerto Rico Department of Natural and Environmental Resources.

L. Recommended ecological restoration courses of action (COAs)

The restoration techniques we recommend for this area consist of the installation of a boardwalk adjacent to the guest house on the eastern part of the site. We also recommend the installation of wooden exclusion fencing and biomimicry matrices to promote the accumulation of sand and areas of planting dune vegetation (see figure below).



Figure 44. Area to be ecologically restored at the end of Calle Monte de Oca, Barrio Bajuras, Isabela. Highlighted areas correspond to each technique that will be used in this area. Yellow represents the location of a wooden boardwalk, the red dot marks the location of a information sign, tan represents the area of the dune crest that where biomimicry matrices will be installed to promote the accumulation of sand. The areas shaded in light green represent locations for the planting of vegetation.

M. Pix4D quality report

Quality Report

Generated with Pix4Dmapper Pro version 4.2.25

Important: Click on the different icons for:

- Help to analyze the results in the Quality Report
- Additional information about the sections

[Click here](#) for additional tips to analyze the Quality Report

Summary ●

Project	Sonia Rican Despues del Swell
Processed	2018-04-04 15:36:07
Camera Model Name(s)	FC330_3.6_4000x3000 (RGB)
Average Ground Sampling Distance (GSD)	1.33 cm / 0.52 in
Area Covered	0.047 km ² / 4.7034 ha / 0.02 sq. mi. / 11.6283 acres
Time for Initial Processing (without report)	02h:14m:47s

Quality Check ●

● Images	median of 36899 keypoints per image	✔
● Dataset	375 out of 379 images calibrated (98%), all images enabled	✔
● Camera Optimization	4.31% relative difference between initial and optimized internal camera parameters	✔
● Matching	median of 7647.68 matches per calibrated image	✔
● Georeferencing	yes, no 3D GCP	⚠

Preview ●



Figure 1: Orthomosaic and the corresponding sparse Digital Surface Model (DSM) before densification.

Calibration Details ●

Number of Calibrated Images	375 out of 379
Number of Geolocated Images	379 out of 379

Initial Image Positions ●

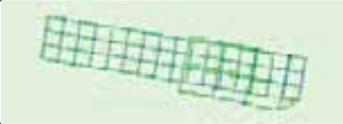


Figure 2: Top view of the initial image position. The green line follows the position of the images in time starting from the large blue dot.

Computed Image/GCPs/Manual Tie Points Positions ●

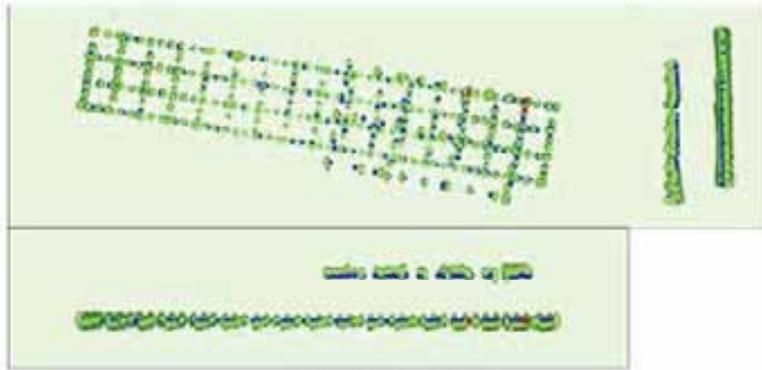


Figure 7: Offset between initial (blue dots) and computed (green dots) image positions as well as the offset between the GCP's initial positions (blue crosses) and their scheduled positions (green crosses) in the fore-view (T1 plane), front-view (T2 plane), and side-view (T3 plane). Red dots indicate disabled or uncollected images. Dark green stripes indicate the absolute position uncertainty of the bundle block adjustment result.

Absolute camera position and orientation uncertainties

	X [m]	Y [m]	Z [m]	Omega [deg/m]	Psi [deg/m]	Kappa [deg/m]
Mean	0.193	0.201	0.392	0.488	0.194	0.104
Sigma	0.038	0.063	0.076	0.006	0.014	0.007

Overlap

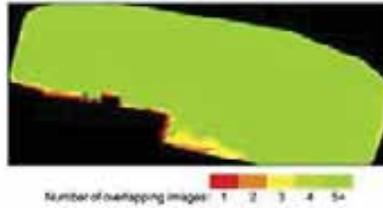


Figure 8: Number of overlapping images computed for each pixel of the orthomosaic. Red and yellow areas indicate low overlap for which poor results may be generated. Green areas indicate an overlap of 3 or 4 images for every pixel. Good quality results will be generated as long as the number of tiepoint matches is also sufficient for these areas (see Figure 6 for tiepoint matches).

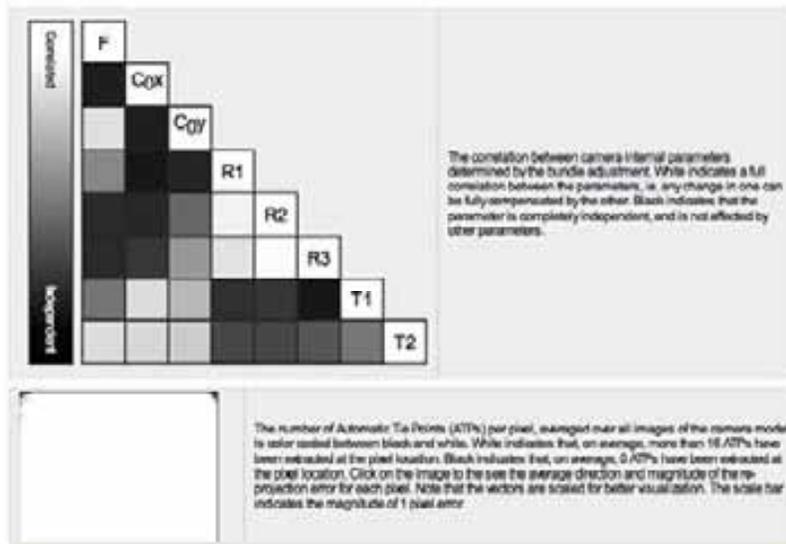
Bundle Block Adjustment Details

Number of 2D Tiepoint Observations for Bundle Block Adjustment	3047399
Number of 3D Points for Bundle Block Adjustment	1128058
Mean Reprojection Error [pixel]	0.187

Internal Camera Parameters

FC330_3.6_4000x3000 (RUC). Sensor Dimensions: 6.317 [mm] x 4.738 [mm]

	Fixed Length	Principal Point x	Principal Point y	R1	R2	R3	T1	T2
Initial Values	2386.733 [pixel] 3.610 [mm]	2000.000 [pixel] 3.159 [mm]	1600.000 [pixel] 2.368 [mm]	-0.001	-0.002	0.000	-0.001	-0.001
Optimized Values	2384.620 [pixel] 3.766 [mm]	1983.407 [pixel] 3.101 [mm]	1470.102 [pixel] 2.323 [mm]	0.001	0.008	0.004	0.001	0.000
Uncertainty (Sigma)	0.213 [pixel] 0.000 [mm]	0.099 [pixel] 0.000 [mm]	0.144 [pixel] 0.000 [mm]	0.000	0.000	0.000	0.000	0.000



2D Keypoints Table

	Number of 2D Keypoints per Image	As a ratio of 1000000 2D Keypoints per Image
Median	36899	7948
Min	19090	100
Max	43654	20803
Mean	37403	8126

3D Points from 2D Keypoint Matches

	Number of 3D Points Observed
In 2 Images	772479
In 3 Images	183572
In 4 Images	75328
In 5 Images	36706
In 6 Images	21900
In 7 Images	12987
In 8 Images	8072
In 9 Images	5120
In 10 Images	3176
In 11 Images	2022
In 12 Images	1368
In 13 Images	836
In 14 Images	627
In 15 Images	433
In 16 Images	305
In 17 Images	251
In 18 Images	204
In 19 Images	158
In 20 Images	114
In 21 Images	79
In 22 Images	69
In 23 Images	47
In 24 Images	27
In 25 Images	30
In 26 Images	14
In 27 Images	18
In 28 Images	13
In 29 Images	12
In 30 Images	10
In 31 Images	11
In 32 Images	5
In 33 Images	2
In 34 Images	0
In 35 Images	3
In 36 Images	2
In 37 Images	1

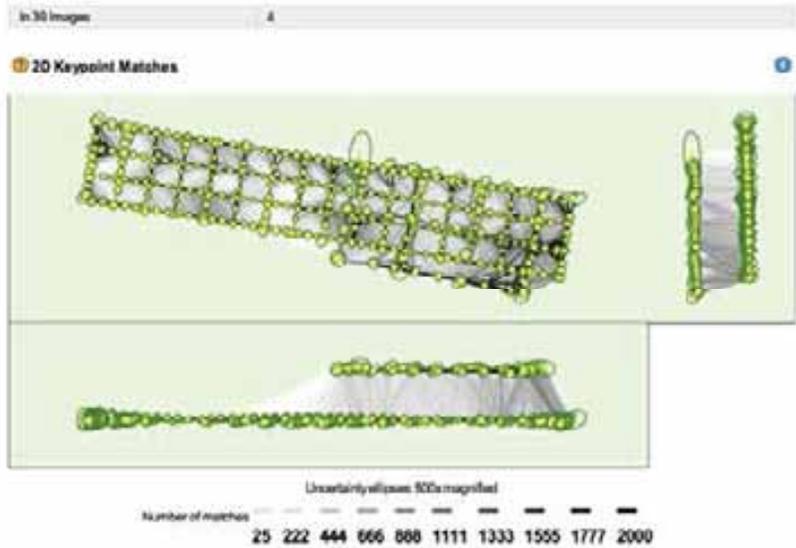


Figure 3: Computed image positions with links between matched images. The thickness of the links indicates the number of matched 2D keypoints between the images. Weight links indicate weak links and require manual inspection of more images. Thick green ellipses indicate the result's camera position uncertainty after bundle block adjustment result.

Relative camera position and orientation uncertainties

	X[m]	Y[m]	Z[m]	Omega (degree)	Psi (degree)	Kappa (degree)
Mean	0.006	0.005	0.006	0.008	0.010	0.006
Sigma	0.002	0.002	0.002	0.003	0.003	0.002

Geolocation Details

Absolute Geolocation Variance

Min Error [m]	Max Error [m]	Geolocation Error X [%]	Geolocation Error Y [%]	Geolocation Error Z [%]
-15.00	15.00	0.00	0.00	0.00
-16.00	-13.00	0.00	0.00	0.00
-12.00	-9.00	0.00	0.00	0.00
-9.00	-6.00	0.00	0.00	0.00
-6.00	-3.00	1.33	1.87	3.89
-3.00	0.00	55.47	91.20	44.00
0.00	3.00	42.40	46.13	53.07
3.00	6.00	0.80	0.80	0.00
6.00	9.00	0.00	0.00	0.00
9.00	12.00	0.00	0.00	0.00
12.00	15.00	0.00	0.00	0.00
15.00	-	0.00	0.00	0.00
Mean [m]		-0.000399	-0.000773	-0.001772
Sigma [m]		1.290219	1.106176	1.290139
RMS Error [m]		1.290219	1.106176	1.290140

Min Error and Max Error represent geolocation error intervals between ± 1.5 and ± 1.0 times the maximum accuracy of all the images. Columns X, Y, Z show the percentage of images with geolocation errors within the provided error intervals. The geolocation error is the difference between the initial and computed image positions. Note that the image geolocation errors do not correspond to the accuracy of the observed 3D points.

Relative Geolocation Variance

Relative Geolocation Error	Images X [%]	Images Y [%]	Images Z [%]
[1.00, 1.00]	99.73	100.00	100.00
[2.00, 2.00]	100.00	100.00	100.00
[3.00, 3.00]	100.00	100.00	100.00
Mean of Geolocation Accuracy [m]	5.000000	5.000000	10.000000
Sigma of Geolocation Accuracy [m]	0.000000	0.000000	0.000000

Images X, Y, Z represent the percentage of images with a relative geolocation error in X, Y, Z.

Geolocation Orientation Variance	RMS (degrees)
Omega	1.890
Phi	1.530
Kappa	2.328

Geolocation RMS error of the orientation angles given by the difference between the initial and computed image orientation angles.

Initial Processing Details

System Information

Hardware	CPU: Intel(R) Core(TM) i5-3330S CPU @ 2.70GHz RAM: 8GB GPU: Intel(R) HD Graphics (Driver: 10.18.10.3412), ROPROD Chained GD (Driver: unknown), ROP Encoder Mirror Driver (Driver: unknown), ROP Reflectix Display Driver (Driver: unknown)
Operating System	Windows 7 Professional, 64-bit

Coordinate Systems

Image Coordinate System	WGS84 (epsg:31466)
Output Coordinate System	WGS84 / UTM Zone 19N (epsg:31466)

Processing Options

Detected Template	3D Mesh
Keypoints Image Scale	Full Image Scale: 1
Advanced: Matching Image Pairs	Aerial Grid or Contour
Advanced: Matching Strategy	Use Geometrically Verified Matching: no
Advanced: Keypoint Detection	Targetted Number of Keypoints: Automatic
Advanced: Collation	Collation Method: Standard Internal Parameters Optimization: All External Parameters Optimization: All Rematch: All, yes

Point Cloud Densification details

Processing Options

Image Scale	multiscale, 1/2 (half image size, Default)
Point Density	Optimal
Minimum Number of Matches	3
3D Textured Mesh Generation	yes
3D Textured Mesh Settings:	Resolution: Medium Resolution (Default) Color Balancing: no
LOD	Generated: no
Advanced: 3D Textured Mesh Settings	Sample Density: Default 1
Advanced: Image Groups	group1
Advanced: Use Processing Area	yes
Advanced: Use Annotations	yes
Time for Point Cloud Densification	01m:29m:43s
Time for Point Cloud Classification	NA
Time for 3D Textured Mesh Generation	20m:38s

Results

Number of Processed Clusters	3
Number of Generated Tiles	1
Number of 3D Densified Points	20418292
Average Density (per m ²)	1,228.1

DSM, Orthomosaic and Index Details

Processing Options

DSM and Orthomosaic Resolution	1 x 0.00 (1.20 (um/px))
--------------------------------	-------------------------

DSM Files	Noise Filtering yes Surface Smoothing yes, Type: Sharp
Raster DSM	Generated yes Without Inverse Distance Weighting Merge Tiles yes
Orthosaic	Generated yes Merge Tiles yes GeoTiff Without Transparency no Google Maps Tiles and HTML no
Time for DSM Generation	34m:47s
Time for Orthosaic Generation	01h:13m:22s
Time for DTM Generation	00s
Time for Contour Lines Generation	00s
Time for Reflectance Map Generation	00s
Time for Index Map Generation	00s

Notes

Notes

Notes

Notes

Site name:

Golondrinas beach, Isabela



A. Physical address:

Golondrinas Beach (after northeasterly swell), Road PR 466, Isabela, Puerto Rico, 00662

B. Date of capture of imagery:

April 27, 2018

C. Coordinates:

18.51395282 N -67.05564977 W

D. Description of site:

This area is known as “Golondrinas Beach” and consists of a narrow strip of beach parallel to PR 466 located to the west of the coconut palm plantation on Barrio Bajuras, Isabela, Puerto Rico. This site is a highly frequented body boarding spot. Cars usually park on the roadside of the westernmost part of the site and there is constant foot traffic in the area inhibiting the growth of dune vegetation. Part of the site is parallel to a recreational trail that runs from that area to Secret Spot Beach (east of the site).

E. Distance from community:

The site is located at a distance of 500 m from the cliff and parallel to road PR 466 and at approximately 28 m from a coastal forest (mainly composed of the Australian pine *Cassuarina equisetifolia*) located to the south. The nearest houses are located on the cliff at an altitude of approximately 30 m above sea level.

F. Aerial imagery

i. Contour map



Figure 45. Contour map of Golondrinas Beach, Isabela Puerto Rico with elevation intervals of 1 meter.

ii. 3D imagery



Figure 46. Aerial 3D image of Golondrinas Beach, Isabela (after the March, 2017 north-easterly swell).

iii. Orthomosaic model



Figure 47. Orthomosaic aerial image of Golondrinas Beach, Isabela (after the March, 2017 north-easterly swell), Isabela.

iv. Density Surface Models (DSM)

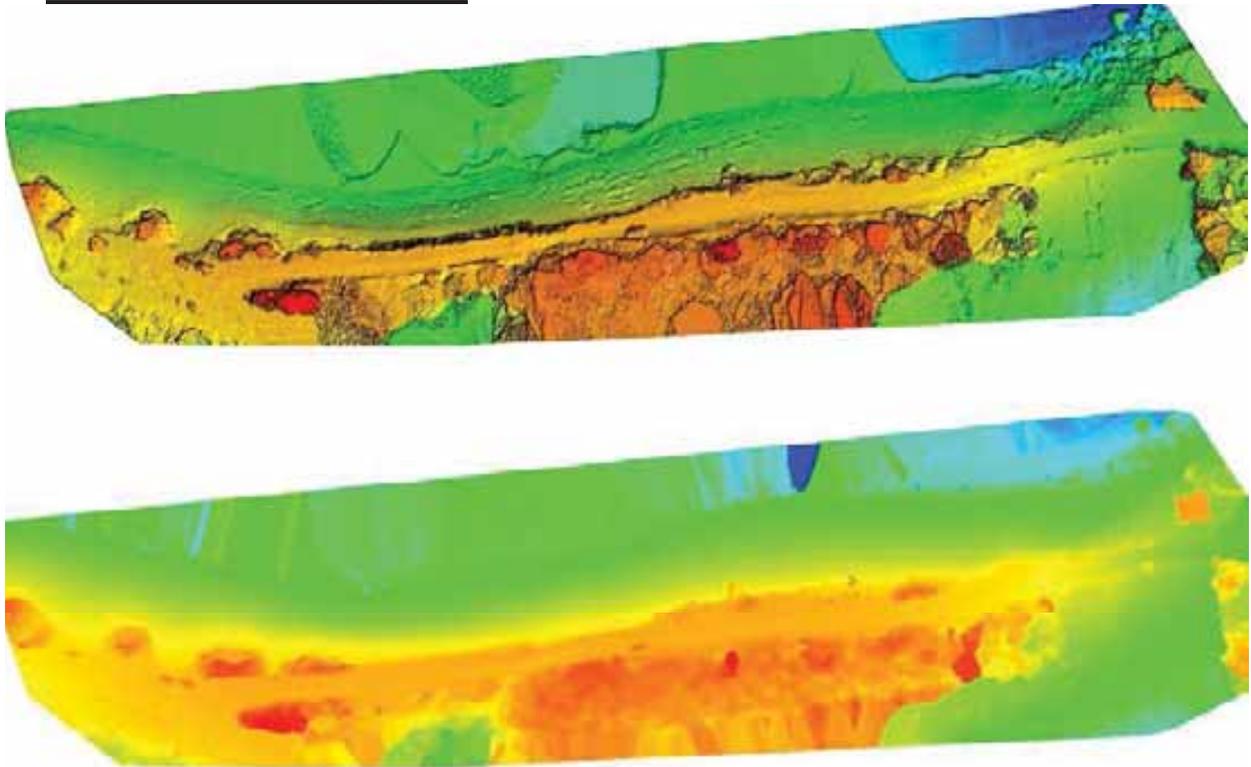


Figure 48. Density surface model (with shading top and without shading bottom) images of Golondrinas Beach (after the March, 2017 north-easterly swell), Isabela.

v. Thermal images

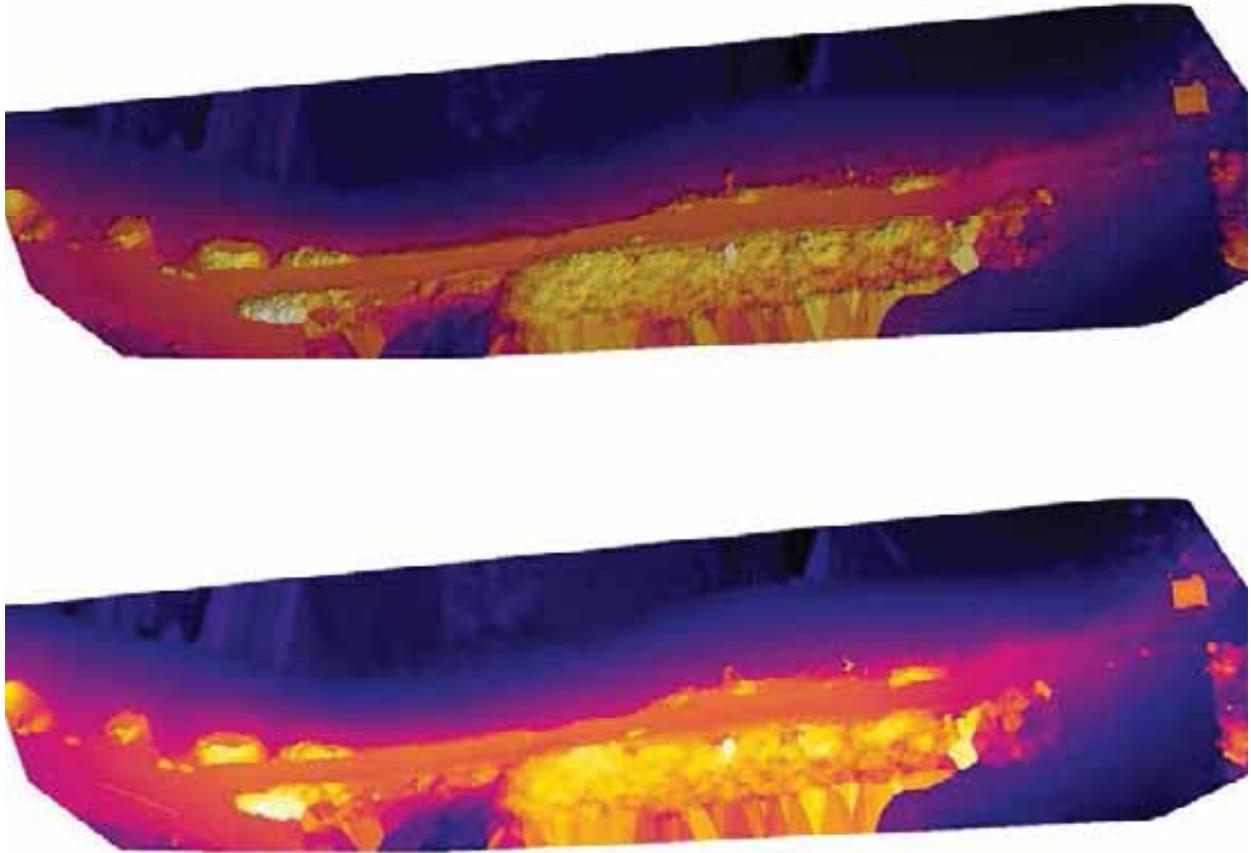


Figure 49. Thermal images (with shading top and without shading bottom) of the dune located at the Golondrinas Beach (after the March, 2017 north-easterly swell), Isabela.

vi. 3D altitude RGB North



Figure 50. Aerial 3D image of Golondrinas Beach, Isabela viewed from the west (after the March, 2017 north-easterly swell).



Figure 51. Three dimensional RGB images of Golondrinas beach (after the March, 2017 north-easterly swell), Isabela viewed from the east.



Figure 52. Three dimensional RGB images Golondrinas beach (after the March, 2017 north-easterly swell), Isabela viewed from the south.

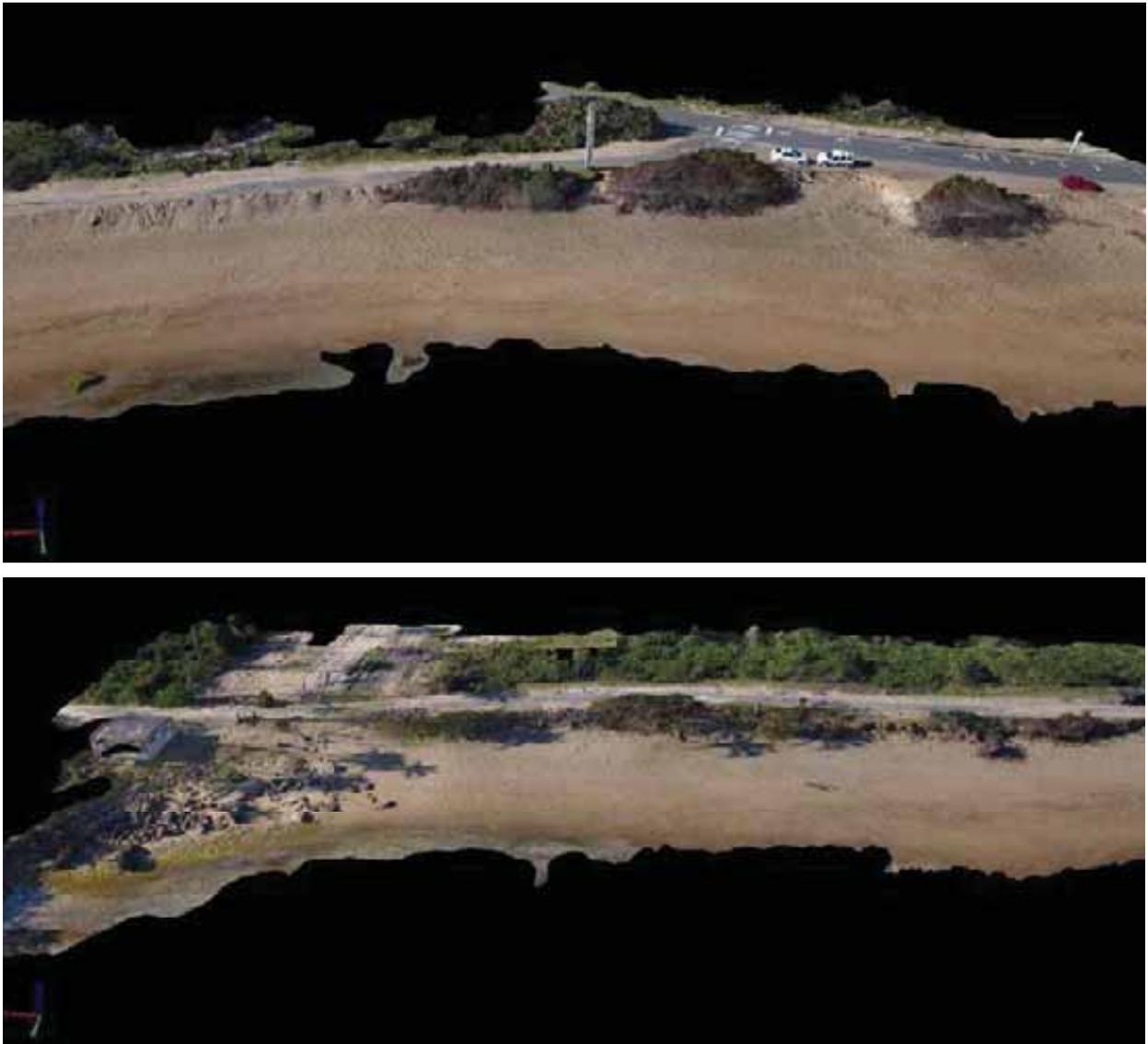


Figure 53. Three dimensional RGB images of Golondrinas beach (after the March, 2017 north-easterly swell), Isabela viewed from the north.

vii. DSM grayscale

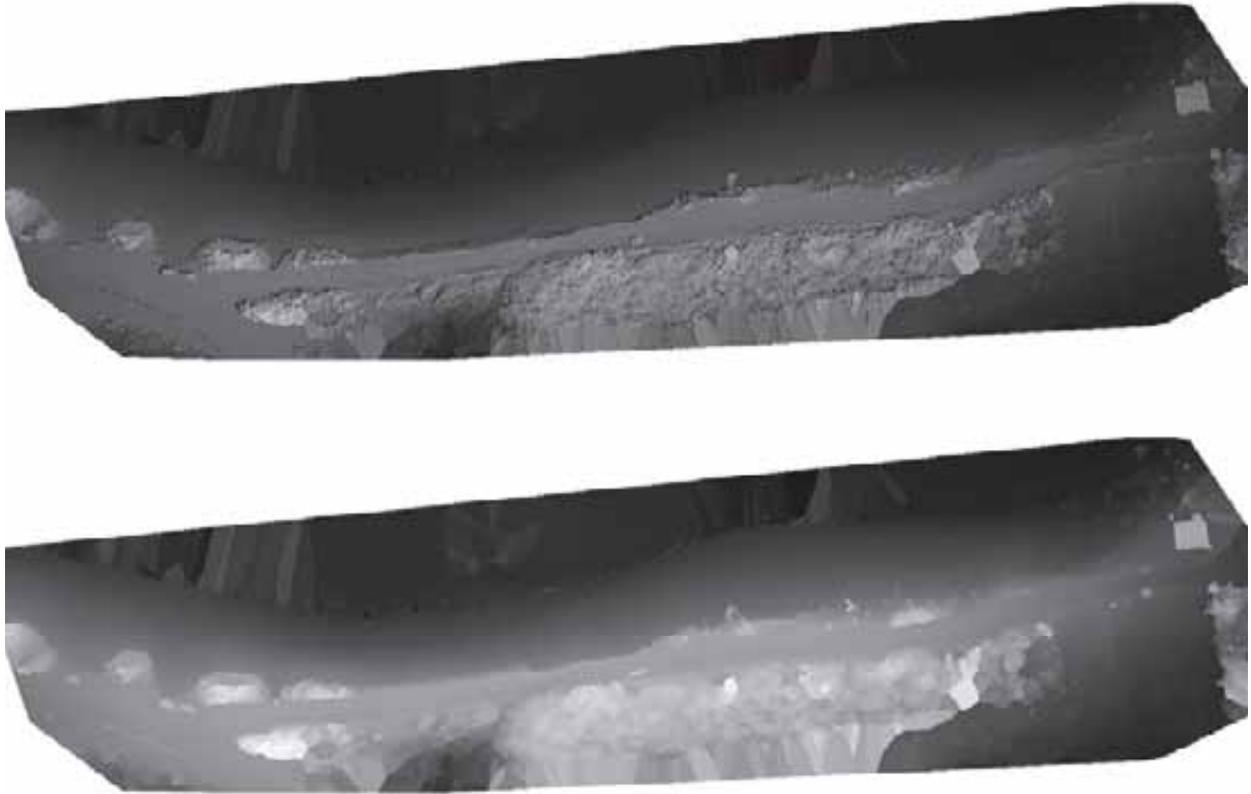


Figure 54. Grayscale DSM images of Golondrinas beach (after the March, 2017 north-easterly swell), Isabela. The top image shows shades and the bottom is not shaded.

Site report

G. Vegetation cover



Figure 55. Vegetation cover was 47 % on Golondrinas beach, Isabela site (after the March, 2017 north-easterly swell) on April 27, 2018. The percent vegetation cover of the total area was calculated from the two pictures.

H. Volume measurements of selected areas of the dunes

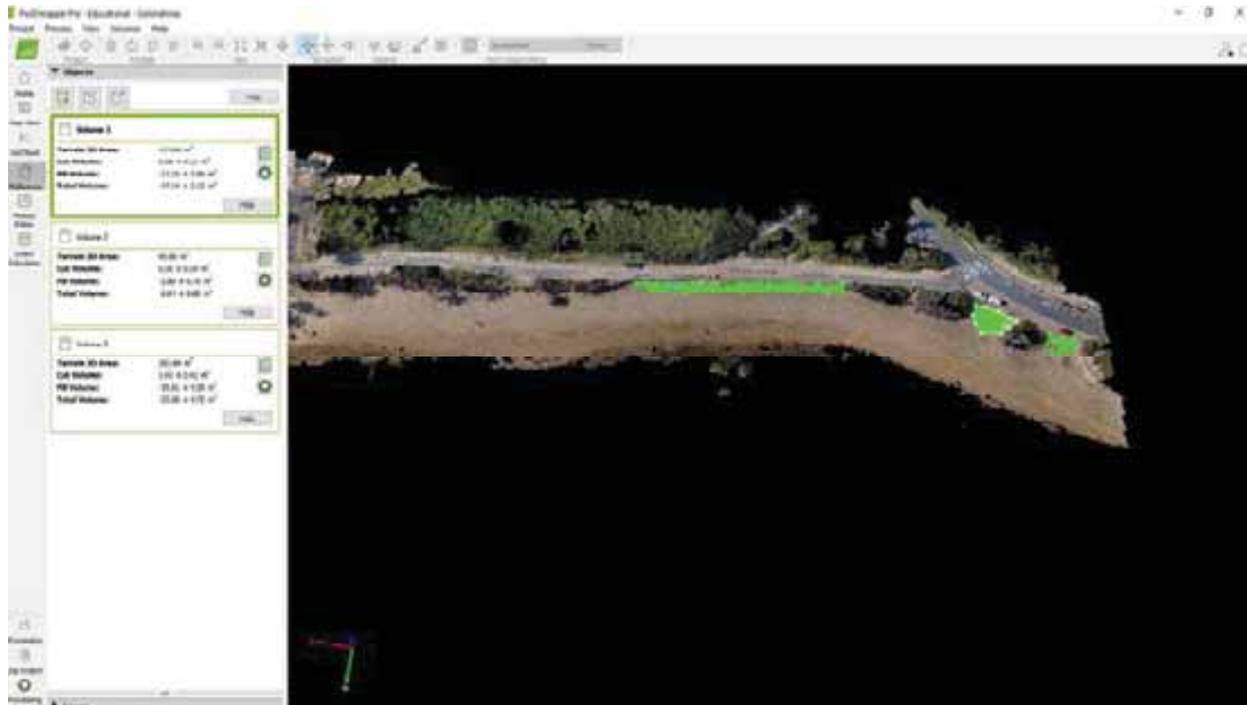


Figure 56. The first polygon (from left to right on the picture) has a 3D area of 113.84 m² and a cut volume of 0.58 ± 0.12 m³, a fill volume of -579.75 ± 12.33 m³ and a total volume of 116.35 ± 31.09 m³. The second polygon (from left to right) has an area of 45.80 m² and a cut volume of 0.16 ± 0.19 m³, a fill volume of -2.80 ± 0.70 m³ and a total volume of -2.64 ± 0.88 m³. The third polygon (from left to right) has an area 263.64 m² and a cut volume of 1.43 ± 0.42 m³, a fill volume of -35.01 ± 4.30 m³ and a total volume of -33.58 ± 4.72 m³. The volume of these three areas will be monitored in subsequent months.

I. Conservation threats

Constant foot and vehicular traffic in this area inhibits plant growth resulting in a fragile system subject to high levels of erosion especially during severe weather. The lack of natural or man-made barriers or vegetation in this area results in high quantities of sand being displaced on to PR-466 and to the other side of this road constantly. Illegal sand extraction on this site is very common especially in the side of the road adjacent to the coastal forest.

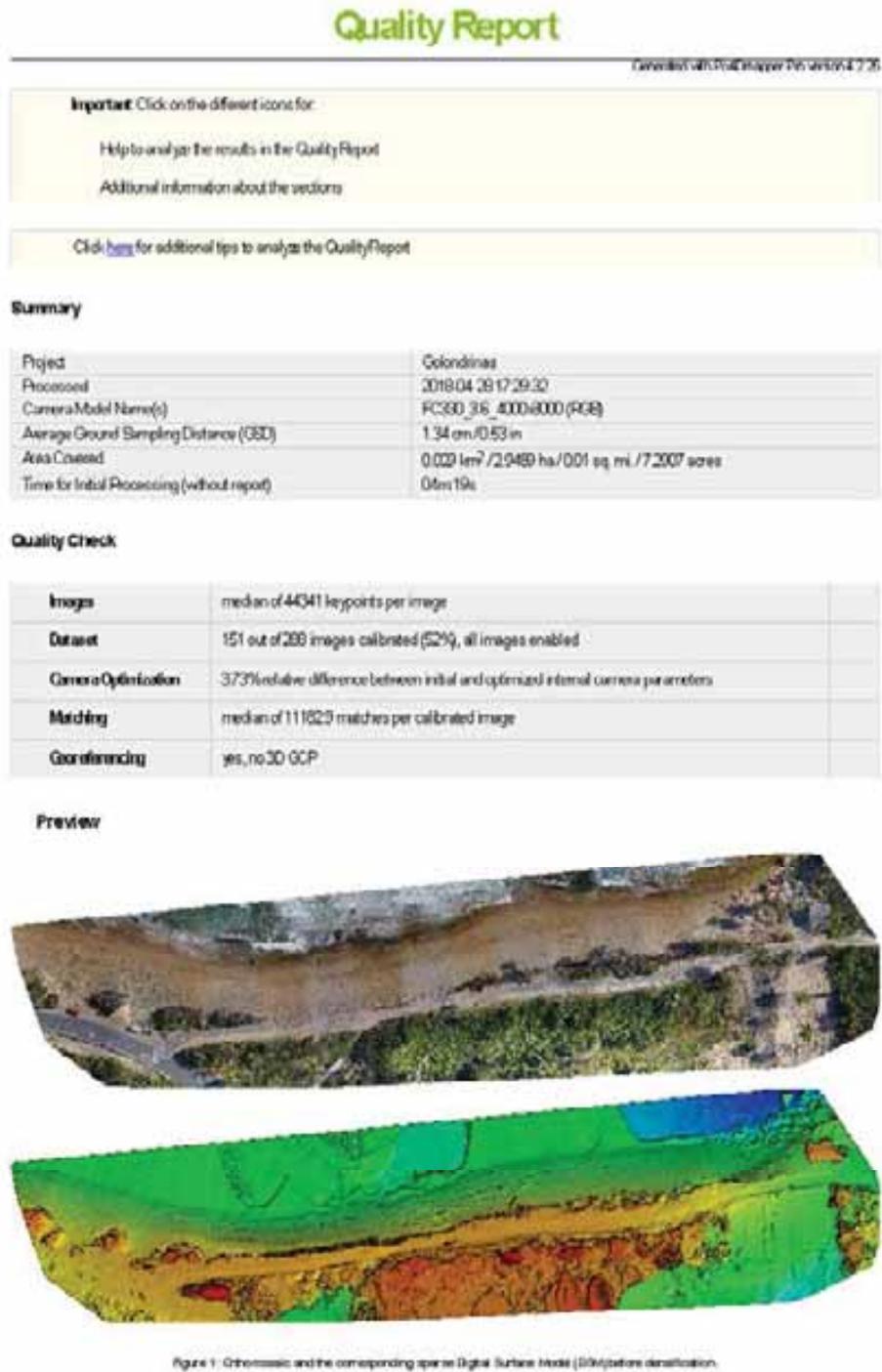
J. Recommended ecological restoration courses of action (COA)

Redirection of foot traffic is of high priority in this area. To do this we are proposing the installation of wooden exclusion fencing, a wooden platform with two small ramps. The installation of a wooden platform has contributed to the redirection of foot traffic and bystanders to a particular area protecting the sensitive vegetation. We are also proposing the installation of biomimicry setups to contain and promote the accumulation of sand in this area. The sand will later be stabilized with the planting of vegetation. An information sign will also be installed on this area to explain the importance of dunes and their restoration to visitors. These structures should promote the formation of a line of primary dune that will protect PR-466 and the land behind it.



Figure 57. Area to be ecologically restored at Golondrinas Beach on PR 466 in Barrio Bajuras, Isabela. Highlighted areas correspond to each technique that will be used in this area. **Yellow** represents the location of wooden boardwalks, platform and barriers, the **red dot** marks the location of an information sign, **light green** marks the area of planting of dune vegetation, **tan** represents the area where biomimicry matrices will be installed to promote the accumulation of sand and areas shaded in light green represent locations for the planting of vegetation.

K. Pix 4D Quality Report



Calibration Details

Number of Calibrated Images	151 out of 200
Number of Geolocated Images	266 out of 266

Initial Image Positions

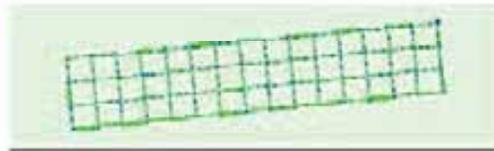


Figure 2: Top view of the initial image position. The green line follows the position of the images in line starting from the large blue dot.

Computed Image/GCPs/Manual Tie Points Positions

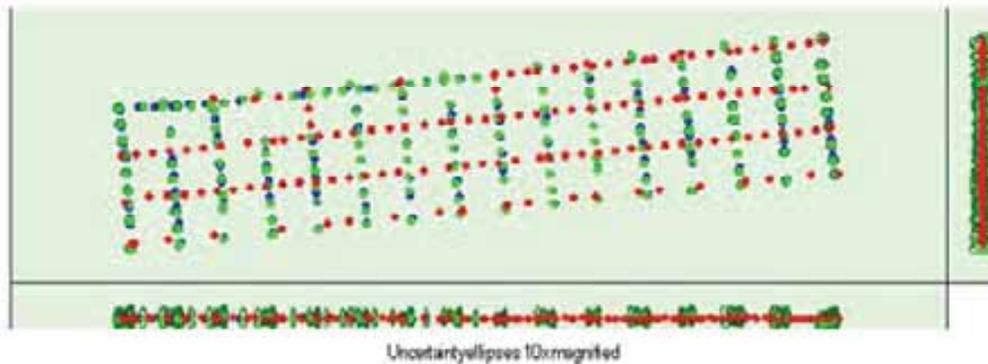


Figure 3: Offset between initial (blue dots) and computed (green dots) image positions as well as the offset between the GCPs initial positions (blue crosses) and their computed positions (green crosses) in the top view (XY plane), front view (XZ plane) and side view (YZ plane). Red dots indicate disabled or uncalibrated images. Dark green ellipses indicate the absolute position uncertainty of the bundle block adjustment result.

Absolute camera position and orientation uncertainties

	X[m]	Y[m]	Z[m]	Omega [degree]	Psi [degree]	Kappa [degree]
Mean	0.151	0.151	0.360	0.009	0.160	0.000
Sigma	0.033	0.033	0.061	0.009	0.025	0.007

Overlap

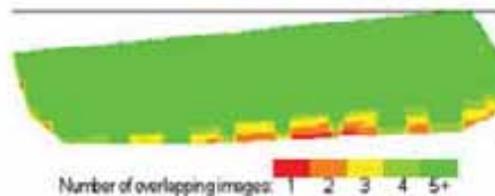


Figure 4: Number of overlapping images computed for each pixel of the orthorectified. Red and yellow areas indicate low overlap for which poor results may be generated. Green areas indicate an overlap of over 4 images for every pixel. Good quality results will be generated as long as the number of tie point matches is also sufficient for these areas (see Figure 5 for tie point matches).

Bundle Block Adjustment Details

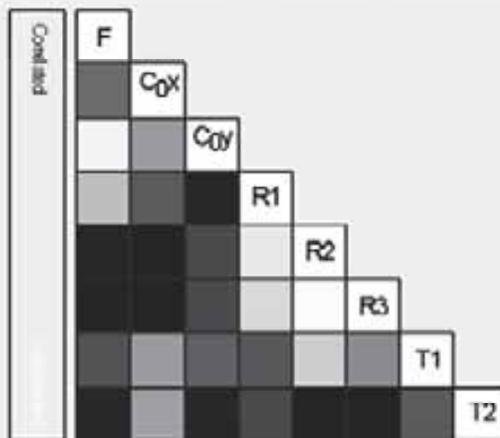
Number of 2D Keypoint Observations for Bundle Block Adjustment	1609009
Number of 3D Points for Bundle Block Adjustment	532366
Mean Reprojection Error [pixels]	0.170

Internal Camera Parameters

FC300_3,6_4000x3000 (RGB), Sensor Dimensions: 6.317 [mm] x 4.738 [mm]

REF ID: FC300_3,6_4000x3000

	Focal Length	Principal Point x	Principal Point y	R1	R2	R3	T1	T2
Initial Values	2205.722 [pixel] 3h31 [mm]	2000.000 [pixel] 3149 [mm]	1500.000 [pixel] 2.469 [mm]	0.001	0.002	0.000	0.001	0.001
Optimized Values	2371.081 [pixel] 3.745 [mm]	1968.370 [pixel] 3.110 [mm]	1491.436 [pixel] 2.366 [mm]	-0.001	-0.002	0.002	0.000	-0.000
Uncertainties (Sigma)	0.439 [pixel] 0.001 [mm]	0.009 [pixel] 0.000 [mm]	0.295 [pixel] 0.000 [mm]	0.000	0.000	0.000	0.000	0.000



The correlation between camera internal parameters determined by the bundle adjustment. White indicates a full correlation between the parameters, i.e. any change in one can be fully compensated by the other. Black indicates that the parameter is completely independent, and is not affected by other parameters.



The number of Automatic Tie Points (ATPs) per pixel, averaged over all images of the camera model, is color coded between black and white. White indicates that, on average, more than 16 ATPs have been extracted at the pixel location. Black indicates that, on average, 0 ATPs have been extracted at the pixel location. Click on the image to see the average direction and magnitude of the reprojection error for each pixel. Note that the vectors are scaled for better visualization. The scale bar indicates the magnitude of 1 pixel error.

2D Keypoints Table

	Number of 2D Keypoints per Image	Number of Matched 2D Keypoints per Image
Median	44341	11183
Min	28131	168
Max	69753	27540
Mean	43918	10661

3D Points from 2D Keypoint Matches

Number of 3D Points Observed

In2 Images	30618
In3 Images	96545
In4 Images	60316
In5 Images	30109
In6 Images	18606
In7 Images	10748
In8 Images	6867
In9 Images	4330
In10 Images	2591
In11 Images	1399
In12 Images	866
In13 Images	540
In14 Images	314
In15 Images	165
In16 Images	84
In17 Images	27
In18 Images	15
In19 Images	4
In20 Images	2

2D Keypoint Matches

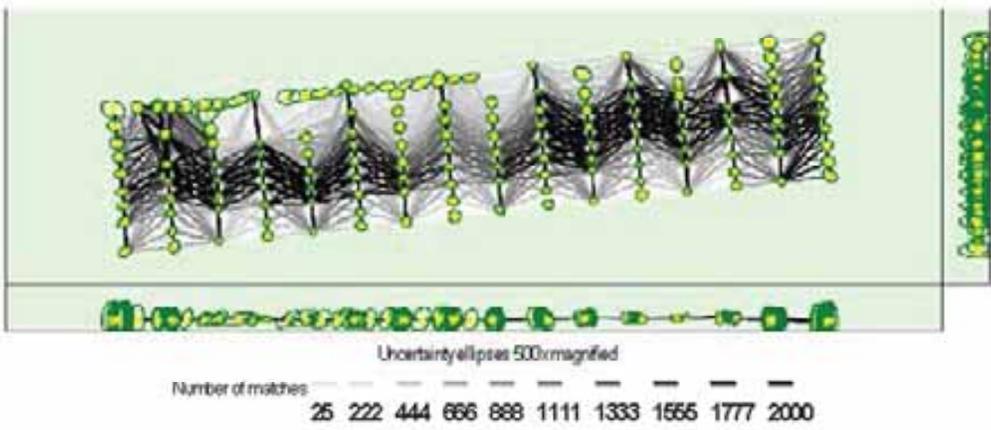


Figure 5. Computed image positions with links between matched images. The darkness of the links indicates the number of matched 2D keypoints between the images. Bright links indicate weak links and require manual tie points or more images. Dark green ellipses indicate the relative camera position uncertainty of the bundle block adjustment result.

Relative camera position and orientation uncertainties

	X[m]	Y[m]	Z[m]	Omega [degree]	Psi [degree]	Kappa [degree]
Mean	0.005	0.004	0.008	0.008	0.012	0.005
Sigma	0.002	0.001	0.004	0.002	0.005	0.002

Geolocation Details

Absolute Geolocation Variance

Mn Error [m]	Max Error [m]	Geolocation Error X [%]	Geolocation Error Y [%]	Geolocation Error Z [%]
-	-15.00	0.00	0.00	0.00

-15.00	-12.00	0.00	0.00	0.00
-12.00	-9.00	0.00	0.00	0.00
-9.00	-6.00	0.00	0.00	0.00
-6.00	-3.00	0.66	0.66	0.00
-3.00	0.00	27.81	47.02	47.68
0.00	3.00	71.52	50.99	52.32
3.00	6.00	0.00	1.32	0.00
6.00	9.00	0.00	0.00	0.00
9.00	12.00	0.00	0.00	0.00
12.00	15.00	0.00	0.00	0.00
15.00		0.00	0.00	0.00
Mean[m]		0.003206	0.001615	0.009175
Sigma[m]		0.596845	1.379961	0.437198
RMS Error [m]		0.596864	1.379962	0.437254

Min Error and Max Error represent geolocation error intervals between -1.5 and 1.5 m are the maximum accuracy of all the images. Columns X, Y, Z show the percentage of images with geolocation errors within the predefined error intervals. The geolocation error is the difference between the initial and computed image positions. Note that the image geolocation errors do not correspond to the accuracy of the observed 3D points.

Relative Geolocation Variance

Relative Geolocation Error	Images X [%]	Images Y [%]	Images Z [%]
{-1.00, 1.00}	100.00	100.00	100.00
{-2.00, 2.00}	100.00	100.00	100.00
{-3.00, 3.00}	100.00	100.00	100.00
Mean of Geolocation Accuracy [m]	5.000000	5.000000	10.000000
Sigma of Geolocation Accuracy [m]	0.000000	0.000000	0.000000

Images X, Y, Z represent the percentage of images with a relative geolocation error in X, Y, Z.

Geolocation Orientational Variance	RMS (degree)
Omega	5.068
Phi	2.375
Kappa	2.668

Geolocation RMS error of the orientation angles given by the difference between the initial and computed image orientation angles.

Initial Processing Details

System Information

Hardware	CPU Intel(R) Core(TM) i7-8700K CPU @ 3.70GHz RAM 16GB GPU NVIDIA GeForce GTX 1070 (Driver: 23.21.139066)
Operating System	Windows 10 Home, 64-bit

Coordinate Systems

Image Coordinate System	WGS84 (epn96)
Output Coordinate System	WGS84 / UTM Zone 18N (epn96)

Processing Options

Detected Template	3D Mips
Keypoints Image Scale	Full Image Scale: 1
Advanced: Matching Image Pairs	Aerial Grid or Corridor

Advanced: Matching Strategy	Use Geometrically Verified Matching: no
Advanced: Keypoint Extraction	Targeted Number of Keypoints: Automatic
Advanced: Calibration	Calibration Method: Standard Internal Parameters Optimization: All External Parameters Optimization: All Rematch: Auto, yes

Point Cloud Densification details

Processing Options

Image Scale	multiscale, 1/2 (Half image size, Default)
Point Density	Optimal
Minimum Number of Matches	3
3D Textured Mesh Generation	yes
3D Textured Mesh Settings:	Resolution: Medium Resolution (default) Color Balancing: no
LCO	Generated: no
Advanced: 3D Textured Mesh Settings	Sample Density Divider: 1
Advanced: Image Groups	group1
Advanced: Use Processing Area	yes
Advanced: Use Annotations	yes
Time for Point Cloud Densification	06m19s
Time for Point Cloud Classification	NA
Time for 3D Textured Mesh Generation	03m29s

Results

Number of Generated Tiles	1
Number of 3D Densified Points	6237434
Average Density (per m ²)	1209.76

DSM, Orthomosaic and Index Details

Processing Options

DSM and Orthomosaic Resolution	1 x GSD (1.34 [cm/pixel])
DSM Filters	Noise Filtering: yes Surface Smoothing: yes, Type: Sharp
Raster DSM	Generated: yes Method: Inverse Distance Weighting Merge Tiles: yes
Orthomosaic	Generated: yes Merge Tiles: yes GeoTIFF Without Transparency: no Google Maps Tiles and KML: no
Time for DSM Generation	05m12s
Time for Orthomosaic Generation	09m32s
Time for DTM Generation	00s
Time for Contour Lines Generation	00s
Time for Reflectance Map Generation	00s
Time for Index Map Generation	00s

Site name:

Haudimar housing complex, Isabela



A. Physical address:

Area behind the Haudimar housing complex (after northeasterly swell), PR 466, Isabela, Puerto Rico, 00662.

B. Date of capture of imagery:

March 14, 2018

C. Coordinates:

18.51470952 N - 67.08933729 W

D. Description of site:

A line of primary dune behind the Haudimar housing complex in Barrio Bajuras Isabela. There is an abandoned wooden boardwalk that behind the dune that is partly covered by sand. The area to the east of the housing complex is eroded and there are two new breaches on the easternmost part of the study site.

E. Distance from community:

This site is located at a distance of 48 m from a the Haudimar housing complex that consists of 14 units, a quad with a swimming pool and a parking lot. It is located at a distance of 293 m from PR 466.

Aerial imagery

i. Contour map



Figure 58. Contour map of the area behind the Haudimar housing complex (after northeasterly swell), in Isabela Puerto Rico with elevation intervals of 1 meter.

ii. 3D imagery

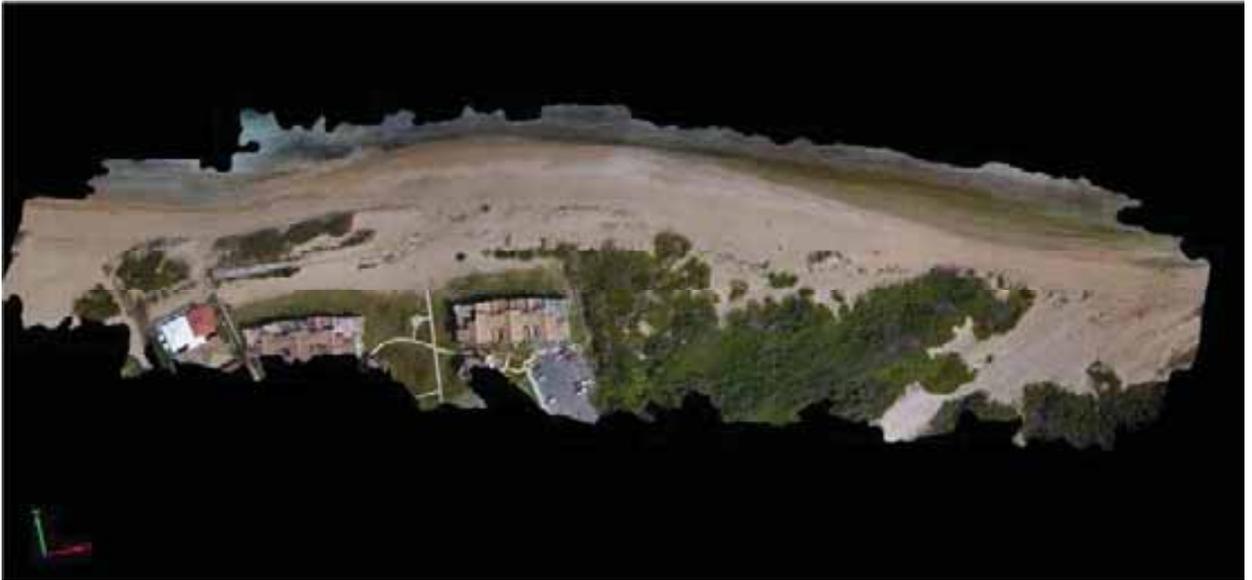


Figure 59. Aerial 3D image of the Haudimar housing complex (after northeasterly swell).

iii. Orthomosaic model



Figure 60. Orthomosaic image of Haudimar housing complex (after northeasterly swell), Isabela.

iv. Density Surface Models (DSM)

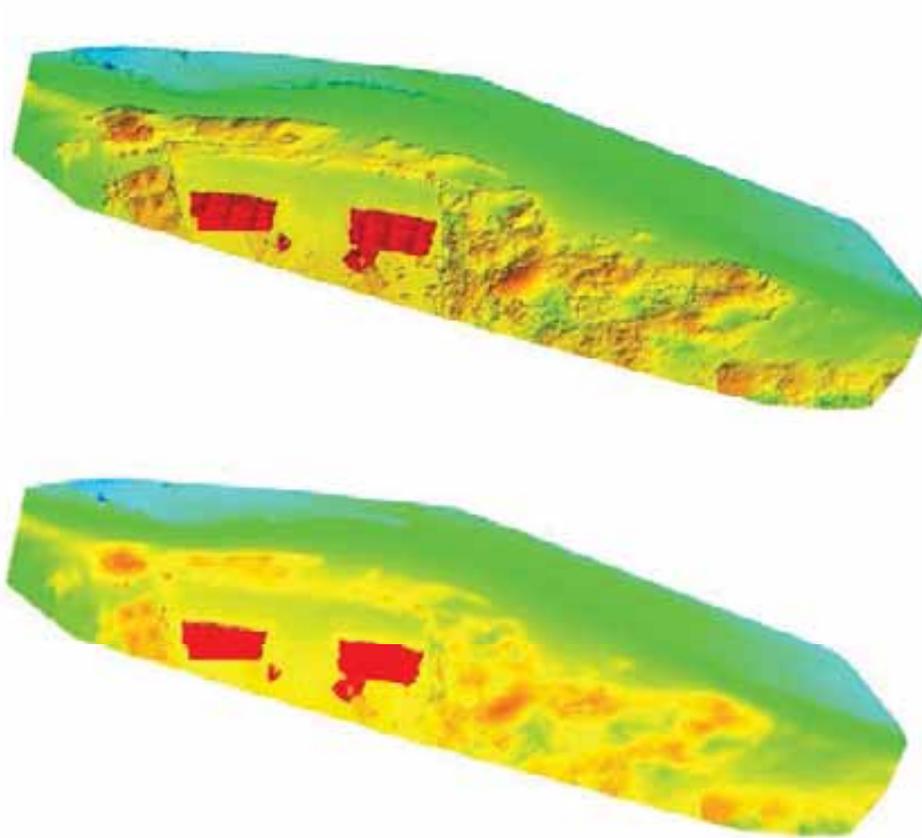


Figure 61. Density surface model (with shading top and without shading bottom) images of the dune located on the Haudimar housing complex (after northeasterly swell), Isabela.

v. Thermal images

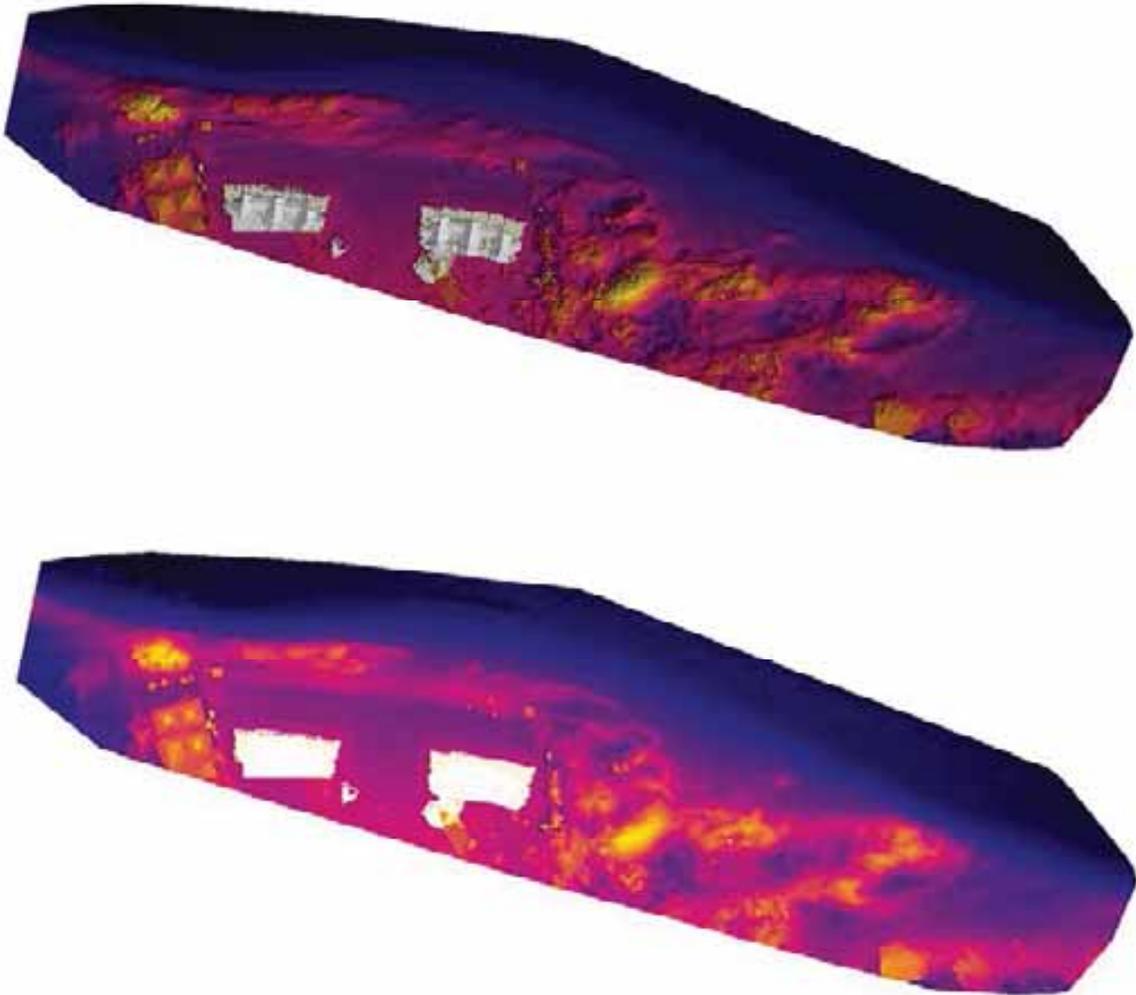


Figure 62. Thermal images (with shading top and without shading bottom) of the Haudimar housing complex (after northeasterly swell), Isabela.

vi. 3D altitude RGB North

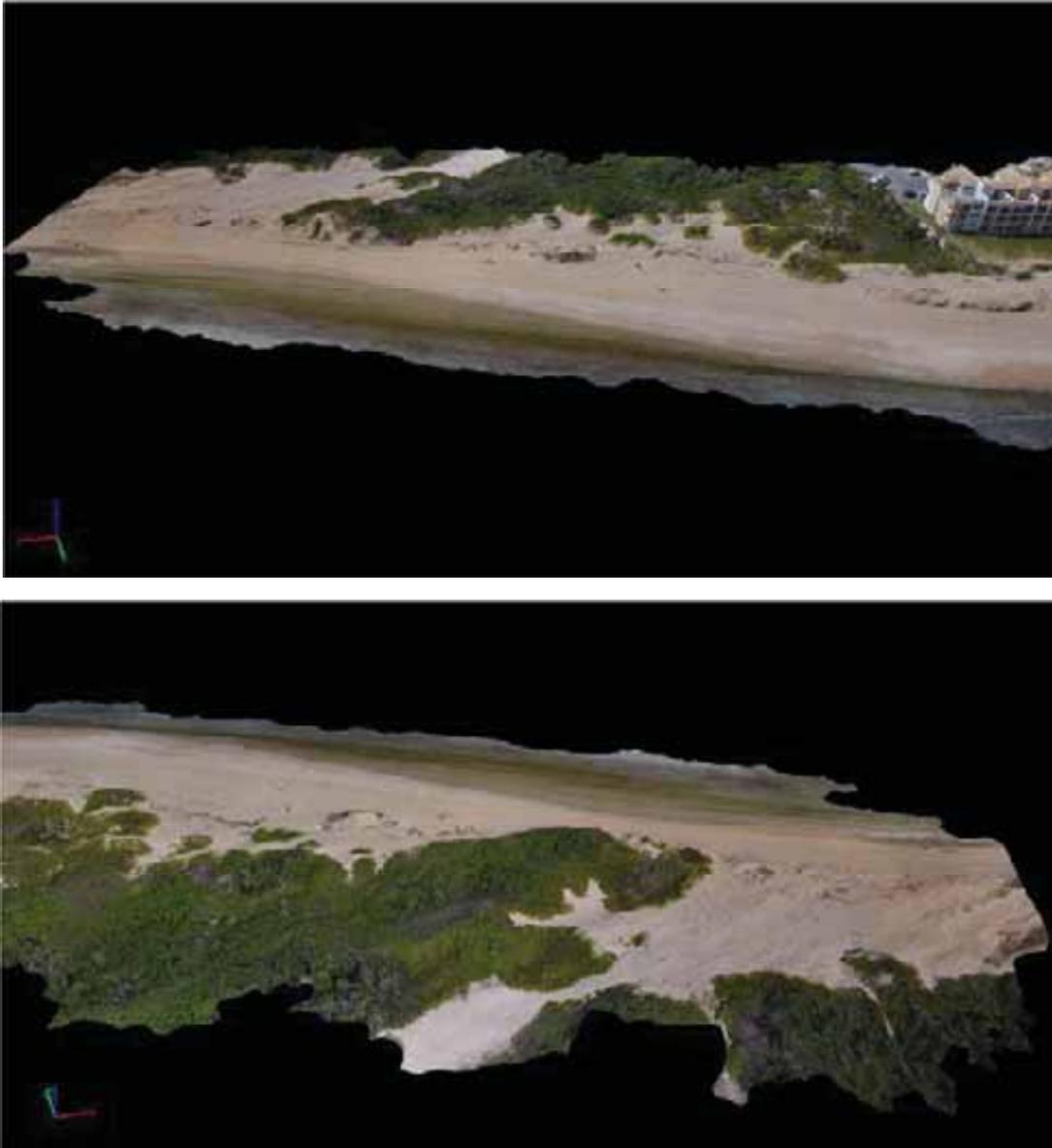


Figure 63. Three dimensional RGB images of the Haudimar housing complex, Isabela. View from the north of the eastern part of the site (top) and from the south of the same area (bottom).

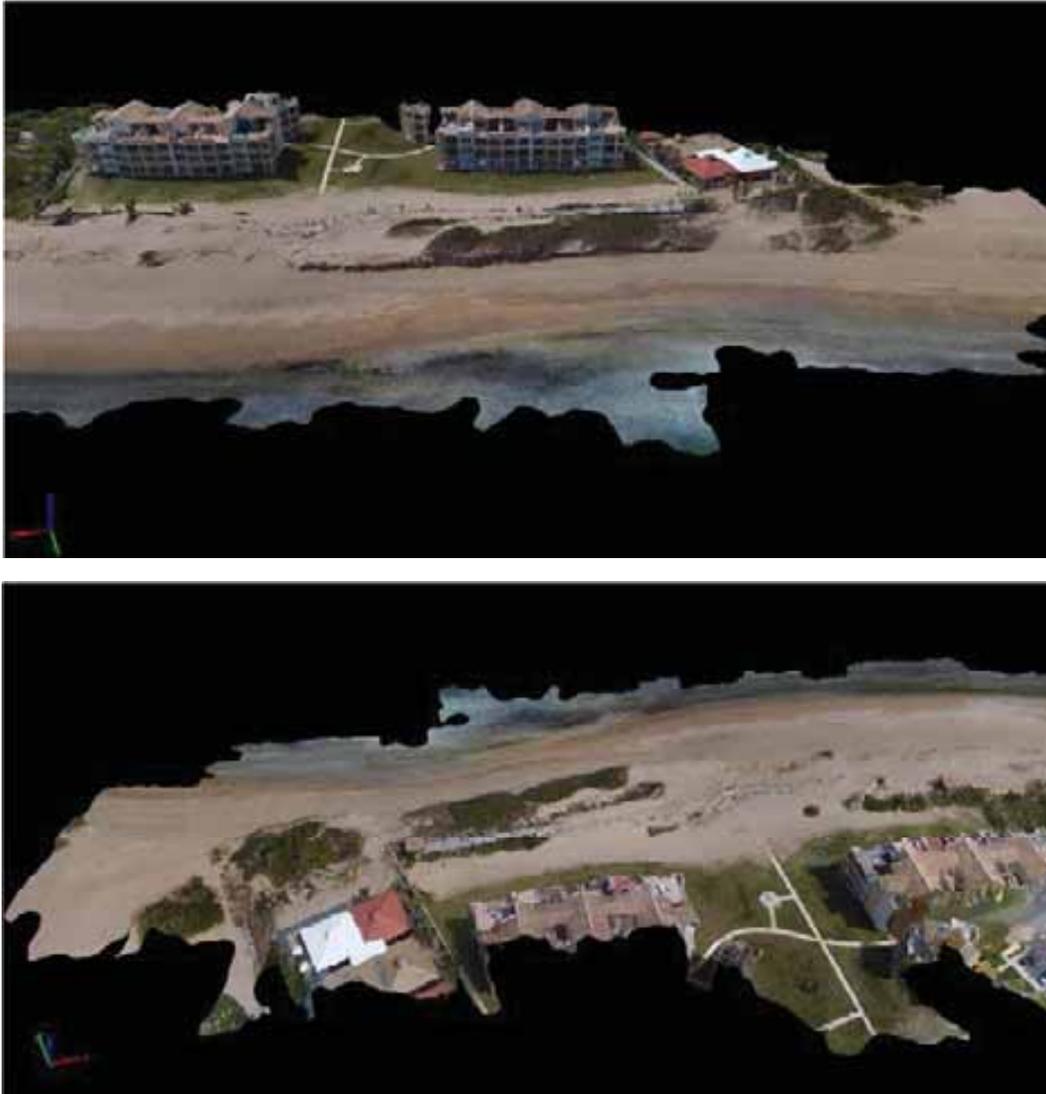


Figure 64. Three dimensional RGB images of the western part of the Haudimar housing complex, Isabela. View from the north (top) and from the south (bottom).

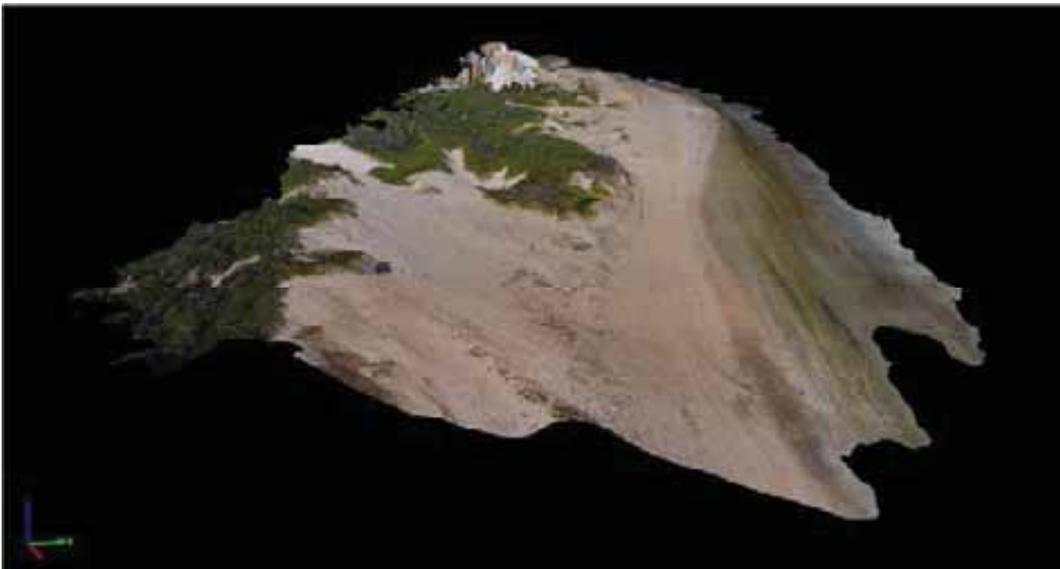


Figure 65. Three dimensional RGB images of the eastern part of the Haudimar housing complex, Isabela. View from the west (top) and from the east (bottom).



Figure 66. Three dimensional RGB images of the western part of the Haudimar housing complex (after northeasterly swell), Isabela. View from the west and from the east. Note the buried wooden boardwalk in front of the housing complex.

vii. DSM grayscale



Figure 67. Grayscale DSM images of the Haudimar housing complex (after swell), Isabela. The top image shows shades and the bottom is not shaded.

Site report

F. Vegetation cover



Figure 68. Images of the area for which vegetation cover is being monitored for the Haudimar housing complex in Isabela, Puerto Rico. The vegetation cover was 35.6% for the eastern part of the site (top image) and 23.6% for the western portion behind the housing complex (bottom image) on March 14, 2018.

I. Volume measurements of selected areas of the dunes

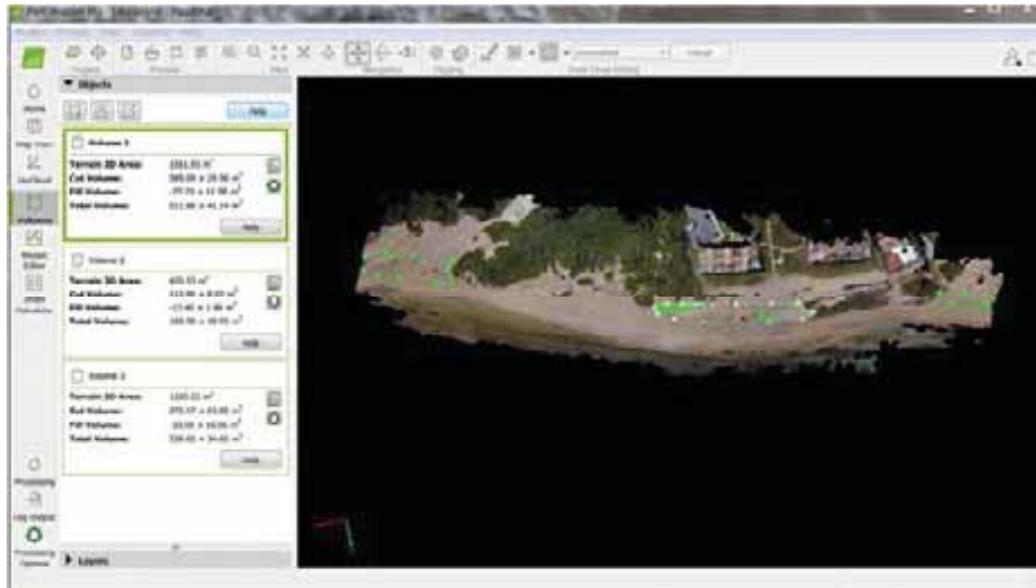


Figure 69. The first polygon (from left to right on the picture) has a 3D area of 1,561.93 m² and a cut volume of 589.09 ± 29.56 m³, a fill volume of -77.23 ± 11.58 m³ and a total volume of 511.86 ± 41.14 m³. The second polygon (from left to right) has an area of 420.53 m² and a cut volume of 112.95 ± 8.97 m³, a fill volume of -12.45 ± 1.96 m³ and a total volume of 100.50 ± 10.93 m³. The third polygon (from left to right) has an area 1,230.22 m² and a cut volume of 272.17 ± 24.05 m³, a fill volume of -33.55 ± 10.56 m³ and a total volume of 238.62 ± 34.62 m³. The volume of these three areas will be monitored in subsequent months to monitor the progress of the restoration process.

J. Conservation threats

This area was severely eroded during the 2017 hurricane season and during the northeasterly swell mainly because the dune in front of the Haudimar housing complex has no vegetation because there is constant foot traffic on the area mainly of residents and visitors. Two large breaches that expose the road and private property were formed after these extreme events (see image below). There is no illegal sand extraction in this area because access to the beach or back dune area is restricted and exclusive to tenants and visitors. There are no significant problems with illegal all terrain vehicles in this area.

K. Recommended ecological restoration courses of action (COA)

The ecological restoration measures that we recommend for this area consist of **the installation of a wooden boardwalk** to direct foot traffic away from sensitive areas where **fencing** (to promote sand accumulation) and **re-vegetation** with dune vegetation will be carried out (see figure below).



Figure 70. Area to be ecologically restored behind the Haudimar housing complex in Barrio Bajuras, Isabela. Highlighted areas correspond to each technique that will be used in this area. **Yellow** represents the location of a wooden boardwalk, **light green** marks the location of planting of dune vegetation, the **red dot** marks the location of an information sign, **tan** represents the area of the dune crest that where biomimicry matrices will be installed to promote the accumulation of sand. The areas shaded in light green represent locations for the planting of dune vegetation.

L. Pix 4D Quality Report

Quality Report

Generated with Pix4Dmapper Pro version 4.2.25

Important: Click on the different icons for:

- ! Help to analyze the results in the Quality Report
- ? Additional information about the sections

[Click here](#) for additional tips to analyze the Quality Report

Summary ?

Project	Haudimar
Processed	2018-04-05 11:33:31
Camera Model Name(s)	FC330_3.6_4000x3000 (RGB)
Average Ground Sampling Distance (GSD)	1.94 cm / 0.76 in
Area Covered	0.051 km ² / 5.0762 ha / 0.02 sq. mi. / 12.5501 acres
Time for Initial Processing (without report)	43m:50s

Quality Check ?

! Images	median of 31995 keypoints per image	✔
! Dataset	174 out of 174 images calibrated (100%), all images enabled	✔
! Camera Optimization	4.52% relative difference between initial and optimized internal camera parameters	✔
! Matching	median of 8715.02 matches per calibrated image	✔
! Georeferencing	yes, no 3D GCP	⚠

Preview ?

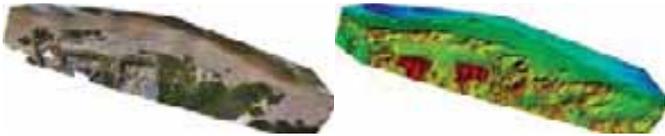


Figure 1: Orthomosaic and the corresponding sparse Digital Surface Model (DSM) before densification.

Calibration Details ?

Number of Calibrated Images	174 out of 174
Number of Geolocated Images	174 out of 174

Initial Image Positions ?

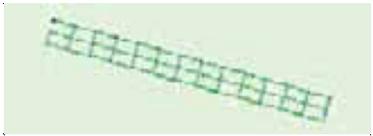
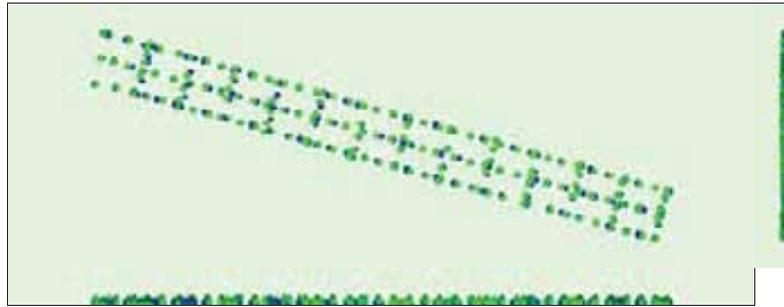


Figure 2: Top view of the initial image position. The green line follows the position of the images in time starting from the large blue dot.

Computed Image/GCPs/Manual Tie Points Positions ?



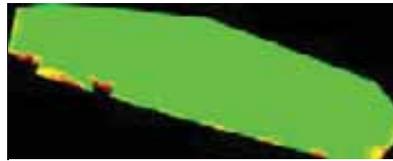
Uncertainty ellipses 10x magnified

Figure 3: Offset between initial (blue dots) and computed (green dots) image positions as well as the offset between the GCPs initial positions (blue crosses) and their computed positions (green crosses) in the top-view (XY plane), front-view (XZ plane), and side-view (YZ plane). Dark green ellipses indicate the absolute position uncertainty of the bundle block adjustment result.

Absolute camera position and orientation uncertainties

	X[m]	Y[m]	Z[m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.143	0.144	0.352	0.835	0.263	0.127
Sigma	0.032	0.032	0.072	0.024	0.063	0.033

Overlap



Number of overlapping images: 1 2 3 4 5+

Figure 4: Number of overlapping images computed for each pixel of the orthomosaic. Red and yellow areas indicate low overlap for which poor results may be generated. Green areas indicate an overlap of over 5 images for every pixel. Good quality results will be generated as long as the number of keypoint matches is also sufficient for these areas (see Figure 5 for keypoint matches).

Bundle Block Adjustment Details

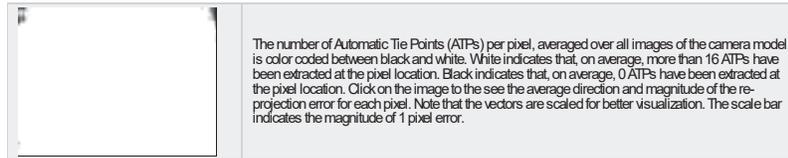
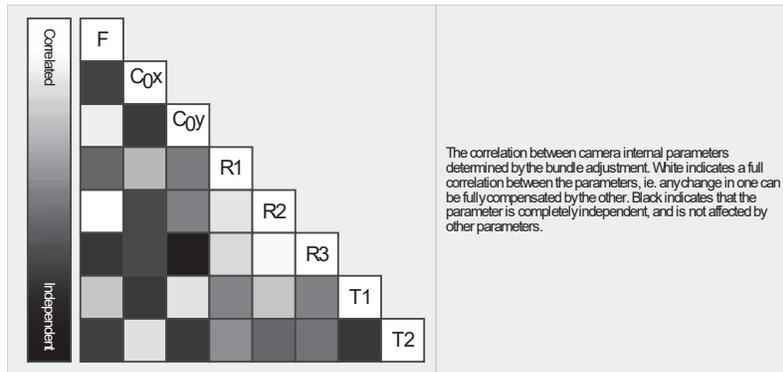
Number of 2D Keypoint Observations for Bundle Block Adjustment	1639822
Number of 3D Points for Bundle Block Adjustment	599889
Mean Reprojection Error [pixels]	0.194

Internal Camera Parameters

FC330_3.6_4000x3000 (RGB). Sensor Dimensions: 6.317 [mm] x 4.738 [mm]

EXIF ID: FC330_3.6_4000x3000

	Focal Length	Principal Point x	Principal Point y	R1	R2	R3	T1	T2
Initial Values	2285.722 [pixel] 3.610 [mm]	2000.006 [pixel] 3.159 [mm]	1500.003 [pixel] 2.369 [mm]	-0.001	-0.002	0.000	-0.001	-0.001
Optimized Values	2389.044 [pixel] 3.773 [mm]	1966.056 [pixel] 3.105 [mm]	1468.056 [pixel] 2.319 [mm]	0.001	-0.007	0.005	-0.000	0.000
Uncertainties (Sigma)	0.242 [pixel] 0.000 [mm]	0.058 [pixel] 0.000 [mm]	0.167 [pixel] 0.000 [mm]	0.000	0.000	0.000	0.000	0.000



2D Keypoints Table

	Number of 2D Keypoints per Image	Number of Matched 2D Keypoints per Image
Median	31995	8715
Mn	20164	1153
Max	57029	23122
Mean	33298	9424

3D Points from 2D Keypoint Matches

	Number of 3D Points Observed
In 2 Images	411965
In 3 Images	96188
In 4 Images	38379
In 5 Images	19687
In 6 Images	11336
In 7 Images	7189
In 8 Images	4672
In 9 Images	3089
In 10 Images	2176
In 11 Images	1536
In 12 Images	957
In 13 Images	735
In 14 Images	585
In 15 Images	411
In 16 Images	295
In 17 Images	212
In 18 Images	148
In 19 Images	111
In 20 Images	79
In 21 Images	42
In 22 Images	42
In 23 Images	24
In 24 Images	13
In 25 Images	9
In 26 Images	5
In 27 Images	3
In 28 Images	1

2D Keypoint Matches

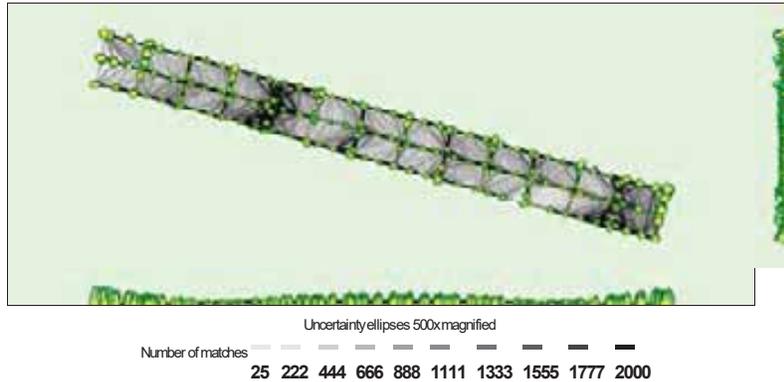


Figure 5: Computed image positions with links between matched images. The darkness of the links indicates the number of matched 2D keypoints between the images. Bright links indicate weak links and require manual tie points or more images. Dark green ellipses indicate the relative camera position uncertainty of the bundle block adjustment result.

Relative camera position and orientation uncertainties

	X[m]	Y[m]	Z[m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.004	0.004	0.008	0.006	0.009	0.004
Sigma	0.001	0.001	0.004	0.002	0.004	0.002

Geolocation Details

Absolute Geolocation Variance

Min Error [m]	Max Error [m]	Geolocation Error X[%]	Geolocation Error Y[%]	Geolocation Error Z[%]
-	-15.00	0.00	0.00	0.00
-15.00	-12.00	0.00	0.00	0.00
-12.00	-9.00	0.00	0.00	0.00
-9.00	-6.00	0.00	0.00	0.00
-6.00	-3.00	6.32	1.15	0.00
-3.00	0.00	37.36	50.57	48.28
0.00	3.00	53.45	47.70	51.72
3.00	6.00	2.87	0.57	0.00
6.00	9.00	0.00	0.00	0.00
9.00	12.00	0.00	0.00	0.00
12.00	15.00	0.00	0.00	0.00
15.00	-	0.00	0.00	0.00
Mean [m]		-0.000548	0.000157	-0.000434
Sigma [m]		1.760474	0.889663	0.571214
RMS Error [m]		1.760474	0.889663	0.571214

Min Error and Max Error represent geolocation error intervals between -1.5 and 1.5 times the maximum accuracy of all the images. Columns X, Y, Z show the percentage of images with geolocation errors within the predefined error intervals. The geolocation error is the difference between the initial and computed image positions. Note that the image geolocation errors do not correspond to the accuracy of the observed 3D points.

Relative Geolocation Variance

Relative Geolocation Error	Images X[%]	Images Y[%]	Images Z[%]
[-1.00, 1.00]	100.00	100.00	100.00
[-2.00, 2.00]	100.00	100.00	100.00
[-3.00, 3.00]	100.00	100.00	100.00
Mean of Geolocation Accuracy [m]	5.000000	5.000000	10.000000
Sigma of Geolocation Accuracy [m]	0.000000	0.000000	0.000000

Images X, Y, Z represent the percentage of images with a relative geolocation error in X, Y, Z

Geolocation Orientational Variance	RMS [degree]
Omega	2.223
Phi	1.545
Kappa	2.602

Geolocation RMS error of the orientation angles given by the difference between the initial and computed image orientation angles.

Initial Processing Details

System Information

Hardware	CPU: Intel(R) Core(TM) i5-3330S CPU @2.70GHz RAM: 8GB GPU: Intel(R) HD Graphics (Driver: 10.18.10.3412), RDPDD Chained DD (Driver: unknown), RDP Encoder Mirror Driver (Driver: unknown), RDP Reflector Display Driver (Driver: unknown)
Operating System	Windows 7 Professional, 64-bit

Coordinate Systems

Image Coordinate System	WGS84 (egm96)
Output Coordinate System	WGS 84 / UTMzone 19N (egm96)

Processing Options

Detected Template	3D Maps
Keypoints Image Scale	Full, Image Scale: 1
Advanced: Matching Image Pairs	Aerial Grid or Corridor
Advanced: Matching Strategy	Use Geometrically Verified Matching: no
Advanced: Keypoint Extraction	Targeted Number of Keypoints: Automatic
Advanced: Calibration	Calibration Method: Standard Internal Parameters Optimization: All External Parameters Optimization: All Rematch: Auto, yes

Point Cloud Densification details

Processing Options

Image Scale	multiscale, 1/2 (Half image size, Default)
Point Density	Optimal
Minimum Number of Matches	3
3D Textured Mesh Generation	yes
3D Textured Mesh Settings:	Resolution: Medium Resolution (default) Color Balancing: no
LOD	Generated: no
Advanced: 3D Textured Mesh Settings	Sample Density Divider: 1
Advanced: Image Groups	group1
Advanced: Use Processing Area	yes
Advanced: Use Annotations	yes
Time for Point Cloud Densification	40m:10s
Time for Point Cloud Classification	NA
Time for 3D Textured Mesh Generation	09m:26s

Results

Number of Generated Tiles	1
Number of 3D Densified Points	11048839
Average Density (per m ³)	435.87

DSM, Orthomosaic and Index Details

Processing Options

DSM and Orthomosaic Resolution	1 x GSD (1.94 [cm/pixel])
DSM Filters	Noise Filtering: yes Surface Smoothing: yes, Type: Sharp
Raster DSM	Generated: yes Method: Inverse Distance Weighting Merge Tiles: yes
Orthomosaic	Generated: yes Merge Tiles: yes GeoTIFF Without Transparency: no Google Maps Tiles and KML: no
Time for DSM Generation	14m:31s

Time for Orthomosaic Generation	28m:01s
Time for DTMGeneration	00s
Time for Contour Lines Generation	00s
Time for Reflectance Map Generation	00s
Time for Index/Map Generation	00s

Site name:

West of Secret Spot Beach

Before Hurricane María



A. Physical address:

West of Secret Spot Beach, Road PR 466, Isabela, Puerto Rico, 00662

B. Date of capture of imagery:

July 29, 2017

C. Coordinates:

18.51398785 N - 67.04845982 W

D. Description of site:

This area is located on the western part of the area commonly known as Secret Spot in Isabela, Puerto Rico. This is a world renowned surfing destination. The dunes in the area were wiped out by commercial sand extraction prior to 2007 but the extreme events of the 2017 hurricane season and the northeasterly swell of March of 2018 severely eroded the areas that had been restored since 2007. This site consists of a large breach on the primary dune of the Isabela dune system. The area had 6 small patches of vegetation prior to the 2017 hurricane season and the northeasterly swell.

E. Distance from community:

This site is located at approximately 124 m from PR 466, 800 m from the cliff and the nearest houses are at this same distance but at 33 m above sea level to the south. Most of the surrounding areas are not developed and uninhabited and the nearest residential development is located at approximately 1.9 m to the east.

F. Aerial imagery

i. Contour map



Figure 71. Contour map of the west of Secret Spot Beach, Isabela Puerto Rico with elevation intervals of 1 meter.

ii. 3D imagery

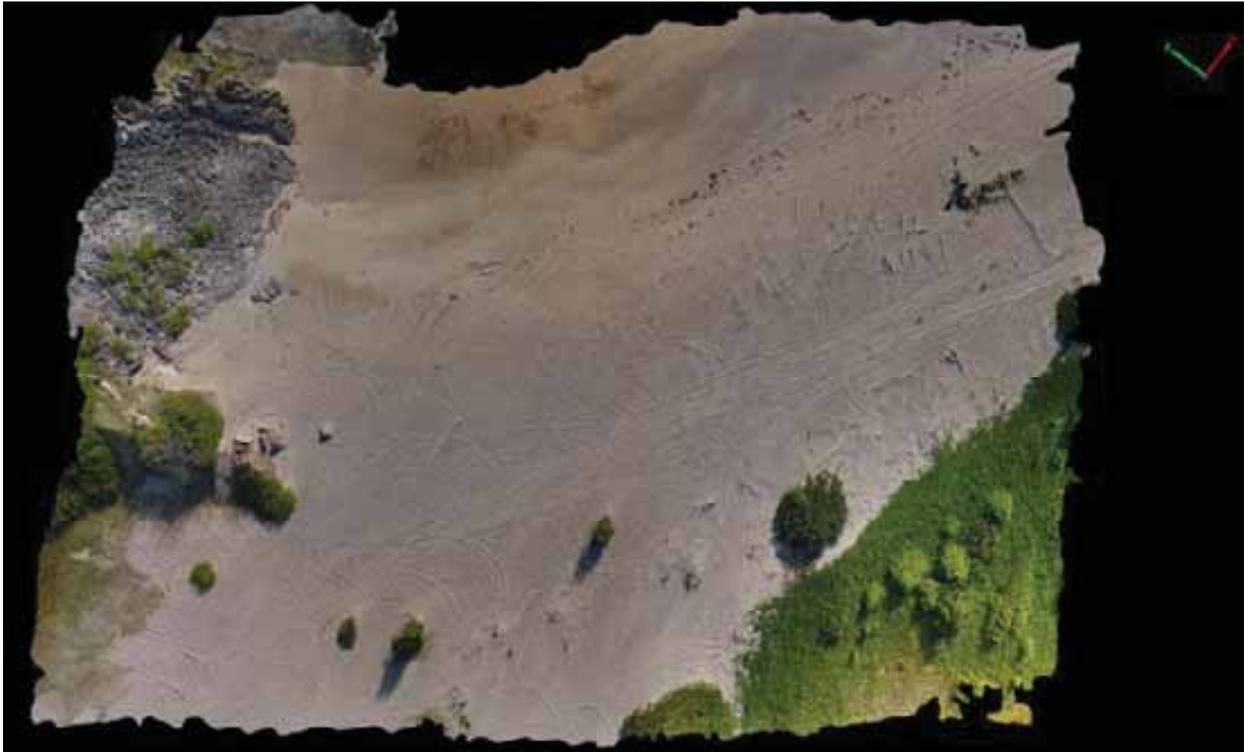


Figure 72. Aerial 3D image of the western part of Secret Spot.

iii. Orthomosaic model



Figure 73. Orthomosaic image of the western part of Secret Spot, Isabela.

iv. Density Surface Models (DSM)

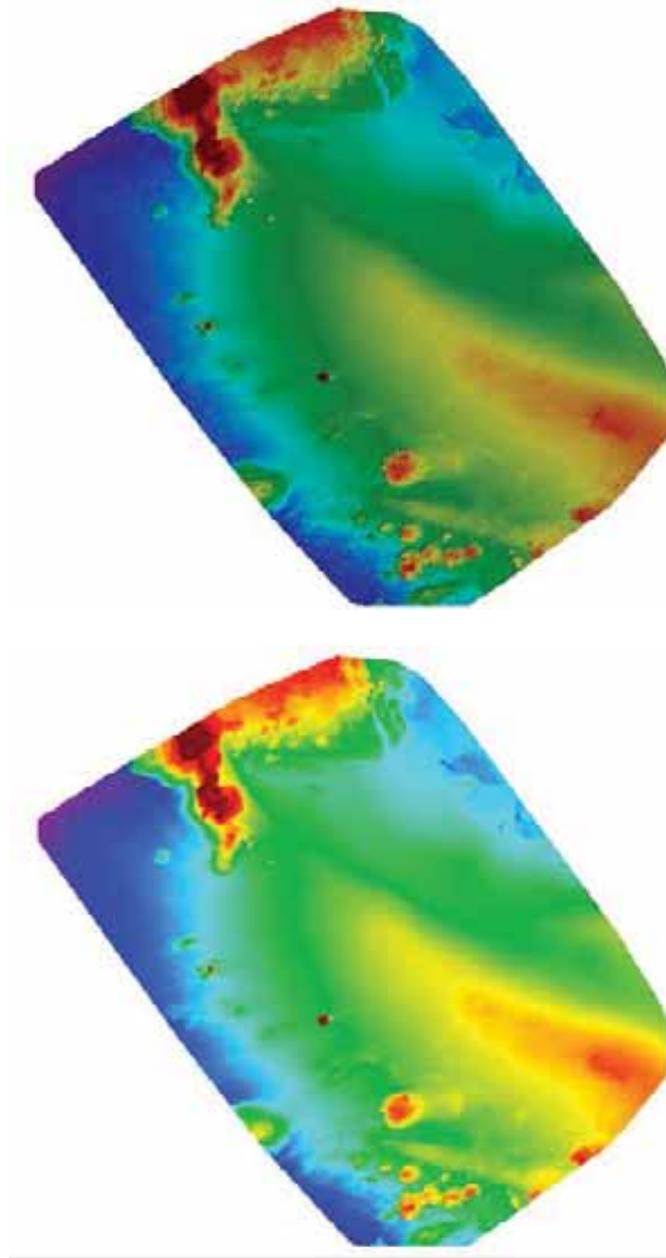


Figure 74. Density surface model (with shading top and without shading bottom) images of the dune located on the western side Secret Spot, Isabela

v. Thermal images

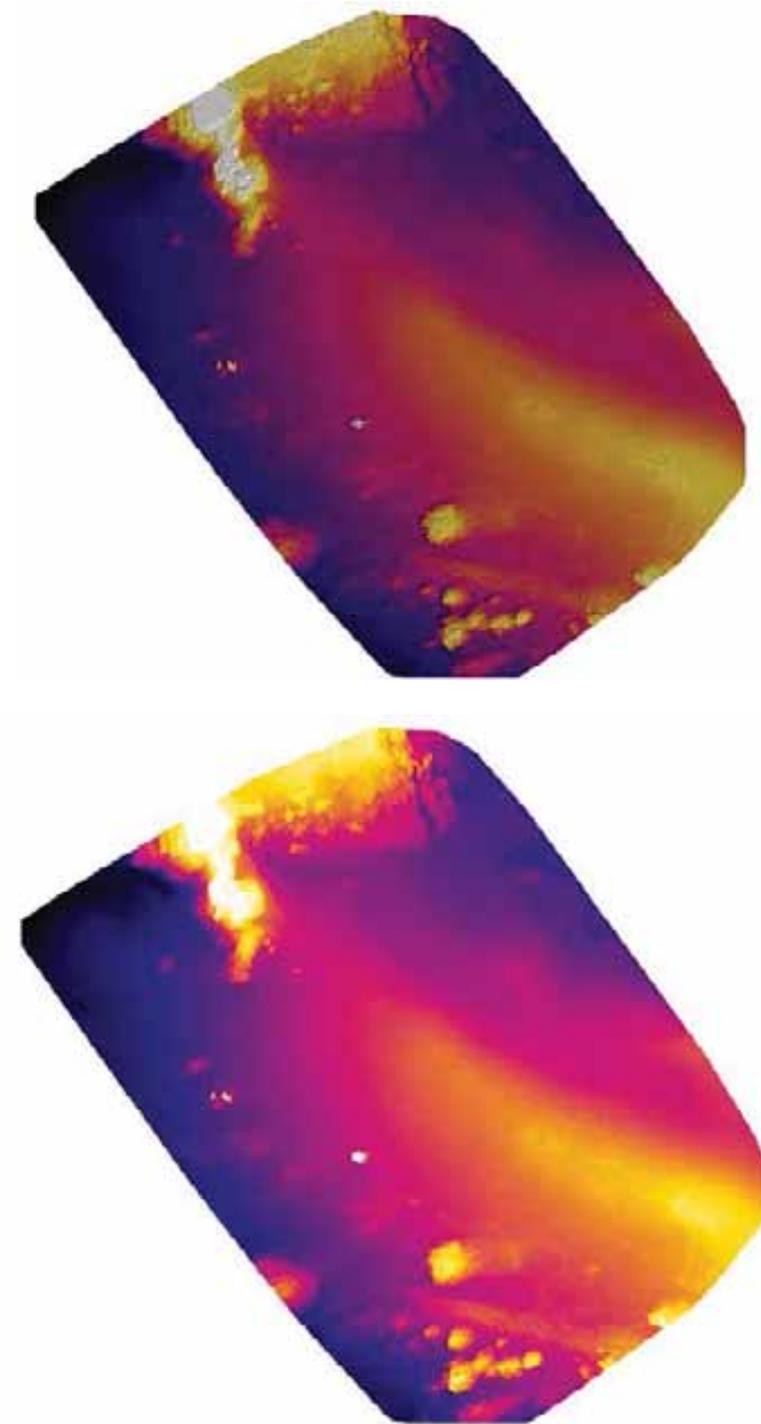


Figure 75. Thermal images (with shading top and without shading bottom) of the dune located at the western part Secret Spot, Isabela.

vi. 3D altitude RGB

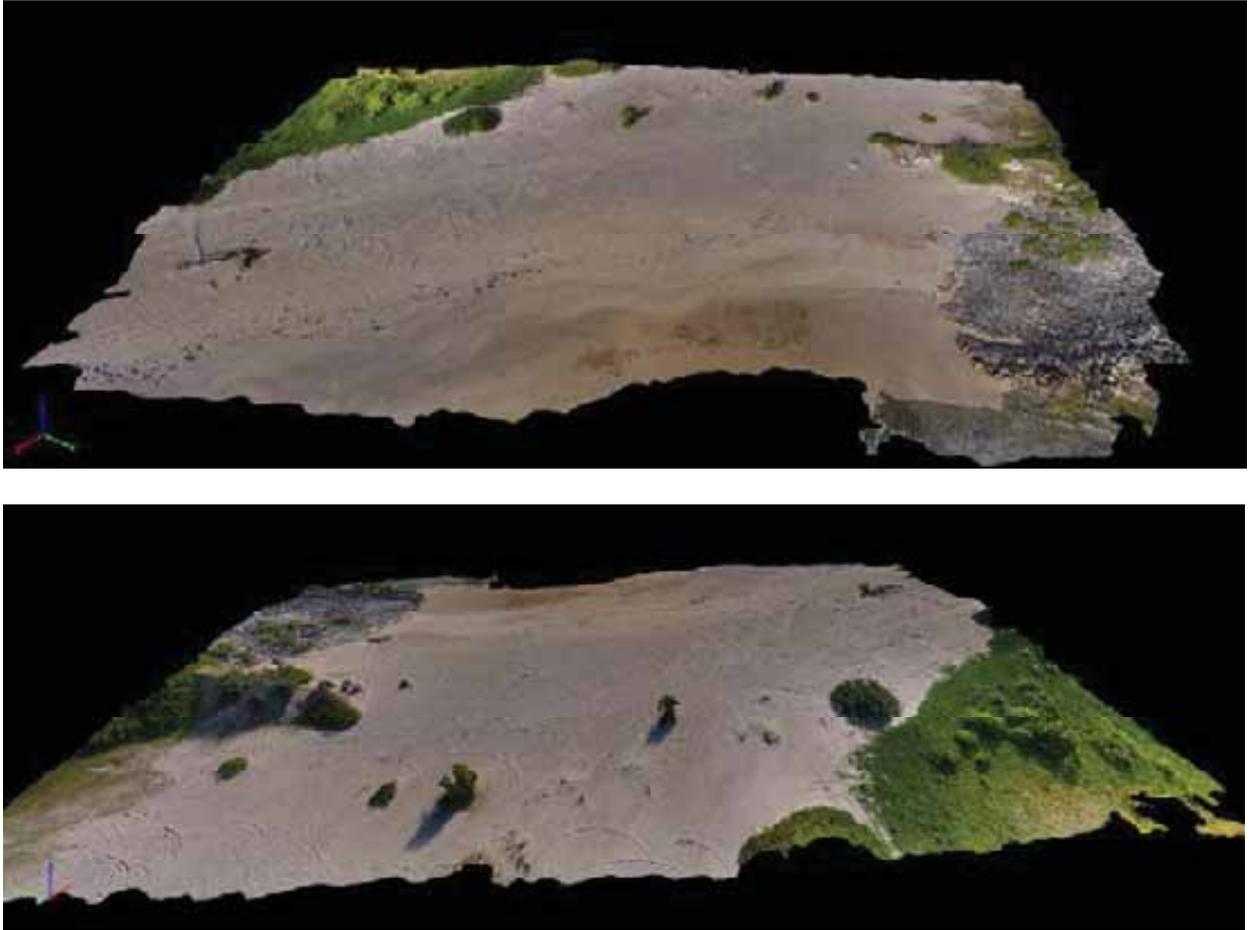


Figure 76. Three dimensional RGB images of the western part of Secret Spot, Isabela. View from the north (top) and from the south (bottom).

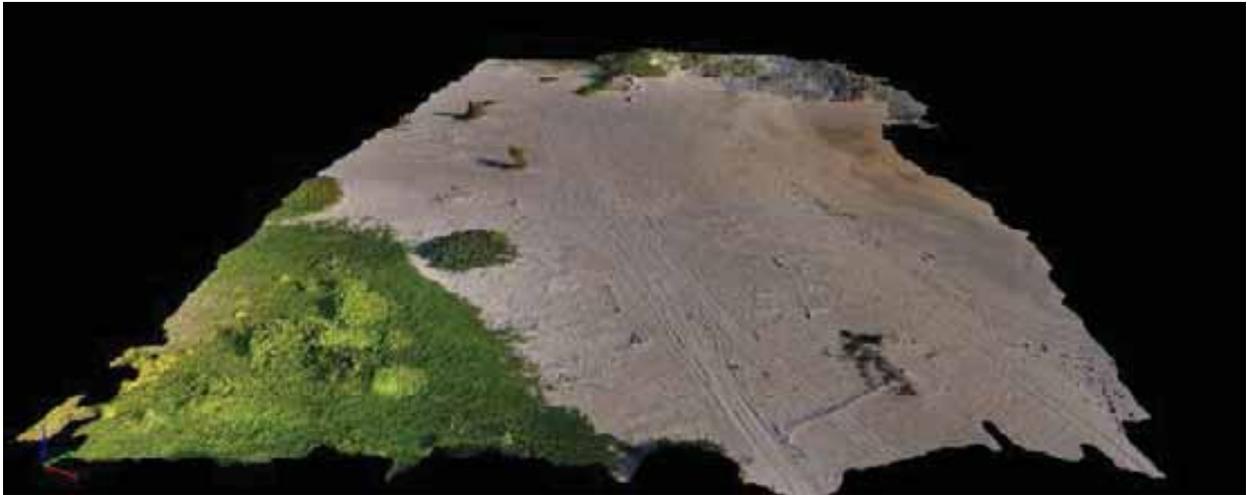


Figure 77. Three dimensional RGB images of the western part of Secret Spot, Isabela. View from the west (top) and from the east (bottom). *Note- Mayer*

vii. DSM grayscale

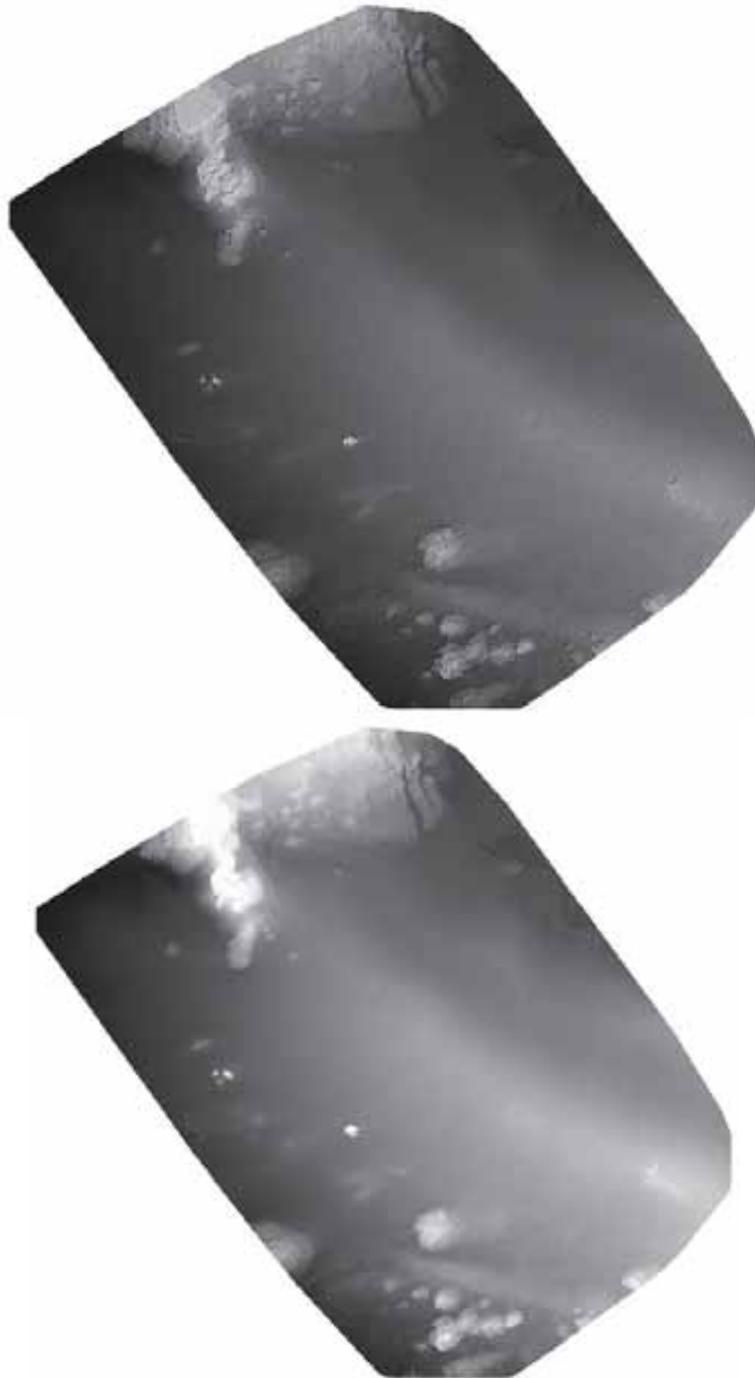


Figure 78. Grayscale DSM images of the dune to the western part of Secret Spot, Isabela. The top image shows shades and the bottom is not shaded

Site report

G. Vegetation cover



Figure 79. Area for which percent vegetation cover is being monitored in the western part of Secret Spot in Isabela, Puerto Rico. The vegetation cover in this area was calculated to be 12 % on July 29, 2017.

K. Pix4D Quality Report

Generated with Pix4Dmapper Pro version 4.2.26

 **Important:** Click on the different icons for:

-  Help to analyze the results in the Quality Report
-  Additional information about the sections

 Click [here](#) for additional tips to analyze the Quality Report

Summary

Project	New Oeste de Secret Spot Antes de María
Processed	2018-04-25 16:32:54
Camera Model Name(s)	FC330_3.6_4000x3000 (RGB)
Average Ground Sampling Distance (GSD)	0.77 cm / 0.30 in
Area Covered	0.013 km ² / 1.3385 ha / 0.01 sq. mi. / 3.3091 acres
Time for Initial Processing (without report)	11m:27s

Quality Check

 Images	median of 30321 keypoints per image	
 Dataset	243 out of 243 images calibrated (100%), all images enabled	
 Camera Optimization	4.76% relative difference between initial and optimized internal camera parameters	
 Matching	median of 15327.6 matches per calibrated image	
 Georeferencing	yes, no 3D GCP	

 **Preview** 

Number of Calibrated Images	out of 243
Number of Geolocated Images	out of 243

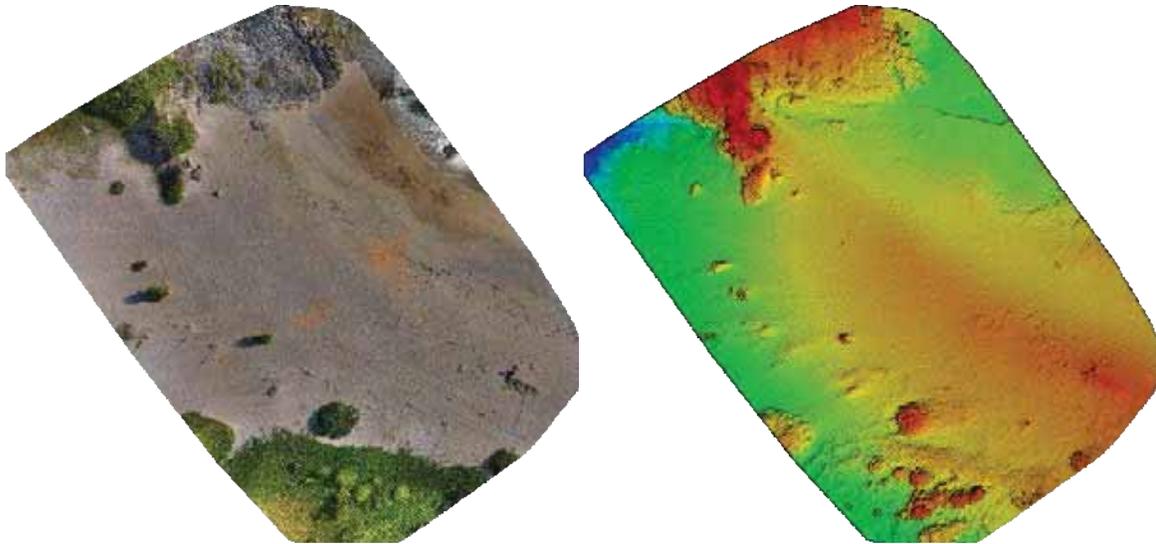


Figure 1: Orthomosaic and the corresponding sparse Digital Surface Model (DSM) before densification.

Calibration Details



Initial Image Positions

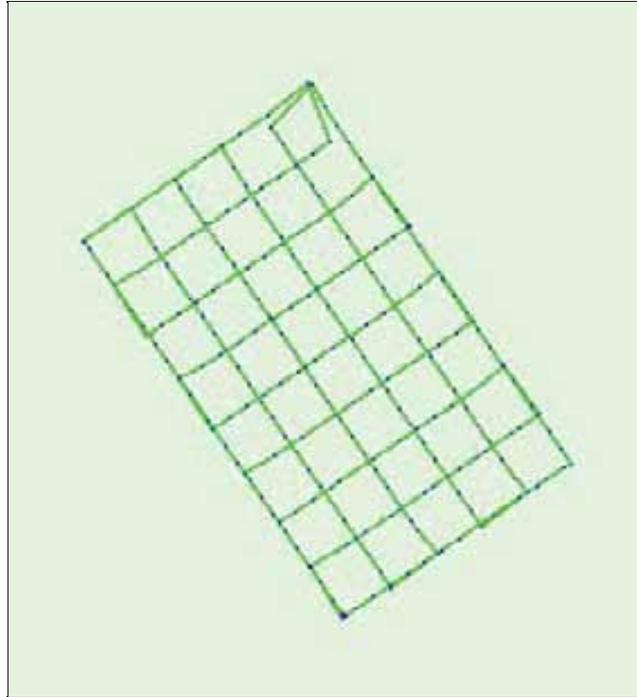
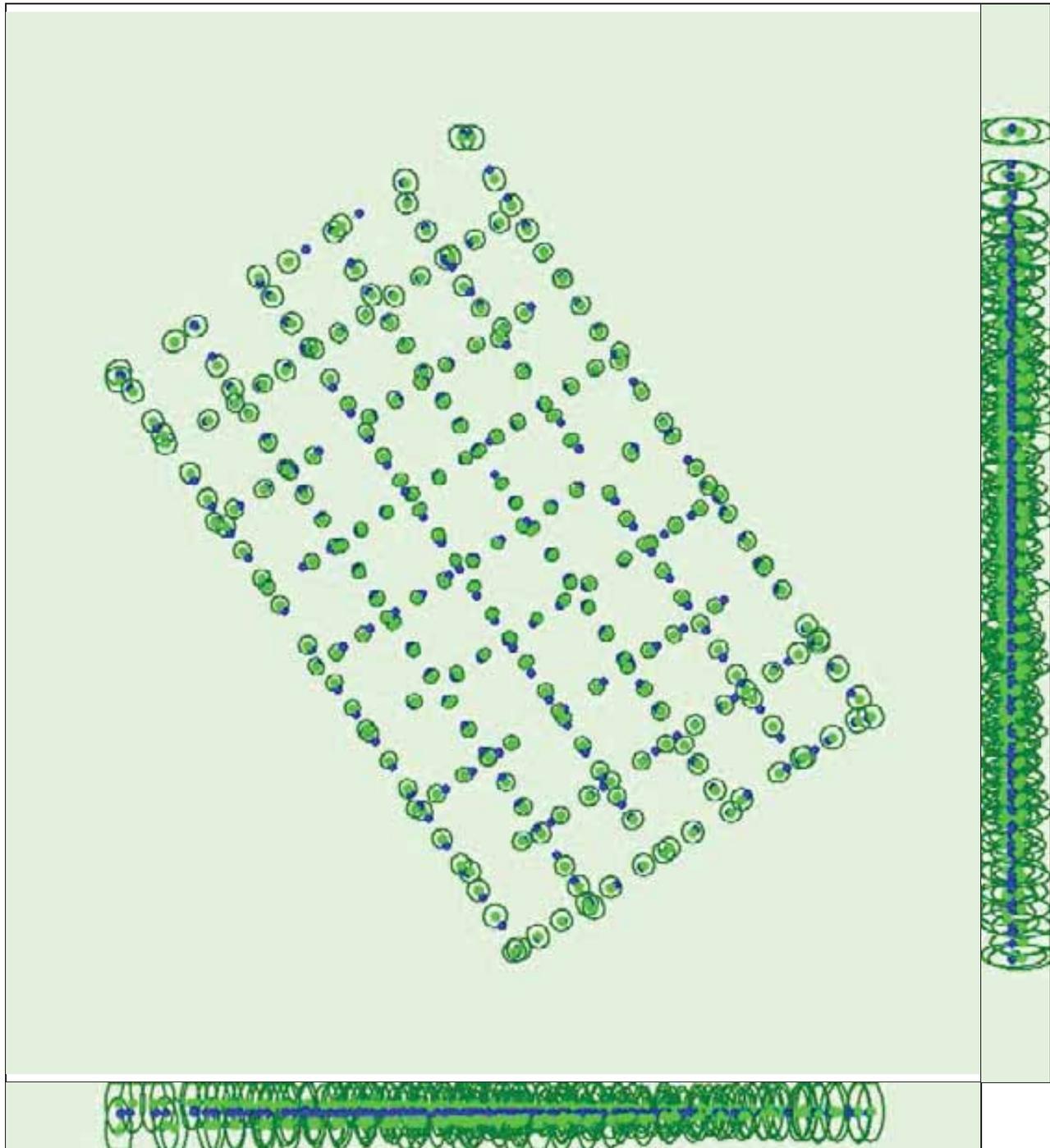


Figure 2: Top view of the initial image position. The green line follows the position of the images in time starting from the large blue dot.

● Computed Image/GCPs/Manual Tie Points Positions ●



Uncertainty ellipses 10x magnified

Figure 3: Offset between initial (blue dots) and computed (green dots) image positions as well as the offset between the GCPs initial positions (blue crosses) and their computed positions (green crosses) in the top-view (XY plane), front-view (XZ plane), and side-view (YZ plane). Dark green ellipses indicate the absolute position uncertainty of the bundle block adjustment result.

Absolute camera position and orientation uncertainties

	X [m]	Y [m]	Z [m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.140	0.140	0.339	0.429	0.466	0.239
Sigma	0.024	0.024	0.075	0.013	0.008	0.008

Overlap

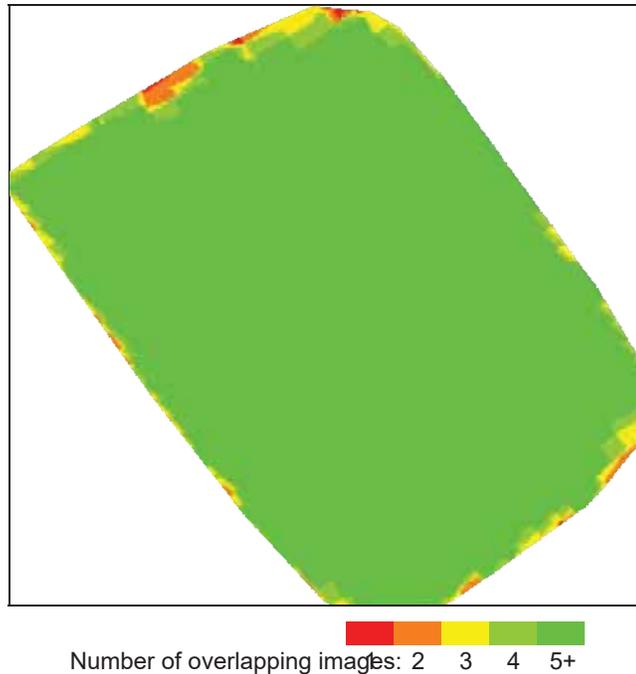


Figure 4: Number of overlapping images computed for each pixel of the orthomosaic. Red and yellow areas indicate low overlap for which poor results may be generated. Green areas indicate an overlap of over 5 images for every pixel. Good quality results will be generated as long as the number of keypoint matches is also sufficient for these areas (see Figure 5 for keypoint matches).

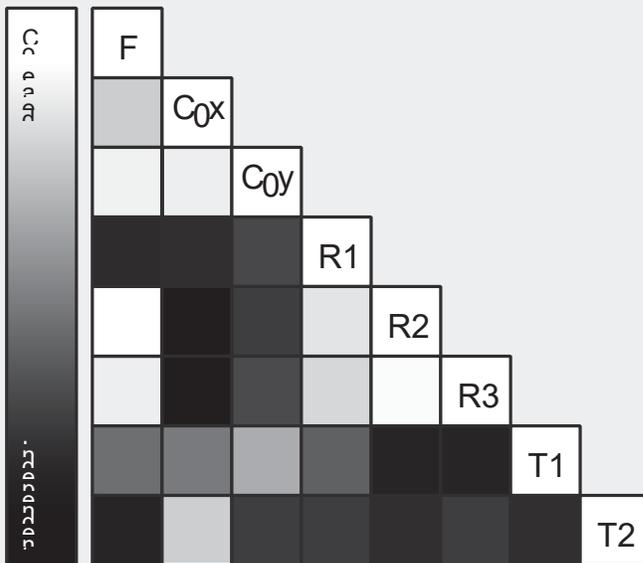
Bundle Block Adjustment Details

Number of 2D Keypoint Observations for Bundle Block Adjustment	3474614
Number of 3D Points for Bundle Block Adjustment	1133095
Mean Reprojection Error [pixels]	0.205

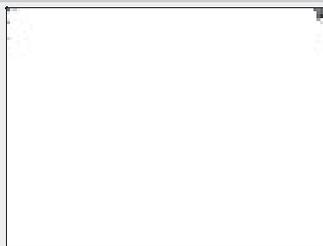
Internal Camera Parameters FC330_3.6_4000x3000 (RGB). Sensor Dimensions: 6.317 [mm] x 4.738 [mm]

EXIF ID: FC330_3.6_4000x3000

	Focal Length	Principal Point x	Principal Point y	R1	R2	R3	T1	T2
Initial Values	2285.722 [pixel] 3.610 [mm]	2000.006 [pixel] 3.159 [mm]	1500.003 [pixel] 2.369 [mm]	- 0.001	- 0.002	0.000	- 0.001	- 0.001
Optimized Values	2394.607 [pixel] 3.782 [mm]	1962.158 [pixel] 3.099 [mm]	1459.510 [pixel] 2.305 [mm]	- 0.001	- 0.002	0.002	0.000	- 0.000
Uncertainties (Sigma)	0.458 [pixel] 0.001 [mm]	0.050 [pixel] 0.000 [mm]	0.234 [pixel] 0.000 [mm]	0.000	0.000	0.000	0.000	0.000



The correlation between camera internal parameters determined by the bundle adjustment. White indicates a full correlation between the parameters, i.e. any change in one can be fully compensated by the other. Black indicates that the parameter is completely independent, and is not affected by other parameters.



The number of Automatic Tie Points (ATPs) per pixel, averaged over all images of the camera model, is color coded between black and white. White indicates that, on average, more than 16 ATPs have been extracted at the pixel location. Black indicates that, on average, 0 ATPs have been extracted at the pixel location. Click on the image to see the average direction and magnitude of the re-projection error for each pixel. Note that the vectors are scaled for better visualization. The scale bar indicates the magnitude of 1 pixel error.

2D Keypoints Table

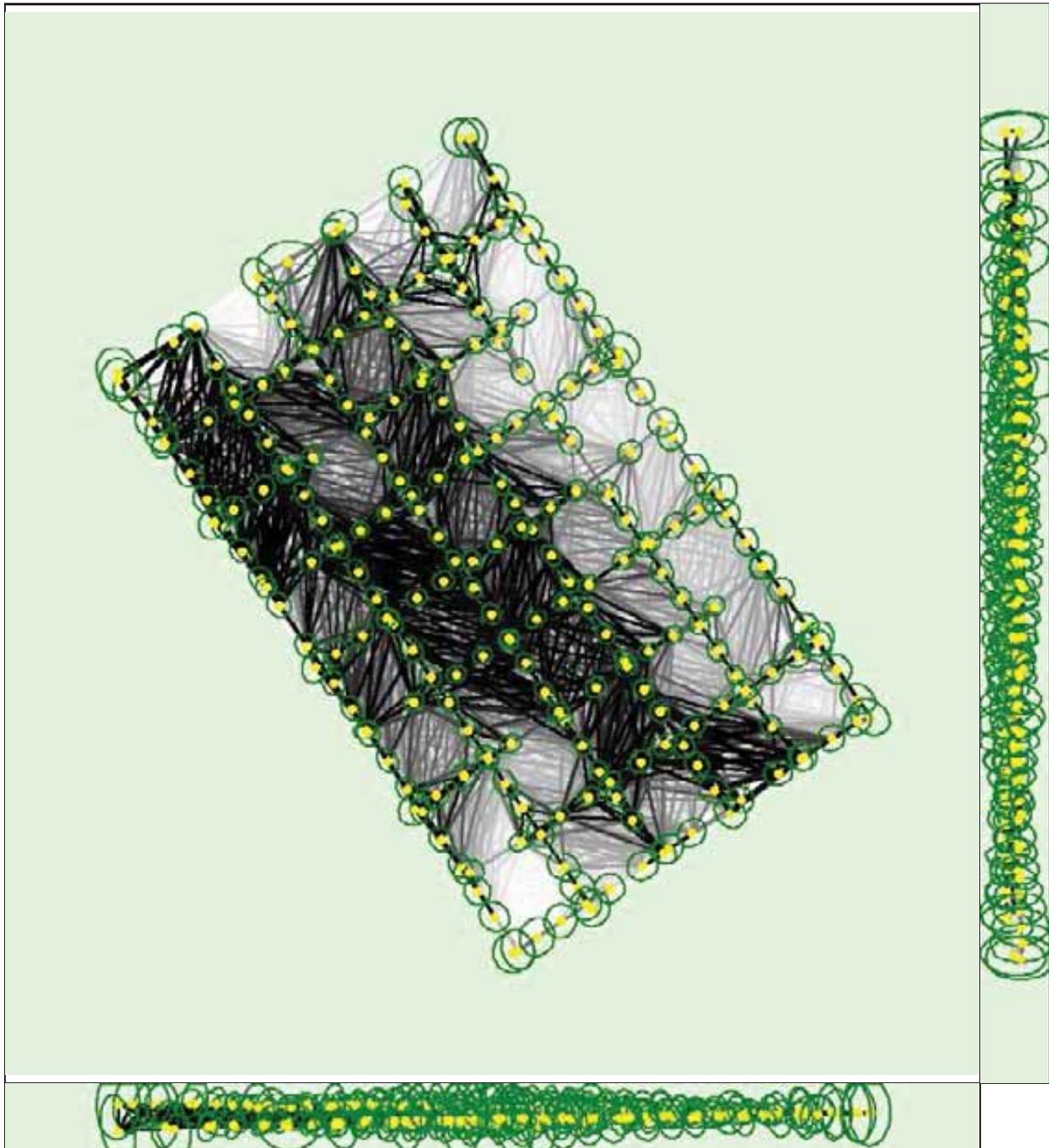
	Number of 2D Keypoints per Image	Number of Matched 2D Keypoints per Image
Median	30321	15328
Min	14573	2949

Max	74916	31365
Mean	32225	14299

3D Points from 2D Keypoint Matches

	Number of 3D Points Observed
In 2 Images	696619
In 3 Images	193215
In 4 Images	87648
In 5 Images	49245
In 6 Images	30503
In 7 Images	20580
In 8 Images	14932
In 9 Images	10991
In 10 Images	7979
In 11 Images	6042
In 12 Images	4563
In 13 Images	3369
In 14 Images	2592
In 15 Images	1904
In 16 Images	1304
In 17 Images	761
In 18 Images	444
In 19 Images	208
In 20 Images	118
In 21 Images	39
In 22 Images	24
In 23 Images	6
In 24 Images	7
In 25 Images	2

2D Keypoint Matches



Uncertainty ellipses 1000x magnified

Number of matches

25	222	444	666	888	1111	1333	1555	1777	2000
----	-----	-----	-----	-----	------	------	------	------	------

Figure 5: Computed image positions with links between matched images. The darkness of the links indicates the number of matched 2D keypoints between the images. Bright links indicate weak links and require manual tie points or more images. Dark green ellipses indicate the relative camera position uncertainty of the bundle block adjustment result.

Relative camera position and orientation uncertainties

	X [m]	Y [m]	Z [m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.002	0.002	0.002	0.009	0.008	0.004
Sigma	0.000	0.000	0.001	0.003	0.003	0.001

Geolocation Details

Absolute Geolocation Variance

Min Error [m]	Max Error [m]	Geolocation Error X [%]	Geolocation Error Y [%]	Geolocation Error Z [%]
-	-15.00	0.00	0.00	0.00
-15.00	-12.00	0.00	0.00	0.00
-12.00	-9.00	0.00	0.00	0.00
-9.00	-6.00	0.00	0.00	0.00
-6.00	-3.00	0.00	0.00	0.00
-3.00	0.00	54.73	42.39	55.14
0.00	3.00	45.27	57.61	44.86
3.00	6.00	0.00	0.00	0.00
6.00	9.00	0.00	0.00	0.00
9.00	12.00	0.00	0.00	0.00
12.00	15.00	0.00	0.00	0.00
15.00	-	0.00	0.00	0.00
Mean [m]		-0.000001	0.000002	-0.000001
Sigma [m]		0.726465	0.781751	1.072132
RMS Error [m]		0.726465	0.781751	1.072132

Min Error and Max Error represent geolocation error intervals between -1.5 and 1.5 times the maximum accuracy of all the images. Columns X, Y, Z show the percentage of images with geolocation errors within the predefined error intervals. The geolocation error is the difference between the initial and computed image positions. Note that the image geolocation errors do not correspond to the accuracy of the observed 3D points.

Relative Geolocation Variance

Relative Geolocation Error	Images X [%]	Images Y [%]	Images Z [%]
[-1.00, 1.00]	100.00	100.00	100.00
[-2.00, 2.00]	100.00	100.00	100.00
[-3.00, 3.00]	100.00	100.00	100.00
Mean of Geolocation Accuracy [m]	5.000000	5.000000	10.000000
Sigma of Geolocation Accuracy [m]	0.000000	0.000000	0.000000

Images X, Y, Z represent the percentage of images with a relative geolocation error in X, Y, Z.

Image Coordinate System	WGS84 (egm96)
Output Coordinate System	WGS 84 / UTM zone 19N (egm96)

Geolocation Orientational Variance	RMS [degree]
Omega	1.550
Phi	1.644
Kappa	0.944

Geolocation RMS error of the orientation angles given by the difference between the initial and computed image orientation angles.

