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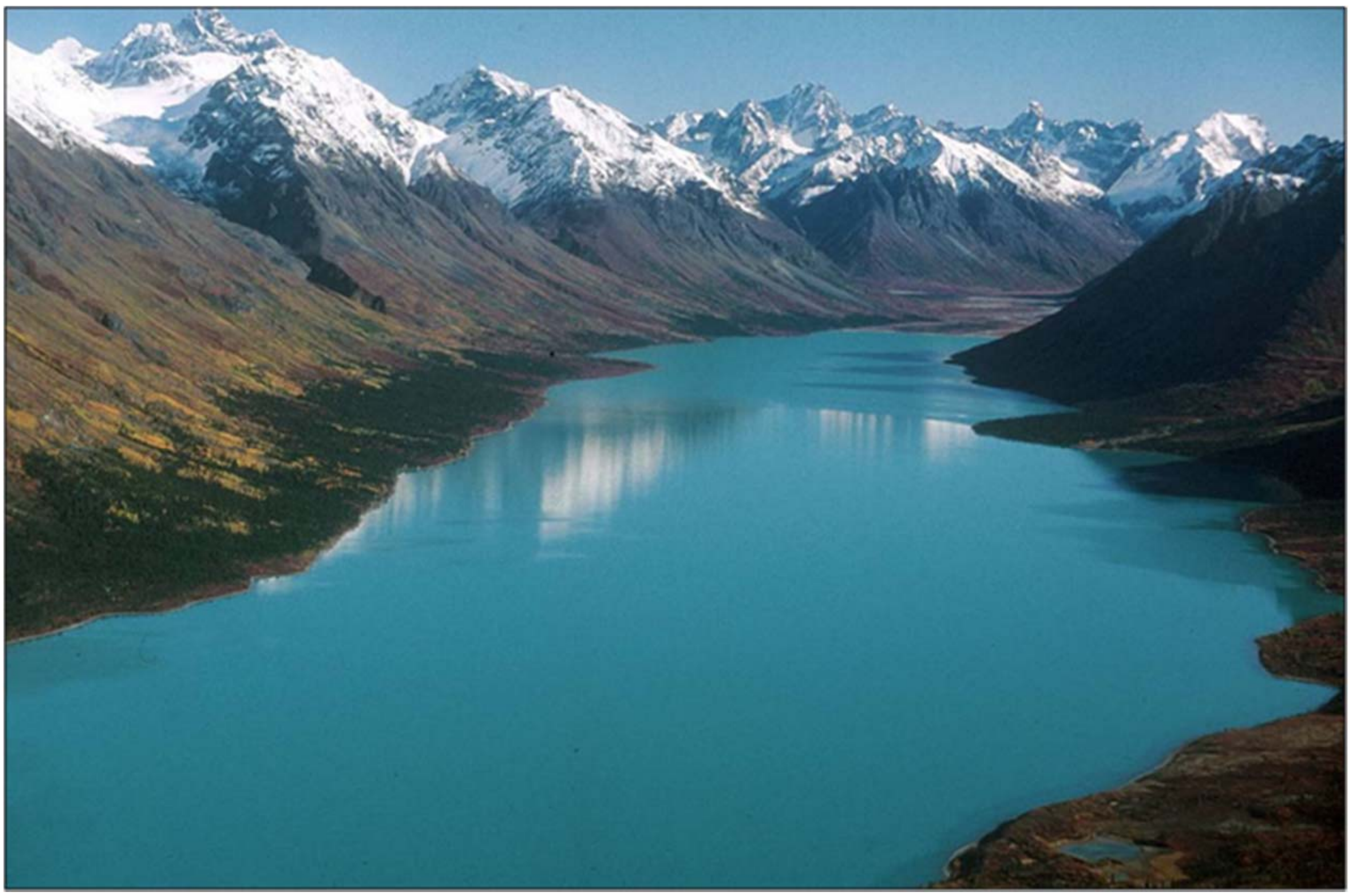
Natural Resource Stewardship and Science

Orthorectification of Historic Imagery for Lake Clark National Park and Preserve and Katmai National Park and Preserve

Final Report

Natural Resource Technical Report NPS/SWAN/NRTR—2014/864



ON THE COVER: Lake Clark within Lake Clark National Park and Preserve (LACL). Image courtesy of the National Park Service, Alaska Region.

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Abstract

Historical imagery is an important asset for the management of the nation's natural resources and serves as a point-in-time record for the assessment of conditions such as: vegetative cover; surface hydrology; wildfire fuel regimes; erosion and deposition; and glacial extent. Alaska's historical imagery frequently consists of scanned hard-copy black and white and color-infrared (CIR) aerial photography acquired through the Alaska High Altitude Aerial Photography Program (AHAP). In this assessment individual black and white, CIR AHAP, and coastal CIR aerial photographs for Lake Clark National Park and Preserve (LACL) and Katmai National Park and Preserve (KATM) are cataloged as both individual orthorectified images and as single seamless mosaic base maps for the time periods of: 1950s and 1980s. Orthorectified coastal aerial images from 2010 and 2011 are also available, however, only as individual images.

The primary objective of this project was to create a digital library of historic aerial photographs that were georeferenced, orthorectified and available for comparison with current imagery from LACL and KATM. Secondarily, this project provided students with the opportunity to learn how to convert data, georeference, orthorectify, mosaic, and color balance, among other skills. Three different software packages were utilized in the creation of the final products thus giving student technicians the opportunity to get hands on experience with different software and increase their understanding of the development of project methodologies.

With the advent of new remote sensing and geographic information systems (GIS) technologies, hard-copy individual aerial imagery can now be converted to digital form through a series of procedures including: pre-processing; georeferencing; orthorectification; and, validation through quality assurance and quality control assessments. The resulting digital products can be cataloged as both individual images and seamless mosaics.

Throughout the performance period of this project, the Southwest Alaska Network (SWAN) of the National Park Service Alaska Region and Saint Mary's University of Minnesota cooperatively compiled a library of 2,142 individual orthorectified images and produced seamless mosaics for both parks. In addition, this project provided the opportunity to test new datasets and processes including: WARP NGA base imagery within LACL; and, the orthorectification of IKONOS images with higher resolution SPOT 5 digital elevation models (DEM) within KATM.

As a follow-on to the aerial photo orthorectification, SMUMN created image mosaics that digitally merged individual orthorectified images together into larger composite images for both the black and white and AHAP orthorectified images. These large format orthorectified image products now permit digital comparison with newly acquired imagery bases such as IKONOS and SPOT 5, where available, and can facilitate informed resource management decisions throughout LACL and KATM.

This report documents a two-phase project in which historical air photos were orthorectified to the IKONOS base imagery for LACL and KATM (Phase 1), and park wide orthorectified photo mosaics were produced for the years of 1950's black and white photos and also for the 1980's AHAP photography (Phase 2).

Acknowledgments

This project was supported by the National Park Service, Southwest Alaska Network, under CESU Task Agreement P11AC91158. Special recognition goes to all the student technicians who contributed to the project. Most notably, David Johnson was responsible for the orthorectification, color balancing and mosaics, assisting with development of methodologies, and post processing. Bonnie Maffitt contributed to the writing, editing, and formatting of the document. Amy Miller, Ecologist, Southwest Alaska Network, John Pinamont, Alaska Region, GIS Specialist, Parker Martin, Alaska Region Inventory Coordinator, Beth Koltun, GIS Specialist, and Jeff Knopf, Senior GIS Analyst for GeoSpatial Services of Saint Mary's University of Minnesota, provided data to SMUMN and/or contributed to the development and review of the orthorectified image products.

List of Acronyms

AHAP – Alaska High Altitude Aerial Photography Program

AOI – Area of Interest

ASTER – National Oceanic and Atmospheric Administration and Japanese Ministry of Economy, Trade, and Industry Advanced Spaceborne Thermal Emission and Reflection Radiometer

CIR – Color Infrared

DOQQ – Digital Ortho Quarter Quad

DPI – Dots per Inch

GIS – Geographic Information Systems

GPS – Global Positioning Systems

LACL – Lake Clark National Park and Preserve

KATM – Katmai National Park and Preserve

METI – Japanese Ministry of Economy, Trade, and Industry

NASA – National Aeronautical and Space Administration

NGA – National Geospatial-Intelligence Agency

NLCD – National Land Cover Dataset

NPS – United States National Park Service

RMS – Root Mean Square

SDMI – Alaska Statewide Digital Mapping Initiative

SRTM – Shuttle Radar Topography Mission

SWAN – Southwest Alaska Inventory and Monitoring Network Unit

USGS – United States Geological Survey

WARP – National Geospatial-Intelligence Agency Web-Based Access and Retrieval Portal

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.

As part of this project, the Southwest Alaska Network has developed high-resolution IKONOS orthorectified imagery products for two of the SWAN parks, Lake Clark National Park and Preserve (LACL) and Katmai National Park and Preserve (KATM). These imagery products provide the base cartographic reference for the parks. Similar products were previously developed for Kenai Fjords National Park (KEFJ) and Aniakchak National Monument and Preserve (ANIA). 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 with current imagery in order to derive assessments of processes that affect landscapes and landforms in the area.

Table 1. Photo characteristics and scan resolution for images acquired for LACL and KATM. Emulsion: B/W=black and white; CIR=color-infrared.

Park	Year(s)	Emulsion	Scale	No. photos	Scan resolution
LACL	1952-57	B/W	1:40,000	706	1200-1800 dpi
	1978-80	CIR	1:63,000	270	1200 dpi
	2010	CIR	1:24,000	112	2200 dpi
KATM	1951	B/W	1:40,000	475	1200-1800 dpi
	1982-84	CIR	1:63,000	315	1200 dpi
	2011	CIR	1:24,000	264	2200 dpi

This project provided student technicians the opportunity to learn new skills and contribute to both the development of orthorectified products and to methodologies for future use on projects of this kind.

A two phased process was utilized; first the historic aerial photos were orthorectified to a high resolution base image for both LACL and KATM. Second, park wide mosaics were created for the black and white photos of the 1950's and for the AHAP photos of the 1980's.

Phase I - Orthorectification

For this phase of the project, SWAN worked cooperatively with Saint Mary's University of Minnesota (SMUMN) to complete orthorectification of aerial photographs taken during 1950's, 1980's, and 2010-2011. 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 LACL and KATM. In addition, the project provided the opportunity to:

- Assess the utility of re-orthorectified IKONOS satellite imagery and SPOT 5 Digital Elevation Models (DEMs) for georeferencing and orthorectification processes;
- Identify and test additional satellite imagery and DEMs from alternative sources (ASTER, SPOT, NGA, SRTM) to support georeferencing and orthorectification where IKONOS data is not available;
- Examine a variety of methodologies for mosaicing individual orthorectified aerial photo frames into a composite image mosaic;
- Further advance an optimized workflow methodology for cost effective orthorectification of aerial photography over extensive study areas and for multiple points in time; and,
- Provide students with experiential learning opportunities.

Phase II - Photo Mosaics

The original Task Agreement for the LACL and KATM 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 park wide composite image.

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 images and mosaics complete with metadata in georeferenced digital format.

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 orthorectified imagery. SMUMN has produced images that were corrected using this approach, and they have shown a horizontal error of approximately 20-30 meters when compared to the control orthorectified imagery, thus meeting the USGS National Map Accuracy Standard (NMAS) for 1:63,360 scale mapping of ±32 meters horizontal accuracy.

Study Area

The study area for the first phase of the project included all of LACL and KATM (**Figure 1**). LACL was first established in 1978 by executive order as a national monument and gained National Park status under the Alaska National Interest Lands Conservation Act (Public Law 107-282) in 1980. The national park hosts a patchwork of habitats including tundra, coastal forest, and riparian wetland ecosystems in its interior. The park is committed to protecting; red salmon fisheries in the Bristol Bay watershed, maintaining the scenic beauty of the Alaska and Aleutian Ranges, and protecting wildlife habitat (National Park Service, Alaska Regional Office, 2009).

KATM, also established by the Alaska National Interest Lands Conservation Act (Public Law 107-282), was designated to preserve the park's unique volcanic landscape along its mountains, alpine valleys, and coastal zones. In addition, KATM serves as a protective preserve for brown bear, moose, caribou, and wolf populations. KATM is most recognized for the volcanic landscape of the 'Valley of Ten Thousand Smokes', a valley filled with several meter thick ash layers that are dissected by river, stream, and creek formed gullies and canyons; a frequent natural attraction at KATM. The large ash field formed as a result of the ash and lava flows from the Novaropta volcano, located along the Aleutian archipelago, eruption in 1912. The 1912 eruption is believed to be the single largest significant eruption of the twentieth century (National Park Service, Alaska Regional Office, 2009).

Historical aerial photography provides a visual record of conditions in both LACL and KATM 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 landscape change. There are a variety of ways in which these historic aerial images might be used once they are in orthorectified, digital form. These include:

- Local and regional vegetation gain/loss studies;
- Glacial advance and retreat;
- Ice condition assessment;
- Identification of landform change; and,
- Climate change studies.

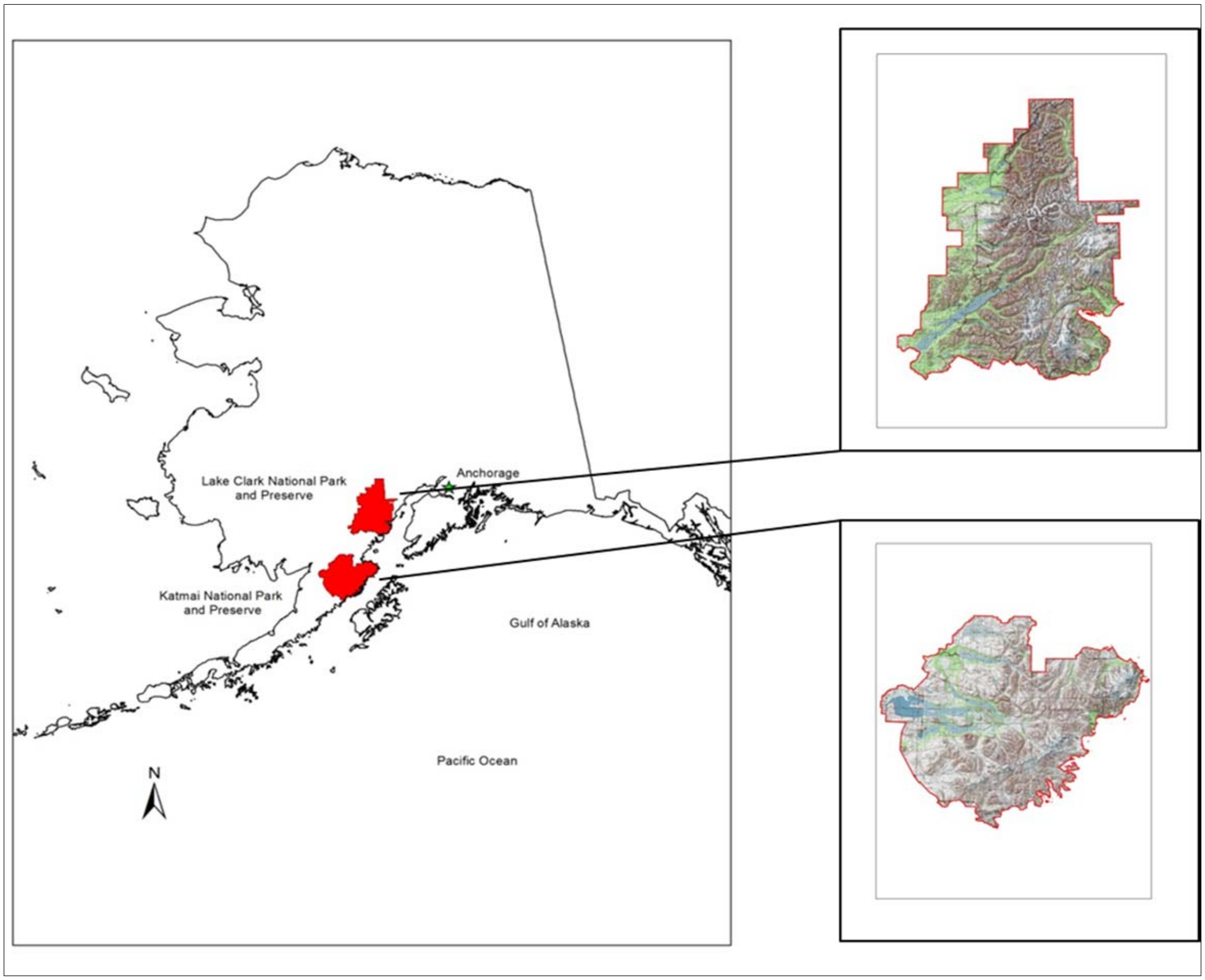

Figure 1. Study areas of interest for photo orthorectification, LACL and KATM National Parks.

