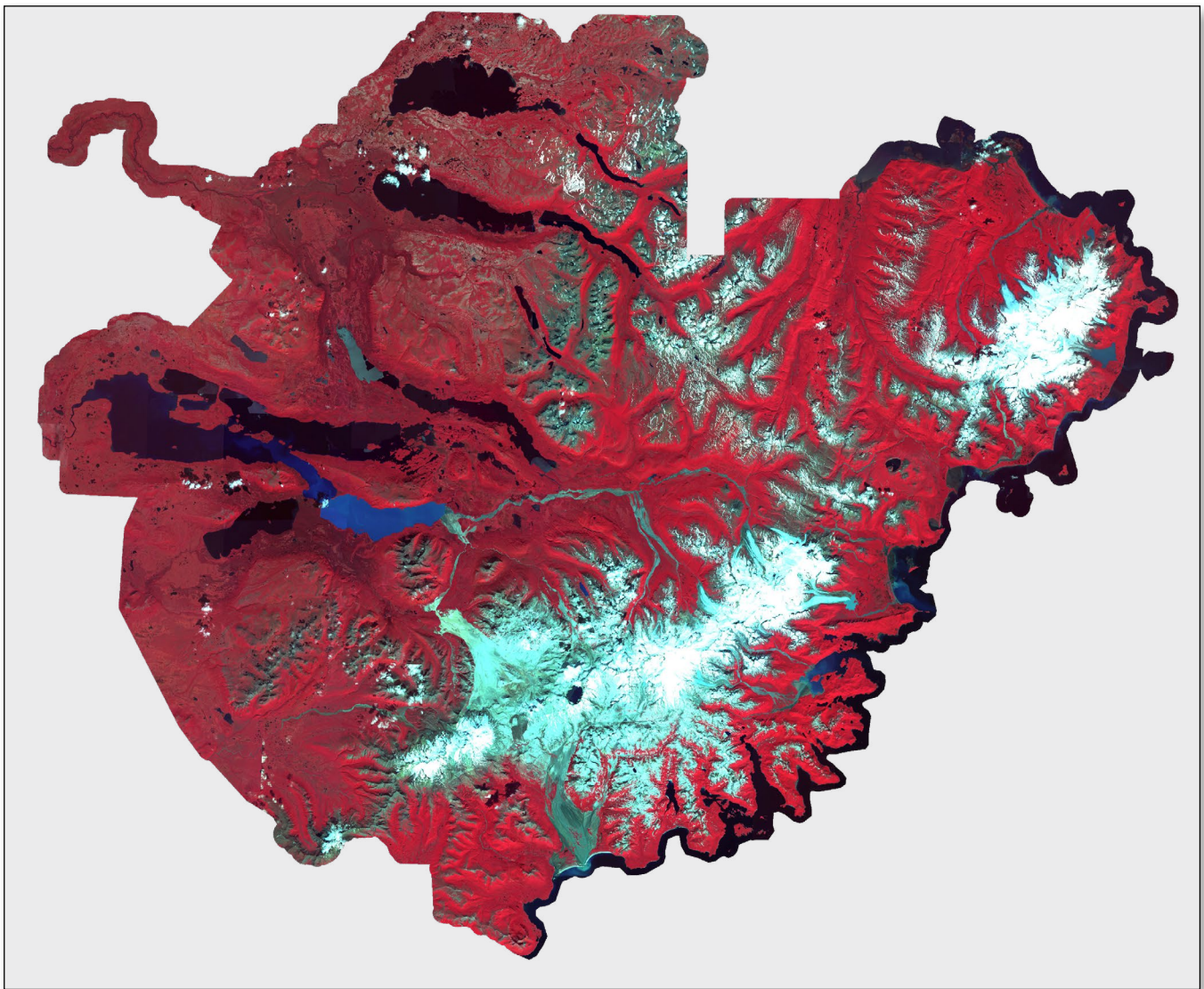




Pleiades Satellite Imagery Acquisition, Processing, and Mosaicking for Katmai National Park and Preserve and Alagnak Wild River, 2014-2016

Natural Resource Report NPS/KATM/NRR—2020/2169



ON THE COVER

Pleiades multispectral surface reflectance mosaic, circa 2015, Katmai and Alagnak, Alaska. See Figure 4 for close-up view. Imagery © CNES (2014-2016), Distribution Airbus DS



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Natural Resource Report NPS/KATM/NRR—2020/2169

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Fort Collins, Colorado

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Abstract

ABR, Inc.—Environmental Research & Services (ABR) worked with the NPS, GeoNorth, and Airbus to prepare a high-resolution satellite imagery mosaic for Katmai National Park and Preserve (KATM) and Alagnak Wild River (ALAG). A set of 4-band (blue/green/red/near-infrared) orthomosaics were compiled from Pleiades satellite imagery collected primarily in summer 2015 over these parklands. The mosaic was based on multispectral satellite imagery (2 m resolution) and pan-sharpened satellite imagery (0.5 m resolution) acquired by the Pleiades constellation of 2 satellites. Positional accuracy met 1:12,000 map scale standards, with 10 m circular error 90% (CE90). The imagery mosaics were color balanced and calibrated to surface reflectance by matching the spectral response to a midsummer Landsat 8 composite using a per-image, per-band linear regression.

Acknowledgements

P. Martyn and B. Koltun (NPS) provided advice on available reference imagery and P. Martyn managed the project. D. Hopwood (GeoNorth) coordinated the imagery acquisition and processing. i-cubed performed the orthorectification for the 2014–2015 imagery. M. Balazs and J. Hickey with GeoNorth performed the orthorectification for the 2016 imagery. D. Dissing (ABR) delineated clouds and prepared report maps, and C.S. Swingley assisted in development of image processing scripts. A. F. Wells (ABR), P. Martyn, B. Koltun, and Brandon Lemire (NPS) reviewed the report, and P. Odom (ABR) formatted the report.

Acronyms and Abbreviations

ABR:	ABR, Inc.—Environmental Research & Services
ALAG:	Alagnak Wild River
AOI:	Area of Interest
CCDC:	Continuous Change Detection and Classification
CE:	Circular error
CIR:	Color infrared
DEM:	Digital Elevation Model
DC:	Digital Count, synonym of DN
DN:	Digital Number
FGDC:	Federal Geographic Data Committee
fSCA:	Fractional Snow Covered Area
GCP:	Ground Control Point
GDAL:	Geospatial Data Abstraction Library
GIS:	Geographic Information System
I&M:	Inventory and Monitoring
IFSAR:	Interferometric Synthetic Aperture Radar
KATM:	Katmai National Park and Preserve
NDSI:	Normalized Difference Snow Index
NPP:	National Park and Preserve
NPS:	National Park Service
QA/QC:	Quality assurance/quality control
RMSE:	Root mean square error
RS:	Remote sensing
SDMI:	Statewide Digital Mapping Initiative
SPOT:	Satellite Pour l’Observation de la Terre
SR:	Surface reflectance
TOAR:	Top of atmosphere reflectance
XML:	eXtensible Markup Language

Introduction

To obtain information on baseline conditions and promote understanding of long-term changes in landscape characteristics and processes in National Parklands the National Park Service (NPS) has developed Inventory and Monitoring (I&M) programs for vegetation, terrestrial wildlife, fish, weather, and coastal and glacial processes. These programs help the NPS to detect natural changes in ecosystem structure and function; to determine the role that human activities (e.g., introduction of invasive species, land disturbances) and broad-scale forces (e.g., climate change, glacial dynamics, volcanism, wildfire) play in the changes observed; and to inform predictions of future ecosystem trajectories. The I&M programs also help the NPS focus their efforts in managing and protecting park resources for the future.

High-resolution (<1 m) satellite imagery is an important Geographic Information System (GIS) and remote sensing (RS) base layer for supporting a variety of activities, including field planning, field navigation, and photo-interpreted and automated analyses of vegetation and landscape features, and is therefore a key component of the I&M program. In support of these objectives, ABR, Inc.—Environmental Research & Services (ABR) worked with the NPS, GeoNorth, and Airbus to prepare a high-resolution satellite imagery mosaic for Katmai National Park and Preserve (KATM) and Alagnak Wild River (ALAG).

A set of 4-band (blue/green/red/near-infrared) orthomosaics were compiled from Pleiades satellite imagery collected primarily in summer 2015 over these parklands. The mosaic was based on multispectral satellite imagery (2 m resolution) and pan-sharpened satellite imagery (0.5 m resolution) acquired by the Pleiades constellation of 2 satellites. The imagery was first cloud-screened using manual masking, then a spectral difference model was applied to select the best imagery to fill

areas that were cloud-affected in all available images. The imagery mosaics were color balanced and calibrated to surface reflectance by matching the spectral response to a midsummer Landsat 8 composite using a per-image, per-band linear regression. Cloudy areas, water, and snow were masked from the model inputs.

Project specifications are as follows:

- A positional accuracy target based on 1:12,000 map scale standards, with 10 m circular error 90% (CE90);
- Cloud cover of 5% or less, using multiple images when necessary;
- Color-balanced pan-sharpened mosaic in 16-bit GeoTiff format;
- Science-ready reflectance calibrated multispectral mosaic in 16-bit GeoTiff format;
- Raw image bundles as ortho-ready panchromatic and multispectral scenes, with associated metadata and ephemeris data;
- Orthorectified single scenes (multispectral, pan-sharpened, and panchromatic);
- Imagery licensed to the National Park Service with a federal/civilian license which allows the data to be shared with all other civilian federal agencies;
- An uplifted license based on the Alaska Statewide Digital Mapping Initiative (SDMI) Statewide SPOT Ortho Image Basemap license (“SDMI license”). The uplift allows the imagery to be shared with U.S state and local governments, academic universities, and Native American tribal governments. It also includes a perpetual non-commercial web services license.
- Descriptive Federal Geographic Data Committee (FGDC) compliant metadata.

Methods

Acquisition

The NPS indicated an interest in an updated high-resolution satellite mosaic for Katmai and Alaganak in early July 2015. ABR identified a preliminary area of interest (AOI) and coordinated with GeoNorth and Airbus to initiate a speculative collect for the AOI. Intensive collections from the two satellites in the Pleiades constellation occurred in July, August, and September 2015. Combined with archived collections from 2013 and 2014, the entirety of Katmai was covered. A portion of Alagnak was not covered in the initial effort, but was collected during summer 2016.

Orthorectification

Based on discussions with the NPS and a review of available control that was collected for the SDMI, we identified two sources of horizontal control that were adequate to meet the 1:12,000 map accuracy standard:

- A 0.5 m orthomosaic covering the Katmai coast, based on 2012 imagery. The mosaic was produced by Aero-Metric, Inc. and the horizontal accuracy was 3 m CE90.
- A 0.3 m orthomosaic covering Brooks Camp and surrounding area, based on 2012 imagery. The mosaic was produced by Aero-Metric, Inc. and the horizontal accuracy was 0.2 RMSE.

There were SDMI control and check points within the footprint of the Brooks Camp orthomosaic, but the orthomosaic had higher accuracy specification and was used instead.

There was also a control point and check point within the AOI east of King Salmon but the scale of 1:18,000 did not meet the project specifications. The Alaska Statewide Digital Mapping Initiative Ortho-Imagery (SPOT), with a national map accuracy standard of 1:24,000 (CE90 of 12.2 meter) also did not meet the project specifications as a source of horizontal control.

For vertical control, the best available in 2015 (when the 2013–2015 imagery was orthorectified) was identified as a SPOT DEM provided by the National Park Service. This was produced by Airbus and had a vertical accuracy of 10 m. When the final 2 Alagnak scenes were processed in 2019, the Interferometric Synthetic Aperture Radar (IFSAR) DEM was available for the study area. This has 3-meter confidence level of 90% for a 0–10 degree slope and a horizontal CE90 of 12.2m. The SPOT DEM was used in the orthorectification of 2013–2015 Pleiades scenes, while the IFSAR DEM was used for the 2016 Pleiades scenes.

Cloud Masking

We manually delineated polygons around cloud-affected areas (clouds and cloud shadows) in each Pleiades image. Two types of cloud status regions were identified in the study area: (1) cloud-free regions that had one or more Pleiades scenes available with negligible clouds; and (2) cloud-affected areas that had one or more Pleiades scenes available, all of which had cloud or cloud-shadow contamination. The cloud-affected areas often had patchy clouds, and we did not attempt to manually delineate each cloud and shadow. Therefore, there were patches of high-quality imagery in the cloud-affected areas. Also, areas with cloud shadows or thin clouds could still have useful information about ground conditions, especially with the high dynamic range of the satellite imagery. The manual cloud masking did miss some small isolated clouds in the nominally cloud-free regions but these are of minimal extent.

