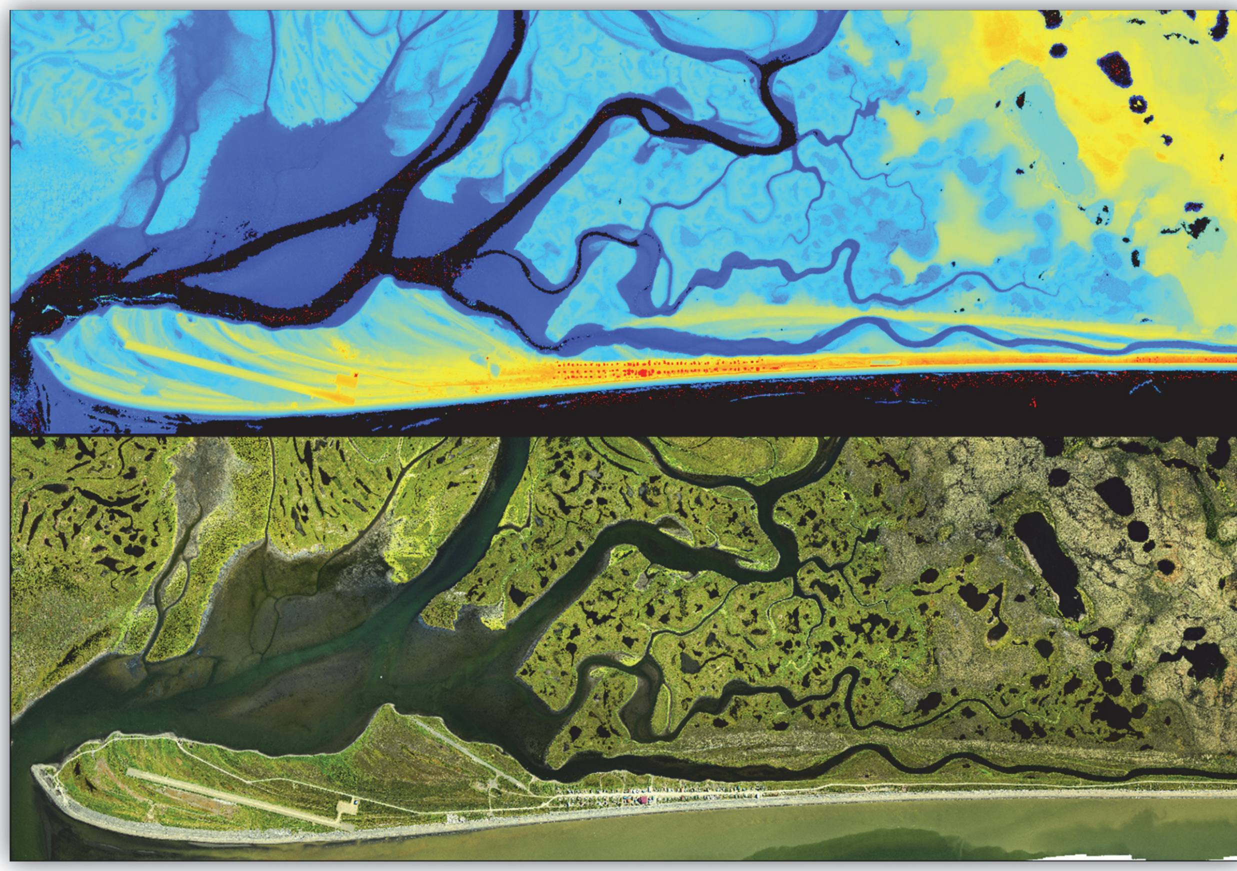
Alaska Division of Geological & Geophysical Surveys

RAW-DATA FILE 2016-1

PHOTOGRAMMETRIC DIGITAL SURFACE MODELS AND ORTHOIMAGERY FOR 26 COASTAL COMMUNITIES OF WESTERN ALASKA

by
Jacquelyn R. Overbeck, Michael D. Hendricks, and Nicole E.M. Kinsman

May 2016



Digital surface model (top) and orthoimage (bottom) of Shaktoolik and surrounding area (collected by Fairbanks Fodar, 2015).

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Note: *This report, including all digital data, explanations, and tables, is available in digital format from the DGGS website (http://dggs.alaska.gov).*

PHOTOGRAMMETRIC DIGITAL SURFACE MODELS AND ORTHOIMAGERY FOR 26 COASTAL COMMUNITIES OF WESTERN ALASKA

by

Jacquelyn R. Overbeck[1], Michael D. Hendricks[1], and Nicole E.M. Kinsman[2]

ABSTRACT

The State of Alaska Division of Geological & Geophysical Surveys acquired photogrammetric digital surface models (DSMs) and co-registered orthorectified aerial images (orthoimages) for the west coast of Alaska in support of coastal vulnerability mapping efforts. This report is a summary of the data collected over 26 developed areas along approximately 3,500 km of coastline in the Bering Sea, Norton Sound, and Yukon–Kuskokwim Delta regions (fig. 1). Aerial photographs were collected between July 31 and September 6, 2015, and processed using Structure-from-Motion (SfM) photogrammetry techniques. Ground control points (GCPs) and checkpoints were collected in support of these data products during a Global Navigation Satellite System (GNSS) survey conducted between August 15 and September 14, 2015. For the purposes of open access to elevation and orthoimagery datasets in coastal regions of Alaska, this collection is being released as a Raw Data File with an open end-user license. The data available for each of the 26 communities consist of the following: (1) Orthoimage raster, (2) Digital Surface Model (DSM) raster, (3) Hillshade raster produced from DSM, and (4) an Orthoimage Hillshade combination raster.

