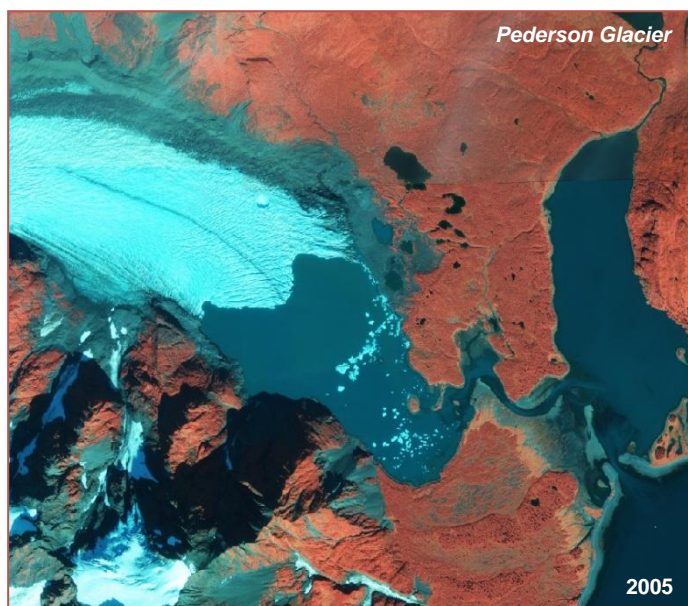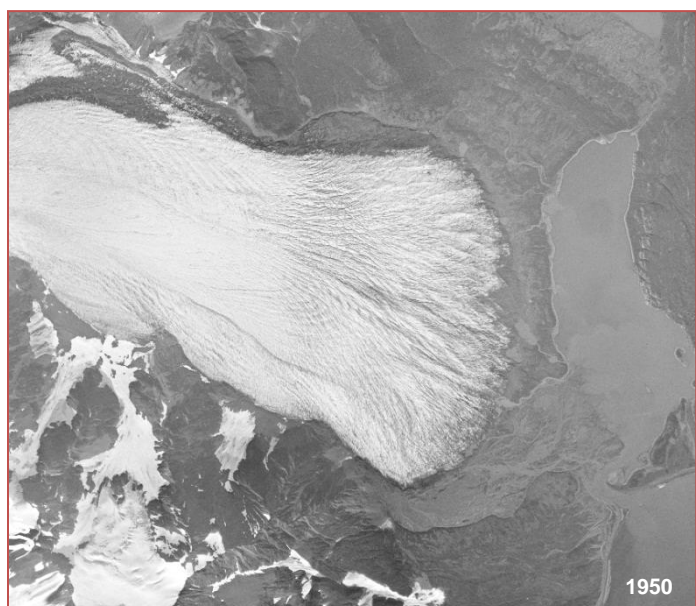# Orthorectification of Historic Imagery for Kenai Fjords National Park and Aniakchak National Monument and Preserve

Final Report

Natural Resource Technical Report NPS/SWAN/NRTR—2011/481

Pederson Glacier

1950

2005

Orthorectification of Historic Imagery for Kenai Fjords National Park and Aniakchak National Monument and Preserve

Final Report

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August 2011

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado publishes a range of reports that address natural resource topics of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Technical Report Series is used to disseminate results of scientific studies in the physical, biological, and social sciences for both the advancement of science and the achievement of the National Park Service mission. The series provides contributors with a forum for displaying comprehensive data that are often deleted from journals because of page limitations.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

This report received formal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data, and whose background and expertise put them on par technically and scientifically with the authors of the information.

Views, statements, findings, conclusions, recommendations, and data in this report do not necessarily reflect views and policies of the National Park Service, U.S. Department of the Interior. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the U.S. Government.

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Please cite this publication as:

Robertson, A. 2011. Orthorectification of historic imagery for Kenai Fjords National Park and Aniakchak National Monument and Preserve: Final Report. Natural Resource Technical Report NPS/SWAN/NRTR—2011/481. National Park Service, Fort Collins, Colorado.

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Abstract

In 2005, the NPS Inventory and Monitoring Program acquired high-resolution IKONOS orthoimage products for two of the SWAN parks, Kenai Fjords National Park (KEFJ) and Aniakchak National Monument and Preserve (ANIA). Over the next several years, the Southwest Alaska Network (SWAN) worked cooperatively with Saint Mary's University of Minnesota (SMUMN) to complete orthorectification of hardcopy aerial photographs for KEFJ and ANIA from the 1950s, 1980s, and 1990s. The objective of the project was to create a library of digital, orthorectified historic aerial photography that could be used in support of ongoing research studies for both KEFJ and ANIA. In addition, this project provided the opportunity to test the functionality and capabilities of different orthorectification software packages; to assess the utility of IKONOS satellite imagery and IKONOS-derived Digital Elevation Models (DEMs) for georeferencing and orthorectification processes; and to develop an optimized workflow methodology for cost effective orthorectification of aerial photography over extensive study areas and for multiple points in time. As a follow-on to the air photo orthorectification, SMUMN created photo mosaics that digitally merged individual photos together into a larger composite image. This second phase of the project was set up to test the mosaicking process for different years of photography and within a variety of geographic locations, as well as testing a variety of geospatial photo mosaicking software packages to determine an optimum mosaicking methodology.

Acknowledgments

Introduction

The Southwest Alaska Network (SWAN), one of 32 NPS Inventory and Monitoring (I&M) networks, is using remote sensing techniques where possible to describe long-term, landscape-scale changes in its constituent parks. Changes in vegetation cover classes, surface hydrology, and glacial extent, for example, can be monitored using remotely-sensed data. These data are intended to inform the design and implementation of other monitoring programs in the SWAN and to facilitate general resource management decisions in the parks.

In 2005, the NPS Inventory and Monitoring Program acquired high-resolution IKONOS orthoimage products for two of the SWAN parks, Kenai Fjords National Park (KEFJ) and Aniakchak National Monument and Preserve (ANIA). These products now provide the base cartographic reference for the parks. Similar products are expected to be developed for Lake Clark National Park & Preserve (LACL), Katmai National Park & Preserve (KATM), and Alagnak Wild River (ALAG) in the future.

In each of these parks there is an historical record of vegetation, landform, snow and ice and other surficial conditions that exist as point in time snapshots in the form of hardcopy aerial photographs (Table 1). With advances in image scanning capabilities, georeferencing procedures and orthorectification techniques it is now possible to have these historic images converted to digital form. Once converted, these images can be compared and contrasted with current imagery in order to derive assessments of changing processes that affect landscapes and landforms in the area. This report documents a two-phase project in which (1) historical air photos were orthorectified to the IKONOS base imagery for KEFJ and ANIA, and (2) orthorectified photo mosaics were produced for KEFJ.

Phase I - Orthorectification
For the first phase of the project, SWAN worked cooperatively with Saint Mary's University of Minnesota (SMUMN) to complete orthorectification of hardcopy aerial photographs from the 1950's, 1980's, and 1990's. The objective of the project was to create a library of digital, orthorectified historic aerial photography that could be used in support of ongoing research studies for both KEFJ and ANIA. In addition, this project provided the opportunity to:

1. Test the functionality and capabilities of different orthorectification software packages;
2. Assess the utility of IKONOS satellite imagery and derived Digital Elevation Models (DEMs) for georeferencing and orthorectification processes; and,
3. Develop an optimized workflow methodology for cost effective orthorectification of aerial photography over extensive study areas and for multiple points in time.

Phase II – Photo mosaics
In 2009, the original Task Agreement for the KEFJ and ANIA project was modified to include a second phase. The primary objective of Phase 2 was to work with the original orthorectified aerial photo imagery from Phase 1 and create a "mosaic" that would digitally merge a variety of the original individual photos together into a larger composite image. Further, this project was setup to test the mosaicking process for different years of photography and within a variety of geographic locations. The project plan also included testing a variety of geospatial photo

mosaicking software packages and development a range of different mosaicking techniques in order to determine an optimum mosaicking methodology.

The desired result of mosaic testing was to develop a final composite image product that was color and tone balanced throughout each of the input orthorectified photo tiles. In addition, the edges of each photo were to be blended so that no seams or cut lines between these tiles were visible and there was no abrupt or strong color change between tiles.

SWAN provided SMUMN with scanned versions of the hardcopy photos as well as base imagery and elevation data in order to complete orthorectification. In return, SMUMN provided the NPS with fully orthorectified aerial imagery complete with metadata in georeferenced digital format.

Table 1. Photo characteristics and scan resolution for images acquired for KEFJ and ANIA. Emulsion: B/W=black and white; CIR=color-infrared. Scale is expressed as inch to the mile.

Park	Year(s)	Emulsion	Scale	No. photos	Scan resolution
KEFJ	1950-52	B/W	1:40,000	183	1200-1800 dpi
	1984-85	CIR	1:63,000	67	1200 dpi
	1993	B/W	1:24,000	104	2000 dpi
ANIA	1957	B/W	1:40,000	75	1200 dpi
	1979	B/W	1:63,000	1	1200 dpi
	1985	CIR	1:65,000	24	1200-1800 dpi
	1993	B/W, CIR	1:24,000	41, 22	2000 dpi

The NPS has previously collaborated with SMUMN to develop a method for digital data conversion and orthorectification of aerial photography. The method makes use of a Digital Elevation Model (DEM), camera calibration reports, and control points taken from existing orthoimagery. SMUMN has produced images that were corrected using this approach, and they have shown a horizontal error of approximately $\pm$20-30m when compared to the control orthoimagery, thus meeting the National Map Accuracy Standard (NMAS) for 1:63,360 scale mapping ($\pm$32m). Registration of the KEFJ and ANIA photo series (1950s-1990s) to IKONOS imagery as part of this Task Agreement required additional control due to the mountainous terrain and various flight-line altitudes that were used in these sets of photography. NPS worked cooperatively with SMUMN to identify and resolve problems associated with processing over the course of the project.

Study Area

Phase I - Orthorectification

The study area for the first phase of the project included all of KEFJ and ANIA. KEFJ is located approximately 110 miles south of Anchorage on the southeastern Kenai Peninsula near the community of Seward (Figure 1). The Gulf of Alaska forms the east coast boundary of the park. KEFJ covers almost 2 million acres of the Kenai Peninsula and contains approximately 65% of the Harding Icefield; the largest ice field that resides completely within the United States. Positioned at the edge of the North Pacific Ocean, this park is exposed to extensive storms and significant precipitation. Annual snowfalls of 400 – 800 inches feed the over 38 glaciers that flow outwards from the Harding Icefield. Terrain within the park is extremely rugged and elevations range from sea level to +/- 6000 feet, often within very short horizontal distances.

ANIA is located 450 miles southwest of Anchorage towards the middle of the Alaska Peninsula (Figure 1). It is located in the tectonic region referred to as the Pacific Ring of Fire and the national monument consists of a six mile-wide volcanic caldera with associated features such as lava flows and cinder cones. The most recent volcanic activity in the caldera was in 1931. The Preserve is also characterized by rugged coastline, the mountains of the Aleutian Range and extensive rivers and small lakes. Dominant vegetation types within the Preserve are tundra and dense shrubs.

Historical aerial photography provides a visual record of conditions in these parks throughout time. These photos provide a valuable source of information regarding vegetation and landform condition that can be assessed against current imagery in order to examine processes that are impacting the landscape through time. There are a variety of ways in which these historic aerial images might be used once they are in orthorectified digital form. These include:

1. Local and regional vegetation gain/loss studies;
2. Glacial advance and retreat;
3. Ice condition assessment;
4. Identification of landform change processes; and,
5. Climate change studies.

Phase II – Photo mosaics

The study area for the second phase of the project was selected by the NPS. It was determined that in order to test a variety of photo and topographic conditions, the project should have one study area in the northern portion of KEFJ and one in the southern portion (Figure 2). In addition, in order to assess a range of mosaicking tools and techniques, SMUMN was to create mosaics from both black and white 1950's era aerial images and 1980's era color infrared (CIR) aerial images. In total, 24 photos were selected for mosaicking in the north study area (6 - 1980's CIR and 18 – 1950's black and white) and 13 photos were selected in the south (5 – 1980's CIR and 8 – 1950's black and white).

Figure 1. Study areas (areas of interest) for photo orthorectification, KEFJ and ANIA.

When selecting digital images for mosaicking, there were some basic guidelines that helped to ensure that the final mosaic was as effective as possible. These include the following:

- Ideally, selected images were to have as much overlap as possible; if possible 60 percent in all four cardinal directions;
- Spectral and tonal variation between the images needed to be as close as possible prior to mosaicking;
- Tonal variation was as tight as possible within each individual image. It is harder to color balance images that range drastically from light (e.g. snow covered mountain peaks) to dark (e.g. open water);

- With images scanned from aerial photographs, every attempt was made to use photos from the same flight line that were captured at approximately the same time of day. This minimized adjustments for sun angle, shadow, glare and orientation of features;
- Images were required to have a minimum amount of haze and/or cloud cover; and, Images needed as many bands as possible to permit radiometric and spectral enhancements that provide the software with more flexibility for color balancing and removing seam lines.