Top of Atmosphere Reflectance Calibration

The procedure to calibrate Pleiades satellite imagery to top of atmosphere reflectance (TOAR) is described in the Pleiades User Guide (Coeurdevey and Gabriel-Robez 2012) with an additional term based on Landsat calibration procedures (Chander et al. 2009). It is important to note that for this procedure to be implemented, the digital count values from the source imagery must represent the sensor native radiometric measurements, and that these values are preserved during the orthorectification process. Applying smoothing resampling, such as cubic convolution, during orthorectification is acceptable. However, applying a scale transformation or contrast stretch to the raw pixel values must be avoided during orthorectification. Our process for performing the top of atmosphere reflectance calibration is described below.

First, the pixel digital count values are converted to radiance:

$$L_b = (DC(b) / Gain(b)) + Bias(b)$$

Where:

b is band (blue, green, red, or near-infrared),

L_b is radiance (in $W \cdot sr^{-1} \cdot m^{-2} \cdot \mu m^{-1}$),

$DC(b)$ is the digital count (pixel value),

$Gain(b)$ is a multiplicative calibration factor, and

$Bias(b)$ is an additive calibration factor.

Gain and bias values for the four multispectral bands were provided in the XML metadata files for each raw image. We extracted these values to a tabular format.

Top of atmosphere reflectance (radiance normalized by the incoming solar irradiance) is calculated as:

$$\rho_b = (\pi \times L_b \times d^2) / (E_0 \times \cos(\theta_s))$$

Where:

ρ_b = top of atmosphere reflectance in each band (unitless),

d = Earth-Sun distance (astronomical units),

E_0 = solar irradiance for that band, and

θ_s = solar zenith angle (degrees).

The solar irradiance value for each of the four multispectral bands and the solar elevation angle for the center of the image were stored in the XML metadata file for each raw image. Solar zenith angle was calculated as 90 minus the solar elevation angle. The Pleiades User Guide (Coeurdevey and Gabriel-Robez 2012) omitted the term for Earth-Sun distance. This term accounts for the fact that the solar radiance is lower when the Earth is further from the sun. We included this term in our calculations using values from Chander et al. (2009). We extracted these data for each source image and stored the results in tabular format. We applied the radiance and reflectance calibrations in a single raster processing step, scaled the final output by 10,000, and stored the results as signed 16 bit multiband GeoTiff files.

The Earth-Sun distance is a function of day of year with the Earth most distant from the sun during 3–6 July (1.0167 astronomical units [Chander et al. 2009]). For 3–6 July, the calculated top of atmosphere reflectance value was about 3.4% higher than it would have been without the Earth-Sun distance term. The Earth was somewhat closer to the sun for other dates used in the mosaic, which ranged from 6 June (1.00952 astronomical units) to 1 September (1.00922 astronomical units). The calculated top of atmosphere values was about 1.9% higher for 6 June and 1 September than it would have been without the Earth-Sun distance term.

Atmospheric Correction/Normalization

Landsat Reference Image

We normalized the imagery for atmospheric effects by matching the blue, green, red, and near-infrared bands of each Pleiades image to a Landsat 8 composite with the same

bands. The Landsat 8 composite was developed in Google Earth Engine using all available Landsat 8 Tier 1 and 2 Surface Reflectance (SR) imagery with an RMSE <15 m from July and August, 2013–2018. The quality assurance (QA) bands were used to mask clouds and cloud shadows and the median surface reflectance value was extracted from the remaining observations. There were holes with no observations after QA masking, mostly because high elevation areas are often cloudy, and the few cloud-free observations over snow and patchy snow are often erroneously classified as cloud. To fill the holes, we first used Landsat 7 imagery with the same QA mask, but a longer record (1999–2018). To fill the small holes that remained after this process, we used median reflectance from the Landsat 7 and 8 time series without any QA masking.

Masking for Calibration Pixels

We carefully masked each Pleiades image and the corresponding pixels of the Landsat reference image to determine the portion of each Pleiades image that would be used for modeling the relationship between Pleiades pixel values and the Landsat reference surface reflectance. The objective was to exclude areas that had highly dynamic reflectance that was not an appropriate target for normalization. First, areas digitized as cloud-affected in each Pleiades scene were masked. These areas were highly variable and affected by clouds and cloud shadows in the Pleiades imagery. Second, we excluded areas mapped as water based on a global surface water map (Pekel 2016) that had been developed using Landsat imagery. Areas with water occurrence >50% were masked out. Water areas are subject to fluctuations in reflectance based on turbidity, ice, inundation dynamics, channel migration, and sun glint. The sun glint problem can be particularly severe for imagery collected at non-nadir imaging geometry, such as the Pleiades imagery.

Finally, we used a new snow phenology product that we recently developed to exclude areas that were expected to have snow cover at the time of the Pleiades acquisition, or within the preceding 14 days. Even small amounts of snow cover in or adjacent to a pixel can have a large effect on spectral values. We used a newly developed “last snow day” metric to mask areas that were expected to have any snow cover for the acquisition date of each Pleiades image, or up to 14 days earlier. The 14-day buffer provided extra assurance that snow-affected ground and areas adjacent to snow-affected ground was excluded from the image normalization.

The new snow phenology product incorporates the Landsat Fractional Snow Covered Area (fSCA) algorithm (Painter et

al 2009, Selkowitz et al. 2017). With fractional snow cover, snow presence can be more accurately mapped when it covers a small portion of the ground (down to 15%). Based on our initial evaluation, it appears to do a better job of mapping snow absence compared to traditional methods using a Normalized Difference Snow Index (NDSI) threshold. We obtained all the Landsat snow fraction data available for 2000–2017 (2018–2019 had not yet been processed). Then, we calculated the median snow fraction for bimonthly epochs (e.g., all images for 1–15 May, 2000–2017). The median snow cover fraction was assigned to the midpoint of each epoch (e.g., 8 May). Then, we interpolated to a daily time step (e.g., a pixel that was 80% snow covered on 23 April and 20% snow covered on 8 May was estimated as 50% snow-covered on 1 May). Finally, we extracted the last date with $\geq 15\%$ snow cover as the “last snow day”. We think this is a more sensitive indicator of true snow absence than the NDSI based snow persistence analysis described in Wells et al. (in review). The NDSI threshold method determines snow absence when NDSI drops below 0.4, among other conditions (Hall et al., 1995; Hall et al., 2002, Macander et al. 2015). However, visual interpretation of Landsat imagery time-series during and after the snowmelt season indicates that remnant snow remains, e.g., in subpixel drift traps, after NDSI drops below 0.4. With a lower NDSI threshold than 0.4, errors mapping non-snow surfaces as snow can occur. We think that the spectral mixture modeling approach of the Landsat fSCA performs better at detecting pixels where snow is present but of low extent (e.g., 15–50%). Since small extents of snow can have a large effect on the observed reflectance, and can be highly variable over the season, it is important to exclude such pixels from the normalization calibration.

Surface Reflectance Normalization

The masking described above was performed at 30-m resolution, i.e. the resolution of the Landsat imagery. The same 30-m masks were applied to the multispectral Pleiades imagery. For the multispectral imagery, we used data that had been calibrated to top of atmosphere reflectance as the input to the normalization. However, we note that the conversion from Pleiades digital count to top of atmosphere reflectance is a linear function, so performing this step is not necessary to the normalization procedure here. Using Pleiades digital count values as inputs to the calibration should yield the same result as using Pleiades top of atmosphere reflectance.

Each masked, multispectral Pleiades image was aggregated to 30-m resolution using averaging. A linear fit was calculated using the unmasked, aggregated Pleiades pixels and the cor-

responding Landsat reference pixels. The unmasked pixels represent the range of variability in the non-snow land portion of each Pleiades image. The slope and offset parameters of the linear fit for each band in each Pleiades image was applied to the original, unmasked, full-resolution Pleiades image to generate a calibrated image with estimated surface reflectance values at 2-m resolution. The normalization analyses were performed in Google Earth Engine. A table with the offset and slope coefficients for each band in each Pleiades image was exported.

We calculated (at 30-m resolution) the absolute value of the difference between normalized Pleiades reflectance and Landsat reference reflectance for each band to map how well the normalized Pleiades image matched the Landsat reference. We then calculated the sum of the absolute differences for all four bands. This summed absolute difference metric provided a spatial map of how well the Pleiades and Landsat matched.

We performed the same masking and linear regression procedure to normalize the pan-sharpened imagery. There was no intermediate linear adjustment to top of atmosphere reflectance, but instead the imagery was normalized directly from digital count to surface reflectance. For the pan-sharpened imagery, we used GDAL scripts to calculate a normalized, surface reflectance output for each pan-sharpened Pleiades image based on the calibration coefficients exported from Google Earth Engine.

Mosaicking and Color Balancing

We developed mosaic cutlines using a two-stage automated approach. First, the cloud-free regions were mosaicked using the Pleiades image that was acquired closest to July 31. This is near peak phenology and is the center date of the Landsat reference imagery. For the cloud-affected regions, we mosaicked using the Pleiades image with the smallest absolute difference from the Landsat reference.

The multispectral mosaic was exported from Google Earth Engine with surface reflectance estimates for four bands and several metadata bands, including a unique image code representing the source imagery scene. Vector mosaic cutlines were developed by exporting the unique image code raster to a vector format. The cutline layer includes a unique code for each Pleiades image, that can be used to lookup metadata for the specific image used in each part of the mosaic (e.g. acquisition date and time, sun and sensor geometry).

For the pan-sharpened mosaic, we created an ArcGIS mosaic dataset from the normalized pan-sharpened images, then

imported the cutline geometry. We defined and updated the overviews, and then exported the mosaic to a tiled GeoTiff. We used GDAL to build overviews for the GeoTiff using a smooth Gaussian kernel.

Because each scene was normalized to a common Landsat reference that was based on midsummer surface reflectance, an additional color balancing step was not required. High radiometric resolution was maintained throughout the process, with the pixel values stored as signed 16 bit integers and scaled by 10,000 (so the range 0–10,000 represents surface reflectance values of 0–1). Different contrast stretches may be applied to the imagery for different purposes.

Results and Discussion

Acquisition

The Pleiades constellation was exceptionally effective at acquiring a large and challenging study area, mostly within a single growing season. Table 1 lists the source images acquired and delivered for this work, with selected metadata fields. All of the images had incidence angles $<25^\circ$. The sensor azimuth angles are around 180° , based on the metadata. This describes the angle between geographic north and the image line direction on the ground (Coeurdevey and Gabriel-Robez 2012). This is different from the azimuth angle reported for some other high resolution satellite imagery (e.g., WorldView-2), which typically has a wide range of sensor azimuth angles because the satellite points to the side to collect targets that are not directly below. The Pleiades user guide (Coeurdevey and Gabriel-Robez 2012) clarifies that the reported azimuth is different from other conventions.

The user must not confuse this azimuth definition with other conventions, typically the angle between geographic North and satellite track on the ground as shown on Figure 46. If the azimuth of the satellite track is not provided, then Figure 46 is for information only.”

The azimuth of the satellite track does not appear to be directly provided in the metadata delivered with the raw Pleiades imagery. Apparent reflectance varies based on the sun-sensor geometry and the bidirectional reflectance distribution function of the surface, and for some applications careful interpretation of the sensor geometry is critical. For such analyses, careful review of section “C.4 Other Informative Geometric Data” (Coeurdevey and Gabriel-Robez 2012) and the source imagery metadata files would be necessary. Sensor geometry is not used in any of our analyses.

Orthorectification

Detailed results of photogrammetric bundle adjustments of the blocks are found in the QA/QC report deliverables provided by GeoNorth.

For the 2013–2015 scenes, the orthorectification bundle adjustment process was performed by GeoNorth and i-cubed and is described here:

Due to the lack of adequate distribution of horizontal control, the orthorectification process was carried out in 6 independent photogrammetric blocks. Block_1a was controlled to the 2012 CIR orthos using manually derived GCPs and automat-

ically derived tie points. [Block 1b was controlled to the Brooks Camp orthomosaic.]

Once an adequate bundle adjustment was achieved, the scenes were orthorectified. These 1st generation scenes were then used as control images for Block_2a and Block_2b. At this stage, an automatic GCP collection algorithm was employed to collect hundreds of GCPs between the scenes of Block_2a and Block_2b and the 1st generation orthos. A GCP refining process was utilized to discard outliers in an iterative process until a desired result was achieved (~ 1.5 m RMSE to 1st generation orthos), after which the scenes were orthorectified.

Following this, the 2nd generation scenes were used to control the remaining scenes that had no control and did not intersect the 1st generation scenes. In order to avoid geometric drift, 2 scenes were orthorectified using RPC info only so as to provide anchors for 3rd generation orthos. Automatic GCPs were collected from the 2nd generation and RPC orthos to the remaining orthos in Block 3a and 3b.