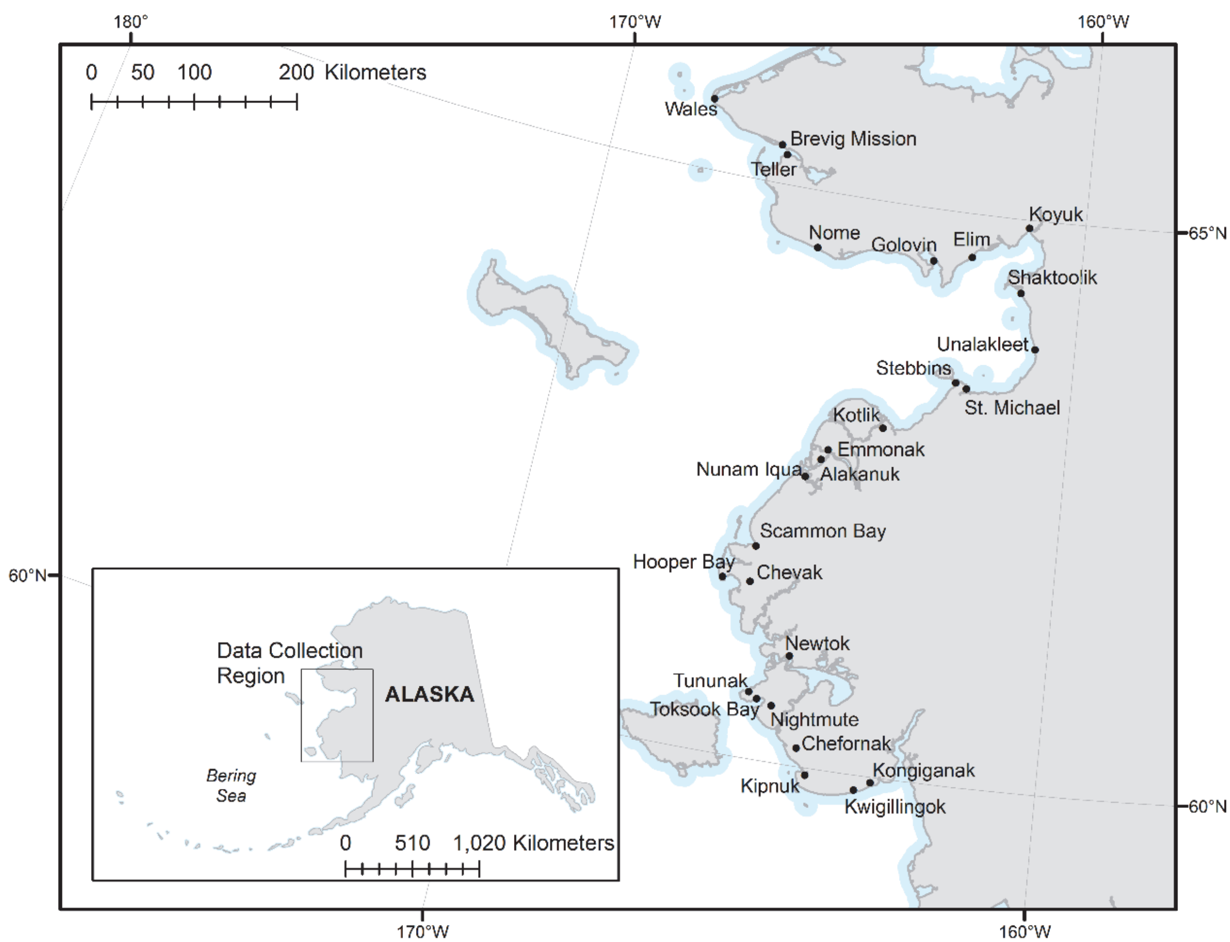

Figure 1. Location map of 26 western Alaska communities mapped in 2015.

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DATA ACQUISITION

Fairbanks Fodar collected aerial photographs between July 31 and September 11, 2015, using a small aircraft (Cessna 170B) platform. The aerial survey was planned so flight lines and photograph frequency provided 60 percent side lap and 80 percent end lap photo coverage, with flying heights between 800 and 2,700 ft (244–823 m) resulting in 10–20 cm ground sample distance (GSD; see table 1) of the aerial photos. A Nikon D800E with a 24 mm Nikkor f/1.4 lens was used to collect 36-megapixel photographs (7,360 × 4,912 pixels per image), in Joint Photographic Experts Group (JPEG) or Nikon Electronic Format (NEF), depending on flight length for the day (because the JPEG format had a smaller file size, it was used on longer flights). Photos were collected at 1- to 3-second intervals. On-board global positioning system (GPS) data were acquired by a Trimble 5700 with roof-mounted antenna approximately 1 m above the camera, collecting at 5 Hertz. Each camera shutter trip placed an event marker onto the GPS datastream for precise timing and location. For more detailed information on flying dates at specific locations, see Appendix A.

Table 1. Community-specific data quality and reference information.

Location	Airport identification code	Orthoimage ground sample distance (GSD) (cm)	Digital surface model GSD (cm)	Vertical shift (m)	Root mean square error (RMSE) (m)	Number of points used to calculate RMSE	Universal transverse mercator zone
Alakanuk	AUK	17	20	0.48	0.063	3	3
Brevig Mission	KTS	15	20	-0.18	0.113	8	3
Chevak	VAK	13	20	0.28	0.040	5	3
Chefornak	CFK	10	20	0.36	0.075	5	3
Elim	ELI	10	20	-0.09	0.103	4	3
Emmonak	EMN	17	20	0.43	0.110	4	3
Golovin	GLV	10	20	0.15	0.030	4	3
Hooper Bay	HPB	9	19	0.37	0.013	4	3
Kipnuk	IIK	19	19	0.25	0.048	4	3
Kongiganak	DUY	9	10	0.19	0.068	5	3
Kotlik	KOT	15	20	0.50	0.071	4	3
Koyuk	KKA	16	20	0.61	0.125	4	4
Kwigillingok	GGV	15	20	0.37	0.081	5	3
Newtok	EWU	9	18	0.28	0.054	4	3
Nightmute	IGT	9	17	0.12	0.040	5	3
Nome	OME	9	18	0.17	0.090	5	3
Nunam Iqua	SXP	16	20	0.43	0.071	4	3
Scammon Bay	SCM	20	20	0.55	0.097	5	4
Shaktoolik	SKK	9	9	-0.21	0.117	4	3
Stebbins	WBB	10	20	-0.21	0.068	4	3
St. Michael	SMK	10	20	-0.21	0.033	4	3
Teller	TER	15	20	0.08	0.127	4	3
Toksook Bay	OOK	16	20	0.23	0.106	5	3
Tununak	TNK	20	20	0.00	0.070	4	3
Unalakleet	UNK	8	17	0.23	0.037	5	4
Wales	WAA	15	20	0.00	0.063	5	3

DATA PROCESSING

Aerial survey GNSS data were processed using Waypoint's Grafnav commercial GNSS software using GPS constellation. Each project was processed using either post-processing kinematic (PPK) or precise point positioning (PPP) methods, depending on the quality of the solution, which was primarily dependent on the distance from Continually Operating Reference Stations (CORS), such that all flights resulted in data with better than 10 cm separation in forward and reverse trajectory solutions. GPS data were processed to the North American Datum 1983 (NAD83; 2011) European Petroleum Survey Group Well Known Identification Number (EPSG) 6318, and the North American Vertical Datum of 1988 (NAVD88; Geoid12A; EPOCH 2010.00).

Photos were individually processed for optimum contrast and exposure using Adobe Camera Raw. To accommodate the large data acquisition volumes, most photos were shot and processed to JPEG format.

Aerial survey GPS data (event marker coordinates) were manually correlated to image filenames using the image timestamp to create a camera external orientation file for import into Agisoft Photoscan Professional (Photoscan) software. The external orientation file provides the X, Y, Z position of the camera for each photograph taken during the survey. Aerial stereophotographs were imported into the photogrammetric software, which uses an SfM algorithm to create a three-dimensional terrain model from the stereo-imagery. The terrain model was then used to orthometrically correct the photos and produce the final orthoimage mosaic in Photoscan. Within the Photoscan software application, standard workflow steps were followed: photo-alignment, alignment optimization, dense point cloud building, mesh creation, DSM and orthoimage creation, and exporting the results.

DATA PRODUCTS

The data available for each of the 26 communities consist of the following: (1) Orthoimage raster, (2) DSM raster, (3) Hillshade raster produced from DSM, and (4) an Orthoimage Hillshade combination raster. In addition, a polygon shapefile is available that shows the data extent and attributes recorded in table 2 for all 26 communities. These data are stored in NAD83 (2011) horizontal datum and projected in Universal Transverse Mercator (UTM) Zone 3 or 4 coordinate systems (meters; EPSG 6332 or 6333, respectively) and NAVD88 (Geoid12A; EPOCH 2010.00) vertical datum, as outlined in the accompanying metadata.

Orthoimagery

Orthoimages contain 3-band, 8-bit, unsigned raster data (red/green/blue; file format–GeoTIFF; source–Fairbanks Fodar) and differential GSD between communities (see table 1). The No Data value is set to 0. The file employs Lempel-Ziv-Welch (LZW) compression. Light exposures in the orthoimages are a result of daily weather conditions, which ranged from low cloud cover, rain, and full sun.

Digital Surface Model (DSM)

The single-band, 32-bit float DSMs represent surface elevations of buildings, vegetation, and uncovered ground surfaces (file format–GeoTIFF; source–Fairbanks Fodar) with differential GSD between communities (see table 1). The No Data value is set to -32767. The file employs LZW compression.