Methods

Phase I - Orthorectification

Digital Conversion Methodology

The digital conversion process employed for this project consisted of the orthorectification of digitally 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 six (6) sub-areas organized by park and photo acquisition timeframe. These sub-areas included:

LACL:

- 1950's black and white;
- 1980's Alaska High Altitude Photography;
- 2010 high resolution coastal aerial imagery.

KATM:

- 1950's black and white;
- 1980's Alaska High Altitude Photography;
- 2011 high resolution coastal aerial imagery.

Image Acquisition and Photo Scanning

The first step in the work flow process was to convert the hardcopy aerial photos to un-georeferenced digital image files using a high resolution desktop scanner. Scanning of the 1950's black and white images and the 1980's AHAP's was done by the U.S. Geological Survey (USGS). Aerial photos were in the USGS archives and digital scans were ordered through the USGS data store. SMUMN was responsible for identifying frames needed for the project. Output images from the scanning process were provided in Tagged Image File Format (TIFF) and at various pixel resolutions. Scanning resolutions ranged from 1200 dpi, to 1800 dpi and some of the sub-project areas were scanned at multiple resolutions. Coastal CIR imagery was acquired by Aerometric Inc. in 2010 through an interagency agreement between the USGS and SWAN, and delivered to SMUMN at a resolution of 2200 dpi.

The basic NPS specifications for the scanned photography purchased for this project included:

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

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. This process involves choosing ground control points from a digital base map reference layer; identifying those same points on the scanned aerial photo; and, then assigning the coordinate value for the control point on the base layer to the equivalent point on the scanned 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 registered from the base imagery. Geographic registration of the LACL and KATM photo series (1950s, 1980s, and coastal CIR's) to the base image 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.

The primary base image layer used for both parks was IKONOS, 1 meter resolution, 4 band, TIFF imagery; however, with KATM the base IKONOS was able to be re-orthorectified with a higher resolution SPOT 5, 20 meter DEM, made available from the Alaska Statewide Digital Mapping Initiative (SDMI). When IKONOS images were made available with rational polynomial coefficient (RPC) files, the images were run through an automatic orthorectification process in ESRI ArcGIS utilizing the high resolution DEM for improved locational accuracy. The RPC file was in essence a sensor calibration model that stored the information in an *xxx_rpc.txt* file. It contained the needed information to georeference the image. This combined with a DEM of higher resolution than what was used originally created a more accurate base image to georeference the scanned images against. An example of shifting of original IKONOS compared to that of re-orthorectified is presented below (**Figure 2**).

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 (**Figure 3**, **Figure 4**). Where this type of data was not available, lower accuracy LANDSAT panchromatic band, 15 meter resolution, was used. SMUMN also had the opportunity to test the National Geospatial-Intelligence Agency WARP (Web-Based Access and Retrieval Portal) imagery which came in the NITF (National Imagery Transmission Format) format. Unfortunately, the IKONOS satellite imagery was clipped tightly to the park boundaries. As a result, this data only provided a georeferencing solution for photos that were contained entirely within the LACL and KATM boundaries (**Figure 5**). For photos that extended beyond LACL and KATM park boundaries, the lower accuracy base layers had to be used to supplement the IKONOS control points.

As AHAP orthorectified images were created for LACL and KATM prior to the orthorectification of the coastal imagery, AHAP was used to supplement the georeferencing process in those areas where the IKONOS imagery was covered by clouds or snow. The previously rectified AHAP images provided a higher resolution base dataset than LANDSAT.

In a minimal number of areas, there were photos in this project that extended beyond the DEM coverage (**Figure 6**, **Figure 7**). Where this occurred, the photos were clipped at the edge of the DEM boundary and any image data extending beyond the DEM was dropped from the final orthorectified image. As a result, these photos appear reduced in size or incomplete. In the future, 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.

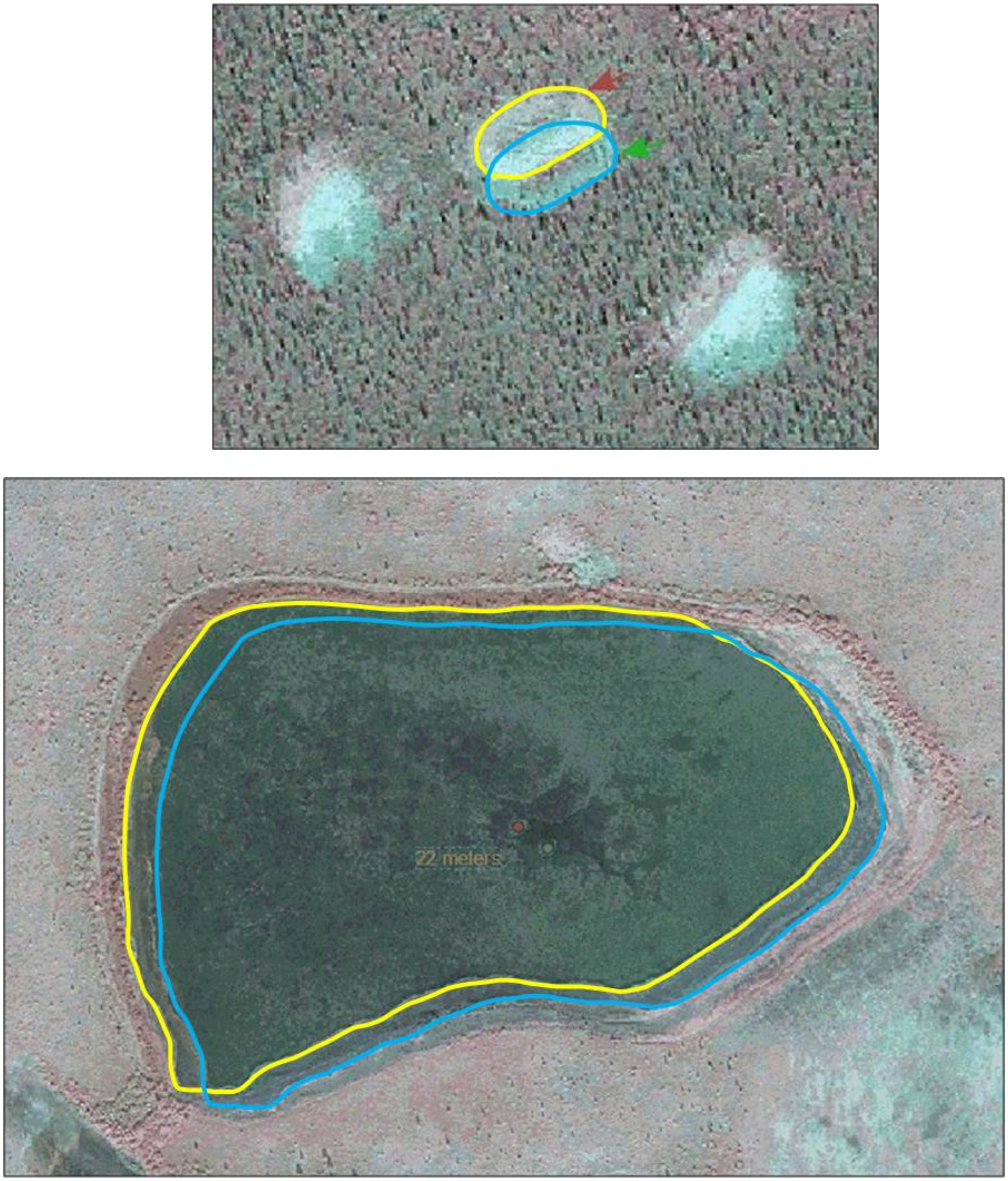

Figure 2. Shift between SPOT 5 DEM spatial corrections (highlighted in blue) versus original IKONOS DEM spatial corrections (highlighted in yellow).

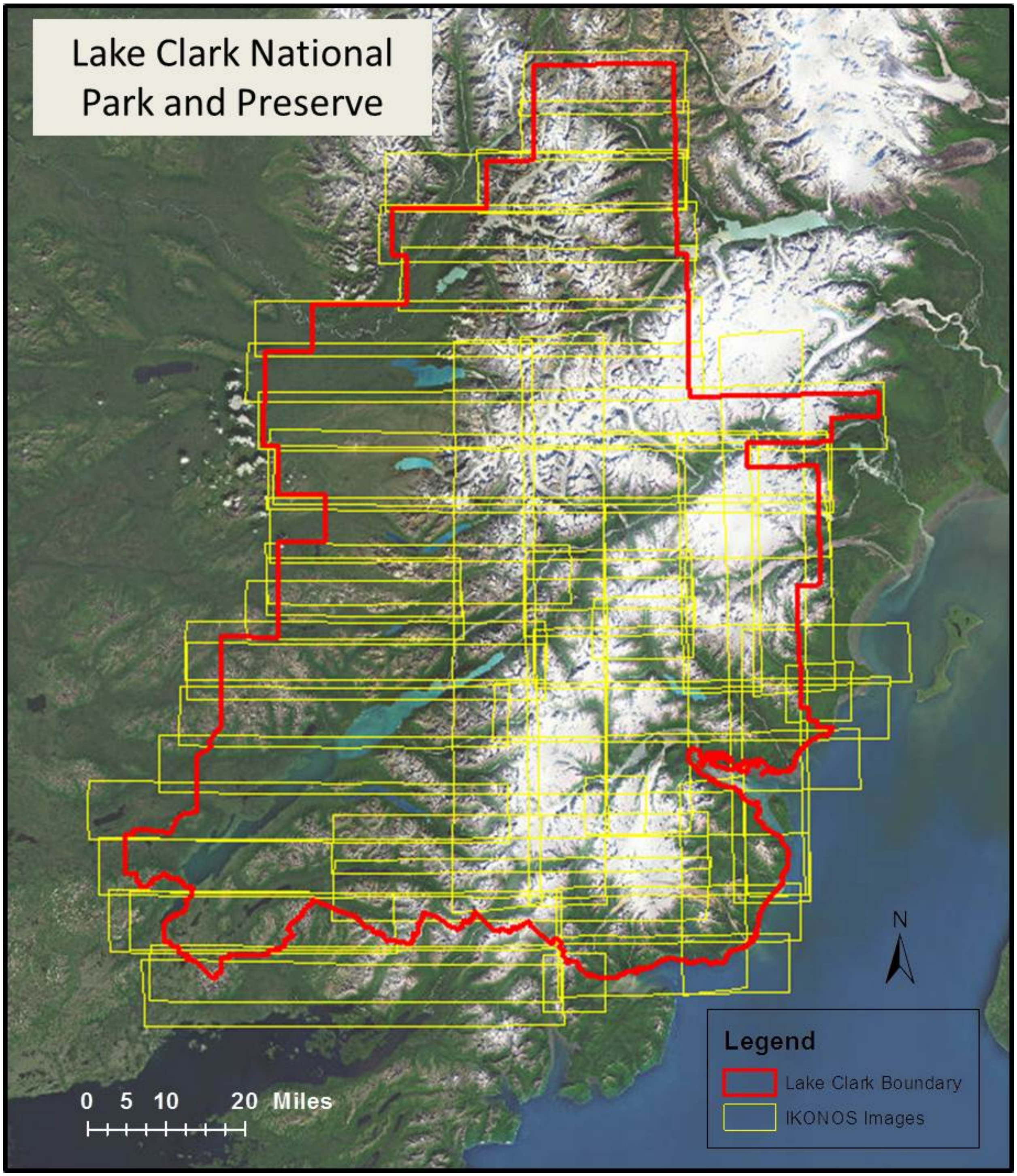

Figure 3. NPS supplied IKONOS coverage for LACL.

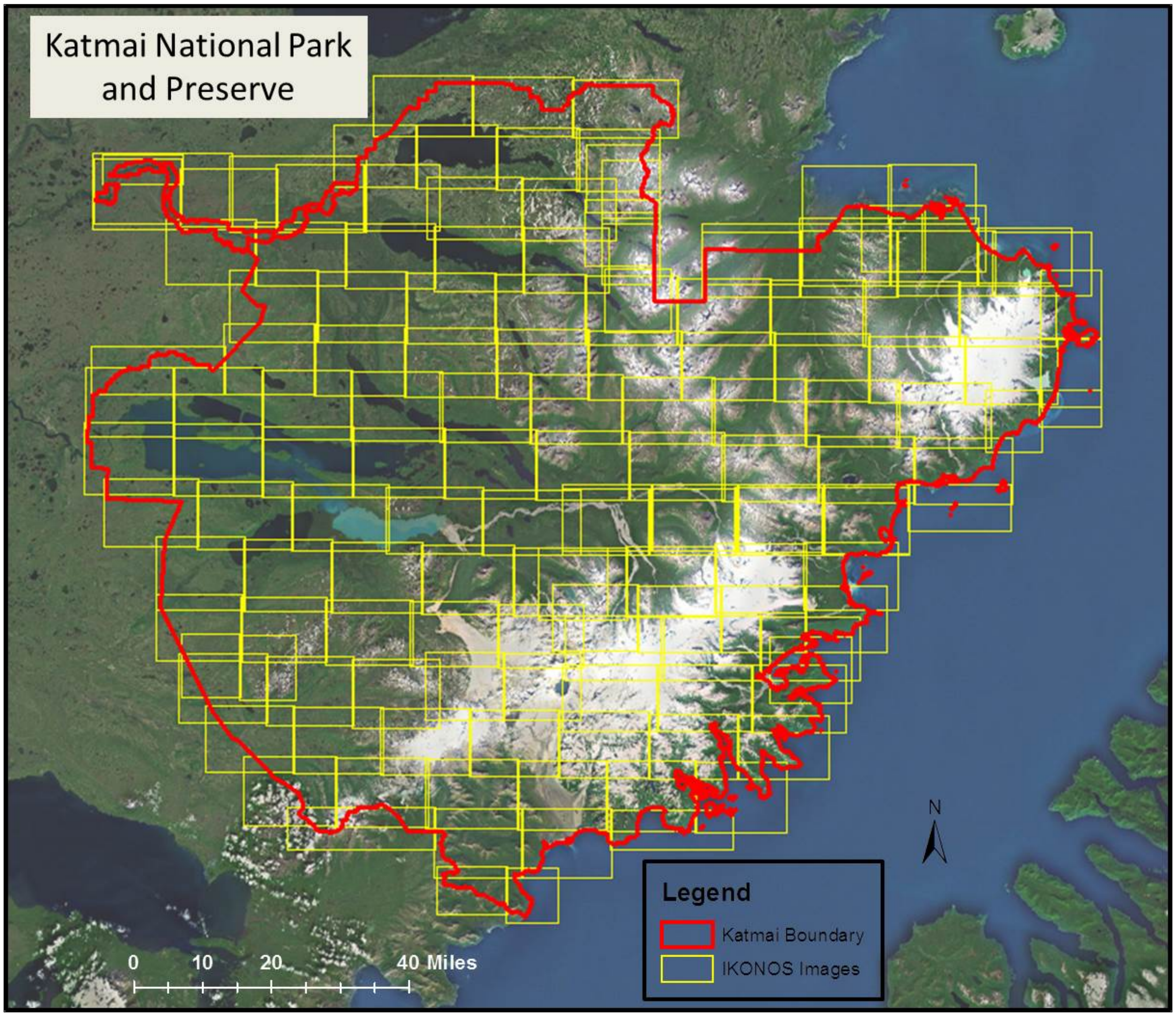

Figure 4. NPS-supplied IKONOS coverage for KATM.

For every orthorectified image, a text file was generated in order to document the approximate error of the georeferencing process. Root Mean Square (RMS) error values were used as the metrics to assess a level of accuracy. RMS values examined the consistency across all the control points and produced a numeric value the analyst used to determine if control points provided a favorable geo-location for the resulting output image. Essentially, a high RMS error caused more shift and less overall accuracy in the output georeferenced image. High RMS errors required the deletion and re-entering of control points to bring RMS error down to an acceptable level.

Typical Root Mean Square errors for areas georeferenced to the IKONOS imagery were between five and 12 meters. Areas that were georeferenced using the LANDSAT panchromatic in conjunction with IKONOS typically had RMS errors of between 15 and 25. 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 25 meter range.

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

Orthorectified photos were in the projection 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].