Figure 2. Study area (area of interest) for photo mosaic development, KEFJ.
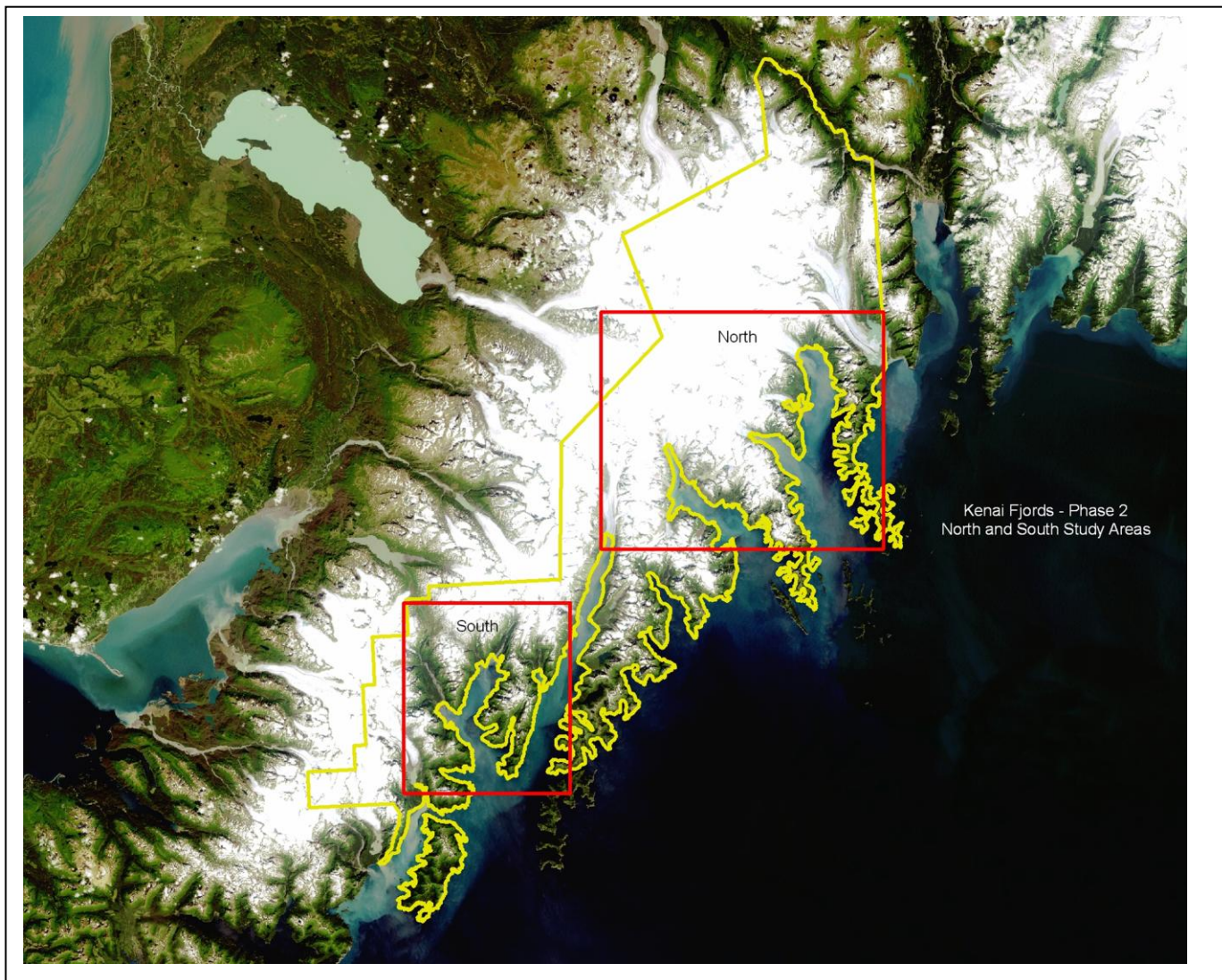
Methods

Phase I – Orthorectification

Digital conversion methodology

The digital conversion process employed for this project consisted of the orthorectification of scanned hard copy aerial photos. The extent of the project area and differences in data available for conversion processing necessitated the segmentation of the project area of interest (AOI) into 6 sub-areas organized by park and photo acquisition timeframe. These sub-areas included:

1. KEFJ:
   - 1950's NASA black and white;
   - 1980's Alaska High Altitude Photography (AHAP); and,
   - 1993 NPS coastal black and white.
2. ANIA:
   - 1950's black and white;
   - 1980's AHAP; and,
   - 1993 NPS coastal color infrared and black and white.

Image Acquisition and Photo Scanning

The first step in the work flow process was to convert the hardcopy aerial photos to unreferenced digital image files using a high resolution desktop scanner. Scanning of the 1950's black and white images and the 1990's coastal images was completed by Aero-Metric, Inc. Scanning of the 1980's AHAP's was done by the USGS. Output images from the scanning process were provided in TIFF format and at various levels of resolution. Scanning resolutions ranged from 1200 dpi, to 2000 dpi and some of the sub-project areas were scanned at multiple resolutions (Table 1). The most significant difference between these various scan resolutions was the output file size of the digital image.

The basic NPS specifications for the scanned photography purchased for this project were as follows:

Scan resolution:	21 micron (1200 dpi) or better
Pixel Depth:	8 bit
File Format:	TIFF
Band Format:	Multi-band (red-green-blue) for color images and single band for black and white images.

Base Layers for Georeferencing

Once the historic aerial photography had been scanned, the next step in the digital conversion process was to georeference the scanned images. Georeferencing or photogrammetric control is the process by which known ground control points are used to provide geographic reference for a scanned aerial image or graphic. This process involves choosing ground control points from a digital map reference layer; identifying those same points on the scanned aerial photo; and, then assigning the coordinate value for the point on the base layer to the equivalent point on the image. A minimum of 5 control points are required for basic georeferencing, however, for most of the scanned aerial photos in this project 15 or more points were used to improve the accuracy

of the georeferencing process. No GPS-derived ground control points were available for use in the georeferencing; all control points were taken from the imagery.

The base data that was used for georeferencing on this project varied across each of the 6 project sub-areas. For each area, the optimum data source was selected based on availability, accuracy and resolution. The best georeferencing results were achieved using fully rectified IKONOS satellite imagery that was provided to SMUMN by the NPS. Where this type of data was not available, lower accuracy Digital Raster Graphics (DRG) and Digital Ortho Quarter Quads (DOQQ) from USGS were used. Unfortunately, the IKONOS satellite imagery was clipped tightly to the park boundaries (Figures 3, 4). As a result, this data only provided a georeferencing solution for photos that were contained entirely within the KEFJ and ANIA boundaries. For photos that extended beyond KEFJ and ANIA (Figures 5, 6), the lower accuracy base layers had to be used.

Figure 3. NPS-supplied IKONOS coverage for KEFJ.
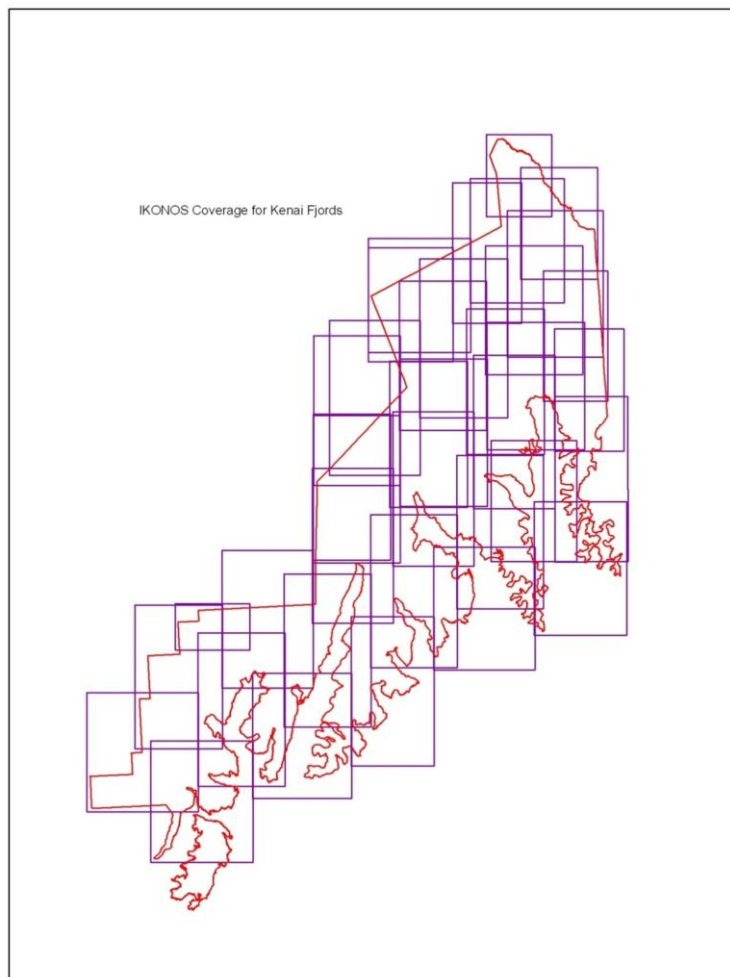
Figure 4. NPS-supplied IKONOS coverage for ANIA.
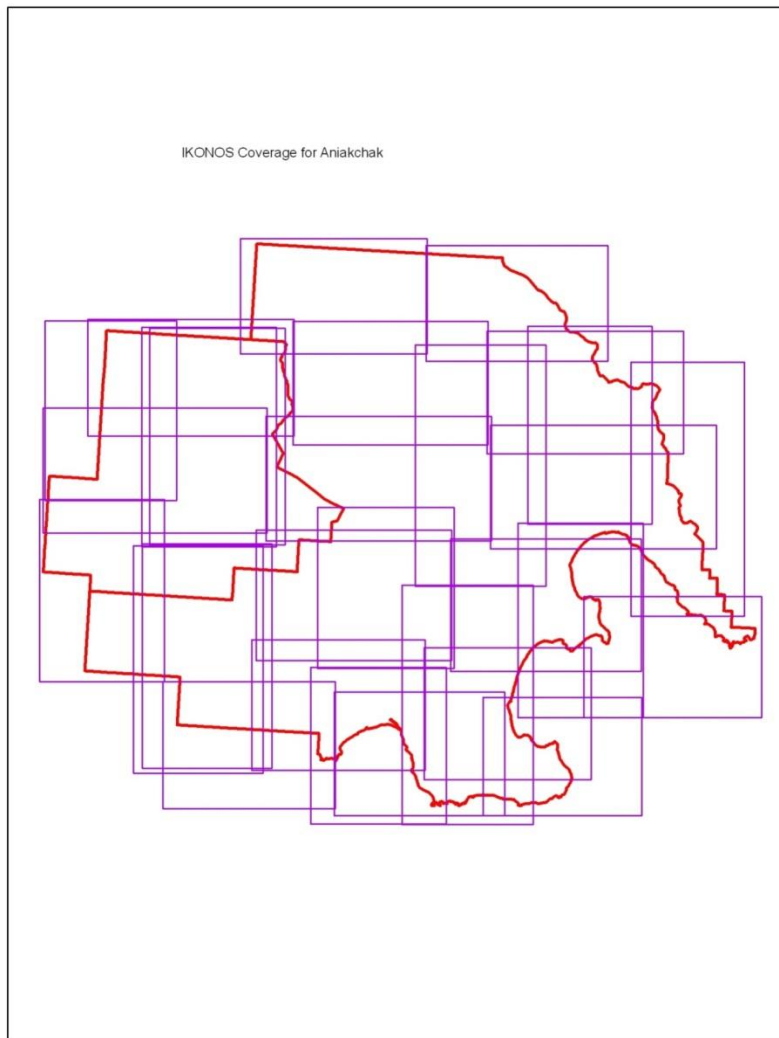
For every photo, a text file was generated in order to document the approximate error of the georeferencing process. Typical Root Mean Square (RMS) error for areas georeferenced to the IKONOS imagery was between 6 and 12 meters. Areas that were georeferenced using the USGS DOQQ's in conjunction with IKONOS typically had RMS errors of between 15 and 20. In some cases, where scanned photos were dominated by ice fields, mountains or water, it was difficult to find an adequate number of quality control points for georeferencing. In these situations, the RMS errors were also typically in the 15 to 20 meter range.

All aerial photographs were georeferenced to North American Datum of 1983 (NAD83-CORS96 or CORS94) and as further specified below:

KEFJ
PROJCS["NAD_1983_UTM_Zone_5N",
GEOGCS["GCS_North_American_1983",
DATUM["D_North_American_1983",
SPHEROID["GRS_1980",6378137,298.257222101]],
PRIMEM["Greenwich",0],
UNIT["Degree",0.017453292519943295]],
PROJECTION["Transverse_Mercator"],
PARAMETER["False_Easting",500000],
PARAMETER["False_Northing",0],
PARAMETER["Central_Meridian",-135],
PARAMETER["Scale_Factor",0.9996],
PARAMETER["Latitude_Of_Origin",0]
UNIT["Meter",1]]

ANIA
PROJCS["NAD_1983_UTM_Zone_4N",
GEOGCS["GCS_North_American_1983",
DATUM["D_North_American_1983",
SPHEROID["GRS_1980",6378137.0,298.257222101]],
PRIMEM["Greenwich",0.0],
UNIT["Degree",0.0174532925199433]],
PROJECTION["Transverse_Mercator"],
PARAMETER["False_Easting",500000.0],
PARAMETER["False_Northing",0.0],
PARAMETER["Central_Meridian",-159.0],
PARAMETER["Scale_Factor",0.9996],
PARAMETER["Latitude_Of_Origin",0.0],
UNIT["Meter",1.0]]

All orthorectified photos were projected from the above projections to Alaska Albers for delivery:

PROJCS["Alaska_Albers_Equal_Area_Conic",
GEOGCS["GCS_North_American_1983",
DATUM["D_North_American_1983",
SPHEROID["GRS_1980",6378137,298.257222101]],
PRIMEM["Greenwich",0],
UNIT["Degree",0.0174532925199432955]],
PROJECTION["Albers"],
PARAMETER["False_Easting",0],
PARAMETER["False_Northing",0],
PARAMETER["Central_Meridian",-154],
PARAMETER["Standard_Parallel_1",55],
PARAMETER["Standard_Parallel_2",65],
PARAMETER["Latitude_Of_Origin",50],
UNIT["Meter",1]]

Figure 5. Coverage of NPS-supplied IKONOS DEMs.