DSM Hillshade

The single-band, 8-bit, unsigned integer rasters represent hillshading of the DSM (file format–GeoTIFF; source–DGGS) with differential GSD between communities (see table 1). The No Data value is set to 255. The file employs LZW compression. The hillshade was produced using Blue Marble Geographic's Global Mapper GIS application. This file has the same spatial resolution as the DSM.

Orthoimagery Hillshade Combination Raster

The orthoimagery hillshade combination rasters contain 3-band, 8-bit, unsigned raster data (red/green/blue; file format–GeoTIFF; source–DGGS) and represents a hillshade-tinted orthoimage. The No Data value is set to 0. The file employs LZW compression. The file was produced with ESRI's ArcGIS using Raster Function templates. This file has the same spatial resolution as the DSM.

Community Data Extent Polygon File

One polygon shapefile is available that shows the data extent and data attributes for all 26 communities (table 2).

Table 2. Polygon shapefile attribute descriptions.

Field	Type	Description
community	String	Community name
code	String	3 digit airport code for community
ortho_gsd	Double	Orthoimage ground sample distance (gsd), that is, raster cell size, in meters
dsm_gsd	Double	DSM ground sample distance (gsd), that is, raster cell size, in meters
vert_shift	Double	Vertical shift, in meters
Rmse	Double	Root mean square error (RMSE) in meters
Num_pts	Short Integer	Number of points used to calculate RMSE
Utm_zone	Short Integer	UTM zone of the delivered data
ortho_gb	Double	Size, in gigabytes, of orthoimage raster file
dsm_gb	Double	Size, in gigabytes, of DSM raster file
dsm_hs_gb	Double	Size, in gigabytes, of DSM hillshade raster file
tint_gb	Double	Size, in gigabytes, of orthoimage hillshade tint raster file

DATA QUALITY

Horizontal accuracies of the orthoimagery were evaluated by comparing the locations of photo-identifiable GCPs to the same point visible in the aerial photos (see Appendix A for examples). The 37 photo-identifiable GCPs and 75 checkpoint elevations taken on stable surfaces across the 26 communities were collected by RECON, LLC (see Appendix B). No horizontal offsets were identified at the pixel scale at any location (see table 1 for location-based GSD), so no horizontal transformation was performed.

The vertical accuracies of the DSMs were evaluated by comparing both the GCP elevations and checkpoint elevations with the DSM elevations separately for each non-contiguous community (with the exception of Stebbins/St. Michael, the data are not contiguous between communities). We reduced the residual difference between GCPs and DSM pixels to zero mean using a vertical shift (see table 1). The remaining residuals were used to determine the Root Mean Square Error (RMSE) at each community, then combined to determine RMSE for the dataset as a whole. The final DSMs had a mean vertical residual of 6.2 cm with +/- one standard deviation of 5.2 cm, with 95 percent of all GCP and checkpoint residuals within 16.7 cm. The RMSE of all GCPs and checkpoints was 8.1 cm, but varied by location (see table 1).

Known anomalies within the data exist on the DSMs over water bodies; these anomalies have not been edited in this data release. Because waves in the nearshore marine or lacustrine environment move at a higher speed than photo-collection, the SfM processing technique for producing DSMs defines those points irregularly (for an example, see fig. 2).

Figure 2. Examples of anomalous elevation values over water at Tununak, Alaska.

ACKNOWLEDGMENTS

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The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the opinions or policies of the U.S. Government. Mention of trade names or commercial products does not constitute their endorsement by the U.S. Government.

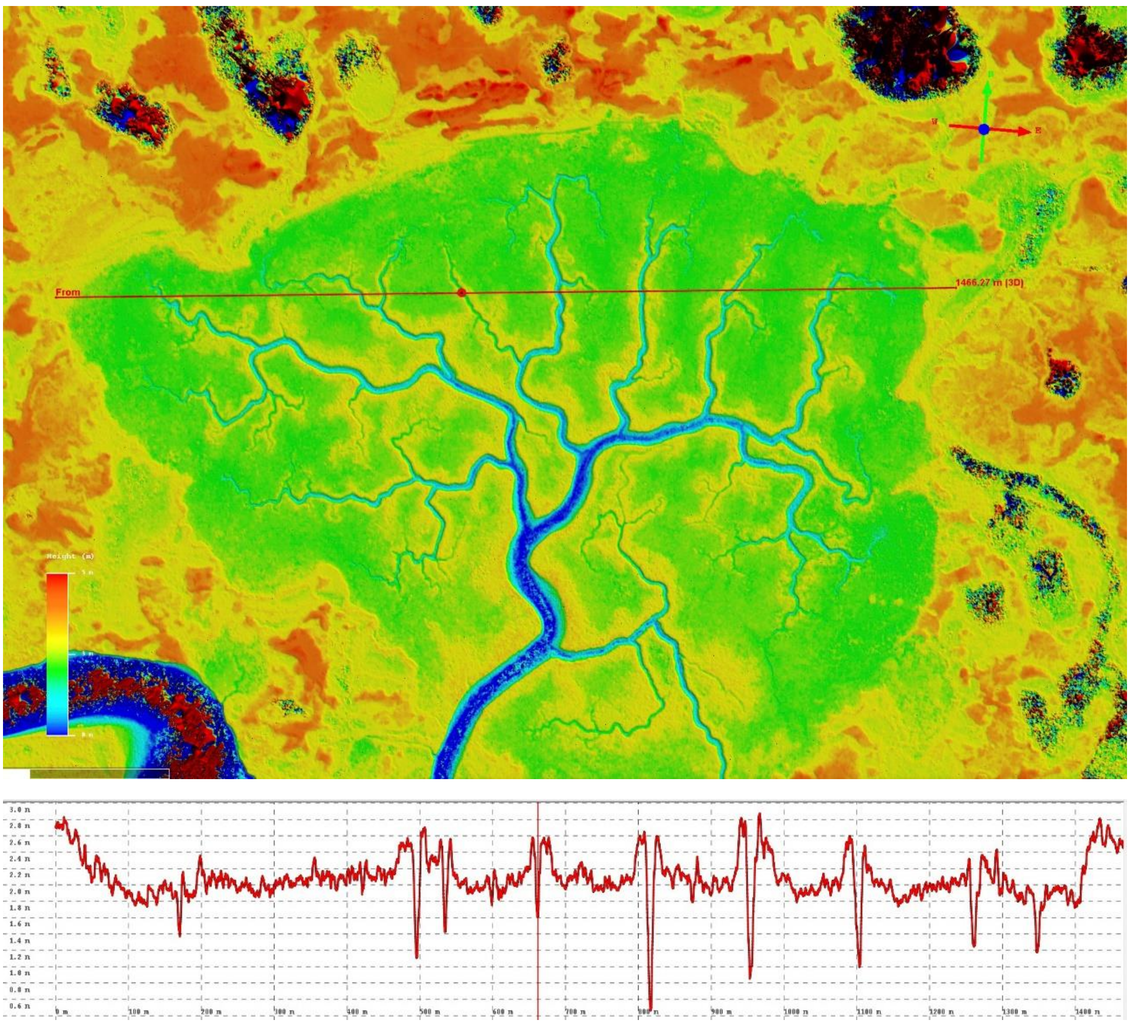
Contract 10-15-053

Coastal Village Data Report

20 February 2016

Submitted to

Alaska Department of Natural Resources



Topography of a drained lake near Kwigillingok showing centimeter-scale relief

Submitted by

Fairbanks Fodar

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Alaska DNR Contract 10-15-053

