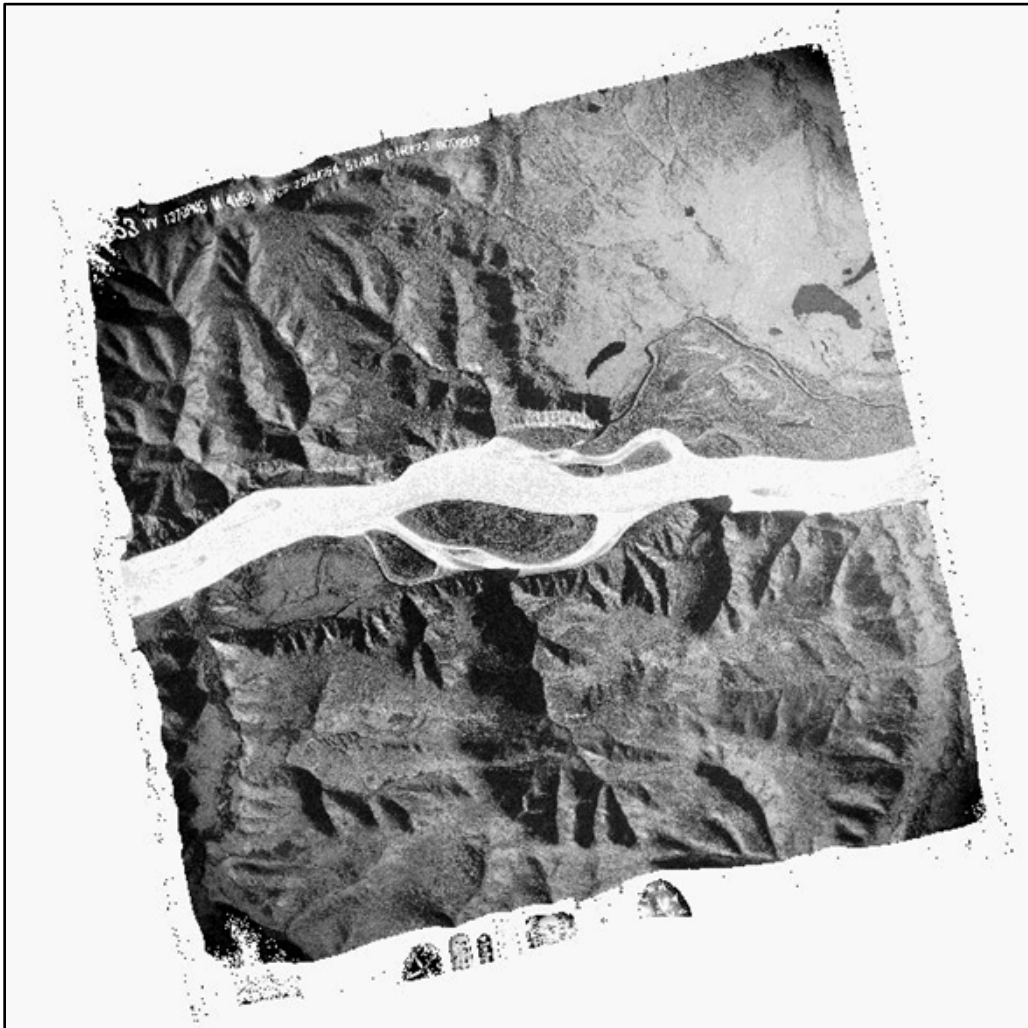




# Orthorectification of Historic Imagery for Yukon Charley Rivers National Preserve

## *Final Report*

Natural Resource Report NPS/CAKN/NRTR-2014/TBD



# **Orthorectification of Historic Imagery for Yukon-Charley Rivers National Preserve**

## *Final Report*

Natural Resource Report NPS/CAKN/NRTR—2014

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Natural Resource Stewardship and Science  
Fort Collins, Colorado

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## Contents

	Page
List of Figures .....	v
Appendixes .....	vi
Abstract .....	vii
Acknowledgments.....	viii
List of Acronyms .....	ix
Introduction.....	1
Study Area .....	3
Methods - Orthorectification.....	5
Results and Discussion .....	11
Literature Cited .....	17