The horizontal accuracy metrics from each block are summarized in Table 2. All blocks easily met the target 1:12,000 map scale standards, with < 10 m circular error 90% (CE90). The distribution of the GCPs (Figure 1) shows that the first generation ortho scenes and GCPs along the coast and at Brooks Camp. The second and third generation orthos had GCPs distributed over most of the study area. Block 4 is GCPs over the two additional images covering Alagnak, which were processed independently.

Cloud Masking

The manual cloud masking to identify cloud-free vs. cloud-affected regions of the mosaic was effective, but time-consuming. There are some cloud files included with the raw imagery. However, these were not orthorectified and so it would take extra work to incorporate them. It would be useful to evaluate them in more detail, but this was beyond the scope of this project. Based on experience with other high-resolution satellite imagery, these layers are often of poor quality. We recommend that orthorectification of the mask layers included with the raw data be specified as a deliverable on future orthorectification jobs to facilitate review and potential use of these layers.

Table 1. List of source images and selected metadata for Pleiades acquisitions, 2013–2016, Katmai and Alagnak, Alaska.

Image Code	ISO Date String	Pleiades Satellite ID	Sensor Azimuth	Incidence Angle	Sun Azimuth	Sun Elevation	Mean Ground Sample Distance (m)
1	2013-07-13Z21:45:54.9	1A	180.0	6.0	165.1	52.4	0.71
2	2013-07-13Z21:46:13.4	1A	180.0	15.8	165.1	52.4	0.74
3	2013-09-23Z21:43:25.8	1B	180.1	5.4	171.4	31.5	0.71
4	2014-06-09Z21:49:37.3	1A	180.0	17.8	167.8	54.8	0.75
5	2014-07-26Z21:39:41.4	1A	180.0	11.4	161.7	50.5	0.72
6	2015-06-15Z21:46:20.9	1A	180.0	11.6	166.6	53.9	0.72
7	2015-07-11Z21:46:34.5	1A	180.0	11.9	167.4	52.9	0.72
8	2015-07-11Z21:46:46.0	1A	180.0	17.1	167.1	52.9	0.75
9	2015-07-11Z21:46:59.6	1A	180.1	19.5	166.5	53.1	0.77
10	2015-07-19Z21:34:11.5	1B	179.9	18.5	162.5	51.4	0.76
11	2015-07-19Z21:34:37.4	1B	180.0	10.3	161.1	51.6	0.72
12	2015-07-19Z21:34:55.4	1B	180.0	14.3	162.6	51.2	0.74
13	2015-07-19Z21:35:12.0	1B	180.0	17.2	161.9	51.7	0.75
14	2015-07-31Z21:41:40.4	1B	180.0	19.6	164.9	48.7	0.77
15	2015-07-31Z21:42:10.0	1B	180.0	5.0	164.4	48.8	0.71
16	2015-07-31Z21:42:21.9	1B	180.0	0.9	164.3	49.2	0.70
17	2015-07-31Z21:42:42.8	1B	180.0	16.3	164.8	48.9	0.74
18	2015-07-31Z21:42:59.3	1B	180.0	18.6	164.1	49.5	0.76
19	2015-08-01Z21:34:45.0	1A	180.0	18.2	162.9	48.4	0.76
20	2015-08-01Z21:34:59.0	1A	180.0	13.1	162.4	48.4	0.73
21	2015-08-01Z21:35:16.4	1A	180.0	12.2	161.4	48.8	0.73
22	2015-08-01Z21:35:34.3	1A	180.0	16.2	162.9	48.3	0.74
23	2015-08-01Z21:35:48.3	1A	180.0	19.1	161.8	48.7	0.76
24	2015-08-05Z21:53:10.3	1B	180.0	16.1	167.1	47.6	0.74
25	2015-08-05Z21:53:26.0	1B	180.0	8.7	166.6	47.7	0.72
26	2015-08-05Z21:53:41.6	1B	180.0	3.5	166.2	47.8	0.71
27	2015-08-05Z21:53:57.0	1B	180.0	16.0	167.9	47.6	0.74
28	2015-08-05Z21:54:13.8	1B	180.0	19.4	167.3	47.9	0.76
29	2015-08-07Z21:38:27.6	1B	180.0	8.0	163.7	46.5	0.71
30	2015-08-07Z21:38:40.8	1B	180.0	6.2	164.9	46.9	0.71

Table 1. List of source images and selected metadata for Pleiades acquisitions, 2013–2016, Katmai and Alagnak, Alaska, continued.

Image Code	ISO Date String	Pleiades Satellite ID	Sensor Azimuth	Incidence Angle	Sun Azimuth	Sun Elevation	Mean Ground Sample Distance (m)
31	2015-08-07Z21:38:50.0	1B	180.0	9.9	164.5	47.0	0.72
32	2015-08-07Z21:39:01.3	1B	180.0	17.7	163.6	46.9	0.75
33	2015-08-11Z21:57:09.4	1A	180.0	24.7	170.6	45.8	0.80
34	2015-08-11Z21:57:18.3	1A	180.0	23.4	169.4	46.5	0.79
35	2015-08-11Z21:57:42.0	1A	180.0	13.6	170.3	45.8	0.73
36	2015-08-11Z21:58:00.0	1A	180.0	12.5	169.2	46.7	0.73
37	2015-08-11Z21:58:19.1	1A	180.1	23.6	170.2	46.2	0.80
38	2015-08-24Z21:56:55.8	1B	180.0	22.0	171.4	42.2	0.78
39	2015-08-24Z21:57:09.4	1B	180.0	20.1	171.2	42.6	0.77
40	2015-08-24Z21:57:26.8	1B	180.0	12.4	170.5	42.5	0.73
41	2015-08-24Z21:57:40.4	1B	180.0	13.9	170.9	42.5	0.73
42	2015-08-24Z21:58:00.1	1B	180.0	17.3	170.5	42.7	0.75
43	2015-08-31Z21:53:07.4	1B	180.0	21.2	170.2	39.6	0.78
44	2015-08-31Z21:53:16.5	1B	180.0	16.1	169.8	39.5	0.75
45	2015-08-31Z21:53:25.5	1B	180.0	11.6	169.4	39.5	0.73
46	2015-08-31Z21:54:10.4	1B	180.0	15.0	170.1	39.9	0.74
47	2015-08-31Z21:54:23.0	1B	180.1	21.8	171.2	40.3	0.78
48	2015-08-31Z21:54:32.1	1B	180.0	23.8	170.5	40.3	0.80
49	2015-09-01Z21:46:23.5	1A	180.0	3.5	168.8	39.1	0.71
50	2015-09-01Z21:46:41.3	1A	180.0	7.1	168.5	39.1	0.71
51	2015-09-01Z21:46:55.8	1A	180.0	10.9	169.1	39.7	0.72
52	2015-09-01Z21:47:05.3	1A	180.0	15.7	169.1	39.7	0.74
53	2016-08-30Z21:45:31.1	1A	180.1	11.7	167.2	39.1	0.73
54	2016-08-30Z21:45:39.1	1A	180.0	9.1	166.9	39.1	0.72

Table 2. Summary of horizontal accuracy metrics for ground control point (GCP) blocks for orthorectification of Pleiades imagery, 2013–2016, Katmai and Alagnak, Alaska.

Block	RMSE (internal, m)	CE90 (internal, m)	CE90 (overall, m)
1a	1.60	2.42	3.85
2a, 2b	1.12	1.70	4.20
3a, 3b	1.58	2.40	4.84
4 (2016-08-30Z21:45:31.1)	1.26	3.43	4.48
4 (2016-08-30Z21:45:39.1)	1.40	3.09	4.33

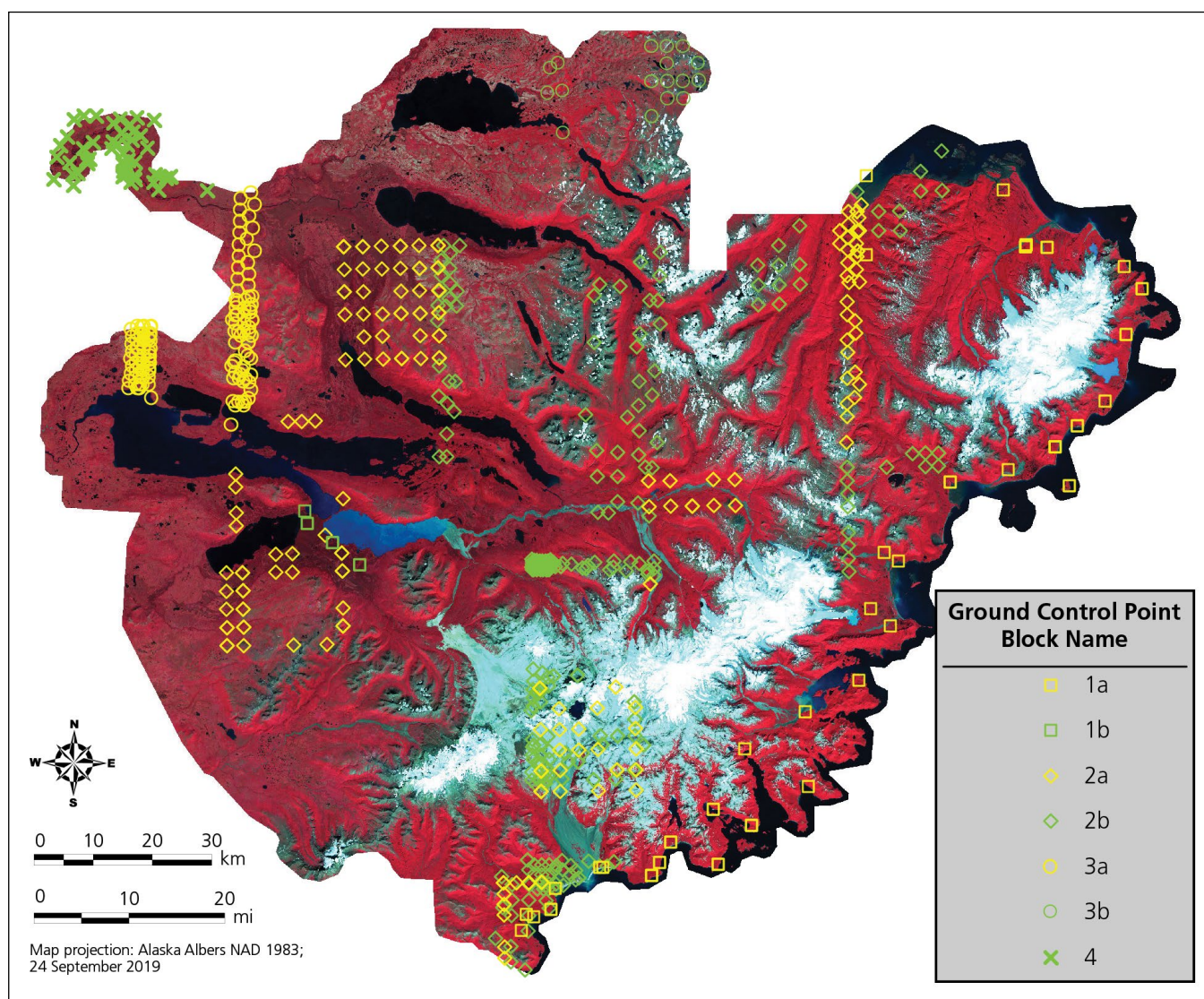


Figure 1. Ground control point (GCP) blocks for orthorectification of Pleiades imagery, 2013–2016, Katmai and Alagnak, Alaska.

Top of Atmosphere Reflectance Calibration

The inputs to the top of atmosphere calibration calculations are provided in Table 3. Bias values were zero for all scenes and are not shown. Non-zero bias settings will be seen in radiometrically compressed 8 bit raw imagery, but that has information loss and should not be ordered. The solar irradiance values are constant over the record for each band.

Atmospheric Correction/Normalization

Landsat Reference Image

The Landsat reference composite (Figure 2) represents recent mid-summer conditions for Katmai NPP. Since it is based on 6 years of Landsat 8 data (2013–2018), it should be interpreted carefully in areas with ongoing landscape change (e.g., floodplains). The importance of including so many years of data can be seen in the sample size panel of Figure 2. While most of coastal Katmai has 16 or more observations, the count of cloud- and cloud shadow-free observations is much lower inland and at high elevations. Much of the highest elevations had no observations that were cloud- and cloud shadow-free (these were filled using cloud- and cloud shadow-masked Landsat 7 data, and if that failed unmasked Landsat 7 and 8 imagery). These filled areas have less reliable Landsat surface reflectance, but are unlikely to be used in the Pleiades reflectance modeling, because they are mostly permanent snow and would be masked.