KEFJ DEM

ANIA DEM

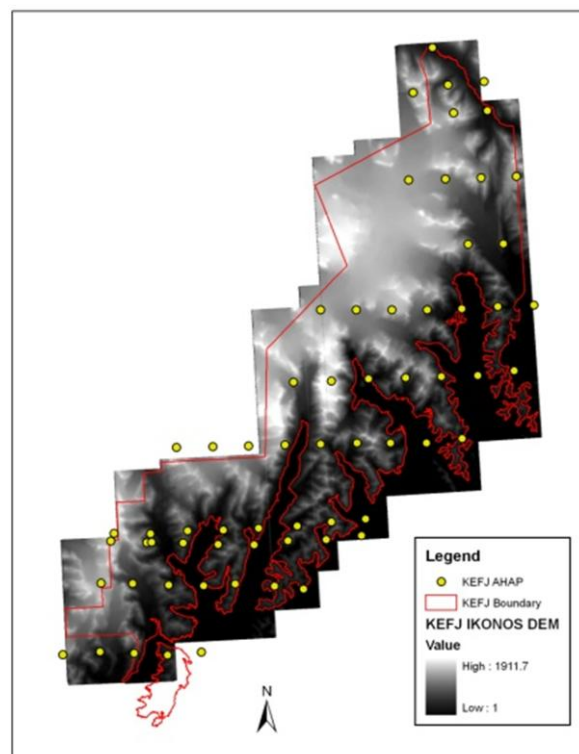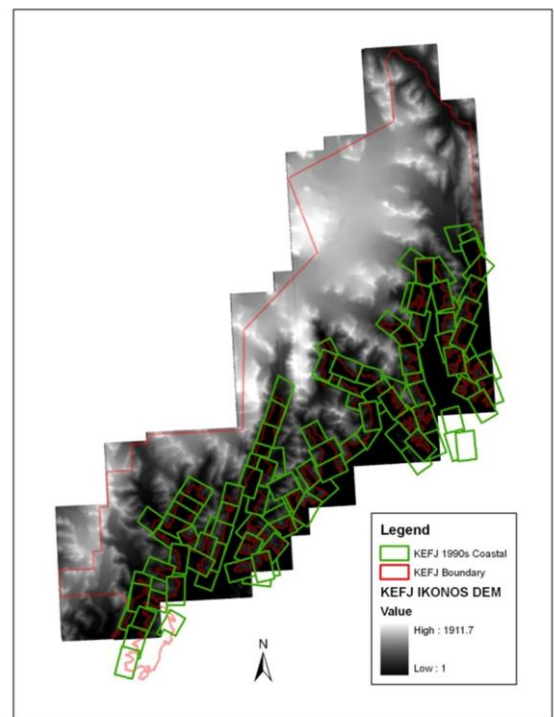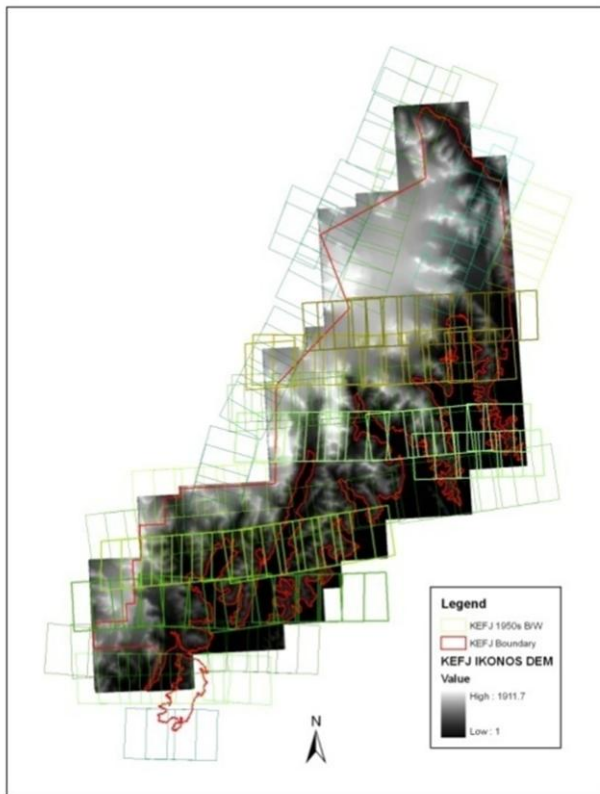Figure 6a. Photo indices for KEFJ showing flight lines and photo footprints.
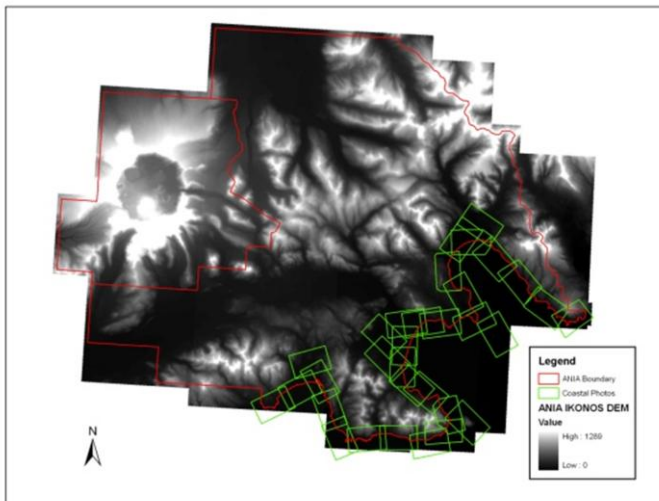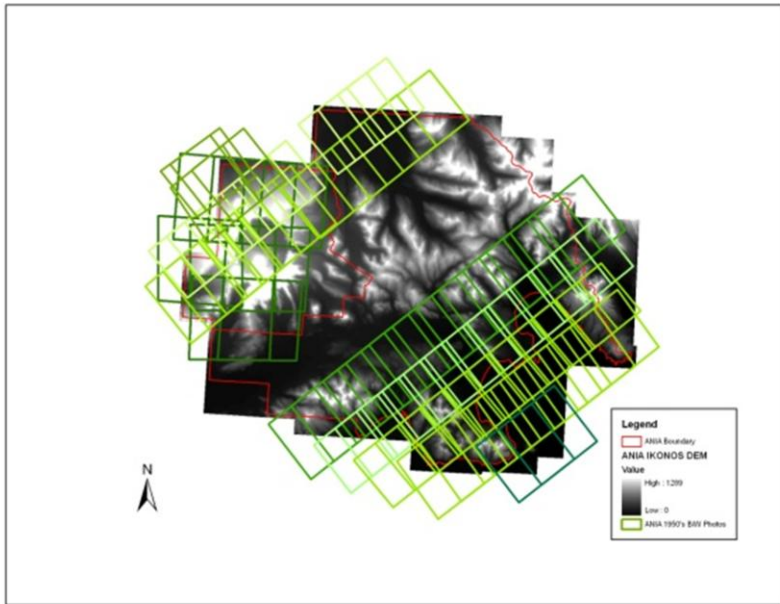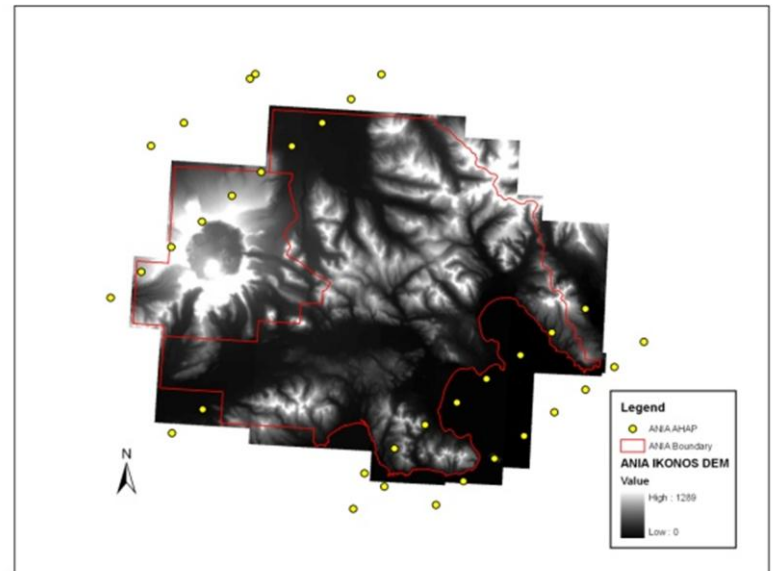
Figure 6b. Photo indices for ANIA showing flight lines and photo footprints.

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Orthorectification
The final step in the digital conversion process was to orthorectify the scanned and georeferenced aerial photographs. Orthorectification is the process by which a digital elevation model (DEM) and camera calibration reports are used to correct image displacement caused by terrain variation and camera lens aberrations. This processing ensures that scanned images reside in both their correct topographic and geographic space.

The primary input for the orthorectification process is a digital elevation model. As with the base layers used in the georeferencing process, a variety of DEM products were available for orthorectifying the photos used in this project. For areas where there was IKONOS satellite imagery provided by NPS, there was also an IKONOS DEM that was built by GeoEye for the orthorectification of the IKONOS imagery. Given that the IKONOS data was limited in its coverage to a tightly clipped boundary along the Park edges, however, other DEM products were required to orthorectify photos that fell outside of the Parks. These DEM's included: NASA Shuttle Radar Topography Mission (SRTM) DEM data and USGS National Elevation Dataset DEM data. Some testing was also conducted using newly available NASA ASTER DEM data. Unfortunately, only a limited amount of ASTER data was commercially available at the time of this project, so it was not used in the orthorectification process.

The IKONOS DEMs (30 meter resolution; Figure 5) were delivered to SMUMN in several separate files. This created problems during the orthorectification process because quite often the scanned aerial photos would cross beyond the edge of one the DEM files. In initial testing, where photos extended beyond the DEM file a "no data strip" was created at the DEM edge during the orthorectification process. This processing artifact carried over to multiple photos that crossed multiple DEM edges and began to create a patchwork of photos surrounded by no data strips across the project study area. In order to alleviate this problem, SMUMN determined that the individual IKONOS DEM files could be merged into one, larger DEM mosaic. In addition, it was determined that the SRTM DEM and the NED DEM could also be mosaicked together with the IKONOS DEM in order to prepare a composite DEM that covered the entire area of scanned photo coverage for the project.

The SRTM DEM is a 30 meter resolution elevation product derived from data captured during an 11 day space shuttle mission in 1999. The SRTM DEM and the IKONOS DEM were merged together with the priority elevation data coming from the IKONOS DEM. In other words, if IKONOS DEM values were present, they were used and the SRTM data was only used to fill "no data" areas and extend the outer edges of the DEM mosaic. Unfortunately, the merged IKONOS and SRTM DEM still did not completely cover the project study area and the SRTM data also contained some no data areas (Figure 5).

To further resolve missing DEM coverage issues SMUMN, merged in USGS NED DEM (60 meter resolution re-sampled to 30 meter using nearest neighbor processing) to extend the composite DEM beyond the edge of the project boundary. As with the previous merge, the IKONOS AND SRTM DEM, where present, took precedence over the lower accuracy NED DEM. All of the calculations and processes used to create this composite DEM were execute in ArcGIS 9.2 using the Spatial Analyst extension. As a final step, the composite DEM was converted to TIFF format, projected to NAD83 (using the projection definition below) and then converted to a .dem format for use in the orthorectification software.

In a minimal number of areas, there were photos in this project that extended beyond the DEM coverage (Figure 6a, 6b). Where this occurred, the photos were clipped at the edge of the DEM boundary and any image data extending beyond the DEM was dropped. As a result, these photos appear reduced in size or incomplete. In the future this type of issue can be resolved by limiting the size of the project study area to only those areas with complete DEM coverage. Preference should be given to project areas where complete IKONOS imagery and DEM are available in order to ensure accuracy in the final orthorectified product.

Another important input to the orthorectification process was the camera calibration report. These reports, created by the United States Geological Survey (USGS), contain correction information that can be used by the orthorectification software to better remove camera distortion and lens aberrations during image processing. These reports are specific to the camera used for each photo acquisition mission and typically contain distortion correction information such as focal length, principle point of symmetry, and X/Y coordinates for the photo fiducial marks.

For this project, complete (useable) camera calibration reports were not available for all of the sub-project areas. For example, none of the reports covering the 1950's era photography in either KEFJ or ANIA were useable because they did not include sufficient data for the orthorectification process (i.e. no fiducial marks and limited lens information). In project sub-areas that had useful camera calibration reports, these data were used to enhance the final orthorectification of the scanned aerial photos (Appendix 1). These sub-areas included:

1. KEFJ:
   - 1980's Alaska High Altitude Photography (AHAP); and,
   - 1993 NPS coastal black and white.
2. ANIA:
   - 1980's AHAP; and,
   - 1993 NPS coastal color infrared and black and white.

The software package used for orthorectification on this project was OrthoMapper rev. 4.35 from Image Processing Software Inc. Initial testing of OrthoMapper versus ERDAS Imagine 9.3 has shown that for processing large amounts of data (e.g. hundreds of scanned aerial photos), OrthoMapper provides a more appropriate environment for production work flows. With OrthoMapper, individual project folders are created for each photo, but when camera calibration information is used it only needs to be entered once and the camera report file generated can be used for every photo associated with it. Whereas in other software camera report information needs to be entered for each photo. Some of the other benefits of OrthoMapper include:

- a streamlined straightforward approach to creating projects;
- simplified user interface and short learning curve to achieve productivity;
- relatively inexpensive initial purchase price and low annual maintenance costs;
- utilization of multiple displays for simplified control point selection; and,

- a tracking feature that, after 2 control points have been added, the non georeferenced image will track with the known geographic locations on the base layer.

Quality Assurance/Quality Control

Quality control of the final product was managed in several different ways. During the georeferencing phase, the amount of error associated with the selection of individual control points was monitored and points that had too much error were eliminated from the final rectification. In addition, as mentioned previously, an average of 15 to 20 control points were chosen per photo in order to ensure that spatial correlation was the best possible.

A second, quality control review was then conducted on every photo following the orthorectification process. This review was completed in digital form in the GIS by displaying the corrected scanned aerial photo on top of the base layer that was used for deriving the control points used in the georeferencing process. The locations of random features that were visible on both images (e.g. lakes, mountain peaks, islands, bays etc.) were then visually reviewed and measured to determine the amount of relative shift in feature position between the base layer and the georeferenced photo. These shifts typically ranged from 2 to 35 meters and were dependant on a variety of photo characteristics including topographic variation, proximity of measured features to the photo edge, accuracy of the base layer used for georeferencing and adequacy of control point selection.

Finally, in order to control model error related to DEM accuracy, the use of the composite DEM was limited to only those photos that extended beyond the boundaries of the IKONOS DEM. If photos were completely within the boundaries of the IKONOS imagery then only the high quality DEM was used for orthorectification.

Phase II – Photo mosaics

Basic approach

The basic mosaicking methodology utilized for this project was as follows:

1. Initial selection of input photos based on image quality, color, tone, texture, histogram variation and overlap.
2. External color and tone balancing
   - used a third party image manipulation package such as Adobe Photoshop,
   - visually matched adjacent images so that not as much adjustment was required during the mosaicking process
3. Sub-setting
   - clipped out the best portions of individual photos before mosaicking,
   - followed natural features (valleys, ridges, streams, roads etc.) in order to mask seams,
   - focused on the center of the photo to minimize distortion from radial displacement.
4. Software mosaicking and color balancing with image stretching and manipulation
5. Touch up of seam lines

Software

Several different software packages were tested to determine which would generate the best possible mosaic output for this project. These included: OrthoMapper 4.75, ER Mapper 7.2, ArcMap Image Analysis Extension 9.3, ERDAS IMAGINE 9.3, and GeoExpress 5.0. Each software package had its own suite of capabilities, strengths and weaknesses. The most important functional elements of mosaicking software were those that controlled the amount of image manipulation that was conducted before during and after the mosaicking process. Not all of these packages provided the user with the same level of image preparation and control; however, all had unique features and different techniques. Software packages with more advanced functionality did not necessarily provide the best final results.

OrthoMapper Version 4.75

OrthoMapper is a software package that is designed specifically for georeferencing, orthorectification and mosaicking. The package is produced by Image Processing Software Inc. and SMUMN has been using it extensively for several years. The appeal of this software is that it is optimized for production work flows in which large numbers of images need to be processed accurately in within a limited time frame.

Part of the inherent functionality of this software is the processing routines required to color balance and mosaic orthorectified aerial and satellite images. There are two ways color balancing can be approached in OrthoMapper:

1. pre-processed color balancing of individual images using a separate software routine outside the mosaicking interface; and,
2. setting parameters within the mosaic interface that can be adjusted based on analysis of each image's spectral histogram.

Color balancing outside the mosaic interface is designed to match average spectral reflectance values and radiometrically normalize the images. In this process, each image that will make up the final composite mosaic is visually examined and a single image is chosen as the one to which all others will be matched. This "seed" or control image is typically the one that has the most pleasing visual range of tone and texture for the final mosaic. Using the statistical information that describes the control image, the color balancing tool is then used to set minimum and maximum values that will be used to adjust surrounding images. This is done to smooth or balance tones across multiple images and bring overall color variation closer together. Typically, spectral values of pixels at the extreme ends of the image histogram such as bright whites (glaciers) and dark grays (open water) are excluded from this processing so that their values do not skew the overall color balance.

Color balancing within the OrthoMapper mosaicking interface is a much more automated process. Once input images are loaded into the software, there are three processing options for tone and color balancing. These include: basic color/tone balance, normalizing brightness, and advanced color balancing. Regardless of the option chosen, OrthoMapper will generate spectral histograms of each band of the input images which the user can examine to select minimum and maximum values for color balancing. The OrthoMapper software will also develop a

recommended color balancing process through automated examination of the image histograms which the user can either select or discard.

For this project, SMUMN tested the results from both color balancing and mosaicking approaches provided by the OrthoMapper software. Based on the test results, it was decided that a combination of both the manual and automated processes would be most effective for the KEFJ mosaics. Initial selection of a control image and pre-processing of all the photos for the mosaic was conducted outside of the mosaicking interface. These images were then run through the mosaicking software and further enhanced in order to produce the most consistent final composite.