Coastal Village Data Report

Fairbanks Fodar
20 February 2016

Executive Summary

This report is a brief summary of the delivery of DSMs and orthomosaics of 29 developed areas along the coast between Wales and Bethel. As part of a much larger effort mapping the entire coastline between these villages to assess coastal vulnerability, in this village delivery we acquired and individually processed over 50,000 photos covering over 1200 km^2 of area at 10-20 cm resolution and performed various quality assessment checks on the data. The data exceed all specs – we delivered more than double the area specified for the villages and the resolutions exceed spec by 10-100%, leading to over 3x more total pixels delivered than required by the contract. Data quality meets or exceeds expectations based on prior work. Compared to GCPs provided by DGGS from another contractor at 27 villages, no horizontal offsets were found; that is, the directly georeferenced data had essentially perfect horizontal placement in the real world. Vertical offsets between GCPs and our directly georeferenced maps had a mean of 10 cm and all were within spec; after reducing the data to zero mean offset, the RMSE residuals were less than 10 cm. For example, the 5 vertical GCPs acquired in Wales had a mean residual of 4 cm compared to our DSMs and a total range of +/7 cm, so here if we applied a 4 cm vertical shift to the data, our vertical accuracy reduces to the precision level of about +/- 7 cm. All villages where multiple GCPs were acquired show a precision level +/- 11 cm or better. Similarly, comparison of millions of points at Unalakleet to a map we made there in 2014 showed a scatter of better than +/- 10 cm in most locations we identified as stable (that is, non-vegetated, not eroding, etc). This report gives a brief overview of our processing methods and data quality checks.

Data Acquisition and Processing

Fairbanks Fodar was awarded contract 10-15-053 on 21 July 2015 and our field work began ten days later on 31 July 2015. Our methods are described in the report associated with this Appendix and in detail in Nolan, M., C. Larsen, and M. Sturm. "Mapping snow depth from manned aircraft on landscape scales at centimeter resolution using structure-from-motion photogrammetry." *The Cryosphere* 9.4 (2015): 1445-1463. For all acquisitions, we used a Cessna 170B flown by a single pilot/operator, controlling a Nikon D800E connected to a survey-grade GPS. Flying altitudes were planned at 2700 feet AGL, though cloud cover often required flying lower and thus decreasing the spacing between flight lines. The target ground sample distance was 17 cm, but was often as low as 8-10 cm by flying lower. As originally planned, the project was due to start in June with a final delivery on October 16, however a variety of issues led to a late start with the contract. Given the unlikelihood of complete project acquisition due to weather, sunlight and tidal constraints in August, our project performance plan prioritized village acquisitions. While we were still able to acquire about 85% of the total area (villages plus coast lines in between), we were able to acquire 100% of the village data. GPS processing was done in the field to ensure data quality. Photographic pre-processing included optimizing the images for contrast and exposure and was mostly accomplished after return to Fairbanks. Data processing was performed in Agisoft Photoscan, as described in this DNR report and the paper cited above. About half of the village data were delivered on October 16 and the remainder on December 1st. DNR found all data within spec and suggested a final vertical shift of the DSMs to optimize with checkpoints which were not provided to Fairbanks Fodar. These optimization shifts were on the order of 10 cm vertically, as detailed in the report. The final data were thus shifted as recommended and delivered on January 12th. As described below, the data were not cropped to match the DCRA village outlines provided by DNR, but rather substantial bonus area was delivered outside of these outlines. Note that these are first-surface DSM and no bald earth or other value-added processing have been performed.

Data Quality Overview

We acquired these data between July 31 and September 6, as noted in Table A1. There are 29 villages in total; note however that we processed Stebbins and St Michaels in the same block and that the DCRA shapefiles use a single outline for Brevig Mission and Teller, which we processed separately, so there is some potential confusion when counting them.

As can be seen in Table A1, we have not only met all specifications but greatly exceeded them in terms of area, GSD, and total pixels delivered. Here we calculated the pixel overdelivery by comparing the measured pixels within a file to the pixels that would have been contained in a file that only met the minimum specs, as calculated by the DCRA area and the GSD spec. This metric indicates a 3.5x over-delivery. The majority of the bonus area comes from extending flight lines beyond the DCRA boundary to ensure complete coverage of it. The majority of the higher resolution comes from flying lower than planned to maximize use of available weather windows (that is, working under lower ceilings than planned). Two villages currently have slightly less than full coverage within the DCRA boundary: Brevig Mission is missing a corner (which will be processed with coastal data) and Tuntutuliak had some cloud cover that obscured <10 % of the area within the DCRA boundary which we will attempt to re-acquire in 2016.

Not only has the data exceeded the geometric specifications above, but it also has exceeded the specs for accuracy and precision. Table 1 in the main report shows the comparisons of the DGGS GCPs to our maps. Note that in all cases, horizontal accuracy was essentially perfect.

‘Essentially’ here means to the best of our ability to determine reliably by eye, but is well within a single pixel; see Figure A1 for some examples. The vertical accuracy was determined by the State to have an RMSE residual offset of only 8 cm for all GCP points, substantially below the 40 cm specification. Further, we compared our 2015 Unalakleet DEM to our 2014 Unalakleet DEM. The results are shown in Figure A2. Here the yellow/green colors represent about +/- 10 cm, and this covers the bulk of the comparison; nearly all locations with larger differences have changed due to vegetation or disturbance, or spatial biasing at building edges. These results, combined with our prior research on technique validation, indicate that these data will be excellent baselines for documenting future change.

Village	Spec GSD (cm)	Actual GSD (cm)	DEM Post (cm)	DCRA Area (km2)	Delivered Area (km2)	Overdelivery (Area, %)	Overdelivery (Pixels, %)	Acquisition Date
Wales	20	15.5	20.0	20	40	101%	334%	8/27-28/2015
Brevig	20	15.1	20.0	58	53	53%	161%	8/27-28/2015
Teller	20	15.2	20.0	n/a	35	n/a	n/a	8/27-28/2015
Nome	10	9.2	18.4	n/a	33	n/a	n/a	8/23/2015
White Mountain	20	18.2	20.0	20	38	89%	228%	8/23/2015
Golovin	10	9.8	20.0	47	70	50%	155%	8/23/2015
Elim	10	10.7	20.0	20	24	21%	107%	8/5/2015
Koyuk	20	16.5	20.0	20	23	16%	171%	8/5/2015
Shaktoolik	10	9.4	9.4	21	32	54%	175%	8/6/2015
Unalakleet	10	8.5	16.9	32	42	31%	184%	7/31/2015
St Michaels	10	10.0	20.0	n/a	n/a	n/a	n/a	8/6/2015
Stebbins	10	10.0	20.0	40	73	181%	182%	8/6/2015
Kotlik	20	15.1	20.0	25	49	97%	345%	8/22/2015
Emmonak	20	17.2	20.0	24	48	100%	271%	8/31/2015
Alakanuk	20	16.8	20.0	27	51	94%	276%	8/31/2015
Nunam	20	16.5	20.0	20	41	104%	299%	8/14/2015
Scammon Bay	20	19.7	20.0	15	99	581%	701%	8/13/2015
Hooper Bay	10	9.5	19.0	13	32	148%	276%	8/13/2015
Cheevak	20	12.8	20.0	13	47	264%	889%	8/13/2015
Newtok	10	9.4	18.0	26	51	93%	219%	9/1/2015
Tunanak	20	19.7	20.0	20	43	115%	222%	9/1/2015
Toksook Bay	20	16.6	20.0	20	33	63%	237%	9/1/2015
Nightmute	20	8.8	18.0	23	47	99%	1042%	8/21, 9/1/2015
Chefornak	20	9.0	20.0	46	83	99%	891%	9/6/2015
Kipnuk	10	9.6	19.2	12	41	249%	380%	8/19/2015
Kwig	20	15.1	20.0	13	57	343%	775%	8/21/2015
Kong	10	9.2	18.0	20	32	64%	195%	8/12/2015
Tunt	20	16.5	20.0	12	53	355%	672%	8/21/2015
Napakiak	20	15.2	20.0	13	36	184%	493%	8/21/2015
			Totals:	**618**	**1307**	**111%**	**266%**	