Surface Reflectance Normalization

The calibration coefficients to convert the multispectral top of atmosphere imagery to surface reflectance (Table 4) can be interpreted to some degree, since the inputs were normalized but were not atmospherically corrected. In general, with a very clear atmosphere, the scale factors would be close to 1. Many scale factors are close to 1, but there are many outliers. In general, the atmosphere affects shorter wavelengths (blue) more than longer wavelengths (near-infrared). In this case, blue had an average scale factor that was furthest from 1 and red had an average scale factor that was closest to 1. The variability of the scale factors among scenes, as measured by standard deviation, minimum, and maximum, was lowest for the near-infrared band. This is expected since atmospheric effects are generally less pronounced in the near-infrared as compared to the visible bands.

An example of the surface reflectance calibration results is seen in Figure 3. With a fixed contrast stretch, the top row of images appears somewhat hazy. The bottom row of images is the Landsat reference, and the result of calibrating the input

Pleiades imagery to match the Landsat reflectance is seen in the middle row. Overall, the calibrated Pleiades imagery appears very similar to the Landsat imagery while possessing much greater detail.

Since the input pan-sharpened imagery was in sensor digital counts rather than a normalized quantity like top of atmosphere reflectance, the correction scale and offset parameters (Table 5) do not have a consistent meaning across different images. They simply describe the formula to convert from digital count to surface reflectance for each pan-sharpened image and are provided so the process can be replicated.

Mosaicking and Color Balancing

The surface reflectance calibrated Pleiades mosaics are presented in Figure 4 (multispectral 2 m resolution) and Figure 5 (pan-sharpened 0.5 m resolution). For presentation, the multispectral mosaic is presented in color infrared band display, while the pan-sharpened mosaic is presented in natural color, but all four bands are included with each product. The surface reflectance normalization and automated mosaicking approach yield a mosaic with consistent radiometry, few noticeable seamlines, and minimal cloud contamination. The improved resolution of the pan-sharpened mosaic (Figure 5) allows vegetation canopies and fine surface features to be resolved.

Of the 54 images provided, 53 were included in the final mosaic (Table 6). One image contributed 1,054 km² of area to the final mosaic, or 5.8% of the total area. 85.9% of the mosaic area was contributed by imagery from July and August, 2015.

The mosaics are stored as multiband GeoTiff files in signed 16 bit format, with internal tiling and pyramids for rapid display at all scales. Reflectance values are scaled by 10,000. The file size for the multispectral (2 m) mosaic is 28 GB while the pan-sharpened mosaic is 466 GB.

Since the image contributing to each portion of the mosaic was tracked, image metadata properties and other mosaic properties can be mapped (Figure 6). For example, the cloudy areas in Figure 6 (lower left) show where the absolute difference metric was used to select which image would contribute data. These areas will be noisier, with inputs from multiple images, and will also include some cloud and shadow. But the extent of these areas is fairly limited.

The day of year and year of the source data are mapped in Figure 6 (right panels). In particular, the location of imagery from June and September can be seen in the upper right

Table 3. Calibration coefficients for top of atmosphere calibration of Pleiades multispectral images, 2013–2016, Katmai and Alagnak, Alaska.

Image Code	ISO Date String	Sun Elevation	d	Gain				Solar Irradiance			
				Blue	Green	Red	NIR	Blue	Green	Red	NIR
1	2013-07-13Z21:45:54.9	52.4	1.01655	9.2	9.36	10.35	15.63	1915	1830	1594	1060
2	2013-07-13Z21:46:13.4	52.4	1.01655	9.2	9.36	10.35	15.63	1915	1830	1594	1060
3	2013-09-23Z21:43:25.8	31.5	1.00346	10.19	10.32	11.43	17.41	1915	1830	1594	1060
4	2014-06-09Z21:49:37.3	54.8	1.01513	9.14	9.29	10.33	15.61	1915	1830	1594	1060
5	2014-07-26Z21:39:41.4	50.5	1.01565	9.14	9.29	10.33	15.61	1915	1830	1594	1060
6	2015-06-15Z21:46:20.9	53.9	1.01577	9.09	9.24	10.32	15.59	1915	1830	1594	1060
7	2015-07-11Z21:46:34.5	52.9	1.01661	9.09	9.24	10.32	15.59	1915	1830	1594	1060
8	2015-07-11Z21:46:46.0	52.9	1.01661	9.09	9.24	10.32	15.59	1915	1830	1594	1060
9	2015-07-11Z21:46:59.6	53.1	1.01661	9.09	9.24	10.32	15.59	1915	1830	1594	1060
10	2015-07-19Z21:34:11.5	51.4	1.01623	10.13	10.18	11.31	17.38	1915	1830	1594	1060
11	2015-07-19Z21:34:37.4	51.6	1.01623	10.13	10.18	11.31	17.38	1915	1830	1594	1060
12	2015-07-19Z21:34:55.4	51.2	1.01623	10.13	10.18	11.31	17.38	1915	1830	1594	1060
13	2015-07-19Z21:35:12.0	51.7	1.01623	10.13	10.18	11.31	17.38	1915	1830	1594	1060
14	2015-07-31Z21:41:40.4	48.7	1.01510	10.13	10.18	11.31	17.38	1915	1830	1594	1060
15	2015-07-31Z21:42:10.0	48.8	1.01510	10.13	10.18	11.31	17.38	1915	1830	1594	1060
16	2015-07-31Z21:42:21.9	49.2	1.01510	10.13	10.18	11.31	17.38	1915	1830	1594	1060
17	2015-07-31Z21:42:42.8	48.9	1.01510	10.13	10.18	11.31	17.38	1915	1830	1594	1060
18	2015-07-31Z21:42:59.3	49.5	1.01510	10.13	10.18	11.31	17.38	1915	1830	1594	1060
19	2015-08-01Z21:34:45.0	48.4	1.01497	9.09	9.24	10.32	15.59	1915	1830	1594	1060
20	2015-08-01Z21:34:59.0	48.4	1.01497	9.09	9.24	10.32	15.59	1915	1830	1594	1060
21	2015-08-01Z21:35:16.4	48.8	1.01497	9.09	9.24	10.32	15.59	1915	1830	1594	1060
22	2015-08-01Z21:35:34.3	48.3	1.01497	9.09	9.24	10.32	15.59	1915	1830	1594	1060
23	2015-08-01Z21:35:48.3	48.7	1.01497	9.09	9.24	10.32	15.59	1915	1830	1594	1060
24	2015-08-05Z21:53:10.3	47.6	1.01444	10.13	10.18	11.31	17.38	1915	1830	1594	1060
25	2015-08-05Z21:53:26.0	47.7	1.01444	10.13	10.18	11.31	17.38	1915	1830	1594	1060
26	2015-08-05Z21:53:41.6	47.8	1.01444	10.13	10.18	11.31	17.38	1915	1830	1594	1060
27	2015-08-05Z21:53:57.0	47.6	1.01444	10.13	10.18	11.31	17.38	1915	1830	1594	1060
28	2015-08-05Z21:54:13.8	47.9	1.01444	10.13	10.18	11.31	17.38	1915	1830	1594	1060
29	2015-08-07Z21:38:27.6	46.5	1.01414	10.13	10.18	11.31	17.38	1915	1830	1594	1060

Table 3. Calibration coefficients for top of atmosphere calibration of Pleiades multispectral images, continued.

Image Code	ISO Date String	Sun Elevation	d	Gain				Solar Irradiance			
				Blue	Green	Red	NIR	Blue	Green	Red	NIR
30	2015-08-07Z21:38:40.8	46.9	1.01414	10.13	10.18	11.31	17.38	1915	1830	1594	1060
31	2015-08-07Z21:38:50.0	47.0	1.01414	10.13	10.18	11.31	17.38	1915	1830	1594	1060
32	2015-08-07Z21:39:01.3	46.9	1.01414	10.13	10.18	11.31	17.38	1915	1830	1594	1060
33	2015-08-11Z21:57:09.4	45.8	1.01351	9.09	9.24	10.32	15.59	1915	1830	1594	1060
34	2015-08-11Z21:57:18.3	46.5	1.01351	9.09	9.24	10.32	15.59	1915	1830	1594	1060
35	2015-08-11Z21:57:42.0	45.8	1.01351	9.09	9.24	10.32	15.59	1915	1830	1594	1060
36	2015-08-11Z21:58:00.0	46.7	1.01351	9.09	9.24	10.32	15.59	1915	1830	1594	1060
37	2015-08-11Z21:58:19.1	46.2	1.01351	9.09	9.24	10.32	15.59	1915	1830	1594	1060
38	2015-08-24Z21:56:55.8	42.2	1.01103	10.13	10.18	11.31	17.38	1915	1830	1594	1060
39	2015-08-24Z21:57:09.4	42.6	1.01103	10.13	10.18	11.31	17.38	1915	1830	1594	1060
40	2015-08-24Z21:57:26.8	42.5	1.01103	10.13	10.18	11.31	17.38	1915	1830	1594	1060
41	2015-08-24Z21:57:40.4	42.5	1.01103	10.13	10.18	11.31	17.38	1915	1830	1594	1060
42	2015-08-24Z21:58:00.1	42.7	1.01103	10.13	10.18	11.31	17.38	1915	1830	1594	1060
43	2015-08-31Z21:53:07.4	39.6	1.00946	10.13	10.18	11.31	17.38	1915	1830	1594	1060
44	2015-08-31Z21:53:16.5	39.5	1.00946	10.13	10.18	11.31	17.38	1915	1830	1594	1060
45	2015-08-31Z21:53:25.5	39.5	1.00946	10.13	10.18	11.31	17.38	1915	1830	1594	1060
46	2015-08-31Z21:54:10.4	39.9	1.00946	10.13	10.18	11.31	17.38	1915	1830	1594	1060
47	2015-08-31Z21:54:23.0	40.3	1.00946	10.13	10.18	11.31	17.38	1915	1830	1594	1060
48	2015-08-31Z21:54:32.1	40.3	1.00946	10.13	10.18	11.31	17.38	1915	1830	1594	1060
49	2015-09-01Z21:46:23.5	39.1	1.00922	9.09	9.24	10.32	15.59	1915	1830	1594	1060
50	2015-09-01Z21:46:41.3	39.1	1.00922	9.09	9.24	10.32	15.59	1915	1830	1594	1060
51	2015-09-01Z21:46:55.8	39.7	1.00922	9.09	9.24	10.32	15.59	1915	1830	1594	1060
52	2015-09-01Z21:47:05.3	39.7	1.00922	9.09	9.24	10.32	15.59	1915	1830	1594	1060
53	2016-08-30Z21:45:31.1	39.1	1.00946	9.18	9.24	10.28	15.46	1915	1831	1594	1060
54	2016-08-30Z21:45:39.1	39.1	1.00946	9.18	9.24	10.28	15.46	1915	1831	1594	1060