ER Mapper 7.2

ER Mapper is a remote sensing and image processing software package that comes bundled in full versions of ERDAS Imagine. This software has not been previously utilized by SMUMN for color balancing and mosaicking and the Kenai Fjords project provided a good opportunity to test this functionality. The ER Mapper mosaicking workflow process came from a tutorial provided by the software manufacturer. The expectation was that the tutorial approach would minimize the learning curve and provide some best practices for the mosaicking process.

This software package provides an image balancing wizard for making color and tone adjustments to images during processing. The use of this wizard was recommended in the tutorial documents for the software. This wizard provides a step by step process that can be followed to color balance and mosaic any number of orthorectified images.

The first step in the process was to load all of the images into the ER Mapper viewer and arrange them in a priority sequence. The images were then analyzed with an ER Mapper smart data algorithm and image statistics were developed. Next, the user determined the amount of contrast stretch that was to be applied to the images. SMUMN found that the default level of 0-255 provided the best results.

The next step was to select various parameters for balancing the input images. ER Mapper contains automated functionality for creating clip regions from the original photos based on where the software determines the seam lines would best be placed. This functionality was tested by SMUMN, however, it was quickly determined that better results were achieved by interactively creating clip regions (image subsets) manually before loading the images into ER Mapper. The most stable and straightforward software for creating clip regions was the subset tool in the Image Analysis extension for ArcView 3.3.

With clipped images ready for mosaicking, ER Mapper then provided a variety of tools for image adjustment including: corrections for water areas; filters for haze (5 in total); and, methods for color matching. Tests conducted by SMUMN indicated that there was little effect on the KEFJ images using the water area corrections and that the haze filter was best set to "none". There were three software methods for color matching including:

- match to the entire mosaic;

- match to an individual image; and,
- skip color matching.

SMUMN tested each option on the KEFJ images. The "skip color matching" option was used to create a control mosaic against which other processing options were assessed. This provided a good baseline.

The process of matching or color balancing all images to the spectral characteristics of an individual "seed" image was conceptually the preferred process; however, this did not always prove to be successful in practice. SMUMN's test indicated that the success of this type of processing depended entirely on the amount of adjustment required to bring an individual image in line with the control image. Where minimal adjustments were required, the process worked fine; however, where significant adjustments were necessary, the balance was not often achieved satisfactorily. In the end, this was very much a trial and error effort with mixed results resulting primarily from the selection of an appropriate control image.

The option of automatically matching colors to the entire mosaic (instead of a seed image) proved to be the most successful process for color balancing in ER Mapper. This process matched overall colors on a band by band basis for each of the input images and attempted, where possible, to preserve original image values. This processing provided the best overall results.

ER Mapper also provided multiple image enhancement techniques for application to the images during color balancing. Each one of these options was tested and it was determine that the "histogram equalize stretch" provide the most consistent results. This image enhancement technique provided a sophisticated method for modifying the dynamic range and contrast of an image by altering the image such that its spectral intensity histogram had a desired shape. This is a non-linear process.

ESRI ArcGIS 9.3

ESRI's ArcMap 9.3 contains some minimal mosaicking capabilities as part of the base functionality of the software. This functionality uses the raster processing algorithms of ESRI's GRID package to simulate the functionality of higher end image processing software packages. As a result, it is imperative that, for all mosaic processing within ArcMap, no data values within the input images must be set to zero. If they are not, the black boarders around the images will cause processing errors including significant negative effects on color balance calculations. In addition, one of the first steps that ArcMap expects is for the user to define the specifications of the output image including the bit level and the number of bands. Other software packages remove these decisions from the user interface.

The mosaic command in ArcMap contains a variety of parameters for defining the mosaic processing methods. The first decision is how to handle areas of overlap between the input images. There are 6 options for this process including: first, last, blend, mean, minimum and maximum. The user must ensure that, if First or Last are chosen as the method for handling

overlap, then the arrangement of the input images plays a major role in defining the quality of the output mosaic.

Each of these options was tested by SMUMN and it was determined that the "First" option (the output cell value of the overlapping areas will be the value from the first raster dataset in the list) provided the most consistent results. During processing, "No Data" values in all input images were set to a value of zero and SMUMN was able to define how no data will be handled in the output mosaic. Setting this value to zero ensured that the output mosaic had no data values already properly set.

The next parameter that had to be defined was the color match method that was employed in the mosaicking process. Testing by SMUMN indicated that this parameter had the single most significant impact on the quality of the final mosaic. Available methods for color matching (image enhancement and transformation) included:

- None: This option did not use any color matching operation when mosaicking raster datasets.
- Statistic Matching: This method matched the statistical differences (minimum, maximum, mean) between the reference overlap area and the source overlap area; then the transformation was applied to the entire target dataset.
- Histogram Matching: This method matched the histogram from the reference overlap area with the source overlap area; then the transformation was applied to the entire target.
- Linear Correlation Matching: This method matched overlapped pixels and interpolated to the rest of the source; pixels that did not have a one-to-one relationship used a weighted average.

As the name implies, the first method (None) didn't apply any color matching statistical algorithm to the mosaic. This provided SMUMN with the ability to generate a control mosaic against which other enhancement methods were assessed.

In an effort to develop the best possible color and tone balanced mosaic for the KEFJ project, SMUMN tested all of the other transformation options. It was determined that the end result was completely dependent on the quality of the input imagery. In general, the histogram matching method generated more consistent, visually appealing results than the other methods.

Image Analysis 9.3

Image Analysis 9.3 is a third–party extension for ArcMap 9.3 that provides more extensive image processing capabilities than those provided with ArcGIS. This extension is developed by ERDAS Inc. and requires ArcMap 9.3 as a platform from which to execute processing functions.

The Image Analysis tool is executed from the main ArcMap window. Much like the basic mosaicking tool in ArcGIS, this package contains tools for handling the overlap areas between individual images. These tools include: order of display, maximum value, minimum value, and average. In addition, Image Analysis includes the option to crop input images by a certain

percent in an attempt to create more appealing seams in the final composite mosaic. The software also includes minimal color balancing methods including: brightness/contrast, histogram matching, and none.

SMUMN initially believed that, since the Image Analysis Extension was developed by an image processing company, it would contain more robust tools and provide superior options to the basic mosaicking capabilities in ArcGIS. Testing by SMUMN concluded that this was not the case for the KEFJ project. In fact, SMUMN encountered features within the software that were completely non-functional and needed to be addressed by the ERDAS technical support team.

One feature in particular was disappointing in its performance. The Look-up-Table function was intended to provide the user with the option to develop custom image enhancement algorithms which could be applied to input images and then saved as an output image for further processing. SMUMN planned to use this tool to pre-process all of the input images that were to be used in the final KEFJ mosaics so that there was more control over the color balancing process. Unfortunately, this tool would not create and permanently save a modified image. This issue was reported ERDAS Technical Support where it was documented as a bug. Further testing of the Image Analysis Extension was abandoned pending the release of a new version of the software.

ERDAS IMAGINE 9.3

ERDAS IMAGINE 9.3 is the most technically advance software package available to SMUMN. This package 1s developed by ERDAS Inc. and it is a fully functional remote sensing and image analysis application.

As with the other packages tested by SMUMN, all of the input images that were brought into IMAGINE for mosaicking were subset (clipped) in ArcView 3.3. During the loading process, pixel values in "no data" areas were set to zero. No statistics or color manipulations were run on the images prior to or during the loading sequence.

Again, as with previously described tests on other software packages, the first run of images through mosaic tools in IMAGINE used all default settings. The purpose of this run was to create a baseline or control mosaic against which other transformation and image manipulation options could be assessed. From this baseline, adjustments were done to better refine the quality of the mosaic. This was a trial and error process that relied upon educated reasoning gained through researching literature on mosaicking techniques and perusing recommendations from the ERDAS Technical Support Team.

There were three primary functions evaluated on each run of the software. These represented the main user controlled options available for image manipulation in IMAGINE, including overlap functions, resample methods, and color corrections (Figure 7).

Figure 7. User options for image manipulation, ERDAS IMAGINE Mosaic Tool.
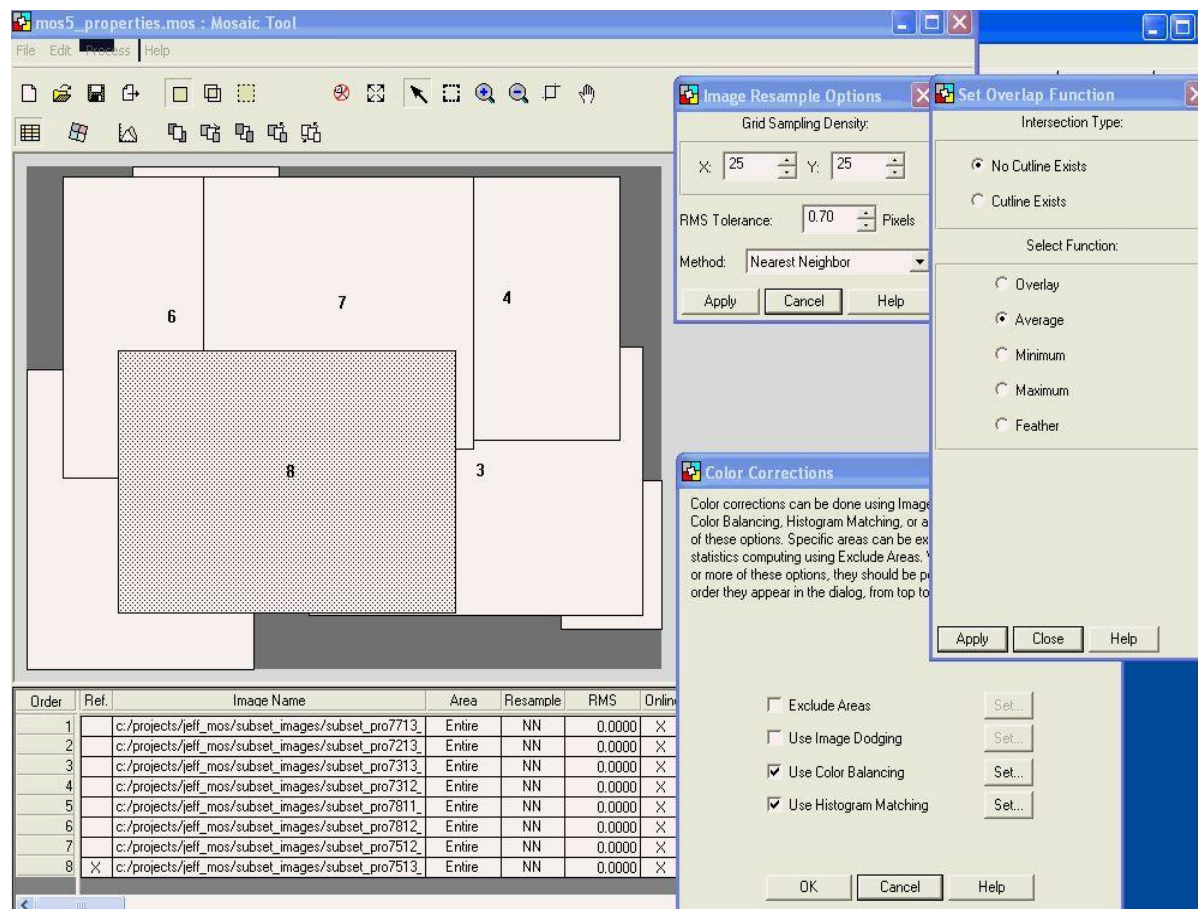
Overlap functions were designed to allow the user to develop a more seamless transition between individual images. These functions included: overlay average, minimum, maximum, and feather. From initial investigations it was assumed that the "feather" function was going to provide the best overlap handling. However, testing by SMUMN determined that the "average" function provided better blending of the overlap areas. Processing using the "average" function created an output mosaic in which the spectral value of each overlapping pixel was created from the average value of each overlapping input pixel. The overlap tool also provided users with the option of creating cutlines during processing. This option was not selected by SMUMN because the input images were already subset around natural features to ensure optimum color balancing at the seams.

Image resample methods provided the opportunity to set/change: the grid sampling density in both X and Y directions; the RMS tolerance of the output mosaic; and the re-sampling method applied. The density determines how many points will be used to transform from input

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coordinates to output coordinates. RMS tolerance determines how much error is allowable between the input and output pixels. The re-sampling method determines how output pixels will be created from combinations of input pixels. Testing by SMUMN indicated that the nearest neighbor re-sampling method produced the best output mosaic because it maintained a one to one pixel relationship.

The color corrections interface provided several options including: exclude areas, use image dodging, use color balancing and use histogram matching. The two options that provided the most flexibility in creating the final composite mosaic were color balancing and histogram matching. The color balancing options in IMAGINE provided a variety of tools for examining image properties and adjusting the spectral parameters of output images. The primary purpose of applying these methods was to resolve illumination variations in images caused by the cameras optics.

SMUMN tested all of the options available for color balancing including: linear, conic, exponential and parabolic. Final results indicated that parabolic color balancing provided the optimum results for the images in the KEFJ project. As mentioned previously, camera optics often created an illumination imbalance where an individual photo was brighter in the center and the faded towards the edges. The parabolic method provided the best attenuation of this effect across the widest range of photos in the mosaicking process. Histogram matching settings provided the best output results when they were left as default for all images.
Given that the illumination characteristics of individual aerial photos varied greatly for the KEFJ project, the selection of the best methods for transforming and enhancing images in IMAGINE was very much a trial and error process. Different combinations of methods, functions and adjustments were applied to the mosaic and the best combinations were selected for production of the final products. This is the recommended approach by the ERDAS Technical Support Team as there is no single recipe that is successful mosaicking in every situation.

GeoExpress

GeoExpress 5.0 is a product of LizardTech Inc. and is primarily an image compression package. This software creates compressed files for spatially referenced images without degrading image quality. The output file type from this processing is proprietary and is called MrSID or simply .sid format. GeoExpress allows the user to define the amount of compression that is applied to an output image. Compression is specified by a ratio (e.g. 2:1, 10:1, 40:1) and is determined as a function of input image file size and desired output file size. The primary reasons that spatially referenced image files are compressed are to preserve storage space and to increase the speed of image display in various software applications.

As a part of the suite of tools that LizardTech provides for image compression, they offer some limited ability to mosaic images together in order to create a single compressed image out of multiple input files. This software package does not offer any image enhancement, manipulation or color balancing tools. As a result, if color balancing and seamless matching are requirements for the final mosaic, images must be fully prepared using other software tools before they can be stitched together in GeoExpress.

Image file size presented a continuous issue in the KEFJ mosaicking project. NPS project specifications called for delivery of the individual orthorectified photos and the final mosaic in Tagged Image File Format (TIFF). This is the most common uncompressed image format currently used for geographically referenced image data because of its flexibility to accommodate spatial referencing by tagging image data with a spatial header. Unfortunately, one of the limitations of TIFF is that it has a maximum file size of 4 Gigabytes (GB).