Table A1. Data delivery overview. *Columns 2 and 3 are postings of the delivered orthomosaics and DEMs respectively. Delivered Area was measured based on actual pixel counts within the DEMs, not the size of the bounding box of the DEM. Overdelivery as a percentage of area was calculated from the DCRA Area and Delivered Area. Overdelivery as a percentage of pixels was calculated comparing actual pixels to files based on the DCRA area and specified GSD. There was no DCRA village outline for Nome, so it is excluded from the percentage calculations. Stebbins and St Michaels were acquired and delivered within a single block, so are grouped for calculations.*

DSM Noise

Within the DCRA village boundaries used as AOIs for this delivery, we have not found nor do we expect to find any spatially correlated noise that exceeds specifications. We planned our flight lines so that all of the area inside the boundary would have a consistent amount of sidelap. The reduction of side lap near the edges of an acquired block often leads to spatially correlated noise in the form of corduroy banding or slight warps. With our data outside the DCRA boundary, this is noise is usually less than +/- 40 cm, but it can sometimes be around +/- 80 cm. When it is exists, it is easy to spot on a shaded relief of a DSM. Again, such noise can only be found outside the AOIs in the 'bonus' area delivered, and typically only within a few hundred meters of the edges. Thus some care should be taken in using the DSMs near the edges. This noise does not affect the orthomosaics.

There are several types of spatially uncorrelated noise. A large and easily observed one is over water bodies. It was known in advance that water bodies would require manual editing and thus our contract was only for solid land surfaces, as photogrammetry cannot resolve water surfaces as accurately as land surfaces. When waves are present, their motion introduces an additional parallax that can causes noise well over 10 m. On calm days when the bottom of a lake is imaged, the refraction caused by the water is not accounted for and also causes larger errors. Thus water bodies require manual hydroflattening. The base random noise level is about +/- 3 cm. Much of this is likely caused by slight uncertainties within the bundle adjustment as well as difficulties in gridding the DSM. On flat surfaces, this noise can sometimes be apparent in the form of small ripples, but usually it is more random. Another source of noise is primarily found on rooftops. Here, metal roofing facing into the sun simply cause exposures to fall outside of what was recordable by the camera in JPG mode, thus point density is greatly reduced and sensor noise is more likely to be interpreted as real, causing lumpy or spiky roofs. The majority of the considerable time we spent photo processing was to manually edit rooftops for best exposure. Overall the roofs came out fine, but there are many ugly ones, though mostly all within spec. In nearly all case however, there is enough real information (eg, ridgelines, edges) that someone could reconstruct an accurate 3D model by hand for each roof, if that were desired.

The only true errors we found in the delivered village data were at Tuntutuliak, where low cloud cover interfered with acquisitions. We attempted to acquire Tunt on two days, with the same problems each day. As it stands, the affected area is less than 10% of the DCRA outline.

More Information

For more information about these acquisitions, please visit the Latest News section of our website for the period July 31 – August 11: http://fairbanksfodar.com/fodar-news .

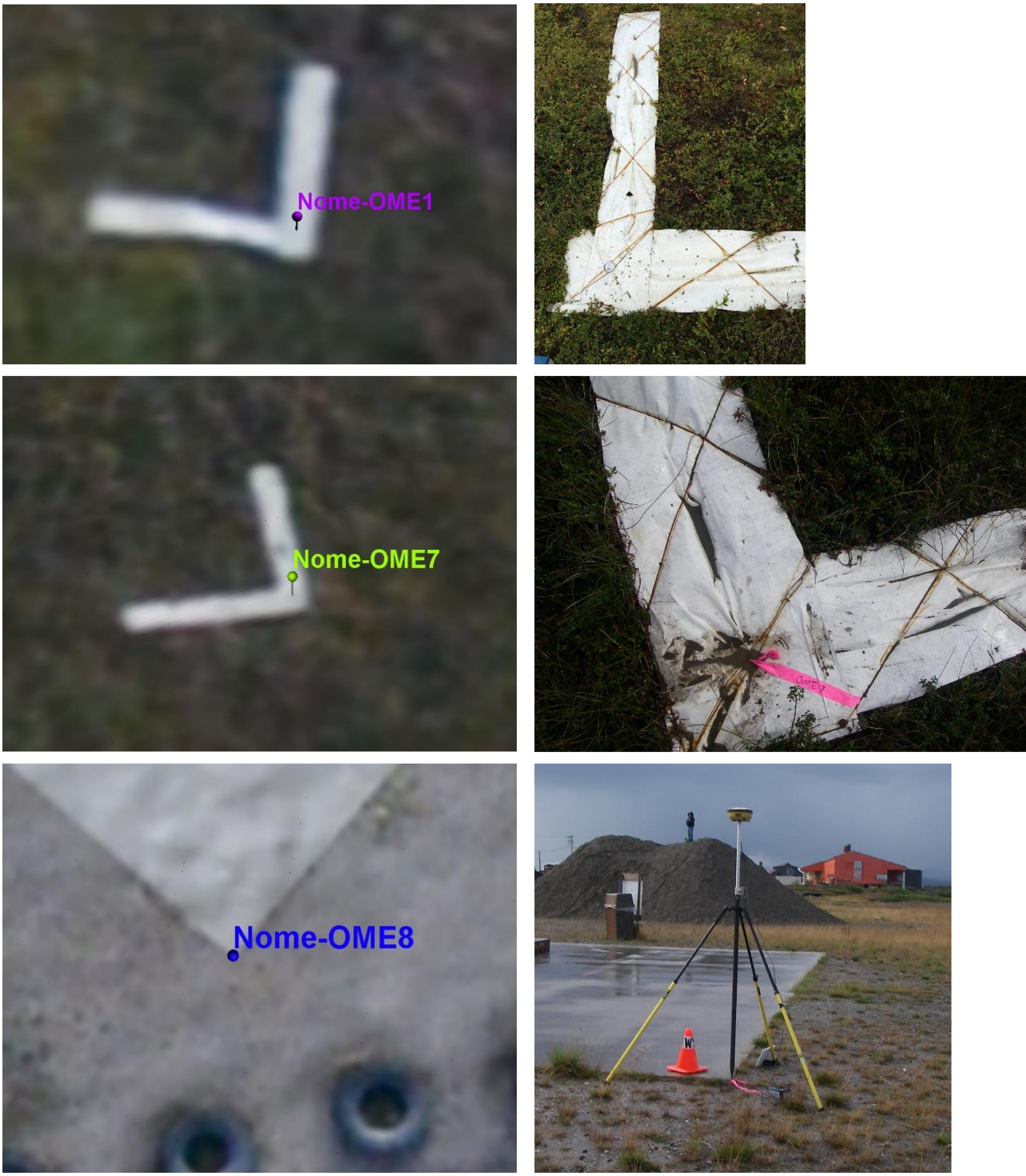


Figure A1. GCP comparison at Nome. At left is are the GCPs overlaid onto our orthoimage and at right is a photograph taken by the survey contractor in the field. Here it can be seen that the horizontal alignment of the data is essentially perfect. This quality was the same for all 29 villages.

A.

B.