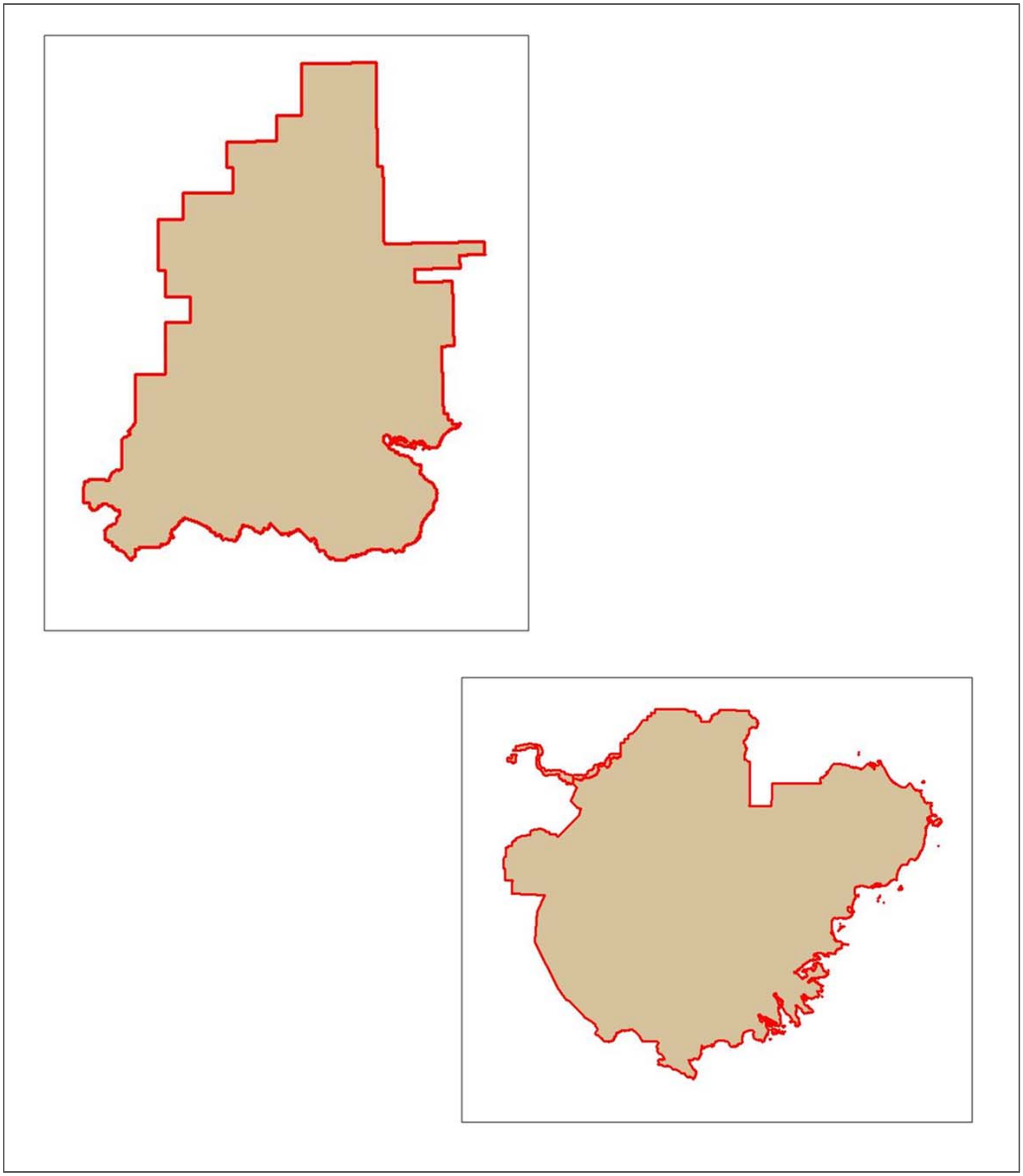

Figure 5. Park Boundary Extents of LACL (top) and KATM Park (bottom).

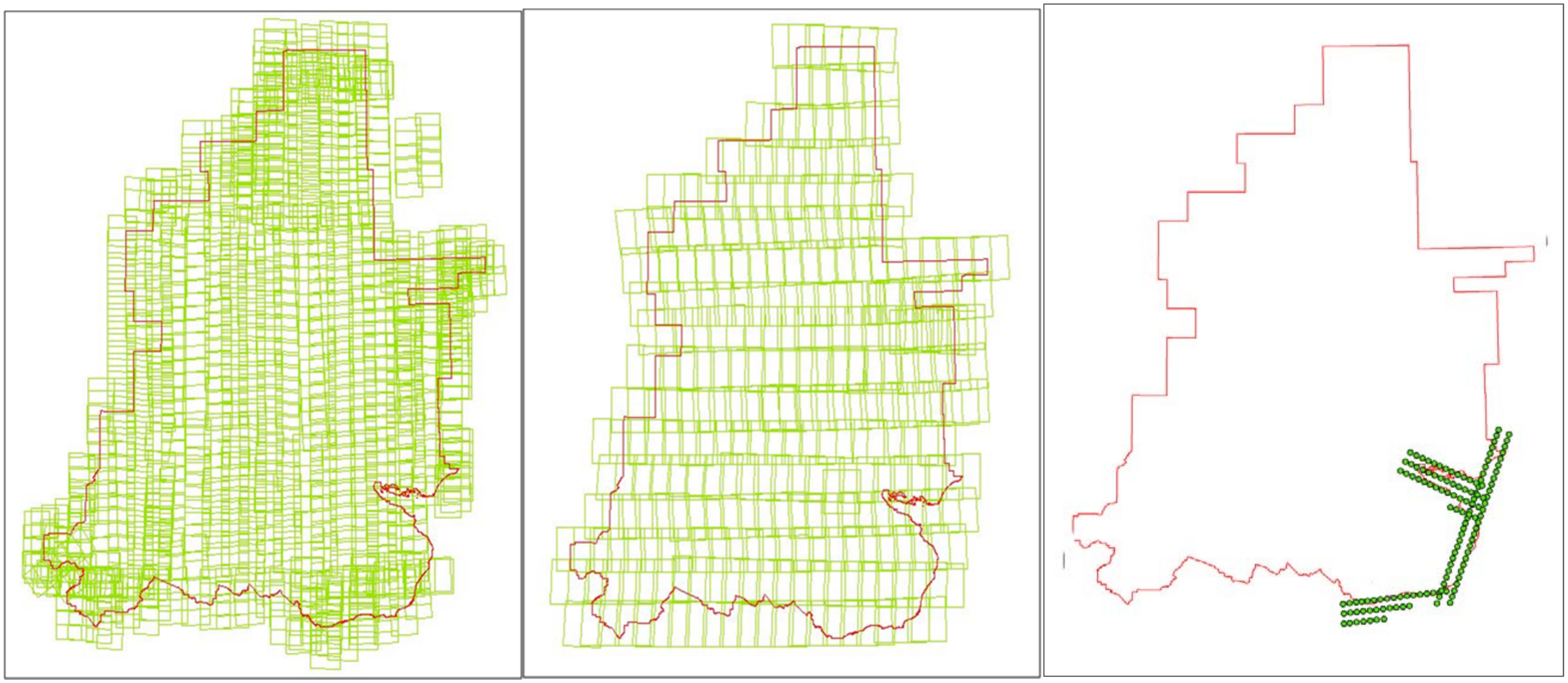

Figure 6. Lake Clark flight lines and photo footprints from the 1950s (left) and 1980s (middle). Coastal flight lines (right) are from 2010.

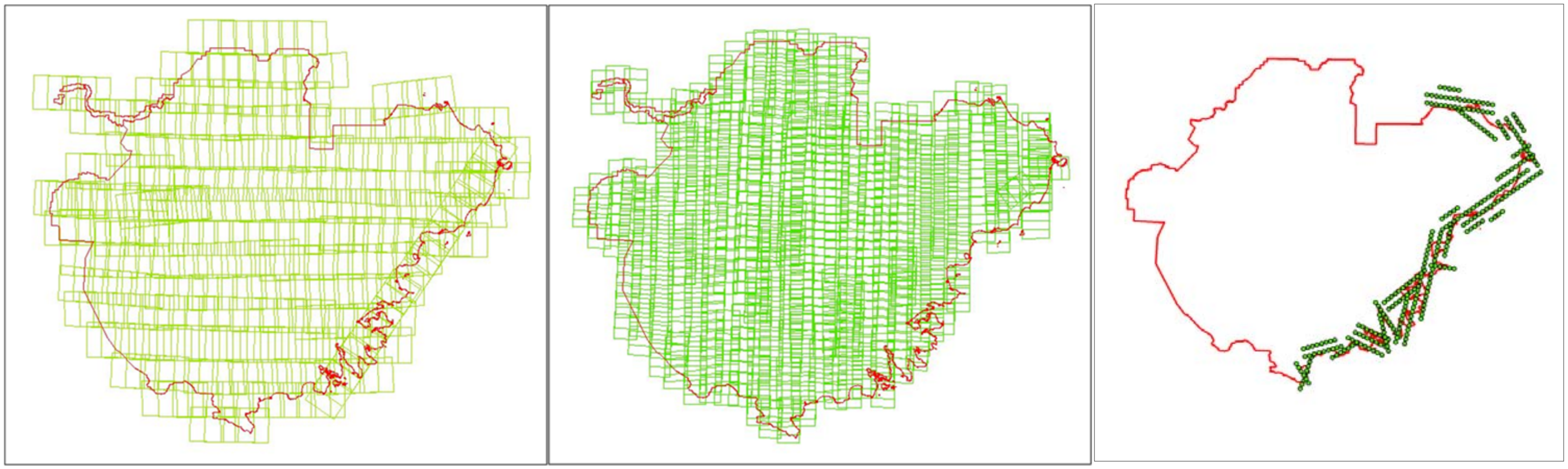

Figure 7. Katmai flight lines and photo footprints taken in the1950s (left) and the1980s (middle). Coastal flight lines (right) were taken in 2011.

Orthorectification

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

The primary input for the orthorectification process involved the use of a digital elevation model (DEM). 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 LACL areas where there was IKONOS satellite imagery provided by the NPS, there was also an IKONOS DEM that was built by GeoEye for the orthorectification of the IKONOS imagery. KATM had a higher resolution SPOT 5 DEM available which provided opportunity for higher accuracy orthorectification.

Given that the IKONOS and SPOT 5 data was limited in its coverage to a tightly clipped boundary along the park edges, other DEM products were required to orthorectify photos that fell partially or fully outside of the parks. These DEM's included NASA Shuttle Radar Topography Mission (SRTM) DEM data and NASA ASTER DEM data produced by the U.S National Aeronautics and Space Administration (NASA) and Japan's Ministry of Economy, Trade, and Industry (METI).

The IKONOS DEMs (30 meter resolution) were delivered to SMUMN in TIFF format. Being clipped to the park boundary not only caused inaccuracy of those parts of the orthorectified image that did not have DEM coverage, but data were sometimes clipped or erased from the orthorectified image in the DEM's "no data" area. In order to alleviate the issues created by clipping and 'no-data' holes in the IKONOS DEM, SMUMN created a composite DEM mosaic using SRTM and ASTER elevation data overlaid by IKONOS DEM. This composite product provided an elevation model that incorporated the entire area of scanned photo coverage for the project. This enabled the utilization of the IKONOS for interior images and a combination of IKONOS and ASTER or SRTM data for images that extended beyond park boundaries. As a result, all available images were orthorectified using the best available DEM.

The SRTM DEM was a 30 meter resolution elevation product derived from data captured during an 11 day space shuttle mission in 1999. There was a limit to the northern extent of acquisition for this dataset. LACL was too far north in latitude to have coverage (**Figure 8)**. Although KATM had full coverage of SRTM DEM, there were significant gaps or "no data" holes within the dataset. Attempts to correct such holes resulted in negative effects to the overall image elevation values. As a result, SMUMN chose to work with the ASTER Elevation Datasets where IKONOS was unavailable.

The ASTER DEM was a 30 meter resolution elevation dataset that, for Alaska, was available from the Alaska Statewide Digital Mapping Initiative (SDMI) website. ASTER DEM provided the coverage needed for both parks and did not have the data holes encountered with SRTM. The ASTER 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 ASTER data was only used to fill no data areas and extend the outer edges of the DEM mosaic beyond Park boundaries.

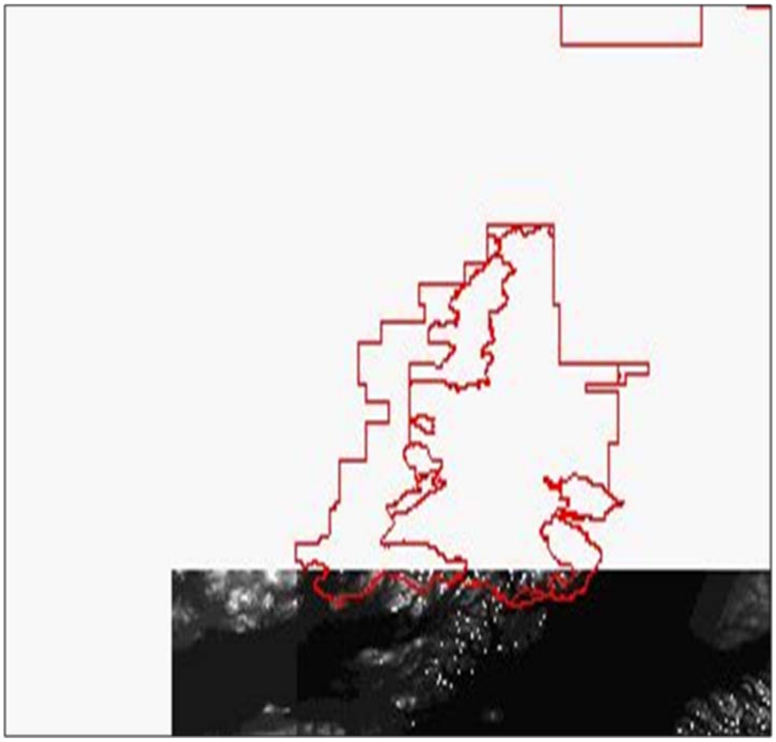

Figure 8. Northern extent of SRTM DEM coverage.

All of the calculations and processes used to create the composite DEM were executed in ArcGIS 10 using the Spatial Analyst extension. ASTER DEM tiles were downloaded and mosaiced into one large DEM ensuring sufficient coverage beyond park boundaries (**Figure 9**). This composite ASTER DEM was then mosaiced with the IKONOS or SPOT 5 DEM with particular attention that ensured the ASTER had lesser priority. As a final step, this multi DEM composite was converted to TIFF format, projected to Alaska Albers Equal Area Conic (using the projection definition above) and then converted to a .DEM format for use in the orthorectification software.

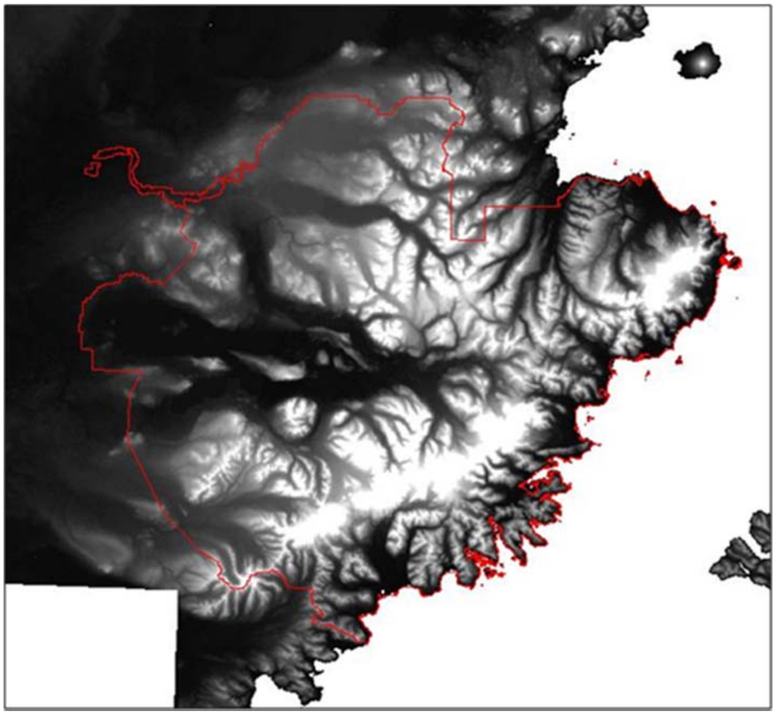

Figure 9. Mosaiced ASTER DEM.

Camera calibration reports provided another important input to the orthorectification process. These reports, created by the United States Geological Survey (USGS), contained camera parameters that were used by the orthorectification software to better account for camera distortion and lens aberrations during image processing. These reports were specific to the camera used for each photo acquisition mission and typically contained 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 LACL or KATM 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 complete camera calibration reports, these data were used to enhance the final orthorectification of the scanned aerial photos (**Appendix A**). These sub-areas included:

- LACL: 1980's Alaska High Altitude Photography (AHAP); 2010 coastal images;
- KATM: 1980's AHAP; 2011 coastal images.