## List of Figures

<b>Figure 1.</b> Photo characteristics and scan resolution for images acquired for YUCH. ....	1
<b>Figure 2.</b> Map of the Yukon-Charley Rivers National Preserve.....	4
<b>Figure 3.</b> Footprints of 1950's black and white scanned photos.....	6
<b>Figure 4.</b> Footprints of 2006-2007 YUCH CIR orthomosaics .....	7
<b>Figure 5.</b> Composite DEM used to orthorectify photos extending over the park boundary .....	9
<b>Figure 6.</b> Sample orthorectified image of areas with larger changes in topographic relief. ....	14
<b>Figure 7.</b> Sample of a typical 1950's black and white orthorectified image .....	15
<b>Figure 8.</b> Missing data resulting from poor overlap between adjacent photographs. ....	16

## List of Appendixes

	Page
Appendix A: Sample Root Mean Square (RMS) Error Report .....	18
Appendix B: Sample 1950's orthorectified image FGDC compliant metadata .....	21

## Abstract

Historical imagery is an important asset in 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 aerial photographs for Yukon-Charley Rivers National Preserve (YUCH) are cataloged as frame by frame orthorectified images for the time period of the 1950's.

With the advent of remote sensing and geographic information system (GIS) technologies it is possible to convert historical hard-copy aerial imagery into digital format. The resulting digital products can then be cataloged as either individual frames or seamless mosaic images. The series of steps executed to complete the digital conversion process include:

- Pre-processing;
- Georeferencing;
- Orthorectification;
- Validation through quality assurance and quality control assessments.

For this project, the Central Alaska Network (CAKN) and other Alaska Region NPS staff worked cooperatively with Saint Mary's University of Minnesota (SMUMN) to compile and catalog a circa 1950 image base for YUCH through the use of georeferencing and orthorectification processes. This project also provided student geospatial technicians with the opportunity to learn how to convert data, georeference, orthorectify, and color balance historical imagery. The creation of final products gave students hands on experience while all quality assurance procedures were carefully conducted by senior staff.

The orthorectified image products are now available to the preserve and permit digital comparison with newly acquired imagery bases where available (e.g., IKONOS, SPOT 5). Assessments of this imagery may beneficially serve to facilitate informed resource management decisions throughout YUCH.

## **Acknowledgments**

The authors extend appreciation to Maggie MacCluskie for serving as Technical Representative for the Central Alaska Network of the National Park Service and Jeffrey Knopf, Senior GIS Analyst for GeoSpatial Services of Saint Mary's University of Minnesota for extensive contributions to the development of this project. Recognition also goes to student geospatial technicians, Kyle Good and Dave Johnson who contributed to this project and to Bonnie Maffitt for the editing and formatting of this report. This report was completed in fulfillment of requirements for Pacific Northwest CESU Task Agreement P11AC91177.



## List of Acronyms

AHAP – Alaska High Altitude Aerial Photography Program

ASTER – Advanced Spaceborne Thermal Emission and Reflection satellite

CAKN – Central Alaska Area Network

CIR – Near infrared imagery

DEM – Digital elevation model

DOQQ – Digital ortho quarter quad

DPI – Dots per inch

DRG – Digital raster graphic

ESRI – Environmental Systems Research Institute

GIS – Geographic information systems technologies

GPS – Global positioning system

I&M – Inventory and Monitoring

NASA – National Aeronautical and Space Administration

NMAS – National map accuracy standards

NPS – National Park Service

RMS – Root mean square error

SMUMN – GeoSpatial Services of Saint Mary’s University of Minnesota

SRTM – Shuttle Radar Topography Mission of 1999

USGS – United States Geological Survey

YUCH – Yukon-Charley Rivers National Preserve

# Introduction

The Central Alaska Area Network (CAKN), 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 CAKN and to facilitate general resource management decisions in the parks.

In YUCH there is a 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. 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 project in which historical black and white air photos were orthorectified to a circa-1950 base image for YUCH.

The Central Alaska Area Network worked cooperatively with Saint Mary’s University of Minnesota (SMUMN) to complete orthorectification of hardcopy aerial photographs from the 1950’s (**Figure 1**). 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 YUCH. This project also provided student technicians at Saint Mary’s University of Minnesota with 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.