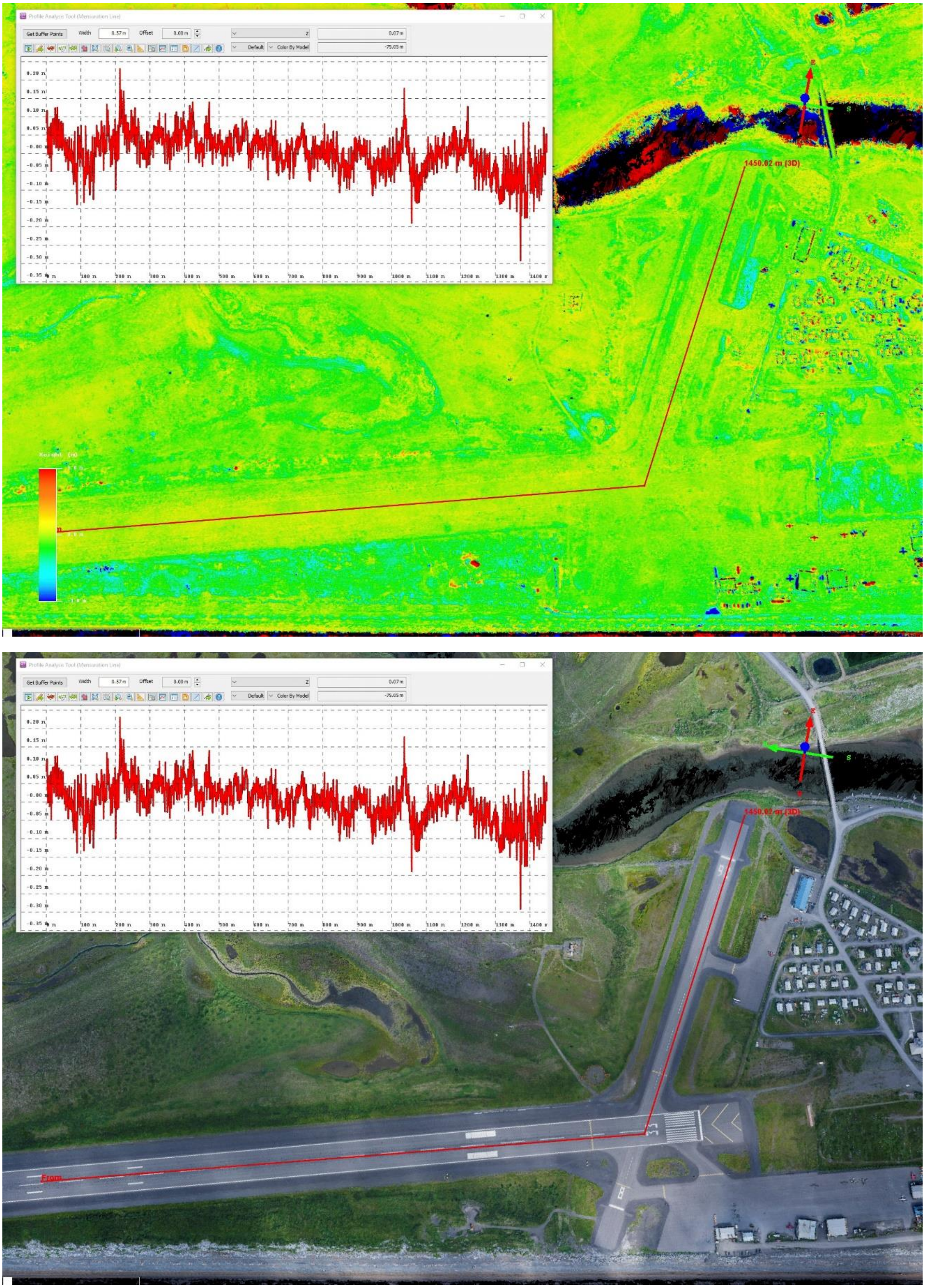
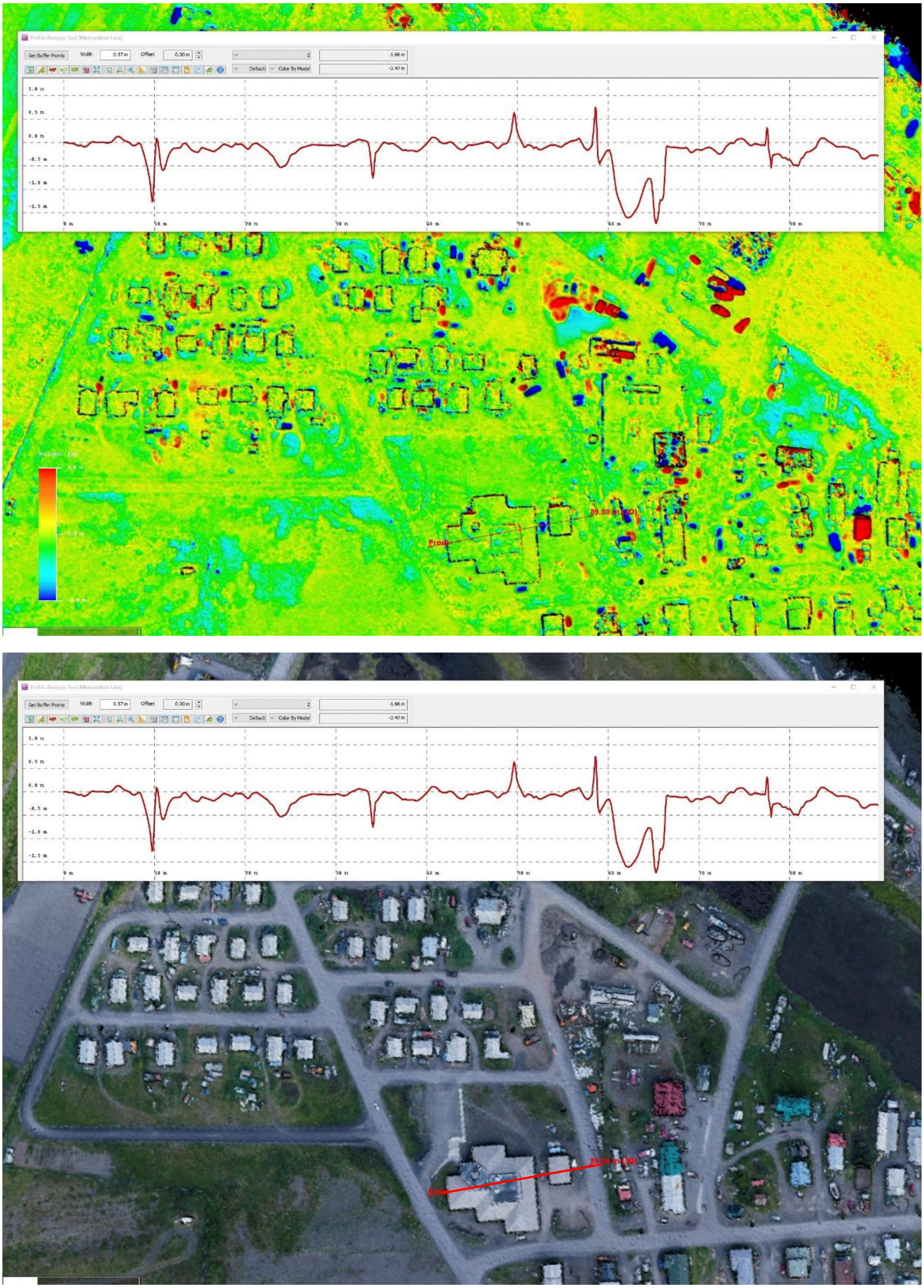


Figure A2 A-B. We subtracted our September 2014 DEM of Unalakleet from our July 2015 one, and colored the results in A. Here the green-yellow transition is no change. As seen in the profile spanning both runways, nearly all of the difference is within +/- 10 cm (vertical ticks are 5 cm). Not all of this difference is noise, some of the longer wavelength variations are motion of the runway itself.

C.