The software package used for orthorectification on this project was OrthoMapper rev. 5.6.7 from Image Processing Software Inc. OrthoMapper was exceptional for processing large amounts of data (e.g. hundreds of scanned aerial photos) and provided a more appropriate environment for production work flows than other software packages. With OrthoMapper, individual project folders were created for each photo, but when camera calibration information was used it only needed to be entered once and the camera report file generated was used for every photo associated with it. In other software, camera report information needs to be entered for each photo.

Some of the other benefits of OrthoMapper included:

- 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 two control points had been added, the non georeferenced image tracked 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 within ArcMap 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 30 meters and were dependent 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. When excessive shift was encountered, the project was re-opened in OrthoMapper and additional control points were added to achieve a better fit between the base image and orthorectified image.

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 Parks. If photos were completely within the boundaries of the Parks then only the high quality DEM was used for orthorectification.

Student technicians were taught quality control procedures and were directly responsible for the quality of orthorectified images. Senior staff educated the technicians about RMS errors and the correct distribution of control points to achieve optimum orthorectification results. Students were also taught how to check images in ArcMap to ensure image alignment was correct. In cases where control point correction was required to alleviate shifting, senior staff explained the correct steps so that student technicians could accomplish corrections on their own.

As a final review senior staff checked the orthorectified images. Student technicians, with staff oversight, also had the opportunity to conduct post processing of the orthorectified images including: assigning spatial information; and, developing and applying metadata. This has expanded students' knowledge to include various processes and tools for creating metadata.

Phase II - Photo Mosaics

Basic Approach

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

- Initial selection of input photos based on image quality, color, tone, texture, histogram variation and overlap;
- External color and tone balancing. This included visually matching adjacent images so that not as much adjustment was required during the mosaicing process;
- Sub-setting that included clipping out the best portions of individual photos before mosaicing, following natural features (valleys, ridges, streams, roads etc.) in order to mask seams, and focus on the center of the photo to minimize distortion from radial displacement;
- Software mosaicing and color balancing with image stretching and manipulation; and,
- Touch up of seam lines.

Software

ERDAS IMAGINE 2011 Mosaic Pro was used as it was found from previous work that this software would generate acceptable quality mosaic output for this type of project. Although, IMAGINE has a "create seam lines tool" for automated and manual subsetting of images prior to mosaicing, ESRI ArcGIS 10 was used for creation of shapefiles that were applied to subset those areas where IMAGINE did not generate acceptable results. The most important functional elements of mosaicing software were those that controlled the amount of image manipulation conducted before, during, and after the mosaicing process.

ERDAS IMAGINE 2011 was the most technically advanced software package available to SMUMN. This package was developed by ERDAS Inc. and it was a fully functional remote sensing and image analysis application.

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. All of the input images that were brought into IMAGINE for mosaicing were subset utilizing the seamline tool in IMAGINE (**Figure 10**).

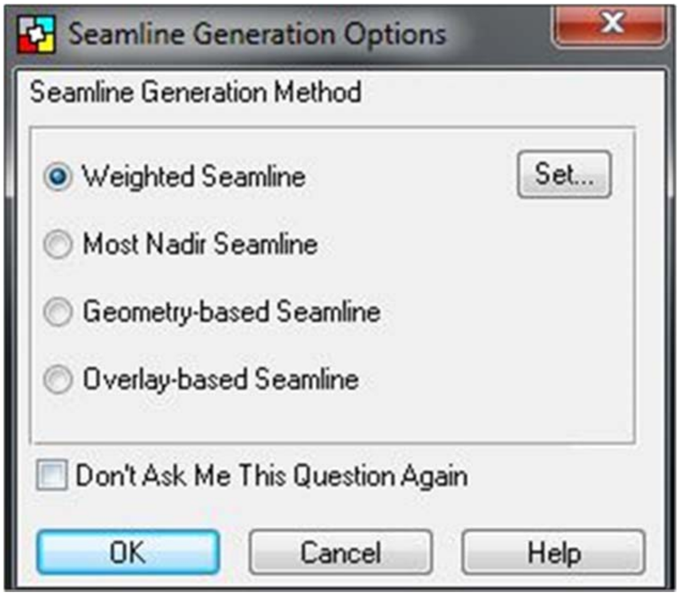

Figure 10. ERDAS IMAGINE Seamline Generation Options.

Again, as with previously described tests on other software packages, the first flight line of images run through Mosaic Pro 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 were assessed. From this baseline, adjustments were made in order to better refine the quality of the mosaic of each flight line. This was a trial and error process that relied upon educated reasoning gained through researching literature on mosaicing techniques and perusing recommendations from the ERDAS Technical Support Team. After mosaiced flight lines were created, the flight lines themselves were mosaiced to form a park-wide mosaic.

There were three primary functions set on each run of the software. These represented the main user controlled options available for image manipulation in IMAGINE, including seamline functions, color corrections, and output image options (**Figure 11**).

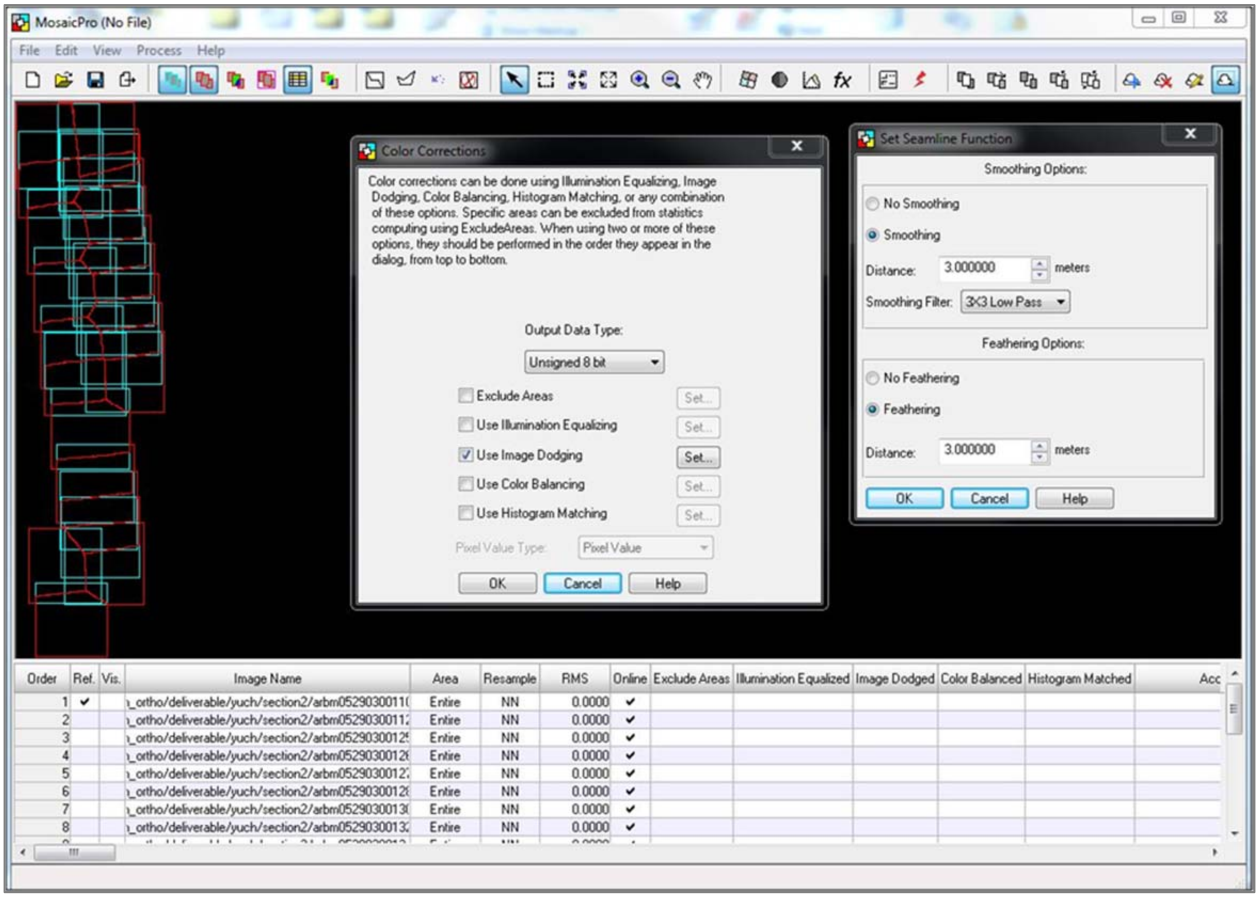

Figure 11. User options for image manipulation, ERDAS IMAGINE Mosaic Tool. Seamlines are in red.

Seamline overlap functions were designed to allow the user to develop a more seamless transition between individual images. These functions included smoothing and feathering. With one meter resolution for the input orthorectified images, a large smoothing and feathering value was not necessary. In fact, during testing, using a large a value for smoothing and feathering caused a smearing result along the seamlines of the output mosaic.

The color corrections interface provided several options including: exclude areas, use image dodging, use color balancing and use histogram matching. Image dodging produced the best looking mosaics in both color and tone. The color balancing options in IMAGINE provided a variety of tools for 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.

With respect to the output image options, the main setting to un-check or shut off was the rescale data option. A final verification that the output cell size, number of layers, and data type were correctly set and that the method was set to union of all inputs was also done in this dialog.

Results and Discussion

Phase I - Orthorectification

Final products for the LACL and KATM orthorectification project included the following:

- 2,142 scanned aerial photos as per the specifications;
- Orthorectified aerial photos delivered as 8 bit pixel depth, 1 meter pixel resolution, TIFF format image files.
- Text reports for each photo orthorectification summarizing accuracy (**Appendix B**);
- The orthorectified products include OGC compliant metadata created with the ESRI ArcGIS 10 metadata editor following the FGDC-STD-001-1998 format (**Appendix C**);
- Deliverable mosaics were a full park mosaic in IMG format, a compressed full mosaic in ECW format, and a mosaic delivered as tiles at a size of 10000 x 10000 pixels.

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 2,142 scanned photos from LACL and KATM. The digital product met the 1:63,360 National Map Accuracy Standard of +/- 32 meters horizontal accuracy for areas where the IKONOS and SPOT 5 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 12 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 both parks where the LANDSAT panchromatic imagery was 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. Images that were orthorectified using lower quality DEM data were documented accordingly in the project metadata.

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 the:

- Number of control points used;
- Displacement of the control points over the surface of the image;
- Resolution of the DEM;
- Extent of the DEM;
- Quality of the composite DEM (where it was used);
- Accuracy and quality of the base layer imagery;
- Quality of the input aerial photo (cloud covered, ice, snow, shadows, scratches, stretch and warp), (**Figure 12**, **Figure 13**, and **Figure 14);**
- Topographic variation of the photo (i.e. significant topographic change over short distances);
- Ability of the software to perform high end transformations;
- Existence of camera calibration reports; and,
- Anomalies with the individual photo (e.g. no fiducials, significant tilt displacement).

The re-orthorectification of IKONOS base imagery for KATM utilizing RPC files and the 20 meter SPOT 5 DEMs produced shifts in the output re-orthorectified base images of on average 10 to 25 meters compared to the original IKONOS base imagery.

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 (**Figure 15**, **Figure 16**, **Figure 17**). Further analysis of these smeared areas indicated that the problem occurred primarily on the 1950’s photos for both LACL and KATM and was possibly due to a combination of factors. 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 contributed to the smearing effect. It was also possible that the composite DEM and significant elevation 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 2200 DPI. The 2200 DPI scanned photos created an output image with a large file size. In cases where camera calibration reports are not available, DPI is needed as an input to the software. A standard DPI for all scans would have been preferred.

Processing times for all stages of georeferencing and orthorectification increased in conjunction with file sizes. A visual comparison of the scans and finished orthorectified photos showed that there was no significant gain in visible image quality between 1200 and 1800 DPI. It is likely that the difference between 1200 and 1800 DPI scanning would be more noticeable at the 1:40,000 scale level and larger. It is our feeling that a DPI of 1800 would be sufficient for all images.

Finally, the mountainous terrain of both LACL and KATM 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. In general, the flatter valley areas adjacent to and between the mountains displayed better horizontal accuracy than the peaks and ridgelines of the mountains.

Testing of the National Geospatial-Intelligence Agency WARP (Web-Based Access and Retrieval Portal) imagery was conducted for the orthorectification of LACL scanned photos that extended beyond park boundaries. This data was not accessible to non-governmental partners and required a government agency for access and download. Data holdings were searched by NPS staff and project area sample images delivered to SMUMN. Findings were not in favor of using National Geospatial-Intelligence Agency data in the orthorectification process. Issues encountered included: images were delivered in non-standard NITF format which did not readily load into ESRI and required a conversion tool; shifting of images made for an inaccurate base; and, image acquisition times were variable and some of the images were acquired at night rendering them unusable for orthorectification purposes. As the datasets available from NGA were changing regularly, this data source may be worth further investigation in the future.

Student technicians contributed to all aspects of the project. Typically the main role for the technicians was to orthorectify images; however, this project provided the opportunity for them to learn additional skills and become conversant with a variety of software packages. These skills included: quality control; image mosaicing; development of project methodologies; and preparation of metadata. Training and oversight was provided by a senior analyst with gradually more and more responsibility being provided to the students as their skill level increased. Students were also given the opportunity to learn about project management and the various roles of senior staff throughout the course of a typical project.

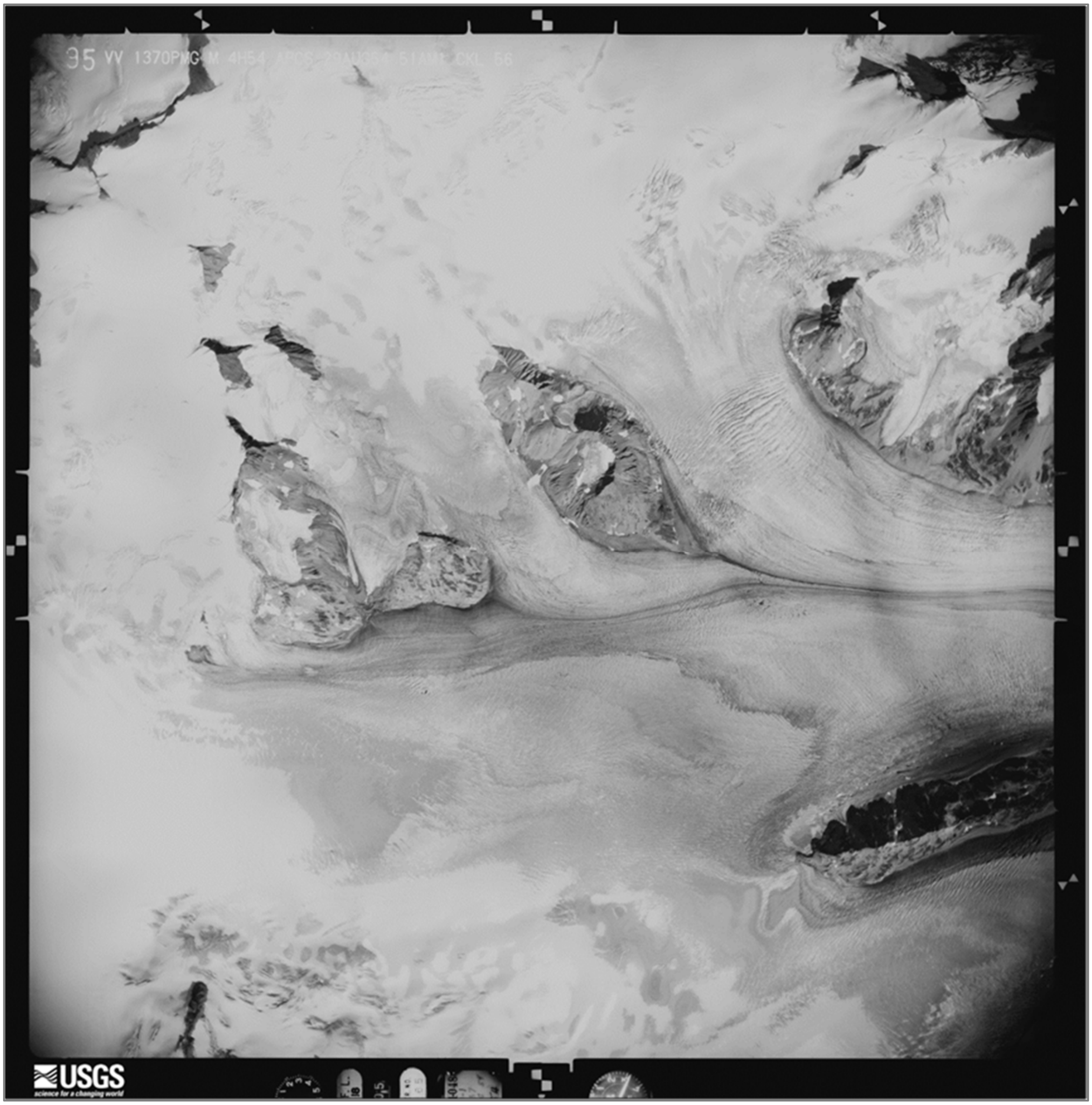

Figure 12. Sample photo of ice field with limited control point opportunities, LACL, 1950s-era.