## Historic 1950’s Black and White Scanned Imagery Specifications

Park	Year(s)	Emulsion	Scale	No. photos	Scan resolution
YUCH	1951-55	B/W	1:40,000	456	1800 dpi

**Figure 1.** Photo characteristics and scan resolution for images acquired for YUCH. Emulsion: B/W=black and white.

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  $\pm 20$ -30 meters (m) when compared to the control orthoimagery, thus meeting the National Map Accuracy Standard (NMAS) for 1:63,360 scale mapping ( $\pm 32$ m). Registration of the YUCH 1950's photo series to high resolution CIR orthorectified imagery as part of this Task Agreement required additional control due to the terrain that was present in these photographs. NPS worked cooperatively with SMUMN to identify and resolve problems associated with processing over the course of the project.

The NPS provided SMUMN with digital color infrared (CIR) orthorectified image mosaics created by Aerometric Inc. Aerial photography used to create these mosaics was acquired in 2006 and 2007 with a pixel resolution of one meter and these provided the base cartographic reference for historical 1950's photo orthorectification in YUCH.

## Study Area

Located in the central interior of Alaska, the project area included all of the Yukon-Charley Rivers National Preserve ( **Figure 2**). Established in 1980 under the Alaska National Interest Lands Conservation Act (Public Law 96-487), YUCH contains in excess of 1.7-million acres of wild and scenic river basins. Located between the Brooks and Alaska mountain ranges, the elevation of the preserve ranges from approximately 600 to 6,000 feet. Two primary climate zones are found within the preserve; sub arctic for portions of the preserve located in lower elevations, and arctic for areas of the preserve located at higher elevations.

YUCH is managed to preserve its undeveloped natural condition for scientific study, habitat protection, as well as historical sites, and geological and paleontological history (Public Law 96-487). The Charley River watershed in East Central Alaska remains a critical habitat for caribou, Dall sheep, wolves, peregrine falcons, moose, and grizzly bear (Public Law 96-487). The entire YUCH preserve includes approximately 115 miles of the Yukon River and 88 miles of the Charley River as well as related rivers, streams, wetlands and lakes.

Historical aerial photography captured in Alaska during the 1950s provides a visual record of conditions in the YUCH preserve throughout time. These photos are a valuable source of information regarding vegetation and landform conditions that can be assessed against current imagery in order to examine processes that are impacting the landscape. 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 processes;
- Climate change studies.