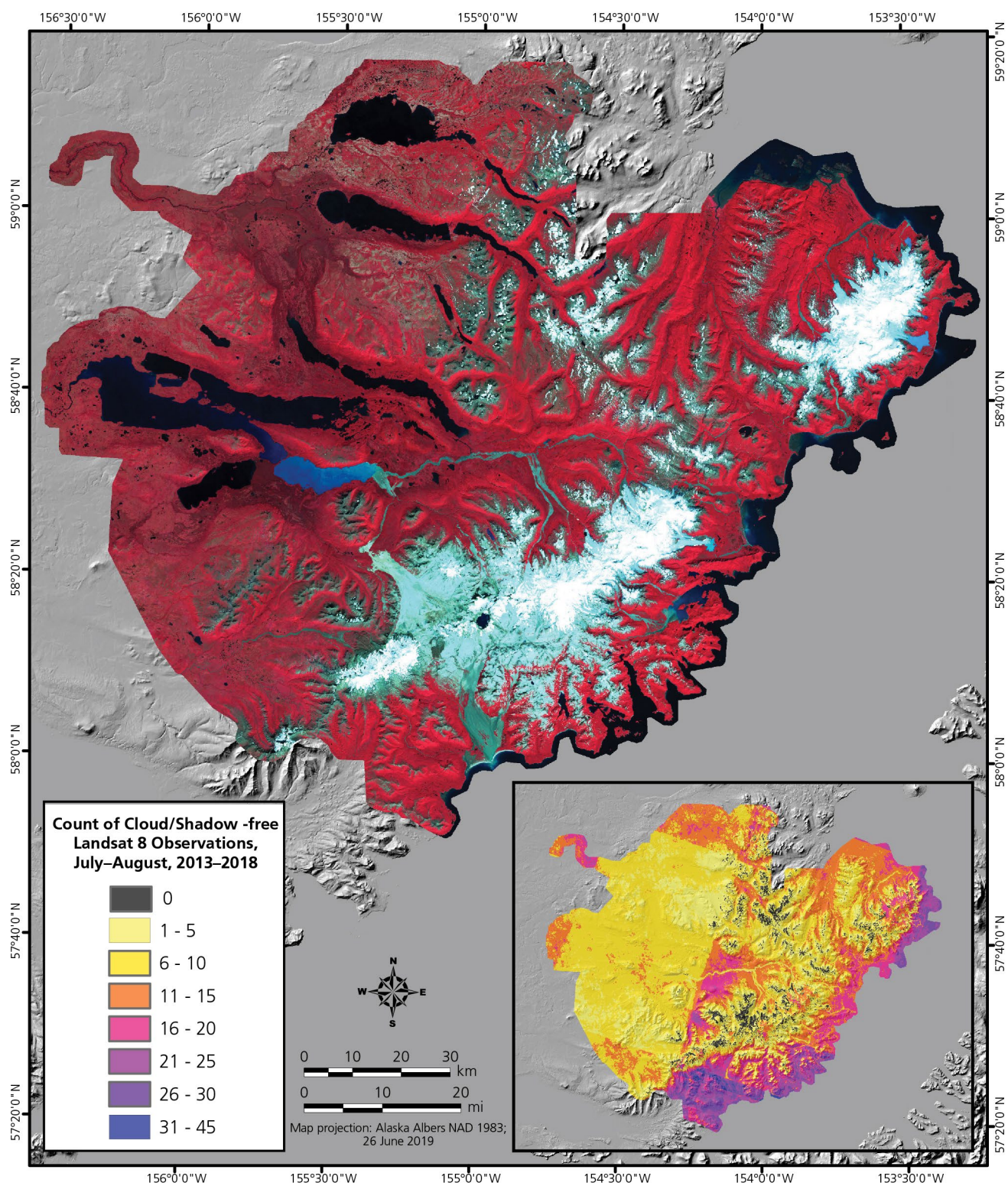


Figure 2. Landsat 8 surface reflectance reference composite, July–August, 2013–2018, Katmai and Alagnak, Alaska. The image is displayed as color infrared (near-infrared/red/green) with a linear contrast stretch from 0–0.6 for the near-infrared band, and 0–0.25 in the red and green bands.

Table 4. Normalization coefficients for surface reflectance calibration of Pleiades multispectral images, 2013–2016, Katmai and Alagnak, Alaska. The calibration inputs were initially calibrated to top of atmosphere reflectance based on image metadata and were scaled by a factor of 10,000.

Image Code	ISO Date String	Blue Offset	Blue Scale	Green Offset	Green Scale	Red Offset	Red Scale	NIR Offset	NIR Scale
1	2013-07-13Z21:45:54.9	-109.5	0.41464	129.7	0.49538	-28.9	0.64740	885.7	0.89001
2	2013-07-13Z21:46:13.4	-521.1	0.78802	-207.7	0.81032	-232.8	0.92529	329.2	0.99722
3	2013-09-23Z21:43:25.8	-719.1	0.96037	-282.9	0.95734	-265.2	0.90401	1617.6	1.01371
4	2014-06-09Z21:49:37.3	-255.6	0.58433	-91.4	0.75537	-57.1	0.59451	1099.8	1.08642
5	2014-07-26Z21:39:41.4	-488.8	0.73519	-322.0	0.93346	-260.4	0.93589	333.4	0.99399
6	2015-06-15Z21:46:20.9	-403.2	0.65692	-258.7	0.83019	-278.1	0.92204	250.0	1.12184
7	2015-07-11Z21:46:34.5	-295.1	0.54719	-183.3	0.73004	-173.7	0.76913	785.3	0.89499
8	2015-07-11Z21:46:46.0	-48.4	0.31715	118.4	0.41487	5.2	0.48531	641.2	0.88756
9	2015-07-11Z21:46:59.6	-344.1	0.62809	-194.3	0.76953	-171.3	0.83613	322.1	0.88213
10	2015-07-19Z21:34:11.5	-548.2	0.88695	-346.9	1.04125	-200.2	1.02275	636.3	0.96269
11	2015-07-19Z21:34:37.4	-550.7	0.88750	-339.7	0.99992	-209.4	0.99941	478.7	0.99339
12	2015-07-19Z21:34:55.4	-442.9	0.64822	-280.5	0.79592	-221.2	0.84583	621.3	0.81409
13	2015-07-19Z21:35:12.0	-503.4	0.73762	-401.8	0.91652	-201.1	0.84950	233.5	0.91530
14	2015-07-31Z21:41:40.4	-213.3	0.59285	-16.2	0.74178	-67.9	0.85917	1070.5	0.85711
15	2015-07-31Z21:42:10.0	-326.9	0.71315	3.1	0.72199	-86.6	0.93381	599.3	0.95313
16	2015-07-31Z21:42:21.9	-654.4	1.03881	-323.2	1.08269	-185.2	1.07703	556.3	1.00789
17	2015-07-31Z21:42:42.8	-495.4	0.74012	-218.3	0.81720	-193.1	0.90474	499.2	0.88097
18	2015-07-31Z21:42:59.3	-851.4	1.05198	-471.6	1.07399	-264.4	1.05187	215.2	0.96765
19	2015-08-01Z21:34:45.0	-506.4	0.89679	-243.1	1.01184	-220.8	1.08421	817.7	0.91823
20	2015-08-01Z21:34:59.0	-469.9	0.85226	-170.4	0.92825	-180.4	1.03785	600.9	0.96614
21	2015-08-01Z21:35:16.4	-769.6	1.11745	-375.7	1.13649	-240.5	1.13649	352.7	0.99559
22	2015-08-01Z21:35:34.3	-98.1	0.34941	63.0	0.47294	-20.6	0.54665	706.3	0.78623
23	2015-08-01Z21:35:48.3	-730.4	0.91614	-399.8	0.95856	-277.5	0.95624	188.3	0.94516
24	2015-08-05Z21:53:10.3	-429.3	0.88137	-172.2	1.03156	-96.1	1.06277	659.0	1.02218
25	2015-08-05Z21:53:26.0	-340.3	0.72996	-248.3	1.05496	-126.2	1.03519	805.1	0.92713
26	2015-08-05Z21:53:41.6	-324.0	0.67954	-150.6	0.88347	-76.1	0.89587	988.4	0.83712
27	2015-08-05Z21:53:57.0	-511.5	0.79823	-257.8	0.89857	-162.5	0.92649	664.9	0.85977
28	2015-08-05Z21:54:13.8	-676.5	0.90717	-563.2	1.16193	-269.0	1.01242	414.6	0.87783
29	2015-08-07Z21:38:27.6	-502.9	0.88420	-190.1	0.91623	-146.9	1.01362	253.7	1.05525
30	2015-08-07Z21:38:40.8	-317.3	0.63239	-169.8	0.81473	-104.0	0.76095	949.3	0.85773

Table 4. Normalization coefficients for surface reflectance calibration of Pleiades multispectral images, continued.

Image Code	ISO Date String	Blue Offset	Blue Scale	Green Offset	Green Scale	Red Offset	Red Scale	NIR Offset	NIR Scale
31	2015-08-07Z21:38:50.0	-501.5	0.80173	-236.5	0.90245	-190.5	0.96432	504.9	0.93187
32	2015-08-07Z21:39:01.3	-711.7	0.93276	-366.5	0.93572	-292.6	1.02365	-51.5	1.05974
33	2015-08-11Z21:57:09.4	-442.8	0.98853	-117.5	1.03749	-89.5	1.14270	608.5	1.05075
34	2015-08-11Z21:57:18.3	-570.6	1.04213	-264.7	1.15729	-230.3	1.25203	652.9	1.00082
35	2015-08-11Z21:57:42.0	-404.3	0.82940	-154.5	0.95609	-150.7	1.05509	707.4	0.98748
36	2015-08-11Z21:58:00.0	-384.0	0.74994	-37.8	0.79933	-126.8	0.97405	846.0	0.85612
37	2015-08-11Z21:58:19.1	-758.5	1.01144	-392.8	1.03149	-277.0	1.04652	520.4	0.92770
38	2015-08-24Z21:56:55.8	-679.8	1.27062	-251.2	1.18574	-245.6	1.35497	622.2	1.21320
39	2015-08-24Z21:57:09.4	-816.7	1.38166	-391.0	1.34319	-251.5	1.34073	808.4	1.00402
40	2015-08-24Z21:57:26.8	-713.5	1.16339	-316.1	1.16939	-197.1	1.15552	596.3	1.07831
41	2015-08-24Z21:57:40.4	-798.6	1.20516	-372.4	1.17588	-254.1	1.18712	460.5	1.11860
42	2015-08-24Z21:58:00.1	-330.2	0.59986	4.7	0.67513	-57.2	0.74725	731.5	0.98501
43	2015-08-31Z21:53:07.4	-545.4	0.96203	-285.9	1.12274	-250.9	1.18436	817.0	1.05179
44	2015-08-31Z21:53:16.5	-532.0	0.95368	-391.5	1.26092	-307.4	1.31757	998.3	0.95215
45	2015-08-31Z21:53:25.5	-566.4	0.94941	-432.5	1.25456	-288.9	1.23623	1045.1	0.89312
46	2015-08-31Z21:54:10.4	-433.5	0.67584	-298.5	0.95586	-160.5	0.87421	611.2	0.98018
47	2015-08-31Z21:54:23.0	-907.5	1.05311	-479.8	1.06462	-405.5	1.09279	254.2	1.17401
48	2015-08-31Z21:54:32.1	-605.4	0.78230	-294.7	0.87459	-250.7	0.92717	1.0	1.05771
49	2015-09-01Z21:46:23.5	-713.9	1.11537	-384.6	1.18117	-347.6	1.25310	674.4	1.06789
50	2015-09-01Z21:46:41.3	-703.6	0.96789	-424.6	1.09056	-309.4	1.06242	355.5	1.07073
51	2015-09-01Z21:46:55.8	-524.2	0.97946	-36.6	0.95846	92.2	0.96566	575.5	0.83064
52	2015-09-01Z21:47:05.3	-901.8	1.17645	-384.5	1.13168	-230.8	1.12924	503.2	0.87532
53	2016-08-30Z21:45:31.1	-305.6	0.62913	-172.2	0.90651	-229.8	1.10427	1220.5	0.80048
54	2016-08-30Z21:45:39.1	-188.8	0.47882	-81.0	0.75694	-160.1	0.95241	1192.1	0.77868
–	Average	-509.0	0.83841	-243.1	0.94602	-189.3	0.98844	626.5	0.96138
–	Standard Deviation	205.1	0.22792	154.8	0.19588	95.4	0.18582	316.1	0.09860
–	Minimum	-907.5	0.31715	-563.2	0.41487	-405.5	0.48531	-51.5	0.77868
–	Maximum	-48.4	1.38166	129.7	1.34319	92.2	1.35497	1617.6	1.21320