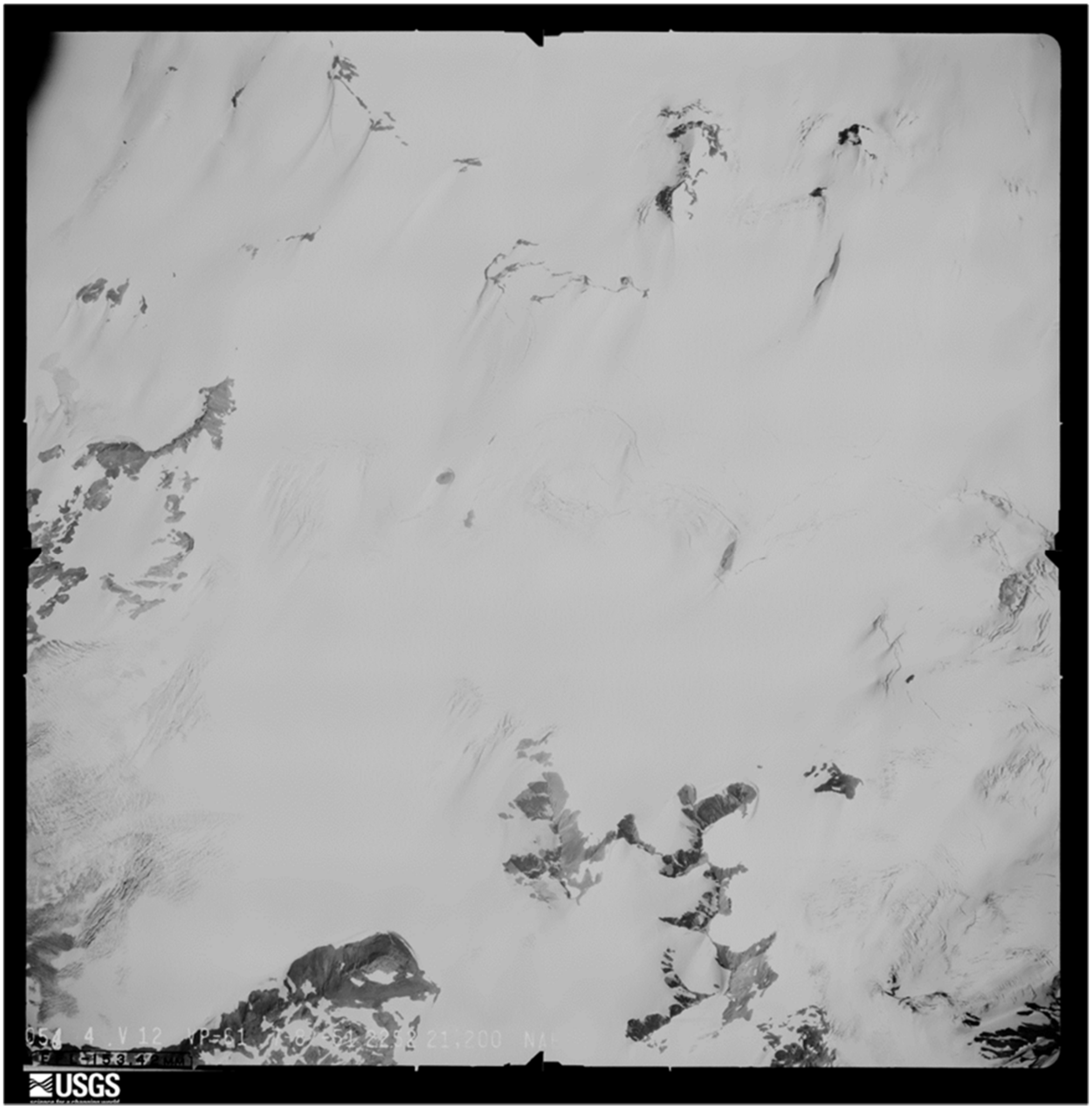

Figure 13. Sample photo of an ice field with limited control point opportunities, KATM, 1950s-era.

Figure 14. Sample orthorectified image, KATM, 1980s era.

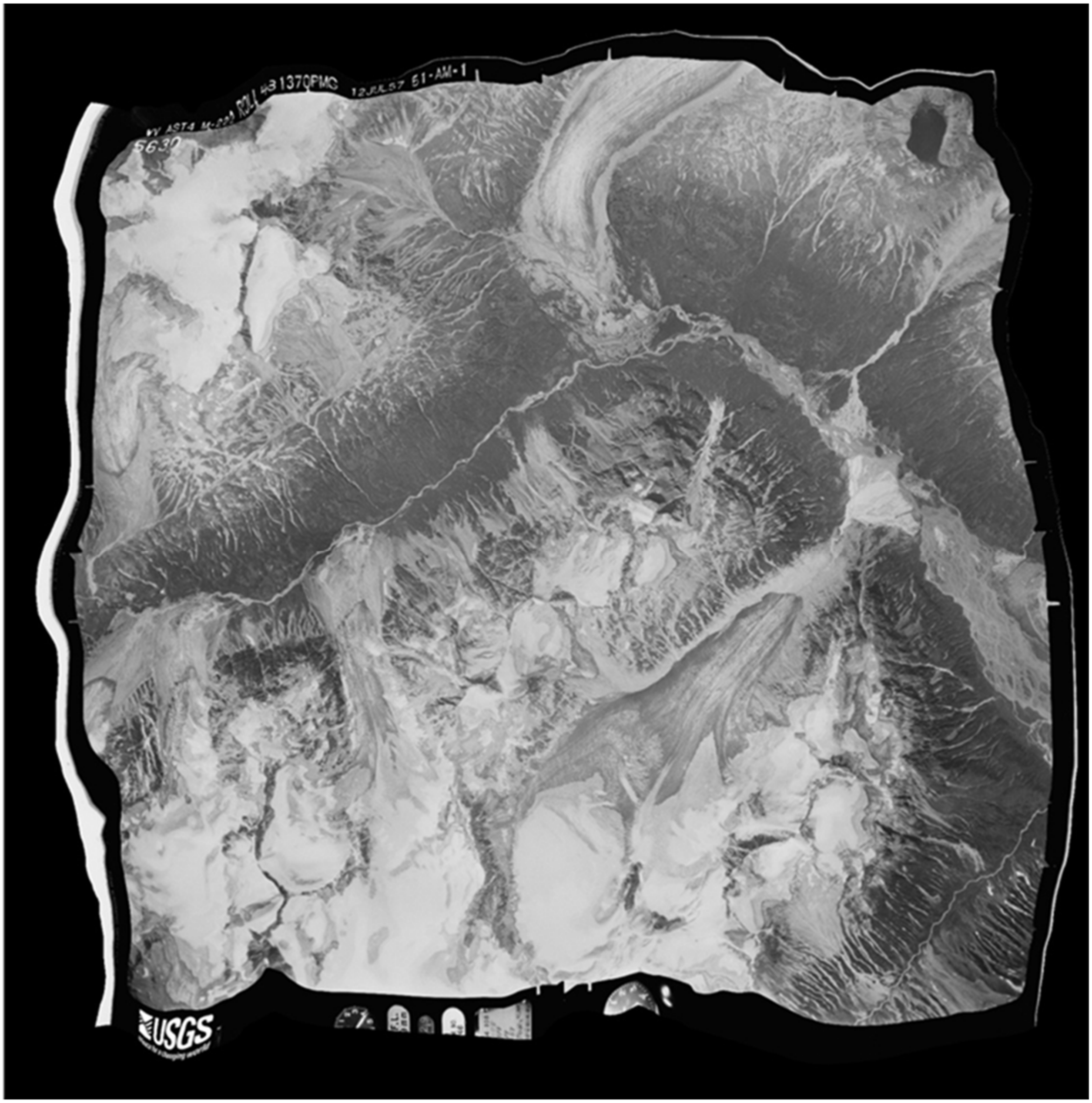

Figure 15. Sample orthorectified image, LACL, 1950's era.

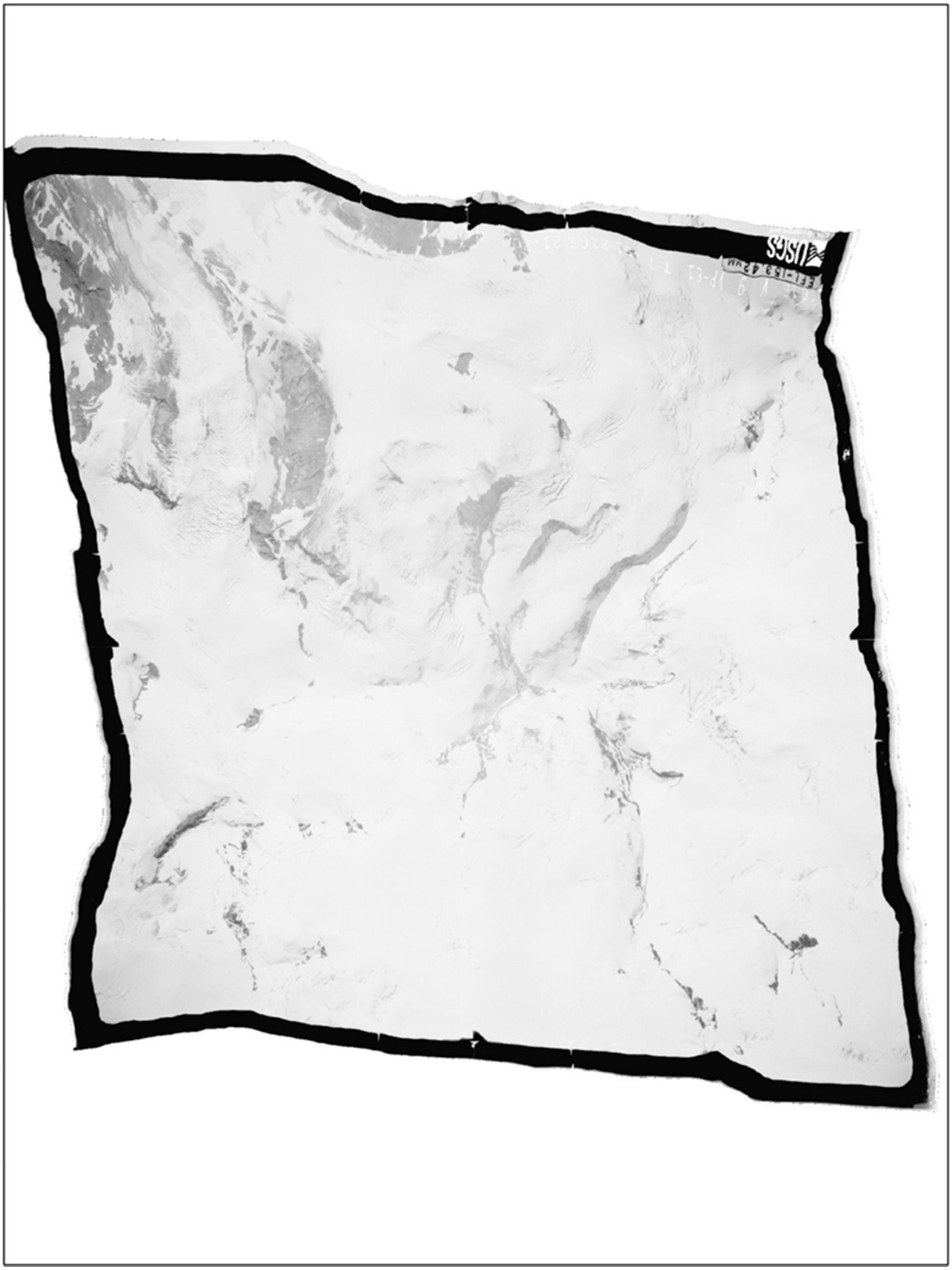

Figure 16. Sample orthorectified ice field image, KATM, 1950s-era.

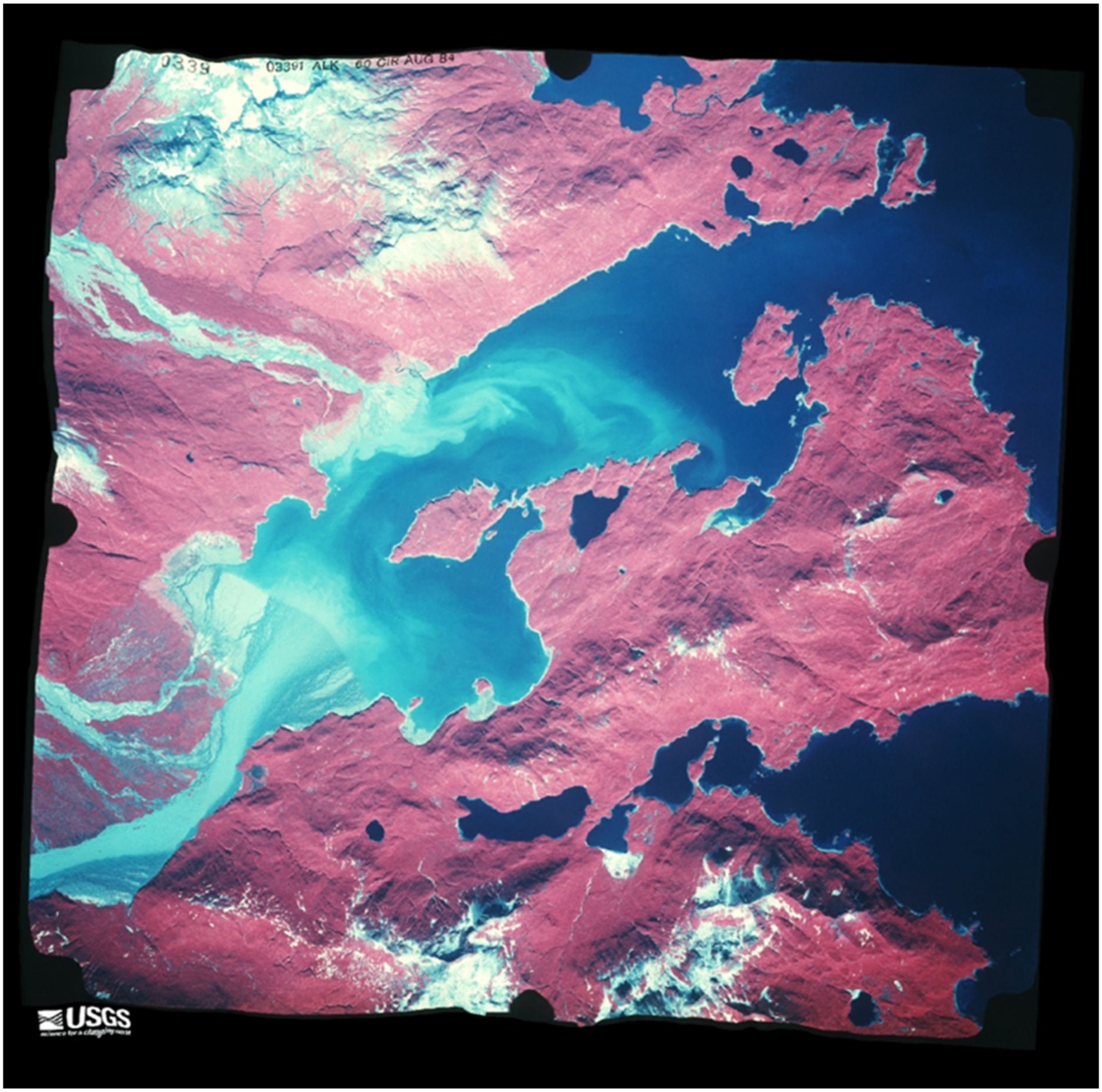

Figure 17. Sample orthorectified image, KATM, 1980s-era.