Initial Processing Details

System Information

Hardware	CPU: Intel(R) Core(TM) i7-8700K CPU @ 3.70GHz RAM: 16GB GPU: NVIDIA GeForce GTX 1070 (Driver: 23.21.13.9065)
Operating System	Windows 10 Home, 64-bit

Coordinate Systems

Processing Options

Detected Template	3D Maps
Keypoints Image Scale	Full, Image Scale: 1
Advanced: Matching Image Pairs	Aerial Grid or Corridor
Advanced: Matching Strategy	Use Geometrically Verified Matching: no
Advanced: Keypoint Extraction	Targeted Number of Keypoints: Automatic
Advanced: Calibration	Calibration Method: Standard Internal Parameters Optimization: All External Parameters Optimization: All Rematch: Auto, yes

Point Cloud Densification details

Processing Options

Image Scale	multiscale, 1/2 (Half image size, Default)
Point Density	Optimal
Minimum Number of Matches	3
3D Textured Mesh Generation	yes
3D Textured Mesh Settings:	Resolution: Medium Resolution (default) Color Balancing: no
LOD	Generated: no
Advanced: 3D Textured Mesh Settings	Sample Density Divider: 1
Advanced: Image Groups	group1
Advanced: Use Processing Area	yes

Advanced: Use Annotations	yes
Time for Point Cloud Densification	14m:55s
Time for Point Cloud Classification	NA
Time for 3D Textured Mesh Generation	06m:27s

Results

Number of Generated Tiles	1
Number of 3D Densified Points	18582918
Average Density (per m ³)	8488.45

DSM, Orthomosaic and Index Details

Processing Options

DSM and Orthomosaic Resolution	1 x GSD (0.767 [cm/pixel])
DSM Filters	Noise Filtering: yes Surface Smoothing: yes, Type: Sharp
Raster DSM	Generated: yes Method: Inverse Distance Weighting Merge Tiles: yes
Orthomosaic	Generated: yes Merge Tiles: yes GeoTIFF Without Transparency: no Google Maps Tiles and KML: no
Time for DSM Generation	10m:13s
Time for Orthomosaic Generation	18m:07s
Time for DTM Generation	00s

Time for Contour Lines Generation	00s
Time for Reflectance Map Generation	00s
Time for Index Map Generation	00s

Site name:

West of Secret Spot Beach, Isabela

After Hurricane María

A. Physical address:

Western part Secret Spot (after María), PR 466, Isabela, Puerto Rico, 00662

B. Date of capture of imagery:

January 13, 2018

C. Coordinates:

18.51398224 N - 67.04852217 W

D. Aerial imagery

i. Contour map

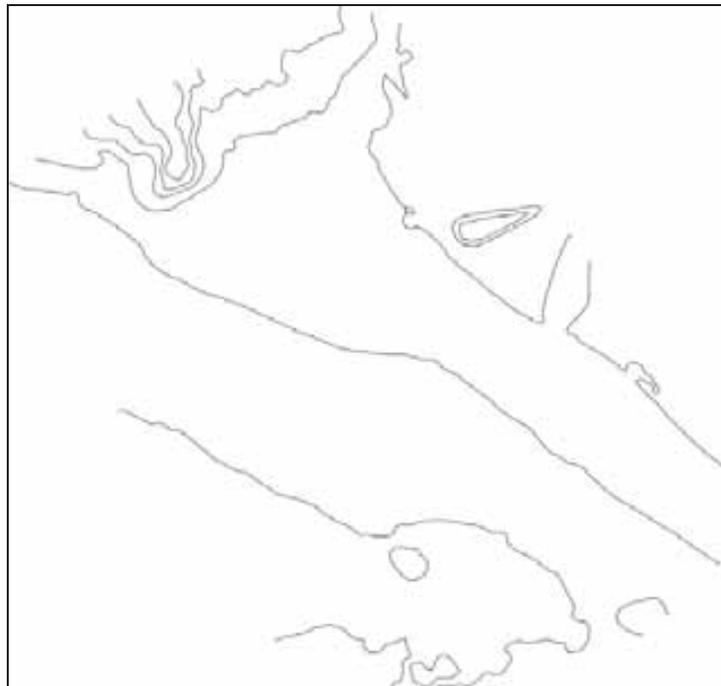


Figure 80. Contour map of West of Secret Spot (after María), Isabela Puerto Rico with elevation intervals of 1 meter.

ii. 3D imagery



Figure 81. Aerial 3D image of the western part of Secret Spot (after Hurricane María).

iii. Orthomosaic model

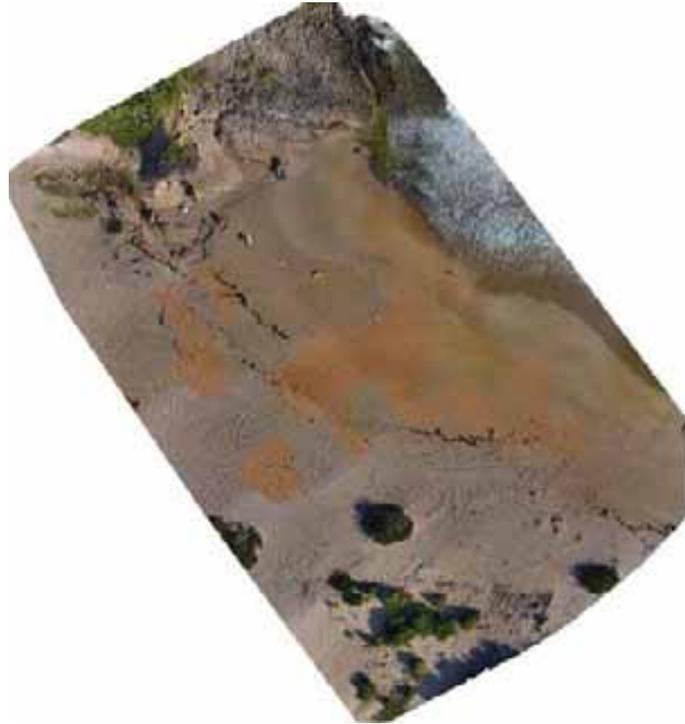


Figure 82. Orthomosaic image of West of Secret Spot (after María) Isabela

iv. Density Surface Models (DSM)

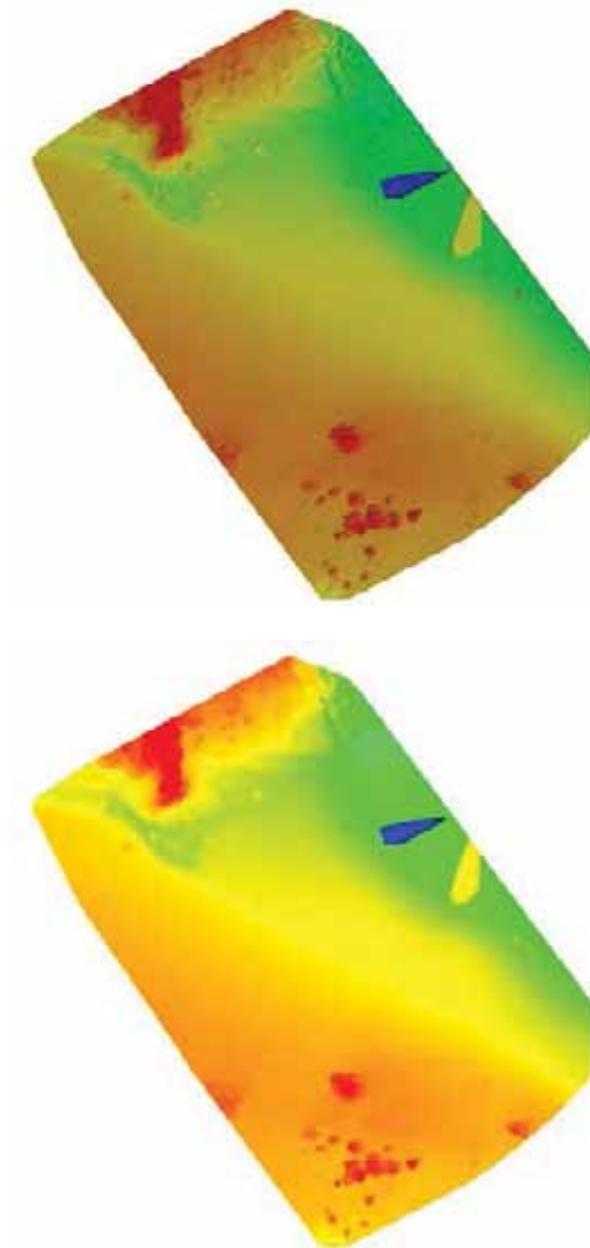


Figure 83. Density surface model (with shading top and without shading bottom) images of the dune located at the West of Secret Spot (after María), Isabela

v. Thermal images

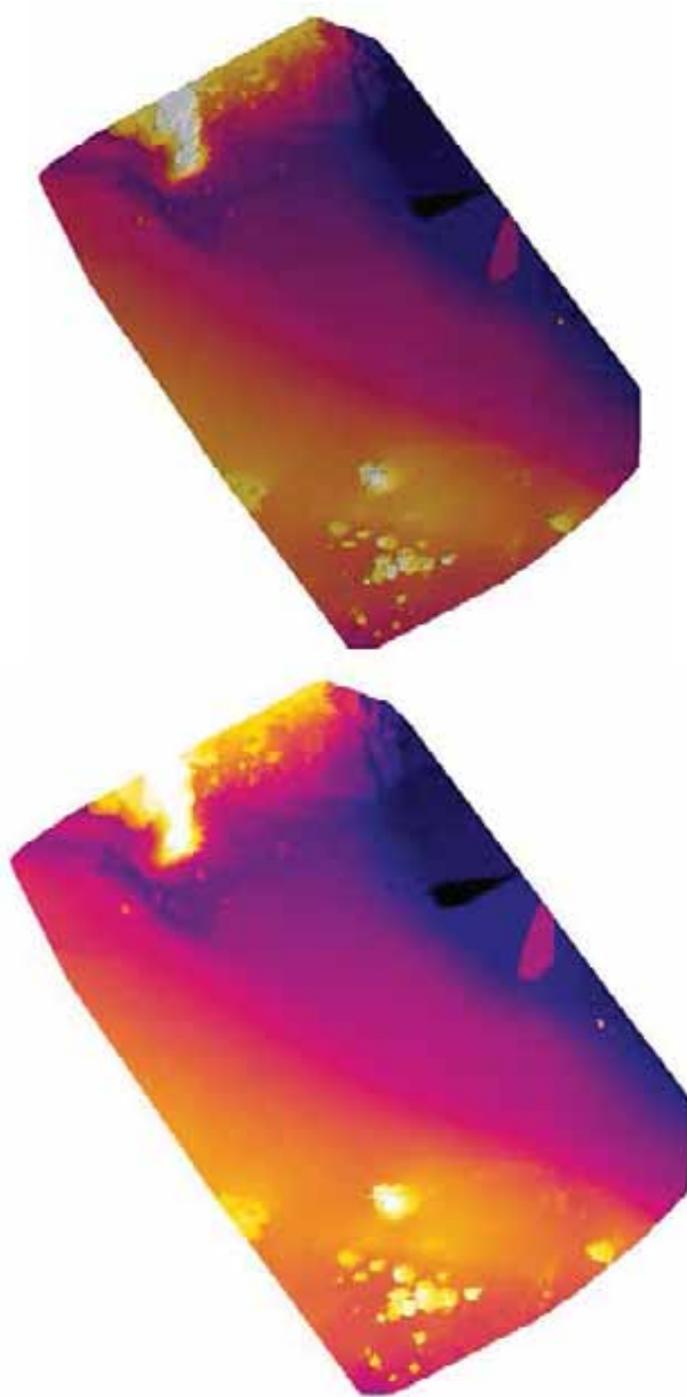


Figure 84. Thermal images (with shading top and without shading bottom) of the dune located at the West of Secret Spot (after María), Isabela

vi. 3D altitude RGB North



Figure 85. Three dimensional RGB images of the West of Secret Spot, Isabela (after María). View from the north (top) and from the south (bottom).



Figure 86. Three dimensional RGB images of the West of Secret Spot (after María), Isabela. View from the west (top) and from the east (bottom).

vii. DSM grayscale

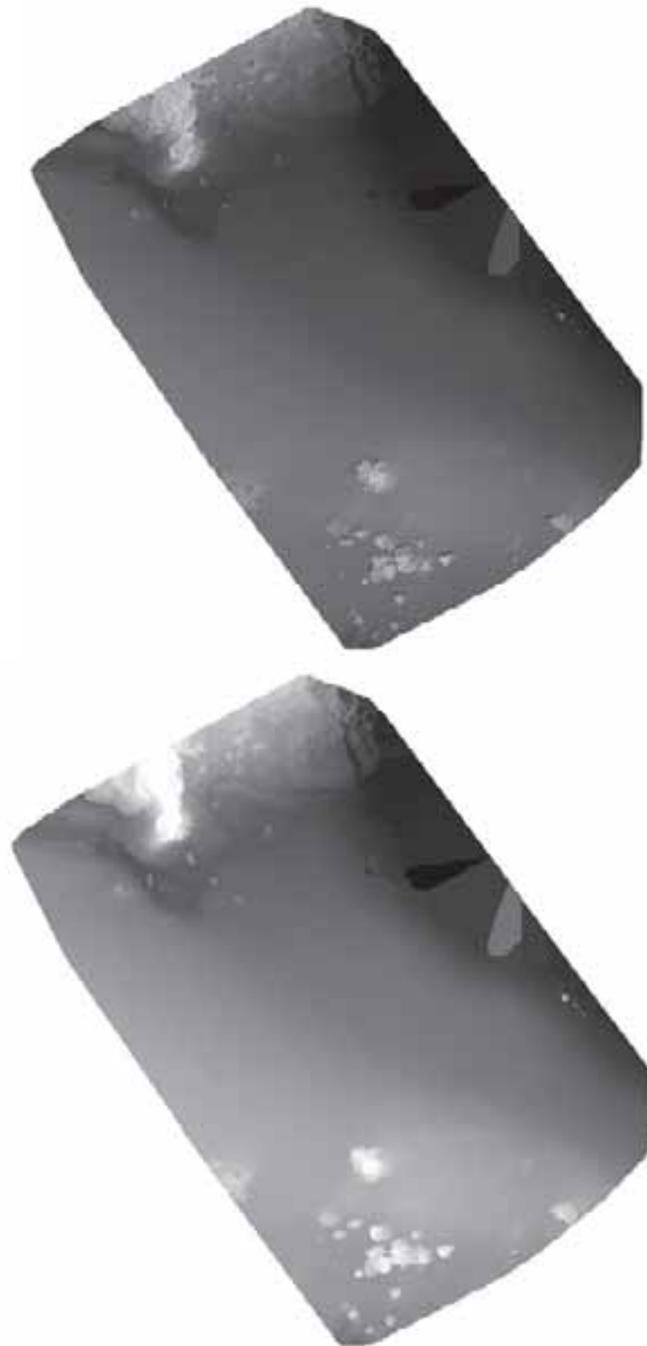


Figure 87. Grayscale DSM images of the dune to the West of Secret Spot (after María), Isabela. The top image shows shades and the bottom is not shaded.

Site report

E. Vegetation cover



Figure 88. Image of the area for which vegetation cover is being monitored for the western part of Secret Spot Beach in Isabela, Puerto Rico. The vegetation cover was 3.6 % on January 13, 2018.

F. Pix 4D Quality Report

Quality Report



Generated with Pix4Dmapper Pro version 4.2.26

- Important: Click on the different icons for:
 - Help to analyze the results in the Quality Report
 - Additional information about the sections

Click [here](#) for additional tips to analyze the Quality Report

Summary



Project	New Oeste de Secret Spot Despues Del Huracan María
Processed	2018-04-26 12:18:11
Camera Model Name(s)	FC330_3.6_4000x3000 (RGB)
Average Ground Sampling Distance (GSD)	0.77 cm / 0.30 in
Area Covered	0.013 km ² / 1.2780 ha / 0.00 sq. mi. / 3.1596 acres
Time for Initial Processing (without report)	12m:04s

Quality Check



Images	median of 38270 keypoints per image	
Dataset	188 out of 194 images calibrated (96%), all images enabled	
Camera Optimization	5.19% relative difference between initial and optimized internal camera parameters	
Matching	median of 16335.6 matches per calibrated image	
Georeferencing	yes, no 3D GCP	

Preview



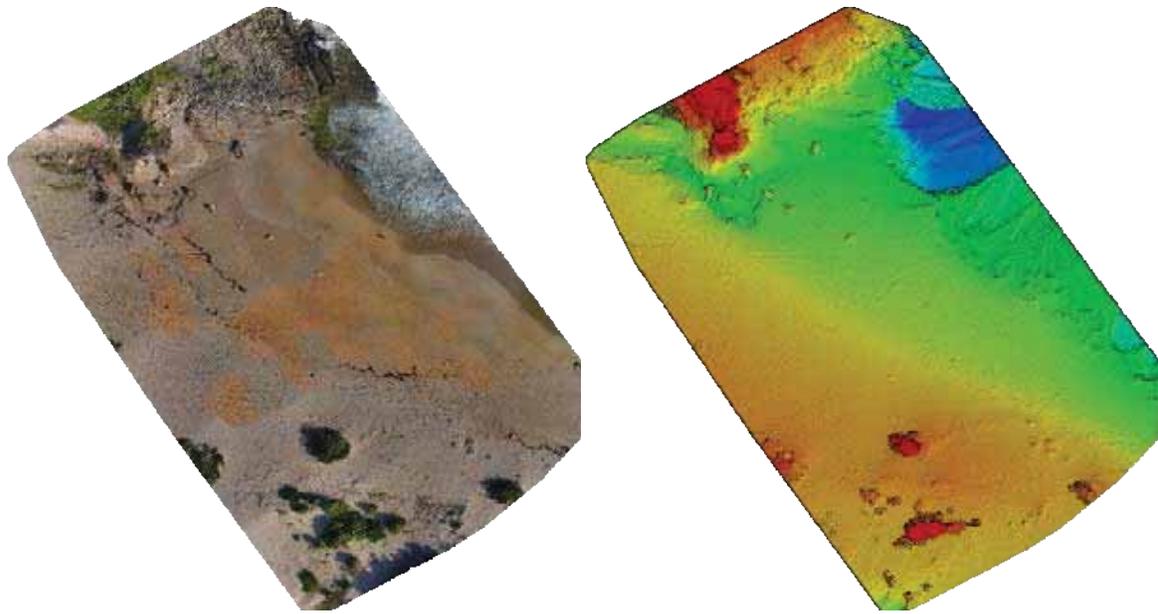


Figure 1: Orthomosaic and the corresponding sparse Digital Surface Model (DSM) before densification.

Calibration Details



Number of Calibrated Images	188 out of 194
Number of Geolocated Images	194 out of 194

Initial Image Positions

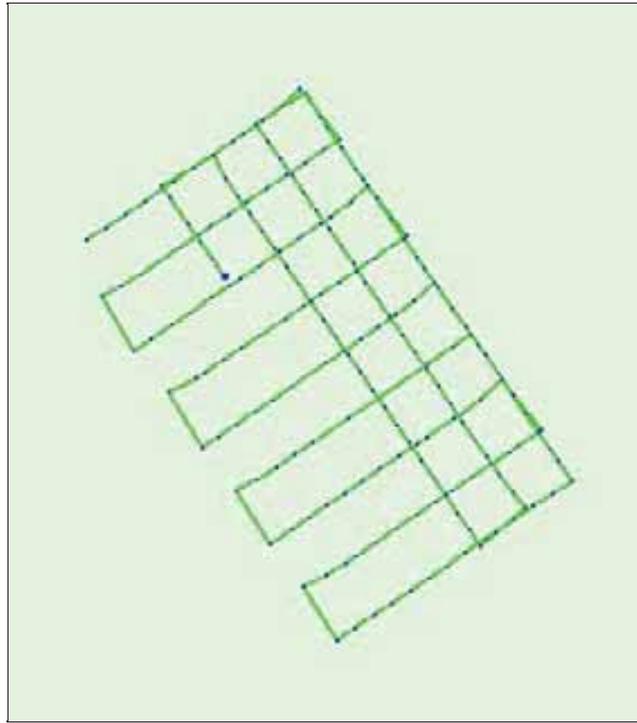
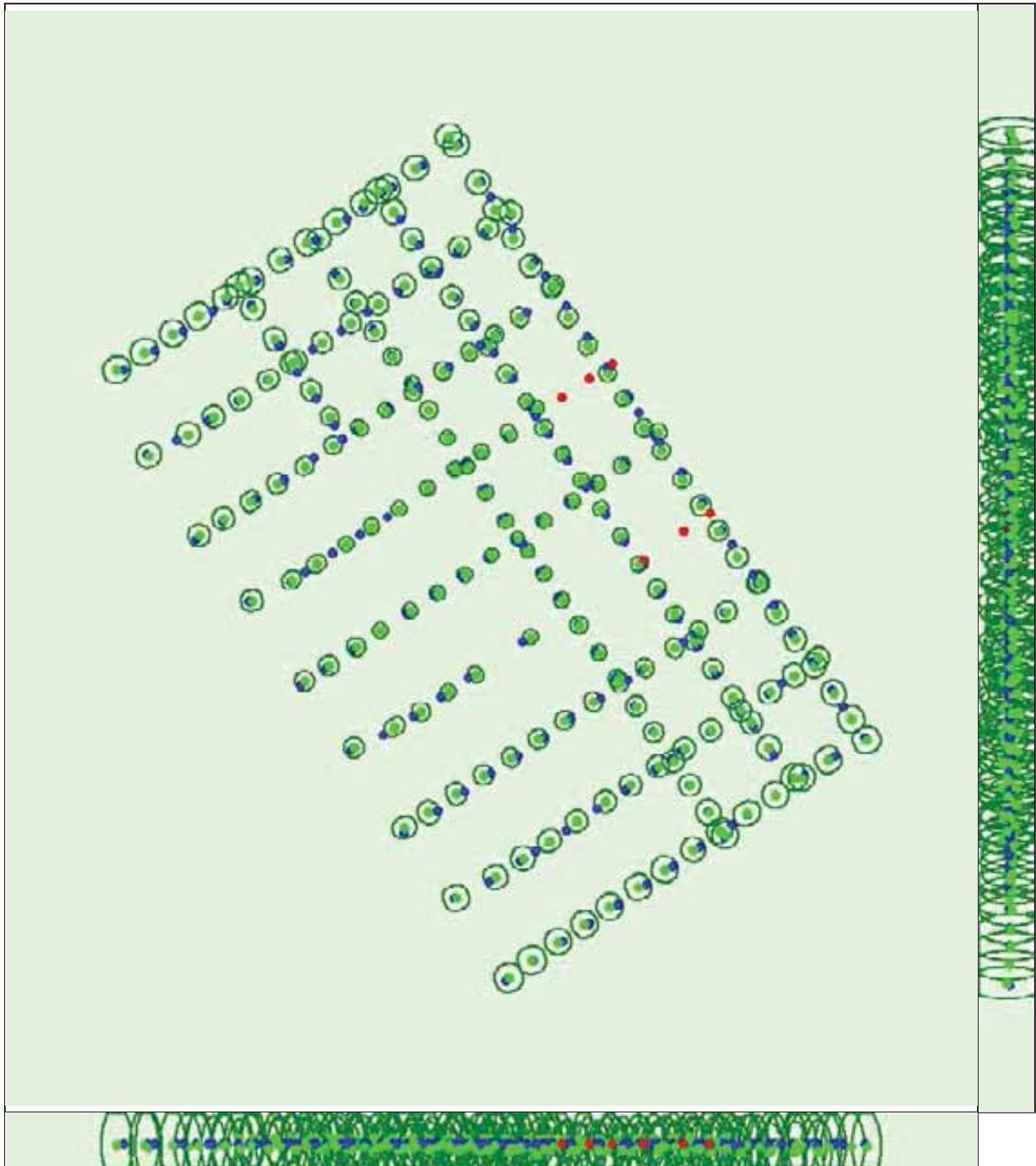


Figure 2: Top view of the initial image position. The green line follows the position of the images in time starting from the large blue dot.

● Computed Image/GCPs/Manual Tie Points Positions ●



Uncertainty ellipses 10x magnified

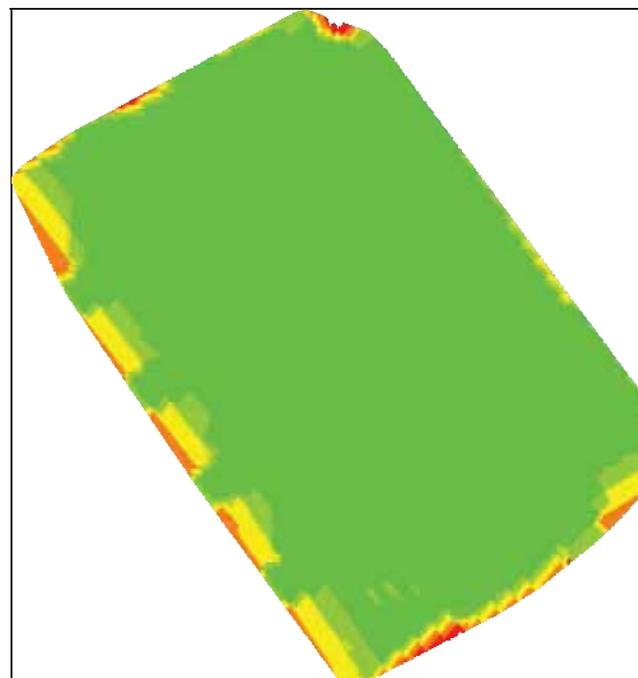
Figure 3: Offset between initial (blue dots) and computed (green dots) image positions as well as the offset between the GCPs initial positions (blue crosses) and their computed positions (green

crosses) in the top-view (XY plane), front-view (XZ plane), and side-view (YZ plane). Red dots indicate disabled or uncalibrated images. Dark green ellipses indicate the absolute position uncertainty of the bundle block adjustment result.

2 Absolute camera position and orientation uncertainties

	X [m]	Y [m]	Z [m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.160	0.160	0.388	0.523	0.567	0.284
Sigma	0.028	0.028	0.087	0.037	0.034	0.019

2 Overlap



Number of overlapping images: 2 3 4 5+

Figure 4: Number of overlapping images computed for each pixel of the orthomosaic. Red and yellow areas indicate low overlap for which poor results may be generated. Green areas indicate an overlap of over 5 images for every pixel. Good quality results will be generated as long as the number of keypoint matches is also sufficient for these areas (see Figure 5 for keypoint matches).

Bundle Block Adjustment Details

Number of 2D Keypoint Observations for Bundle Block Adjustment	3012361
Number of 3D Points for Bundle Block Adjustment	1037185



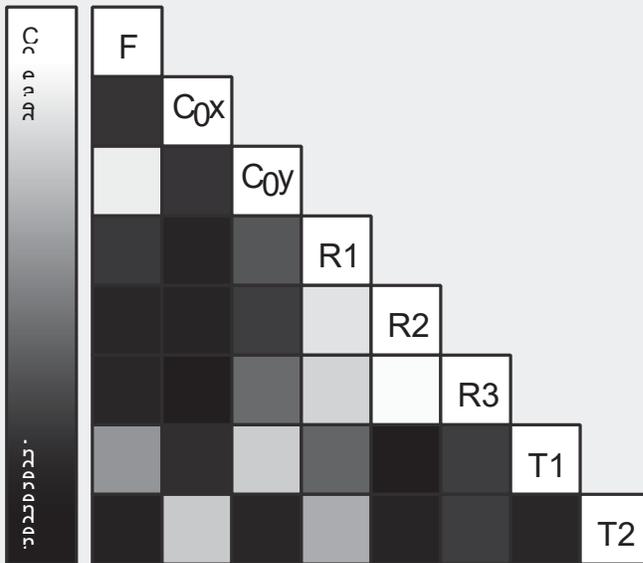
Mean Reprojection Error [pixels]	0.233
----------------------------------	-------

Internal Camera Parameters FC330_3.6_4000x3000 (RGB). Sensor Dimensions: 6.317 [mm] x 4.738 [mm]



EXIF ID: FC330_3.6_4000x3000

	Focal Length	Principal Point x	Principal Point y	R1	R2	R3	T1	T2
Initial Values	2285.722 [pixel] 3.610 [mm]	2000.006 [pixel] 3.159 [mm]	1500.003 [pixel] 2.369 [mm]	-0.001	-0.002	0.000	-0.001	-0.001
Optimized Values	2404.421 [pixel] 3.797 [mm]	1961.846 [pixel] 3.098 [mm]	1456.665 [pixel] 2.301 [mm]	-0.001	-0.004	0.003	0.000	-0.000
Uncertainties (Sigma)	0.402 [pixel] 0.001 [mm]	0.063 [pixel] 0.000 [mm]	0.235 [pixel] 0.000 [mm]	0.000	0.000	0.000	0.000	0.000



The correlation between camera internal parameters determined by the bundle adjustment. White indicates a full correlation between the parameters, ie. any change in one can be fully compensated by the other. Black indicates that the parameter is completely independent, and is not affected by other parameters.



The number of Automatic Tie Points (ATPs) per pixel, averaged over all images of the camera motion, is color coded between black and white. White indicates that, on average, more than 16 ATPs have been extracted at the pixel location. Black indicates that, on average, 0 ATPs have been extracted at the pixel location. Click on the image to see the average direction and magnitude of the re-projection error for each pixel. Note that the vectors are scaled for better visualization. The scale bar indicates the magnitude of 1 pixel error.

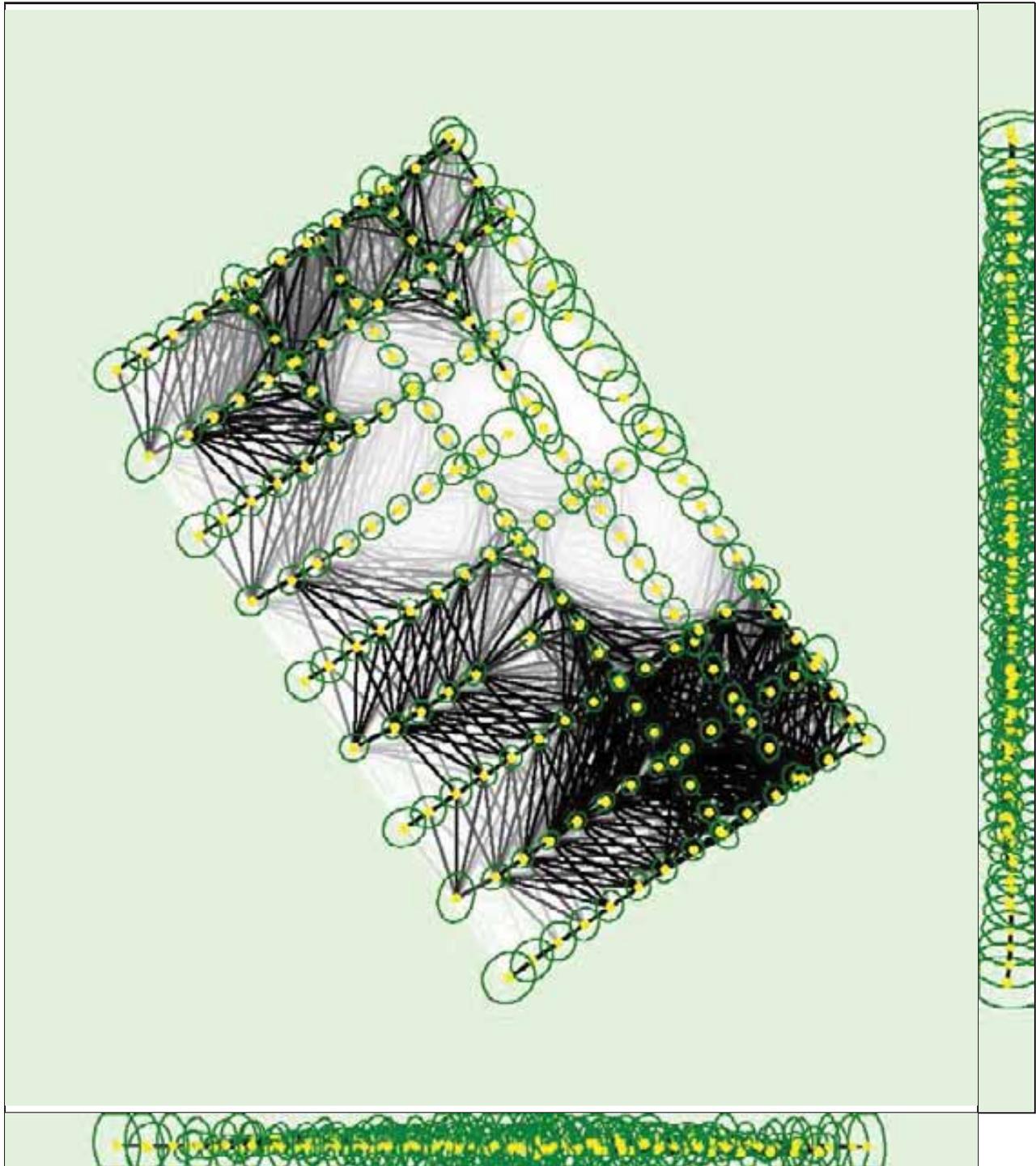
2D Keypoints Table

	Number of 2D Keypoints per Image	Number of Matched 2D Keypoints per Image
Median	38270	16336
Min	12447	132
Max	73112	37083
Mean	37019	16023

3D Points from 2D Keypoint Matches

	Number of 3D Points Observed
In 2 Images	633599
In 3 Images	193476
In 4 Images	90303
In 5 Images	49109
In 6 Images	25456
In 7 Images	15460
In 8 Images	9878
In 9 Images	6415
In 10 Images	4336
In 11 Images	2949
In 12 Images	2140
In 13 Images	1507
In 14 Images	1022
In 15 Images	663
In 16 Images	371
In 17 Images	243
In 18 Images	125
In 19 Images	73
In 20 Images	36
In 21 Images	15

2D Keypoint Matches



Uncertainty ellipses 1000x magnified

Number of matches

25 222 444 666 888 1111 1333 1555 1777 2000

Figure 5: Computed image positions with links between matched images. The darkness of the links indicates the number of matched 2D keypoints between the images. Bright links indicate weak links and require manual tie points or more images. Dark green ellipses indicate the relative camera position uncertainty of the bundle block adjustment result.

Relative camera position and orientation uncertainties

	X [m]	Y [m]	Z [m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.002	0.002	0.003	0.010	0.009	0.005
Sigma	0.001	0.001	0.001	0.003	0.003	0.002

Geolocation Details

Absolute Geolocation Variance

Min Error [m]	Max Error [m]	Geolocation Error X [%]	Geolocation Error Y [%]	Geolocation Error Z [%]
-	-15.00	0.00	0.00	0.00
-15.00	-12.00	0.00	0.00	0.00
-12.00	-9.00	0.00	0.00	0.00
-9.00	-6.00	0.00	0.00	0.00
-6.00	-3.00	0.00	0.00	0.00
-3.00	0.00	59.57	54.79	37.77
0.00	3.00	40.43	45.21	62.23
3.00	6.00	0.00	0.00	0.00
6.00	9.00	0.00	0.00	0.00
9.00	12.00	0.00	0.00	0.00
12.00	15.00	0.00	0.00	0.00
15.00	-	0.00	0.00	0.00
Mean [m]		-0.032153	-0.011123	0.095026
Sigma [m]		0.808498	0.703465	0.520658
RMS Error [m]		0.809138	0.703553	0.529259

Min Error and Max Error represent geolocation error intervals between -1.5 and 1.5 times the maximum accuracy of all the images. Columns X, Y, Z show the percentage of images with geolocation errors within the predefined error intervals. The geolocation error is the difference between the initial and computed image positions. Note that the image geolocation errors do not correspond to the accuracy of the observed 3D points.

Image Coordinate System	WGS84 (egm96)
Output Coordinate System	WGS 84 / UTM zone 19N (egm96)

Relative Geolocation Variance

Relative Geolocation Error	Images X [%]	Images Y [%]	Images Z [%]
[-1.00, 1.00]	100.00	100.00	100.00
[-2.00, 2.00]	100.00	100.00	100.00
[-3.00, 3.00]	100.00	100.00	100.00
Mean of Geolocation Accuracy [m]	5.000000	5.000000	10.000000
Sigma of Geolocation Accuracy [m]	0.000000	0.000000	0.000000

Images X, Y, Z represent the percentage of images with a relative geolocation error in X, Y, Z.

Geolocation Orientational Variance	RMS [degree]
Omega	1.794
Phi	1.893
Kappa	3.340

Geolocation RMS error of the orientation angles given by the difference between the initial and computed image orientation angles.

Initial Processing Details

System Information

Hardware	CPU: Intel(R) Core(TM) i7-8700K CPU @ 3.70GHz RAM: 16GB GPU: NVIDIA GeForce GTX 1070 (Driver: 23.21.13.9065)
Operating System	Windows 10 Home, 64-bit

Coordinate Systems

Processing Options

Detected Template	3D Maps
Keypoints Image Scale	Full, Image Scale: 1
Advanced: Matching Image Pairs	Aerial Grid or Corridor
Advanced: Matching Strategy	Use Geometrically Verified Matching: no
Advanced: Keypoint Extraction	Targeted Number of Keypoints: Automatic
Advanced: Calibration	Calibration Method: Standard Internal Parameters Optimization: All External Parameters Optimization: All Rematch: Auto, yes

Point Cloud Densification details

Processing Options

Image Scale	multiscale, 1/2 (Half image size, Default)
Point Density	Optimal
Minimum Number of Matches	3
3D Textured Mesh Generation	yes
3D Textured Mesh Settings:	Resolution: Medium Resolution (default) Color Balancing: no
LOD	Generated: no
Advanced: 3D Textured Mesh Settings	Sample Density Divider: 1
Advanced: Image Groups	group1
Advanced: Use Processing Area	yes
Advanced: Use Annotations	yes
Time for Point Cloud Densification	09m:44s
Time for Point Cloud Classification	NA
Time for 3D Textured Mesh Generation	04m:03s

Results

Number of Generated Tiles	1
Number of 3D Densified Points	13654791
Average Density (per m ³)	7765.24

DSM, Orthomosaic and Index Details

Processing Options

DSM and Orthomosaic Resolution	1 x GSD (0.772 [cm/pixel])
DSM Filters	Noise Filtering: yes Surface Smoothing: yes, Type: Sharp
Raster DSM	Generated: yes Method: Inverse Distance Weighting Merge Tiles: yes
Orthomosaic	Generated: yes Merge Tiles: yes GeoTIFF Without Transparency: no Google Maps Tiles and KML: no
Time for DSM Generation	07m:36s
Time for Orthomosaic Generation	14m:18s

Time for DTM Generation	00s
Time for Contour Lines Generation	00s
Time for Reflectance Map Generation	00s
Time for Index Map Generation	00s

Generated with Pix4Dmapper Pro version 4.2.25

Site name:

West of Secret Spot Beach, Isabela

After the March 2017 North-Easterly Swell

A. Physical address:

Western Secret Spot, Road PR 466, Isabela, Puerto Rico, 00662

B. Date of capture of imagery:

March 19, 2018

C. Coordinates:

18.51391670 N -67.04840420 W

F. Aerial imagery

i. Contour map



Figure . Contour map of West of Secret Spot (after swell), Isabela Puerto Rico with elevation intervals of 1 meter.

ii. 3D imagery

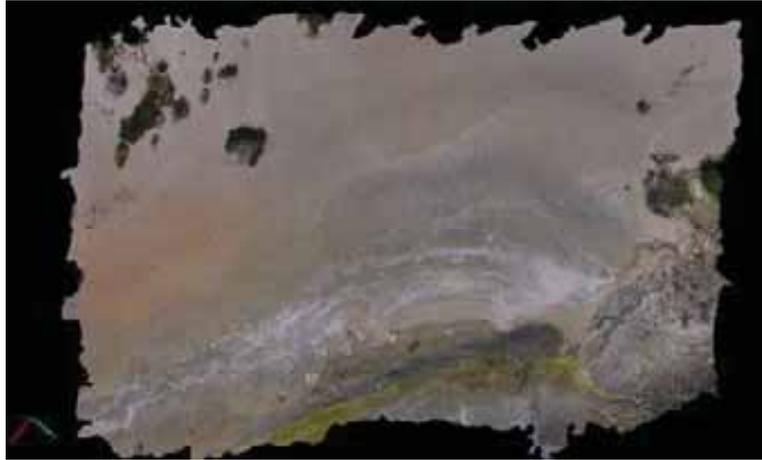


Figure . Aerial 3D image of the west of Secret Spot (after northeasterly swell)

iii. Orthomosaic model

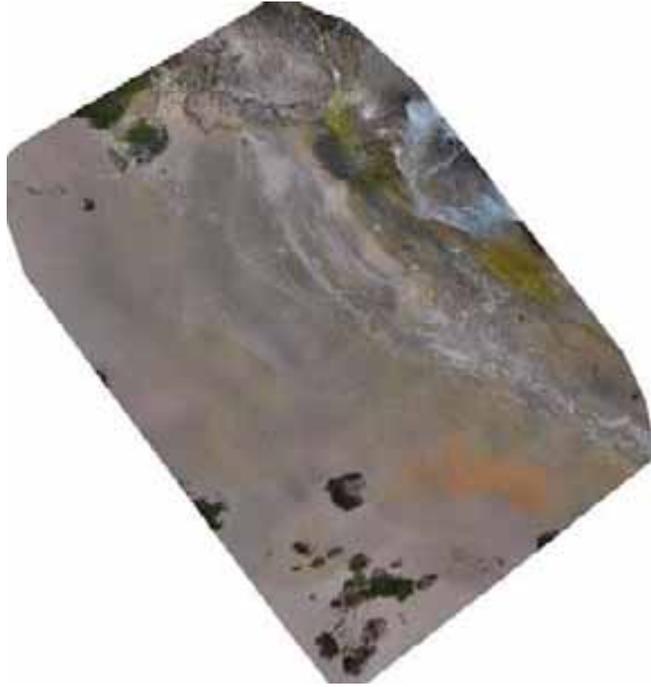


Figure . Orthomosaic image of the west of Secret Spot (after swell), Isabela

iv. Density Surface Models (DSM)

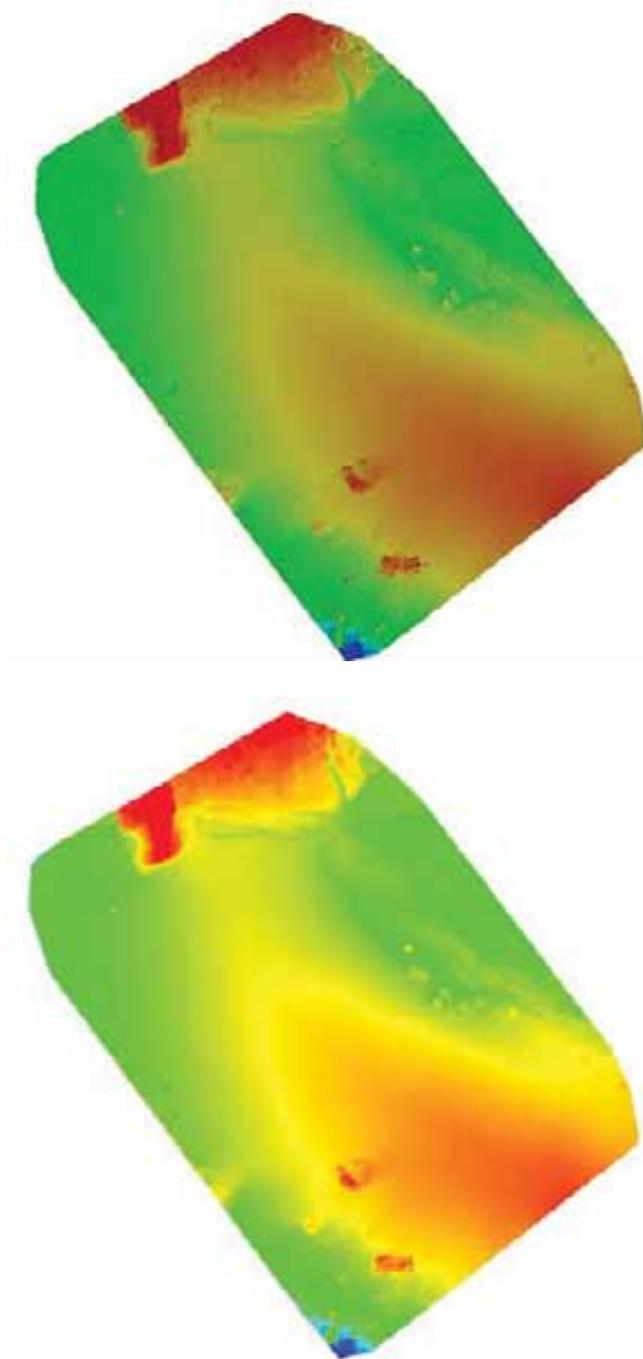


Figure . Density surface model (with shading top and without shading bottom) images of the dune located at the west of Secret Spot (after swell), Isabela

v. Thermal images

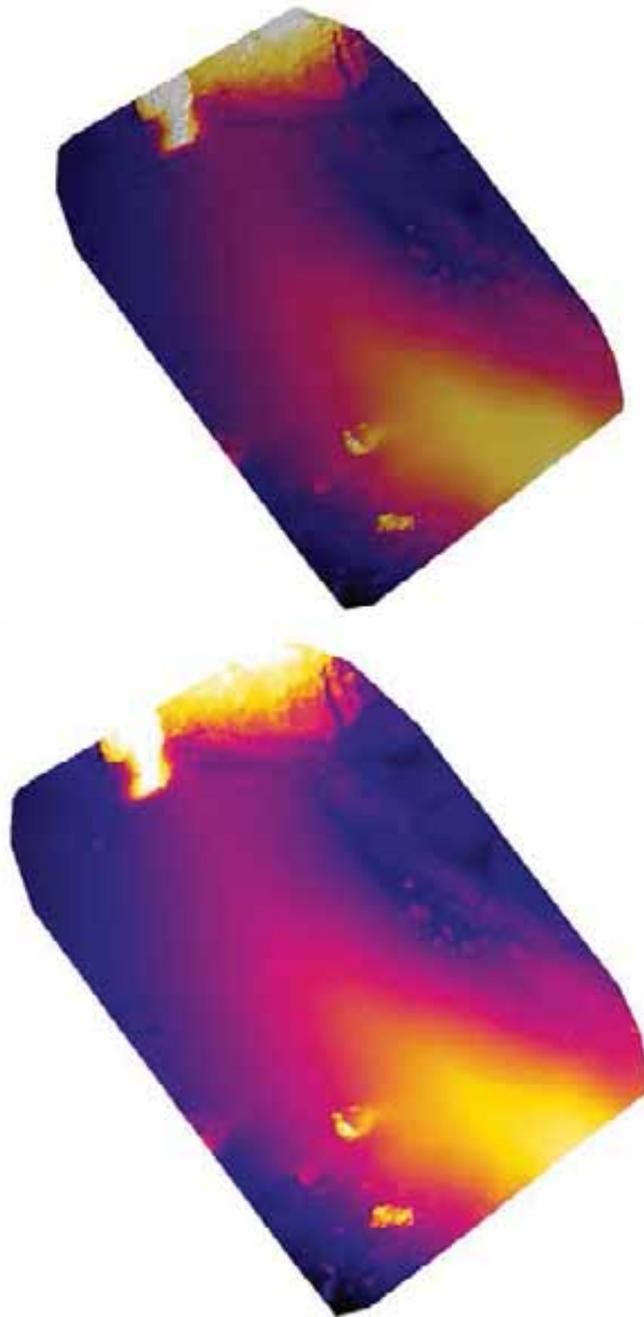


Figure . Thermal images (with shading top and without shading bottom) of the dune located at the west of Secret Spot (after swell), Isabela

vi. 3D altitude RGB

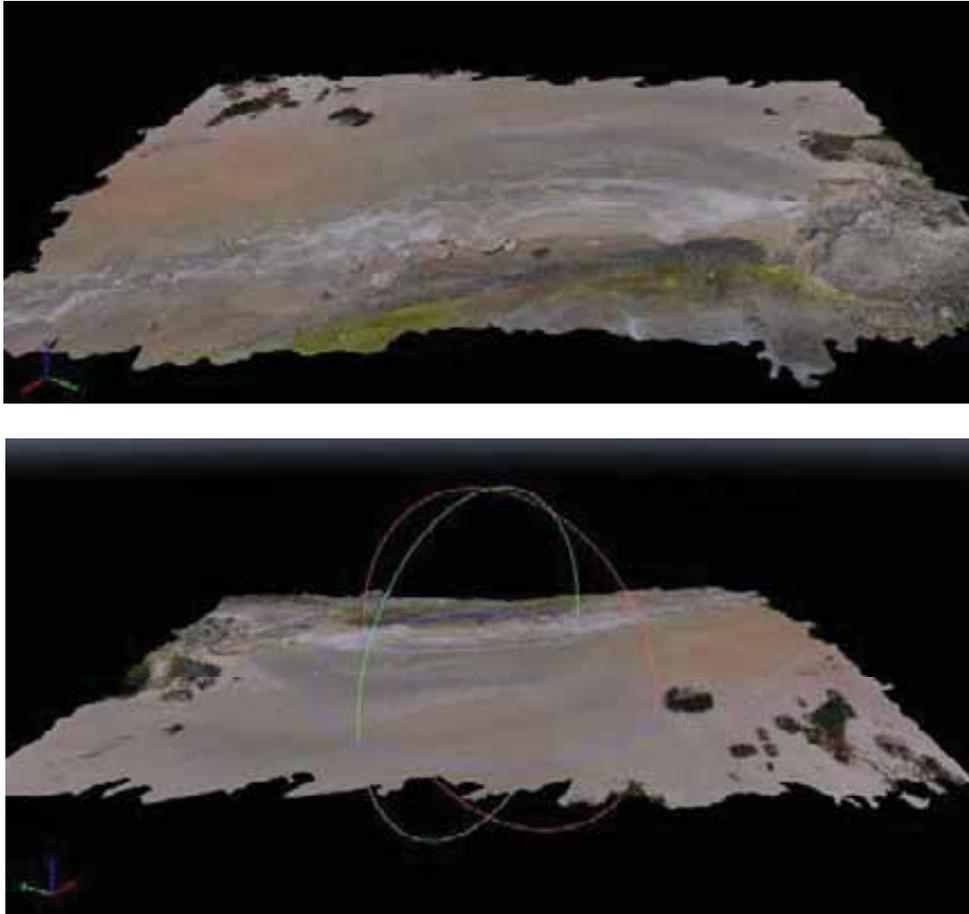


Figure . Three dimensional RGB images of the west of Secret Spot, Isabela (after northeasterly swell). View from the north (top) and from the south (bottom).

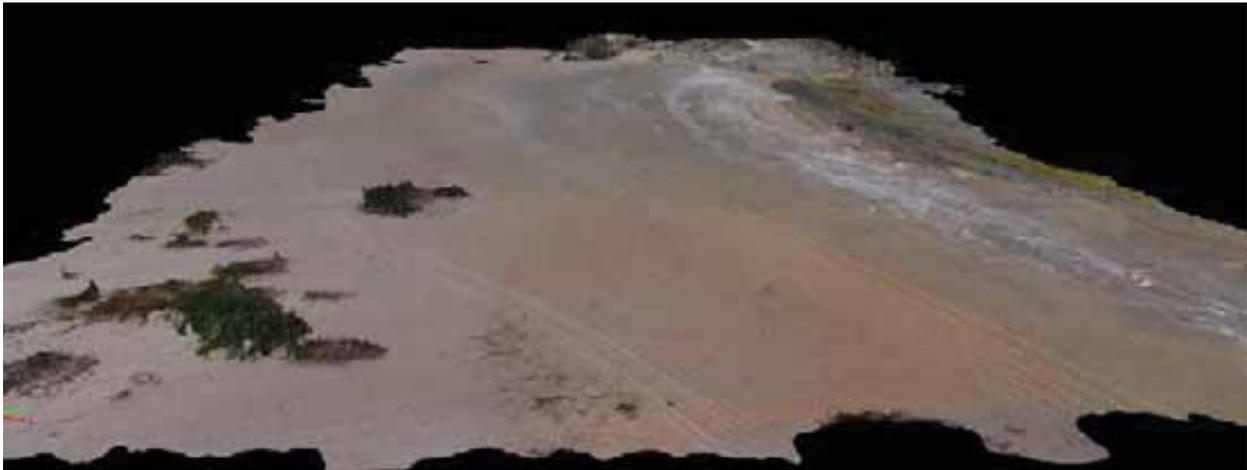
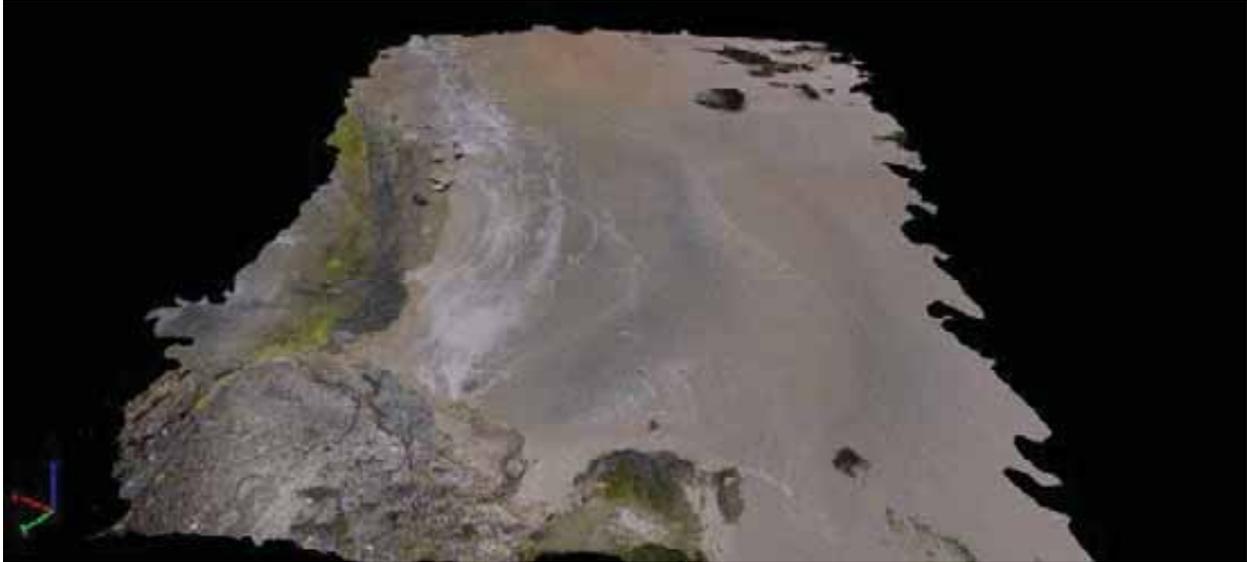


Figure . Three dimensional RGB images of the west of Secret Spot (after northeasterly swell), Isabela. View from the west (top) and from the east (bottom). *Note- Mayer*

vii. DSM grayscale

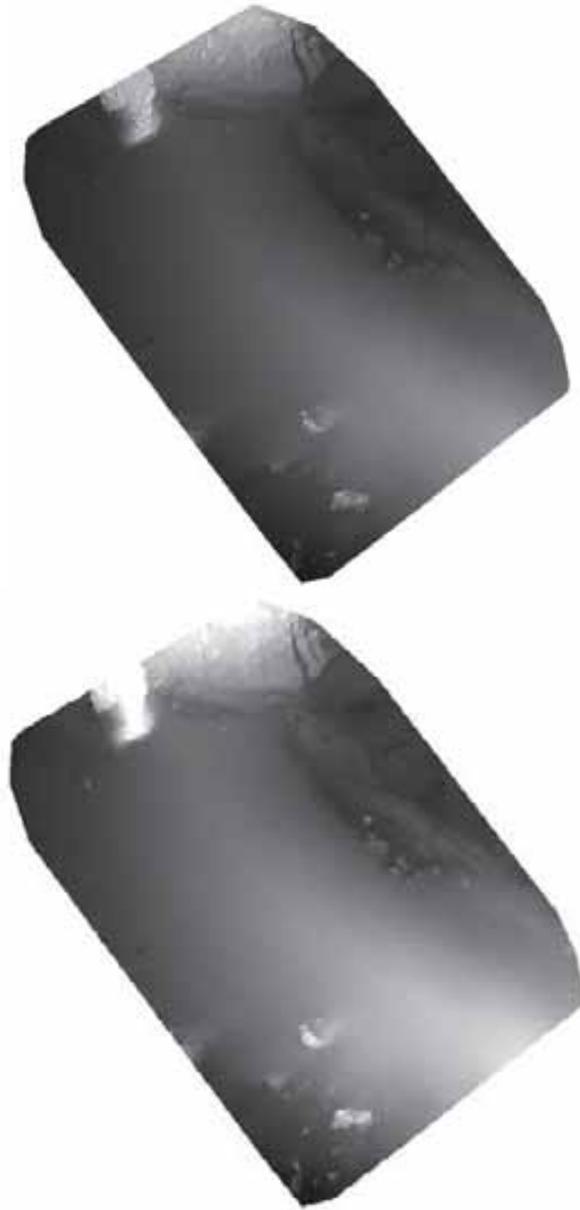


Figure . Grayscale DSM images of the dune to the west of Secret Spot (after swell), Isabela. The top image shows shades and the bottom is not shaded.

G. Site report

H. Vegetation cover



Figure. Image of the area for which vegetation cover is being monitored for the western part of Secret Spot Beach in Isabela, Puerto Rico. The vegetation cover was 3.1 % on March 19, 2018.

I. Volume measurements of selected areas of the dunes

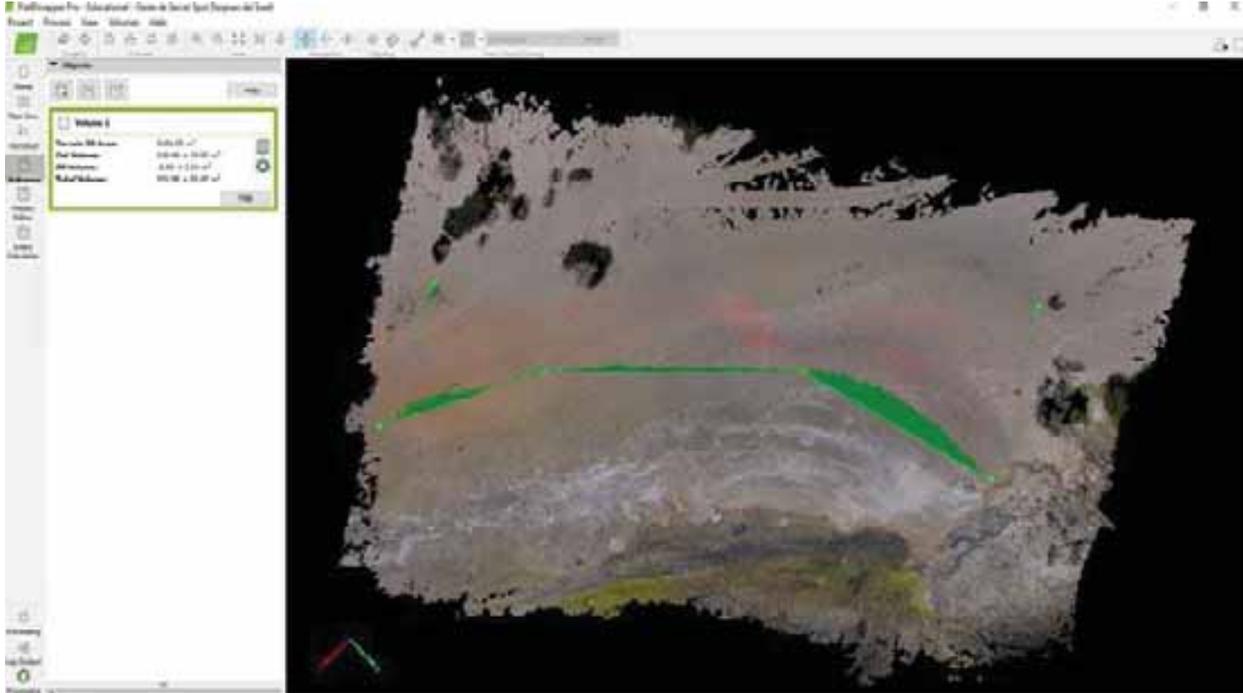


Figure. The polygon (from left to right on the picture) has a 3D area of 2,101.25 m² and a cut volume of 240.48 ± 19.93 m³, a fill volume of - 8.90 ± 2.54 m³ and a total volume of 231.58 ± 22.47 m³. The volume of this area will be monitored in subsequent months to monitor the progress of the restoration process.

J. Conservation threats

The main conservation threat in this area is illegal traffic of all-terrain vehicles. There is low incidence of sand extraction and of foot traffic due to the remoteness and long distance from PR 466.

K. Recommended ecological restoration courses of action (COA)

The recommended ecological restoration techniques for this area consist of the installation of biomimicry matrices. The area will be planted with dune vegetation in order to stabilize the accumulated sand. Two information signs will be installed in this area to advise people of the importance of dune restoration and of the importance of not interfering with any of the plants or fencing.

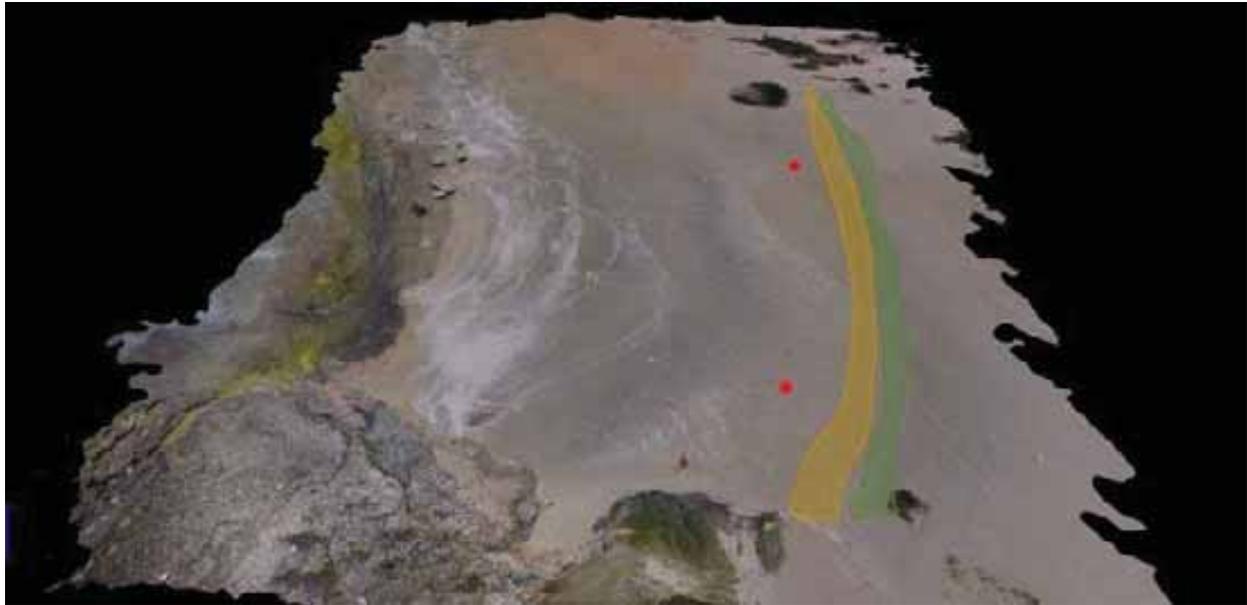


Figure. Area to be ecologically restored on the western part of Secret Spot Beach in Barrio Bajuras, Isabela, Puerto Rico. Highlighted areas correspond to each technique that will be used in this area. **Yellow** represents the location of a wooden boardwalk, the **red dot** marks the location of an information sign, **light green** marks the location of planting of dune vegetation, **tan** represents the area of the dune crest that where biomimicry matrices will be installed to promote the accumulation of sand. The areas shaded in light green represent locations for the planting of dune vegetation.



Figure. View of the breach on the west of Secret Spot beach in Isabela, Puerto Rico.



Figure. Displaced sand on the recreational path to the south of the western part of Secret Spot.



Figure. Displaced sand on the recreational path to the south of the western part of Secret Spot.

L. Pix4D Quality Report

Generated with Pix4Dmapper Pro version 4.2.25

1 Important: Click on the different icons for:

- 2** Help to analyze the results in the Quality Report
- 1** Additional information about the sections

 Click [here](#) for additional tips to analyze the Quality Report

Summary

Project	Oeste de Secret Spot Despues del Swell
Processed	2018-04-06 19:34:30
Camera Model Name(s)	FC330_3.6_4000x3000 (RGB)
Average Ground Sampling Distance (GSD)	0.73 cm / 0.29 in
Area Covered	0.013 km ² / 1.2625 ha / 0.00 sq. mi. / 3.1214 acres
Time for Initial Processing (without report)	42m:18s

Quality Check

1 Images	median of 18004 keypoints per image	
2 Dataset	256 out of 256 images calibrated (100%), all images enabled	
2 Camera Optimization	4.17% relative difference between initial and optimized internal camera parameters	
2 Matching	median of 5010.95 matches per calibrated image	
2 Georeferencing	yes, no 3D GCP	

1 Preview 

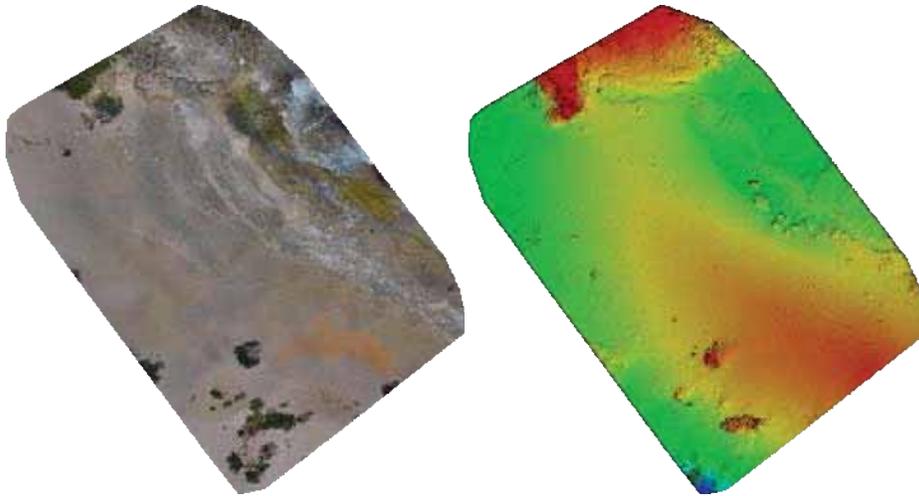


Figure 1: Orthomosaic and the corresponding sparse Digital Surface Model (DSM) before densification.

Number of Calibrated Images	256 out of 256
Number of Geolocated Images	256 out of 256

Initial Image Positions

Figure 2: Top view of the initial image position. The green line follows the position of the images in time starting from the large blue dot.

Figure 3: Offset between initial (blue dots) and computed (green dots) image positions as well as the offset between the GCPs initial positions (blue crosses) and their computed positions (green crosses) in the top-view (XY plane), front-view (XZ plane), and side-view (YZ plane). Dark green ellipses indicate the absolute position uncertainty of the bundle block adjustment result.

Absolute camera position and orientation uncertainties

	X [m]	Y [m]	Z [m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.161	0.161	0.392	0.519	0.520	0.287
Sigma	0.027	0.027	0.084	0.035	0.017	0.024

Overlap

Figure 4: Number of overlapping images computed for each pixel of the orthomosaic.

Red and yellow areas indicate low overlap for which poor results may be generated. Green areas indicate an overlap of over 5 images for every pixel. Good quality results will be generated as long as the number of keypoint matches is also sufficient for these areas (see Figure 5 for keypoint matches).

Number of 2D Keypoint Observations for Bundle Block Adjustment	1527628
Number of 3D Points for Bundle Block Adjustment	627004
Mean Reprojection Error [pixels]	0.178

Internal Camera Parameters FC330_3.6_4000x3000 (RGB). Sensor Dimensions: 6.317 [mm] x 4.738 [mm]

EXIF ID: FC330_3.6_4000x3000

	Focal Length	Principal Point x	Principal Point y	R1	R2	R3	T1	T2
Initial Values	2285.722 [pixel] 3.610 [mm]	2000.006 [pixel] 3.159 [mm]	1500.003 [pixel] 2.369 [mm]	-0.001	-0.002	0.000	-0.001	-0.001
Optimized Values	2381.256 [pixel] 3.761 [mm]	1963.467 [pixel] 3.101 [mm]	1464.752 [pixel] 2.313 [mm]	-0.001	-0.005	0.003	0.001	0.000
Uncertainties (Sigma)	0.332 [pixel] 0.001 [mm]	0.068 [pixel] 0.000 [mm]	0.208 [pixel] 0.000 [mm]	0.000	0.000	0.000	0.000	0.000
<p>The correlation between camera internal parameters determined by the bundle adjustment. White indicates a full correlation between the parameters, ie. any change in one can be fully compensated by the other. Black indicates that the parameter is completely independent, and is not affected by other parameters.</p>								

	Number of 2D Keypoints per Image	Number of Matched 2D Keypoints per Image
Median	18004	5011
Min	14608	1269
Max	55665	21405
Mean	23038	5967

3D Points from 2D Keypoint Matches

	Number of 3D Points Observed
In 2 Images	469366

In 3 Images	97036
In 4 Images	33652
In 5 Images	13764
In 6 Images	6322
In 7 Images	3153
In 8 Images	1645
In 9 Images	937
In 10 Images	472
In 11 Images	279
In 12 Images	166
In 13 Images	97
In 14 Images	51
In 15 Images	33
In 16 Images	20
In 17 Images	8
In 18 Images	1
In 19 Images	1
In 20 Images	1

2D Keypoint Matches

25 222 444 666 888 1111 1333 1555 1777 2000

Figure 5: Computed image positions with links between matched images. The darkness of the links indicates the number of matched 2D keypoints between the images. Bright links indicate weak links and require manual tie points or more images. Dark green ellipses indicate the relative camera position uncertainty of the bundle block adjustment result.

Relative camera position and orientation uncertainties

	X [m]	Y [m]	Z [m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.002	0.002	0.003	0.010	0.009	0.005
Sigma	0.001	0.001	0.001	0.003	0.003	0.002

Absolute Geolocation Variance

Min Error [m]	Max Error [m]	Geolocation Error X [%]	Geolocation Error Y [%]	Geolocation Error Z [%]
-	-15.00	0.00	0.00	0.00
-15.00	-12.00	0.00	0.00	0.00
-12.00	-9.00	0.00	0.00	0.00
-9.00	-6.00	0.00	0.00	0.00
-6.00	-3.00	0.00	0.00	0.00
-3.00	0.00	55.86	49.22	57.42
0.00	3.00	44.14	50.78	42.58
3.00	6.00	0.00	0.00	0.00
6.00	9.00	0.00	0.00	0.00
9.00	12.00	0.00	0.00	0.00

12.00	15.00	0.00	0.00	0.00
15.00	-	0.00	0.00	0.00
Mean [m]		-0.006490	-0.003295	0.009596
Sigma [m]		0.790832	0.768666	0.656111
RMS Error [m]		0.790858	0.768673	0.656181

Min Error and Max Error represent geolocation error intervals between -1.5 and 1.5 times the maximum accuracy of all the images. Columns X, Y, Z show the percentage of images with geolocation errors within the predefined error intervals. The geolocation error is the difference between the initial and computed image positions. Note that the image geolocation errors do not correspond to the accuracy of the observed 3D points.

Relative Geolocation Variance

Relative Geolocation Error	Images X [%]	Images Y [%]	Images Z [%]
[-1.00, 1.00]	100.00	100.00	100.00
[-2.00, 2.00]	100.00	100.00	100.00
[-3.00, 3.00]	100.00	100.00	100.00
Mean of Geolocation Accuracy [m]	5.000000	5.000000	10.000000
Sigma of Geolocation Accuracy [m]	0.000000	0.000000	0.000000

Images X, Y, Z represent the percentage of images with a relative geolocation error in X, Y, Z.

Geolocation Orientational Variance	RMS [degree]
Omega	3.341
Phi	2.734
Kappa	4.406

Geolocation RMS error of the orientation angles given by the difference between the initial and computed image orientation angles.

Hardware	CPU: Intel(R) Core(TM) i5-3330S CPU @ 2.70GHz RAM: 8GB GPU: Intel(R) HD Graphics (Driver: 10.18.10.3412), RDPDD Chained DD (Driver: unknown), RDP Encoder Mirror Driver (Driver: unknown), RDP Reflector Display Driver (Driver: unknown)
Operating System	Windows 7 Professional, 64-bit

Coordinate Systems

Image Coordinate System	WGS84 (egm96)
Output Coordinate System	WGS 84 / UTM zone 19N (egm96)

Processing Options

Detected Template	3D Maps
Keypoints Image Scale	Full, Image Scale: 1
Advanced: Matching Image Pairs	Aerial Grid or Corridor
Advanced: Matching Strategy	Use Geometrically Verified Matching: no
Advanced: Keypoint Extraction	Targeted Number of Keypoints: Automatic
Advanced: Calibration	Calibration Method: Standard Internal Parameters Optimization: All External Parameters Optimization: All Rematch: Auto, yes

Image Scale	multiscale, 1/2 (Half image size, Default)
Point Density	Optimal
Minimum Number of Matches	3
3D Textured Mesh Generation	yes
3D Textured Mesh Settings:	Resolution: Medium Resolution (default) Color Balancing: no
LOD	Generated: no
Advanced: 3D Textured Mesh Settings	Sample Density Divider: 1
Advanced: Image Groups	group1
Advanced: Use Processing Area	yes
Advanced: Use Annotations	yes
Time for Point Cloud Densification	01h:18m:40s
Time for Point Cloud Classification	NA
Time for 3D Textured Mesh Generation	01h:04m:01s

Results

Number of Processed Clusters	2
Number of Generated Tiles	1
Number of 3D Densified Points	21196342
Average Density (per m ³)	11695.4

DSM and Orthomosaic Resolution	1 x GSD (0.726 [cm/pixel])
DSM Filters	Noise Filtering: yes Surface Smoothing: yes, Type: Sharp
Raster DSM	Generated: yes Method: Inverse Distance Weighting Merge Tiles: yes
Orthomosaic	Generated: yes Merge Tiles: yes GeoTIFF Without Transparency: no Google Maps Tiles and KML: no
Time for DSM Generation	28m:58s
Time for Orthomosaic Generation	49m:05s
Time for DTM Generation	00s
Time for Contour Lines Generation	00s
Time for Reflectance Map Generation	00s
Time for Index Map Generation	00s

Site name:

Secret Spot beach, Isabela

Before hurricane María



A. Physical address:

The eastern portion of Secret Spot Beach parallel to road PR 466 Isabela, Puerto Rico, 00662

B. Date of capture of imagery:

July 11, 2017

C. Coordinates:

18.51320800 N -67.04373277 W

D. Description of site:

This location is a popular surf destination and consists of a wide beach (65.33 m wide) and back dune area (101 m wide). The dune was completely breached during the 2017 hurricane season. The area is now characterized by a 76 m wide breach on the primary dune.

E. Distance from community:

This site is located at an approximate distance of 113 m from PR-466 and 520 m from the cliff. It is not near any houses or buildings.

F. Aerial imagery

i. Contour map



Figure 89. Contour map of the eastern part of Secret Spot Beach (before hurricane María), Isabela Puerto Rico with elevation intervals of 1 meter.

ii. 3D imagery

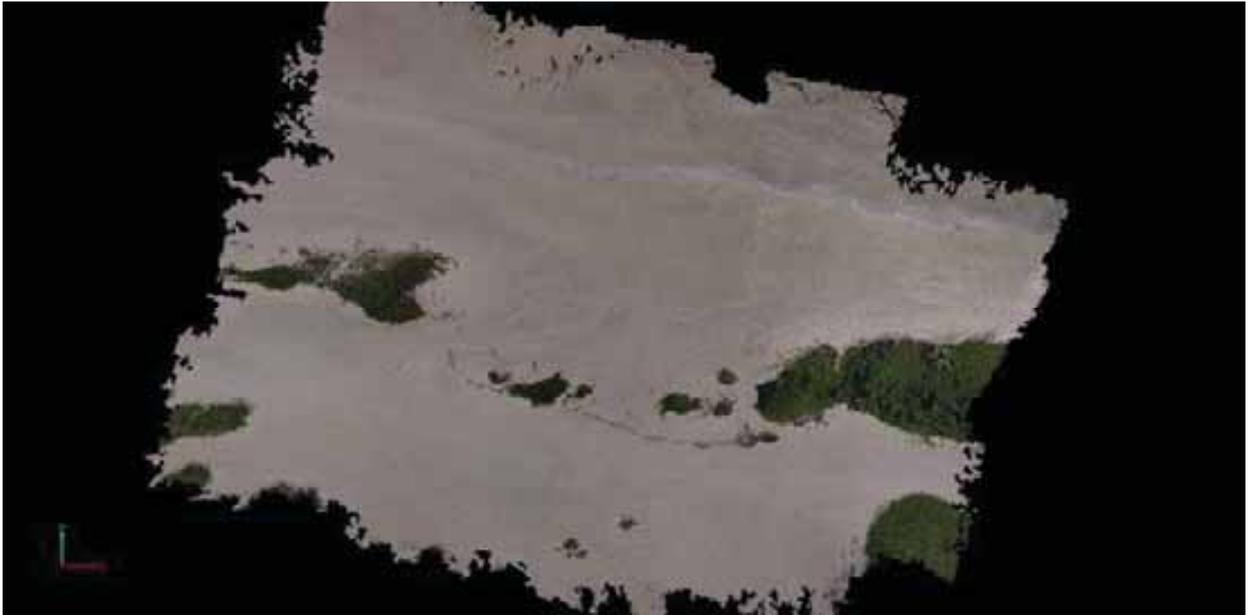


Figure 90. Aerial 3D image of the eastern part of Secret Spot Beach, Isabela (before hurricane María).

iii. Orthomosaic model

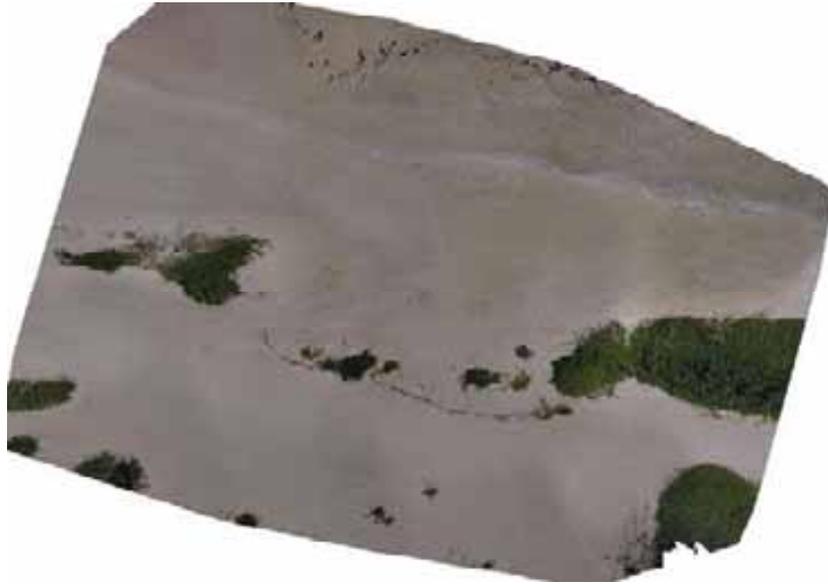


Figure 91. Orthomosaic image of The eastern part of Secret Spot Beach (before hurricane María) Isabela.

iv. Density Surface Models (DSM)

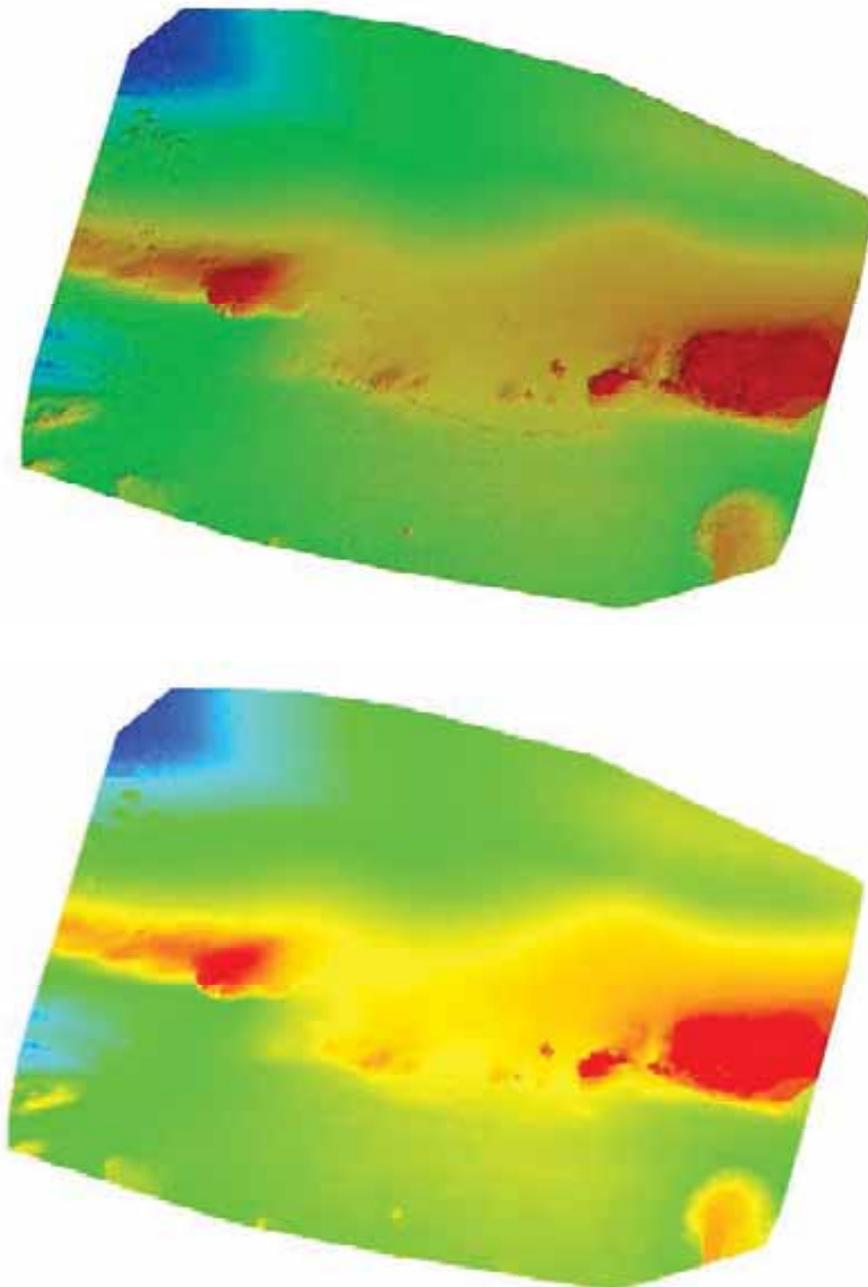


Figure 92. Density surface model (with shading top and without shading bottom) images of the dune located on the eastern part of Secret Spot Beach (before hurricane María), Isabela

v. Thermal images

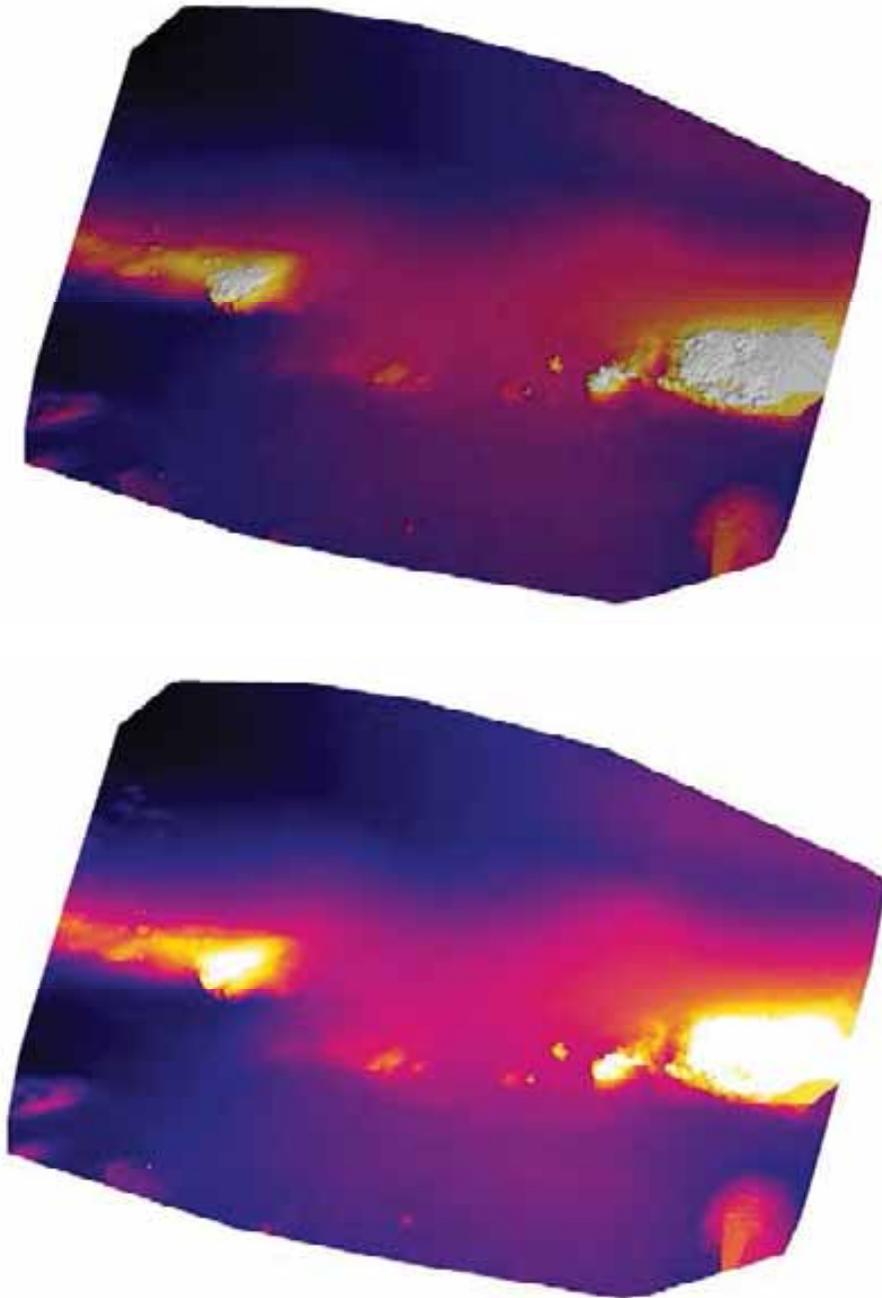


Figure 93. Thermal images (with shading top and without shading bottom) of the dune located on the eastern part of Secret Spot Beach, Isabela (before hurricane María).

vi. 3D altitude RGB North

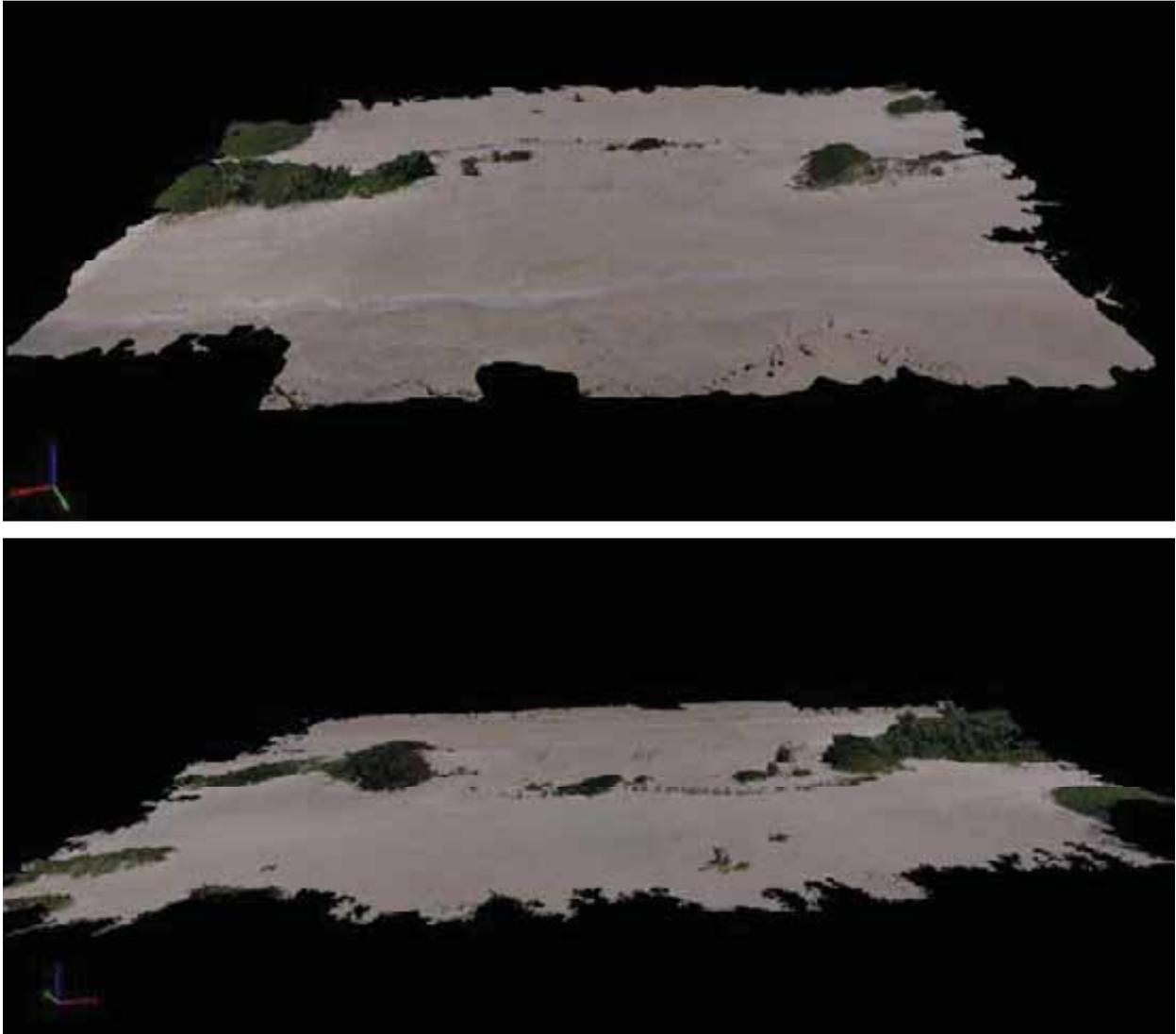


Figure 94. Three dimensional RGB images of the eastern part of Secret Spot Beach, Isabela (before hurricane María). View from the north (top) and from the south (bottom).

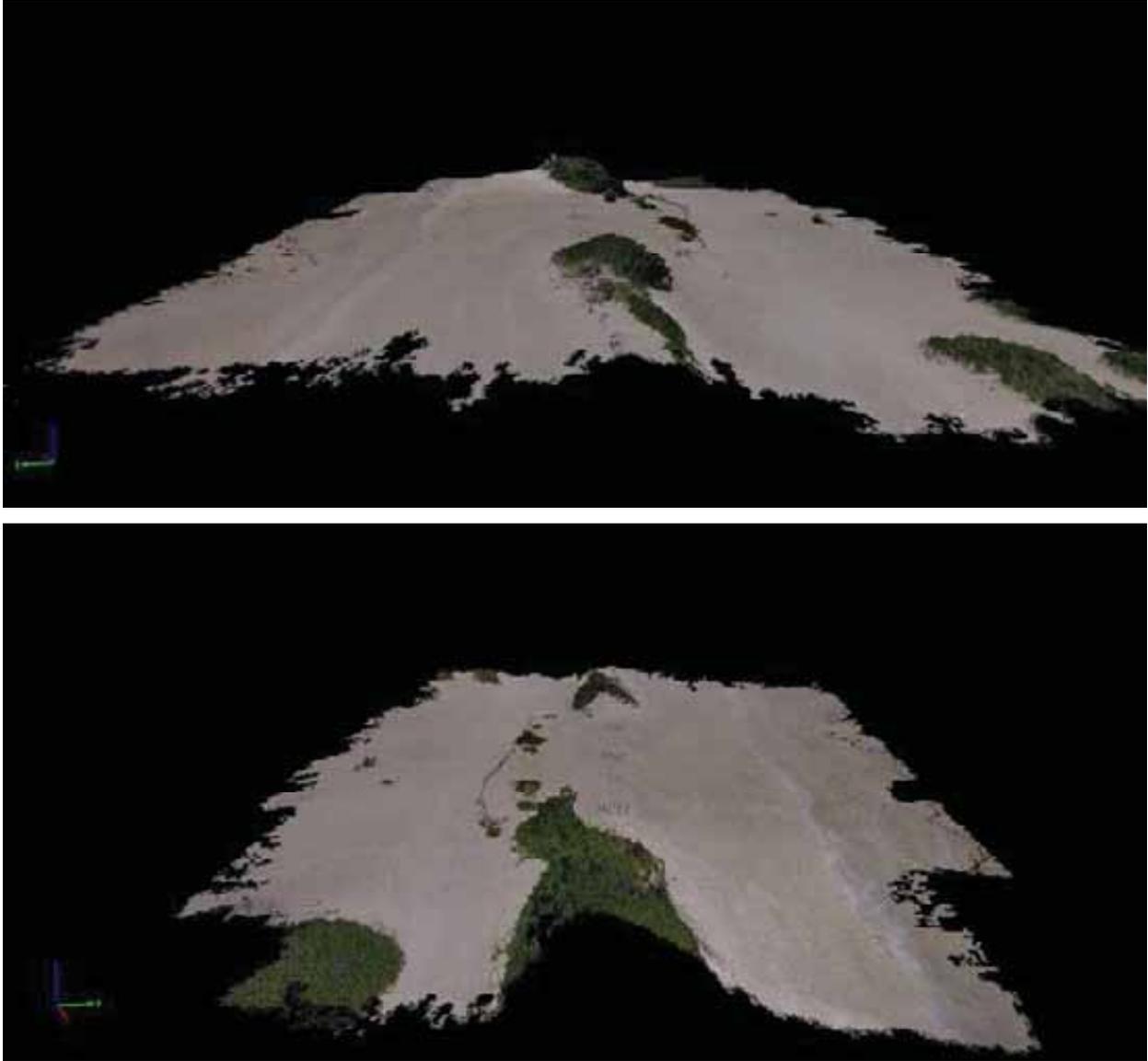


Figure 95. Three dimensional RGB images of the The eastern part of Secret Spot Beach (before hurricane María), Isabela. View from the west (top) and from the east (bottom). *Note- Mayer*

vii. DSM grayscale

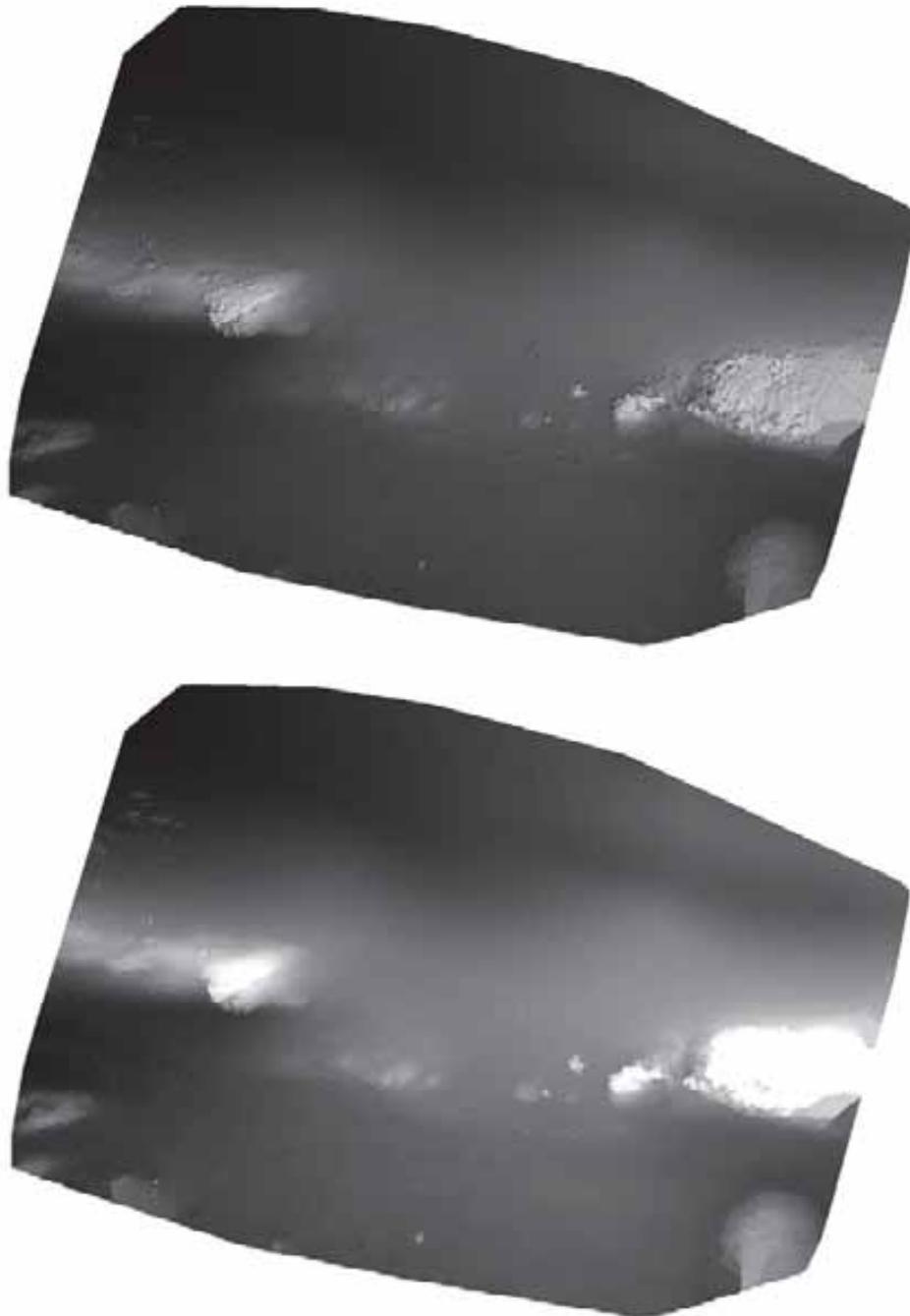


Figure 96. Grayscale DSM images of the dune to the The eastern part of Secret Spot Beach (before hurricane María), Isabela. The top image shows shades and the bottom is not shaded.

G. Pix 4D Quality Report

Quality Report



Generated with Pix4Dmapper Pro version 4.1.22

Important: Click on the different icons for:

- Help to analyze the results in the Quality Report
- Additional information about the sections

Click [here](#) for additional tips to analyze the Quality Report

Summary

Project	Mision Secret Spot Antes Del Huracan Maria
Processed	2018-01-13 18:46:25
Camera Model Name(s)	FC330_3.6_4000x3000 (RGB)
Average Ground Sampling Distance (GSD)	1.31 cm / 0.51 in
Area Covered	0.014 km ² / 1.3696 ha / 0.01 sq. mi. / 3.3860 acres
Time for Initial Processing (without report)	11m:39s

Quality Check

Images	median of 20643 keypoints per image	✓
Dataset	84 out of 84 images calibrated (100%), all images enabled	✓
Camera Optimization	4.18% relative difference between initial and optimized internal camera parameters	✓
Matching	median of 4552.54 matches per calibrated image	✓
Georeferencing	yes, no 3D GCP	⚠

Preview

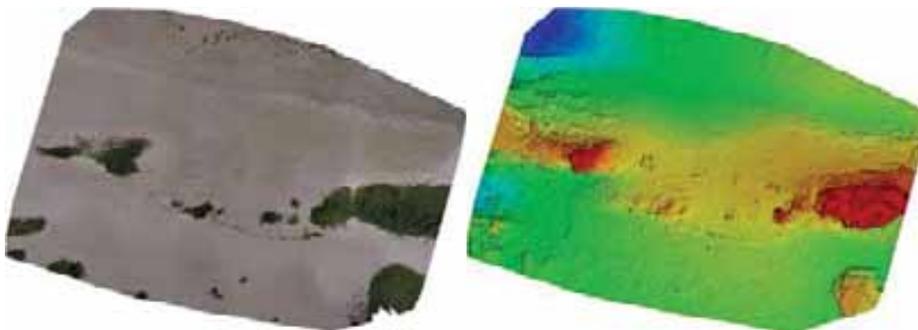


Figure 1: Orthomosaic and the corresponding sparse Digital Surface Model (DSM) before densification.

Calibration Details

Number of Calibrated Images	84 out of 84
Number of Geolocated Images	84 out of 84

Initial Image Positions

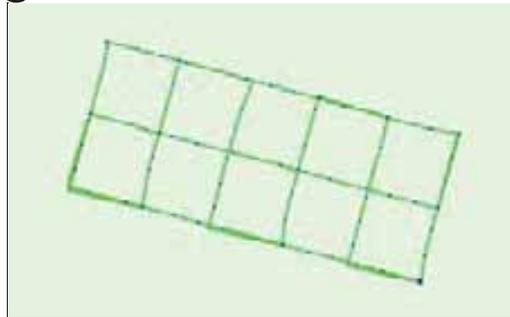
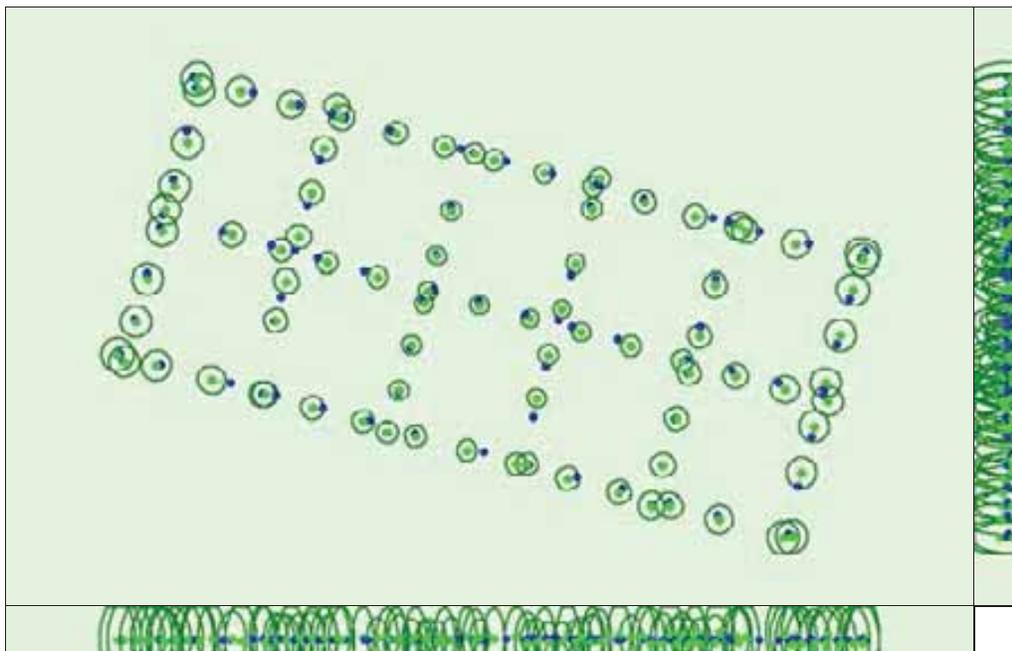


Figure 2: Top view of the initial image position. The green line follows the position of the images in time starting from the large blue dot.

Computed Image/GCPs/Manual Tie Points Positions



Uncertainty ellipses 10x magnified

Figure 3: Offset between initial (blue dots) and computed (green dots) image positions as well as the offset between the GCPs initial positions (blue crosses) and their computed positions (green crosses) in the top-view (XY plane), front-view (XZ plane), and side-view (YZ plane). Dark green ellipses indicate the absolute position uncertainty of the bundle block adjustment result.

📌 Absolute camera position and orientation uncertainties

	X [m]	Y [m]	Z [m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.169	0.169	0.410	0.960	0.488	0.286
Sigma	0.031	0.031	0.086	0.016	0.028	0.021

📌 Overlap

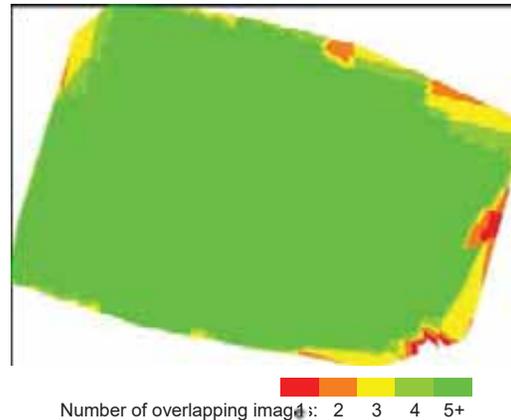


Figure 4: Number of overlapping images computed for each pixel of the orthomosaic. Red and yellow areas indicate low overlap for which poor results may be generated. Green areas indicate an overlap of over 5 images for every pixel. Good quality results will be generated as long as the number of keypoint matches is also sufficient for these areas (see Figure 5 for keypoint matches).

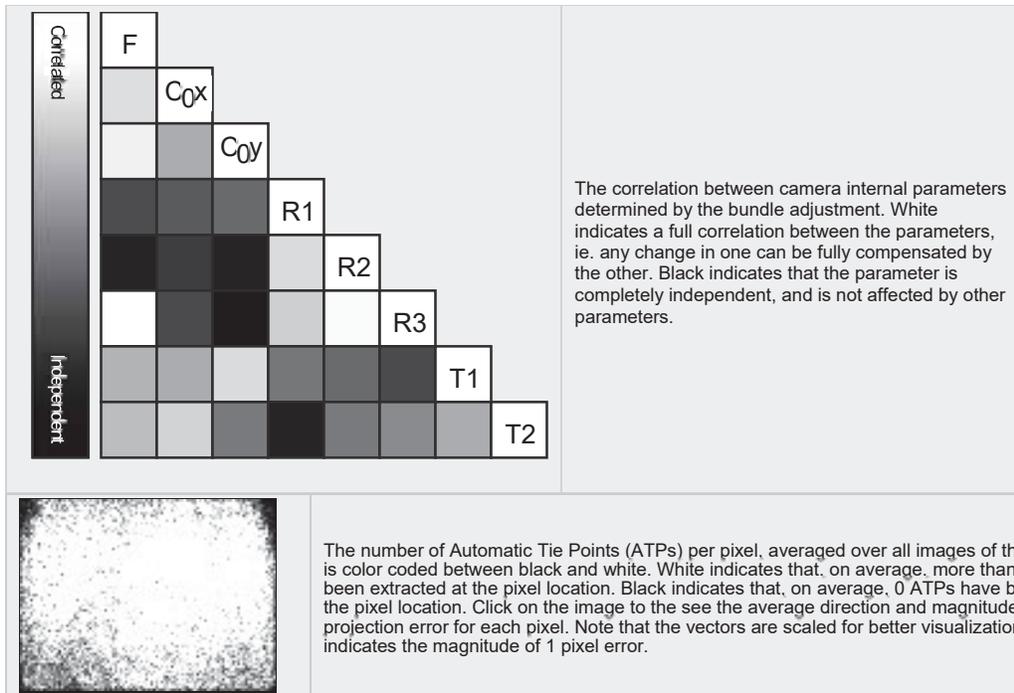
Bundle Block Adjustment Details

Number of 2D Keypoint Observations for Bundle Block Adjustment	394056
Number of 3D Points for Bundle Block Adjustment	163895
Mean Reprojection Error [pixels]	0.191

📌 Internal Camera Parameters FC330_3.6_4000x3000 (RGB). Sensor Dimensions: 6.317 [mm] x 4.738 [mm]

EXIF ID: FC330_3.6_4000x3000

	Focal Length	Principal Point x	Principal Point y	R1	R2	R3	T1	T2
Initial Values	2285.722 [pixel] 3.610 [mm]	2000.006 [pixel] 3.159 [mm]	1500.003 [pixel] 2.369 [mm]	-0.001	-0.002	0.000	-0.001	-0.001
Optimized Values	2381.323 [pixel] 3.761 [mm]	1965.650 [pixel] 3.104 [mm]	1470.445 [pixel] 2.322 [mm]	-0.000	-0.004	0.003	0.000	0.000
Uncertainties (Sigma)	0.530 [pixel] 0.001 [mm]	0.084 [pixel] 0.000 [mm]	0.328 [pixel] 0.001 [mm]	0.000	0.000	0.000	0.000	0.000



2D Keypoints Table

	Number of 2D Keypoints per Image	Number of Matched 2D Keypoints per Image
Median	20643	4553
Min	18796	2631
Max	33235	7230
Mean	21495	4691

3D Points from 2D Keypoint Matches

	Number of 3D Points Observed
In 2 Images	125765
In 3 Images	23821
In 4 Images	7655
In 5 Images	3387
In 6 Images	1518
In 7 Images	813
In 8 Images	402
In 9 Images	230
In 10 Images	123
In 11 Images	92
In 12 Images	39
In 13 Images	20
In 14 Images	15
In 15 Images	6
In 16 Images	5
In 17 Images	2

In 19 Images	1
In 20 Images	1

2D Keypoint Matches

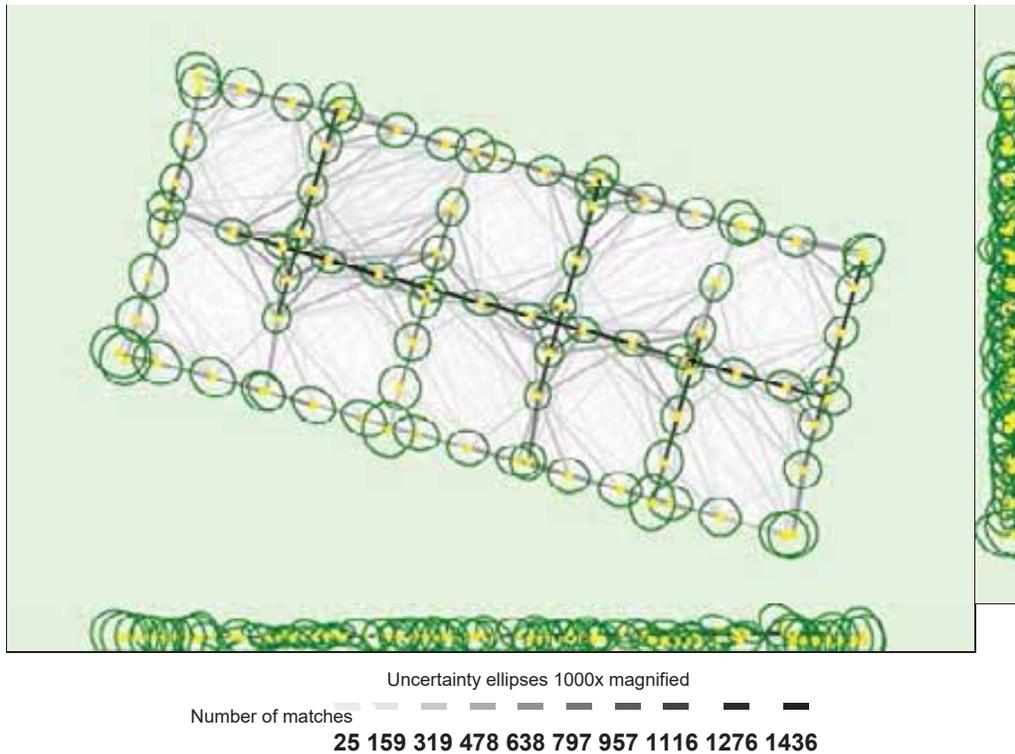


Figure 5: Computed image positions with links between matched images. The darkness of the links indicates the number of matched 2D keypoints between the images. Bright links indicate weak links and require manual tie points or more images. Dark green ellipses indicate the relative camera position uncertainty of the bundle block adjustment result.

Relative camera position and orientation uncertainties

	X [m]	Y [m]	Z [m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.002	0.002	0.002	0.006	0.008	0.004
Sigma	0.000	0.000	0.001	0.002	0.003	0.001

Geolocation Details

Absolute Geolocation Variance

Min Error [m]	Max Error [m]	Geolocation Error X [%]	Geolocation Error Y [%]	Geolocation Error Z [%]
-	-15.00	0.00	0.00	0.00
-15.00	-12.00	0.00	0.00	0.00
-12.00	-9.00	0.00	0.00	0.00
-9.00	-6.00	0.00	0.00	0.00

Sigma of Geolocation Accuracy [m]	0.000000	0.000000	0.000000
--	----------	----------	----------

-6.00	-3.00	0.00	0.00	0.00
-3.00	0.00	67.86	36.90	48.81
0.00	3.00	32.14	63.10	51.19
3.00	6.00	0.00	0.00	0.00
6.00	9.00	0.00	0.00	0.00
9.00	12.00	0.00	0.00	0.00
12.00	15.00	0.00	0.00	0.00
15.00	-	0.00	0.00	0.00
Mean [m]		0.000008	0.000002	-0.000007
Sigma [m]		0.902939	0.763695	0.367307
RMS Error [m]		0.902939	0.763695	0.367307

Min Error and Max Error represent geolocation error intervals between -1.5 and 1.5 times the maximum accuracy of all the images. Columns X, Y, Z show the percentage of images with geolocation errors within the predefined error intervals. The geolocation error is the difference between the initial and computed image positions. Note that the image geolocation errors do not correspond to the accuracy of the observed 3D points.

Relative Geolocation Variance

Relative Geolocation Error	Images X [%]	Images Y [%]	Images Z [%]
[-1.00, 1.00]	100.00	100.00	100.00
[-2.00, 2.00]	100.00	100.00	100.00
[-3.00, 3.00]	100.00	100.00	100.00
Mean of Geolocation Accuracy [m]	5.000000	5.000000	10.000000

Images X, Y, Z represent the percentage of images with a relative geolocation error in X, Y, Z.

Geolocation Orientational Variance	RMS [degree]
Omega	1.144
Phi	1.146
Kappa	1.760

Geolocation RMS error of the orientation angles given by the difference between the initial and computed image orientation angles.

Initial Processing Details

System Information

Hardware	CPU: Intel(R) Core(TM) i5-3330S CPU @ 2.70GHz RAM: 8GB GPU: Intel(R) HD Graphics (Driver: 10.18.10.3412), RDPDD Chained DD (Driver: unknown), RDP Encoder Mirror Driver (Driver: unknown), RDP Reflector Display Driver (Driver: unknown)
Operating System	Windows 7 Professional, 64-bit

Coordinate Systems

Image Coordinate System	WGS84 (egm96)
Output Coordinate System	WGS 84 / UTM zone 19N (egm96)

Processing Options

Detected Template	3D Maps
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Keypoints Image Scale	Full, Image Scale: 1
Advanced: Matching Image Pairs	Aerial Grid or Corridor
Advanced: Matching Strategy	Use Geometrically Verified Matching: no
Advanced: Keypoint Extraction	Targeted Number of Keypoints: Automatic
Advanced: Calibration	Calibration Method: Standard Internal Parameters Optimization: All External Parameters Optimization: All Rematch: Auto, yes

Point Cloud Densification details

Processing Options

Image Scale	multiscale, 1/2 (Half image size, Default)
Point Density	Optimal
Minimum Number of Matches	3
3D Textured Mesh Generation	yes
3D Textured Mesh Settings:	Resolution: Medium Resolution (default) Color Balancing: no
LOD	Generated: no
Advanced: 3D Textured Mesh Settings	Sample Density Divider: 1
Advanced: Image Groups	group1
Advanced: Use Processing Area	yes
Advanced: Use Annotations	yes
Time for Point Cloud Densification	24m:52s
Time for Point Cloud Classification	NA
Time for 3D Textured Mesh Generation	05m:21s

Results

Number of Generated Tiles	1
Number of 3D Densified Points	6619348
Average Density (per m ³)	1534.57

DSM, Orthomosaic and Index Details

Processing Options

DSM and Orthomosaic Resolution	1 x GSD (1.31 [cm/pixel])
DSM Filters	Noise Filtering: yes Surface Smoothing: yes, Type: Sharp
Raster DSM	Generated: yes Method: Inverse Distance Weighting Merge Tiles: yes
Orthomosaic	Generated: yes Merge Tiles: yes GeoTIFF Without Transparency: no Google Maps Tiles and KML: no
Time for DSM Generation	09m:50s
Time for Orthomosaic Generation	17m:41s

Time for DTM Generation	00s
Time for Contour Lines Generation	00s
Time for Reflectance Map Generation	00s
Time for Index Map Generation	00s

Site name:

Eastern part of Secret Spot beach, Isabela, Puerto Rico

After Hurricane María

A. Physical address:

Eastern part of Secret Spot, PR 466 street, Isabela, Puerto Rico, 00662

B. Date of capture of imagery:

January 13, 2018

C. Coordinates:

18.51320800 N -67.04373277 W

D. Aerial imagery

i. Contour map

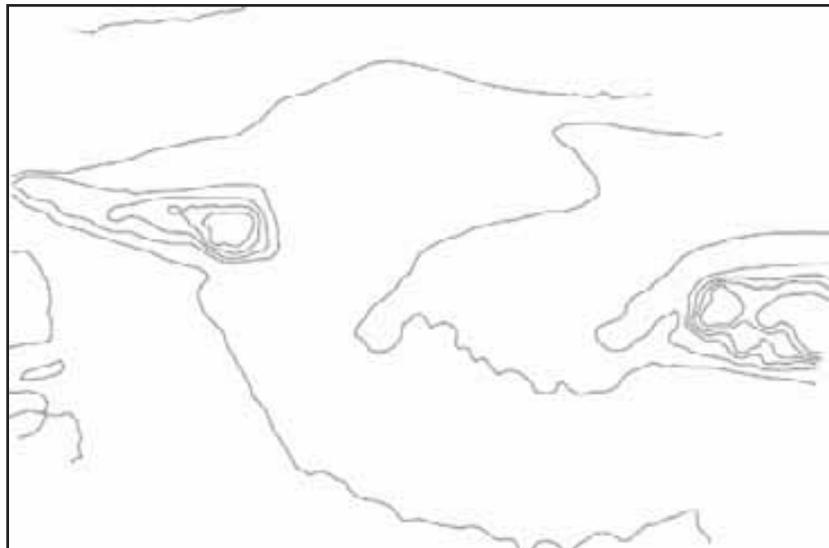


Figure 97. Contour map of Eastern part Secret Spot (after hurricane María), Isabela Puerto Rico with elevation intervals of 1 meter.

ii. 3D imagery



Figure 98. Aerial 3D image of the eastern part Secret Spot, Isabela (after hurricane María).

iii. Orthomosaic model

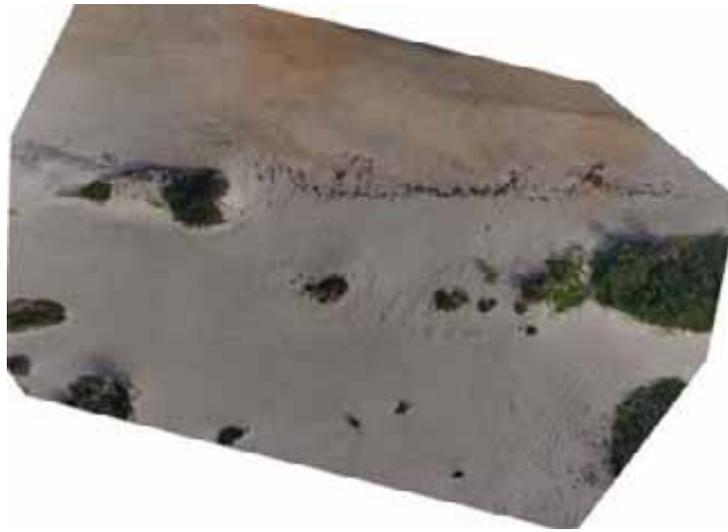


Figure 99. Orthomosaic image of the eastern part Secret Spot, Isabela (after hurricane María).

iv. Density Surface Models (DSM)

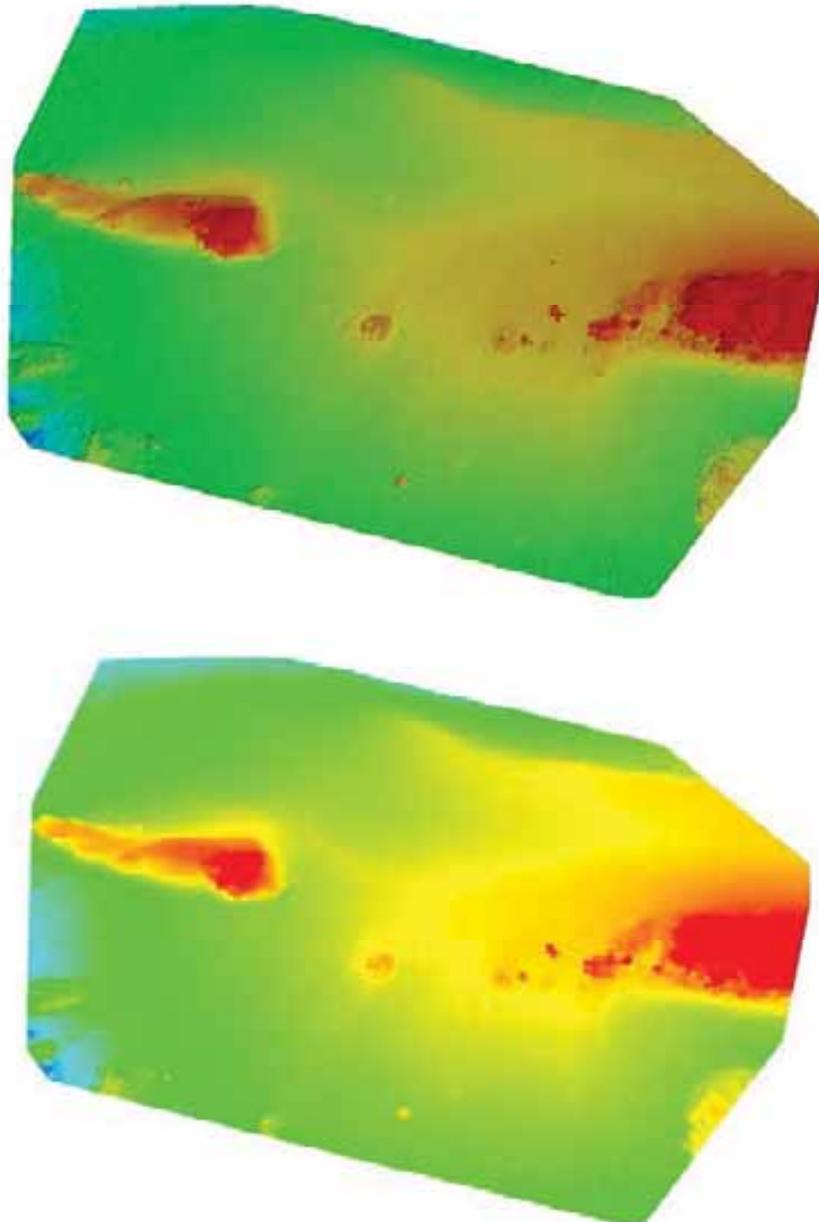


Figure 100. Density surface model (with shading top and without shading bottom) images of the dune located at the eastern part Secret Spot (after hurricane María), Isabela

v. Thermal images

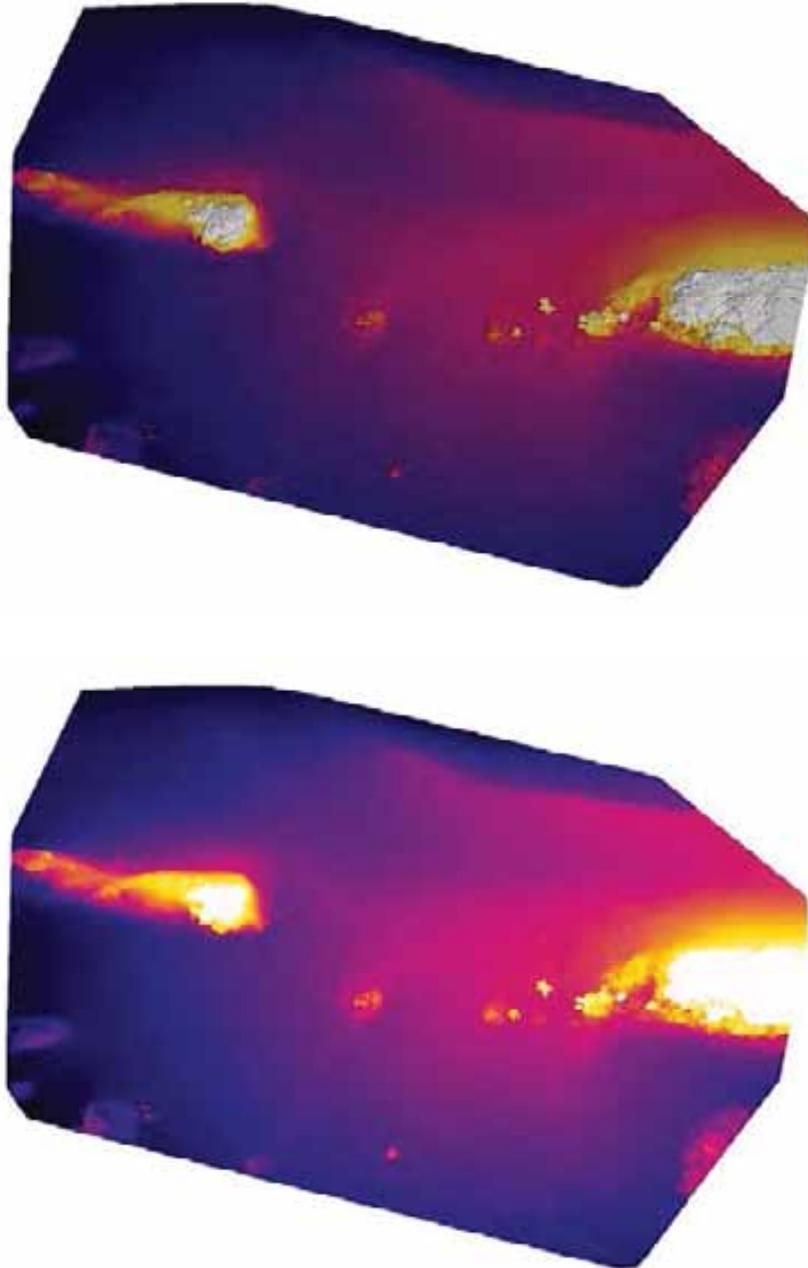


Figure 101. Thermal images (with shading top and without shading bottom) of the dune located at the eastern part Secret Spot (after hurricane María), Isabela

vi. 3D altitude RGB North

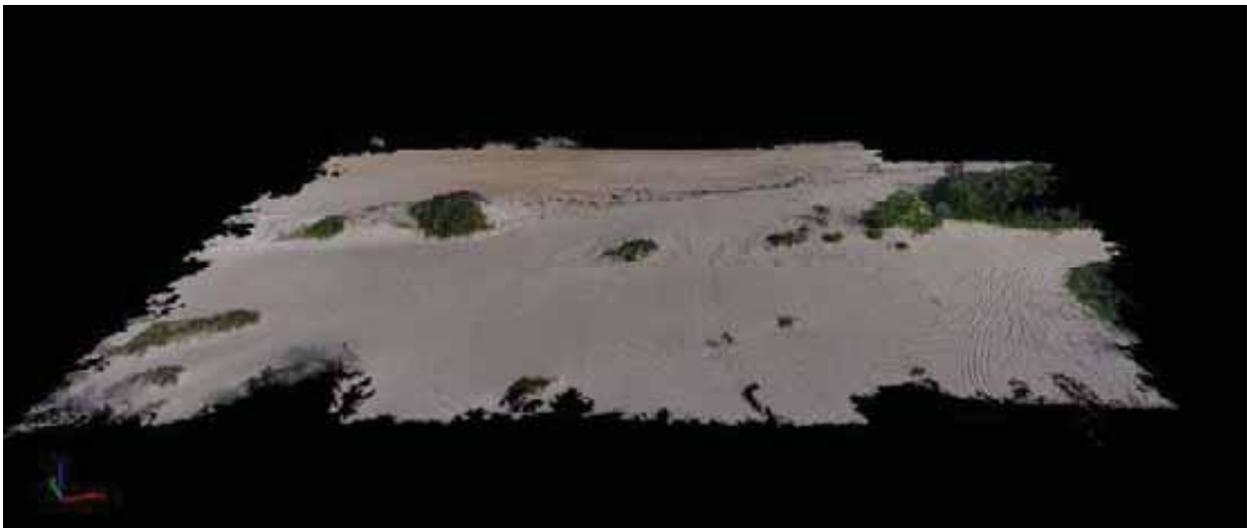


Figure 102. Three dimensional RGB images of the eastern part Secret Spot, Isabela (after hurricane María). View from the north (top) and from the south (bottom).



Figure 103. Three dimensional RGB images of the eastern part Secret Spot (after hurricane María), Isabela. View from the west (top) and from the east (bottom). *Note- Mayer*

vii. DSM grayscale

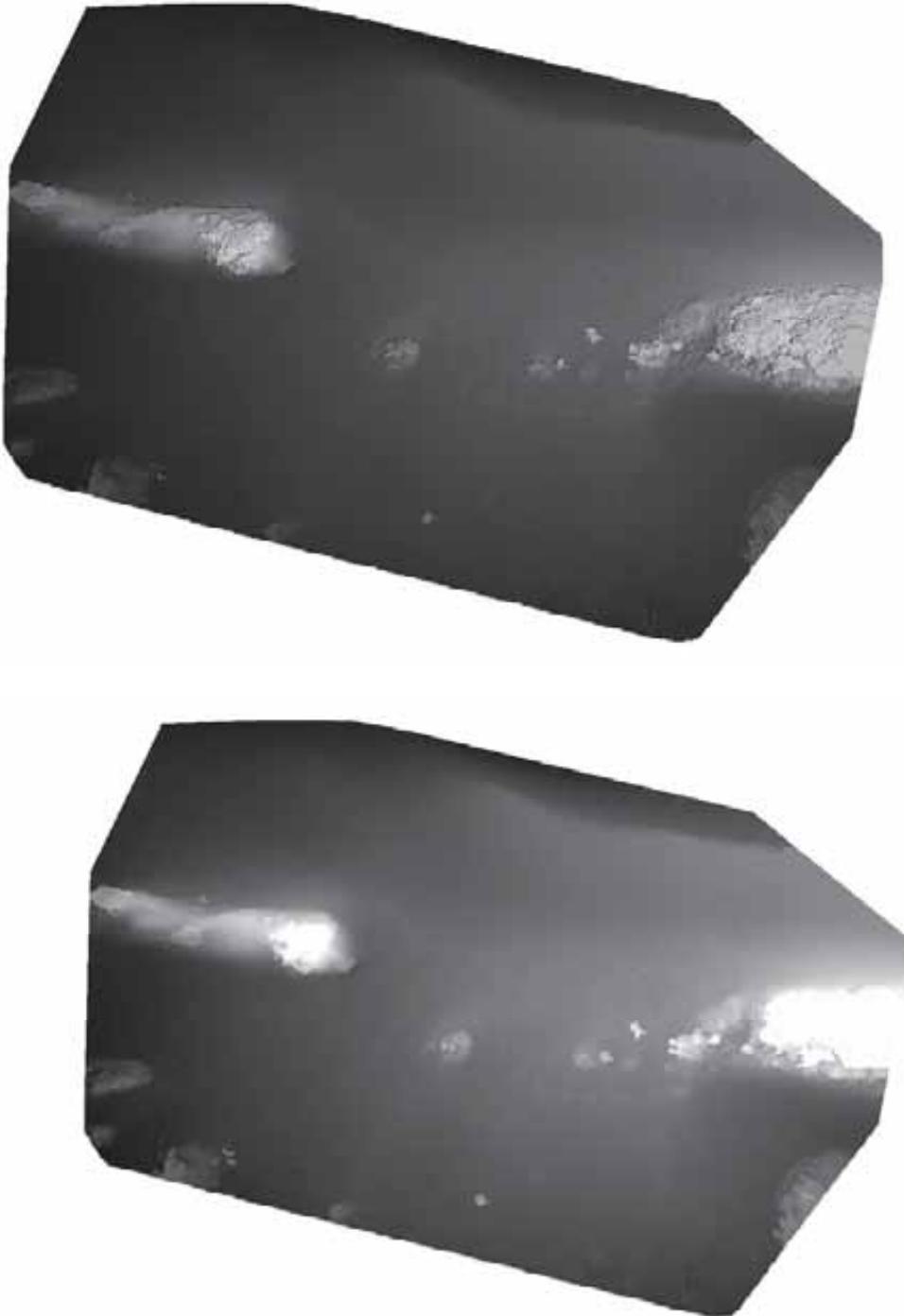


Figure 104. Grayscale DSM images of the dune to the eastern part Secret Spot (after hurricane María), Isabela. The top image shows shades and the bottom is not shaded.

E. Pix 4D Quality Report

Quality Report



Generated with Pix4Dmapper Pro version 4.1.22

Important: Click on the different icons for:

- Help to analyze the results in the Quality Report
- Additional information about the sections

Click [here](#) for additional tips to analyze the Quality Report

Summary

Project	Mision Secret Spot Despues Del Huracan María
Processed	2018-01-15 07:40:20
Camera Model Name(s)	FC330_3.6_4000x3000 (RGB)
Average Ground Sampling Distance (GSD)	1.27 cm / 0.50 in
Area Covered	0.012 km ² / 1.2339 ha / 0.00 sq. mi. / 3.0506 acres
Time for Initial Processing (without report)	15m:51s

Quality Check

Images	median of 20502 keypoints per image	✓
Dataset	81 out of 81 images calibrated (100%), all images enabled	✓
Camera Optimization	5.41% relative difference between initial and optimized internal camera parameters	⚠
Matching	median of 8338.2 matches per calibrated image	✓
Georeferencing	yes, no 3D GCP	⚠

Preview

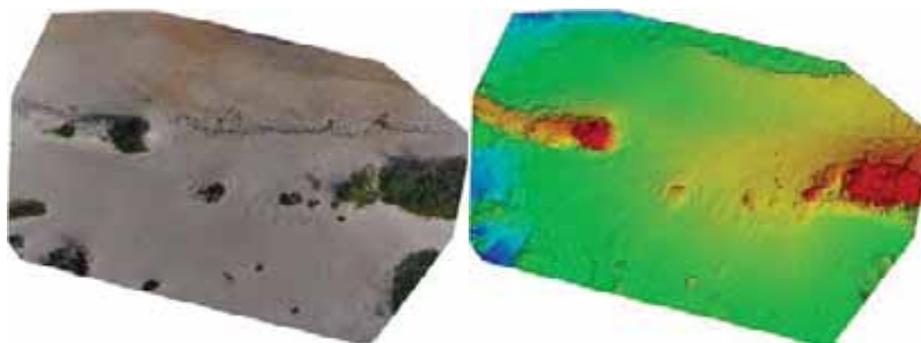


Figure 1: Orthomosaic and the corresponding sparse Digital Surface Model (DSM) before densification.

Calibration Details

Number of Calibrated Images	81 out of 81
Number of Geolocated Images	81 out of 81

Initial Image Positions

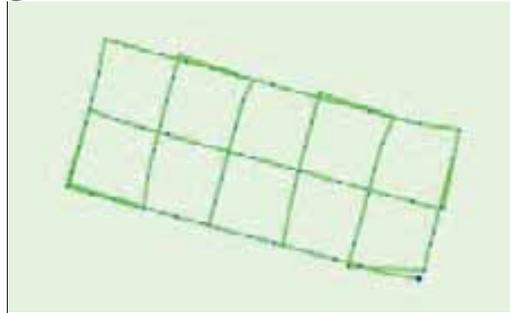
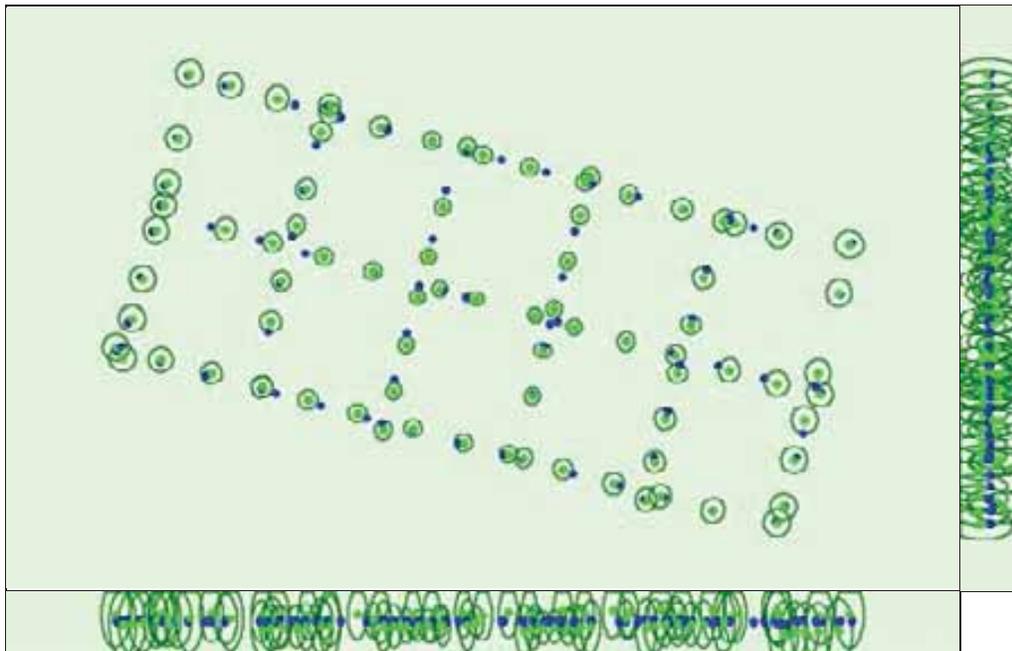


Figure 2: Top view of the initial image position. The green line follows the position of the images in time starting from the large blue dot.

