**Contract 10-15-053**

# Progress Report:

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**Submitted to**

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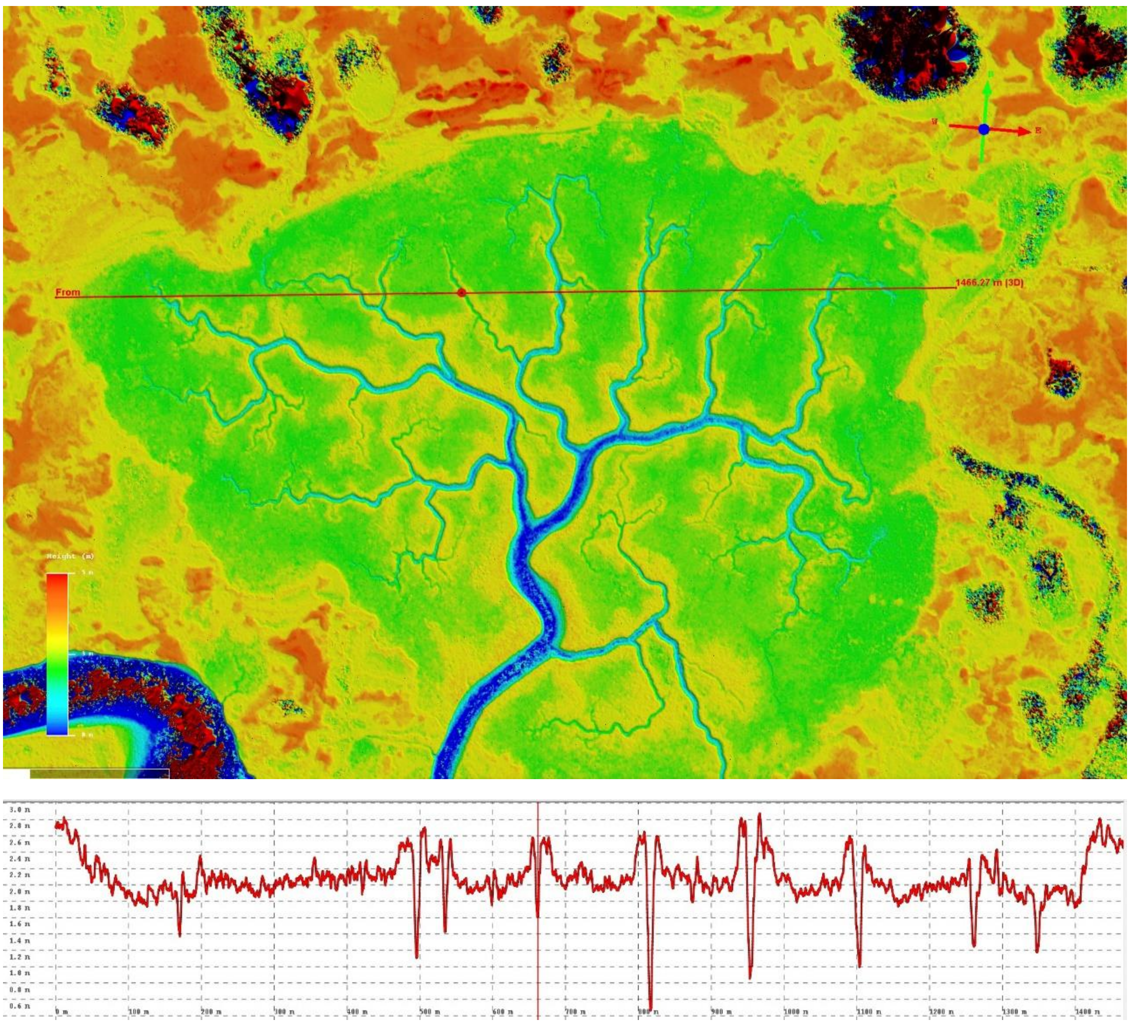


*Topography of a drained lake near Kwigillingok*

Submitted by

# Fairbanks Fodar

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## Executive Summary

This month we finished processing DEMs and orthoimages for all 29 villages from Wales to Bethel and are now prepared to deliver the data. To accomplish this, we 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 have provided more than double the area specified 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, but we have not performed our final vertical adjustment as we will wait until all coastal data are processed and we have all other GCPs to do a final network adjustment. For example, the 5 vertical GCPs acquired in Wales had a mean residual of 4 cm and total range of +/7 cm, so here if we applied a 4 cm vertical shift to the data, our vertical accuracy would reduce to the precision level of < +/- 7 cm. All villages where multiple GCPs were acquired show a precision level +/- 10 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). Thus we anticipate the final data will have a near-perfect horizontal accuracy and a vertical accuracy of better than +/- 15 cm. This report gives a brief overview of our processing methods and data quality checks, including text for the metadata template provided by DGGS. This report is not the final report for these data, though here we seek comments as to what other information should be included in that report so that we can finalize and submit it.

## Introduction

Since returning from the field in mid-September, we have been focusing on processing and delivering the village data. 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. The villages are shown in Table 1, along with various parameters related to specifications. Screenshots of the DEM and orthomosaic for each village are shown in Appendix 1.

As can be seen, 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 overdelivery. The majority of the bonus area comes from extending flight lines beyond the DCRA boundary to ensure complete coverage of it, and rather than crop those extra data out we have provided them at no additional charge. 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). Note that some of this extra area within the current village files would have also been delivered as part of the coastal data but in terms of our overdelivery estimate this duplication is likely offset in part or whole by the fact that the DCRA areas contain a lot of open water; we did not attempt to sort that out and don't consider this statistic rigorous, it is meant simply to demonstrate our commitment to providing the best product possible. 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.

| | Spec | Actual | DEM Post | DCRA Area | Delivered Area | Overdelivery | Overdelivery | Acquisition |
|---|---|---|---|---|---|---|---|---|
| **Village** | **GSD (cm)** | **GSD (cm)** | **(cm)** | **(km2)** | **(km2)** | **(Area, %)** | **(Pixels, %)** | **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 1. 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.

Not only has the data exceeded the geometric specifications above, but it also has exceeded the specs for accuracy and precision. Table 2 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, but is within a single pixel. When future maps are compared to these maps, subpixel alignment can be calculated algorithmically for further improvement. It would take a very carefully planned GCPs to use for subpixel alignment when pixels are only 10-20 cm wide. The vertical accuracy was within spec and within our expectations from prior work. Note that shown here is our directly georeferenced accuracy –

| | | | Residuals | |
|---|---|---|---|---|
| **Village** | **GCP Name** | **Easting** | **Northing** | **Vertical** |
| **Wales** | A | 0 | 0 | -0.032 |
| **Wales** | C | 0 | 0 | -0.003 |
| **Wales** | D | 0 | 0 | 0.030 |
| **Wales** | G | 0 | 0 | -0.113 |
| **Wales** | I | 0 | 0 | -0.070 |
| **Brevig Mission** | KTS2 | 0 | 0 | -0.060 |
| **Brevig Mission** | KTS3 | 0 | 0 | 0.280 |
| **Brevig Mission** | KTS5 | 0 | 0 | -0.160 |
| **Brevig Mission** | KTS7 | 0 | 0 | -0.290 |
| **Teller** | TER1 | 0 | 0 | 0.210 |
| **Koyuk** | KKA2 | 0 | 0 | 0.780 |
| **Koyuk** | KKA5 | 0 | 0 | 0.820 |
| **Elim** | ELI8 | 0 | 0 | -0.170 |
| **Elim** | ELI6 | 0 | 0 | -0.160 |
| **Elim** | ELI5 | 0 | 0 | -0.080 |
| **Golovin** | GLV2 | 0 | 0 | 0.170 |
| **Golovin** | GLV1 | 0 | 0 | 0.160 |
| **Nome** | OME1 | 0 | 0 | 0.210 |
| **Nome** | OME8 | 0 | 0 | 0.250 |
| **Nome** | OME7 | 0 | 0 | 0.130 |
| **Shaktoolik** | SKK5 | 0 | 0 | -0.290 |
| **Shaktoolik** | SKK7 | 0 | 0 | -0.120 |
| **Unalakleet** | UNK1 | 0 | 0 | 0.210 |
| **Unalakleet** | UNK6 | 0 | 0 | 0.300 |
| **Stebbins** | WBBA | 0 | 0 | -0.140 |
| **Saint Michael** | SMKA | 0 | 0 | -0.170 |
| **Kotlik** | 2A9B | 0 | 0 | 0.400 |
| **Emmonak** | EMNC | 0 | 0 | 0.430 |
| **Nunam Iqua** | SXPB | 0 | 0 | 0.320 |
| **Scammon Bay** | SCMC | 0 | 0 | 0.440 |
| **Chevak** | VAKB | 0 | 0 | 0.290 |
| **Hooper Bay** | HPBA | 0 | 0 | 0.380 |
| **Newtok** | EWUB | 0 | 0 | 0.370 |
| **Tununak** | 4KAA | 0 | 0 | -0.100 |
| **Toksook Bay** | OOKB | 0 | 0 | 0.130 |
| **Nightmute** | IGTB | 0 | 0 | 0.070 |
| **Chefornak** | CFKB | 0 | 0 | 0.210 |
| **Kongiganak** | DUYB | 0 | 0 | 0.190 |
| **Kipnuk** | IIKB | 0 | 0 | 0.210 |
| **Kwigillingok** | GGVB | 0 | 0 | 0.420 |

**Table 2. GCP Comparisons.** The horizontal accuracy of our maps was perfect, and the directly georeferenced vertical results within spec. Once we have all data sources available, the vertical residuals seen here will reduce to near zero and the accuracy will approach the precision level. The precision level can be roughly assessed here by looking at the scatter within a single village about its mean, or about +/- 10 cm.

once we have the full set of GCPs as well as the coastal data processed, we will use these data to reduce the residual offsets to near zero mean. At this point, accuracy reduces to the precision level, which prior studies have shown to be < +/- 15 cm. Here we found that at all villages where we had multiple GCPs, the scatter about the mean residual for those comparisons was also within 10 cm. Further, we compared our 2015 Unalakleet DEM to our 2014 Unalakleet DEM. The results are shown in Figure 1. 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, except in the rivers and some sections of the upper boundary which are water or edge noise. Thus these results, combined with our prior research on technique validation, indicate that our final accuracy will be well within spec and result in an excellent baseline for documenting future change.

We did not apply any vertical shifts to the delivered village data because we felt it would be best to do this only once, and that that the adjustment should include all possible contributing information. This includes additional GCPs and the coastal data. For a vertical shift to be reliable, there should be enough GCPs to produce a meaningful and statistical mean offset. With the list above, only Wales and Brevig Mission really qualify. The issue is that if only a single GCP is used and the associated DEM pixels happens to fall towards the edge or outside of the 95% precision level, all of the data will be made worse by shifting by that particular residual. Further, many of these GCPs are not suitable for vertical comparisons. Appendix 2 compares photographs of each GCP with a 3D oblique comparison of fodar data. As can be seen, many of these GCPs were taken on the edge of boardwalks or utility boxes, and such edge features cause spatial biasing in the fodar data. This may be what is causing the largest offset, at Koyuk, but we have not yet investigated this thoroughly.

## Data Processing: Metadata Description

This section contains text in the form of the metadata template provided to us. Please provide comments as to any additional detail required.

**A. How was the data set created?**

**1. From what previous works were the data drawn.**

*The technique is fully described in this paper, along with substantial validation data:*

*Nolan, M., Larsen, C., and Sturm, M.: Mapping snow-depth from manned-aircraft on landscape scales at centimeter resolution using Structure-from-Motion photogrammetry, The Cryosphere Discussions, 9, 333-381, 2015b.*

*These papers contain additional validation data:*

*Gibbs, A., Nolan, M., and Richmond, B.: Evaluating changes to Arctic coastal bluffs using repeat aerial photography and Structure-from-Motion elevation models in: Coastal Sediments 2015, World Scientific, 2015.*

*Kinsman, N., Gibbs, A., and Nolan, M.: Evaluation of vector coastline features extracted from 'Structure-from-Motion' derived elevation data, in: Coastal Sediments 2015, World Scientific, 2015.*

*Nolan, M., and DesLauriers, K.: Which are the tallest peaks in the US Arctic? Fodar settles the debate., The Cryosphere, Submitted, 2015a.*

**2. How were the data generated, processed, and modified?**

*Acquisition. The data were acquired using a Cessna 170B flown by Nolan, with no separate equipment operator. Village flight lines were pre-planned to be acquired at 17 cm or 10 cm GSD, depending on village. Some villages were flown at lower altitudes to accommodate clouds. Flying heights ranged from 800' to 2700'. Exposures were adjusted in the air to suit environmental conditions. A Nikon D800E with 24 mm Nikkor f/1.4 lens was used for all acquisitions. Data were acquired on 22 mission days from 31 July to 11 September 2015.*

*GPS Processing. GPS data were acquired by a Trimble 5700 with roof-mounted antenna. Data were processed using Waypoint's Grafnav commercial GNNS software. Many daily flights were more than 100 km from a CORS location. Each project was processed using both the PPK and PPP methods and the results evaluated to see which was superior, primarily by examining the difference between forward and reverse solutions, and the better one selected. Except for occasional spikes, all flights resulted in data with better than 10 cm separation in forward and reverse trajectory solutions. GPS data were processed to NAD83(2011) NGVD88 GEOID12A.*

*Photo Processing. More than 50,000 photos were individually processed for optimum contrast and exposure using Adobe's Camera Raw. To accommodate the large data acquisition volumes, most photos were shot as JPG and the subsequent processing also resulted in JPG format. Photo quality was in general fine, especially considering that many were taken just beneath a low, thick overcast or in the rain.*

*Photogrammetric Processing. The GPS and photo data were processed within Agisoft's Photoscan to create the required DEMs and Orthomosaics. The data were output as GeoTiffs with appropriate headers. As described below, all data came out within spec as directly georeferenced results. Additional detail on workflow is described in the report.*

**B. How reliable are the data; what problems remain in the data set?**

**1. How well have observations been checked?**

*All data were examined visually in an interactive 3D environment to ensure data quality. No misalignments between orthoimage and DEMs were found down to the subpixel level, and all visual inspections revealed no problems or anomalies that were not expected. Specifically, water bodies have a large, spiky noise associated with them, but this was expected and will be dealt with through manual* *editing later. All beaches showed vertical elevations of 0-2 m, which is within the range of the geoid errors, and were flat, with no spatial correlated errors such as warps or tilts.*

**2. How accurate are the geographic locations?**

*At all except three villages, DGGS provided us photo-identifiable GCPs taken in fall 2015 by another contractor. We examined each of these GCPs and could find no horizontal offsets at any location. That is, the spatial accuracy of these fodar maps is subpixel, or < 15 cm. Thus no manual shifts of the data were applied horizontally as none could be determined. In the future, when comparing these maps to newer fodar maps, image processing could be used to create a subpixel alignment that might benefit change-detection analyses.*

**3. How accurate are the heights or depths?**

*Previous work in flat terrain like this demonstrated a vertical accuracy of +/- 30 cm (95% RMSE) for the directly georeferenced product. Comparison to 38 GCPs provided by the State across 27 of the villages, the delivered DEMs showed a mean residual of 10 cm with +/- 44 cm (95% RMSE) scatter, about the same as our prior research and within spec for the project. Many of these points were acquired on the edges of boardwalks or utility boxes, so their quality for this purpose is not high. Using the 5 vertical GCPs provided from Wales, the mean residual was -4 cm with all points within 7 cm of that. We differenced the Unalakleet DEM of this delivery to a similar DEM we made in 2014 and found that most stable points ($n>10^7$) were within +/- 10 cm, as described in more detail in the report. Once we have all GCP for the villages, their mean residuals from the directly georeferenced DEM will be reduced to near zero, resulting in an accuracy at the precision level of ~+/- 10 cm.*

**4. Where are the gaps in the data? What is missing?**

*We compared each village delivery to the DCRA village shapefile boundaries and found that only Brevig Mission was missing a small corner. However, the data exist here but were accidentally not processed; this will be corrected when we deliver the coastal data for the area. Tuntutuliak had some cloud cover that affect DEM accuracy over <10 % of the DCRA boundary; we have some images from a different day that we will try to substitute to improve quality there.*

**5. How consistent are the relationships among the observations, including topology?**

*With the exception of Stebbins/St Michael and Teller/Brevig Misison, the villages are not contiguous. When the intervening coastlines are processed, we will compare these DEMs to the villages and make a final network adjustment if required. Given the close correspondence to the GCP data to our directly georeferenced DEMs and the perfect horizontal alignment, there is unlikely to be any inconsistency beyond 20 cm between villages. That is, the uncertainty in the geoid will likely be a larger source of vertical error than the fodar data itself.*

## Data Processing: Workflow Considerations

We spent some time exploring the relationship between GSD, point cloud density, data quality, and the specifications to produce an optimal workflow that balanced data quality and processing time. Here we present our findings in terms of how we processed the data, as well as some recommendations for future contractual specifications that will help ensure these quality standards on other projects.

The primary contractual specification here regarding resolution is Ground Sample Distance (GSD). GSD in the context of photogrammetry is a raster acquisition specification used to base decisions on flying heights and lens selection. The specification was for 20 cm or better for all data, with some villages at 10 cm or better. These specifications were met or exceeded at all village locations, and likely at all other locations though we have not yet confirmed this directly. Because terrain height varies yet our flying heights are typically at a constant altitude, actual GSD varies. We planned our flights to acquire a 17 cm **mean** GSD, such that all pixels would fall below 20 cm GSD, and this seems to have been accomplished. So one parameter to keep in mind is whether the GSD specification is meant as a mean or maximum.

The contract had no specification for point density of the point cloud, and this is probably a good thing. Unlike the orthoimage, the DEMs are not created directly from photo pixels, but rather from a mesh created from the point cloud reduced from those photos. Photogrammetry is a passive technique, where sunshine and natural ground contrast place important controls on final point density. Thus the density of this point cloud will vary based on the natural contrast and lighting, as well as the nature of the surface. Lidar is an active technique, which uses a laser that can be set to sample the ground at a particular rate and thus achieve a particular point density, assuming some things about ground reflectance. So unlike lidar, it is not possible for a photogrammetric operator to control the point density, as there is not a one-to-one relationship between GSD (which can be controlled) and point density (which is controlled largely by nature). That being said, there are various ways point density can be optimized for a given GSD (such as by waiting for the best lighting or other environmental conditions, by using the best optical hardware, by photo processing for optimal contrast, by the amount of endlap and sidelap during acquisitions, and by photogrammetrically processing in different ways). Some of these can perhaps be specified, but some are simply a matter of operate skill, and all need to work well together as a package.

The ultimate question for contracting then becomes what exactly to specify such that the vendor delivers a DEM at a posting that is supported by the underlying point density. That is, posting does not necessarily have anything to do with GSD, as interpolation can create a DEM of any posting regardless of point cloud density. From our analysis, GSD is still probably the best first order control, followed by specifying that the photogrammetric bundle adjustment utilizes an effective GSD of no more than double the acquisition GSD. The most popular SfM software currently is Agisoft's Photoscan (which is what we use), and here this specification would be to process at the "High" mode, which uses 2x2 pixels, and would result in a point cloud with a scale roughly double the GSD. Our experience with processing at the Ultra High level (that is, trying match each single pixel) is that not only do processing times increase 5-8 times (with each village on average taking 3-5 days already at High), but that the software is often unable to find suitable contrast trying to match pixel-to-pixel and often either fails (leaving voids) or amplifies noise. That is, to detect contrast, there must be a contrast boundary, yet not all such boundaries are of the same quality or are even real, especially at the single pixel level. Further, motion artifacts (such as wind blowing through leaves or pixel blur) can result in a lower point density at Ultra

High than High (as motion noise is essentially filtered at larger scales), and the percentage of high quality points is increased in High vs Ultra High as worse ones are filtered out in the former. In our prior work on glaciers and forests, we have always used the High setting for these reasons and similar ones, as it seems to provide the best compromise between data quality and processing speed; however we occasionally still need to fill gaps even at this level using results from the Medium setting. SfM photogrammetry is a rapidly evolving in terms of techniques so these constraints will likely be minimized in the future, but this is where we are currently.

Figure 2 shows some of the thinking that went behind our workflow decisions. Here you can see that the point cloud density is much higher around buildings, due to points along their vertical walls. A GSD of 20 cm would result in a point cloud density of 25 points per square meter (ppsm) (that is, a 20 cm scale), if every pixel resulted in a unique point (ignoring overlap). Here the color scale is set so that the colors represent densities of 25 ppsm or higher. Note that these data were processed on High (which results in a mean point density of about 9 ppsm for 17 cm GSD). Thus objects with sharp vertical boundaries get proportionally better point densities, which is where it is needed most for resolving object boundaries. We find this same increased density around infrastructure at all of the villages we tested. Thus processing at Ultra High has little effect on the DEM quality of buildings since the point density is already sufficient there, though positional accuracy could improve by up to half a pixel, or 5-10 cm. In any case, for resolving building locations for local surveying purposes, the orthoimage (or point cloud) is a better product, as it would take a GSD of 1-2 cm to eliminate spatial biasing caused by building edges.

Thus our workflow was to process all Villages at the High setting in Photoscan. Nominal acquisition GSDs were 17 cm and 9 cm, depending on village. These GSDs resulted in DEMs with natural postings of 18 cm and 34 cm. For villages with the smaller GSD, we exported the DEMs from Photoscan at double that GSD (ie, 18-20 cm) and left them at that resolution. For villages with the larger GSD, we exported the DEMs at 20 cm directly from Photoscan. Thus all of the DEMs have postings of about 17-20 cm, and all make direct use of the increased point density around buildings (that is, not interpolated from another DEM but exported directly from the photogrammetric mesh). We found that DEMs with higher postings than this became quite problematic to work with due to file size, even with our powerful computers.

Note that the quality of orthoimages are essentially unaffected by the choice DEM processing method. Here we orthorectified all of the orthoimages against the DEM created at double their posting. Of more importance than underlying DEM to orthoimage quality is the file handling. Specifically, the best image quality is preserved by not allowing the image to be resampled to change resolution, as this reduces contrast. We therefore processed the orthoimages to the measured GSD and exported it at that level without further resampling to deliver the highest resolution possible. For example, GSD at Newtok was 9.38 cm and we preserved this in the final delivered file. Because 9.38 cm is the mean GSD, there could be appreciably large areas with better GSD, especially for lines that were flown lower due to clouds. However, we did not explore this further and exported each orthomosaic at its measured GSD, noting other possibilities for future reference. The raw photos also often have a bit more detail than is preserved through orthorectification process.

## Data Processing: Blunders

We noticed and corrected several blunders during processing.

The Stebbins and St Michaels block was processed in UTM4, as it lies just on the UTM 3 boundary and the preceding data was in UTM 4. These village data were reprojected in Global Mapper after processing. We have no photo-identifiable GCPs for these villages, but we have no reason to suspect further error here.

Shaktoolik was processed with GPS coordinates processed in WGS84 rather than NAD83(2011), resulting in a ~1.5 offset found with the GCP analysis. These data were reprojected into NAD83 and checked against the GCPs.

Toksook Bay was processed with GPS in ellipsoid heights. Given the short spatial distance and tiny gradient in Geoid heights across it, we used the mean geoid height to correct it (ie., assuming a constant geoid offset for the village).

Chefornak was also processed with GPS in ellipsoid heights. Given the tiny gradient in Geoid heights across it (<2 cm), we used the mean geoid height to correct it.

Perhaps the biggest blunder of all was exporting all geotiffs out of Photoscan with the WGS84 projection. The actual data values were all NAD83 NAVD88 GEOID12A, but the header data erroneously listed them all at WGS84. This error was not caught until after the GCP analysis was nearly complete when the Shaktoolik blunder was caught; that is, since the DEM data and the GCPs were both in the same coordinate system, the GCP analysis was not affected except in the one project that was in the wrong coordinate system. This launched a series of phone calls and emails over the next week with Agisoft and Blue Marble to determine how to create geotiff headers with the correct information. The issues here related primarily to vertical datums. Global Mapper has essentially no vertical datum support, though this is planned. The latest version of Photoscan (released last week) has rudimentary vertical header information, but still requires a custom written .prj file and for this to be forcibly written into the geotiff header externally. We spent quite a bit of time learning the .prj specifications and writing such files, but in the end decided it could introduce errors we cant currently test for and thus decided to leave out any vertical datum information from the headers or .prj files. Thus after the GCP analysis, we re-exported about half of the data from Photoscan to both correct this issue and to improve orthoimage quality, and in the remaining data we fixed the header using Global Mapper (note that this is not a reprojection, but rather editing the header and leaving the data alone). We re-checked about half the GCPs to ensure quality, but note it is likely that 1 or 2 files still have the WGS84 header information (more blunders). Note that the first delivery of villages in September suffered from this issue, so these files should be deleted and replaced by the new ones.

## Data Processing: Errors

Within the DCRA boundaries, we have not found nor do we expect to find any spatially correlated noise that exceeds specs. 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. Often this is noise is 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 DEM. Figure 3 gives some examples of this noise.

While this edge noise does not exist within the DCRA boundaries, it does exist in the over-delivered data. We decided not to crop the data to the boundaries, as we felt there was a lot of useful information contained in the area outside of it. In terms of the orthoimage, it is likely as accurate as the area inside the boundary. The DEMs, however, all suffer edge noise to some degree, so some care should be taken in using it. Generally speaking most of this noise is within spec, but because it is spatially correlated it may lead to results that look real but are not in terms of drainage especially in creation of synthetic hydrological channel maps.

There are several types of spatially uncorrelated noise. The primary one is a base random noise level of about +/- 3 cm. Much of this is likely caused by slight uncertainties within the bundle adjustment as well as difficulties in gridding the DEM. 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. There is potentially yet more tweaking that could be done, but generally the best way to approach this is to shoot in raw mode, but this was simply not possible given the time constraints for acquisitions (much larger files means landing more frequently to change cards). Overall the roofs came out ok, 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. Figure 4 has some examples of roofs.

The only true errors we found in the delivered village data were found in Tuntutuliak, where low cloud cover interfered with acquisitions. We attempted to acquire Tunt on two days, with the same problems each day. We have not yet tried to combine images from both days to find a cloud free set, so this is yet possible. As it stands, the affected area is less than 10% of the DCRA outline.

## Future Steps

We would like to get feedback on this report so that we can add any additional information needed to the final report on the Village data. We would also like feedback on the data itself.

In the next day or two we hope to release a blog post about the data as well as have most or all of the data online in Fodar Earth. If DGGS would like to coordinate some sort of press release regarding the data, we can hold that off a few more days.