D.



FigureA 2 C-D. Another comparison of 2014-2015 Unalakleet data, as in A-B. Here a transect (50 cm vertical ticks) is run across the complex roof of the clinic, which shows no horizontal offsets and a vertical change of essentially zero, as expected. Small spikes are at the edges of the buildings, with amplitudes of only ~1 m, which is excellent considering the spatial biasing such edges cause. The ~1.5 m excursion on the right side of the clinic is caused by a parked car having moved. Careful examination of the difference image reveals moved boats, cars, snow machines, and small buildings, as well as gravel extraction.

Ground Control Data for
Aerial Survey of Western Alaska

FINAL PRODUCT REPORT

State of Alaska
Department of Natural Resources

ASP #10-15-047

October 15, 2015

RECON LLC
481 W. Arctic Ave.
Palmer, AK 99645

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INTRODUCTION

This final project report has been produced by RECON LLC (RECON) for the Alaska Department of Natural Resources (DNR) under project contract ASP 10-15-047, providing Ground Control Data for Aerial Survey of Western Alaska.

1.0 PROJECT OVERVIEW

RECON's scope of work under ASP 10-15-047 is to obtain an accurate and useful database of ground control points (GCPs) along the western coastline of Alaska, according to the criteria described in the project contract. DNR's Division of Geological & Geophysical Surveys (DGGS) intends to use this network of GCPs, including check points and benchmark ties, to verify the accuracy and quality of coastal orthoimagery and topographic data to be acquired by DNR in 2015. DNR's overall goal in the acquisition of these data is to improve the ability to orthorectify future products of aerial imaging to be acquired in Alaska's coastal regions, which products may be used as resources for conducting critical tasks such as emergency support, community planning, and environmental monitoring along the coast and within coastal communities. The project's area of interest (AOI) follows approximately 3,500 km of Alaska's western coast from Bering Strait to Kuskokwim Bay (see Appendix A – Map of Area of Interest). DNR has contracted with Fairbanks Fodar to provide aerial imagery products immediately related to this control survey, using structure-from-motion (SfM) technology.

The Final Point Summary included in the Final Products should be used for final control and orthorectification of aerial imagery products and for publication as DNR sees fit.

2.0 PROJECT METHODOLOGY

RECON's general methodology has been developed over time to support several successful surveying and mapping projects involving a variety of traditional remote sensing technologies. This survey methodology and GCP selection criteria have been adapted to suit the particular needs of the DNR ground control project scope and to meet the project specifications as defined by the contract. All survey work supporting this project was performed directly by or under the supervision of a Professional Land Surveyor registered in the State of Alaska. RECON subcontracted with Hattenburg Dilley & Linnell, LLC (HDL), and JOA Surveys, LLC (JOA), to assemble a strong and experienced survey team to complete the project within DNR's specified timeframe.

2.1 Project Execution Plan

RECON submitted the official Project Execution Plan to DNR on 11 August 2015. The plan was developed in coordination with the DGGS Project Technical Manager, Nicole Kinsman, who reviewed and approved the plan with only two clarifications: 1) ellipsoid height was added as a data item to be provided in the Preliminary Coordinate File, and 2) it was confirmed that sufficient documentation would be provided in the Final Report to identify ground control features.

In general, project methodology conformed to the specifications of the Project Execution Plan as approved. Any subsequent deviations from the methodology have been described in the appropriate section of this Final Report.

2.2 Field Operations

Field work was completed within the expected schedule and with no significant issues. Field activities commenced on 15 August 2015 and concluded on 14 September 2015. Field survey was conducted by three task forces made up of personnel from RECON, HDL, and JOA, as described in the Project Execution Plan:

- Developed Area Sites, Northern Region (Brevig Mission to Unalakleet)
- Developed Area Sites, Southern Region (Saint Michael to Kongiganak)
- Remote Sites, Entire Region

Logistics of accommodations, fuel supply, and other resources were organized in advance by RECON staff. Major support hubs included Bethel, St Mary's, Unalakleet, and Nome, as expected. In the interest of community outreach, RECON developed a brief written description of the project goals and basic methodology, which permitting staff used in their advance communications with landowners and which field personnel distributed as needed while traveling throughout the AOI.

Personnel working in the developed areas used a combination of scheduled air travel and chartered fixed-wing travel to reach survey sites. Personnel working in the remote sites used a light helicopter to reach survey sites. This approach worked very well, and field personnel and pilots paid close attention to active weather patterns in their respective region, focusing each day's work in the area where weather-related delays were least likely to impact progress.

2.3 Survey Procedure

Field personnel surveyed 67 photo-identifiable GCPs along the coast, with at least one GCP in each of the 25 developed areas identified in the contract. A total of 81 check points (including GCP bases) were surveyed throughout the AOI, including at least 2 within 5 km of each of the 25 developed areas. A total of 27 GNSS ties to tidal benchmarks were surveyed. Ties were made to three or more existing tidal benchmarks in Lost River, Elim, Hooper Bay, Nome, Toksook Bay, Shaktoolik, and Nunam Iqua. Ties were made to two existing tidal benchmarks in Teller and Unalakleet, because only two tidal benchmarks were suitable for GPS occupations. Positioning was tied to CORS stations as outlined in Section 3.0 (Data Processing). Maps of the general location of GCPs are included with the final deliverables. All in all, the total number of points surveyed was more than the project contract required.

All GCPs surveyed under this contract were spaced in intervals no greater than 50 km. It may be worth noting that the northernmost GCP in RECON's project scope was located at the area of Lost River, taking advantage of the opportunity to acquire GPS at additional existing tide stations there. RECON understands that DGGS intended to survey a GCP in Wales, in support of similar project goals but independent of RECON's project scope. RECON estimates that the GCP at Lost River is approximately 49.6 km (straight-line distance) from the approximate village center at Wales, so depending on where the DGGS GCP is located, the interval between those two points may be slightly greater than 50 km.

RECON discussed survey methodology with Fairbanks Fodar and made every effort to define our GCP site criteria in a way that complemented their data acquisition plan using SfM technology. In any cases of uncertainty, RECON employed the method that would best reflect the intent of DNR's scope and specifications as defined in the project contract for the ground control survey.

2.3.1 Selection of Photo-Identifiable GCPs

Community-based GCPs were used as often as possible. Site selection efforts utilized existing imagery and topographic data to locate GCPs within villages, focusing on photo-identifiable locations at or near airstrips, schools, or DOT facilities in the communities. Examples of these photo-identifiable points include: historical photo panels, sidewalk corners, asphalt and concrete aprons, basketball courts, boardwalks, concrete transformer bases, etc. A permanent survey monument appropriate for the site conditions was set as required.

For GCPs in remote areas between communities, RECON selected sites based on image and topographic interpretation of historic beach ridges above debris line, "high" points in the Yukon-Kuskokwim Delta region, and rock outcrops in the northern region. In the Yukon-Kuskokwim Delta region, RECON's strategy was to gain an aerial view and identify "micro-features." Where no photo-identifiable points exist, RECON field surveyors set a permanent survey mark with a 40 cm x 40 cm aluminum plate appropriate for site conditions. Some plates remain as permanent monuments, and some were removed at the conclusion of the field season when requested by the landowner. Due to the necessity of establishing new photo-identifiable features (such as aluminum plates) in especially remote areas, RECON periodically informed Fairbanks Fodar of the field survey progress in an effort to coordinate the SfM data acquisition with the actions of the field surveyors.

GCPs will be identifiable from aerial or satellite photos with ground sampling distances between 0.2 m and 1.0 m. All permanent survey marks were marked with the project identifier (WAK015) and GCP code. All GCPs were documented with photos as described in Section 2.3.2, and all remote GCPs were further documented with a low-level oblique photo and field sketches to aid in imagery identification.