Computed Image/GCPs/Manual Tie Points Positions



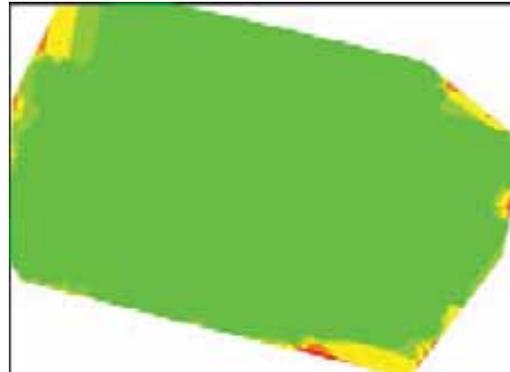
Uncertainty ellipses 10x magnified

Figure 3: Offset between initial (blue dots) and computed (green dots) image positions as well as the offset between the GCPs initial positions (blue crosses) and their computed positions (green crosses) in the top-view (XY plane), front-view (XZ plane), and side-view (YZ plane). Dark green ellipses indicate the absolute position uncertainty of the bundle block adjustment result.

📌 Absolute camera position and orientation uncertainties

	X [m]	Y [m]	Z [m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.141	0.141	0.343	0.784	0.451	0.259
Sigma	0.026	0.026	0.071	0.070	0.072	0.031

📌 Overlap



Number of overlapping images: 2 3 4 5+

Figure 4: Number of overlapping images computed for each pixel of the orthomosaic. Red and yellow areas indicate low overlap for which poor results may be generated. Green areas indicate an overlap of over 5 images for every pixel. Good quality results will be generated as long as the number of keypoint matches is also sufficient for these areas (see Figure 5 for keypoint matches).

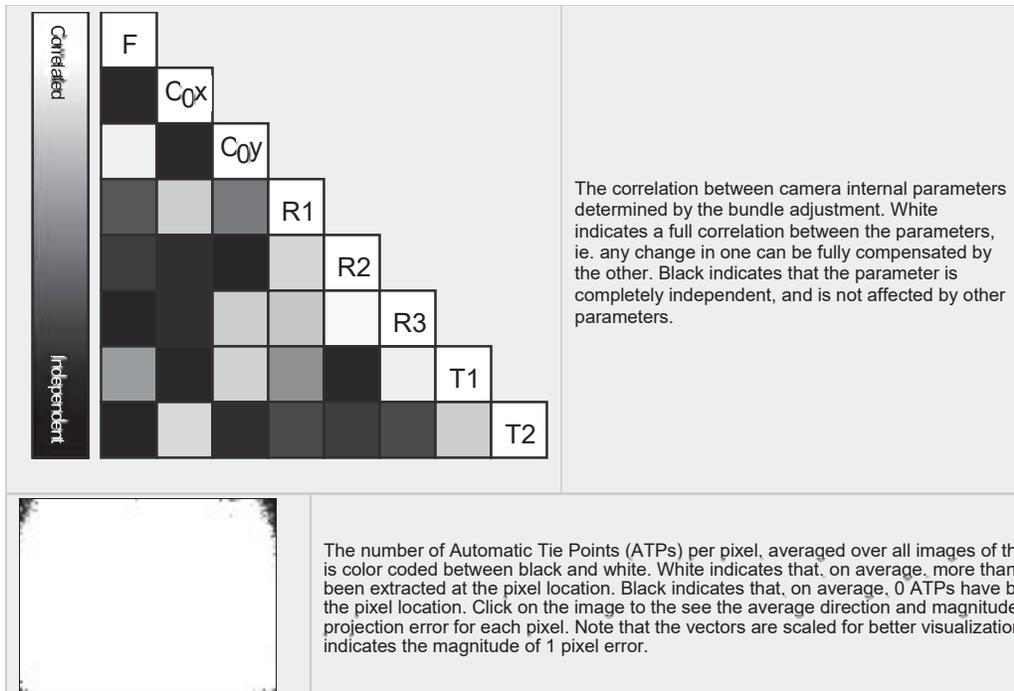
Bundle Block Adjustment Details

Number of 2D Keypoint Observations for Bundle Block Adjustment	796274
Number of 3D Points for Bundle Block Adjustment	249118
Mean Reprojection Error [pixels]	0.219

📌 Internal Camera Parameters FC330_3.6_4000x3000 (RGB). Sensor Dimensions: 6.317 [mm] x 4.738 [mm]

EXIF ID: FC330_3.6_4000x3000

	Focal Length	Principal Point x	Principal Point y	R1	R2	R3	T1	T2
Initial Values	2285.722 [pixel] 3.610 [mm]	2000.006 [pixel] 3.159 [mm]	1500.003 [pixel] 2.369 [mm]	-0.001	-0.002	0.000	-0.001	-0.001
Optimized Values	2409.449 [pixel] 3.805 [mm]	1960.494 [pixel] 3.096 [mm]	1454.433 [pixel] 2.297 [mm]	0.001	-0.006	0.004	-0.000	-0.000
Uncertainties (Sigma)	0.464 [pixel] 0.001 [mm]	0.058 [pixel] 0.000 [mm]	0.273 [pixel] 0.000 [mm]	0.000	0.000	0.000	0.000	0.000



The number of Automatic Tie Points (ATPs) per pixel, averaged over all images of the camera model, is color coded between black and white. White indicates that, on average, more than 16 ATPs have been extracted at the pixel location. Black indicates that, on average, 0 ATPs have been extracted at the pixel location. Click on the image to see the average direction and magnitude of the re-projection error for each pixel. Note that the vectors are scaled for better visualization. The scale bar indicates the magnitude of 1 pixel error.

2D Keypoints Table

	Number of 2D Keypoints per Image	Number of Matched 2D Keypoints per Image
Median	20502	8338
Min	15667	2729
Max	44564	20546
Mean	23398	9831

3D Points from 2D Keypoint Matches

	Number of 3D Points Observed
In 2 Images	145564
In 3 Images	43719
In 4 Images	20485
In 5 Images	11872
In 6 Images	7535
In 7 Images	5415
In 8 Images	4065
In 9 Images	2844
In 10 Images	2188
In 11 Images	1757
In 12 Images	1175
In 13 Images	930
In 14 Images	609
In 15 Images	413
In 16 Images	251
In 17 Images	142

In 18 Images	82
In 19 Images	35
In 20 Images	19
In 21 Images	11
In 22 Images	5
In 23 Images	1
In 25 Images	1

2D Keypoint Matches

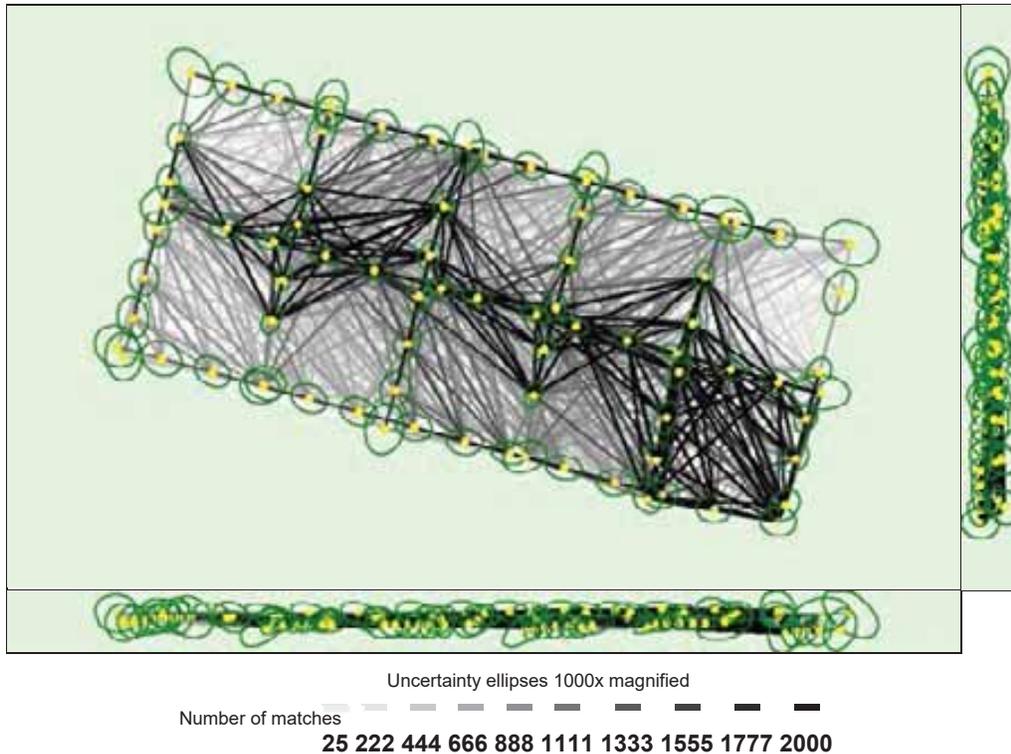


Figure 5: Computed image positions with links between matched images. The darkness of the links indicates the number of matched 2D keypoints between the images. Bright links indicate weak links and require manual tie points or more images. Dark green ellipses indicate the relative camera position uncertainty of the bundle block adjustment result.

Relative camera position and orientation uncertainties

	X [m]	Y [m]	Z [m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.002	0.002	0.002	0.005	0.006	0.003
Sigma	0.001	0.001	0.001	0.002	0.002	0.001

Geolocation Details

Absolute Geolocation Variance

Min Error [m]	Max Error [m]	Geolocation Error X [%]	Geolocation Error Y [%]	Geolocation Error Z [%]
-	-15.00	0.00	0.00	0.00
-15.00	-12.00	0.00	0.00	0.00
-12.00	-9.00	0.00	0.00	0.00
-9.00	-6.00	0.00	0.00	0.00
-6.00	-3.00	0.00	0.00	0.00
-3.00	0.00	54.32	51.85	49.38
0.00	3.00	45.68	48.15	50.62
3.00	6.00	0.00	0.00	0.00
6.00	9.00	0.00	0.00	0.00
9.00	12.00	0.00	0.00	0.00
12.00	15.00	0.00	0.00	0.00
15.00	-	0.00	0.00	0.00
Mean [m]		-0.028307	-0.008711	-0.006805
Sigma [m]		0.926743	0.861450	0.855515
RMS Error [m]		0.927176	0.861494	0.855542

Min Error and Max Error represent geolocation error intervals between -1.5 and 1.5 times the maximum accuracy of all the images. Columns X, Y, Z show the percentage of images with geolocation errors within the predefined error intervals. The geolocation error is the difference between the initial and computed image positions. Note that the image geolocation errors do not correspond to the accuracy of the observed 3D points.

Relative Geolocation Variance

Relative Geolocation Error	Images X [%]	Images Y [%]	Images Z [%]
[-1.00, 1.00]	100.00	100.00	100.00
[-2.00, 2.00]	100.00	100.00	100.00
[-3.00, 3.00]	100.00	100.00	100.00
Mean of Geolocation Accuracy [m]	5.000000	5.000000	10.000000
Sigma of Geolocation Accuracy [m]	0.000000	0.000000	0.000000

Images X, Y, Z represent the percentage of images with a relative geolocation error in X, Y, Z.

Geolocation Orientational Variance	RMS [degree]
Omega	1.939
Phi	2.330
Kappa	4.720

Geolocation RMS error of the orientation angles given by the difference between the initial and computed image orientation angles.

Initial Processing Details

System Information

Hardware	CPU: Intel(R) Core(TM) i5-3330S CPU @ 2.70GHz RAM: 8GB GPU: Intel(R) HD Graphics (Driver: 10.18.10.3412), RDPDD Chained DD (Driver: unknown), RDP Encoder Mirror Driver (Driver: unknown), RDP Reflector Display Driver (Driver: unknown)
Operating System	Windows 7 Professional, 64-bit

Coordinate Systems



Image Coordinate System	WGS84 (egm96)
Output Coordinate System	WGS 84 / UTM zone 19N (egm96)

Processing Options



Detected Template	3D Maps
Keypoints Image Scale	Full, Image Scale: 1
Advanced: Matching Image Pairs	Aerial Grid or Corridor
Advanced: Matching Strategy	Use Geometrically Verified Matching: no
Advanced: Keypoint Extraction	Targeted Number of Keypoints: Automatic
Advanced: Calibration	Calibration Method: Standard Internal Parameters Optimization: All External Parameters Optimization: All Rematch: Auto, yes

Point Cloud Densification details



Processing Options



Image Scale	multiscale, 1/2 (Half image size, Default)
Point Density	Optimal
Minimum Number of Matches	3
3D Textured Mesh Generation	yes
3D Textured Mesh Settings:	Resolution: Medium Resolution (default) Color Balancing: no
LOD	Generated: no
Advanced: 3D Textured Mesh Settings	Sample Density Divider: 1
Advanced: Image Groups	group1
Advanced: Use Processing Area	yes
Advanced: Use Annotations	yes
Time for Point Cloud Densification	17m:55s
Time for Point Cloud Classification	NA
Time for 3D Textured Mesh Generation	04m:50s

Results



Number of Generated Tiles	1
Number of 3D Densified Points	5471416
Average Density (per m ³)	1547.81

DSM, Orthomosaic and Index Details



Processing Options



DSM and Orthomosaic Resolution	1 x GSD (1.27 [cm/pixel])
DSM Filters	Noise Filtering: yes

	Surface Smoothing: yes, Type: Sharp
Raster DSM	Generated: yes Method: Inverse Distance Weighting Merge Tiles: yes
Orthomosaic	Generated: yes Merge Tiles: yes GeoTIFF Without Transparency: no Google Maps Tiles and KML: no
Time for DSM Generation	08m:32s
Time for Orthomosaic Generation	13m:39s
Time for DTM Generation	00s
Time for Contour Lines Generation	00s
Time for Reflectance Map Generation	00s
Time for Index Map Generation	00s

Site name:

Eastern part of Secret Spot beach, Isabela

After March 2018 northeasterly swell

A. Physical address:

The eastern part of Secret Spot Beach parallel to road PR 466 Isabela, Puerto Rico, 00662

B. Date of capture of imagery:

March 28, 2018

C. Coordinates:

18.51320800 N - 67.04373277 W

D. Aerial imagery

i. Contour map

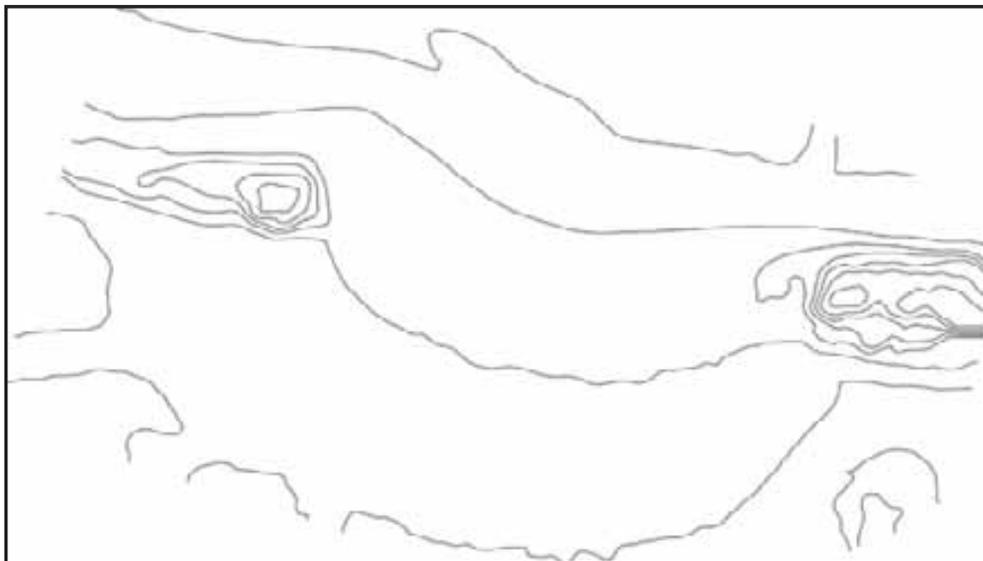


Figure 105. Contour map of the eastern part of Secret Spot Beach (after swell), Isabela Puerto Rico with elevation intervals of 1 meter.

ii. 3D imagery



Figure 106. Aerial 3D image of the eastern part of Secret Spot Beach, Isabela (after swell).

iii. Orthomosaic model

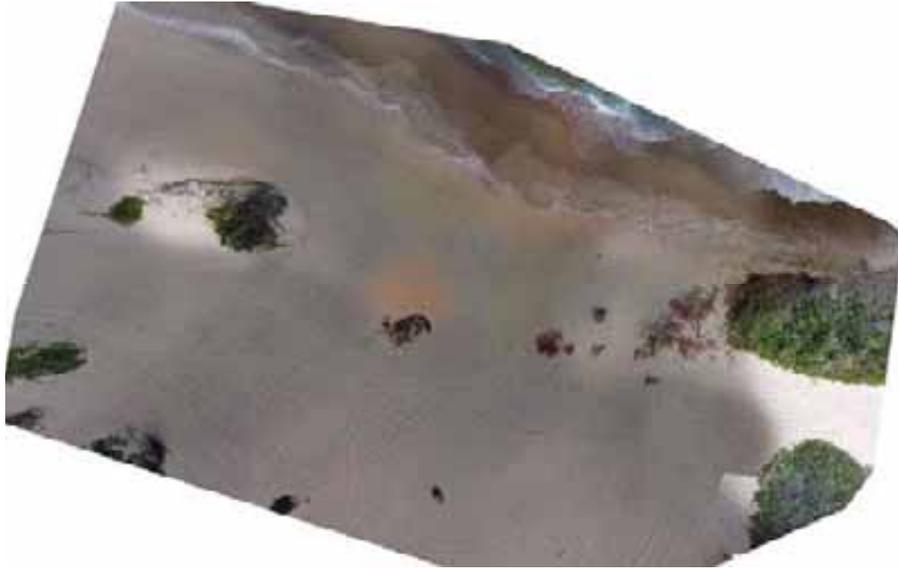


Figure 107. Orthomosaic image of the eastern part of Secret Spot Beach (after swell), Isabela.

iv. Density Surface Models (DSM)

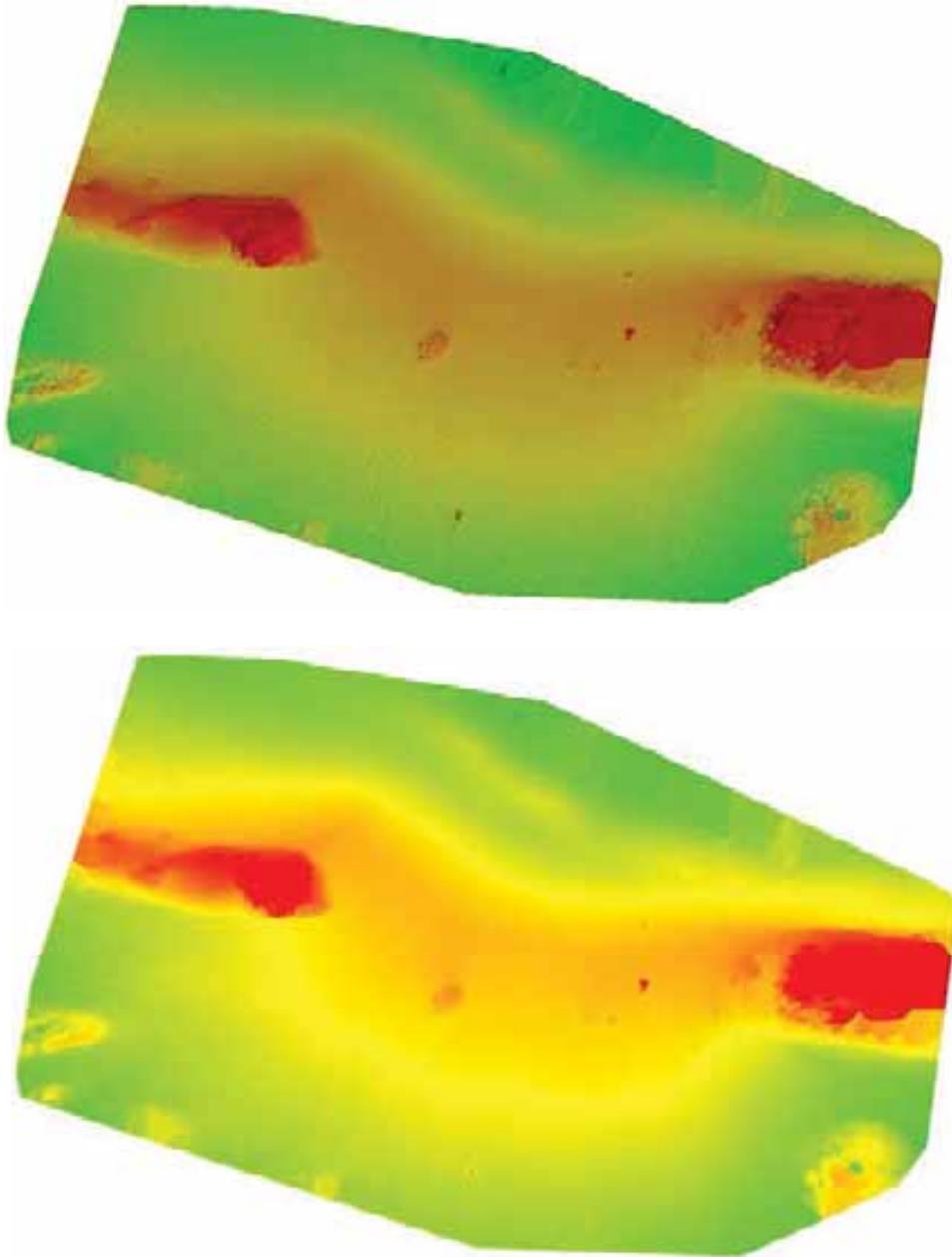


Figure 108. Density surface model (with shading top and without shading bottom) images of the dune located at the the eastern part of Secret Spot Beach (after swell), Isabela

v. Thermal images

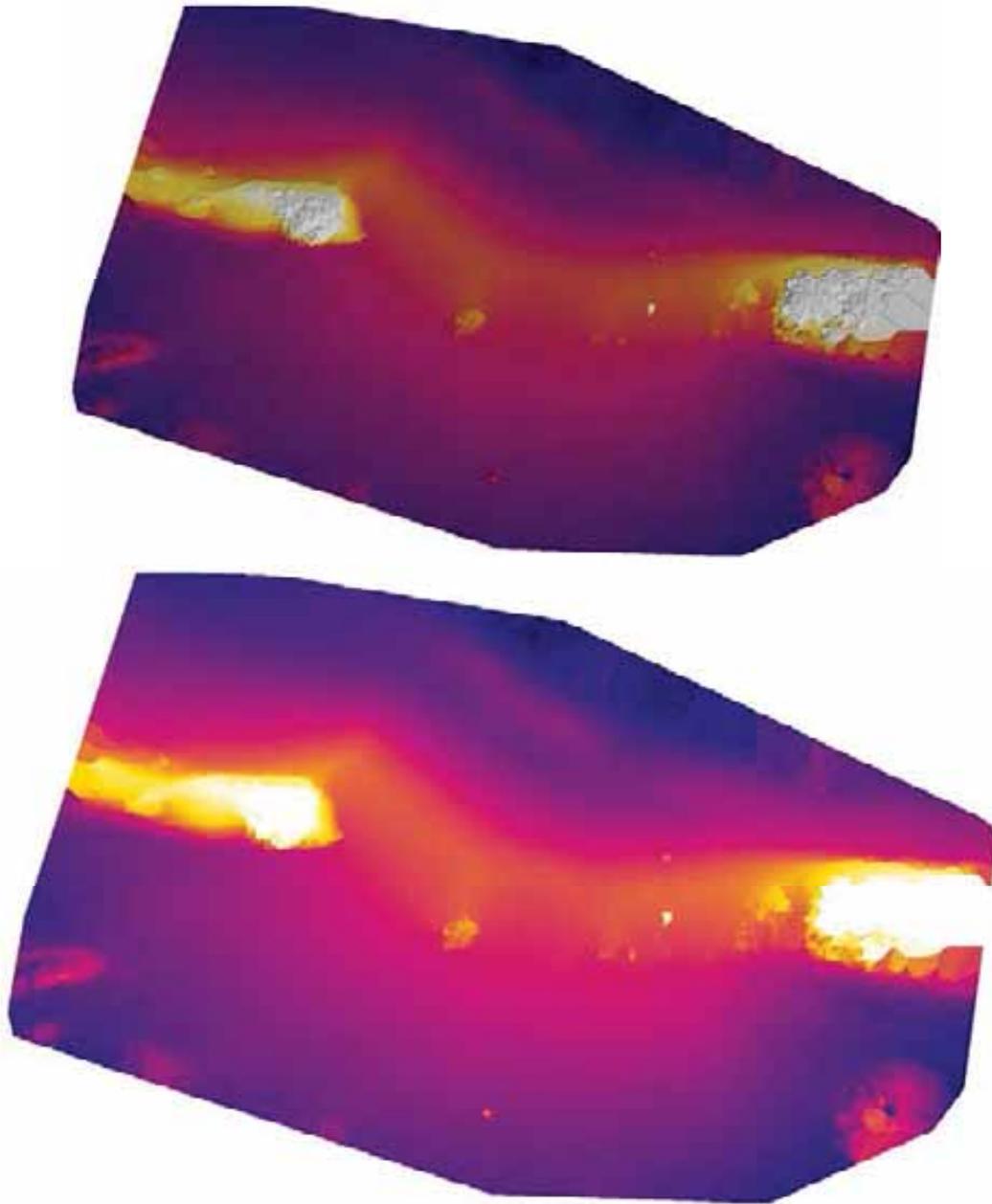


Figure 109. Thermal images (with shading top and without shading bottom) of the dune located at the the eastern part of Secret Spot Beach (after swell), Isabela

vi. 3D altitude RGB North



Figure 110. Three dimensional RGB images of the the eastern part of Secret Spot Beach, Isabela (after swell). View from the north (top) and from the south (bottom).

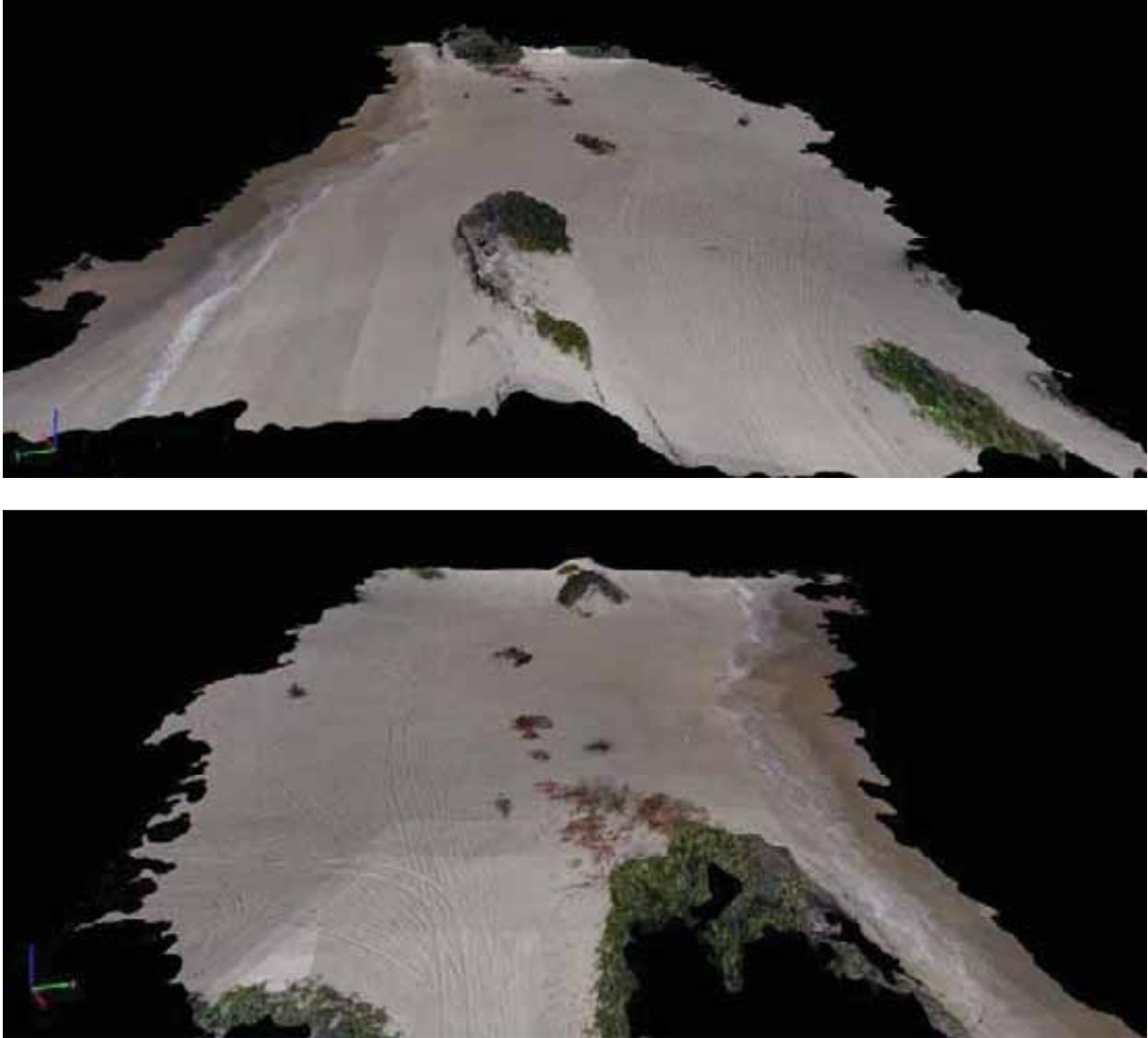


Figure 111. Three dimensional RGB images of the eastern part of Secret Spot Beach (after swell), Isabela. View from the west (top) and from the east (bottom).

vii. DSM grayscale

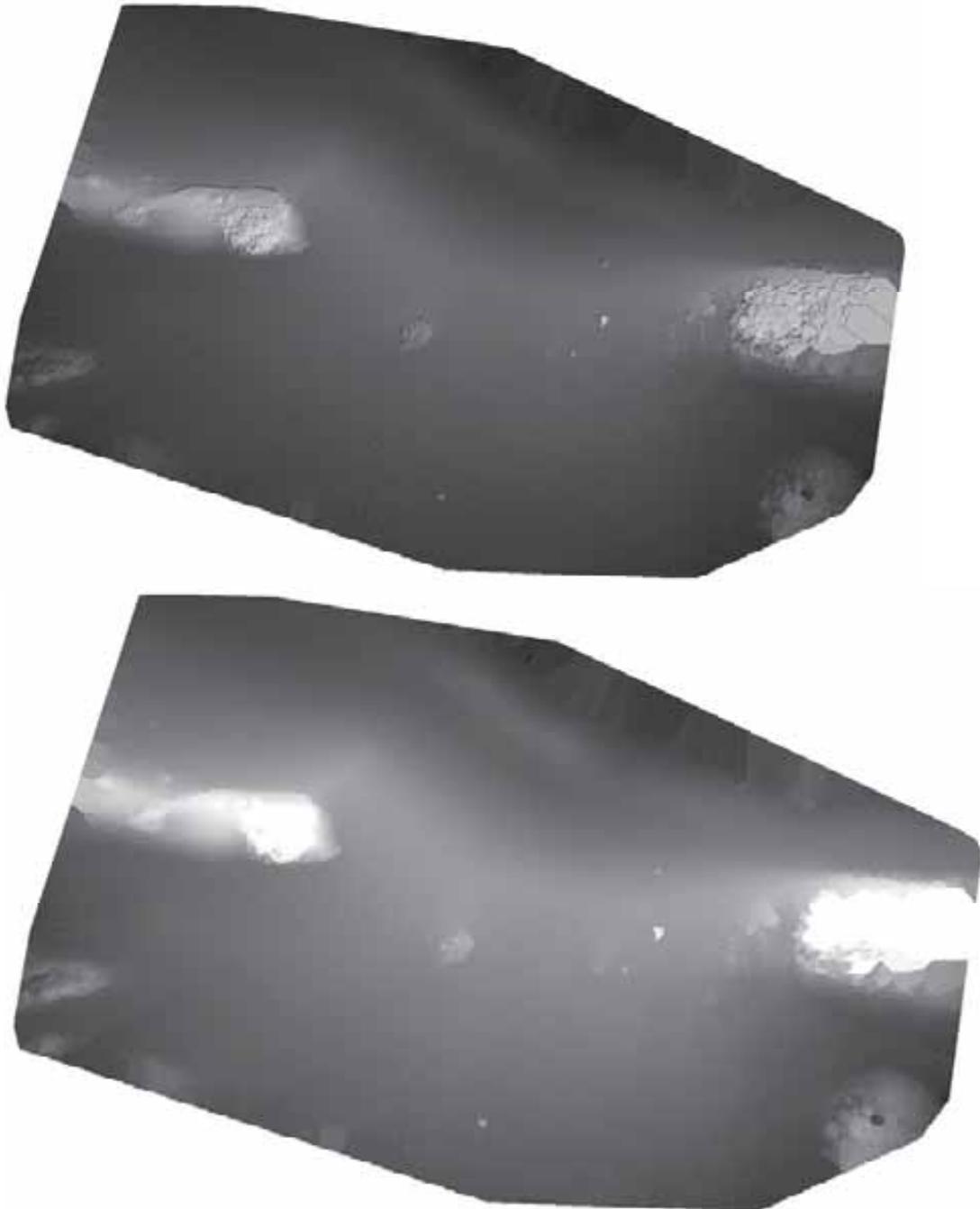


Figure 112. Grayscale DSM images of the dune to the eastern part of Secret Spot Beach (after swell), Isabela. The top image shows shades and the bottom is not shaded.

Site report

E. Vegetation cover



Figure 113. Vegetation covered 13.3% of the area on the breached dune on July 11, 2017 (before hurricanes Irma and María), 7.1% on January 13, 2018 (after hurricane María) and 5.8% on March 28, 2018 (after the northeasterly swell) of the area at the eastern part of Secret Spot Beach.

I. Volume measurements of selected areas of the dunes

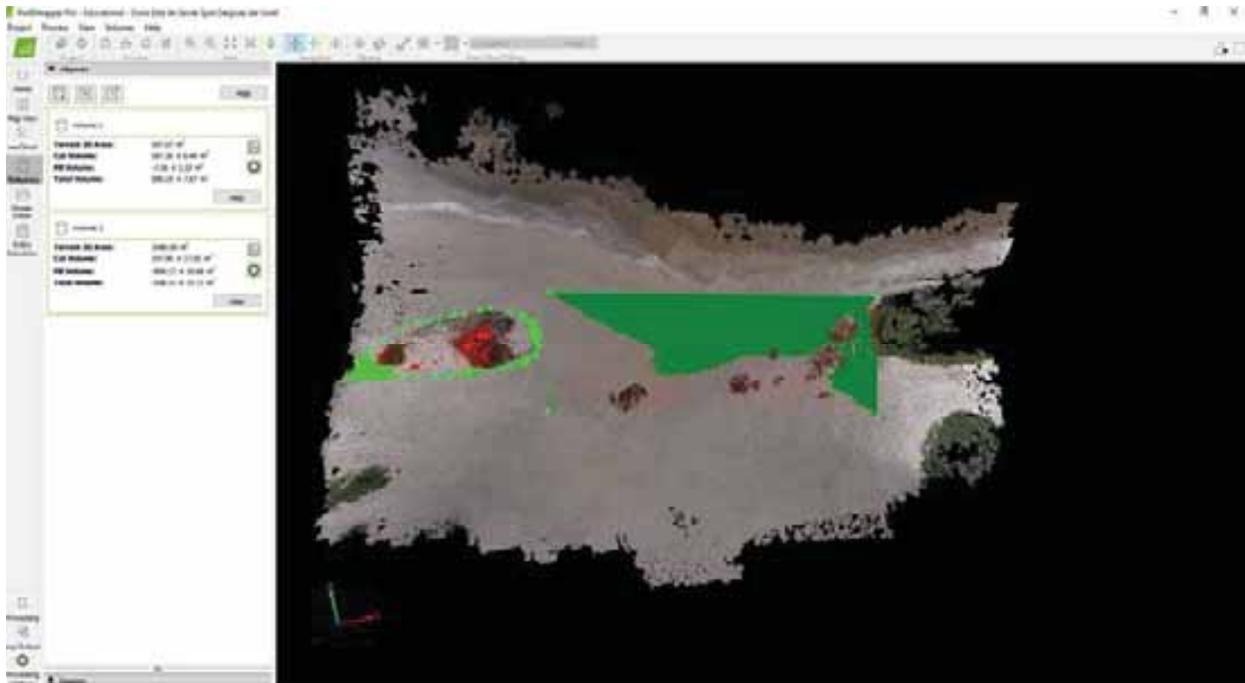


Figure 114. The first polygon (from left to right on the picture) has a 3D area of 597.07 m^2 and a cut volume of $587.26 \pm 6.44 \text{ m}^3$, a fill volume of $-7.16 \pm 1.23 \text{ m}^3$ and a total volume of $580.10 \pm 7.67 \text{ m}^3$. The second polygon (from left to right) has an area of 2086.09 m^2 and a cut volume of $197.90 \pm 17.05 \text{ m}^3$, a fill volume of $-404.12 \pm 16.68 \text{ m}^3$ and a total volume of $-206.22 \pm 33.73 \text{ m}^3$. The volume of these two areas will be monitored in subsequent months as a method to assess the progress of the restoration activities.

J. Conservation threats

This area was severely affected by the 2017 hurricanes and the strong northeasterly swell of March of 2018. This area had been restored since 2007 but all these efforts were destroyed in the last 8 months. The vegetation cover and sand accumulation in the area was significantly reduced by the strong waves. The area is also subject to erosion caused by high illegal all-terrain vehicle traffic (see tire tracks on image below). This is the most significant conservation threat in the area, coupled with low sand accumulation relative to other parts of the Isabela dune system.

The incidence of sand extraction is low due to the high visibility of the area and the long distance from PR-466.

K. Recommended ecological restoration courses of action (COA)

This area was in the process of being ecologically restored (note sand, exclusion fencing and biomimicry matrices on the aerial pictures of the area from before hurricane María). All these efforts were destroyed by the extreme weather caused by two major storms and a strong northeasterly swell. This is a large breach that needs to be restored as soon as possible by the installation of exclusion fencing to keep all terrain vehicles and foot traffic out of sensitive areas. Sand accumulation in this area is lower than in other areas of this dune system but the installation of biomimicry matrices followed by the planting of vegetation are needed to stabilize it.

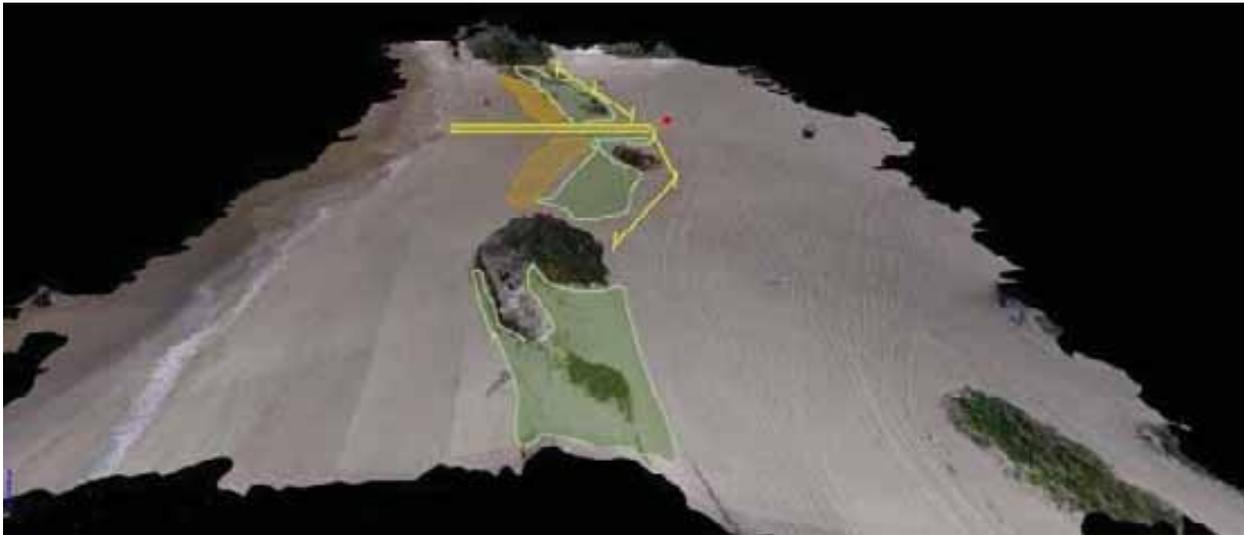


Figure 115. Area to be ecologically restored at the eastern part of Secret Spot Beach on PR 466 in Barrio Bajuras, Isabela. Highlighted areas correspond to each technique that will be used in this area. **Yellow** represents the location of wooden boardwalks, platform and barriers, the **red dot** marks the location of an information sign, **light green** marks the location of planting of dune vegetation, **tan** represents the area where biomimicry matrices will be installed to promote the accumulation of sand and areas shaded in light green represent locations for the planting of vegetation. Note the tire tracks on the back dune area. All the sand in this area is from a wash-over fan from the creation of this breach during a northeasterly event in 2008.

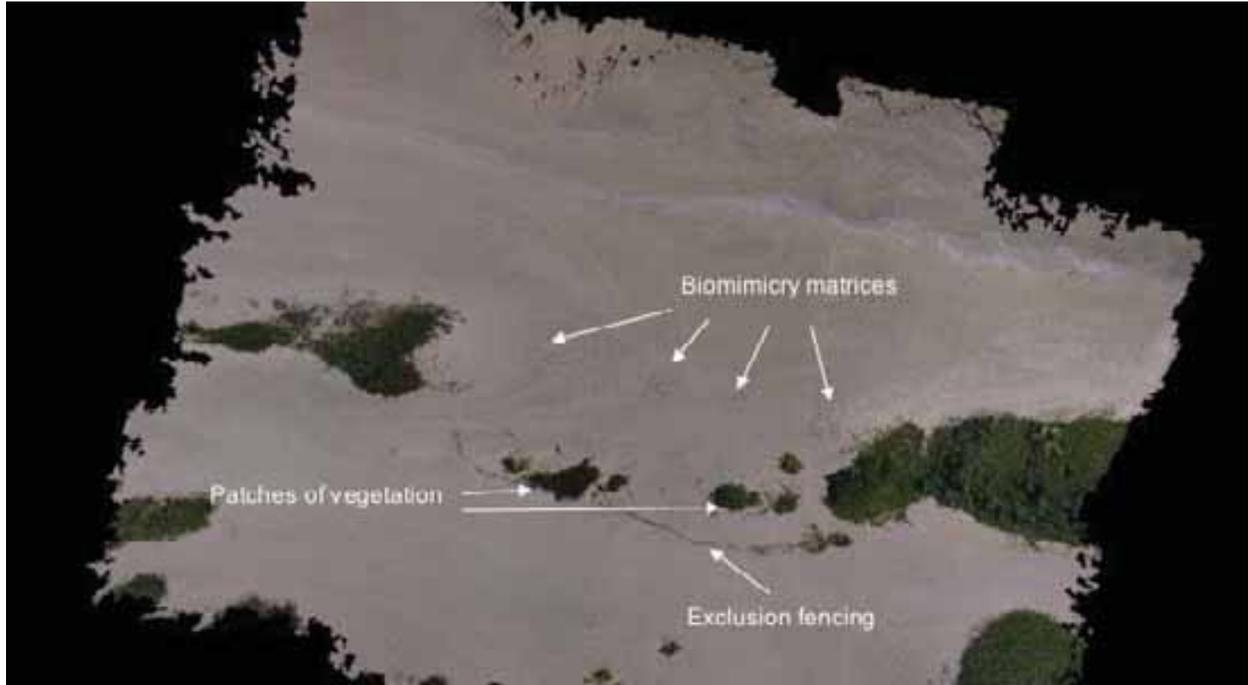


Figure 116. This is a diagram of the ecological restoration efforts on the area prior to hurricane María. Note the biomimicry matrices that had been installed to trap sand on the fore dune and the patches of vegetation that had been created by planting sea grapes and beach bean since 2007. Also a segment of exclusion fencing is visible on the picture. This was installed to block the traffic of all terrain vehicles which is one of the main conservation threats in this area. All of these structures and a significant portion of the patches of vegetation were destroyed by extreme weather in past months.

F. Pix 4D Quality Report

Quality Report



Generated with Pix4Dmapper Pro version 4.2.25

Important: Click on the different icons for:

- Help to analyze the results in the Quality Report
- Additional information about the sections

Click [here](#) for additional tips to analyze the Quality Report

Summary

Project	Duna Este de Secret Spot Despues del Swell
Processed	2018-04-05 20:12:11
Camera Model Name(s)	FC330_3.6_4000x3000 (RGB)
Average Ground Sampling Distance (GSD)	1.17 cm / 0.46 in
Area Covered	0.011 km ² / 1.1418 ha / 0.00 sq. mi. / 2.8230 acres
Time for Initial Processing (without report)	12m:11s

Quality Check

Images	median of 22370 keypoints per image	✓
Dataset	80 out of 80 images calibrated (100%), all images enabled	✓
Camera Optimization	4.57% relative difference between initial and optimized internal camera parameters	✓
Matching	median of 7006.65 matches per calibrated image	✓
Georeferencing	yes, no 3D GCP	⚠

Preview

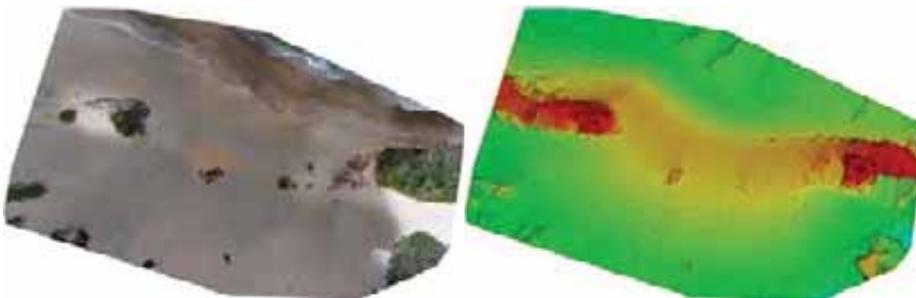


Figure 1: Orthomosaic and the corresponding sparse Digital Surface Model (DSM) before densification.

Calibration Details

Number of Calibrated Images	80 out of 80
Number of Geolocated Images	80 out of 80

Initial Image Positions

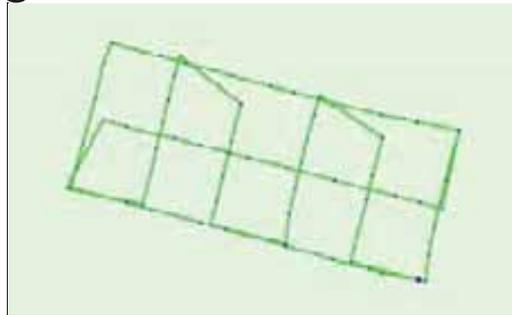
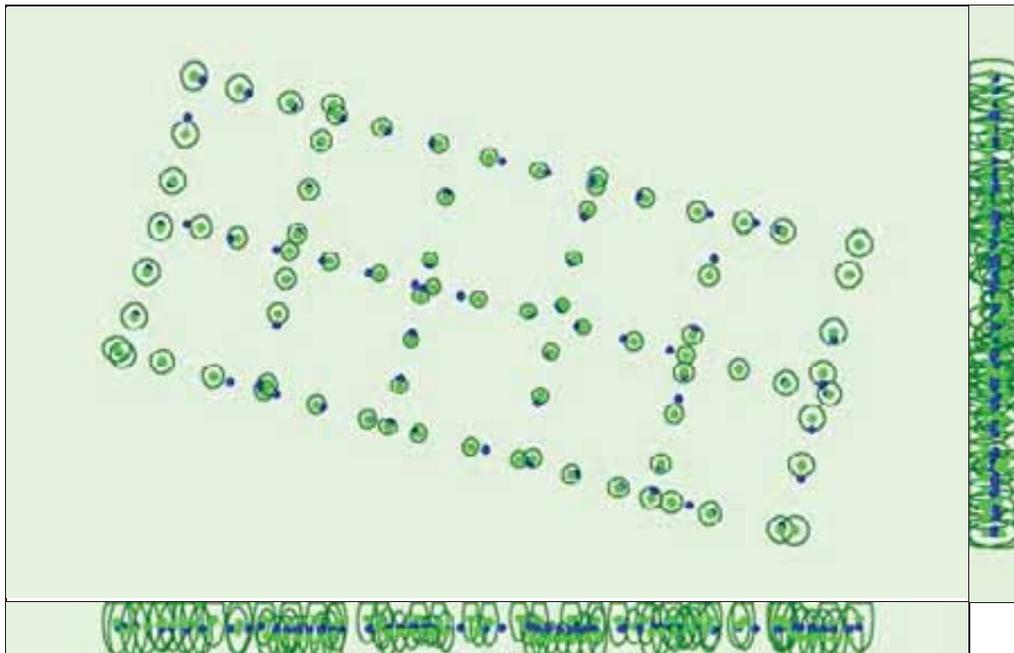


Figure 2: Top view of the initial image position. The green line follows the position of the images in time starting from the large blue dot.

Computed Image/GCPs/Manual Tie Points Positions



Uncertainty ellipses 10x magnified

Figure 3: Offset between initial (blue dots) and computed (green dots) image positions as well as the offset between the GCPs initial positions (blue crosses) and their computed positions (green crosses) in the top-view (XY plane), front-view (XZ plane), and side-view (YZ plane). Dark green ellipses indicate the absolute position uncertainty of the bundle block adjustment result.

📍 Absolute camera position and orientation uncertainties

	X [m]	Y [m]	Z [m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.134	0.135	0.326	0.776	0.391	0.250
Sigma	0.025	0.024	0.069	0.012	0.020	0.025

📍 Overlap

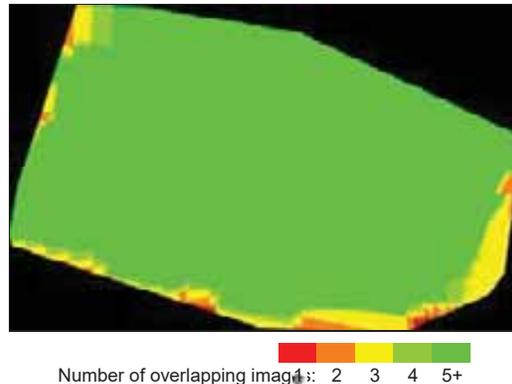


Figure 4: Number of overlapping images computed for each pixel of the orthomosaic. Red and yellow areas indicate low overlap for which poor results may be generated. Green areas indicate an overlap of over 5 images for every pixel. Good quality results will be generated as long as the number of keypoint matches is also sufficient for these areas (see Figure 5 for keypoint matches).

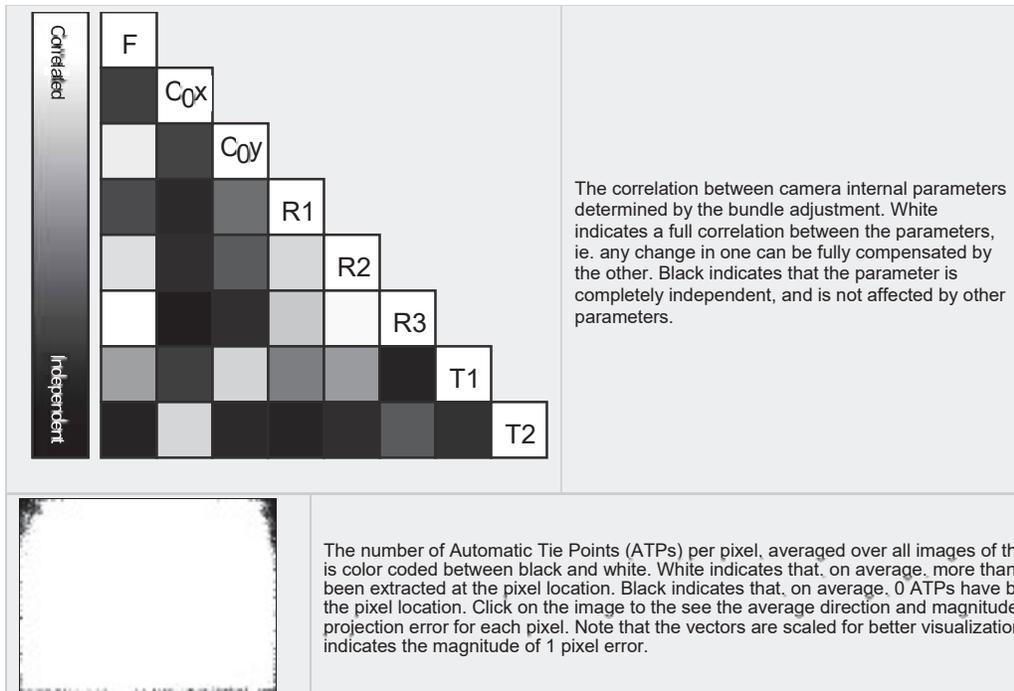
Bundle Block Adjustment Details

Number of 2D Keypoint Observations for Bundle Block Adjustment	661142
Number of 3D Points for Bundle Block Adjustment	237001
Mean Reprojection Error [pixels]	0.185

Internal Camera Parameters FC330_3.6_4000x3000 (RGB). Sensor Dimensions: 6.317 [mm] x 4.738 [mm]

EXIF ID: FC330_3.6_4000x3000

	Focal Length	Principal Point x	Principal Point y	R1	R2	R3	T1	T2
Initial Values	2285.722 [pixel] 3.610 [mm]	2000.006 [pixel] 3.159 [mm]	1500.003 [pixel] 2.369 [mm]	-0.001	-0.002	0.000	-0.001	-0.001
Optimized Values	2390.347 [pixel] 3.775 [mm]	1965.333 [pixel] 3.104 [mm]	1463.405 [pixel] 2.311 [mm]	0.000	-0.005	0.003	0.000	0.000
Uncertainties (Sigma)	0.379 [pixel] 0.001 [mm]	0.067 [pixel] 0.000 [mm]	0.247 [pixel] 0.000 [mm]	0.000	0.000	0.000	0.000	0.000



2D Keypoints Table

	Number of 2D Keypoints per Image	Number of Matched 2D Keypoints per Image
Median	22370	7007
Min	18377	762
Max	42873	18457
Mean	23636	8264

3D Points from 2D Keypoint Matches

	Number of 3D Points Observed
In 2 Images	151688
In 3 Images	42453
In 4 Images	18699
In 5 Images	9801
In 6 Images	5611
In 7 Images	3490
In 8 Images	2222
In 9 Images	1345
In 10 Images	805
In 11 Images	461
In 12 Images	213
In 13 Images	110
In 14 Images	58
In 15 Images	20
In 16 Images	18
In 17 Images	5

In 18 Images	1
In 19 Images	1

2D Keypoint Matches

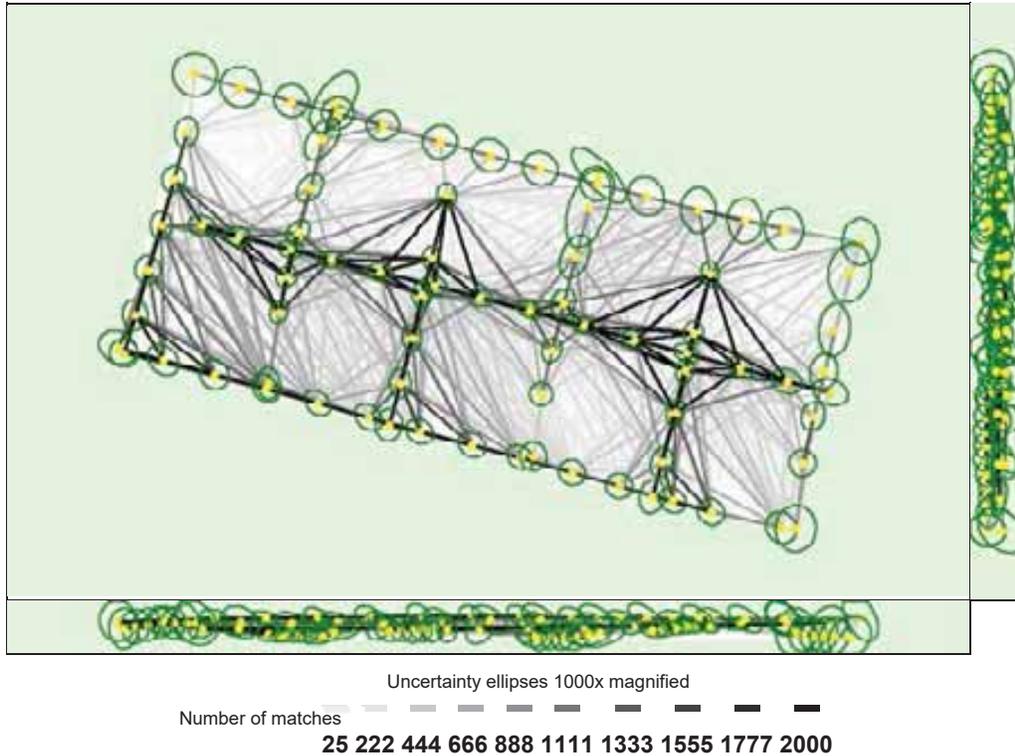


Figure 5: Computed image positions with links between matched images. The darkness of the links indicates the number of matched 2D keypoints between the images. Bright links indicate weak links and require manual tie points or more images. Dark green ellipses indicate the relative camera position uncertainty of the bundle block adjustment result.

Relative camera position and orientation uncertainties

	X [m]	Y [m]	Z [m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.002	0.002	0.002	0.006	0.007	0.004
Sigma	0.000	0.001	0.001	0.002	0.002	0.001

Geolocation Details

Absolute Geolocation Variance

Min Error [m]	Max Error [m]	Geolocation Error X [%]	Geolocation Error Y [%]	Geolocation Error Z [%]
-	-15.00	0.00	0.00	0.00
-15.00	-12.00	0.00	0.00	0.00
-12.00	-9.00	0.00	0.00	0.00
-9.00	-6.00	0.00	0.00	0.00

Sigma of Geolocation Accuracy [m]	0.000000	0.000000	0.000000
--	----------	----------	----------

-6.00	-3.00	0.00	0.00	0.00
-3.00	0.00	48.75	50.00	47.50
0.00	3.00	51.25	50.00	52.50
3.00	6.00	0.00	0.00	0.00
6.00	9.00	0.00	0.00	0.00
9.00	12.00	0.00	0.00	0.00
12.00	15.00	0.00	0.00	0.00
15.00	-	0.00	0.00	0.00
Mean [m]		0.000000	0.000004	0.000009
Sigma [m]		0.905738	0.691676	0.853906
RMS Error [m]		0.905738	0.691676	0.853906

Min Error and Max Error represent geolocation error intervals between -1.5 and 1.5 times the maximum accuracy of all the images. Columns X, Y, Z show the percentage of images with geolocation errors within the predefined error intervals. The geolocation error is the difference between the initial and computed image positions. Note that the image geolocation errors do not correspond to the accuracy of the observed 3D points.

Relative Geolocation Variance

Relative Geolocation Error	Images X [%]	Images Y [%]	Images Z [%]
[-1.00, 1.00]	100.00	100.00	100.00
[-2.00, 2.00]	100.00	100.00	100.00
[-3.00, 3.00]	100.00	100.00	100.00
Mean of Geolocation Accuracy [m]	5.000000	5.000000	10.000000

Images X, Y, Z represent the percentage of images with a relative geolocation error in X, Y, Z.

Geolocation Orientational Variance	RMS [degree]
Omega	3.210
Phi	2.419
Kappa	2.631

Geolocation RMS error of the orientation angles given by the difference between the initial and computed image orientation angles.

Initial Processing Details

System Information

Hardware	CPU: Intel(R) Core(TM) i5-3330S CPU @ 2.70GHz RAM: 8GB GPU: Intel(R) HD Graphics (Driver: 10.18.10.3412), RDPDD Chained DD (Driver: unknown), RDP Encoder Mirror Driver (Driver: unknown), RDP Reflector Display Driver (Driver: unknown)
Operating System	Windows 7 Professional, 64-bit

Coordinate Systems

Image Coordinate System	WGS84 (egm96)
Output Coordinate System	WGS 84 / UTM zone 19N (egm96)

Processing Options

Detected Template	3D Maps
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Keypoints Image Scale	Full, Image Scale: 1
Advanced: Matching Image Pairs	Aerial Grid or Corridor
Advanced: Matching Strategy	Use Geometrically Verified Matching: no
Advanced: Keypoint Extraction	Targeted Number of Keypoints: Automatic
Advanced: Calibration	Calibration Method: Standard Internal Parameters Optimization: All External Parameters Optimization: All Rematch: Auto, yes

Point Cloud Densification details

Processing Options

Image Scale	multiscale, 1/2 (Half image size, Default)
Point Density	Optimal
Minimum Number of Matches	3
3D Textured Mesh Generation	yes
3D Textured Mesh Settings:	Resolution: Medium Resolution (default) Color Balancing: no
LOD	Generated: no
Advanced: 3D Textured Mesh Settings	Sample Density Divider: 1
Advanced: Image Groups	group1
Advanced: Use Processing Area	yes
Advanced: Use Annotations	yes
Time for Point Cloud Densification	16m:39s
Time for Point Cloud Classification	NA
Time for 3D Textured Mesh Generation	04m:31s

Results

Number of Generated Tiles	1
Number of 3D Densified Points	5747547
Average Density (per m ³)	2015.47

DSM, Orthomosaic and Index Details

Processing Options

DSM and Orthomosaic Resolution	1 x GSD (1.17 [cm/pixel])
DSM Filters	Noise Filtering: yes Surface Smoothing: yes, Type: Sharp
Raster DSM	Generated: yes Method: Inverse Distance Weighting Merge Tiles: yes
Orthomosaic	Generated: yes Merge Tiles: yes GeoTIFF Without Transparency: no Google Maps Tiles and KML: no
Time for DSM Generation	08m:54s
Time for Orthomosaic Generation	13m:01s

Time for DTM Generation	00s
Time for Contour Lines Generation	00s
Time for Reflectance Map Generation	00s
Time for Index Map Generation	00s

Site name:

Breach between Middles Beach and Secret Spot, Isabela



Physical address:

Breach between Middles and Secret Spot (after swell), PR 466 street, Isabela, Puerto Rico, 00662

A. Date of capture of imagery:

March 28, 2018

B. Coordinates:

18.51291419 N - 67.04249823 W

C. Description of site:

This site consists of a breach on the primary dune between Secret Spot and Middles Beaches in Isabela. This breach was created during the March 2018 northeasterly swell. The area had very little vegetation due to foot traffic reducing the stability of the sand in the area.

D. Distance from community:

80 m from PR 466, 486 m from cliff. The nearest houses are at a distance of 486 m to the south of this location and at an elevation of 30 m above sea level.

E. Aerial imagery

i. Contour map

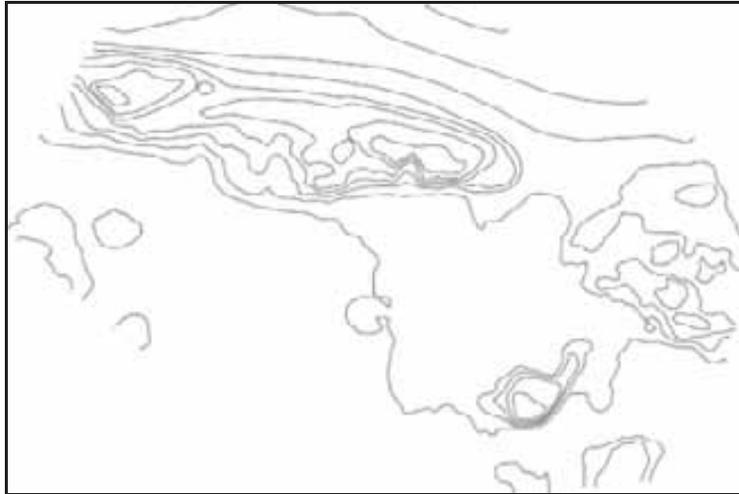


Figure 118. Contour map of a breach between Middles and Secret Spot Beaches (after swell), Isabela, Puerto Rico with elevation intervals of 1 meter.

ii. 3D imagery

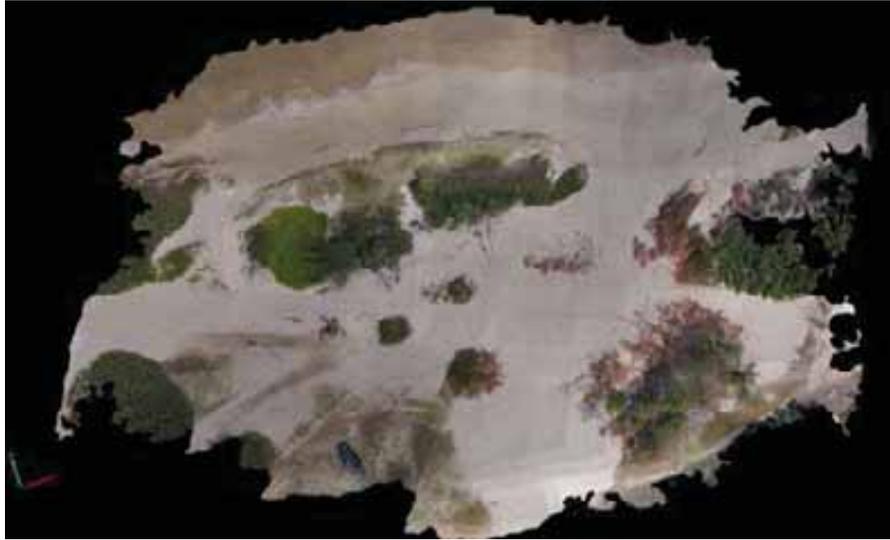


Figure 119. Aerial 3D image of breach between Middles and Secret Spot (after swell)

iii. Orthomosaic model



Figure 120. Orthomosaic image of Breach between Middles and Secret Spot (after swell)Isabela

iv. Density Surface Models (DSM)

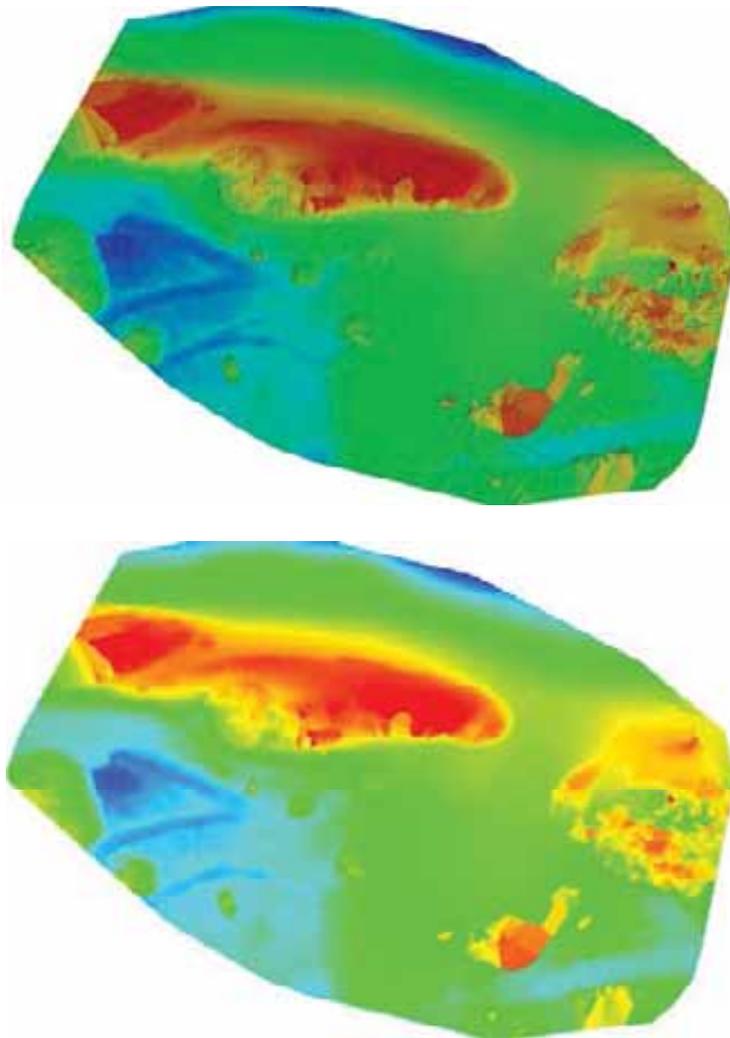


Figure 121. Density surface model (with shading top and without shading bottom) images of the dune located at the Breach between Middles and Secret Spot (after swell), Isabela

v. Thermal images

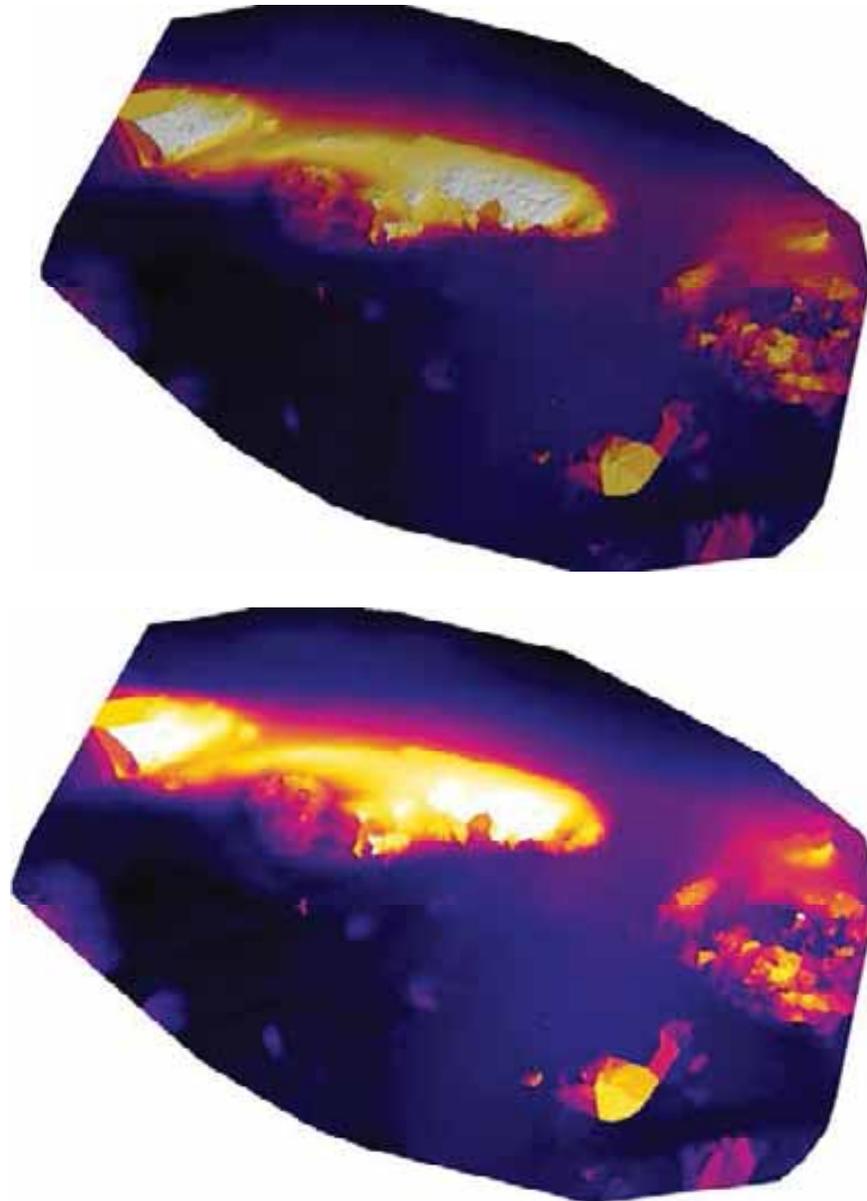


Figure 122. Thermal images (with shading top and without shading bottom) of the dune located at the Breach between Middles and Secret Spot (after swell), Isabela

vi. 3D altitude RGB North

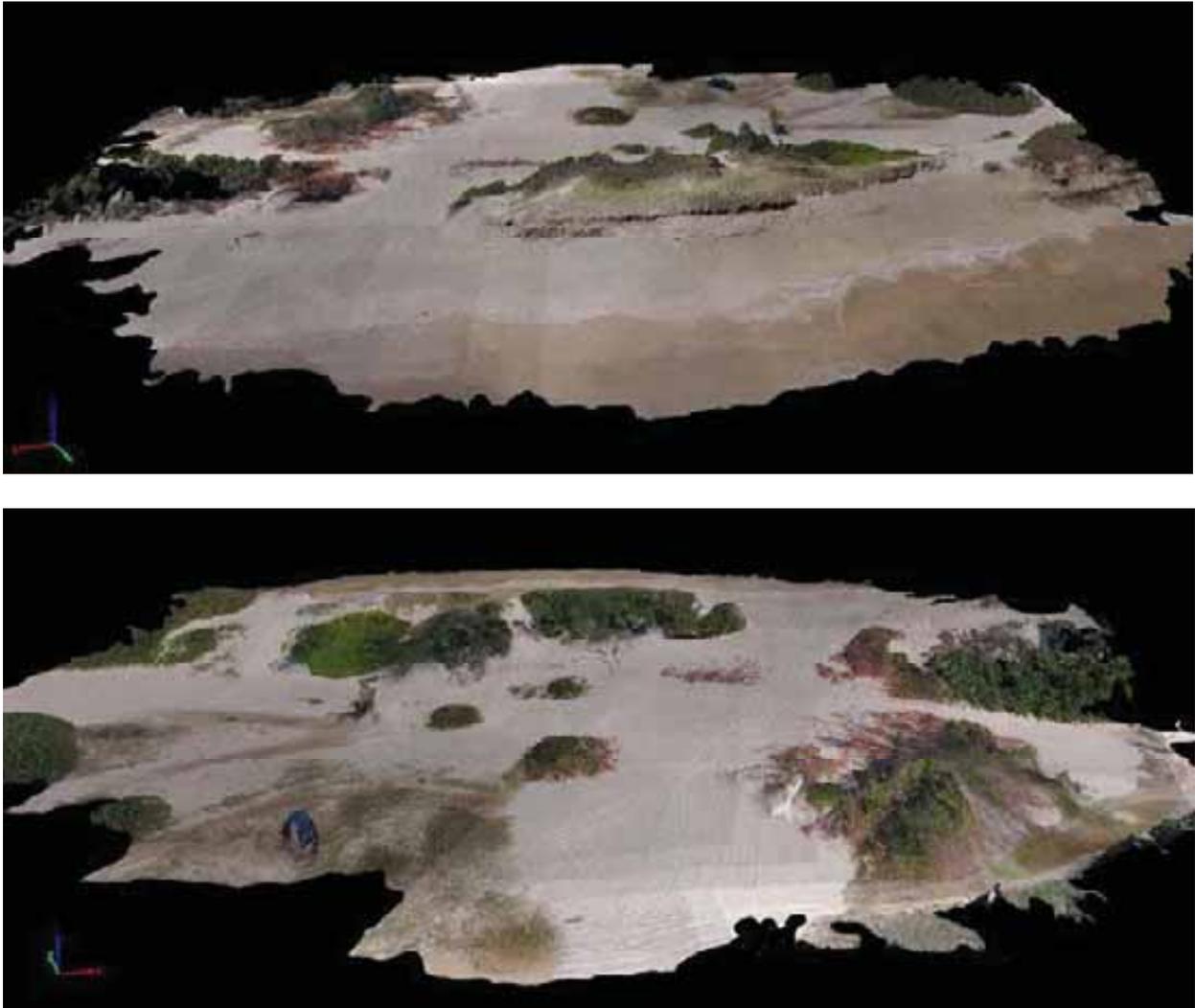


Figure 123. Three dimensional RGB images of the Breach between Middles and Secret Spot (after swell), Isabela. View from the north (top) and from the south (bottom).

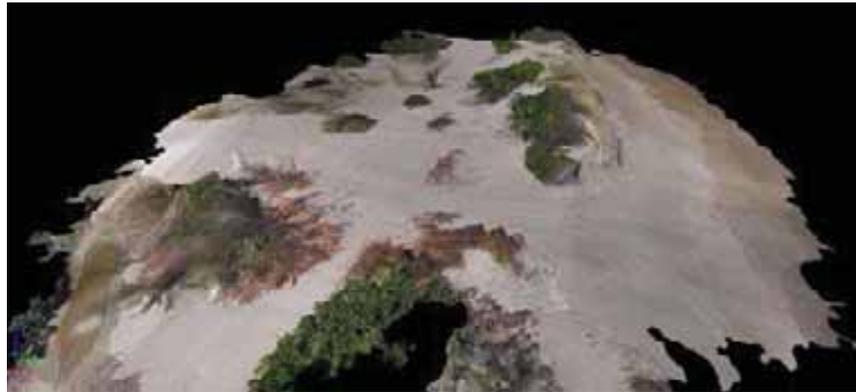


Figure 124. Three dimensional RGB images of the breach between Middles and Secret Spot (after swell), Isabela. View from the west (top) and from the east (bottom).

vii. DSM grayscale

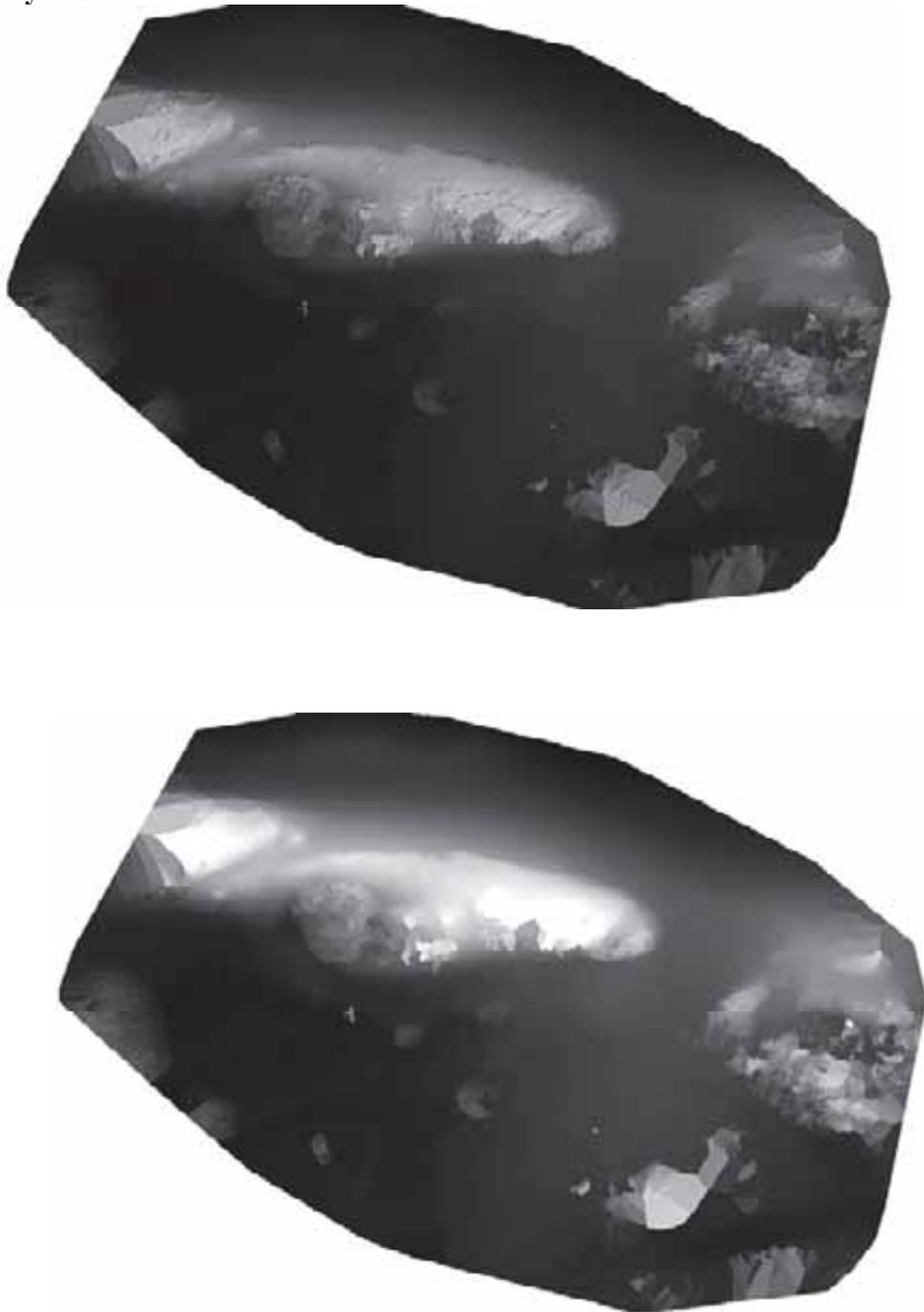


Figure 125. Grayscale DSM images of the dune to the breach between Middles and Secret Spot (after swell), Isabela. The top image shows shades and the bottom is not shaded.

viii. On the ground pictures



Figure 126. View from the ground of the breach between Middles and Secret Spot beaches in Isabela. This was created during the March 2018 northeasterly swell.

Site report

F. Vegetation cover



Figure 127 Vegetation covers 40 % of the area of the breach between Middles and Secret Spot (after swell), Isabela on March 28, 2018.

H. Volume measurements of selected areas of the dunes

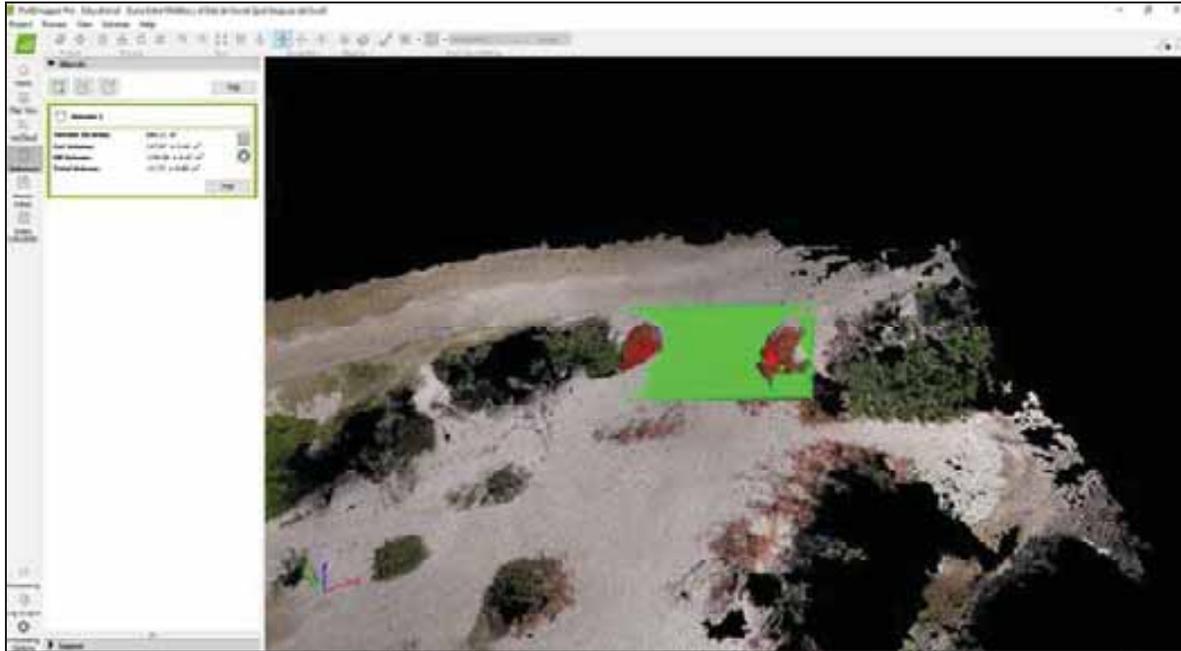


Figure 128. The polygon has a 3D area of 640.21 m^2 and a cut volume of $147.87 \pm 2.46 \text{ m}^3$, a fill volume of $-159.58 \pm 6.42 \text{ m}^3$ and a total volume of $-11.71 \pm 8.88 \text{ m}^3$. The volume of the polygon will be monitored in subsequent months to monitor the progress of the restoration process.

I. Conservation threats

This area consists of a breach in the primary dune. The main conservation threat in this area is heavy foot traffic and illegal all terrain-vehicle traffic (note tire tracks on the figure below). Illegal sand extraction is not common in this area.

J. Recommended ecological restoration courses of action (COA)

The breach will be restored using wooden pallets and biomimicry matrices to promote the accumulation of sand. The accumulated sand will be stabilized by planting dune vegetation.

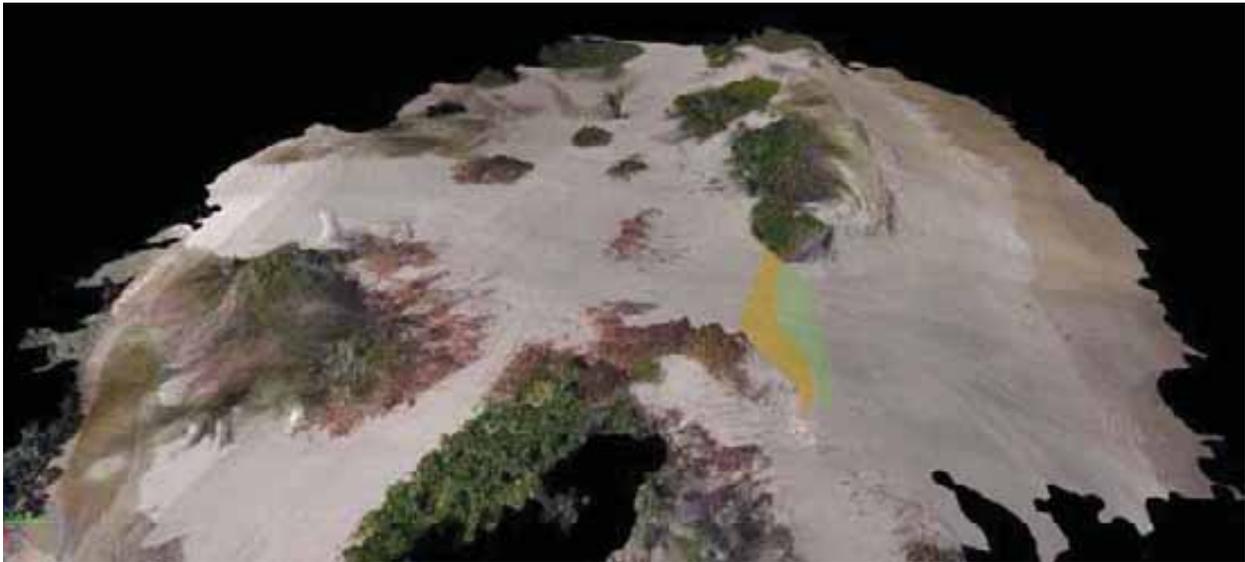


Figure 129. Area to be ecologically restored on the breach between Middles and Secret Spot in Barrio Bajuras, Isabela. Highlighted areas correspond to each technique that will be used in this area. Areas shaded in tan color represent the area of the dune crest that where biomimicry matrices will be installed to promote the accumulation of sand. The areas shaded in light green represent locations for the planting of dune vegetation.

K. Pix 4D Quality Report

Quality Report



Generated with Pix4Dmapper Pro version 4.2.25

1 Important: Click on the different icons for:

- 2** Help to analyze the results in the Quality Report
- 1** Additional information about the sections

Click [here](#) for additional tips to analyze the Quality Report

Summary



Project	Duna Entre Middles y el Este de Secret Spot Despues del Swell
Processed	2018-04-06 17:38:54
Camera Model Name(s)	FC330_3.6_4000x3000 (RGB)
Average Ground Sampling Distance (GSD)	1.16 cm / 0.46 in
Area Covered	0.011 km ² / 1.1073 ha / 0.00 sq. mi. / 2.7376 acres
Time for Initial Processing (without report)	18m:29s

Quality Check



2 Images	median of 33465 keypoints per image	
2 Dataset	79 out of 79 images calibrated (100%), all images enabled	
2 Camera Optimization	4.46% relative difference between initial and optimized internal camera parameters	
2 Matching	median of 7488.92 matches per calibrated image	
2 Georeferencing	yes, no 3D GCP	

3 Preview

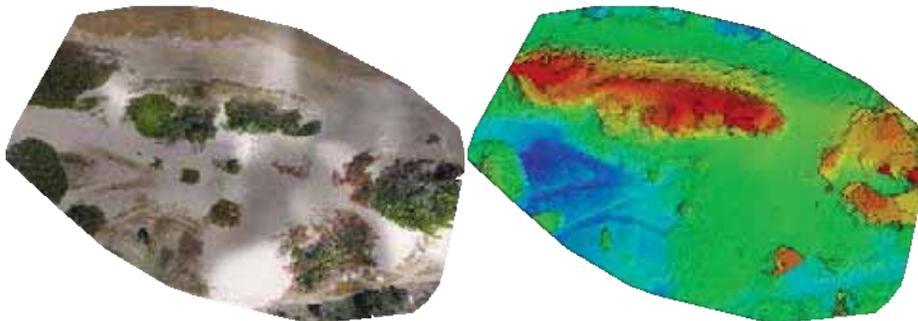


Figure 1: Orthomosaic and the corresponding sparse Digital Surface Model (DSM) before densification.

Calibration Details



Number of Calibrated Images	79 out of 79
Number of Geolocated Images	79 out of 79

Initial Image Positions

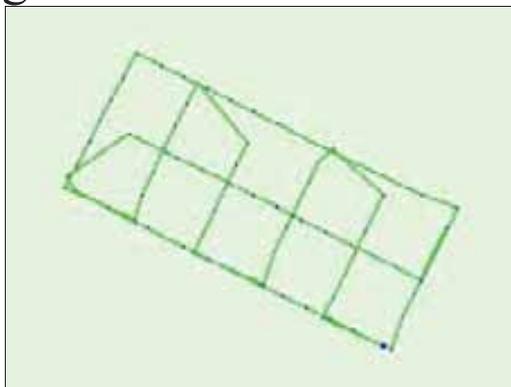
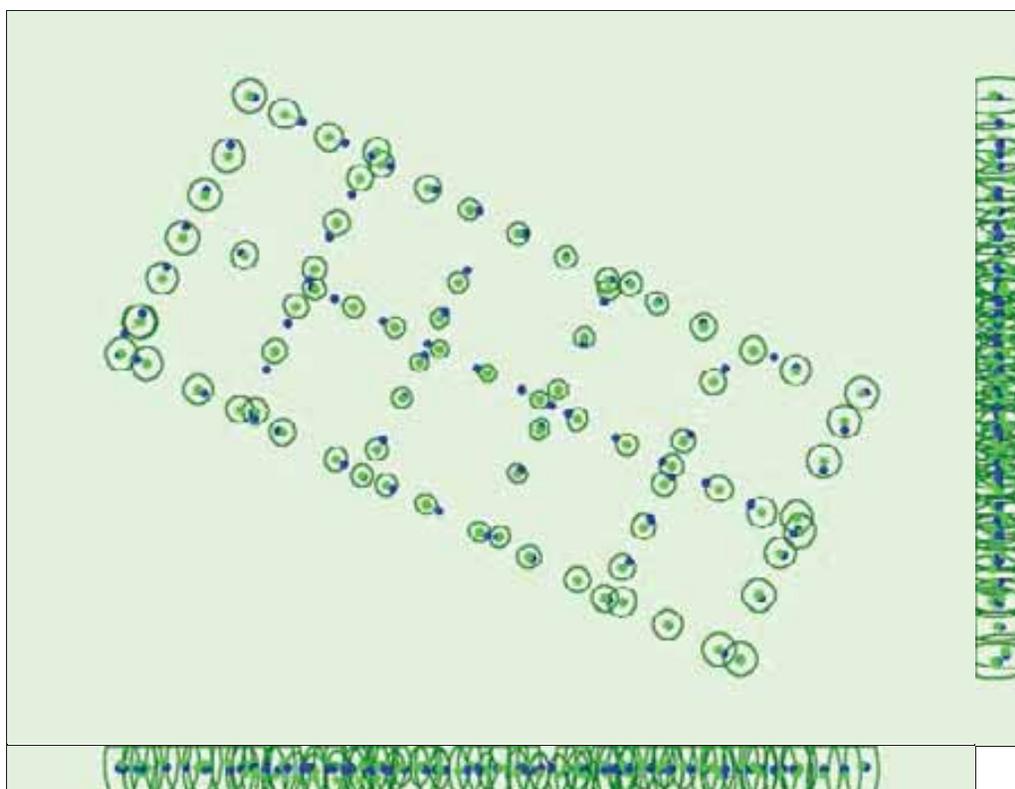


Figure 2: Top view of the initial image position. The green line follows the position of the images in time starting from the large blue dot.

Computed Image/GCPs/Manual Tie Points Positions



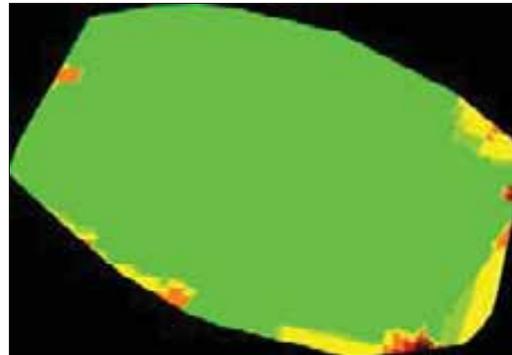
Uncertainty ellipses 10x magnified

Figure 3: Offset between initial (blue dots) and computed (green dots) image positions as well as the offset between the GCPs initial positions (blue crosses) and their computed positions (green crosses) in the top-view (XY plane), front-view (XZ plane), and side-view (YZ plane). Dark green ellipses indicate the absolute position uncertainty of the bundle block adjustment result.

❗ Absolute camera position and orientation uncertainties

	X [m]	Y [m]	Z [m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.171	0.171	0.415	0.978	0.521	0.323
Sigma	0.031	0.031	0.087	0.056	0.054	0.036

❗ Overlap



Number of overlapping images: 2 3 4 5+

Figure 4: Number of overlapping images computed for each pixel of the orthomosaic.

Red and yellow areas indicate low overlap for which poor results may be generated. Green areas indicate an overlap of over 5 images for every pixel. Good quality results will be generated as long as the number of keypoint matches is also sufficient for these areas (see Figure 5 for keypoint matches).

Bundle Block Adjustment Details

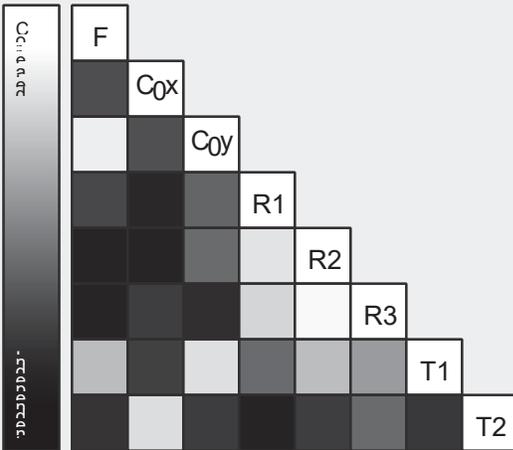
Number of 2D Keypoint Observations for Bundle Block Adjustment	639655
Number of 3D Points for Bundle Block Adjustment	240815

Internal Camera Parameters FC330_3.6_4000x3000 (RGB). Sensor Dimensions: 6.317 [mm] x 4.738 [mm]

EXIF ID: FC330_3.6_4000x3000

	Focal Length	Principal Point x	Principal Point y	R1	R2	R3	T1	T2
Initial Values	2285.722 [pixel] 3.610 [mm]	2000.006 [pixel] 3.159 [mm]	1500.003 [pixel] 2.369 [mm]	-0.001	-0.002	0.000	-0.001	-0.001
Optimized Values	2387.667 [pixel] 3.771 [mm]	1966.662 [pixel] 3.106 [mm]	1465.620 [pixel] 2.315 [mm]	-0.001	-0.004	0.003	0.000	0.000

Uncertainties (Sigma)	0.335 [pixel] 0.001 [mm]	0.085 [pixel] 0.000 [mm]	0.251 [pixel] 0.000 [mm]	0.000	0.000	0.000	0.000	0.000
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The correlation between camera internal parameters determined by the bundle adjustment. White indicates a full correlation between the parameters, ie. any change in one can be fully compensated by the other. Black indicates that the parameter is completely independent, and is not affected by other parameters.



The number of Automatic Tie Points (ATPs) per pixel, averaged over all images of the camera model, is color coded between black and white. White indicates that, on average, more than 16 ATPs have been extracted at the pixel location. Black indicates that, on average, 0 ATPs have been extracted at the pixel location. Click on the image to see the average direction and magnitude of the re-projection error for each pixel. Note that the vectors are scaled for better visualization. The scale bar indicates the magnitude of 1 pixel error.

2D Keypoints Table

	Number of 2D Keypoints per Image	Number of Matched 2D Keypoints per Image
Median	33465	7489
Min	17451	2258
Max	56870	18385
Mean	33296	8097

3D Points from 2D Keypoint Matches

	Number of 3D Points Observed
In 2 Images	163155
In 3 Images	42142
In 4 Images	16724
In 5 Images	7845
In 6 Images	4413
In 7 Images	2601
In 8 Images	1631
In 9 Images	1076
In 10 Images	619
In 11 Images	317
In 12 Images	170
In 13 Images	76
In 14 Images	29
In 15 Images	6

In 16 Images	8
In 17 Images	2
In 18 Images	1

2D Keypoint Matches

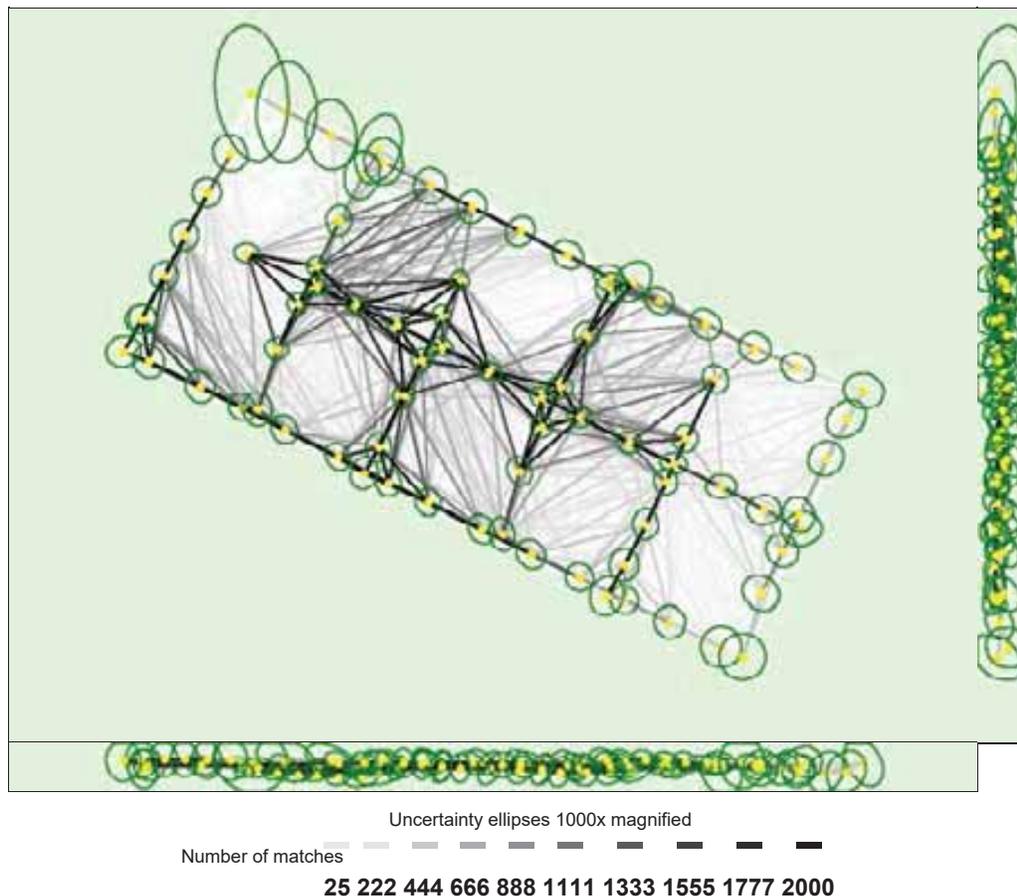


Figure 5: Computed image positions with links between matched images. The darkness of the links indicates the number of matched 2D keypoints between the images. Bright links indicate weak links and require manual tie points or more images. Dark green ellipses indicate the relative camera position uncertainty of the bundle block adjustment result.

Relative camera position and orientation uncertainties

	X [m]	Y [m]	Z [m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.002	0.002	0.002	0.006	0.007	0.004
Sigma	0.001	0.001	0.001	0.002	0.003	0.002

Geolocation Details

📍 Absolute Geolocation Variance



Min Error [m]	Max Error [m]	Geolocation Error X [%]	Geolocation Error Y [%]	Geolocation Error Z [%]
-	-15.00	0.00	0.00	0.00
-15.00	-12.00	0.00	0.00	0.00
-12.00	-9.00	0.00	0.00	0.00
-9.00	-6.00	0.00	0.00	0.00
-6.00	-3.00	0.00	0.00	0.00
-3.00	0.00	44.30	49.37	59.49
0.00	3.00	55.70	50.63	40.51
3.00	6.00	0.00	0.00	0.00
6.00	9.00	0.00	0.00	0.00
9.00	12.00	0.00	0.00	0.00
12.00	15.00	0.00	0.00	0.00
15.00	-	0.00	0.00	0.00
Mean [m]		-0.000001	0.000002	-0.000012
Sigma [m]		1.044830	0.989486	0.607023
RMS Error [m]		1.044830	0.989486	0.607023

Min Error and Max Error represent geolocation error intervals between -1.5 and 1.5 times the maximum accuracy of all the images. Columns X, Y, Z show the percentage of images with geolocation errors within the predefined error intervals. The geolocation error is the difference between the initial and computed image positions. Note that the image geolocation errors do not correspond to the accuracy of the observed 3D points.

📍 Relative Geolocation Variance



Relative Geolocation Error	Images X [%]	Images Y [%]	Images Z [%]	
[-1.00, 1.00]	100.00	100.00	100.00	
[-2.00, 2.00]	100.00	100.00	100.00	
[-3.00, 3.00]	100.00	100.00	100.00	
Mean of Geolocation Accuracy [m]		5.000000	5.000000	10.000000
Sigma of Geolocation Accuracy [m]		0.000000	0.000000	0.000000

Images X, Y, Z represent the percentage of images with a relative geolocation error in X, Y, Z.

Geolocation Orientational Variance	RMS [degree]
Omega	2.880
Phi	2.559
Kappa	6.900

Geolocation RMS error of the orientation angles given by the difference between the initial and computed image orientation angles.

Initial Processing Details



System Information



Hardware	CPU: Intel(R) Core(TM) i5-3330S CPU @ 2.70GHz RAM: 8GB GPU: Intel(R) HD Graphics (Driver: 10.18.10.3412), RDPDD Chained DD (Driver: unknown), RDP Encoder Mirror Driver (Driver: unknown), RDP Reflector Display Driver (Driver: unknown)
Operating System	Windows 7 Professional, 64-bit

Coordinate Systems



Image Coordinate System	WGS84 (egm96)
Output Coordinate System	WGS 84 / UTM zone 19N (egm96)

Processing Options



Detected Template	3D Maps
Keypoints Image Scale	Full, Image Scale: 1
Advanced: Matching Image Pairs	Aerial Grid or Corridor
Advanced: Matching Strategy	Use Geometrically Verified Matching: no
Advanced: Keypoint Extraction	Targeted Number of Keypoints: Automatic
Advanced: Calibra	Calibration Method: Standard Internal Parameters Optimization: All External Parameters Optimization: All Rematch: Auto, yes

Point Cloud Densification details



Processing Options



Image Scale	multiscale, 1/2 (Half image size, Default)
Point Density	Optimal
Minimum Number of Matches	3
3D Textured Mesh Generation	yes
3D Textured Mesh Settings:	Resolution: Medium Resolution (default) Color Balancing: no
LOD	Generated: no
Advanced: 3D Textured Mesh Settings	Sample Density Divider: 1
Advanced: Image Groups	group1
Advanced: Use Processing Area	yes
Advanced: Use Annotations	yes
Time for Point Cloud Densification	15m:15s
Time for Point Cloud Classification	NA
Time for 3D Textured Mesh Generation	04m:36s

Results



Number of Generated Tiles	1
Number of 3D Densified Points	5693569
Average Density (per m ³)	1952.72

DSM, Orthomosaic and Index Details



Processing Options



DSM and Orthomosaic Resolution	1 x GSD (1.16 [cm/pixel])
DSM Filters	Noise Filtering: yes Surface Smoothing: yes, Type: Sharp
Raster DSM	Generated: yes Method: Inverse Distance Weighting Merge Tiles: yes
Orthomosaic	Generated: yes Merge Tiles: yes GeoTIFF Without Transparency: no Google Maps Tiles and KML: no
Time for DSM Generation	10m:52s
Time for Orthomosaic Generation	13m:08s
Time for DTM Generation	00s
Time for Contour Lines Generation	00s
Time for Reflectance Map Generation	00s
Time for Index Map Generation	00s

Site name: Middles Beach (After Hurricane María)



A. Physical address:

Middles Beach (After hurricane María), PR 466, Isabela, Puerto Rico, 00662

B. Date of capture of imagery:

January 16, 2018

C. Coordinates:

18.51252560 N - 67.04017016 W

D. Description of site:

The site is located on a segment of primary dune parallel to road PR-466 and is an important and world renowned surfing destination. This was the site of commercial sand extraction from the early 1960's until the 1980's and has been one of our main dune restoration sites since 2007. We have had several cooperative agreements with the U.S. Fish and Wildlife Service for its ecological restoration. Several types of fencing and biomimicry matrices have been installed in this area to promote the accumulation of sand. Native vegetation has also been planted in this area in order to stabilize it. Also, a wooden boardwalk and an observation platform were built in 2013 to move foot traffic away from the vegetated areas. This was a very effective method of promoting and increasing vegetative cover in this area. There are also several information signs in this area. The area was badly breached during the 2017 hurricane season especially in areas where people still walk over the vegetation.

Visitors park their cars on the back-dune area. These cars are mostly from people that come to this area to surf, park in the back-dune area.

E. Distance from community:

The site is located at a distance of 32 m from PR 466 and 442 m from cliff.

Aerial imagery

E. Contour map

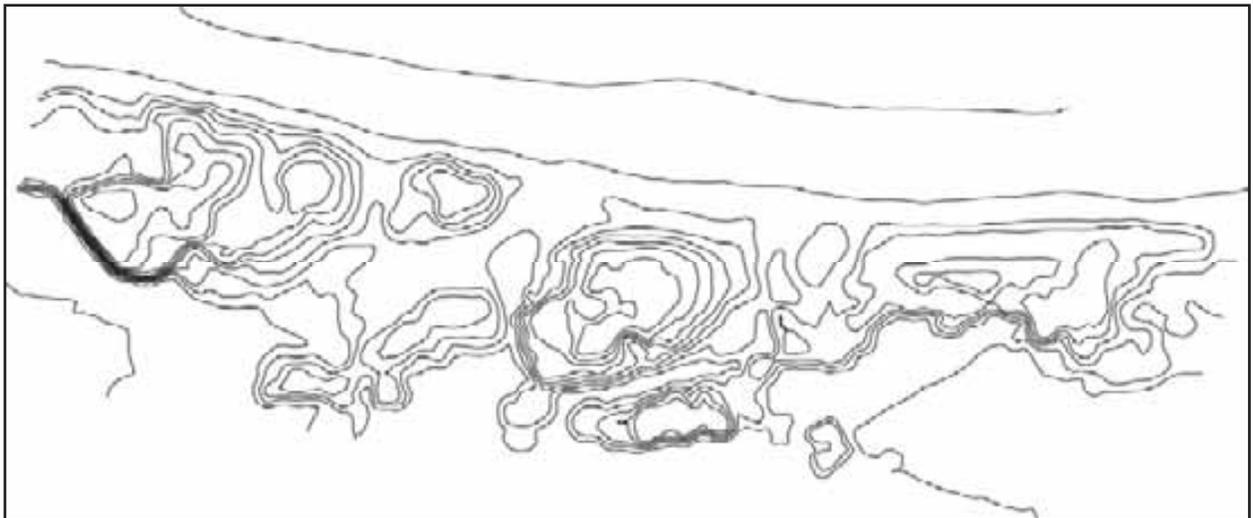


Figure 130. Contour map of Middles Beach (After hurricane María), Isabela, Puerto Rico with elevation intervals of 1 meter.

i. 3D imagery



Figure 131. Aerial 3D image of Middles Beach (After hurricane María), Isabela, Puerto Rico. View from north.

iii. Orthomosaic model



Figure 132. Orthomosaic image of Middles Beach (after hurricane María), Isabela, Puerto Rico.

ii. Density Surface Models (DSM)

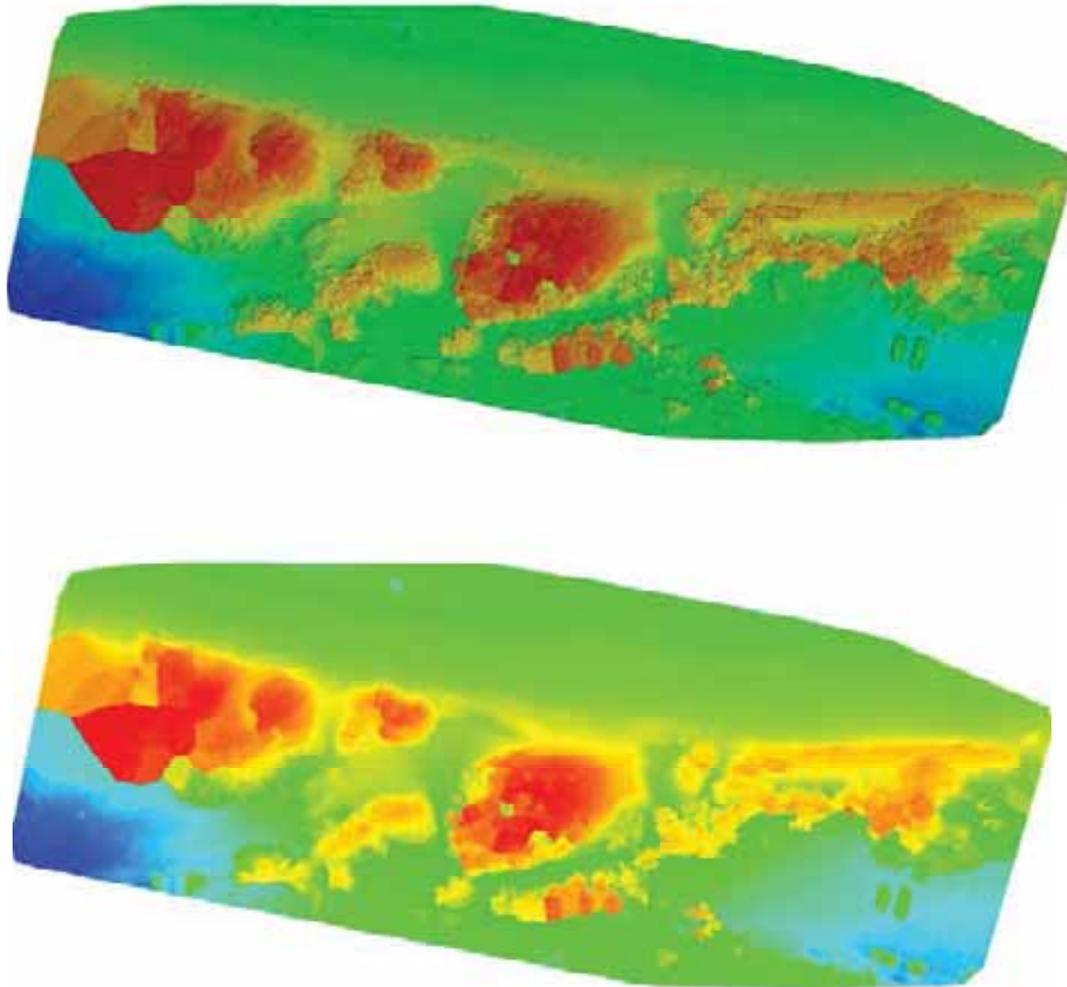


Figure 133. Density surface model (with shading top and without shading bottom) images of Middles Beach (After hurricane María), Isabela, Puerto Rico.

iv. Thermal images

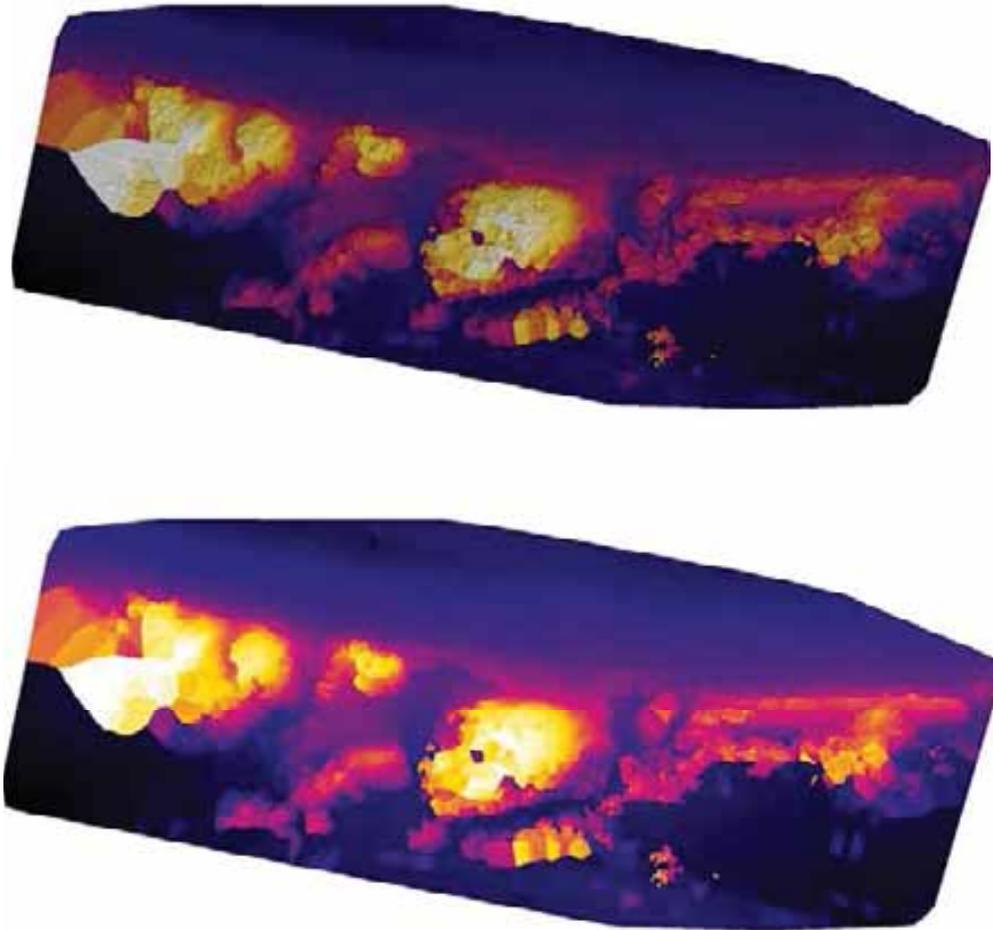


Figure 134. Thermal images (with shading top and without shading bottom) of Middles Beach (After hurricane María), Isabela, Puerto Rico.

v. 3D altitude RGB North



Figure 135. Three dimensional RGB images of Middles Beach (After hurricane María), Isabela, Puerto Rico. View from the north (top) and from the south (bottom).



Figure 136. Three dimensional RGB images of Middles Beach (after María), Isabela. View from the west (top) and from the east (bottom).

vi. DSM grayscale

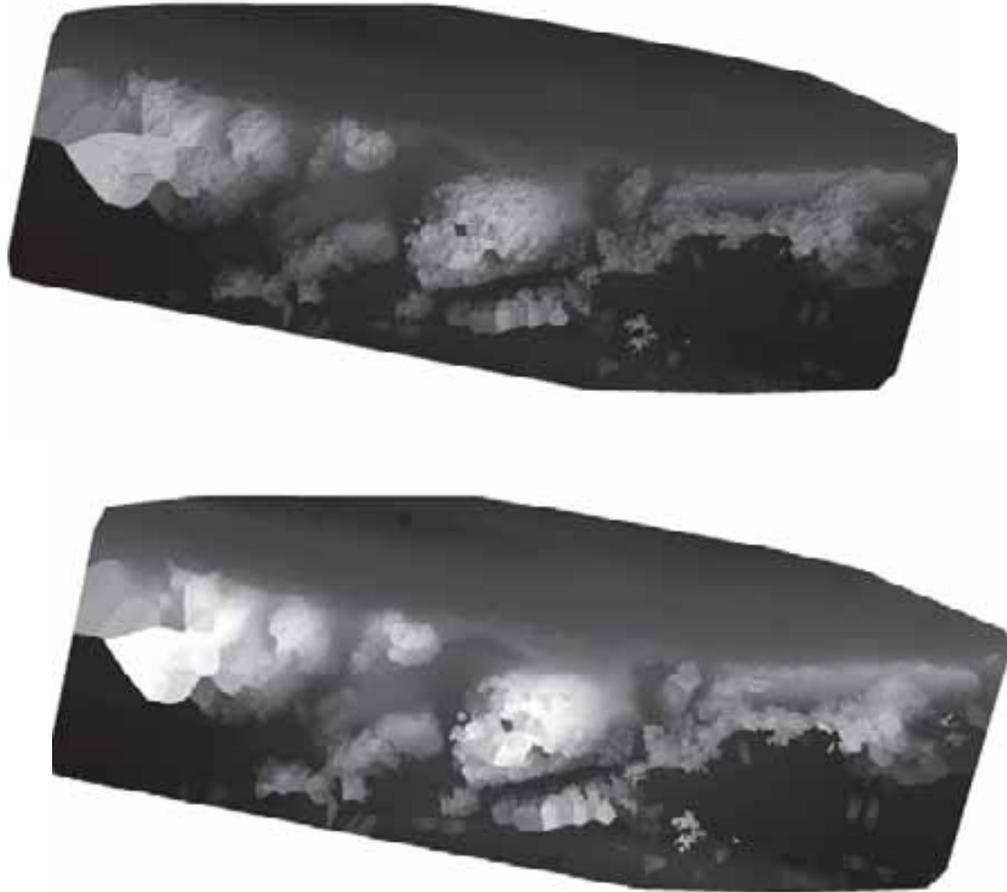


Figure 137. Grayscale DSM images of the dune to Middles Beach (After hurricane María), Isabela, Puerto Rico. The top image has shading and the bottom is not shaded.

vii. On the ground pictures



Figure 138. Severely eroded part of the dune crest in Middles beach. Note the condition of the boardwalk on the middles beach platform after the 2017 hurricane season.

K. Pix 4D Quality Report

Generated with Pix4Dmapper Pro version 4.1.22

Quality Report

Important: Click on the different icons for:

- Help to analyze the results in the Quality Report
- Additional information about the sections

Click [here](#) for additional tips to analyze the Quality Report

Summary

Project	Mision Middles Despues de Maria
Processed	2018-01-16 11:10:41
Camera Model Name(s)	FC330_3.6_4000x3000 (RGB)
Average Ground Sampling Distance (GSD)	1.05 cm / 0.41 in
Area Covered	0.011 km ² / 1.0686 ha / 0.00 sq. mi. / 2.6419 acres
Time for Initial Processing (without report)	45m:30s

Quality Check

Images	median of 51365 keypoints per image	
Dataset	101 out of 101 images calibrated (100%), all images enabled	
Camera Optimization	4.72% relative difference between initial and optimized internal camera parameters	
Matching	median of 14269.2 matches per calibrated image	
Georeferencing	yes, no 3D GCP	

Preview

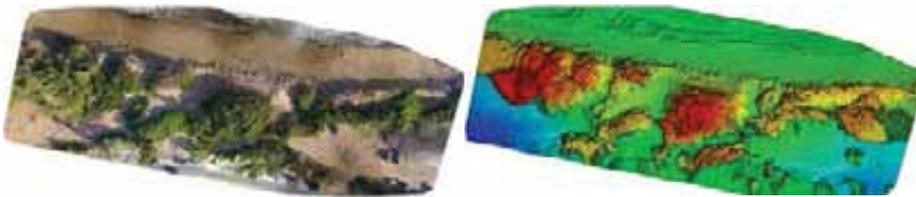


Figure 1: Orthomosaic and the corresponding sparse Digital Surface Model (DSM) before densification.

Calibration Details

Number of Calibrated Images	101 out of 101
Number of Geolocated Images	101 out of 101

Initial Image Positions

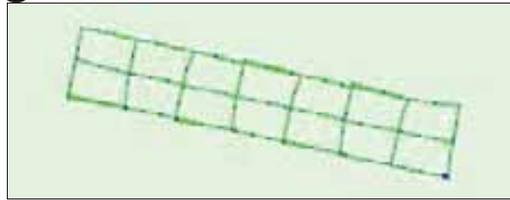
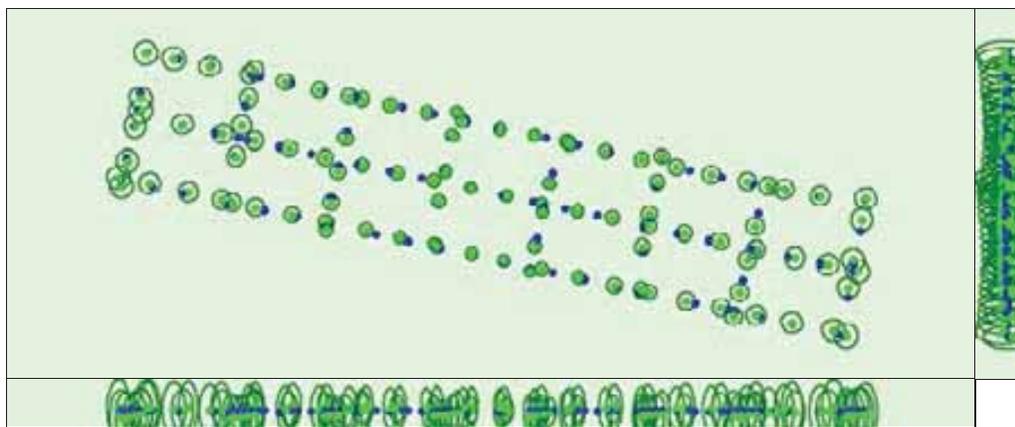


Figure 2: Top view of the initial image position. The green line follows the position of the images in time starting from the large blue dot.

Computed Image/GCPs/Manual Tie Points Positions



Uncertainty ellipses 10x magnified

Figure 3: Offset between initial (blue dots) and computed (green dots) image positions as well as the offset between the GCPs initial positions (blue crosses) and their computed positions (green crosses) in the top-view (XY plane), front-view (XZ plane), and side-view (YZ plane). Dark green ellipses indicate the absolute position uncertainty of the bundle block adjustment result.

Absolute camera position and orientation uncertainties

	X [m]	Y [m]	Z [m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.140	0.141	0.343	1.318	0.426	0.244
Sigma	0.030	0.030	0.071	0.085	0.132	0.053

Overlap

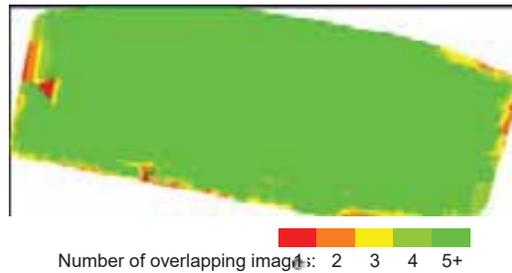


Figure 4: Number of overlapping images computed for each pixel of the orthomosaic. Red and yellow areas indicate low overlap for which poor results may be generated. Green areas indicate an overlap of over 5 images for every pixel. Good quality results will be generated as long as the number of keypoint matches is also sufficient for these areas (see Figure 5 for keypoint matches).

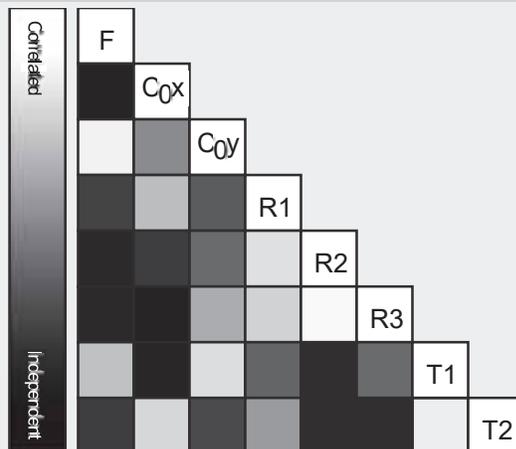
Bundle Block Adjustment Details

Number of 2D Keypoint Observations for Bundle Block Adjustment	1501738
Number of 3D Points for Bundle Block Adjustment	500433
Mean Reprojection Error [pixels]	0.201

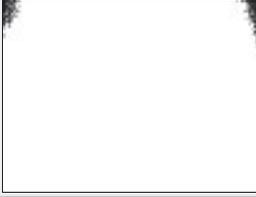
Internal Camera Parameters FC330_3.6_4000x3000 (RGB). Sensor Dimensions: 6.317 [mm] x 4.738 [mm]

EXIF ID: FC330_3.6_4000x3000

	Focal Length	Principal Point x	Principal Point y	R1	R2	R3	T1	T2
Initial Values	2285.722 [pixel] 3.610 [mm]	2000.006 [pixel] 3.159 [mm]	1500.003 [pixel] 2.369 [mm]	- 0.001	- 0.002	0.000	- 0.001	- 0.001
Optimized Values	2393.710 [pixel] 3.781 [mm]	1962.310 [pixel] 3.099 [mm]	1463.428 [pixel] 2.311 [mm]	0.000	- 0.006	0.004	0.000	- 0.000
Uncertainties (Sigma)	0.265 [pixel] 0.000 [mm]	0.061 [pixel] 0.000 [mm]	0.187 [pixel] 0.000 [mm]	0.000	0.000	0.000	0.000	0.000



The correlation between camera internal parameters determined by the bundle adjustment. White indicates a full correlation between the parameters, ie. any change in one can be fully compensated by the other. Black indicates that the parameter is completely independent, and is not affected by other parameters.



The number of Automatic Tie Points (ATPs) per pixel, averaged over all images of the camera model, is color coded between black and white. White indicates that, on average, more than 16 ATPs have been extracted at the pixel location. Black indicates that, on average, 0 ATPs have been extracted at the pixel location. Click on the image to see the average direction and magnitude of the re-projection error for each pixel. Note that the vectors are scaled for better visualization. The scale bar indicates the magnitude of 1 pixel error.

2D Keypoints Table



	Number of 2D Keypoints per Image	Number of Matched 2D Keypoints per Image
Median	51365	14269
Min	33309	2760
Max	64079	30681
Mean	49587	14869

3D Points from 2D Keypoint Matches



	Number of 3D Points Observed
In 2 Images	302329
In 3 Images	89091
In 4 Images	41706
In 5 Images	23042
In 6 Images	14739
In 7 Images	9523
In 8 Images	6798
In 9 Images	4797
In 10 Images	3314
In 11 Images	2065
In 12 Images	1445
In 13 Images	796
In 14 Images	439
In 15 Images	226
In 16 Images	80
In 17 Images	25
In 18 Images	9
In 19 Images	7
In 20 Images	1
In 22 Images	1

2D Keypoint Matches

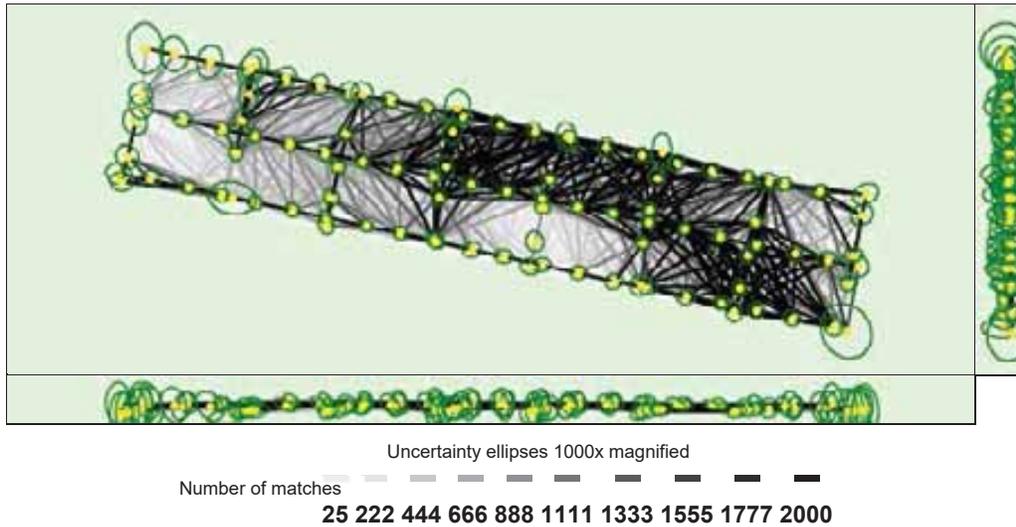


Figure 5: Computed image positions with links between matched images. The darkness of the links indicates the number of matched 2D keypoints between the images. Bright links indicate weak links and require manual tie points or more images. Dark green ellipses indicate the relative camera position uncertainty of the bundle block adjustment result.

Relative camera position and orientation uncertainties

	X [m]	Y [m]	Z [m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.002	0.002	0.002	0.005	0.007	0.003
Sigma	0.000	0.001	0.001	0.002	0.003	0.001

Geolocation Details

Absolute Geolocation Variance

Geolocation Orientational Variance					RMS [degree]
Omega					1.795
Phi					1.750
Min Error [m]	Max Error [m]	Geolocation Error X [%]	Geolocation Error Y [%]	Geolocation Error Z [%]	
-	-15.00	0.00	0.00	0.00	
-15.00	-12.00	0.00	0.00	0.00	
-12.00	-9.00	0.00	0.00	0.00	
-9.00	-6.00	0.00	0.00	0.00	
-6.00	-3.00	0.00	0.00	0.00	
-3.00	0.00	52.48	59.41	58.42	
0.00	3.00	47.52	40.59	41.58	
3.00	6.00	0.00	0.00	0.00	

Kappa	2.893
-------	-------

6.00	9.00	0.00	0.00	0.00
9.00	12.00	0.00	0.00	0.00
12.00	15.00	0.00	0.00	0.00
15.00	-	0.00	0.00	0.00
Mean [m]		0.000315	0.000688	-0.000207
Sigma [m]		0.935657	0.666619	0.548272
RMS Error [m]		0.935657	0.666620	0.548272

Min Error and Max Error represent geolocation error intervals between -1.5 and 1.5 times the maximum accuracy of all the images. Columns X, Y, Z show the percentage of images with geolocation errors within the predefined error intervals. The geolocation error is the difference between the initial and computed image positions. Note that the image geolocation errors do not correspond to the accuracy of the observed 3D points.

Relative Geolocation Variance

Relative Geolocation Error	Images X [%]	Images Y [%]	Images Z [%]
[-1.00, 1.00]	100.00	100.00	100.00
[-2.00, 2.00]	100.00	100.00	100.00
[-3.00, 3.00]	100.00	100.00	100.00
Mean of Geolocation Accuracy [m]	5.000000	5.000000	10.000000
Sigma of Geolocation Accuracy [m]	0.000000	0.000000	0.000000

Images X, Y, Z represent the percentage of images with a relative geolocation error in X, Y, Z.

Geolocation RMS error of the orientation angles given by the difference between the initial and computed image orientation angles.

Initial Processing Details

System Information

Hardware	CPU: Intel(R) Core(TM) i5-3330S CPU @ 2.70GHz RAM: 8GB GPU: Intel(R) HD Graphics (Driver: 10.18.10.3412), RDPDD Chained DD (Driver: unknown), RDP Encoder Mirror Driver (Driver: unknown), RDP Reflector Display Driver (Driver: unknown)
Operating System	Windows 7 Professional, 64-bit

Coordinate Systems

Image Coordinate System	WGS84 (egm96)
Output Coordinate System	WGS 84 / UTM zone 19N (egm96)

Processing Options

Detected Template	3D Maps
Keypoints Image Scale	Full, Image Scale: 1
Advanced: Matching Image Pairs	Aerial Grid or Corridor
Advanced: Matching Strategy	Use Geometrically Verified Matching: no
Advanced: Keypoint Extraction	Targeted Number of Keypoints: Automatic
Advanced: Calibration	Calibration Method: Standard Internal Parameters Optimization: All External Parameters Optimization: All Rematch: Auto, yes

Point Cloud Densification details



Processing Options



Image Scale	multiscale, 1/2 (Half image size, Default)
Point Density	Optimal
Minimum Number of Matches	3
3D Textured Mesh Generation	yes
3D Textured Mesh Settings:	Resolution: Medium Resolution (default) Color Balancing: no
LOD	Generated: no
Advanced: 3D Textured Mesh Settings	Sample Density Divider: 1
Advanced: Image Groups	group1
Advanced: Use Processing Area	yes
Advanced: Use Annotations	yes
Time for Point Cloud Densification	21m:27s
Time for Point Cloud Classification	NA
Time for 3D Textured Mesh Generation	05m:18s

Results



Number of Generated Tiles	1
Number of 3D Densified Points	6510318
Average Density (per m ³)	2483.42

DSM, Orthomosaic and Index Details



Processing Options



DSM and Orthomosaic Resolution	1 x GSD (1.05 [cm/pixel])
DSM Filters	Noise Filtering: yes Surface Smoothing: yes, Type: Sharp
Raster DSM	Generated: yes Method: Inverse Distance Weighting Merge Tiles: yes
Orthomosaic	Generated: yes Merge Tiles: yes GeoTIFF Without Transparency: no Google Maps Tiles and KML: no

Time for DSM Generation	10m:36s
Time for Orthomosaic Generation	18m:55s
Time for DTM Generation	00s
Time for Contour Lines Generation	00s
Time for Reflectance Map Generation	00s
Time for Index Map Generation	00s

Site name:

Middles Beach, Isabela

After northeasterly swell

A. Physical address:

Middles Beach - PR 466, Isabela, Puerto Rico, 00662.