Our next priority is to process the coastal data acquired in 2015. Here our thought was to start with the southern data, as this is where the largest gaps are. Knowing where these gaps are is critical to mission planning for 2016. Likely we will also start by creating orthomosaics of the entire southern area using a low resolution DEM (1 -2 m), as this will provide what's needed to determine gaps much more quickly than processing in full to start with. In retrospect, it was probably a mistake to process the village data first, as some duplication of effort is now needed. That is, if data were processed from north to south, villages would have seamlessly blended in the overall network without further adjustment as we processed everything marching down the coast, whether in a village or not. Nonetheless, processing the villages led to some useful insights into processing large jobs and it does provide the State with a complete and robust data set that they can use for most purposes without further adjustments and without waiting for overall project completion.

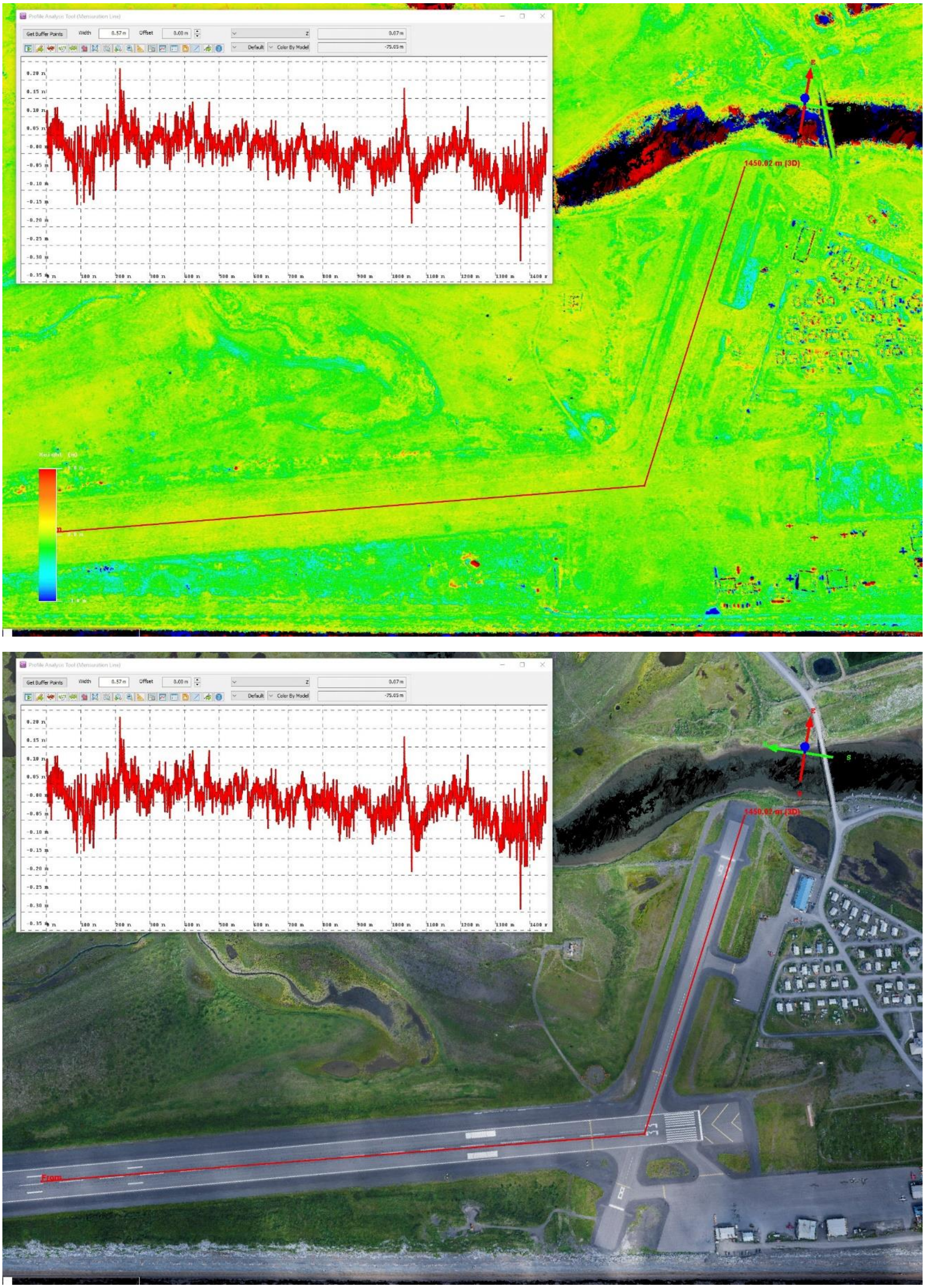


Figure 1 A-B. We subtracted our September 2014 DEM of Unalakleet from our July 2015 one, and colored the results in A. Here the green-yellow transition is no change. As seen in the profile spanning both runways, the nearly all of the difference is within +/- 10 cm. Not all of this is noise, some of the longer wavelength variations are motion of the runway itself.

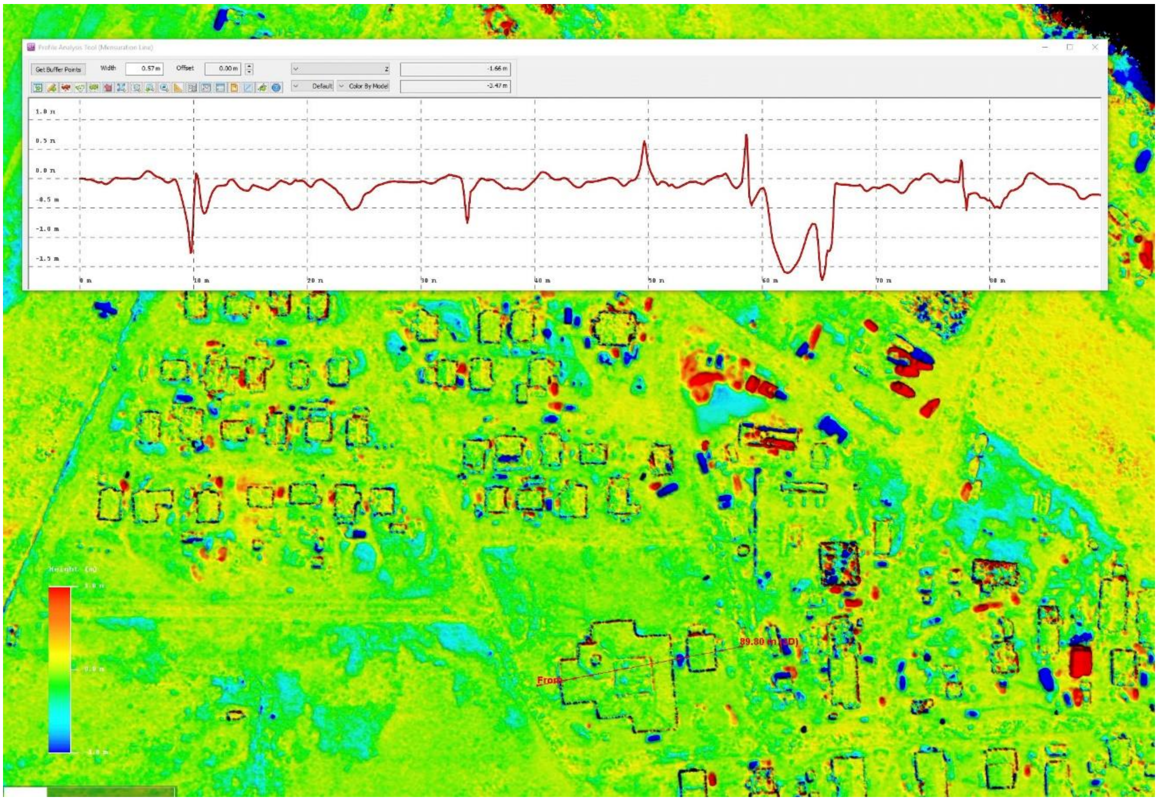


Figure 1 C-D. Another comparison of 2014-2015 Unalakleet data, as in A-B. Here a transect (50 cm vertical ticks) is run across the complex roof of the clinic, which shows no horizontal offsets and a vertical change of essentially zero, as expected. Small spikes are the edges of the buildings, with amplitudes of only ~1 m, which is excellent considering the spatial biasing such edges cause. The ~1.5 m excursion on the right side 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.

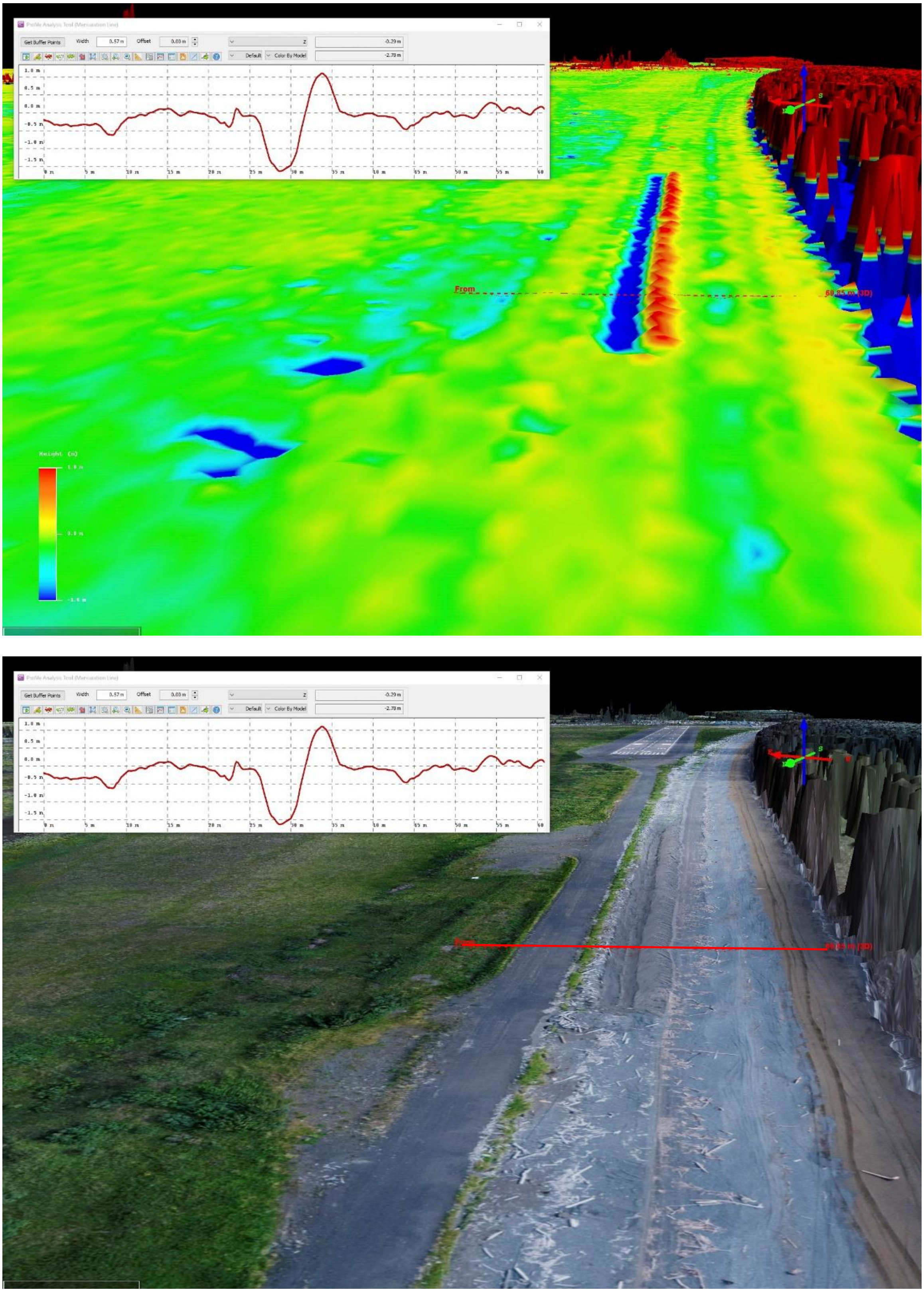



Figure 1 E-F. Another Unalakleet comparison, as previously. Here we can find changes along the beach, which is one of the main goals of acquiring baseline maps like these. Someone has created a long, 1.5 m deep trench, perhaps in an effort to drain the uphill side of the road which is showing signs of thermokarst. More subtle changes can be seen extending up the coastline, caused by wave action.

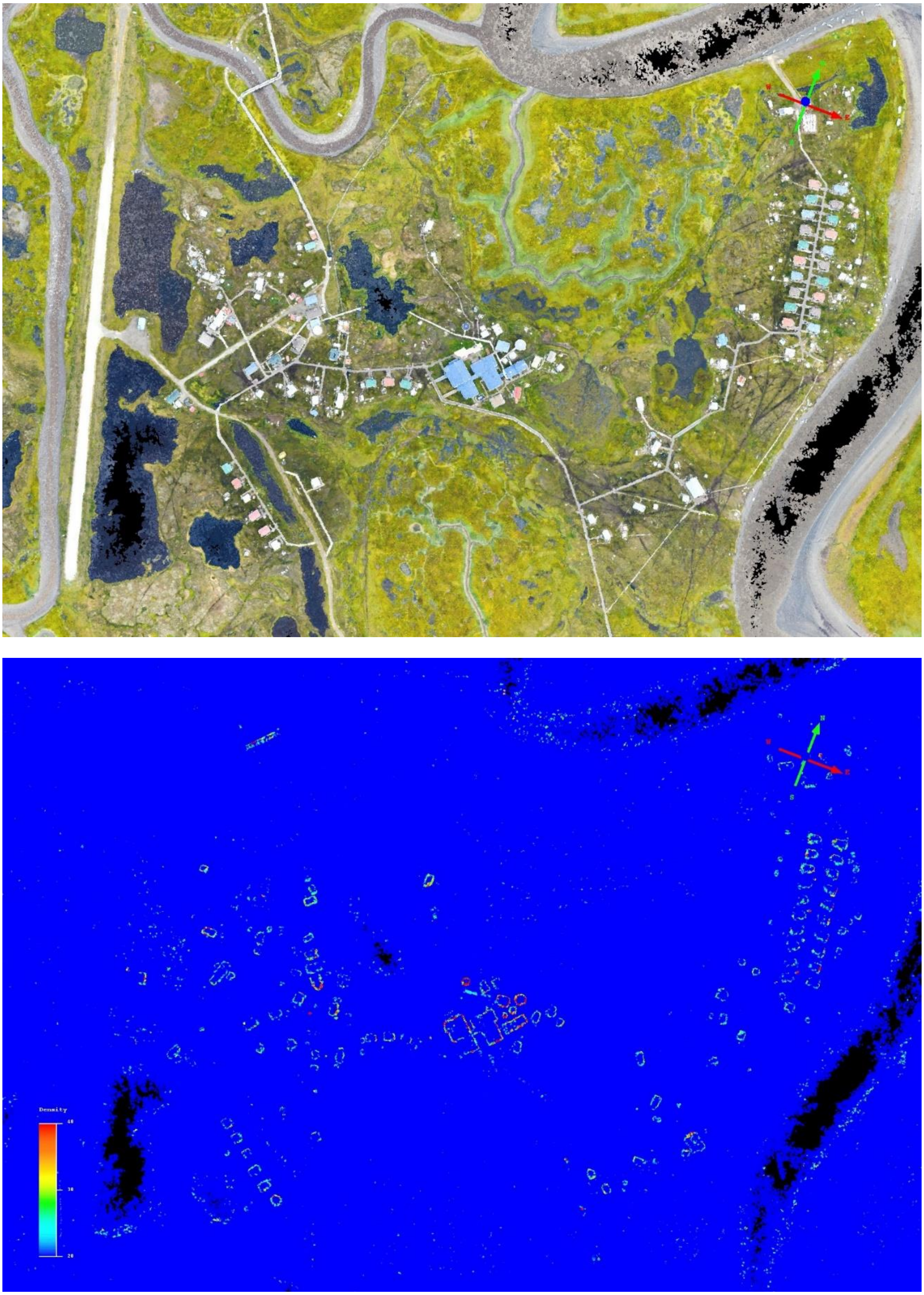


Figure 2 A-B. At top, point cloud of Kwig. At bottom, point density of that cloud, ranging from 20 (blue) to 40 (red). Note that all building walls have a point density of 25 ppsm or higher, which averaged out would be a point every 20 cm.

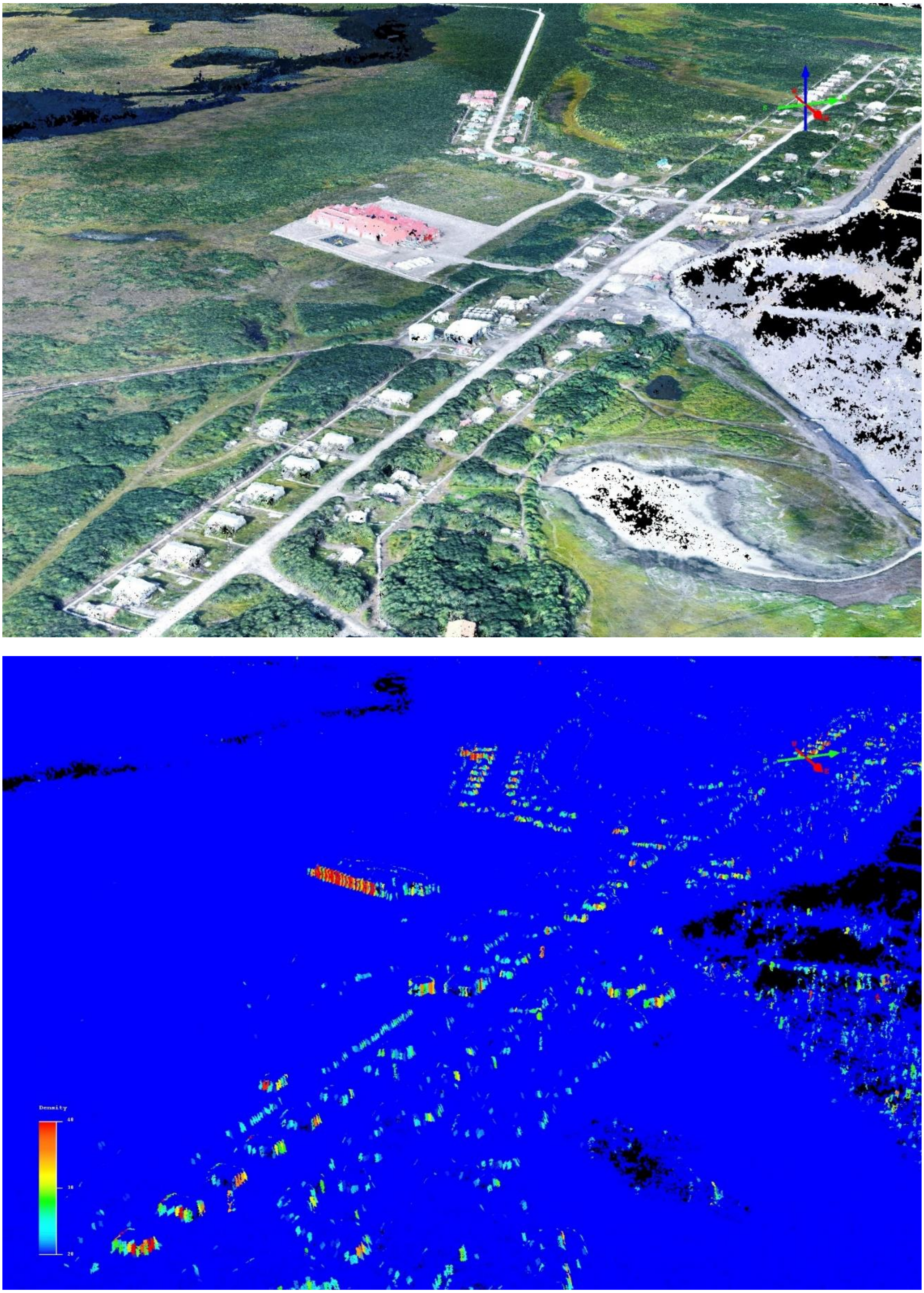



Figure 2 C-D. Oblique view of Alakanuk, similar to A-B. Again building walls have a point density of 25 or higher.

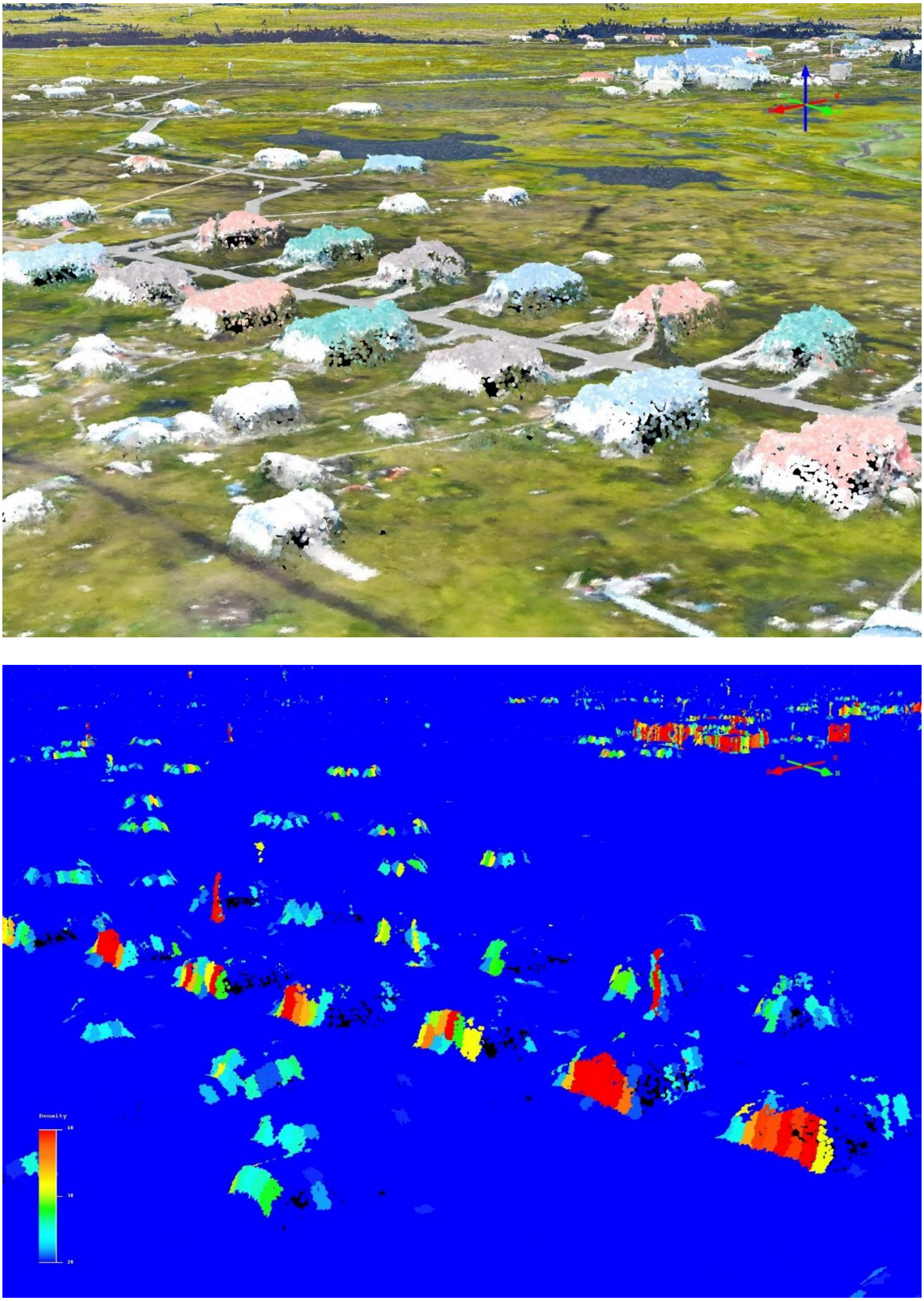
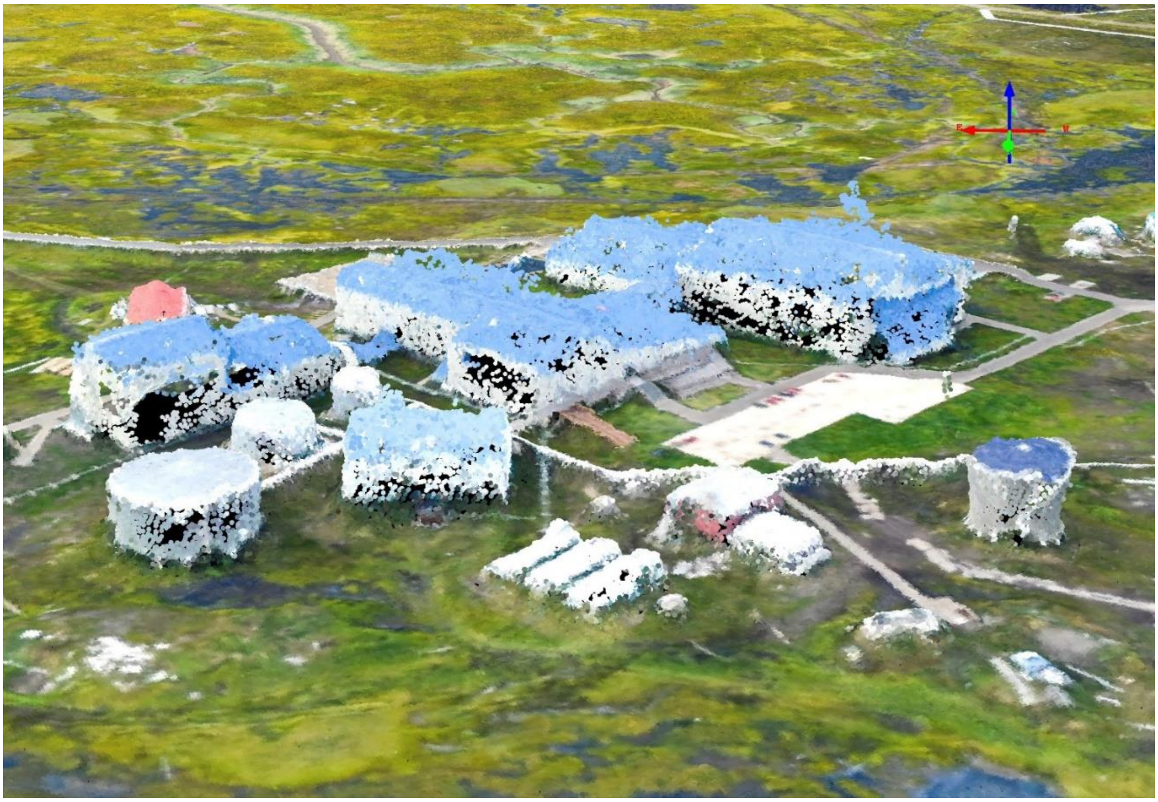


Figure 2 E-F. Oblique view of Kwig, similar to A-B, detailing the point density of building walls. Note also the telephone poles highlighted in the lower image.