Phase II - Photo Mosaics

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 occurred 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 mosaicing 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 had a significant effect on the quality of the final composite image. The mosaicing software was always trying to balance spectral reflectance from each end of the visible light spectrum. In doing so, the software tried to darken very light areas (e.g. glaciers) and brighten very dark areas (deep open water). The tradeoff was usually that areas of moderate reflectance in between the extremes (bare ground, vegetation, rock etc.) became either over or under exposed as the software tried to balance the overall image tone between the light and dark areas at the ends of the image histogram.

ERDAS IMAGINE was not the only software package used in the mosaic creation process. In some cases ArcGIS 10 was used to create shapefiles to subset flight lines prior to re-mosaicing them to the park wide mosaic. This was because IMAGINE could not automatically produce adequate seamlines with the flight line mosaics in all cases. Occasionally the process also required manual manipulation to correct seamlines. The view window and editing tools of ArcGIS 10 were more time and cost effective than completing the seamline process in IMAGINE alone. In some cases, orthorectifeid images were subset in ArcGIS 10 prior to being loaded into IMAGINE Mosaic Pro for re-mosaicing of the flight lines.

It was further determined, through the experience and recommendations from the ERDAS Technical Support Team, that there was no single approach that was successful for image mosaicing in every situation. Testing and refinement of methods was ever changing as the images used with each project carried their own anomalies with them.

This issue was further complicated by adjacent photo flight lines that were flown at different times of the day (or on different days entirely) and were opposite in orientation. In some cases, camera optics also affected the spectral variation of a specific image. This was more common with older photography (1940’s and 50’s) where images were often considerably lighter in the center than towards the frame edges. In addition, re-sampling during the orthorectification process also had unintended consequences for image tone. During re-sampling, the spectral reflectance values of individual pixels were modified as adjacent cells were merged and separated. This skewed spectral values away from those on overlapping images and created more abrupt transitions between photos (**Figure 18**, **Figure 19**).

Image matching issues were typically addressed by having as much overlap as possible between the photos that were being used to develop the mosaic. Having approximately sixty percent overlap ensured there was maximum flexibility in choosing the portion of each image that made up the final mosaic. This simplified color balance and seam blending and also minimized image distortion issues resulting from radial displacement, which increased 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 mosaicing project was that photo edges bend and stretch in order to adjust for topographic variation in the terrain. This was most common in mountainous areas where flat aerial images were adjusted to fill peaks and valleys. If there was insufficient overlap between photos (10% or less) then it was entirely possible that terrain adjustments created gaps or no data areas along the margins of each photo which, in turn, created holes in the final composite mosaic (**Figure 20**).

In the end, SMUMN provided the NPS with fully orthorectified aerial imagery complete with metadata in georeferenced digital format (**Figure 21**, **Figure 22**, **Figure 23**, and **Figure 24**). Deliverable mosaics included a full mosaic in IMG format, a compressed full mosaic in ECW format, and a mosaic delivered as tiles at a size of 10000 x 10000 pixels. All three products were created from the 1950's and 1980's orthorectified images of each park.

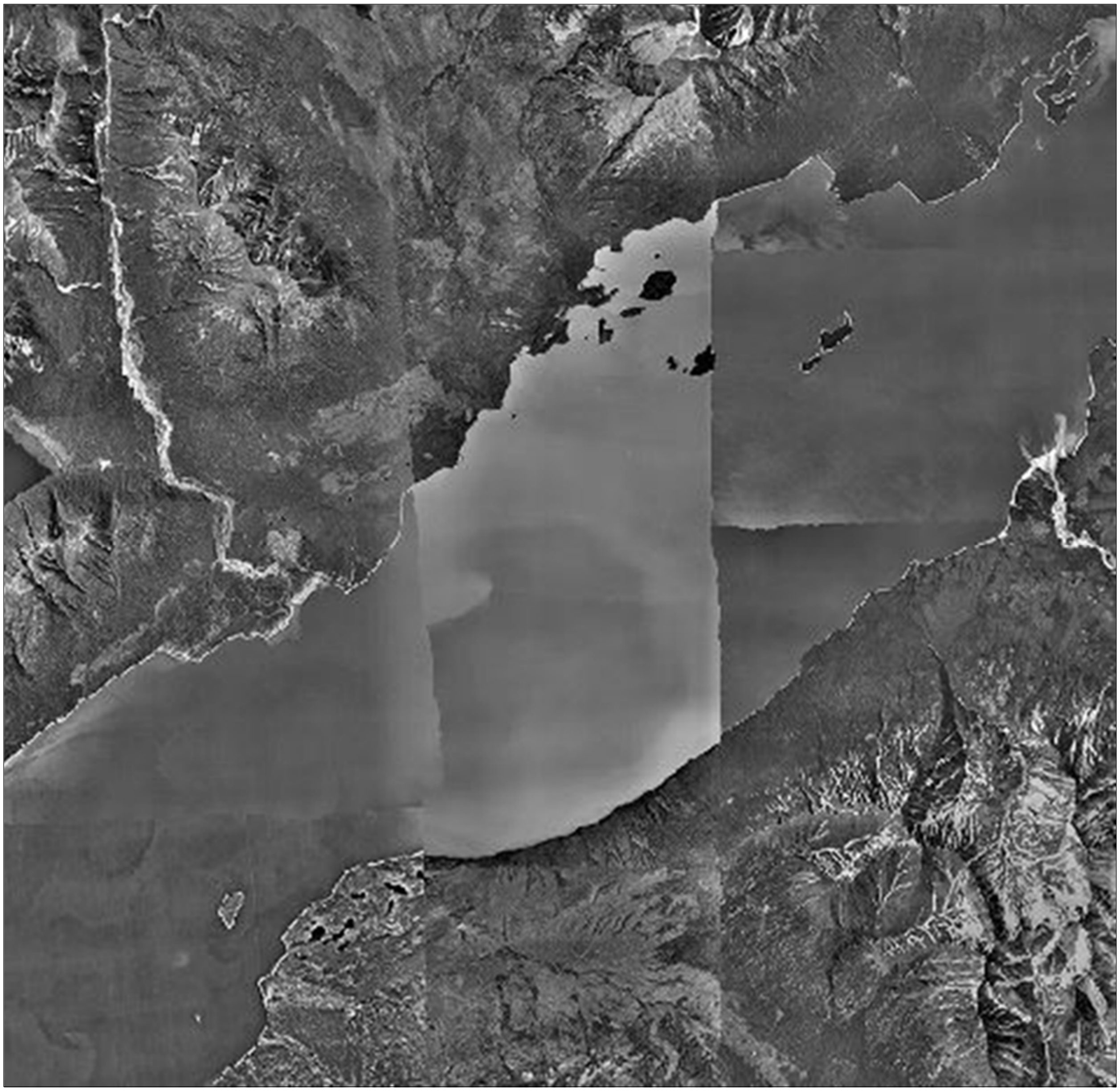

Figure 18. Mosaic of orthorectified, 1950s-era black-and-white photos from LACL showing differences between images.

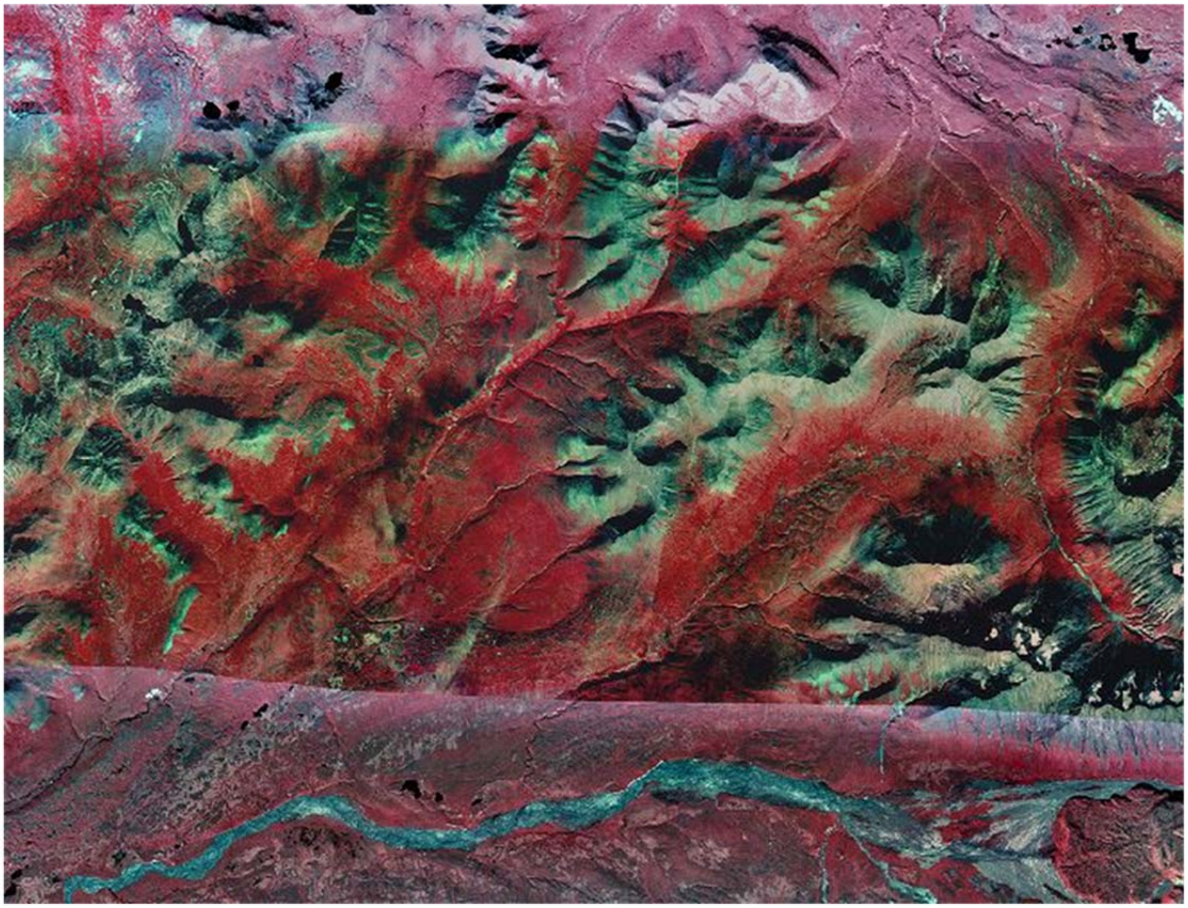

Figure 19. Mosaic of orthorectified, 1980s-era CIR photos from KATM showing tone and emulsion differences across dates and flight lines.

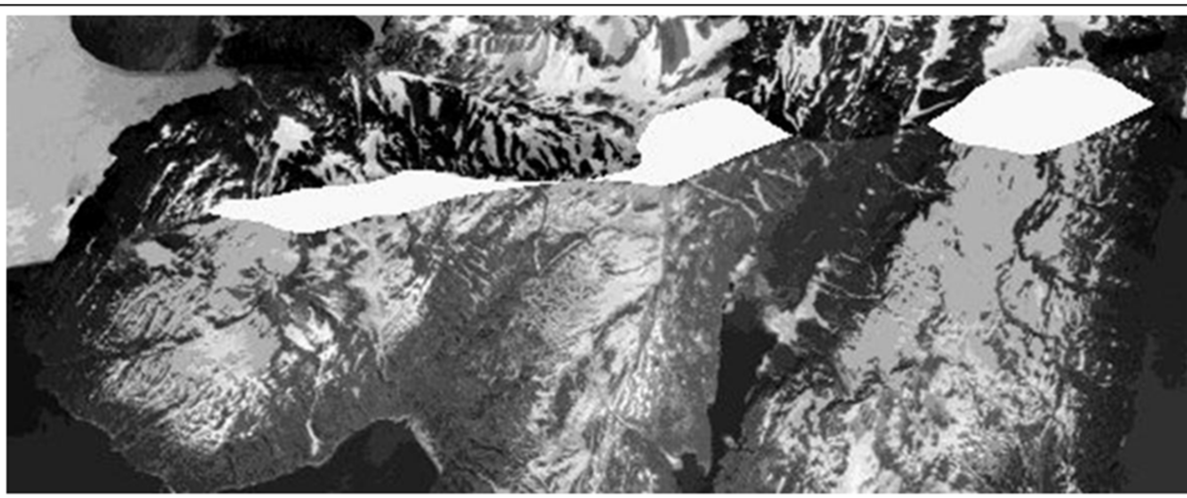

Figure 20. Missing data (white areas) resulting from insufficient overlap between adjacent photos

Figure 21. Complete mosaiced series of black and white 1950's images, LACL

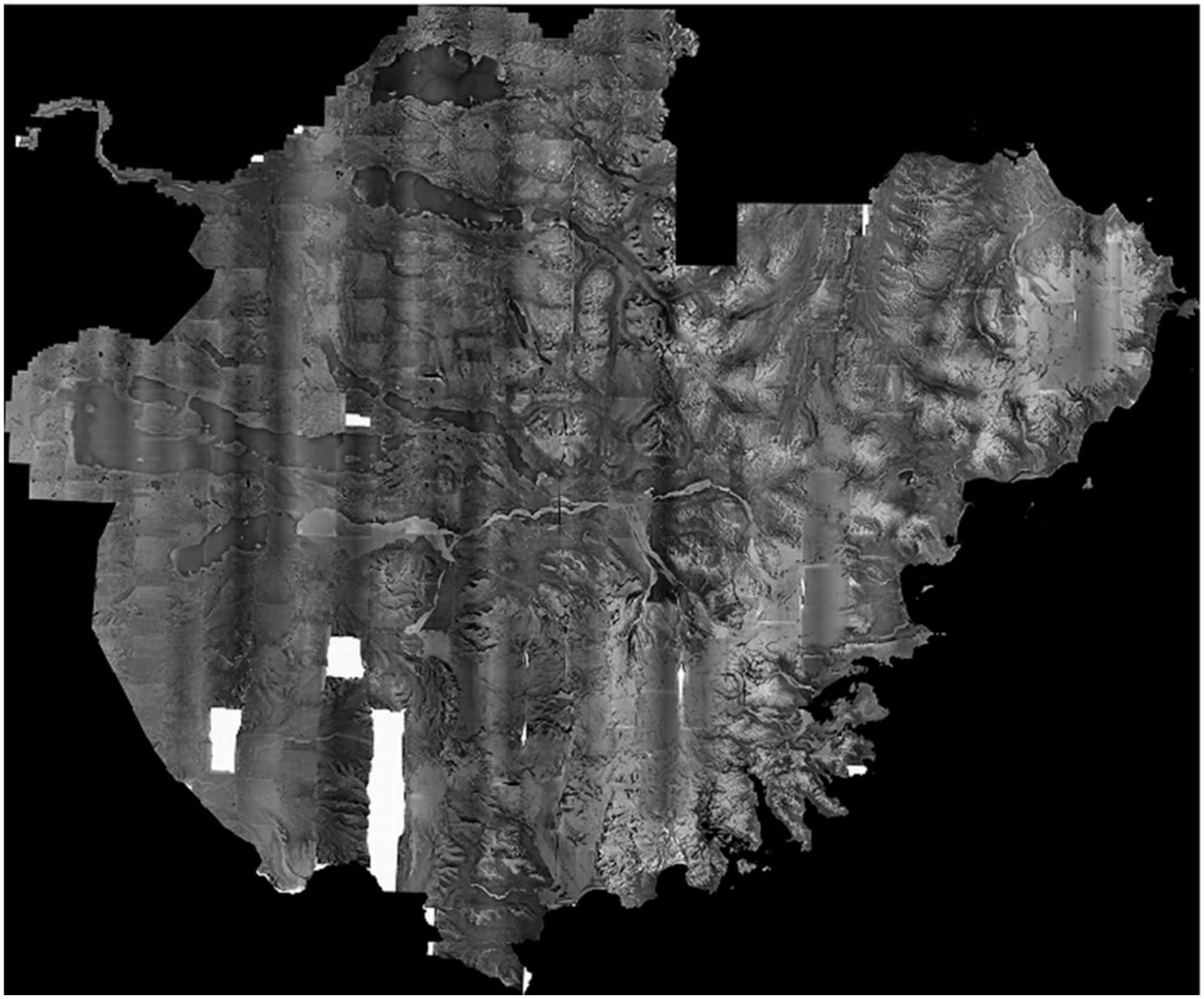

Figure 22. Complete mosaiced series of black and white 1950's images of KATM. The white areas in the mosaic represent absence of data.