The individual orthorectified photos that were selected for mosaicking on the KEFJ project ranged in size from 0.8 to 1.2 GB. Given the TIFF file limitations, this large original file size limited the number of photos that could be mosaicked together into a single composite image. One method that was proposed to circumvent this issue was to compress and mosaic the photos using GeoExpress. Unfortunately, testing by SMUMN indicated that this was not a viable approach for the KEFJ project.   The composite mosaic produced by GeoExpress was of lower quality that those resulting from the other software packages. In addition, when the file compression methodology was discussed with NPS, they reiterated their preference for delivery of the final product as an uncompressed TIFF file.

Results and Discussion

Phase I - Orthorectification

Final products for the KEFJ and ANIA orthorectification project included the following:

1. 456 scanned aerial photos as per the specifications listed above (e.g., Figures 8, 9).
2. Orthorectified aerial photos delivered as 8 bit pixel depth, 1 meter pixel resolution, TIFF format files (e.g., Figures 10-12). These files all included OGC compliant metadata created with the ESRI ArcGIS 9.2 metadata editor following the FGDC-STD-001-1998 format. This metadata indicated which base data set and DEM were used to orthorectify each photo.
3. Text reports for each photo orthorectification summarizing the average horizontal Root Mean Square (RMS) inherent in the rectification process (e.g., Appendix 2).
4. The ortho products include OGC compliant metadata created with the ESRI ArcGIS 9.2 metadata editor following the FGDC-STD-001-1998 format (e.g., Appendix 2).

The primary objective of this project was to create a digital library of historic aerial photographs that were georeferenced, orthorectified and available for comparison and evaluation with current imagery. This objective was achieved for 456 scanned photos from KEFJ and ANIA. The digital product meets the 1:63,360 National Map Accuracy Standard of +/- 32 meters horizontal accuracy for areas where the IKONOS DEM and IKONOS imagery were available. The use of the higher quality DEM and the incorporation of the camera calibration report in the rectification process generally led to horizontal RMS errors of between 5 and 10 meters. In addition, the selection of between 15 and 20 control points per photo and the care taken by editors when selecting these points contributed to improved georeferencing.

In areas of KEFJ where the USGS DOQQ's and DRG's were used for georeferencing, and in areas where the merged DEM was used for orthorectification, horizontal accuracy ranged between 15 and 40 meters. Unfortunately, it was not possible to achieve better results in areas where the IKONOS imagery and DEM were unavailable.

During the orthorectification process there was a certain amount of shifting that occurred in the final digital images. The amount of shifting was a factor of many different elements including:

1. The number of control points used;
2. The displacement of the control points over the surface of the image;
3. The resolution of the DEM;
4. The extent of the DEM;
5. The quality of the composite DEM (where it was used);
6. The accuracy and quality of the base layer imagery;
7. The quality of the input aerial photo (e.g., cloud covered, shadows, scratches, stretch and warp);

8. The topographic variation of the photo (i.e. significant topographic change over short distances);
9. The ability of the software to perform high end transformations;
10. The existence of camera calibration reports; and,
11. Anomalies with the individual photo (e.g. no fiducials, significant tilt displacement)

An artifact of the orthorectification process commonly described as image smear was also identified on certain photos during the quality control process. These issues appeared to occur towards the outer edges of orthorectified photos and in areas of significant topographic relief (Figures 10-12). Further analysis of these smeared areas indicated that the problem occurred primarily on the 1950's photos for both KEFJ and ANIA and was possibly due to the fact that no camera calibration reports were available for these photos. The speculation was that these photos probably contained a significant amount of radial displacement and lens aberration caused by the older camera technology employed during photo acquisition and, having no camera calibration reports available for software adjustment during orthorectification created the smearing effect. It is also possible that the composite DEM and significant elevational changes over short distances contributed to this problem.

Photo scan resolution was another issue that needed to be addressed throughout the project. The historic photos used in this project were scanned at various resolutions (expressed in either dots per inch (DPI) or microns). These resolutions ranged from 1200 dpi to 2000 dpi. The 2000 dpi scanned photos created an output image with a large file size. This was an issue because with larger file sizes it was more difficult for ArcGIS and OrthoMapper software to display the data. In addition, processing times for all stages of georeferencing and orthorectification increased in parallel with file sizes. A visual comparison of the scans and finished orthorectified photos showed there was no significant gain in image quality between 1200 and 2000 dpi. It is likely that the difference between 1200 and 2000 dpi scanning would be more noticeable at the 1:40000 scale level and larger.

File size increases were further complicated by the fact that the OrthoMapper software required all input images to be projected in Universal Transverse Mercator (UTM) format whereas NPS required delivery of the final data in an Alaska Albers projection. This necessitated projecting the images from UTM to Albers as the final processing step. The change in orientation from one projection to another increased the file size even further. For example, a photo scan that started out at 300MB increased in size to 1.5GB once it was orthorectified and projected to Alaska Albers.

Finally, the mountainous terrain of both KEFJ and ANIA contributed to shifting in the final orthorectified product. Even with the highest resolution DEM it was difficult for the OrthoMapper software to rubber sheet (stretch and warp) the images around high elevations and significant changes in elevation over short horizontal distances. This was further complicated on some photos by the range in topographic variation from sea level to 6000 feet on a single image, and the inability to located control points in the ocean in order to stabilize the orthorectification adjustment. In general, the flatter valley areas adjacent to and between the mountains displayed better horizontal accuracy than the peaks and ridgelines of the mountains.

The total numbers of orthorectified images were:

KEFJ 1950's Black and White – 137 out of 183
KEFJ 1980's AHAP – 59 out of 67
KEFJ 1990's Coastal – 100 out of 104
ANIA 1950's Black and White – 76 out of 76
ANIA 1980's AHAP – 21 out of 24
ANIA 1990's Black and White – 41   Color – 22. Total 63 out of 63

Phase II – Photo mosaics
There were many issues and variables that were considered when developing the image mosaicking methodology for this project. When working with aerial photo images, as opposed to satellite imagery, the most important factors were the significant variation in color, tone, texture, shadow, glare, haze, cloud, feature displacement and orientation that occurs both within each photo and between photos. This variation made it difficult to match adjacent photos together and create a pleasing transition from one image to the next in a composite mosaic. Further challenges in the mosaicking process resulted from the fact that there were only three bands of image data to work with on color aerial photos and one band of data on black and white photos. This limited the variety of image enhancements that were available to adjust adjacent photos and blend seam lines.

Spectral variation both within individual photos and between photos can have a significant effect on the quality of the final composite image. Mosaicking software is always trying to balance spectral reflectance from each end of the visible light spectrum. In doing so, the software will try to darken very light areas (e.g. glaciers) and brighten very dark areas (deep open water). The tradeoff is usually that areas of moderate reflectance in between these extremes (bare ground, vegetation, rock etc.) become either over or under exposed as the software tries to balance the overall image tone between the light and dark areas at the ends of the image histogram.

Figure 8. Sample photo of Harding Icefield, KEFJ, 1950s-era.

Figure 9. Sample photo of Northwestern Lagoon, KEFJ, 1950s-era.
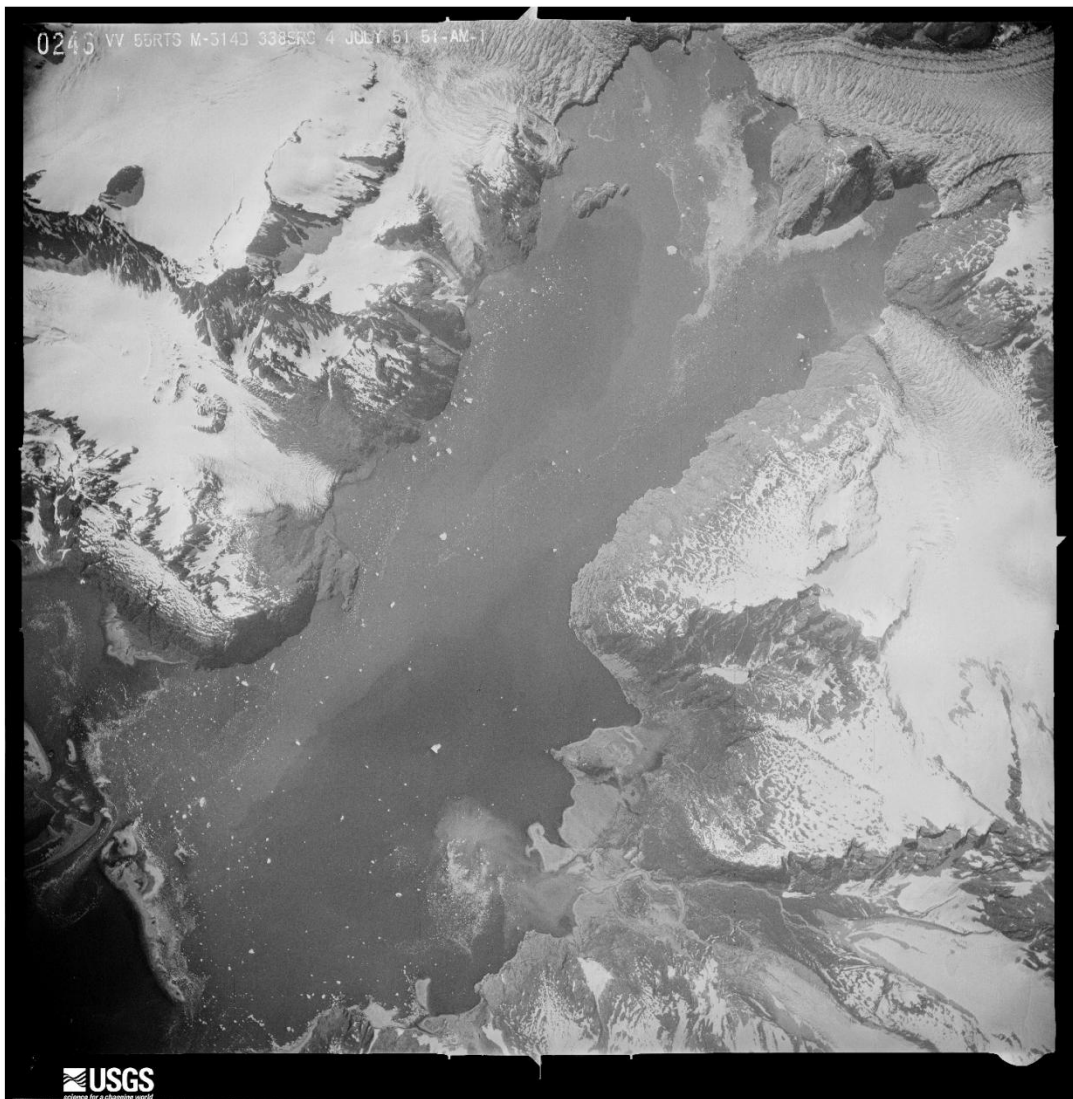
Figure 10. Sample orthorectified image, Northwestern Lagoon, KEFJ, 1950s-era.
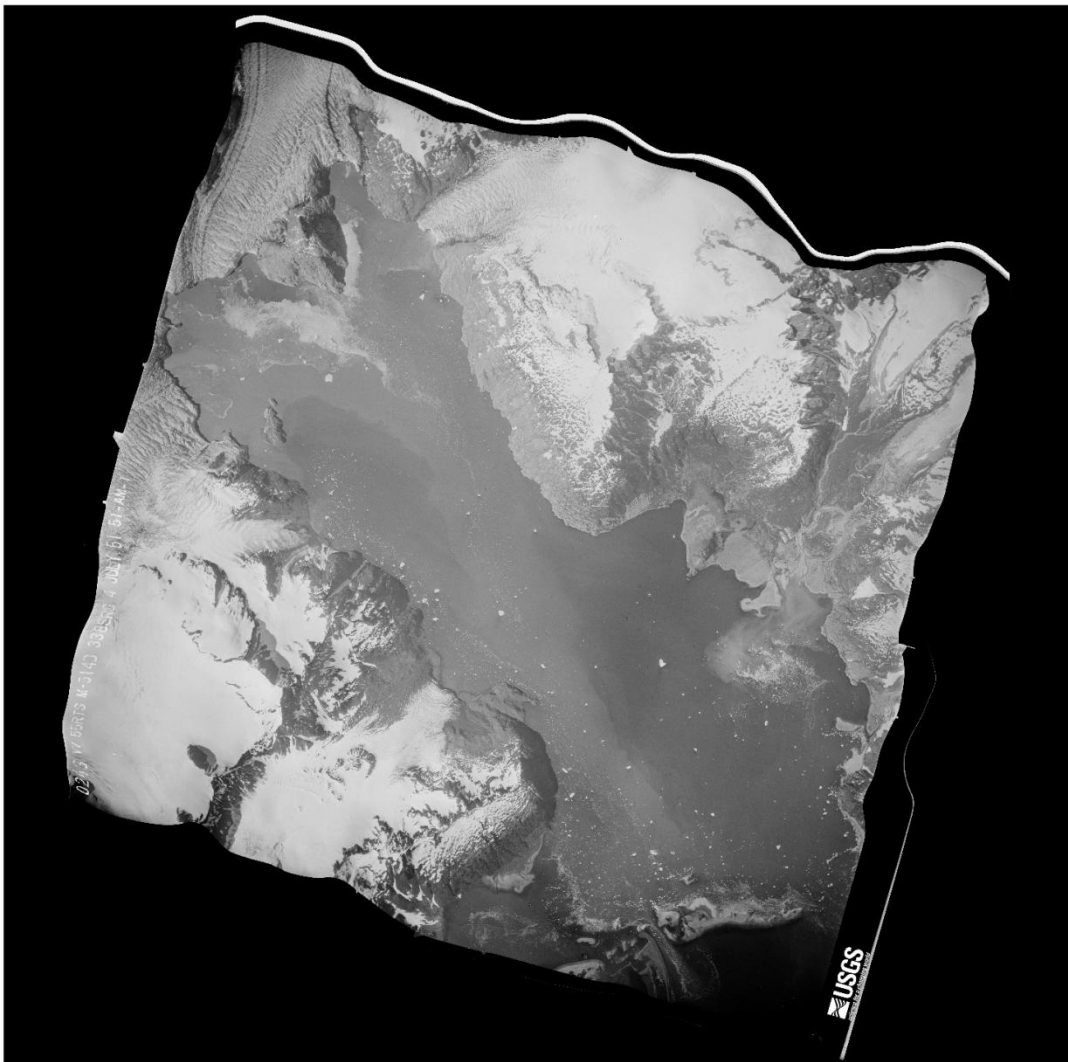
Figure 11. Sample orthorectified image, ANIA, 1980s-era.
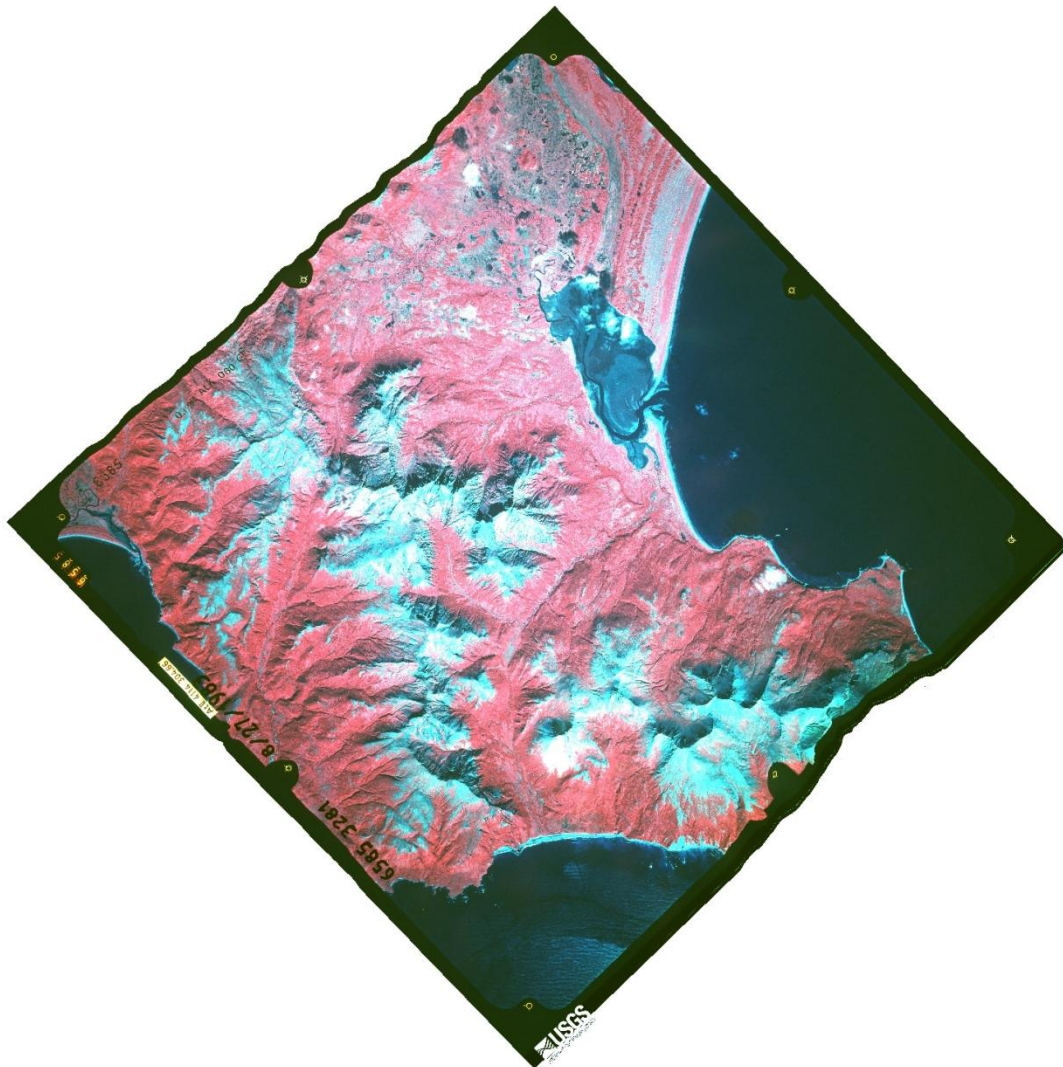
Figure 12. Sample orthorectified image, KEFJ, 1993.
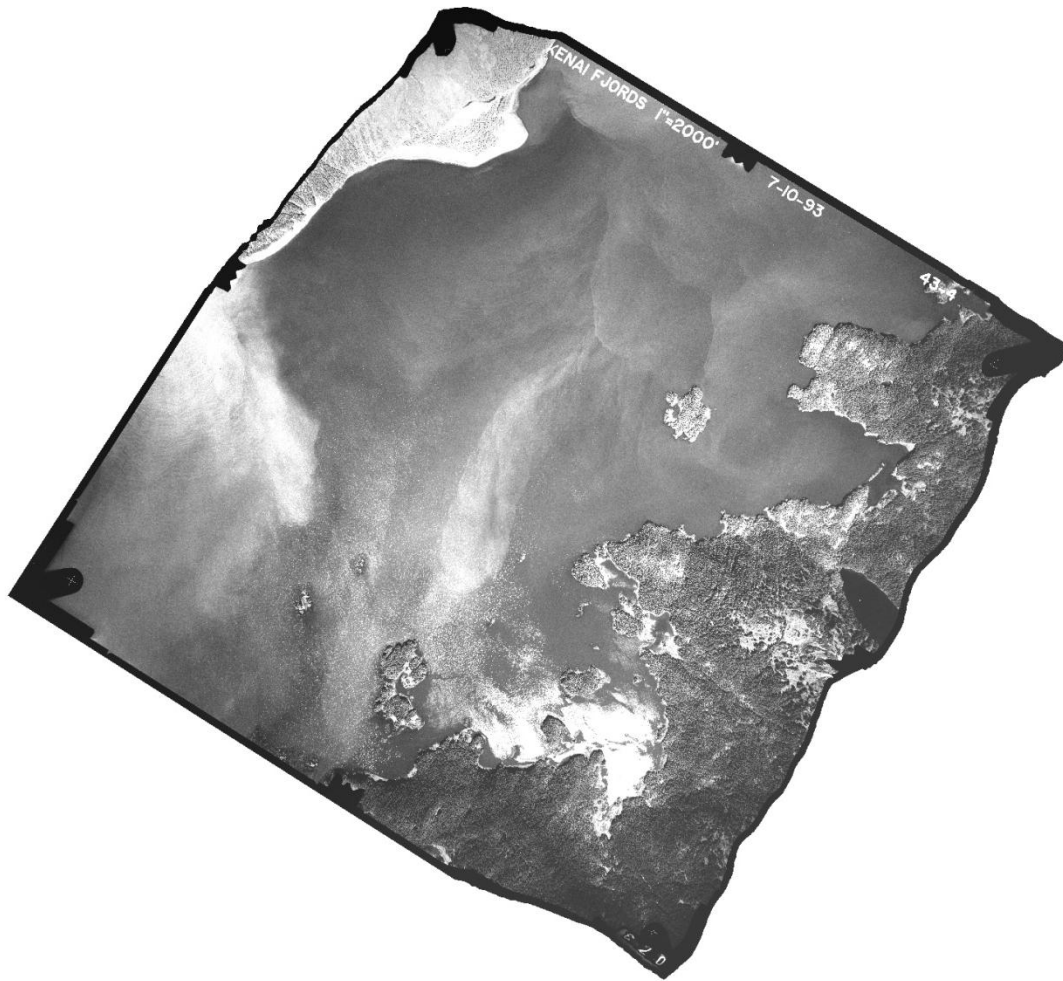
This issue is further complicated by adjacent photo flight lines that are flown at different times of the day (or on different days entirely) and are opposite in orientation.