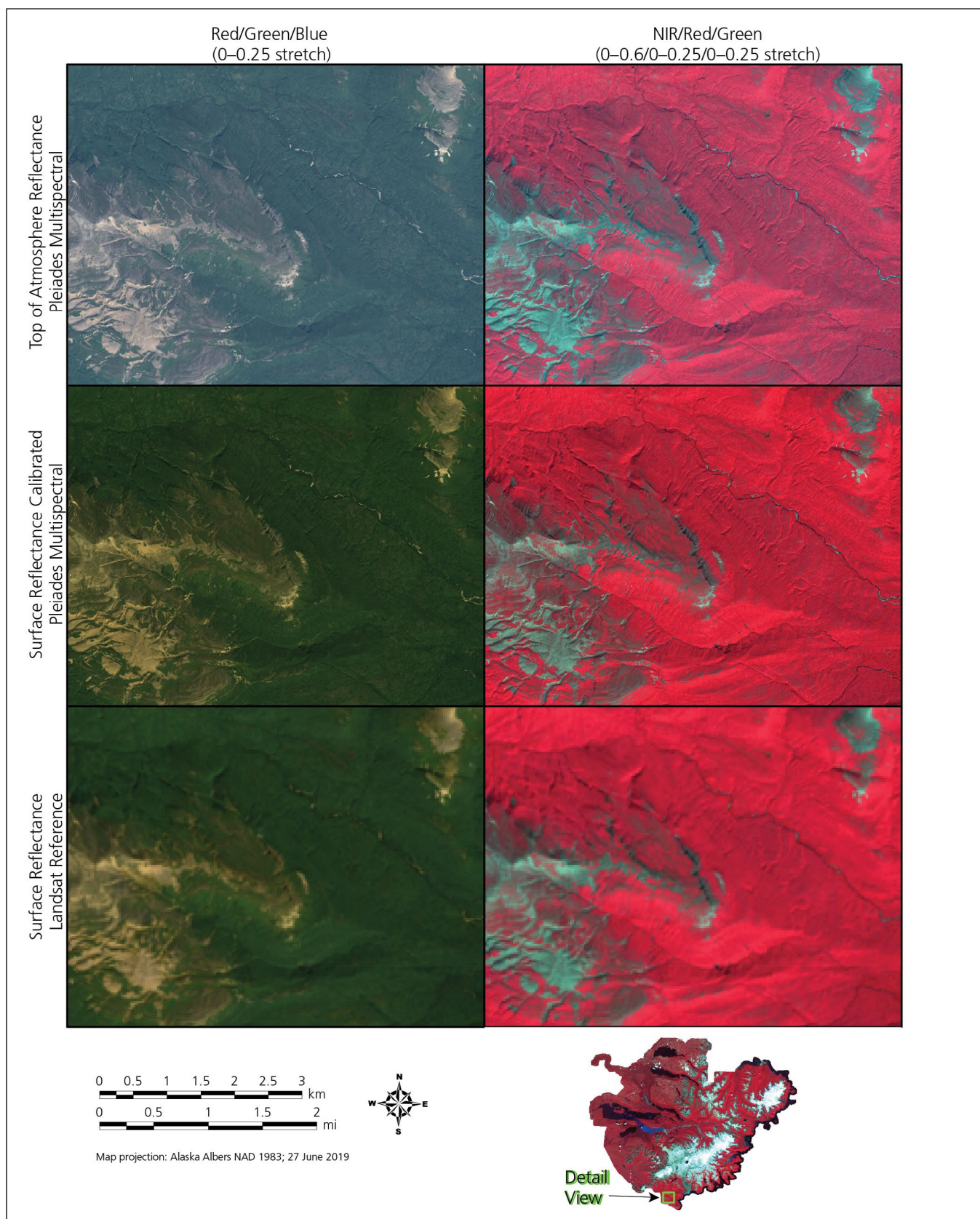


Figure 3. Comparison of Pleiades multispectral image calibrated to top of atmosphere reflectance and surface reflectance, and Landsat reference image, 2014-07-26, Katmai and Alagnak, Alaska. The images are displayed as color infrared (near-infrared/red/green) with a linear contrast stretch from 0–0.6 for the near-infrared band, and 0–0.25 in the red and green bands.

Table 5. Normalization coefficients for surface reflectance calibration of Pleiades pan-sharpened images, 2013–2016, Katmai and Alagnak, Alaska. The calibration inputs were digital numbers from the pan-sharpening algorithm stored as 16 bit unsigned integers.

Image Code	ISO Date String	Blue Offset	Blue Scale	Green Offset	Green Scale	Red Offset	Red Scale	NIR Offset	NIR Scale
1	2013-07-13Z21:45:54.9	-141.7	1.01786	90.2	1.25898	-66.8	1.69122	768.8	2.28460
2	2013-07-13Z21:46:13.4	-545.0	1.86431	-244.6	2.00370	-262.9	2.35731	242.9	2.53095
3	2013-09-23Z21:43:25.8	-783.1	3.15412	-340.8	3.26471	-315.1	3.22397	1482.9	3.56373
4	2014-06-09Z21:49:37.3	-350.6	1.51553	-206.7	2.02783	-135.5	1.66057	830.0	2.88962
5	2014-07-26Z21:39:41.4	-553.7	1.90652	-404.3	2.50688	-318.8	2.58330	-9.1	2.75900
6	2015-06-15Z21:46:20.9	-386.3	1.46616	-252.8	1.93424	-279.7	2.21831	226.7	2.74282
7	2015-07-11Z21:46:34.5	-295.3	1.27795	-201.1	1.79579	-189.0	1.94954	716.8	2.25797
8	2015-07-11Z21:46:46.0	-58.6	0.74906	103.4	1.01385	-10.5	1.22084	586.2	2.21619
9	2015-07-11Z21:46:59.6	-375.7	1.51702	-228.5	1.91237	-190.8	2.10540	241.1	2.21786
10	2015-07-19Z21:34:11.5	-588.9	1.98273	-394.5	2.44352	-222.8	2.45402	597.6	2.22448
11	2015-07-19Z21:34:37.4	-572.5	1.91727	-372.9	2.27119	-231.2	2.32681	446.8	2.25100
12	2015-07-19Z21:34:55.4	-459.9	1.41036	-313.4	1.83005	-236.4	1.97353	606.1	1.84632
13	2015-07-19Z21:35:12.0	-535.3	1.62798	-442.9	2.12053	-215.7	1.99662	131.9	2.12435
14	2015-07-31Z21:41:40.4	-244.6	1.38573	-52.6	1.80975	-92.5	2.13536	1029.8	2.03800
15	2015-07-31Z21:42:10.0	-388.6	1.68981	-55.2	1.78492	-128.5	2.32344	566.9	2.25851
16	2015-07-31Z21:42:21.9	-688.2	2.33244	-357.7	2.53285	-214.0	2.59901	514.6	2.36959
17	2015-07-31Z21:42:42.8	-508.4	1.64749	-250.7	1.93201	-217.3	2.19246	471.8	2.07295
18	2015-07-31Z21:42:59.3	-890.9	2.35144	-512.1	2.50030	-299.5	2.52637	171.9	2.26946
19	2015-08-01Z21:34:45.0	-511.7	2.21434	-266.3	2.61860	-242.8	2.87744	763.7	2.44892
20	2015-08-01Z21:34:59.0	-488.3	2.14431	-201.7	2.43718	-207.1	2.78418	541.9	2.57898
21	2015-08-01Z21:35:16.4	-816.1	2.82075	-423.3	2.95414	-285.5	3.03369	297.1	2.64374
22	2015-08-01Z21:35:34.3	-133.7	0.94628	23.2	1.31027	-51.1	1.54848	631.4	2.11463
23	2015-08-01Z21:35:48.3	-769.8	2.31090	-441.0	2.49215	-313.2	2.55237	119.7	2.50761
24	2015-08-05Z21:53:10.3	-445.8	2.02810	-193.8	2.48429	-106.4	2.61159	631.1	2.45871
25	2015-08-05Z21:53:26.0	-316.9	1.58084	-228.4	2.41106	-111.8	2.44098	827.4	2.18654
26	2015-08-05Z21:53:41.6	-330.7	1.54189	-171.0	2.12232	-76.0	2.16317	932.1	2.03833
27	2015-08-05Z21:53:57.0	-509.7	1.79232	-261.8	2.11439	-166.3	2.25195	637.2	2.06737
28	2015-08-05Z21:54:13.8	-462.3	1.57593	-430.4	2.37271	-203.6	2.17506	363.4	2.13086
29	2015-08-07Z21:38:27.6	-556.1	2.12513	-244.7	2.30172	-187.0	2.59921	199.7	2.60294
30	2015-08-07Z21:38:40.8	-294.3	1.36579	-175.5	1.91319	-106.1	1.80465	916.8	2.08232

Table 5. Normalization coefficients for surface reflectance calibration of Pleiades pan-sharpened images, 2013–2016, continued.

Image Code	ISO Date String	Blue Offset	Blue Scale	Green Offset	Green Scale	Red Offset	Red Scale	NIR Offset	NIR Scale
31	2015-08-07Z21:38:50.0	-537.0	1.88532	-281.9	2.22830	-221.0	2.43041	432.3	2.28634
32	2015-08-07Z21:39:01.3	-724.7	2.14140	-383.1	2.24537	-305.3	2.52926	-60.5	2.55039
33	2015-08-11Z21:57:09.4	-468.3	2.61525	-144.7	2.83421	-114.0	3.20102	568.2	2.91357
34	2015-08-11Z21:57:18.3	-592.1	2.71803	-289.7	3.11693	-252.8	3.46899	625.1	2.73048
35	2015-08-11Z21:57:42.0	-423.9	2.19174	-183.0	2.62285	-174.8	2.96606	642.5	2.75662
36	2015-08-11Z21:58:00.0	-345.0	1.79857	-11.7	2.00798	-119.9	2.58095	844.1	2.30043
37	2015-08-11Z21:58:19.1	-759.7	2.59220	-398.1	2.73134	-285.5	2.85826	498.8	2.53068
38	2015-08-24Z21:56:55.8	-738.6	3.29015	-301.1	3.20141	-283.0	3.74621	515.3	3.28920
39	2015-08-24Z21:57:09.4	-834.9	3.40460	-407.8	3.44540	-266.3	3.55025	789.4	2.60850
40	2015-08-24Z21:57:26.8	-766.5	2.99514	-369.4	3.15630	-234.8	3.21700	455.3	2.96361
41	2015-08-24Z21:57:40.4	-876.5	3.15161	-443.1	3.20726	-303.6	3.32323	287.2	3.08342
42	2015-08-24Z21:58:00.1	-408.6	1.64784	-74.7	1.93265	-122.8	2.21060	457.7	2.78549
43	2015-08-31Z21:53:07.4	-594.0	2.61840	-358.6	3.25963	-300.1	3.51091	625.4	3.09574
44	2015-08-31Z21:53:16.5	-652.6	2.80482	-533.1	3.86191	-411.8	4.13763	834.8	2.81823
45	2015-08-31Z21:53:25.5	-675.2	2.75062	-575.4	3.84106	-391.8	3.91673	789.3	2.78664
46	2015-08-31Z21:54:10.4	-473.8	1.83274	-380.0	2.78764	-219.2	2.64467	330.9	2.93333
47	2015-08-31Z21:54:23.0	-962.8	2.79220	-526.0	2.92769	-438.8	3.08785	188.2	3.21041
48	2015-08-31Z21:54:32.1	-644.1	2.06324	-332.6	2.39670	-279.8	2.60821	-28.6	2.87871
49	2015-09-01Z21:46:23.5	-833.7	3.60787	-497.4	3.94350	-439.6	4.29457	376.1	3.68838
50	2015-09-01Z21:46:41.3	-810.4	3.11129	-533.5	3.63161	-387.5	3.64755	84.4	3.69297
51	2015-09-01Z21:46:55.8	-704.8	3.02858	-215.1	3.04595	-90.1	3.15015	405.9	2.70309
52	2015-09-01Z21:47:05.3	-996.2	3.51398	-473.8	3.47791	-318.5	3.56279	411.8	2.76759
53	2016-08-30Z21:45:31.1	-550.6	2.58276	-499.0	3.92618	-536.2	4.92317	512.4	3.41312
54	2016-08-30Z21:45:39.1	-389.3	1.98455	-369.0	3.29861	-426.4	4.20223	429.6	3.41352

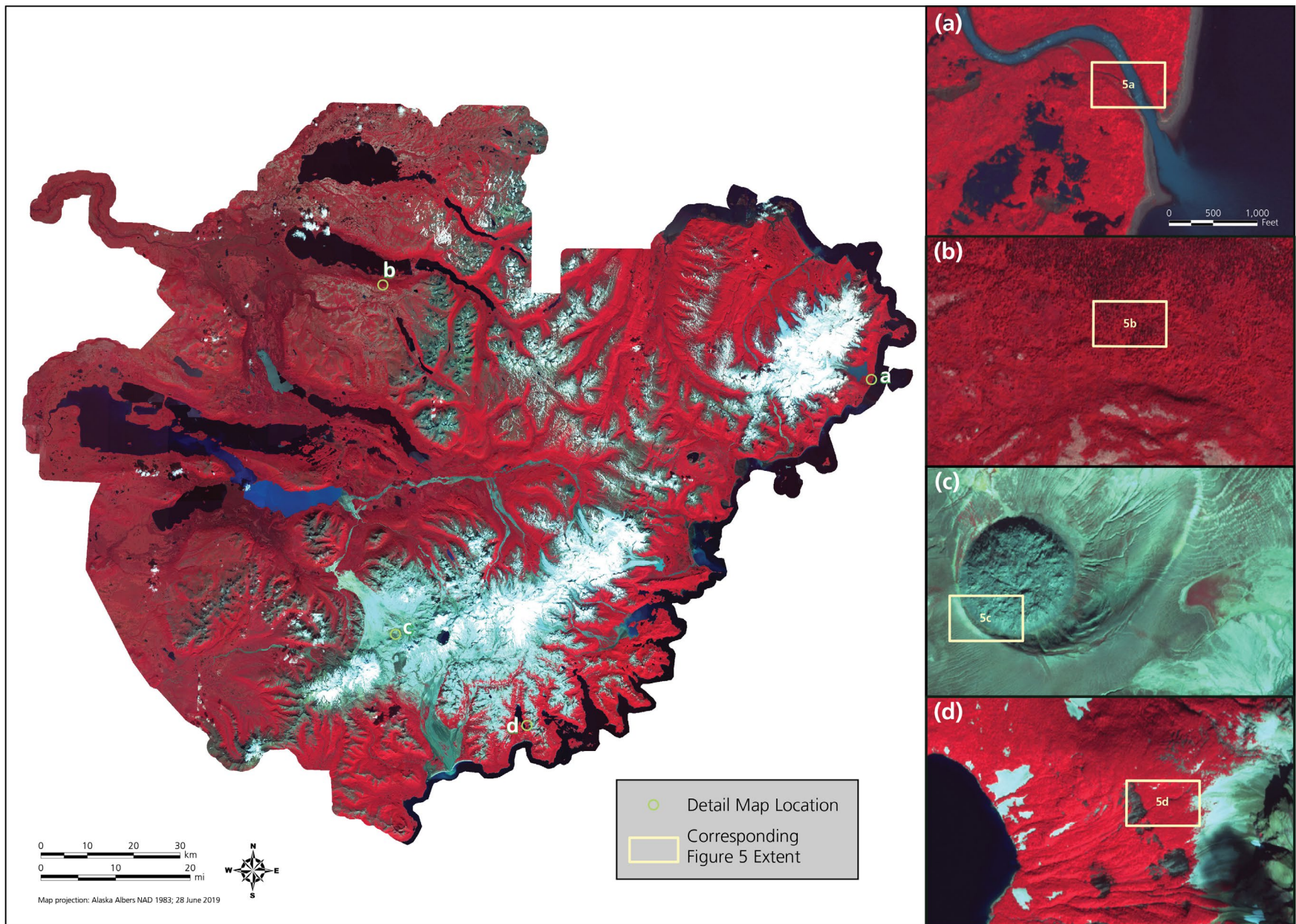


Figure 4. Pleiades multispectral surface reflectance mosaic, circa 2015, Katmai and Alagnak, Alaska. The image is displayed as color infrared (near-infrared/red/green) with a linear contrast stretch from 0–0.6 for the near-infrared band, and 0–0.25 in the red and green bands.