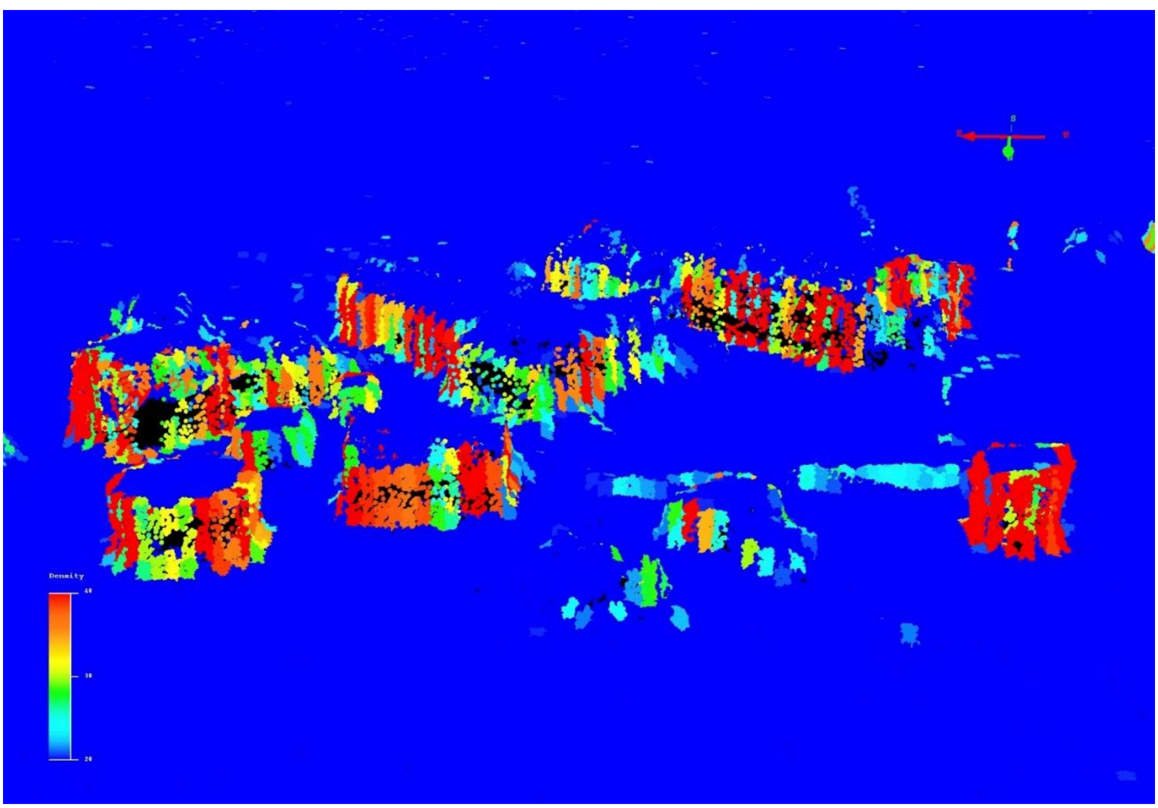


Figure 2 G-H.  Oblique view of the school at Kwig, similar to A-B.  These images all demonstrate that processing at the High setting (utilizing a 2x2 pixel search chip, or about 37 cm) yields a point cloud with sufficient density to grid the resulting mesh at 20 cm and still yield useful new information.

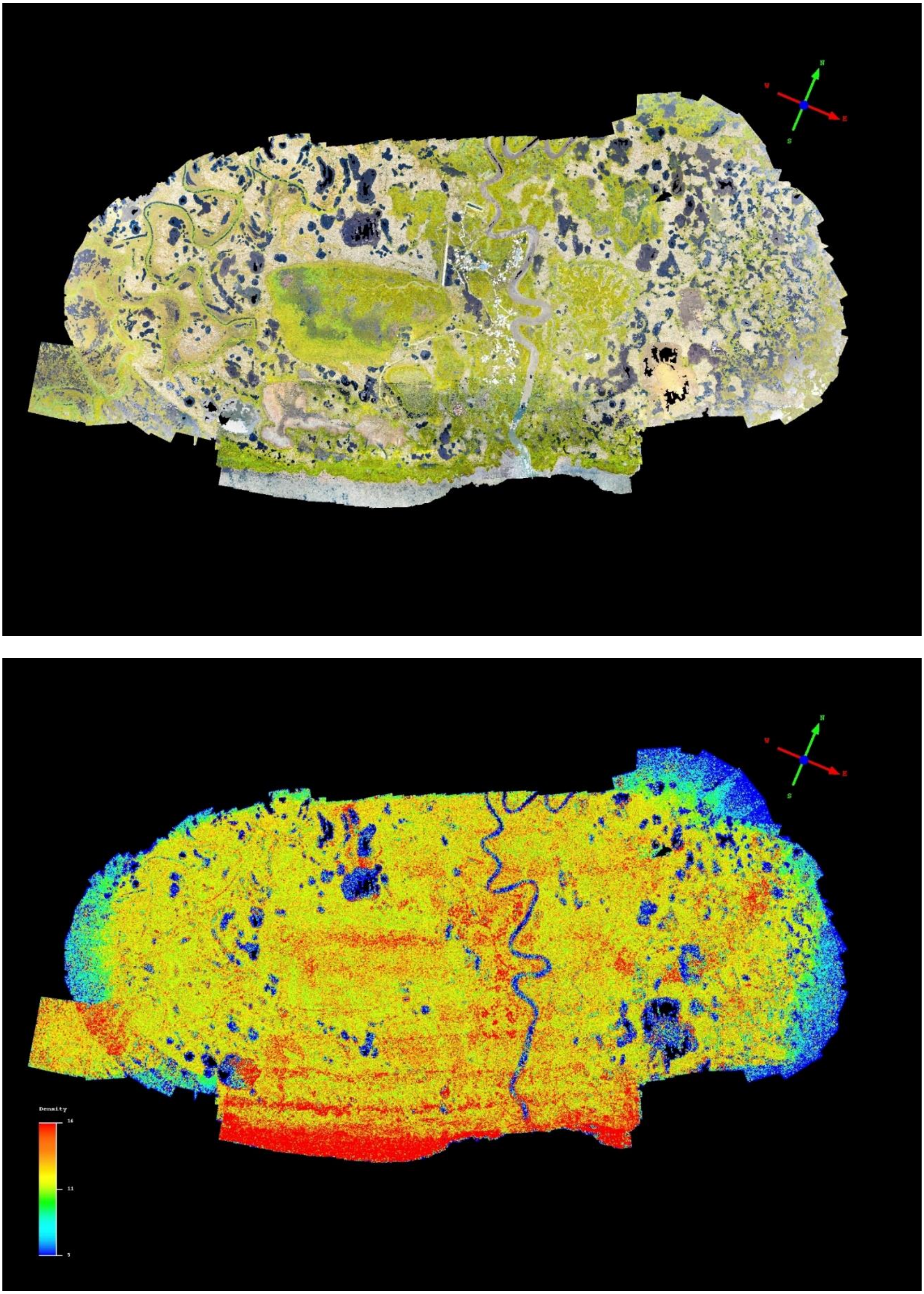
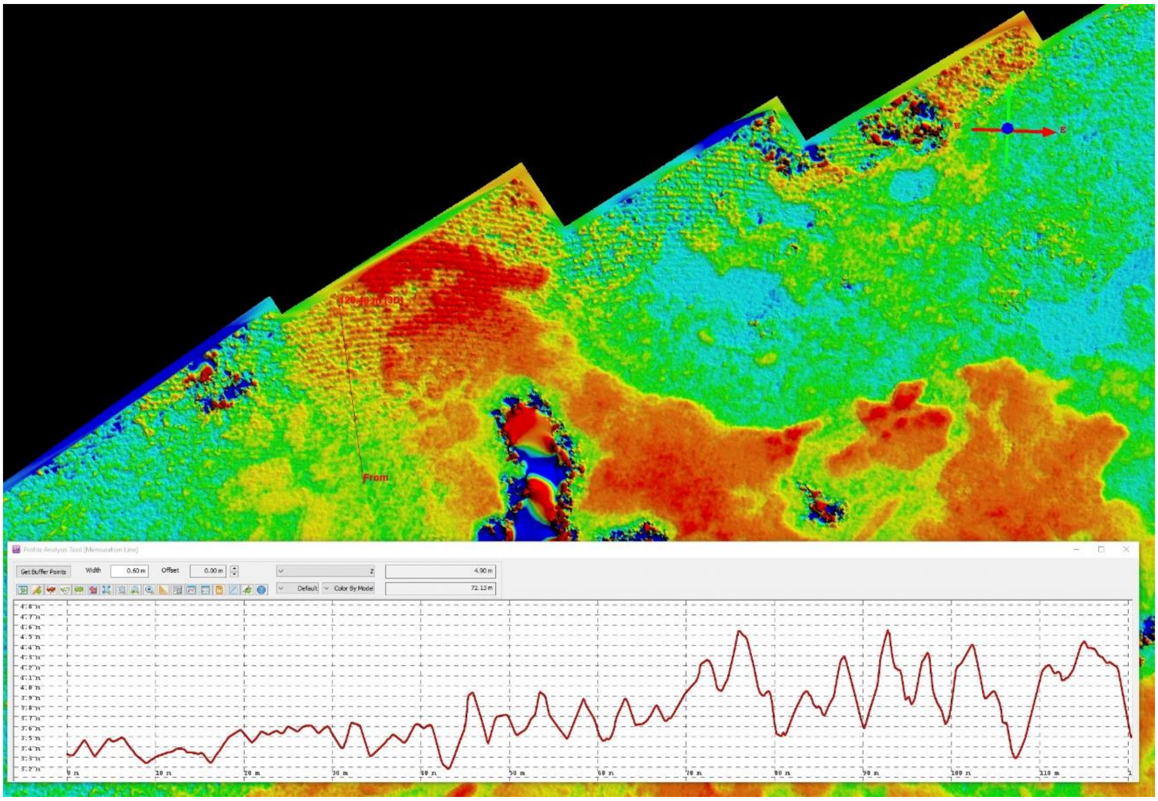



Figure 3 A-B Top view of Kwig as point cloud (A) and point cloud density (B), with beach towards bottom. Note that the four lines closest to the beach were flown lower, thus point density is increased there, especially because the beach was planned with full sidelap. Notice how the other three sides shows differing degrees of decreased point density due to decreased sidelap. It is particularly noticeable at the left and right side, where turns were made and sidelap was often zero. Note that these artifacts are at most 600-700 m wide, and the DCRA village outline (not shown) is quite far from these edge artifacts.



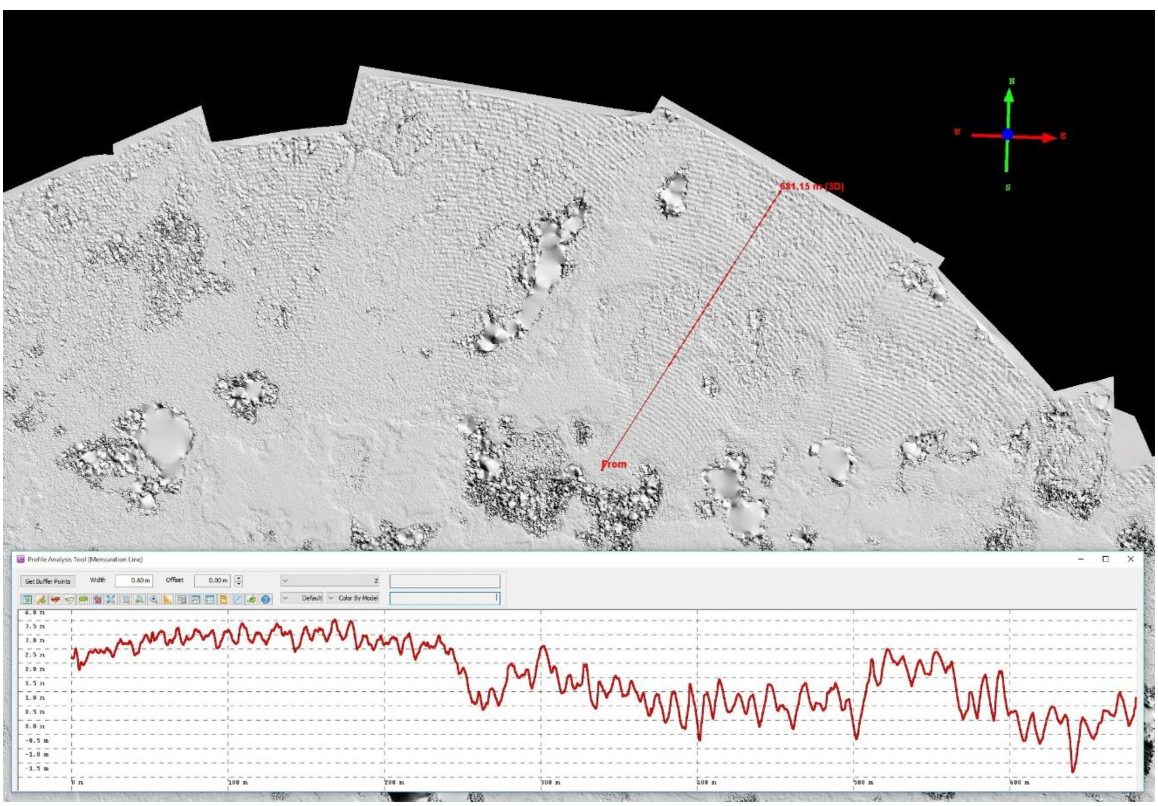


Figure 3 C-D. Detail of edge artifacts. C) A close-up near the top edge of 3A-B, showing that edge artifacts disappear by 100 m inboard, with a maximum amplitude of about +/- 40 cm. D) A close-up of the right edge of 3A-B, showing that edge artifacts propagate further inboard here (up to about 700 m) and have higher amplitude towards the outboard edge, about +/- 80 cm.

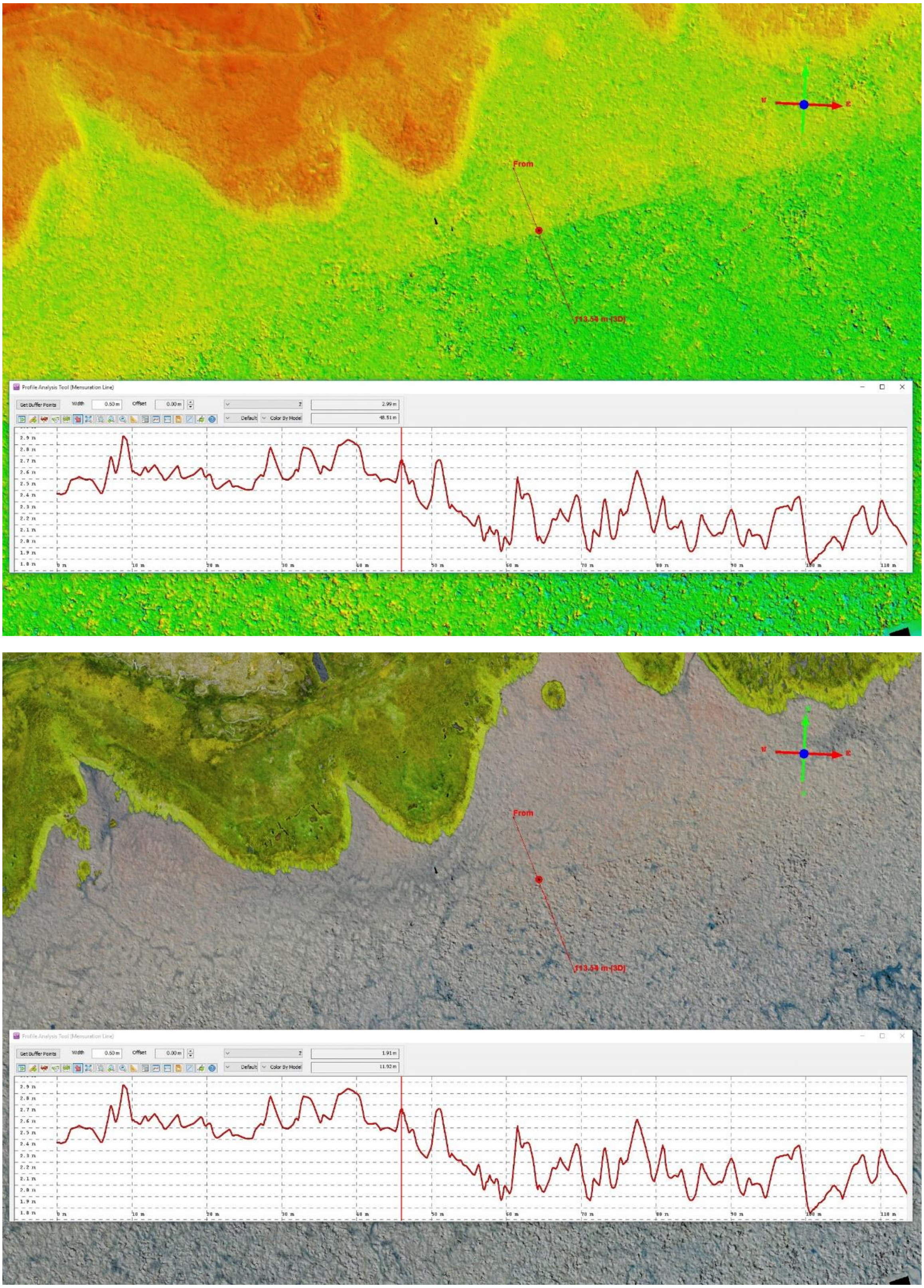



Figure 3 E-F.  Occasionally artifacts like these can be found in the interior of a block where all data should be good.  This seam has a maximum amplitude of only 10 cm, and seems to be caused by a thin cloud cover on one of the flight lines reducing ground contrast and causing a slight misalignment and/or a difference in flying height on a different day.  Note also this artifact appears only on the wet mudflats, which are a challenge due to thin amounts of liquid water on the surface that refract slightly.

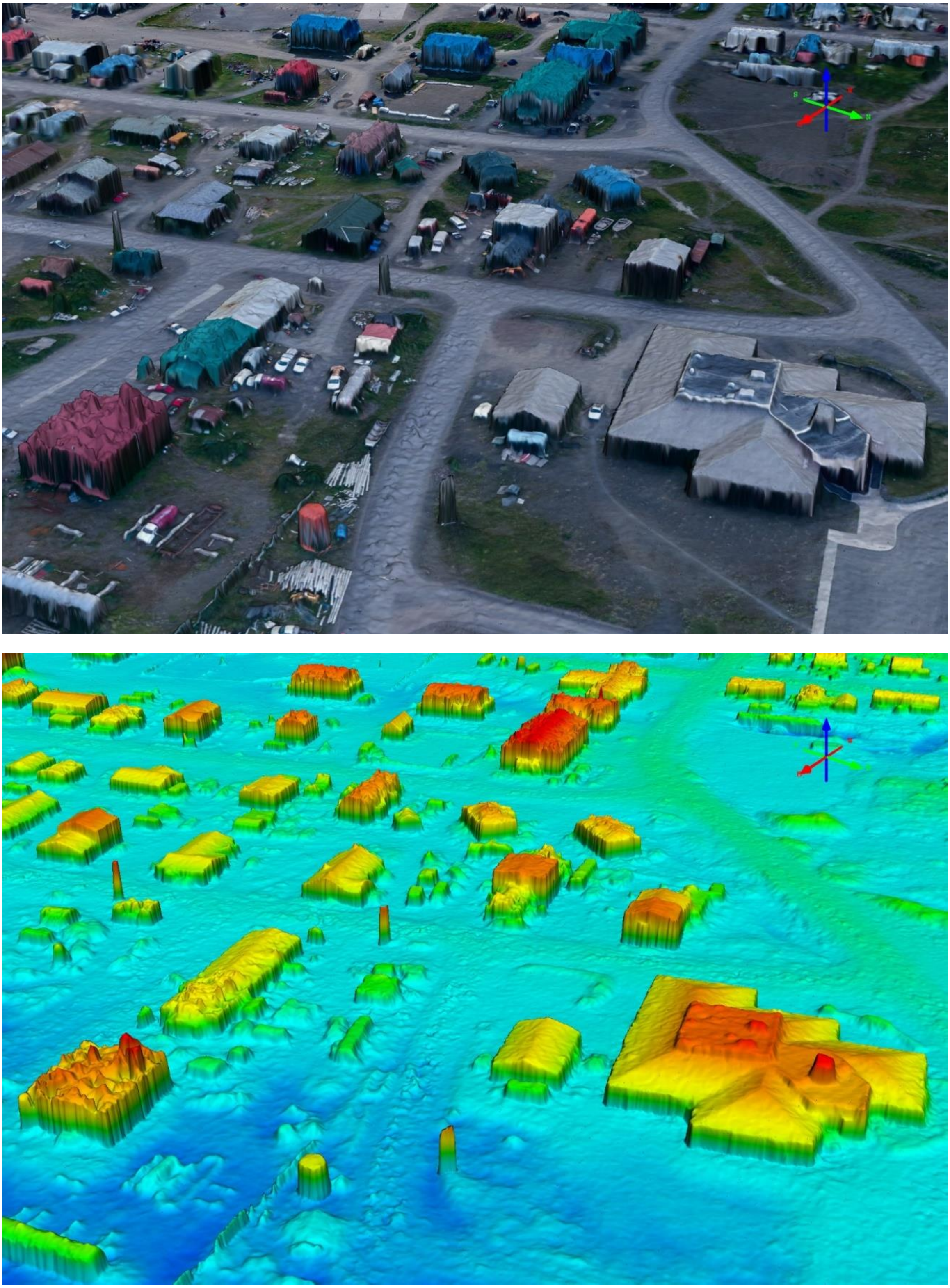


Figure 4 A-B. Some roofs in Unalakleet. Roof accuracy is hit or miss, because the highly reflective metal roof can blow out highlights and eliminate contrast when the angle with the sun is right for it. The roof of the clinic at right came out great, whereas the red roof at left has a lot of noise. These problems are preventable, if enough time and funding is put into planning and acquisitions.

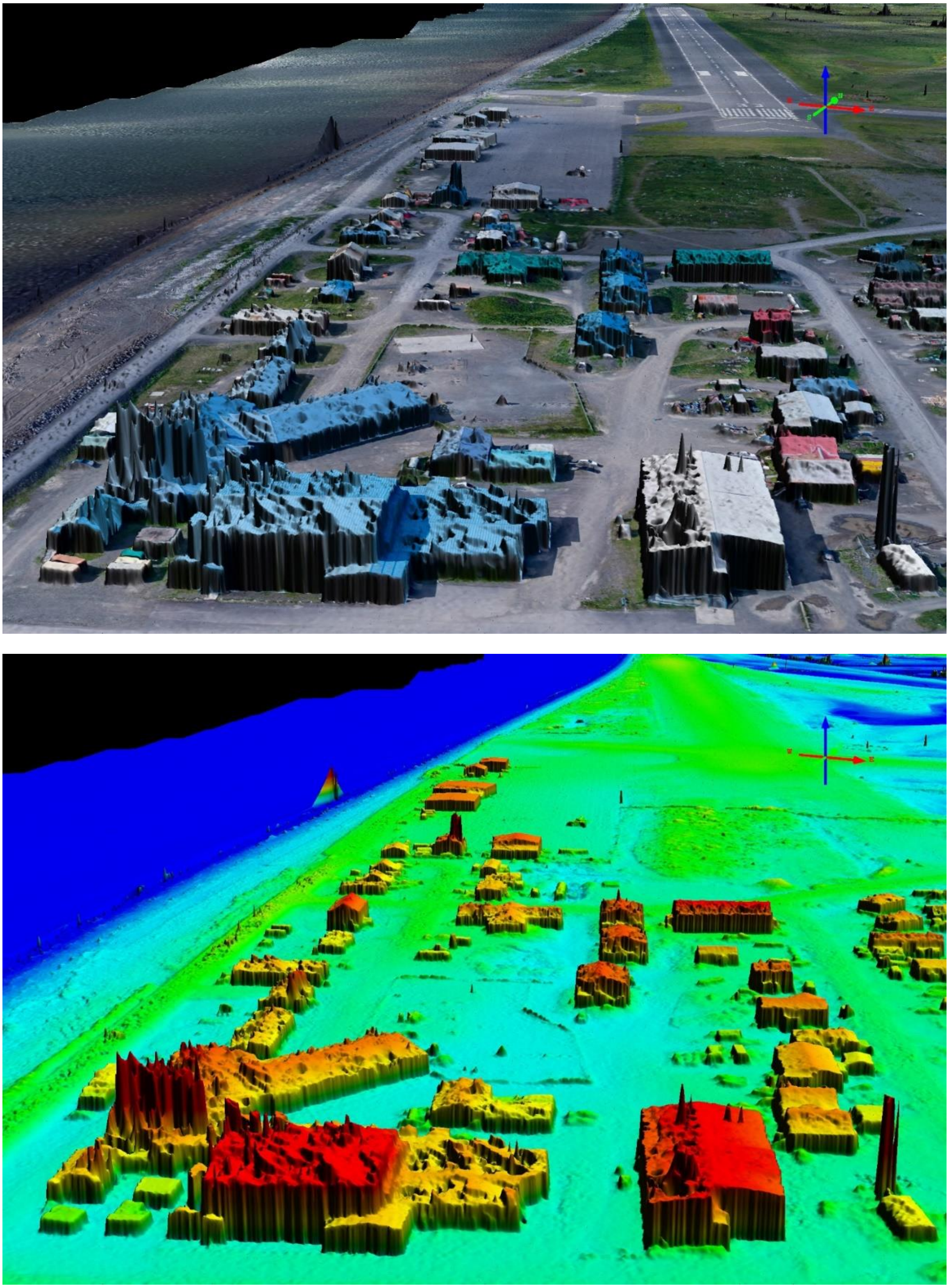


Figure 4 C-D. More roofs in Unalakleet. In the building at right, you can clearly see how solar aspect plays an important role in determining contrast. The blue roof of the school at left shows similar features.