In some cases, camera optics can also affect the spectral variation of a specific image. This is more common with older photography (1940's and 50's) where images are often considerably lighter in the center than towards the frame edges. In addition, re-sampling during the orthorectification process can also have unintended consequences for image tone. During re-sampling, the spectral reflectance values of individual pixels are modified as adjacent cells are merged and separated. This can skew spectral values away from those on overlapping images that have not been re-sampled and can create more abrupt transitions between photos (e.g., Figures 13, 14).

Typically, these image matching issues are addressed by having as much overlap as possible between the photos that are being used to develop the mosaic. Having approximately sixty percent overlap ensures there is maximum flexibility in choosing the portion of each image that will make up the final mosaic. This simplifies color balance and seam blending and also minimizes image distortion issues resulting from radial displacement; which increases on each photo toward the outer edges of the frame.

Another important issue related to photo overlap that must be considered when orthorectifying images as part of a mosaicking project is that photo edges will bend and stretch in order to adjust for topographic variation in the terrain. This is most common in mountainous areas where flat aerial images must be adjusted to fill peaks and valleys. If there is insufficient overlap between photos (10% or less) then it is entirely possible that terrain adjustments will create gaps or no data areas along the margins of each photo and this will create holes in the final composite mosaic (e.g., Figure 15). This was the case on the KEFJ project.

Figure 13. Mosaic of orthorectified, 1950s-era black-and-white photos from KEFJ showing mismatch between frames and areas of missing data.
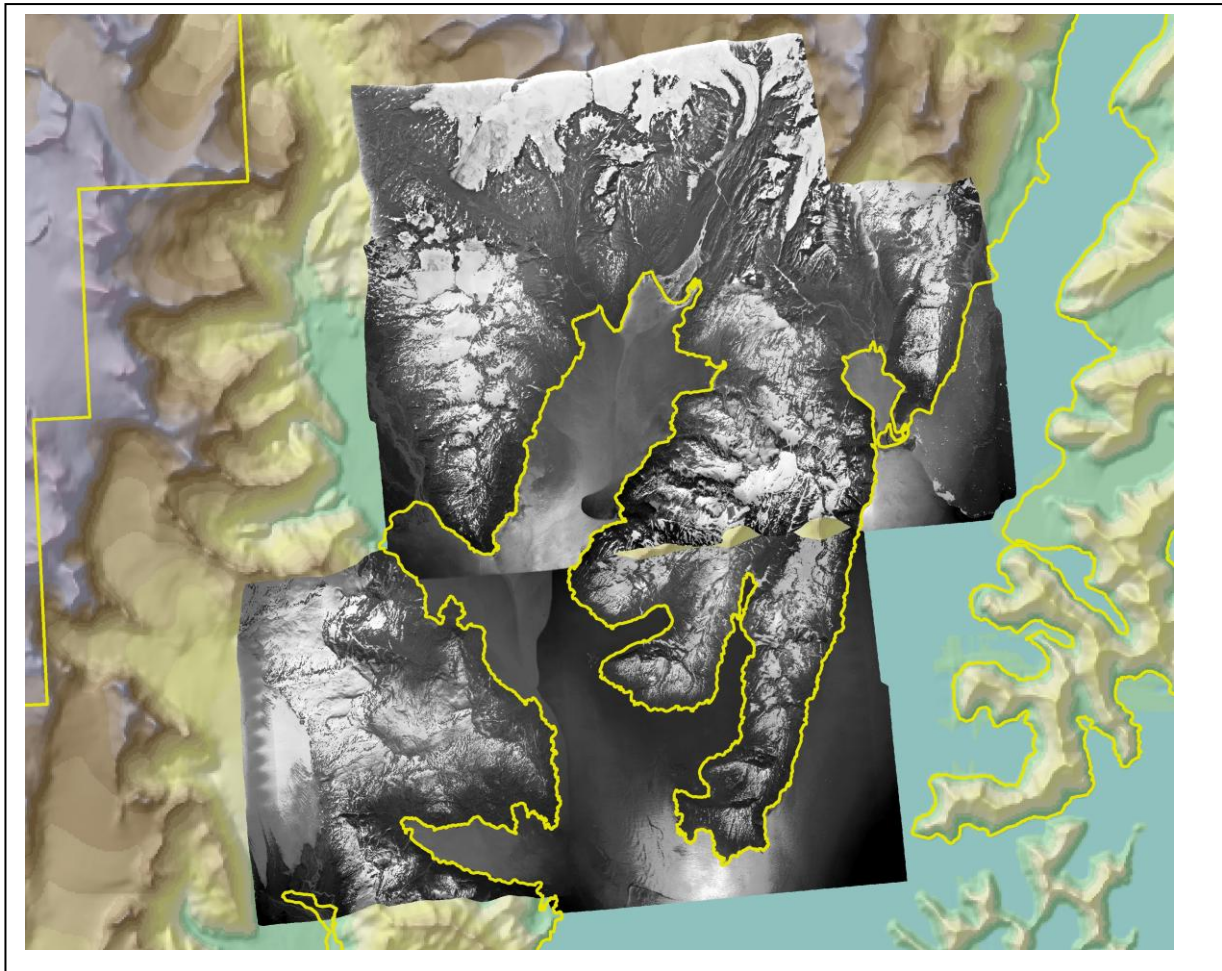
Figure 14. Mosaic of orthorectified, 1980s-era CIR photos from KEFJ.
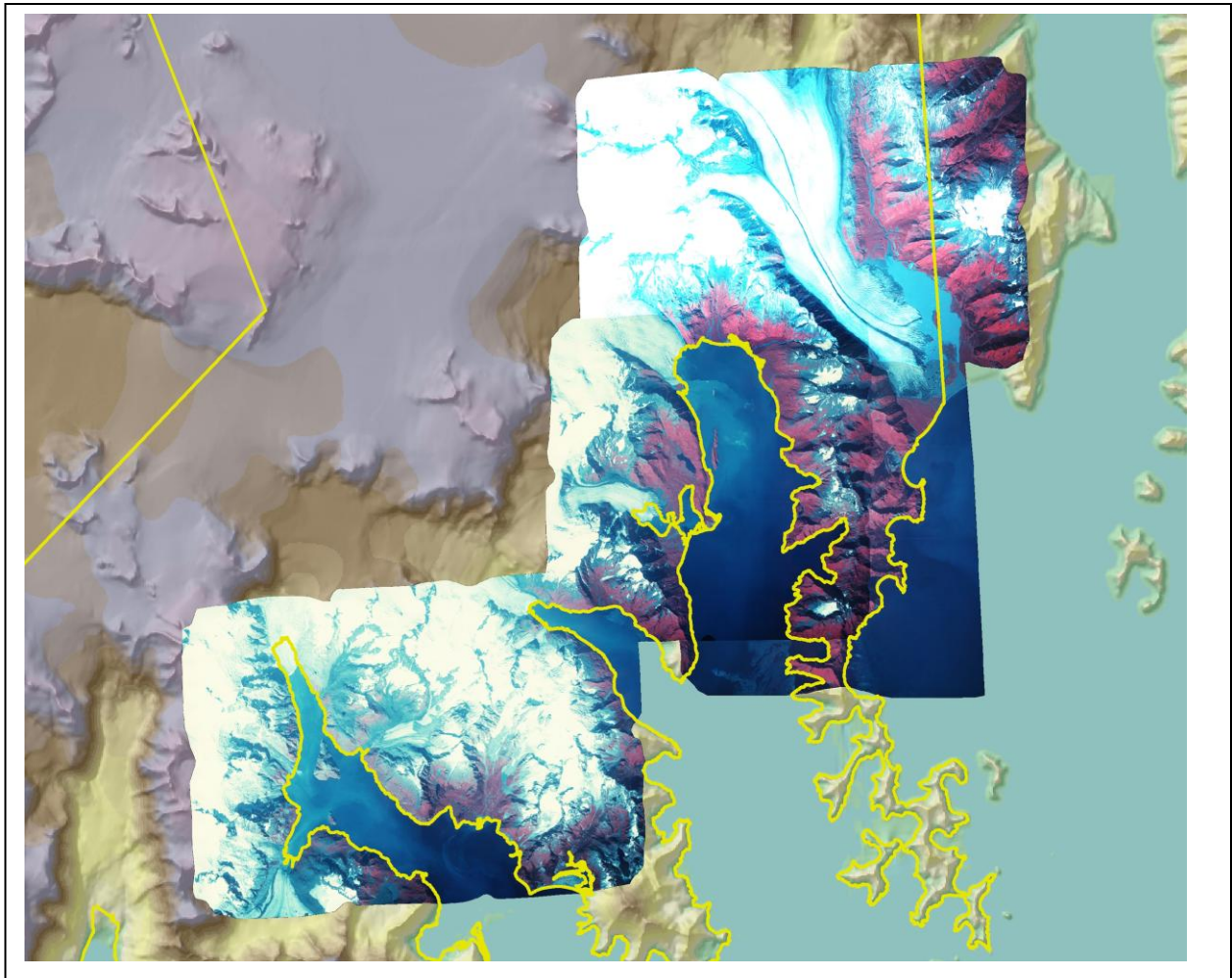
Figure 15. Missing data (white) resulting from poor overlap between adjacent photos.