B. Date of capture of imagery:

March 7, 2018

C. Coordinates:

18.51252560 N - 67.04017016 W

Aerial imagery

E. Contour map

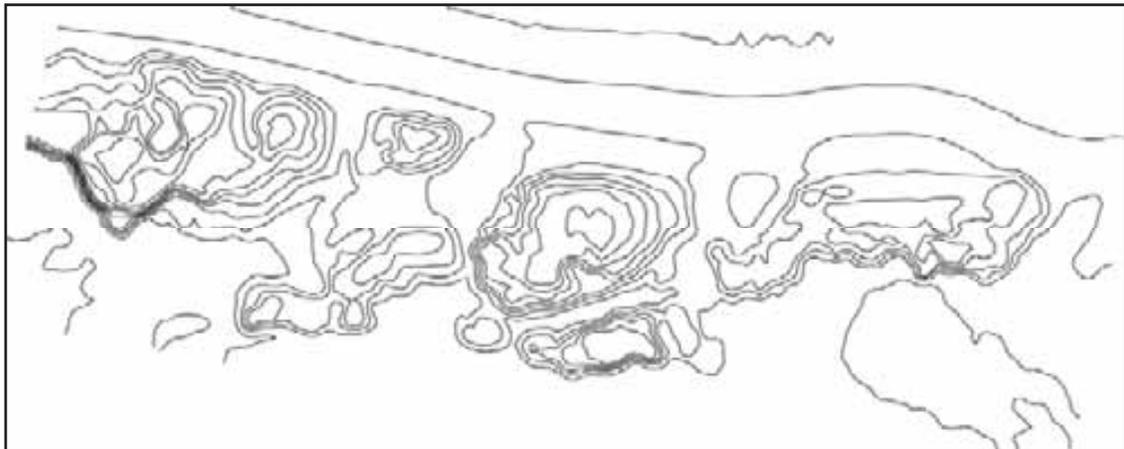


Figure 139. Contour map of Middles Beach, Isabela (after northeasterly swell), Puerto Rico with an elevation of 1 meter.

i. 3D imagery



Figure 139. Aerial 3D image of Middles Beach, Isabela (after northeasterly swell).

ii. Orthomosaic model



Figure 140. Orthomosaic image of Middles Beach, Isabela (after northeasterly swell).

iv. Density Surface Models (DSM)

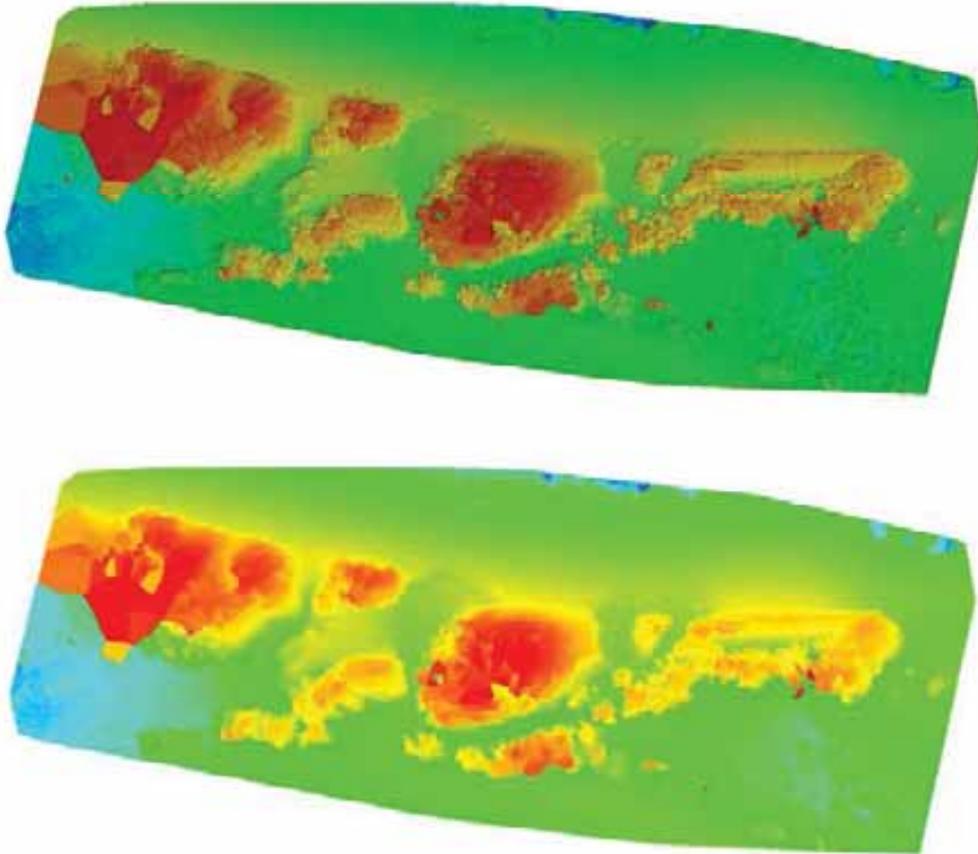


Figure 141. Density surface model (with shading top and without shading bottom) images of the dune located at Middles Beach, Isabela (after northeasterly swell).

v. Thermal images

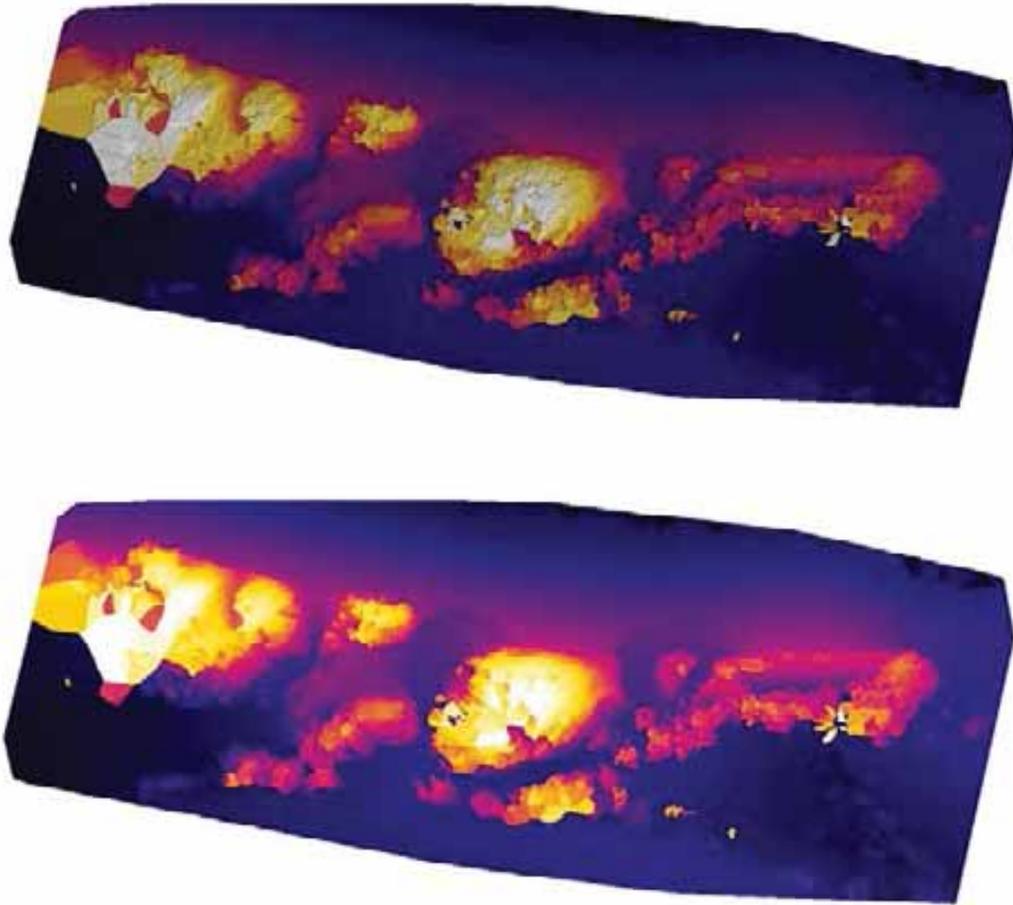


Figure 142. Thermal images (with shading top and without shading bottom) of the dune located at Middles Beach, Isabela (after northeasterly swell).

vi. 3D altitude RGB North

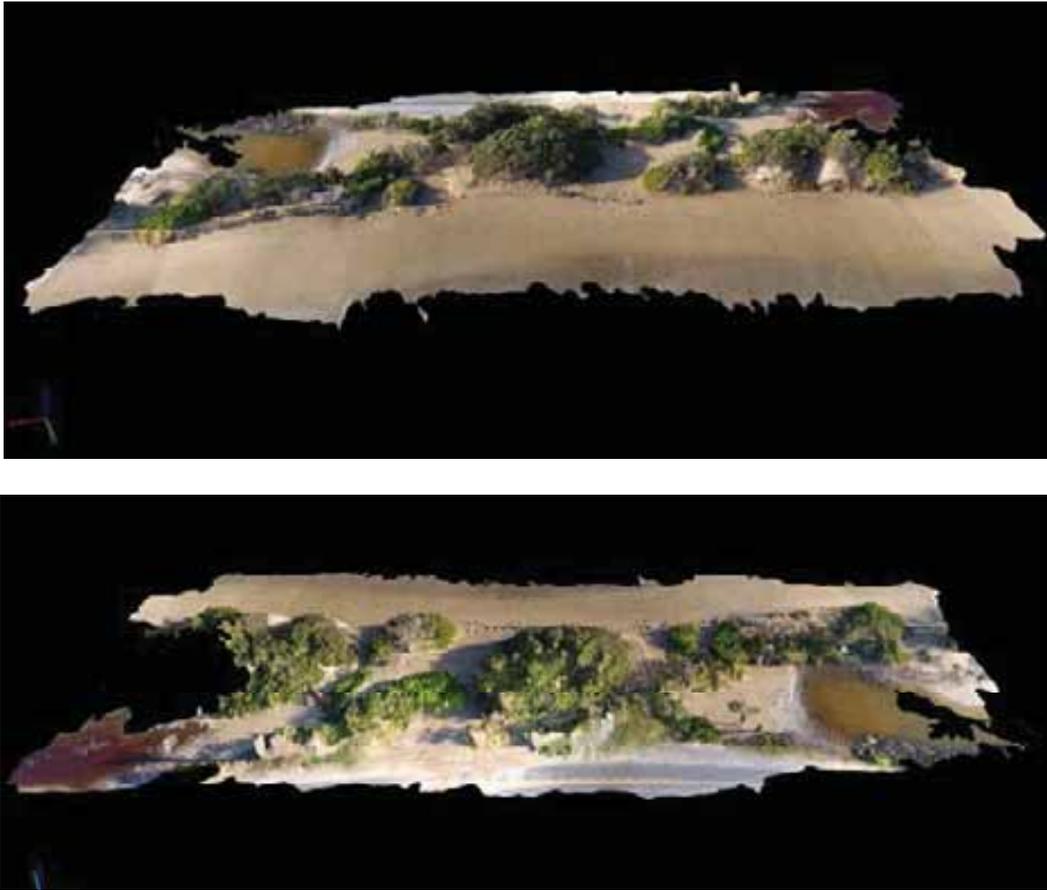


Figure143. Three dimensional RGB images of Middles Beach, Isabela (after northeasterly swell). View from the north (top) and from the south (bottom).



Figure 144. Three dimensional RGB images of Middles Beach, Isabela (after northeasterly swell). View from the west (top) and from the east (bottom).

vii. DSM grayscale

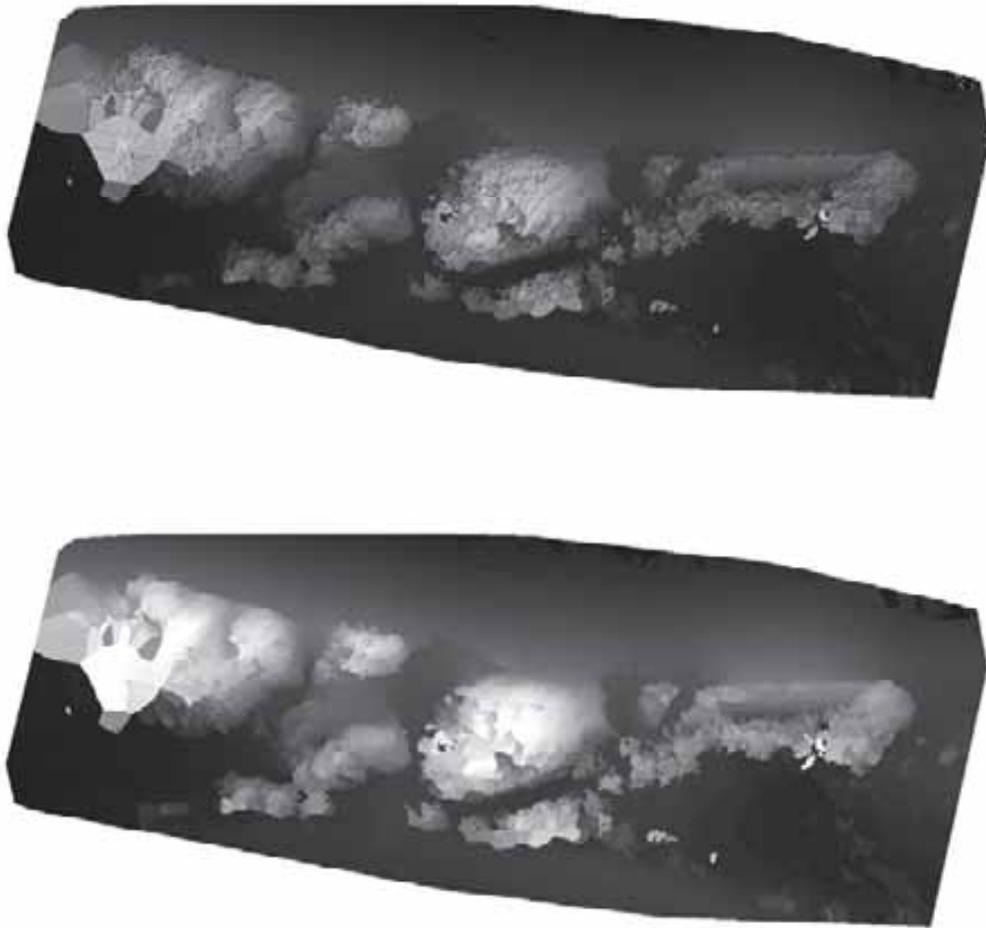


Figure 145. Grayscale DSM images of Middles Beach, Isabela (after northeasterly swell). The top image shows shades and the bottom is not shaded.

Site report

A. Vegetation cover



Figure 146. Images of the area for which vegetation cover is being monitored for the Middles Beach site in Isabela, Puerto Rico. The vegetation cover is 47.1% on January 16, 2018 (top) and 41.3% on March 7, 2018 (bottom).

H. Volume measurements of selected areas of the dunes

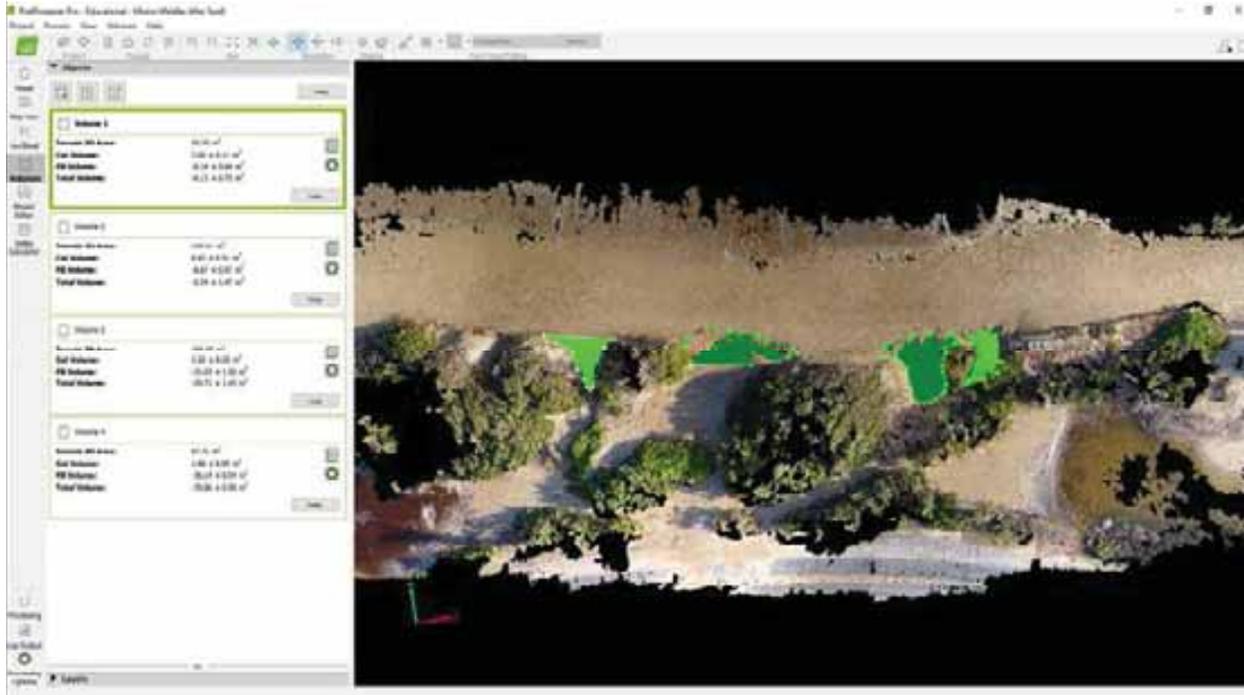


Figure 147. The first polygon (from left to right on the picture) has a 3D area of 113.84 m² and a cut volume of 0.58 ± 0.12 m³, a fill volume of -579.75 ± 12.33 m³ and a total volume of 116.35 ± 31.09 m³. The second polygon (from left to right) has an area of 45.80 m² and a cut volume of 0.16 ± 0.19 m³, a fill volume of -2.80 ± 0.70 m³ and a total volume of -2.64 ± 0.88 m³. The third polygon (from left to right) has an area 263.64 m² and a cut volume of 1.43 ± 0.42 m³, a fill volume of -35.01 ± 4.30 m³ and a total volume of -33.58 ± 4.72 m³. The volume of these three areas will be monitored in subsequent months.

J. Conservation threats

Middles beach is a very popular surfing location that is subject to constant heavy foot traffic. The access trails are areas where no vegetation grows and were breached during the extreme weather events of 2017 and early 2018. This site is where several surfing contests are held every year. Even though we try to collaborate with the contest sponsors and request that their security officers help us protect the vegetated areas of this system there is always some damage to the system during one of these events. Heavy foot traffic is the main threat in this area.

K. Recommended ecological restoration courses of action (COA)

We recommend the installation of exclusion fencing, two wooden boardwalks (one on the main entrance and replacement of the broken boardwalk leading to the observation platform), two information signs. Biomimicry matrices will also be installed to promote the accumulation of sand and the accumulated sand will be stabilized with the planting of dune vegetation.



Figure 148. Area to be ecologically restored at Middles Beach on PR 466 in Barrio Bajuras, Isabela. **Highlighted areas correspond to each technique that will be used in this area.** Yellow represents the location of wooden boardwalks, platform and barriers, the red dot marks the location of an information sign, tan represents the area where biomimicry matrices will be installed to promote the accumulation of sand and areas shaded in light green represent locations for the planting of vegetation.

L. Pix 4D Quality Report

Quality Report



Generated with Pix4Dmapper Pro version 4.2.26

Important: Click on the different icons for:

- Help to analyze the results in the Quality Report
- Additional information about the sections

Click [here](#) for additional tips to analyze the Quality Report

Summary



Project	Mision Middles After Swell
Processed	2018-04-30 20:14:46
Camera Model Name(s)	FC330_3.6_4000x3000 (RGB)
Average Ground Sampling Distance (GSD)	1.09 cm / 0.43 in
Area Covered	0.010 km ² / 1.0474 ha / 0.00 sq. mi. / 2.5895 acres
Time for Initial Processing (without report)	02m:56s

Quality Check



Images	median of 30176 keypoints per image	
Dataset	102 out of 102 images calibrated (100%), all images enabled	
Camera Optimization	4.48% relative difference between initial and optimized internal camera parameters	
Matching	median of 7193.94 matches per calibrated image	
Georeferencing	yes, no 3D GCP	

Preview

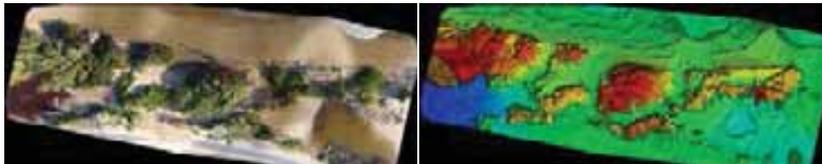


Figure 1: Orthomosaic and the corresponding sparse Digital Surface Model (DSM) before densification.

Calibration Details



Number of Calibrated Images	102 out of 102
Number of Geolocated Images	102 out of 102

Initial Image Positions



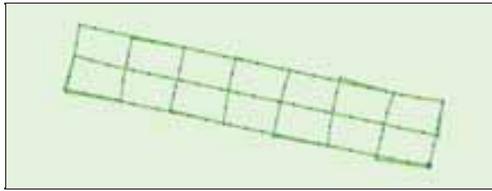


Figure 2: Top view of the initial image position. The green line follows the position of the images in time starting from the large blue dot.

1 Computed Image/GCPs/Manual Tie Points Positions

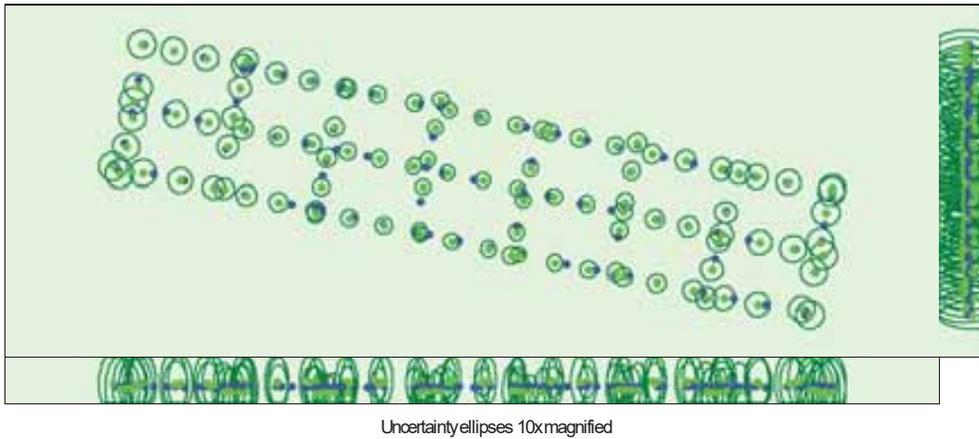


Figure 3: Offset between initial (blue dots) and computed (green dots) image positions as well as the offset between the GCPs initial positions (blue crosses) and their computed positions (green crosses) in the top-view (XY plane), front-view (XZ plane), and side-view (YZ plane). Dark green ellipses indicate the absolute position uncertainty of the bundle block adjustment result.

1 Absolute camera position and orientation uncertainties

	X[m]	Y[m]	Z[m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.177	0.178	0.433	1.667	0.472	0.274
Sigma	0.038	0.037	0.088	0.024	0.063	0.029

1 Overlap

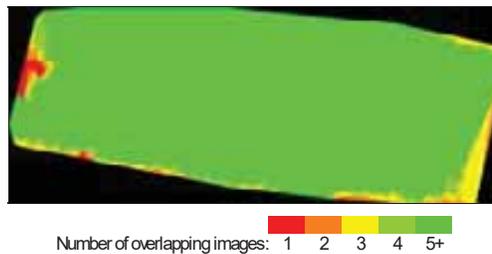


Figure 4: Number of overlapping images computed for each pixel of the orthomosaic. Red and yellow areas indicate low overlap for which poor results may be generated. Green areas indicate an overlap of over 5 images for every pixel. Good quality results will be generated as long as the number of keypoint matches is also sufficient for these areas (see Figure 5 for keypoint matches).

Bundle Block Adjustment Details

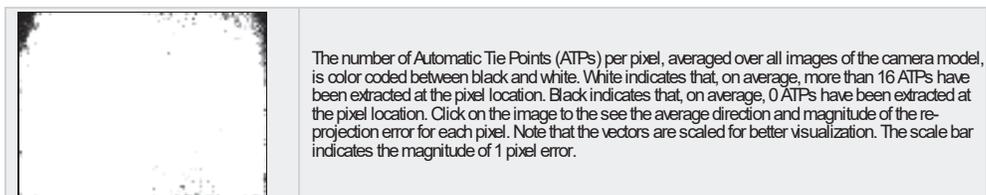
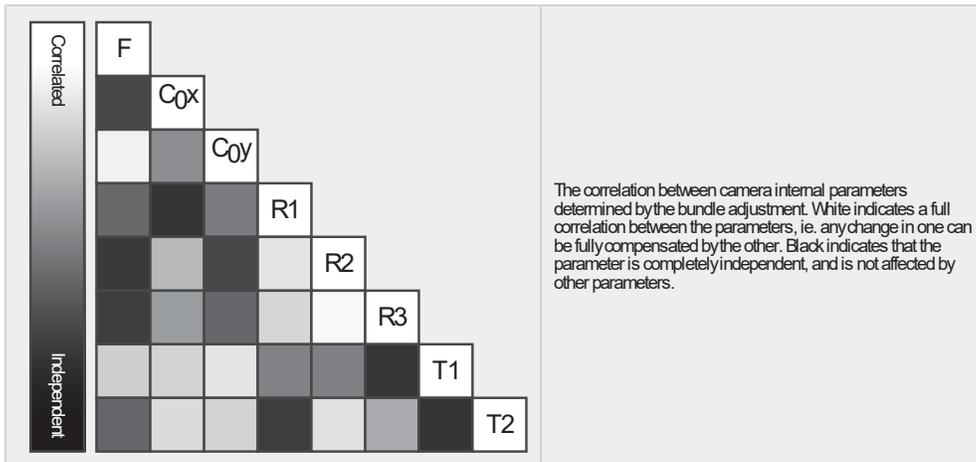
Number of 2D Keypoint Observations for Bundle Block Adjustment	739428
Number of 3D Points for Bundle Block Adjustment	270043
Mean Reprojection Error [pixels]	0.202

Internal Camera Parameters

FC330_3.6_4000x3000 (RGB). Sensor Dimensions: 6.317 [mm] x 4.738 [mm]

EXIF ID: FC330_3.6_4000x3000

	Focal Length	Principal Point x	Principal Point y	R1	R2	R3	T1	T2
Initial Values	2285.722 [pixel] 3.610 [mm]	2000.006 [pixel] 3.159 [mm]	1500.003 [pixel] 2.369 [mm]	-0.001	-0.002	0.000	-0.001	-0.001
Optimized Values	2388.171 [pixel] 3.772 [mm]	1968.294 [pixel] 3.109 [mm]	1468.397 [pixel] 2.319 [mm]	0.001	-0.006	0.004	0.000	0.000
Uncertainties (Sigma)	0.341 [pixel] 0.001 [mm]	0.081 [pixel] 0.000 [mm]	0.248 [pixel] 0.000 [mm]	0.000	0.000	0.000	0.000	0.000



2D Keypoints Table

	Number of 2D Keypoints per Image	Number of Matched 2D Keypoints per Image
Median	30176	7194
Mn	18308	257
Max	59293	16649
Mean	33537	7249

3D Points from 2D Keypoint Matches

Number of 3D Points Observed

In 2 Images	184464
In 3 Images	42711
In 4 Images	17853
In 5 Images	9476
In 6 Images	5623
In 7 Images	3176
In 8 Images	2109
In 9 Images	1437
In 10 Images	995
In 11 Images	807
In 12 Images	507
In 13 Images	338
In 14 Images	197
In 15 Images	139
In 16 Images	98
In 17 Images	50
In 18 Images	24
In 19 Images	15
In 20 Images	9
In 21 Images	4
In 22 Images	4
In 23 Images	4
In 24 Images	2
In 25 Images	1

2D Keypoint Matches

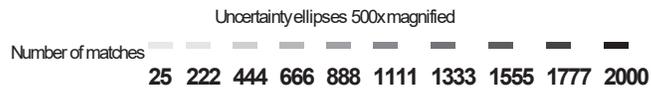
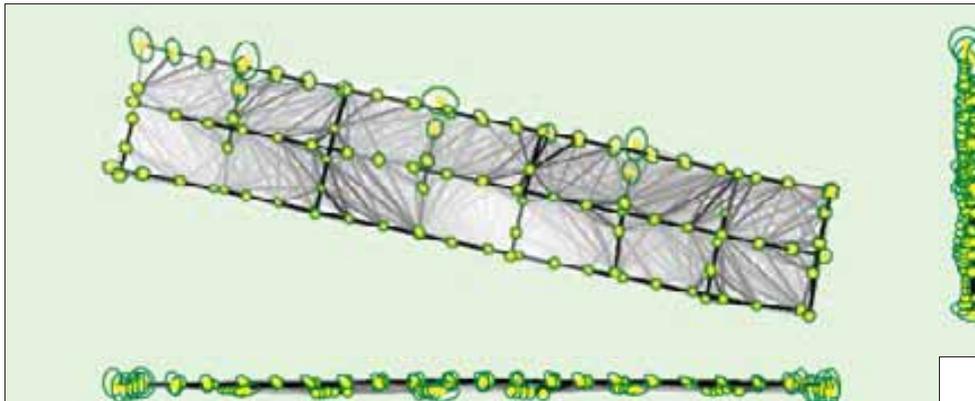


Figure 5: Computed image positions with links between matched images. The darkness of the links indicates the number of matched 2D keypoints between the images. Bright links indicate weak links and require manual tie points or more images. Dark green ellipses indicate the relative camera position uncertainty of the bundle block adjustment result.

Relative camera position and orientation uncertainties

	X[m]	Y[m]	Z[m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.002	0.002	0.003	0.006	0.009	0.005
Sigma	0.001	0.001	0.001	0.002	0.004	0.002

Geolocation Details

Absolute Geolocation Variance

Min Error [m]	Max Error [m]	Geolocation Error X[%]	Geolocation Error Y[%]	Geolocation Error Z[%]
-	-15.00	0.00	0.00	0.00
-15.00	-12.00	0.00	0.00	0.00
-12.00	-9.00	0.00	0.00	0.00
-9.00	-6.00	0.00	0.00	0.00
-6.00	-3.00	0.00	0.00	0.00
-3.00	0.00	52.94	51.96	59.80
0.00	3.00	47.06	48.04	40.20
3.00	6.00	0.00	0.00	0.00
6.00	9.00	0.00	0.00	0.00
9.00	12.00	0.00	0.00	0.00
12.00	15.00	0.00	0.00	0.00
15.00	-	0.00	0.00	0.00
Mean [m]		0.027942	-0.026491	-0.032143
Sigma [m]		0.852015	0.657284	0.707801
RMS Error [m]		0.852473	0.657818	0.708531

Min Error and Max Error represent geolocation error intervals between -1.5 and 1.5 times the maximum accuracy of all the images. Columns X, Y, Z show the percentage of images with geolocation errors within the predefined error intervals. The geolocation error is the difference between the initial and computed image positions. Note that the image geolocation errors do not correspond to the accuracy of the observed 3D points.

Relative Geolocation Variance

Relative Geolocation Error	Images X[%]	Images Y[%]	Images Z[%]	
[-1.00, 1.00]	100.00	100.00	100.00	
[-2.00, 2.00]	100.00	100.00	100.00	
[-3.00, 3.00]	100.00	100.00	100.00	
Mean of Geolocation Accuracy [m]		5.000000	5.000000	10.000000
Sigma of Geolocation Accuracy [m]		0.000000	0.000000	0.000000

Images X, Y, Z represent the percentage of images with a relative geolocation error in X, Y, Z.

Geolocation Orientational Variance	RMS [degree]
Omega	0.977
Phi	1.220
Kappa	1.690

Geolocation RMS error of the orientation angles given by the difference between the initial and computed image orientation angles.

Initial Processing Details

System Information

Hardware	CPU: Intel(R) Core(TM) i7-8700K CPU @3.70GHz RAM 16GB GPU: NVIDIA GeForce GTX 1070 (Driver: 23.21.13.9065)
Operating System	Windows 10 Home, 64-bit

Coordinate Systems

Image Coordinate System	WGS84 (egm96)
Output Coordinate System	WGS 84 / UTMzone 19N (egm96)

Processing Options

Detected Template	<input checked="" type="checkbox"/> 3D Maps
Keypoints Image Scale	Full, Image Scale: 1
Advanced: Matching Image Pairs	Aerial Grid or Corridor
Advanced: Matching Strategy	Use Geometrically Verified Matching: no
Advanced: Keypoint Extraction	Targeted Number of Keypoints: Automatic
Advanced: Calibration	Calibration Method: Standard Internal Parameters Optimization: All External Parameters Optimization: All Rematch: Auto, yes

Point Cloud Densification details

Processing Options

Image Scale	multiscale, 1/2 (Half image size, Default)
Point Density	Optimal
Minimum Number of Matches	3
3D Textured Mesh Generation	yes
3D Textured Mesh Settings:	Resolution: Medium Resolution (default) Color Balancing: no
LOD	Generated: no
Advanced: 3D Textured Mesh Settings	Sample Density Divider: 1
Advanced: Image Groups	group 1
Advanced: Use Processing Area	yes
Advanced: Use Annotations	yes
Time for Point Cloud Densification	06m:16s
Time for Point Cloud Classification	NA
Time for 3D Textured Mesh Generation	02m:42s

Results

Number of Generated Tiles	1
Number of 3D Densified Points	6875958
Average Density (per m ³)	2154.76

DSM, Orthomosaic and Index Details

Processing Options

DSM and Orthomosaic Resolution	1 x GSD (1.09 [cm/pixel])
DSM Filters	Noise Filtering: yes Surface Smoothing: yes, Type: Sharp
Raster DSM	Generated: yes Method: Inverse Distance Weighting Merge Tiles: yes
Orthomosaic	Generated: yes Merge Tiles: yes GeoTIFF Without Transparency: no Google Maps Tiles and KML: no
Time for DSM Generation	06m:25s
Time for Orthomosaic Generation	05m:49s
Time for DTM Generation	00s

Time for Contour Lines Generation	00s
Time for Reflectance Map Generation	00s
Time for Index Map Generation	00s

Site name:

Poza Teodoro, Isabela

Before hurricane María



A. Physical address:

Poza de Teodoro, parallel to PR 466, Isabela, Puerto Rico, 00662

B. Date of capture of imagery:

May 22, 2017

C. Coordinates:

18.51169368 N -67.03622750 W

D. Description of site:

This is a site located parallel to PR-466 in Isabela. It is a very popular recreation spot due to a tidal pool that is used for swimming and snorkeling that is located in this area. The primary dune was breached during a northeasterly on 2008. This area has been the main site of our dune restoration program since that date. Our restoration efforts have resulted in the accumulation of over 9 m of sand on the middle part of the breach. A wooden boardwalk was installed in the area in 2015 and has been used successfully by hundreds of people. The area also has information signs and has been planted with plants such as beach grape, beach bean and sea lavender. The plants have stabilized some areas. The area to the east of the boardwalk is being restored with biomimicry matrices and sand exclusion fences. The backdune area is relatively wide and is covered with sand

from a wash-over fan that was created back in 2008 when the dune was breached. This area is used as a parking lot.

E. Distance from community:

This site is located at an approximate distance of 176 m from PR-466, 432 m from cliff and 500 m to the east of the nearest houses.

F. Aerial imagery

i. Contour map

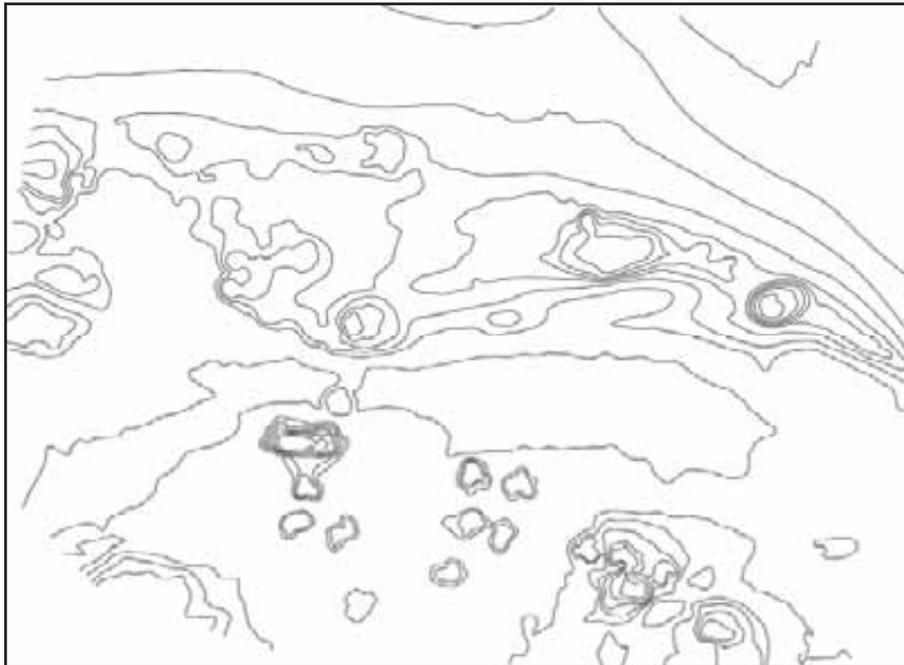


Figure 161. Contour map of Poza Teodoro (before María), Isabela, Puerto Rico Puerto Rico with elevation intervals of 1 meter.

ii. 3D imagery



Figure 162. Aerial 3D image of Poza Teodoro (before María), Isabela, Puerto Rico, Puerto Rico.

iii. Orthomosaic model

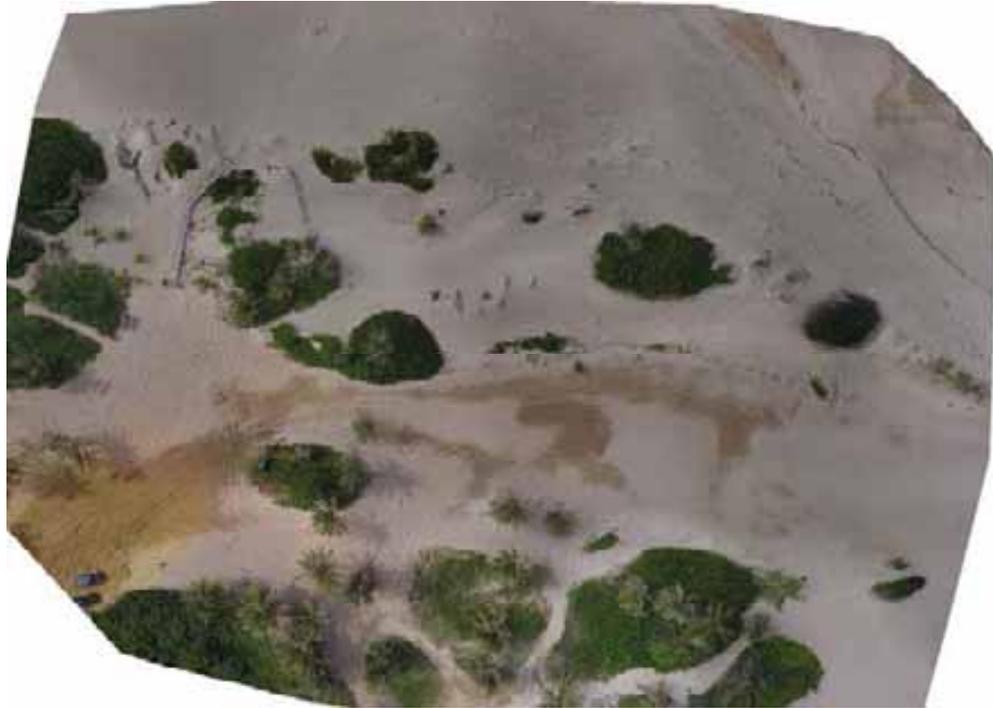


Figure 163. Orthomosaic image of Poza Teodoro (before María), Isabela, Puerto Rico.

iv. Density Surface Models (DSM)

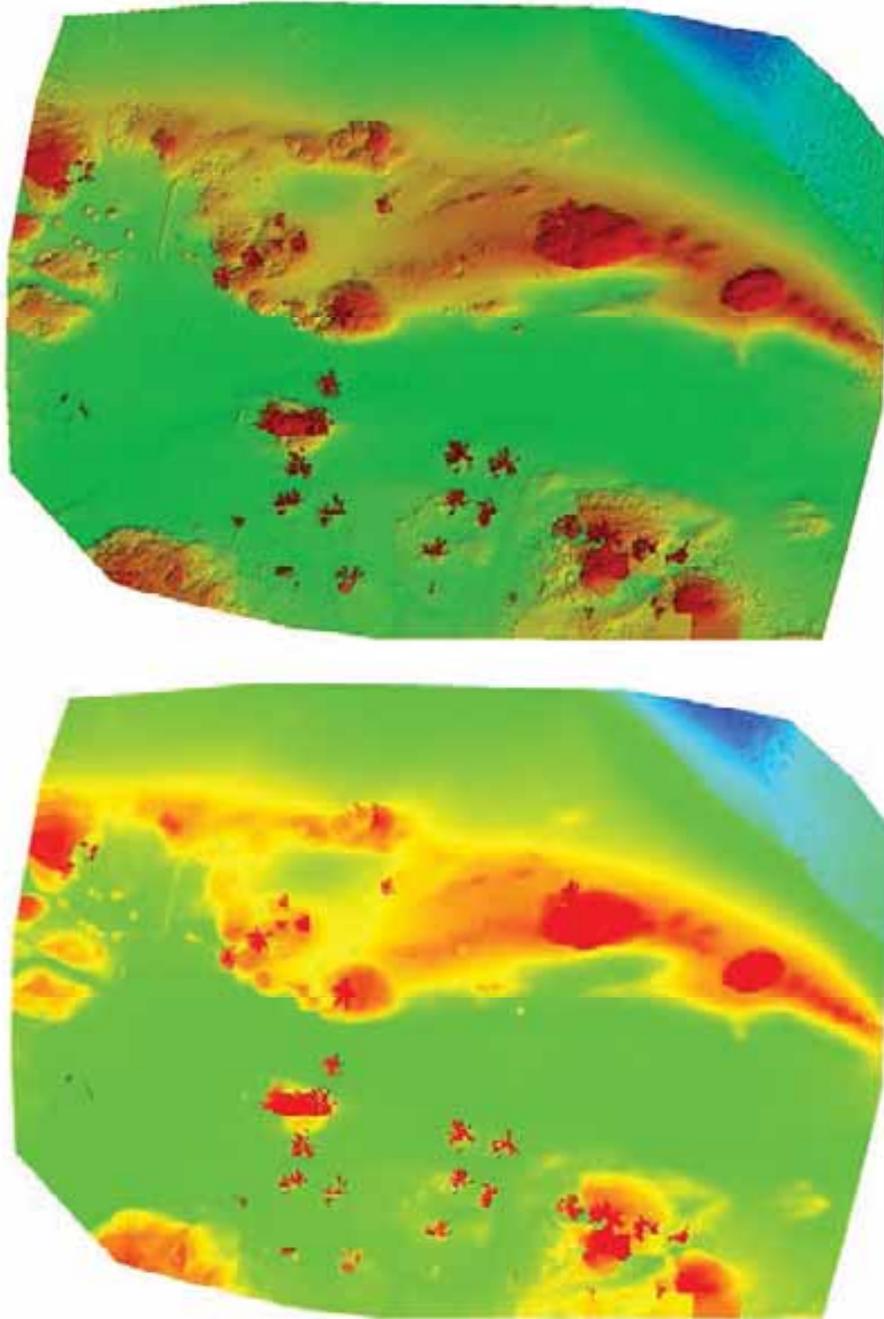


Figure 164. Density surface model (with shading top and without shading bottom) images of the dune located at the Poza Teodoro (before María), Isabela, Puerto Rico.

v. Thermal images

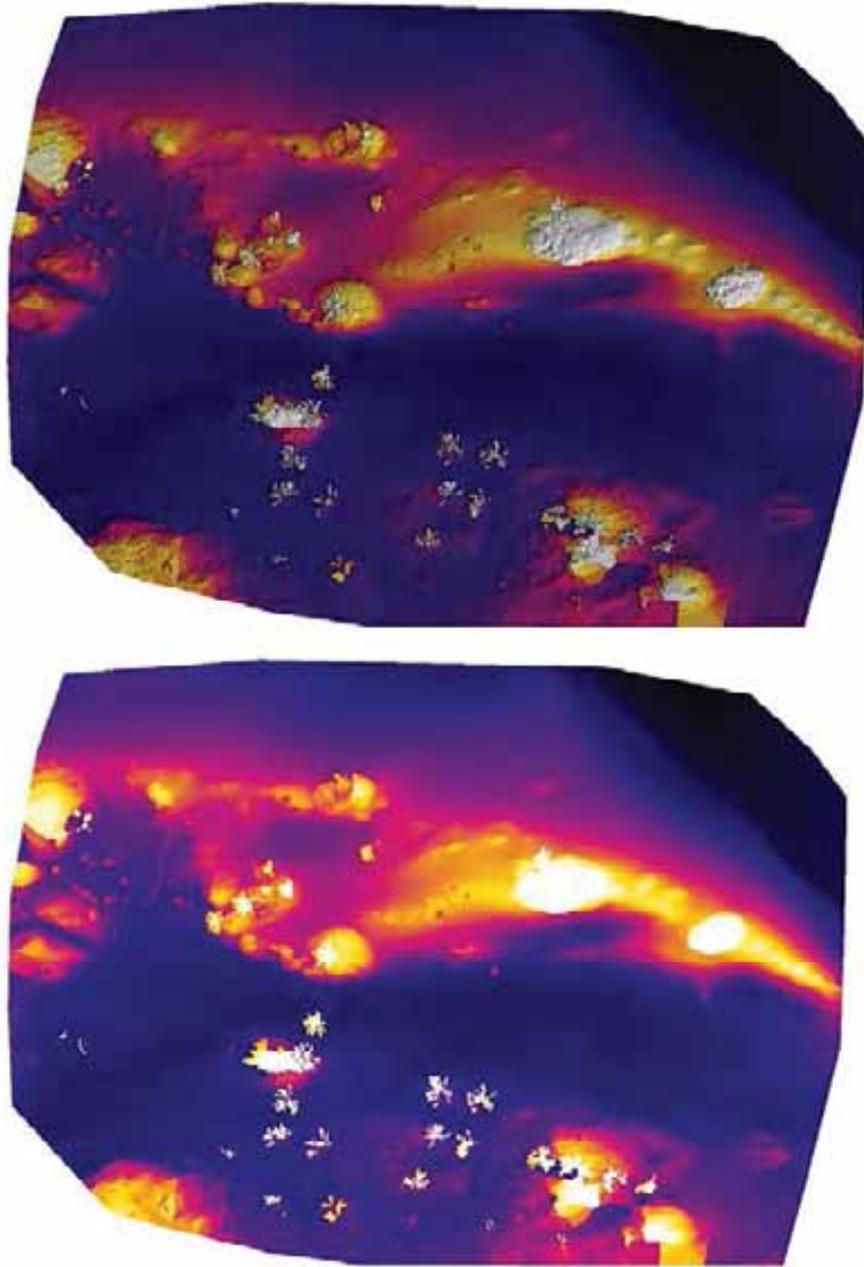


Figure 165. Thermal images (with shading top and without shading bottom) of the dune located at the Poza Teodoro (before María), Isabela, Puerto Rico.

vi. 3D altitude RGB North

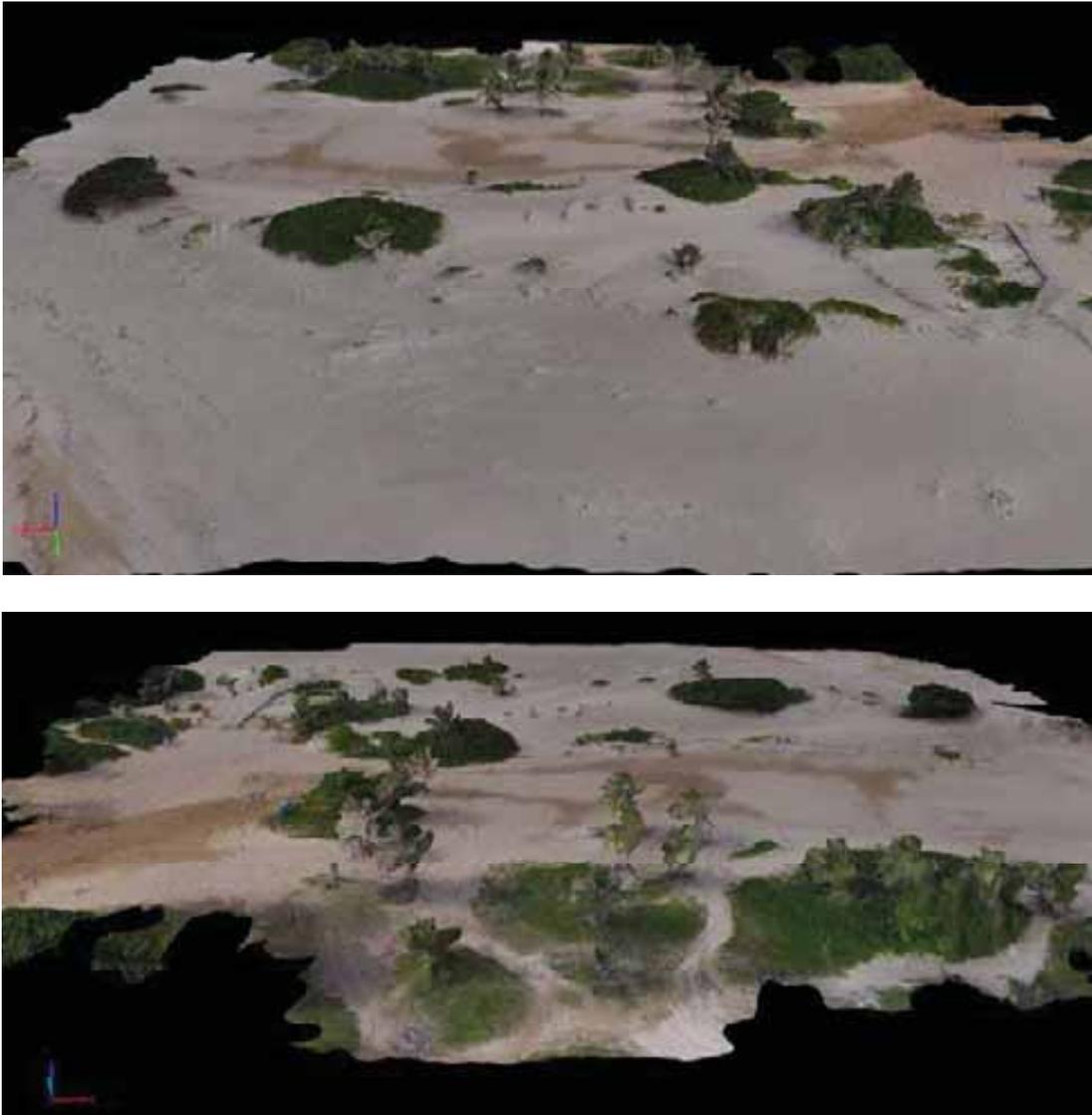


Figure 166. Three dimensional RGB images of the Poza Teodoro (before María), Isabela, Puerto Rico. View from the north (top) and from the south (bottom).

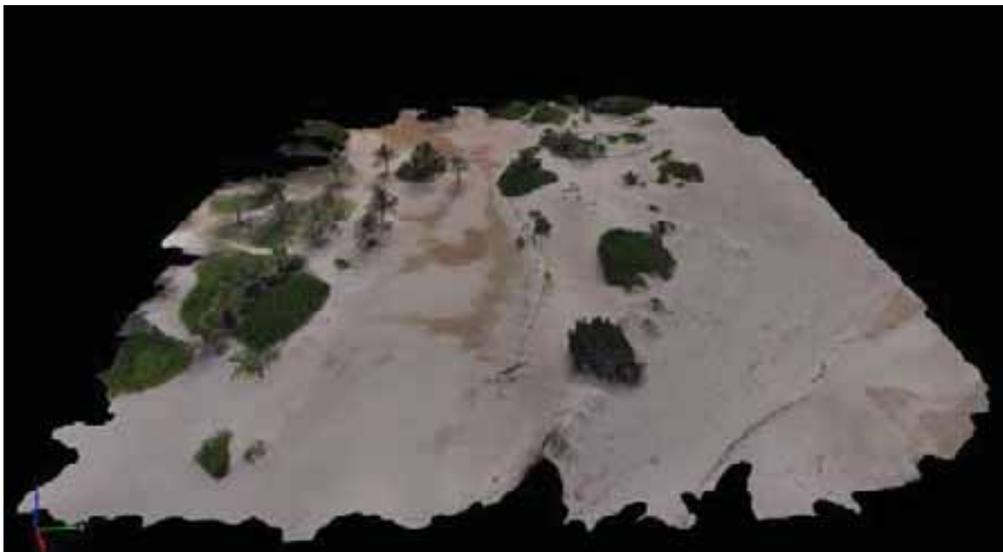


Figure 167. Three dimensional RGB images of the Poza Teodoro (before María), Isabela, Puerto Rico. View from the west (top) and from the east (bottom).

vii. DSM grayscale

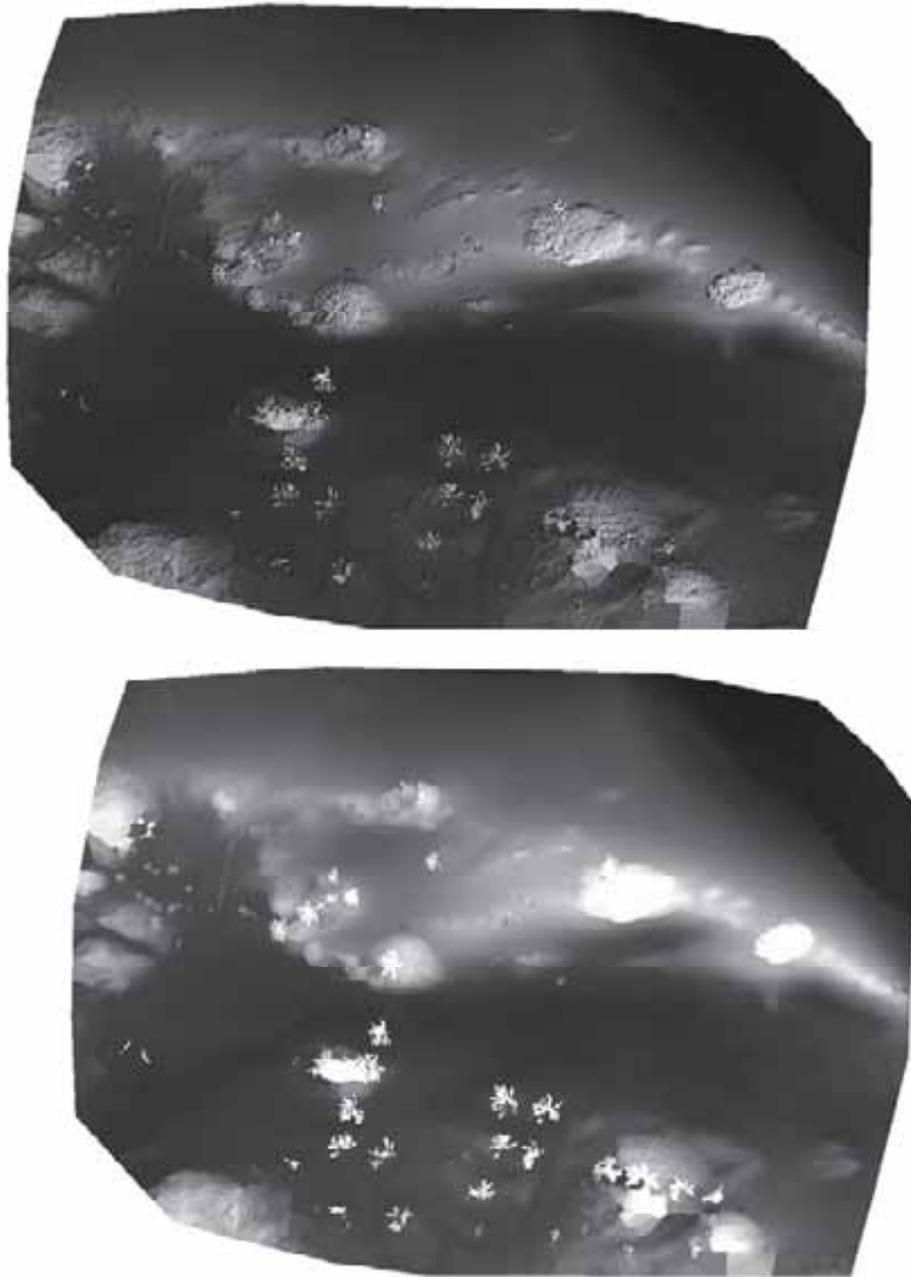


Figure 168. Grayscale DSM images of the Poza Teodoro (before María), Isabela, Puerto Rico. The top image shows shades and the bottom is not shaded.

G. Pix 4D Quality Report

Quality Report

Generated with Pix4Dmapper Pro version 4.1.22

1 Important: Click on the different icons for:

-  Help to analyze the results in the Quality Report
-  Additional information about the sections

 Click [here](#) for additional tips to analyze the Quality Report

Summary

Project	Mision Teodoro Andres Del Huracan Maria
Processed	2018-01-15 10:54:57
Camera Model Name(s)	FC330_3.6_4000x3000 (RGB)
Average Ground Sampling Distance (GSD)	1.38 cm / 0.54 in
Area Covered	0.026 km ² / 2.5907 ha / 0.01 sq. mi. / 6.4050 acres
Time for Initial Processing (without report)	01h:16m:36s

Quality Check

 Images	median of 24136 keypoints per image	
 Dataset	245 out of 245 images calibrated (100%), all images enabled	
 Camera Optimization	4.83% relative difference between initial and optimized internal camera parameters	
 Matching	median of 10444.3 matches per calibrated image	
 Georeferencing	yes, no 3D GCP	

Preview

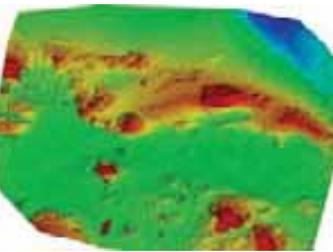



Figure 1: Orthomosaic and the corresponding sparse Digital Surface Model (DSM) before densification.

Calibration Details

Number of Calibrated Images	245 out of 245
Number of Geolocated Images	245 out of 245

Initial Image Positions

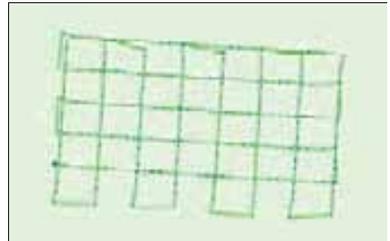


Figure 2: Top view of the initial image position. The green line follows the position of the images in time starting from the large blue dot.

1 Computed Image/GCPs/Manual Tie Points Positions

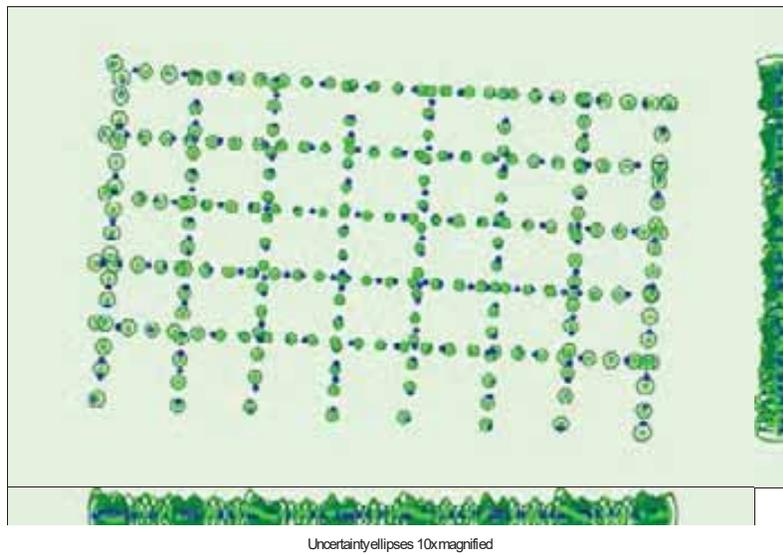


Figure 3: Offset between initial (blue dots) and computed (green dots) image positions as well as the offset between the GCPs initial positions (blue crosses) and their computed positions (green crosses) in the top-view (XY plane), front-view (XZ plane), and side-view (YZ plane). Dark green ellipses indicate the absolute position uncertainty of the bundle block adjustment result.

1 Absolute camera position and orientation uncertainties

	X[m]	Y[m]	Z[m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.135	0.135	0.328	0.490	0.287	0.168
Sigma	0.024	0.024	0.073	0.045	0.044	0.015

1 Overlap



Number of overlapping images: 1 2 3 4 5+

Figure 4: Number of overlapping images computed for each pixel of the orthomosaic. Red and yellow areas indicate low overlap for which poor results may be generated. Green areas indicate an overlap of over 5 images for every pixel. Good quality results will be generated as long as the number of keypoint matches is also sufficient for these areas (see Figure 5 for keypoint matches).

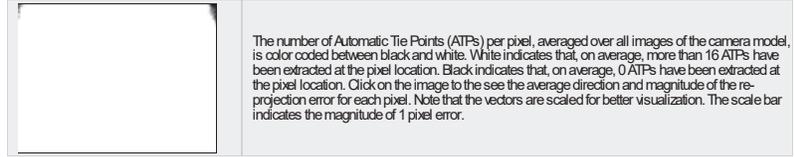
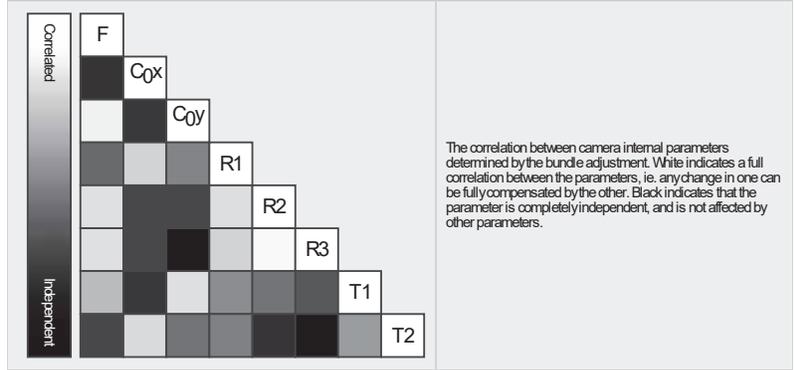
Bundle Block Adjustment Details

Number of 2D Keypoint Observations for Bundle Block Adjustment	2929432
Number of 3D Points for Bundle Block Adjustment	901274
Mean Reprojection Error [pixels]	0.207

1 Internal Camera Parameters

FC330_3.6_4000x3000 (RGB). Sensor Dimensions: 6.317 [mm] x 4.738 [mm]

	Focal Length	Principal Point x	Principal Point y	R1	R2	R3	T1	T2
Initial Values	2285.722 [pixel] 3.610 [mm]	2000.006 [pixel] 3.159 [mm]	1500.003 [pixel] 2.369 [mm]	-0.001	-0.002	0.000	-0.001	-0.001
Optimized Values	2396.334 [pixel] 3.785 [mm]	1961.389 [pixel] 3.098 [mm]	1460.084 [pixel] 2.306 [mm]	-0.000	-0.004	0.003	-0.000	-0.000
Uncertainties (Sigma)	0.323 [pixel] 0.001 [mm]	0.047 [pixel] 0.000 [mm]	0.203 [pixel] 0.000 [mm]	0.000	0.000	0.000	0.000	0.000



2D Keypoints Table

	Number of 2D Keypoints per Image	Number of Matched 2D Keypoints per Image
Median	24136	10444
Mn	18168	646
Max	49646	30086
Mean	27697	11957

3D Points from 2D Keypoint Matches

	Number of 3D Points Observed
In 2 Images	529675
In 3 Images	157334
In 4 Images	74653
In 5 Images	42992
In 6 Images	27198
In 7 Images	18170
In 8 Images	12732
In 9 Images	8913
In 10 Images	6422
In 11 Images	4828
In 12 Images	3815
In 13 Images	2971
In 14 Images	2276
In 15 Images	1873
In 16 Images	1451
In 17 Images	1135
In 18 Images	929
In 19 Images	715
In 20 Images	587
In 21 Images	463
In 22 Images	417
In 23 Images	322
In 24 Images	262
In 25 Images	206
In 26 Images	153
In 27 Images	146
In 28 Images	113

In 29 Images	109
In 30 Images	83
In 31 Images	68
In 32 Images	61
In 33 Images	57
In 34 Images	39
In 35 Images	29
In 36 Images	14
In 37 Images	11
In 38 Images	14
In 39 Images	4
In 40 Images	6
In 41 Images	7
In 42 Images	4
In 43 Images	6
In 44 Images	4
In 45 Images	4
In 47 Images	2
In 49 Images	1

2D Keypoint Matches

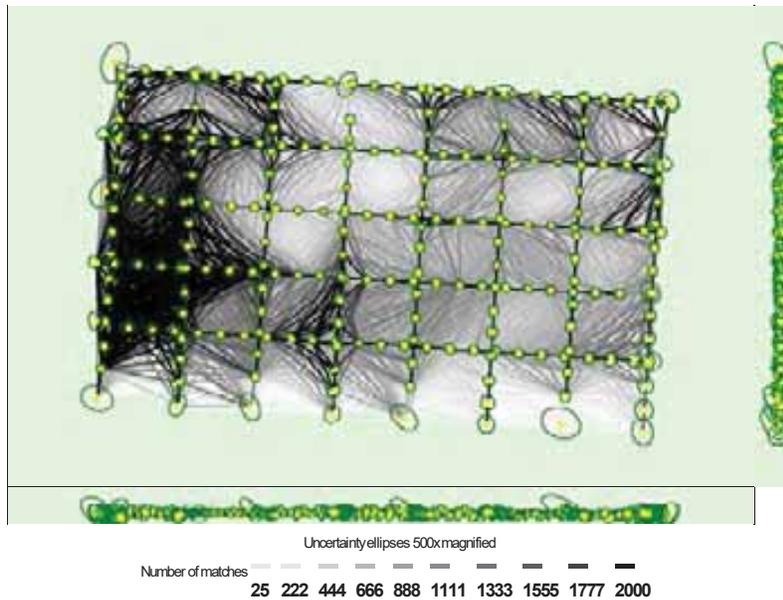


Figure 5: Computed image positions with links between matched images. The darkness of the links indicates the number of matched 2D keypoints between the images. Bright links indicate weak links and require manual tie points or more images. Dark green ellipses indicate the relative camera position uncertainty of the bundle block adjustment result.

Relative camera position and orientation uncertainties

	X[m]	Y[m]	Z[m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.003	0.003	0.002	0.006	0.007	0.003
Sigma	0.001	0.001	0.001	0.002	0.002	0.001

Geolocation Details

Absolute Geolocation Variance

Mn Error [m]	MaxError [m]	Geolocation Error X[%]	Geolocation Error Y[%]	Geolocation Error Z[%]
-	-15.00	0.00	0.00	0.00
-15.00	-12.00	0.00	0.00	0.00
-12.00	-9.00	0.00	0.00	0.00
-9.00	-6.00	0.00	0.00	0.00

-6.00	-3.00	0.41	0.41	0.00
-3.00	0.00	35.92	35.51	51.02
0.00	3.00	63.27	63.27	48.98
3.00	6.00	0.41	0.82	0.00
6.00	9.00	0.00	0.00	0.00
9.00	12.00	0.00	0.00	0.00
12.00	15.00	0.00	0.00	0.00
15.00	-	0.00	0.00	0.00
Mean [m]		-0.000000	-0.000000	0.000000
Sigma [m]		1.052627	1.109444	0.383571
RMS Error [m]		1.052627	1.109444	0.383571

Min Error and Max Error represent geolocation error intervals between -1.5 and 1.5 times the maximum accuracy of all the images. Columns X, Y, Z show the percentage of images with geolocation errors within the predefined error intervals. The geolocation error is the difference between the initial and computed image positions. Note that the image geolocation errors do not correspond to the accuracy of the observed 3D points.

Relative Geolocation Variance

Relative Geolocation Error	Images X[%]	Images Y[%]	Images Z[%]
[-1.00, 1.00]	99.59	100.00	100.00
[-2.00, 2.00]	100.00	100.00	100.00
[-3.00, 3.00]	100.00	100.00	100.00
Mean of Geolocation Accuracy [m]	5.000000	5.000000	10.000000
Sigma of Geolocation Accuracy [m]	0.000000	0.000000	0.000000

Images X, Y, Z represent the percentage of images with a relative geolocation error in X, Y, Z.

Geolocation Orientational Variance	RMS [degree]
Omega	1.657
Phi	1.819
Kappa	3.464

Geolocation RMS error of the orientation angles given by the difference between the initial and computed image orientation angles.

Initial Processing Details

System Information

Hardware	CPU: Intel(R) Core(TM) i5-3330S CPU @2.70GHz RAM 8GB GPU: Intel(R) HD Graphics (Driver: 10.18.10.3412), RDPDD Chained DD (Driver: unknown), RDP Encoder Mirror Driver (Driver: unknown), RDP Reflector Display Driver (Driver: unknown)
Operating System	Windows 7 Professional, 64-bit

Coordinate Systems

Image Coordinate System	WGS84 (egm96)
Output Coordinate System	WGS 84 / UTMzone 19N (egm96)

Processing Options

Detected Template	3D Maps
Keypoints Image Scale	Full, Image Scale: 1
Advanced: Matching Image Pairs	Aerial Grid or Corridor
Advanced: Matching Strategy	Use Geometrically Verified Matching: no
Advanced: Keypoint Extraction	Targeted Number of Keypoints: Automatic
Advanced: Calibration	Calibration Method: Standard Internal Parameters Optimization: All External Parameters Optimization: All Rematch: Auto, yes

Point Cloud Densification details

Processing Options

Image Scale	multiscale, 1/2 (Half image size, Default)
Point Density	Optimal
Minimum Number of Matches	3
3D Textured Mesh Generation	yes

3D Textured Mesh Settings:	Resolution: Medium Resolution (default) Color Balancing: no
LOD	Generated: no
Advanced: 3D Textured Mesh Settings	Sample Density Divider: 1
Advanced: Image Groups	group1
Advanced: Use Processing Area	yes
Advanced: Use Annotations	yes
Time for Point Cloud Densification	01h:28m:27s
Time for Point Cloud Classification	NA
Time for 3D Textured Mesh Generation	10m:58s

Results

Number of Generated Tiles	1
Number of 3D Densified Points	14211536
Average Density (per m ³)	1626.66

DSM, Orthomosaic and Index Details

Processing Options

DSM and Orthomosaic Resolution	1 x GSD (1.38 [cm/pixel])
DSM Filters	Noise Filtering: yes Surface Smoothing: yes, Type: Sharp
Raster DSM	Generated: yes Method: Inverse Distance Weighting Merge Tiles: yes
Orthomosaic	Generated: yes Merge Tiles: yes GeoTIFF Without Transparency: no Google Maps Tiles and KML: no
Time for DSM Generation	18m:20s
Time for Orthomosaic Generation	45m:54s
Time for DTMGeneration	00s
Time for Contour Lines Generation	00s
Time for Reflectance Map Generation	00s
Time for Index Map Generation	00s

Site name:

Poza Teodoro, Isabela

After hurricane María

A. Physical address:

Poza Teodoro (after María), PR-466, Isabela, Puerto Rico, 00662

B. Date of capture of imagery:

January 16, 2018

C. Coordinates:

18.51169368 N - 67.03622750 W

D. Aerial imagery

i. Contour map

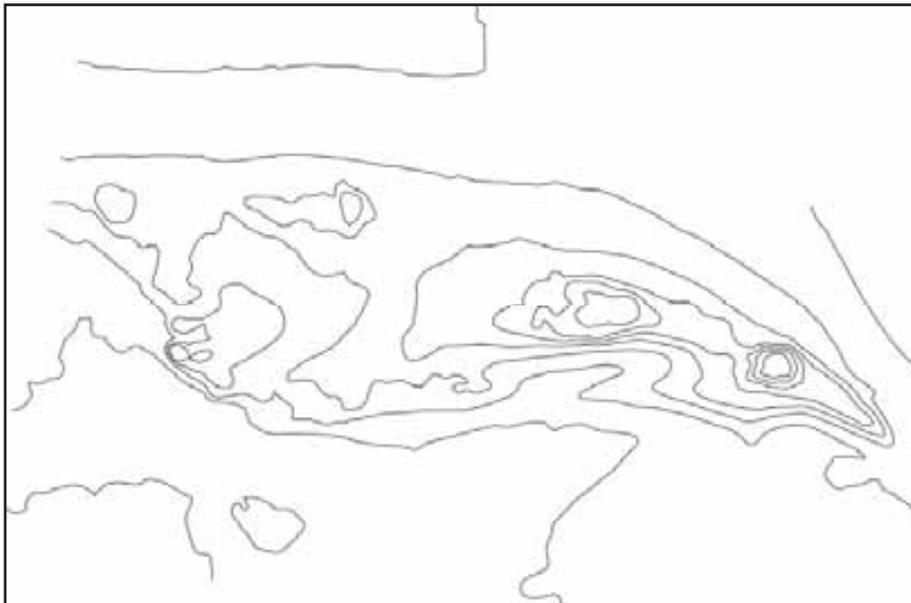


Figure 169. Contour map of Poza Teodoro (after María), Isabela, Puerto Rico with elevation intervals of 1 meter.

ii. 3D imagery



Figure 170. Aerial 3D image of Poza Teodoro (after hurricane María), Isabela, Puerto Rico.

iii. Orthomosaic model



Figure 171. Orthomosaic image of Poza Teodoro (after hurricane María), Isabela, Puerto Rico.

iv. Density Surface Models (DSM)

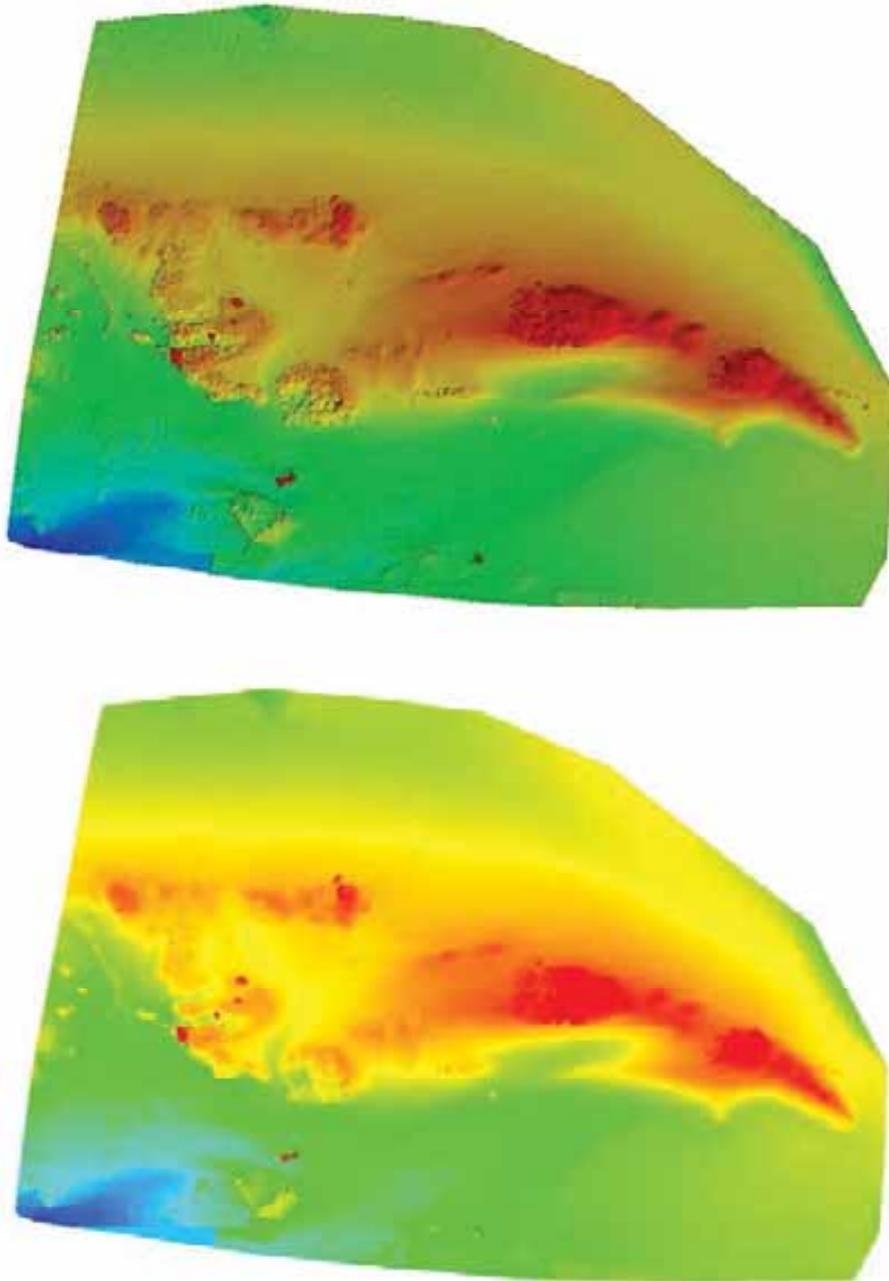


Figure 172. Density surface model (with shading top and without shading bottom) images of the dune located at the Poza Teodoro (after hurricane María), Isabela, Puerto Rico.

v. Thermal images

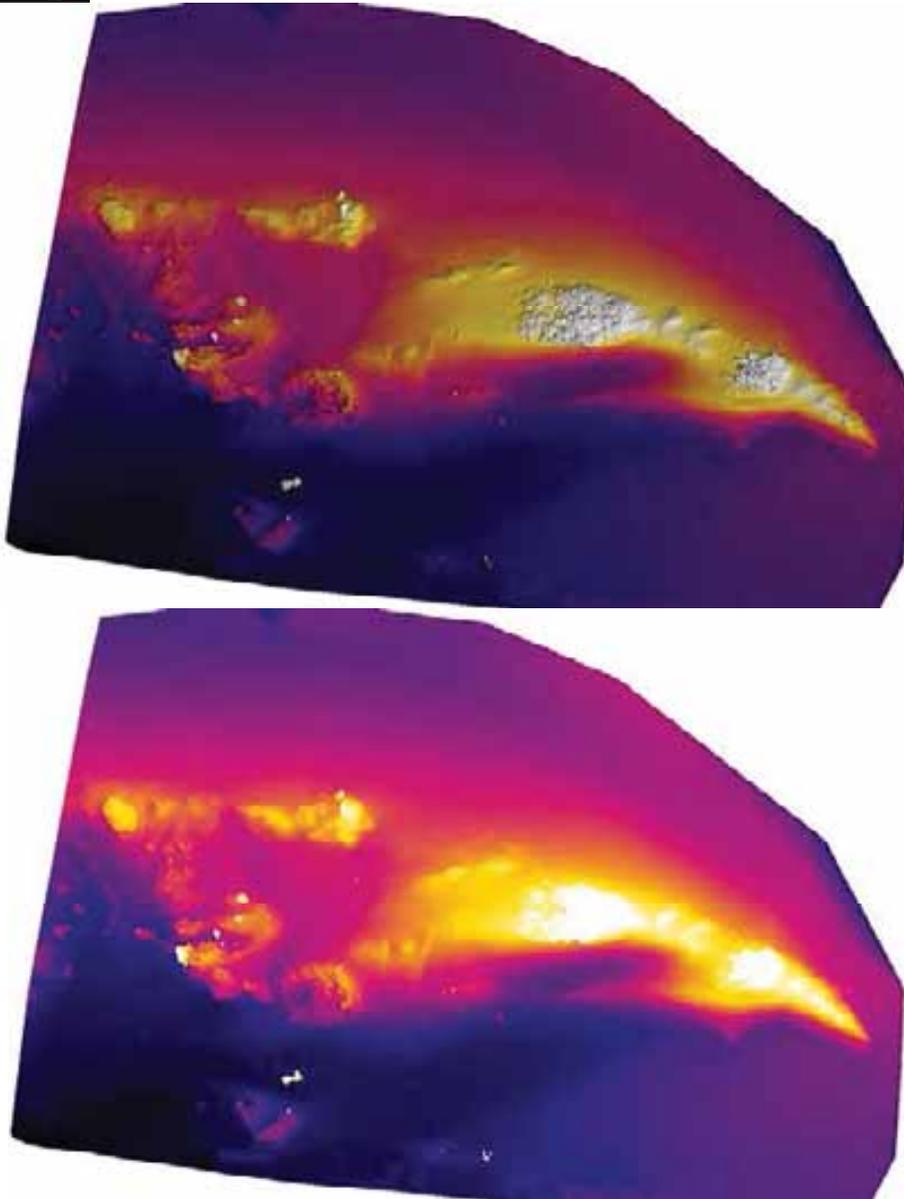


Figure 173. Thermal images (with shading top and without shading bottom) of the dune located at the Poza Teodoro (after hurricane María), Isabela, Puerto Rico

vi. 3D altitude RGB North

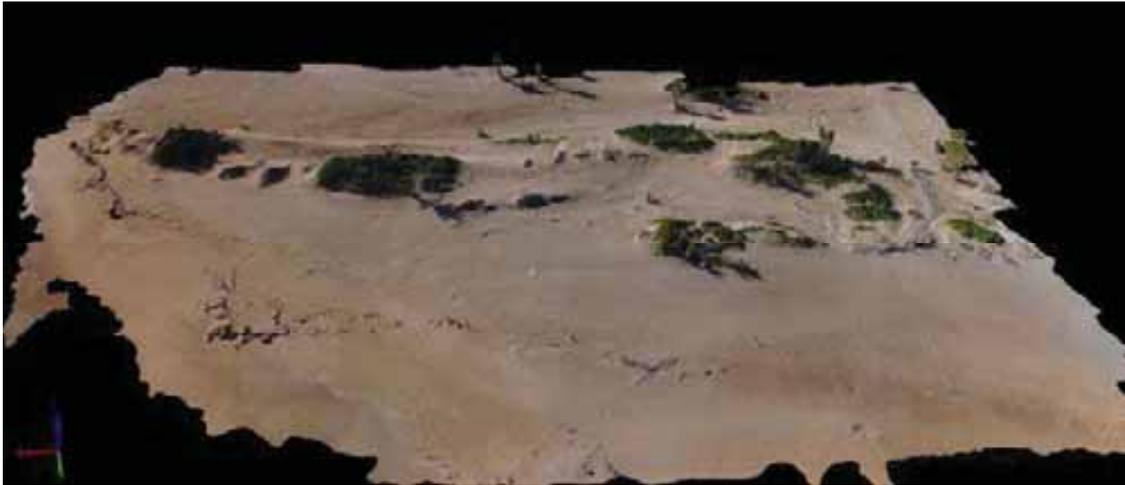


Figure 174. Three dimensional RGB images of the Poza Teodoro (after María), Isabela, Puerto Rico. View from the north (top) and from the south (bottom).

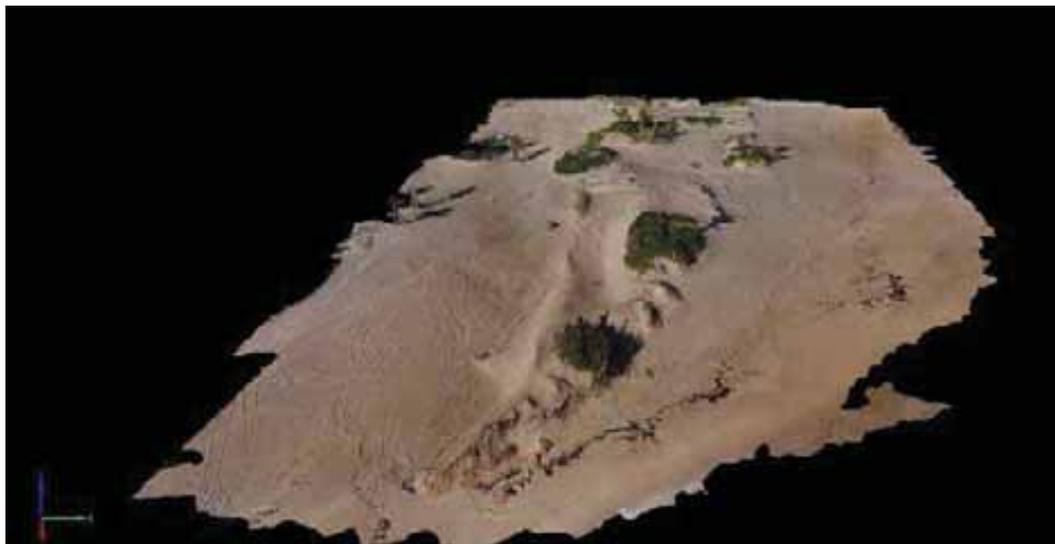


Figure 175. Three dimensional RGB images of the Poza Teodoro (after María), Isabela, Puerto Rico. View from the west (top) and from the east (bottom).

vii. DSM grayscale

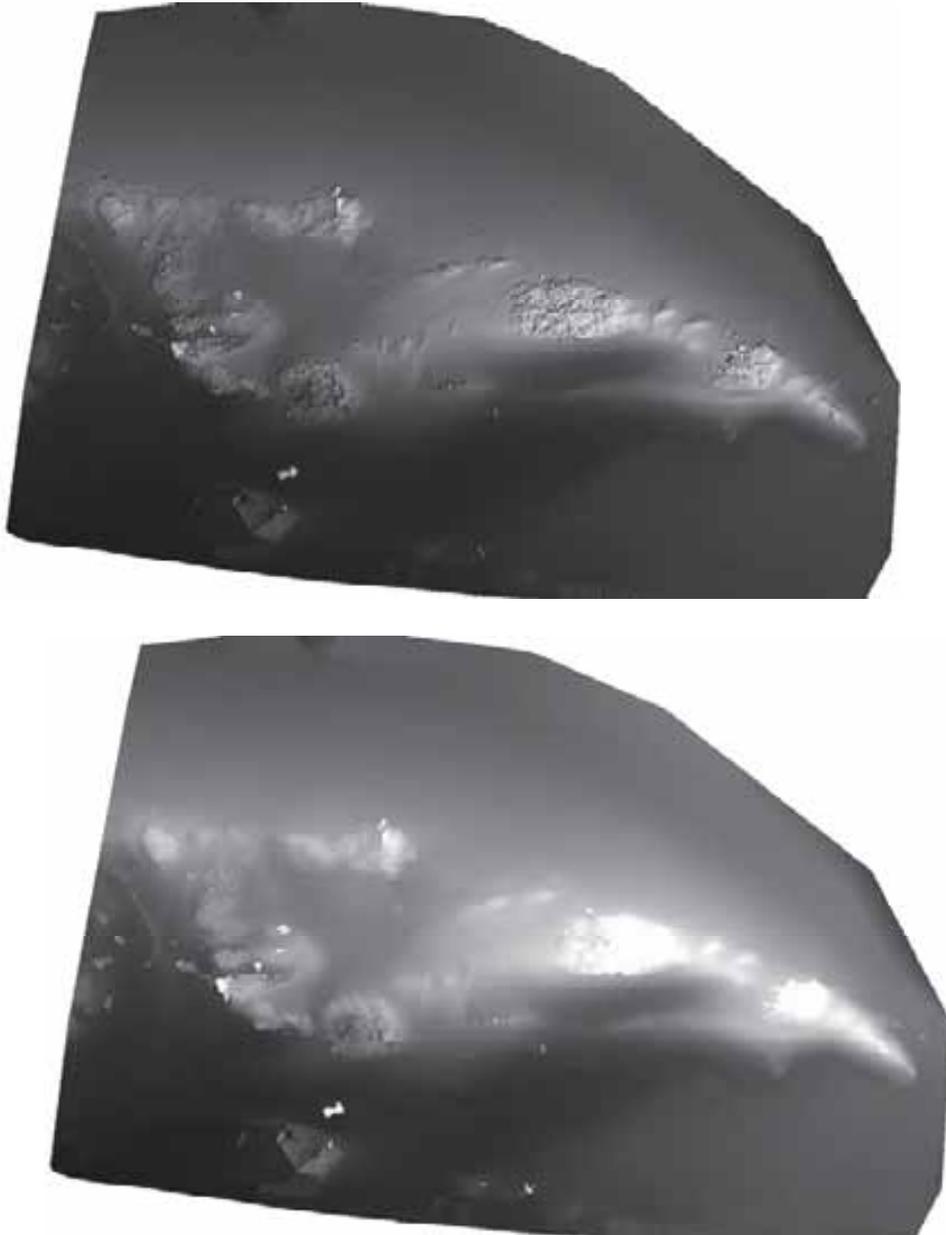


Figure 176. Grayscale DSM images of the dune to the Poza Teodoro (after hurricane María), Isabela, Puerto Rico. The top image shows shades and the bottom is not shaded.

E. Pix 4D Quality Report.

Quality Report

Generated with Pix4Dmapper Pro version 4.1.22

Important: Click on the different icons for:

- Help to analyze the results in the Quality Report
- Additional information about the sections

Click [here](#) for additional tips to analyze the Quality Report

Summary

Project	Mision Teodoro Después de Maria
Processed	2018-01-16 13:15:44
Camera Model Name(s)	FC330_3.6_4000x3000 (RGB)
Average Ground Sampling Distance (GSD)	1.15 cm / 0.45 in
Area Covered	0.019 km ² / 1.8987 ha / 0.01 sq. mi. / 4.6942 acres
Time for Initial Processing (without report)	42m31s

Quality Check

Images	median of 36098 keypoints per image	✓
Dataset	137 out of 137 images calibrated (100%), all images enabled	✓
Camera Optimization	5.31% relative difference between initial and optimized internal camera parameters	⚠
Matching	median of 17149.7 matches per calibrated image	✓
Georeferencing	yes, no 3D GCP	⚠

Preview

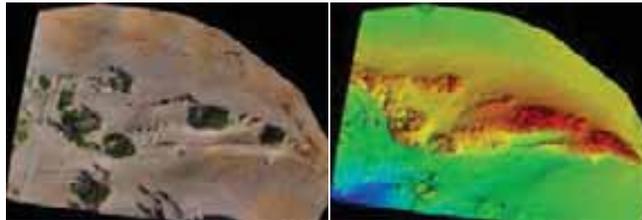


Figure 1: Orthomosaic and the corresponding sparse Digital Surface Model (DSM) before densification.

Calibration Details

Number of Calibrated Images	137 out of 137
Number of Geolocated Images	137 out of 137

Initial Image Positions

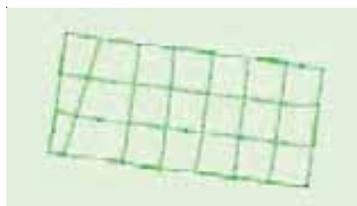


Figure 2: Top view of the initial image position. The green line follows the position of the images in time starting from the large blue dot.

Computed Image/GCPs/Manual Tie Points Positions



Uncertainty ellipses 10x magnified

Figure 3: Offset between initial (blue dots) and computed (green dots) image positions as well as the offset between the GCPs initial positions (blue crosses) and their computed positions (green crosses) in the top-view (XY plane), front-view (XZ plane), and side-view (YZ plane). Dark green ellipses indicate the absolute position uncertainty of the bundle block adjustment result.

Absolute camera position and orientation uncertainties

	X[m]	Y[m]	Z[m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.148	0.148	0.360	0.561	0.317	0.188
Sigma	0.028	0.028	0.078	0.061	0.060	0.021

Overlap

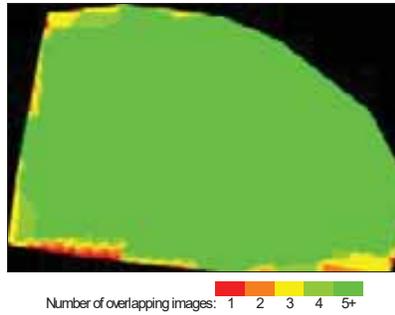


Figure 4: Number of overlapping images computed for each pixel of the orthomosaic. Red and yellow areas indicate low overlap for which poor results may be generated. Green areas indicate an overlap of over 5 images for every pixel. Good quality results will be generated as long as the number of keypoint matches is also sufficient for these areas (see Figure 5 for keypoint matches).

Bundle Block Adjustment Details

Number of 2D Keypoint Observations for Bundle Block Adjustment	2305974
Number of 3D Points for Bundle Block Adjustment	789625
Mean Reprojection Error [pixels]	0.248

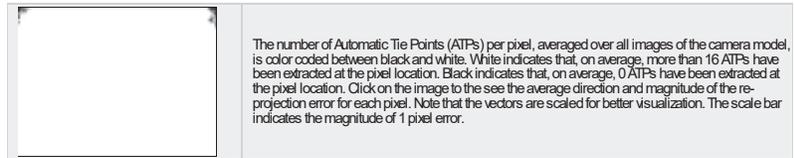
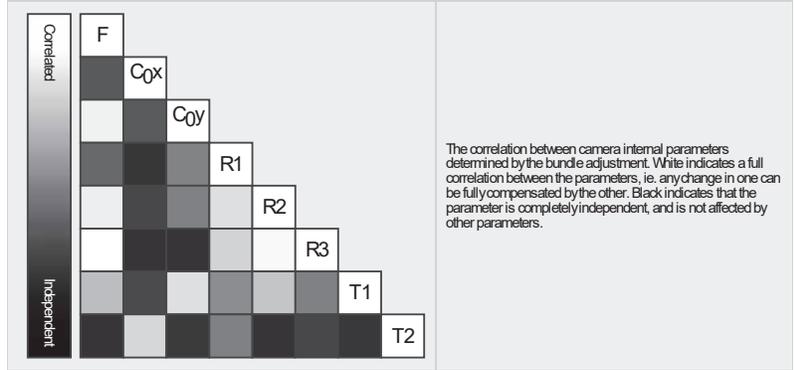
Internal Camera Parameters

FC330_3.6_4000x3000 (RGB). Sensor Dimensions: 6.317 [mm] x 4.738 [mm]

EXIF ID: FC330_3.6_4000x3000

	Focal Length	Principal Point x	Principal Point y	R1	R2	R3	T1	T2

Initial Values	2285.722 [pixel] 3.610 [mm]	2000.006 [pixel] 3.159 [mm]	1500.003 [pixel] 2.369 [mm]	-0.001	-0.002	0.000	-0.001	-0.001
Optimized Values	2407.156 [pixel] 3.802 [mm]	1963.100 [pixel] 3.100 [mm]	1454.108 [pixel] 2.297 [mm]	0.000	-0.006	0.004	0.000	-0.000
Uncertainties (Sigma)	0.318 [pixel] 0.001 [mm]	0.053 [pixel] 0.000 [mm]	0.210 [pixel] 0.000 [mm]	0.000	0.000	0.000	0.000	0.000



2D Keypoints Table

	Number of 2D Keypoints per Image	Number of Matched 2D Keypoints per Image
Median	36098	17150
Mn	20717	506
Max	57442	34721
Mean	37060	16832

3D Points from 2D Keypoint Matches

	Number of 3D Points Observed
In 2 Images	478264
In 3 Images	145526
In 4 Images	69046
In 5 Images	37996
In 6 Images	22439
In 7 Images	13714
In 8 Images	8562
In 9 Images	5370
In 10 Images	3472
In 11 Images	2150
In 12 Images	1301
In 13 Images	773
In 14 Images	475
In 15 Images	253
In 16 Images	152
In 17 Images	80
In 18 Images	25
In 19 Images	18
In 20 Images	4
In 21 Images	4
In 22 Images	1

2D Keypoint Matches

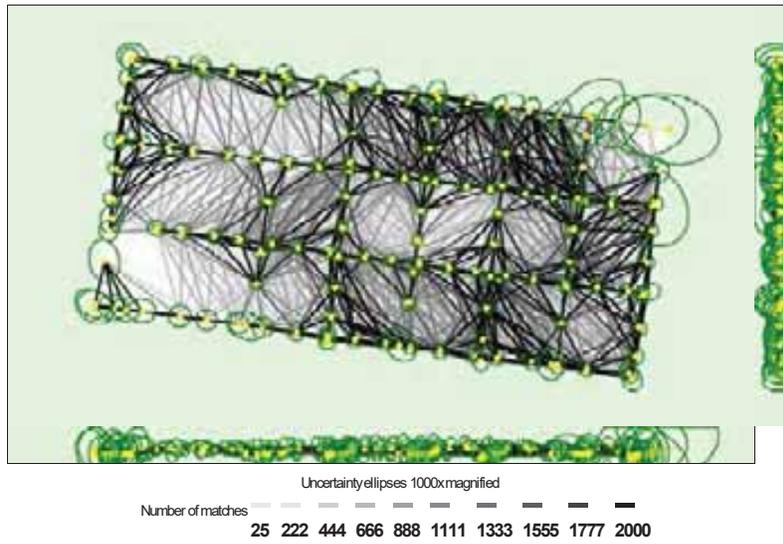


Figure 5: Computed image positions with links between matched images. The darkness of the links indicates the number of matched 2D keypoints between the images. Bright links indicate weak links and require manual tie points or more images. Dark green ellipses indicate the relative camera position uncertainty of the bundle block adjustment result.

Relative camera position and orientation uncertainties

	X[m]	Y[m]	Z[m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.002	0.002	0.003	0.006	0.008	0.004
Sigma	0.001	0.001	0.001	0.004	0.003	0.002

Geolocation Details

Absolute Geolocation Variance

Min Error [m]	Max Error [m]	Geolocation Error X[%]	Geolocation Error Y[%]	Geolocation Error Z[%]
-	-15.00	0.00	0.00	0.00
-15.00	-12.00	0.00	0.00	0.00
-12.00	-9.00	0.00	0.00	0.00
-9.00	-6.00	0.00	0.00	0.00
-6.00	-3.00	0.73	0.00	0.00
-3.00	0.00	26.28	53.28	48.18
0.00	3.00	72.26	46.72	51.82
3.00	6.00	0.73	0.00	0.00
6.00	9.00	0.00	0.00	0.00
9.00	12.00	0.00	0.00	0.00
12.00	15.00	0.00	0.00	0.00
15.00	-	0.00	0.00	0.00
Mean [m]		-0.000000	0.000000	0.000000
Sigma [m]		1.193189	0.900946	0.761189
RMS Error [m]		1.193189	0.900946	0.761189

Min Error and Max Error represent geolocation error intervals between -1.5 and 1.5 times the maximum accuracy of all the images. Columns X, Y, Z show the percentage of images with geolocation errors within the predefined error intervals. The geolocation error is the difference between the initial and computed image positions. Note that the image geolocation errors do not correspond to the accuracy of the observed 3D points.

Relative Geolocation Variance

Relative Geolocation Error	Images X[%]	Images Y[%]	Images Z[%]
[-1.00, 1.00]	100.00	100.00	100.00
[-2.00, 2.00]	100.00	100.00	100.00
[-3.00, 3.00]	100.00	100.00	100.00
Mean of Geolocation Accuracy [m]	5.000000	5.000000	10.000000
Sigma of Geolocation Accuracy [m]	0.000000	0.000000	0.000000

Images X, Y, Z represent the percentage of images with a relative geolocation error in X, Y, Z.

Geolocation Orientational Variance	RMS [degree]
Omega	1.902
Phi	2.188
Kappa	4.403

Geolocation RMS error of the orientation angles given by the difference between the initial and computed image orientation angles.

Initial Processing Details

System Information

Hardware	CPU: Intel(R) Core(TM) i5-3330S CPU @2.70GHz RAM 8GB GPU: Intel(R) HD Graphics (Driver: 10.18.10.3412), RDPDD Chained DD (Driver: unknown), RDP Encoder Mirror Driver (Driver: unknown), RDP Reflector Display Driver (Driver: unknown)
Operating System	Windows 7 Professional, 64-bit

Coordinate Systems

Image Coordinate System	WGS84 (egm96)
Output Coordinate System	WGS 84 / UTMzone 19N (egm96)

Processing Options

Detected Template	3D Maps
Keypoints Image Scale	Full, Image Scale: 1
Advanced: Matching Image Pairs	Aerial Grid or Corridor
Advanced: Matching Strategy	Use Geometrically Verified Matching: no
Advanced: Keypoint Extraction	Targeted Number of Keypoints: Automatic
Advanced: Calibration	Calibration Method: Standard Internal Parameters Optimization: All External Parameters Optimization: All Rematch: Auto, yes

Point Cloud Densification details

Processing Options

Image Scale	multiscale, 1/2 (Half image size, Default)
Point Density	Optimal
Minimum Number of Matches	3
3D Textured Mesh Generation	yes
3D Textured Mesh Settings:	Resolution: Medium Resolution (default) Color Balancing: no
LOD	Generated: no
Advanced: 3D Textured Mesh Settings	Sample Density Divider: 1
Advanced: Image Groups	group1
Advanced: Use Processing Area	yes
Advanced: Use Annotations	yes
Time for Point Cloud Densification	28m:42s
Time for Point Cloud Classification	NA
Time for 3D Textured Mesh Generation	06m:44s

Results

Number of Generated Tiles	1
Number of 3D Densified Points	9824430
Average Density (per m ³)	2119.65

DSM, Orthomosaic and Index Details

Processing Options

DSM and Orthomosaic Resolution	1 x GSD (1.15 [cm/pixel])
DSM Filters	Noise Filtering: yes Surface Smoothing: yes, Type: Sharp

Raster DSM	Generated: yes Method: Inverse Distance Weighting Merge Tiles: yes
Orthomosaic	Generated: yes Merge Tiles: yes GeoTIFF Without Transparency: no Google Maps Tiles and KML: no
Time for DSM Generation	15m:09s
Time for Orthomosaic Generation	24m:49s
Time for DTM Generation	00s
Time for Contour Lines Generation	00s
Time for Reflectance Map Generation	00s
Time for Index Map Generation	00s

Site name:

Poza Teodoro, Isabela

A. Physical address:

Poza de Teodoro, parallel to PR 466, Isabela, Puerto Rico, 00662

B. Date of capture of imagery:

March 7, 2018

C. Coordinates:

18.51188941 N - 67.03607148 W

D. Aerial imagery

i. Contour map

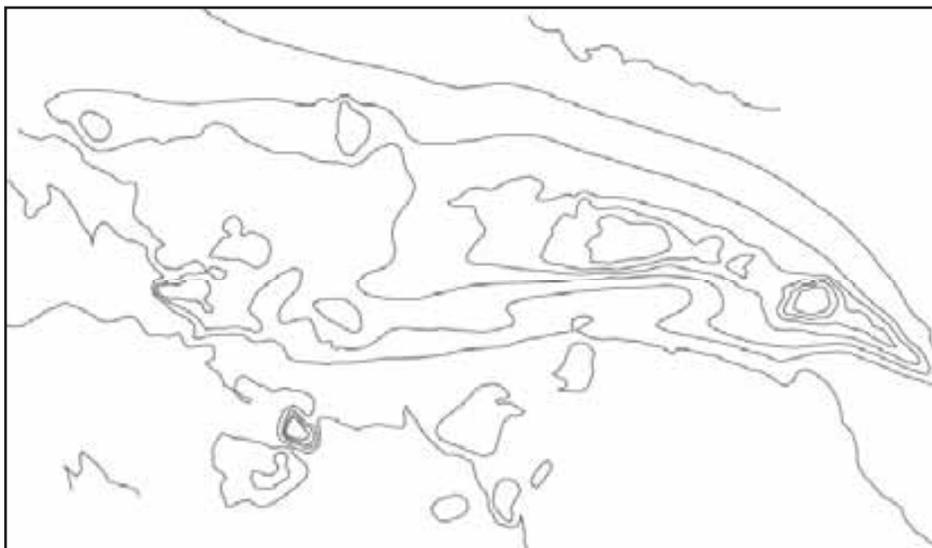


Figure 176. Contour map of Poza Teodoro (after swell), Isabela, Puerto Rico with elevation intervals of 1 meter.

ii. 3D imagery

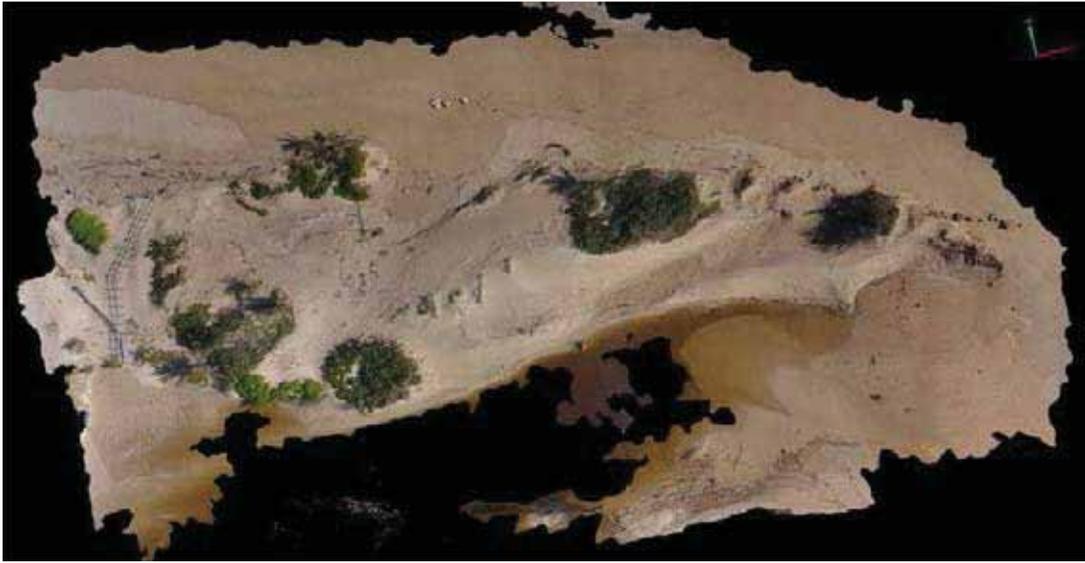


Figure 177. Aerial 3D image of Poza Teodoro (after swell), Isabela, Puerto Rico.

iii. Orthomosaic model



Figure 178. Orthomosaic image of Poza Teodoro (after swell), Isabela, Puerto Rico.

iv. Density Surface Models (DSM)

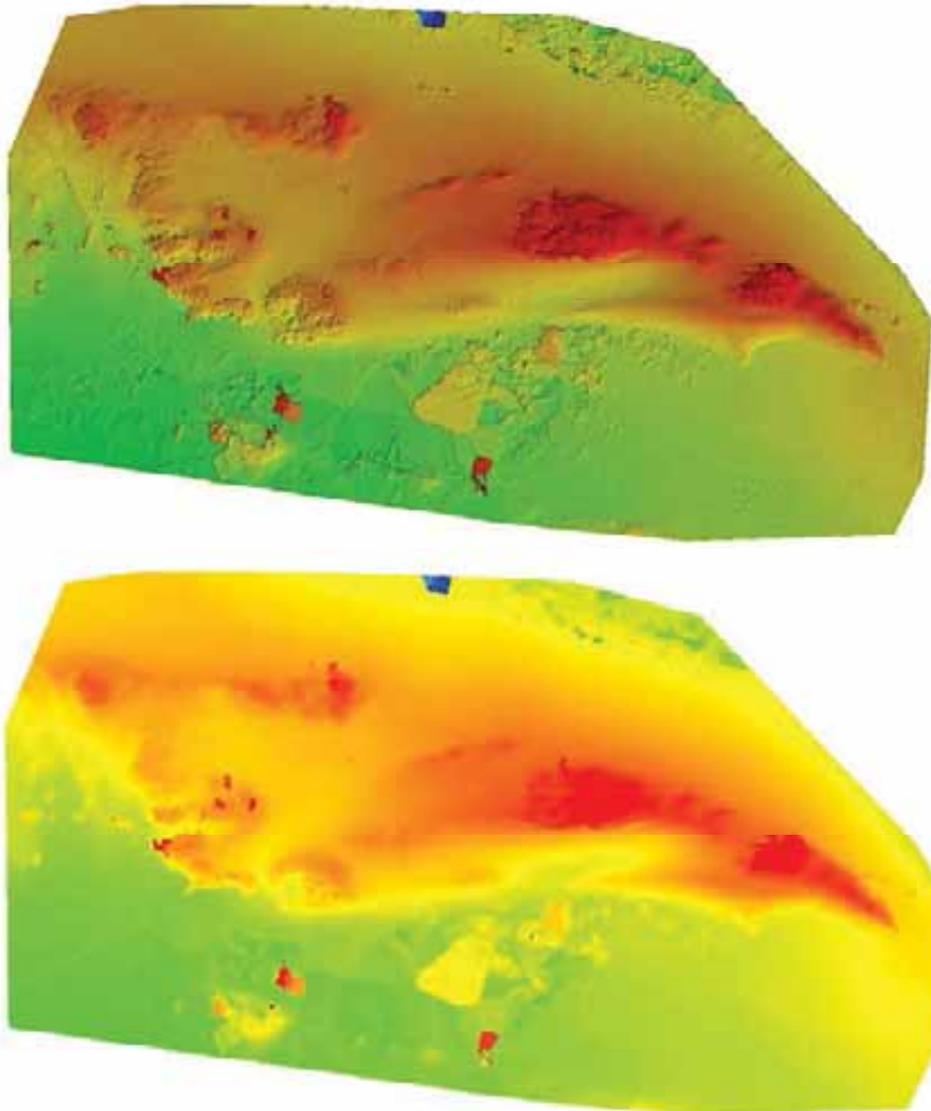


Figure 179. Density surface model (with shading top and without shading bottom) images of the dune located at the Poza Teodoro (after swell), Isabela, Puerto Rico.

v. Thermal images

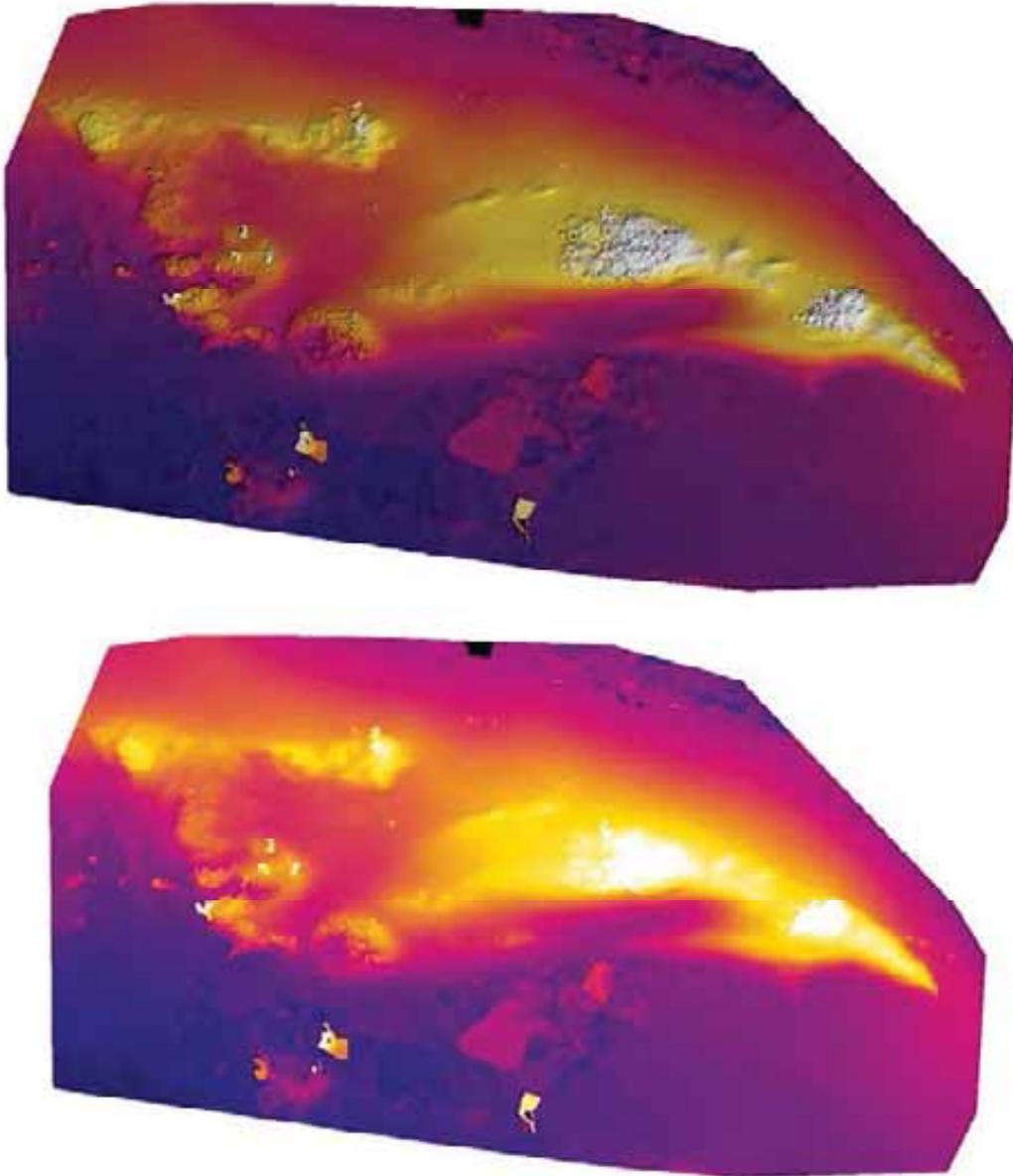


Figure 180. Thermal images (with shading top and without shading bottom) of the dune located at the Poza Teodoro (after swell), Isabela, Puerto Rico.

v. 3D altitude RGB North

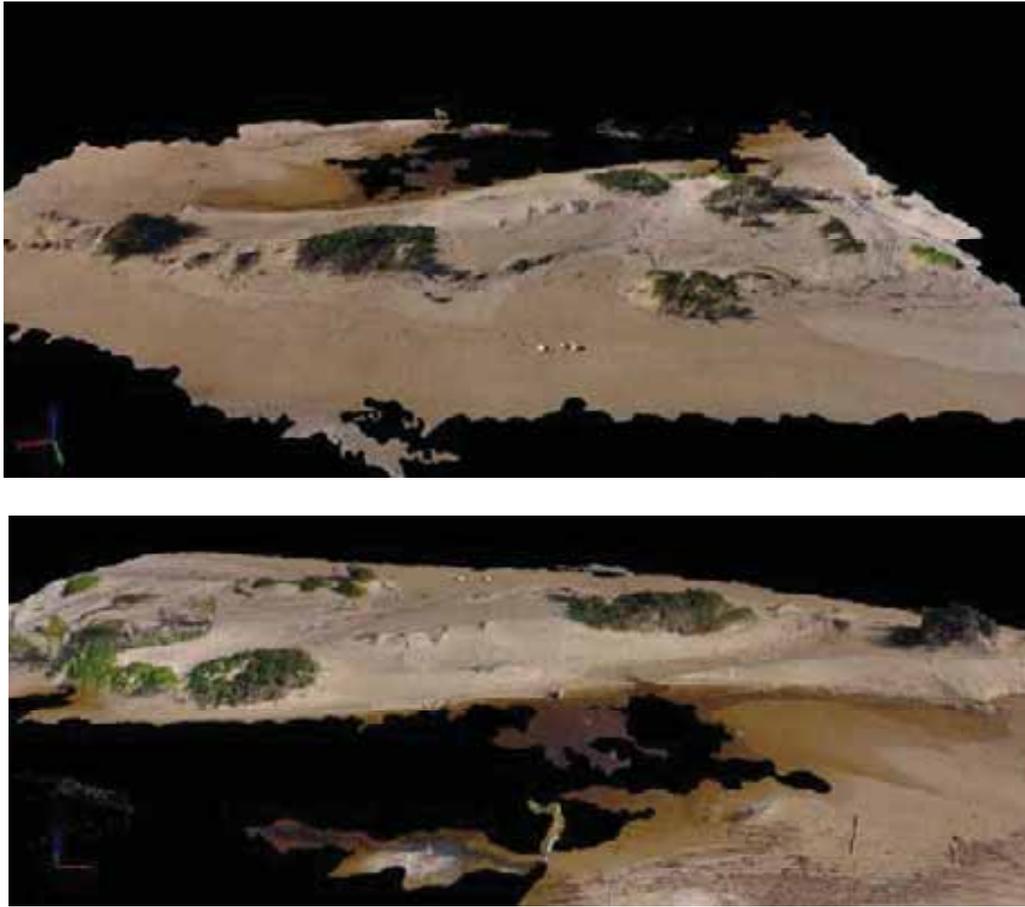


Figure 181. Three dimensional RGB images of the Poza Teodoro (after swell), Isabela, Puerto Rico. View from the north (top) and from the south (bottom).

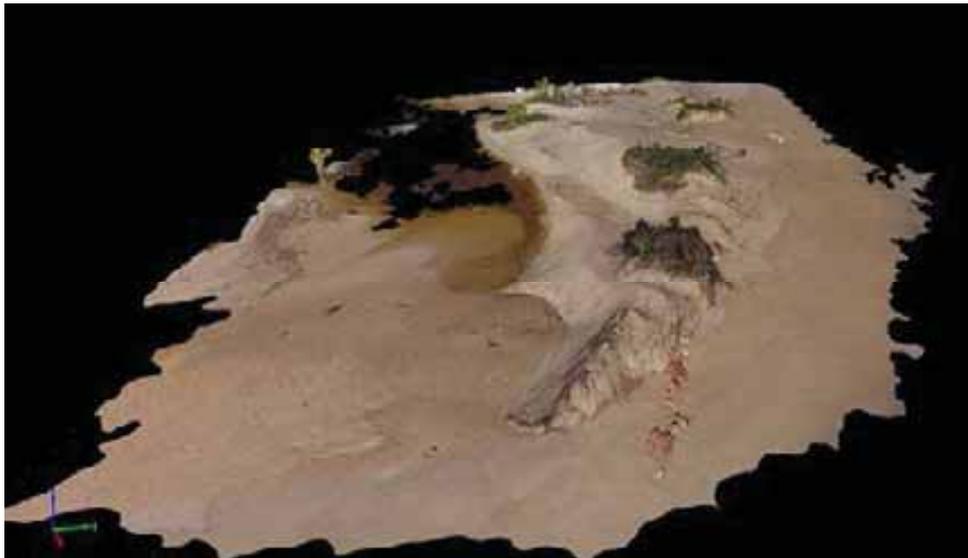


Figure 182. Three dimensional RGB images of the Poza Teodoro (after swell), Isabela. View from the west (top) and from the east (bottom).

vii. DSM grayscale

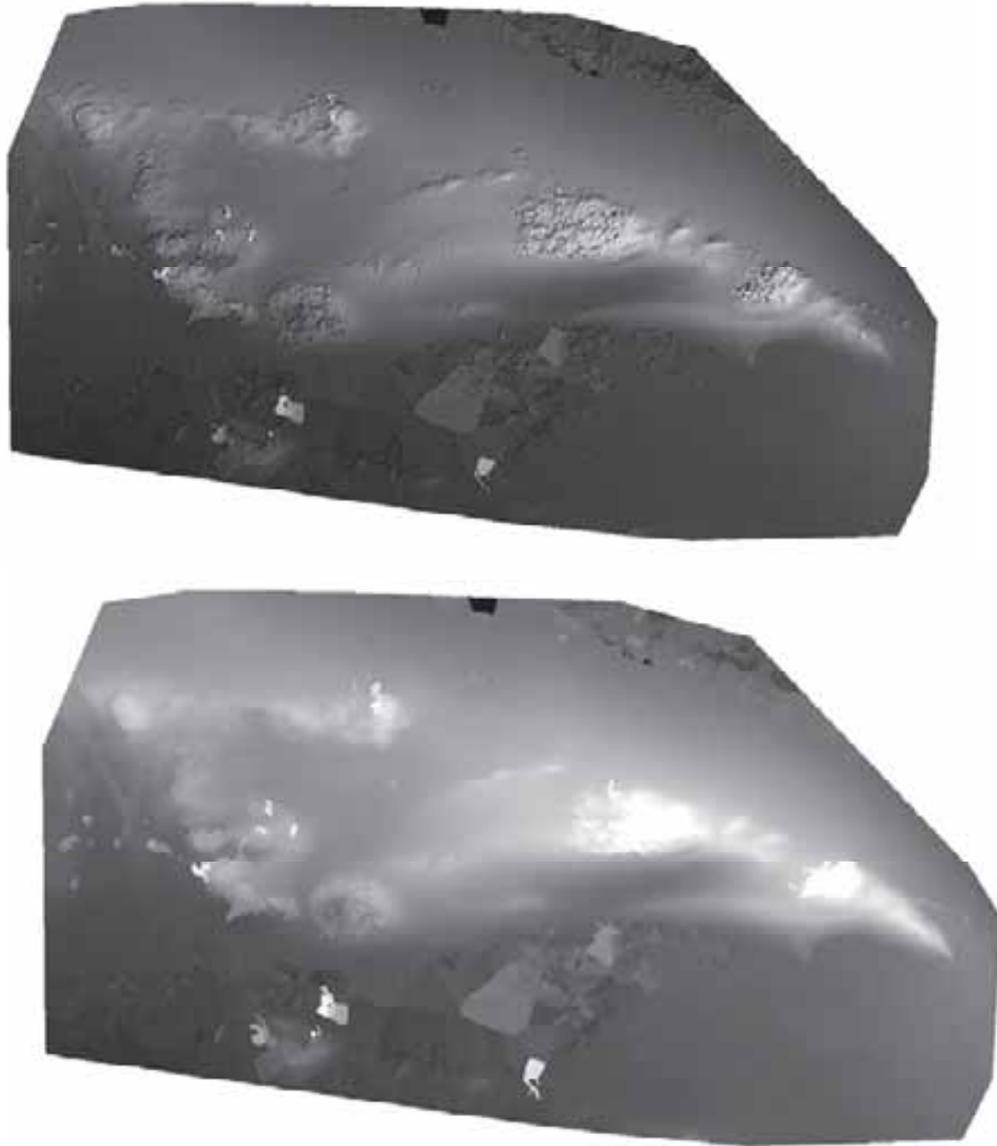


Figure 183. Grayscale DSM images of the dune to the Poza Teodoro (after swell), Isabela. The top image shows shades and the bottom is not shaded.

Site report

E. Vegetation cover

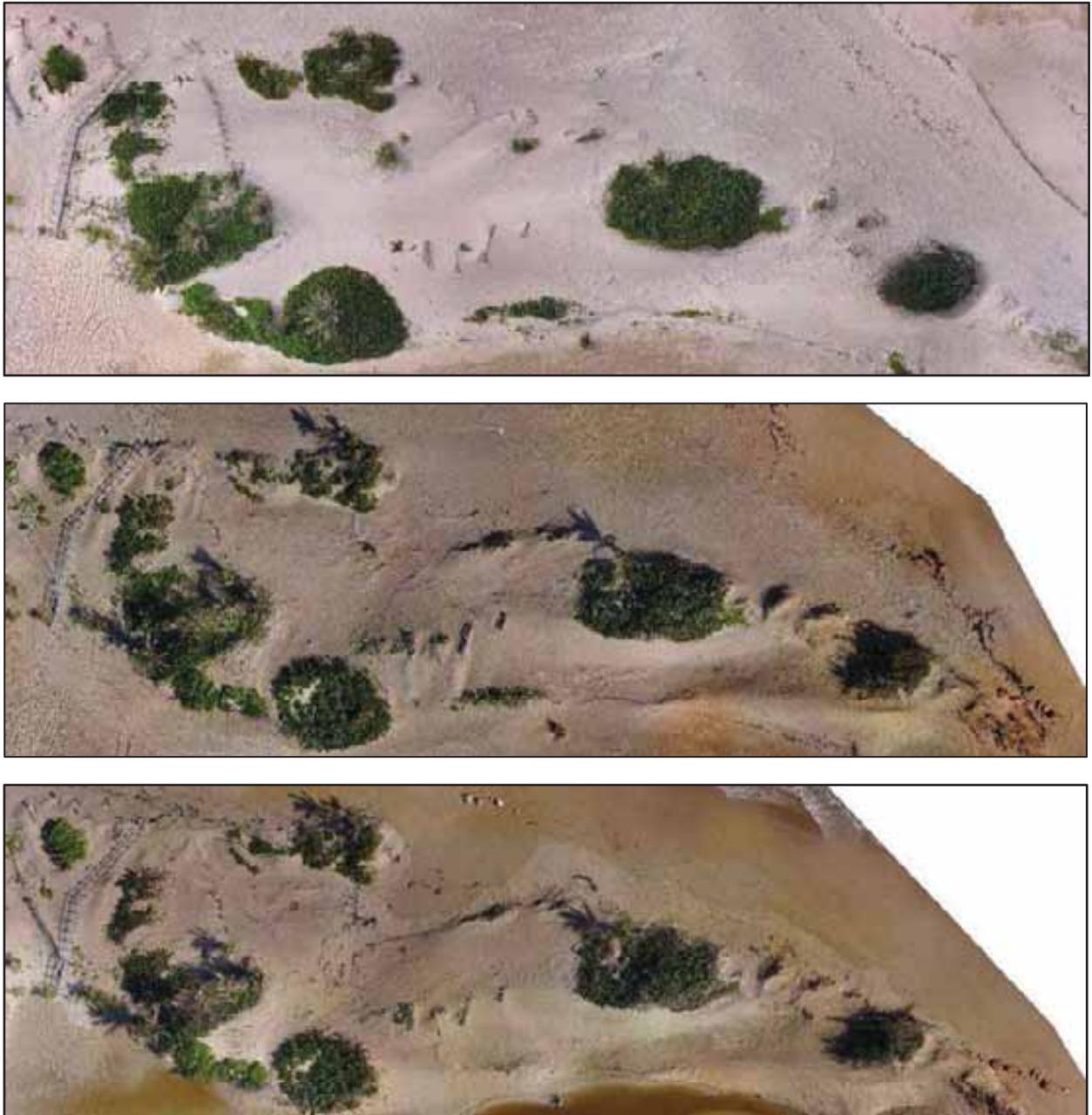


Figure 184. Vegetation cover was 22.7 % on Poza de Teodoro before hurricane María (May 22, 2018) (top), 19.6 % after hurricane María and before the northeasterly swell (January 16, 2018) (middle) and 17.8 % after the northeasterly swell (March 7, 2018) (bottom).

I. Volume measurements of selected areas of the dunes

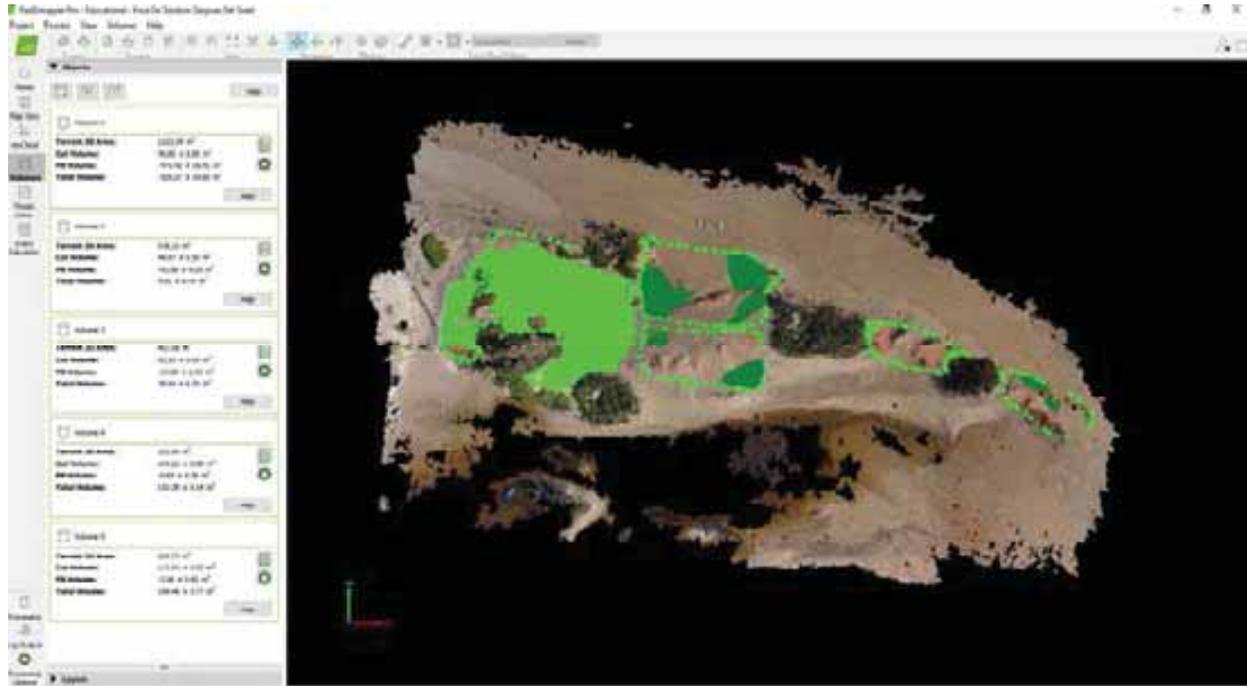


Figure 185. The first polygon (from left to right on the picture) has a 3D area of 1223.34 m² and a cut volume of 46.06 ± 2.65 m³, a fill volume of - 471.42 ± 16.41 m³ and a total volume of - 425.37 ± 19.05 m³. The second polygon (top second from left to right) has an area of 578.32 m² and a cut volume of 48.87 ± 5.50 m³, a fill volume of - 43.96 ± 4.29 m³ and a total volume of 4.91 ± 9.79 m³. The third polygon (bottom second from left to right) has an area 401.68 m² and a cut volume of 93.29 ± 5.00 m³, a fill volume of - 14.69 ± 1.73 m³ and a total volume of 78.60 ± 6.73 m³. The fourth polygon (from left to right) has an area of 202.0 m² and a cut volume of 133.23 ± 2.88 m³, a fill volume of - 0.93 ± 0.26 m³ and a total volume of 132.29 ± 3.14 m³. The fifth polygon (from left to right) has an area of 265.73 m² and a cut volume of 112.55 ± 2.92 m³, a fill volume of - 3.06 ± 0.85 m³ and a total volume of 109.49 ± 3.77 m³. The volume of these five areas will be monitored in subsequent months.

J. Conservation threats

The main conservation threats on this area is foot and vehicular traffic on the primary dune. Even though the existing boardwalk has contributed to the redirection of some of the foot traffic people still walk over the dunes in the area. Also vehicular traffic is relatively heavy in the back-dune area and across the primary dune mainly to the east of the boardwalk.

K. Recommended ecological restoration courses of action (COA)

We propose the installation of wooden barriers on both ends of the existing boardwalk. This will direct foot traffic away from the dune. We also propose the installation of biomimicry matrices on the primary dune and the subsequent planting of dune vegetation to stabilize the accumulated sand.



Figure 186. Area to be ecologically restored at Poza de Teodoro in Barrio Bajuras, Isabela. Highlighted areas correspond to each technique that will be used in this area. **Yellow** represents the location of wooden boardwalks, platform and barriers, the **red dot** marks the location of an information sign, light green marks the location of planting of dune vegetation, tan represents the area where biomimicry matrices will be installed to promote the accumulation of sand and areas shaded in light green represent locations for the planting of vegetation.

F. Pix 4D Quality Report

Quality Report Generated with Pix4Dmapper Pro version 4.1.25

Important: Click on the different icons for:

- Help to analyze the results in the Quality Report
- Additional information about the sections

[Click here](#) for additional tips to analyze the Quality Report

Summary ●

Project	Poza De Teodoro Despues Del Swell
Processed	2018-03-07 17:27:50
Camera Model Name(s)	FC330_3,6_4000x6000 (RGB)
Average Ground Sampling Distance (GSD)	1.16 cm / 0.45 in
Area Covered	0.016 km ² / 1.5837 ha / 0.01 sq. mi. / 3.9154 acres
Time for Initial Processing (without report)	11m:17s

Quality Check ●

● Images	median of 22288 keypoints per image	●
● Dataset	139 out of 146 images calibrated (95%), all images enabled	●
● Camera Optimization	5.02% relative difference between initial and optimized internal camera parameters	▲
● Matching	median of 6543.08 matches per calibrated image	●
● Georeferencing	yes, no 3D GCP	▲

Preview ●



Figure 1: Orthomosaic and the corresponding sparse Digital Surface Model (DSM) before densification.

Calibration Details ●

Number of Calibrated Images	139 out of 146
Number of Geolocated Images	146 out of 146

Initial Image Positions ●

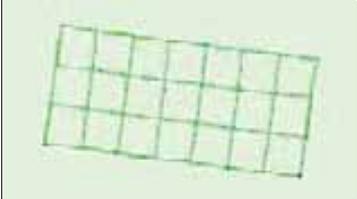


Figure 2: Top view of the initial image position. The green line follows the position of the images in time starting from the large blue dot.