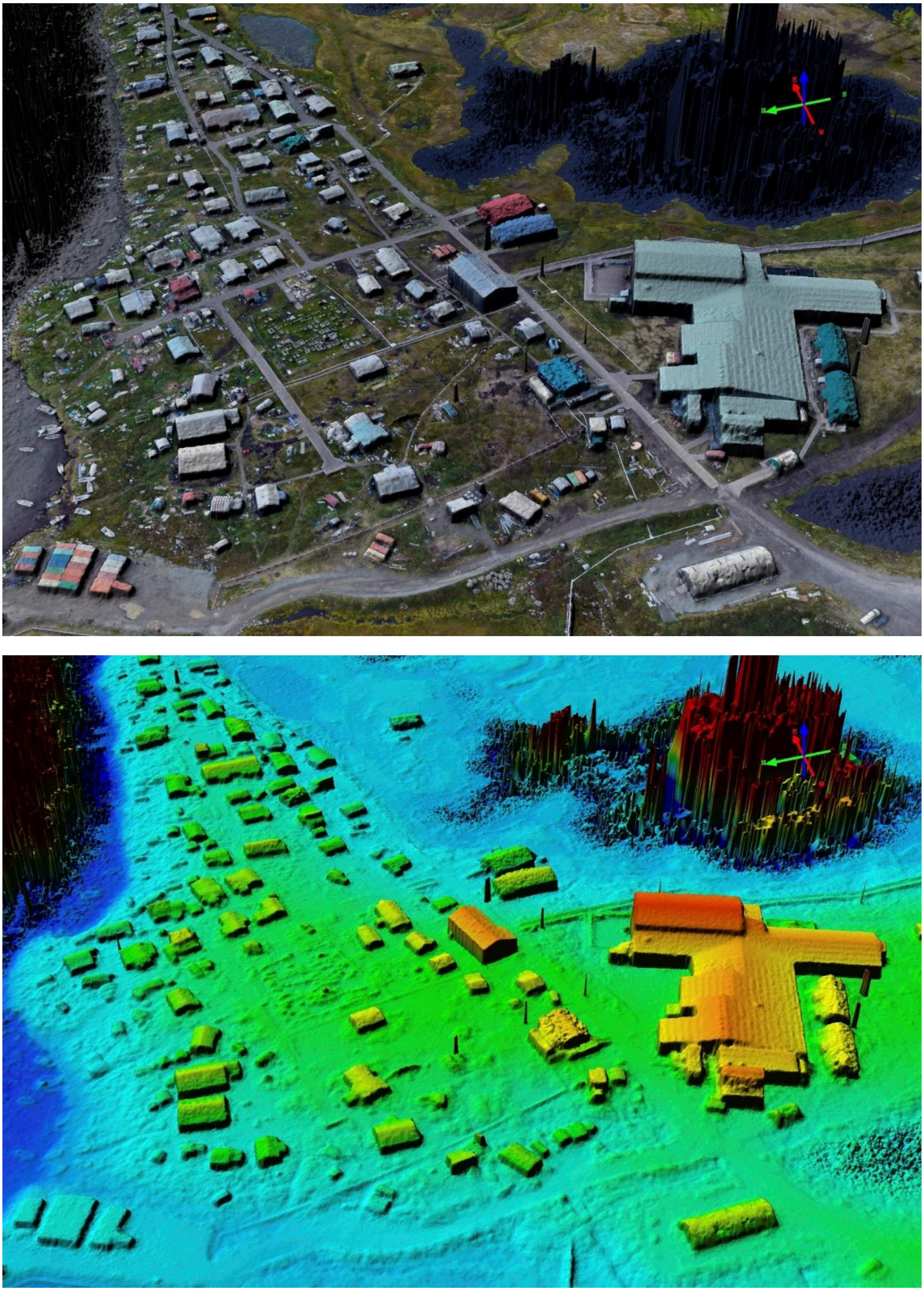
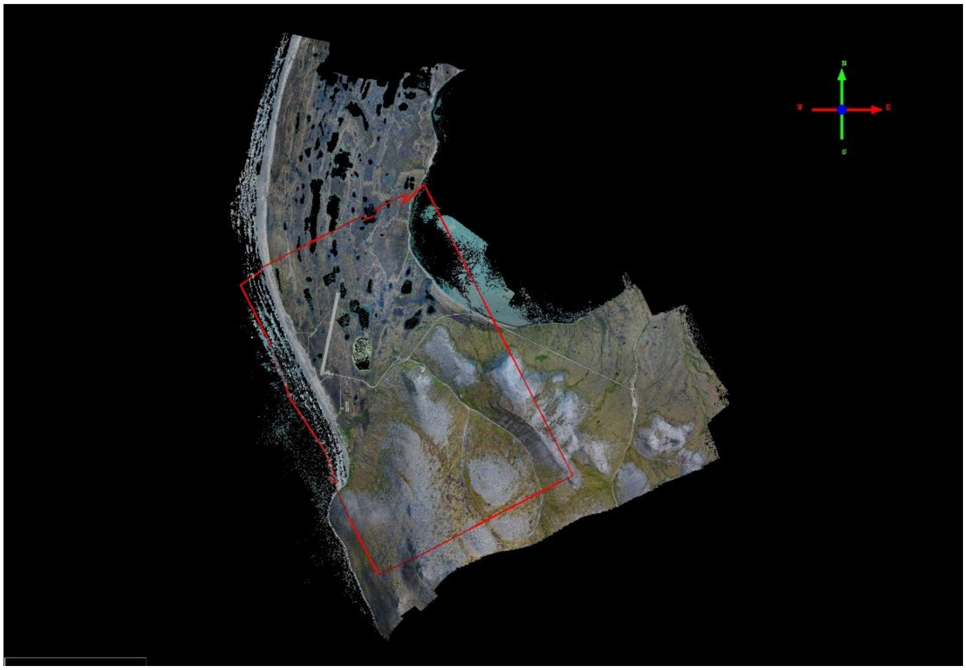


Figure 4 E-F.  Under a low, thin overcast, the clouds act as a diffuser and more evenly illuminate roof tops.  Here are some roofs in Chefornak that don't display any noise dependent on solar aspect, though a few shiny roofs have a bit more noise than others for similar reasons.

# Appendix 1:
# Village DEM and Orthoimages

# Wales



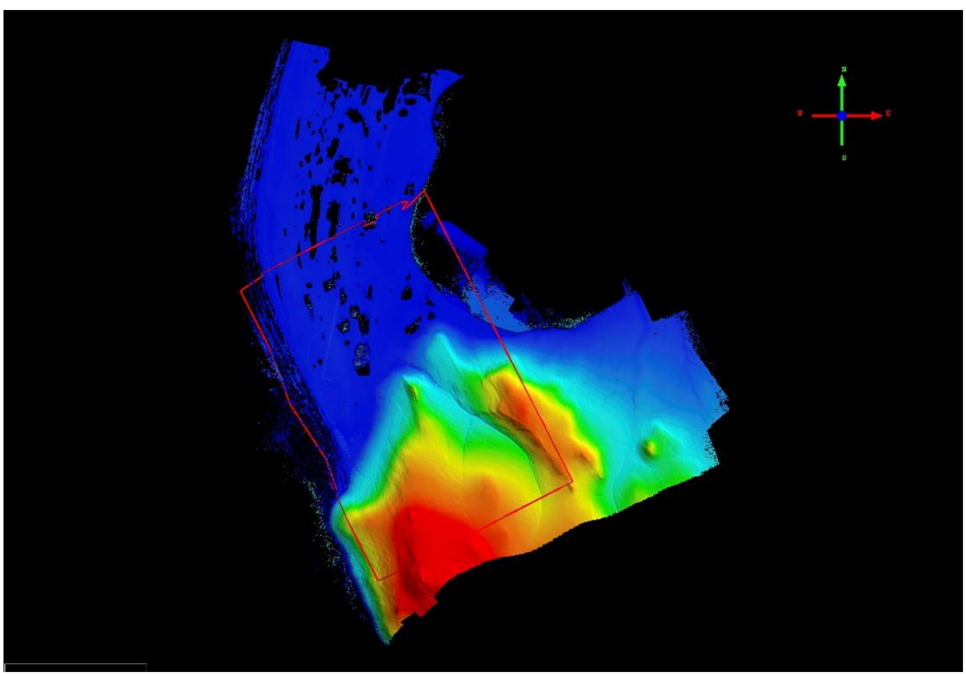


**Image GSD:** 15.5 cm
**DEM posting:** 20.0 cm
**Acquisition Date:** 8/27/2015, 8/28/2015

# Brevig Mission

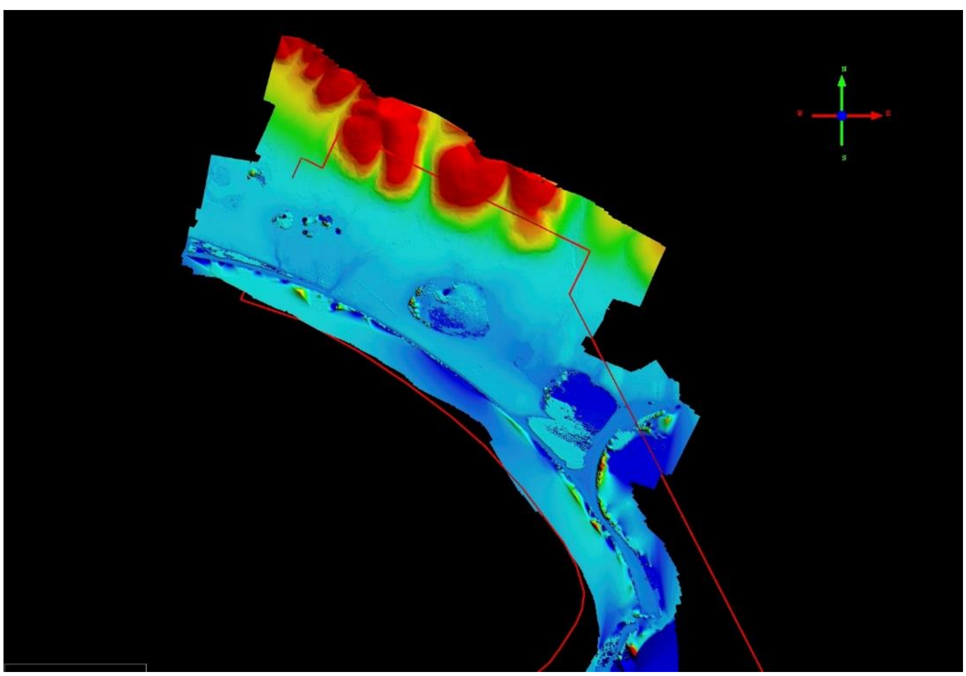


**Image GSD:** 15.07 cm
**DEM posting:** 20.00 cm
**Acquisition Date:** 8/27/2015, 8/28/2015

# Teller

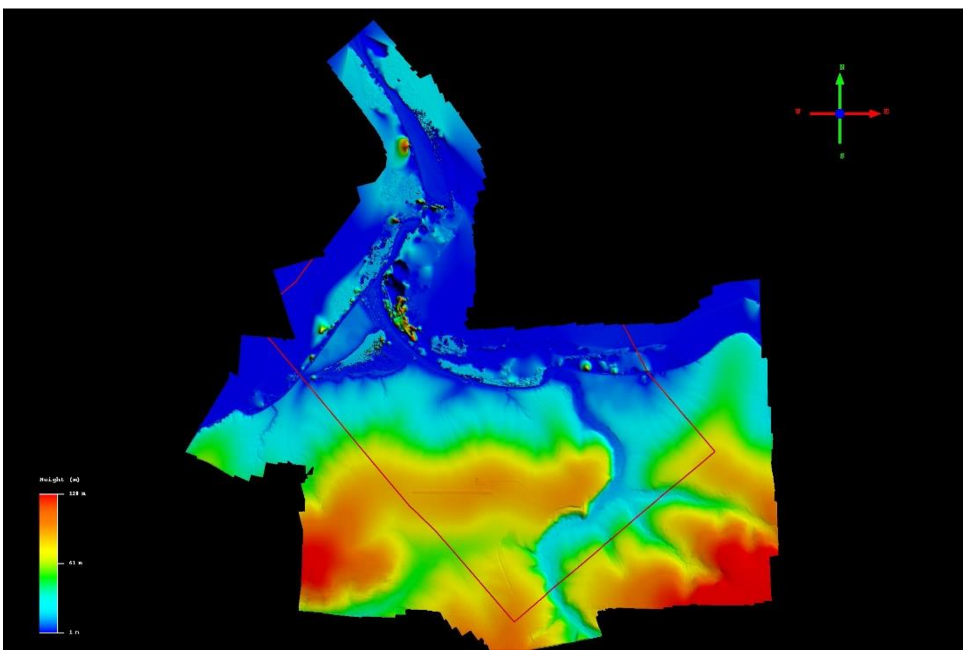
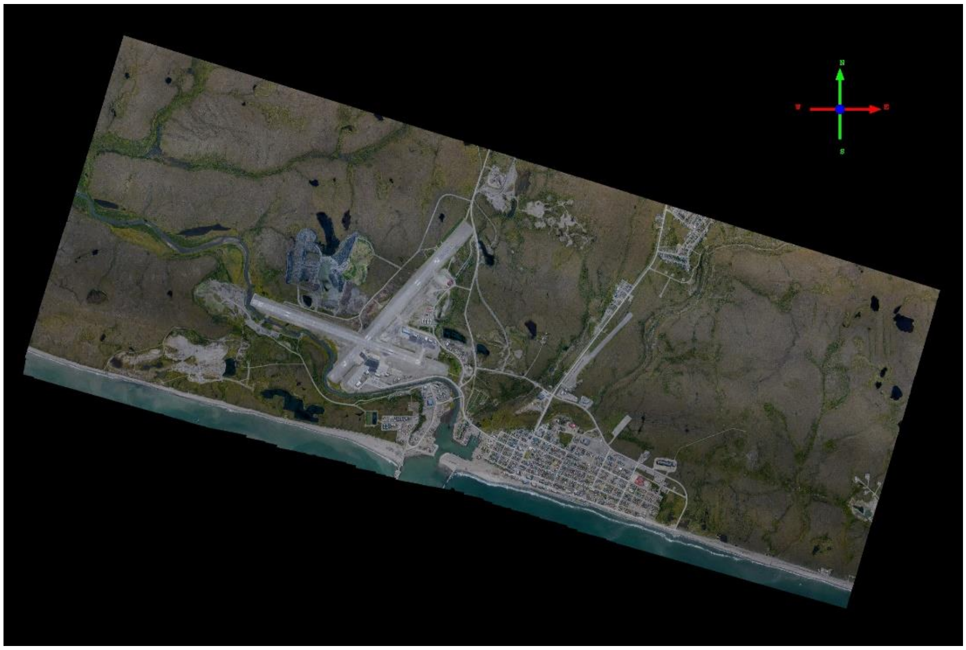


**Image GSD:** 15.2 cm
**DEM posting:** 20.0 cm
**Acquisition Date:** 8/27/2015, 8/28/2015

# Nome



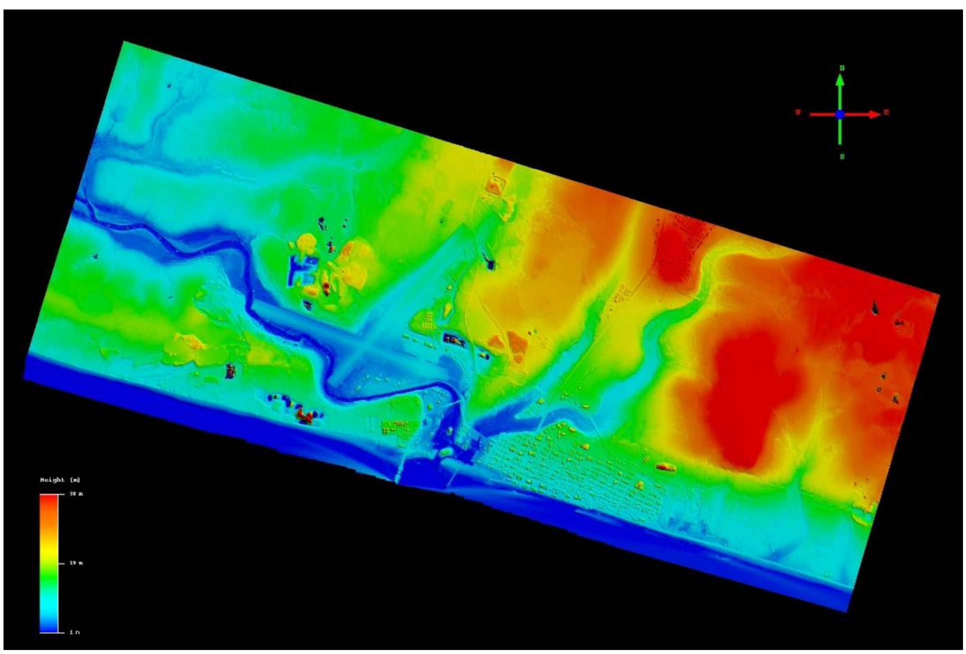
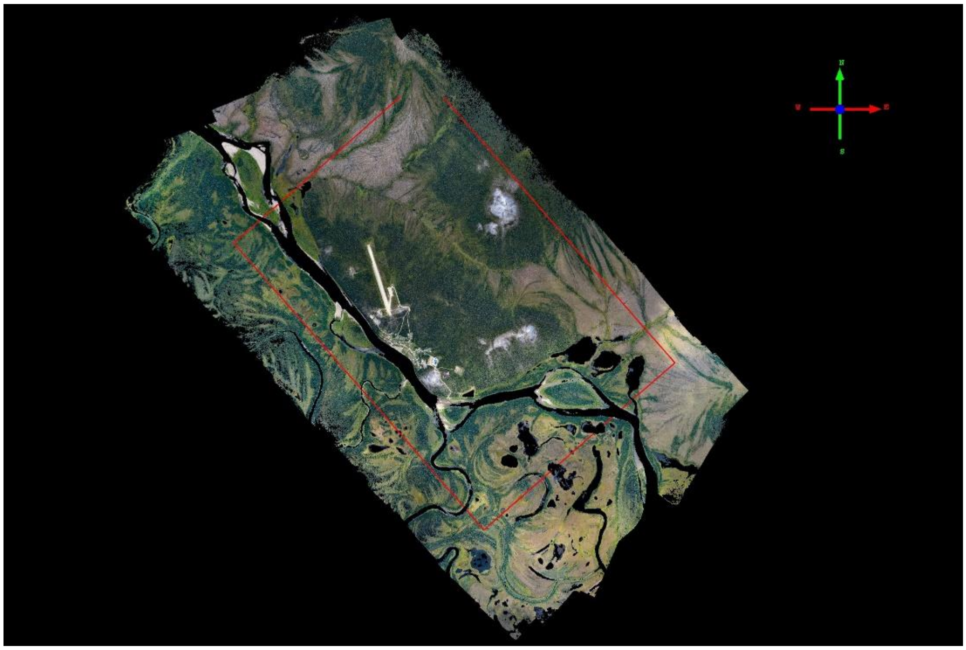



**Image GSD:** 9.2 cm
**DEM posting:** 18.4 cm
**Acquisition Date:** 8/23/2015

# White Mountain



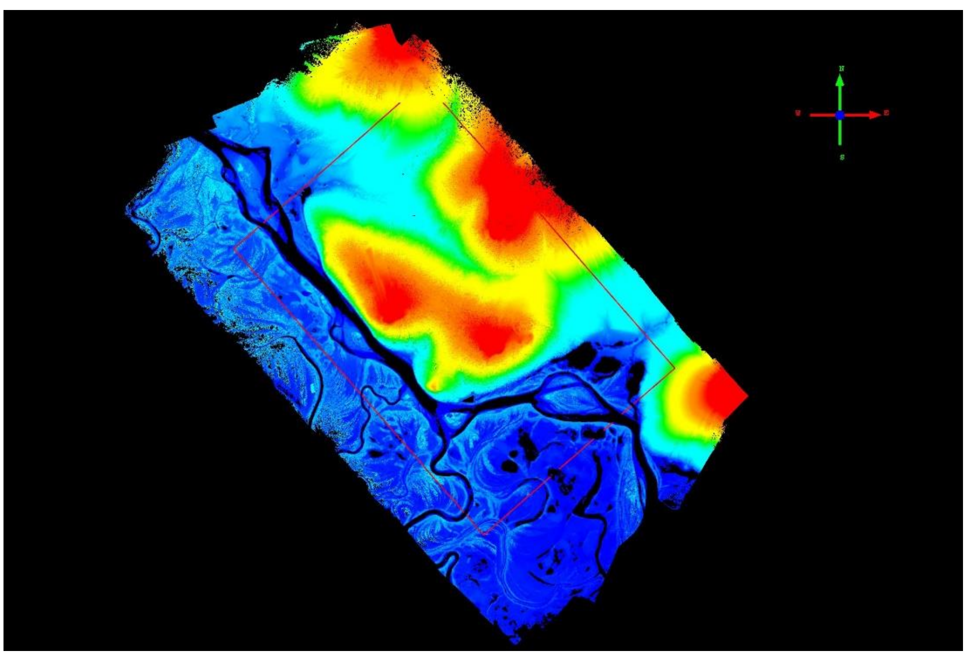
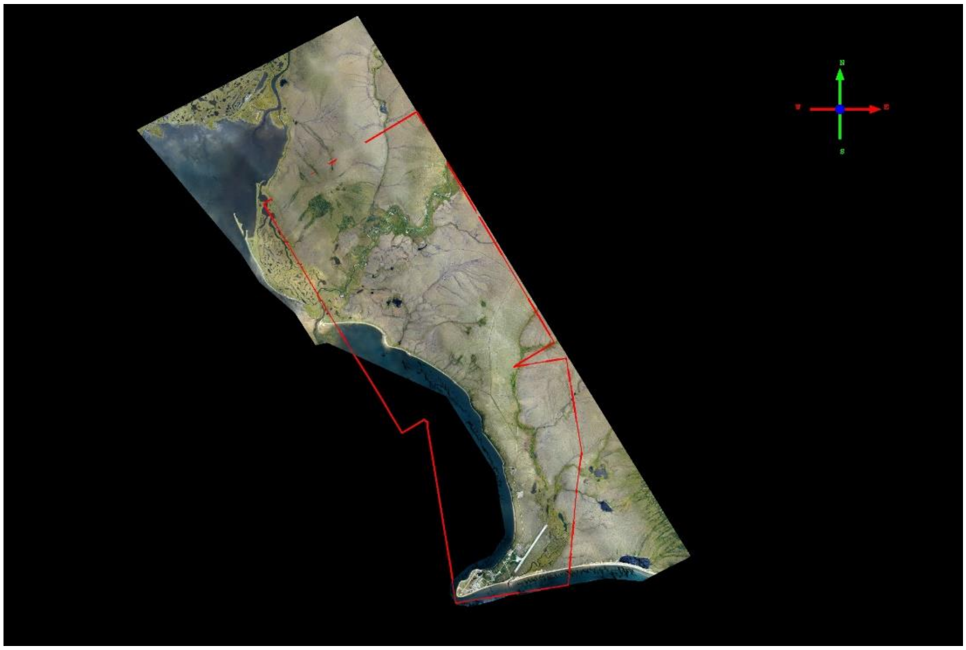


**Image GSD:** 18.2 cm
**DEM posting:** 20.0 cm
**Acquisition Date:** 8/23/2015

# Golovin



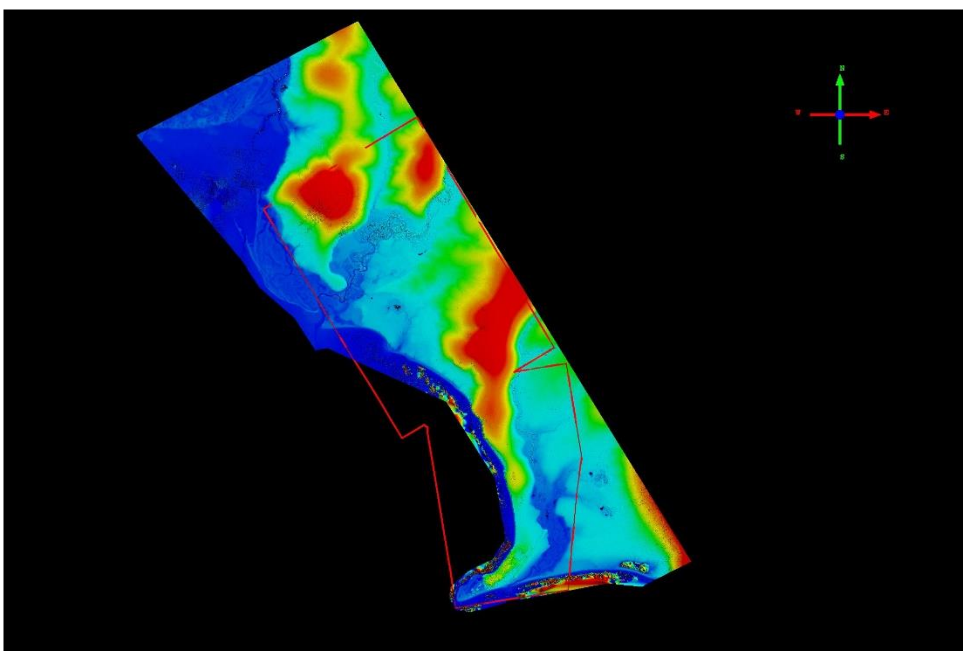


**Image GSD:** 9.8 cm
**DEM posting:** 20.0 cm
**Acquisition Date:** 8/23/2015

# Elim

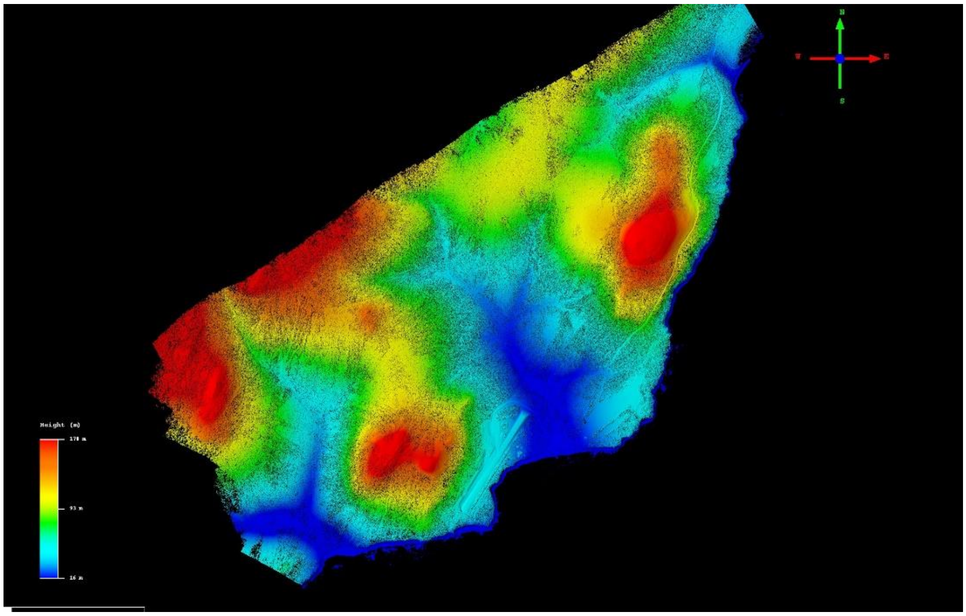
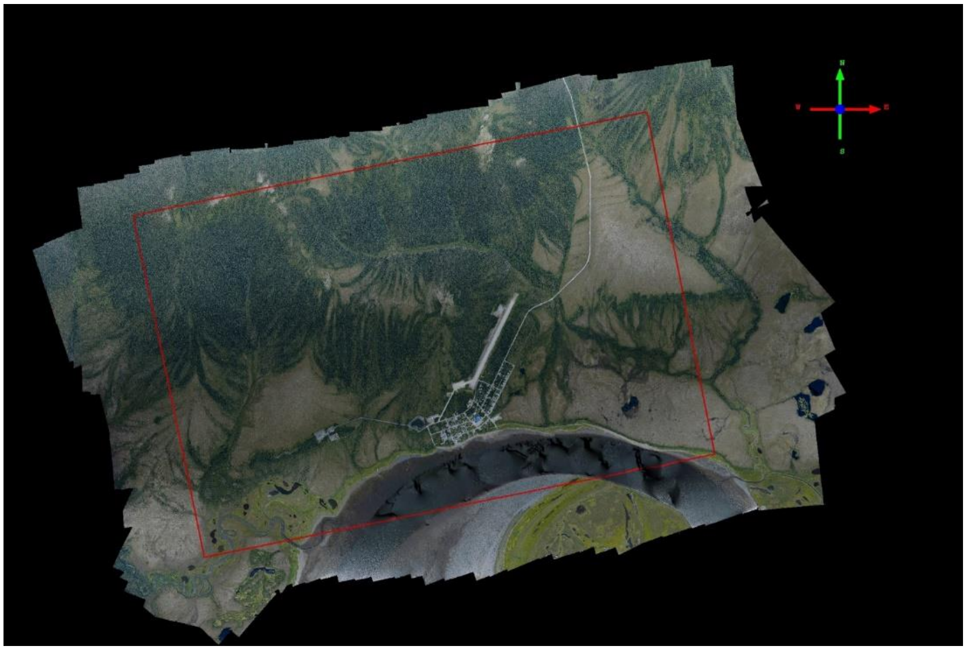