Appendix 1 – Camera calibration reports

USGS Report No. RSAS/939

United States Department of the Interior

GEOLOGICAL SURVEY
RESTON, VA. 22092

REPORT OF CALIBRATION   February 2, 1984
of Aerial Mapping Camera

Camera type: Wild RC10   Camera serial no.:   1384
Lens type: Wild Aviotar II   Lens serial no.:   At II 4105
Nominal focal length: 305 mm   Maximum aperture: f/4
                                        Test aperture: f/6.6*

Submitted by: NASA, Ames Research Center
               Moffett Field, California 94035

Reference: NASA, Ames Research Center purchase order No. R/A-03352C (VJT),
               dated February 4, 1983.

These measurements were made on Kodak Micro-flat glass plates, 0.25 inch thick,
with spectroscopic emulsion type V-F Panchromatic, developed in D-19 at 68° F
for 3 minutes with continuous agitation. These photographic plates were exposed
on a multicollimator camera calibrator using a white light source rated at
approximately 5200K.

I.   Calibrated Focal Length: 304.976 mm

This measurement is considered accurate within 0.005 mm

II. Radial Distortion

Field angle	$\bar{D}_C$	D_C for azimuth angle			
		0° A-C	90° A-D	180° B-D	270° B-C
degrees	um	um	um	um	um
7.5	−1	1	0	−3	−3
15	1	5	0	−3	3
22.5	0	−4	2	0	1

The radial distortion is measured for each of four radii of the focal plane
separated by 90° in azimuth. To minimize plotting error due to distortion,
a full least-squares solution is used to determine the calibrated focal length.
$\bar{D}_C$ is the average distortion for a given field angle. Values of distortion D_C
based on the calibrated focal length referred to the calibrated principal point
(point of symmetry) are listed for azimuths 0°, 90°, 180° and 270°. The
radial distortion is given in micrometers and indicates the radial displacement
of the image from its ideal position for the calibrated focal length. A posi-
tive value indicates a displacement away from the center of the field. These
measurements are considered accurate within 5 um.

* Limitation imposed by collimator aperture.

(1 of 3)

III. Resolving Power in cycles/mm

Area-weighted average resolution: 42.1

Field angle:	0°	7.5°	15°	22.5°
Radial lines	96	57	20	24
Tangential lines	96	81	57	48

The resolving power is obtained by photographing a series of test bars and examining the resultant image with appropriate magnification to find the spatial frequency of the finest pattern in which the bars can be counted with reasonable confidence. The series of patterns has spatial frequencies from 2.5 to 135 cycles/mm in a geometric series having a ratio of the 4th root of 2. Radial lines are parallel to a radius from the center of the field, and tangential lines are perpendicular to a radius.

IV. Filter Parallelism

The two surfaces of the Wild 525 Pan No. 4437 filter accompanying this camera are within 10 seconds of being parallel. This filter was used for the calibration.
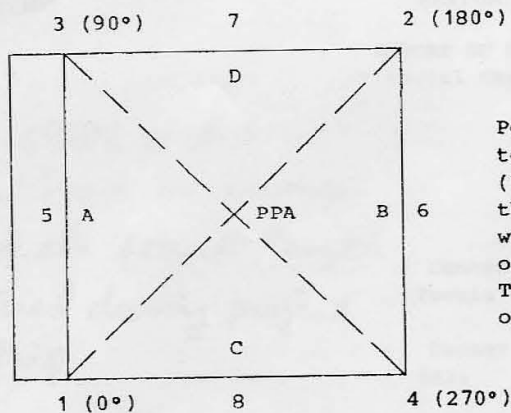
V. Shutter Calibration

Indicated shutter speed	Effective shutter speed	Efficiency
1/200	4.50 ms = 1/220 s	75%
1/400	2.25 ms = 1/440 s	75%
1/600	1.58 ms = 1/630 s	75%
1/800	1.19 ms = 1/840 s	75%
1/975	0.95 ms = 1/1050 s	75%

The effective shutter speeds were determined with the lens at aperture f/4. The method is considered accurate within 3 percent. The technique used is Method I described in American National Standard PH3.48-1972(R1978).

VI. Film Platen

The film platen mounted in Wild RC10 drive unit No. 1384-64 does not depart from a true plane by more than 13 um (0.0005 in).

(2 of 3)

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VII. Principal Point and Fiducial Coordinates

```
    3 (90°)        7         2 (180°)

   ┌──────────────────────────────┐
   │  ╲           D          ╱     │
   │    ╲                  ╱       │
   │      ╲              ╱         │
 5 │  A     ╲          ╱     B     │ 6
   │          ╲X PPA ╱             │
   │          ╱      ╲             │
   │        ╱          ╲           │
   │      ╱      C       ╲         │
   └──────────────────────────────┘

    1 (0°)         8         4 (270°)
```

Positions of all points are referenced to the principal point of autocollimation (PPA) as origin. The diagram indicates the orientation of the reference points when the camera is viewed from the back, or a contact positive with the emulsion up. The direction-of-flight fiducial marker or data strip is to the left.

	X coordinate	Y coordinate
Indicated principal point, corner fiducials (G)	-0.003 mm	-0.008 mm
Indicated principal point, midside fiducials	-0.005	-0.003
Principal point of autocollimation	0.0	0.0
Calibrated principal point (point of symmetry)	0.046	-0.002

Fiducial Marks

	X	Y
1	-106.010 mm	-106.010 mm
2	106.005	105.995
3	-105.998	105.998
4	105.989	-106.010
5	-110.005	-0.004
6	109.992	-0.001
7	0.002	110.004
8	-0.012	-110.014

VIII. Distances Between Fiducial Marks

Corner fiducials (diagonals)

       1-2: 299.827 mm   3-4: 299.810 mm

Lines joining these markers intersect at an angle of 89° 59' 55"

Midside fiducials

       5-6: 219.997 mm   7-8: 220.018 mm

Lines joining these markers intersect at an angle of 89° 59' 44"

Corner fiducials (perimeter)

       1-3: 212.008 mm   2-3: 212.003 mm
       1-4: 211.999 mm   2-4: 212.005 mm

The method of measuring these distances is considered accurate within 0.005 mm.

This report supersedes the previous calibration of this camera contained in USGS Report of Calibration No. RT-R/512, dated March 26, 1979.

William P. Tayman

William P. Tayman
Chief, Optical Science Section
National Mapping Division

(3 of 3)

United States Department of the Interior

GEOLOGICAL SURVEY
RESTON, VA. 22092

REPORT OF CALIBRATION   March 18, 1983
of Aerial Mapping Camera

Camera type: Wild RC 10   Camera serial no.:   1470
Lens type: Wild Aviotar II   Lens serial no.:   AT II 4114
Nominal focal length: 305 mm   Maximum aperture: f/4
                                              Test aperture: f/4

Submitted by: NASA, Ames Research Center
                Moffett Field, California 94035

Reference: NASA, Ames purchase order No. R/A-03352C (VJT)
                dated February 4, 1983.

These measurements were made on Kodak micro flat glass plates, 0.25 inch thick,
with spectroscopic emulsion type V-F Panchromatic, developed in D-19 at 68° F
for three minutes with continuous agitation. These photographic plates were
exposed on a multicollimator camera calibrator using a white light source rated
at approximately 5200K.

I. Calibrated Focal Length: 304.660 mm

This measurement is considered accurate within 0.005 mm.

II. Radial Distortion

Field angle	$\bar{D}_c$	D_c for azimuth angle			
		0° A-C	90° A-D	180° B-D	270° B-C
degrees	um	um	um	um	um
7.5	-3	-7	-3	-1	0
15	-1	-8	2	2	2
22.5	1	2	3	-3	3

The radial distortion is measured for each of four radii of the focal plane
separated by 90° in azimuth. To minimize plotting error due to distortion, a
full least-squares solution is used to determine the calibrated focal length.
$\bar{D}_c$ is the average distortion for a given field angle. Values of distortion
D_c based on the calibrated focal length referred to the calibrated principal
point (point of symmetry) are listed for azimuths 0°, 90°, 180° and 270°. The
radial distortion is given in micrometers and indicates the radial displacement
of the image from its ideal position for the calibrated focal length. A posi-
tive value indicates a displacement away from the center of the field. These
measurements are considered accurate within 5 um.

(1 of 3)

III. Resolving Power in cycles/mm

Area-weighted average resolution: 39.0

Field angle:	0°	7.5°	15°	22.5°
Radial lines	81	57	20	14
Tangential lines	81	81	57	48

The resolving power is obtained by photographing a series of test bars and examining the resultant image with appropriate magnification to find the spatial frequency of the finest pattern in which the bars can be counted with reasonable confidence. The series of patterns has spatial frequencies from 2.5 to 135 cycles/mm in a geometric series having a ratio of the 4th root of 2. Radial lines are parallel to a radius from the center of the field, and tangential lines are perpendicular to a radius.

IV. Filter Parallelism

The two surfaces of the Wild 525 Pan No. 4039 filter accompanying this camera are within ten seconds of being parallel. This filter was used for the calibration.

V. Shutter Calibration

Indicated shutter speed	Effective shutter speed	Efficiency
1/200	4.50 ms = 1/220 s	72%
1/400	2.25 ms = 1/440 s	72%
1/600	1.50 ms = 1/670 s	72%

The effective shutter speeds were determined with the lens at aperture f/4. The method is considered accurate within 3%. The technique used is Method I described in American National Standard PH3.48-1972(R1978).

VI. Film Platen

The film platen mounted in Wild RC10 drive unit No. 1470-120 does not depart from a true plane by more than 13 um (0.0005 in.).

VII. Principal Point and Fiducial Coordinates
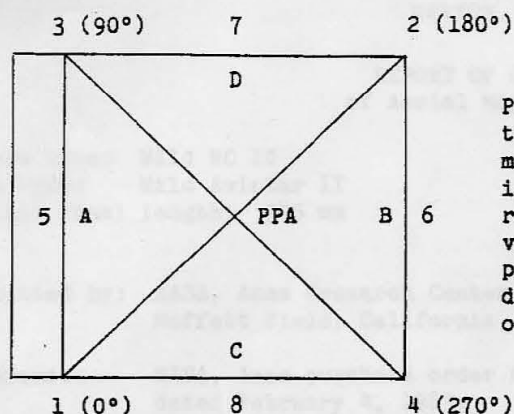
```
   3 (90°)      7        2 (180°)
```


Positions of all points are referenced to the principal point of autocollimation (PPA) as origin. The diagram indicates the orientation of the reference points when the camera is viewed from the back or a contact positive with the emulsion up. The direction-of-flight fiducial marker or data strip is to the left.

```
   1 (0°)       8        4 (270°)
```

	X coordinate	Y coordinate
Indicated principal point, corner fiducials	-0.012 mm	-0.015 mm
Indicated principal point, midside fiducials	-0.016	-0.018
Principal point of autocollimation	0.0	0.0
Calibrated principal point (point of symmetry)	-0.009	0.006

Fiducial Marks

1	-106.014 mm	-106.018
2	105.988	105.987
3	-106.006	105.986
4	105.983	-106.018
5	-110.015	-0.017
6	109.982	-0.019
7	-0.009	109.979
8	-0.023	-110.012

VIII. Distances Between Fiducial Marks

Corner fiducials (diagonals)
       1-2: 299.818 mm   3-4: 299.808 mm
Lines joining these markers intersect at an angle of 89° 59' 52"

Midside fiducials
       5-6: 219.997 mm   7-8: 219.991 mm
Lines joining these markers intersect at an angle of 89° 59' 49"

Corner fiducials (perimeter)
       1-3: 212.004 mm   2-3: 211.994 mm
       1-4: 211.998 mm   2-4: 212.005 mm

The method of measuring these distances is considered accurate within 0.005 mm.

This report supersedes the previous calibration of this camera contained in USGS Report of Calibration No. RT-R/581, dated January 9, 1980.

William P. Tayman
Chief, Optical Science Section
National Mapping Division

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United States Department of the Interior

GEOLOGICAL SURVEY
RESTON, VA 22092

REPORT OF CALIBRATION   January 31, 1992
of Aerial Mapping Camera

Camera type: Zeiss RMK A 15/23*   Camera serial no.:   137472
Lens type: Zeiss Pleogon A2/4   Lens serial no.:   137502
Nominal focal length: 153 mm   Maximum aperture: f/4
                                          Test aperture: f/4

Submitted by: Aero-Metric Engineering, Inc.
                Sheboygan, Wisconsin

Reference: Aero-Metric Engineering, Inc., purchase
                order No. 6223, dated January 10, 1992.

These measurements were made on Kodak Micro-flat glass plates, 0.25 inch
thick, with spectroscopic emulsion type 157-01 Panchromatic, developed in D-19
at 68° F for 3 minutes with continuous agitation. These photographic plates
were exposed on a multicollimator camera calibrator using a white light source
rated at approximately 5200K.

I.   Calibrated Focal Length: 153.697 mm

This measurement is considered accurate within 0.005 mm

II. Radial Distortion

Field angle	$\bar{D}_c$	D_c for azimuth angle			
		0° A-C	90° A-D	180° B-D	270° B-C
degrees	um	um	um	um	um
7.5	-1	-3	0	1	-2
15	-2	-4	-1	0	-2
22.7	-3	-6	-2	-1	-2
30	-2	-3	-1	-2	-1
35	-1	-1	-1	-1	0
40	5	4	7	1	7

The radial distortion is measured for each of four radii of the focal plane
separated by 90° in azimuth. To minimize plotting error due to distortion, a
full least-squares solution is used to determine the calibrated focal length.
$\bar{D}_c$ is the average distortion for a given field angle. Values of distortion D_c
based on the calibrated focal length referred to the calibrated principal
point (point of symmetry) are listed for azimuths 0°, 90°, 180° and 270°. The
radial distortion is given in micrometers and indicates the radial displace-
ment away from the center of the field. These measurements are considered
accurate within 5 um.

* Equipped with Forward Motion Compensation

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III. Resolving Power in cycles/mm

Area-weighted average resolution: 81

Field angle:	0°	7.5°	15°	22.7°	30°	35°	40°
Radial lines	134	113	95	95	95	80	80
Tangential lines	134	113	95	80	67	67	57

The resolving power is obtained by photographing a series of test bars and examining the resultant image with appropriate magnification to find the spatial frequency of the finest pattern in which the bars can be counted with reasonable confidence. The series of patterns has spatial frequencies from 5 to 268 cycles/mm in a geometric series having a ratio of the 4th root of 2. Radial lines are parallel to a radius from the center of the field, and tangential lines are perpendicular to a radius.

IV. Filter Parallelism

The two surfaces of the B No. 137562, the KL No. 137547 and the C-F No. 140131 filters accompanying this camera are within 10 seconds of being parallel. The B filter was used for the calibration.