Figure 5. Pleiades pan-sharpened surface reflectance mosaic, circa 2015, Katmai and Alagnak, Alaska. The image is displayed as natural color (red/green/blue) with a linear contrast stretch from 0–0.25 for each band.

Table 6. Area summary of Pleiades source images included in color-balanced surface reflectance mosaic, 2013–2016, Katmai and Alagnak, Alaska.

Image Code	ISO Date String	Footprint Area (sq. km)	Cutline Area (sq. km)	Proportion of Footprint Included in Mosaic	Proportion of Mosaic Area	Year	Month
1	2013-07-13Z21:45:54.9	998.5	206.0	20.6%	1.1%	2013	7
2	2013-07-13Z21:46:13.4	1133.7	473.1	41.7%	2.6%	2013	7
3	2013-09-23Z21:43:25.8	254.4	33.7	13.2%	0.2%	2013	9
4	2014-06-09Z21:49:37.3	196.3	0.0	0.0%	0.0%	2014	6
5	2014-07-26Z21:39:41.4	355.2	337.2	94.9%	1.8%	2014	7
6	2015-06-15Z21:46:20.9	402.5	148.7	36.9%	0.8%	2015	6
7	2015-07-11Z21:46:34.5	244.5	22.2	9.1%	0.1%	2015	7
8	2015-07-11Z21:46:46.0	765.5	491.7	64.2%	2.7%	2015	7
9	2015-07-11Z21:46:59.6	430.0	221.3	51.5%	1.2%	2015	7
10	2015-07-19Z21:34:11.5	126.0	71.3	56.6%	0.4%	2015	7
11	2015-07-19Z21:34:37.4	1073.0	435.5	40.6%	2.4%	2015	7
12	2015-07-19Z21:34:55.4	1261.1	378.4	30.0%	2.1%	2015	7
13	2015-07-19Z21:35:12.0	392.9	335.1	85.3%	1.8%	2015	7
14	2015-07-31Z21:41:40.4	1095.6	308.7	28.2%	1.7%	2015	7
15	2015-07-31Z21:42:10.0	739.5	183.2	24.8%	1.0%	2015	7
16	2015-07-31Z21:42:21.9	1423.0	79.8	5.6%	0.4%	2015	7
17	2015-07-31Z21:42:42.8	1522.4	249.8	16.4%	1.4%	2015	7
18	2015-07-31Z21:42:59.3	858.1	120.0	14.0%	0.7%	2015	7
19	2015-08-01Z21:34:45.0	830.7	411.6	49.6%	2.2%	2015	8
20	2015-08-01Z21:34:59.0	1517.4	927.2	61.1%	5.0%	2015	8
21	2015-08-01Z21:35:16.4	1158.3	817.6	70.6%	4.4%	2015	8
22	2015-08-01Z21:35:34.3	1052.3	486.1	46.2%	2.6%	2015	8
23	2015-08-01Z21:35:48.3	1502.0	1301.5	86.7%	7.1%	2015	8
24	2015-08-05Z21:53:10.3	968.2	359.6	37.1%	2.0%	2015	8
25	2015-08-05Z21:53:26.0	878.6	449.6	51.2%	2.4%	2015	8
26	2015-08-05Z21:53:41.6	526.8	358.9	68.1%	1.9%	2015	8
27	2015-08-05Z21:53:57.0	1442.9	814.7	56.5%	4.4%	2015	8
28	2015-08-05Z21:54:13.8	449.1	360.6	80.3%	2.0%	2015	8
29	2015-08-07Z21:38:27.6	365.3	300.5	82.3%	1.6%	2015	8
30	2015-08-07Z21:38:40.8	403.1	264.3	65.6%	1.4%	2015	8

Table 6. Area summary of Pleiades source images included in color-balanced surface reflectance mosaic, continued.

Image Code	ISO Date String	Footprint Area (sq. km)	Cutline Area (sq. km)	Proportion of Footprint Included in Mosaic	Proportion of Mosaic Area	Year	Month
31	2015-08-07Z21:38:50.0	396.8	184.9	46.6%	1.0%	2015	8
32	2015-08-07Z21:39:01.3	1178.6	556.3	47.2%	3.0%	2015	8
33	2015-08-11Z21:57:09.4	278.4	13.0	4.7%	0.1%	2015	8
34	2015-08-11Z21:57:18.3	2340.4	604.3	25.8%	3.3%	2015	8
35	2015-08-11Z21:57:42.0	399.7	250.9	62.8%	1.4%	2015	8
36	2015-08-11Z21:58:00.0	1145.0	431.2	37.7%	2.3%	2015	8
37	2015-08-11Z21:58:19.1	2525.2	1054.5	41.8%	5.7%	2015	8
38	2015-08-24Z21:56:55.8	1226.8	241.0	19.6%	1.3%	2015	8
39	2015-08-24Z21:57:09.4	1223.9	325.4	26.6%	1.8%	2015	8
40	2015-08-24Z21:57:26.8	802.9	553.7	69.0%	3.0%	2015	8
41	2015-08-24Z21:57:40.4	434.0	335.4	77.3%	1.8%	2015	8
42	2015-08-24Z21:58:00.1	166.2	86.2	51.9%	0.5%	2015	8
43	2015-08-31Z21:53:07.4	442.3	296.1	66.9%	1.6%	2015	8
44	2015-08-31Z21:53:16.5	315.7	200.9	63.6%	1.1%	2015	8
45	2015-08-31Z21:53:25.5	307.9	132.6	43.1%	0.7%	2015	8
46	2015-08-31Z21:54:10.4	717.4	528.9	73.7%	2.9%	2015	8
47	2015-08-31Z21:54:23.0	462.2	134.1	29.0%	0.7%	2015	8
48	2015-08-31Z21:54:32.1	85.2	13.2	15.5%	0.1%	2015	8
49	2015-09-01Z21:46:23.5	1116.9	507.3	45.4%	2.8%	2015	9
50	2015-09-01Z21:46:41.3	1132.2	587.8	51.9%	3.2%	2015	9
51	2015-09-01Z21:46:55.8	416.3	71.4	17.2%	0.4%	2015	9
52	2015-09-01Z21:47:05.3	432.7	211.7	48.9%	1.1%	2015	9
53	2016-08-30Z21:45:31.1	78.0	10.2	13.1%	0.1%	2016	8
54	2016-08-30Z21:45:39.1	159.1	147.1	92.5%	0.8%	2016	8
–	–	42150.7	18425.8	43.70%	100.0%	–	–
–	July and August 2015	–	15691.7	–	85.2%	–	–
–	July and August	–	16865.3	–	91.5%	–	–

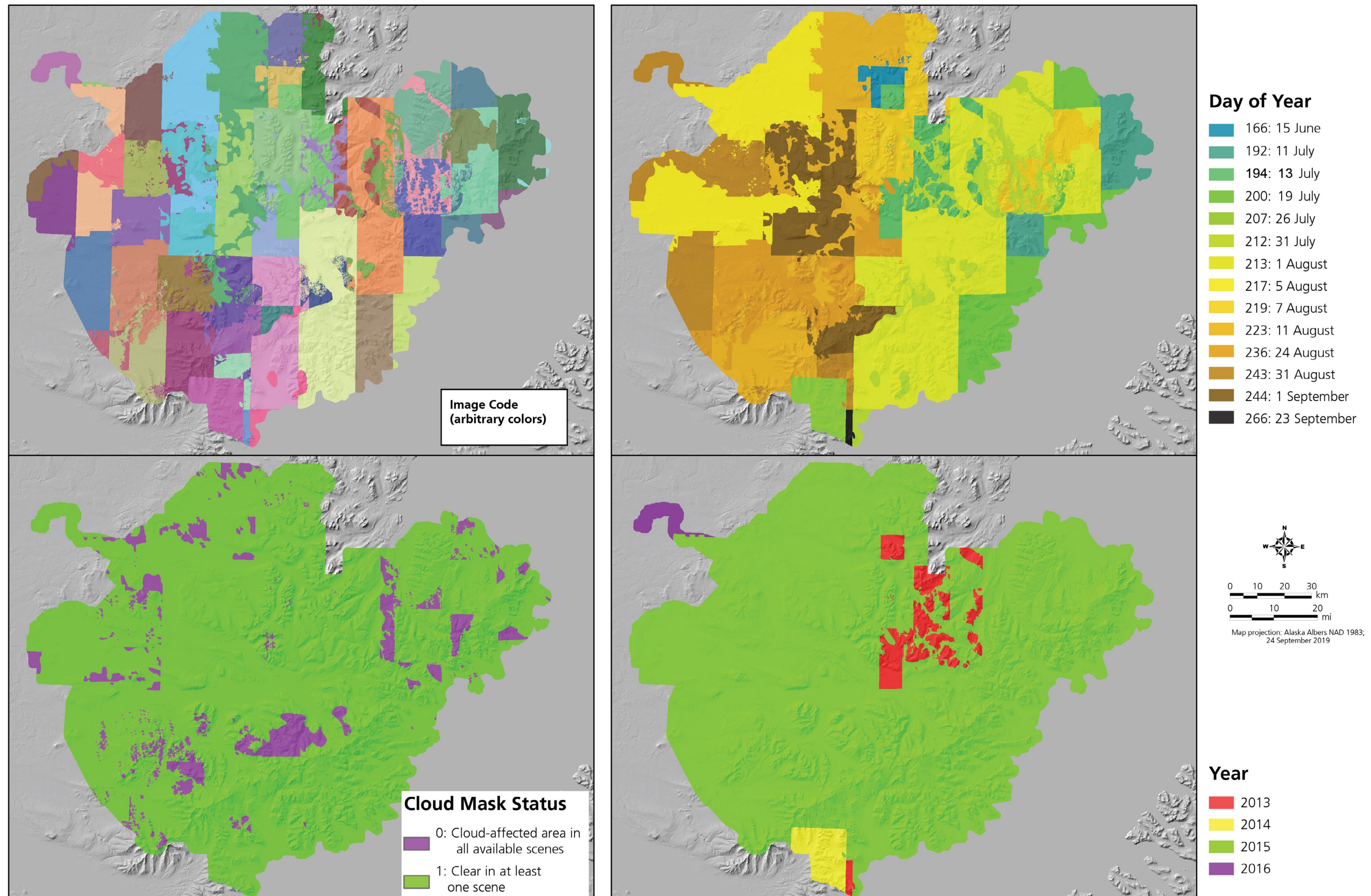


Figure 6. Pleiades multispectral surface reflectance mosaic source images and selected metadata, circa 2015, Katmai and Alagnak, Alaska.

panel. These areas will have unusual phenology compared to the rest of the image, either early phenology with less developed annual vegetation growth and more snow (June) or late phenology with some vegetation senescence (September). They were also normalized to a Landsat midsummer reference based on July and August imagery. Fortunately these areas are of very limited spatial extent. An approach that matched the reference Landsat image to the date of each Pleiades image could reduce the potential bias from phenological mismatch between the high-resolution imagery and the Landsat reference. This could be accomplished using modeled reflectance based on the Continuous Change Detection and Classification (CCDC) temporal breakpoint algorithm (Zhu and Woodcock 2014), but was beyond the scope of the current effort.