**Image GSD:** 10.6
**DEM posting:** 20.0 cm
**Acquisition Date:** 8/5/2015

# Koyuk



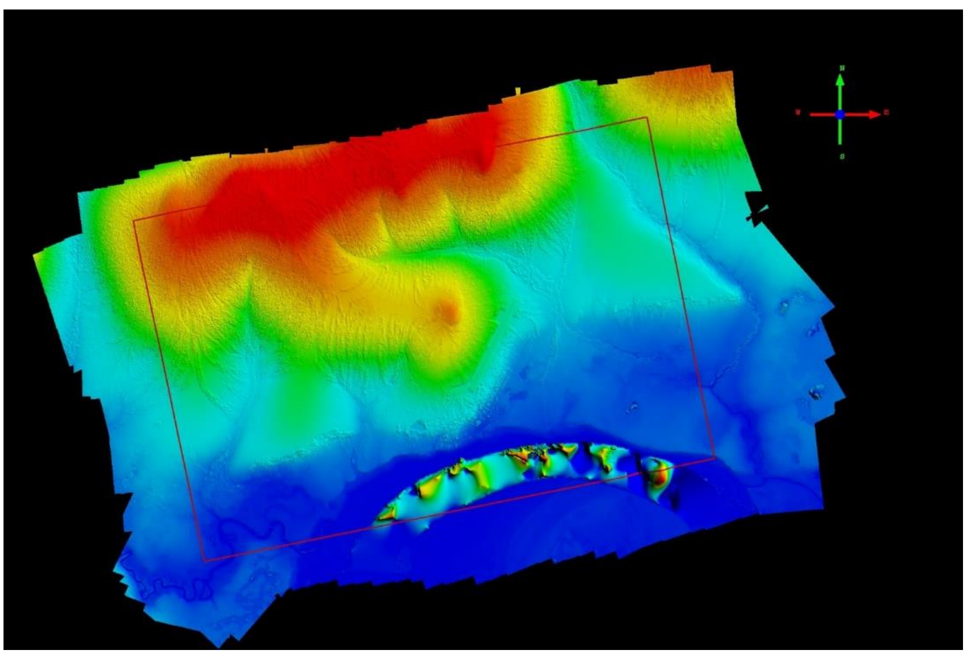
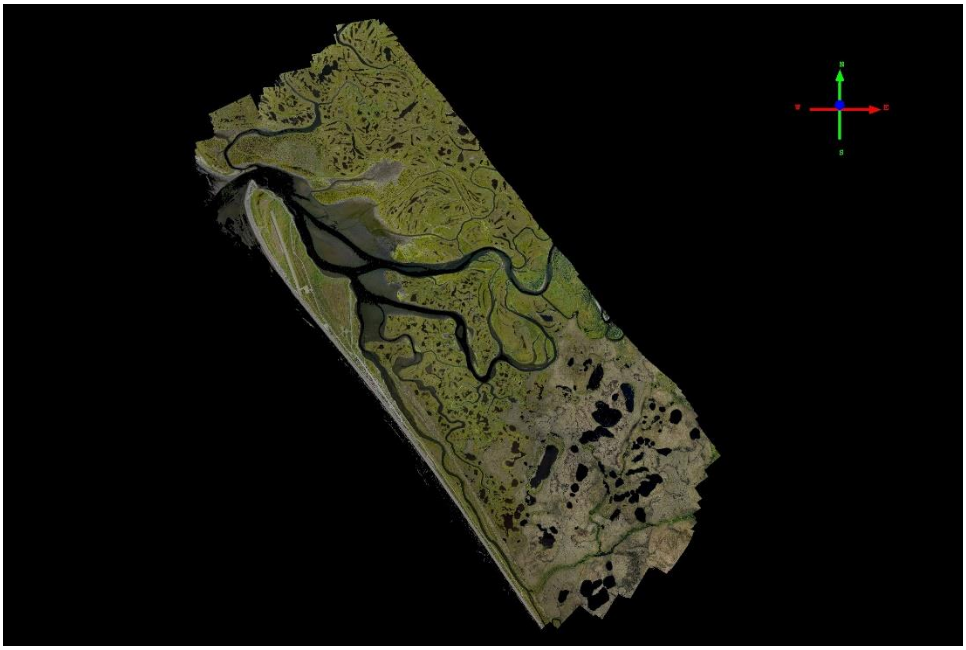


**Image GSD:** 16.5 cm
**DEM posting:** 20.0 cm
**Acquisition Date:** 8/5/2015

# Shaktoolik



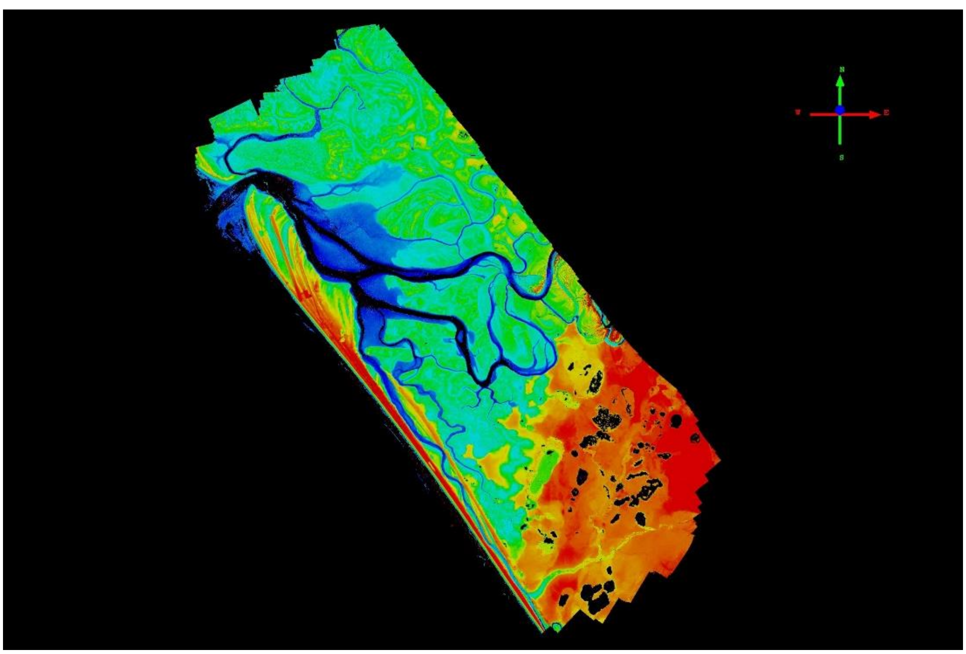
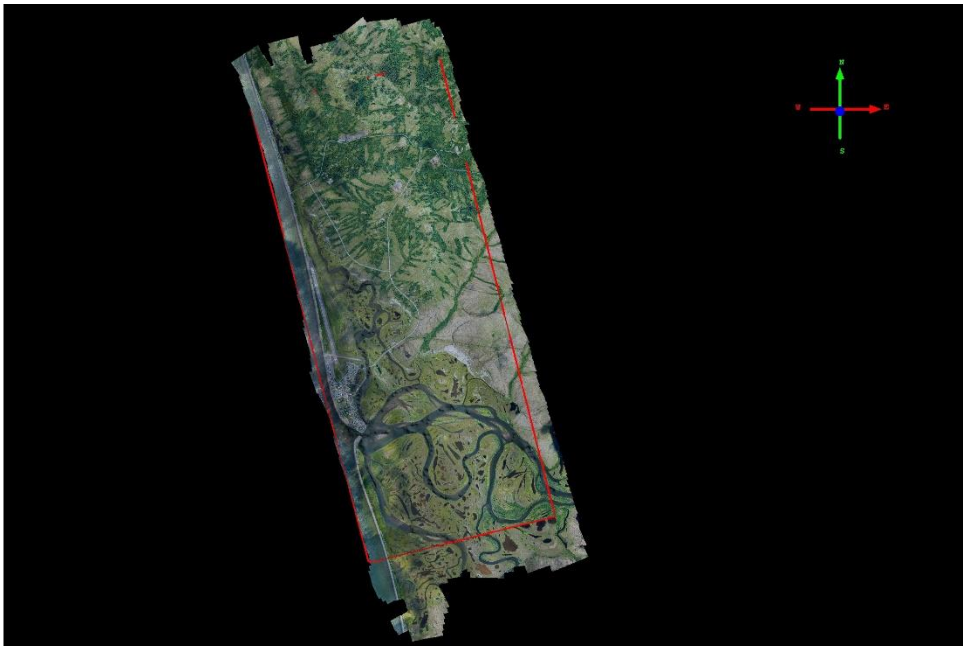


**Image GSD:** 9.4 cm
**DEM posting:** 9.4 cm
**Acquisition Date:** 8/6/2015

# Unalakleet



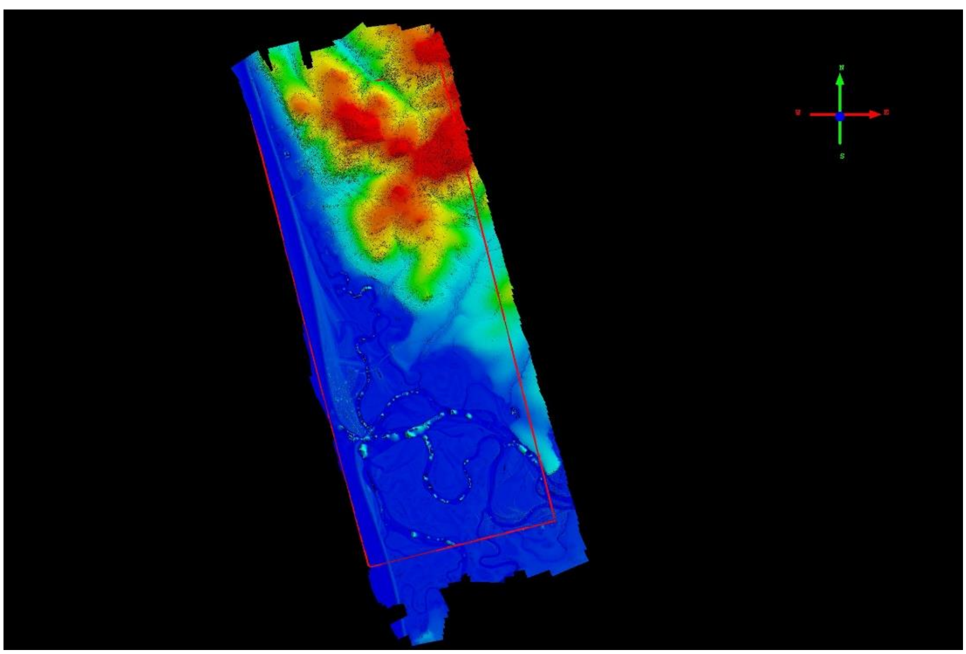


**Image GSD:** 8.5 cm
**DEM posting:** 16.9 cm
**Acquisition Date:** 7/31/2015

# Stebbins / St Michael

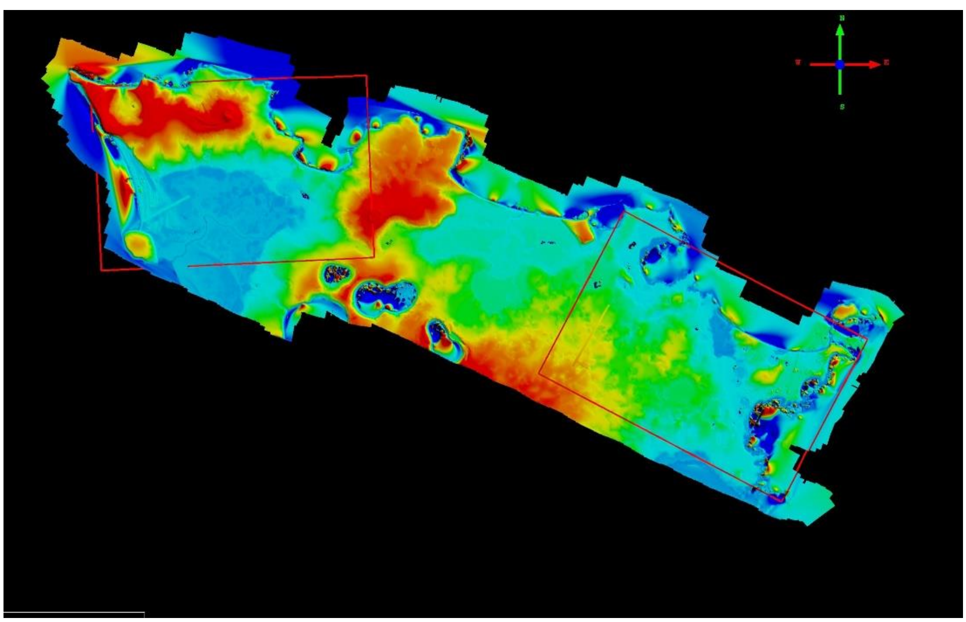
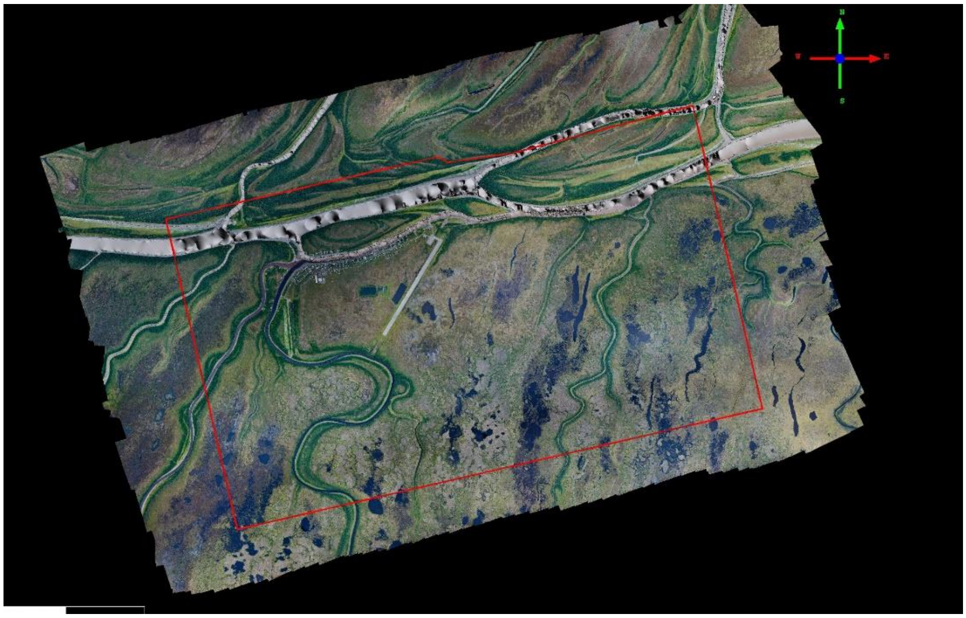


**Image GSD:** 10.0 cm
**DEM posting:** 20.0 cm
**Acquisition Date:** 8/6/2015

# Kotlik



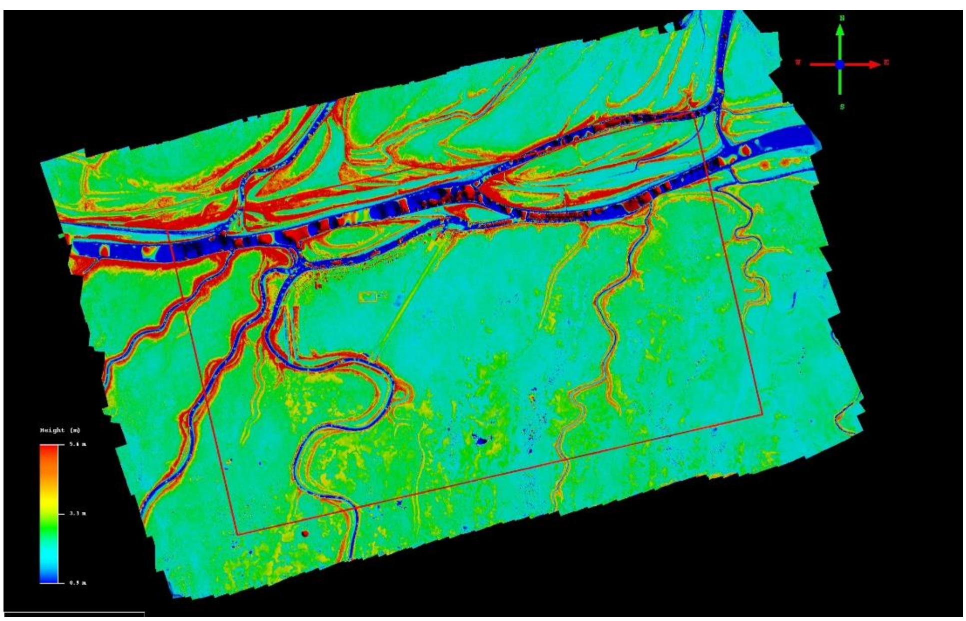
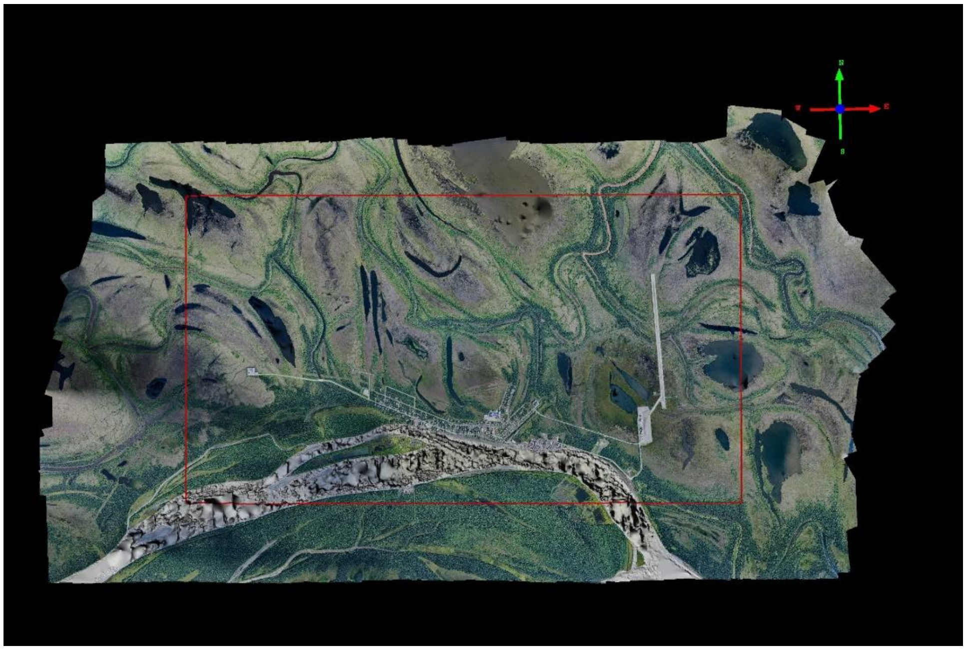


**Image GSD:** 15.1 cm
**DEM posting:** 20.0 cm
**Acquisition Date:** 8/22/2015

# Emmonak



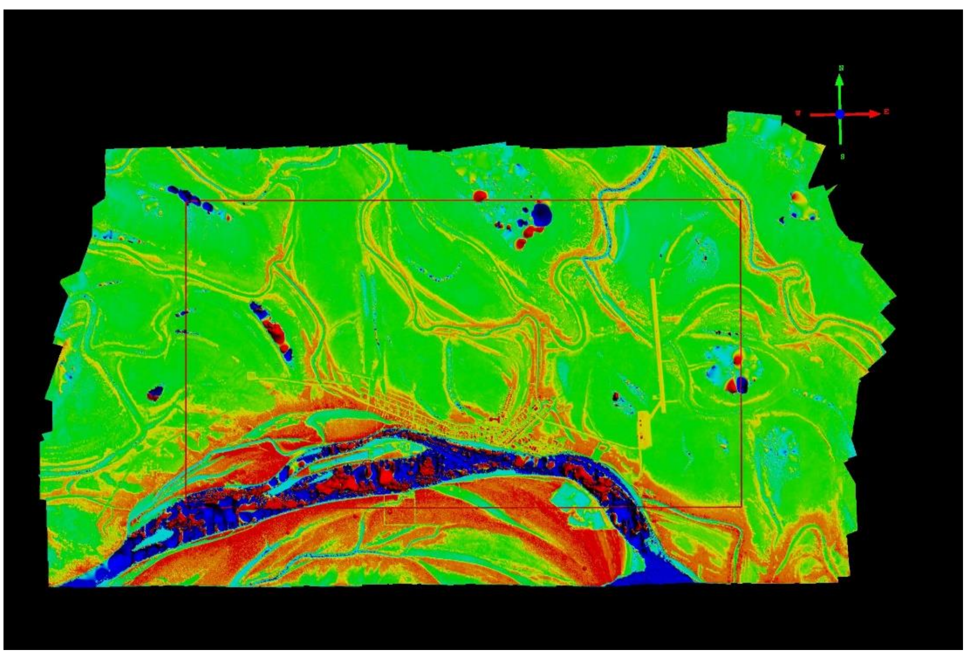


**Image GSD:** 17.2 cm
**DEM posting:** 20.0 cm
**Acquisition Date:** 8/31/2015

# Alakanuk

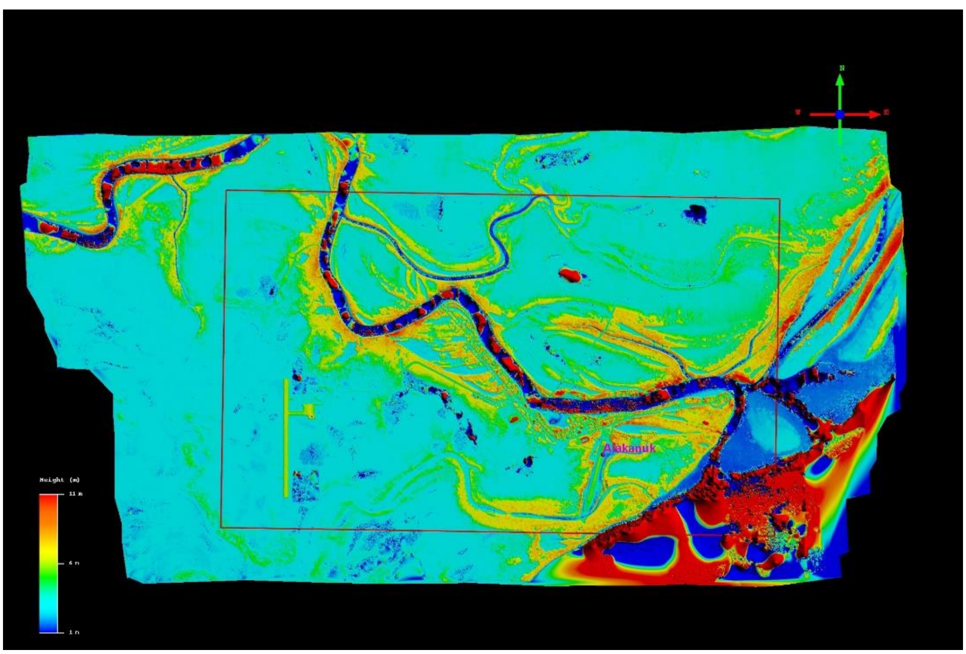
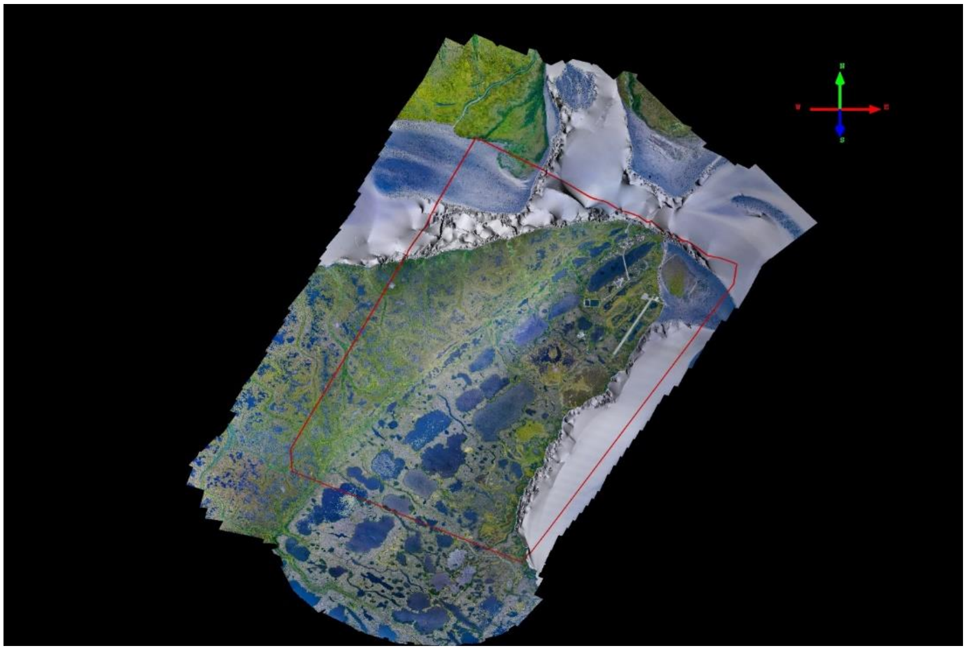