# Yukon-Charley Rivers National Preserve

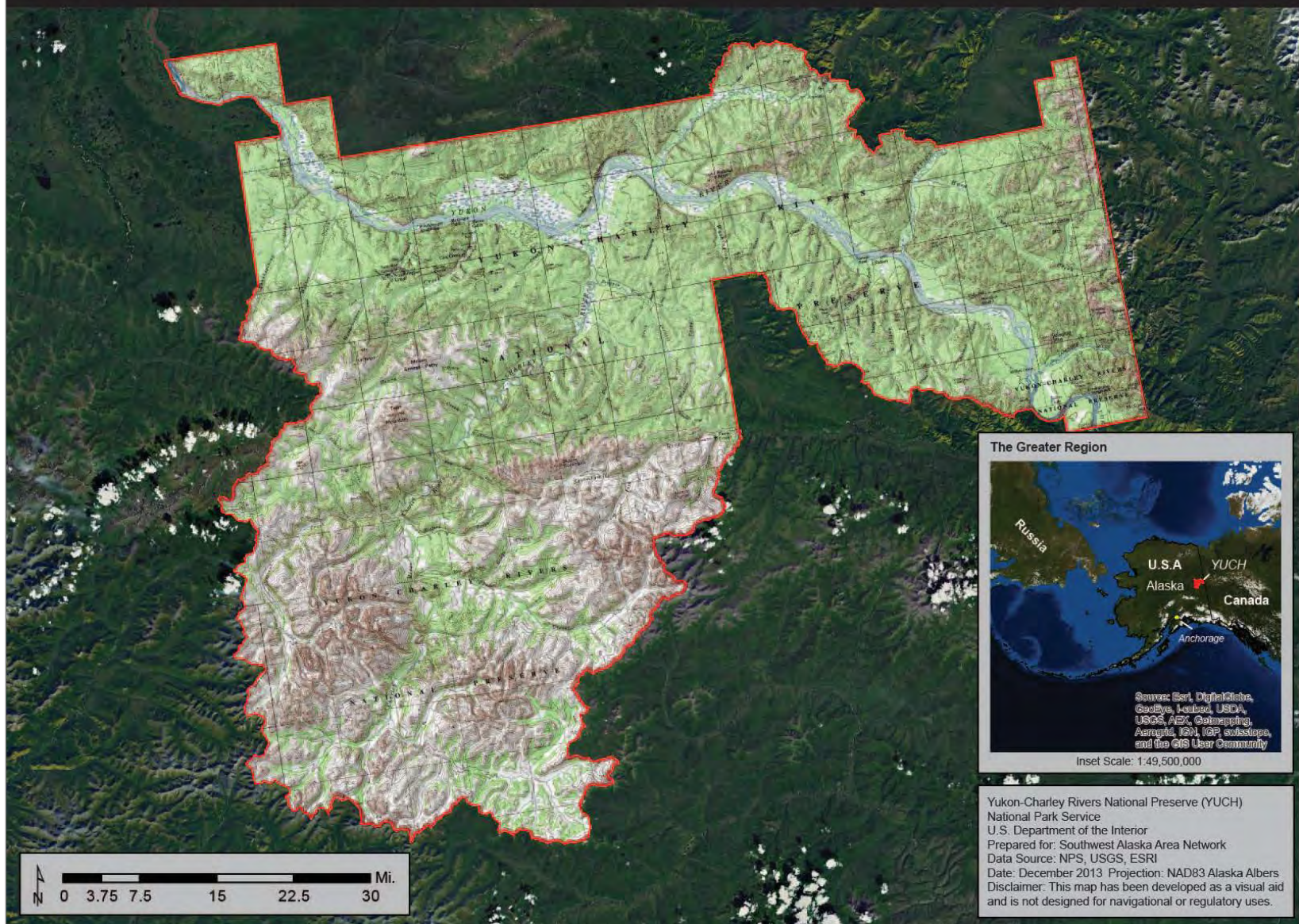


Figure 2. Map of the Yukon-Charley Rivers National Preserve.

## Methods - Orthorectification

The digital conversion process employed for this project consisted of the orthorectification of scanned hard copy aerial photos acquired during the 1950's. These photos were acquired as a black and white emulsion at a scale of 1:40,000 by the NASA Jet Propulsion Library between 1951 and 1955. Complete image coverage existed for the entire preserve.

### 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 was completed by U.S. Geological Survey (USGS) (**Figure 3**). Digital images produced from the scanning process were provided to SMUMN in Tagged Image Interchange Format (TIFF). The scanning resolution was 14 microns or 1800 dots per inch (DPI).