2.3.2 Data Acquisition

Project data were collected using dual-frequency static GPS receivers. At each GCP or GCP base, a single point was selected as the primary control station. This primary control station had a minimum of two 4-hour sessions of data collected. In cases where a permanent monument was not able to be set or was impractical to set at the GCP, a GCP base monument was set and the GCP was surveyed with RTK or fast-static sessions. When possible, the GCP and tidal benchmarks were occupied in two 4-hour sessions on each mark, with longer sessions if conditions allowed. Occupations used a combination of fixed-height tripods or tripods and rods with bipods, with each occupation at a different height than was used previously at the same point when not using a fixed-height rod. The height of the antenna was measured vertically from the survey mark or geographical feature to the bottom of the antenna. Data was collected at 15-second epochs at all occupations. Check points were acquired using static, real-time-kinematic (RTK), or fast-static techniques collected at the beginning and ending of GCP or GCP base occupation.

At each GCP, GCP base, or tidal benchmark session, the observer completed a GPS field form citing the name of the point, the antenna height, the measurement point, start time, stop time, antenna type, personnel, a site description, and a site sketch. These Field Survey Forms were developed by and are owned by JOA Surveys. In addition, the observer obtained detailed photographs of the point surveyed, including the following views: from standing height, horizontal image(s) showing the tripod relative to the vicinity, the antenna model, the antenna height, and a legible sign identifier of each set monument.

2.3.3 Equipment and Software

Project data were collected using dual-frequency static GPS receivers. Processing methods and software are described in Section 3.0.

The following equipment models were used by field surveyors:

- Leica: 1200, GS10, GS14, GS15
- CHC: OPUS X90-D
- Topcon: Hiper II, Hiper V2

2.3.4 Spatial Reference Framework

RECON complied with the spatial reference framework established in the contract, using the following specifications:

- Vertical Datum: NAVD 88, using the GEOID 12B model
- Horizontal Datum: NAD 83 (2011) epoch 2010.00
- Projection: UTM (zones 3, 4 within AOI)
- Units: Meters

3.0 DATA PROCESSING

GPS observations were processed using OPUS Projects, the latest GPS processing software from the National Geodetic Survey (NGS). OPUS Projects is a web-based online processor, so the user is not responsible for any software installation, maintenance, setup, and dependencies, and this reduces the likelihood of processing inconsistencies or errors. OPUS Projects uses the latest NGS PAGES baseline processing software which is required for publication by the NGS. The trained user sets up a project and assigns the project a code, which is used by the field crews to upload static GPS observations to the appropriate project. For this project in western Alaska, the field crews populated OPUS Projects with their data using the code WAK015.

The processing approach was based on Dr. Gerald L. Mader's approach of relative positioning with HUB and Distant CORS. Dr. Mader recommends a maximum baseline length of 100km from the hub to the furthest point in the network, but a 100km baseline length in western Alaska would require the installation of dozens of base stations in remote locations with limited accessibility. To make this project viable, the Data Manager extended the baseline length to 150km as stated in the Project Execution Plan. Due to a gap in the Yukon-Kuskokwim Delta region, the existing CORS network does not provide coverage for baseline lengths of <150 km throughout the entire project area, and this gap was filled for the purposes of this project by installing a temporary GNSS base station in Emmonak. The base station consisted of a GNSS antenna mounted to a building roof. The antenna and receiver were connected to a laptop via USB and serial adapter cable. The receiver logged data every 30 seconds and wrote a data file every 24 hours to an FTP server. The Distant CORS is one which is more than 1000 km from the HUB CORS. The use of a Distant CORS helps to stabilize the tropospheric corrections. Long observations (>24 hrs) reduced mutual visibility issues at the two CORS. The HUB CORS provided the relative positioning.

Initially, the entire project was conceptualized as a single GPS processing project. However, the three task forces in the field did not observe GPS simultaneously in the same 150km region due to a number of logistical factors and project needs. The resulting baseline sessions would not allow for a single hub processing schema. Processing was initially conducted by carefully selecting observations within 150km of a CORS, and then processing other points for the same session in a different processing scenario, but this method was troublesome due to the volume of data and the multitudes of sessions. As a productive solution, the single project in OPUS was translated into six smaller projects, each with points within a 150km radius of the nearest CORS or the base in Emmonak. The respective GPS observations were uploaded to each of the six projects for processing as originally anticipated.

Prior to baseline processing, either IGS station WHIT in Whitehorse, Yukon Territory, or IGS station FAIR in Fairbanks, Alaska, was brought into each project to better resolve the tropospheric conditions. Data was processed in a radial method, with the nearest CORS being the only hub station. The exception is the base station installed at Emmonak. All of the remaining CORS plus the IGS station were included in the processing. Piecewise continuous tropospheric models were used in the processing.

OPUS Projects has defaults of 0.020m peak-to-peak horizontally and 0.040m vertically. This threshold had to be increased to 0.035m horizontally, while the vertical threshold remained the same. OPUS Projects also has defaults of 80% of the observations and 80% of the fixed integers, both of which had to be reduced to 70%, the minimums for OPUS Shared. All stations met the modified minimums with the exception of OME5, which used 63.8% of the observations in the processing.

When processing was complete for each of the six projects, adjustments were performed using GPSCOM, a Helmert blocking program within OPUS Projects. A free adjustment was first made constraining only the nearest CORS. A constrained adjustment was then performed constraining all CORS positions. No vertical constraints were applied as none of the stations observed were vertical marks. A TIGHT constraint was applied to all CORS, as NGS currently is having problems with the NORMAL constraint. With the TIGHT constraint, the CORS are fixed at the sub-millimeter level of their published positions. All adjustments came out favorably, with millimeter-level correction to the positions.

3.1 Quality Control

All field personnel adhered to the methodology and field procedures listed in the Project Execution Plan. The Lead Surveyor and Survey Manager held conferences with field personnel prior to mobilization to discuss and clarify methodology, and each team member had opportunities to review the document. The field techniques followed NGS Technical Memorandum 58: Guidelines for Establishing GPS Derived Ellipsoid Heights (Standards: 2 cm and 5 cm). Predetermined point and file naming conventions along with form, photo, and field book structure were defined prior to survey and were followed by all field personnel.

4.0 DELIVERABLES

Items deliverable to DNR were completed according to the schedule and specifications defined in the signed contract. All items were delivered in soft copy (digital) format, with hard copies of reports available upon request.

- **Project Execution Plan**: 11 August 2015
- **Monthly Reports**: 31 August 2015, 30 September 2015, and 15 October 2015
- **Preliminary Coordinate File**: 30 September 2015
- **Final Products**: 15 October 2015

The Final Point Summary included in the Final Products should be used for final control and orthorectification of aerial imagery products and for publication as DNR sees fit.

4.1 Final Product Deliverables

This report document is delivered with several attachments in fulfillment of the contract requirements. Following is a list of deliverables as organized by RECON and provided in digital folders.

1. Report – description of the completed project, survey methodology, and data processing
2. Data Dictionary – outline of data delivered and file naming scheme
3. Digital Photos – record photographs of survey sites (as described in Section 2.3.2)
4. RINEX Files – survey data files
5. Field Notes – PDF scans of original field notebooks (as described in Section 2.3.2)
6. Location Maps – reference maps of as-surveyed points
7. Processing Summary – summary of processing information
8. Final Point Summary – XLS file of final point locations for GCPs, check points, and tidal bench marks

SUMMARY

RECON appreciates the opportunity to provide ground control surveying services to the Alaska Department of Natural Resources. With any comments on this report or the overall project, please contact Megan Ross at 907-746-3630 or megan@reconllc.net.