**Image GSD:** 16.7 cm
**DEM posting:** 20.0 cm
**Acquisition Date:** 8/31/2015

# Nunam Iqua



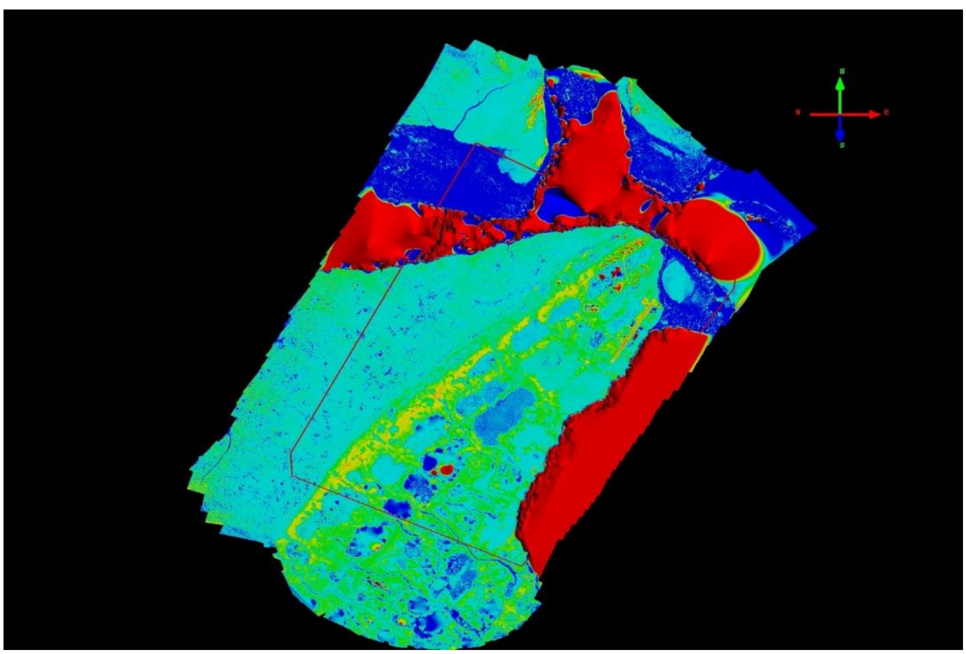
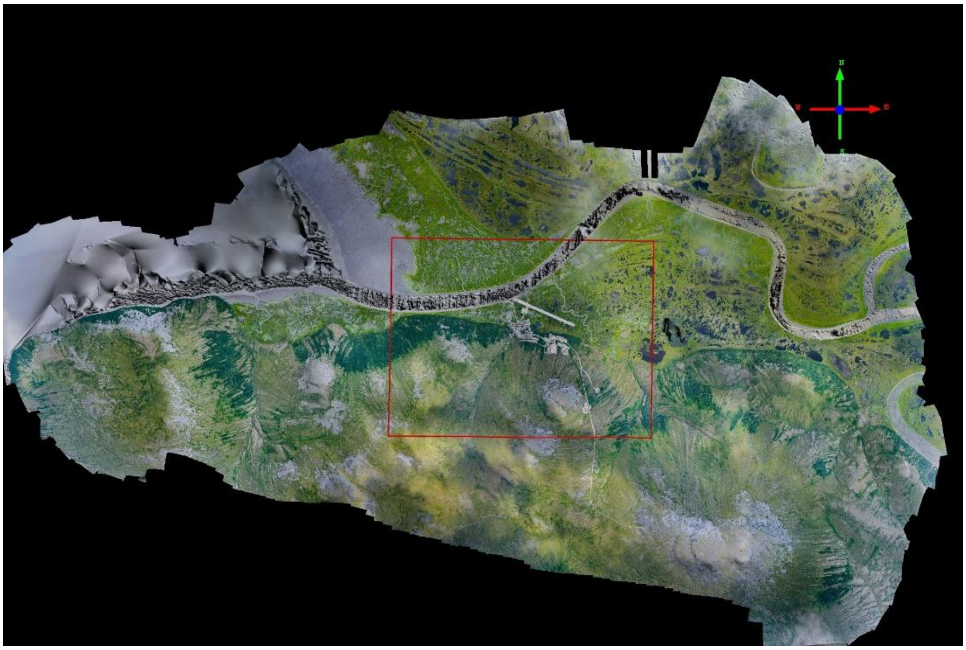


**Image GSD:** 16.5 cm
**DEM posting:** 20.0 cm
**Acquisition Date:** 8/14/2015

# Scammon Bay



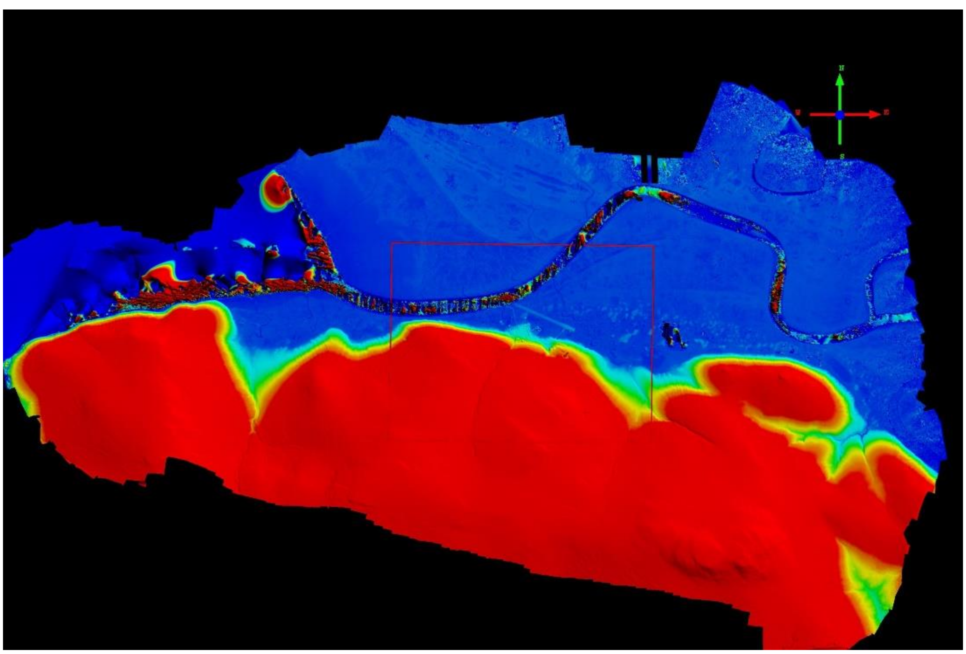
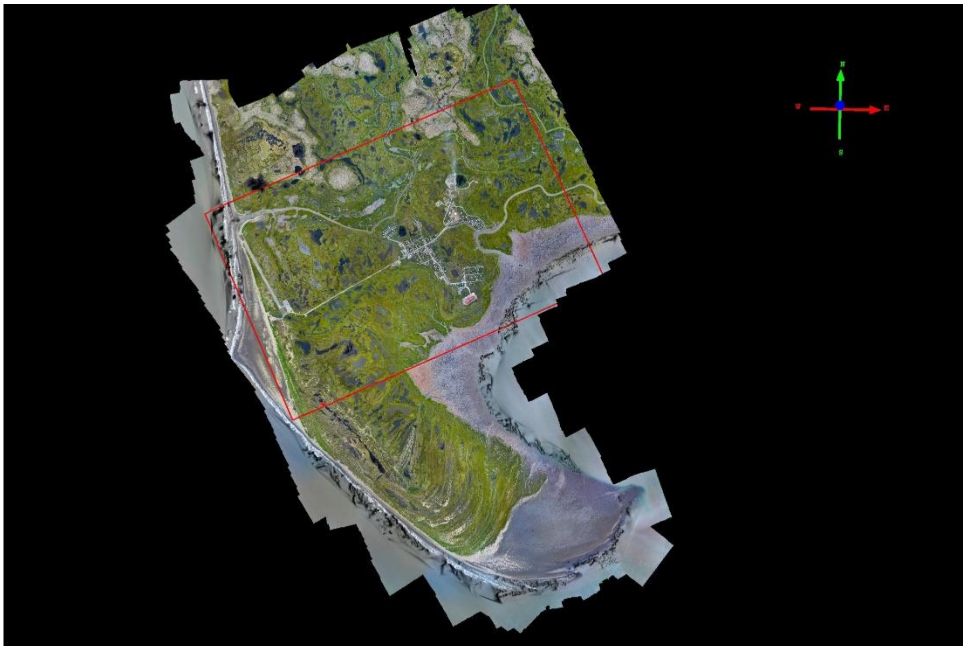


**Image GSD:** 19.7 cm
**DEM posting:** 20.0 cm
**Acquisition Date:** 8/13/2015

# Hooper Bay



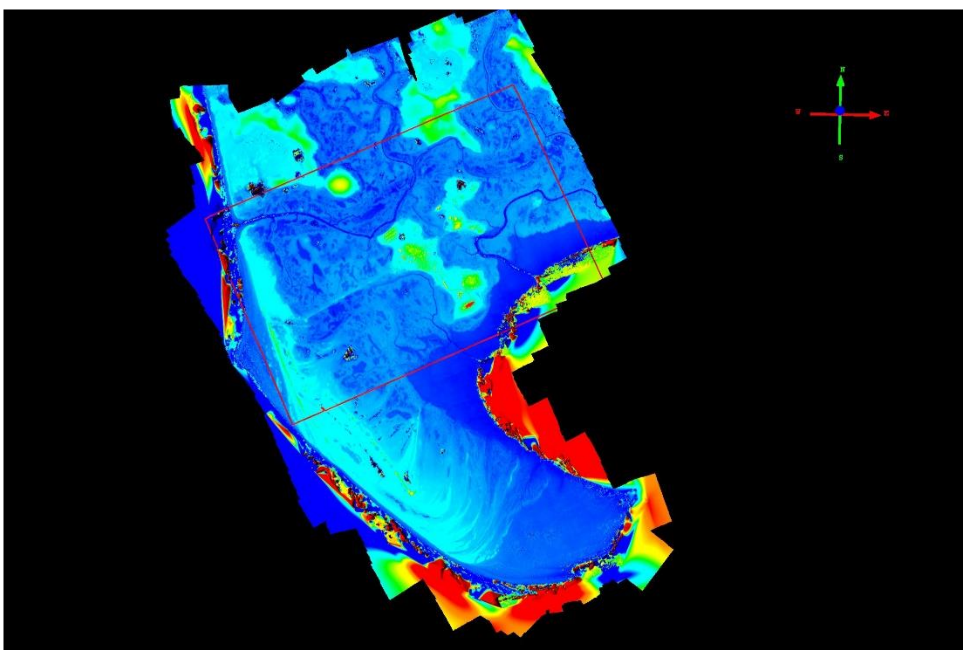
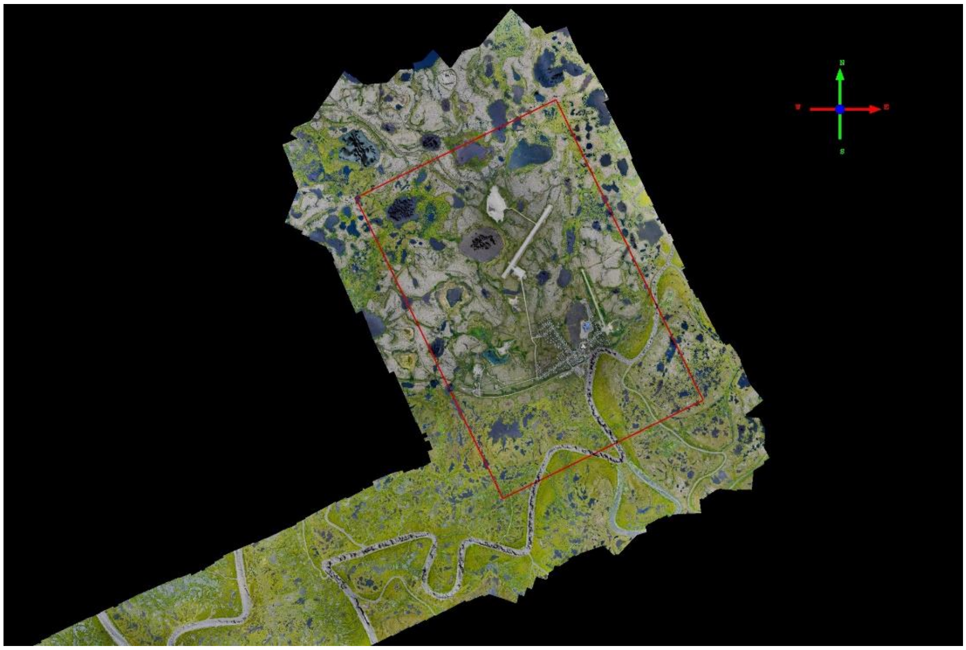


**Image GSD:** 9.5 cm
**DEM posting:** 19.0 cm
**Acquisition Date:** 8/13/2015

# Cheevak



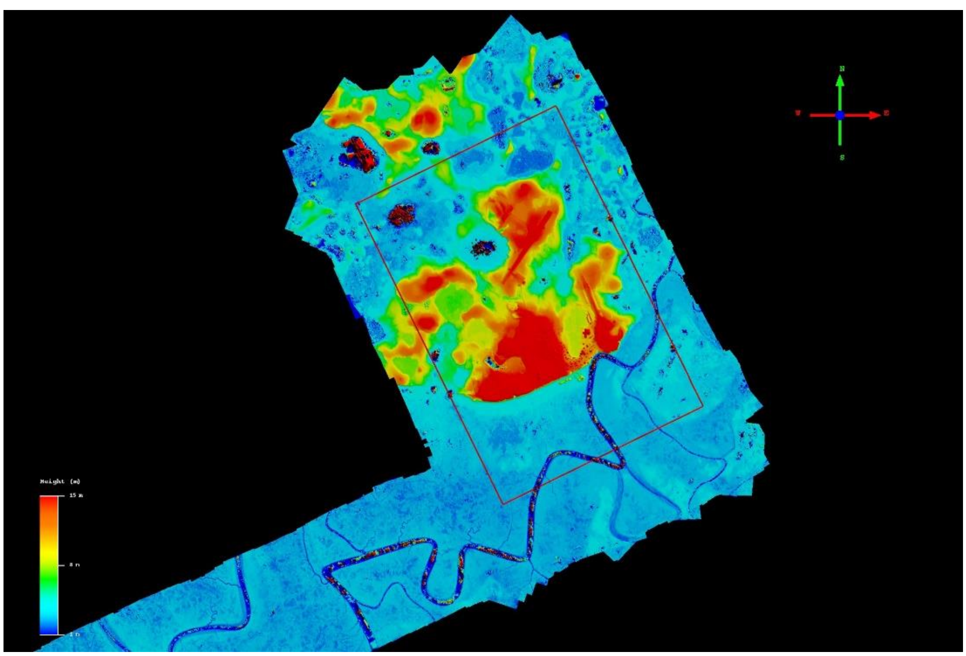


**Image GSD:** 12.8 cm
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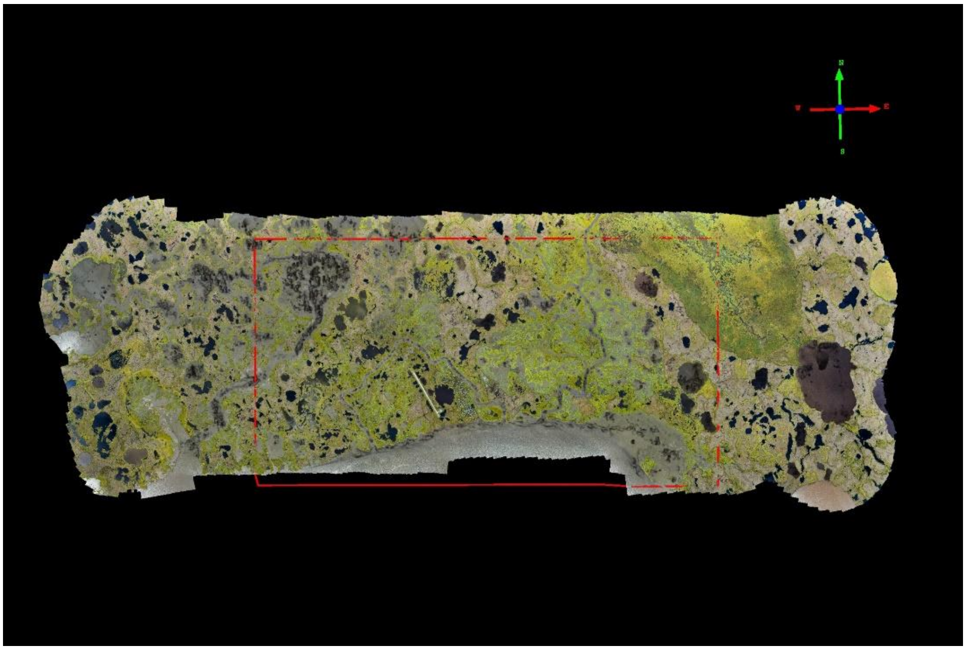
**Acquisition Date:** 8/13/2015

# Newtok



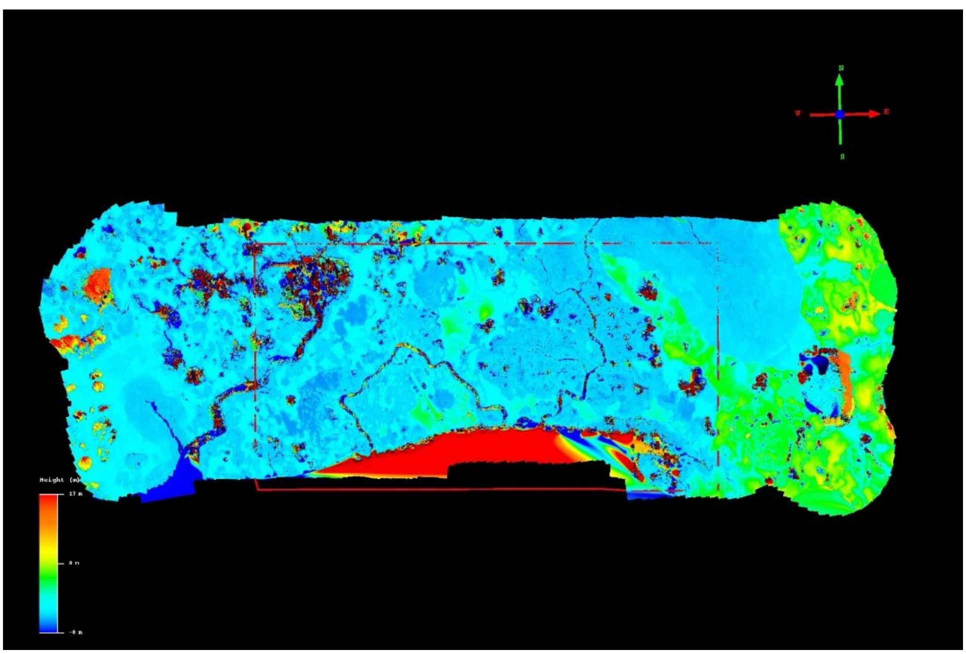
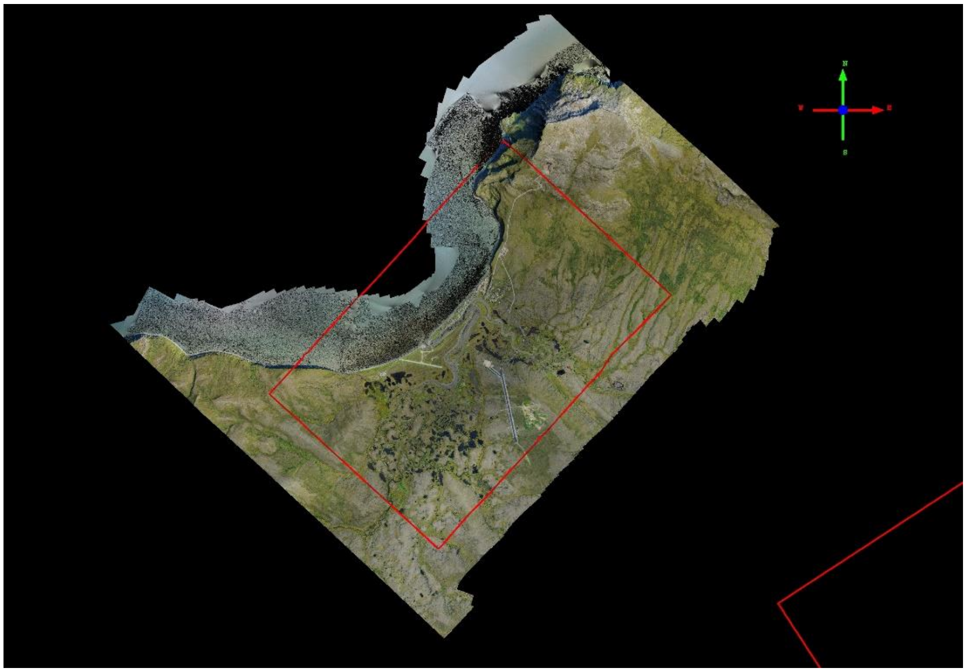


**Image GSD:** 9.4 cm
**DEM posting:** 18.0 cm
**Acquisition Date:** 9/1/2015

# Tununak



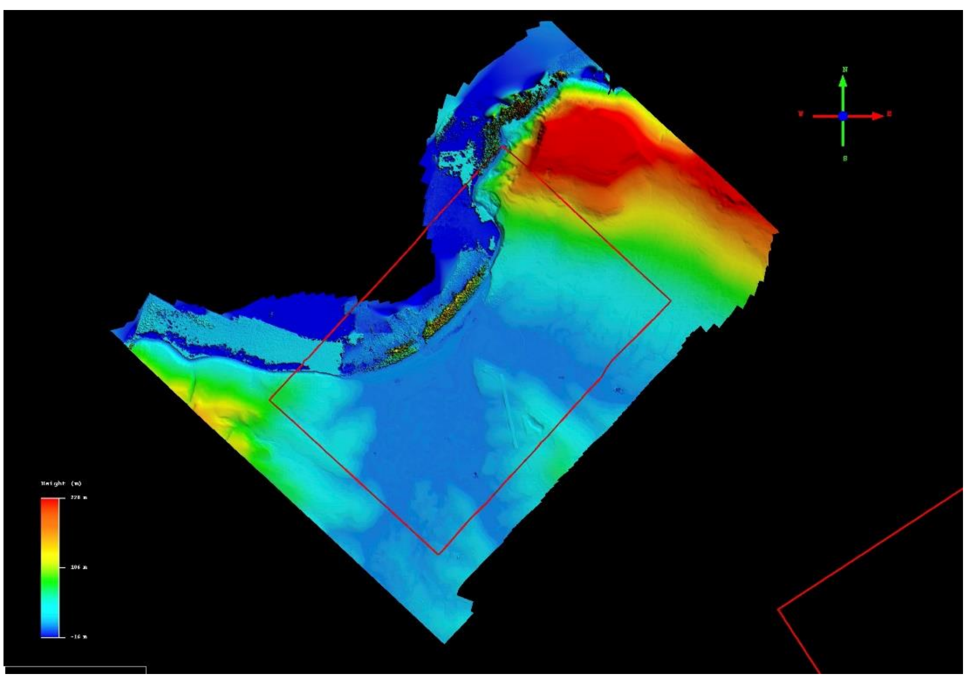
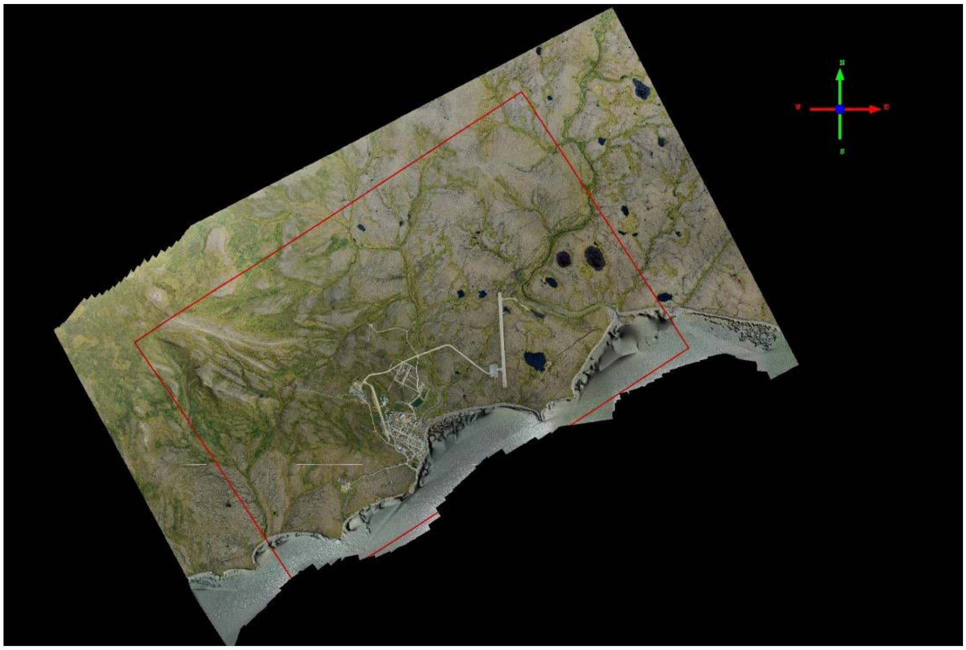