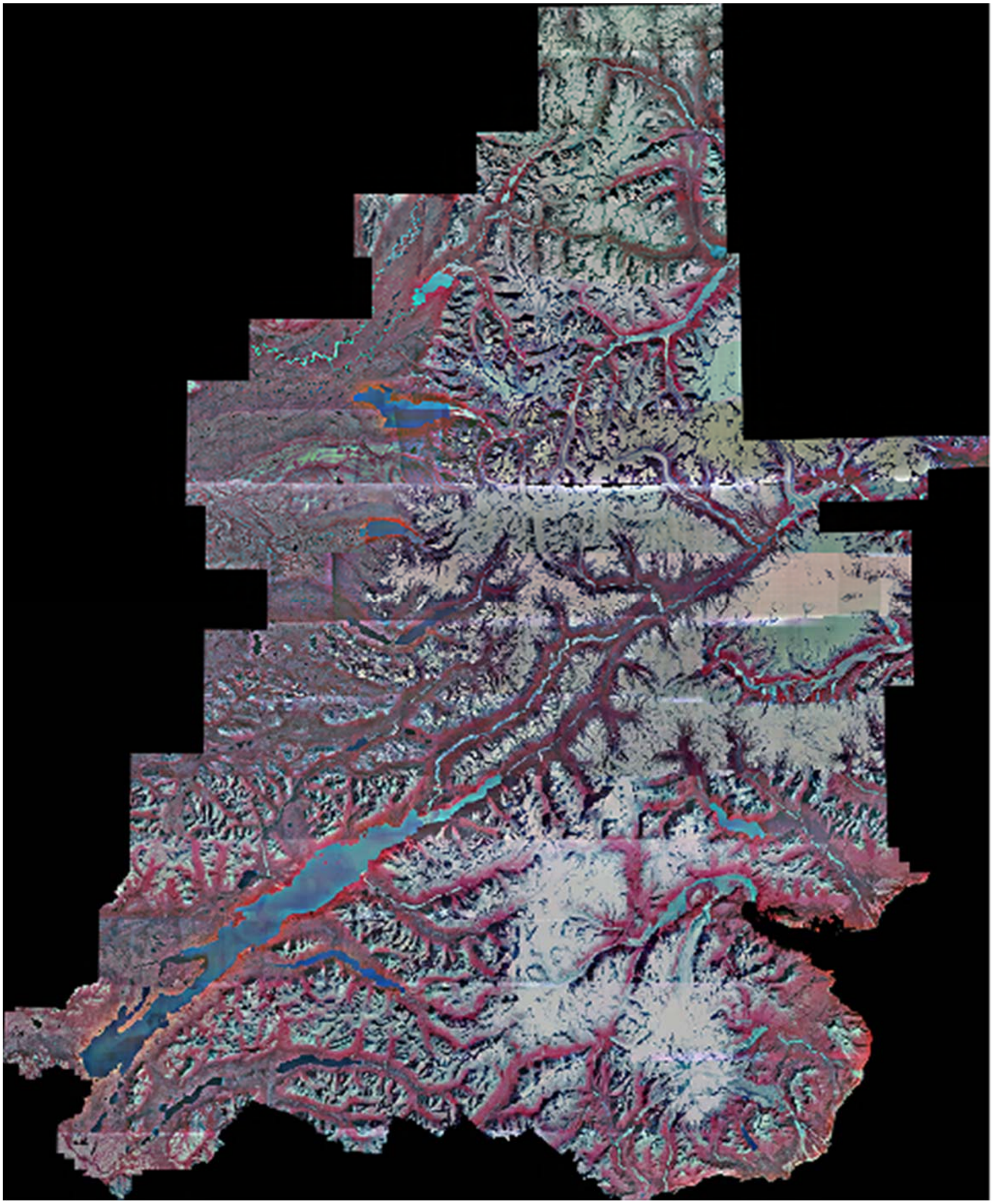

Figure 23. Complete mosaiced series of CIR 1980's images, LACL.

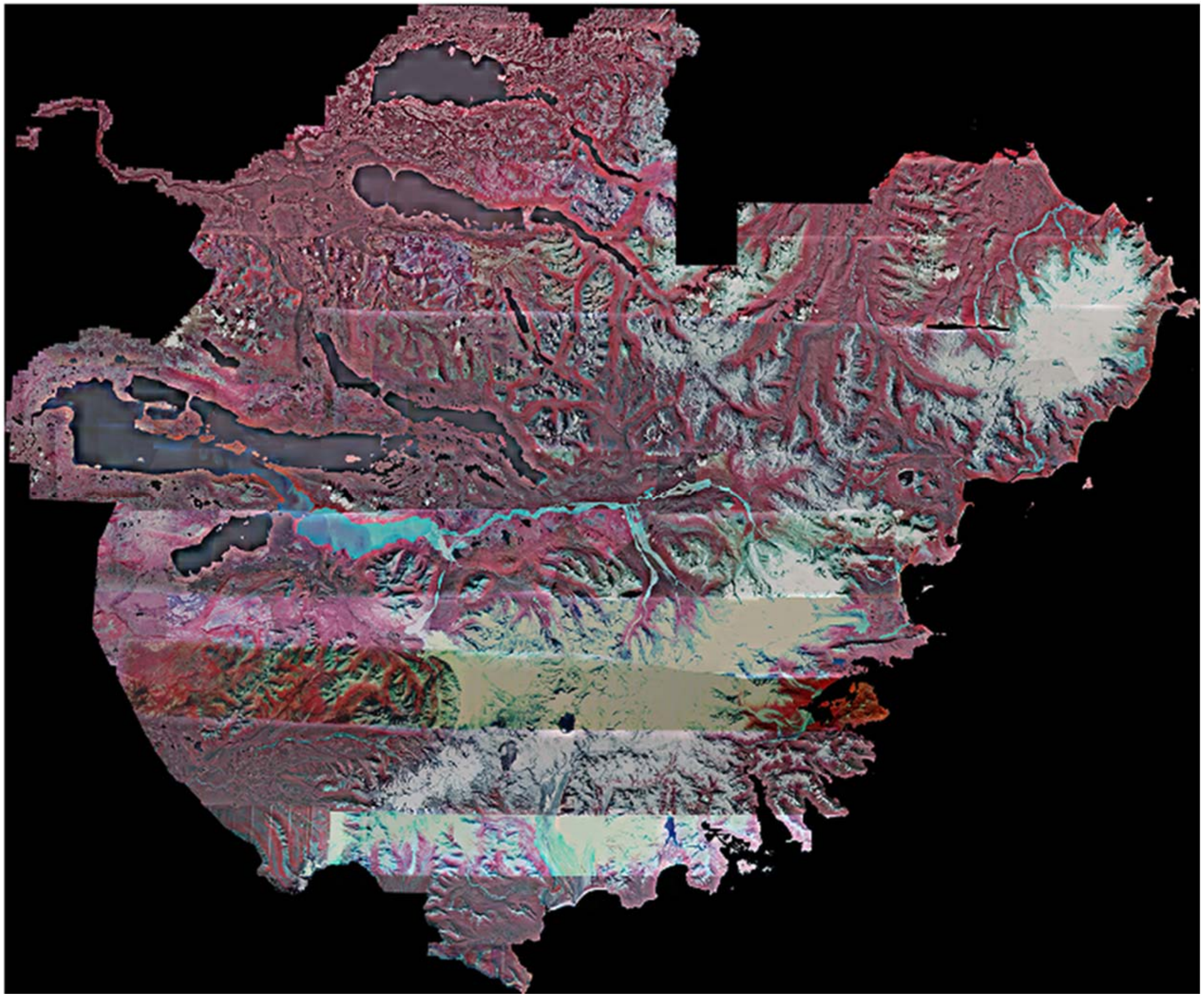

Figure 24. Complete mosaiced series of CIR 1980's images, KATM.

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National Park Service, Alaska Regional Office, National Park Service, Denver Service Center. (2009). Katmai National Park and Preserve Foundation Statement. Retrieved from http://www.nps.gov/katm/foundation_statement

National Park Service, Alaska Regional Office, National Park Service, Denver Service Center. (2009). Lake Clark National Park and Preserve Foundation Statement. Retrieved from http://nps.gov/lacl/foundation_statement

Appendix A - Camera Calibration Reports

(rev. 8-75)

USGS Report No. RT-R/512

United States Department of the Interior

GEOLOGICAL SURVEY
RESTON, VIRGINIA 22092

REPORT OF CALIBRATION March 26, 1979

of Aerial Mapping Camera

Camera type Wild Heerbrugg RC10
Lens type Wild Aviotar II
Nominal focal length 305 mm

Camera serial no. 1384
Lens serial no. AtII 4105
Maximum aperture f/4
Test aperture f/4

Submitted by
NASA Ames Research Center
Moffett Field, California 94035

Reference: Letter dated October 27, 1978 from Mr. Thomas R. Pochari

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 3500K.

I. Calibrated Focal Length: 304.960 mm

This measurement is considered accurate within 0.010 mm

II. Radial Distortion:

Field angle (degrees)	$\bar{D}_c$	D_c for azimuth angle 0° A-C	90° A-D	180° B-D	270° B-C
	μm	μm	μm	μm	μm
7.5	-1	0	-3	-2	-1
15	-1	3	-2	-5	2
22.5	1	-3	4	1	2

The radial distortion is measured for each of 4 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 micrometres and indicates the radial displacement of the image from its ideal position for the calibrated focal length. A positive value indicates a displacement away from the center of the field. These measurements are considered accurate within 5 μm.

(1 of 3)

III. Resolving power in cycles/mm   Area-weighted average resolution 42.7

Field angle:	0°	7.5°	15°	22.5°	30°	35°	40°
Radial lines	81	57	24	24			
Tangential lines	81	81	57	48			

The resolving power is obtained by photographing a series of test bars and examining the resulting 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 ten seconds of being parallel. This filter was used for the calibration.

V. Shutter Calibration

Indicated shutter speed	Effective shutter speed	Efficiency
1/200	6.00 ms = 1/170 s	77%
1/400	2.75 ms = 1/360 s	77%
1/600	1.75 ms = 1/570 s	77%
1/800	1.25 ms = 1/800 s	77%
1/1000	1.00 ms = 1/1000 s	77%

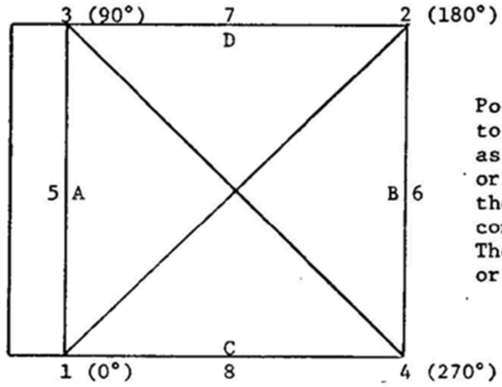
The effective shutter speeds were determined with the lens at aperture f/4 The method is considered accurate within 3%. The technique used is Method I described in American National Standard PH3.48-1972.

VI. Magazine Platen

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

(2 of 3)

VII. Principal Point and Fiducial Coordinates



Positions of all points are referenced to the principal point of autocollimation 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	-0.011 mm	-0.006 mm
Indicated principal point, midside fiducials	-0.009	-0.003
Principal point of autocollimation	0.0	0.0
Calibrated principal point (point of symmetry)	0.011	-0.002

Fiducial Marks		
1	-106.021 mm	-106.003 mm
2	105.999	105.991
3	-106.000	105.990
4	105.978	-106.003
5	-110.011	-0.007
6	109.987	0.002
7	0.002	109.992
8	-0.020	-110.008

VIII. Distances Between Fiducial Marks

Corner fiducials (diagonals)

1-2 299.823 mm 3-4 299.793 mm

Lines joining these markers intersect at an angle of 90° 00' 05"

Midside fiducials

5-6 219.998 mm 7-8 220.000 mm

Lines joining these markers intersect at an angle of 89° 59' 31"

Corner fiducials (perimeter)

1-3 211.993 mm 2-3 211.999 mm

1-4 211.999 mm 2-4 211.994 mm

The method of measuring these distances is considered accurate within 0.005 mm.
The report supersedes the previous calibration of this camera contained in USGS Report of Calibration No. RT-R/420, dated May 31, 1978.

William P. Tayman
Branch of Research and Design
Topographic Division

(3 of 3)

United States Department of the Interior

GEOLOGICAL SURVEY
RESTON, VA. 22092

REPORT OF CALIBRATION
of Aerial Mapping Camera

March 18, 1983

Camera type: Wild RC 10
Lens type: Wild Aviotar II
Nominal focal length: 305 mm

Camera serial no.: 1470
Lens serial no.: AT II 4114
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 positive value indicates a displacement away from the center of the field. These measurements are considered accurate within 5 um.

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

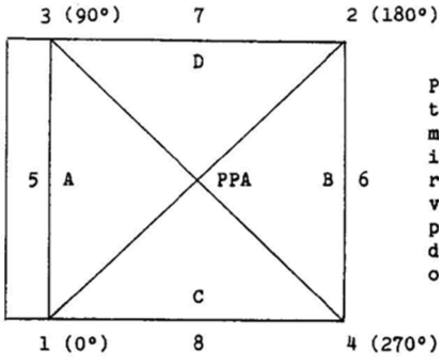
Indicated shutter speed	Effective shutter speed	Efficiency
1/200	4.50 ms = 1/220 s	72%
1/400	2.25 ms = 1/440 s	72%
1/600	1.50 ms = 1/670 s	72%

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



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	-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

USGS Report No. RSAS/939

United States Department of the Interior

GEOLOGICAL SURVEY
RESTON, VA. 22092

REPORT OF CALIBRATION
of Aerial Mapping Camera

February 2, 1984

Camera type: Wild RC10
Lens type: Wild Aviotar II
Nominal focal length: 305 mm

Camera serial no.: 1384
Lens serial no.: At II 4105
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 positive 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

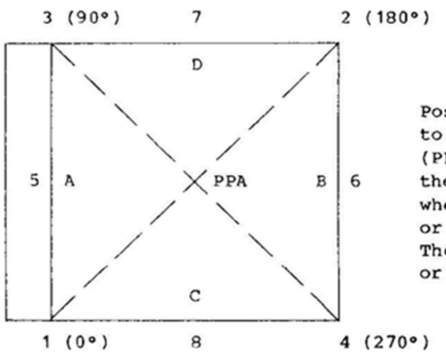
Indicated shutter speed	Effective shutter speed	Efficiency
1/200	4.50 ms = 1/220 s	75%
1/400	2.25 ms = 1/440 s	75%
1/600	1.58 ms = 1/630 s	75%
1/800	1.19 ms = 1/840 s	75%
1/975	0.95 ms = 1/1050 s	75%

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).

VII. Principal Point and Fiducial Coordinates



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		
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
Chief, Optical Science Section
National Mapping Division

(3 of 3)

Form 9-1780
Rev. 8-75)

USGS Report No. RT-R/382

United States Department of the Interior

GEOLOGICAL SURVEY
RESTON, VIRGINIA 22092

REPORT OF CALIBRATION

January 24, 1978

of Aerial Mapping Camera

Camera type Wild Heerbrugg RC10
Lens type Wild Aviotar II
Nominal focal length 304 mm

Camera serial no. 1758
Lens serial no. AtII 4114
Maximum aperture f/4
Test aperture f/4

Submitted by
NASA Ames Research Center
Moffett Field, California 94035

Reference: Letter dated January 20, 1978 from Mr. Thomas R. Pochari

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 3500K.

I. Calibrated Focal Length: 304.661 mm

This measurement is considered accurate within 0.010 mm

II. Radial Distortion:

Field angle (degrees)	$\bar{D}_c$	D_c for azimuth angle 0° A-C	90° A-D	180° B-D	270° B-C
	µm	µm	µm	µm	µm
7.5	-2	-5	-2	-4	1
15	-1	0	-1	-5	1
22.5	2	-1	4	0	3

The radial distortion is measured for each of 4 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 micrometres and indicates the radial displacement of the image from its ideal position for the calibrated focal length. A positive value indicates a displacement away from the center of the field. These measurements are considered accurate within 5 µm.

(1 of 3)

III. Resolving power in cycles/mm   Area-weighted average resolution 37.1

Field angle:	0°	7.5°	15°	22.5°	30°	35°	40°
Radial lines	81	68	16	14			
Tangential lines	81	68	57	48			

The resolving power is obtained by photographing a series of test bars and examining the resulting 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	4.2 ms = 1/240 s	74%
1/400	2.1 ms = 1/470 s	74%
1/600	1.4 ms = 1/710 s	74%
1/800	1.1 ms = 1/940 s	72%
1/1000	0.9 ms = 1/1170 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.

VI. Magazine Platen

The platen mounted in Wild RC10 film magazine No. 1758-139 does not depart from a true plane by more than 13 μm (0.0005 in).