V. Shutter Calibration

Indicated shutter speed	Effective shutter speed	Efficiency
1/100	8.82 ms = 1/115 s	85%
1/200	4.60 ms = 1/215 s	85%
1/300	3.07 ms = 1/325 s	85%
1/400	2.30 ms = 1/435 s	85%
1/500	1.79 ms = 1/560 s	85%

The effective shutter speeds were determined with the lens at aperture f/4. The method is considered accurate within 3 percent. The technique used is Method I described in American National Standard PH3.48-1972(R1978).

VI. Magazine Platen

The platens mounted in CC24 film magazines No. 136192 and No. 136200 do not depart from a true plane by more than 13 um (0.0005 in).

The platens for these film magazines are equipped with identification markers that will register "CZ274" for magazine No. 136192 and "CZ293" for magazine No. 136200 in the data strip area for each exposure.

This camera is equipped with an EMI-2 automatic exposure control, with the detector located beside the camera lens.

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VII. Principal Points and Fiducial Coordinates
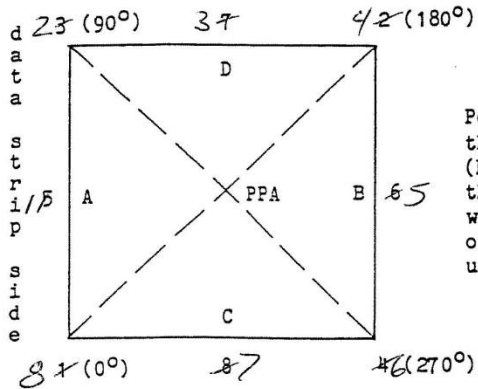
d 2̶3̶ (90°)   3̶7̶   4̶2̶(180°)
a
t
a

s
t
r
i 1̶/̶5̶ | A   PPA   B   6̶5̶
p

s
i
d
e   8̶1̶(0°)   8̶7̶   4̶6̶(270°)

(The diagram shows a square with corners labeled D (top), A (left), B (right), C (bottom), PPA at center, with diagonals drawn.)

Positions of all points are referenced to the principal point of autocollimation (PPA) as origin. The diagram indicates the orientation of the reference points when the camera is viewed from the back, or a contact positive with the emulsion up. The data strip is to the left.

	X coordinate	Y coordinate
Indicated principal point, corner fiducials	0.005 mm	-0.002 mm
Indicated principal point, midside fiducials	0.006	-0.012
Principal point of autocollimation	0.0	0.0
Calibrated principal point (point of symmetry)	0.025	-0.017

Fiducial Marks

	X	Y
8̶1̶	-103.950 mm	-103.971 mm
4̶2̶	103.944	103.951
2̶3̶	-103.935	103.927
6̶4̶	103.985	-103.971
1̶5̶	-112.996	-0.017
5̶6̶	113.013	-0.006
3̶7̶	0.002	112.995
7̶8̶	0.010	-113.004

VIII. Distances Between Fiducial Marks

Corner fiducials (diagonals)
      1-2: 294.026 mm   3-4: 294.028 mm
Lines joining these markers intersect at an angle of 89° 59' 57"

Midside fiducials
      5-6: 226.009 mm   7-8: 225.999 mm
Lines joining these markers intersect at an angle of 89° 59' 57"

Corner fiducials (perimeter)
      1-3: 207.898 mm   2-3: 207.879 mm
      1-4: 207.935 mm   2-4: 207.922 mm

The method of measuring these distances is considered accurate within 0.005 mm.
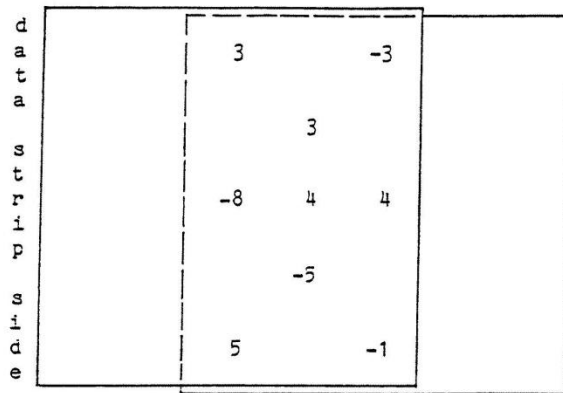
(3 of 5)

IX. Stereomodel Flatness

Magazine No.: 136192   Base/Height ratio: 0.6

Platen ID: CZ274   Maximum angle of field tested: 40°

```
d  ┌──────┌──────────────────┐──────────┐
a  │      ┆                   ┆          │
t  │      ┆   3          -3   ┆          │
a  │      ┆                   ┆          │
   │      ┆          3        ┆          │
s  │      ┆                   ┆          │
t  │      ┆                   ┆          │
r  │      ┆  -8      4      4 ┆          │
i  │      ┆                   ┆          │
p  │      ┆         -5        ┆          │
   │      ┆                   ┆          │
s  │      ┆                   ┆          │
i  │      ┆   5         -1    ┆          │
d  │      ┆                   ┆          │
e  └──────└───────────────────┘──────────┘
```

Stereomodel
Test point array
(values in micrometers)

The values shown on the diagram are the average departures from flatness (at negative scale) for two computer-simulated stereomodels based on comparator measurements on contact glass (Kodak Micro-flat) diapositives made from Kodak 2405 film exposures. These measurements are considered accurate within 5 um.

X. Resolving Power in cycles/mm

Area-weighted average resolution: 44   Film: Type 2405

Field angle:	0°	7.5°	15°	22.7°	30°	35°	40°
Radial lines	67	57	57	48	48	40	40
Tangential lines	67	57	57	48	40	40	28

(4 of 5)
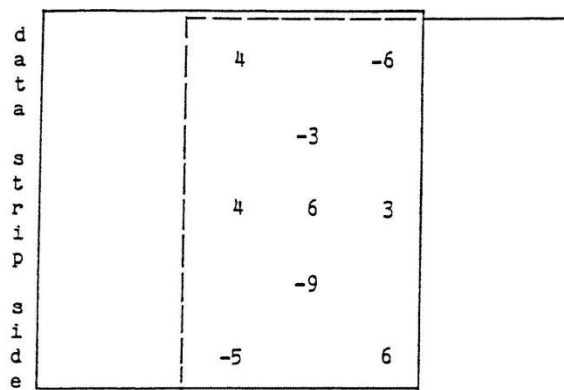
48

IX. Stereomodel Flatness

Magazine No.: 136200   Base/Height ratio: 0.6

Platen ID: CZ293   Maximum angle of field tested: 40°

Stereomodel
Test point array
(values in micrometers)

The values shown on the diagram are the average departures from flatness (at negative scale) for two computer-simulated stereomodels based on comparator measurements on contact glass (Kodak Micro-flat) diapositives made from Kodak 2405 film exposures. These measurements are considered accurate within 5 um.

X. Resolving Power in cycles/mm

Area-weighted average resolution: 43   Film: Type 2405

Field angle:	0°	7.5°	15°	22.7°	30°	35°	40°
Radial lines	67	57	57	48	48	40	40
Tangential lines	67	57	57	40	40	34	28

This aerial mapping camera calibration report supersedes the previously issued USGS Report No. OSL/1422, dated February 17, 1989.

Bradish F. Johnson

Bradish F. Johnson
Chief, Optical Science Laboratory
National Mapping Division

(5 of 5)

FILM RADIAL DISTORTION, STEREOMODEL FLATNESS AND RESOLVING POWER

Magazine No.: 136200 Base/Height ratio: 0.6
Platen ID: CZ293 Maximum angle of field tested: 40°

Calibrated Focal Length

    flash plate: 153.697 mm
    film: 153.708 mm

IX. Radial Distortion

Field angle	$\bar{D}_c$	D_c for azimuth angle			
		0° A-C	90° A-D	180° B-D	270° B-C
degrees	um	um	um	um	um
7.5	-1	2	7	-3	-8
15	0	0	9	-3	-5
22.7	1	2	7	-3	-4
30	-2	0	2	-7	-5
35	-2	-1	-2	-3	0
40	3	-3	1	4	.8

X. Stereomodel Flatness

The values shown on the diagram are the average departures from flatness (at negative scale) for two computer-simulated stereomodels based on comparator measurements on contact glass (Kodak micro flat) diapositives made from Kodak 2405 film exposures. These measurements are considered accurate within 5 um.

Stereomodel test point array
(values in micrometers)

XI. Resolving Power in cycles/mm

Area-weighted average resolution: 43   Film: Type 2405

Field angle:	0°	7.5°	15°	22.7°	30°	35°	40°
Radial lines	67	57	57	48	48	40	40
Tangential lines	67	57	57	40	40	34	28

This aerial mapping camera calibration report supersedes the previously issued USGS Report No. OSL/1422, dated February 17, 1989.

Bradish F. Johnson

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National Mapping Division

(suppl. 5 of 5)

Appendix 2 – Example RMS and metadata reports

Photo - AB583003275ROLL_5897_A.LAN

Number of points processed: 17

Ground Control Coordinates

Point Name	X	Y	Z
VC1	542870.81	6323766.00	78.25
VC2	550911.56	6326170.50	79.11
VC3	545661.69	6333423.50	14.10
VC4	540194.81	6329401.50	20.00
VC5	549361.31	6330318.00	30.88
VC6	551940.56	6322977.00	153.09
VC7	546058.31	6326559.00	59.30
VC8	543008.19	6331643.50	18.24
VC9	540362.81	6325990.50	46.13
VC10	546571.31	6323403.00	117.52
VC11	543737.81	6329227.50	27.00
VC12	540385.31	6322639.50	83.17
VC13	554916.56	6325854.00	84.88
VC14	551538.56	6328444.50	54.67
VC15	546931.31	6329778.00	33.88
VC16	548680.31	6325243.50	88.00
VC17	542987.81	6326841.00	46.00

Photo Control Coordinates

Point Name	Column	Row	x	y	dR	dX	dY
VC1	2949.0	5294.0	-55.308	5.915	0.0000	0.0000	0.0000
VC2	8320.0	8142.0	58.631	-53.885	0.0000	0.0000	0.0000
VC3	9299.5	1780.0	78.801	80.866	0.0000	0.0000	0.0000
VC4	4463.0	1030.0	-23.639	96.306	0.0000	0.0000	0.0000
VC5	9609.0	5241.0	85.658	7.635	0.0000	0.0000	0.0000
VC6	7241.0	10334.0	35.986	-100.380	0.0000	0.0000	0.0000
VC7	6029.0	5485.0	9.903	2.149	0.0000	0.0000	0.0000
VC8	7054.0	1325.0	31.231	90.295	0.0000	0.0000	0.0000
VC9	2794.0	2861.0	-58.804	57.400	0.0000	0.0000	0.0000
VC10	4683.0	7368.0	-18.421	-37.829	0.0000	0.0000	0.0000
VC11	6183.0	2924.0	12.936	56.371	0.0000	0.0000	0.0000
VC12	1077.0	4595.0	-94.994	20.543	0.0000	0.0000	0.0000
VC13	10197.0	10341.0	98.556	-100.263	0.0000	0.0000	0.0000
VC14	9773.0	7303.0	89.312	-35.996	0.0000	0.0000	0.0000
VC15	8104.0	4284.0	53.718	27.757	0.0000	0.0000	0.0000
VC16	6710.0	7495.0	24.495	-40.335	0.0000	0.0000	0.0000
VC17	4590.0	3770.0	-20.708	38.321	0.0000	0.0000	0.0000

Mean Difference in dX and dY: 0.0000   0.0000
Standard Deviation in dX and dY: 0.0000   0.0000

Initial Approximations:
Omega = 0.000
Phi   = 0.000
Kappa = 44.585
XL   = 546242.3
YL   = 6327157.7
ZL   = 10031.8

A solution has been found after 3 iterations
Standard Deviation of unit weight = 0.1195794

Omega =   0.15 (Degrees)
Phi   = -0.54 (Degrees)
Kappa = 44.52 (Degrees)
XL   = 545605.8

YL   = 6325977.9
ZL   = 10002.9

The Covariance Matrix (omega phi kappa X Y Z)
(Angles in radians multiplied by 1000)

```
  1.43136
 -0.19755  0.77895
  0.02493  0.05199  0.13224
 -2.14317  9.20832  0.76428  112.677
-15.53359  1.95810 -0.35096  21.068  172.410
 -2.05105  1.42771  0.05012  15.909  20.528  17.319
```

Standard Deviation for Omega: 246.77 (Seconds)
Standard Deviation for   Phi: 182.05 (Seconds)
Standard Deviation for Kappa: 75.01 (Seconds)
Standard Deviation for   XL: 10.61 (Meters)
Standard Deviation for   YL: 13.13 (Meters)
Standard Deviation for   ZL: 4.16 (Meters)

Residuals for the points entered

```
Point ID  Cols   Rows
    VC1  -3.09   2.63
    VC2   3.27  -6.69
    VC3   0.17   4.39
    VC4   0.70   0.40
    VC5  -2.96   4.69
    VC6   7.48  -9.47
    VC7   1.20   2.78
    VC8   6.57  -1.20
    VC9  -5.89   0.67
   VC10   4.95  -8.57
   VC11 -10.97  -9.10
   VC12   0.77  -1.55
   VC13   2.91   9.08
   VC14  -5.44   7.41
   VC15  -1.75   5.45
   VC16   4.28  -0.85
   VC17  -2.28   0.17

   Col RMS =   4.70
   Row RMS =   5.52
```

Stylesheet: AKSO FGDC

alb_BM03480100097_ORTHO.TIF

National Park Service
U.S. Department of Interior

Description   **Spatial**   **Attributes**

Description
Abstract
This data set contains digital aerial photo imagery of Kenai Fjords National Park in Alaska. The imagery was procured from air photo flying missions conducted by the U.S. Air Force in 1950, 1951 and 1952. The photo immulsion is black and white and the scale of the final hardcopy photo print products is 1:40000. Scanned digital imagery at a resolution of 1200 dpi or 1800 dpi was provided by the National Park Service to Saiint Mary's University of Minnesota GeoSpatial Services The scanned images were georeferenced and orthorectifed using NPS supplied IKONOS imagery and IKONOS digital elevation models. The IKONOS imagery was 1 meter resolution, pan-fused multispectral, 16 bit pixel depth. The IKONOS DEM data was 24.5 meter resoltuion, single band, 16 bit pixel depth.

The IKONOS data did not cover all of the areas for which orthorectification was required. In areas outside of this coverage, previously acquired NPS DOQQ imagery and a digital elevation model derived from a combination of the IKONOS DEM data, NASA shuttle mission SRTM data and USGS NED data was used for orthorectification. The final output orthorectified images are 8 bit, single band TIFF format image files. See data quality notes for more information.

Purpose
The orthorectified aerial photo imagery for Kenai Fjords National Park is a multi-purpose georefereced spatial dataset that is intended to be used as a backdrop for a variety of Park mapping projects.

Links to graphics describing the data
- None (None): None

Keywords
Theme
Digital Georectified Image, Orthorectified Image, Orthorectification, Georeferenced Image, Land Cover, Color Infrared Photography
Place
Kenai Fjords National Park, Alaska, GNIS ID# 1419645, Kenai Peninsula

_____

Status of the data

Time period for which the data is relevant

Publication Information

_____

Data storage and access information

Details about this document
Contents last updated: 20100215 at time 10572100
Who completed this document
Andrew Robertson
REQUIRED: The person responsible for the metadata information.
Saint Mary's University of Minnesota, GeoSpatial Sevices

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