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

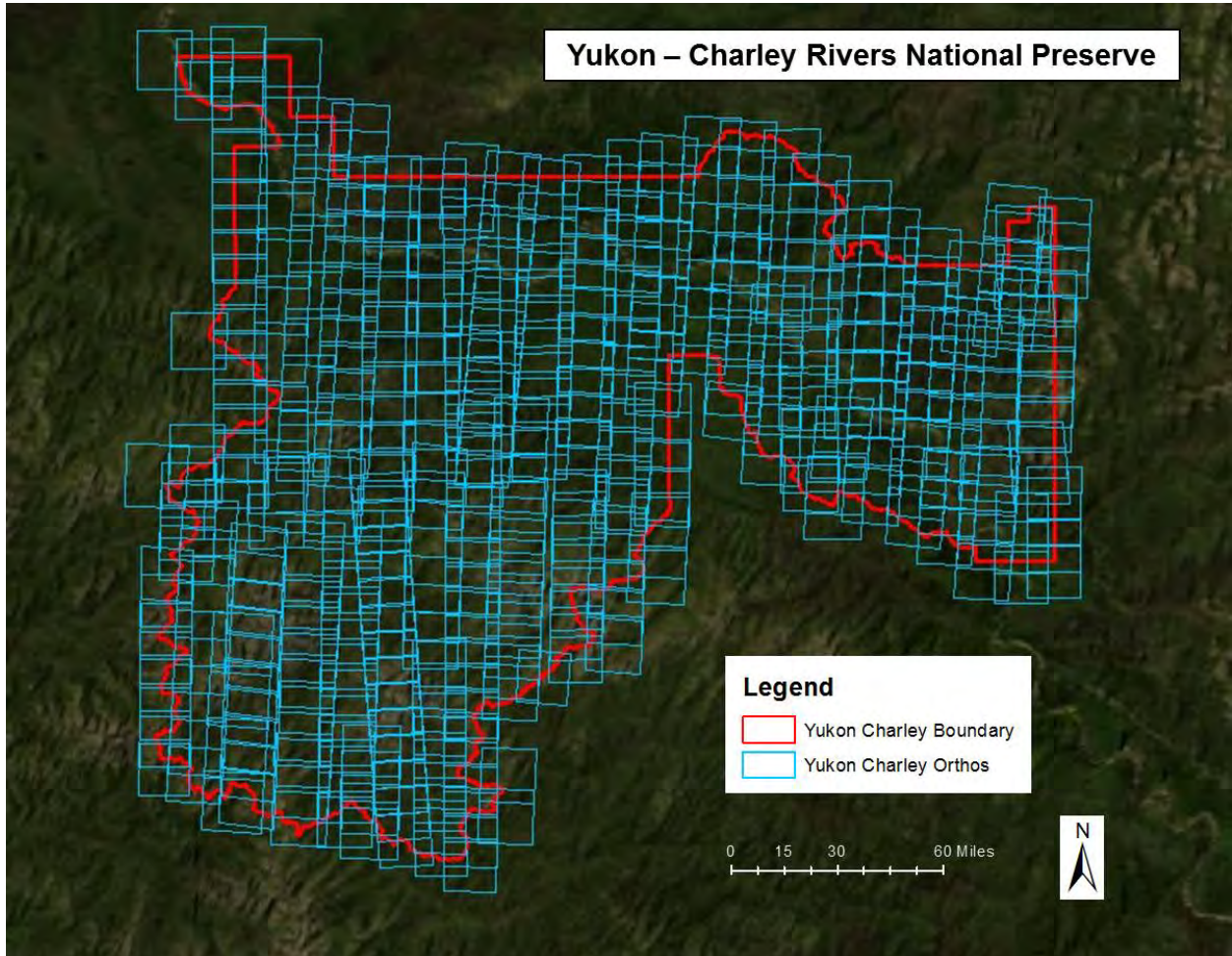
- Scan resolution: 14 micron (1800 dpi)
- Pixel Depth: 8 bit
- File Format: TIFF
- Band Format: Single band for black and white images