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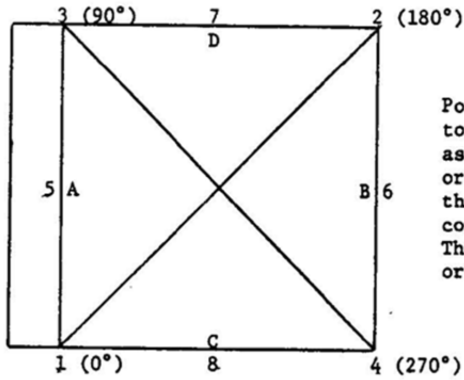
VII. Principal Point and Fiducial Coordinates



Positions of all points are referenced to the principal point of autocollimation 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	0.006 mm	-0.011 mm
Indicated principal point, midside fiducials	0.006	0.016
Principal point of autocollimation	0.0	0.0
Calibrated principal point (point of symmetry)	0.004	-0.001

Fiducial Marks		
1	-105.987 mm	-106.016 mm
2	105.991	105.986
3	-105.995	105.985
4	106.016	-106.016
5	-109.978	-0.014
6	109.985	-0.017
7	0.003	109.985
8	0.009	-110.013

VIII. Distances Between Fiducial Marks

Corner fiducials (diagonals)
1-2 299.799 mm   3-4 299.821 mm
Lines joining these markers intersect at an angle of 89° 59' 53"

Midside fiducials
5-6 219.962 mm   7-8 219.998 mm
Lines joining these markers intersect at an angle of 90° 00' 09"

Corner fiducials (perimeter)
1-3 212.001 mm   2-3 211.986 mm
1-4 212.002 mm   2-4 212.002 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/105, dated August 16, 1974.

William P. Tayman
Branch of Research and Design
Topographic Division

(3 of 3)

(rev. 8-75)

RT-R/420

United States Department of the Interior

GEOLOGICAL SURVEY
RESTON, VIRGINIA 22092

REPORT OF CALIBRATION May 31, 1978

of Aerial Mapping Camera

Camera type Wild Heerbrugg RC10
Lens type Wild Aviotar II
Nominal focal length 304 mm

Camera serial no. 1384
Lens serial no. AtII 4105
Maximum aperture f/4
Test aperture f/4

Submitted by
NASA Ames Research Center
Moffett Field, California 94035

Reference: Letter dated January 20, 1978 from Mr. Thomas R. Pochari

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 3500K.

I. Calibrated Focal Length: 304.956 mm

This measurement is considered accurate within 0.010 mm

II. Radial Distortion:

Field angle (degrees)	$\overline{D}_c$	D_c for azimuth angle 0° A-C	90° A-D	180° B-D	270° B-C
	µm	µm	µm	µm	µm
7.5	-3	-5	-2	-4	-1
15	0	1	1	-5	2
22.5	1	-6	7	-4	7

The radial distortion is measured for each of 4 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. $\overline{D}_c$ 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 micrometres and indicates the radial displacement of the image from its ideal position for the calibrated focal length. A positive value indicates a displacement away from the center of the field. These measurements are considered accurate within 5 µm.

(1 of 3)

III. Resolving power in cycles/mm   Area-weighted average resolution 42.7

Field angle:	0°	7.5°	15°	22.5°	30°	35°	40°
Radial lines	81	57	24	24			
Tangential lines	81	81	57	48			

The resolving power is obtained by photographing a series of test bars and examining the resulting 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 ten seconds of being parallel. This filter was used for the Calibration.

V. Shutter Calibration

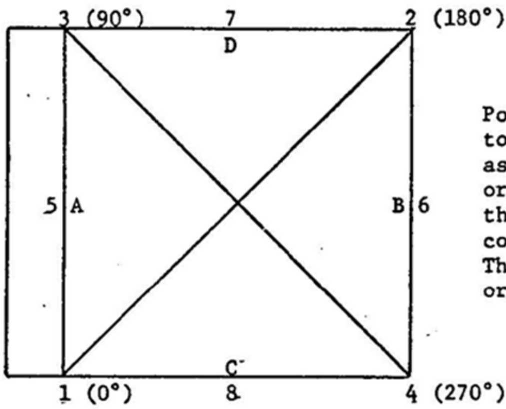
Indicated shutter speed	Effective shutter speed	Efficiency
1/200	4.2 ms = 1/240 s	74%
1/400	2.1 ms = 1/470 s	74%
1/600	1.4 ms = 1/710 s	74%
1/800	1.1 ms = 1/940 s	72%
1/1000	0.9 ms = 1/1170 s	72%

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.

VI. Magazine Platen

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

VII. Principal Point and Fiducial Coordinates



Positions of all points are referenced to the principal point of autocollimation 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	-0.015 mm	-0.005 mm
Indicated principal point, midside fiducials	-0.016	-0.002
Principal point of autocollimation	0.0	0.0
Calibrated principal point (point of symmetry)	0.022	-0.002
Fiducial Marks		
1	-106.017 mm	-106.003 mm
2	105.986	105.992
3	-106.010	105.992
4	105.982	-106.003
5	-110.017	-0.006
6	109.981	0.003
7	-0.014	110.004
8	-0.017	-110.007

VIII. Distances Between Fiducial Marks

Corner fiducials (diagonals)

1-2 299.812 mm 3-4 299.803 mm

Lines joining these markers intersect at an angle of 90° 00" 02"

Midside fiducials

5-6 219.998 mm 7-8 220.010 mm

Lines joining these markers intersect at an angle of 89° 59' 49"

Corner fiducials (perimeter)

1-3 211.994 mm 2-3 211.996 mm

1-4 211.998 mm 2-4 211.995 mm

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

The report supersedes the previous calibration of this camera contained in USGS Report of Calibration No. RT-R/64, dated April 18, 1974

William P. Tayman

William P. Tayman
Branch of Research and Design
Topographic Division

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(rev. 8-75) USGS Report No. RT-R/512

United States Department of the Interior

GEOLOGICAL SURVEY
RESTON, VIRGINIA 22092

REPORT OF CALIBRATION March 26, 1979

of Aerial Mapping Camera

Camera type Wild Heerbrugg RC10
Lens type Wild Aviotar II
Nominal focal length 305 mm

Camera serial no. 1384
Lens serial no. AtII 4105
Maximum aperture f/4
Test aperture f/4

Submitted by
NASA Ames Research Center
Moffett Field, California 94035

Reference: Letter dated October 27, 1978 from Mr. Thomas R. Pochari

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 3500K.

I. Calibrated Focal Length: 304.960 mm

This measurement is considered accurate within 0.010 mm

II. Radial Distortion:

Field angle (degrees)	$\bar{D}_c$	D_c for azimuth angle 0° A-C	90° A-D	180° B-D	270° B-C
	µm	µm	µm	µm	µm
7.5	-1	0	-3	-2	-1
15	-1	3	-2	-5	2
22.5	1	-3	4	1	2

The radial distortion is measured for each of 4 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 micrometres and indicates the radial displacement of the image from its ideal position for the calibrated focal length. A positive value indicates a displacement away from the center of the field. These measurements are considered accurate within 5 µm.

(1 of 3)

III. Resolving power in cycles/mm   Area-weighted average resolution 42.7

Field angle:	0°	7.5°	15°	22.5°	30°	35°	40°
Radial lines	81	57	24	24			
Tangential lines	81	81	57	48			

The resolving power is obtained by photographing a series of test bars and examining the resulting 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 ten seconds of being parallel. This filter was used for the calibration.

V. Shutter Calibration

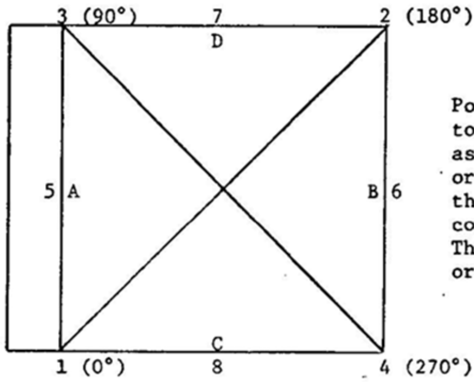
Indicated shutter speed	Effective shutter speed	Efficiency
1/200	6.00 ms = 1/170 s	77%
1/400	2.75 ms = 1/360 s	77%
1/600	1.75 ms = 1/570 s	77%
1/800	1.25 ms = 1/800 s	77%
1/1000	1.00 ms = 1/1000 s	77%

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.

VI. Magazine Platen

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

VII. Principal Point and Fiducial Coordinates



Positions of all points are referenced to the principal point of autocollimation 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	-0.011 mm	-0.006 mm
Indicated principal point, midside fiducials	-0.009	-0.003
Principal point of autocollimation	0.0	0.0
Calibrated principal point (point of symmetry)	0.011	-0.002

Fiducial Marks		
1	-106.021 mm	-106.003 mm
2	105.999	105.991
3	-106.000	105.990
4	105.978	-106.003
5	-110.011	-0.007
6	109.987	0.002
7	0.002	109.992
8	-0.020	-110.008

VIII. Distances Between Fiducial Marks

Corner fiducials (diagonals)

1-2 299.823 mm   3-4 299.793 mm

Lines joining these markers intersect at an angle of 90° 00' 05"

Midside fiducials

5-6 219.998 mm   7-8 220.000 mm

Lines joining these markers intersect at an angle of 89° 59' 31"

Corner fiducials (perimeter)

1-3 211.993 mm   2-3 211.999 mm

1-4 211.999 mm   2-4 211.994 mm

The method of measuring these distances is considered accurate within 0.005 mm.
The report supersedes the previous calibration of this camera contained in USGS Report of Calibration No. RT-R/420, dated May 31, 1978.

William P. Tayman
Branch of Research and Design
Topographic Division

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Appendix B – Example RMS and Metadata Reports

Single Space Resection for C:\KATMAI\SECTION_3\5820031221812\5820031221812.LAN

Number of points processed: 24

Ground Control Coordinates

Point Name	X	Y	Z
VC1	-67333.50	987281.50	500.04
VC2	-69010.00	985539.50	647.97
VC3	-64715.50	984945.50	526.35
VC4	-70126.00	987353.00	577.11
VC5	-68616.50	983836.50	679.00
VC6	-69309.50	989993.50	476.73
VC7	-68863.00	992182.00	489.95
VC8	-69474.50	994887.50	235.89
VC9	-67824.50	994610.50	257.41
VC10	-65106.00	993241.50	578.11
VC11	-60096.41	993293.06	818.04
VC12	-62047.41	992478.06	645.63
VC13	-61476.91	990690.06	622.79
VC14	-58830.41	989280.06	712.62
VC15	-62014.41	986461.06	736.68
VC16	-59551.41	986314.06	982.49
VC17	-59296.41	983264.06	779.12
VC18	-62854.41	983770.06	766.98
VC19	-61581.41	994473.06	783.87
VC20	-65443.41	991884.06	561.46

VC21	-63584.41	988900.06	689.69
VC22	-62555.41	987492.06	728.74
VC23	-65545.41	989414.06	574.71
VC24	-62514.91	991269.06	604.48

Photo Control Coordinates

Point Name	Column	Row	x	y	dR	dX	dY
VC1	3539.0	7373.0	-43.434	-35.960	0.0000	0.0010	0.0008
VC2	2332.0	8715.7	-68.831	-64.114	0.0000	0.0003	0.0003
VC3	5514.0	9005.0	-1.996	-70.286	0.0000	0.0000	0.0011
VC4	1468.0	7405.5	-86.941	-36.579	0.0000	0.0004	0.0002
VC5	2663.5	9963.5	-61.905	-90.324	-0.0000	-0.0001	-0.0002
VC6	2019.0	5454.0	-75.307	4.378	0.0000	0.0010	-0.0001
VC7	2290.0	3851.3	-69.567	38.018	0.0000	0.0008	-0.0005
VC8	1817.0	1953.7	-79.447	77.877	-0.0000	-0.0002	0.0002
VC9	3015.5	2110.0	-54.274	74.557	0.0000	0.0003	-0.0004
VC10	5014.5	2978.0	-12.307	56.270	0.0000	0.0003	-0.0012
VC11	8710.0	2780.0	65.329	60.313	0.0000	-0.0005	-0.0004
VC12	7277.5	3448.5	35.216	46.321	0.0000	-0.0008	-0.0010
VC13	7741.5	4738.5	44.924	19.222	0.0000	-0.0011	-0.0005
VC14	9726.0	5693.0	86.585	-0.879	0.0000	-0.0007	0.0000
VC15	7473.0	7845.0	39.191	-45.992	0.0000	-0.0008	0.0009
VC16	9331.0	7904.0	78.221	-47.289	0.0000	-0.0005	0.0003
VC17	9561.0	10121.0	82.987	-93.845	-0.0000	0.0006	-0.0007
VC18	6928.0	9860.0	27.683	-88.282	0.0000	-0.0002	0.0005

VC19	7581.0	1962.0	41.637	77.523	0.0000	-0.0003	-0.0006
VC20	4801.0	3971.0	-16.822	35.428	0.0000	0.0005	-0.0010
VC21	6248.0	6101.0	13.510	-9.337	0.0000	-0.0005	0.0003
VC22	7049.0	7107.0	30.306	-30.484	0.0000	-0.0008	0.0008
VC23	4792.0	5773.0	-17.065	-2.406	0.0000	0.0006	0.0001
VC24	6963.3	4344.7	28.590	27.515	0.0000	-0.0008	-0.0008

Mean Differenence in dX and dY: -0.0001 -0.0001

Standard Deviation in dX and dY: 0.0006 0.0007

Initial Approximations:

Omega = 0.000

Phi = 0.000

Kappa = -2.201

XL = -64490.5

YL = 989285.6

ZL = 20556.6

A solution has been found after 3 iterations
Standard Deviation of unit weight = 0.2074057

Omega = 0.37 (Degrees)

Phi = -1.08 (Degrees)

Kappa = -2.01 (Degrees)

XL = -64806.0

YL = 989407.3

ZL = 20439.4

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

10.30715					
-3.08781	11.52401				
0.31399	-0.30283	0.31181			
-62.74891	235.66946	-6.26680	4827.151		
-210.64400	62.48836	-6.39355	1269.749	4312.476	
3.45477	-1.06750	0.10522	-23.578	-69.547	118.111

Standard Deviation for Omega: 662.21 (Seconds)

Standard Deviation for Phi: 700.21 (Seconds)

Standard Deviation for Kappa: 115.18 (Seconds)

Standard Deviation for XL: 69.48 (Meters)

Standard Deviation for YL: 65.67 (Meters)

Standard Deviation for ZL: 10.87 (Meters)

Residuals for the points entered

Point ID	Cols	Rows
VC1	-7.96	-7.48
VC2	-8.77	-10.45
VC3	-6.58	-10.10
VC4	-13.31	-8.35
VC5	-8.55	-15.16
VC6	-13.57	1.22

VC7	-11.54	7.75
VC8	-12.12	18.40
VC9	-10.10	17.43
VC10	0.20	9.95
VC11	15.41	5.73
VC12	8.54	6.66
VC13	10.68	4.08
VC14	15.53	0.33
VC15	5.50	-7.02
VC16	7.94	-11.50
VC17	6.53	-11.87
VC18	0.81	-7.35
VC19	11.74	13.05
VC20	-3.22	2.44
VC21	2.03	1.32
VC22	7.39	-0.92
VC23	-2.79	-2.01
VC24	5.65	4.94

Col RMS = 9.24

Row RMS = 9.24

Appendix C - Example Final Image Metadata Report

5780026164796_ORTHO.TIF

Raster Dataset

Thumbnail Not Available

Tags

Digital Georectified Image, Orthorectified Image, Orthorectification, Georeferenced Image, Land Cover, Color Infrared Photography

Summary

The orthorectified aerial photo imagery for Lake Clark 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.

Description

This data set contains digital aerial photo imagery of Lake Clark National Park in Alaska. The imagery was procured from air photo flying missions conducted by the NASA Ames Research Center in 1978 and 1980 . The photo immulsion is color infra-red and the scale of the final hardcopy photo print products is +/- 1:63000. Scanned digital imagery at a resolution of 1200 dpi was provided by the National Park Service to Saint 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 30 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, acquired Landsat 7 (panchromatic) imagery and a digital elevation model derived from a combination of the IKONOS DEM data and ASTER data was used for orthorectification. The final output orthorectified images are 8 bit, multi-band TIFF format image files. See data quality notes for more information.

Credits

Saint Mary's University of Minnesota, GeoSpatial Services.

Use limitations

Usage constraints are imposed by the National Park Service, Anchorage Alaska. Please see contact information for more details.

ArcGIS Metadata ▶

Topics and Keywords ▶

* CONTENT TYPE Downloadable Data

Hide Topics and Keywords ▲

Citation ▶

* TITLE 5780026164796_ORTHO.TIF

PRESENTATION FORMATS * digital map

NPS 188/124370. 127/124370, April 2014

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U.S. Department of the Interior

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