Figure 7 shows the summed absolute difference metric. The metric was not exported for the two Alagnak scenes, which were processed after the rest of the mosaic. Lower values represent areas with smaller differences between the normalized Pleiades imagery and the Landsat reference. These areas are more likely to have a high quality calibration. Areas with larger differences could represent remnant clouds or shadows. The zoomed in area on Figure 7 shows where multiple scenes were patched together using the summed absolute difference metric. Green areas with low values (Figure 7, panel b) have a good calibration and are cloud and cloud shadow-free. The yellow/orange patches in the center of the zoomed area represent clouds and shadows that could not be masked out. In the mosaic for those areas, there is a mix of shadows and clouds. In general if the available imagery had a mix of good imagery, clouds, and shadows, this process favored the good imagery, then very thin clouds or cloud edges, then shadows, and finally thick clouds.

There are also larger summed absolute differences over water and snow. These were excluded from the calibration process and are also prone to wide seasonal fluctuations in reflectance. In some cases the Landsat and/or Pleiades imagery may be saturated over snow which makes the difference metric unreliable. Calibrating water and snow-covered areas to surface reflectance is generally challenging. Such areas are highly dynamic and often have extremely low (water) or high (snow) reflectance. Our process was focused on calibrating snow-free land areas of the imagery.

The normalizations were performed in Google Earth Engine. We uploaded 2-m resolution multispectral top of atmosphere reflectance scenes and 2-m pan-sharpened Digital Number (DN) scenes (aggregated using average resampling from the 0.5 m pan-sharpened DN). It should also work to upload

aggregated 30 m resolution scenes, if they are generated correctly. For instance, inputs to the calibration should be aggregated using average resampling and to the same snap raster cell alignment as the Landsat imagery.

The same normalization that was performed on Pleiades multispectral and pan-sharpened imagery can be performed on DigitalGlobe/Maxtor imagery such as IKONOS, QuickBird, GeoEye-1, WorldView-2 and WorldView-3. Such imagery is available to NPS and cooperators at no direct cost under the terms of the NextView license. However, the NextView license is much more restrictive than the uplifted license purchased as part of this effort, which allows, for example, perpetual non-commercial use in web services.

It would be possible to put the raw imagery in an ArcGIS mosaic dataset and then perform the pan-sharpening, orthorectification, calibration, and mosaicking steps using image functions. The calibration parameters for each Pleiades image should remain valid and could be applied on-the-fly in a future workflow. It can be very slow and complicated to deal with ArcGIS mosaic datasets, but an approach like that could leverage improved DEMs and GCPs. Since the orthorectification was completed, a new Interferometric Synthetic Aperture Radar DEM (5-m resolution) has become available for KATM and ALAG and would likely provide improved results over the DEM used. Any UAS imagery collection in the study area that included stable areas (i.e., not glaciers) and that incorporated survey-grade ground control tiles would provide excellent future GCPs for the Pleiades imagery. In practice, workflows to update orthomosaics using updated DEM and GCPs while maintaining all the existing GCPs and bundle adjustments remain a challenge.

The manual cloud-masking step was time-consuming and, unlike other steps in our workflow, was not automated. It would be worthwhile to investigate the internal cloud mask from the Pleiades imagery and to consider other approaches to automate the cloud-masking process. If the internal cloud mask is not accurate enough, machine learning approaches to develop improved cloud and cloud-shadow masks could be explored. An alternative is to rely exclusively on the summed absolute difference metric to select observations. This would be entirely automated but would result in a much noisier mosaic.

Rigorous atmospheric correction of high-resolution satellite imagery is an area of active research and development. The empirical approach described here is practical and scalable, but is likely to eventually be replaced or supplemented by more advanced models.

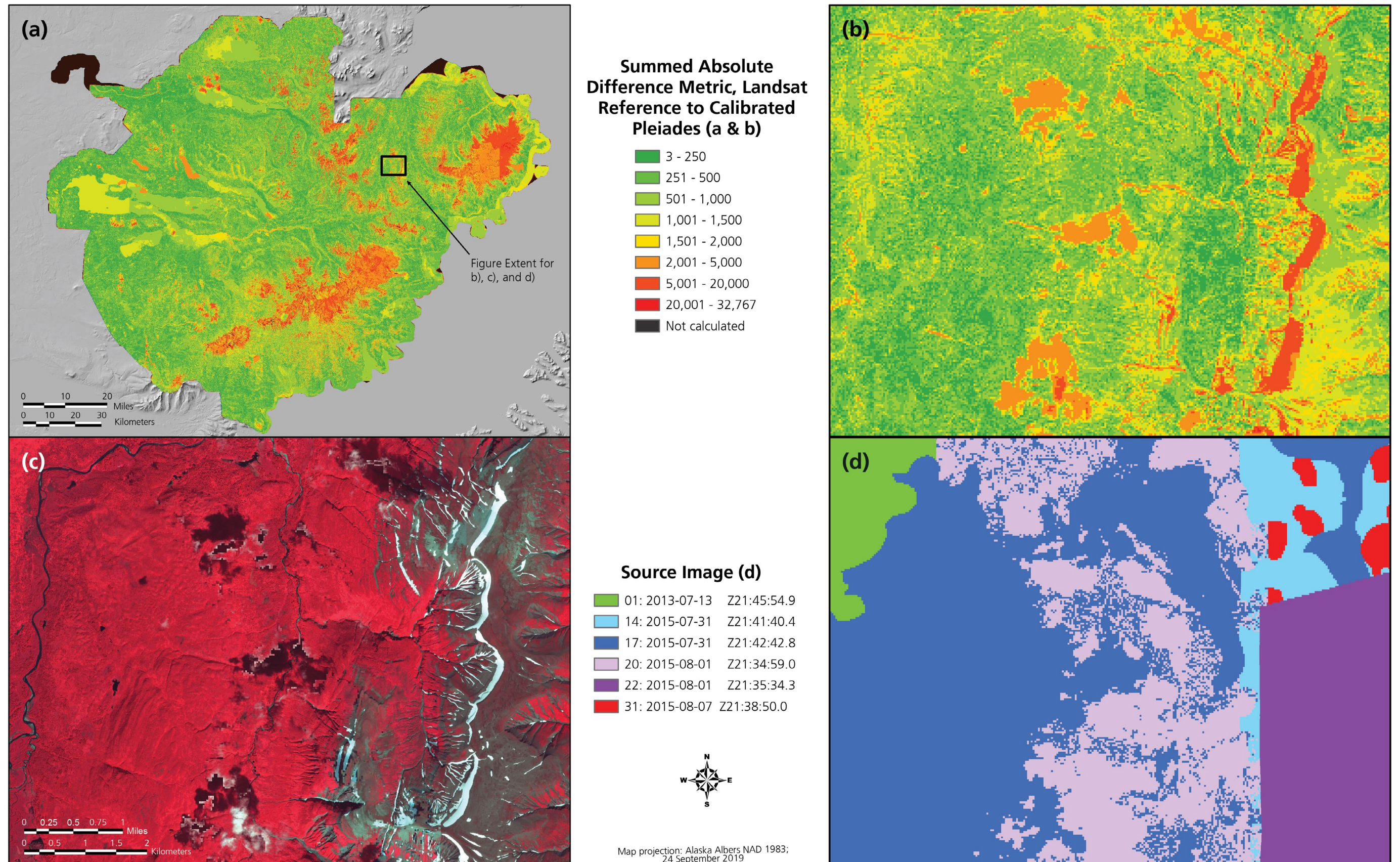


Figure 7. Pleiades multispectral surface reflectance mosaic, circa 2015, absolute difference metric from calibration, Katmai and Alagnak, Alaska.

Conclusion

We worked with GeoNorth and Airbus to acquire and orthorectify a set of Pleiades images covering Katmai NPP and Alagnak. The individual orthoimage blocks have estimated circular error 90% (CE90) ranging from 3.84–4.25 m, which exceeds national map accuracy standards for 1:12,000 scale.

We developed an automated workflow to calibrate the multispectral (2 m) and pan-sharpened (0.5) images to surface reflectance using a Landsat reference composite as a calibration target. The workflow also provided a method to automatically select the best image to include for each portion of the mosaic.

The source imagery, individual orthoimages, and mosaics are licensed to the National Park Service with a federal/

civilian license which allows the data to be shared with all other civilian federal agencies. An uplifted license is also provided, based on the Alaska Statewide Digital Mapping Initiative Statewide SPOT Ortho Image Basemap license (“SDMI license”). The uplift allows the imagery to be shared with U.S State and Local governments, academic universities, and Native American tribal governments. It also includes a perpetual non-commercial web services license.

The source imagery, individual orthoimages, mosaics, QA/QC information, metadata, and other supporting information are provided to the NPS on a hard drive data deliverable. Appendix 1 provides a listing of all data and files compiled and delivered with this report.

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Appendix 1. Listing of all data and files compiled and delivered with the final report for the Pleiades Satellite Imagery Acquisition, Processing, and Mosaicking for Katmai National Park and Preserve and Alagnak Wild River, 2014-2016.

Source	Type	Deliverable Description	Path
ABR	GIS/RS	Last Snow Day raster used for masking	\GIS\Pleiades\ancillary\KATM_LastSnowDay_015pct_LandsatSnowF-CA_2000-2017.tif
ABR	GIS/RS	Landsat reference mosaic	\GIS\Pleiades\landsat_ref\landsat_8_2013_2018_JuneJuly_CSMsk_median_filled7_v20190610.tif
ABR	GIS/RS	Landsat reference mosaic, observation count	\GIS\Pleiades\landsat_ref\landsat_8_2013_2018_JuneJuly_CSMsk_median_filled7_v20190610.tif
Geonorth/Airbus	GIS/RS	Pleiades imagery licenses	\GIS\Pleiades\license
ABR	GIS/RS	Pleiades flat multispectral mosaic, calibrated to surface reflectance based on Landsat reference	\GIS\Pleiades\mosaic\KATM_ALAG_Pleiades_Mosaic_2015_Multispectral_SR_BGRN_v20190624.tif
ABR	GIS/RS	Pleiades flat pan-sharpened mosaic, calibrated to surface reflectance based on Landsat reference	\GIS\Pleiades\mosaic\KATM_ALAG_Pleiades_Mosaic_2015_Pansharpened_SR_BGRN_v20190624.tif
ABR	GIS/RS	Cloud status summary raster	\GIS\Pleiades\mosaic\metadata_rasters\cloud_with_alagnak.tif
ABR	GIS/RS	Summed absolute difference metric, multispectral mosaic	\GIS\Pleiades\mosaic\metadata_rasters\katm_ms_mosaic_corr_20190611_Sum-AbsDiff.tif
ABR	GIS/RS	<i>Pleiades 2 m Multispectral Mosaic</i> , calibrated to surface reflectance based on Landsat reference	\GIS\Pleiades\orthos\pleiades.gdb\katm_pleiades_multispectral_20190624
ABR	GIS/RS	Pleiades pan-sharpened mosaic dataset, calibrated to surface reflectance based on Landsat reference	\GIS\Pleiades\orthos\pleiades.gdb\katm_pleiades_pansharpened_20190624
Geonorth/Airbus	GIS/RS	Pleiades multispectral orthos, native digital counts	\GIS\Pleiades\orthos\MS
ABR	GIS/RS	Pleiades multispectral orthos, calibrated to surface reflectance	\GIS\Pleiades\orthos\MS_SR
ABR	GIS/RS	Pleiades multispectral orthos, calibrated to top of atmosphere reflectance	\GIS\Pleiades\orthos\MS_TOAR
Geonorth/Airbus	GIS/RS	Pleiades panchromatic orthos, native digital counts	\GIS\Pleiades\orthos\P
Geonorth/Airbus	GIS/RS	Pleiades pan-sharpened orthos, native digital counts	\GIS\Pleiades\orthos\PMS
Geonorth/Airbus	GIS/RS	Pleiades pan-sharpened orthos, calibrated to surface reflectance	\GIS\Pleiades\orthos\PMS_SR
Geonorth/Airbus	GIS/RS	Pleiades orthorectification report, GCPs, image chips, etc.	\GIS\Pleiades\orthos\qaqc
Geonorth/Airbus	GIS/RS	Pleiades raw image bundles	\GIS\Pleiades\source
ABR	GIS/RS	Pleiades acquisition AOI	\GIS\Pleiades\vector\study_area\final_akalb83_katm_alag_pleiades_aoi_20150926.shp
ABR	GIS/RS	Pleiades mosaic extent	\GIS\Pleiades\vector\study_area\katm_pleiades_mosaic_area.shp
ABR	GIS/RS	Polygon cutlines for Pleiades mosaic	\GIS\Pleiades\mosaic\cutlines.gdb\katm_pleiades_mosaic_cutlines_with_Alagnak_20190624
ABR	GIS/RS	Cloud mask polygons for Pleiades scenes	\GIS\Pleiades\vector\clouds

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