Computed Image/GCPs/Manual Tie Points Positions ●

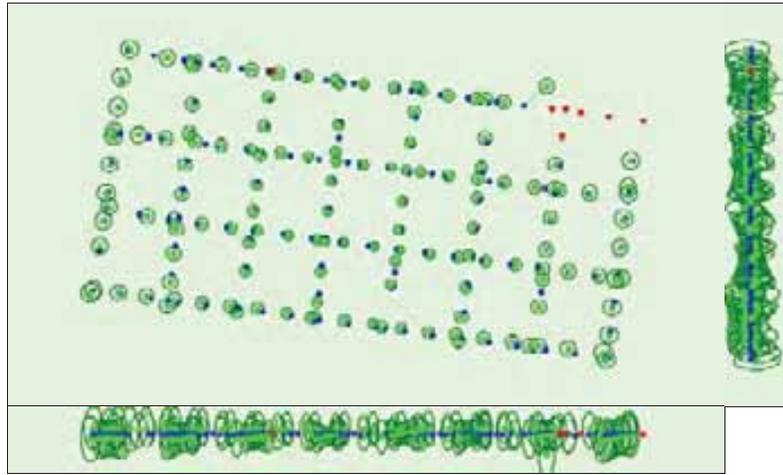


Figure 3: Offset between initial (blue dots) and computed (green dots) image positions as well as the offset between the GCPs initial positions (blue crosses) and their computed positions (green crosses) in the top-view (XY plane), front-view (XZ plane), and side-view (YZ plane). Red dots indicate disabled or uncalibrated images. Dark green ellipses indicate the absolute position uncertainty of the bundle block adjustment result.

Absolute camera position and orientation uncertainties

	X[m]	Y[m]	Z[m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.163	0.163	0.395	0.670	0.335	0.205
Sigma	0.030	0.030	0.084	0.003	0.011	0.014

Overlap

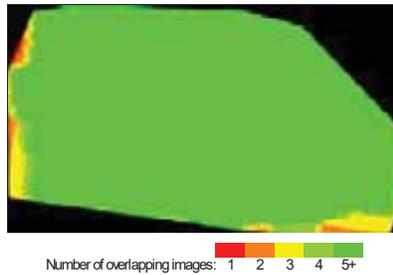


Figure 4: Number of overlapping images computed for each pixel of the orthomosaic. Red and yellow areas indicate low overlap for which poor results may be generated. Green areas indicate an overlap of over 5 images for every pixel. Good quality results will be generated as long as the number of keypoint matches is also sufficient for these areas (see Figure 5 for keypoint matches).

Bundle Block Adjustment Details

Number of 2D Keypoint Observations for Bundle Block Adjustment	931436
Number of 3D Points for Bundle Block Adjustment	330424
Mean Reprojection Error [pixels]	0.204

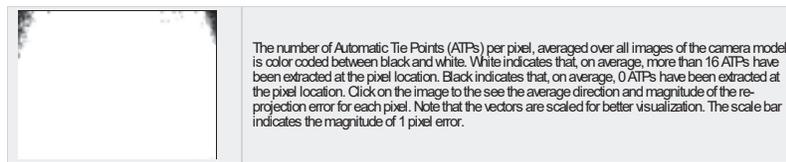
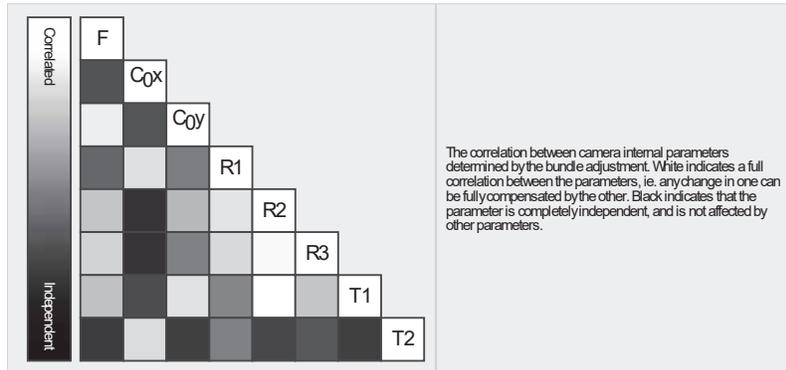
Internal Camera Parameters

FC330_3.6_4000x3000 (RGB). Sensor Dimensions: 6.317 [mm] x 4.738 [mm]

EXIF ID: FC330_3.6_4000x3000

	Focal Length	Principal Point x	Principal Point y	R1	R2	R3	T1	T2
Initial Values	2285.722 [pixel] 3.610 [mm]	2000.006 [pixel] 3.159 [mm]	1500.003 [pixel] 2.369 [mm]	-0.001	-0.002	0.000	-0.001	-0.001
Optimized Values	2400.539 [pixel] 3.791 [mm]	1965.048 [pixel] 3.104 [mm]	1456.922 [pixel] 2.301 [mm]	0.002	-0.008	0.005	0.000	0.000

Uncertainties (Sigma)	0.315 [pixel] 0.000 [mm]	0.064 [pixel] 0.000 [mm]	0.208 [pixel] 0.000 [mm]	0.000	0.000	0.000	0.000	0.000
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2D Keypoints Table

	Number of 2D Keypoints per Image	Number of Matched 2D Keypoints per Image
Median	22288	6543
Mn	16979	87
Max	42190	17190
Mean	24034	6701

3D Points from 2D Keypoint Matches

	Number of 3D Points Observed
In 2 Images	213609
In 3 Images	57550
In 4 Images	24880
In 5 Images	13172
In 6 Images	7478
In 7 Images	4861
In 8 Images	3110
In 9 Images	1998
In 10 Images	1251
In 11 Images	863
In 12 Images	576
In 13 Images	435
In 14 Images	249
In 15 Images	170
In 16 Images	107
In 17 Images	41
In 18 Images	32
In 19 Images	21
In 20 Images	12
In 21 Images	3
In 22 Images	3
In 23 Images	1
In 24 Images	1
In 25 Images	1

2D Keypoint Matches

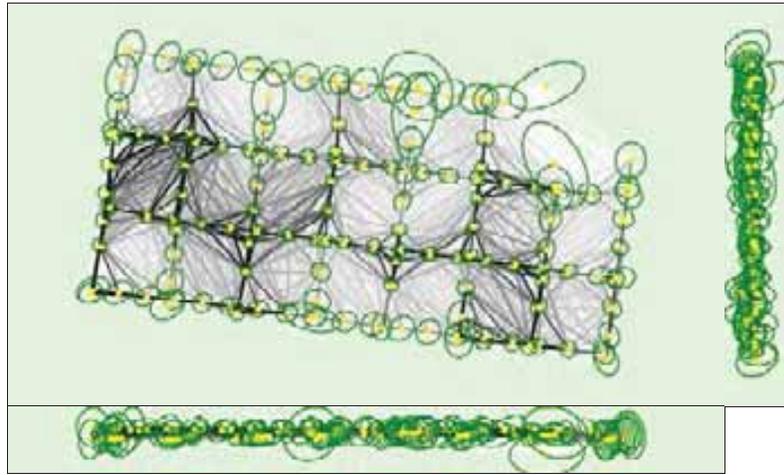


Figure 5: Computed image positions with links between matched images. The darkness of the links indicates the number of matched 2D keypoints between the images. Bright links indicate weak links and require manual tie points or more images. Dark green ellipses indicate the relative camera position uncertainty of the bundle block adjustment result.

Relative camera position and orientation uncertainties

	X[m]	Y[m]	Z[m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.003	0.003	0.003	0.007	0.008	0.004
Sigma	0.001	0.001	0.001	0.003	0.003	0.002

Geolocation Details

Absolute Geolocation Variance

Min Error [m]	MaxError [m]	Geolocation Error X[%]	Geolocation Error Y[%]	Geolocation Error Z[%]
-	-15.00	0.00	0.00	0.00
-15.00	-12.00	0.00	0.00	0.00
-12.00	-9.00	0.00	0.00	0.00
-9.00	-6.00	0.00	0.00	0.00
-6.00	-3.00	1.44	1.44	0.00
-3.00	0.00	31.65	46.76	51.08
0.00	3.00	66.91	51.08	48.20
3.00	6.00	0.00	0.72	0.72
6.00	9.00	0.00	0.00	0.00
9.00	12.00	0.00	0.00	0.00
12.00	15.00	0.00	0.00	0.00
15.00	-	0.00	0.00	0.00
Mean [m]		-0.000248	-0.000211	0.000216
Sigma [m]		1.220711	0.902974	1.017798
RMS Error [m]		1.220711	0.902974	1.017798

Min Error and Max Error represent geolocation error intervals between -1.5 and 1.5 times the maximum accuracy of all the images. Columns X, Y, Z show the percentage of images with geolocation errors within the predefined error intervals. The geolocation error is the difference between the initial and computed image positions. Note that the image geolocation errors do not correspond to the accuracy of the observed 3D points.

Relative Geolocation Variance

Relative Geolocation Error	Images X[%]	Images Y[%]	Images Z[%]
[-1.00, 1.00]	99.28	100.00	100.00
[-2.00, 2.00]	100.00	100.00	100.00
[-3.00, 3.00]	100.00	100.00	100.00
Mean of Geolocation Accuracy [m]	5.000000	5.000000	10.000000
Sigma of Geolocation Accuracy [m]	0.000000	0.000000	0.000000

Images X, Y, Z represent the percentage of images with a relative geolocation error in X, Y, Z

Geolocation Orientational Variance	RMS [degree]
Omega	1.849
Phi	1.905
Kappa	1.565

Geolocation RMS error of the orientation angles given by the difference between the initial and computed image orientation angles.

Initial Processing Details

System Information

Hardware	CPU: Intel(R) Core(TM) i5-3330S CPU @2.70GHz RAM 8GB GPU: Intel(R) HD Graphics (Driver: 10.18.10.3412), RDPDD Chained DD (Driver: unknown), RDP Encoder Mirror Driver (Driver: unknown), RDP Reflector Display Driver (Driver: unknown)
Operating System	Windows 7 Professional, 64-bit

Coordinate Systems

Image Coordinate System	WGS84 (egm96)
Output Coordinate System	WGS 84 / UTMzone 19N (egm96)

Processing Options

Detected Template	3D Maps
Keypoints Image Scale	Full, Image Scale: 1
Advanced: Matching Image Pairs	Aerial Grid or Corridor
Advanced: Matching Strategy	Use Geometrically Verified Matching: no
Advanced: Keypoint Extraction	Targeted Number of Keypoints: Automatic
Advanced: Calibration	Calibration Method: Standard Internal Parameters Optimization: All External Parameters Optimization: All Rematch: Auto, yes

Point Cloud Densification details

Processing Options

Image Scale	multiscale, 1/2 (Half image size, Default)
Point Density	Optimal
Minimum Number of Matches	3
3D Textured Mesh Generation	yes
3D Textured Mesh Settings:	Resolution: Medium Resolution (default) Color Balancing: no
LOD	Generated: no
Advanced: 3D Textured Mesh Settings	Sample Density Divider: 1
Advanced: Image Groups	group1
Advanced: Use Processing Area	yes
Advanced: Use Annotations	yes
Time for Point Cloud Densification	31m:04s
Time for Point Cloud Classification	NA
Time for 3D Textured Mesh Generation	06m:04s

Results

Number of Generated Tiles	1
Number of 3D Densified Points	7988476
Average Density (per m ³)	2122.8

DSM, Orthomosaic and Index Details

Processing Options

DSM and Orthomosaic Resolution	1 x GSD (1.16 [cm/pixel])
--------------------------------	---------------------------

DSMFilters	Noise Filtering: yes Surface Smoothing: yes, Type: Sharp
Raster DSM	Generated: yes Method: Inverse Distance Weighting Merge Tiles: yes
Orthomosaic	Generated: yes Merge Tiles: yes GeoTIFF Without Transparency: no Google Maps Tiles and KML: no
Time for DSM Generation	11m:26s
Time for Orthomosaic Generation	24m:13s
Time for DTMGeneration	00s
Time for Contour Lines Generation	00s
Time for Reflectance Map Generation	00s
Time for IndexMap Generation	00s

Site name:

Shore Island beach, Isabela



A. Physical address:

Shore Island Beach, PR 466, Isabela, Puerto Rico, 00662

B. Date of capture of imagery:

March 19, 2018

C. Coordinates:

18.50903629 N - 67.028782 W

D. Description of site:

This site consists of a thin strip of primary dune adjacent to PR-466. It is a popular body boarding spot. Cars park on the side of the road. There is a narrow entrance to the beach and it is also adjacent to the recreational path that runs parallel to PR-466.

E. Distance from community:

This location is right on PR-466 and at an approximate distance of 100 meters from the Costa Dorada Beach Resort and 250 from cliff.

F. Aerial imagery

i. Contour map

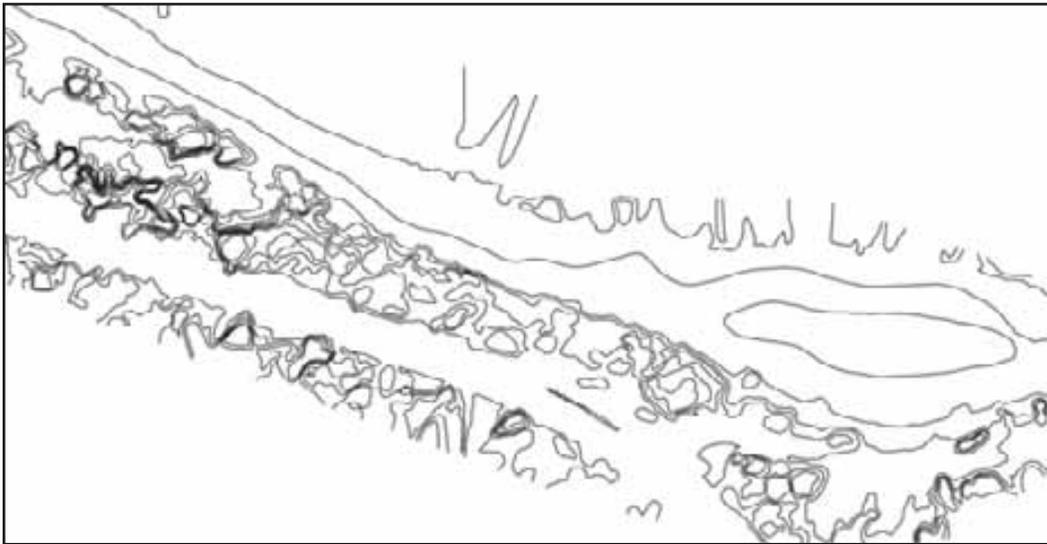


Figure 187. Contour map of Shore Island (after swell), Isabela, Puerto Rico with elevation intervals of 1 meter.

ii. 3D imagery



Figure 188. Aerial 3D image of Shore Island (after swell) Isabela

iii. Orthomosaic model



Figure 189. Orthomosaic image of East Middles (after swell) Isabela.

iv. Density Surface Models (DSM)

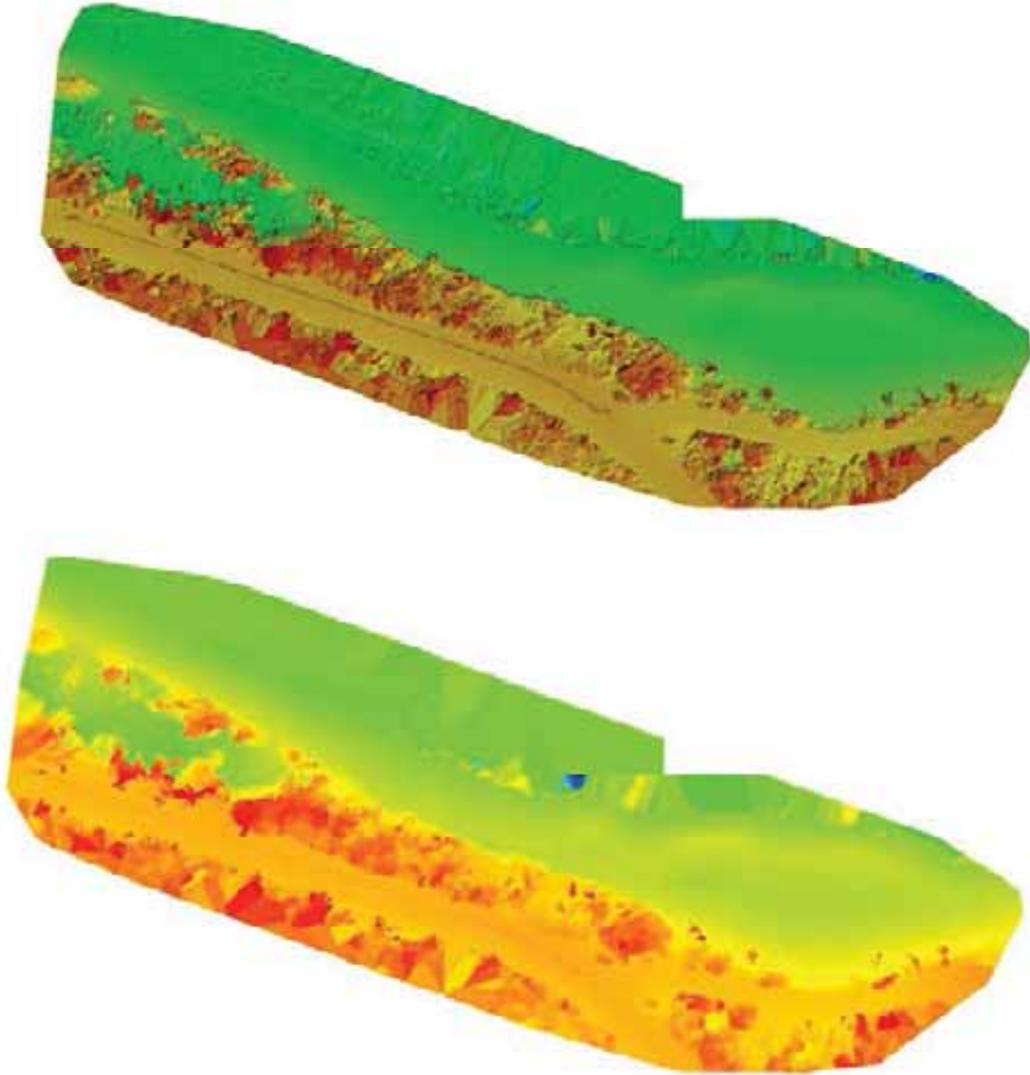


Figure 190. Density surface model (with shading top and without shading bottom) images of the dune located at the Shore Island (after swell), Isabela

v. Thermal images

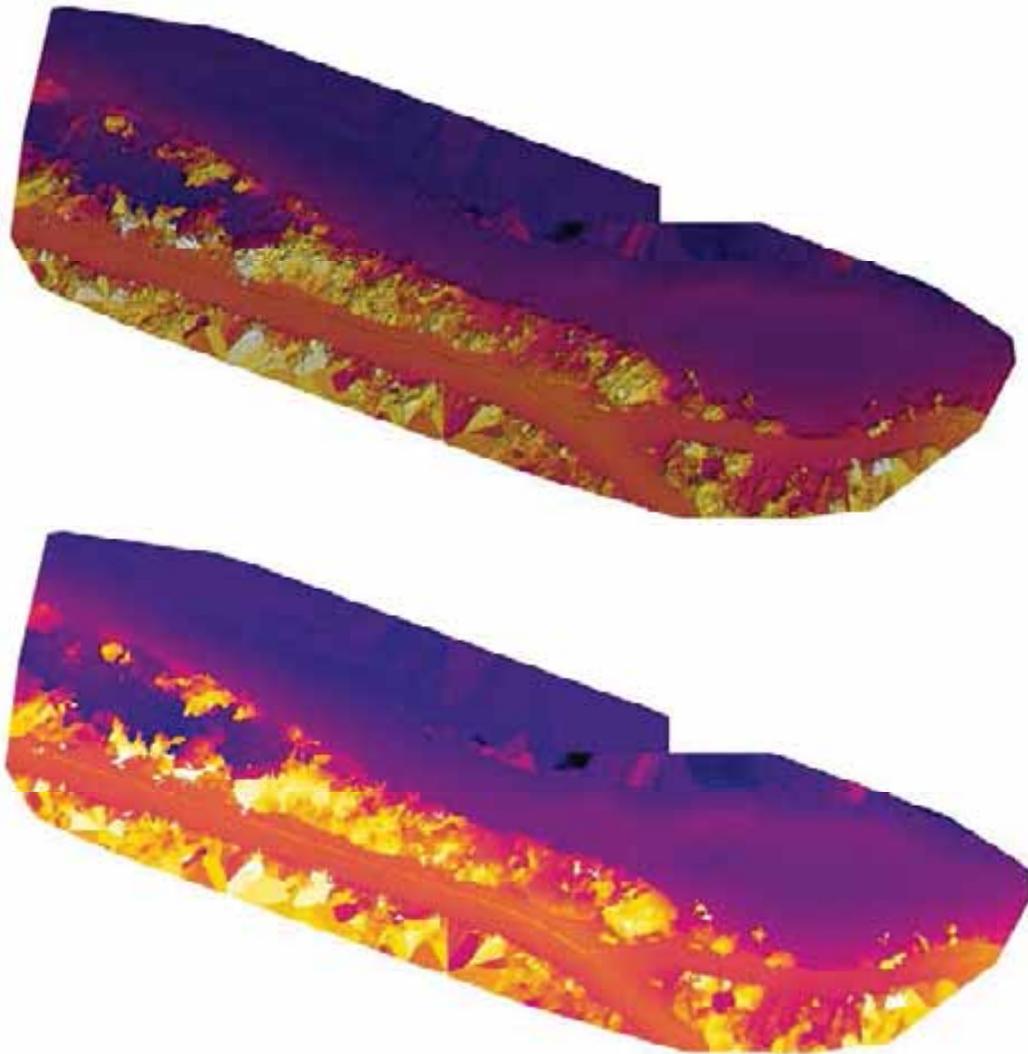


Figure 191. Thermal images (with shading top and without shading bottom) of the dune located at the Shore Island (after swell), Isabela

vi. 3D altitude RGB North

Eastern section - Shore Island

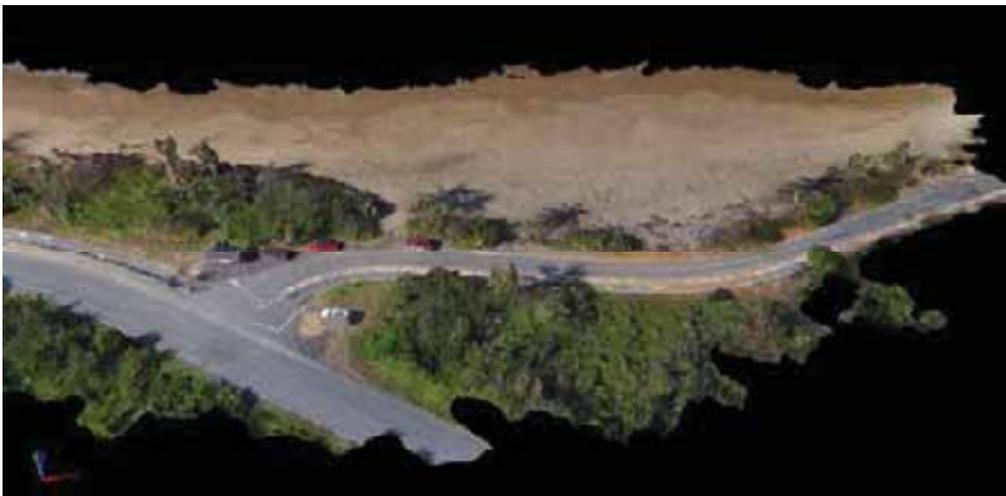
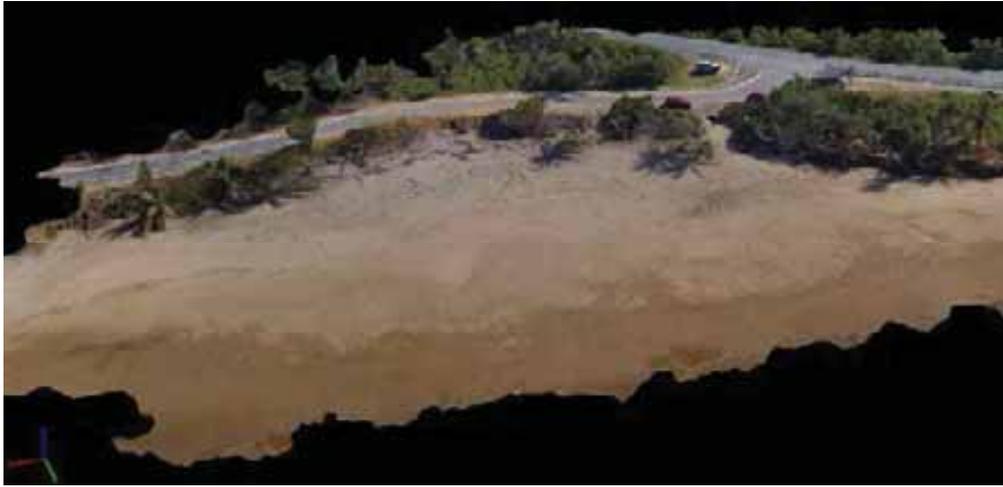


Figure 192. Three dimensional RGB images of the Shore Island (after swell), Isabela. View from the north (top) and from the south (bottom).

Western section - Shore Island

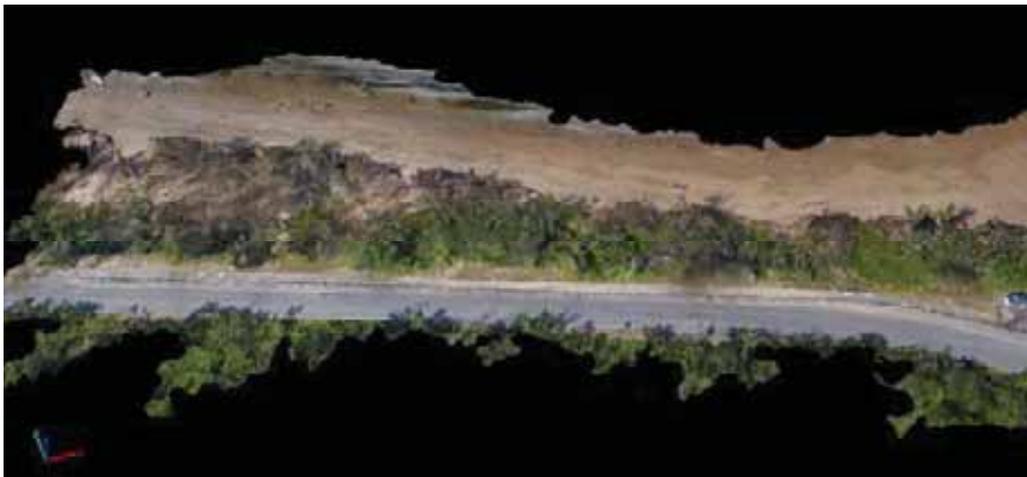


Figure 193. Three dimensional RGB images of the Shore Island (after swell), Isabela. View from the north (top) and from the south (bottom).

Eastern section - Shore Island



Figure 194. Three dimensional RGB images of the Shore Island (after swell), Isabela. View from the west (top) and from the east (bottom).

Western section - Shore Island



Figure 195. Three dimensional RGB images of the Shore Island (after swell), Isabela. View from the west (top) and from the east (bottom).

vii. DSM grayscale



Figure 196. Grayscale DSM images of the dune to the Shore Island (after swell), Isabela. The top image shows shades and the bottom is not shaded.

Site report

G. Vegetation cover



Figure 197. Vegetation covered 40.4% of the area on the western section of Shore Island (top) and 49.8 % on the eastern section of Shore Island in Isabela on March 19, 2018

H. Volume measurements of selected areas of the dunes

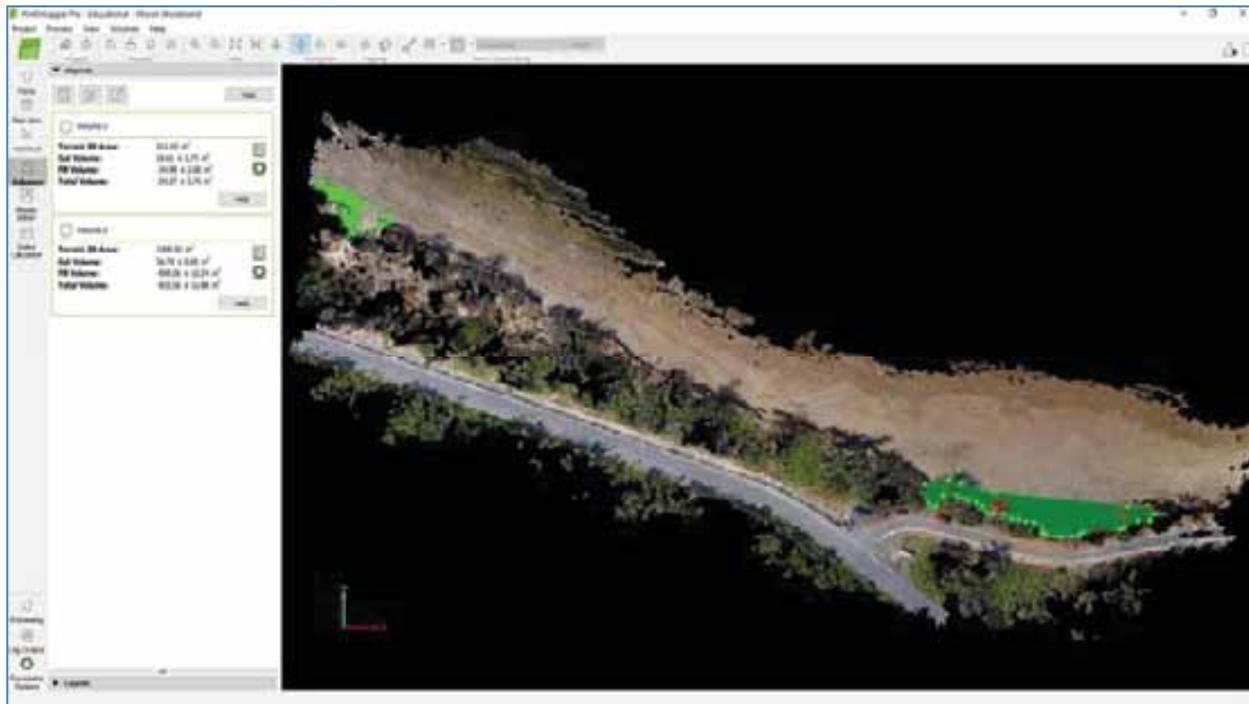


Figure 198. The first polygon (from left to right on the picture) has a 3D area of 211.43 m² and a cut volume of 10.61 ± 1.74 m³, a fill volume of - 34.98 ± 2.00 m³ and a total volume of 24.37 ± 3.74 m³. The second polygon (from left to right on the picture) has a 3D area of 1,305.92 m² and a cut volume of 56.70 ± 0.65 m³, a fill volume of - 890.26 ± 12.24 m³ and a total volume of - 833.56 ± 12.88 m³. The volume of these areas will be monitored in subsequent months to monitor the progress of the restoration process.

I. Conservation threats

The main conservation threat in this area is foot traffic especially on the beach entrance.

J. Recommended ecological restoration courses of action (COA)

We recommend the installation of a boardwalk on the beach entrance as well as the installation of biomimicry matrices and planting dune vegetation on that segment of primary dune.



Figure 199. Area to be ecologically restored in Shore Island Beach in Isabela, Puerto Rico. Highlighted areas correspond to each technique that will be used in this area. Yellow represents the location of a wooden boardwalk, the red dot marks the location of an information sign, light green marks the location of planting of dune vegetation, tan represents the area of the dune crest that where biomimicry matrices will be installed to promote the accumulation of sand. The areas shaded in light green represent locations for the planting of dune vegetation.

K. Pix 4D Quality Report

Quality Report Generated with Pix4Dmapper Pro version 4.2.25

Important: Click on the different icons for:

- Help to analyze the results in the Quality Report
- Additional information about the sections

● Click [here](#) for additional tips to analyze the Quality Report

Summary 1

Project	Mision ShoreIsland
Processed	2018-03-31 18:41:38
Camera Model Name(s)	FC330_3.6_4000x3000 (RGB)
Average Ground Sampling Distance (GSD)	1.40 cm / 0.55 in
Area Covered	0.030 km ² / 3.0454 ha / 0.01 sq. mi. / 7.5293 acres
Time for Initial Processing (without report)	01h:44m:25s

Quality Check 2

● Images	median of 36496 keypoints per image	✔
● Dataset	273 out of 310 images calibrated (88%), all images enabled	⚠
● Camera Optimization	3.97% relative difference between initial and optimized internal camera parameters	✔
● Matching	median of 5536.14 matches per calibrated image	✔
● Georeferencing	yes, no 3D GCP	⚠

Preview 3

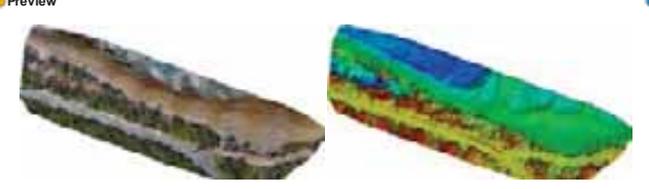


Figure 1: Orthomosaic and the corresponding sparse Digital Surface Model (DSM) before densification.

Calibration Details 4

Number of Calibrated Images	273 out of 310
Number of Geolocated Images	310 out of 310

Initial Image Positions 5

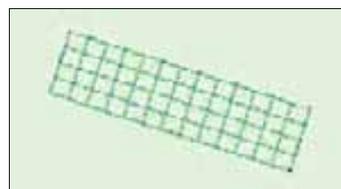
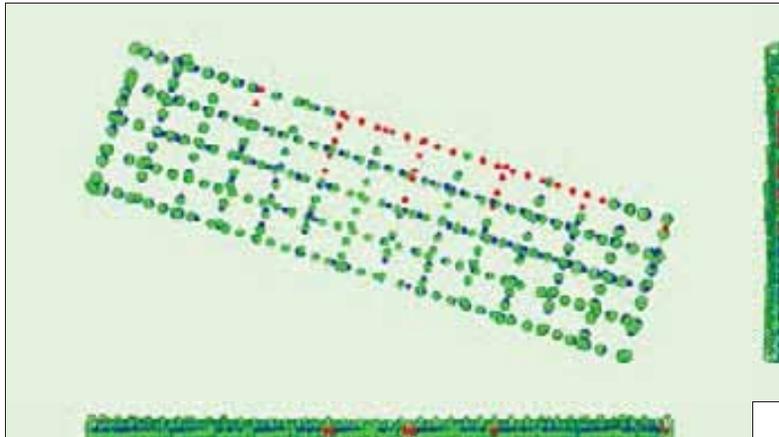


Figure 2: Top view of the initial image position. The green line follows the position of the images in time starting from the large blue dot.

Computed Image/GCPs/Manual Tie Points Positions 6



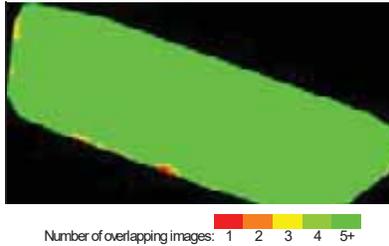
Uncertainty ellipses 10x magnified

Figure 3: Offset between initial (blue dots) and computed (green dots) image positions as well as the offset between the GCPs initial positions (blue crosses) and their computed positions (green crosses) in the top-view (XY plane), front-view (XZ plane), and side-view (YZ plane). Red dots indicate disabled or uncalibrated images. Dark green ellipses indicate the absolute position uncertainty of the bundle block adjustment result.

Absolute camera position and orientation uncertainties

	X[m]	Y[m]	Z[m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.197	0.197	0.479	0.747	0.282	0.156
Sigma	0.039	0.039	0.109	0.011	0.027	0.015

Overlap



Number of overlapping images: 1 2 3 4 5+

Figure 4: Number of overlapping images computed for each pixel of the orthomosaic. Red and yellow areas indicate low overlap for which poor results may be generated. Green areas indicate an overlap of over 5 images for every pixel. Good quality results will be generated as long as the number of keypoint matches is also sufficient for these areas (see Figure 5 for keypoint matches).

Bundle Block Adjustment Details

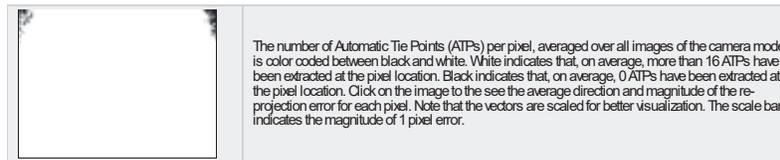
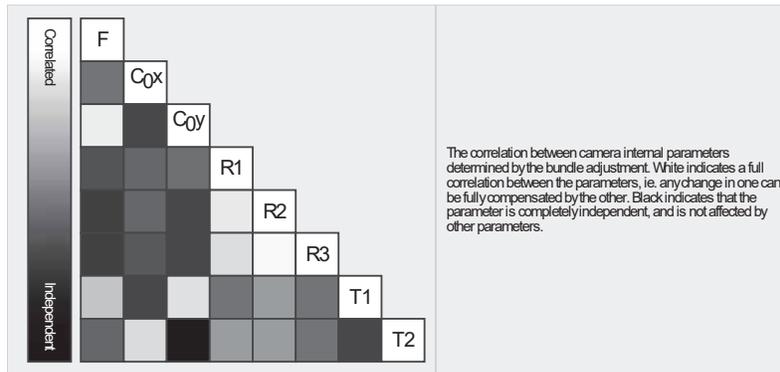
Number of 2D Keypoint Observations for Bundle Block Adjustment	1698675
Number of 3D Points for Bundle Block Adjustment	581191
Mean Reprojection Error [pixels]	0.196

Internal Camera Parameters

FC330_3.6_4000x3000 (RGB). Sensor Dimensions: 6.317 [mm] x 4.738 [mm]

EXIF ID: FC330_3.6_4000x3000

	Focal Length	Principal Point x	Principal Point y	R1	R2	R3	T1	T2
Initial Values	2285.722 [pixel] 3.610 [mm]	2000.006 [pixel] 3.159 [mm]	1500.003 [pixel] 2.369 [mm]	-0.001	-0.002	0.000	-0.001	-0.001
Optimized Values	2376.492 [pixel] 3.753 [mm]	1963.810 [pixel] 3.102 [mm]	1469.229 [pixel] 2.320 [mm]	0.001	-0.007	0.004	0.000	0.000
Uncertainties (Sigma)	0.283 [pixel] 0.000 [mm]	0.073 [pixel] 0.000 [mm]	0.207 [pixel] 0.000 [mm]	0.000	0.000	0.000	0.000	0.000



2D Keypoints Table

	Number of 2D Keypoints per Image	Number of Matched 2D Keypoints per Image
Median	36496	5536
Mn	18417	56
Max	62839	23679
Mean	37369	6222

3D Points from 2D Keypoint Matches

	Number of 3D Points Observed
In 2 Images	373668
In 3 Images	95917
In 4 Images	43518
In 5 Images	23465
In 6 Images	14471
In 7 Images	8918
In 8 Images	6153
In 9 Images	4289
In 10 Images	3074
In 11 Images	2215
In 12 Images	1549
In 13 Images	1141
In 14 Images	746
In 15 Images	592
In 16 Images	411
In 17 Images	317
In 18 Images	205
In 19 Images	146
In 20 Images	111
In 21 Images	84
In 22 Images	60
In 23 Images	47
In 24 Images	29
In 25 Images	22
In 26 Images	14
In 27 Images	10
In 28 Images	4
In 29 Images	4
In 30 Images	6
In 31 Images	2
In 32 Images	1
In 33 Images	1
In 35 Images	1

2D Keypoint Matches

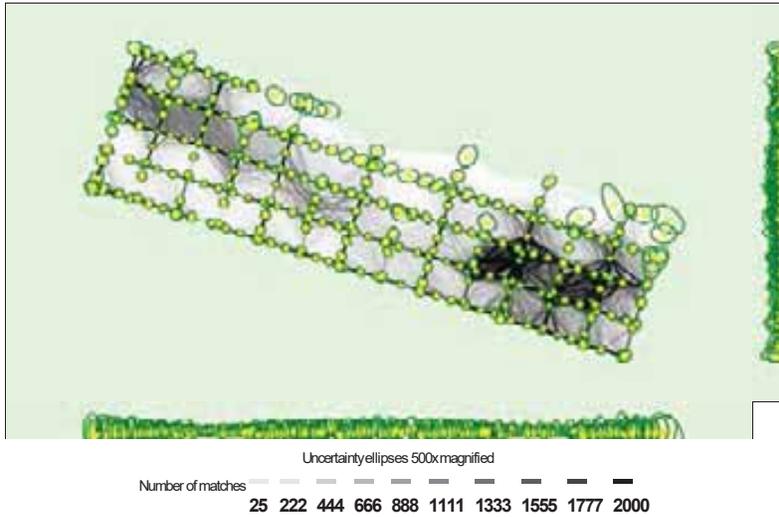


Figure 5: Computed image positions with links between matched images. The darkness of the links indicates the number of matched 2D keypoints between the images. Bright links indicate weak links and require manual tie points or more images. Dark green ellipses indicate the relative camera position uncertainty of the bundle block adjustment result.

Relative camera position and orientation uncertainties

	X[m]	Y[m]	Z[m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.005	0.005	0.007	0.009	0.013	0.007
Sigma	0.002	0.002	0.003	0.003	0.004	0.003

Geolocation Details

Absolute Geolocation Variance

Min Error [m]	Max Error [m]	Geolocation Error X[%]	Geolocation Error Y[%]	Geolocation Error Z[%]
-	-15.00	0.00	0.00	0.00
-15.00	-12.00	0.00	0.00	0.00
-12.00	-9.00	0.00	0.00	0.00
-9.00	-6.00	0.00	0.37	0.00
-6.00	-3.00	1.47	1.10	0.00
-3.00	0.00	54.21	47.62	54.21
0.00	3.00	40.66	50.92	45.79
3.00	6.00	3.66	0.00	0.00
6.00	9.00	0.00	0.00	0.00
9.00	12.00	0.00	0.00	0.00
12.00	15.00	0.00	0.00	0.00
15.00	-	0.00	0.00	0.00
Mean [m]		-0.004375	0.015035	-0.003773
Sigma [m]		1.374903	1.108837	0.939148
RMS Error [m]		1.374910	1.108939	0.939156

Min Error and Max Error represent geolocation error intervals between -1.5 and 1.5 times the maximum accuracy of all the images. Columns X, Y, Z show the percentage of images with geolocation errors within the predefined error intervals. The geolocation error is the difference between the initial and computed image positions. Note that the image geolocation errors do not correspond to the accuracy of the observed 3D points.

Relative Geolocation Variance

Relative Geolocation Error	Images X[%]	Images Y[%]	Images Z[%]
[-1.00, 1.00]	100.00	99.63	100.00
[-2.00, 2.00]	100.00	100.00	100.00
[-3.00, 3.00]	100.00	100.00	100.00
Mean of Geolocation Accuracy [m]	5.000000	5.000000	10.000000
Sigma of Geolocation Accuracy [m]	0.000000	0.000000	0.000000

Images X, Y, Z represent the percentage of images with a relative geolocation error in X, Y, Z.

Geolocation Orientational Variance	RMS [degree]
Omega	1.715
Phi	2.139
Kappa	1.522

Geolocation RMS error of the orientation angles given by the difference between the initial and computed image orientation angles.

Initial Processing Details

System Information

Hardware	CPU: Intel(R) Core(TM) i5-3330S CPU @2.70GHz RAM: 8GB GPU: Intel(R) HD Graphics (Driver: 10.18.10.3412), RDPDD Chained DD (Driver: unknown), RDP Encoder Mirror Driver (Driver: unknown), RDP Reflector Display Driver (Driver: unknown)
Operating System	Windows 7 Professional, 64-bit

Coordinate Systems

Image Coordinate System	WGS84 (egm96)
Output Coordinate System	WGS84 / UTMzone 19N (egm96)

Processing Options

Detected Template	3D Maps
Keypoints Image Scale	Full, Image Scale: 1
Advanced: Matching Image Pairs	Aerial Grid or Corridor
Advanced: Matching Strategy	Use Geometrically Verified Matching: no
Advanced: Keypoint Extraction	Targeted Number of Keypoints: Automatic
Advanced: Calibration	Calibration Method: Standard Internal Parameters Optimization: All External Parameters Optimization: All Rematch: Auto, yes

Point Cloud Densification details

Processing Options

Image Scale	multiscale, 1/2 (Half image size, Default)
Point Density	Optimal
Minimum Number of Matches	3
3D Textured Mesh Generation	yes
3D Textured Mesh Settings:	Resolution: Medium Resolution (default) Color Balancing: no
LOD	Generated: no
Advanced: 3D Textured Mesh Settings	Sample Density Divider: 1
Advanced: Image Groups	group1
Advanced: Use Processing Area	yes
Advanced: Use Annotations	yes
Time for Point Cloud Densification	01h:39m:10s
Time for Point Cloud Classification	NA
Time for 3D Textured Mesh Generation	11m:17s

Results

Number of Processed Clusters	2
Number of Generated Tiles	1
Number of 3D Densified Points	14477698
Average Density (per m ²)	1432.37

DSM, Orthomosaic and Index Details

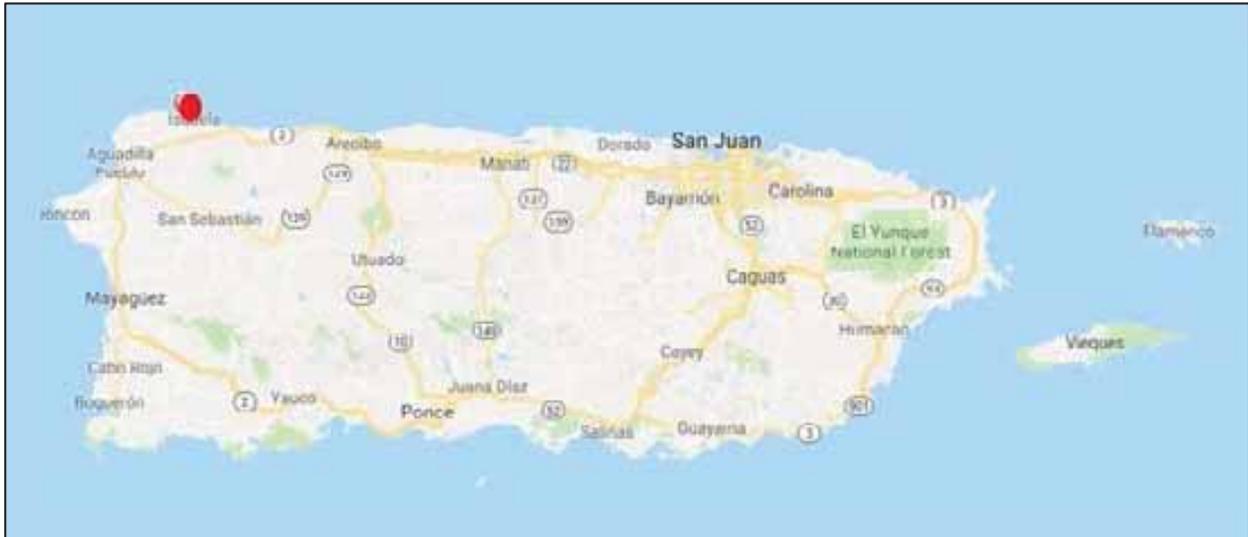
Processing Options

DSM and Orthomosaic Resolution	1 x GSD (1.4 [cm/pixel])
DSM Filters	Noise Filtering: yes Surface Smoothing: yes, Type: Sharp

Raster DSM	Generated: yes Method: Inverse Distance Weighting Merge Tiles: yes
Orthomosaic	Generated: yes Merge Tiles: yes GeoTIFF Without Transparency: no Google Maps Tiles and KML: no
Time for DSM Generation	21m:32s
Time for Orthomosaic Generation	54m:07s
Time for DTM Generation	00s
Time for Contour Lines Generation	00s
Time for Reflectance Map Generation	00s
Time for Index Map Generation	00s

Site name:

Pozo Brujo, Isabela



A. Physical address:

Pozo Brujo, Isabela, Puerto Rico, 00662

B. Date of capture of imagery:

February 28, 2018

C. Coordinates:

18.50775070 N - 67.01181807 W

D. Description of site:

This is a remote location of primary dune to the east of Villa Pesquera in Isabela.

E. Distance from community:

This site is part of the primary dune at approximately 500 m to the east of Villa Pesquera, 252 m from the cliff (to the south of the site) and from the nearest house which is located at approximately 55 m above sea level.

F. Aerial imagery

i. Contour map



Figure 200. Contour map of Pozo Brujo (after Maria), Isabela Puerto Rico with elevation intervals of 1 meter.

ii. 3D imagery



Figure 201. Aerial 3D image of Pozo Brujo (after María),

iii. Orthomosaic model



Figure 202. Orthomosaic image of Pozo Brujo (after María), Isabela

iv. Density Surface Models (DSM)

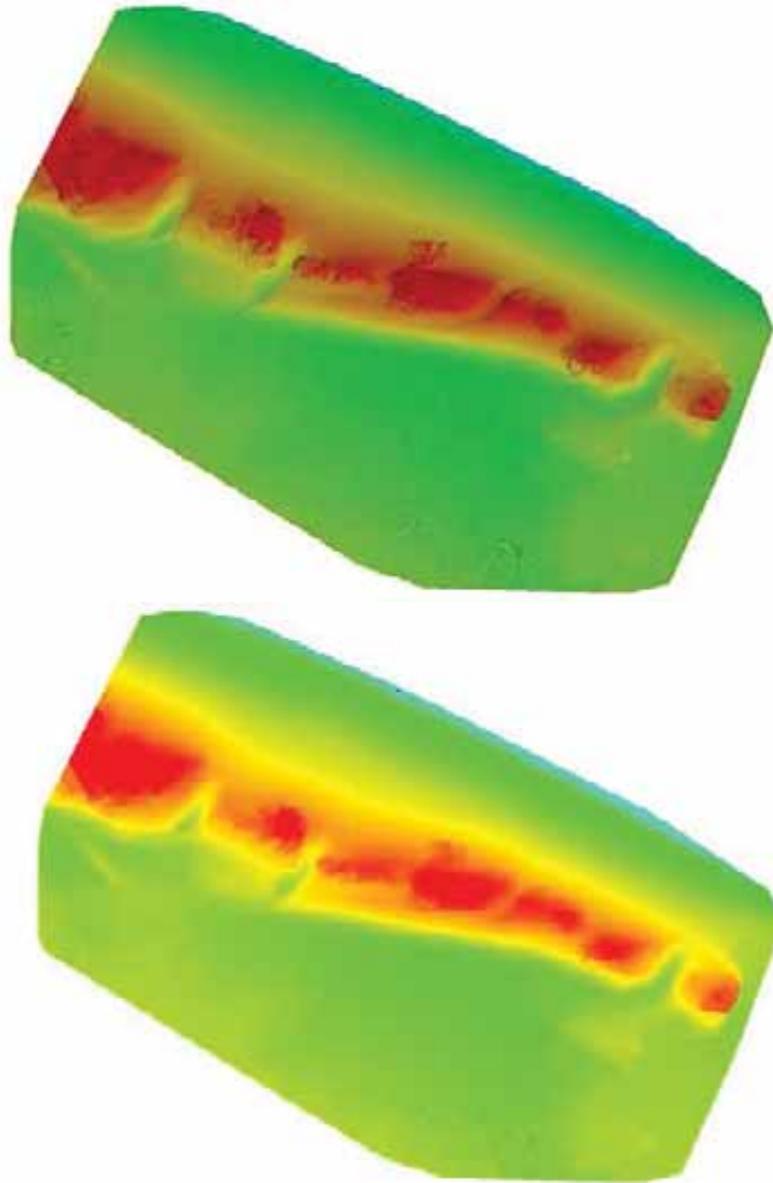


Figure 203. Density surface model (with shading top and without shading bottom) images of the dune located at the Pozo Brujo (after María), Isabela.

v. Thermal images

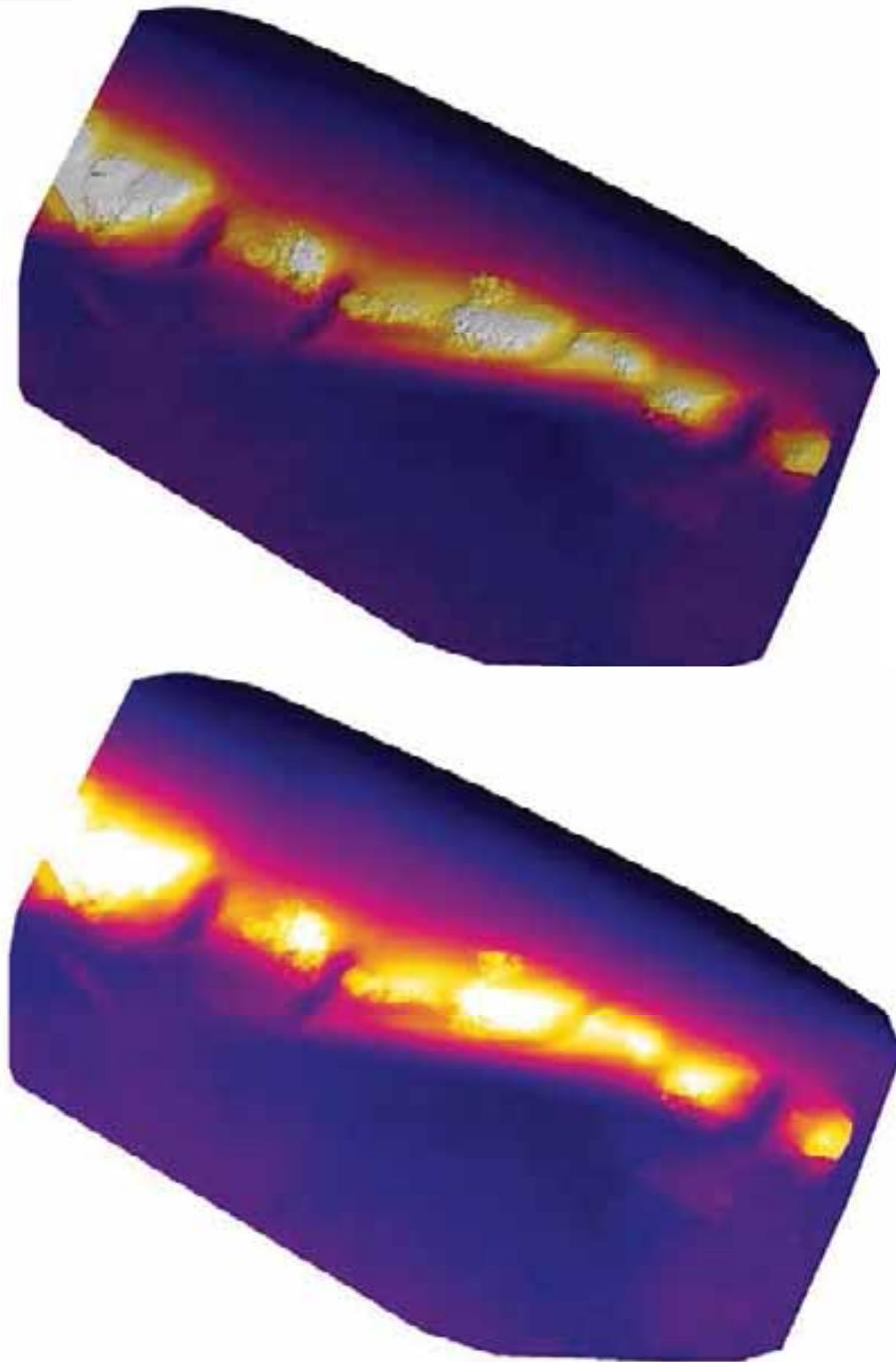


Figure 204. Thermal images (with shading top and without shading bottom) of the dune located at the Pozo Brujo (after María), Isabela

vi. 3D altitude RGB North

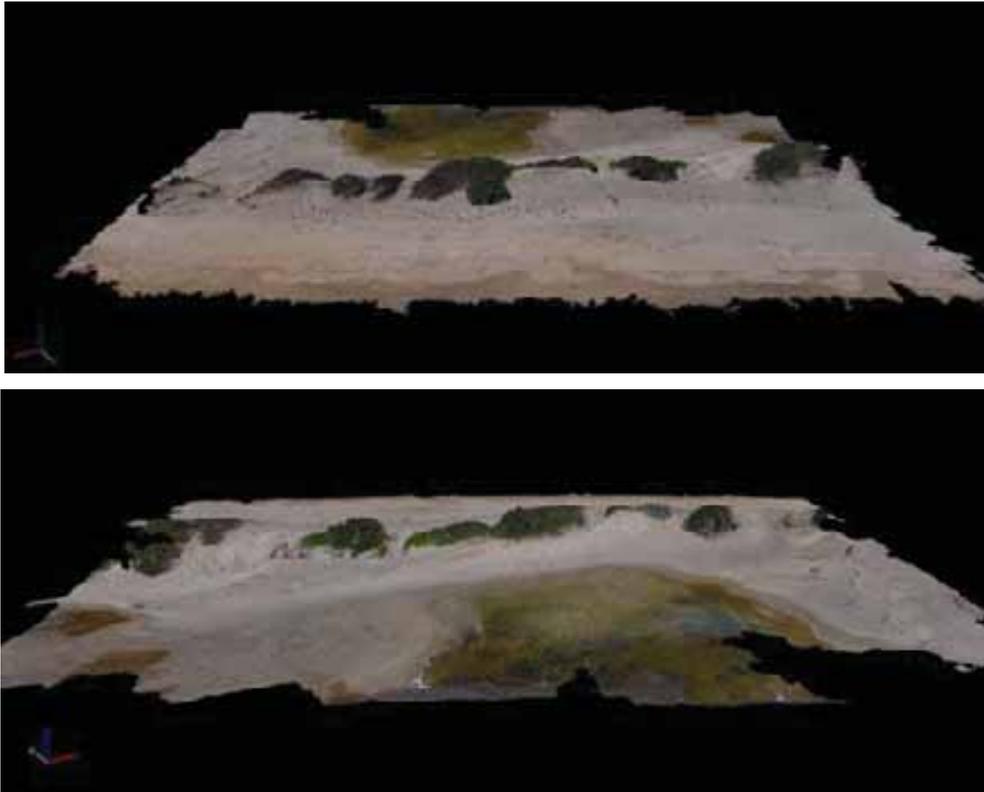


Figure 205. Three dimensional RGB images of the Pozo Brujo (after María), Isabela. View from the north (top) and from the south (bottom).

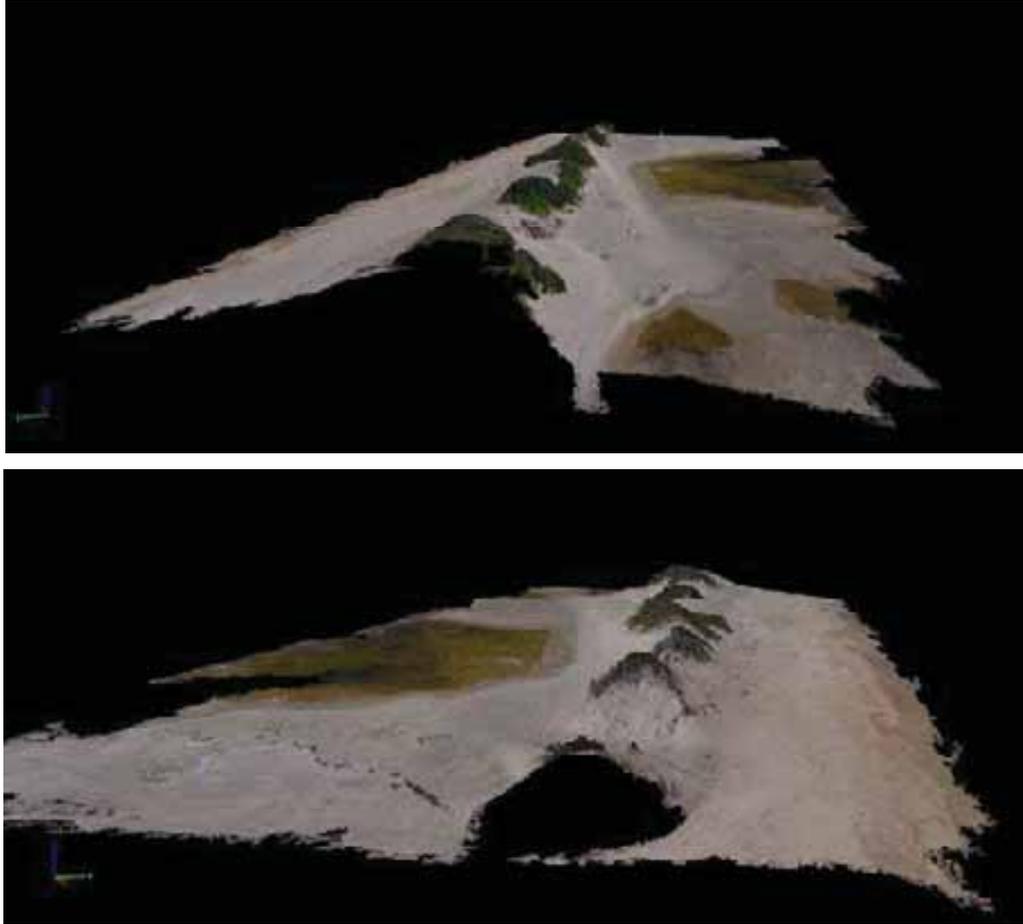


Figure 206. Three dimensional RGB images of the Pozo Brujo (after María), Isabela. View from the west (top) and from the east (bottom).

vii. DSM grayscale



Figure 207. Grayscale DSM images of the dune to the Pozo Brujo (after María), Isabela. The top image shows shades and the bottom is not shaded.

Site report

G. Vegetation cover



Figure 208. Vegetation covered 18.7 % of the area at Pozo Brujo (after María), Isabela on February 28, 2018.

I. Volume measurements of selected areas of the dunes

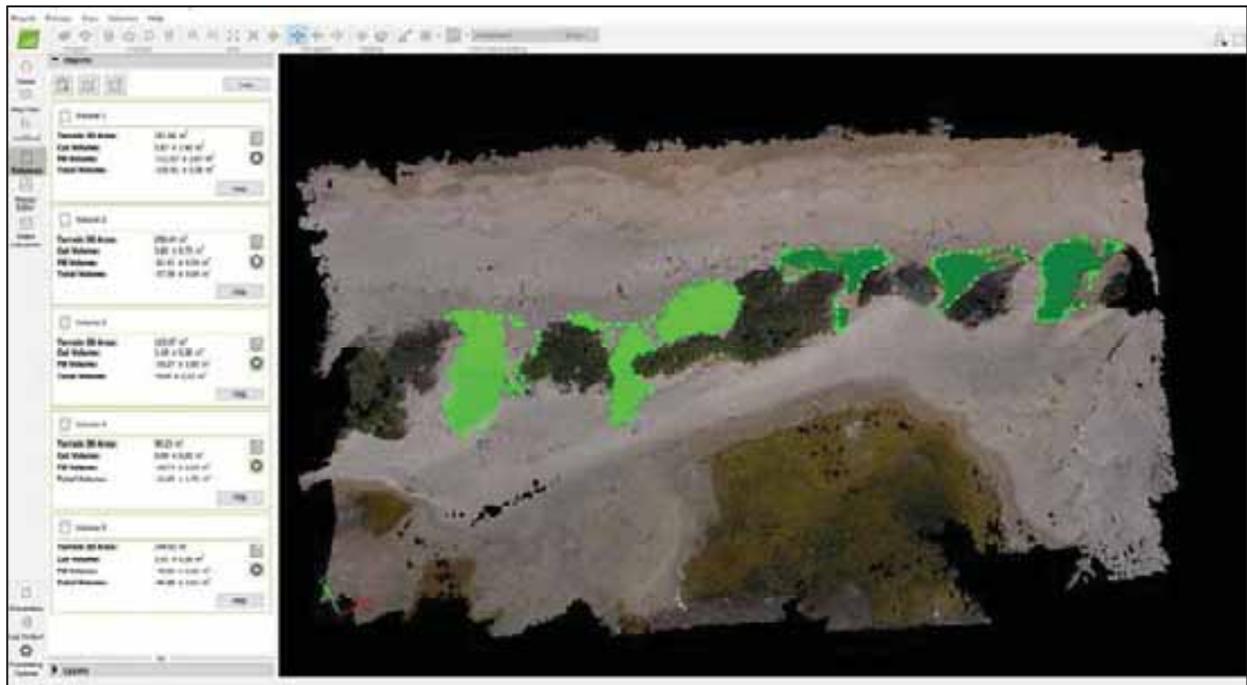


Figure 209. Three dimensional aerial picture of the Pozo Brujo dune in Isabela with five areas marked by polygons for which three dimensional area, cut volume, fill volume and total volume were calculated using the Pix4D software. Refer to image above for the data. The order of the data is from left to right on the image.

J. Conservation threats

The main conservation threats in this remote area are heavy traffic of illegal all terrain vehicles and illegal sand extraction. The remoteness of this area makes law enforcement difficult.

K. Recommended ecological restoration courses of action (COA)

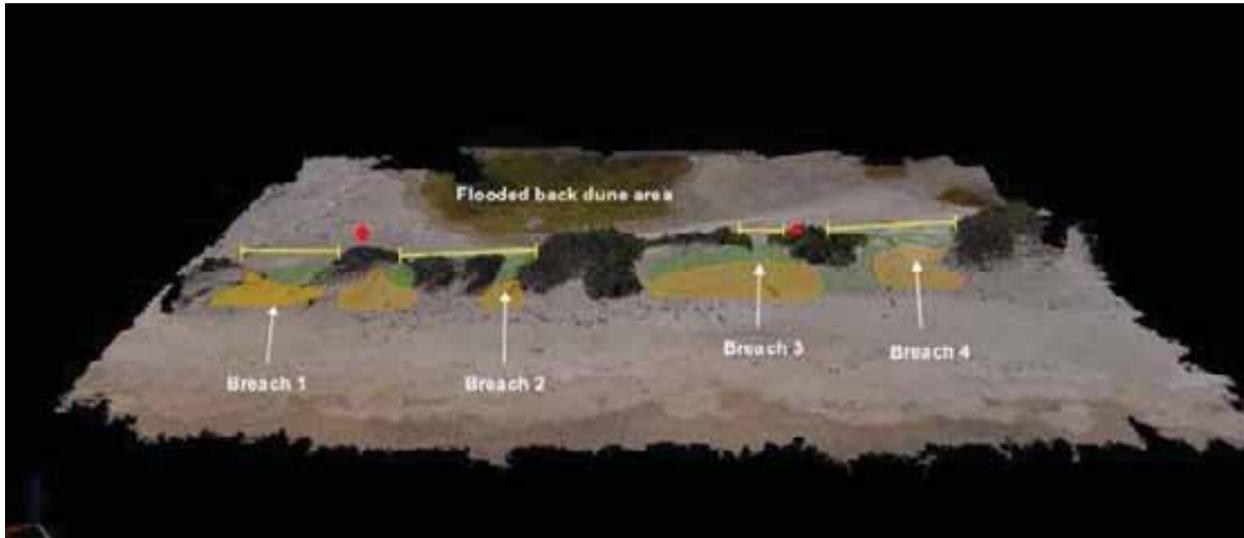


Figure 210. Area to be ecologically restored in Pozo Brujo Isabela, Puerto Rico. Highlighted areas correspond to each technique that will be used in this area. Yellow represents the location of a wooden boardwalk, light green marks the location of planting of dune vegetation, the red dot marks the location of an information sign, tan represents the area of the dune crest that where biomimicry matrices will be installed to promote the accumulation of sand. The areas shaded in light green represent locations for the planting of dune vegetation.

L. Pix 4D Quality Report

Quality Report



Generated with Pix4Dmapper Pro version 4.1.25

Important: Click on the different icons for:

- Help to analyze the results in the Quality Report
- Additional information about the sections

Click [here](#) for additional tips to analyze the Quality Report

Summary

Project	Misión Pozo Brujo 02
Processed	2018-03-01 16:37:29
Camera Model Name(s)	FC330_3.6_4000x3000 (RGB)
Average Ground Sampling Distance (GSD)	1.31 cm / 0.52 in
Area Covered	0.014 km ² / 1.3502 ha / 0.01 sq. mi. / 3.3382 acres
Time for Initial Processing (without report)	16m:02s

Quality Check

Images	median of 21044 keypoints per image	✓
Dataset	95 out of 95 images calibrated (100%), all images enabled	✓
Camera Optimization	3.29% relative difference between initial and optimized internal camera parameters	✓
Matching	median of 5598.92 matches per calibrated image	✓
Georeferencing	yes, no 3D GCP	⚠

Preview

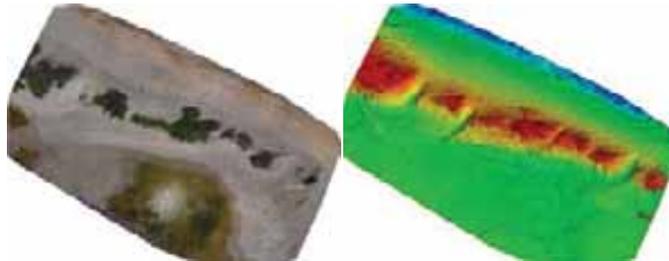


Figure 1: Orthomosaic and the corresponding sparse Digital Surface Model (DSM) before densification.

Calibration Details

Number of Calibrated Images	95 out of 95
Number of Geolocated Images	95 out of 95

Initial Image Positions

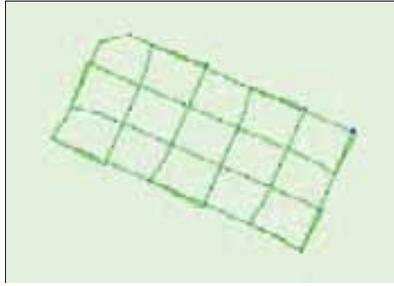
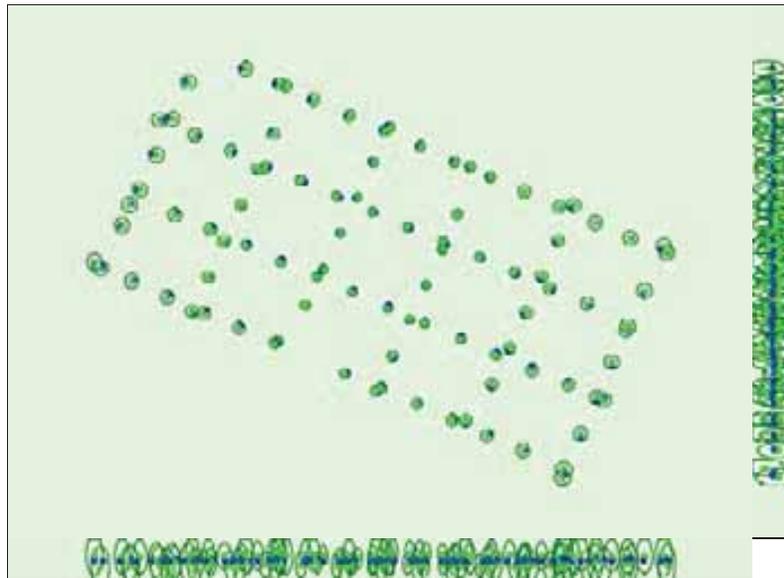


Figure 2: Top view of the initial image position. The green line follows the position of the images in time starting from the large blue dot.

Computed Image/GCPs/Manual Tie Points Positions



Uncertainty ellipses 10x magnified

Figure 3: Offset between initial (blue dots) and computed (green dots) image positions as well as the offset between the GCPs initial positions (blue crosses) and their computed positions (green crosses) in the top-view (XY plane), front-view (XZ plane), and side-view (YZ plane). Dark green ellipses indicate the absolute position uncertainty of the bundle block adjustment result.

Absolute camera position and orientation uncertainties

	X[m]	Y[m]	Z[m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.119	0.119	0.289	0.571	0.367	0.203
Sigma	0.021	0.021	0.061	0.013	0.017	0.012

Overlap

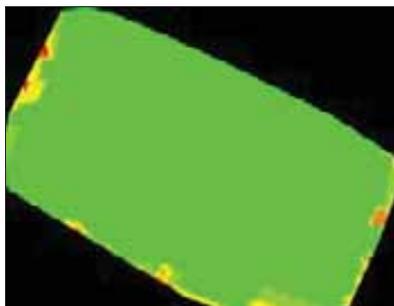




Figure 4: Number of overlapping images computed for each pixel of the orthomosaic. Red and yellow areas indicate low overlap for which poor results may be generated. Green areas indicate an overlap of over 5 images for every pixel. Good quality results will be generated as long as the number of keypoint matches is also sufficient for these areas (see Figure 5 for keypoint matches).

Bundle Block Adjustment Details

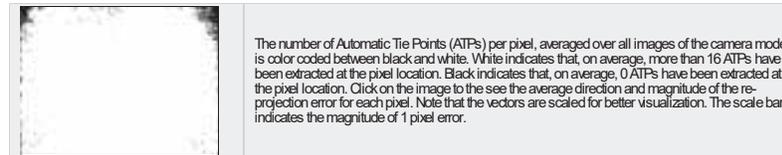
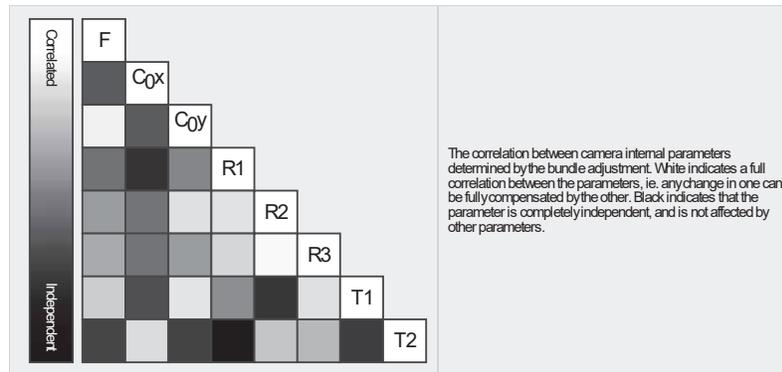
Number of 2D Keypoint Observations for Bundle Block Adjustment	553807
Number of 3D Points for Bundle Block Adjustment	199419
Mean Reprojection Error [pixels]	0.162

Internal Camera Parameters

FC330_3.6_4000x3000 (RGB). Sensor Dimensions: 6.317 [mm] x 4.738 [mm]

EXIF ID: FC330_3.6_4000x3000

	Focal Length	Principal Point x	Principal Point y	R1	R2	R3	T1	T2
Initial Values	2285.722 [pixel] 3.610 [mm]	2000.006 [pixel] 3.159 [mm]	1500.003 [pixel] 2.369 [mm]	-0.001	-0.002	0.000	-0.001	-0.001
Optimized Values	2360.970 [pixel] 3.729 [mm]	1961.363 [pixel] 3.098 [mm]	1492.892 [pixel] 2.358 [mm]	0.000	-0.006	0.004	-0.000	-0.000
Uncertainties (Sigma)	0.253 [pixel] 0.000 [mm]	0.052 [pixel] 0.000 [mm]	0.176 [pixel] 0.000 [mm]	0.000	0.000	0.000	0.000	0.000



2D Keypoints Table

	Number of 2D Keypoints per Image	Number of Matched 2D Keypoints per Image
Median	21044	5599
Mn	19042	1399
Max	38188	9530
Mean	23602	5830

3D Points from 2D Keypoint Matches

	Number of 3D Points Observed
In 2 Images	131918
In 3 Images	33619
In 4 Images	14479
In 5 Images	7811
In 6 Images	4228
In 7 Images	2508
In 8 Images	1576
In 9 Images	1031

In 10 Images	686
In 11 Images	459
In 12 Images	357
In 13 Images	226
In 14 Images	167
In 15 Images	124
In 16 Images	75
In 17 Images	52
In 18 Images	34
In 19 Images	22
In 20 Images	13
In 21 Images	7
In 22 Images	11
In 23 Images	4
In 24 Images	2

2D Keypoint Matches

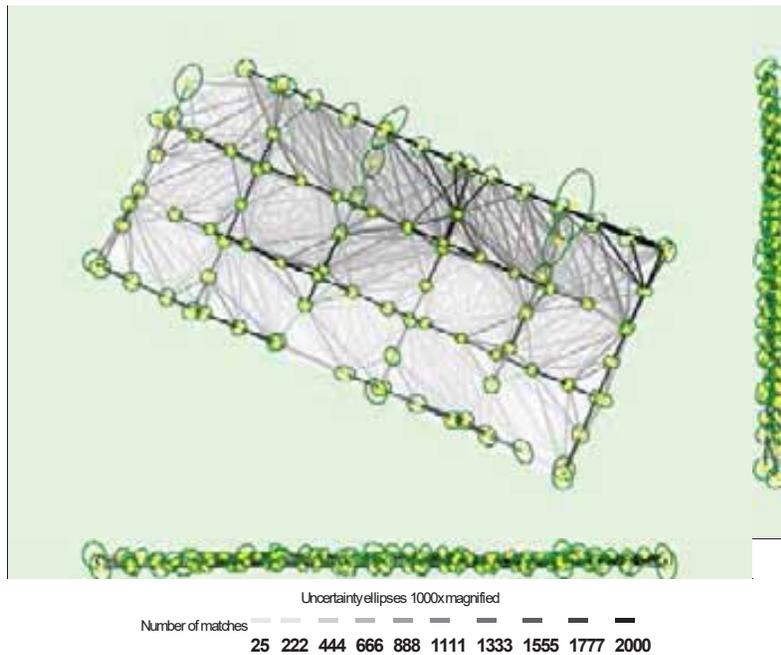


Figure 5: Computed image positions with links between matched images. The darkness of the links indicates the number of matched 2D keypoints between the images. Bright links indicate weak links and require manual tie points or more images. Dark green ellipses indicate the relative camera position uncertainty of the bundle block adjustment result.

Relative camera position and orientation uncertainties

	X[m]	Y[m]	Z[m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.002	0.002	0.001	0.004	0.005	0.002
Sigma	0.000	0.001	0.000	0.002	0.002	0.001

Geolocation Details

Absolute Geolocation Variance

Mn Error [m]	Max Error [m]	Geolocation Error X[%]	Geolocation Error Y[%]	Geolocation Error Z[%]
-	-15.00	0.00	0.00	0.00
-15.00	-12.00	0.00	0.00	0.00
-12.00	-9.00	0.00	0.00	0.00
-9.00	-6.00	0.00	0.00	0.00
-6.00	-3.00	0.00	0.00	0.00

-3.00	0.00	44.21	47.37	46.32
0.00	3.00	55.79	52.63	53.68
3.00	6.00	0.00	0.00	0.00
6.00	9.00	0.00	0.00	0.00
9.00	12.00	0.00	0.00	0.00
12.00	15.00	0.00	0.00	0.00
15.00	-	0.00	0.00	0.00
Mean [m]		-0.000000	0.000000	-0.000000
Sigma [m]		0.373992	0.321318	0.868684
RMS Error [m]		0.373992	0.321318	0.868684

Min Error and Max Error represent geolocation error intervals between -1.5 and 1.5 times the maximum accuracy of all the images. Columns X, Y, Z show the percentage of images with geolocation errors within the predefined error intervals. The geolocation error is the difference between the initial and computed image positions. Note that the image geolocation errors do not correspond to the accuracy of the observed 3D points.

Relative Geolocation Variance

Relative Geolocation Error	Images X[%]	Images Y[%]	Images Z[%]
[-1.00, 1.00]	100.00	100.00	100.00
[-2.00, 2.00]	100.00	100.00	100.00
[-3.00, 3.00]	100.00	100.00	100.00
Mean of Geolocation Accuracy [m]	5.000000	5.000000	10.000000
Sigma of Geolocation Accuracy [m]	0.000000	0.000000	0.000000

Images X, Y, Z represent the percentage of images with a relative geolocation error in X, Y, Z.

Geolocation Orientational Variance	RMS [degree]
Omega	2.121
Phi	1.233
Kappa	1.951

Geolocation RMS error of the orientation angles given by the difference between the initial and computed image orientation angles.

Initial Processing Details

System Information

Hardware	CPU: Intel(R) Core(TM) i5-3330S CPU @2.70GHz RAM 8GB GPU: Intel(R) HD Graphics (Driver: 10.18.10.3412), RDPDD Chained DD (Driver: unknown), RDP Encoder Mirror Driver (Driver: unknown), RDP Reflector Display Driver (Driver: unknown)
Operating System	Windows 7 Professional, 64-bit

Coordinate Systems

Image Coordinate System	WGS84 (egm96)
Output Coordinate System	WGS 84 / UTMzone 19N (egm96)

Processing Options

Detected Template	3D Maps
Keypoints Image Scale	Full, Image Scale: 1
Advanced: Matching Image Pairs	Aerial Grid or Corridor
Advanced: Matching Strategy	Use Geometrically Verified Matching: no
Advanced: Keypoint Extraction	Targeted Number of Keypoints: Automatic
Advanced: Calibration	Calibration Method: Standard Internal Parameters Optimization: All External Parameters Optimization: All Rematch: Auto, yes

Point Cloud Densification details

Processing Options

Image Scale	multiscale, 1/2 (Half image size, Default)
Point Density	Optimal
Minimum Number of Matches	3
3D Textured Mesh Generation	yes

3D Textured Mesh Settings:	Resolution: Medium Resolution (default) Color Balancing: no
LOD	Generated: no
Advanced: 3D Textured Mesh Settings	Sample Density Divider: 1
Advanced: Image Groups	group1
Advanced: Use Processing Area	yes
Advanced: Use Annotations	yes
Time for Point Cloud Densification	24m:12s
Time for Point Cloud Classification	NA
Time for 3D Textured Mesh Generation	05m:14s

Results

Number of Generated Tiles	1
Number of 3D Densified Points	6347960
Average Density (per m ³)	1526.26

DSM, Orthomosaic and Index Details

Processing Options

DSM and Orthomosaic Resolution	1 x GSD (1.31 [cm/pixel])
DSM Filters	Noise Filtering: yes Surface Smoothing: yes, Type: Sharp
Raster DSM	Generated: yes Method: Inverse Distance Weighting Merge Tiles: yes
Orthomosaic	Generated: yes Merge Tiles: yes GeoTIFF Without Transparency: no Google Maps Tiles and KML: no
Time for DSM Generation	07m:52s
Time for Orthomosaic Generation	17m:23s
Time for DTMGeneration	00s
Time for Contour Lines Generation	00s
Time for Reflectance Map Generation	00s
Time for Index Map Generation	00s

Site name:

Villa Pesquera, Camuy



A. Physical address:

Road PR-485, Camuy, Puerto Rico, 00627

B. Date of capture of imagery:

April 27, 2018

C. Coordinates:

18.490889 N - 66.864334 W

D. Description of site:

This is an area right on PR-485 east to the Villa Pesquera in Camuy. The area consists of a small line of dunes with several breaches that were formed during the northeasterly swell of March of 2018. The area is subject to heavy foot traffic of people crossing from the road to the beach.

E. Distance from community:

This site is at an approximate distance of 22 m from PR-485, 130 m from the nearest house which is located to the east of the site. There are houses at an approximate distance of 300 m to the south of the site. This is relatively unprotected and flat terrain.

F. Aerial imagery

i. Contour map



Figure 211. Contour map of Villa Pesquera, Camuy Puerto Rico with elevation intervals of 1 meter.

ii. 3D imagery

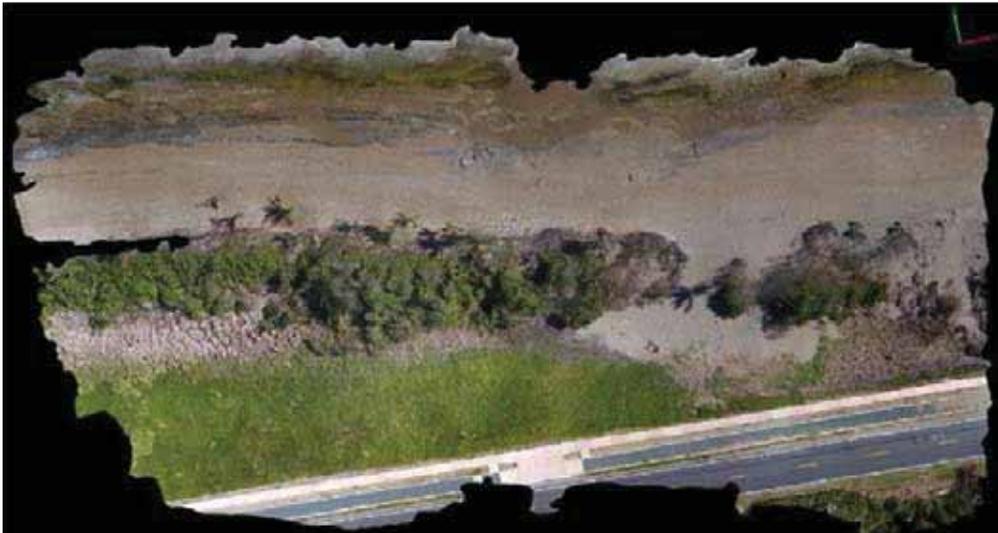


Figure 212. Aerial 3D image of the Villa Pesquera area, Camuy.

iii. Orthomosaic model



Figure 213. Orthomosaic image of the Villa Pesquera area, Camuy.

iii. Density Surface Models (DSM)

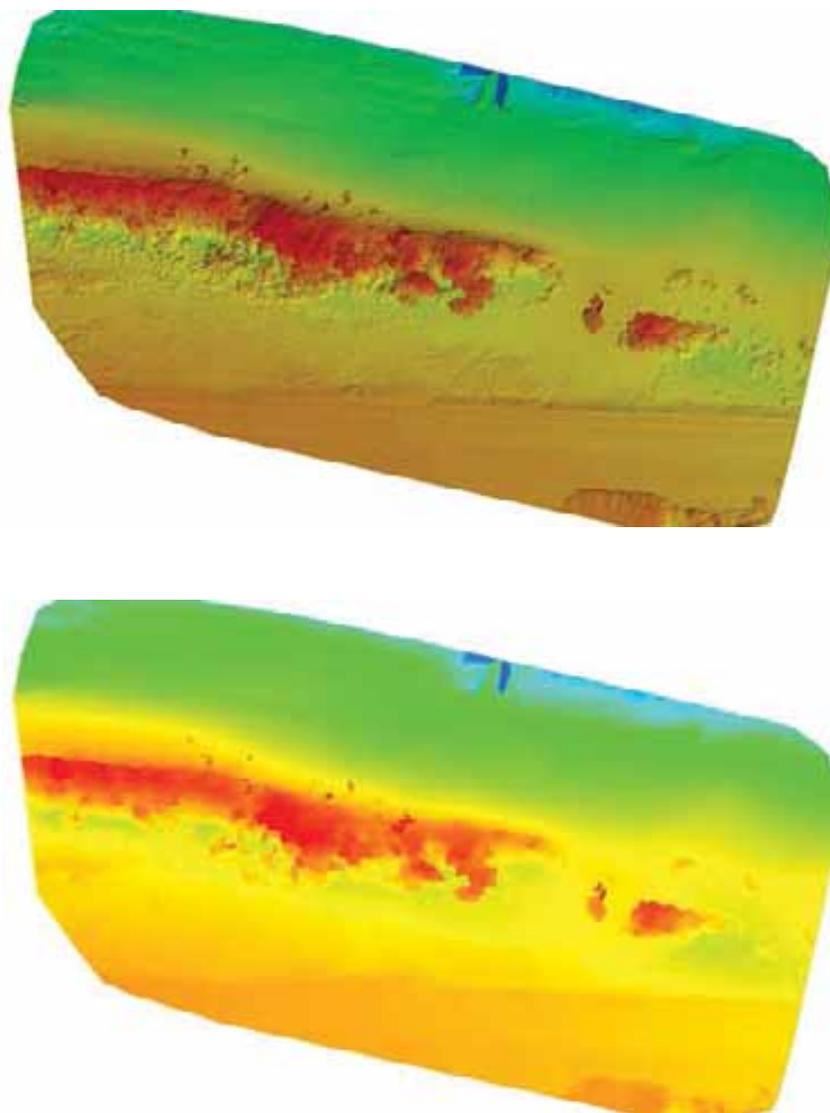


Figure 214. Density surface model (with shading top and without shading bottom) images of the dune located at Villa Pesquera, Camuy

v. Thermal images

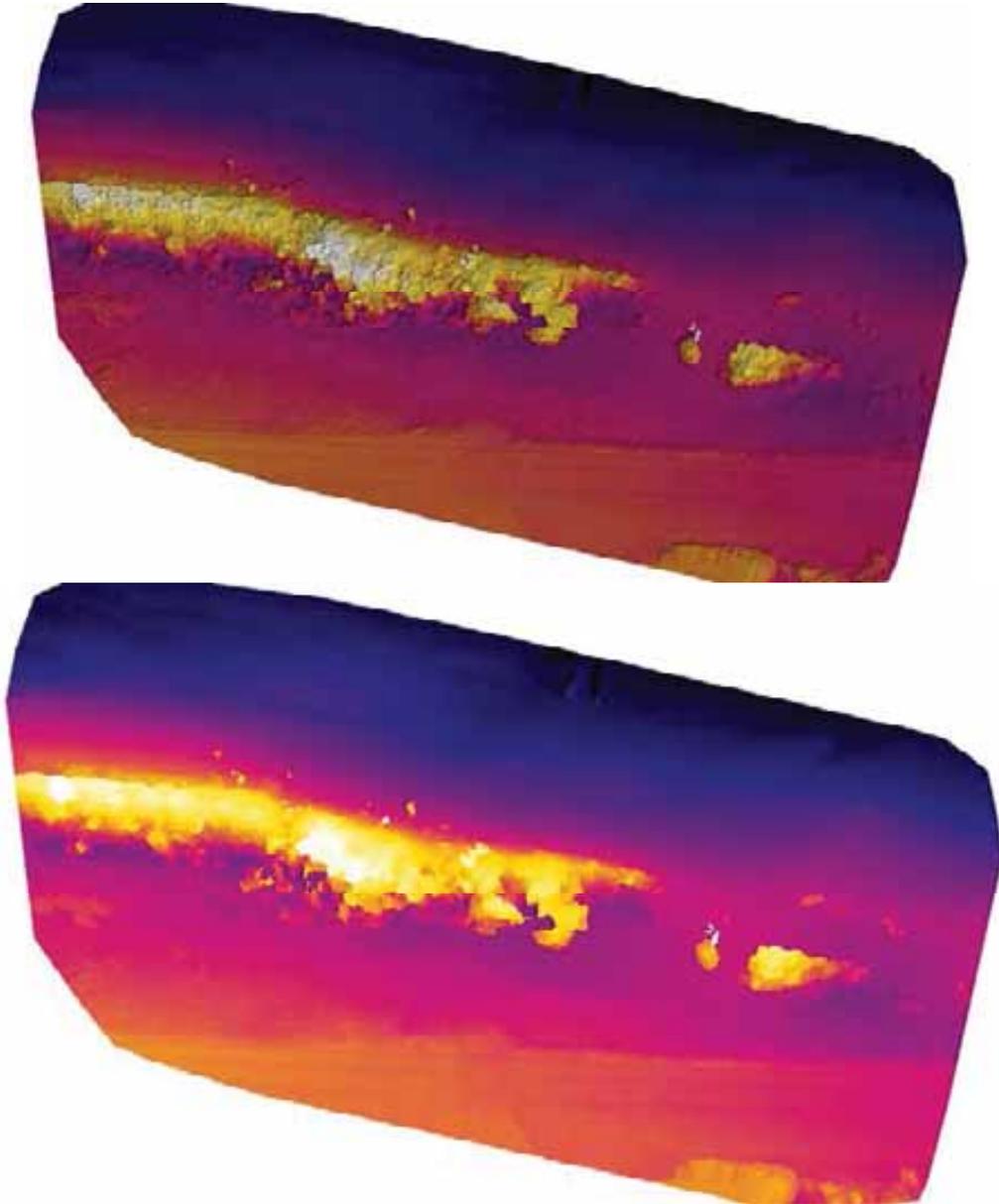


Figure 215. Thermal images (with shading top and without shading bottom) of the dune located at Villa Pesquera, Camuy

vi. 3D altitude RGB North



Figure 216. Three dimensional RGB images of Villa Pesquera, Camuy. View from the north (top) and from the south (bottom).

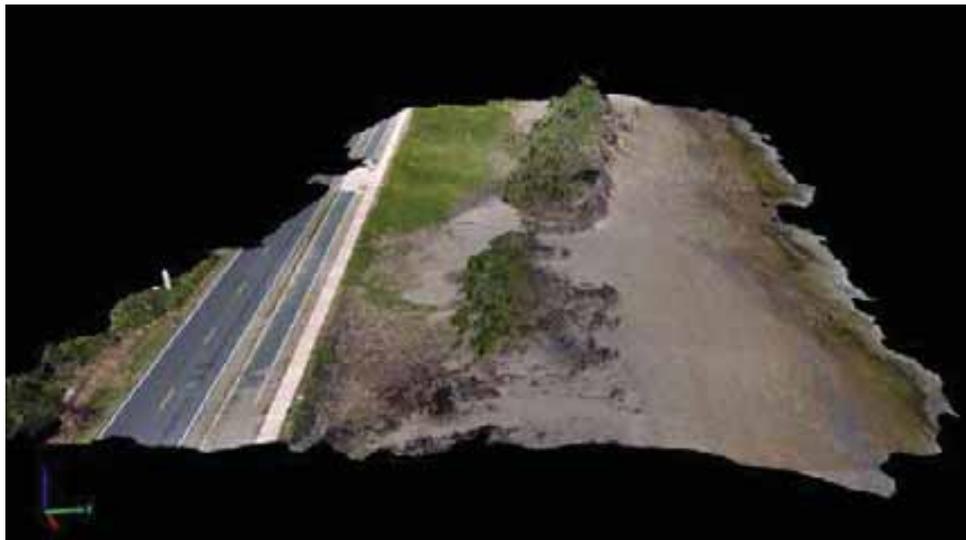


Figure 217. Three dimensional RGB images of Villa Pesquera, Camuy. View from the west (top) and from the east (bottom).

vii. DSM grayscale

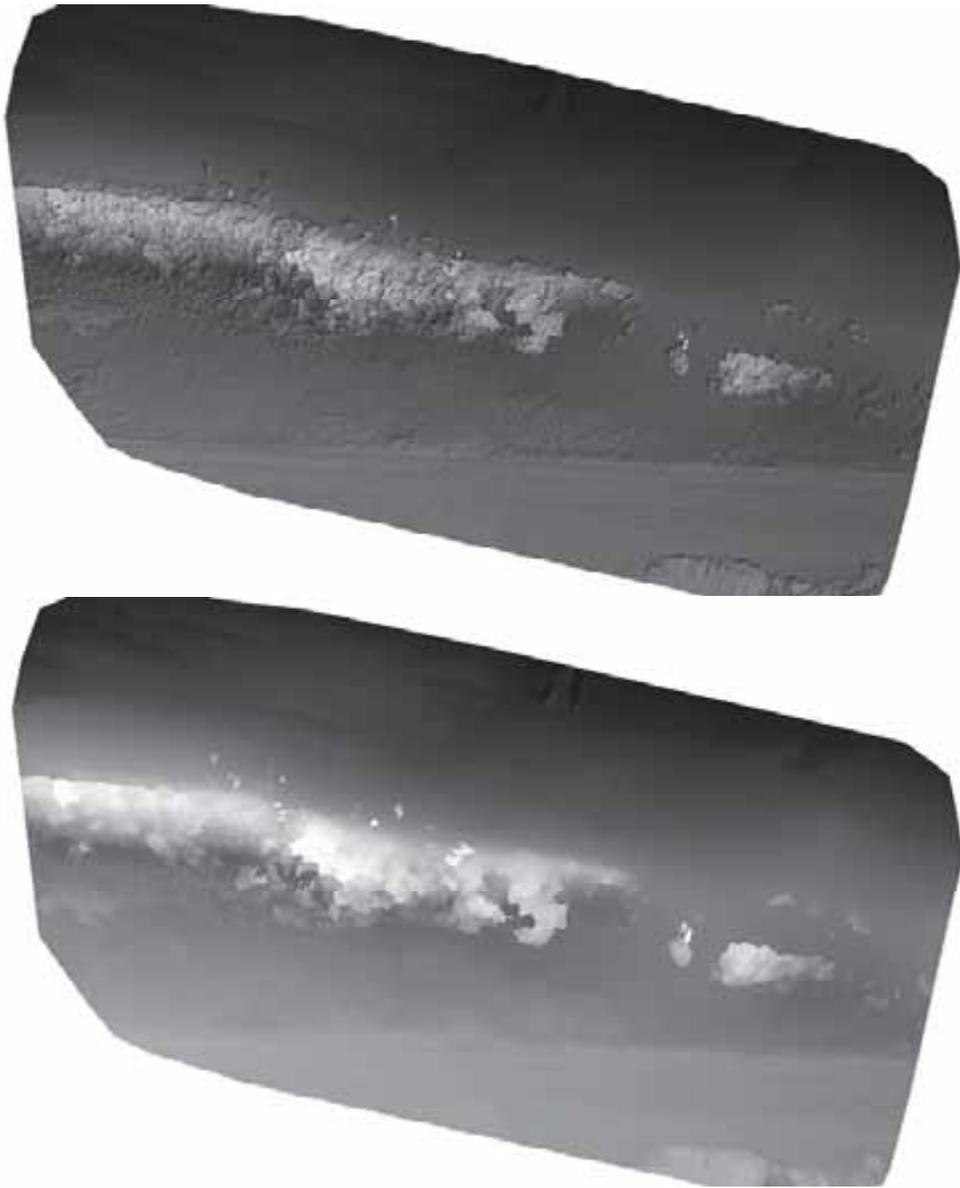


Figure 218. Grayscale DSM images of Villa Pesquera, Camuy. The top image shows shades and the bottom is not shaded.

Site report

G. Vegetation cover



Figure 219. Vegetation covered 32.9% of the Villa Pesquera area in Camuy on April 27, 2018 (after the northeasterly swell).

I. Volume measurements of selected areas of the dunes



Figure 220. Three dimensional aerial picture of the Villa Pesquera area in Camuy with two areas marked by polygons for which three dimensional area, cut volume, fill volume and total volume were calculated using the Pix4D software. Refer to image above for the data. The order of the data is from left to right on the image.

J. Conservation threats

This area is subject to heavy foot traffic and illegal sand extraction. There is a significant sand displacement onto the road and there is no sand relocation program in place.

K. Recommended ecological restoration courses of action (COA)

We recommend the installation of an elevated wooden boardwalk to direct foot traffic away from sensitive areas of the dune. Also biomimicry matrices could be installed and the accumulated sand can be stabilized with dune vegetation. A segment of exclusion fencing constructed from treated wood would help exclude cars from the sensitive dune vegetation.

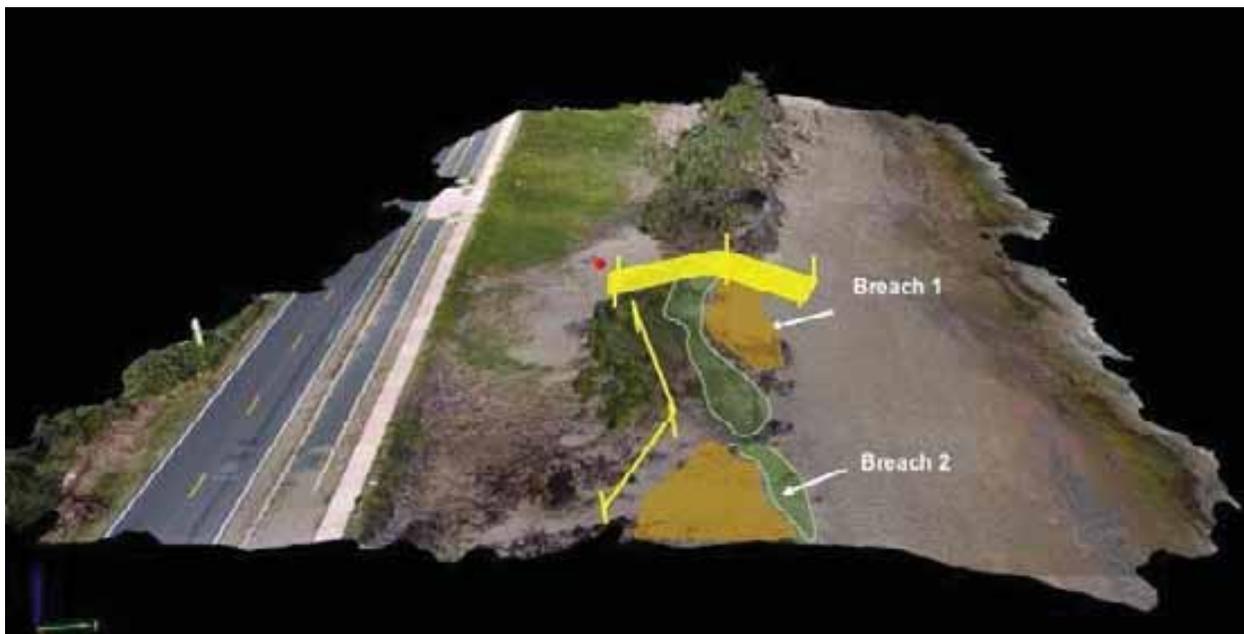


Figure 221. Area to be ecologically restored in the Villa Pesquera area in Camuy, Puerto Rico. Highlighted areas correspond to each technique that will be used in this area. **Yellow** represents the location of a wooden boardwalk, the **red dot** marks the location of an information sign, **tan** represents the area of the dune crest that where biomimicry matrices will be installed to promote the accumulation of sand. The areas shaded in **light green** represent locations for the planting of dune vegetation.



Figure 222. Displaced sand along PR-485 in front of the Villa Pesquera area site in Camuy, Puerto Rico.

L. Pix 4D Quality Report

Quality Report



Generated with Pix4Dmapper Pro version 4.2.26

⚠ Important: Click on the different icons for:

- 🔍 Help to analyze the results in the Quality Report
- ℹ Additional information about the sections

💡 Click [here](#) for additional tips to analyze the Quality Report

Summary



Project	Camuy Dunas Al Lado De La Villa Pesquera 02
Processed	2018-04-28 20:56:44
Camera Model Name(s)	FC330_3.6_4000x3000 (RGB)
Average Ground Sampling Distance (GSD)	1.01 cm / 0.40 in
Area Covered	0.013 km ² / 1.2716 ha / 0.00 sq. mi. / 3.1439 acres
Time for Initial Processing (without report)	07m:33s

Quality Check



🔍 Images	median of 41237 keypoints per image	✅
🔍 Dataset	186 out of 193 images calibrated (96%), all images enabled	✅
🔍 Camera Optimization	5.5% relative difference between initial and optimized internal camera parameters	⚠
🔍 Matching	median of 10028.8 matches per calibrated image	✅
🔍 Georeferencing	yes, no 3D GCP	⚠

🔍 Preview

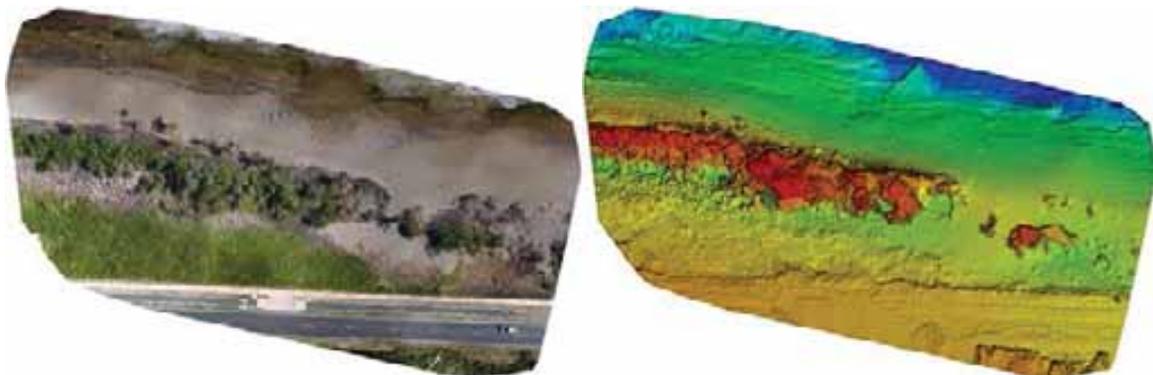


Figure 1: Orthomosaic and the corresponding sparse Digital Surface Model (DSM) before densification.

Calibration Details

Number of Calibrated Images	186 out of 193
Number of Geolocated Images	193 out of 193

Initial Image Positions

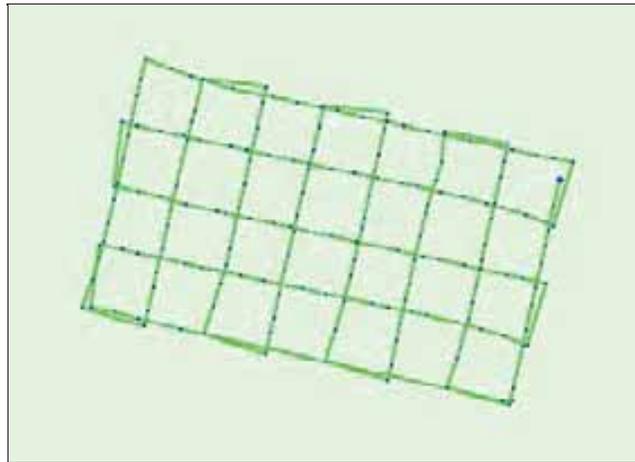
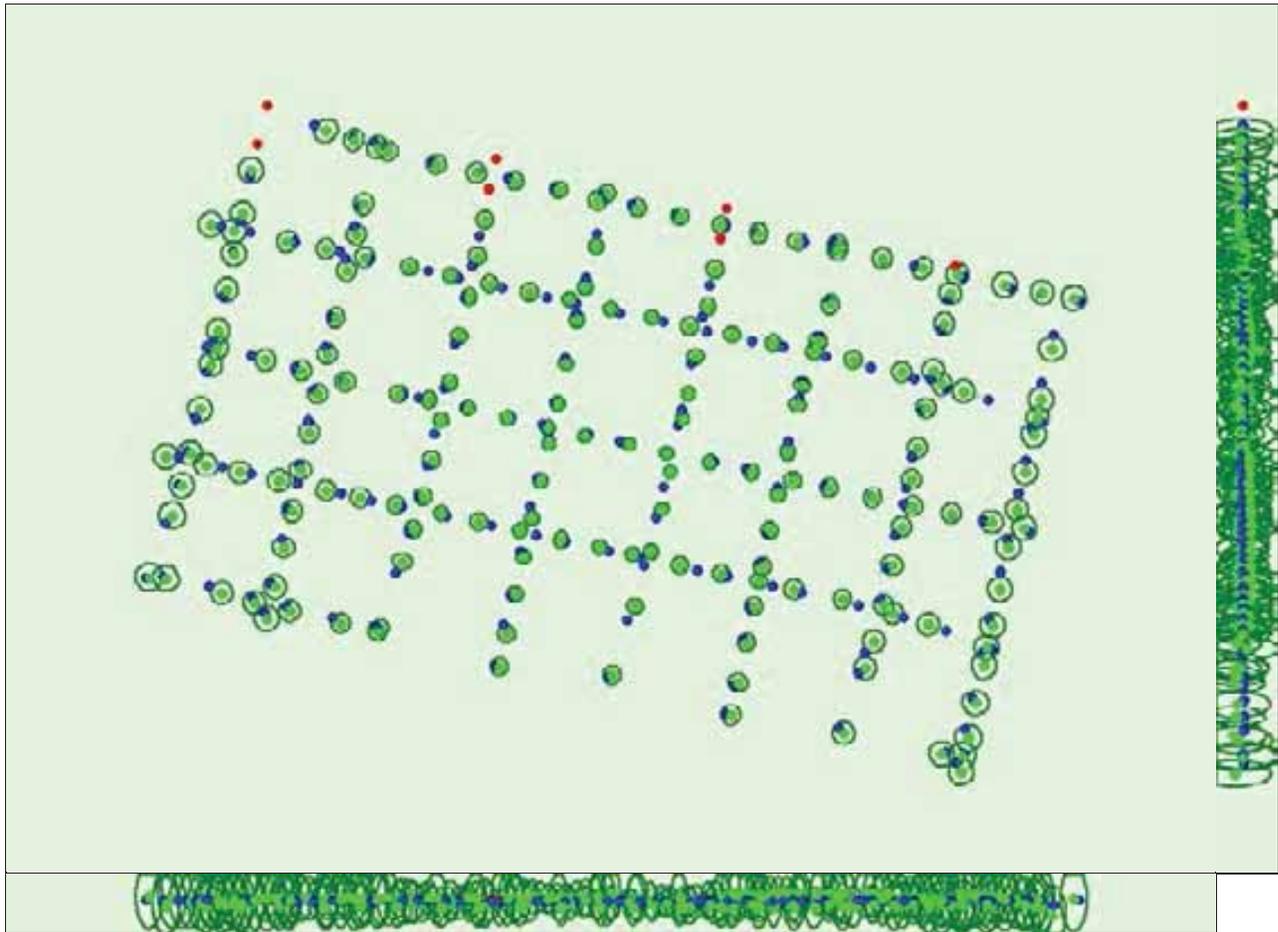


Figure 2: Top view of the initial image position. The green line follows the position of the

	X [m]	Y [m]	Z [m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.142	0.142	0.344	0.530	0.319	0.161
Sigma	0.025	0.025	0.077	0.016	0.025	0.012

images in time starting from the large blue dot.



Uncertainty ellipses 10x magnified

Figure 3: Offset between initial (blue dots) and computed (green dots) image positions as well as the offset between the GCPs initial positions (blue crosses) and their computed positions (green crosses) in the top-view (XY plane), front-view (XZ plane), and side-view (YZ plane). Red dots indicate disabled or uncalibrated images. Dark green ellipses indicate the absolute position uncertainty of the bundle block adjustment result.

🔍 Absolute camera position and orientation uncertainties

🔍 Overlap

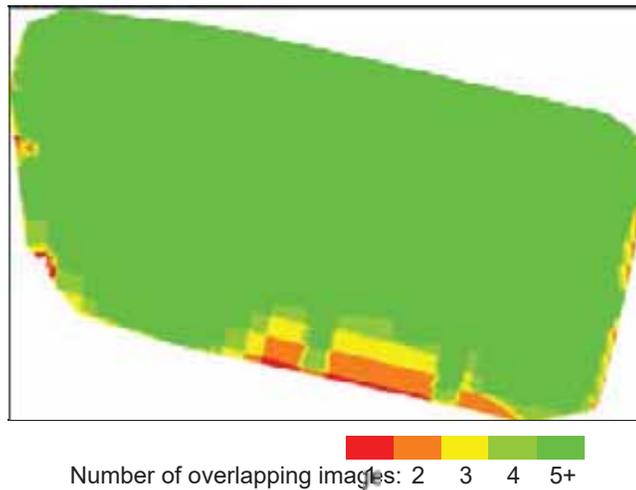


Figure 4: Number of overlapping images computed for each pixel of the orthomosaic. Red and yellow areas indicate low overlap for which poor results may be generated. Green areas indicate an overlap of over 5 images for every pixel. Good quality results will be generated as long as the number of keypoint matches is also sufficient for these areas (see Figure 5 for keypoint matches).

Bundle Block Adjustment Details



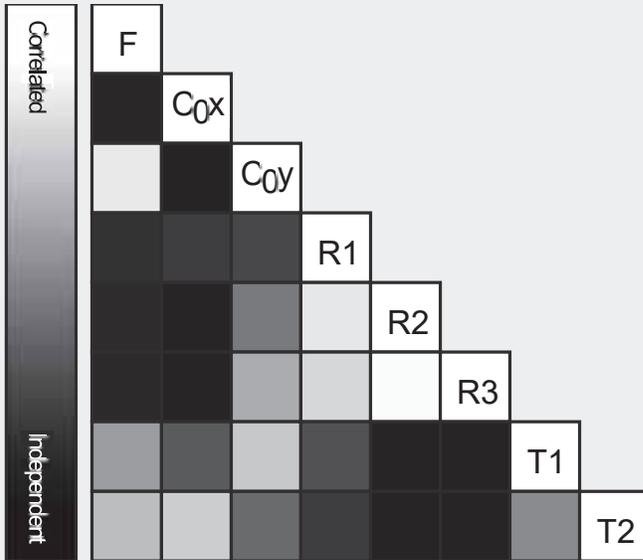
Number of 2D Keypoint Observations for Bundle Block Adjustment	1943823
Number of 3D Points for Bundle Block Adjustment	666438
Mean Reprojection Error [pixels]	0.172

Internal Camera Parameters FC330_3.6_4000x3000 (RGB). Sensor Dimensions: 6.317 [mm] x 4.738 [mm]

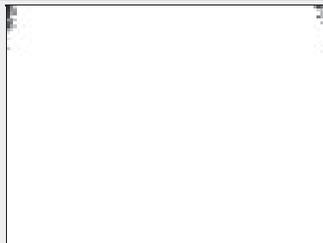


EXIF ID: FC330_3.6_4000x3000

	Focal Length	Principal Point x	Principal Point y	R1	R2	R3	T1	T2
Initial Values	2285.722 [pixel] 3.610 [mm]	2000.006 [pixel] 3.159 [mm]	1500.003 [pixel] 2.369 [mm]	- 0.001	- 0.002	0.000	- 0.001	- 0.001
Optimized Values	2411.530 [pixel] 3.809 [mm]	1962.152 [pixel] 3.099 [mm]	1461.318 [pixel] 2.308 [mm]	- 0.002	- 0.004	0.002	0.000	- 0.000
Uncertainties (Sigma)	0.277 [pixel] 0.000 [mm]	0.059 [pixel] 0.000 [mm]	0.147 [pixel] 0.000 [mm]	0.000	0.000	0.000	0.000	0.000



The correlation between camera internal parameters determined by the bundle adjustment. White indicates a full correlation between the parameters, ie. any change in one can be fully compensated by the other. Black indicates that the parameter is completely independent, and is not affected by other parameters.



The number of Automatic Tie Points (ATPs) per pixel, averaged over all images of the camera model. The image is color coded between black and white. White indicates that, on average, more than 16 ATPs have been extracted at the pixel location. Black indicates that, on average, 0 ATPs have been extracted at the pixel location. Click on the image to see the average direction and magnitude of the re-projection error for each pixel. Note that the vectors are scaled for better visualization. The scale bar indicates the magnitude of 1 pixel error.

2D Keypoints Table

	Number of 2D Keypoints per Image	Number of Matched 2D Keypoints per Image
Median	41237	10029
Min	27018	568
Max	62493	21903
Mean	42206	10451

3D Points from 2D Keypoint Matches



	Number of 3D Points Observed
In 2 Images	423643
In 3 Images	112327
In 4 Images	50287
In 5 Images	28258
In 6 Images	17505
In 7 Images	11367
In 8 Images	7478
In 9 Images	4991
In 10 Images	3409
In 11 Images	2457
In 12 Images	1563
In 13 Images	1046
In 14 Images	648
In 15 Images	421
In 16 Images	298
In 17 Images	216
In 18 Images	176
In 19 Images	114
In 20 Images	72
In 21 Images	51
In 22 Images	30
In 23 Images	34
In 24 Images	18
In 25 Images	14
In 26 Images	5
In 27 Images	5
In 28 Images	3
In 29 Images	1
In 31 Images	1

2D Keypoint Matches

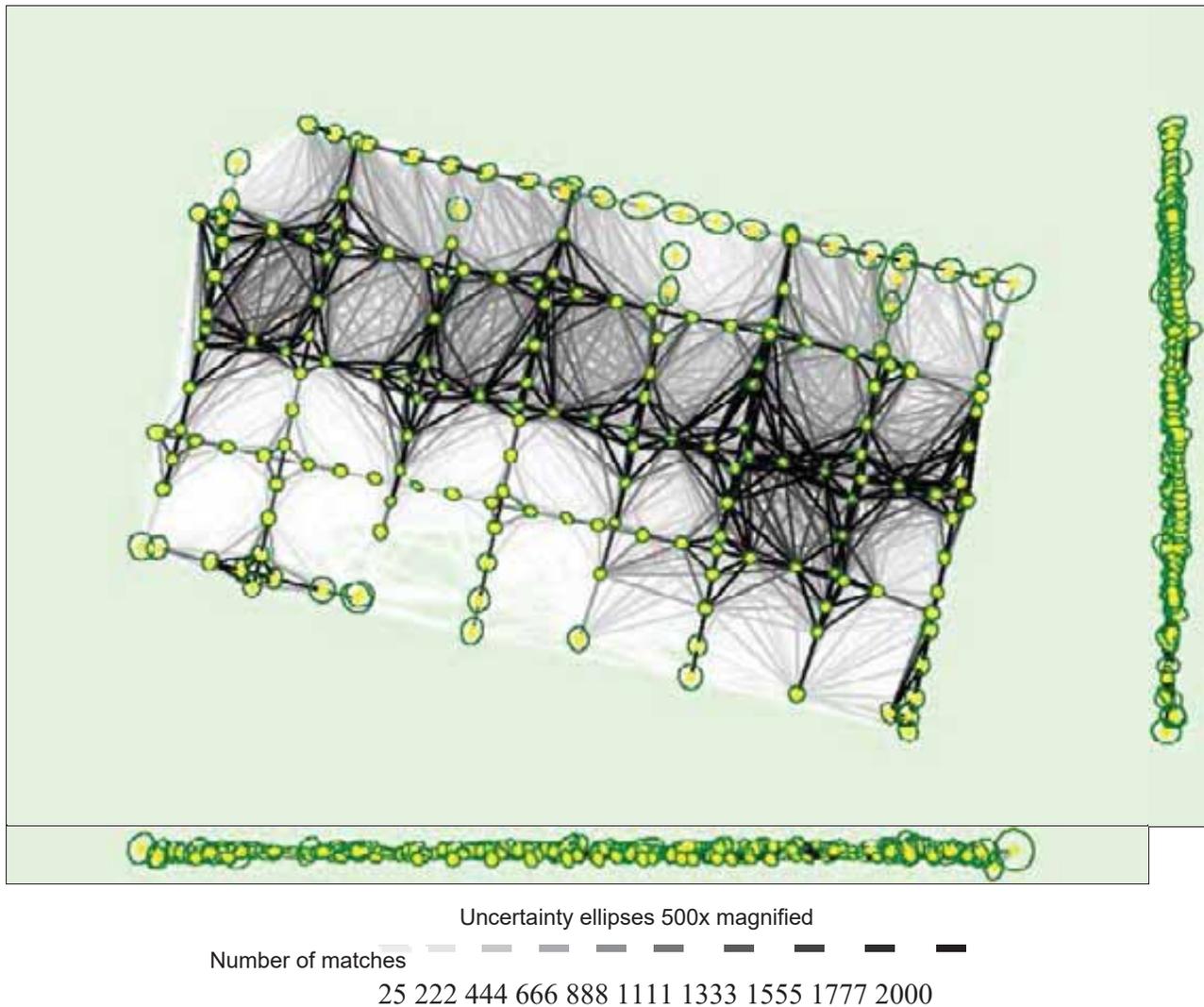


Figure 5: Computed image positions with links between matched images. The darkness of the links indicates the number of matched 2D keypoints between the images. Bright links indicate weak links and require manual tie points or more images. Dark green ellipses indicate the relative camera position uncertainty of the bundle block adjustment result.

Relative camera position and orientation uncertainties

	X [m]	Y [m]	Z [m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.002	0.002	0.002	0.007	0.008	0.004
Sigma	0.001	0.001	0.001	0.003	0.002	0.002

Geolocation Details

🔍 Absolute Geolocation Variance



Min Error [m]	Max Error [m]	Geolocation Error X [%]	Geolocation Error Y [%]	Geolocation Error Z [%]
-	-15.00	0.00	0.00	0.00
-15.00	-12.00	0.00	0.00	0.00
-12.00	-9.00	0.00	0.00	0.00
-9.00	-6.00	0.00	0.00	0.00
-6.00	-3.00	0.00	0.00	0.00
-3.00	0.00	63.98	49.46	54.30
0.00	3.00	35.48	50.54	45.70
3.00	6.00	0.54	0.00	0.00
6.00	9.00	0.00	0.00	0.00
9.00	12.00	0.00	0.00	0.00
12.00	15.00	0.00	0.00	0.00
15.00	-	0.00	0.00	0.00
Mean [m]		0.004059	0.005541	-0.007243
Sigma [m]		1.061183	0.922284	0.512409
RMS Error [m]		1.061190	0.922301	0.512460

Min Error and Max Error represent geolocation error intervals between -1.5 and 1.5 times the maximum accuracy of all the images. Columns X, Y, Z show the percentage of images with geolocation errors within the predefined error intervals. The geolocation error is the difference between the initial and computed image positions. Note that the image geolocation errors do not correspond to the accuracy of the observed 3D points.

🔍 Relative Geolocation Variance



Relative Geolocation Error	Images X [%]	Images Y [%]	Images Z [%]
[-1.00, 1.00]	100.00	100.00	100.00
[-2.00, 2.00]	100.00	100.00	100.00
[-3.00, 3.00]	100.00	100.00	100.00
Mean of Geolocation Accuracy [m]	5.000000	5.000000	10.000000
Sigma of Geolocation Accuracy [m]	0.000000	0.000000	0.000000

Images X, Y, Z represent the percentage of images with a relative geolocation error in X, Y, Z.

Geolocation Orientational Variance	RMS [degree]
Omega	3.945
Phi	3.570
Kappa	4.911

Geolocation RMS error of the orientation angles given by the difference between the initial and computed image orientation angles.

Initial Processing Details

System Information

Hardware	CPU: Intel(R) Core(TM) i7-8700K CPU @ 3.70GHz RAM: 16GB GPU: NVIDIA GeForce GTX 1070 (Driver: 23.21.13.9065)
Operating System	Windows 10 Home, 64-bit

Coordinate Systems

Image Coordinate System	WGS84 (egm96)
Output Coordinate System	WGS 84 / UTM zone 19N (egm96)

Processing Options

Detected Template	3D Maps
Keypoints Image Scale	Full, Image Scale: 1
Advanced: Matching Image Pairs	Aerial Grid or Corridor
Advanced: Matching Strategy	Use Geometrically Verified Matching: no
Advanced: Keypoint Extraction	Targeted Number of Keypoints: Automatic
Advanced: Calibration	Calibration Method: Standard Internal Parameters Optimization: All External Parameters Optimization: All Rematch: Auto, yes

Point Cloud Densification details

Processing Options

Image Scale	multiscale, 1/2 (Half image size, Default)
Point Density	Optimal
Minimum Number of Matches	3
3D Textured Mesh Generation	yes
3D Textured Mesh Settings:	Resolution: Medium Resolution (default) Color Balancing: no
LOD	Generated: no
Advanced: 3D Textured Mesh Settings	Sample Density Divider: 1

Advanced: Image Groups	group1
Advanced: Use Processing Area	yes
Advanced: Use Annotations	yes
Time for Point Cloud Densification	10m:10s
Time for Point Cloud Classification	NA
Time for 3D Textured Mesh Generation	03m:48s

Results



Number of Generated Tiles	1
Number of 3D Densified Points	10939560
Average Density (per m ³)	3560.41

DSM, Orthomosaic and Index Details



Processing Options



DSM and Orthomosaic Resolution	1 x GSD (1.01 [cm/pixel])
DSM Filters	Noise Filtering: yes Surface Smoothing: yes, Type: Sharp
Raster DSM	Generated: yes Method: Inverse Distance Weighting Merge Tiles: yes
Orthomosaic	Generated: yes Merge Tiles: yes GeoTIFF Without Transparency: no Google Maps Tiles and KML: no
Time for DSM Generation	05m:53s
Time for Orthomosaic Generation	09m:12s
Time for DTM Generation	00s
Time for Contour Lines Generation	00s
Time for Reflectance Map Generation	00s
Time for Index Map Generation	00s

Site name:

Finca Nolla Nature Reserve (FNNR), Camuy, Puerto Rico



A. Physical address:

At the end of Pedro Amador Road, Camuy, Puerto Rico, 00627

B. Date of capture of imagery:

March 15, 2018

C. Coordinates:

18.48897792 N - 66.84463090 W

D. Description of site:

This site is located on the easternmost limit of the Finca Nolla Nature Reserve in Finca Nolla, Camuy. It consists of a 52 m long breached portion of primary dune with no vegetation. This area had been ecologically restored by Vida Marina since 2014 but most of the sand that had accumulated in this area (approximately 6 m) was washed away by the two major storms of 2017 and the northeasterly swell of March 2018. Part of a biomimicry set up is still left after these extreme events.

E. Distance from community:

This site is located at a distance of approximately 192.98 m from a densely populated area known as “Sector Calle Abajo” and at a distance of approximately 395.29 m from Amador Brall Road (PR 485).

F. Aerial imagery

i. Contour map

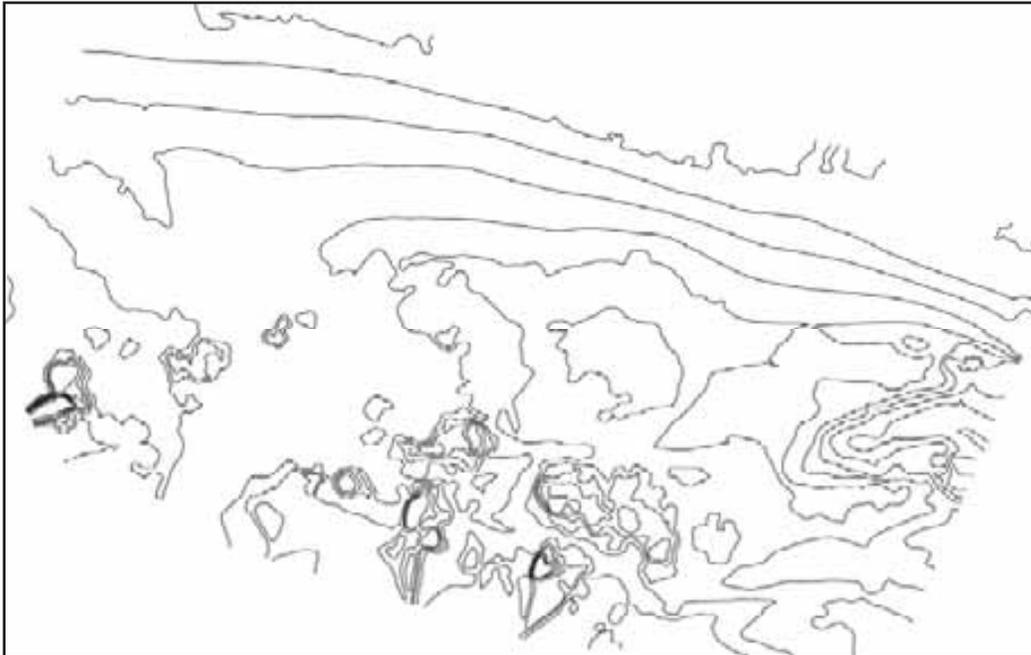


Figure 223. Contour map of Dune east of the Finca Nolla Nature Reserve, Camuy Puerto Rico with elevation intervals of 1 meter.

ii. 3D imagery



Figure 224. Aerial 3D image of the east of the FNNR, Camuy.

iii. Orthomosaic model



Figure 225. Orthomosaic image of Dune east of the FNNR, Camuy.

iv. Density Surface Models (DSM)

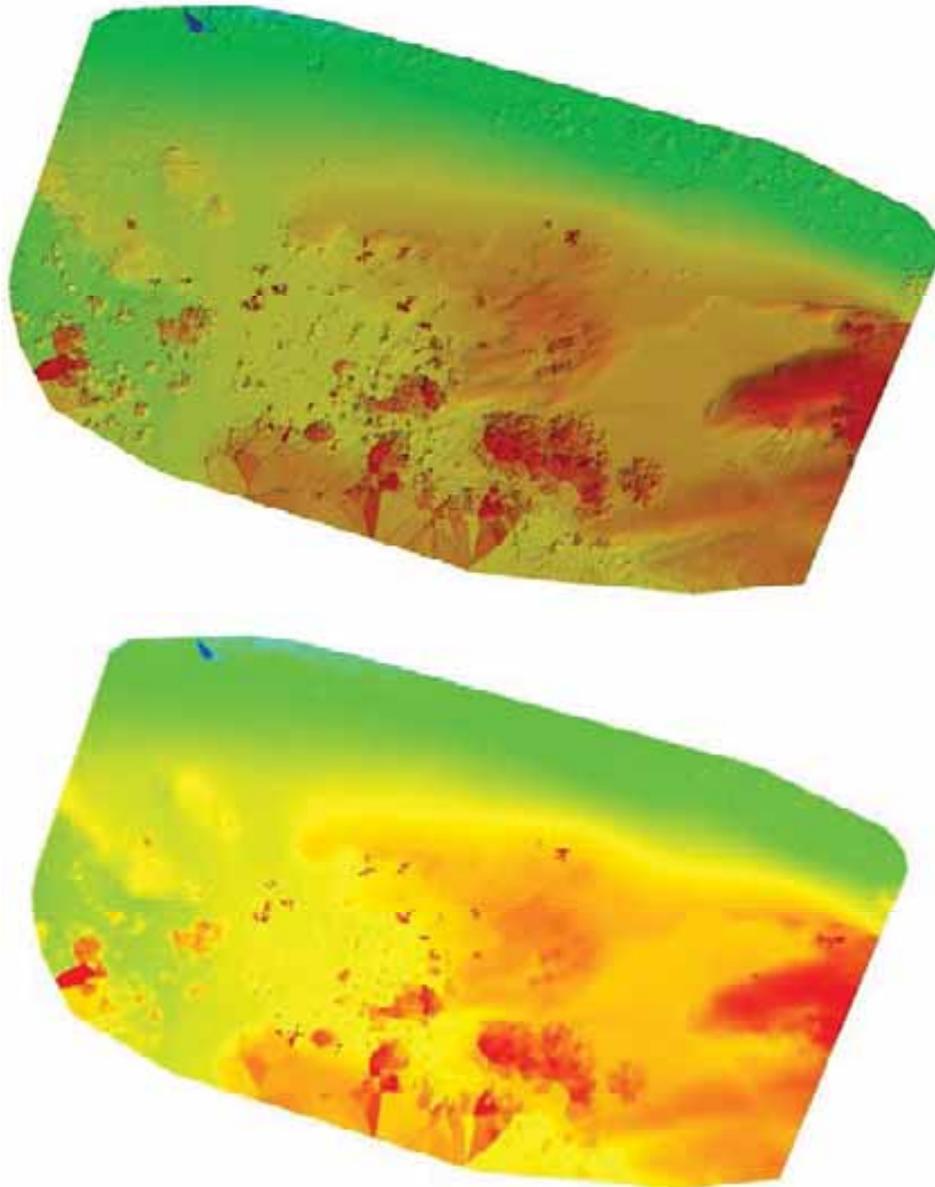


Figure 226. Density surface model (with shading top and without shading bottom) images of the dune located on the east of the FNNR in Camuy.

v. Thermal images

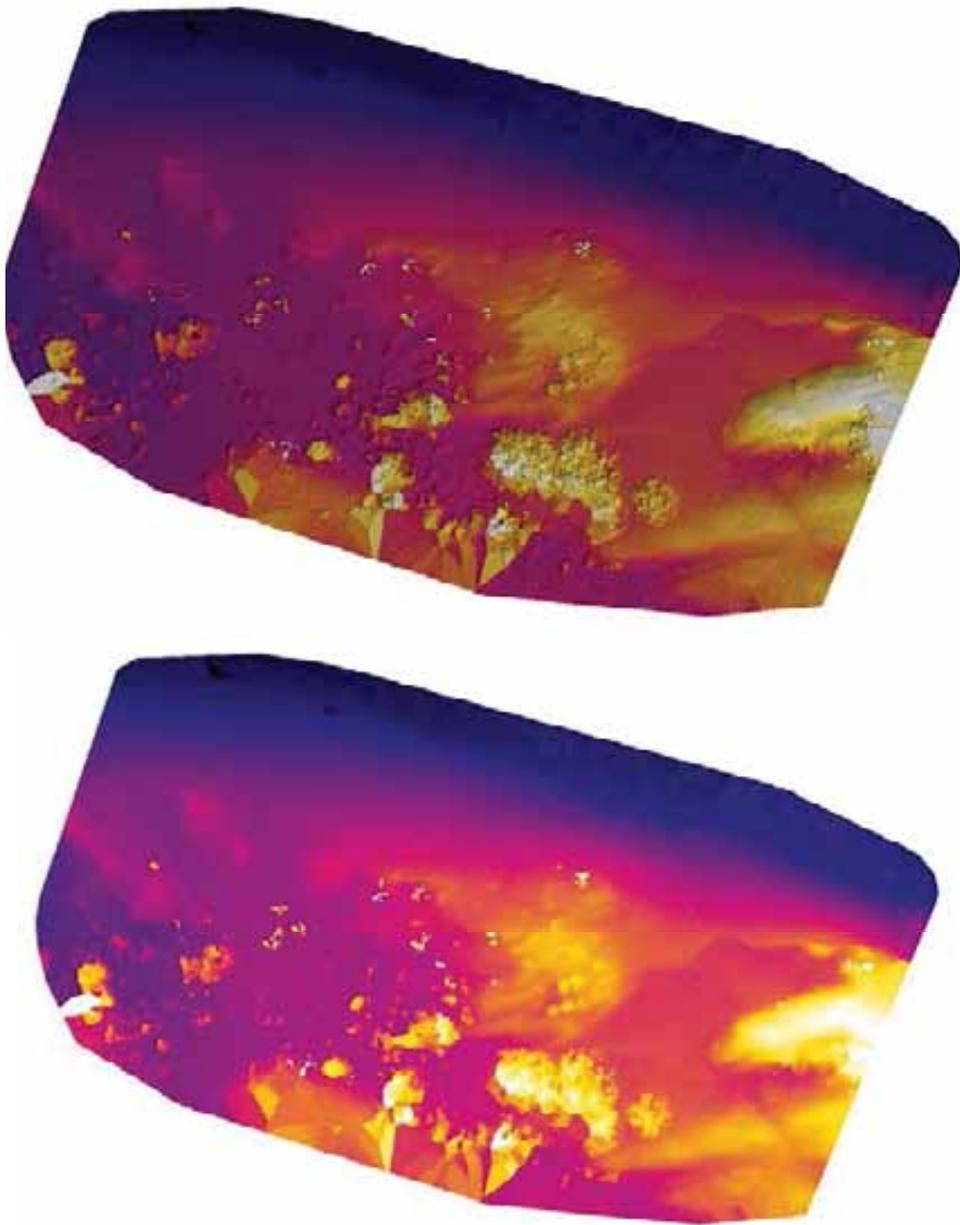


Figure 227. Thermal images (with shading top and without shading bottom) of the dune located on the east of the FNNR in Camuy.

v. **3D altitude RGB North**

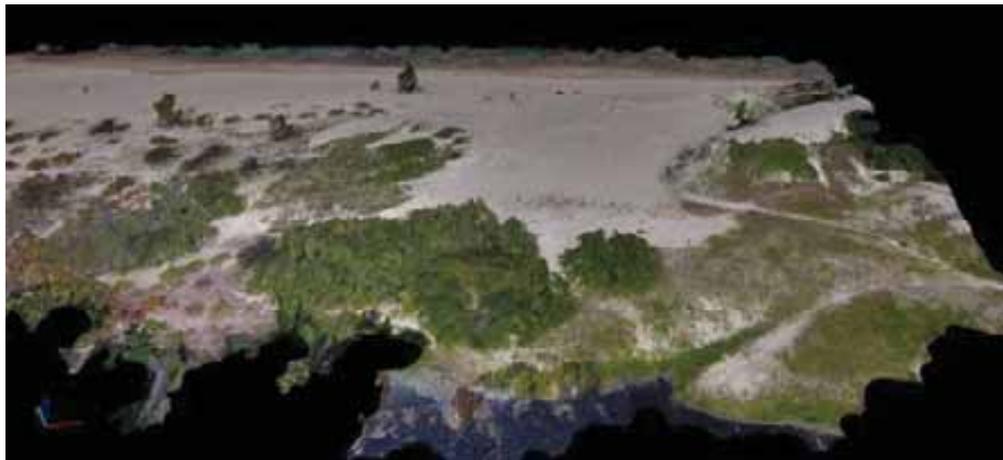


Figure 228. Three dimensional RGB images of the easternmost part of the study site on the east of the FNNR in Camuy, Puerto Rico. The top image is a view from the north and the bottom is a view from the south.