**Image GSD:** 19.7 cm
**DEM posting:** 20.0 cm
**Acquisition Date:** 9/1/2015

# Toksook Bay



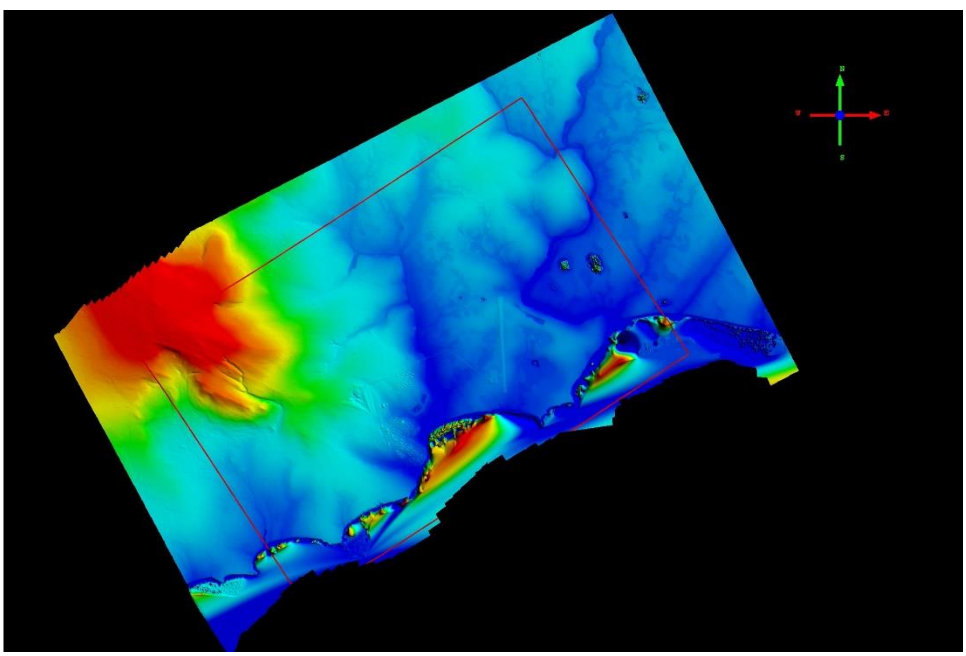


**Image GSD:** 16.6 cm
**DEM posting:** 20.0 cm
**Acquisition Date:** 9/1/2015

# Nightmute

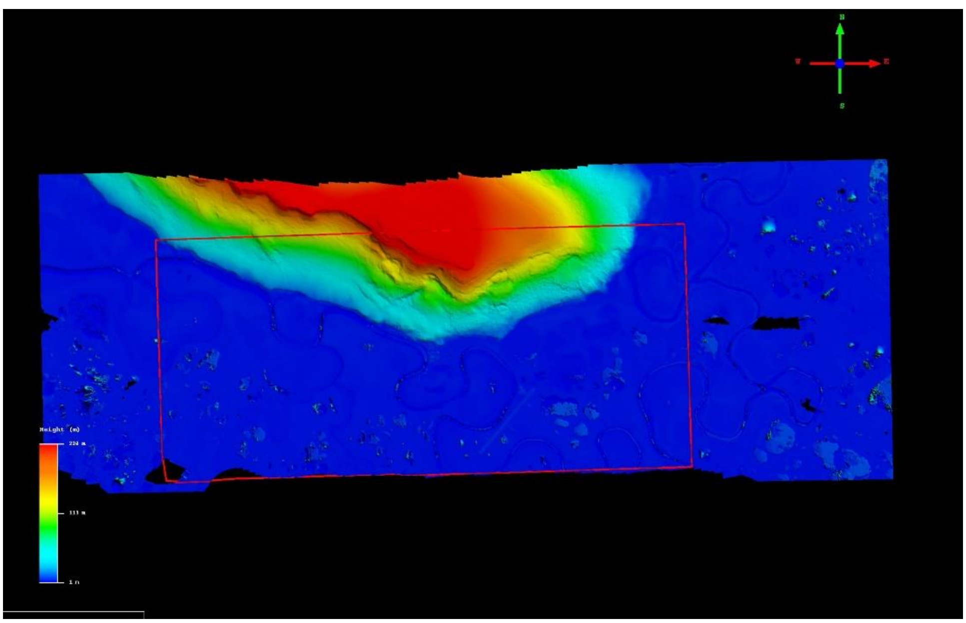
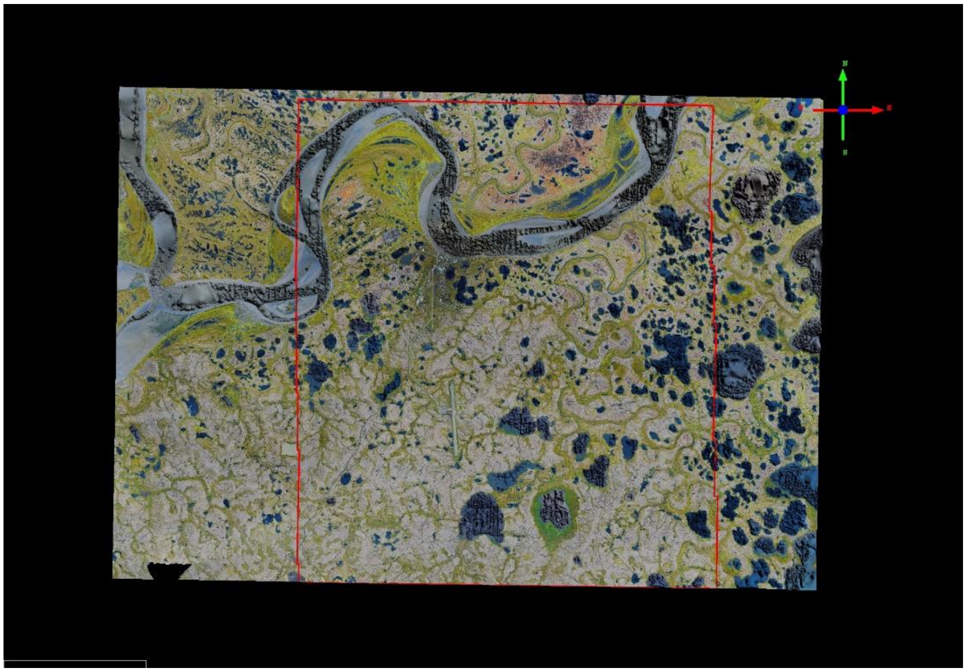


**Image GSD:** 8.8 cm
**DEM posting:** 18.0 cm
**Acquisition Date:** 8/21/2015, 9/1/2015

# Chefornak



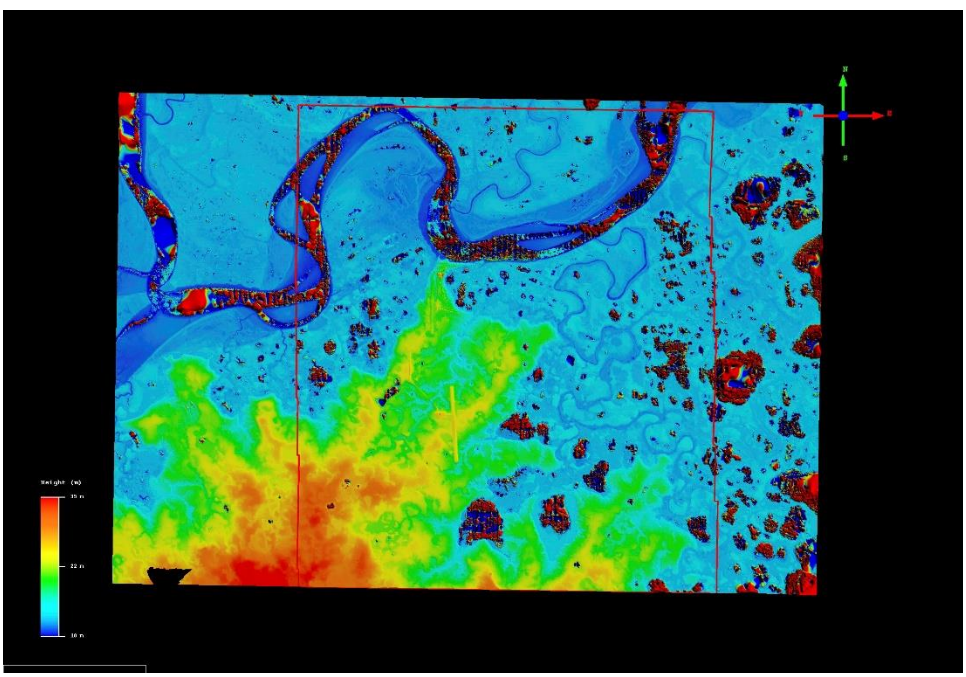


**Image GSD:** 10.1 cm
**DEM posting:** 20.0 cm
**Acquisition Date:** 9/6/2015

# Kipnuk

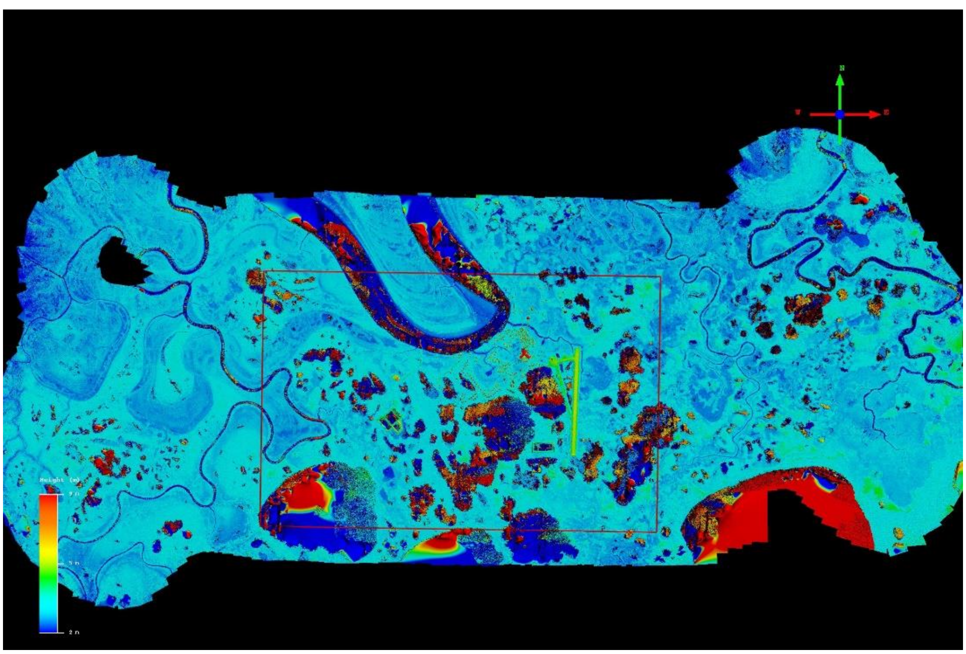
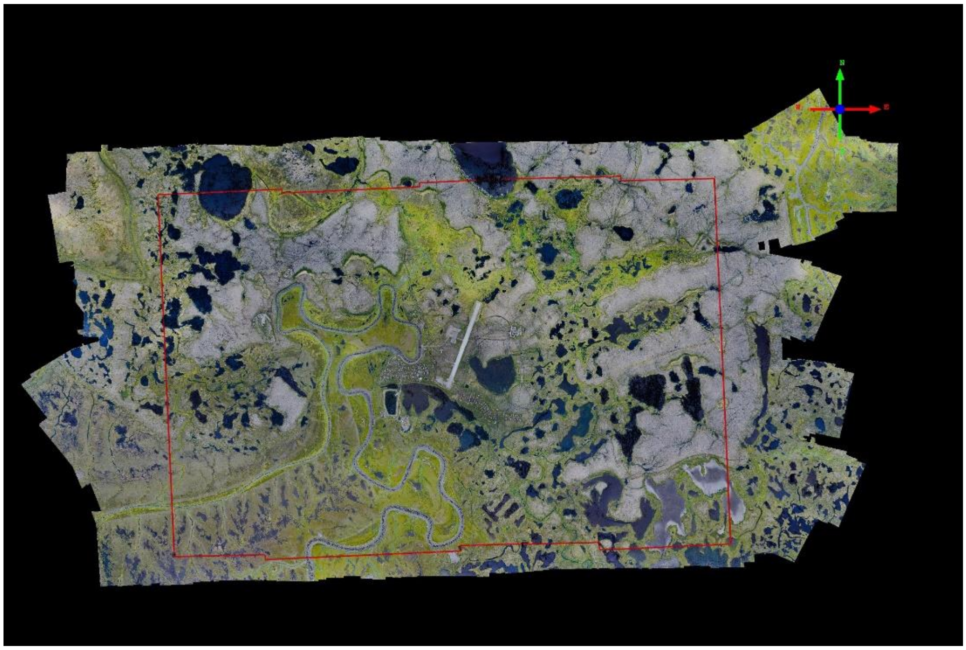


**Image GSD:** 9.6 cm
**DEM posting:** 19.2 cm
**Acquisition Date:** 8/19/2015

# Kong



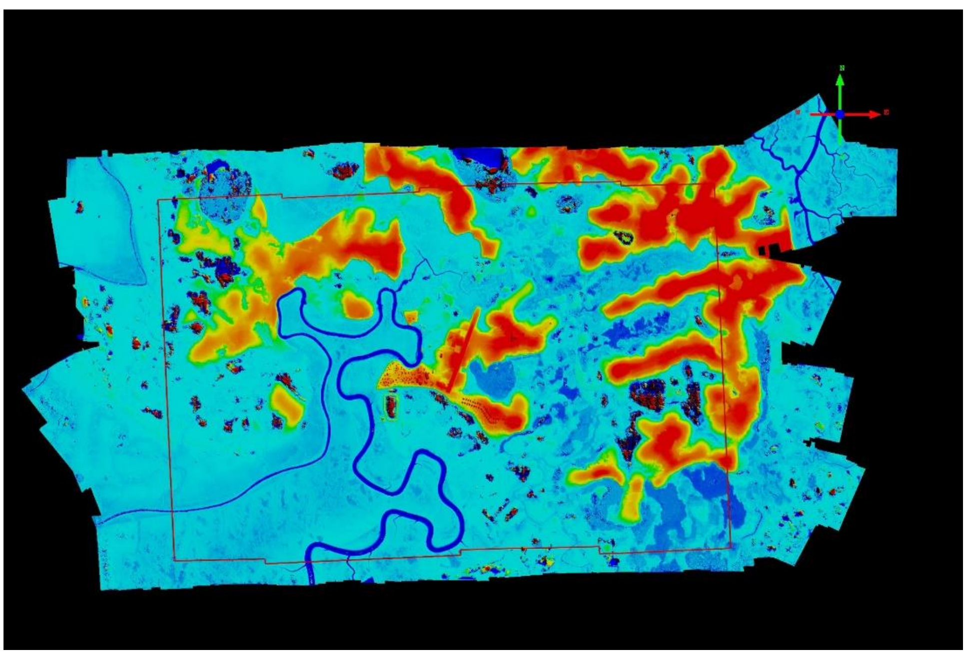
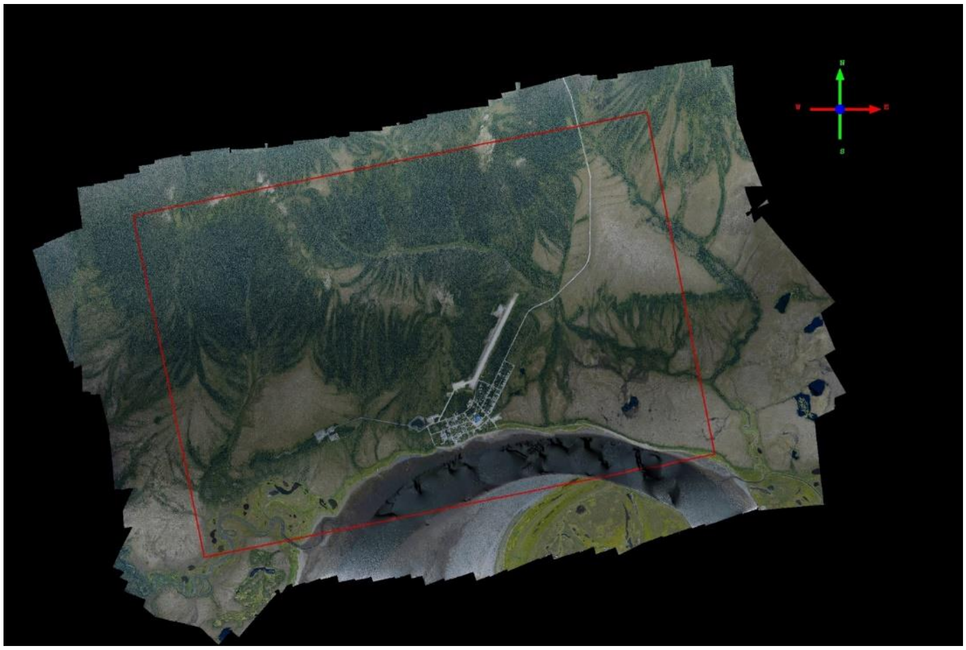


**Image GSD:** 9.2 cm
**DEM posting:** 18.0 cm
**Acquisition Date:** 8/12/2015

# Kwig



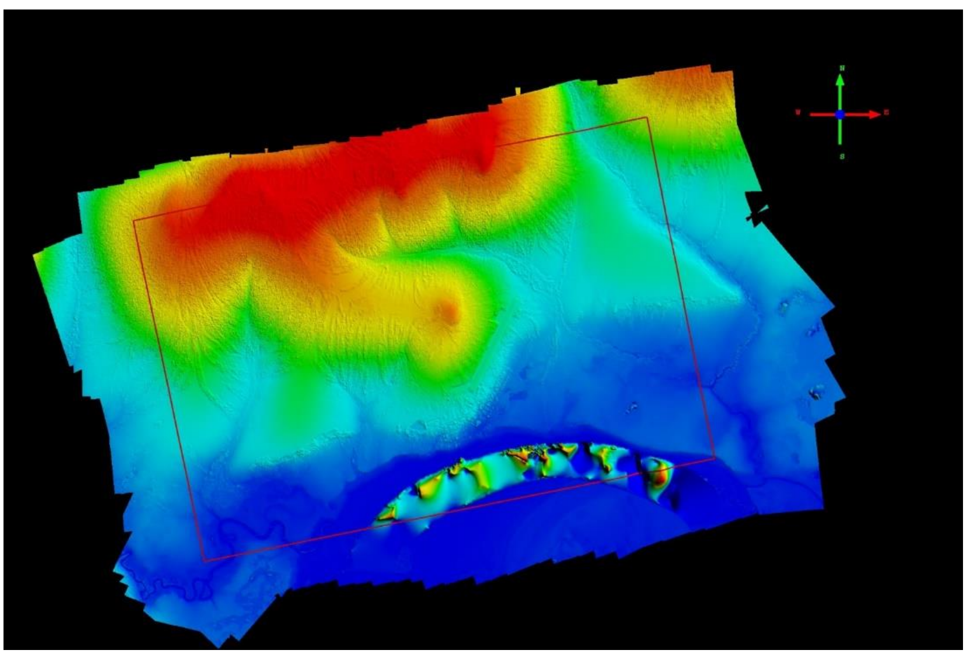


**Image GSD:** 15.1 m
**DEM posting:** 20.0 cm
**Acquisition Date:** 8/21/2015

# Tunt

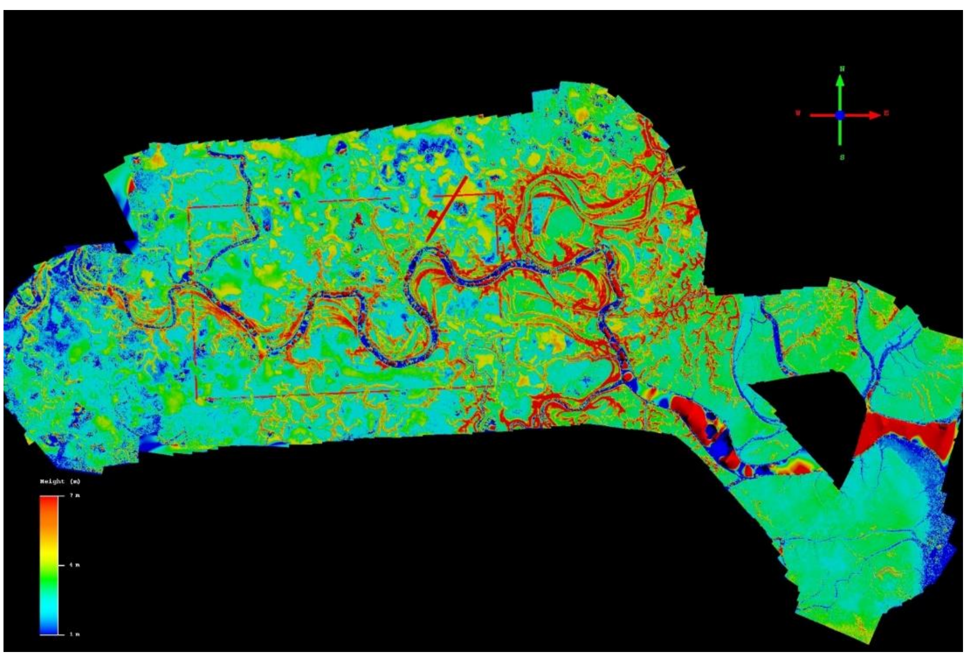


**Image GSD:** 16.5 cm
**DEM posting:** 20.00 cm
**Acquisition Date:** 8/21/2015

# Napakiak

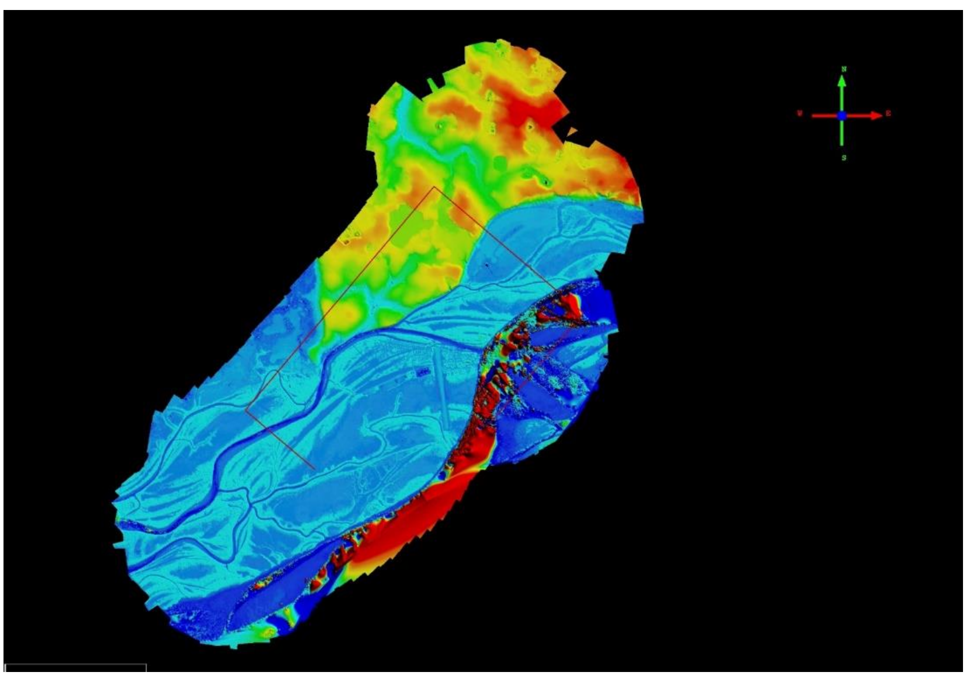


**Image GSD:** 15.2 cm
**DEM posting:** 20.0 cm
**Acquisition Date:** 8/21/2015

# Appendix 2:
# GCP Comparisons

Shown here are photos taken by the GCP collectors compared to 3D visualizations of those locations using the fodar data.

Only the vertical offset is given numerically,
as horizontal offsets were all zero.
Positive numbers mean the GCP was higher than fodar.

# Brevig Mission

| | |
|---|---|
| KTS2 | -0.060m |
| KTS3 | 0.280m |
| KTS5 | -0.160m |
| KTS7 | -0.290m |


Notes say boardwalk is 7 cm higher than ground, so this point is near perfect.


Poor vertical GCP location, deck is 80 cm off ground. Fodar elevation of deck corresponds with GCP height, but not at edge.

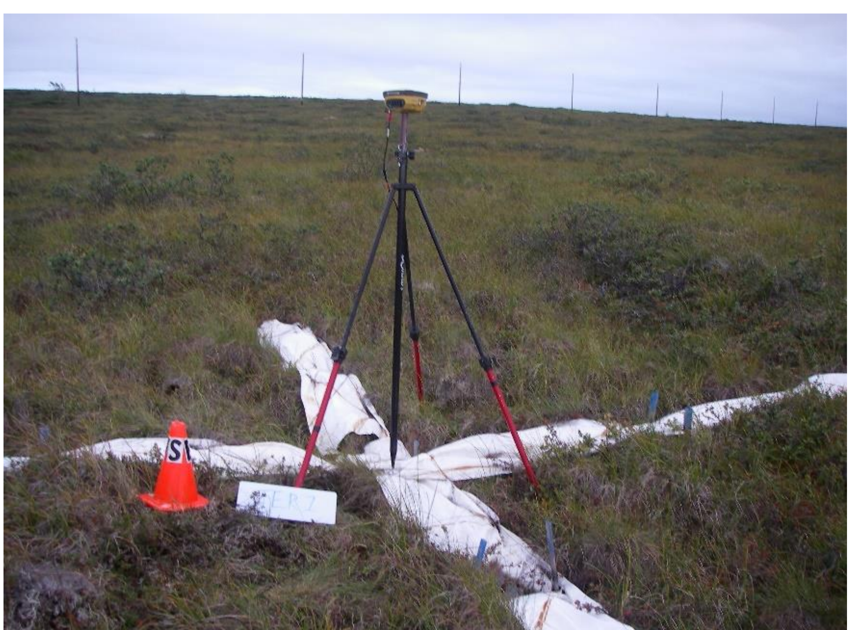

OK vertical point, but slightly in ditch, and not photo target.


Poor vertical GCP, lumber is 10 cm higher, as is bush, and topography is sloped.

# Teller

TER1: 0.210 m

Great horizontal GCP,
OK vertical GCP, as the uneven terrain and
shrubbery adds some unknown noise.