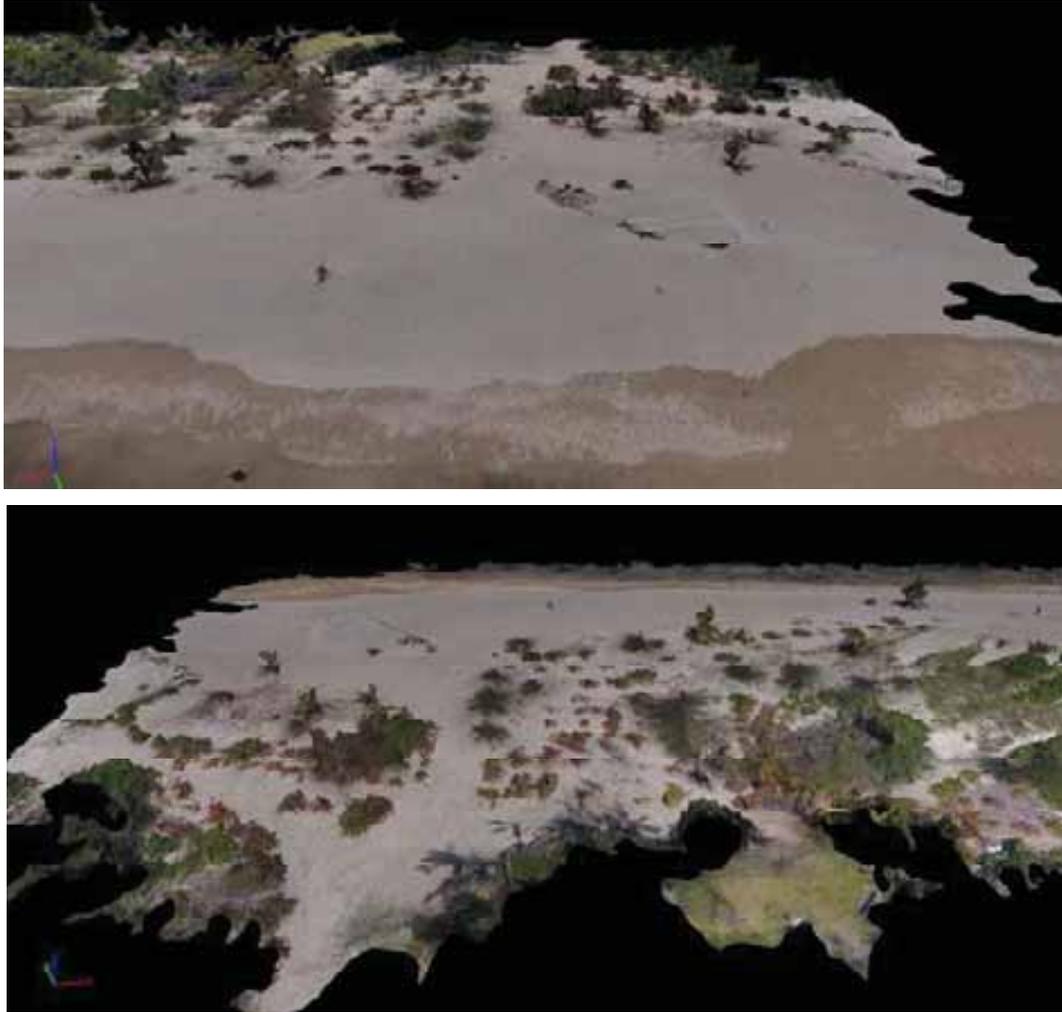


Figure 229. Three dimensional RGB images of the eastern part of the FNNR in Camuy. View from the north (top) and from the south (bottom).

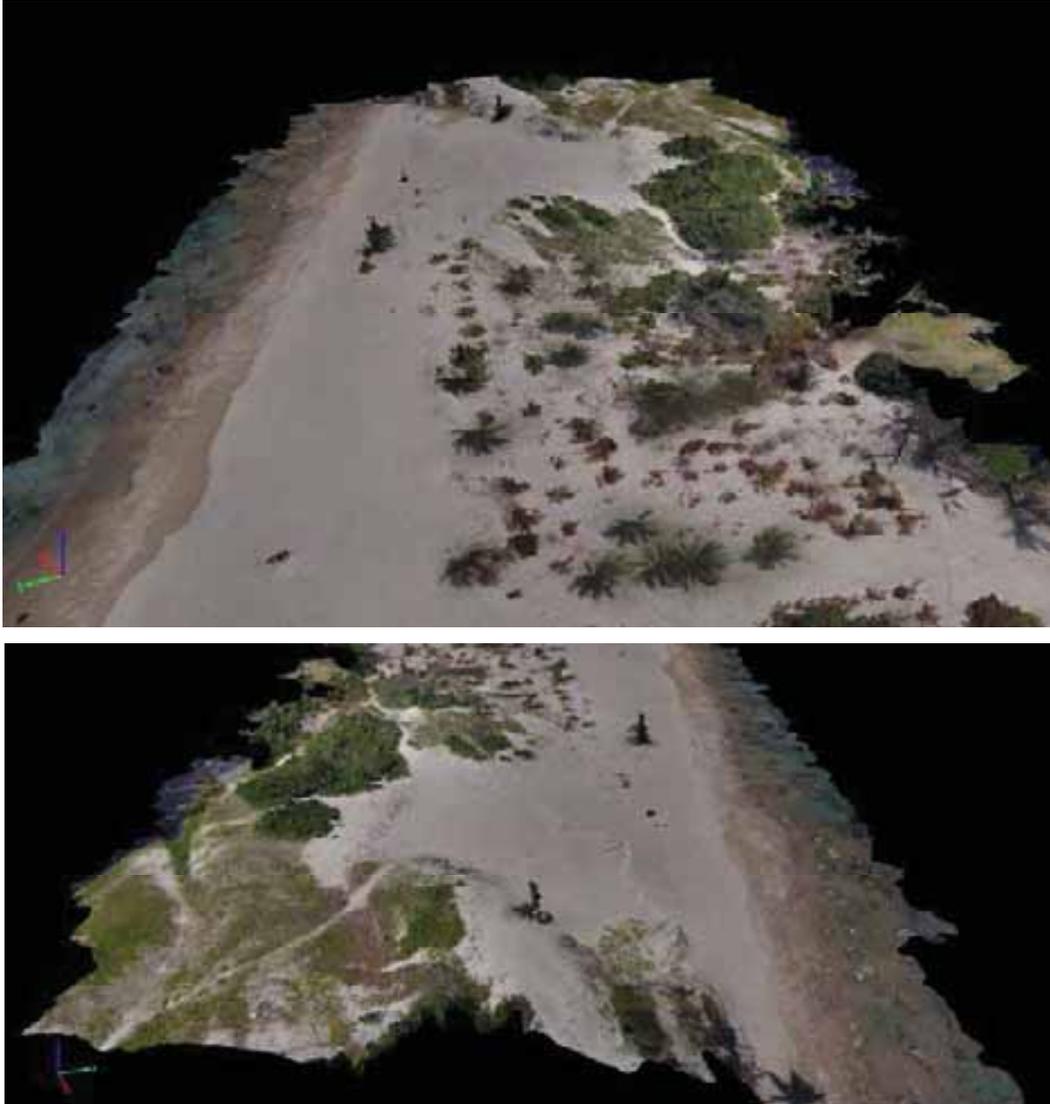


Figure 230. Three dimensional RGB images of the easternmost part of the study site on the east of the FNNR in Camuy, Puerto Rico. The top image is a view from the west and the bottom is a view from the east.

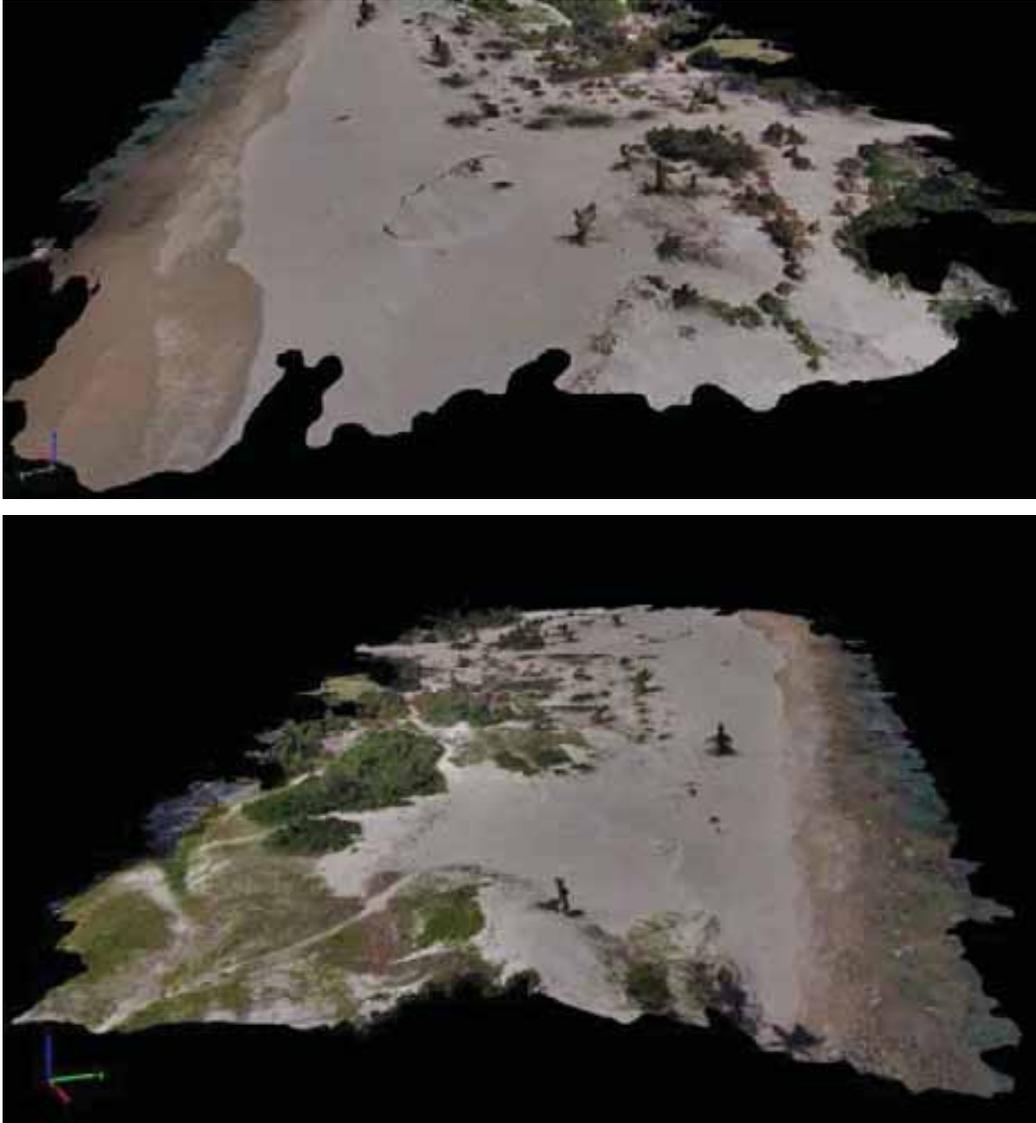


Figure 231. Three dimensional RGB images of the easternmost part of the study site on the east of the FNNR in Camuy, Puerto Rico. The top image is a view from the east and the bottom is a view from the west.

vii. DSM grayscale

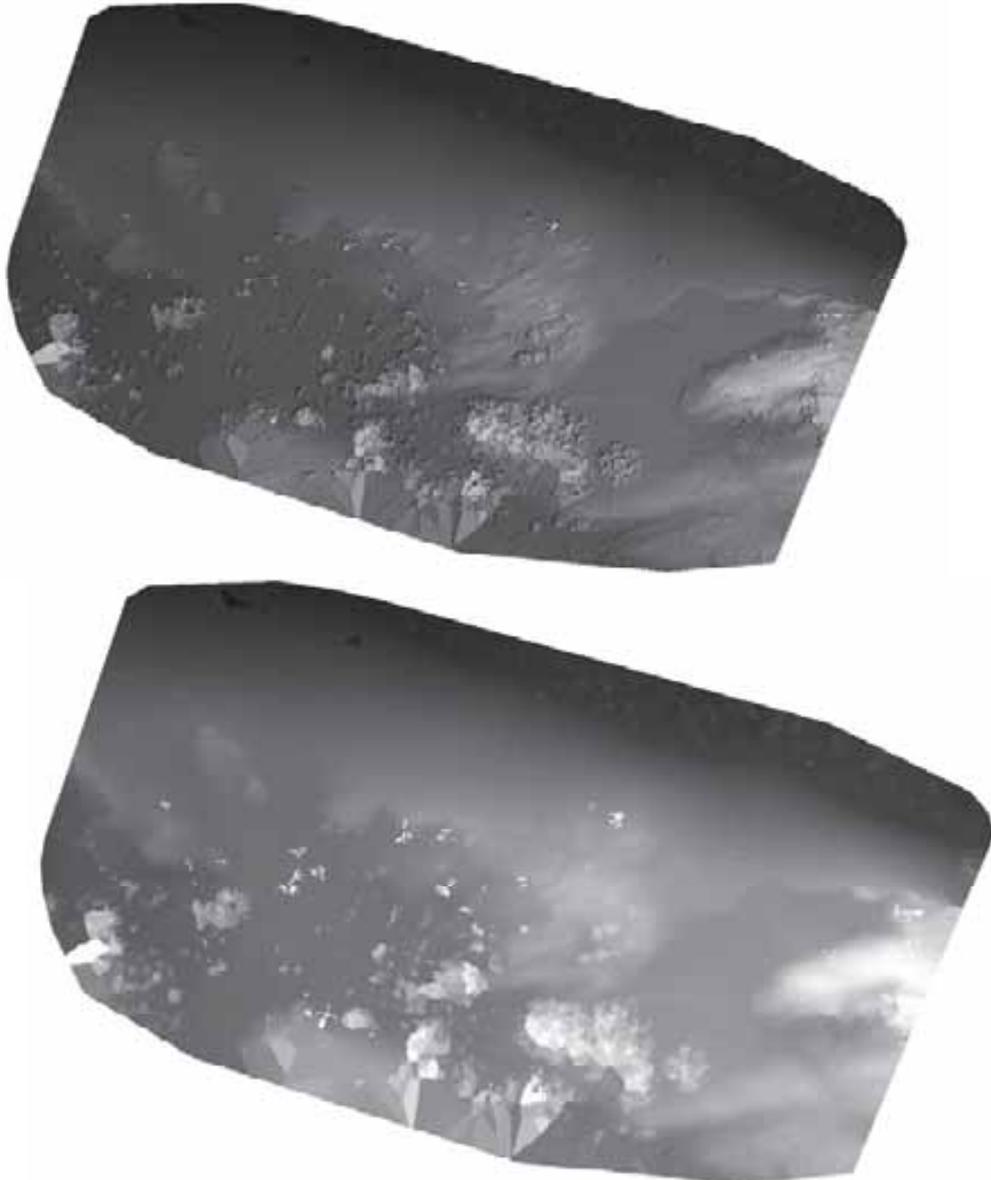


Figure 232. Grayscale DSM images of the dune to the Dune east side Finca Nolla (after swell), Camuy. The top image shows shades and the bottom is not shaded.

Site report

G. Vegetation cover



Figure 233. Images of the area for which vegetation cover is being monitored for the eastern part of the FNNR in Camuy, Puerto Rico. The vegetation cover was 16.9% for this site on March 15, 2018.

I. Volume measurements of selected areas of the dunes

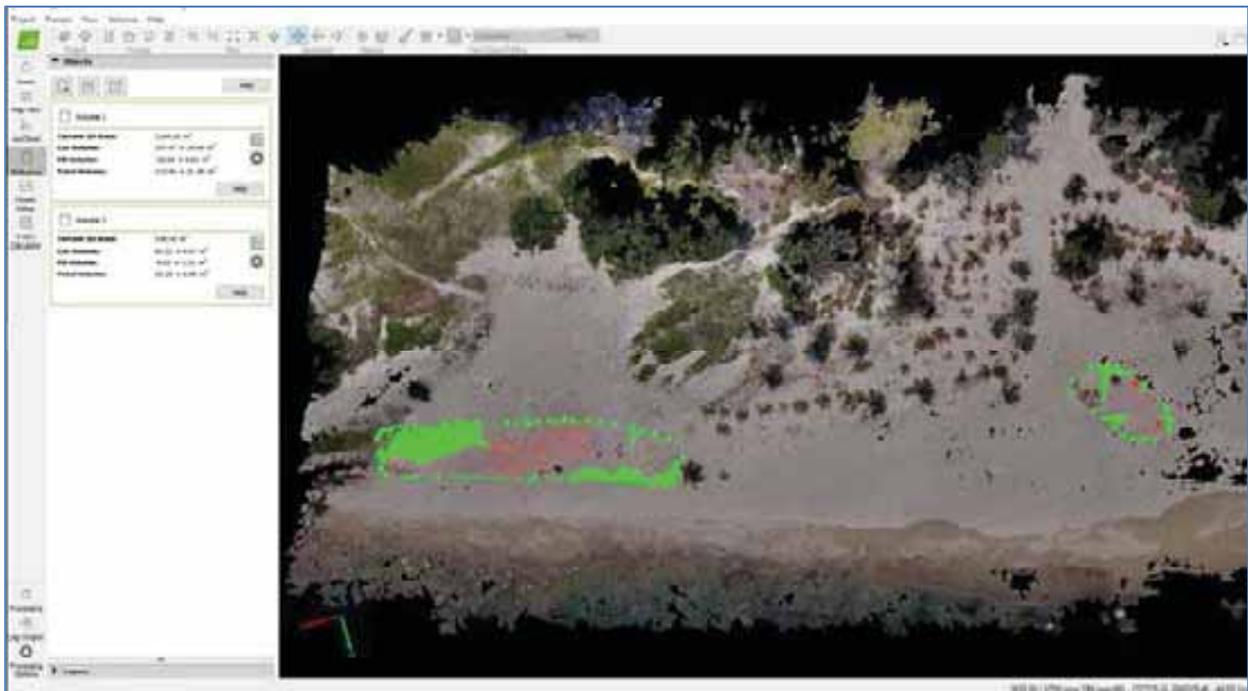


Figure 234. Three dimensional aerial picture of the eastern portion of the Finca Nolla Nature Reserve in Camuy with two areas marked by polygons for which three dimensional area, cut volume, fill volume and total volume were calculated using the Pix4D software. Refer to image above for the data. The order of the data is from left to right on the image.

J. Conservation threats

This area is part of a Nature Reserve and even though law enforcement is minimal to non-existent the incidence of foot or all terrain vehicle traffic is very low as well as illegal sand extraction. The coastal dunes in this area were extremely exploited by commercial sand extraction and vegetation was completely destroyed in some areas. The coast is relatively protected from strong waves by consolidated dunes and a very thick strip of eolianite.

K. Recommended ecological restoration courses of action (COA)

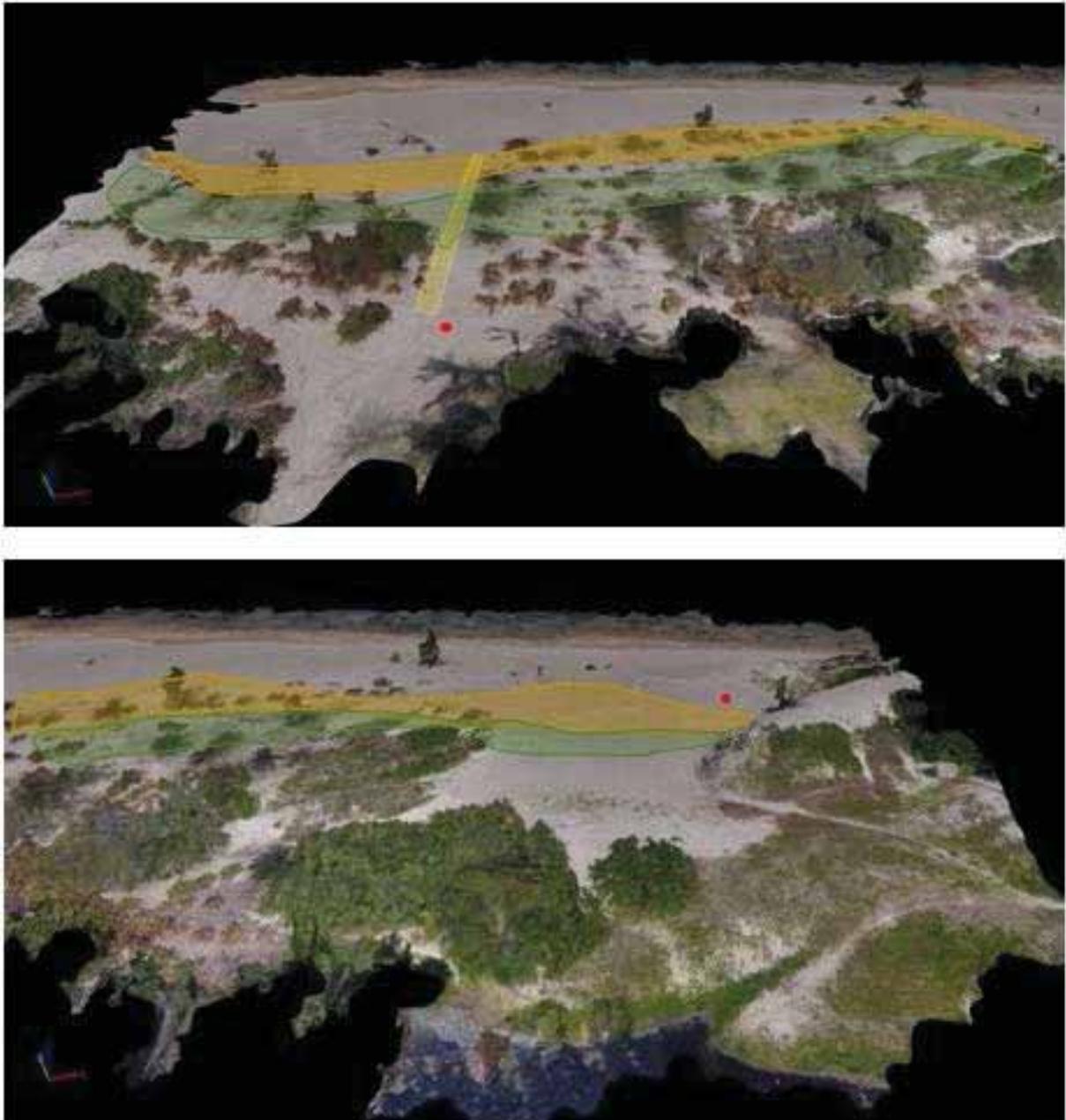


Figure 235. Area to be ecologically restored in the eastern most part of the Finca Nolla Nature Reserve in Camuy, Puerto Rico. Highlighted areas correspond to each technique that will be used in this area. **Yellow** represents the location of a wooden boardwalk, the **red dot** marks the location of an information sign, **tan** represents the area of the dune crest that where biomimicry matrices will be installed to promote the accumulation of sand. The areas shaded in light green represent locations for the planting of dune vegetation.

L. Pix 4D Quality Report

Quality Report

Generated with Pix4Dmapper Pro version 4.2.25

Important: Click on the different icons for:

- Help to analyze the results in the Quality Report
- Additional information about the sections

Click [here](#) for additional tips to analyze the Quality Report

Summary

Project	Duna de Bobby Finca Nolla
Processed	2018-03-30 17:47:22
Camera Model Name(s)	FC330_3.6_4000x3000 (RGB)
Average Ground Sampling Distance (GSD)	1.26 cm / 0.50 in
Area Covered	0.035 km ² / 3.5434 ha / 0.01 sq. mi. / 8.7605 acres
Time for Initial Processing (without report)	01h:11m:52s

Quality Check

Images	median of 24688 keypoints per image	✔
Dataset	272 out of 272 images calibrated (100%), all images enabled	✔
Camera Optimization	4.81% relative difference between initial and optimized internal camera parameters	✔
Matching	median of 6298.66 matches per calibrated image	✔
Georeferencing	yes, no 3D GCP	⚠

Preview

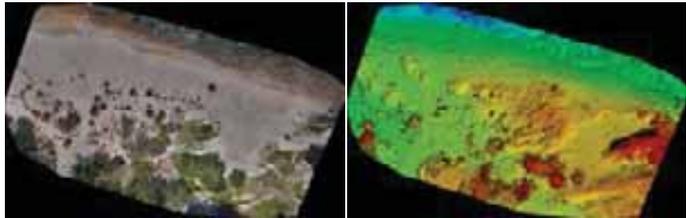


Figure 1: Orthomosaic and the corresponding sparse Digital Surface Model (DSM) before densification.

Calibration Details

Number of Calibrated Images	272 out of 272
Number of Geolocated Images	272 out of 272

Initial Image Positions

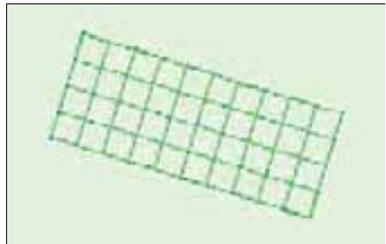
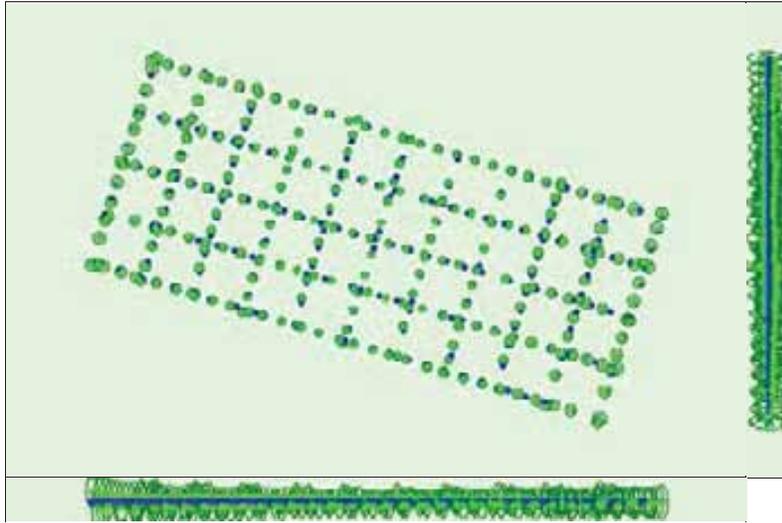


Figure 2: Top view of the initial image position. The green line follows the position of the images in time starting from the large blue dot.

1 Computed Image/GCPs/Manual Tie Points Positions



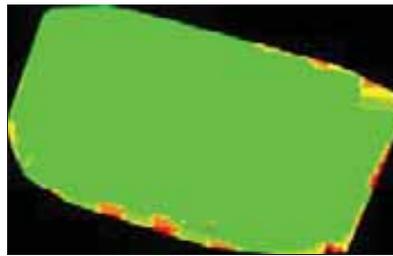
Uncertainty ellipses 10x magnified

Figure 3: Offset between initial (blue dots) and computed (green dots) image positions as well as the offset between the GCPs initial positions (blue crosses) and their computed positions (green crosses) in the top-view (XY plane), front-view (XZ plane), and side-view (YZ plane). Dark green ellipses indicate the absolute position uncertainty of the bundle block adjustment result.

1 Absolute camera position and orientation uncertainties

	X[m]	Y[m]	Z[m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.177	0.178	0.431	0.518	0.257	0.150
Sigma	0.034	0.034	0.093	0.010	0.016	0.012

1 Overlap



Number of overlapping images: 1 2 3 4 5+

Figure 4: Number of overlapping images computed for each pixel of the orthomosaic. Red and yellow areas indicate low overlap for which poor results may be generated. Green areas indicate an overlap of over 5 images for every pixel. Good quality results will be generated as long as the number of keypoint matches is also sufficient for these areas (see Figure 5 for keypoint matches).

Bundle Block Adjustment Details

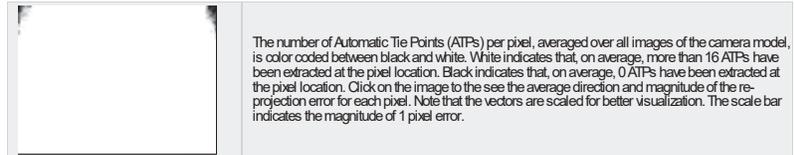
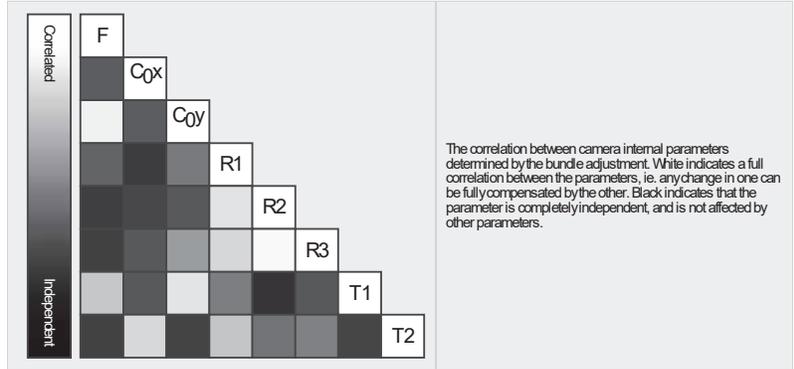
Number of 2D Keypoint Observations for Bundle Block Adjustment	1930454
Number of 3D Points for Bundle Block Adjustment	755748
Mean Reprojection Error [pixels]	0.191

1 Internal Camera Parameters

FC330_3.6_4000x3000 (RGB). Sensor Dimensions: 6.317 [mm] x 4.738 [mm]

EXIF ID: FC330_3.6_4000x3000

	Focal Length	Principal Point x	Principal Point y	R1	R2	R3	T1	T2
Initial Values	2285.722 [pixel] 3.610 [mm]	2000.006 [pixel] 3.159 [mm]	1500.003 [pixel] 2.369 [mm]	-0.001	-0.002	0.000	-0.001	-0.001
Optimized Values	2395.892 [pixel] 3.784 [mm]	1964.143 [pixel] 3.102 [mm]	1461.052 [pixel] 2.308 [mm]	-0.000	-0.004	0.003	0.000	0.000
Uncertainties (Sigma)	0.367 [pixel] 0.001 [mm]	0.071 [pixel] 0.000 [mm]	0.250 [pixel] 0.000 [mm]	0.000	0.000	0.000	0.000	0.000



2D Keypoints Table

	Number of 2D Keypoints per Image	Number of Matched 2D Keypoints per Image
Median	24688	6299
Mn	16147	1260
Max	62279	19671
Mean	32137	7097

3D Points from 2D Keypoint Matches

	Number of 3D Points Observed
In 2 Images	544620
In 3 Images	118960
In 4 Images	44995
In 5 Images	21208
In 6 Images	10594
In 7 Images	5855
In 8 Images	3431
In 9 Images	2176
In 10 Images	1328
In 11 Images	841
In 12 Images	522
In 13 Images	411
In 14 Images	291
In 15 Images	182
In 16 Images	131
In 17 Images	89
In 18 Images	49
In 19 Images	32
In 20 Images	18
In 21 Images	4
In 22 Images	7
In 23 Images	2
In 24 Images	2

2D Keypoint Matches

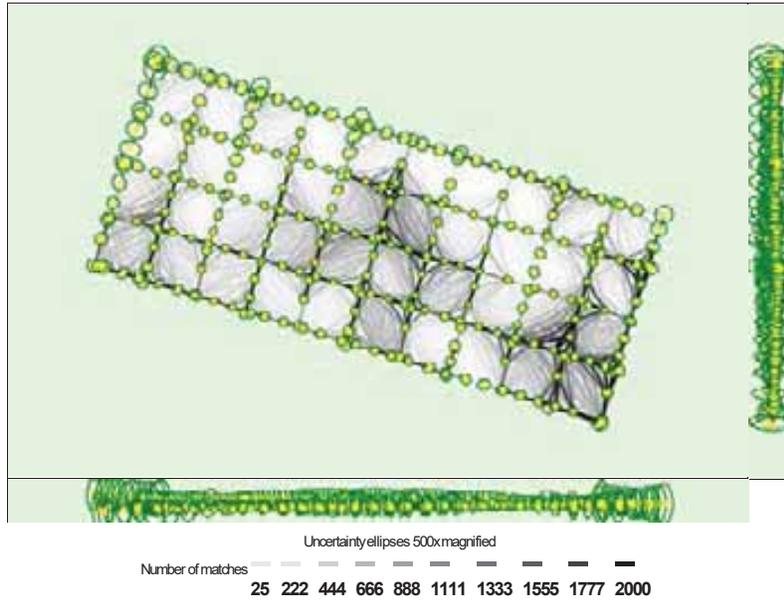


Figure 5: Computed image positions with links between matched images. The darkness of the links indicates the number of matched 2D keypoints between the images. Bright links indicate weak links and require manual tie points or more images. Dark green ellipses indicate the relative camera position uncertainty of the bundle block adjustment result.

Relative camera position and orientation uncertainties

	X[m]	Y[m]	Z[m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.004	0.004	0.006	0.010	0.013	0.006
Sigma	0.001	0.001	0.003	0.003	0.005	0.002

Geolocation Details

Absolute Geolocation Variance

Min Error [m]	Max Error [m]	Geolocation Error X[%]	Geolocation Error Y[%]	Geolocation Error Z[%]
-	-15.00	0.00	0.00	0.00
-15.00	-12.00	0.00	0.00	0.00
-12.00	-9.00	0.00	0.00	0.00
-9.00	-6.00	0.00	0.00	0.00
-6.00	-3.00	1.10	0.00	0.37
-3.00	0.00	43.38	47.79	45.59
0.00	3.00	55.51	52.21	54.04
3.00	6.00	0.00	0.00	0.00
6.00	9.00	0.00	0.00	0.00
9.00	12.00	0.00	0.00	0.00
12.00	15.00	0.00	0.00	0.00
15.00	-	0.00	0.00	0.00
Mean [m]		0.000007	0.000004	-0.000036
Sigma [m]		1.071698	0.955515	1.427383
RMS Error [m]		1.071698	0.955515	1.427383

Min Error and Max Error represent geolocation error intervals between -1.5 and 1.5 times the maximum accuracy of all the images. Columns X, Y, Z show the percentage of images with geolocation errors within the predefined error intervals. The geolocation error is the difference between the initial and computed image positions. Note that the image geolocation errors do not correspond to the accuracy of the observed 3D points.

Relative Geolocation Variance

Relative Geolocation Error	Images X[%]	Images Y[%]	Images Z[%]
[-1.00, 1.00]	100.00	100.00	100.00
[-2.00, 2.00]	100.00	100.00	100.00
[-3.00, 3.00]	100.00	100.00	100.00

Mean of Geolocation Accuracy [m]	5.000000	5.000000	10.000000
Sigma of Geolocation Accuracy [m]	0.000000	0.000000	0.000000

Images X, Y, Z represent the percentage of images with a relative geolocation error in X, Y, Z.

Geolocation Orientational Variance	RMS [degree]
Omega	2.108
Phi	1.772
Kappa	2.567

Geolocation RMS error of the orientation angles given by the difference between the initial and computed image orientation angles.

Initial Processing Details

System Information

Hardware	CPU: Intel(R) Core(TM) i5-3330S CPU @2.70GHz RAM: 8GB GPU: Intel(R) HD Graphics (Driver: 10.18.10.3412), RDPDD Chained DD (Driver: unknown), RDP Encoder Mirror Driver (Driver: unknown), RDP Reflector Display Driver (Driver: unknown)
Operating System	Windows 7 Professional, 64-bit

Coordinate Systems

Image Coordinate System	WGS84 (egm96)
Output Coordinate System	WGS 84 / UTMzone 19N (egm96)

Processing Options

Detected Template	3D Maps
Keypoints Image Scale	Full, Image Scale: 1
Advanced: Matching Image Pairs	Aerial Grid or Corridor
Advanced: Matching Strategy	Use Geometrically Verified Matching: no
Advanced: Keypoint Extraction	Targeted Number of Keypoints: Automatic
Advanced: Calibration	Calibration Method: Standard Internal Parameters Optimization: All External Parameters Optimization: All Rematch: Auto, yes

Point Cloud Densification details

Processing Options

Image Scale	multiscale, 1/2 (Half image size, Default)
Point Density	Optimal
Minimum Number of Matches	3
3D Textured Mesh Generation	yes
3D Textured Mesh Settings:	Resolution: Medium Resolution (default) Color Balancing: no
LOD	Generated: no
Advanced: 3D Textured Mesh Settings	Sample Density Divider: 1
Advanced: Image Groups	group1
Advanced: Use Processing Area	yes
Advanced: Use Annotations	yes
Time for Point Cloud Densification	01h:47m:41s
Time for Point Cloud Classification	NA
Time for 3D Textured Mesh Generation	23m:42s

Results

Number of Processed Clusters	2
Number of Generated Tiles	1
Number of 3D Densified Points	20850332
Average Density (per m ³)	2002.02

DSM, Orthomosaic and Index Details

Processing Options



DSM and Orthomosaic Resolution	1 x GSD (1.26 [cm/pixel])
DSM Filters	Noise Filtering: yes Surface Smoothing: yes, Type: Sharp
Raster DSM	Generated: yes Method: Inverse Distance Weighting Merge Tiles: yes
Orthomosaic	Generated: yes Merge Tiles: yes GeoTIFF Without Transparency: no Google Maps Tiles and KML: no
Time for DSM Generation	31m:09s
Time for Orthomosaic Generation	48m:20s
Time for DTM Generation	00s
Time for Contour Lines Generation	00s
Time for Reflectance Map Generation	00s
Time for Index Map Generation	00s

Site name:

Costa norte, Hatillo (Highly populated area)



A. Physical address:

Costa Norte housing complex, PR 4490, Hatillo, Puerto Rico, 00659.

B. Date of capture of imagery:

March 15, 2018

C. Coordinates:

18.49169953 N – 66.78509576 W

D. Description of site:

This site consists of a segment of rocky beach behind the densely populated Costa Norte housing complex which is adjacent to road PR 2 in the municipality of Hatillo. The eastern portion of this area was heavily eroded by rain runoff during the 2017 hurricane season. The primary dune has several small breaches resulting from lack of vegetation due to heavy foot traffic to the beach.

E. Distance from community:

This site is located at an approximate distance of 80 m from the houses and 413 m from road PR 2. This is an 456 m x 400 m block of houses that is unprotected from extreme wave action because the primary dune is non-existent.

Aerial imagery

i. Contour map



Figure 236. Contour map of the area behind the Costa Norte housing complex, in Hatillo Puerto Rico with elevation intervals of 1 meter.

ii. 3D imagery



Figure 237. Aerial 3D image of the Costa Norte housing complex, Hatillo.

iii. Orthomosaic model



Figure 238. Orthomosaic image of Costa Norte housing complex, Hatillo.

iv. Density Surface Models (DSM)

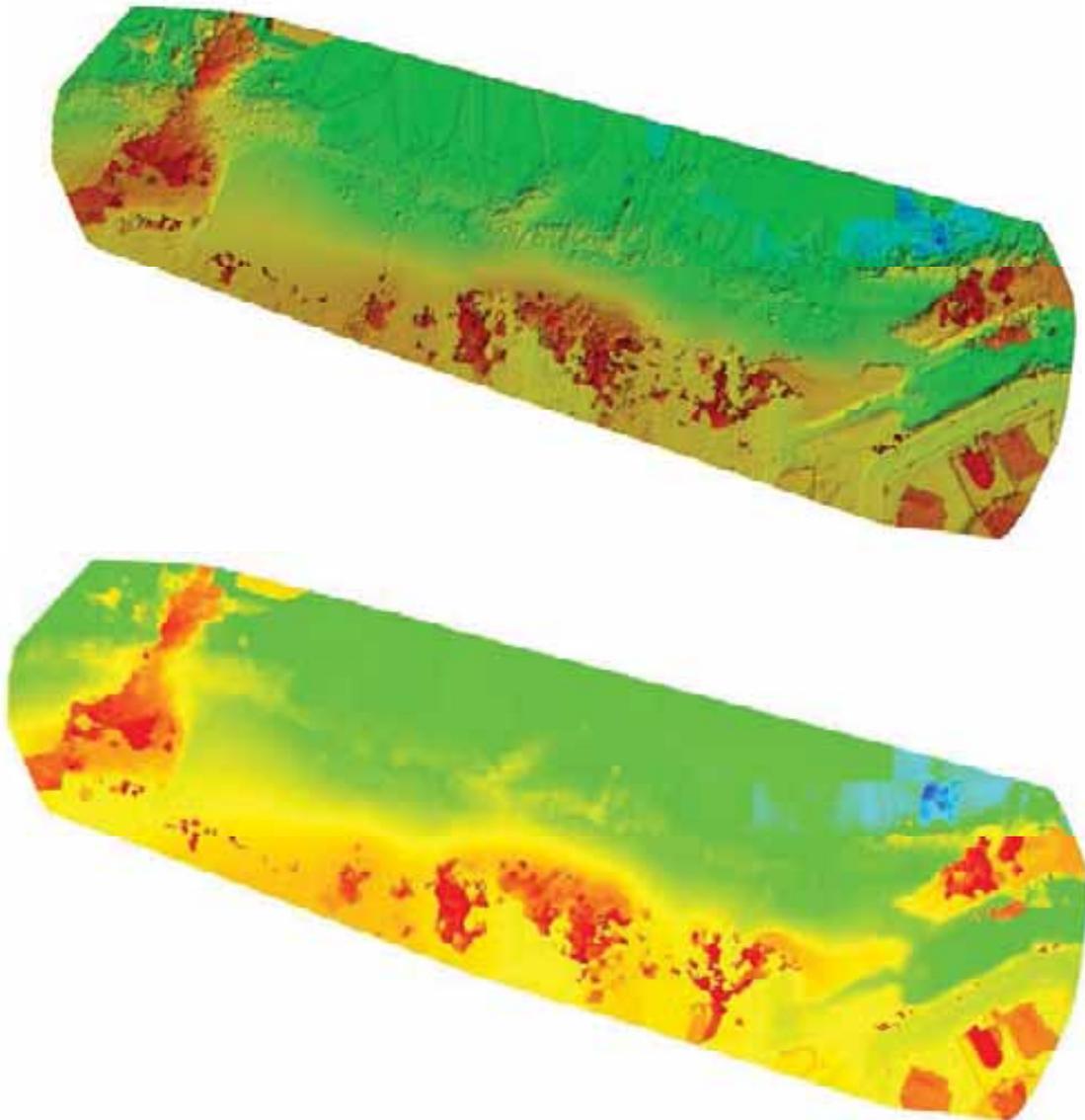


Figure 239. Density surface model (with shading top and without shading bottom) images of the dune located on the Costa Norte housing complex, Hatillo.

v. Thermal images

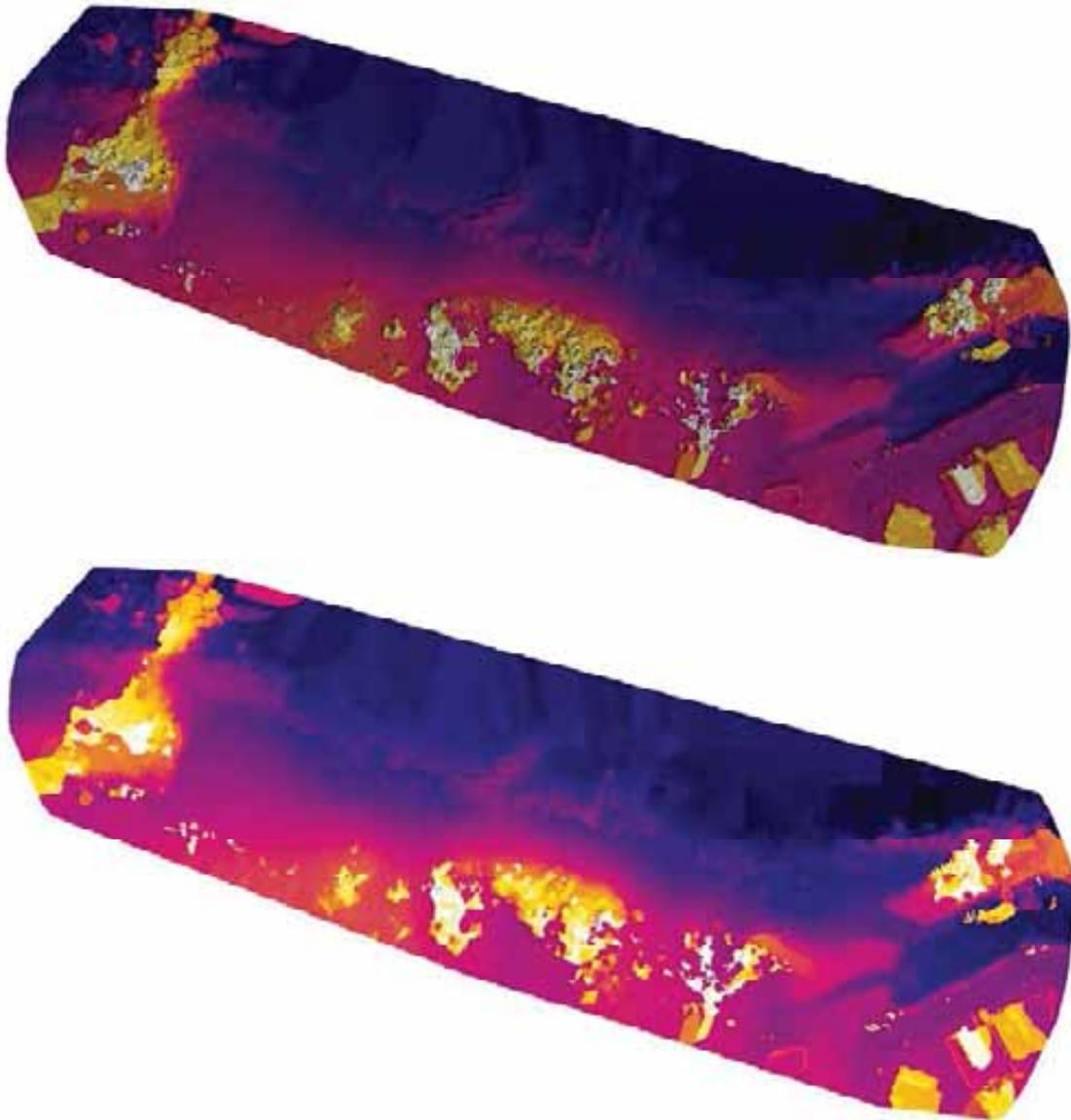


Figure 240. Thermal images (with shading top and without shading bottom) of the Costa Norte housing complex, Hatillo.

vi. 3D altitude RGB North

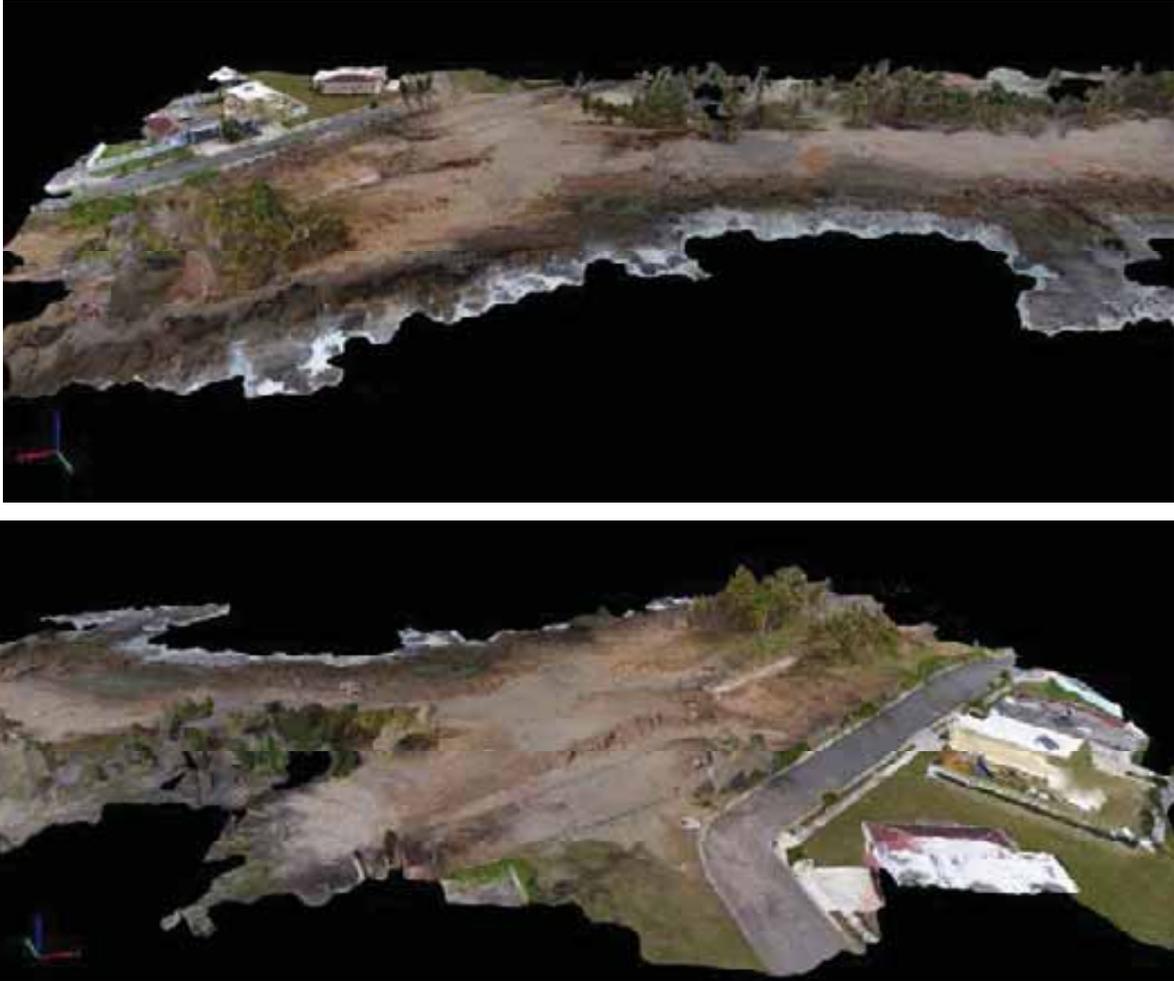


Figure 241. Three dimensional RGB images of the Costa Norte housing complex, Hatillo. View from the northeast (top) and from the southeast of the same area (bottom).

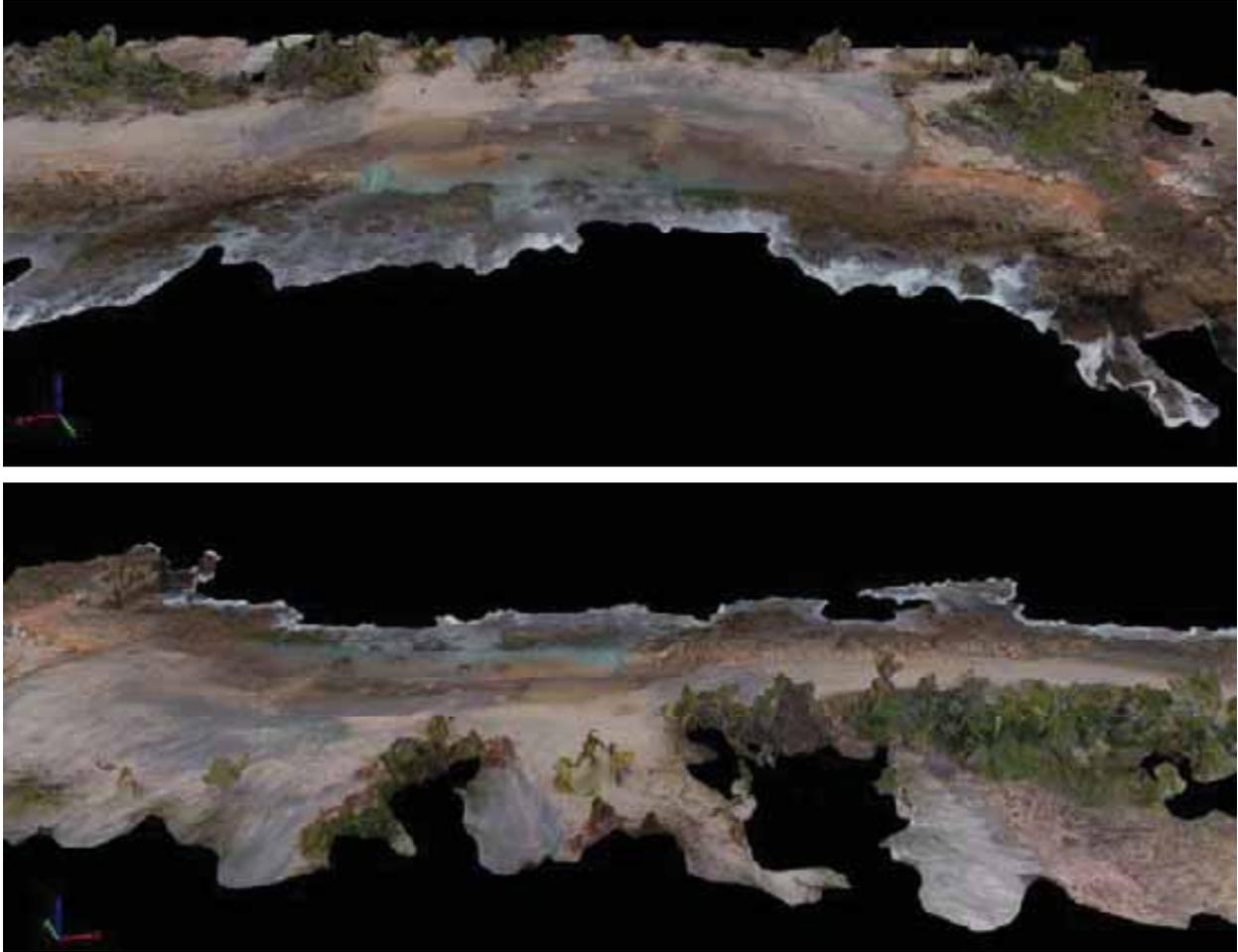


Figure 242. Three dimensional RGB images of the Costa Norte housing complex, Hatillo. View from the north (top) and from the south of the same area (bottom).

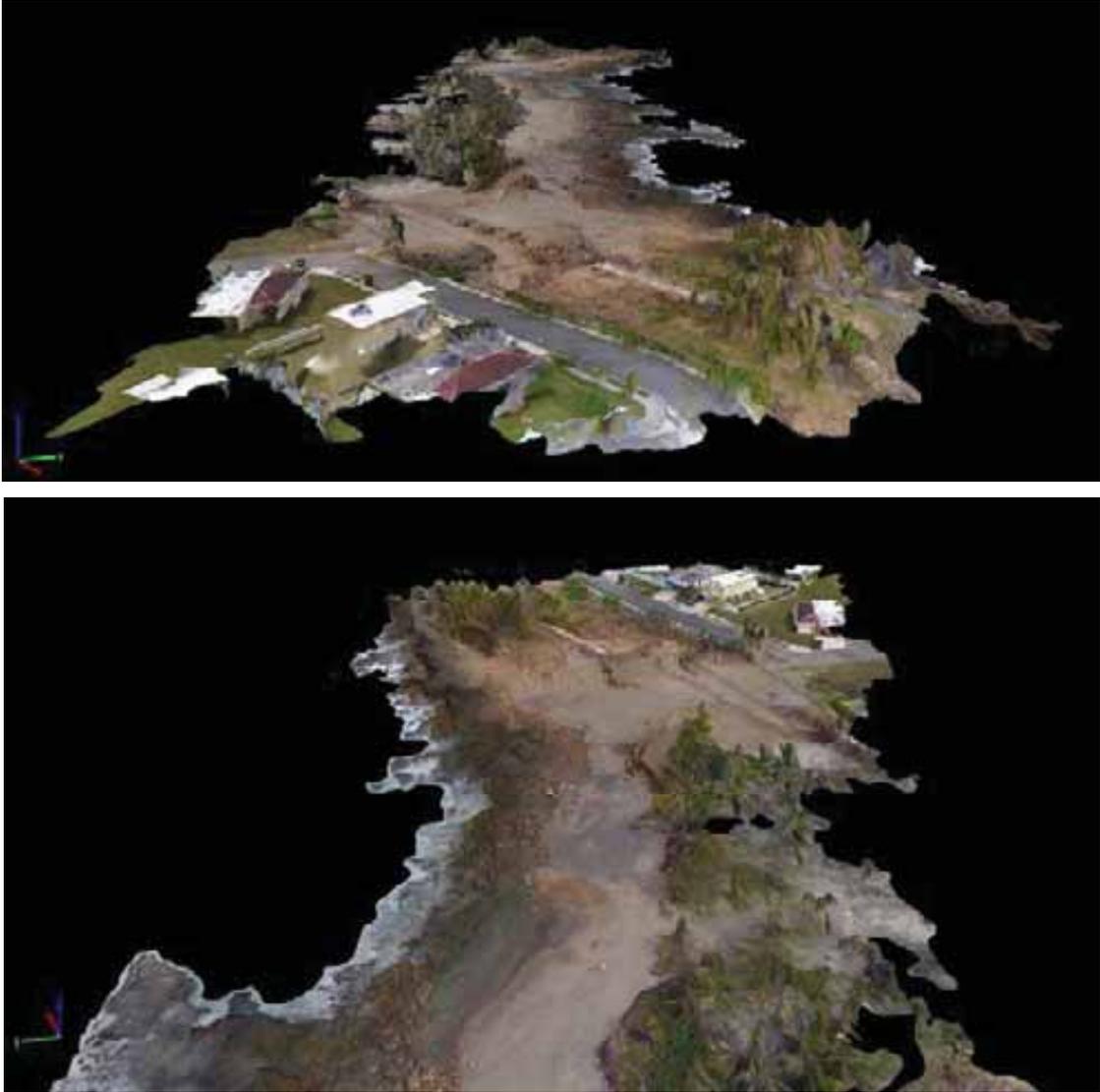


Figure 243. Three dimensional RGB images of the Costa Norte housing complex, Hatillo. View from the east (top) and from the west of the same area (bottom).

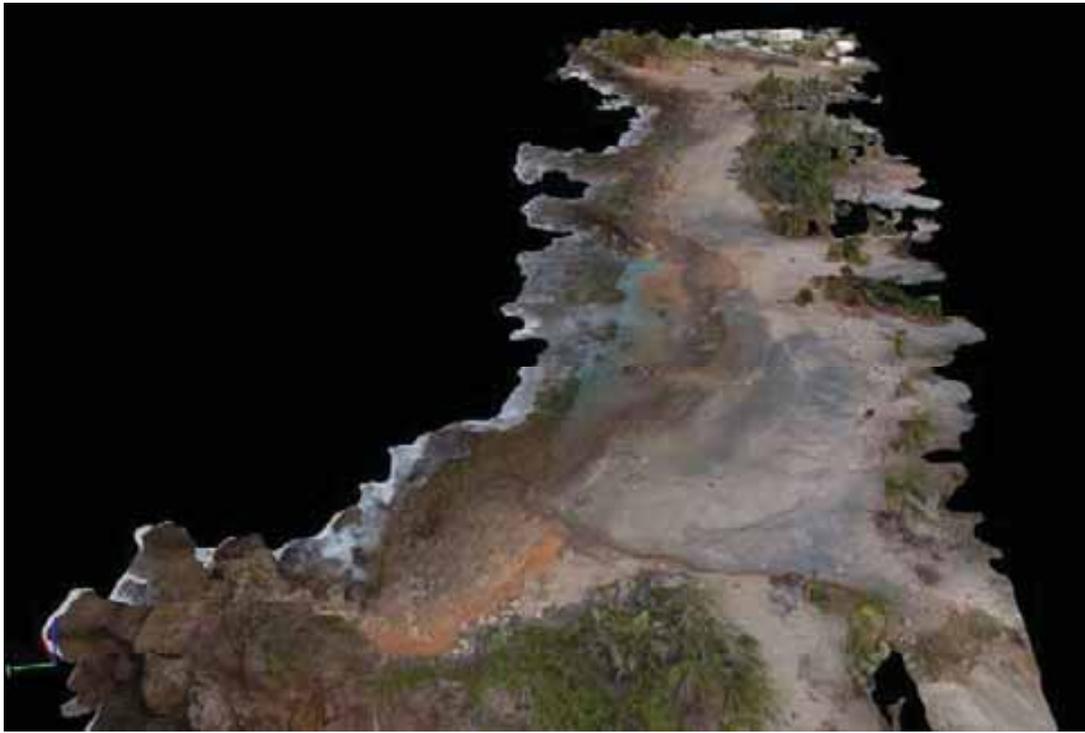


Figure 244. Three dimensional RGB images of the Costa Norte housing complex, Hatillo. View from the east (top) and from the west of the same area (bottom).

vii. DSM grayscale



Figure 245. Grayscale DSM images of Costa Norte housing complex. The top image shows shades and the bottom is not shaded.

Site report

F. Vegetation cover



Figure 246. Vegetation covered 27.6% of the area of the Costa Norte housing complex on March 15, 2018 (after northeasterly swell).

G. Volume measurements of selected areas of the dunes

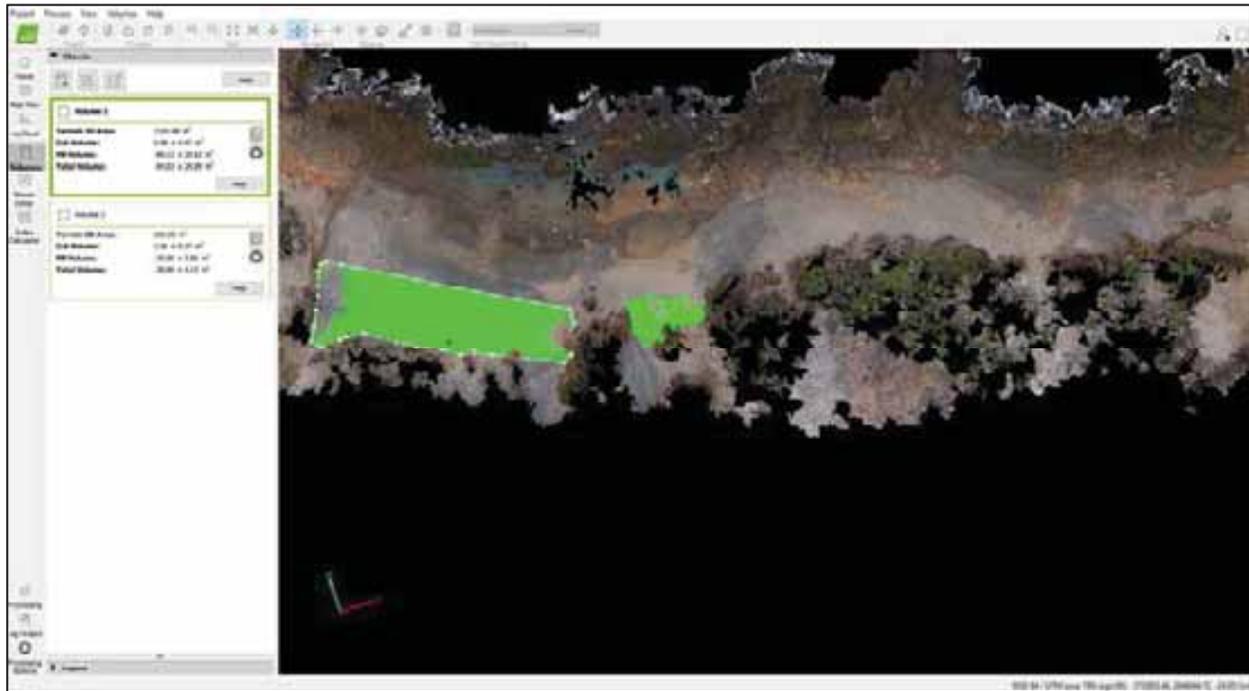


Figure 247. Three dimensional aerial picture of the Costa Norte, Hatillo with two areas marked by polygons for which three dimensional area, cut volume, fill volume and total volume were calculated using the Pix4D software. Refer to image above for the data. The order of the data is from left to right on the image.

H. Conservation threats

The main conservation threats in this area are heavy foot traffic from residents and visitors of this beach and heavy rainwater runoff on the eastern portion of this area. This area has limited access for the public therefore the incidence of illegal sand extraction or all terrain-vehicle traffic is almost non-existent.

I. Recommended ecological restoration courses of action (COA)

This area needs a wooden boardwalk to re-direct foot traffic from the breached areas. Foot traffic is currently random in this area creating multiple paths on the dune vegetation. Two information signs on the importance of using the boardwalk and on the importance of ecological restoration of dunes will be installed. Several matrices of biomimicry setups will be installed to promote sand accumulation in the area. The areas of sand accumulation will be stabilized with dune vegetation and the area of high rain runoff will be stabilized with vetiver grass.



Figure 248. Area to be ecologically restored behind the Costa Norte housing complex in Hatillo, Puerto Rico. Highlighted areas correspond to each technique that will be used in this area. Yellow represents the location of a wooden boardwalk, the red dot marks the location of an information sign, dark green marks the location of dune vegetation, light green marks the location of vetiver grass, tan represents the area of the dune crest that where biomimicry matrices will be installed to promote the accumulation of sand. The areas shaded in light green represent locations for the planting of dune vegetation.

J. Pix 4D Quality Report

Quality Report



Generated with Pix4Dmapper Pro version 4.2.26

Important: Click on the different icons for:

- Help to analyze the results in the Quality Report
- Additional information about the sections

Click [here](#) for additional tips to analyze the Quality Report

Summary

Project	Hatillo Costa Norte
Processed	2018-05-05 18:17:39
Camera Model Name(s)	FC330_3.6_4000x3000 (RGB)
Average Ground Sampling Distance (GSD)	1.67 cm / 0.66 in
Area Covered	0.049 km ² / 4.8721 ha / 0.02 sq. mi. / 12.0454 acres
Time for Initial Processing (without report)	04m:35s

Quality Check

Images	median of 34661 keypoints per image	
Dataset	195 out of 203 images calibrated (96%), all images enabled	
Camera Optimization	4.32% relative difference between initial and optimized internal camera parameters	
Matching	median of 7237.22 matches per calibrated image	
Georeferencing	yes, no 3D GCP	

Preview

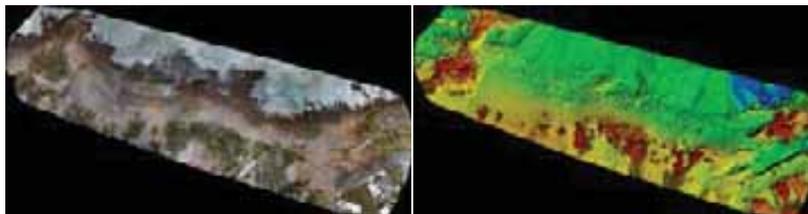


Figure 1: Orthomosaic and the corresponding sparse Digital Surface Model (DSM) before densification.

Calibration Details

Number of Calibrated Images	195 out of 203
Number of Geolocated Images	203 out of 203

Initial Image Positions

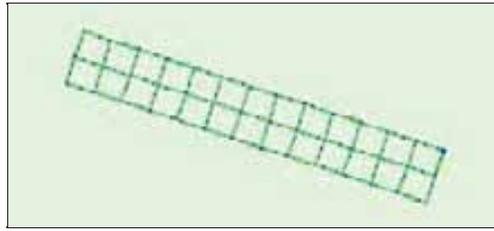


Figure 2: Top view of the initial image position. The green line follows the position of the images in time starting from the large blue dot.

Computed Image/GCPs/Manual Tie Points Positions

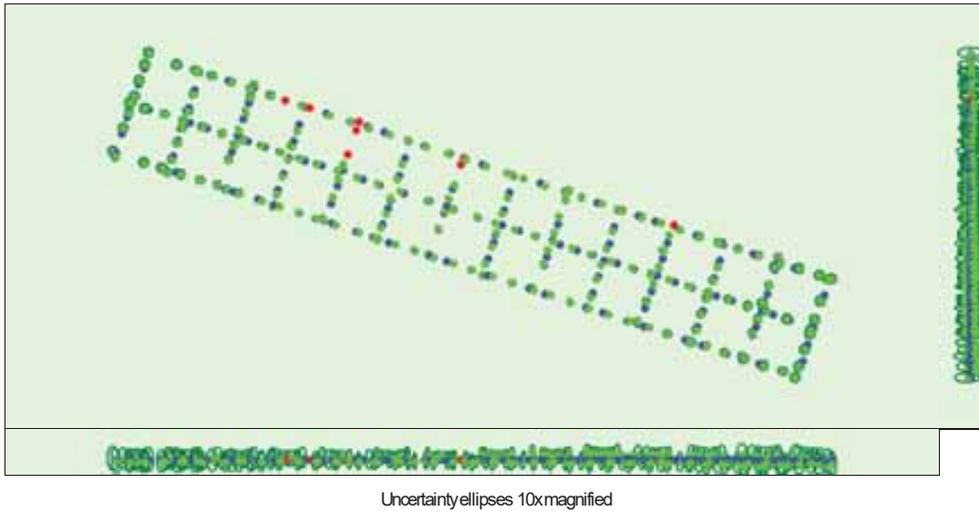


Figure 3: Offset between initial (blue dots) and computed (green dots) image positions as well as the offset between the GCPs initial positions (blue crosses) and their computed positions (green crosses) in the top-view (XY plane), front-view (XZ plane), and side-view (YZ plane). Red dots indicate disabled or uncalibrated images. Dark green ellipses indicate the absolute position uncertainty of the bundle block adjustment result.

Absolute camera position and orientation uncertainties

	X[m]	Y[m]	Z[m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.172	0.173	0.420	0.713	0.261	0.133
Sigma	0.037	0.037	0.088	0.023	0.048	0.027

Overlap

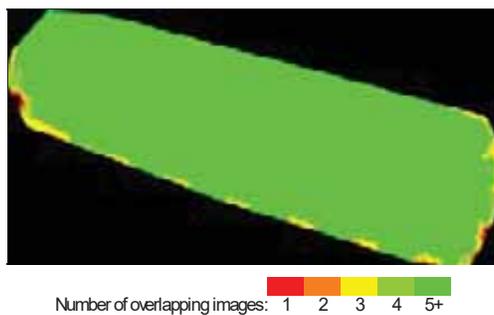


Figure 4: Number of overlapping images computed for each pixel of the orthomosaic.

Red and yellow areas indicate low overlap for which poor results may be generated. Green areas indicate an overlap of over 5 images for every pixel. Good quality results will be generated as long as the number of keypoint matches is also sufficient for these areas (see Figure 5 for keypoint matches).

Bundle Block Adjustment Details

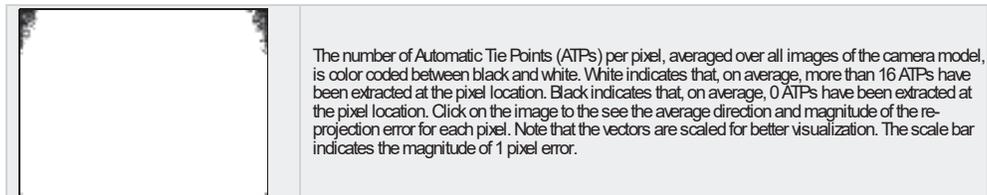
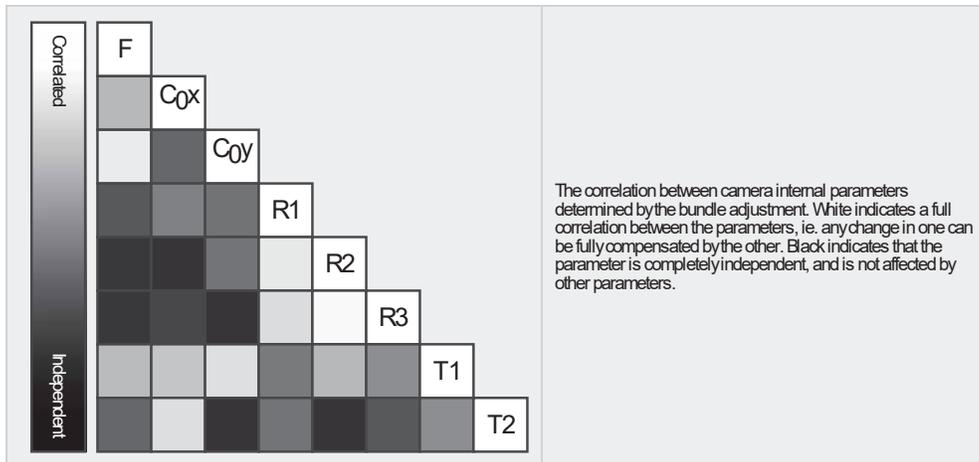
Number of 2D Keypoint Observations for Bundle Block Adjustment	1430426
Number of 3D Points for Bundle Block Adjustment	554886
Mean Reprojection Error [pixels]	0.182

Internal Camera Parameters

FC330_3.6_4000x3000 (RGB). Sensor Dimensions: 6.317 [mm] x 4.738 [mm]

EXIF ID: FC330_3.6_4000x3000

	Focal Length	Principal Point x	Principal Point y	R1	R2	R3	T1	T2
Initial Values	2285.722 [pixel] 3.610 [mm]	2000.006 [pixel] 3.159 [mm]	1500.003 [pixel] 2.369 [mm]	-0.001	-0.002	0.000	-0.001	-0.001
Optimized Values	2384.672 [pixel] 3.766 [mm]	1964.807 [pixel] 3.103 [mm]	1468.719 [pixel] 2.320 [mm]	0.000	-0.005	0.003	0.000	0.000
Uncertainties (Sigma)	0.311 [pixel] 0.000 [mm]	0.073 [pixel] 0.000 [mm]	0.214 [pixel] 0.000 [mm]	0.000	0.000	0.000	0.000	0.000



2D Keypoints Table

	Number of 2D Keypoints per Image	Number of Matched 2D Keypoints per Image
Median	34661	7237
Mn	19449	184
Max	47522	15996
Mean	34291	7336

3D Points from 2D Keypoint Matches

	Number of 3D Points Observed
In 2 Images	392575
In 3 Images	92152
In 4 Images	34550
In 5 Images	16029
In 6 Images	7951
In 7 Images	4286
In 8 Images	2664
In 9 Images	1661
In 10 Images	1029
In 11 Images	620
In 12 Images	415
In 13 Images	293
In 14 Images	205
In 15 Images	144
In 16 Images	109
In 17 Images	67
In 18 Images	48
In 19 Images	27
In 20 Images	24
In 21 Images	13
In 22 Images	9
In 23 Images	7
In 24 Images	2
In 25 Images	1
In 26 Images	4
In 28 Images	1

2D Keypoint Matches

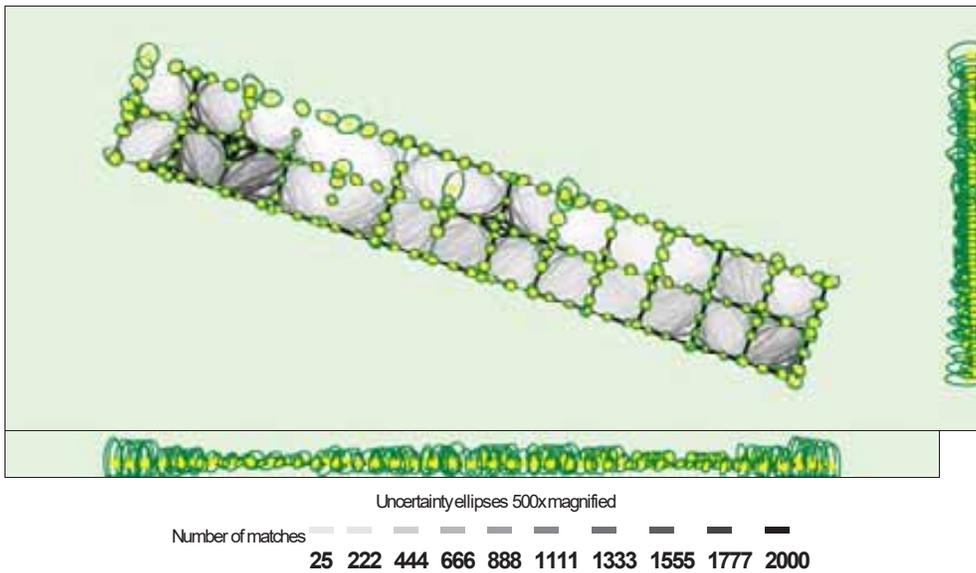


Figure 5: Computed image positions with links between matched images. The darkness of the links indicates the number of matched 2D keypoints between the images. Bright links indicate weak links and require manual tie points or more images. Dark green ellipses indicate the relative camera position uncertainty of the bundle block adjustment result.

Relative camera position and orientation uncertainties

	X[m]	Y[m]	Z[m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.006	0.005	0.010	0.009	0.013	0.007
Sigma	0.002	0.002	0.005	0.003	0.005	0.002

Geolocation Details

Absolute Geolocation Variance

Mn Error [m]	MaxError [m]	Geolocation Error X[%]	Geolocation Error Y[%]	Geolocation Error Z[%]
-	-15.00	0.00	0.00	0.00
-15.00	-12.00	0.00	0.00	0.00
-12.00	-9.00	0.00	0.00	0.00
-9.00	-6.00	0.00	0.00	0.00
-6.00	-3.00	1.03	7.69	0.00
-3.00	0.00	45.64	40.00	47.18
0.00	3.00	50.77	51.28	52.82
3.00	6.00	2.56	1.03	0.00
6.00	9.00	0.00	0.00	0.00
9.00	12.00	0.00	0.00	0.00
12.00	15.00	0.00	0.00	0.00
15.00	-	0.00	0.00	0.00
Mean [m]		-0.008237	0.006325	0.003643
Sigma [m]		1.342162	1.525894	1.368781
RMS Error [m]		1.342188	1.525907	1.368786

Min Error and Max Error represent geolocation error intervals between -1.5 and 1.5 times the maximum accuracy of all the images. Columns X, Y, Z show the percentage of images with geolocation errors within the predefined error intervals. The geolocation error is the difference between the initial and computed image positions. Note that the image geolocation errors do not correspond to the accuracy of the observed 3D points.

Relative Geolocation Variance

Relative Geolocation Error	Images X[%]	Images Y[%]	Images Z[%]
[-1.00, 1.00]	100.00	100.00	100.00
[-2.00, 2.00]	100.00	100.00	100.00
[-3.00, 3.00]	100.00	100.00	100.00
Mean of Geolocation Accuracy [m]	5.000000	5.000000	10.000000
Sigma of Geolocation Accuracy [m]	0.000000	0.000000	0.000000

Images X, Y, Z represent the percentage of images with a relative geolocation error in X, Y, Z.

Geolocation Orientational Variance	RMS [degree]
Omega	2.415
Phi	2.032
Kappa	2.589

Geolocation RMS error of the orientation angles given by the difference between the initial and computed image orientation angles.

Initial Processing Details

System Information

Hardware	CPU: Intel(R) Core(TM) i7-8700K CPU @3.70GHz RAM: 16GB GPU: NVIDIA GeForce GTX 1070 (Driver: 23.21.13.9065)
Operating System	Windows 10 Home, 64-bit

Coordinate Systems

Image Coordinate System	WGS84 (egm96)
Output Coordinate System	WGS 84 / UTM, zone 19N (egm96)

Processing Options

Detected Template	3D Maps
Keypoints Image Scale	Full, Image Scale: 1
Advanced: Matching Image Pairs	Aerial Grid or Corridor
Advanced: Matching Strategy	Use Geometrically Verified Matching: no
Advanced: Keypoint Extraction	Targeted Number of Keypoints: Automatic
Advanced: Calibration	Calibration Method: Standard Internal Parameters Optimization: All External Parameters Optimization: All Rematch: Auto, yes

Point Cloud Densification details

Processing Options

Image Scale	multiscale, 1/2 (Half image size, Default)
Point Density	Optimal
Minimum Number of Matches	3
3D Textured Mesh Generation	yes
3D Textured Mesh Settings:	Resolution: Medium Resolution (default) Color Balancing: no
LOD	Generated: no
Advanced: 3D Textured Mesh Settings	Sample Density/Divider: 1
Advanced: Image Groups	group1
Advanced: Use Processing Area	yes
Advanced: Use Annotations	yes
Time for Point Cloud Densification	09m:32s
Time for Point Cloud Classification	NA
Time for 3D Textured Mesh Generation	04m:30s

Results

Number of Generated Tiles	1
Number of 3D Densified Points	10752344
Average Density (per m ³)	718.61

DSM, Orthomosaic and Index Details

Processing Options

DSM and Orthomosaic Resolution	1 x GSD (1.67 [cm/pixel])
--------------------------------	---------------------------

DSMFilters	Noise Filtering: yes Surface Smoothing: yes, Type: Sharp
Raster DSM	Generated: yes Method: Inverse Distance Weighting Merge Tiles: yes
Orthomosaic	Generated: yes Merge Tiles: yes GeoTIFF Without Transparency: no Google Maps Tiles and KML: no
Time for DSM Generation	07m:10s
Time for Orthomosaic Generation	13m:49s
Time for DTM Generation	00s
Time for Contour Lines Generation	00s
Time for Reflectance Map Generation	00s
Time for Index Map Generation	00s

Site name:

Jarealito Sector, Arecibo (highly populated area)



Physical address:

Jarealito sector, PR 655 Arecibo, Puerto Rico, 00612

Date of capture of imagery:

March 15, 2018

A. Coordinates:

18.48075322 N - 66.69241833W

B. Description of site:

This site consists of a line of primary dune with several breaches on areas that are used as beach accesses. The densely populated neighborhood that is located in this area is at approximately 10 m above sea level.

C. Distance from community:

This site is located at an approximate distance of 20 m from a densely populated neighborhood that is approximately 10 m above sea level.

D. Aerial imagery

i. Contour map



Figure 237. Contour map of Jarealito 1st spot, Arecibo, Puerto Rico with elevation intervals of 1 meter.

ii. 3D imagery



Figure 238. Aerial 3D image of Jarealito Sector, Arecibo.

ii. Orthomosaic model



Figure 239. Orthomosaic image of Jarealito Sector, Arecibo.

ii. Density Surface Models (DSM)

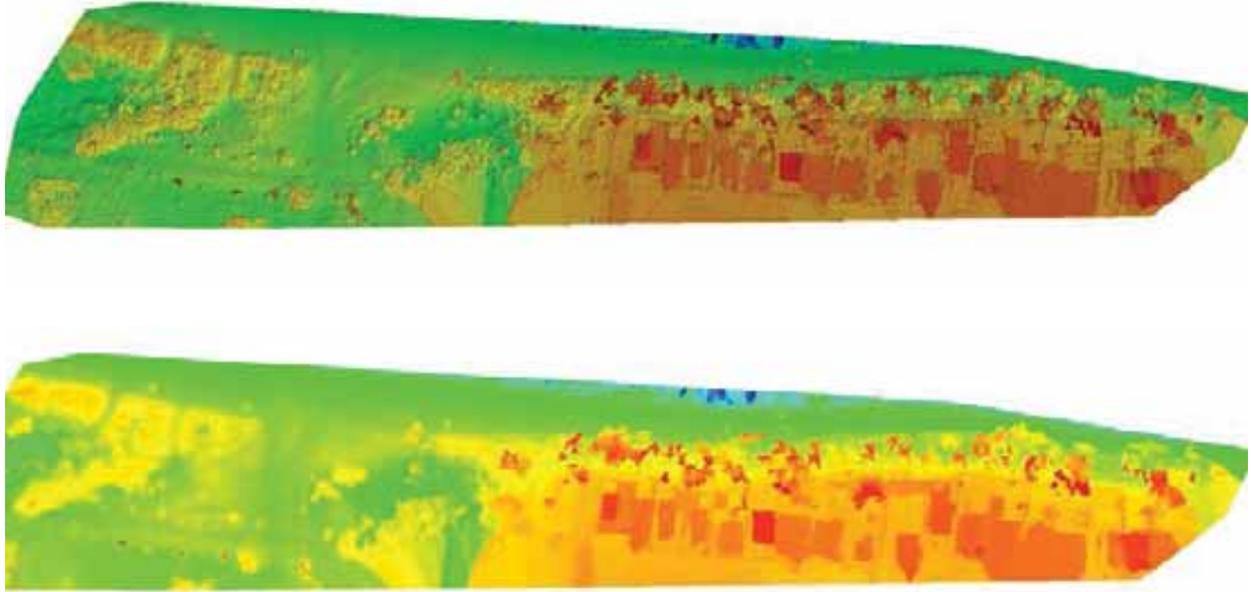


Figure 240. Density surface model (with shading top and without shading bottom) images of the dune located at Jarealito Sector, Arcibo

iii. Thermal images

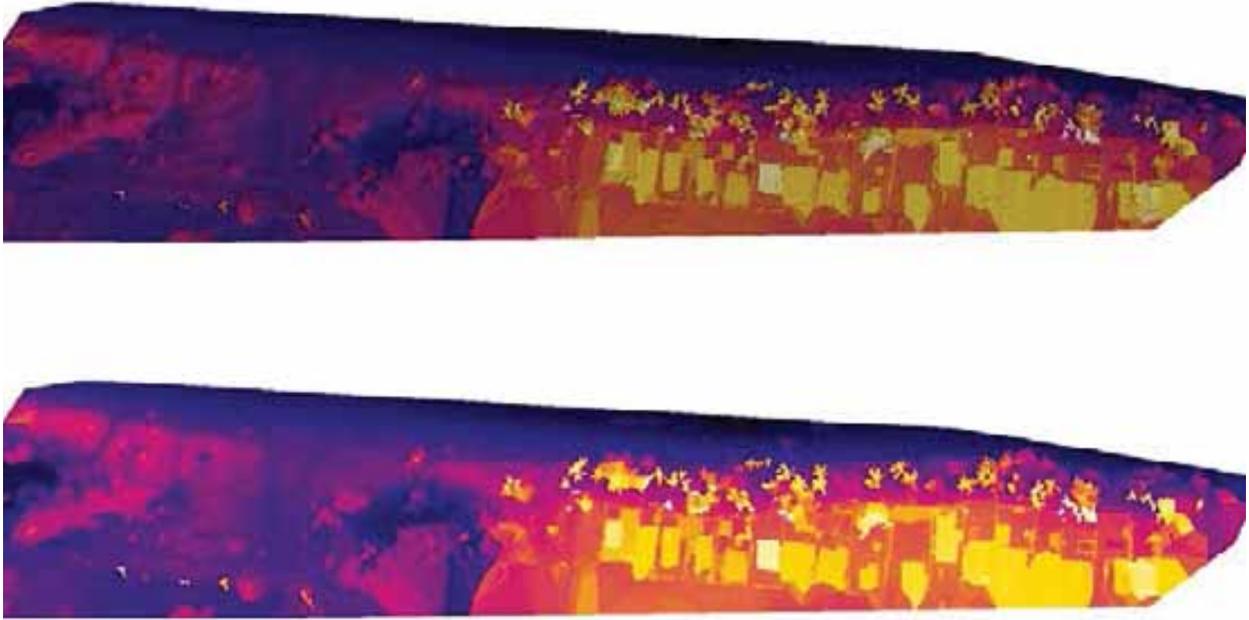


Figure 241. Thermal images (with shading top and without shading bottom) of the dune located at Jarealito Sector, Arcibo

iii. 3D altitude RGB North



Figure 242. Three dimensional RGB images of Jarealito Sector, Arecibo. View from the north (top) and from the south (bottom).



Figure 243. Three dimensional RGB images of the eastern portion of the Jarealito Sector, Arecibo. View from the north (top) and from the south (bottom).

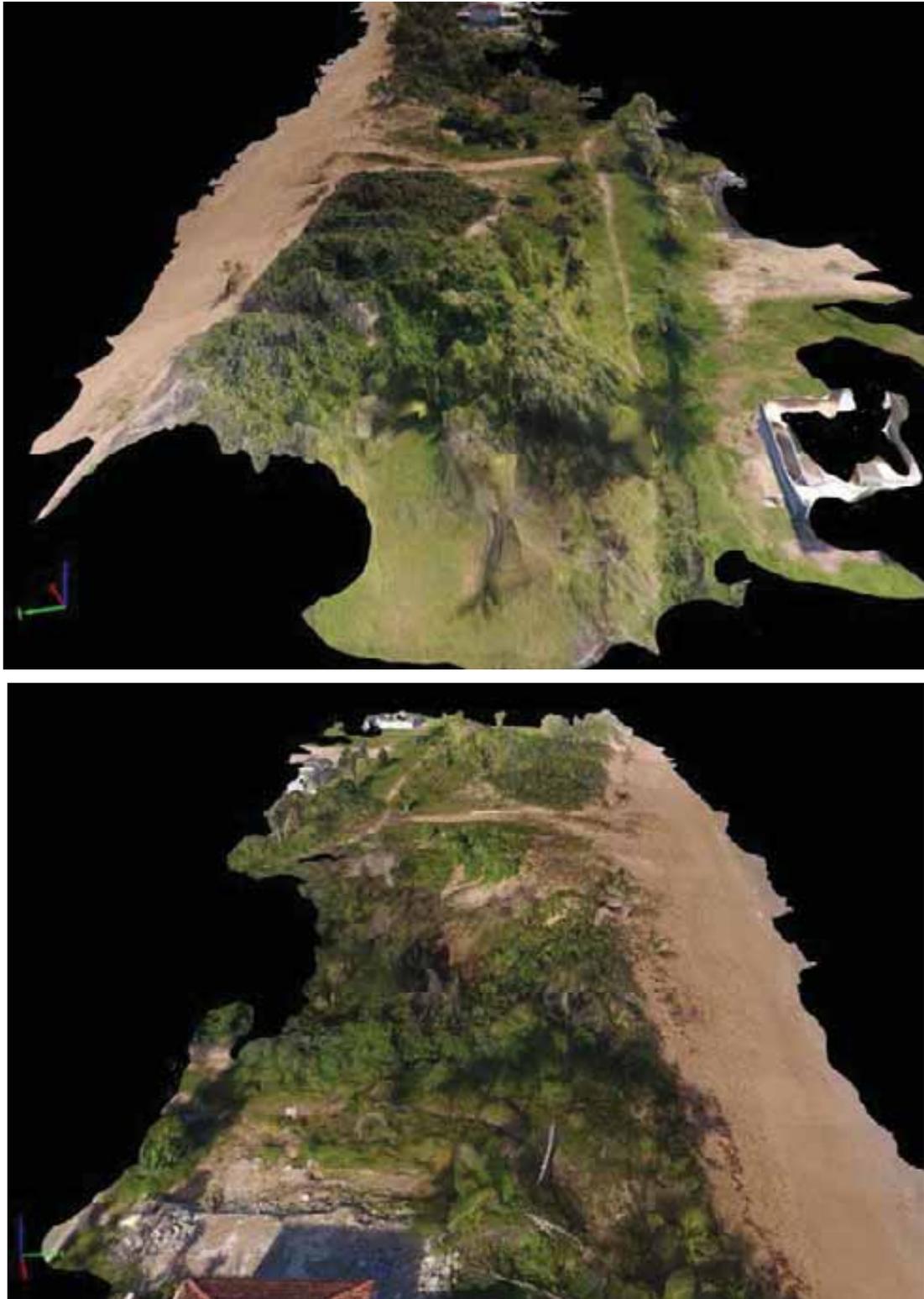


Figure 244. Three dimensional RGB images of Jarealito sector, Arecibo. View from the west (top) and from the east (bottom).



Figure 245. Three dimensional RGB images of Jarealito sector, Arcibo. View from the west (top) and from the east (bottom).

iv. DSM grayscale



Figure 246. Grayscale DSM images of the dune at Jarealito sector, Arecibo. The top image shows shades and the bottom is not shaded.

v. On the ground pictures



Figure 247. Trail from populated area to the beach. This is located on the western part of the site.

Site report

F. Vegetation cover



Figure 248. Vegetation covered 68.4% of the area to the west of the Jarealito Sector on the picture on top and 38.7% of the east of the area of Jarealito Sector in Arecibo, Puerto Rico on March 15, 2018 (after northeasterly swell).

G. Volume measurements of selected areas of the dunes

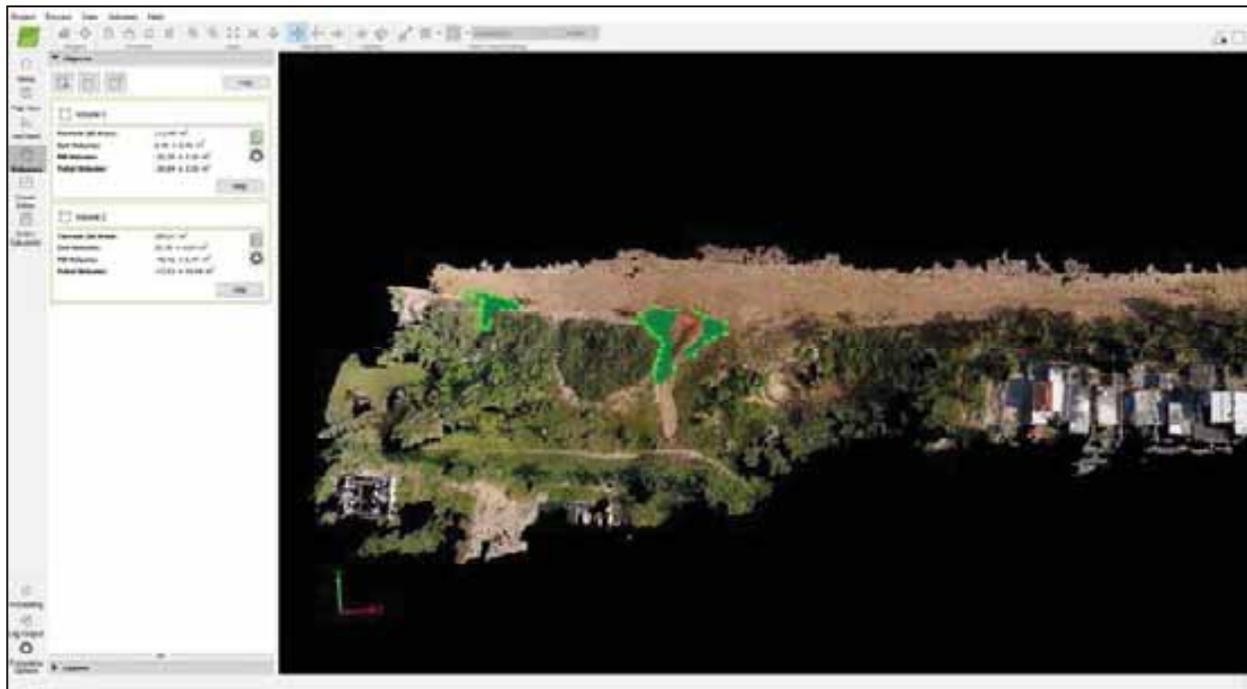


Figure 248. Three dimensional aerial picture of the Costa Norte, Hatillo with two areas marked by polygons for which three dimensional area, cut volume, fill volume and total volume were calculated using the Pix4D software. Refer to image above for the data. The order of the data is from left to right on the image.

H. Conservation threats

The primary threats in this area are foot traffic on the fore dune area and through paths that are used as beach accesses by locals and beachgoers. There is also an area that was eroded by rain runoff during the 2017 hurricane season. This is the main beach access on this site.

I. Recommended ecological restoration courses of action (COA)

We recommend the planting of vetiver grass on the back dune area of the main path (see image below) to stabilize the area and protect it from rain runoff. We also recommend to install a wooden boardwalk on this path to re-direct people away from the sensitive areas. Dune vegetation will be planted on both sides of the boardwalk and biomimicry matrices will be installed on the fore dune area on both sides of the boardwalk. We also recommend re-vegetating the foredune area to the east of the future boardwalk with dune vegetation.



Figure 249. Area to be ecologically restored behind the Costa Norte housing complex in Hatillo, Puerto Rico. Highlighted areas correspond to each technique that will be used in this area. **Yellow** represents the location of a wooden boardwalk, the **red dot** marks the location of an information sign, **dark green** marks the location of dune vegetation, **light green** marks the location of vetiver grass, tan represents the area of the dune crest that where biomimicry matrices will be installed to promote the accumulation of sand. The areas shaded in light green represent locations for the planting of dune vegetation.

J. Pix 4D Quality Report

Generated with Pix4Dmapper Pro version 4.2.25

Quality Report

! Important: Click on the different icons for:

- ?** Help to analyze the results in the Quality Report
- i** Additional information about the sections

💡 Click [here](#) for additional tips to analyze the Quality Report

Summary

Project	Jarealito Arecibo Seccion 1
Processed	2018-03-28 14:23:45
Camera Model Name(s)	FC330_3.6_4000x3000 (RGB)
Average Ground Sampling Distance (GSD)	1.87 cm / 0.74 in
Area Covered	0.034 km ² / 3.4124 ha / 0.01 sq. mi. / 8.4367 acres
Time for Initial Processing (without report)	01h:03m:03s

Quality Check

? Images	median of 39171 keypoints per image	✓
? Dataset	176 out of 178 images calibrated (98%), all images enabled	✓
? Camera Optimization	2.14% relative difference between initial and optimized internal camera parameters	✓
? Matching	median of 6397.61 matches per calibrated image	✓
? Georeferencing	yes, no 3D GCP	⚠

? Preview

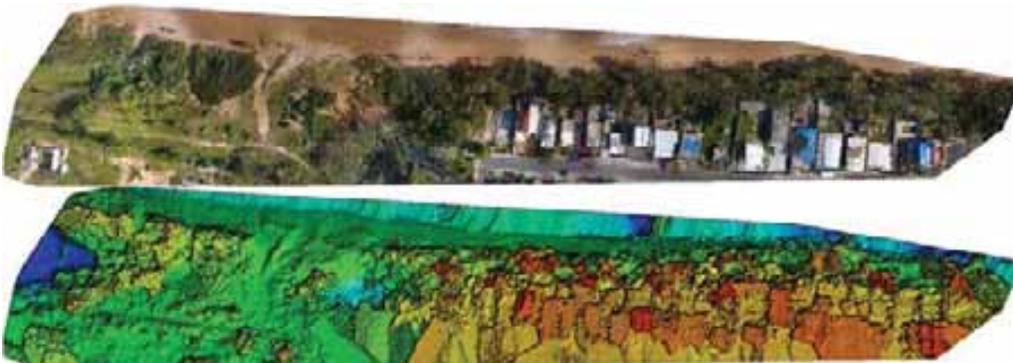


Figure 1: Orthomosaic and the corresponding sparse Digital Surface Model (DSM) before densification.

Calibration Details

Number of Calibrated Images	176 out of 178
Number of Geolocated Images	178 out of 178

Initial Image Positions

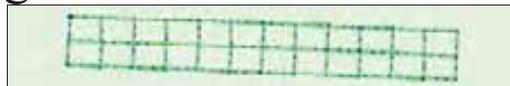


Figure 2: Top view of the initial image position. The green line follows the position of the images in time starting from the large blue dot.

Computed Image/GCPs/Manual Tie Points Positions

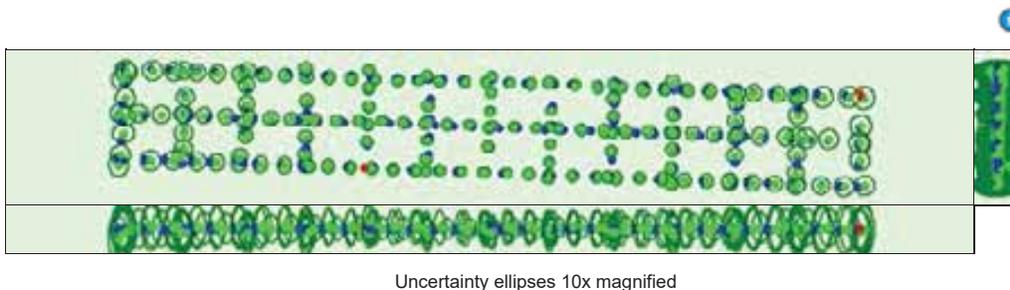


Figure 3: Offset between initial (blue dots) and computed (green dots) image positions as well as the offset between the GCPs initial positions (blue crosses) and their computed positions (green crosses) in the top-view (XY plane), front-view (XZ plane), and side-view (YZ plane). Red dots indicate disabled or uncalibrated images. Dark green ellipses indicate the absolute position uncertainty of the bundle block adjustment result.

Absolute camera position and orientation uncertainties

	X [m]	Y [m]	Z [m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.356	0.357	0.870	1.736	0.431	0.417
Sigma	0.078	0.078	0.181	0.167	0.153	0.393

Overlap

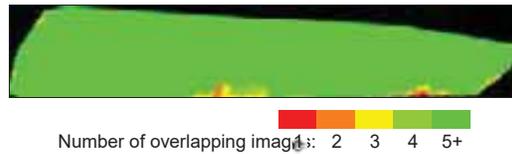


Figure 4: Number of overlapping images computed for each pixel of the orthomosaic. Red and yellow areas indicate low overlap for which poor results may be generated. Green areas indicate an overlap of over 5 images for every pixel. Good quality results will be generated as long as the number of keypoint matches is also sufficient for these areas (see Figure 5 for keypoint matches).

Bundle Block Adjustment Details

Number of 2D Keypoint Observations for Bundle Block Adjustment	1342829
Number of 3D Points for Bundle Block Adjustment	489082
Mean Reprojection Error [pixels]	0.379

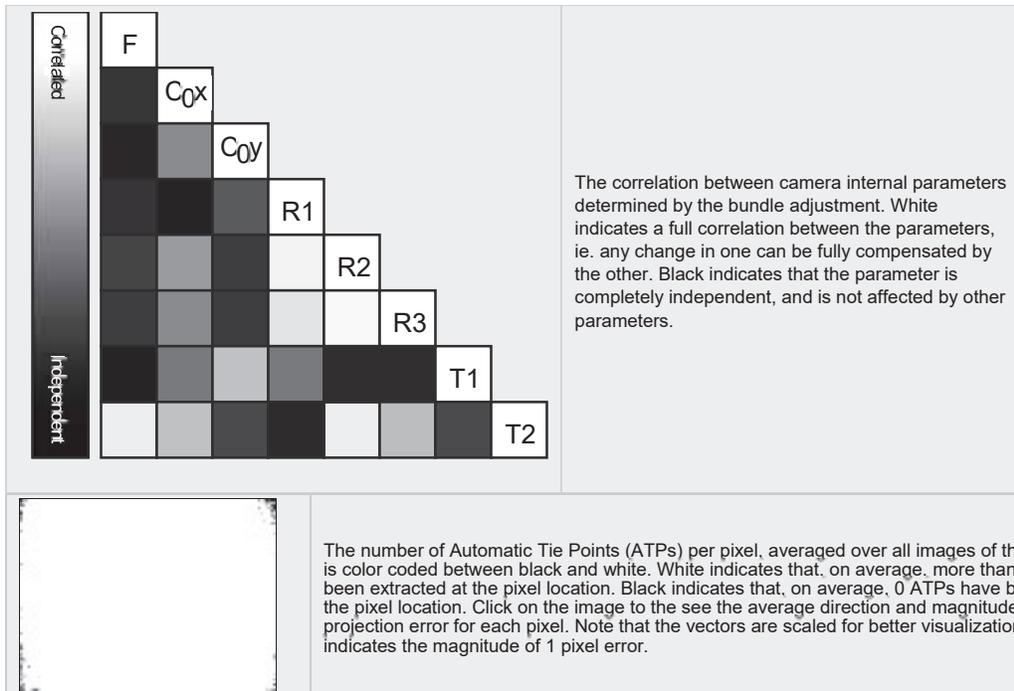


Internal Camera Parameters FC330_3.6_4000x3000 (RGB). Sensor Dimensions: 6.317 [mm] x 4.738 [mm]



EXIF ID: FC330_3.6_4000x3000

	Focal Length	Principal Point x	Principal Point y	R1	R2	R3	T1	T2
Initial Values	2285.722 [pixel] 3.610 [mm]	2000.006 [pixel] 3.159 [mm]	1500.003 [pixel] 2.369 [mm]	-0.001	-0.002	0.000	-0.001	-0.001
Optimized Values	2334.750 [pixel] 3.687 [mm]	1982.210 [pixel] 3.131 [mm]	1505.081 [pixel] 2.377 [mm]	0.001	-0.012	0.008	0.000	-0.000
Uncertainties (Sigma)	0.230 [pixel] 0.000 [mm]	0.154 [pixel] 0.000 [mm]	0.140 [pixel] 0.000 [mm]	0.000	0.000	0.000	0.000	0.000



2D Keypoints Table

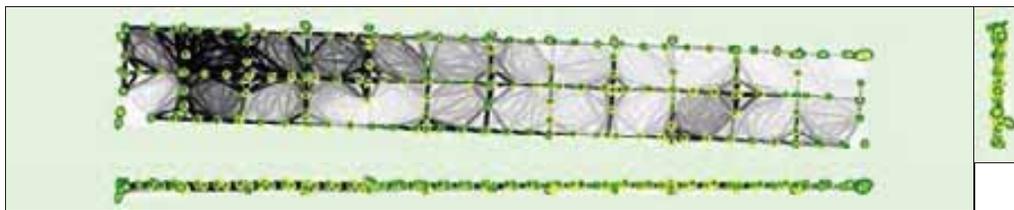
	Number of 2D Keypoints per Image	Number of Matched 2D Keypoints per Image
Median	39171	6398
Min	23584	253
Max	62930	26385
Mean	40920	7630

3D Points from 2D Keypoint Matches

	Number of 3D Points Observed
In 2 Images	337683
In 3 Images	75590
In 4 Images	31521
In 5 Images	15767
In 6 Images	9301
In 7 Images	5947
In 8 Images	3845
In 9 Images	2613
In 10 Images	1901
In 11 Images	1388
In 12 Images	1078
In 13 Images	760
In 14 Images	530
In 15 Images	369

In 16 Images	259
In 17 Images	205
In 18 Images	112
In 19 Images	83
In 20 Images	51
In 21 Images	28
In 22 Images	22
In 23 Images	13
In 24 Images	8
In 25 Images	3
In 26 Images	2
In 27 Images	3

2D Keypoint Matches



Uncertainty ellipses 100x magnified

Number of matches

25 222 444 666 888 1111 1333 1555 1777 2000

Figure 5: Computed image positions with links between matched images. The darkness of the links indicates the number of matched 2D keypoints between the images. Bright links indicate weak links and require manual tie points or more images. Dark green ellipses indicate the relative camera position uncertainty of the bundle block adjustment result.

Relative camera position and orientation uncertainties

	X [m]	Y [m]	Z [m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.013	0.011	0.012	0.015	0.017	0.012
Sigma	0.005	0.004	0.005	0.005	0.006	0.005

Geolocation Details

Absolute Geolocation Variance

Min Error [m]	Max Error [m]	Geolocation Error X [%]	Geolocation Error Y [%]	Geolocation Error Z [%]
-	-15.00	0.00	0.00	0.00
-15.00	-12.00	0.00	0.00	0.00
-12.00	-9.00	0.00	0.00	0.00
-9.00	-6.00	0.00	0.00	0.00
-6.00	-3.00	3.41	1.70	0.57

-3.00	0.00	39.77	41.48	57.39
0.00	3.00	50.57	54.55	41.48
3.00	6.00	6.25	2.27	0.57
6.00	9.00	0.00	0.00	0.00
9.00	12.00	0.00	0.00	0.00
12.00	15.00	0.00	0.00	0.00
15.00	-	0.00	0.00	0.00
Mean [m]		0.001378	-0.001457	0.007206
Sigma [m]		1.646904	1.257674	0.970227
RMS Error [m]		1.646904	1.257675	0.970254

Min Error and Max Error represent geolocation error intervals between -1.5 and 1.5 times the maximum accuracy of all the images. Columns X, Y, Z show the percentage of images with geolocation errors within the predefined error intervals. The geolocation error is the difference between the initial and computed image positions. Note that the image geolocation errors do not correspond to the accuracy of the observed 3D points.

Relative Geolocation Variance

Relative Geolocation Error	Images X [%]	Images Y [%]	Images Z [%]
[-1.00, 1.00]	100.00	100.00	100.00
[-2.00, 2.00]	100.00	100.00	100.00
[-3.00, 3.00]	100.00	100.00	100.00
Mean of Geolocation Accuracy [m]	5.000000	5.000000	10.000000
Sigma of Geolocation Accuracy [m]	0.000000	0.000000	0.000000

Images X, Y, Z represent the percentage of images with a relative geolocation error in X, Y, Z.

Geolocation Orientational Variance	RMS [degree]
Omega	10.949
Phi	13.441
Kappa	5.559

Geolocation RMS error of the orientation angles given by the difference between the initial and computed image orientation angles.

Initial Processing Details

System Information

Hardware	CPU: Intel(R) Core(TM) i5-3330S CPU @ 2.70GHz RAM: 8GB GPU: Intel(R) HD Graphics (Driver: 10.18.10.3412), RDPDD Chained DD (Driver: unknown), RDP Encoder Mirror Driver (Driver: unknown), RDP Reflector Display Driver (Driver: unknown)
Operating System	Windows 7 Professional, 64-bit

Coordinate Systems



Image Coordinate System	WGS84 (egm96)
Output Coordinate System	WGS 84 / UTM zone 19N (egm96)

Processing Options



Detected Template	3D Maps
Keypoints Image Scale	Full, Image Scale: 1
Advanced: Matching Image Pairs	Aerial Grid or Corridor
Advanced: Matching Strategy	Use Geometrically Verified Matching: no
Advanced: Keypoint Extraction	Targeted Number of Keypoints: Automatic
Advanced: Calibration	Calibration Method: Standard Internal Parameters Optimization: All External Parameters Optimization: All Rematch: Auto, yes

Point Cloud Densification details



Processing Options



Image Scale	multiscale, 1/2 (Half image size, Default)
Point Density	Optimal
Minimum Number of Matches	3
3D Textured Mesh Generation	yes
3D Textured Mesh Settings:	Resolution: Medium Resolution (default) Color Balancing: no
LOD	Generated: no
Advanced: 3D Textured Mesh Settings	Sample Density Divider: 1
Advanced: Image Groups	group1
Advanced: Use Processing Area	yes
Advanced: Use Annotations	yes
Time for Point Cloud Densification	29m:14s
Time for Point Cloud Classification	NA
Time for 3D Textured Mesh Generation	06m:39s

Results



Number of Generated Tiles	1
Number of 3D Densified Points	7579201
Average Density (per m ³)	389.21

DSM, Orthomosaic and Index Details



Processing Options



DSM and Orthomosaic Resolution	1 x GSD (1.87 [cm/pixel])
--------------------------------	---------------------------

DSM Filters	Noise Filtering: yes Surface Smoothing: yes, Type: Sharp
Raster DSM	Generated: yes Method: Inverse Distance Weighting Merge Tiles: yes
Orthomosaic	Generated: yes Merge Tiles: yes GeoTIFF Without Transparency: no Google Maps Tiles and KML: no
Time for DSM Generation	14m:17s
Time for Orthomosaic Generation	27m:10s
Time for DTM Generation	00s
Time for Contour Lines Generation	00s
Time for Reflectance Map Generation	00s
Time for Index Map Generation	00s

Site name:

Maranto Beach, Arecibo

Before the 2017 hurricane season



A. Physical address:

Maranto Beach, PR 681, Arecibo, Puerto Rico, 00612.

B. Date of capture of imagery:

October 20, 2016

C. Coordinates:

18.49206879 N – 66.61994164 W

D. Description of site:

This site consists of an approximately 217 m wide breach on the primary dune parallel to road PR 681 on the area known as Maranto in Arecibo, Puerto Rico. There are houses located to the south of the site but they are not very close to each other (approximately 100 m apart).

This area has been restored by Vida Marina since 2011. Wooden sand fencing and planting of dune vegetation have resulted in the creation of patches of embryonic dunes that withstood the extreme events of late 2017 and the strong northeasterly swell of March of 2018.

E. Distance from community:

This site is located at a distance of approximately 74 m from “La Playita” restaurant/bar and 96 m from PR 681. The nearest houses are located at a distance of approximately 109.42 m.

F. Aerial imagery

i. Contour map

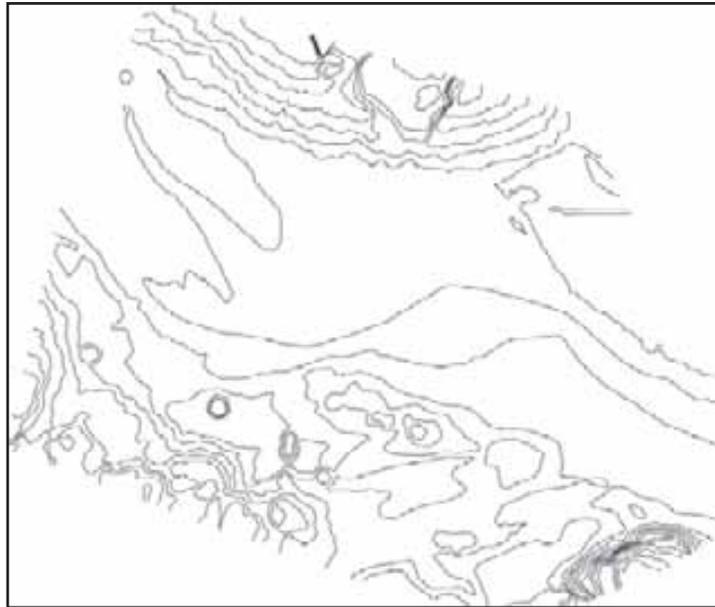


Figure 250. Contour map of the area behind Maranto Beach, Arecibo Puerto Rico with elevation intervals of 1 meter.

ii. 3D imagery



Figure 251. Aerial 3D image of Maranto Beach, Arcibo.

iii. Orthomosaic model

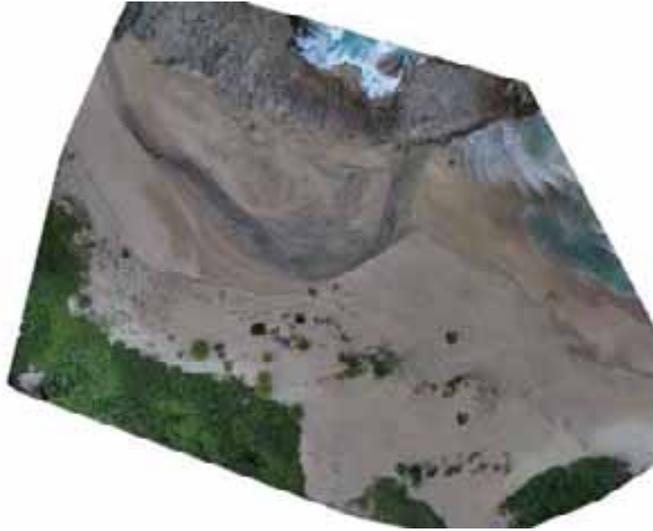


Figure 251. Orthomosaic image of Maranto Beach, Arcibo.

iv. Density Surface Models (DSM)

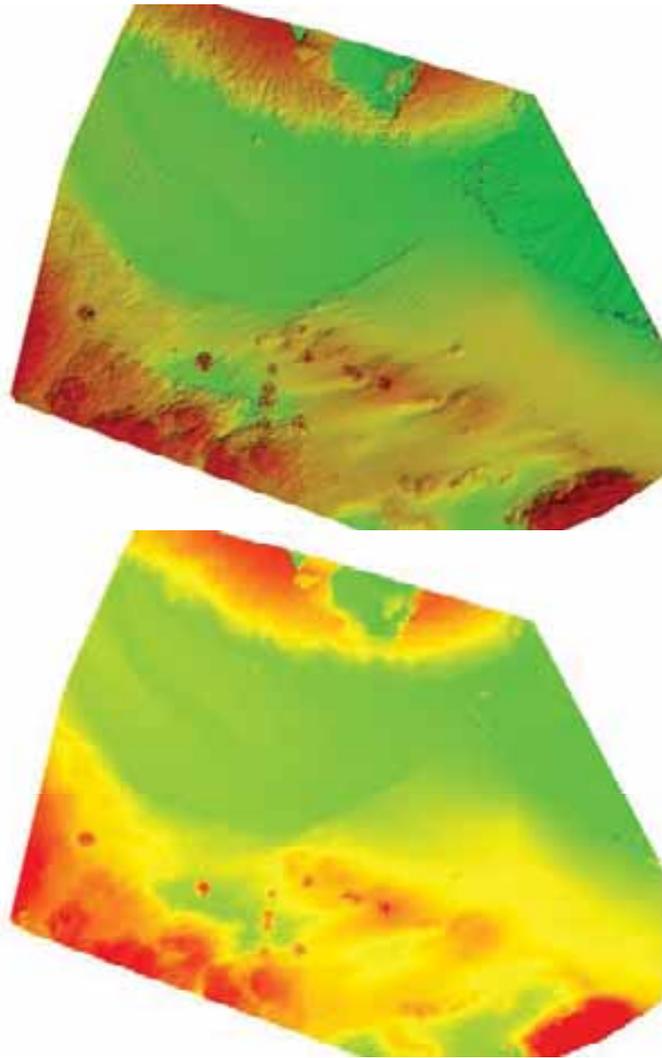


Figure 252. Density surface model (with shading top and without shading bottom) images of the dune located on Maranto Beach, Arcibo.

v. Thermal images

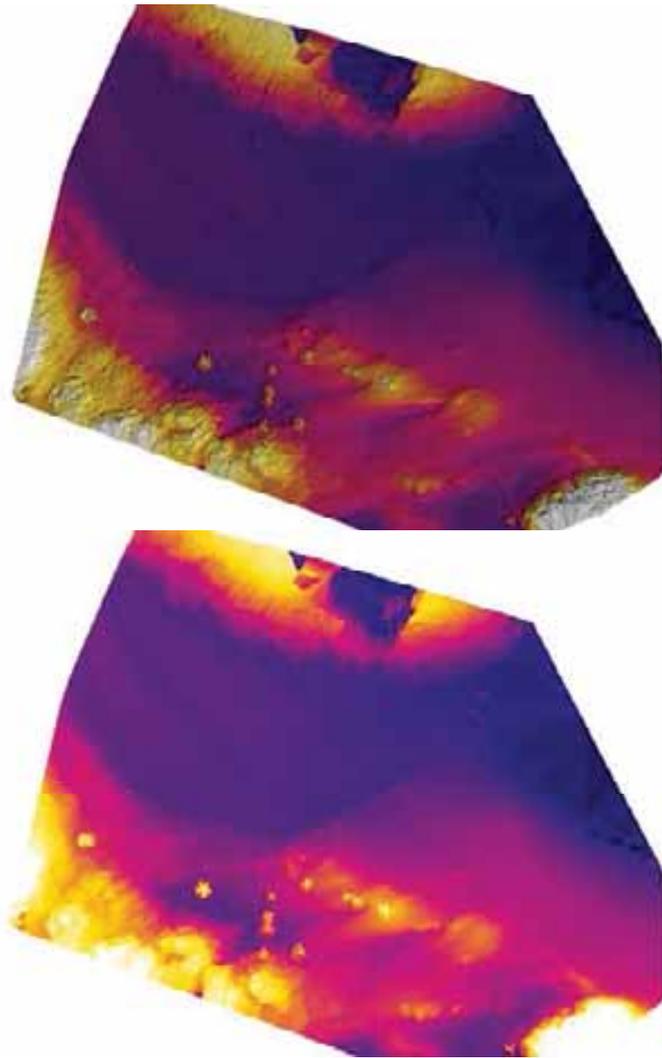


Figure 253. Thermal images (with shading top and without shading bottom) of the Maranto Beach, Arcibo.

vi. 3D altitude RGB North

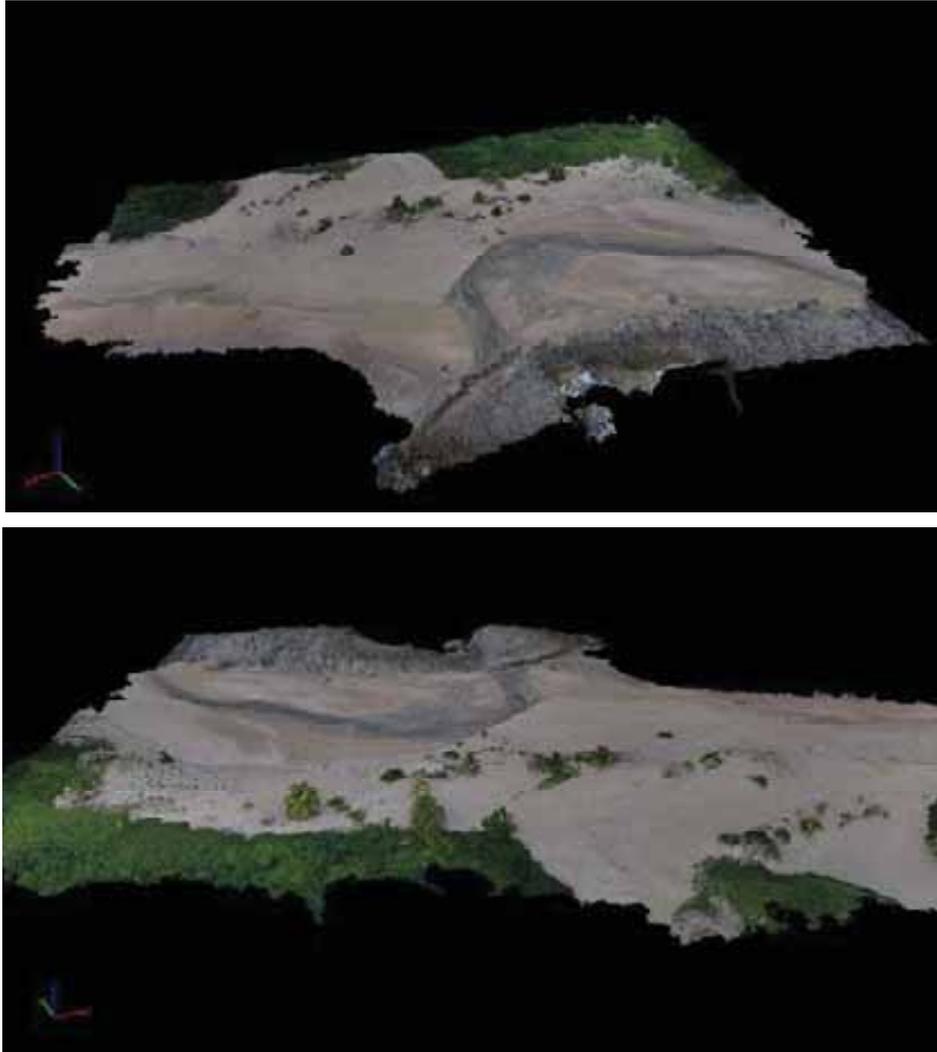


Figure 254. Three dimensional RGB images of the Maranto Beach, Arcibo. View from the north of the eastern part of the site (top) and from the south of the same area (bottom).

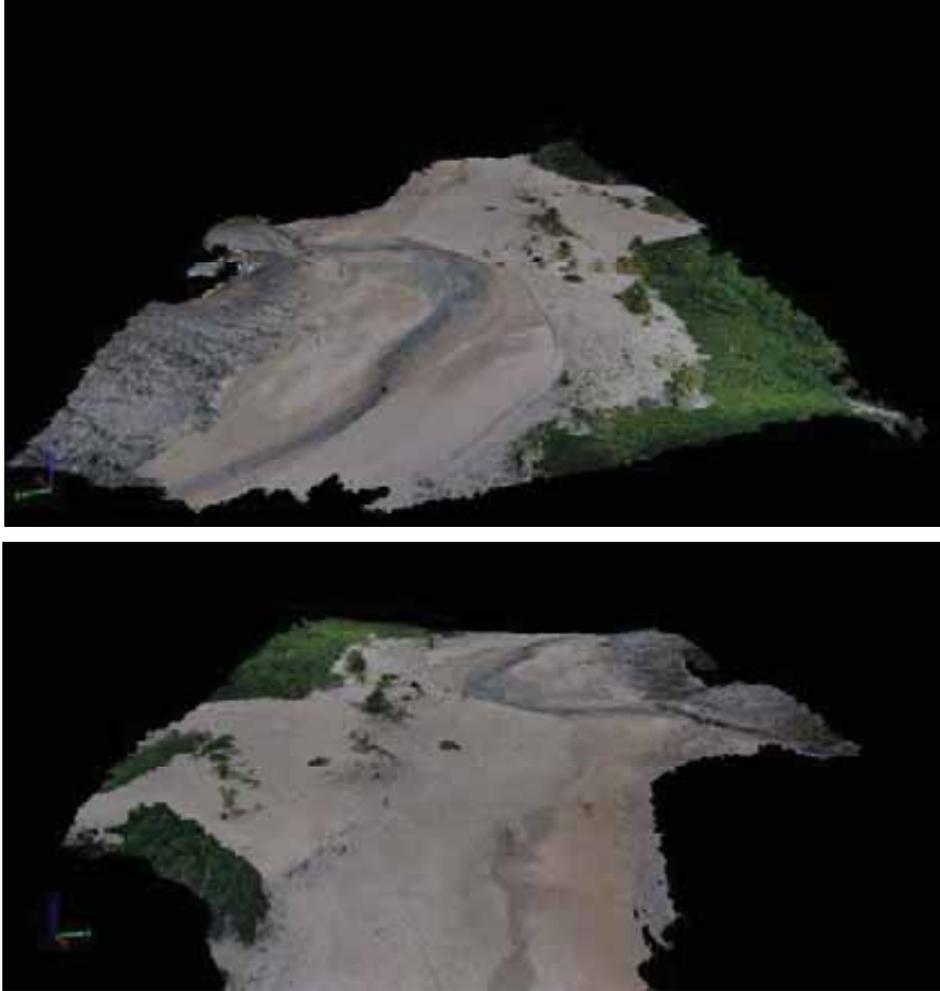


Figure 255. Three dimensional RGB images of the eastern part of the Maranto Beach, Arcibo. View from the west (top) and from the east (bottom).

vii. DSM grayscale

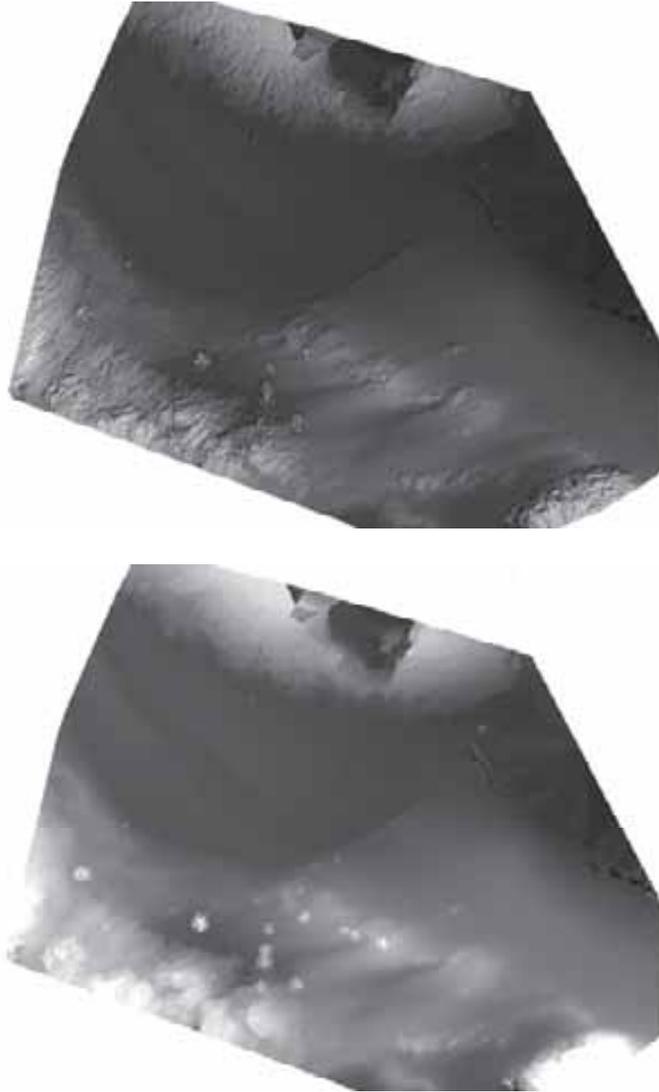


Figure 256. Grayscale DSM images of the Maranto Beach, Arcibo. The top image shows shades and the bottom is not shaded.

Site report

G. Vegetation cover



Figure 257. Images of the area for which vegetation cover is being monitored for Maranto Beach in Arecibo, Puerto Rico. The vegetation cover was 20.40% for the eastern part of the site on October 20, 2016.

H. Pix 4D Quality Report

Quality Report



Generated with Pix4Dmapper Pro version 4.2.26

Important: Click on the different icons for:

- Help to analyze the results in the Quality Report
- Additional information about the sections

Click [here](#) for additional tips to analyze the Quality Report

Summary

Project	Mision Maranto Antes del Huracan Maria
Processed	2018-05-07 10:43:47
Camera Model Name(s)	FC330_3.6_4000x3000 (RGB)
Average Ground Sampling Distance (GSD)	1.43 cm / 0.56 in
Area Covered	0.035 km ² / 3.5298 ha / 0.01 sq. mi. / 8.7269 acres
Time for Initial Processing (without report)	12m:17s

Quality Check

Images	median of 19534 keypoints per image	✓
Dataset	385 out of 398 images calibrated (96%), all images enabled	✓
Camera Optimization	5.2% relative difference between initial and optimized internal camera parameters	⚠
Matching	median of 6617.29 matches per calibrated image	✓
Georeferencing	yes, no 3D GCP	⚠

Preview

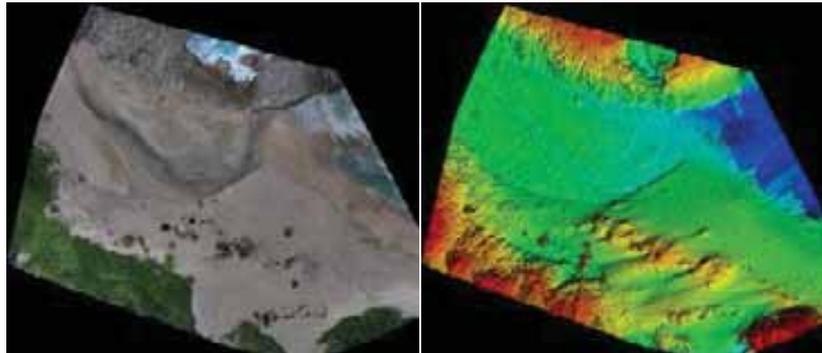


Figure 1: Orthomosaic and the corresponding sparse Digital Surface Model (DSM) before densification.

Calibration Details

Number of Calibrated Images	385 out of 398
-----------------------------	----------------

Initial Image Positions

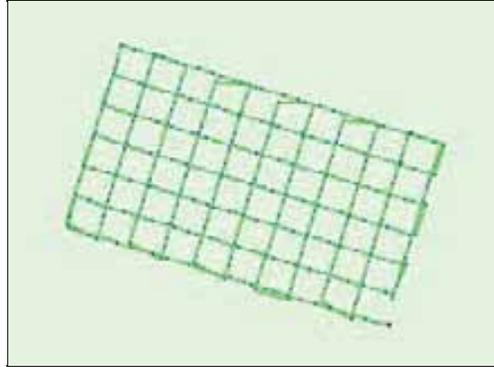
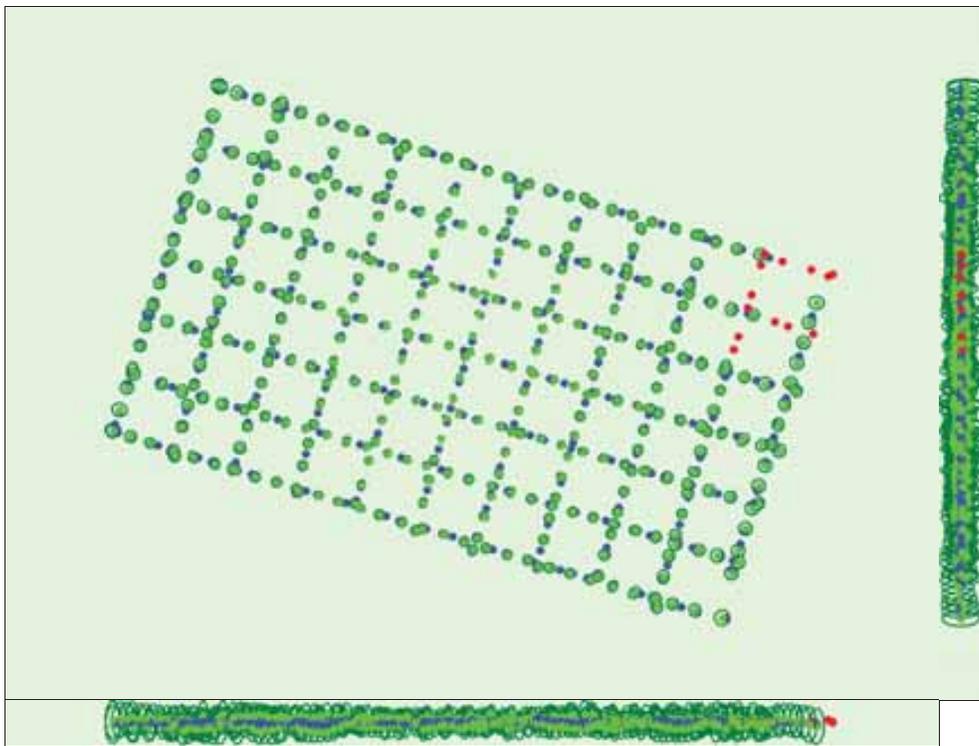


Figure 2: Top view of the initial image position. The green line follows the position of the images in time starting from the large blue dot.

Computed Image/GCPs/Manual Tie Points Positions



Uncertainty ellipses 10x magnified

Figure 3: Offset between initial (blue dots) and computed (green dots) image positions as well as the offset between the GCPs initial positions (blue crosses) and their computed positions (green crosses) in the top-view (XY plane), front-view (XZ plane), and side-view (YZ plane). Red dots indicate disabled or uncalibrated images. Dark green ellipses indicate the absolute position uncertainty of the bundle block adjustment result.

Absolute camera position and orientation uncertainties

	X[m]	Y[m]	Z[m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.144	0.144	0.350	0.357	0.230	0.137
Sigma	0.025	0.025	0.076	0.025	0.025	0.011

Overlap

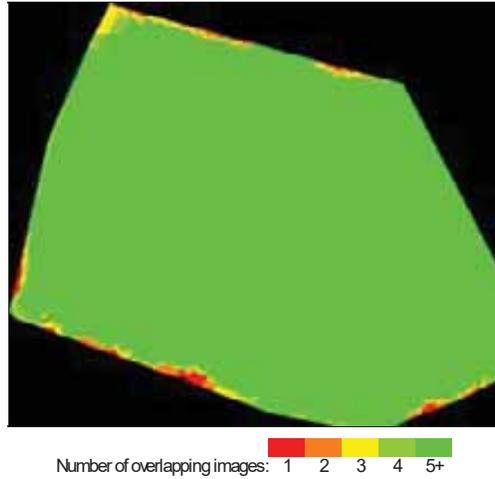


Figure 4: Number of overlapping images computed for each pixel of the orthomosaic. Red and yellow areas indicate low overlap for which poor results may be generated. Green areas indicate an overlap of over 5 images for every pixel. Good quality results will be generated as long as the number of keypoint matches is also sufficient for these areas (see Figure 5 for keypoint matches).

Bundle Block Adjustment Details

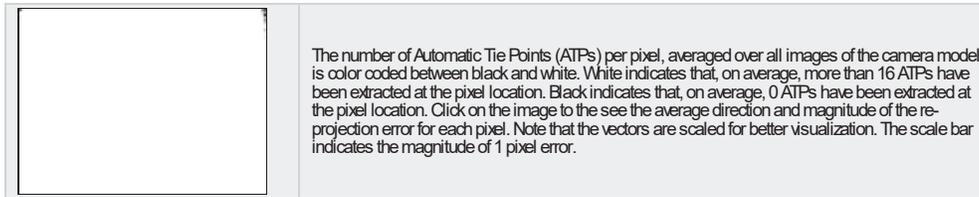
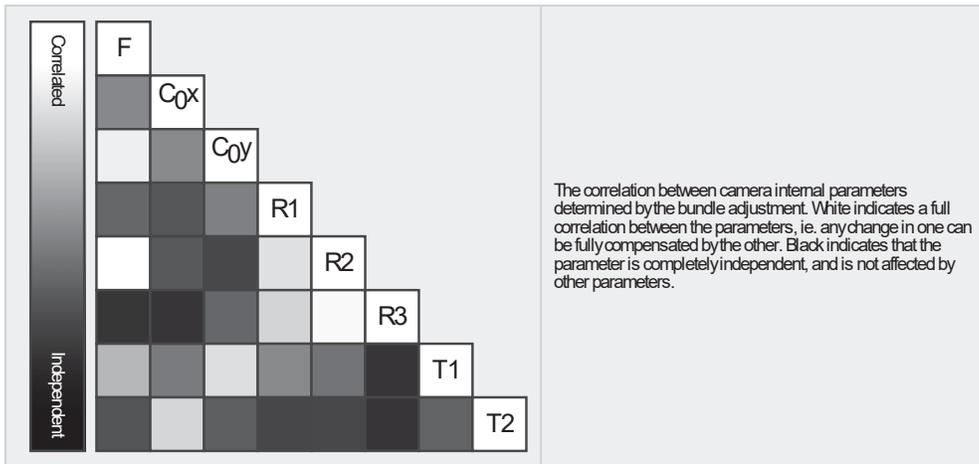
Number of 2D Keypoint Observations for Bundle Block Adjustment	2978830
Number of 3D Points for Bundle Block Adjustment	999374
Mean Reprojection Error [pixels]	0.199

Internal Camera Parameters

FC330_3.6_4000x3000 (RGB). Sensor Dimensions: 6.317 [mm] x 4.738 [mm]

EXIF ID: FC330_3.6_4000x3000

	Focal Length	Principal Point x	Principal Point y	R1	R2	R3	T1	T2
Initial Values	2285.722 [pixel] 3.610 [mm]	2000.006 [pixel] 3.159 [mm]	1500.003 [pixel] 2.369 [mm]	-0.001	-0.002	0.000	-0.001	-0.001
Optimized Values	2404.691 [pixel] 3.798 [mm]	1979.685 [pixel] 3.127 [mm]	1455.980 [pixel] 2.300 [mm]	0.002	-0.004	0.001	-0.000	-0.000
Uncertainties (Sigma)	0.406 [pixel] 0.001 [mm]	0.066 [pixel] 0.000 [mm]	0.250 [pixel] 0.000 [mm]	0.000	0.000	0.000	0.000	0.000



2D Keypoints Table

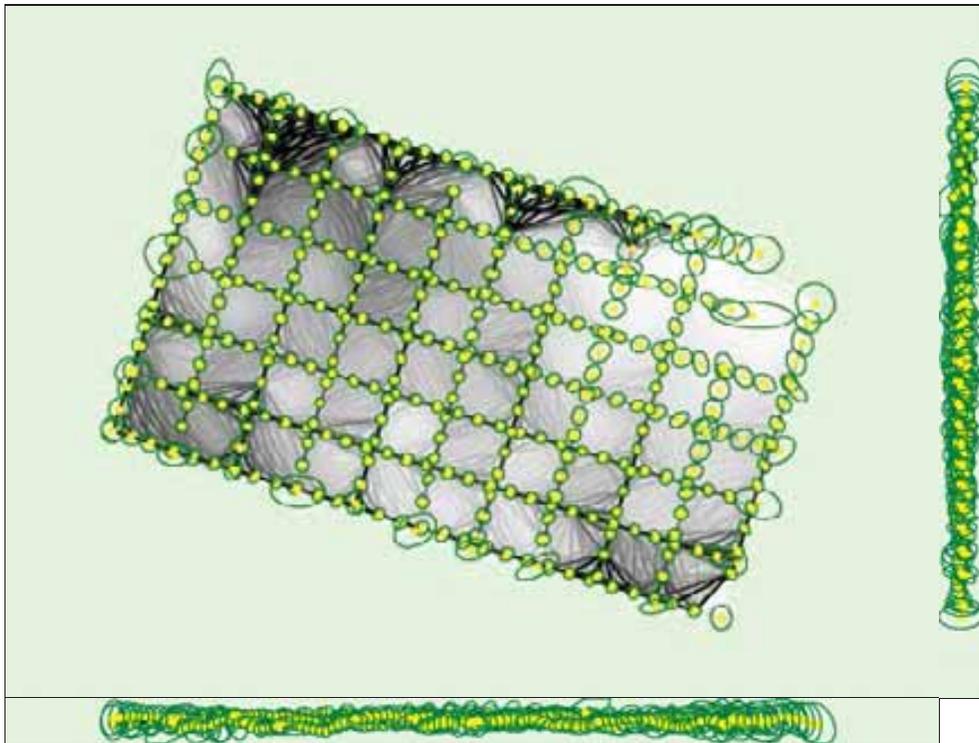
	Number of 2D Keypoints per Image	Number of Matched 2D Keypoints per Image
Median	19534	6617
Mn	15802	79
Max	62308	25120
Mean	22971	7737

3D Points from 2D Keypoint Matches

	Number of 3D Points Observed
In 2 Images	638003
In 3 Images	170246
In 4 Images	73818
In 5 Images	38972
In 6 Images	23562
In 7 Images	15239
In 8 Images	10276
In 9 Images	7394
In 10 Images	5249
In 11 Images	3744
In 12 Images	2677
In 13 Images	2098
In 14 Images	1431
In 15 Images	1184
In 16 Images	938
In 17 Images	793
In 18 Images	645
In 19 Images	548
In 20 Images	421
In 21 Images	336
In 22 Images	297

In 23 Images	266
In 24 Images	195
In 25 Images	165
In 26 Images	151
In 27 Images	118
In 28 Images	119
In 29 Images	75
In 30 Images	72
In 31 Images	58
In 32 Images	59
In 33 Images	38
In 34 Images	31
In 35 Images	27
In 36 Images	20
In 37 Images	23
In 38 Images	15
In 39 Images	11
In 40 Images	16
In 41 Images	10
In 42 Images	6
In 43 Images	8
In 44 Images	8
In 45 Images	6
In 46 Images	1
In 47 Images	1
In 48 Images	2
In 50 Images	2

2D Keypoint Matches



Uncertainty ellipses 500x magnified

Number of matches 25 222 444 666 888 1111 1333 1555 1777 2000

Figure 5: Computed image positions with links between matched images. The darkness of the links indicates the number of matched 2D keypoints between the images. Bright links indicate weak links and require manual tie points or more images. Dark green ellipses indicate the relative camera position uncertainty of the bundle block adjustment result.

Relative camera position and orientation uncertainties

	X[m]	Y[m]	Z[m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.005	0.005	0.005	0.010	0.011	0.006
Sigma	0.002	0.002	0.002	0.004	0.004	0.002

Geolocation Details

Absolute Geolocation Variance

Min Error [m]	Max Error [m]	Geolocation Error X[%]	Geolocation Error Y[%]	Geolocation Error Z[%]
-	-15.00	0.00	0.00	0.00
-15.00	-12.00	0.00	0.00	0.00
-12.00	-9.00	0.00	0.00	0.00
-9.00	-6.00	0.00	0.00	0.00
-6.00	-3.00	0.52	0.52	0.00
-3.00	0.00	53.25	47.53	49.35
0.00	3.00	45.97	51.95	50.65
3.00	6.00	0.26	0.00	0.00
6.00	9.00	0.00	0.00	0.00
9.00	12.00	0.00	0.00	0.00
12.00	15.00	0.00	0.00	0.00
15.00	-	0.00	0.00	0.00
Mean [m]		-0.000173	0.000147	0.000193
Sigma [m]		1.069902	1.046722	0.913689
RMS Error [m]		1.069902	1.046722	0.913689

Min Error and Max Error represent geolocation error intervals between -1.5 and 1.5 times the maximum accuracy of all the images. Columns X, Y, Z show the percentage of images with geolocation errors within the predefined error intervals. The geolocation error is the difference between the initial and computed image positions. Note that the image geolocation errors do not correspond to the accuracy of the observed 3D points.

Relative Geolocation Variance

Relative Geolocation Error	Images X[%]	Images Y[%]	Images Z[%]
[-1.00, 1.00]	100.00	100.00	100.00
[-2.00, 2.00]	100.00	100.00	100.00
[-3.00, 3.00]	100.00	100.00	100.00
Mean of Geolocation Accuracy [m]	5.000000	5.000000	10.000000
Sigma of Geolocation Accuracy [m]	0.000000	0.000000	0.000000

Images X, Y, Z represent the percentage of images with a relative geolocation error in X, Y, Z.

Geolocation Orientational Variance	RMS [degree]
Omega	2.743
Phi	2.692
Kappa	3.954

Geolocation RMS error of the orientation angles given by the difference between the initial and computed image orientation angles.

Initial Processing Details

System Information

Hardware	CPU: Intel(R) Core(TM) i7-8700K CPU @3.70GHz RAM: 16GB GPU: NVIDIA GeForce GTX 1070 (Driver: 23.21.13.9065)
Operating System	Windows 10 Home, 64-bit

Coordinate Systems

Image Coordinate System	WGS84 (egm96)
Output Coordinate System	WGS 84 / UTMzone 19N (egm96)

Processing Options

Detected Template	No Template Available
Keypoints Image Scale	Full, Image Scale: 1
Advanced: Matching Image Pairs	Aerial Grid or Corridor
Advanced: Matching Strategy	Use Geometrically Verified Matching: no
Advanced: Keypoint Extraction	Targeted Number of Keypoints: Automatic
Advanced: Calibration	Calibration Method: Standard Internal Parameters Optimization: All External Parameters Optimization: All Rematch: Auto, yes

Point Cloud Densification details

Processing Options

Image Scale	multiscale, 1/2 (Half image size, Default)
Point Density	Optimal
Minimum Number of Matches	3
3D Textured Mesh Generation	yes
3D Textured Mesh Settings:	Resolution: Medium Resolution (default) Color Balancing: no
LCD	Generated: no
Advanced: 3D Textured Mesh Settings	Sample Density Divider: 1
Advanced: Image Groups	group 1
Advanced: Use Processing Area	yes
Advanced: Use Annotations	yes
Time for Point Cloud Densification	40m:32s
Time for Point Cloud Classification	NA
Time for 3D Textured Mesh Generation	08m:31s

Results

Number of Generated Tiles	1
Number of 3D Densified Points	21976757
Average Density (per m ³)	1829.15

DSM, Orthomosaic and Index Details

Processing Options



DSM and Orthomosaic Resolution	1 x GSD (1.43 [cm/pixel])
DSM Filters	Noise Filtering: yes Surface Smoothing: yes, Type: Sharp
Raster DSM	Generated: yes Method: Inverse Distance Weighting Merge Tiles: yes
Orthomosaic	Generated: yes Merge Tiles: yes GeoTIFF Without Transparency: no Google Maps Tiles and KML: no
Raster DTM	Generated: yes Merge Tiles: yes
DTM Resolution	5 x GSD (1.43 [cm/pixel])
Contour Lines Generation	Generated: yes Contour Base [m]: 0 Elevation Interval [m]: 1 Resolution [cm]: 100 Minimum Line Size [vertices]: 20
Time for DSM Generation	14m:30s
Time for Orthomosaic Generation	23m:57s
Time for DTM Generation	05m:34s
Time for Contour Lines Generation	01s
Time for Reflectance Map Generation	00s
Time for Index Map Generation	00s

Site name:

Maranto, Arecibo

After hurricane María



A. Physical address:

Maranto Beach, PR 681, Arecibo, Puerto Rico, 00612.

B. Date of capture of imagery:

January 17, 2018

C. Coordinates:

18.49209792 N – 66.619813 W

D. Aerial imagery

i. Contour map



Figure 258. Contour map of the area behind Maranto Beach, Arecibo Puerto Rico with elevation intervals of 1 meter.

ii. 3D imagery



Figure 259. Aerial 3D image of Maranto Beach, Arecibo.

ii. Orthomosaic model



Figure 260. Orthomosaic image of Maranto Beach, Arcibo.

iii. Density Surface Models (DSM)

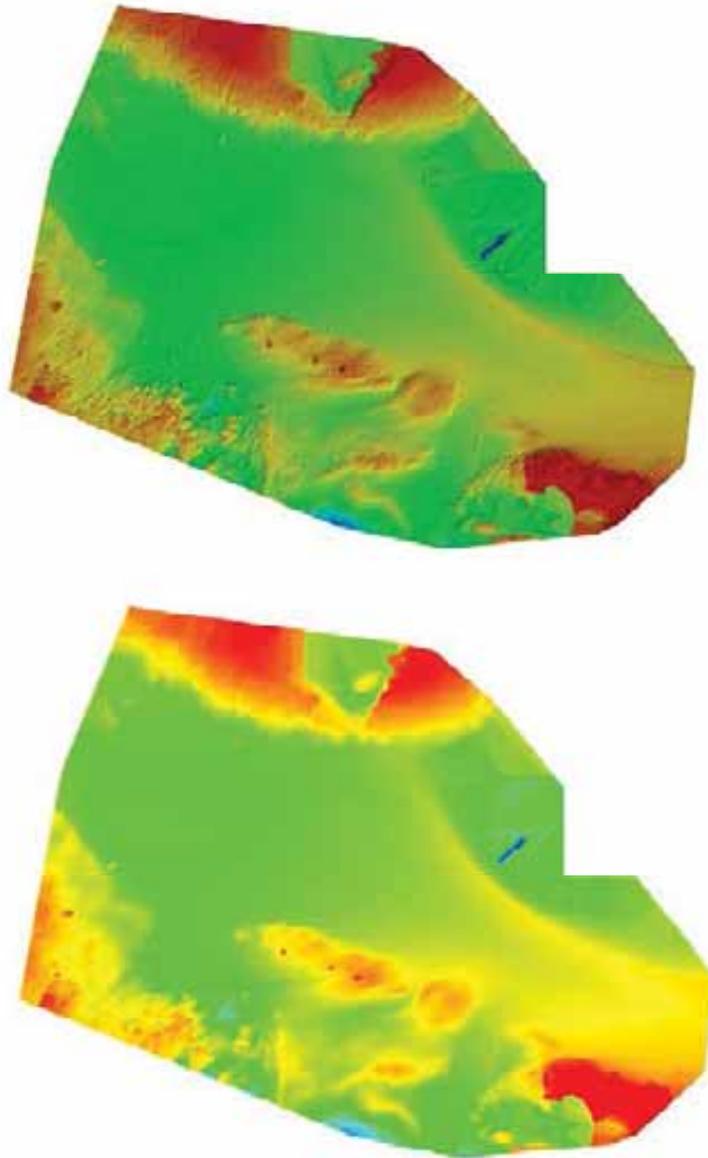


Figure 261. Density surface model (with shading top and without shading bottom) images of the dune located on the Maranto (after Maria), Arecibo.

v. Thermal images

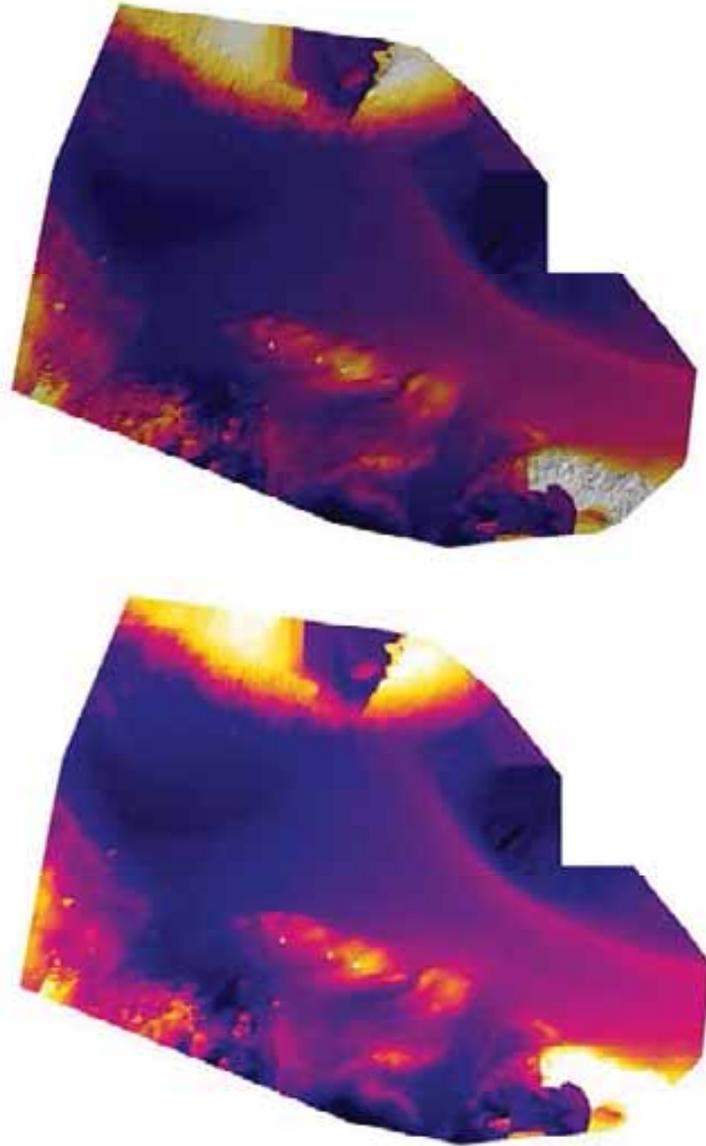


Figure 262. Thermal images (with shading top and without shading bottom) of the Maranto Beach, Arcibo.

vi. 3D altitude RGB North

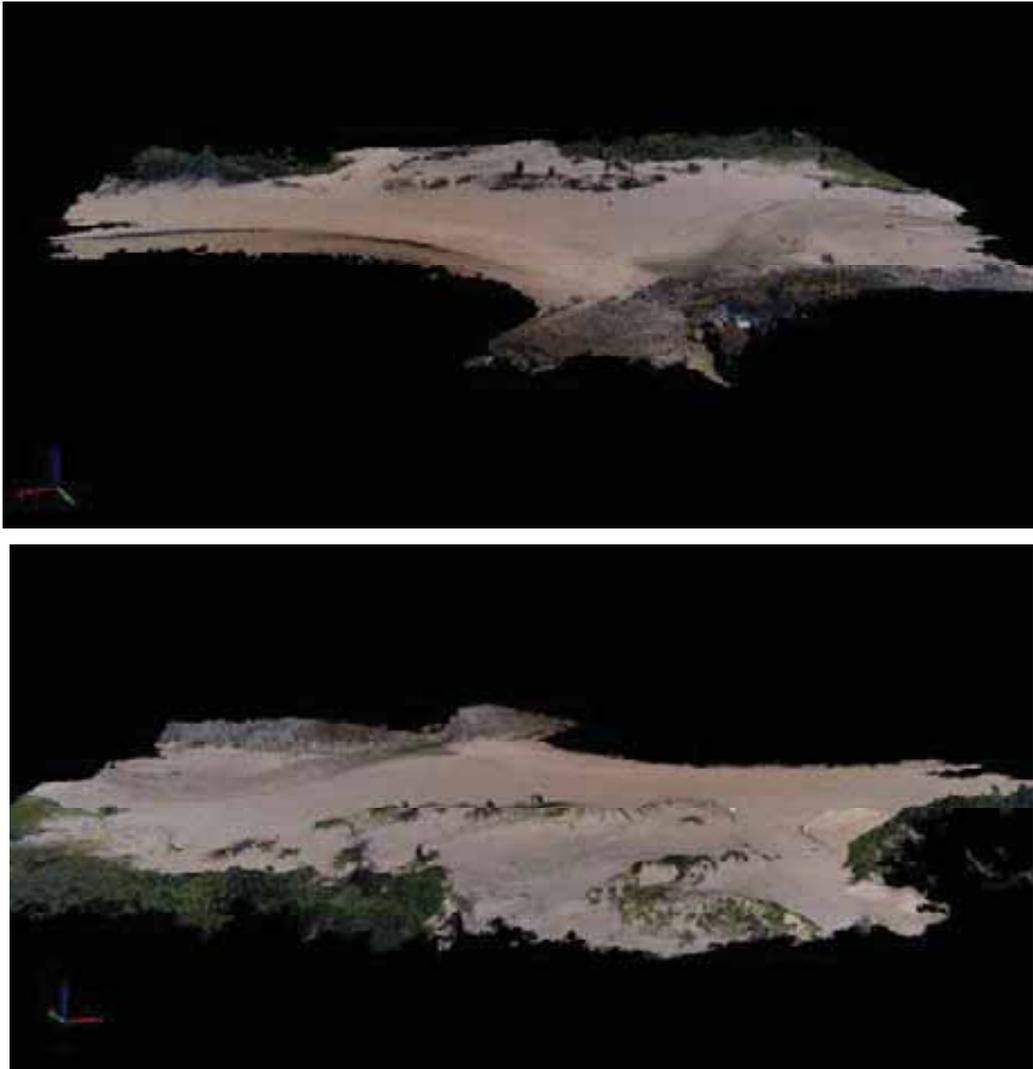


Figure 263. Three dimensional RGB images of the Maranto Beach, Arecibo. View from the north of the eastern part of the site (top) and from the south of the same area (bottom).

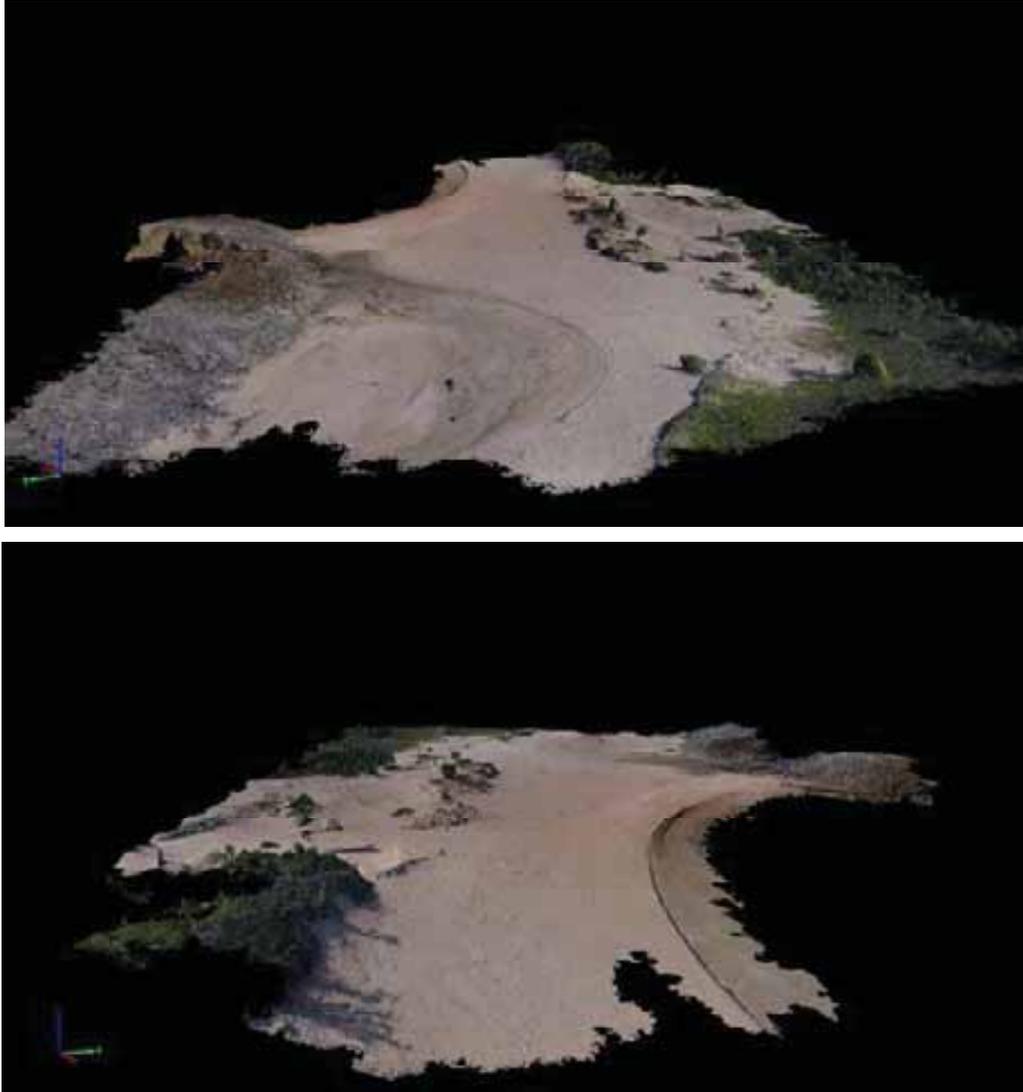


Figure 264. Three dimensional RGB images of the Maranto Beach, Arcibo. View from the north of the eastern part of the site (top) and from the south of the same area (bottom).

vii. DSM grayscale

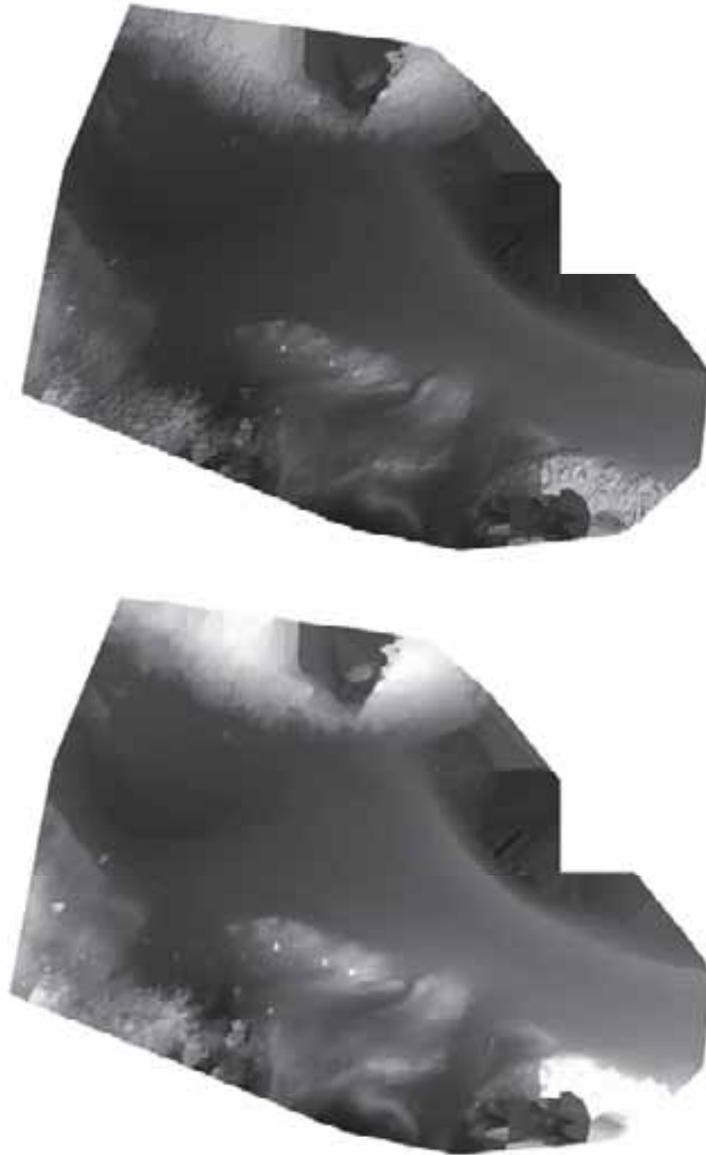


Figure 265. Grayscale DSM images of the Maranto Beach, Arcibo. The top image shows shades and the bottom is not shaded.

Site report

E. Vegetation cover



Figure 266. Images of the area for which vegetation cover is being monitored for the Maranto Beach in Arecibo, Puerto Rico. The vegetation cover was 16.90% for the eastern part of the site on January 17, 2018.

F. Pix 4D Quality Report

Quality Report



Generated with Pix4Dmapper Pro version 4.1.22

1 Important: Click on the different icons for:

- 2** Help to analyze the results in the Quality Report
- 3** Additional information about the sections

Click [here](#) for additional tips to analyze the Quality Report

Summary

Project	Mision Miranto Despues del Huracan Maria
Processed	2018-01-19 10:33:06
Camera Model Name(s)	FC330_3.6_4000x3000 (RGB)
Average Ground Sampling Distance (GSD)	2.09 cm / 0.82 in
Area Covered	0.039 km ² / 3.9293 ha / 0.02 sq. mi. / 9.7146 acres
Time for Initial Processing (without report)	11m:09s

Quality Check

1 Images	median of 23883 keypoints per image	
2 Dataset	68 out of 76 images calibrated (89%), all images enabled	
3 Camera Optimization	4.54% relative difference between initial and optimized internal camera parameters	
4 Matching	median of 5853.79 matches per calibrated image	
5 Georeferencing	yes, no 3D GCP	

6 Preview

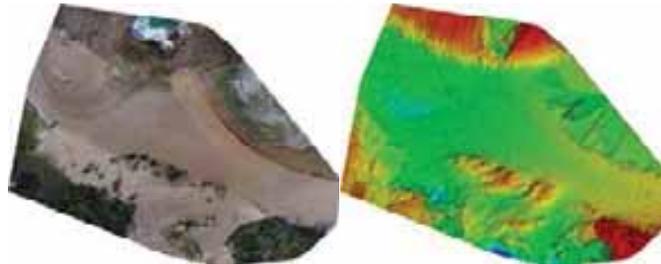


Figure 1: Orthomosaic and the corresponding sparse Digital Surface Model (DSM) before densification.

Calibration Details

Number of Calibrated Images	68 out of 76
Number of Geolocated Images	76 out of 76

7 Initial Image Positions

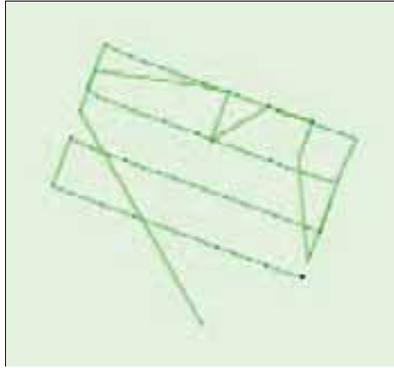


Figure 2: Top view of the initial image position. The green line follows the position of the images in time starting from the large blue dot.

Computed Image/GCPs/Manual Tie Points Positions

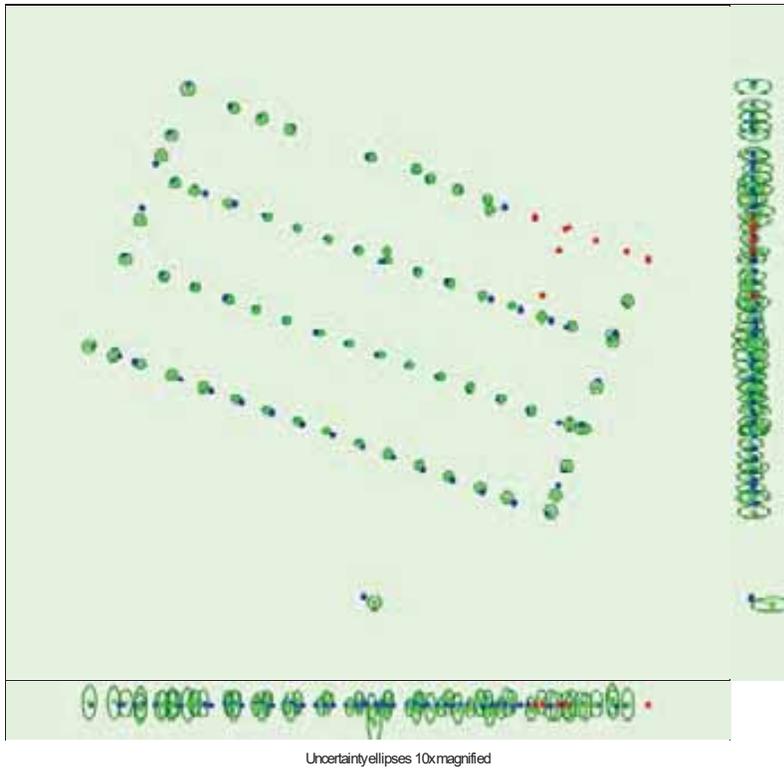


Figure 3: Offset between initial (blue dots) and computed (green dots) image positions as well as the offset between the GCPs initial positions (blue crosses) and their computed positions (green crosses) in the top-view (XY plane), front-view (XZ plane), and side-view (YZ plane). Red dots indicate disabled or uncalibrated images. Dark green ellipses indicate the absolute position uncertainty of the bundle block adjustment result.

Absolute camera position and orientation uncertainties

	X[m]	Y[m]	Z[m]	Omega [degree]	Psi [degree]	Kappa [degree]
Mean	0.183	0.183	0.443	0.421	0.263	0.158
Sigma	0.031	0.031	0.096	0.016	0.017	0.009

Overlap

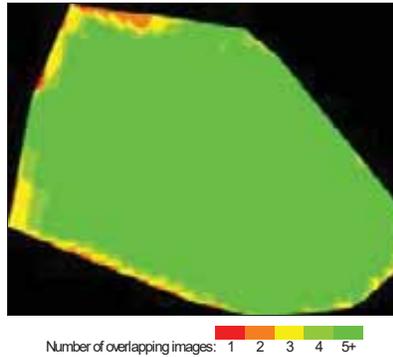


Figure 4: Number of overlapping images computed for each pixel of the orthomosaic. Red and yellow areas indicate low overlap for which poor results may be generated. Green areas indicate an overlap of over 5 images for every pixel. Good quality results will be generated as long as the number of keypoint matches is also sufficient for these areas (see Figure 5 for keypoint matches).

Bundle Block Adjustment Details

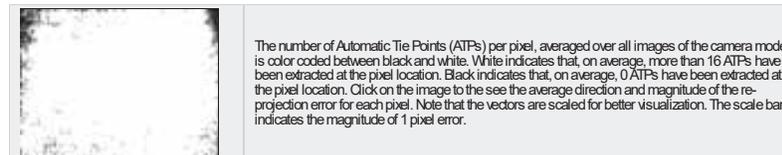
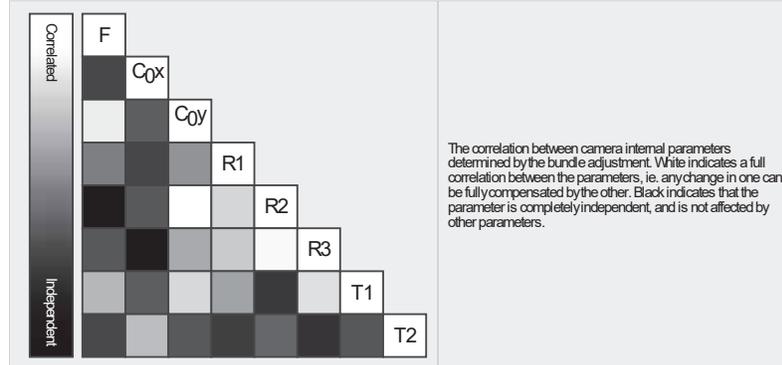
Number of 2D Keypoint Observations for Bundle Block Adjustment	491951
Number of 3D Points for Bundle Block Adjustment	191075
Mean Reprojection Error [pixels]	0.182

Internal Camera Parameters

FC330_3.6_4000x3000 (RGB). Sensor Dimensions: 6.317 [mm] x 4.738 [mm]

EXIF ID: FC330_3.6_4000x3000

	Focal Length	Principal Point _x	Principal Point _y	R1	R2	R3	T1	T2
Initial Values	2285.722 [pixel] 3.610 [mm]	2000.006 [pixel] 3.159 [mm]	1500.003 [pixel] 2.369 [mm]	-0.001	-0.002	0.000	-0.001	-0.001
Optimized Values	2389.550 [pixel] 3.774 [mm]	1962.847 [pixel] 3.100 [mm]	1469.616 [pixel] 2.321 [mm]	-0.003	-0.004	0.003	0.001	-0.000
Uncertainties (Sigma)	0.593 [pixel] 0.001 [mm]	0.102 [pixel] 0.000 [mm]	0.376 [pixel] 0.001 [mm]	0.000	0.000	0.000	0.000	0.000



2D Keypoints Table

	Number of 2D Keypoints per Image	Number of Matched 2D Keypoints per Image
Median	23883	5854
Mn	17081	78

Max	58244	16335
Mean	26486	7235

3D Points from 2D Keypoint Matches

	Number of 3D Points Observed
In 2 Images	130485
In 3 Images	34074
In 4 Images	13689
In 5 Images	7057
In 6 Images	3395
In 7 Images	1346
In 8 Images	581
In 9 Images	286
In 10 Images	98
In 11 Images	49
In 12 Images	12
In 13 Images	1
In 14 Images	2

2D Keypoint Matches

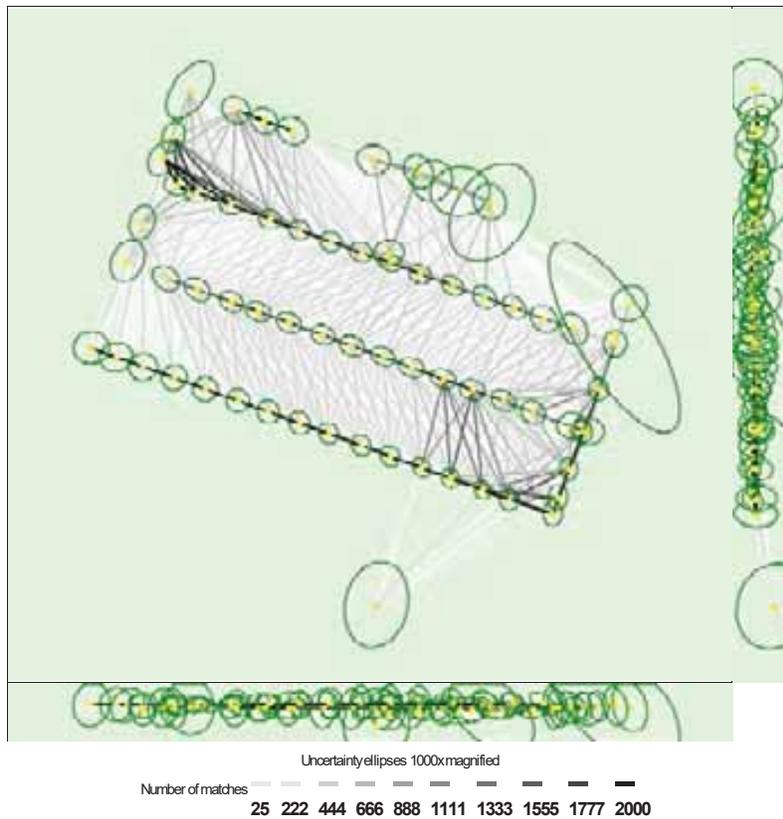


Figure 5: Computed image positions with links between matched images. The darkness of the links indicates the number of matched 2D keypoints between the images. Bright links indicate weak links and require manual tie points or more images. Dark green ellipses indicate the relative camera position uncertainty of the bundle block adjustment result.

Relative camera position and orientation uncertainties

	X[m]	Y[m]	Z[m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.005	0.005	0.005	0.009	0.011	0.006
Sigma	0.003	0.004	0.003	0.006	0.005	0.002

Geolocation Details

Absolute Geolocation Variance

Mn Error [m]	MaxError [m]	Geolocation Error X[%]	Geolocation Error Y[%]	Geolocation Error Z[%]
-	-15.00	0.00	0.00	0.00
-15.00	-12.00	0.00	0.00	0.00
-12.00	-9.00	0.00	0.00	0.00
-9.00	-6.00	0.00	0.00	0.00
-6.00	-3.00	2.94	1.47	0.00
-3.00	0.00	57.35	48.53	55.88
0.00	3.00	33.82	47.06	42.65
3.00	6.00	5.88	2.94	0.00
6.00	9.00	0.00	0.00	1.47
9.00	12.00	0.00	0.00	0.00
12.00	15.00	0.00	0.00	0.00
15.00	-	0.00	0.00	0.00
Mean [m]		0.000000	0.000005	-0.000009
Sigma [m]		1.694213	1.331388	1.372220
RMS Error [m]		1.694213	1.331388	1.372220

Min Error and Max Error represent geolocation error intervals between -1.5 and 1.5 times the maximum accuracy of all the images. Columns X, Y, Z show the percentage of images with geolocation errors within the predefined error intervals. The geolocation error is the difference between the initial and computed image positions. Note that the image geolocation errors do not correspond to the accuracy of the observed 3D points.

Relative Geolocation Variance

Relative Geolocation Error	Images X[%]	Images Y[%]	Images Z[%]
[-1.00, 1.00]	98.53	100.00	100.00
[-2.00, 2.00]	100.00	100.00	100.00
[-3.00, 3.00]	100.00	100.00	100.00
Mean of Geolocation Accuracy [m]	5.000000	5.000000	10.000000
Sigma of Geolocation Accuracy [m]	0.000000	0.000000	0.000000

Images X, Y, Z represent the percentage of images with a relative geolocation error in X, Y, Z.

Geolocation Orientational Variance	RMS [degree]
Omega	1.967
Phi	1.900
Kappa	4.178

Geolocation RMS error of the orientation angles given by the difference between the initial and computed image orientation angles.

Initial Processing Details

System Information

Hardware	CPU: Intel(R) Core(TM) i5-3330S CPU @2.70GHz RAM 8GB GPU: Intel(R) HD Graphics (Driver: 10.18.10.3412), RDPDD Chained DD (Driver: unknown), RDP Encoder Mirror Driver (Driver: unknown), RDP Reflector Display Driver (Driver: unknown)
Operating System	Windows 7 Professional, 64-bit

Coordinate Systems

Image Coordinate System	WGS84 (egm96)
Output Coordinate System	WGS 84 / UTMzone 19N (egm96)

Processing Options

Detected Template	3D Maps
Keypoints Image Scale	Full, Image Scale: 1
Advanced: Matching Image Pairs	Aerial Grid or Corridor
Advanced: Matching Strategy	Use Geometrically Verified Matching: no
Advanced: Keypoint Extraction	Targeted Number of Keypoints: Automatic
Advanced: Calibration	Calibration Method: Standard Internal Parameters Optimization: All External Parameters Optimization: All Rematch: Auto, yes

Point Cloud Densification details

Processing Options

Image Scale	multiscale, 1/2 (Half image size, Default)
Point Density	Optimal
Minimum Number of Matches	3
3D Textured Mesh Generation	yes
3D Textured Mesh Settings:	Resolution: Medium Resolution (default) Color Balancing: no
LOD	Generated: no
Advanced: 3D Textured Mesh Settings	Sample Density Divider: 1
Advanced: Image Groups	group1
Advanced: Use Processing Area	yes
Advanced: Use Annotations	yes
Time for Point Cloud Densification	12m:58s
Time for Point Cloud Classification	NA
Time for 3D Textured Mesh Generation	04m:23s

Results

Number of Generated Tiles	1
Number of 3D Densified Points	5028140
Average Density (per m ³)	335.97

DSM, Orthomosaic and Index Details

Processing Options

DSM and Orthomosaic Resolution	1 x GSD (2.09 [cm/pixel])
DSM Filters	Noise Filtering: yes Surface Smoothing: yes, Type: Sharp
Raster DSM	Generated: yes Method: Inverse Distance Weighting Merge Tiles: yes
Orthomosaic	Generated: yes Merge Tiles: yes GeoTIFF Without Transparency: no Google Maps Tiles and KML: no
Time for DSM Generation	08m:04s
Time for Orthomosaic Generation	12m:15s
Time for DTMGeneration	00s
Time for Contour Lines Generation	00s
Time for Reflectance Map Generation	00s
Time for Index Map Generation	00s

Site name:

Maranto, Arecibo

After March, 2018 northeasterly swell



A. Physical address:

Maranto Beach, PR 681, Arecibo, Puerto Rico, 00612.

B. Date of capture of imagery:

March 15, 2018

C. Coordinates:

18.49209792 N – 66.619813 W

D. Aerial imagery

i. Contour map

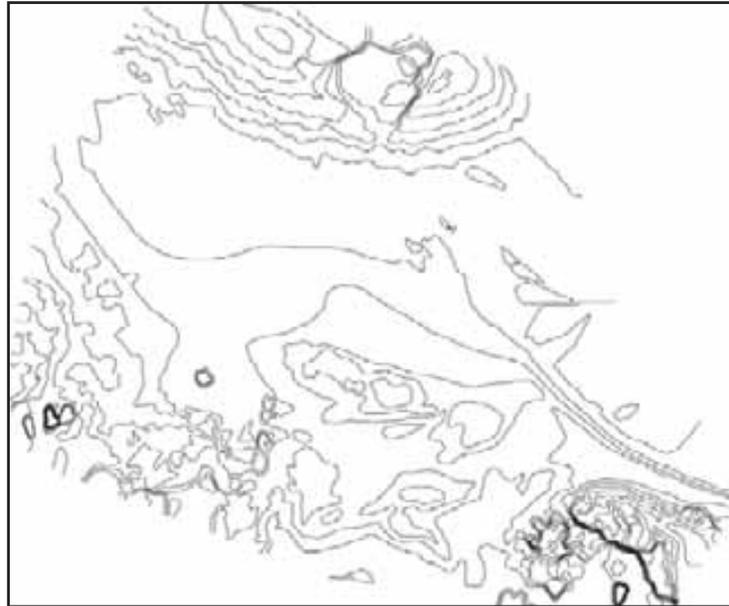


Figure 267. Contour map of the area behind the Maranto (after swell), in Arecibo Puerto Rico with elevation intervals of 1 meter.

ii. 3D imagery

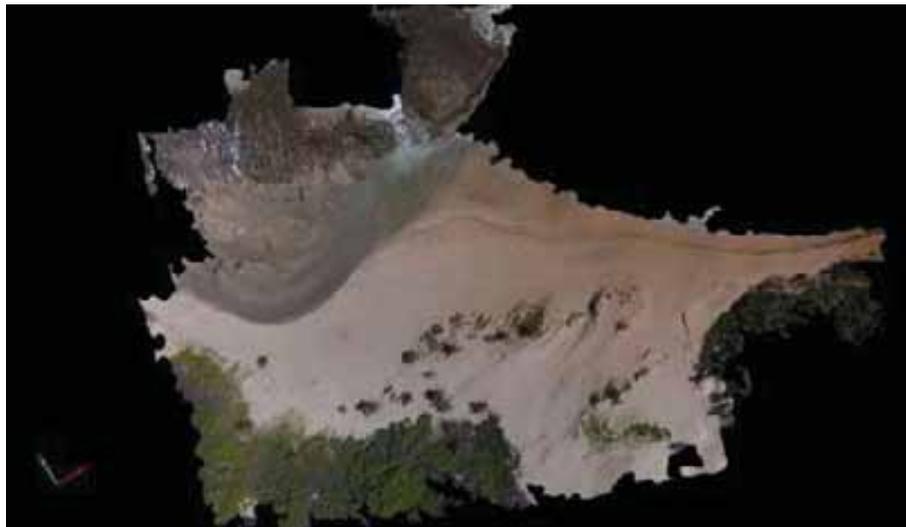


Figure 268. Aerial 3D image of the Maranto (after swell), Arecibo.

iii. Orthomosaic model



Figure 269. Orthomosaic image of Maranto Beach, Arcibo.

iv. Density Surface Models (DSM)

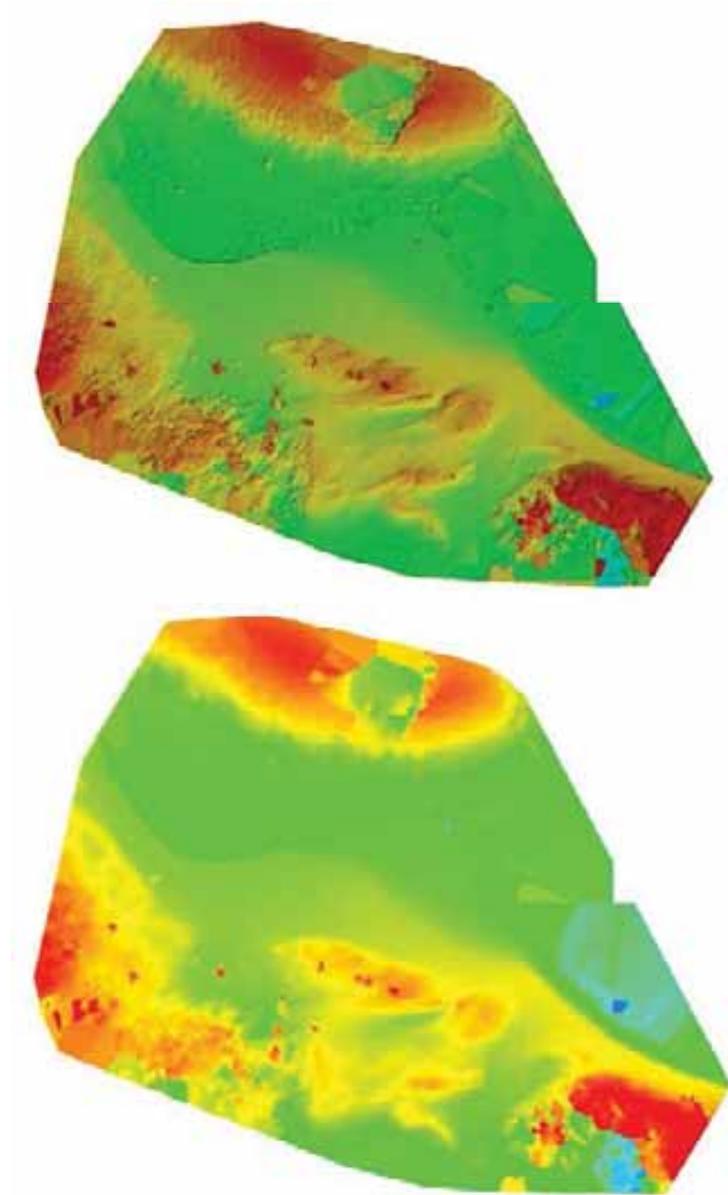


Figure 270. Density surface model (with shading top and without shading bottom) images of the dune located on Maranto Beach, Arecibo.

v. Thermal images

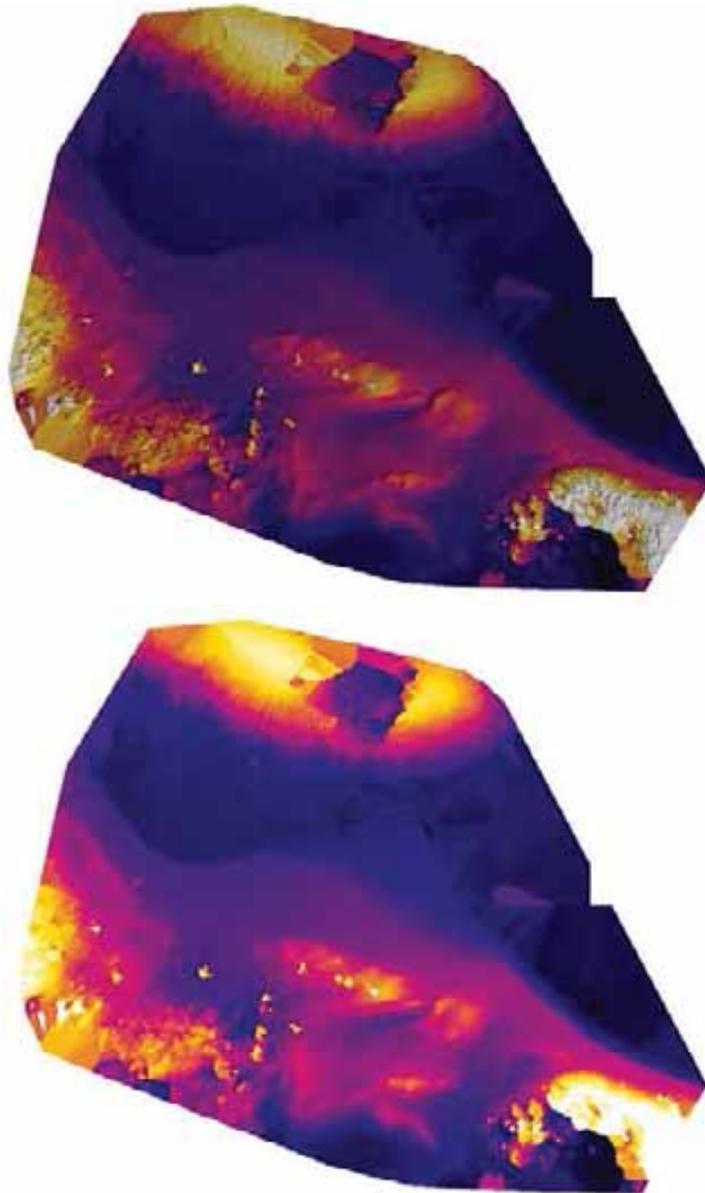


Figure 271. Thermal images (with shading top and without shading bottom) of the Maranto Beach, Arcibo.

vi. 3D altitude RGB North

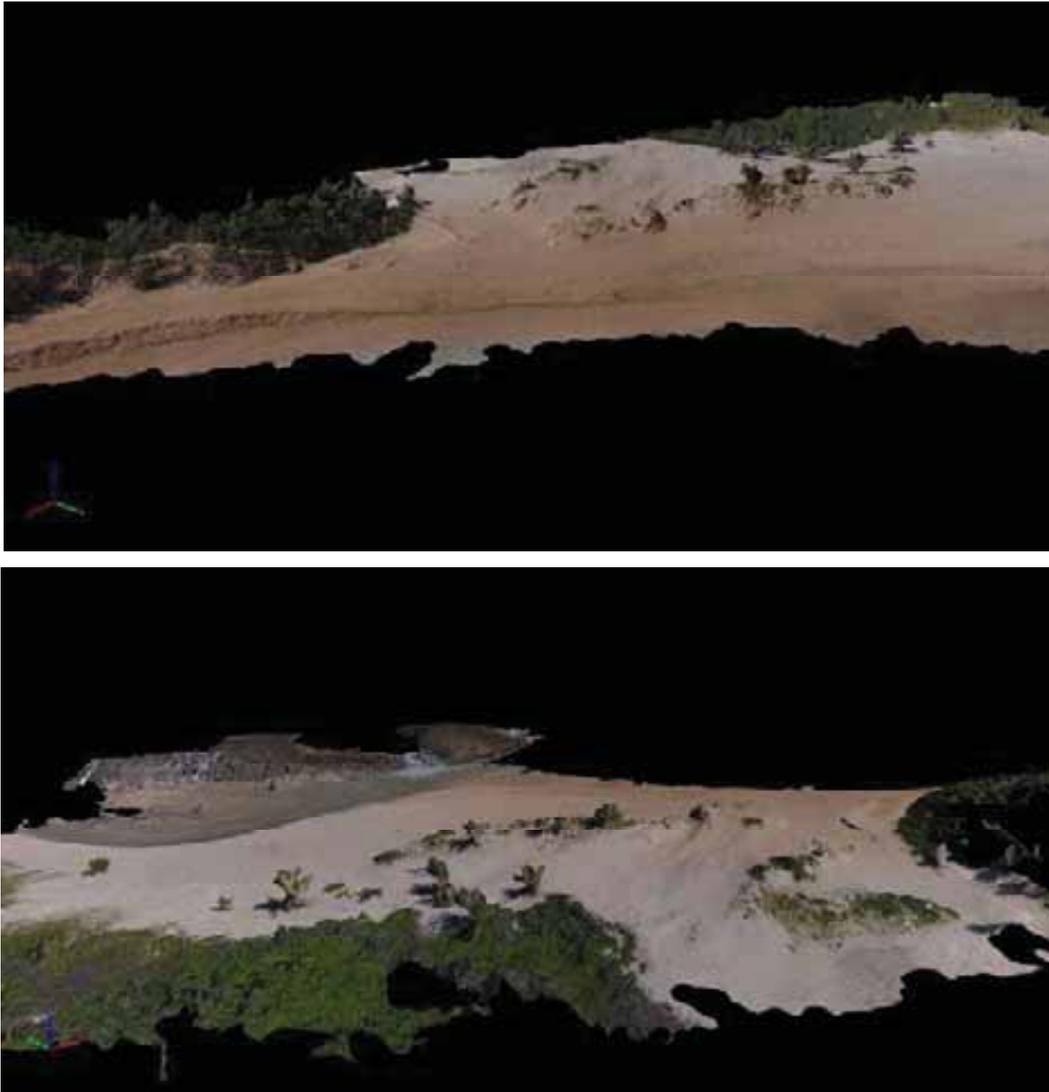


Figure 272. Three dimensional RGB images of the Maranto Beach, Arcibo. View from the north of the eastern part of the site (top) and from the south of the same area (bottom).



Figure 273. Three dimensional RGB images of the eastern part of the Maranto Beach, Arcibo. View from the west (top) and from the east (bottom).

vii. DSM grayscale

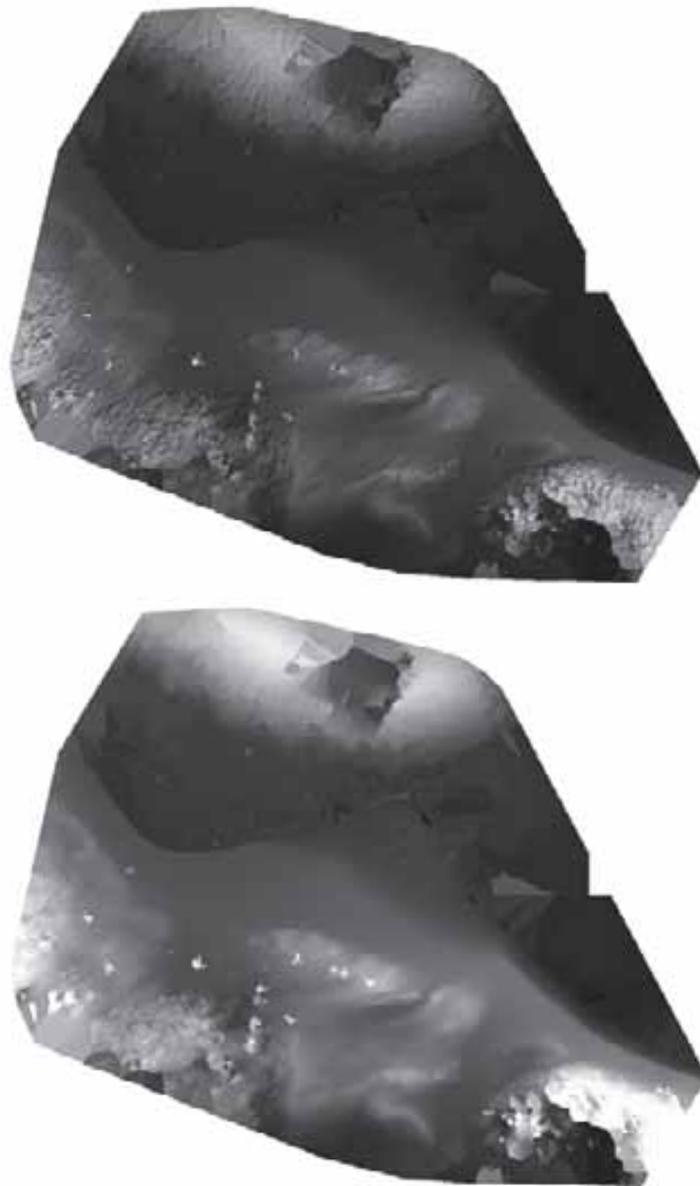


Figure 274. Grayscale DSM images of the Maranto Beach, Arcibo. The top image shows shades and the bottom is not shaded.

Site report

E. Vegetation cover



Figure 275. Images of the area for which vegetation cover is being monitored for Maranto Beach in Arecibo, Puerto Rico. The vegetation cover was 20.40% for the eastern part of the site on October 20, 2016.

F. Volume measurements of selected areas of the dunes



Figure 276. Three dimensional aerial picture of Maranto Beach, Arecibo with four areas marked by polygons for which three dimensional area, cut volume, fill volume and total volume were calculated using the Pix4D software. Refer to image above for the data. The order of the data is from left to right on the image.

G. Conservation threats

The main conservation threats in this area consist of heavy foot and all-terrain vehicle traffic, illegal sand extraction. The extreme weather events of late 2017 and early 2018 reduced the amount of vegetation cover and reduced the amount of sand in the area.

H. Recommended ecological restoration courses of action (COA)

This area has been restored since 2011 and the patches of existing embryonic dune need to be further stabilized with additional vegetation.

The ecological restoration measures that we recommend for this area consist of the installation of an extra segment of wooden boardwalk to existing one (see figure 276) in order to re-direct foot traffic away from sensitive areas that are being restored. We recommend installation of biomimicry matrices to promote the accumulation of sand followed by stabilization of these areas with dune vegetation.



Figure 277. Area to be ecologically restored in Maranto Beach in Arecibo. Highlighted areas correspond to each technique that will be used in this area. **Yellow** represents the location of a wooden boardwalk, the **red dot** marks the location of an information sign, **tan** represents the area of the dune crest that where biomimicry matrices will be installed to promote the accumulation of sand. The areas shaded in **light green** represent locations for the planting of dune vegetation.

I. Pix 4D Quality Report

Quality Report



Generated with Pix4Dmapper Pro version 4.2.25

Important: Click on the different icons for:

- Help to analyze the results in the Quality Report
- Additional information about the sections

Click [here](#) for additional tips to analyze the Quality Report

Summary

Project	Maranto Despues del Swell
Processed	2018-04-03 14:10:27
Camera Model Name(s)	FC330_3,6_4000x3000 (RGB)
Average Ground Sampling Distance (GSD)	2.24 cm / 0.88 in
Area Covered	0.043 km ² / 4.3371 ha / 0.02 sq. mi. / 10.7228 acres
Time for Initial Processing (without report)	25m:51s

Quality Check

Images	median of 28785 keypoints per image	✔
Dataset	114 out of 126 images calibrated (90%), all images enabled	⚠
Camera Optimization	5.05% relative difference between initial and optimized internal camera parameters	⚠
Matching	median of 6190.86 matches per calibrated image	✔
Georeferencing	yes, no 3D GCP	⚠

Preview

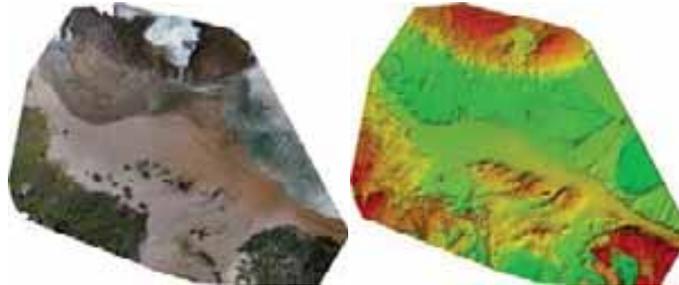


Figure 1: Orthomosaic and the corresponding sparse Digital Surface Model (DSM) before densification.

Calibration Details

Number of Calibrated Images	114 out of 126
Number of Geolocated Images	126 out of 126

Initial Image Positions

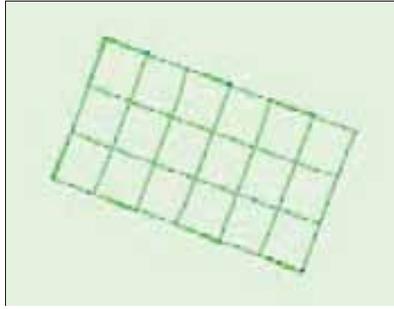
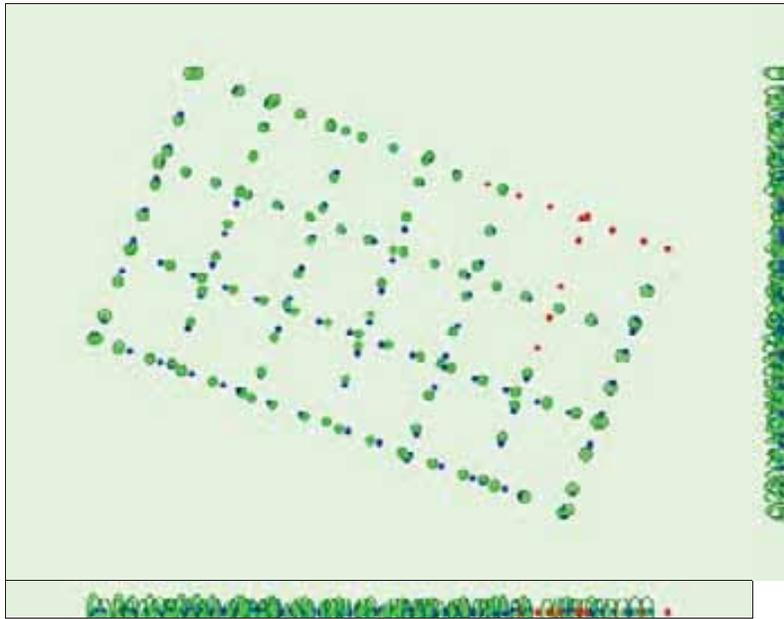


Figure 2: Top view of the initial image position. The green line follows the position of the images in time starting from the large blue dot.

1 Computed Image/GCPs/Manual Tie Points Positions



Uncertainty ellipses 10x magnified

Figure 3: Offset between initial (blue dots) and computed (green dots) image positions as well as the offset between the GCPs initial positions (blue crosses) and their computed positions (green crosses) in the top-view (XY plane), front-view (XZ plane), and side-view (YZ plane). Red dots indicate disabled or uncalibrated images. Dark green ellipses indicate the absolute position uncertainty of the bundle block adjustment result.

1 Absolute camera position and orientation uncertainties

	X[m]	Y[m]	Z[m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.163	0.163	0.396	0.408	0.240	0.143
Sigma	0.029	0.029	0.086	0.004	0.007	0.008

1 Overlap

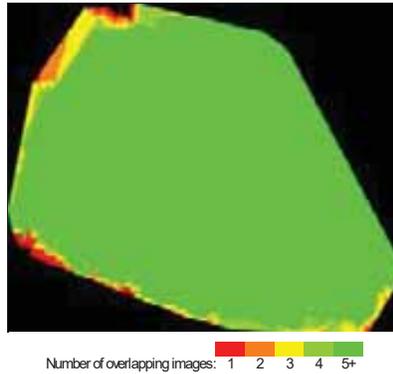


Figure 4: Number of overlapping images computed for each pixel of the orthomosaic. Red and yellow areas indicate low overlap for which poor results may be generated. Green areas indicate an overlap of over 5 images for every pixel. Good quality results will be generated as long as the number of keypoint matches is also sufficient for these areas (see Figure 5 for keypoint matches).

Bundle Block Adjustment Details

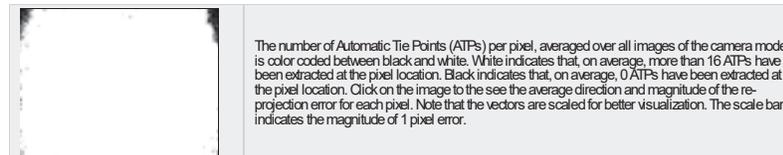
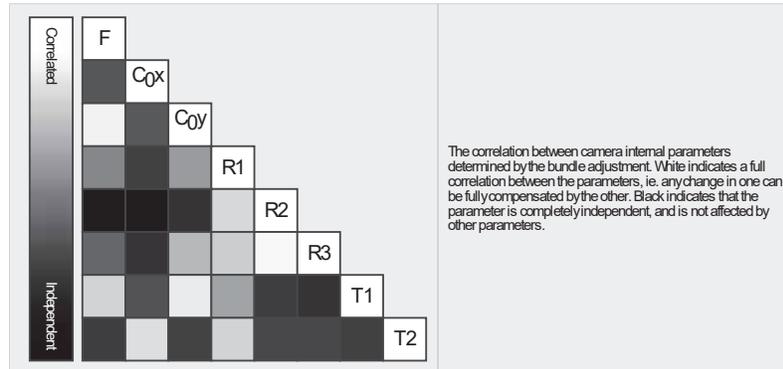
Number of 2D Keypoint Observations for Bundle Block Adjustment	779318
Number of 3D Points for Bundle Block Adjustment	288809
Mean Reprojection Error [pixels]	0.188

Internal Camera Parameters

FC330_3_6_4000x3000 (RGB). Sensor Dimensions: 6.317 [mm] x 4.738 [mm]

EXIF ID: FC330_3_6_4000x3000

	Focal Length	Principal Point x	Principal Point y	R1	R2	R3	T1	T2
Initial Values	2285.722 [pixel] 3.610 [mm]	2000.006 [pixel] 3.159 [mm]	1500.003 [pixel] 2.369 [mm]	-0.001	-0.002	0.000	-0.001	-0.001
Optimized Values	2401.277 [pixel] 3.793 [mm]	1965.917 [pixel] 3.105 [mm]	1459.305 [pixel] 2.305 [mm]	0.002	-0.007	0.004	-0.000	0.000
Uncertainties (Sigma)	0.417 [pixel] 0.001 [mm]	0.073 [pixel] 0.000 [mm]	0.281 [pixel] 0.000 [mm]	0.000	0.000	0.000	0.000	0.000



2D Keypoints Table

	Number of 2D Keypoints per Image	Number of Matched 2D Keypoints per Image
Median	28785	6191

Mn	17240	158
Max	54157	18768
Mean	30268	6836

3D Points from 2D Keypoint Matches

	Number of 3D Points Observed
In 2 Images	194551
In 3 Images	49144
In 4 Images	20300
In 5 Images	10297
In 6 Images	5646
In 7 Images	3454
In 8 Images	2016
In 9 Images	1326
In 10 Images	796
In 11 Images	495
In 12 Images	301
In 13 Images	205
In 14 Images	115
In 15 Images	61
In 16 Images	45
In 17 Images	26
In 18 Images	15
In 19 Images	9
In 20 Images	1
In 21 Images	1
In 22 Images	1
In 23 Images	1
In 28 Images	1
In 29 Images	1
In 30 Images	1

2D Keypoint Matches

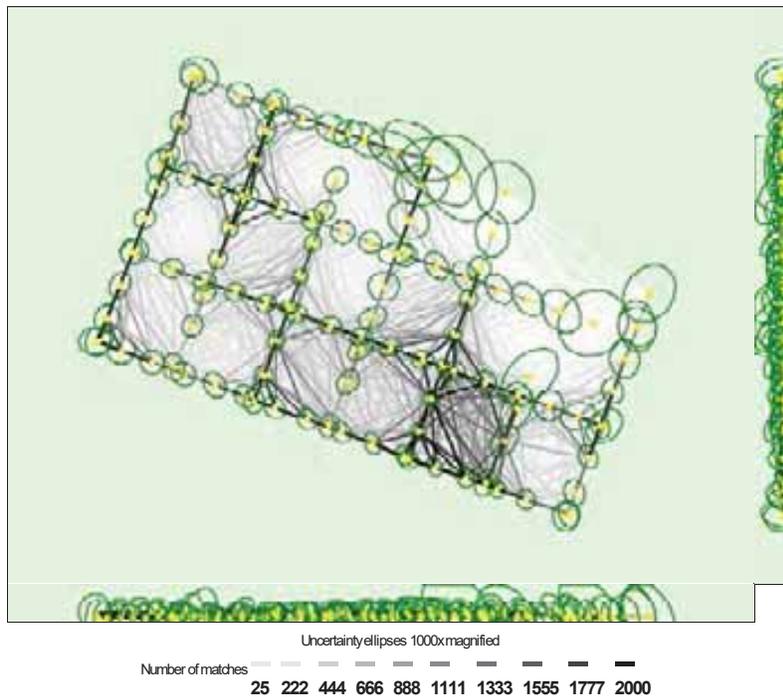


Figure 5: Computed image positions with links between matched images. The darkness of the links indicates the number of matched 2D keypoints between the images. Bright links indicate weak links and require manual tie points or more images. Dark green ellipses indicate the relative camera position uncertainty of the bundle block adjustment result.

Relative camera position and orientation uncertainties

	X[m]	Y[m]	Z[m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.005	0.005	0.005	0.007	0.008	0.004
Sigma	0.002	0.002	0.002	0.003	0.004	0.002

Geolocation Details

Absolute Geolocation Variance

Mn Error [m]	MaxError [m]	Geolocation Error X[%]	Geolocation Error Y[%]	Geolocation Error Z[%]
-	-15.00	0.00	0.00	0.00
-15.00	-12.00	0.00	0.00	0.00
-12.00	-9.00	0.00	0.00	0.00
-9.00	-6.00	0.00	0.00	0.00
-6.00	-3.00	5.26	3.51	0.00
-3.00	0.00	38.60	50.88	50.00
0.00	3.00	50.88	42.11	50.00
3.00	6.00	5.26	3.51	0.00
6.00	9.00	0.00	0.00	0.00
9.00	12.00	0.00	0.00	0.00
12.00	15.00	0.00	0.00	0.00
15.00	-	0.00	0.00	0.00
Mean [m]		-0.005439	-0.001528	-0.002851
Sigma [m]		1.593042	1.512006	0.613554
RMS Error [m]		1.593051	1.512007	0.613560

Min Error and Max Error represent geolocation error intervals between -1.5 and 1.5 times the maximum accuracy of all the images. Columns X, Y, Z show the percentage of images with geolocation errors within the predefined error intervals. The geolocation error is the difference between the initial and computed image positions. Note that the image geolocation errors do not correspond to the accuracy of the observed 3D points.

Relative Geolocation Variance

Relative Geolocation Error	Images X[%]	Images Y[%]	Images Z[%]
[-1.00, 1.00]	100.00	100.00	100.00
[-2.00, 2.00]	100.00	100.00	100.00
[-3.00, 3.00]	100.00	100.00	100.00
Mean of Geolocation Accuracy [m]	5.000000	5.000000	10.000000
Sigma of Geolocation Accuracy [m]	0.000000	0.000000	0.000000

Images X, Y, Z represent the percentage of images with a relative geolocation error in X, Y, Z.

Geolocation Orientational Variance	RMS [degree]
Omega	1.409
Phi	1.662
Kappa	1.709

Geolocation RMS error of the orientation angles given by the difference between the initial and computed image orientation angles.

Initial Processing Details

System Information

Hardware	CPU: Intel(R) Core(TM) i5-3330S CPU @2.70GHz RAM 8GB GPU: Intel(R) HD Graphics (Driver: 10.18.10.3412), RDPDD Chained DD (Driver: unknown), RDP Encoder Mirror Driver (Driver: unknown), RDP Reflector Display Driver (Driver: unknown)
Operating System	Windows 7 Professional, 64-bit

Coordinate Systems

Image Coordinate System	WGS84 (egm96)
Output Coordinate System	WGS 84 / UTMzone 19N (egm96)

Processing Options

Detected Template	3D Maps
Keypoints Image Scale	Full, Image Scale: 1

Advanced: Matching Image Pairs	Aerial Grid or Corridor
Advanced: Matching Strategy	Use Geometrically Verified Matching: no
Advanced: Keypoint Extraction	Targeted Number of Keypoints: Automatic
Advanced: Calibration	Calibration Method: Standard Internal Parameters Optimization: All External Parameters Optimization: All Rematch: Auto, yes

Point Cloud Densification details

Processing Options

Image Scale	multiscale, 1/2 (Half image size, Default)
Point Density	Optimal
Minimum Number of Matches	3
3D Textured Mesh Generation	yes
3D Textured Mesh Settings:	Resolution: Medium Resolution (default) Color Balancing: no
LOD	Generated: no
Advanced: 3D Textured Mesh Settings	Sample Density Divider: 1
Advanced: Image Groups	group1
Advanced: Use Processing Area	yes
Advanced: Use Annotations	yes
Time for Point Cloud Densification	23m:23s
Time for Point Cloud Classification	NA
Time for 3D Textured Mesh Generation	05m:15s

Results

Number of Generated Tiles	1
Number of 3D Densified Points	5777596
Average Density (per m ³)	293.81

DSM, Orthomosaic and Index Details

Processing Options

DSM and Orthomosaic Resolution	1 x GSD (2.24 [cm/pixel])
DSM Filters	Noise Filtering: yes Surface Smoothing: yes, Type: Sharp
Raster DSM	Generated: yes Method: Inverse Distance Weighting Merge Tiles: yes
Orthomosaic	Generated: yes Merge Tiles: yes GeoTIFF Without Transparency: no Google Maps Tiles and KML: no
Time for DSM Generation	09m:39s
Time for Orthomosaic Generation	17m:15s
Time for DTM Generation	00s
Time for Contour Lines Generation	00s
Time for Reflectance Map Generation	00s
Time for Index Map Generation	00s

Site name:

Playa Poza de las Mujeres, Manatí

After northeasterly swell of March 2018



A. Physical address:

Poza de las Mujeres, Road PR 6684, Manatí, Puerto Rico, 00617.

B. Date of capture of imagery:

March 22, 2018

C. Coordinates:

18.475878221 N – 66.50531699 W

D. Description of site:

The site is a very popular tourist destination that was severely eroded during Hurricane María in September 20, 2017. All the vegetation was washed away by flood waters creating an approximately 146 m wide breach. A house collapsed due to the erosion caused by the flood waters.

E. Distance from community:

This site is located at a distance of 150 m from road PR 6684 and at a distance of 668 m from the nearest house (to the east).

Aerial imagery

i. Contour map

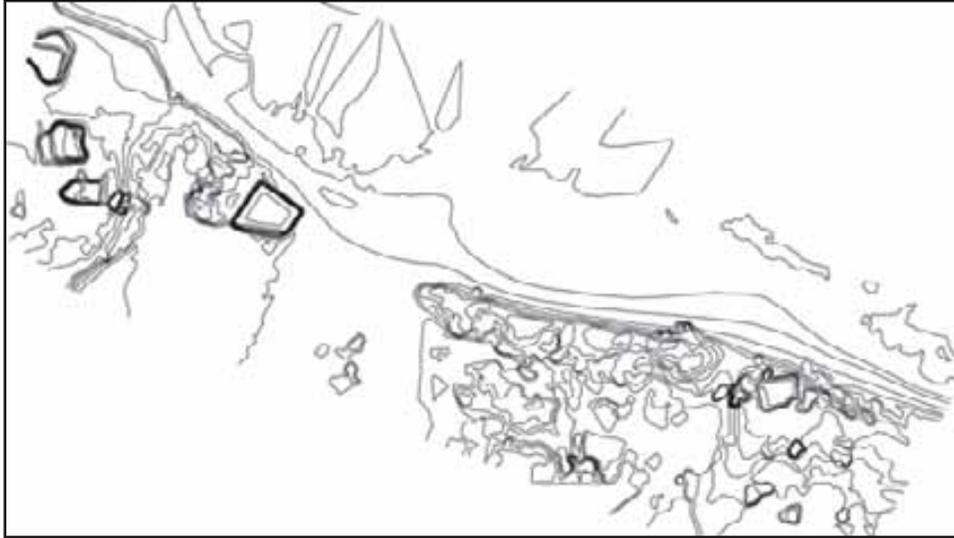


Figure 278. Contour map of the area behind the Poza de las Mujeres area (after northeasterly swell), in Manatí Puerto Rico with elevation intervals of 1 meter.

ii. 3D imagery



Figure 279. Aerial 3D image of the Poza de las Mujeres area (after northeasterly swell), Manatí.

ii. Orthomosaic model



Figure 280. Orthomosaic image of Poza de las Mujeres area (after northeasterly swell), Manatí.

iii. Density Surface Models (DSM)

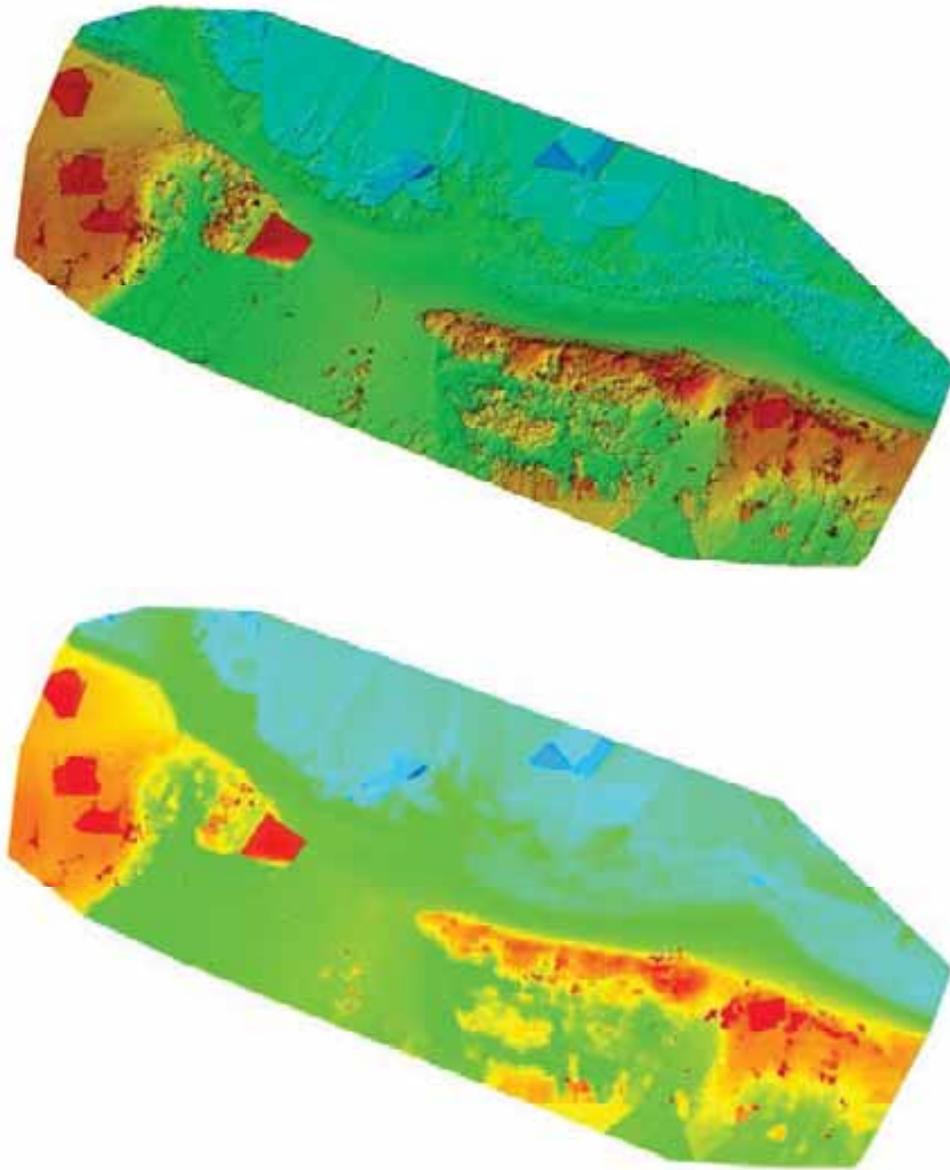


Figure 281. Density surface model (with shading top and without shading bottom) images of the dune located on the Poza de las Mujeres (after northeasterly swell), Manatí.

iv. Thermal images

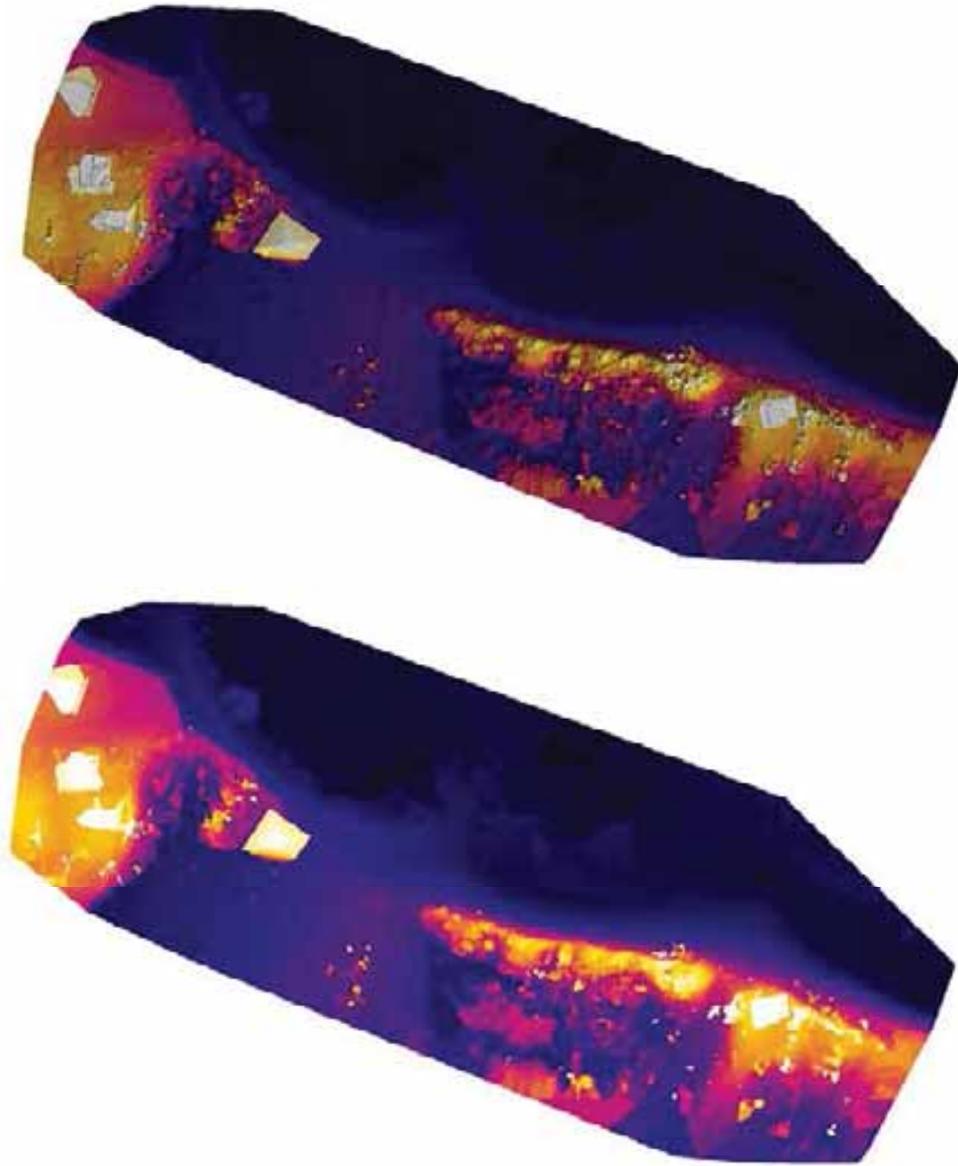


Figure 282. Thermal images (with shading top and without shading bottom) of the Poza de las Mujeres (after northeasterly swell), Manatí.

vi. 3D altitude RGB North

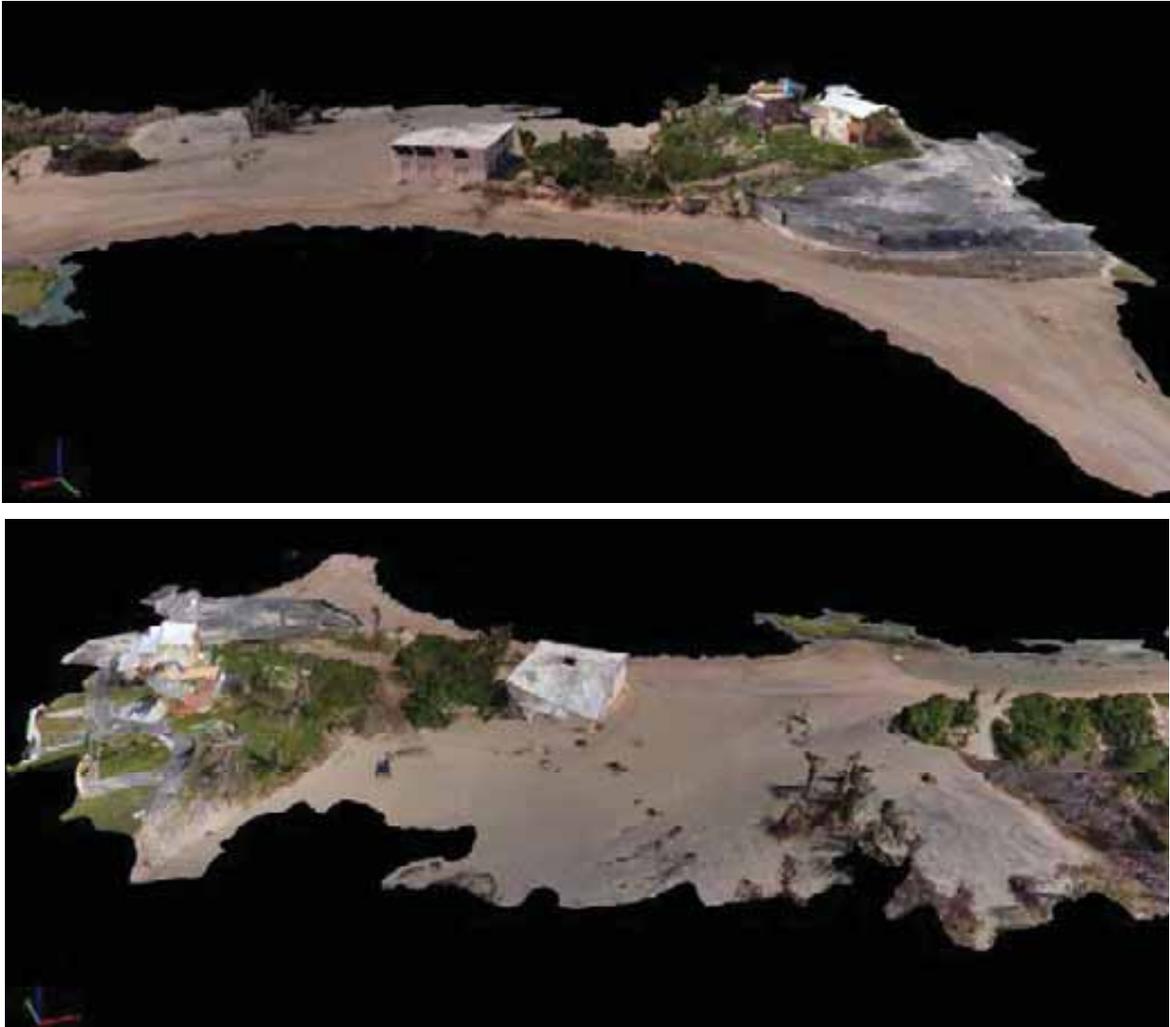


Figure 283. Three dimensional RGB images of the western part of Poza de las Mujeres, Manatí. View from the north of the eastern part of the site (top) and from the south of the same area (bottom).

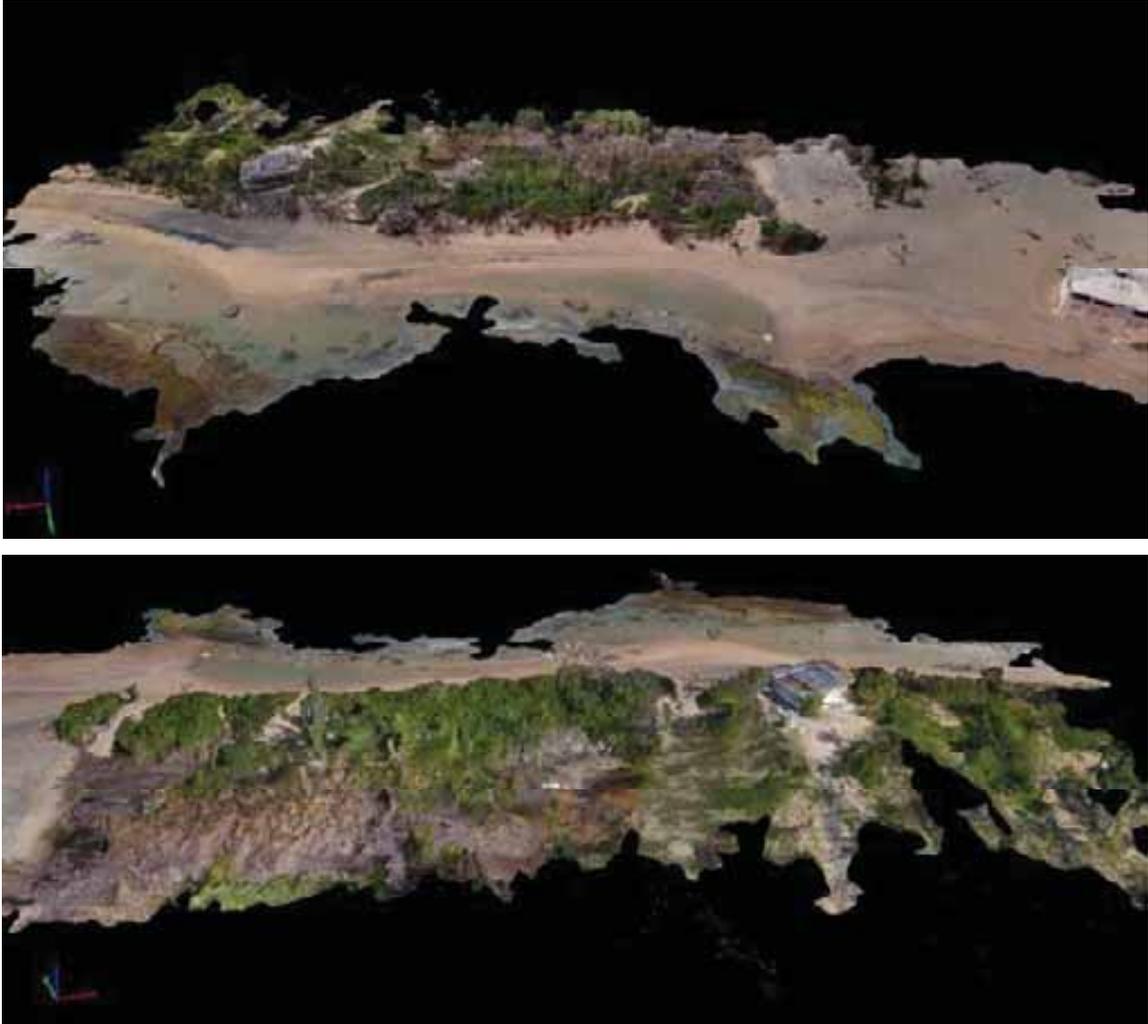


Figure 284. Three dimensional RGB images of the eastern part of Poza de las Mujeres, Manatí. View from the north of the eastern part of the site (top) and from the south of the same area (bottom).

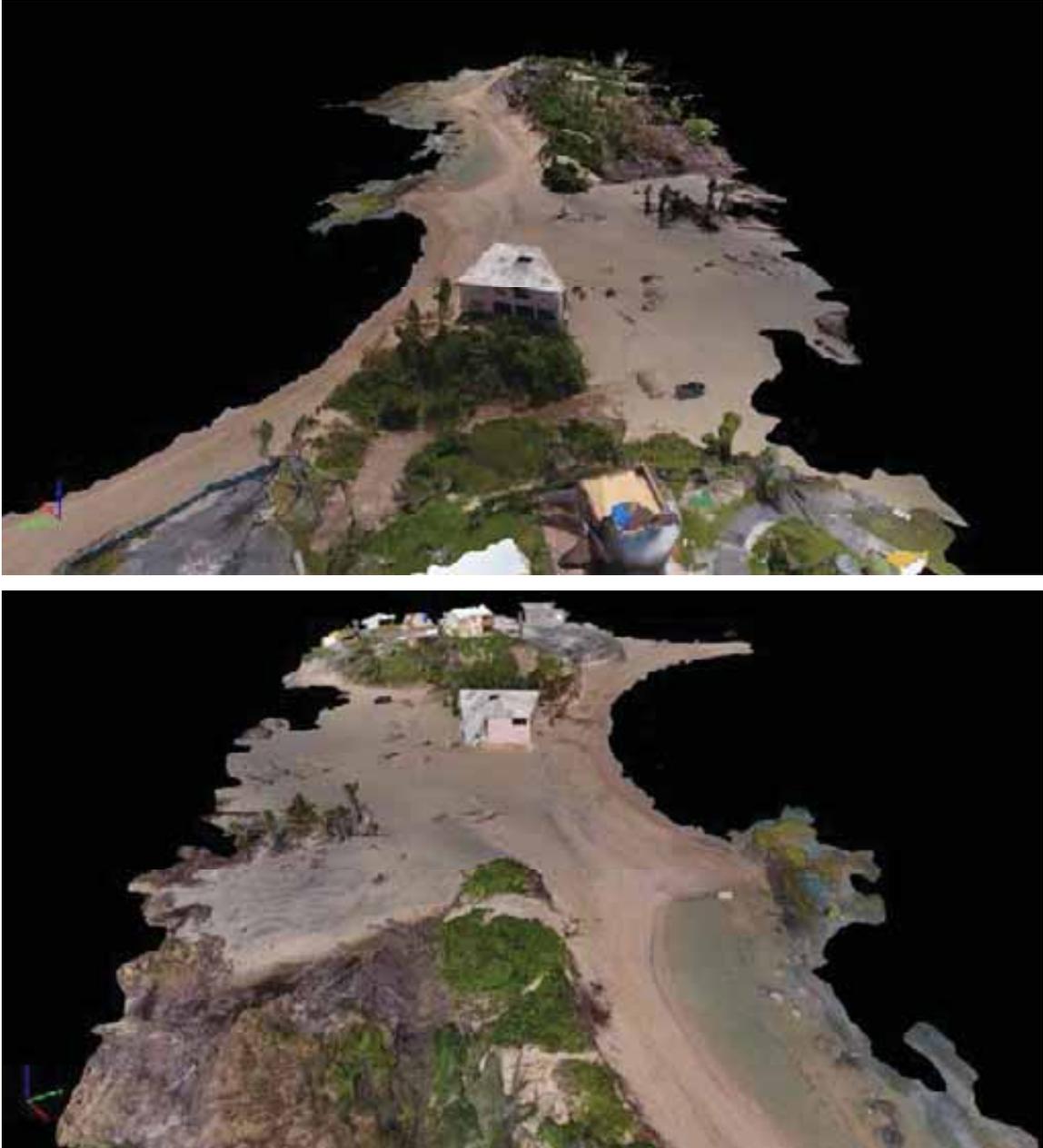


Figure 285. Three dimensional RGB images of the western part of the Poza de las Mujeres, Manatí. View from the west (top) and from the east (bottom).

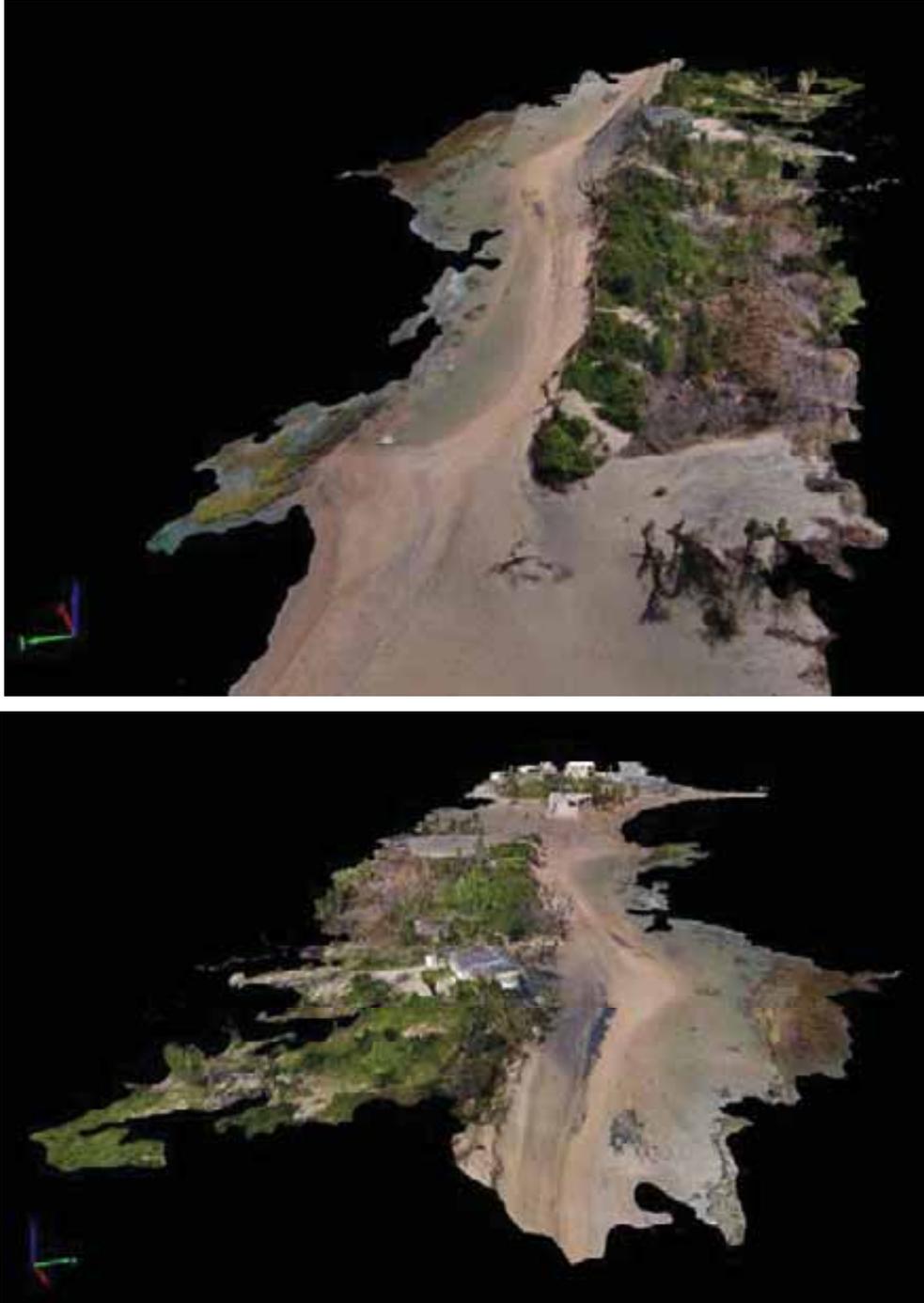


Figure 286. Three dimensional RGB images of the eastern part of the Poza de las Mujeres, Manatí. View from the west (top) and from the east (bottom).

vii. DSM grayscale



Figure 287. Grayscale DSM images of the Poza de las Mujeres (after swell), Manatí. The top image shows shades and the bottom is not shaded.

Site report

F. Vegetation cover



Figure 288. Images of the area for which vegetation cover is being monitored for the Poza de las Mujeres in Manatí, Puerto Rico. The vegetation cover was 37.3% for the eastern part of the site on March 22, 2018.

I. Volume measurements of selected areas of the dunes



Figure 289. Three dimensional aerial picture of Poza de las Mujeres in Manatí with three areas marked by polygons for which three dimensional area, cut volume, fill volume and total volume were calculated using the Pix4D software. Refer to image above for the data. The order of the data is from left to right on the image.

J. Conservation threats



Figure 290. Area of severe erosion in Poza de las Mujeres in Manatí.

K. Recommended ecological restoration courses of action (COA)

We recommend the installation of a wooden walkover to re-direct foot traffic out of sensitive areas and two biomimicry matrices to promote the accumulation of sand. We also propose the planting of dune vegetation to stabilize the sand that accumulates. Planting of vetiver grass could also contribute to the stabilization of the backdune area.



Figure 291. Area to be ecologically restored behind the Poza de las Mujeres, Manatí. Highlighted areas correspond to each technique that will be used in this area. Yellow represents the location of a wooden boardwalk, the red dot marks the location of an information sign, tan represents the area of the dune crest that where biomimicry matrices will be installed to promote the accumulation of sand. The areas shaded in light green represent locations for the planting of dune vegetation.

L. Pix 4D Quality Report

Quality Report

Generated with Pix4Dmapper Pro version 4.2.25

Important: Click on the different icons for:

- Help to analyze the results in the Quality Report
- Additional information about the sections

Click [here](#) for additional tips to analyze the Quality Report

Summary

Project	Playa Piza de las Mujeres en Manati
Processed	2018-04-02 19:05:20
Camera Model Name(s)	FC330_3.6_4000x3000 (RGB)
Average Ground Sampling Distance (GSD)	1.95 cm / 0.77 in
Area Covered	0.049 km ² / 4.9119 ha / 0.02 sq. mi. / 12.1439 acres
Time for Initial Processing (without report)	47m21s

Quality Check

Images	median of 35599 keypoints per image	✓
Dataset	174 out of 182 Images calibrated (95%), all images enabled	✓
Camera Optimization	4.57% relative difference between initial and optimized internal camera parameters	✓
Matching	median of 4864.53 matches per calibrated image	✓
Georeferencing	yes, no 3D GCP	⚠

Preview

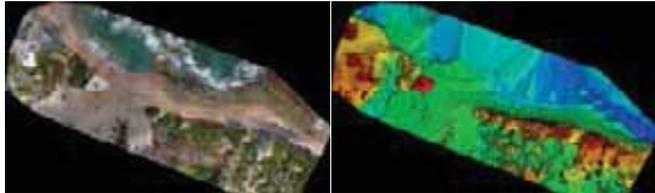


Figure 1: Orthomosaic and the corresponding sparse Digital Surface Model (DSM) before densification.

Calibration Details

Number of Calibrated Images	174 out of 182
Number of Geolocated Images	182 out of 182

Initial Image Positions

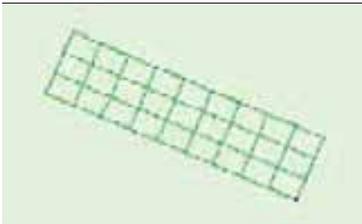
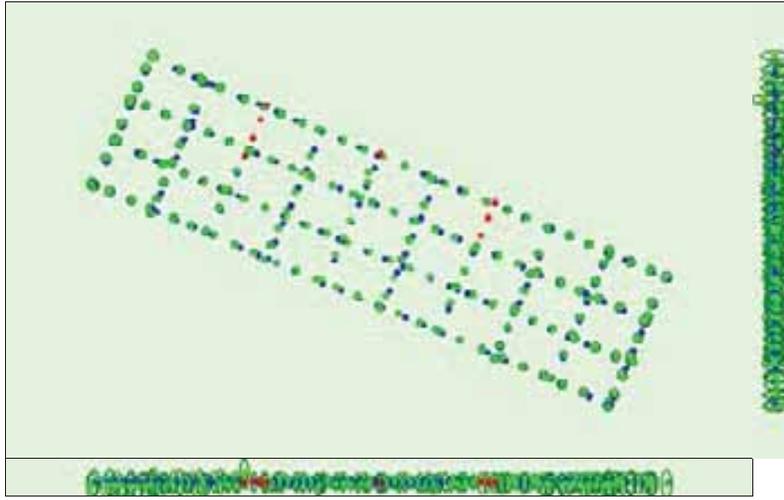


Figure 2: Top view of the initial image position. The green line follows the position of the images in time starting from the large blue dot.

1 Computed Image/GCPs/Manual Tie Points Positions



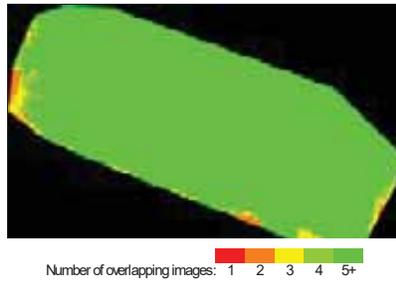
Uncertainty ellipses 10x magnified

Figure 3: Offset between initial (blue dots) and computed (green dots) image positions as well as the offset between the GCPs initial positions (blue crosses) and their computed positions (green crosses) in the top-view (XY plane), front-view (XZ plane), and side-view (YZ plane). Red dots indicate disabled or uncalibrated images. Dark green ellipses indicate the absolute position uncertainty of the bundle block adjustment result.

1 Absolute camera position and orientation uncertainties

	X[m]	Y[m]	Z[m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.189	0.189	0.461	0.589	0.294	0.152
Sigma	0.039	0.039	0.099	0.015	0.023	0.015

1 Overlap



Number of overlapping images: 1 2 3 4 5+

Figure 4: Number of overlapping images computed for each pixel of the orthomosaic. Red and yellow areas indicate low overlap for which poor results may be generated. Green areas indicate an overlap of over 5 images for every pixel. Good quality results will be generated as long as the number of keypoint matches is also sufficient for these areas (see Figure 5 for keypoint matches).

Bundle Block Adjustment Details

Number of 2D Keypoint Observations for Bundle Block Adjustment	918485
Number of 3D Points for Bundle Block Adjustment	341520
Mean Reprojection Error [pixels]	0.194

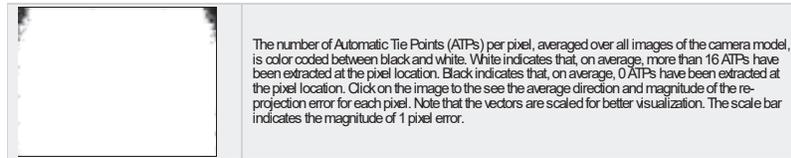
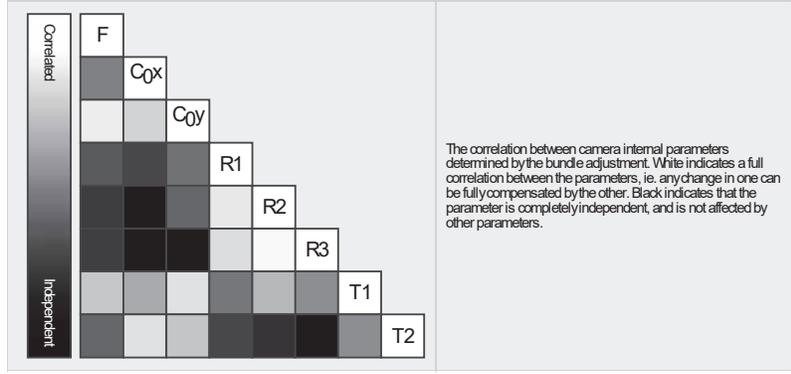
1 Internal Camera Parameters

FC330_3.6_4000x3000 (RGB). Sensor Dimensions: 6.317 [mm] x 4.738 [mm]

EXIF ID: FC330_3.6_4000x3000

	Focal Length	Principal Point x	Principal Point y	R1	R2	R3	T1	T2

Initial Values	2285.722 [pixel] 3.610 [mm]	2000.006 [pixel] 3.159 [mm]	1500.003 [pixel] 2.369 [mm]	-0.001	-0.002	0.000	-0.001	-0.001
Optimized Values	2390.225 [pixel] 3.775 [mm]	1965.201 [pixel] 3.104 [mm]	1465.685 [pixel] 2.315 [mm]	0.001	-0.007	0.004	0.000	0.000
Uncertainties (Sigma)	0.294 [pixel] 0.000 [mm]	0.078 [pixel] 0.000 [mm]	0.219 [pixel] 0.000 [mm]	0.000	0.000	0.000	0.000	0.000



2D Keypoints Table

	Number of 2D Keypoints per Image	Number of Matched 2D Keypoints per Image
Median	35599	4865
Mn	17957	163
Max	60368	13062
Mean	36079	5279

3D Points from 2D Keypoint Matches

	Number of 3D Points Observed
In 2 Images	236873
In 3 Images	54515
In 4 Images	21809
In 5 Images	10859
In 6 Images	6207
In 7 Images	3885
In 8 Images	2404
In 9 Images	1544
In 10 Images	1044
In 11 Images	716
In 12 Images	533
In 13 Images	352
In 14 Images	220
In 15 Images	172
In 16 Images	103
In 17 Images	76
In 18 Images	61
In 19 Images	47
In 20 Images	29
In 21 Images	21
In 22 Images	17
In 23 Images	8
In 24 Images	9
In 25 Images	8
In 26 Images	1
In 27 Images	3
In 28 Images	1
In 29 Images	1
In 30 Images	2

2D Keypoint Matches

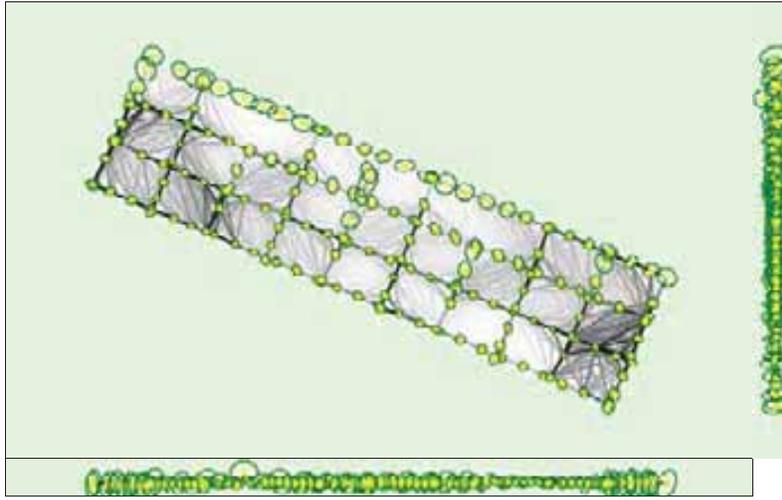


Figure 5: Computed image positions with links between matched images. The darkness of the links indicates the number of matched 2D keypoints between the images. Bright links indicate weak links and require manual tie points or more images. Dark green ellipses indicate the relative camera position uncertainty of the bundle block adjustment result.

Relative camera position and orientation uncertainties

	X[m]	Y[m]	Z[m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.006	0.005	0.007	0.008	0.010	0.006
Sigma	0.002	0.002	0.003	0.002	0.003	0.002

Geolocation Details

Absolute Geolocation Variance

Min Error [m]	Max Error [m]	Geolocation Error X[%]	Geolocation Error Y[%]	Geolocation Error Z[%]
-	-15.00	0.00	0.00	0.00
-15.00	-12.00	0.00	0.00	0.00
-12.00	-9.00	0.00	0.00	0.00
-9.00	-6.00	0.00	0.00	0.00
-6.00	-3.00	6.90	0.57	0.57
-3.00	0.00	39.66	59.20	47.70
0.00	3.00	51.15	36.78	51.72
3.00	6.00	2.30	3.45	0.00
6.00	9.00	0.00	0.00	0.00
9.00	12.00	0.00	0.00	0.00
12.00	15.00	0.00	0.00	0.00
15.00	-	0.00	0.00	0.00
Mean [m]		0.010148	0.010614	0.026247
Sigma [m]		1.696662	1.327694	0.759721
RMS Error [m]		1.696662	1.327737	0.760174

Min Error and Max Error represent geolocation error intervals between -1.5 and 1.5 times the maximum accuracy of all the images. Columns X, Y, Z show the percentage of images with geolocation errors within the predefined error intervals. The geolocation error is the difference between the initial and computed image positions. Note that the image geolocation errors do not correspond to the accuracy of the observed 3D points.

Relative Geolocation Variance

Relative Geolocation Error	Images X[%]	Images Y[%]	Images Z[%]
[-1.00, 1.00]	100.00	100.00	100.00
[-2.00, 2.00]	100.00	100.00	100.00

[-3.00, 3.00]	100.00	100.00	100.00
Mean of Geolocation Accuracy [m]	5.000000	5.000000	10.000000
Sigma of Geolocation Accuracy [m]	0.000000	0.000000	0.000000

Images X, Y, Z represent the percentage of images with a relative geolocation error in X, Y, Z.

Geolocation Orientational Variance	RMS [degree]
Omega	1.751
Phi	2.261
Kappa	1.318

Geolocation RMS error of the orientation angles given by the difference between the initial and computed image orientation angles.

Initial Processing Details

System Information

Hardware	CPU: Intel(R) Core(TM) i5-3330S CPU @2.70GHz RAM 8GB GPU: Intel(R) HD Graphics (Driver: 10.18.10.3412), RDPDD Chained DD (Driver: unknown), RDP Encoder Mirror Driver (Driver: unknown), RDP Reflector Display Driver (Driver: unknown)
Operating System	Windows 7 Professional, 64-bit

Coordinate Systems

Image Coordinate System	WGS84 (egm96)
Output Coordinate System	WGS 84 / UTMzone 19N (egm96)

Processing Options

Detected Template	3D Maps
Keypoints Image Scale	Full, Image Scale: 1
Advanced: Matching Image Pairs	Aerial Grid or Corridor
Advanced: Matching Strategy	Use Geometrically Verified Matching: no
Advanced: Keypoint Extraction	Targeted Number of Keypoints: Automatic
Advanced: Calibration	Calibration Method: Standard Internal Parameters Optimization: All External Parameters Optimization: All Rematch: Auto, yes

Point Cloud Densification details

Processing Options

Image Scale	multiscale, 1/2 (Half image size, Default)
Point Density	Optimal
Minimum Number of Matches	3
3D Textured Mesh Generation	yes
3D Textured Mesh Settings:	Resolution: Medium Resolution (default) Color Balancing: no
LOD	Generated: no
Advanced: 3D Textured Mesh Settings	Sample Density Divider: 1
Advanced: Image Groups	group1
Advanced: Use Processing Area	yes
Advanced: Use Annotations	yes
Time for Point Cloud Densification	30m:36s
Time for Point Cloud Classification	NA
Time for 3D Textured Mesh Generation	06m:36s

Results

Number of Generated Tiles	1
Number of 3D Densified Points	7874407
Average Density (per m ³)	419.68

DSM, Orthomosaic and Index Details

Processing Options



DSM and Orthomosaic Resolution	1 x GSD (1.95 [cm/pixel])
DSM Filters	Noise Filtering: yes Surface Smoothing: yes, Type: Sharp
Raster DSM	Generated: yes Method: Inverse Distance Weighting Merge Tiles: yes
Orthomosaic	Generated: yes Merge Tiles: yes GeoTIFF Without Transparency: no Google Maps Tiles and KML: no
Time for DSM Generation	14m:20s
Time for Orthomosaic Generation	33m:27s
Time for DTM Generation	00s
Time for Contour Lines Generation	00s
Time for Reflectance Map Generation	00s
Time for Index Map Generation	00s

Site name:

Mar Chiquita, Manatí

After northeasterly swell of March 2018



A. Physical address:

Mar Chiquita, PR 648, Manatí, Puerto Rico, 00674.

B. Date of capture of imagery:

March 22, 2018

C. Coordinates:

18.47233532 N – 66.48357757 W

D. Description of site:

The site is located on the area known as Mar Chiquita in Manatí. The primary dune is breached in front of the area that is used as a parking lot.

E. Distance from community:

The site is located at an approximate distance of 68 m from road PR 648 and adjacent to four houses and a highly populated area.

Aerial imagery

i. Contour map



Figure 292. Contour map of the area behind the Mar Chiquita area (after northeasterly swell), in Manatí Puerto Rico with elevation intervals of 1 meter.

ii. 3D imagery

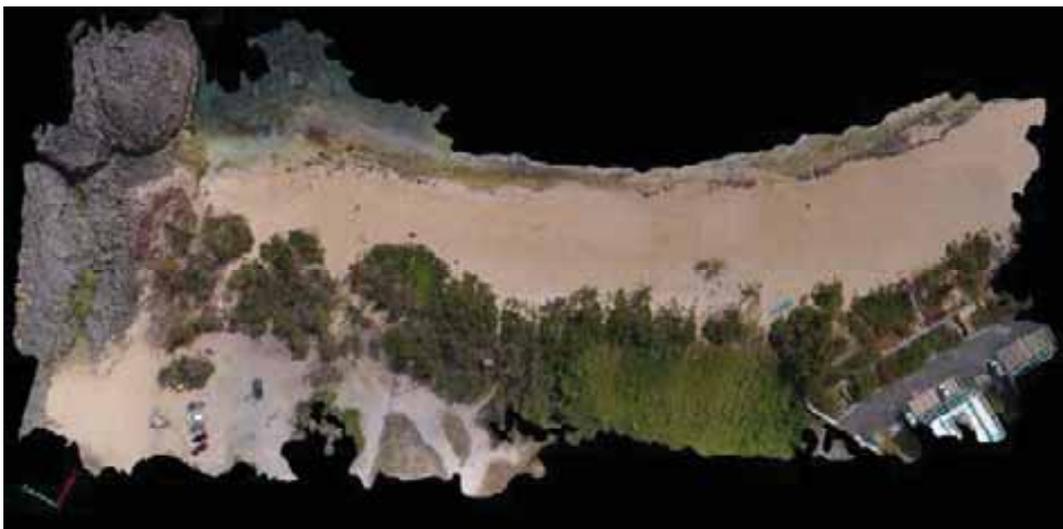


Figure 293. Aerial 3D image of the Mar Chiquita area (after northeasterly swell), Manatí.

iii. Orthomosaic model



Figure 294. Orthomosaic image of Mar Chiquita area (after northeasterly swell), Manatí.

iv. Density Surface Models (DSM)

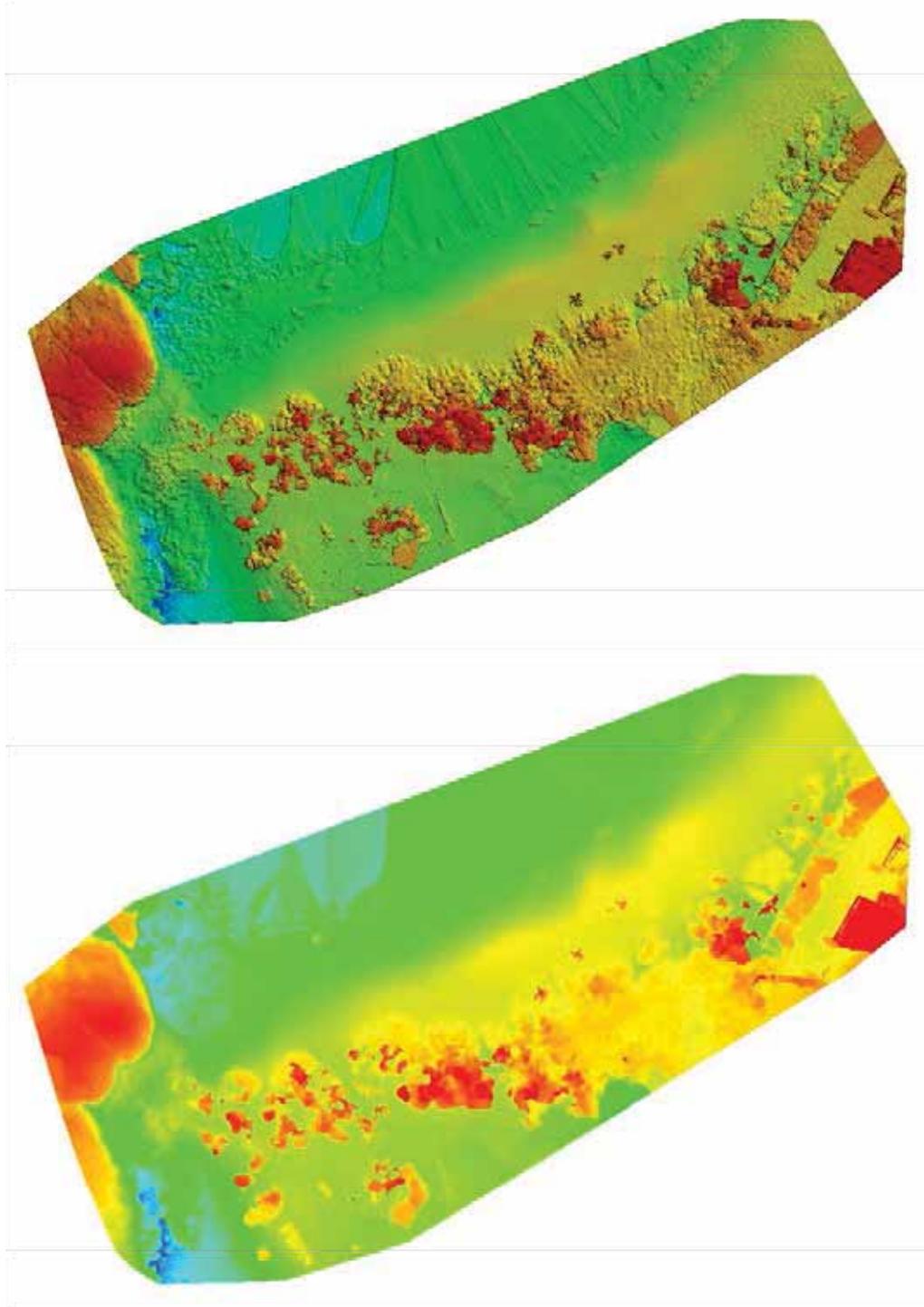


Figure 295. Density surface model (with shading top and without shading bottom) images of the dune located on the Mar Chiquita area (after northeasterly swell), Manatí.

v. Thermal images

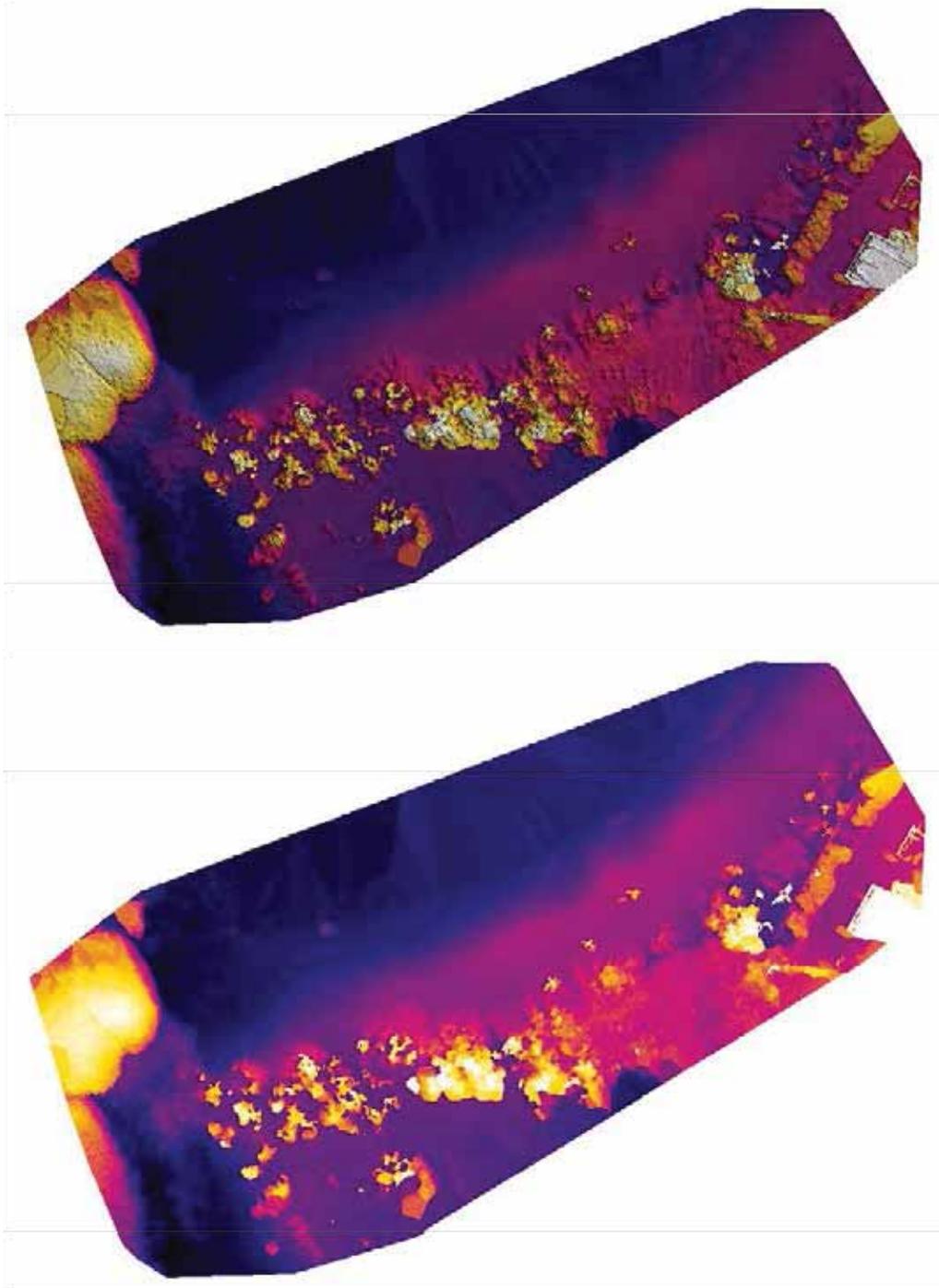


Figure 296. Thermal images (with shading top and without shading bottom) of the Mar Chiquita area (after northeasterly swell), Manatí.

vi. 3D altitude RGB North

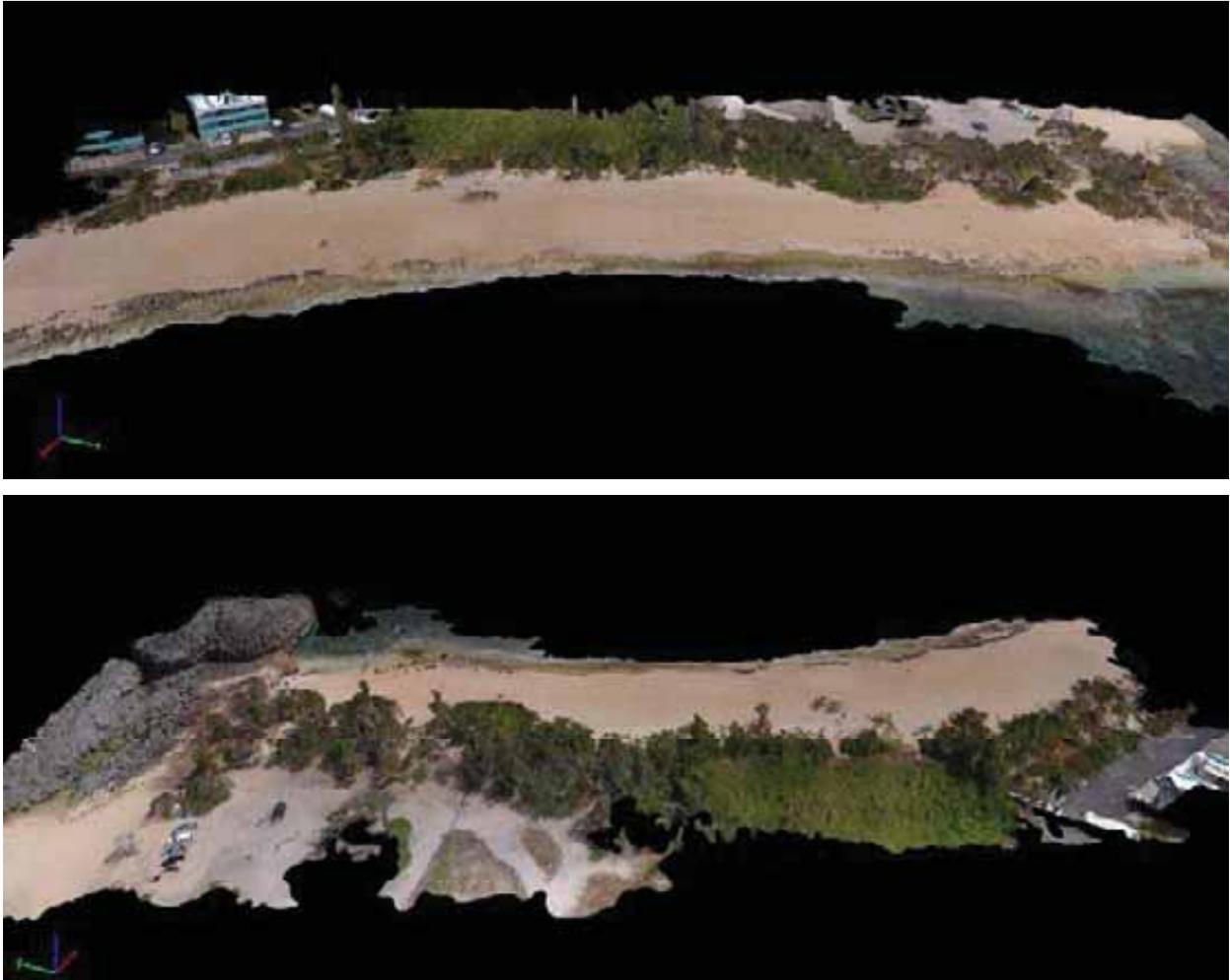


Figure 297. Three dimensional RGB images of the Mar Chiquita area, Manatí. View from the north of the eastern part of the site (top) and from the south of the same area (bottom).