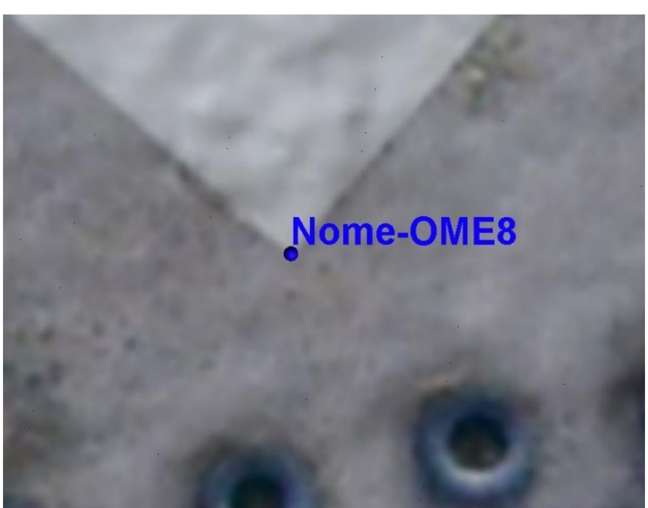



# Nome

OME1: 0.21 m
OME7: 0.13 m
OME8: 0.25 m

These are all great GCPs in vertical and horizontal.





# Golovin

GLV2: 0.17 m
GLV1: 0.16 m

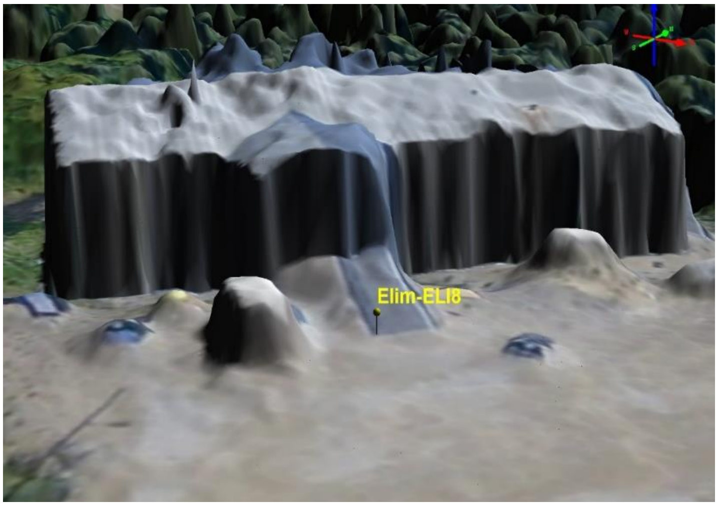
Both GCPs appear fine for both vertical and horizontal, though shrubbery and slightly sloped ground add unknown noise.



# Elim

ELI8: -0.17 m
ELI6: -0.16 m
ELI5: -0.08 m

All GCPs are great horizontally, ELI8 has surrounding terrain variations.

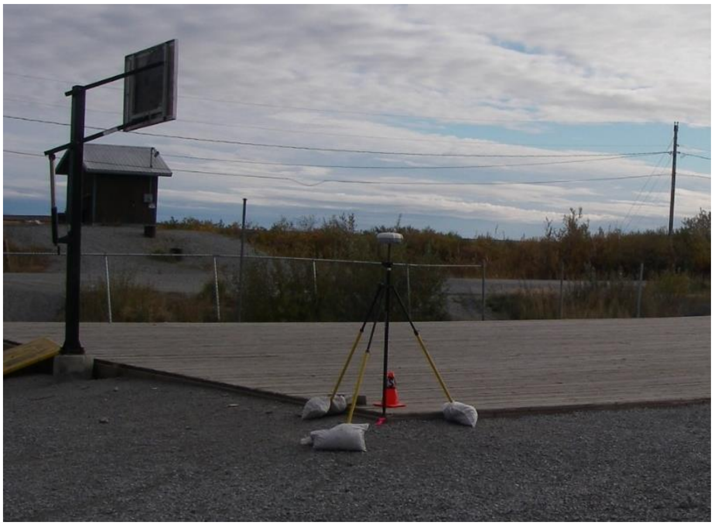




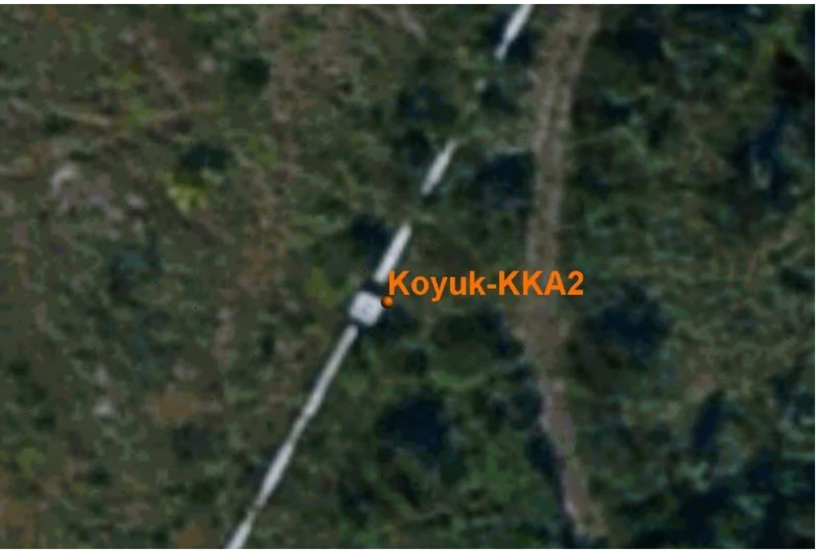
# Koyuk

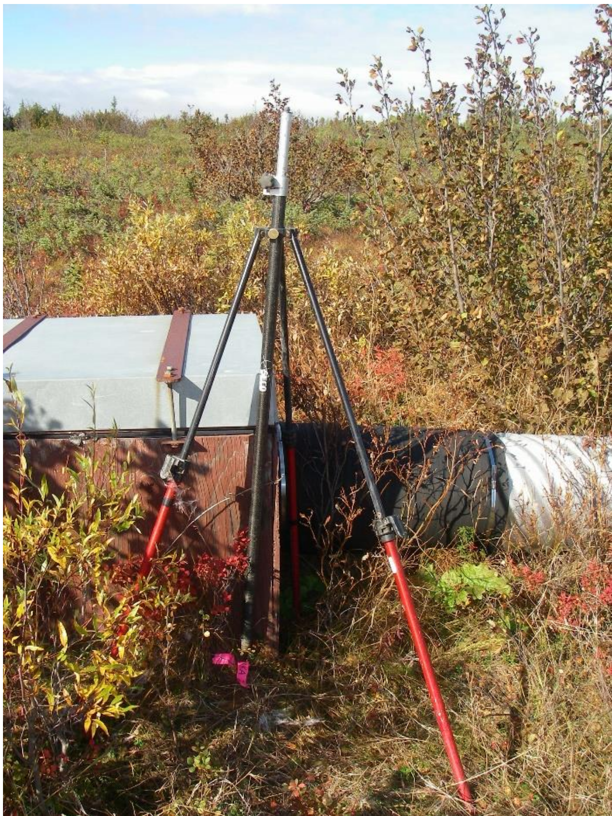
KKA2: 0.78 m
KKA5: 0.80 m

Great GCP for horizontal and vertical.

Poor GCP for vertical.
Fodar shows 0.78 low, but box is 0.84 m high, which is suspicious.

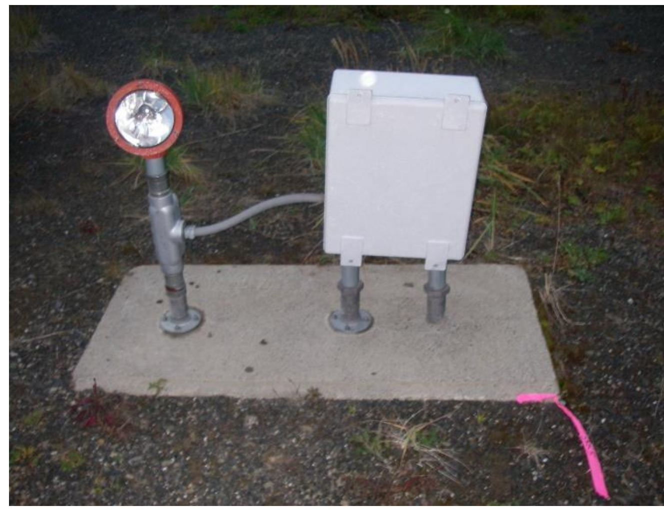


# Shaktoolik

SKK5: -0.29 m
SKK7: -0.12 m

Utility box introduces noise to fodar elevations.

Platform is higher than surrounding terrain.


# Unalakleet

UNK1: 0.21 m
UNK6: 0.30 m

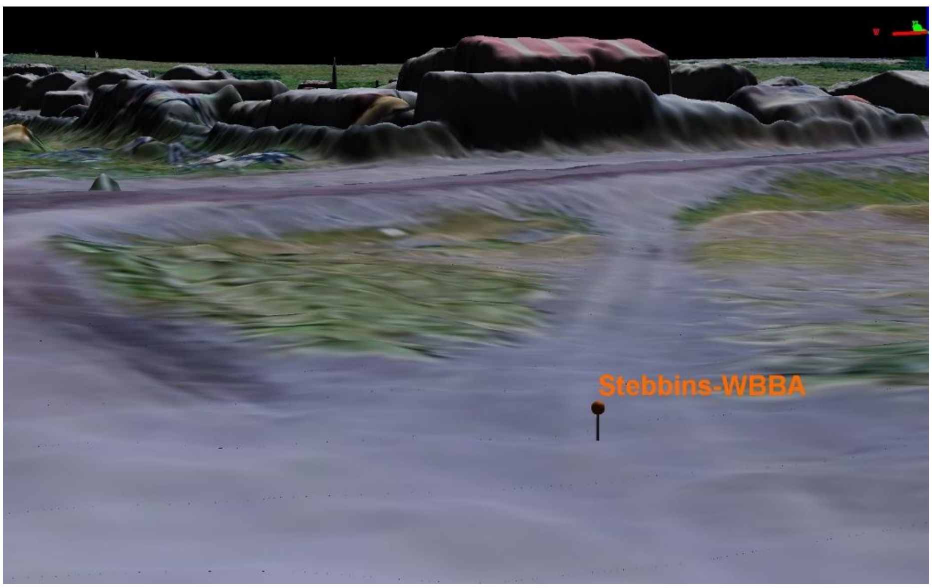
Both appear to be great GCPs in horizontal and vertical, with some vertical noise due to terrain.



# Stebbins

WBBA:  -0.140m

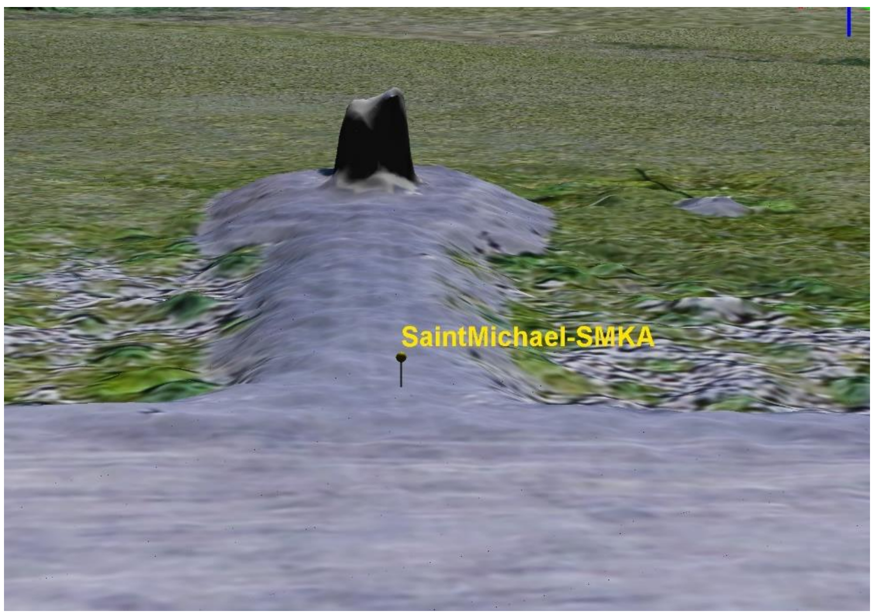
Minor terrain variations around GCP,
no photo identifiable target.

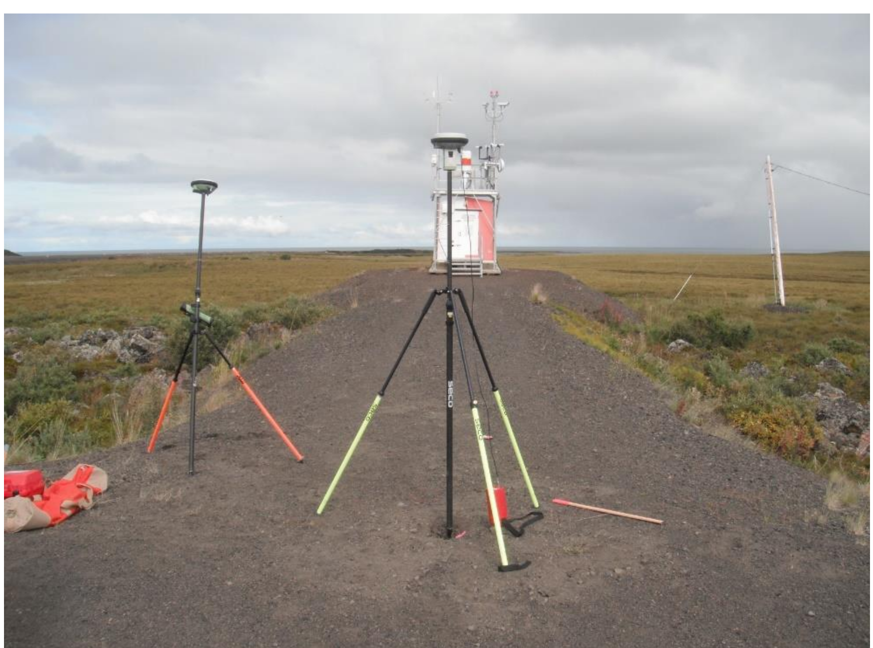



# Saint Michael

SMKA: -0.170 m

Great vertical GCP, no photo identifiable target.

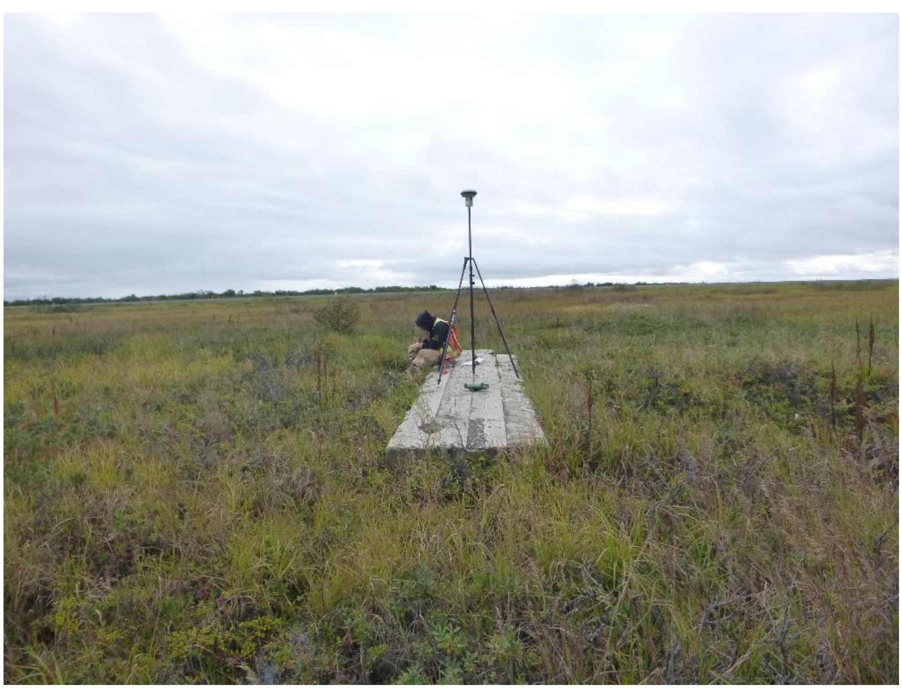


# Kotlik

2A9B: 0.40m

GCP lies above surrounding terrain and introduces noise to fodar

# Emmonak

EMNC: 0.43m

Poor GCP for horizontal – nothing photo identifiable.
Vertical quality ok, but slight slope to terrain.


# Alakanuk

AUKA: 0.39 m

Poor GCP location for horizontal, no notes on distance from edges.  Good GCP for vertical.


# Nunam Iqua

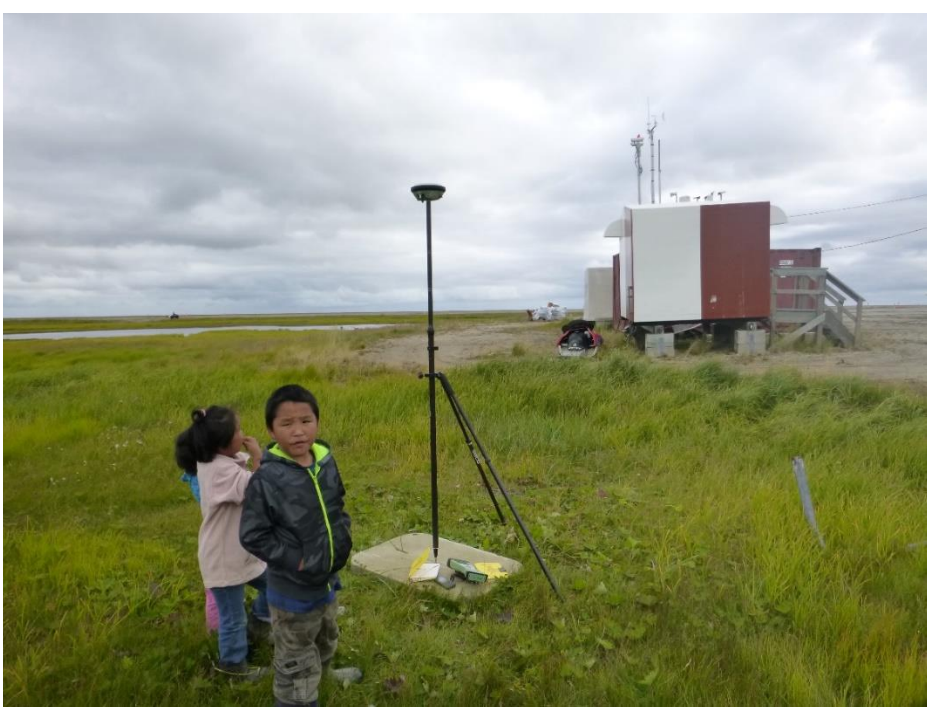
SXPB: 0.32 m

Poor GCP for horizontal, good for vertical but in slight ditch.


# Scammon Bay

SCMC:  0.440 m

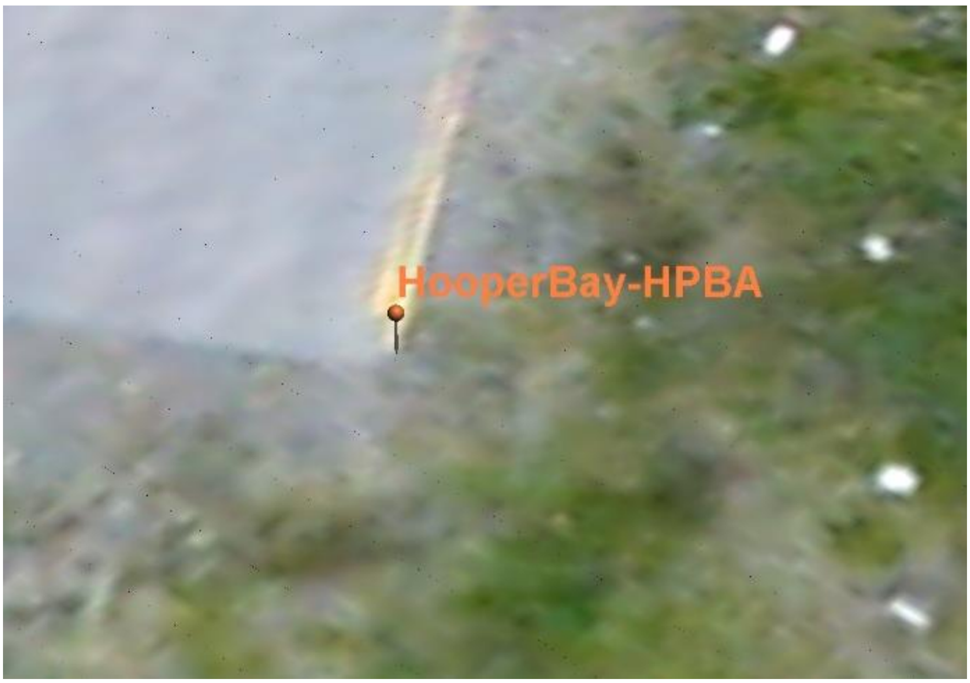
Good GCP for horizontal and vertical.

# Hooper Bay

HPBA: 0.380 m

Good horizontal GCP, terrain variations add slight noise.




# Cheevak

VAKB: 0.290 m

Good horizontal and vertical GCP


# Newtok

EWUB: 0.370 m

OK GCP, at the edge of a vertical change so adds some noise.


# Tunanak

4KAA: -0.10 m

No photo identifiable target, but good vertical.


# Toksook Bay

OOKB: 0.130 m

Great GCP for horizontal and vertical


# Nightmute

IGTB: 0.070 m

Great vertical and horizontal GCP


# Kipnuk

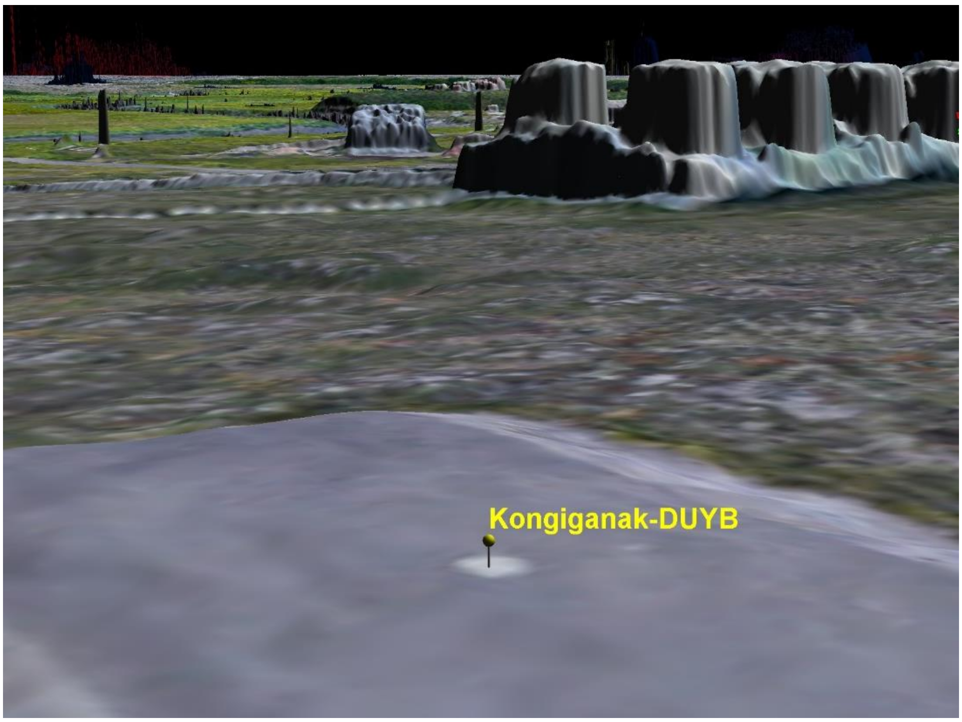
IIKB: 0.210 m

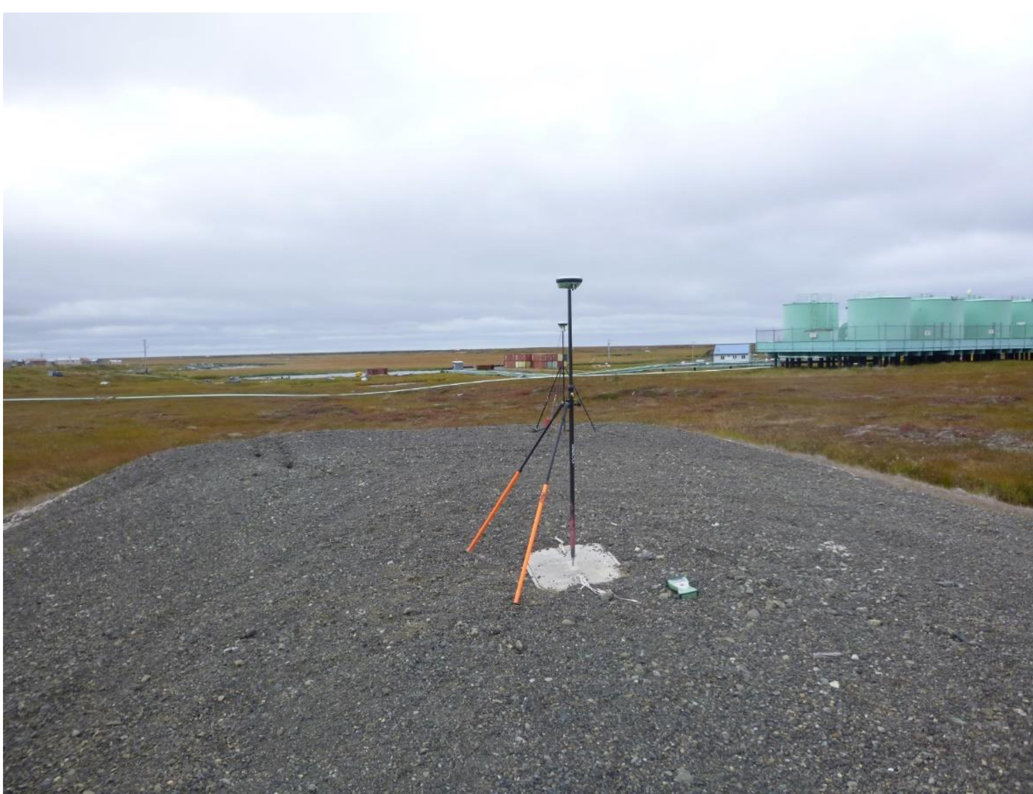
Great GCP for horizontal and vertical


# Kongiganak

DUYB: 0.190 m

Good horizontal and vertical GCP



# Kiwgillingok

GGVB: 0.420 m

OK GCP for horizontal,
surrounding relief adds noise to vertical