Figure 298. Three dimensional RGB images of the eastern part of the Mar Chiquita area, Manatí. View from the west (top) and from the east (bottom).

vii. DSM grayscale

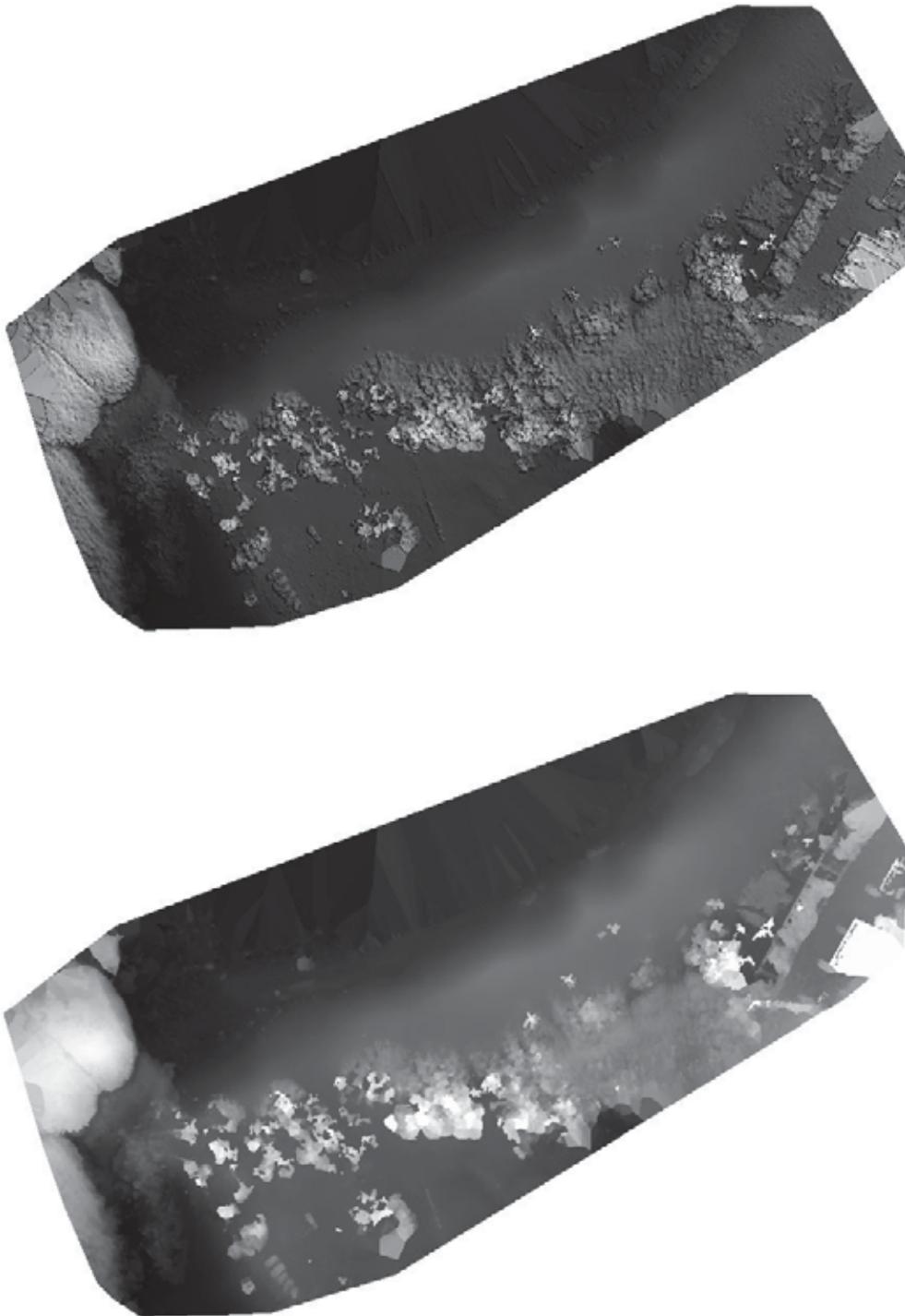


Figure 299. Grayscale DSM images of the Mar Chiquita (after swell) area, Manatí. The top image shows shades and the bottom is not shaded.

Site report

F. Vegetation cover



Figure 300. Vegetation covered 52% of the area of Mar Chiquita in Manatí area, Puerto Rico on March 22, 2018 (after northeasterly swell).

K. Recommended ecological restoration courses of action (COA)

We suggest the installation of a wooden boardwalk in front of the area used as parking as well as several biomimicry matrices on the foredune area. This areas will be stabilized with dune vegetation when sand accumulates.



Figure 302. Area to be ecologically restored in Mar Chiquita, Manatí. Highlighted areas correspond to each technique that will be used in this area. Yellow represents the location of a wooden boardwalk, the red dot marks the location of an information sign, tan represents the area of the dune crest that where biomimicry matrices will be installed to promote the accumulation of sand.

L. Pix 4D Quality Report

Quality Report



Generated with Pix4Dmapper Pro version 4.2.25

Important: Click on the different icons for:

- Help to analyze the results in the Quality Report
- Additional information about the sections

Click [here](#) for additional tips to analyze the Quality Report

Summary

Project	Playa al Este de Mar Chiquita Seccion 3 Mar del Plata
Processed	2018-04-02 16:21:30
Camera Model Name(s)	FC330_3,6_4000x3000 (RGB)
Average Ground Sampling Distance (GSD)	1.93 cm / 0.76 in
Area Covered	0.033 km ² / 3.3215 ha / 0.01 sq. mi. / 8.2119 acres
Time for Initial Processing (without report)	37m:45s

Quality Check

Images	median of 50954 keypoints per image	✓
Dataset	81 out of 81 images calibrated (100%), all images enabled	✓
Camera Optimization	4.23% relative difference between initial and optimized internal camera parameters	✓
Matching	median of 16834.6 matches per calibrated image	✓
Georeferencing	yes, no 3D GCP	⚠

Preview

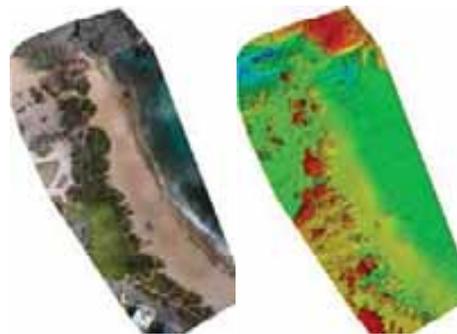


Figure 1: Orthomosaic and the corresponding sparse Digital Surface Model (DSM) before densification.

Calibration Details

Number of Calibrated Images	81 out of 81
Number of Geolocated Images	81 out of 81

Initial Image Positions

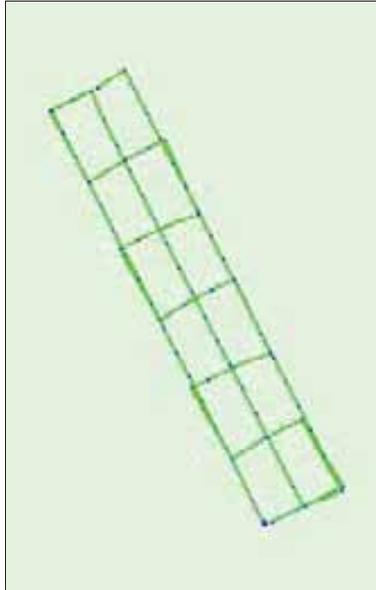


Figure 2: Top view of the initial image position. The green line follows the position of the images in time starting from the large blue dot.

📌 Computed Image/GCPs/Manual Tie Points Positions



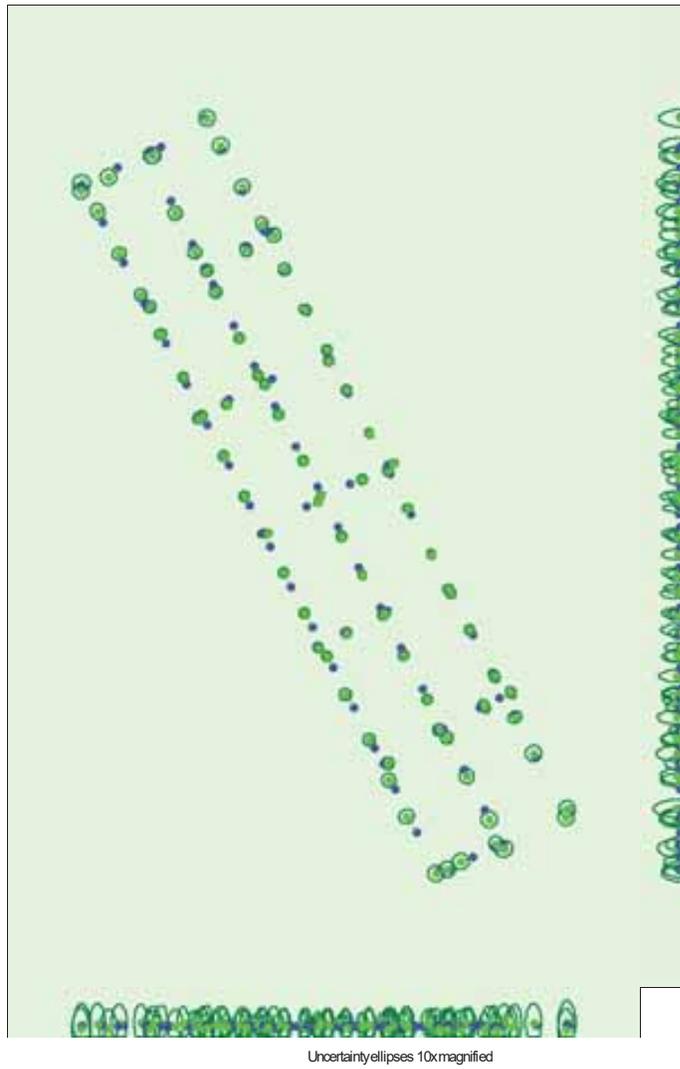
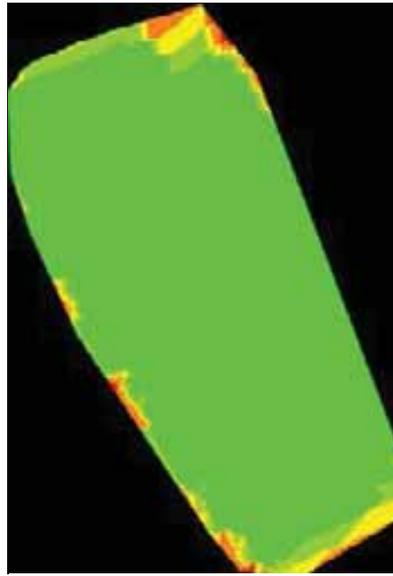


Figure 3: Offset between initial (blue dots) and computed (green dots) image positions as well as the offset between the GCPs initial positions (blue crosses) and their computed positions (green crosses) in the top-view (XY plane), front-view (XZ plane), and side-view (YZ plane). Dark green ellipses indicate the absolute position uncertainty of the bundle block adjustment result.

Absolute camera position and orientation uncertainties

	X[m]	Y[m]	Z[m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.150	0.149	0.366	0.452	0.785	0.333
Sigma	0.032	0.032	0.074	0.056	0.025	0.028

Overlap



Number of overlapping images: 1 2 3 4 5+

Figure 4: Number of overlapping images computed for each pixel of the orthomosaic. Red and yellow areas indicate low overlap for which poor results may be generated. Green areas indicate an overlap of over 5 images for every pixel. Good quality results will be generated as long as the number of keypoint matches is also sufficient for these areas (see Figure 5 for keypoint matches).

Bundle Block Adjustment Details

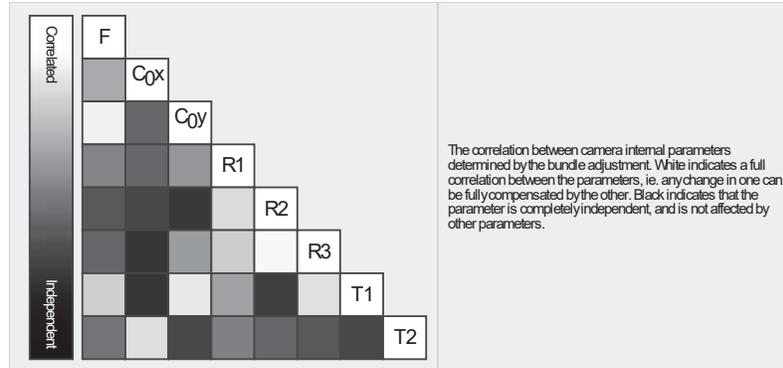
Number of 2D Keypoint Observations for Bundle Block Adjustment	1401003
Number of 3D Points for Bundle Block Adjustment	463221
Mean Reprojection Error [pixels]	0.208

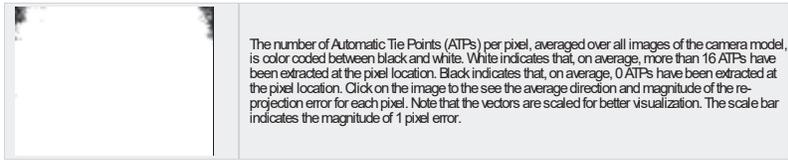
Internal Camera Parameters

FC330_3.6_4000x3000 (RGB). Sensor Dimensions: 6.317 [mm] x 4.738 [mm]

EXIF ID: FC330_3.6_4000x3000

	Focal Length	Principal Point x	Principal Point y	R1	R2	R3	T1	T2
Initial Values	2285.722 [pixel] 3.610 [mm]	2000.006 [pixel] 3.159 [mm]	1500.003 [pixel] 2.369 [mm]	-0.001	-0.002	0.000	-0.001	-0.001
Optimized Values	2382.626 [pixel] 3.763 [mm]	1967.773 [pixel] 3.108 [mm]	1466.474 [pixel] 2.316 [mm]	0.003	-0.009	0.006	-0.000	0.000
Uncertainties (Sigma)	0.310 [pixel] 0.000 [mm]	0.063 [pixel] 0.000 [mm]	0.216 [pixel] 0.000 [mm]	0.000	0.000	0.000	0.000	0.000





2D Keypoints Table

	Number of 2D Keypoints per Image	Number of Matched 2D Keypoints per Image
Median	50954	16835
Mn	34018	5982
Max	63503	26321
Mean	51188	17296

3D Points from 2D Keypoint Matches

	Number of 3D Points Observed
In 2 Images	283355
In 3 Images	78295
In 4 Images	37095
In 5 Images	21286
In 6 Images	13687
In 7 Images	9407
In 8 Images	6644
In 9 Images	4830
In 10 Images	3102
In 11 Images	2126
In 12 Images	1383
In 13 Images	818
In 14 Images	513
In 15 Images	257
In 16 Images	164
In 17 Images	111
In 18 Images	68
In 19 Images	36
In 20 Images	24
In 21 Images	11
In 22 Images	5
In 23 Images	4

2D Keypoint Matches

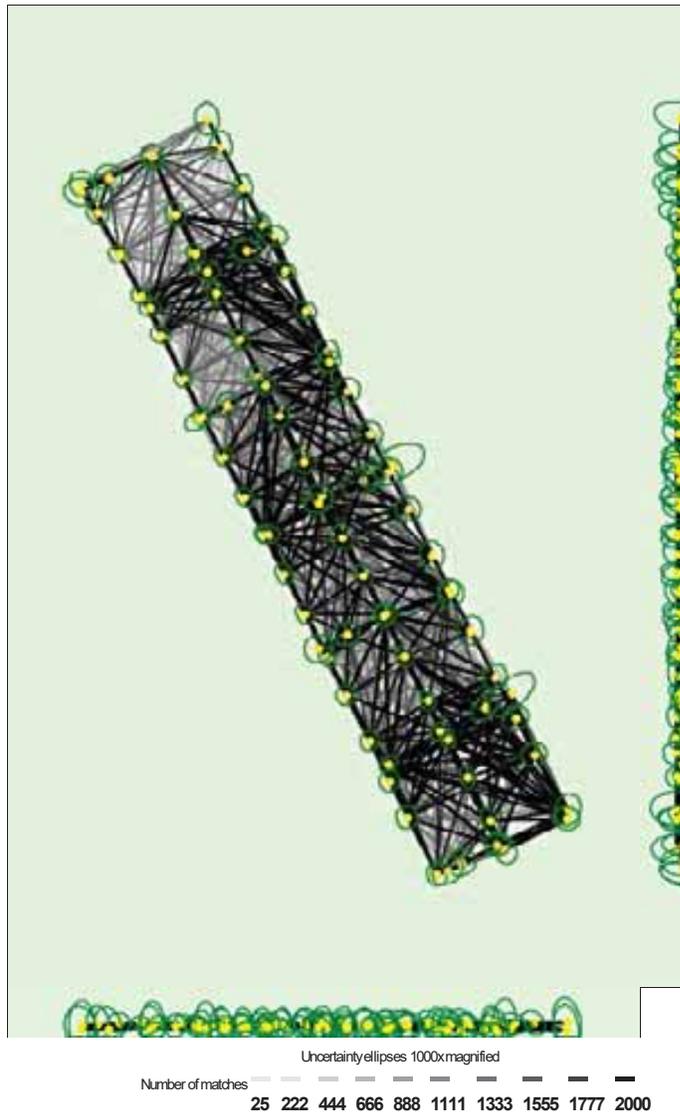


Figure 5: Computed image positions with links between matched images. The darkness of the links indicates the number of matched 2D keypoints between the images. Bright links indicate weak links and require manual tie points or more images. Dark green ellipses indicate the relative camera position uncertainty of the bundle block adjustment result.

Relative camera position and orientation uncertainties

	X[m]	Y[m]	Z[m]	Omega [degree]	Psi [degree]	Kappa [degree]
Mean	0.003	0.003	0.003	0.007	0.005	0.003
Sigma	0.001	0.001	0.001	0.002	0.001	0.001

Geolocation Details

Absolute Geolocation Variance

Min Error [m]	Max Error [m]	Geolocation Error X[%]	Geolocation Error Y[%]	Geolocation Error Z[%]
-	-15.00	0.00	0.00	0.00
-15.00	-12.00	0.00	0.00	0.00

-12.00	-9.00	0.00	0.00	0.00
-9.00	-6.00	0.00	0.00	0.00
-6.00	-3.00	1.23	4.94	0.00
-3.00	0.00	51.85	44.44	55.56
0.00	3.00	46.91	46.91	44.44
3.00	6.00	0.00	3.70	0.00
6.00	9.00	0.00	0.00	0.00
9.00	12.00	0.00	0.00	0.00
12.00	15.00	0.00	0.00	0.00
15.00	-	0.00	0.00	0.00
Mean [m]		0.006258	0.007271	0.022185
Sigma [m]		1.135159	1.688927	0.510717
RMS Error [m]		1.135176	1.688943	0.511199

Min Error and Max Error represent geolocation error intervals between -1.5 and 1.5 times the maximum accuracy of all the images. Columns X, Y, Z show the percentage of images with geolocation errors within the predefined error intervals. The geolocation error is the difference between the initial and computed image positions. Note that the image geolocation errors do not correspond to the accuracy of the observed 3D points.

Relative Geolocation Variance

Relative Geolocation Error	Images X [%]	Images Y [%]	Images Z [%]
[-1.00, 1.00]	100.00	100.00	100.00
[-2.00, 2.00]	100.00	100.00	100.00
[-3.00, 3.00]	100.00	100.00	100.00
Mean of Geolocation Accuracy [m]	5.000000	5.000000	10.000000
Sigma of Geolocation Accuracy [m]	0.000000	0.000000	0.000000

Images X, Y, Z represent the percentage of images with a relative geolocation error in X, Y, Z.

Geolocation Orientational Variance	RMS [degree]
Omega	2.184
Phi	1.248
Kappa	1.316

Geolocation RMS error of the orientation angles given by the difference between the initial and computed image orientation angles.

Initial Processing Details

System Information

Hardware	CPU: Intel(R) Core(TM) i5-3330S CPU @2.70GHz RAM: 8GB GPU: Intel(R) HD Graphics (Driver: 10.18.10.3412), RDPDD Chained DD (Driver: unknown), RDP Encoder Mirror Driver (Driver: unknown), RDP Reflector Display Driver (Driver: unknown)
Operating System	Windows 7 Professional, 64-bit

Coordinate Systems

Image Coordinate System	WGS84 (egm96)
Output Coordinate System	WGS 84 / UTMzone 19N (egm96)

Processing Options

Detected Template	3D Maps
Keypoints Image Scale	Full, Image Scale: 1
Advanced: Matching Image Pairs	Aerial Grid or Corridor
Advanced: Matching Strategy	Use Geometrically Verified Matching: no
Advanced: Keypoint Extraction	Targeted Number of Keypoints: Automatic
Advanced: Calibration	Calibration Method: Standard Internal Parameters Optimization: All External Parameters Optimization: All Rematch: Auto, yes

Point Cloud Densification details

Processing Options

Image Scale	multiscale, 1/2 (Half image size, Default)
Point Density	Optimal

Minimum Number of Matches	3
3D Textured Mesh Generation	yes
3D Textured Mesh Settings:	Resolution: Medium Resolution (default) Color Balancing: no
LOD	Generated: no
Advanced: 3D Textured Mesh Settings	Sample Density Divider: 1
Advanced: Image Groups	group1
Advanced: Use Processing Area	yes
Advanced: Use Annotations	yes
Time for Point Cloud Densification	15m:05s
Time for Point Cloud Classification	NA
Time for 3D Textured Mesh Generation	04m:22s

Results

Number of Generated Tiles	1
Number of 3D Densified Points	4899633
Average Density (per m ³)	335.75

DSM, Orthomosaic and Index Details

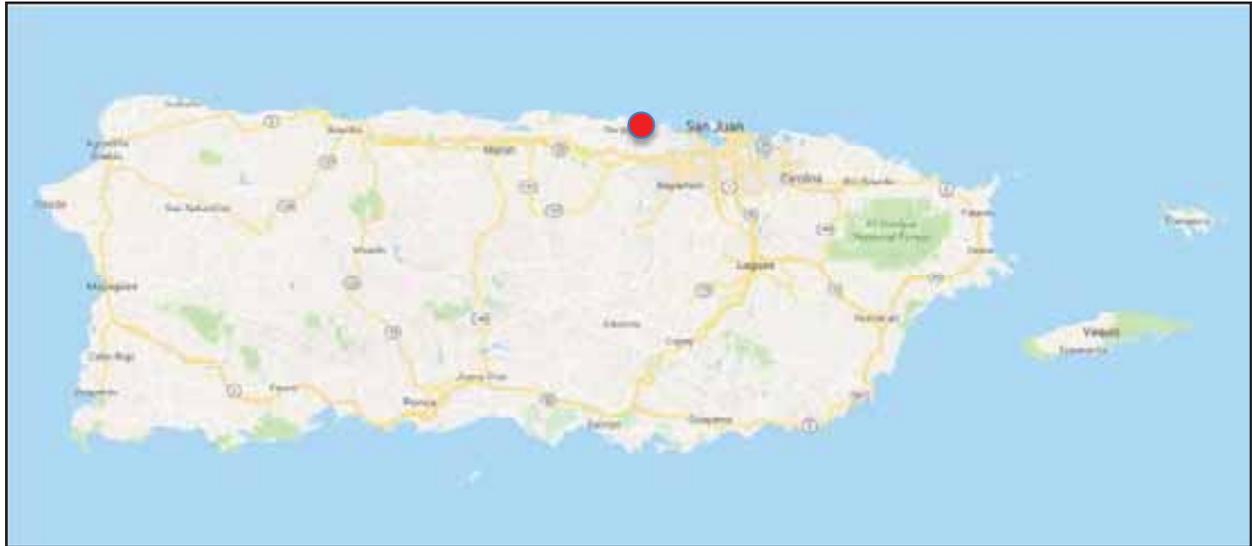
Processing Options

DSM and Orthomosaic Resolution	1 x GSD (1.93 [cm/pixel])
DSM Filters	Noise Filtering: yes Surface Smoothing: yes, Type: Sharp
Raster DSM	Generated: yes Method: Inverse Distance Weighting Merge Tiles: yes
Orthomosaic	Generated: yes Merge Tiles: yes GeoTIFF Without Transparency: no Google Maps Tiles and KML: no
Time for DSM Generation	08m:31s
Time for Orthomosaic Generation	18m:20s
Time for DTMGeneration	00s
Time for Contour Lines Generation	00s
Time for Reflectance Map Generation	00s
Time for Index Map Generation	00s

Site name:

El Caracol, Dorado

After northeasterly swell of March, 2018.



A. Physical address:

El Caracol (after northeasterly swell), Road PR 165, Dorado, Puerto Rico, 00949.

B. Date of capture of imagery:

March 20, 2018

C. Coordinates:

18.47069098 N - 66.24706395 W

D. Description of site:

This site consists of a breached segment of primary dune in front of El Caracol restaurant in Dorado, Puerto Rico. It is parallel to road PR 165. The road and private property behind the dune line would benefit from a stable segment of dune. This area is also a very productive sea turtle nesting beach. Any restoration work will benefit the habitat of at least three species of sea turtles including leatherbacks, green and hawksbill sea turtles.

This area is within the **Playa Grande Nature Reserve**.

E. Distance from community:

This site is located at a distance of approximately 9 m from El Caracol restaurant and at approximately 52 m from road PR 165. There is a highly populated area at a distance of 1.8 km to the south west of this location.

Aerial imagery

i. Contour map



Figure 303. Contour map of the area behind the El Caracol (after northeasterly swell), in Dorado Puerto Rico with elevation intervals of 1 meter.

ii. 3D imagery



Figure 304. Aerial 3D image of the El Caracol (after northeasterly swell), Dorado.

iii. Orthomosaic model



Figure 305. Orthomosaic image of El Caracol (after northeasterly swell), Dorado.

iv. Density Surface Models (DSM)

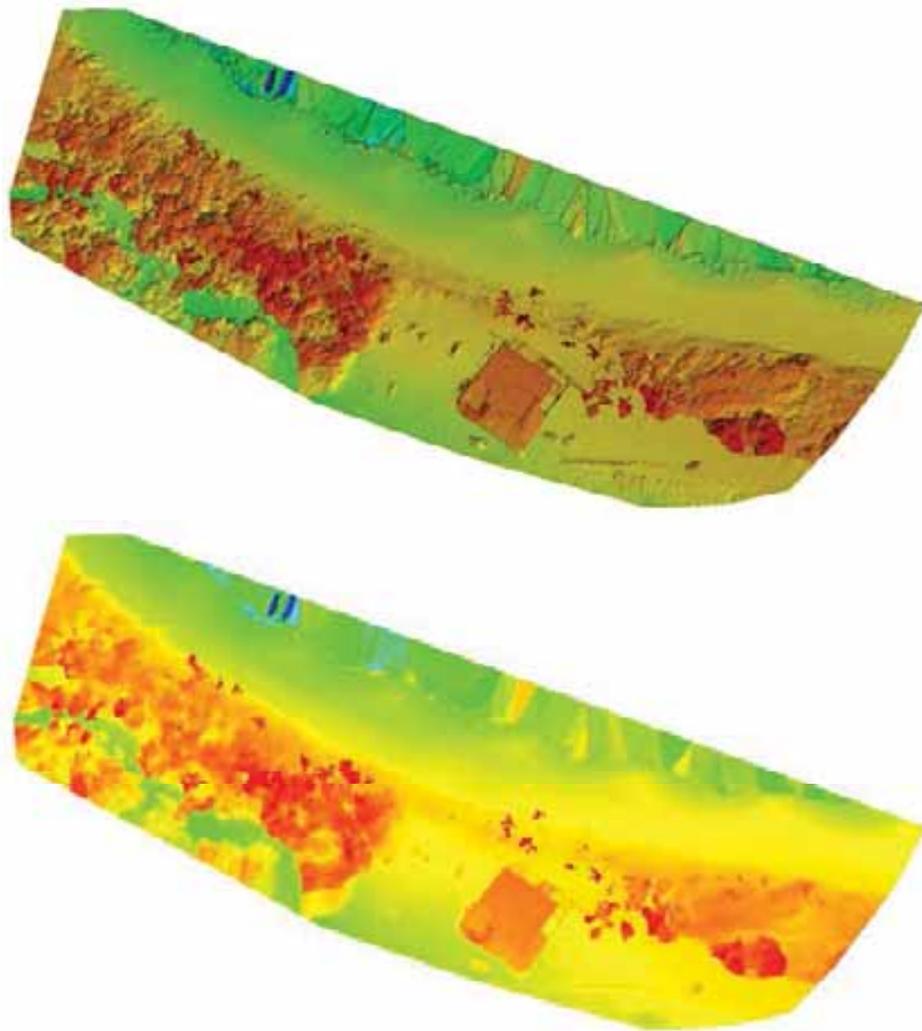


Figure 306. Density surface model (with shading top and without shading bottom) images of the dune located on the El Caracol (after northeasterly swell), Dorado.

v. Thermal images

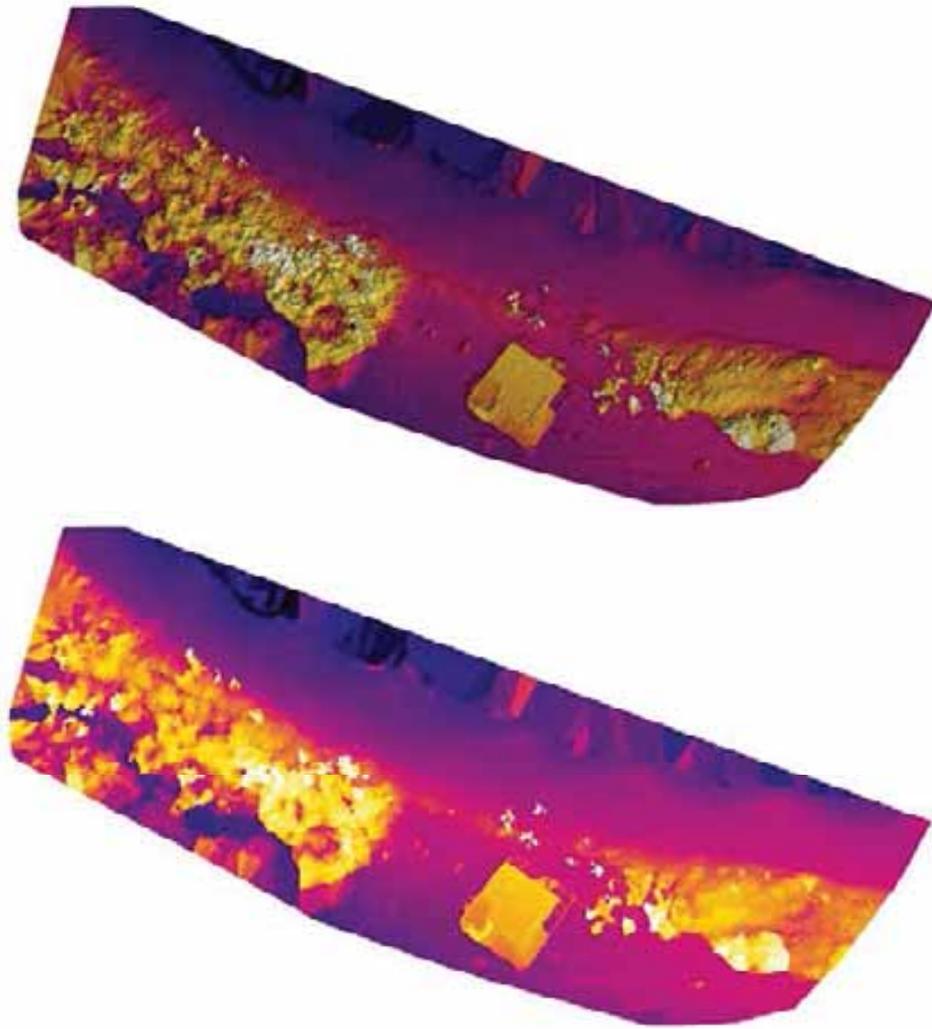


Figure 307. Thermal images (with shading top and without shading bottom) of the El Caracol (after northeasterly swell), Dorado.

vi. 3D altitude RGB North

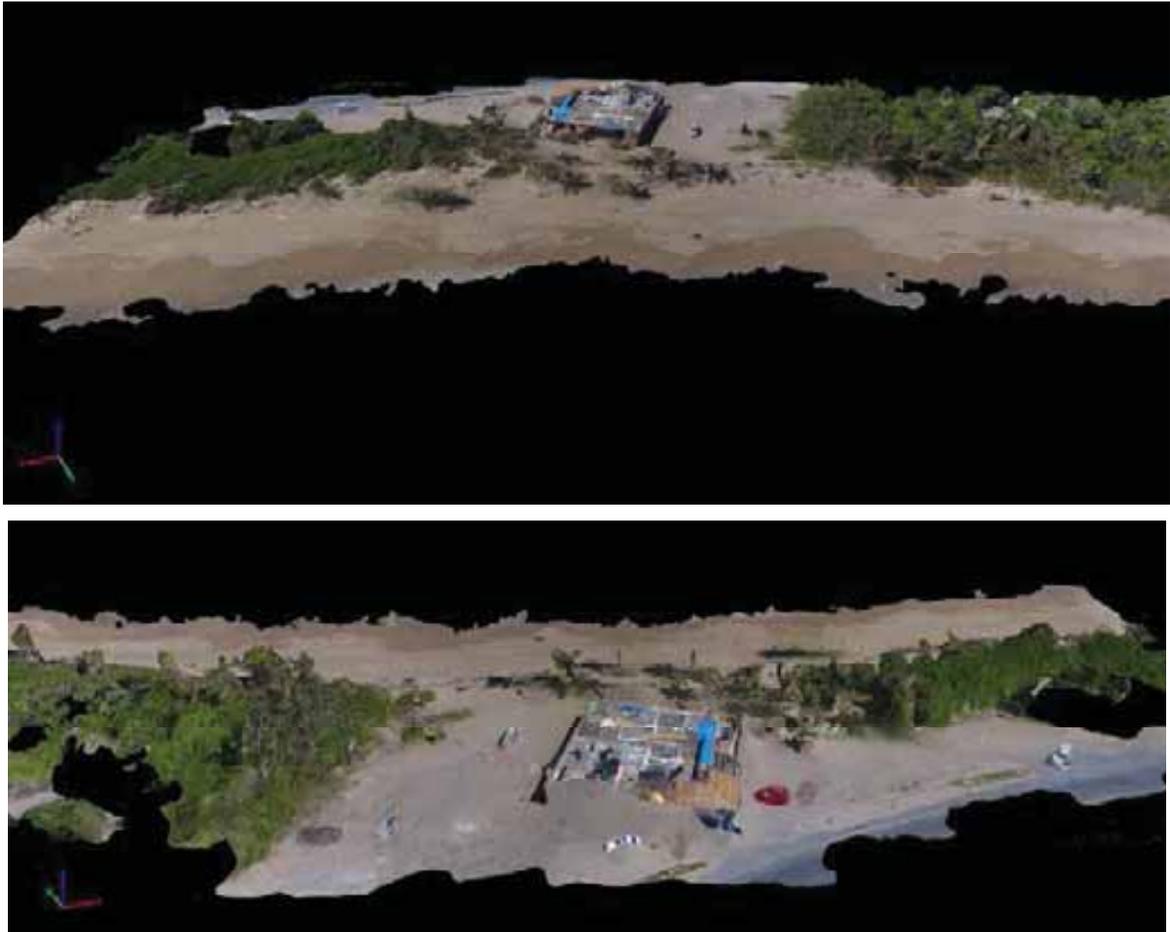


Figure 308. Three dimensional RGB images of the El Caracol, Dorado. View from the north of the eastern part of the site (top) and from the south of the same area (bottom).



Figure 309. Three dimensional RGB images of the eastern part of the El Caracol, Dorado. View from the west (top) and from the east (bottom).

vii. DSM grayscale



Figure 310. Grayscale DSM images of the El Caracol (after swell), Dorado. The top image shows shades and the bottom is not shaded.

Site report

F. Vegetation cover



Figure 311. Images of the area for which vegetation cover is being monitored for the El Caracol in Dorado, Puerto Rico. The vegetation cover was 53.3% for the eastern part of the site March 20, 2018.

I. Volume measurements of selected areas of the dunes

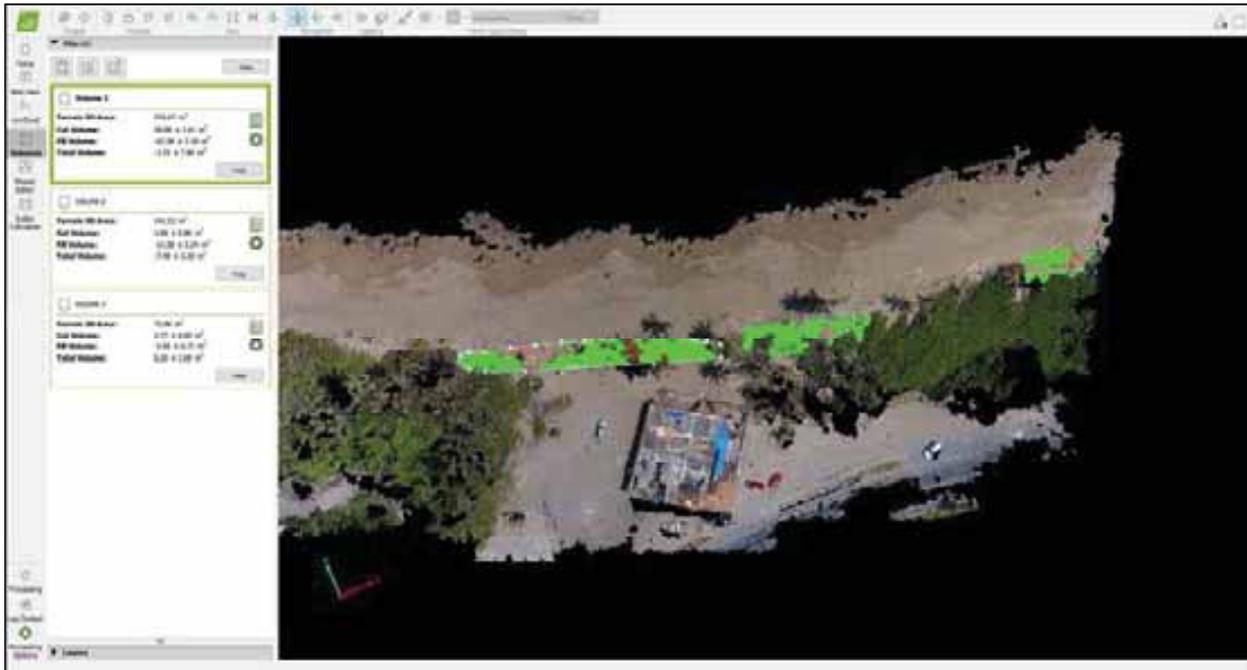


Figure 312. Three dimensional aerial picture of El Caracol area in Dorado with three areas marked by polygons for which three dimensional area, cut volume, fill volume and total volume were calculated using the Pix4D software. Refer to image above for the data. The order of the data is from left to right on the image.

J. Conservation threats

The main conservation threat in this area is extreme foot and vehicular traffic on the primary dune area. Illegal sand extraction is also a significant problem in this area. This area is also used as an illegal dumpster.

K. Recommended ecological restoration courses of action (COA)

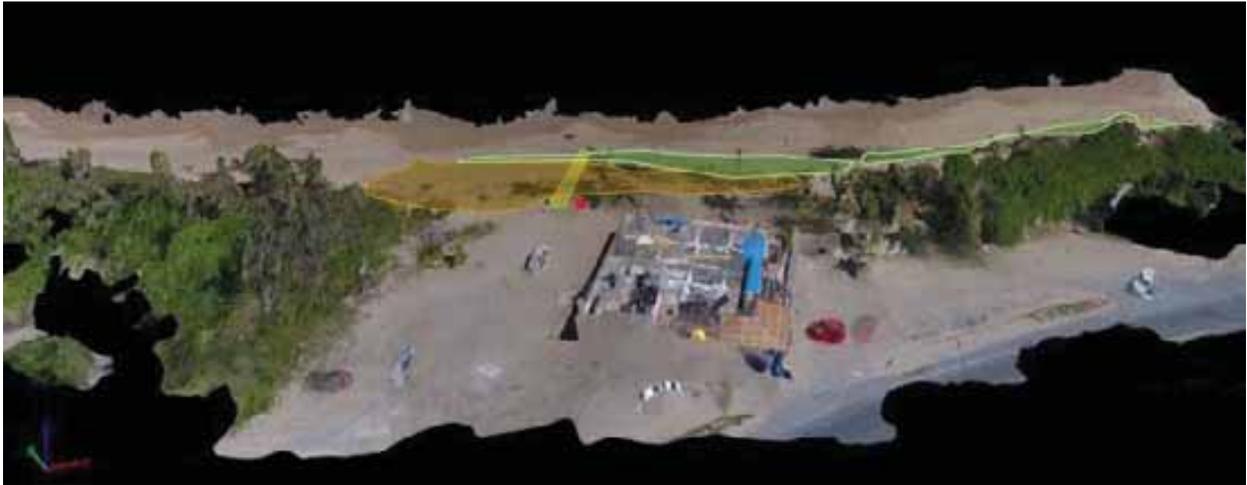


Figure 313. Area to be ecologically restored behind el Caracol area in Dorado, Puerto Rico. Highlighted areas correspond to each technique that will be used in this area. Yellow represents the location of a wooden boardwalk, the red dot marks the location of an information sign, tan represents the area of the dune crest that where biomimicry matrices will be installed to promote the accumulation of sand. The areas shaded in light green represent locations for the planting of dune vegetation.

L. Pix 4D Quality Report

Quality Report

Generated with Pix4Dmapper Pro version 4.2.25

Important: Click on the different icons for:

- Help to analyze the results in the Quality Report
- Additional information about the sections

Click [here](#) for additional tips to analyze the Quality Report

Summary

Project	El Caracol en Dorado
Processed	2018-04-01 21:28:54
Camera Model Name(s)	FC330_3.6_4000x3000 (RGB)
Average Ground Sampling Distance (GSD)	1.68 cm / 0.66 in
Area Covered	0.021 km ² / 2.0877 ha / 0.01 sq. mi. / 5.1614 acres
Time for Initial Processing (without report)	24m.32s

Quality Check

Images	median of 34667 keypoints per image	✓
Dataset	97 out of 98 images calibrated (98%), all images enabled	✓
Camera Optimization	4.6% relative difference between initial and optimized internal camera parameters	✓
Matching	median of 7664.19 matches per calibrated image	✓
Georeferencing	yes, no 3D GCP	⚠

Preview

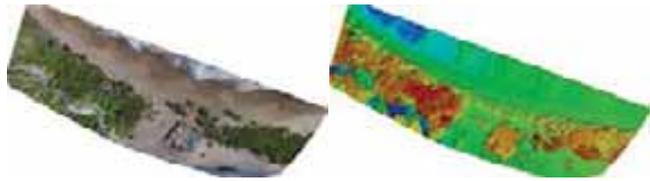


Figure 1: Orthomosaic and the corresponding sparse Digital Surface Model (DSM) before densification.

Calibration Details

Number of Calibrated Images	97 out of 98
Number of Geolocated Images	98 out of 98

Initial Image Positions

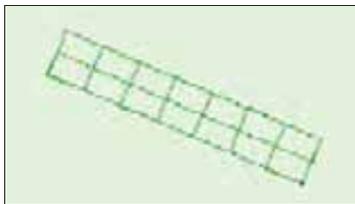
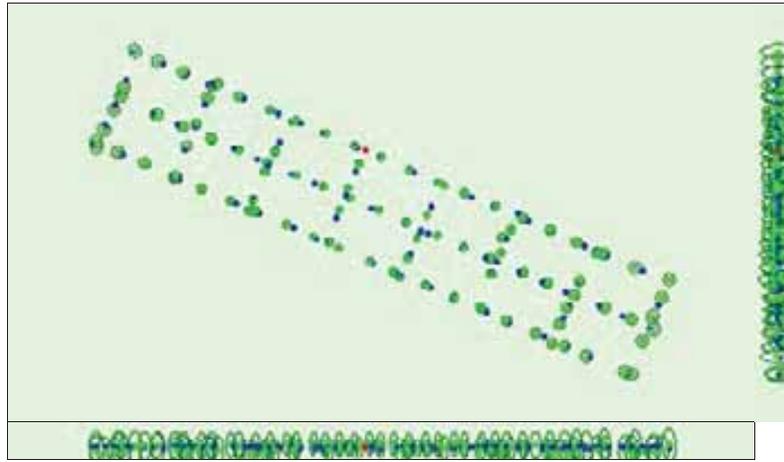


Figure 2: Top view of the initial image position. The green line follows the position of the images in time starting from the large blue dot.

Computed Image/GCPs/Manual Tie Points Positions



Uncertainty ellipses 10x magnified

Figure 3: Offset between initial (blue dots) and computed (green dots) image positions as well as the offset between the GCPs initial positions (blue crosses) and their computed positions (green crosses) in the top-view (XY plane), front-view (XZ plane), and side-view (YZ plane). Red dots indicate disabled or uncalibrated images. Dark green ellipses indicate the absolute position uncertainty of the bundle block adjustment result.

1 Absolute camera position and orientation uncertainties

	X[m]	Y[m]	Z[m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.158	0.158	0.385	0.981	0.434	0.215
Sigma	0.033	0.033	0.080	0.027	0.047	0.031

1 Overlap



Number of overlapping images: 1 2 3 4 5+

Figure 4: Number of overlapping images computed for each pixel of the orthomosaic. Red and yellow areas indicate low overlap for which poor results may be generated. Green areas indicate an overlap of over 5 images for every pixel. Good quality results will be generated as long as the number of keypoint matches is also sufficient for these areas (see Figure 5 for keypoint matches).

Bundle Block Adjustment Details

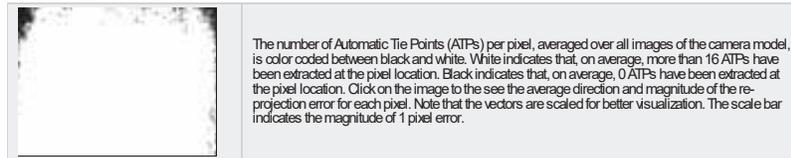
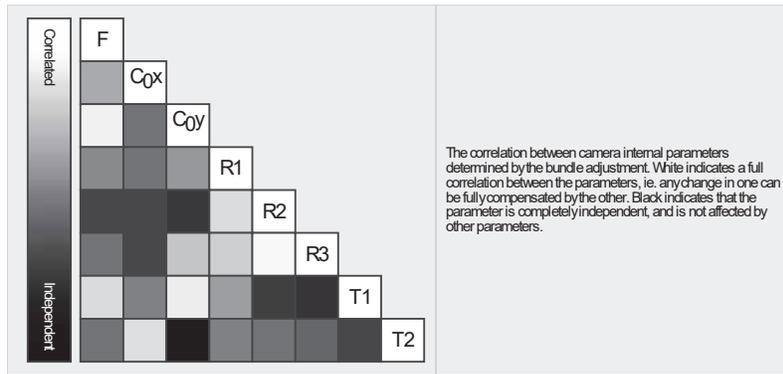
Number of 2D Keypoint Observations for Bundle Block Adjustment	756679
Number of 3D Points for Bundle Block Adjustment	277641
Mean Reprojection Error [pixels]	0.187

1 Internal Camera Parameters

FC330_3.6_4000x3000 (RGB). Sensor Dimensions: 6.317 [mm] x 4.738 [mm]

EXIF ID: FC330_3.6_4000x3000

	Focal Length	Principal Point x	Principal Point y	R1	R2	R3	T1	T2
Initial Values	2285.722 [pixel] 3.610 [mm]	2000.006 [pixel] 3.159 [mm]	1500.003 [pixel] 2.369 [mm]	-0.001	-0.002	0.000	-0.001	-0.001
Optimized Values	2390.963 [pixel] 3.776 [mm]	1965.887 [pixel] 3.105 [mm]	1465.664 [pixel] 2.315 [mm]	0.002	-0.009	0.005	-0.000	0.000
Uncertainties (Sigma)	0.330 [pixel] 0.001 [mm]	0.076 [pixel] 0.000 [mm]	0.248 [pixel] 0.000 [mm]	0.000	0.000	0.000	0.000	0.000



2D Keypoints Table

	Number of 2D Keypoints per Image	Number of Matched 2D Keypoints per Image
Median	34667	7664
Mn	17234	130
Max	60405	20644
Mean	34425	7801

3D Points from 2D Keypoint Matches

	Number of 3D Points Observed
In 2 Images	189315
In 3 Images	44700
In 4 Images	18643
In 5 Images	9484
In 6 Images	5712
In 7 Images	3515
In 8 Images	2258
In 9 Images	1425
In 10 Images	833
In 11 Images	521
In 12 Images	319
In 13 Images	247
In 14 Images	161
In 15 Images	121
In 16 Images	113
In 17 Images	70
In 18 Images	66
In 19 Images	44
In 20 Images	35
In 21 Images	25
In 22 Images	17
In 23 Images	10
In 24 Images	4
In 25 Images	3

2D Keypoint Matches

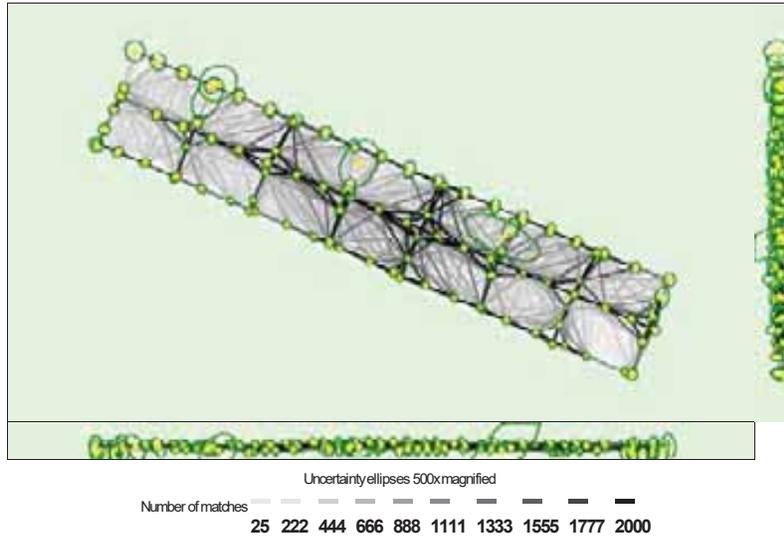


Figure 5: Computed image positions with links between matched images. The darkness of the links indicates the number of matched 2D keypoints between the images. Bright links indicate weak links and require manual tie points or more images. Dark green ellipses indicate the relative camera position uncertainty of the bundle block adjustment result.

Relative camera position and orientation uncertainties

	X[m]	Y[m]	Z[m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.004	0.004	0.004	0.008	0.009	0.005
Sigma	0.003	0.002	0.003	0.004	0.005	0.003

Geolocation Details

Absolute Geolocation Variance

Min Error [m]	Max Error [m]	Geolocation Error X[%]	Geolocation Error Y[%]	Geolocation Error Z[%]
-	-15.00	0.00	0.00	0.00
-15.00	-12.00	0.00	0.00	0.00
-12.00	-9.00	0.00	0.00	0.00
-9.00	-6.00	0.00	0.00	0.00
-6.00	-3.00	3.09	0.00	0.00
-3.00	0.00	50.52	57.73	52.58
0.00	3.00	45.36	41.24	47.42
3.00	6.00	1.03	0.00	0.00
6.00	9.00	0.00	1.03	0.00
9.00	12.00	0.00	0.00	0.00
12.00	15.00	0.00	0.00	0.00
15.00	-	0.00	0.00	0.00
Mean [m]		0.000713	0.000627	-0.000349
Sigma [m]		1.362726	1.325495	0.824623
RMS Error [m]		1.362726	1.325495	0.824623

Min Error and Max Error represent geolocation error intervals between -1.5 and 1.5 times the maximum accuracy of all the images. Columns X, Y, Z show the percentage of images with geolocation errors within the predefined error intervals. The geolocation error is the difference between the initial and computed image positions. Note that the image geolocation errors do not correspond to the accuracy of the observed 3D points.

Relative Geolocation Variance

Relative Geolocation Error	Images X[%]	Images Y[%]	Images Z[%]
[-1.00, 1.00]	100.00	98.97	100.00
[-2.00, 2.00]	100.00	100.00	100.00
[-3.00, 3.00]	100.00	100.00	100.00
Mean of Geolocation Accuracy [m]	5.000000	5.000000	10.000000
Sigma of Geolocation Accuracy [m]	0.000000	0.000000	0.000000

Images X, Y, Z represent the percentage of images with a relative geolocation error in X, Y, Z.

Geolocation Orientational Variance	RMS [degree]
Omega	2.311
Phi	2.601
Kappa	1.527

Geolocation RMS error of the orientation angles given by the difference between the initial and computed image orientation angles.

Initial Processing Details

System Information

Hardware	CPU: Intel(R) Core(TM) i5-3330S CPU @2.70GHz RAM 8GB GPU: Intel(R) HD Graphics (Driver: 10.18.10.3412), RDPDD Chained DD (Driver: unknown), RDP Encoder Mirror Driver (Driver: unknown), RDP Reflector Display Driver (Driver: unknown)
Operating System	Windows 7 Professional, 64-bit

Coordinate Systems

Image Coordinate System	WGS84 (egm96)
Output Coordinate System	WGS 84 / UTMzone 19N (egm96)

Processing Options

Detected Template	3D Maps
Keypoints Image Scale	Full, Image Scale: 1
Advanced: Matching Image Pairs	Aerial Grid or Corridor
Advanced: Matching Strategy	Use Geometrically Verified Matching: no
Advanced: Keypoint Extraction	Targeted Number of Keypoints: Automatic
Advanced: Calibration	Calibration Method: Standard Internal Parameters Optimization: All External Parameters Optimization: All Rematch: Auto, yes

Point Cloud Densification details

Processing Options

Image Scale	multiscale, 1/2 (Half image size, Default)
Point Density	Optimal
Minimum Number of Matches	3
3D Textured Mesh Generation	yes
3D Textured Mesh Settings:	Resolution: Medium Resolution (default) Color Balancing: no
LOD	Generated: no
Advanced: 3D Textured Mesh Settings	Sample Density Divider: 1
Advanced: Image Groups	group1
Advanced: Use Processing Area	yes
Advanced: Use Annotations	yes
Time for Point Cloud Densification	16m:58s
Time for Point Cloud Classification	NA
Time for 3D Textured Mesh Generation	04m:25s

Results

Number of Generated Tiles	1
Number of 3D Densified Points	4750045
Average Density (per m ³)	536.17

DSM, Orthomosaic and Index Details

Processing Options

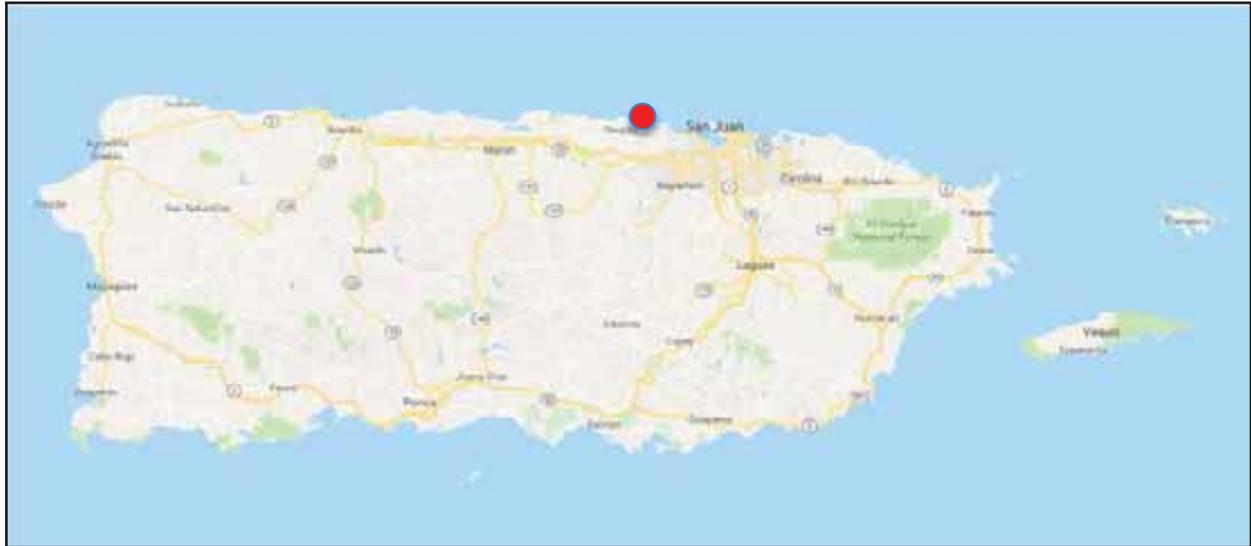
DSM and Orthomosaic Resolution	1 x GSD (1.68 [cm/pixel])
DSM Filters	Noise Filtering: yes Surface Smoothing: yes, Type: Sharp

Raster DSM	Generated: yes Method: Inverse Distance Weighting Merge Tiles: yes
Orthomosaic	Generated: yes Merge Tiles: yes GeoTIFF Without Transparency: no Google Maps Tiles and KML: no
Time for DSM Generation	08m.23s
Time for Orthomosaic Generation	19m.08s
Time for DTMGeneration	00s
Time for Contour Lines Generation	00s
Time for Reflectance Map Generation	00s
Time for IndexMap Generation	00s

Site name:

El Unico, Dorado

After the March 2018 north easterly swell



A. Physical address:

El Único (after northeasterly swell) area, road PR 165, Dorado, Puerto Rico, 00949.

B. Date of capture of imagery:

March 20, 2018

C. Coordinates:

18.46784795 N – 66.23658189 W

D. Description of site:

This site consists of a breached segment of primary dune in front of El Caracol restaurant in Dorado, Puerto Rico. It is parallel to road PR 165. The road and private property behind the dune line would benefit from a stable segment of dune. This area is also a very productive sea turtle nesting beach. Any restoration work will benefit the habitat of at least three species of sea turtles including leatherbacks, green and hawksbill sea turtles. The area had been the site of an attempt to restore the primary dune by the local NGO Chelonia. All the sand fencing in this area was destroyed during the 2017 hurricane season.

This area is within the **Playa Grande Nature Reserve**.

E. Distance from community:

This site is located at a distance of approximately 25 m from PR 165. The site is located at an approximate distance of 2 km of the highly populated area of La Monserrate in Toa Baja that is located to the south of this site.

Aerial imagery

i. Contour map

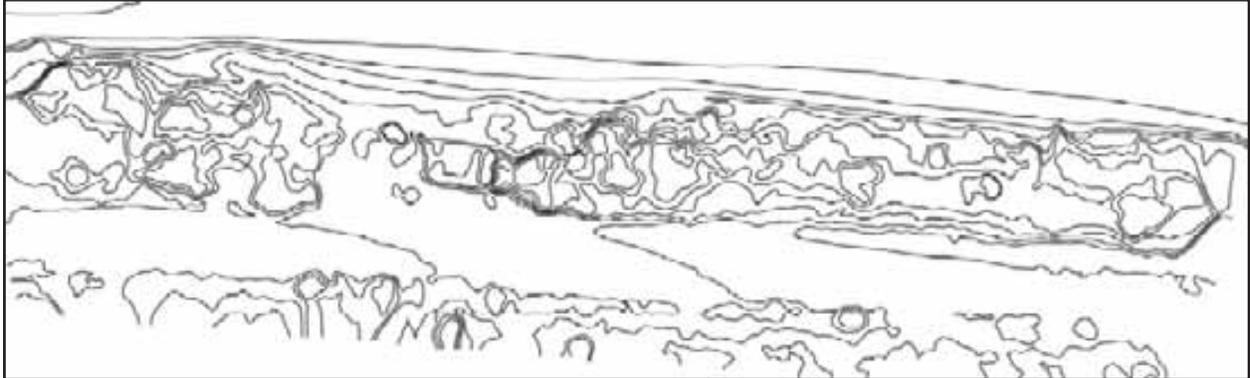


Figure 314. Contour map of the area behind the El Único (after northeasterly swell), in Dorado Puerto Rico with elevation intervals of 1 meter.

ii. 3D imagery



Figure 315. Aerial 3D image of the El Único (after northeasterly swell), Dorado.

iii. Orthomosaic model



Figure 316. Orthomosaic image of El Único (after northeasterly swell), Dorado.

iv. Density Surface Models (DSM)

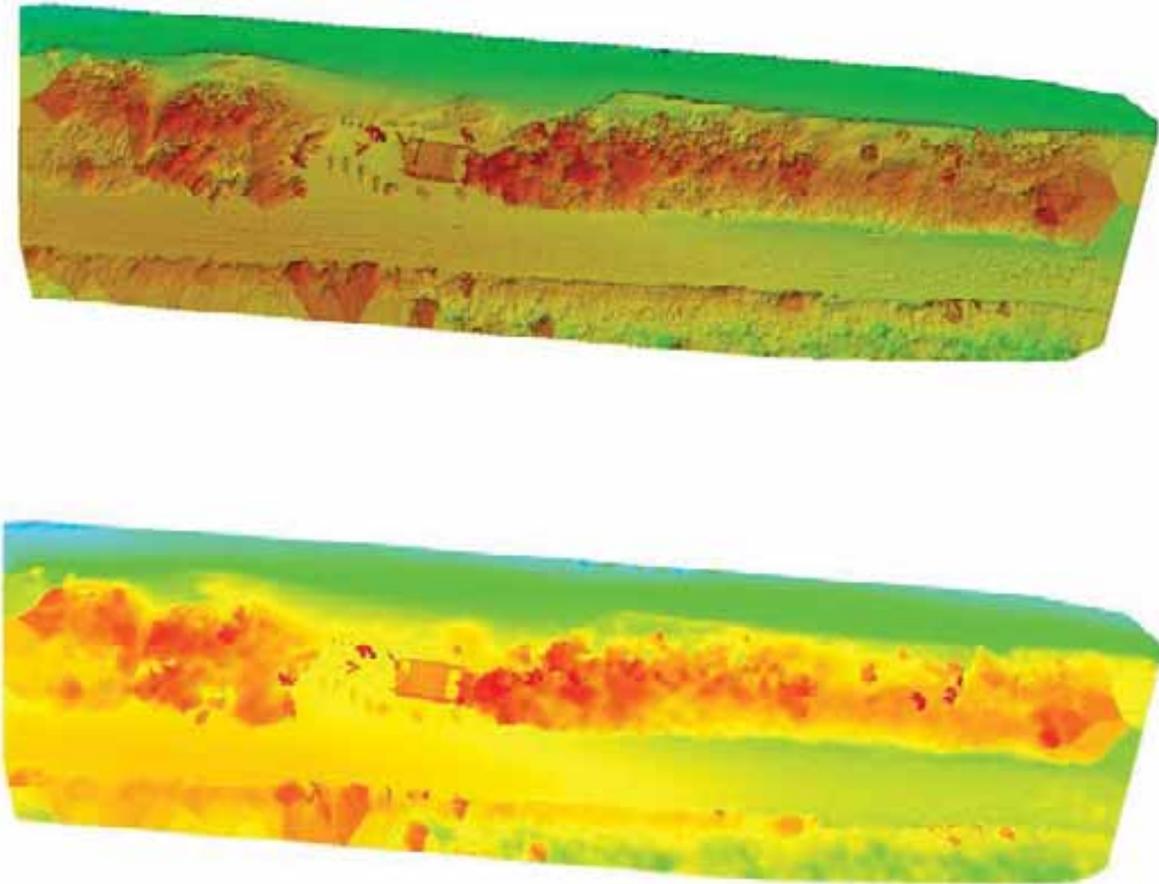


Figure 317. Density surface model (with shading top and without shading bottom) images of the dune located on the El Único (after northeasterly swell), Dorado.

v. Thermal images

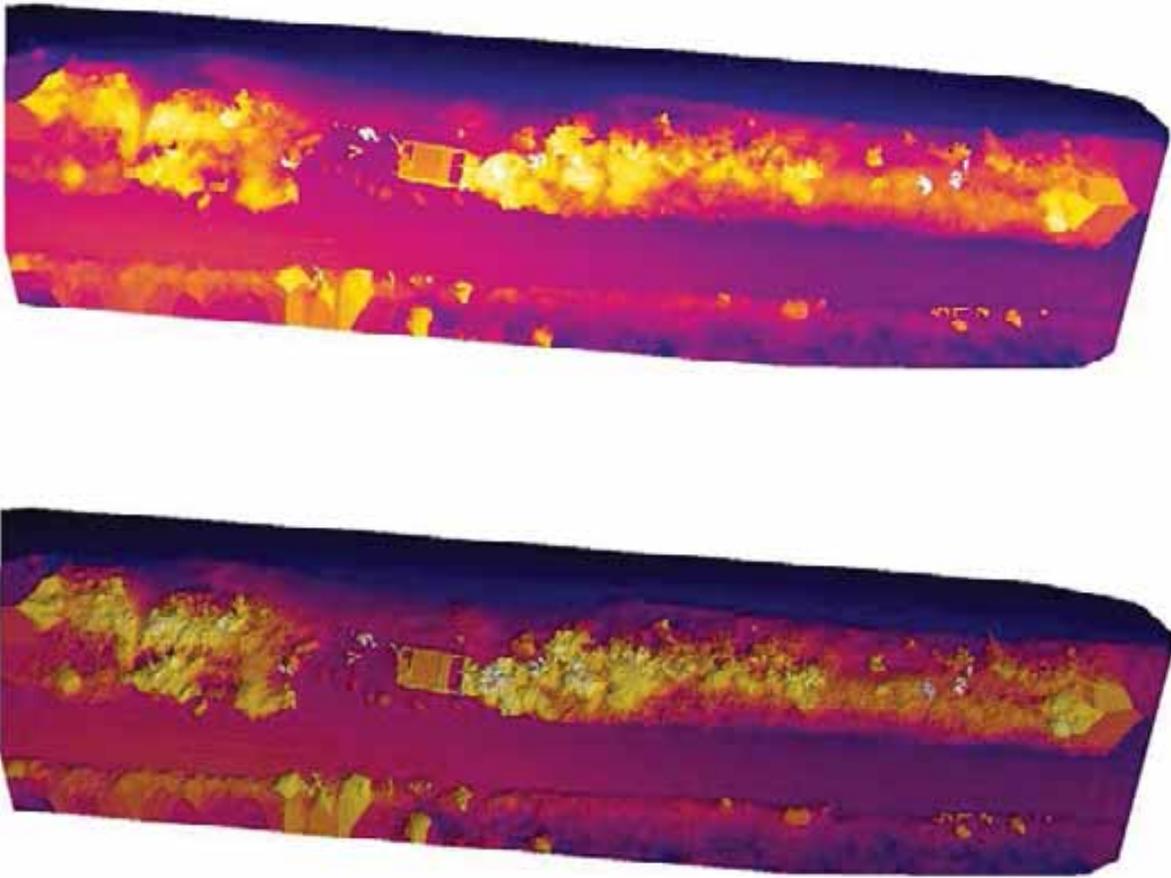


Figure 318. Thermal images (with shading top and without shading bottom) of the El Único (after northeasterly swell), Dorado.

vi. 3D altitude RGB North



Figure 319. Three dimensional RGB images of the El Único, Dorado. View from the north of the western part of the site (top) and from the south of the same area (bottom).



Figure 320. Three dimensional RGB images of the El Único, Dorado. View from the north of the eastern part of the site (top) and from the south of the same area (bottom).

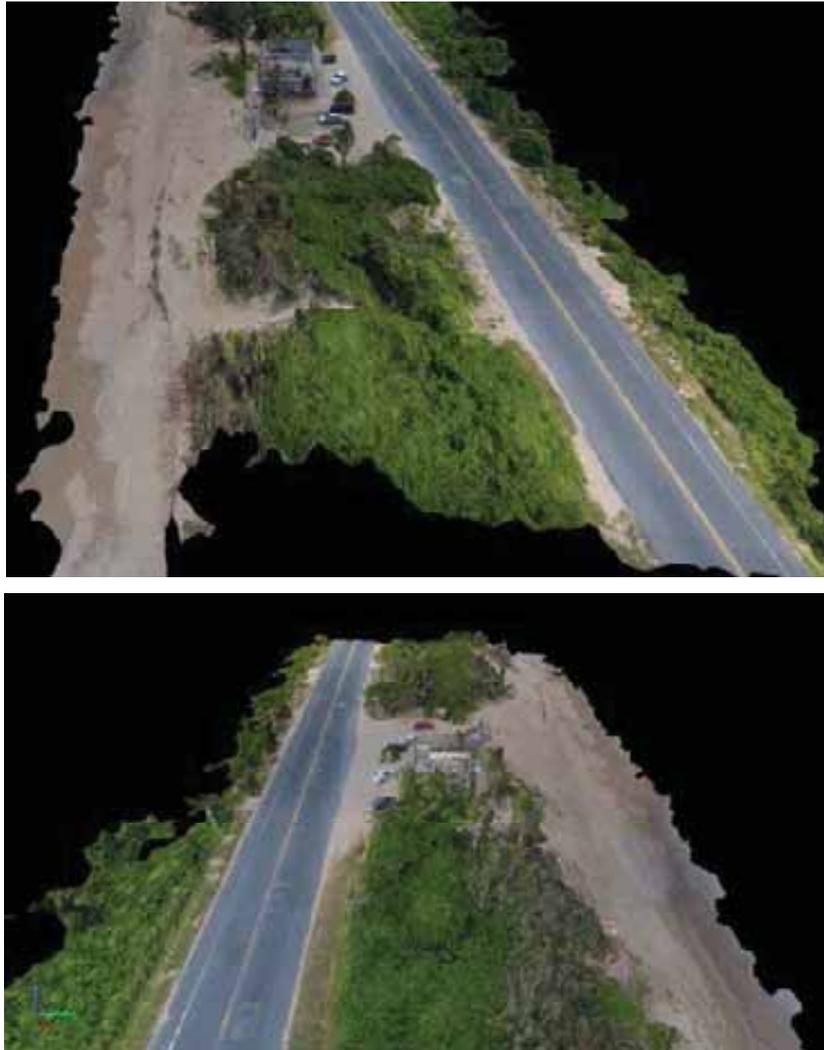


Figure 321. Three dimensional RGB images of the El Único, Dorado. View from the west of the eastern part of the site (top) and from the east of the same area (bottom).



Figure 322. Three dimensional RGB images of the western part of the El Unico, Dorado. View from the west (top) and from the east (bottom).

vii. DSM grayscale



Figure 323. Grayscale DSM images of the El Único (after swell), Dorado. The top image shows shades and the bottom is not shaded.

Site report

F. Vegetation cover



Figure 324. Vegetation covered 59.1% of the area of El Único in Dorado, Puerto Rico on March 20, 2018 (after northeasterly swell).

I. Volume measurements of selected areas of the dunes

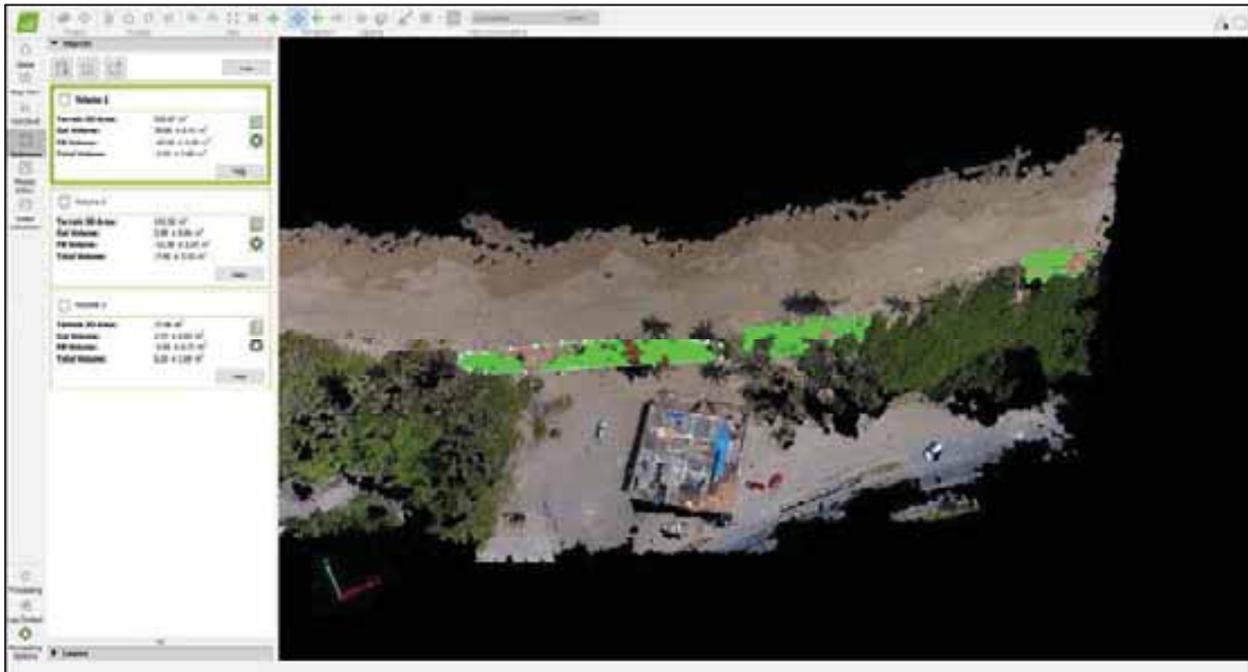


Figure 325. Three dimensional aerial picture of El Caracol area in Dorado with three areas marked by polygons for which three dimensional area, cut volume, fill volume and total volume were calculated using the Pix4D software. Refer to image above for the data. The order of the data is from left to right on the image.

J. Conservation threats

The main conservation threat in this area is extreme foot and vehicular traffic on the primary dune area. Illegal sand extraction is also a significant problem in this area. This area is also used as an illegal dumpster.

K. Recommended ecological restoration courses of action (COA)

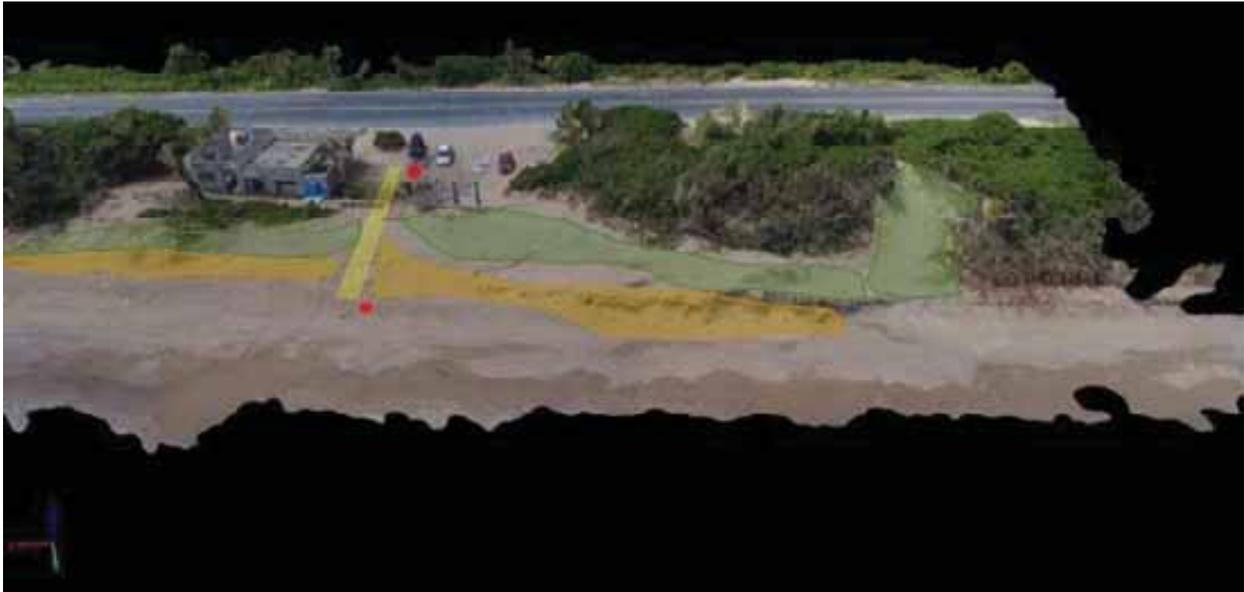


Figure 326. Area to be ecologically restored in Playa Único, Dorado. Highlighted areas correspond to each technique that will be used in this area. Yellow represents the location of a wooden boardwalk, the red dot marks the location of an information sign, tan represents the area of the dune crest that where biomimicry matrices will be installed to promote the accumulation of sand. The areas shaded in light green represent locations for the planting of dune vegetation.

L. Pix 4D Quality Report

Quality Report



Generated with Pix4Dmapper Pro version 4.2.26

Important: Click on the different icons for:

- Help to analyze the results in the Quality Report
- Additional information about the sections

Click [here](#) for additional tips to analyze the Quality Report

Summary

Project	El Unico en Dorado
Processed	2018-05-07 21:03:28
Camera Model Name(s)	FC330_36_4000x3000 (RGB)
Average Ground Sampling Distance (GSD)	2.01 cm / 0.79 in
Area Covered	0.023 km ² / 2.2791 ha / 0.01 sq. mi. / 5.6346 acres
Time for Initial Processing (without report)	02m:10s

Quality Check

Images	median of 31398 keypoints per image	✓
Dataset	91 out of 95 images calibrated (95%), all images enabled	✓
Camera Optimization	4.8% relative difference between initial and optimized internal camera parameters	✓
Matching	median of 5766.19 matches per calibrated image	✓
Georeferencing	yes, no 3D GCP	⚠

Preview

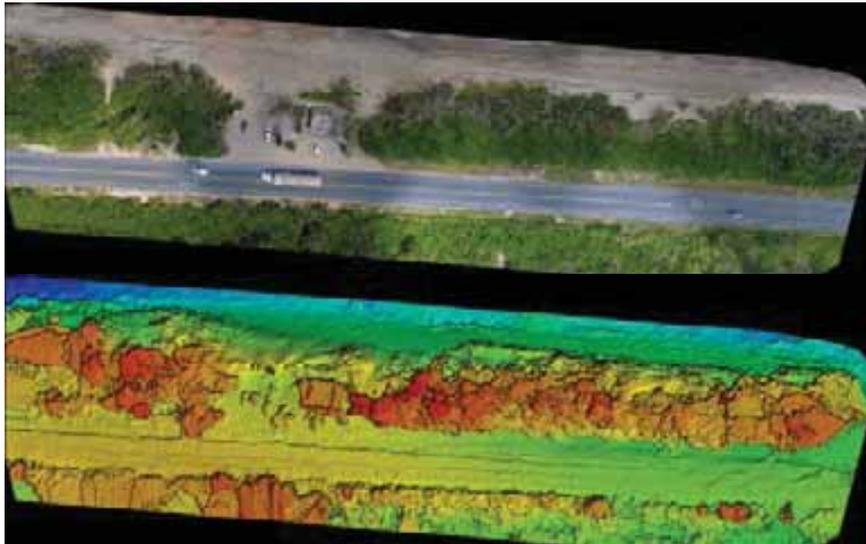


Figure 1: Orthomosaic and the corresponding sparse Digital Surface Model (DSM) before densification.

Calibration Details

Number of Calibrated Images	91 out of 95
Number of Geolocated Images	95 out of 95

Initial Image Positions

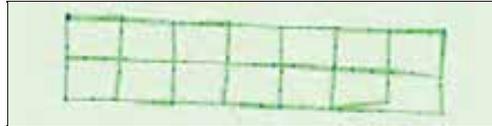


Figure 2: Top view of the initial image position. The green line follows the position of the images in time starting from the large blue dot.

Computed Image/GCPs/Manual Tie Points Positions

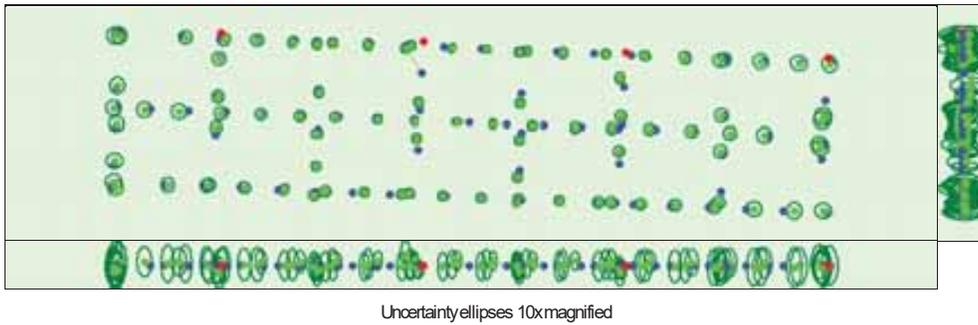


Figure 3: Offset between initial (blue dots) and computed (green dots) image positions as well as the offset between the GCPs initial positions (blue crosses) and their computed positions (green crosses) in the top-view (XY plane), front-view (XZ plane), and side-view (YZ plane). Red dots indicate disabled or uncalibrated images. Dark green ellipses indicate the absolute position uncertainty of the bundle block adjustment result.

Absolute camera position and orientation uncertainties

	X[m]	Y[m]	Z[m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.167	0.168	0.408	0.864	0.231	0.147
Sigma	0.035	0.035	0.084	0.006	0.018	0.011

Overlap

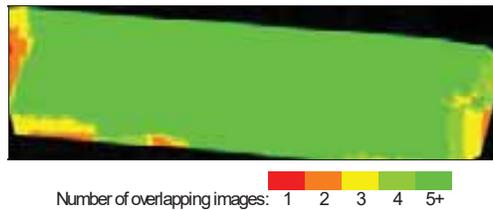


Figure 4: Number of overlapping images computed for each pixel of the orthomosaic. Red and yellow areas indicate low overlap for which poor results may be generated. Green areas indicate an overlap of over 5 images for every pixel. Good quality results will be generated as long as the number of keypoint matches is also sufficient for these areas (see Figure 5 for keypoint matches).

Bundle Block Adjustment Details

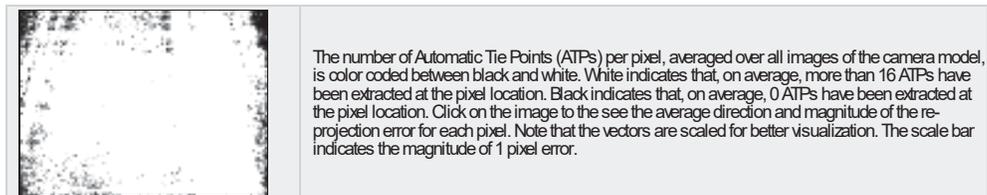
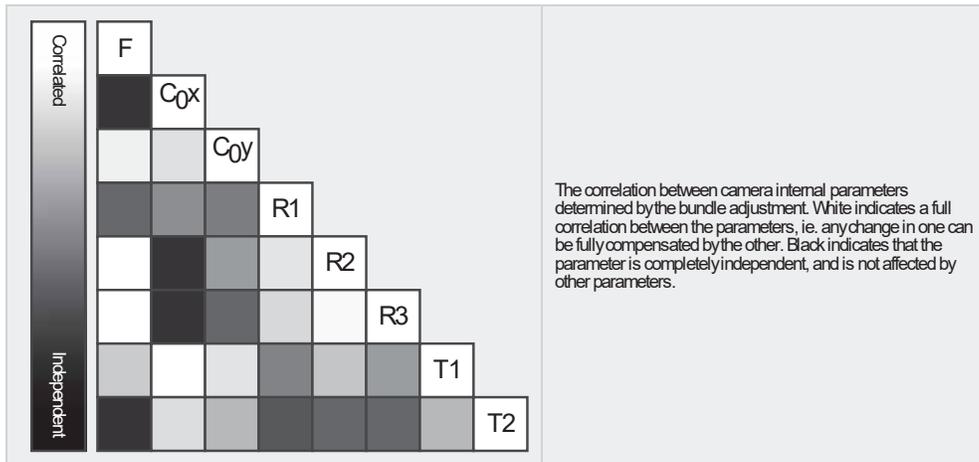
Number of 2D Keypoint Observations for Bundle Block Adjustment	543541
Number of 3D Points for Bundle Block Adjustment	207718
Mean Reprojection Error [pixels]	0.184

Internal Camera Parameters

FC330_3.6_4000x3000 (RGB). Sensor Dimensions: 6.317 [mm] x 4.738 [mm]

EXIF ID: FC330_3.6_4000x3000

	Focal Length	Principal Point x	Principal Point y	R1	R2	R3	T1	T2
Initial Values	2285.722 [pixel] 3.610 [mm]	2000.006 [pixel] 3.159 [mm]	1500.003 [pixel] 2.369 [mm]	-0.001	-0.002	0.000	-0.001	-0.001
Optimized Values	2395.438 [pixel] 3.783 [mm]	1964.531 [pixel] 3.103 [mm]	1464.110 [pixel] 2.312 [mm]	0.001	-0.008	0.005	0.000	0.000
Uncertainties (Sigma)	0.343 [pixel] 0.001 [mm]	0.084 [pixel] 0.000 [mm]	0.247 [pixel] 0.000 [mm]	0.000	0.000	0.000	0.000	0.000



2D Keypoints Table

	Number of 2D Keypoints per Image	Number of Matched 2D Keypoints per Image
Median	31398	5766
Min	19597	85
Max	53343	12428
Mean	31738	5973

3D Points from 2D Keypoint Matches

Number of 3D Points Observed

In 2 Images	149685
In 3 Images	30715
In 4 Images	11893
In 5 Images	5931
In 6 Images	3493
In 7 Images	2114
In 8 Images	1303
In 9 Images	903
In 10 Images	581
In 11 Images	317
In 12 Images	215
In 13 Images	188
In 14 Images	115
In 15 Images	90
In 16 Images	59
In 17 Images	32
In 18 Images	15
In 19 Images	20
In 20 Images	14
In 21 Images	11
In 22 Images	8
In 23 Images	7
In 24 Images	5
In 25 Images	1
In 26 Images	1
In 27 Images	2

2D Keypoint Matches

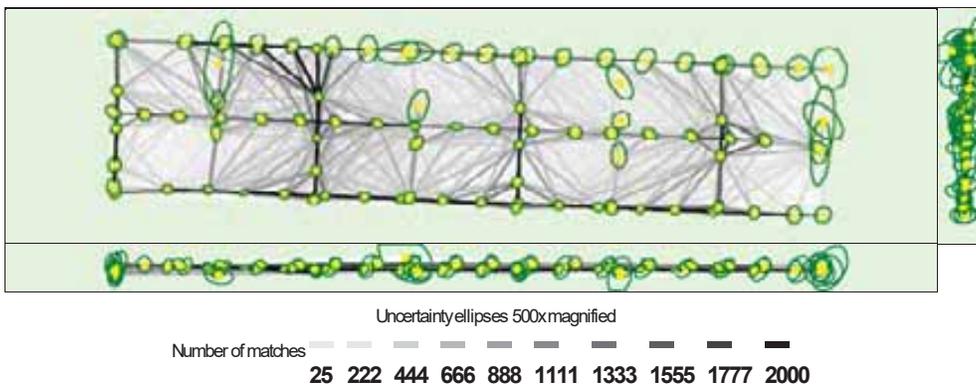


Figure 5: Computed image positions with links between matched images. The darkness of the links indicates the number of matched 2D keypoints between the images. Bright links indicate weak links and require manual tie points or more images. Dark green ellipses indicate the relative camera position uncertainty of the bundle block adjustment result.

Relative camera position and orientation uncertainties

	X[m]	Y[m]	Z[m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.004	0.005	0.005	0.007	0.008	0.005
Sigma	0.002	0.004	0.002	0.005	0.003	0.002

Geolocation Details

Absolute Geolocation Variance

Min Error [m]	Max Error [m]	Geolocation Error X[%]	Geolocation Error Y[%]	Geolocation Error Z[%]
-	-15.00	0.00	0.00	0.00
-15.00	-12.00	0.00	0.00	0.00
-12.00	-9.00	0.00	0.00	0.00
-9.00	-6.00	0.00	1.10	0.00
-6.00	-3.00	5.49	3.30	1.10
-3.00	0.00	36.26	28.57	45.05
0.00	3.00	53.85	64.84	53.85
3.00	6.00	4.40	2.20	0.00
6.00	9.00	0.00	0.00	0.00
9.00	12.00	0.00	0.00	0.00
12.00	15.00	0.00	0.00	0.00
15.00	-	0.00	0.00	0.00
Mean [m]		-0.017429	-0.005882	-0.004916
Sigma [m]		1.469391	1.277950	0.892543
RMS Error [m]		1.469494	1.277963	0.892557

Min Error and Max Error represent geolocation error intervals between -1.5 and 1.5 times the maximum accuracy of all the images. Columns X, Y, Z show the percentage of images with geolocation errors within the predefined error intervals. The geolocation error is the difference between the initial and computed image positions. Note that the image geolocation errors do not correspond to the accuracy of the observed 3D points.

Relative Geolocation Variance

Relative Geolocation Error	Images X[%]	Images Y[%]	Images Z[%]
[-1.00, 1.00]	100.00	98.90	100.00
[-2.00, 2.00]	100.00	100.00	100.00
[-3.00, 3.00]	100.00	100.00	100.00
Mean of Geolocation Accuracy [m]	5.000000	5.000000	10.000000
Sigma of Geolocation Accuracy [m]	0.000000	0.000000	0.000000

Images X, Y, Z represent the percentage of images with a relative geolocation error in X, Y, Z.

Geolocation Orientational Variance	RMS [degree]
Omega	2.816
Phi	2.574
Kappa	1.310

Geolocation RMS error of the orientation angles given by the difference between the initial and computed image orientation angles.

Initial Processing Details

System Information

Hardware	CPU: Intel(R) Core(TM) i7-8700K CPU @3.70GHz RAM: 16GB GPU: NVIDIA GeForce GTX 1070 (Driver: 23.21.13.9065)
Operating System	Windows 10 Home, 64-bit

Coordinate Systems

Image Coordinate System	WGS84 (egm96)
Output Coordinate System	WGS 84 / UTM zone 19N (egm96)

Processing Options



Detected Template	No Template Available
Keypoints Image Scale	Full, Image Scale: 1
Advanced: Matching Image Pairs	Aerial Grid or Corridor
Advanced: Matching Strategy	Use Geometrically Verified Matching: no
Advanced: Keypoint Extraction	Targeted Number of Keypoints: Automatic
Advanced: Calibration	Calibration Method: Standard Internal Parameters Optimization: All External Parameters Optimization: All Rematch: Auto, yes

Point Cloud Densification details



Processing Options



Image Scale	multiscale, 1/2 (Half image size, Default)
Point Density	Optimal
Minimum Number of Matches	3
3D Textured Mesh Generation	yes
3D Textured Mesh Settings:	Resolution: Medium Resolution (default) Color Balancing: no
LCD	Generated: no
Advanced: 3D Textured Mesh Settings	Sample Density/Divider: 1
Advanced: Image Groups	group1
Advanced: Use Processing Area	yes
Advanced: Use Annotations	yes
Time for Point Cloud Densification	04m:29s
Time for Point Cloud Classification	NA
Time for 3D Textured Mesh Generation	02m:06s

Results



Number of Generated Tiles	1
Number of 3D Densified Points	4591765
Average Density (per m ³)	353.54

DSM, Orthomosaic and Index Details



Processing Options



DSM and Orthomosaic Resolution	1 x GSD (2.01 [cm/pixel])
DSM Filters	Noise Filtering: yes Surface Smoothing: yes, Type: Sharp
Raster DSM	Generated: yes Method: Inverse Distance Weighting Merge Tiles: yes
Orthomosaic	Generated: yes Merge Tiles: yes GeoTIFF Without Transparency: no Google Maps Tiles and KML: no
Raster DTM	Generated: yes Merge Tiles: yes
DTM Resolution	5 x GSD (2.01 [cm/pixel])
Contour Lines Generation	Generated: yes Contour Base [m]: 0 Elevation Interval [m]: 5 Resolution [cm]: 100 Minimum Line Size [vertices]: 20

Time for DSM Generation	02m:16s
Time for Orthomosaic Generation	04m:07s
Time for DTM Generation	56s
Time for Contour Lines Generation	01s
Time for Reflectance Map Generation	00s
Time for Index Map Generation	00s

Site name:

Northeastern Ecological Corridor, Luquillo

After the northeasterly swell of March of 2018



Physical address:

Northeastern Ecological Corridor, Road PR 3, Luquillo, Puerto Rico, 00773

Date of capture of imagery:

April 18, 2018

A. Coordinates:

18.36832751 N - 69.70086946 W

B. Description of site:

The site is located within the northeastern ecological corridor in Luquillo, Puerto Rico in a coastal area with a very small line of primary dunes. The area is an important sea turtle nesting beach that could benefit from the installation of fencing to promote sand accumulation.

C. Distance from community:

This area is located at an approximate distance of 1.07 km from road PR 3 that is located to the south. The nearest residential area is located at an approximate distance of 1.48 km to the southwest.

D. Aerial imagery

i. Contour map



Figure 327. Contour map of Northeastern Ecological Corridor, Luquillo, Puerto Rico with elevation intervals of 1 meter.

ii. 3D imagery



Figure 328. Aerial 3D image of Northeastern Ecological Corridor, Luquillo.

ii. Orthomosaic model



Figure 329. Orthomosaic image of Northeastern Ecological Corridor, Luquillo.

ii. Density Surface Models (DSM)

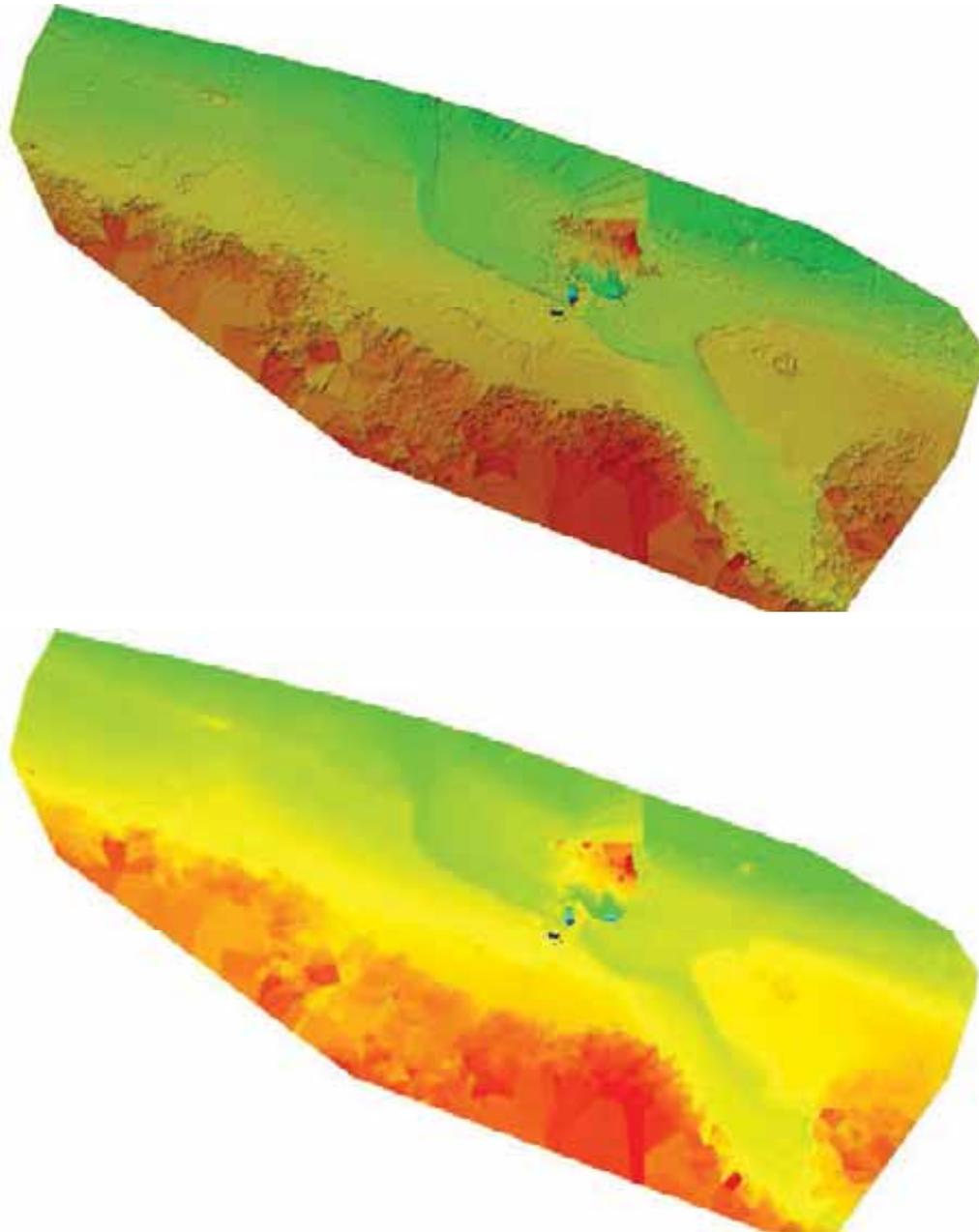


Figure 330. Density surface model (with shading top and without shading bottom) images of the dune located at Northeastern Ecological Corridor, Luquillo.

iii. Thermal images

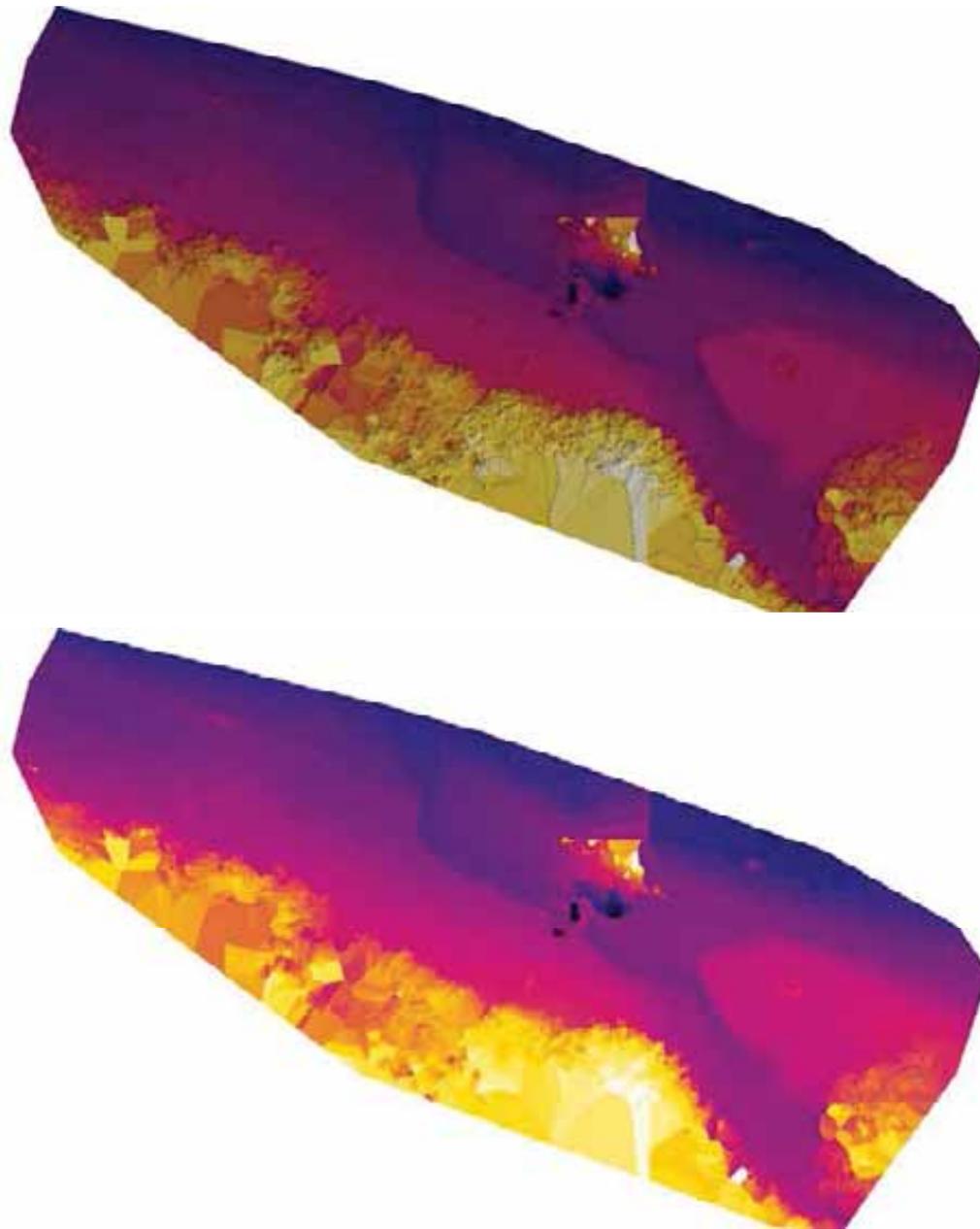


Figure 331. Thermal images (with shading top and without shading bottom) of the dune located at Northeastern Ecological Corridor, Luquillo.

iii. 3D altitude RGB North

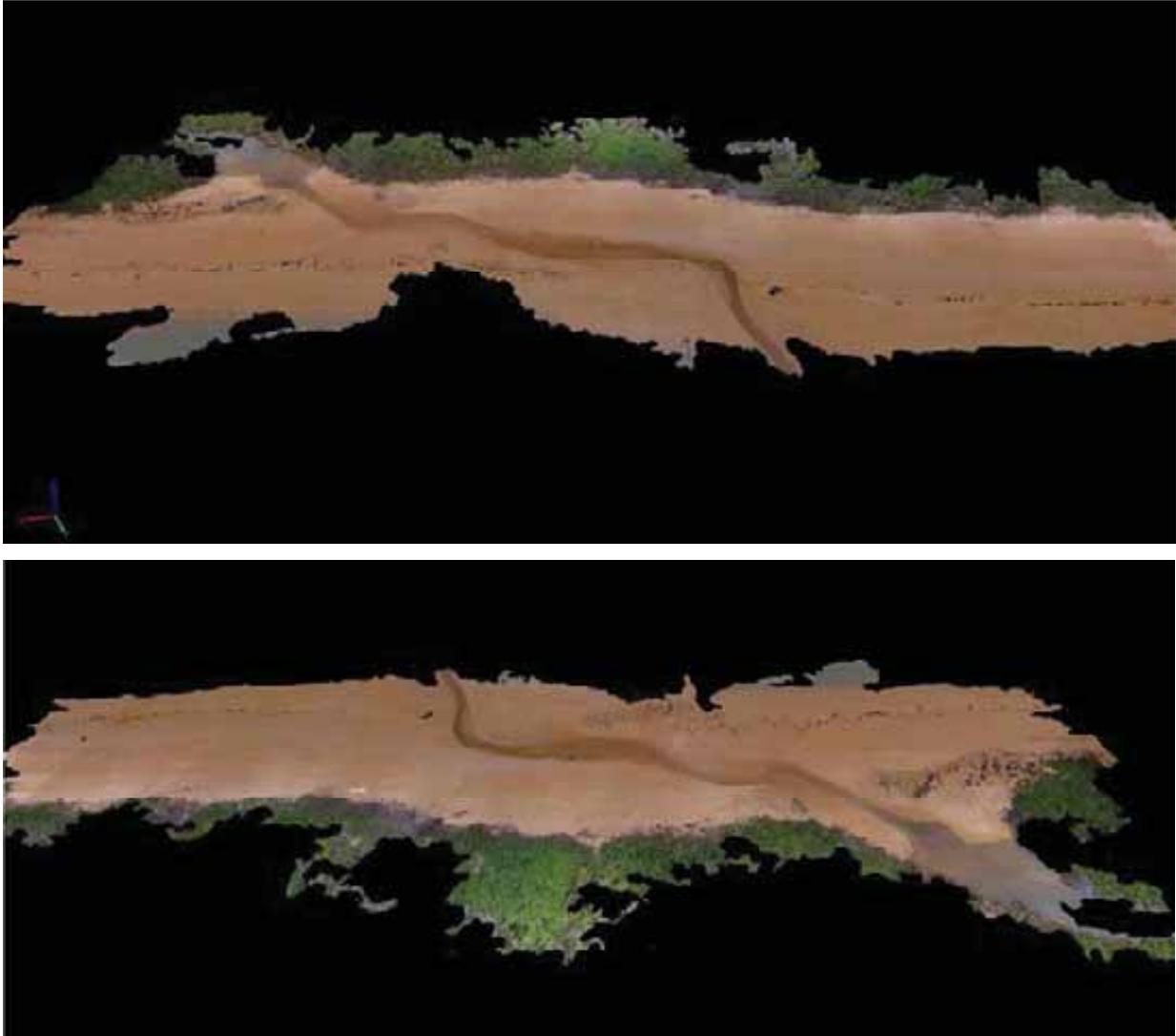


Figure 332. Three dimensional RGB images of Northeastern Ecological Corridor, Luquillo. View from the north (top) and from the south (bottom).



Figure 333. Three dimensional RGB images of Northeastern Ecological Corridor, Luquillo. View from the west (top) and from the east (bottom).

iv. DSM grayscale



Figure 334. Grayscale DSM images of the dune at Northeastern Ecological Corridor, Luquillo. The top image shows shades and the bottom is not shaded.

Site report

F. Vegetation cover



Figure 335. Vegetation covered 56.4% of the area of the Northeastern Ecological Corridor in Luquillo, Puerto Rico on April 18, 2018 (after northeasterly swell).

G. Volume measurements of selected areas of the dunes

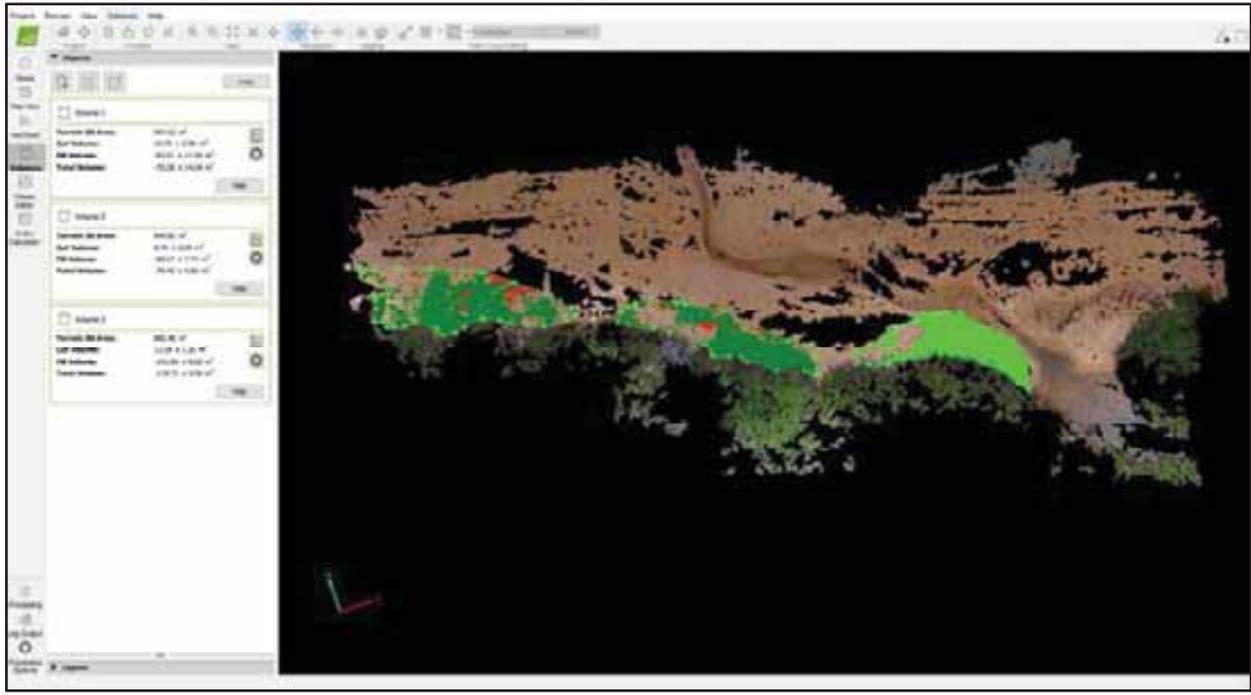


Figure 336. Three dimensional aerial picture of the Northeastern Ecological Corridor with three areas marked by polygons for which three dimensional area, cut volume, fill volume and total volume were calculated using the Pix4D software. Refer to image above for the data. The order of the data is from left to right on the image.

H. Conservation threats

No significant conservation threats because this site is within a remote and protected area of a nature reserve.

I. Recommended ecological restoration courses of action (COA)

Sand accumulation on this primary dune could increase from sand accumulation biomimicry matrices.

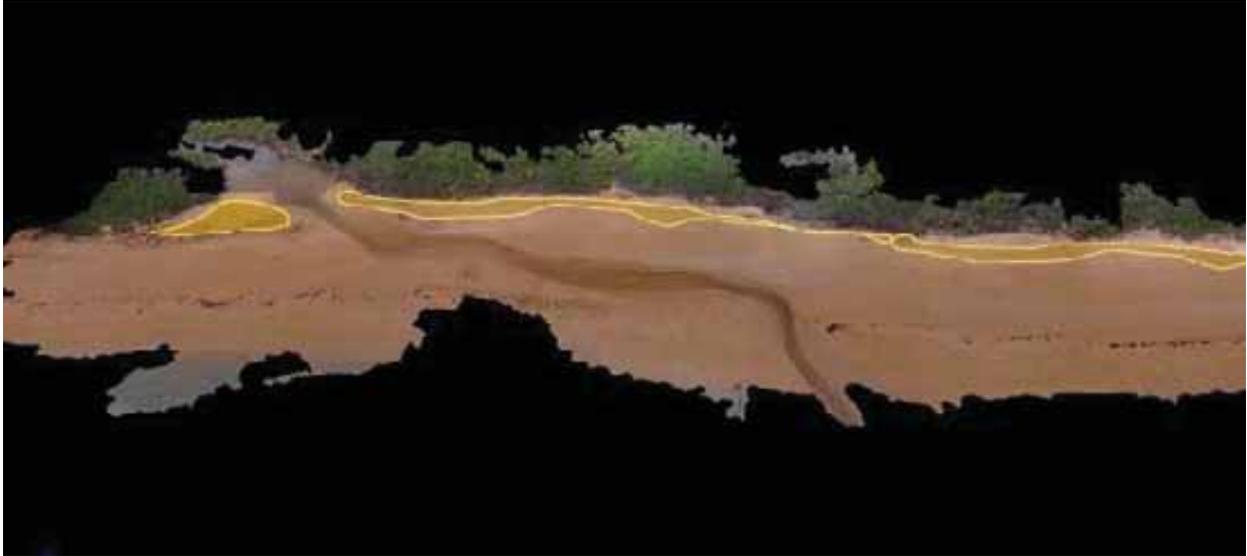


Figure 249. Area to be ecologically restored on the Northeastern Ecological Corridor in Luquillo, Puerto Rico. Highlighted regions represent the area of the dune crest where biomimicry matrices will be installed to promote the accumulation of sand.

J. Pix 4D Quality Report

Quality Report



Generated with Pix4Dmapper Pro version 4.2.26

Important: Click on the different icons for:

- Help to analyze the results in the Quality Report
- Additional information about the sections

Click [here](#) for additional tips to analyze the Quality Report

Summary



Project	CEN
Processed	2018-05-08 17:05:57
Camera Model Name(s)	FC330_3.6_4000x3000 (RGB)
Average Ground Sampling Distance (GSD)	1.12 cm / 0.44 in
Area Covered	0.022 km ² / 2.1999 ha / 0.01 sq. mi. / 5.4390 acres
Time for Initial Processing (without report)	04m:29s

Quality Check



Images	median of 17406 keypoints per image	
Dataset	171 out of 189 images calibrated (90%), all images enabled	
Camera Optimization	0.71% relative difference between initial and optimized internal camera parameters	
Matching	median of 2167.21 matches per calibrated image	
Georeferencing	yes, no 3D GCP	

Preview



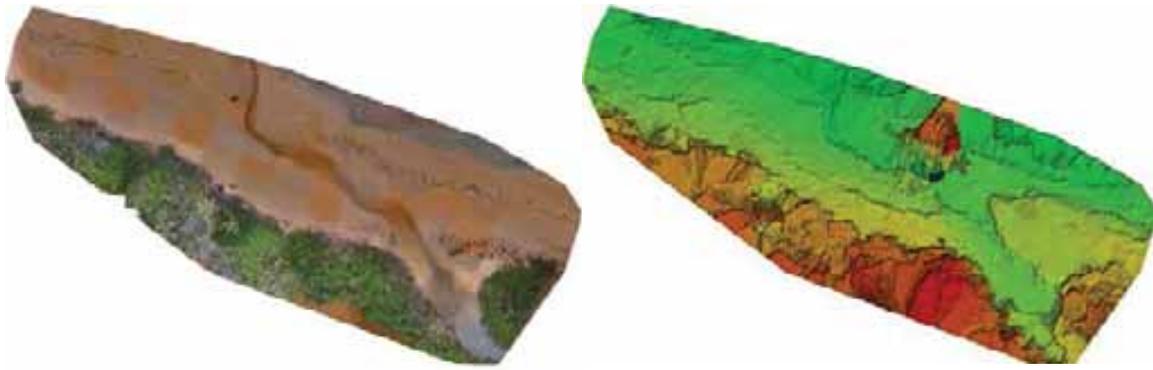


Figure 1: Orthomosaic and the corresponding sparse Digital Surface Model (DSM) before densification.

Calibration Details

Number of Calibrated Images	171 out of 189
Number of Geolocated Images	189 out of 189

Initial Image Positions

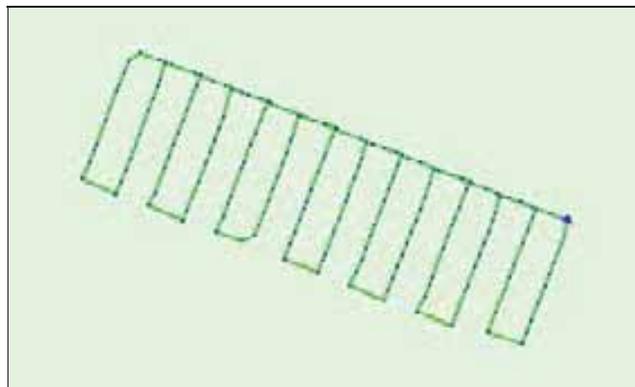
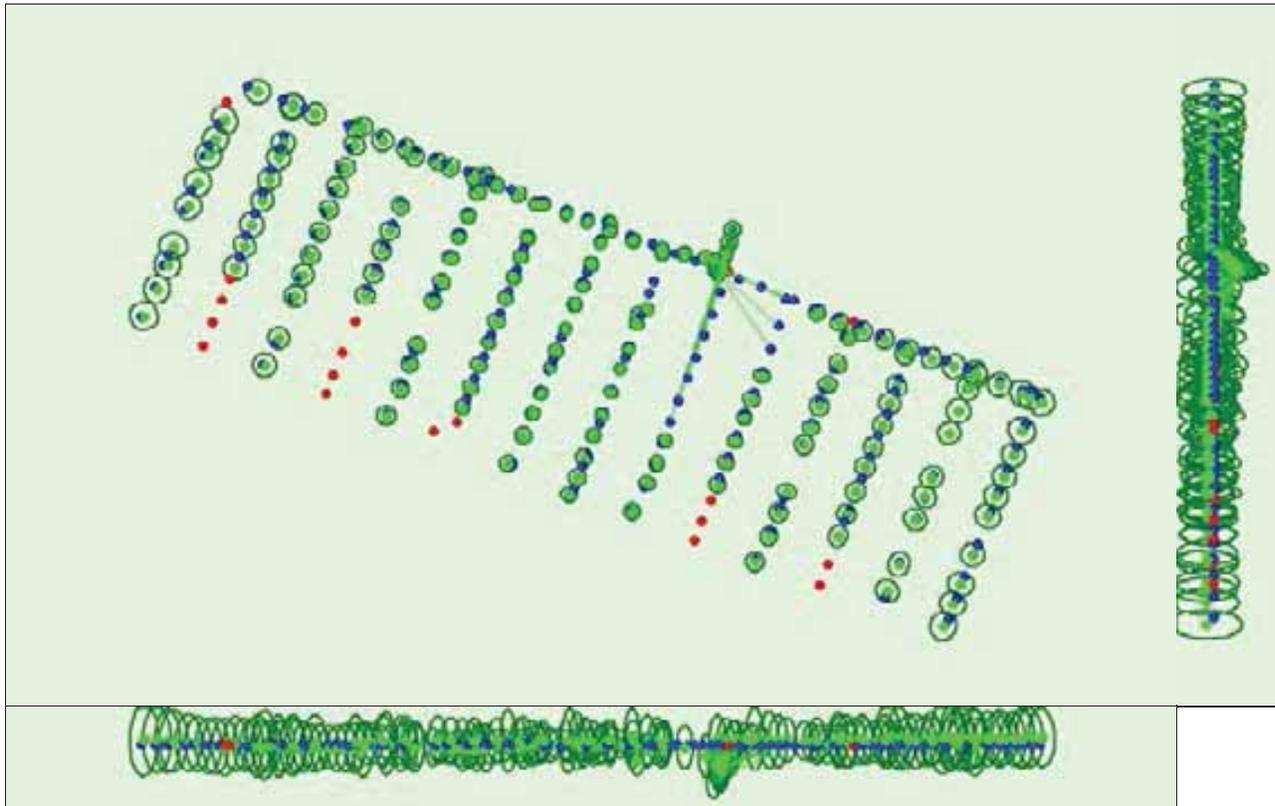


Figure 2: Top view of the initial image position. The green line follows the position of the images in time starting from the large blue dot.



Uncertainty ellipses 10x magnified

Figure 3: Offset between initial (blue dots) and computed (green dots) image positions as well as the offset between the GCPs initial positions (blue crosses) and their computed positions (green crosses) in the top-view (XY plane), front-view (XZ plane), and side-view (YZ plane). Red dots indicate disabled or uncalibrated images. Dark green ellipses indicate the absolute position uncertainty of the bundle block adjustment result.

Absolute camera position and orientation uncertainties

	X [m]	Y [m]	Z [m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.240	0.241	0.585	0.917	0.364	0.236
Sigma	0.050	0.049	0.122	0.064	0.054	0.105

Overlap

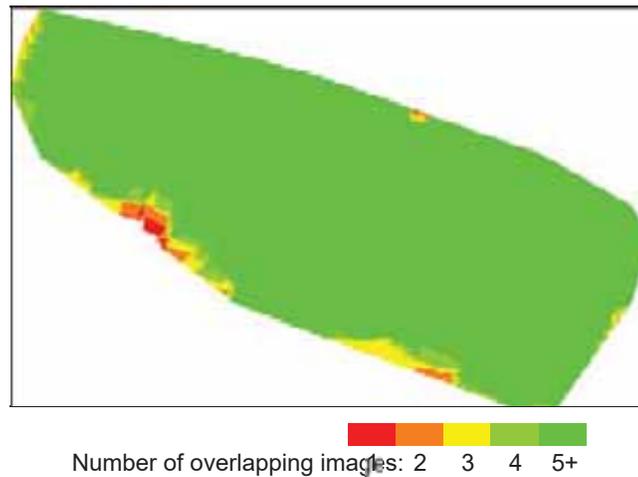


Figure 4: Number of overlapping images computed for each pixel of the orthomosaic. Red and yellow areas indicate low overlap for which poor results may be generated. Green areas indicate an overlap of over 5 images for every pixel. Good quality results will be generated as long as the number of keypoint matches is also sufficient for these areas (see Figure 5 for keypoint matches).

Bundle Block Adjustment Details



Number of 2D Keypoint Observations for Bundle Block Adjustment	383232
Number of 3D Points for Bundle Block Adjustment	157654
Mean Reprojection Error [pixels]	0.197

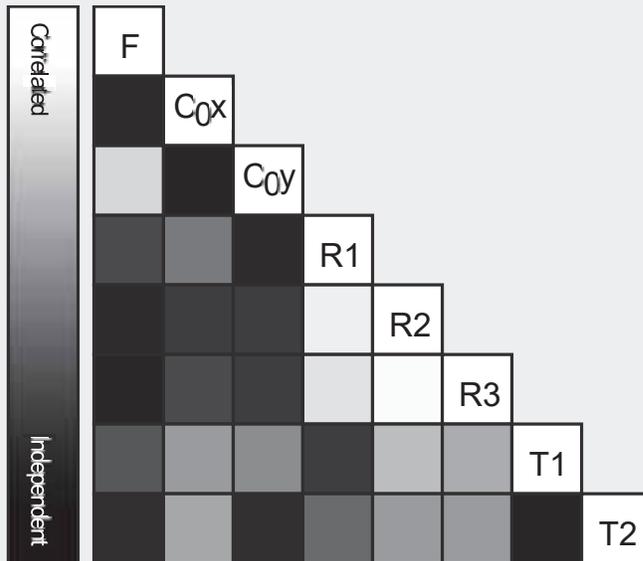
Internal Camera Parameters FC330_3.6_4000x3000 (RGB). Sensor Dimensions: 6.317 [mm] x 4.738 [mm]



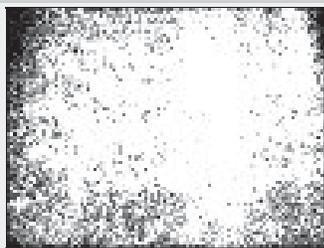
EXIF ID: FC330_3.6_4000x3000

	Focal Length	Principal Point x	Principal Point y	R1	R2	R3	T1	T2

Initial Values	2285.722 [pixel] 3.610 [mm]	2000.006 [pixel] 3.159 [mm]	1500.003 [pixel] 2.369 [mm]	- 0.001	- 0.002	0.000	- 0.001	- 0.001
Optimized Values	2302.046 [pixel] 3.636 [mm]	1975.910 [pixel] 3.121 [mm]	1506.791 [pixel] 2.380 [mm]	- 0.001	- 0.005	0.003	0.001	0.000
Uncertainties (Sigma)	0.442 [pixel] 0.001 [mm]	0.173 [pixel] 0.000 [mm]	0.345 [pixel] 0.001 [mm]	0.000	0.000	0.000	0.000	0.000



The correlation between camera internal parameters determined by the bundle adjustment. White indicates a full correlation between the parameters, ie. any change in one can be fully compensated by the other. Black indicates that the parameter is completely independent, and is not affected by other parameters.



The number of Automatic Tie Points (ATPs) per pixel, averaged over all images of the camera model, is color coded between black and white. White indicates that, on average, more than 16 ATPs have been extracted at the pixel location. Black indicates that, on average, 0 ATPs have been extracted at the pixel location. Click on the image to see the average direction and magnitude of the re-projection error for each pixel. Note that the vectors are scaled for better visualization. The scale bar indicates the magnitude of 1 pixel error.

2D Keypoints Table

	Number of 2D Keypoints per Image	Number of Matched 2D Keypoints per Image
Median	17406	2167
Min	12944	302
Max	77967	9605
Mean	24783	2241

3D Points from 2D Keypoint Matches

	Number of 3D Points Observed

In 2 Images	122167
In 3 Images	20621
In 4 Images	7290
In 5 Images	3279
In 6 Images	1840
In 7 Images	1007
In 8 Images	636
In 9 Images	354
In 10 Images	207
In 11 Images	111
In 12 Images	78
In 13 Images	34
In 14 Images	15
In 15 Images	6
In 16 Images	5
In 17 Images	4

2D Keypoint Matches

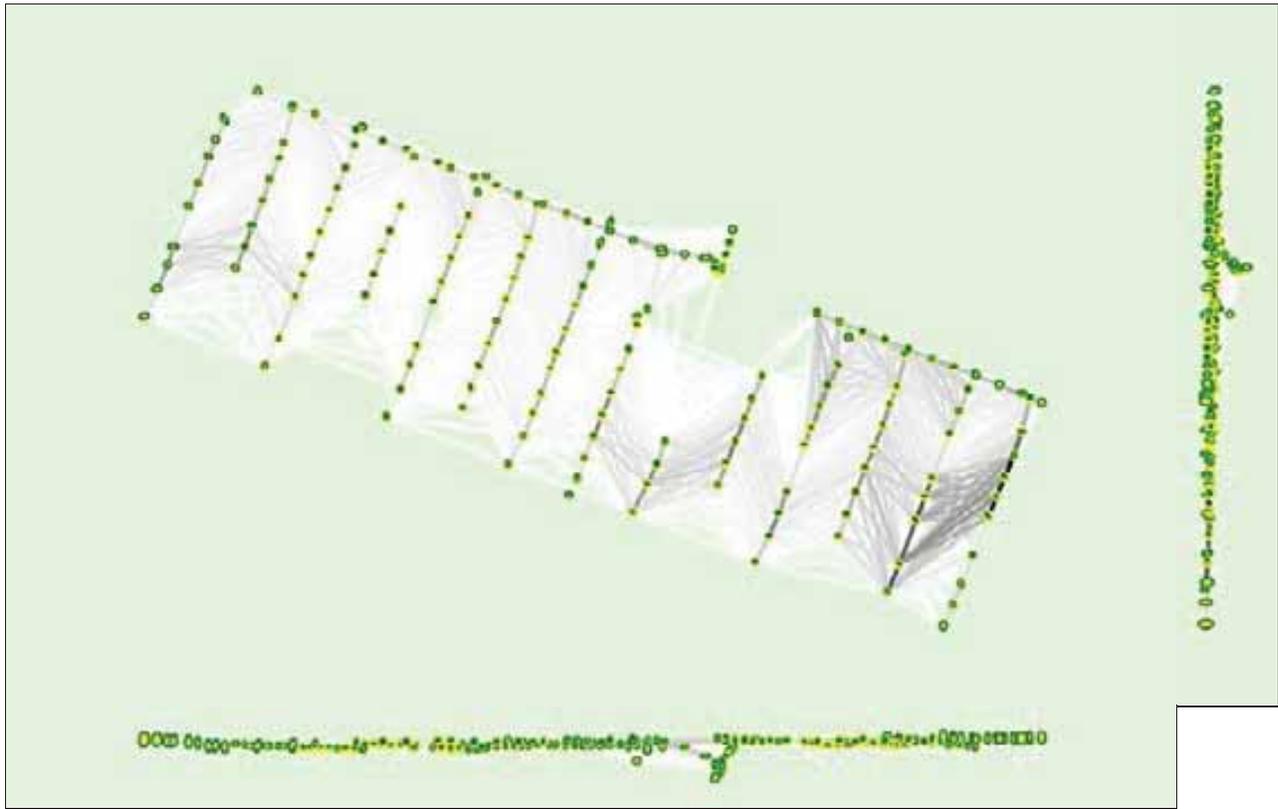


Figure 5: Computed image positions with links between matched images. The darkness of the links indicates the number of matched 2D keypoints between the images. Bright links indicate weak links and require manual tie points or more images. Dark green ellipses indicate the relative camera position uncertainty of the bundle block adjustment result.

Relative camera position and orientation uncertainties

	X [m]	Y [m]	Z [m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.007	0.006	0.008	0.014	0.016	0.010
Sigma	0.002	0.002	0.003	0.004	0.005	0.004

Geolocation Details

🔍 Absolute Geolocation Variance



Min Error [m]	Max Error [m]	Geolocation Error X [%]	Geolocation Error Y [%]	Geolocation Error Z [%]
-	-15.00	0.00	2.38	0.00
-15.00	-12.00	0.00	0.60	0.00
-12.00	-9.00	0.60	0.60	0.00
-9.00	-6.00	0.60	0.60	0.00
-6.00	-3.00	0.60	1.19	0.00
-3.00	0.00	54.17	21.43	59.52
0.00	3.00	40.48	69.05	33.33
3.00	6.00	1.19	3.57	4.76
6.00	9.00	0.00	0.60	2.38
9.00	12.00	0.60	0.00	0.00
12.00	15.00	1.19	0.00	0.00
15.00	-	0.60	0.00	0.00
Mean [m]		-0.013354	0.089796	0.030182
Sigma [m]		2.531049	4.183715	1.680338
RMS Error [m]		2.531084	4.184678	1.680609

Min Error and Max Error represent geolocation error intervals between -1.5 and 1.5 times the maximum accuracy of all the images. Columns X, Y, Z show the percentage of images with geolocation errors within the predefined error intervals. The geolocation error is the difference between the initial and computed image positions. Note that the image geolocation errors do not correspond to the accuracy of the observed 3D points.

🔍 Relative Geolocation Variance



Relative Geolocation Error	Images X [%]	Images Y [%]	Images Z [%]
[-1.00, 1.00]	96.43	94.64	100.00
[-2.00, 2.00]	98.21	96.43	100.00
[-3.00, 3.00]	99.40	97.62	100.00
Mean of Geolocation Accuracy [m]	5.000000	5.000000	10.000000
Sigma of Geolocation Accuracy [m]	0.000000	0.000000	0.000000

Images X, Y, Z represent the percentage of images with a relative geolocation error in X, Y, Z.

Geolocation Orientational Variance	RMS [degree]
Omega	11.084
Phi	5.742
Kappa	4.042

Geolocation RMS error of the orientation angles given by the difference between the initial and computed image orientation angles.

Initial Processing Details



System Information



Hardware	CPU: Intel(R) Core(TM) i7-8700K CPU @ 3.70GHz RAM: 16GB GPU: NVIDIA GeForce GTX 1070 (Driver: 23.21.13.9065)
Operating System	Windows 10 Home, 64-bit

Coordinate Systems



Image Coordinate System	WGS84 (egm96)
Output Coordinate System	WGS 84 / UTM zone 20N (egm96)

Processing Options



Detected Template	3D Maps
Keypoints Image Scale	Full, Image Scale: 1
Advanced: Matching Image Pairs	Aerial Grid or Corridor
Advanced: Matching Strategy	Use Geometrically Verified Matching: no
Advanced: Keypoint Extraction	Targeted Number of Keypoints: Automatic
Advanced: Calibration	Calibration Method: Standard Internal Parameters Optimization: All External Parameters Optimization: All Rematch: Auto, yes

Point Cloud Densification details



Processing Options



Image Scale	multiscale, 1/2 (Half image size, Default)
Point Density	Optimal
Minimum Number of Matches	3
3D Textured Mesh Generation	yes
3D Textured Mesh Settings:	Resolution: Medium Resolution (default) Color Balancing: no
LOD	Generated: no
Advanced: 3D Textured Mesh Settings	Sample Density Divider: 1
Advanced: Image Groups	group1
Advanced: Use Processing Area	yes

Advanced: Use Annotations	yes
Time for Point Cloud Densification	07m:29s
Time for Point Cloud Classification	NA
Time for 3D Textured Mesh Generation	03m:30s

Results



Number of Generated Tiles	1
Number of 3D Densified Points	7941426
Average Density (per m ³)	1886.01

DSM, Orthomosaic and Index Details



Processing Options



DSM and Orthomosaic Resolution	1 x GSD (1.12 [cm/pixel])
DSM Filters	Noise Filtering: yes Surface Smoothing: yes, Type: Sharp
Raster DSM	Generated: yes Method: Inverse Distance Weighting Merge Tiles: yes
Orthomosaic	Generated: yes Merge Tiles: yes GeoTIFF Without Transparency: no Google Maps Tiles and KML: no
Time for DSM Generation	05m:45s
Time for Orthomosaic Generation	16m:39s
Time for DTM Generation	00s
Time for Contour Lines Generation	00s
Time for Reflectance Map Generation	00s
Time for Index Map Generation	00s

Appendix

Cut volume - V_c is the volume between the base and the 3D terrain, when the terrain is higher than the base.

$$\text{Cut volume} = V_C = V_{C1} + V_{C2} + \dots V_{CN}$$

Fill volume - V_F is the volume between the base and the terrain when the terrain is lower than the base.

$$\text{Fill volume} = V_F = V_{F1} + V_{F2} + \dots V_{FN}$$

Orthomosaic - The orthomosaic is a 2D map. Each point contains X, Y and color information. The orthomosaic has uniform scale and can be used for 2D measurements (distance, surface). It corrects the following problems of the input images: Perspective of the camera, Different scale based on the distance that each point of the object / ground has from the camera.

References:

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