### Base Layers for Georeferencing

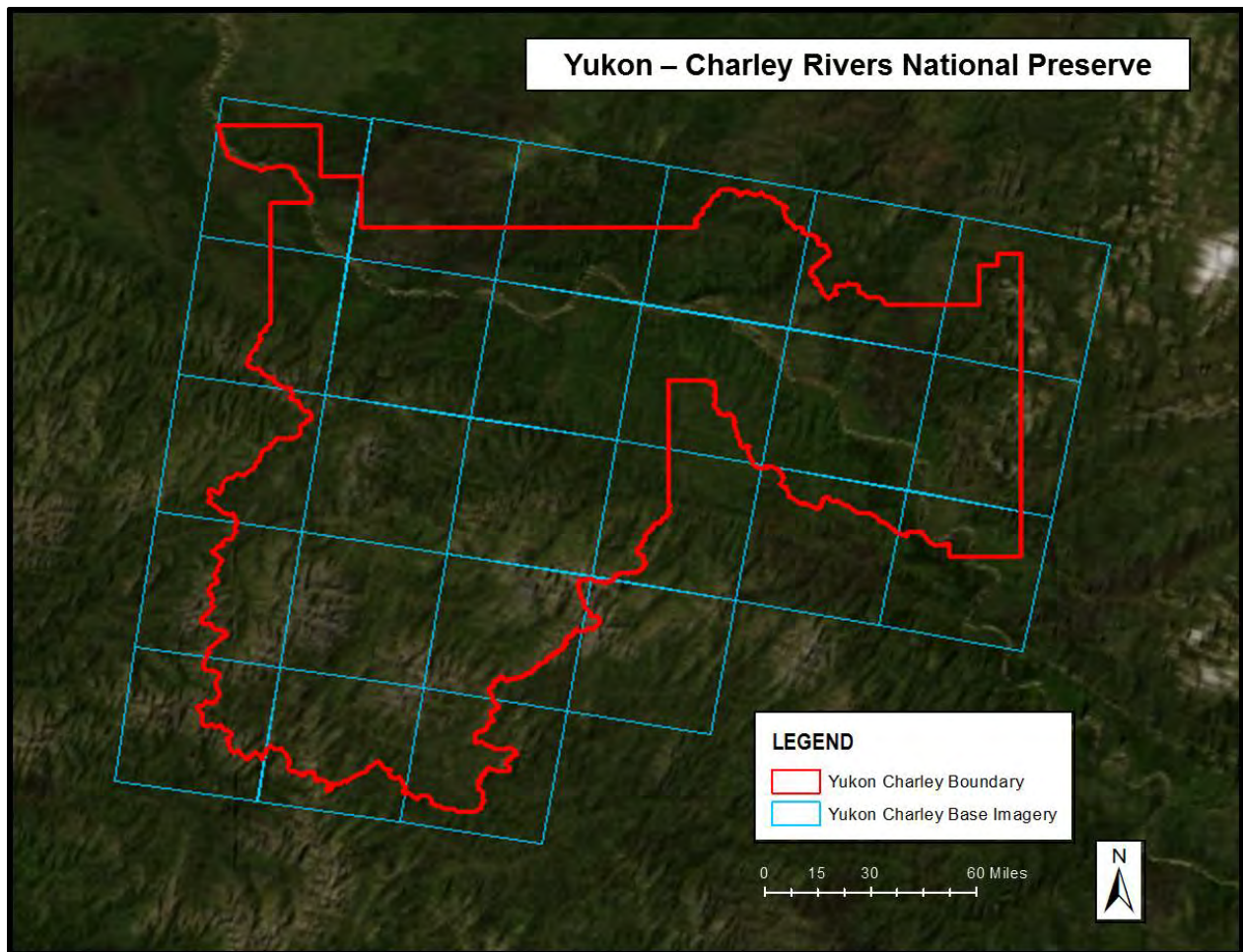
Once the historic aerial photography had been scanned, the next step in the digital conversion process was to georeference the scanned images. Georeferencing or photogrammetric control is the process by which known ground control points are used to provide geographic reference for point on a scanned aerial image or graphic. This process involves selecting ground control points from a digital map reference layer; identifying those same points and associated features 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 global positioning system (GPS) derived ground control points were available for use in the georeferencing; all control points were taken from the reference imagery.

The base data used for georeferencing on this project were one meter resolution digital color infrared (CIR) orthomosaics created from 2006 and 2007 aerial photography (**Figure 4**). The orthomosaics were created by Aerometric Inc. and made available to SMUMN by the NPS. The optimum data source was selected based on availability, accuracy and resolution.

Unfortunately, the 2006-2007 CIR orthomosaic imagery was clipped tightly to the park administrative boundary. As a result, this data only provided a georeferencing solution for photos that were contained entirely within the YUCH boundaries. For photos that extended beyond the preserve, a lower accuracy base layer, Landsat 7 panchromatic, was used for georeferencing. This secondary base layer was used very sparingly as it was not only less accurate, with a resolution of 15 meters, but it also resulted in decreased horizontal accuracy within the final product.



**Figure 3.** Footprints of 1950's black and white scanned photos.



**Figure 4.** Footprints of 2006-2007 YUCH CIR orthomosaics.

For every photo, a text file was generated in order to document the approximate error of the georeferencing process. Root Mean Square (RMS) error was the metric that was used to describe differences between locations that have been digitally assigned on two scanned images and estimate spatial accuracy. Typical RMS errors for areas georeferenced to the 2006-2007 CIR orthomosaic imagery were between 6 and 12 meters. Areas that were georeferenced using the Landsat 7 in conjunction with CIR orthomosaic's typically had RMS errors of between 15 and 20 meters. In some cases, where scanned photos were dominated by ice fields, mountains or water, or cloud cover 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) and projected to the Alaska Albers coordinate system for delivery. The specifications used for this map projection were as follows:

```
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]]
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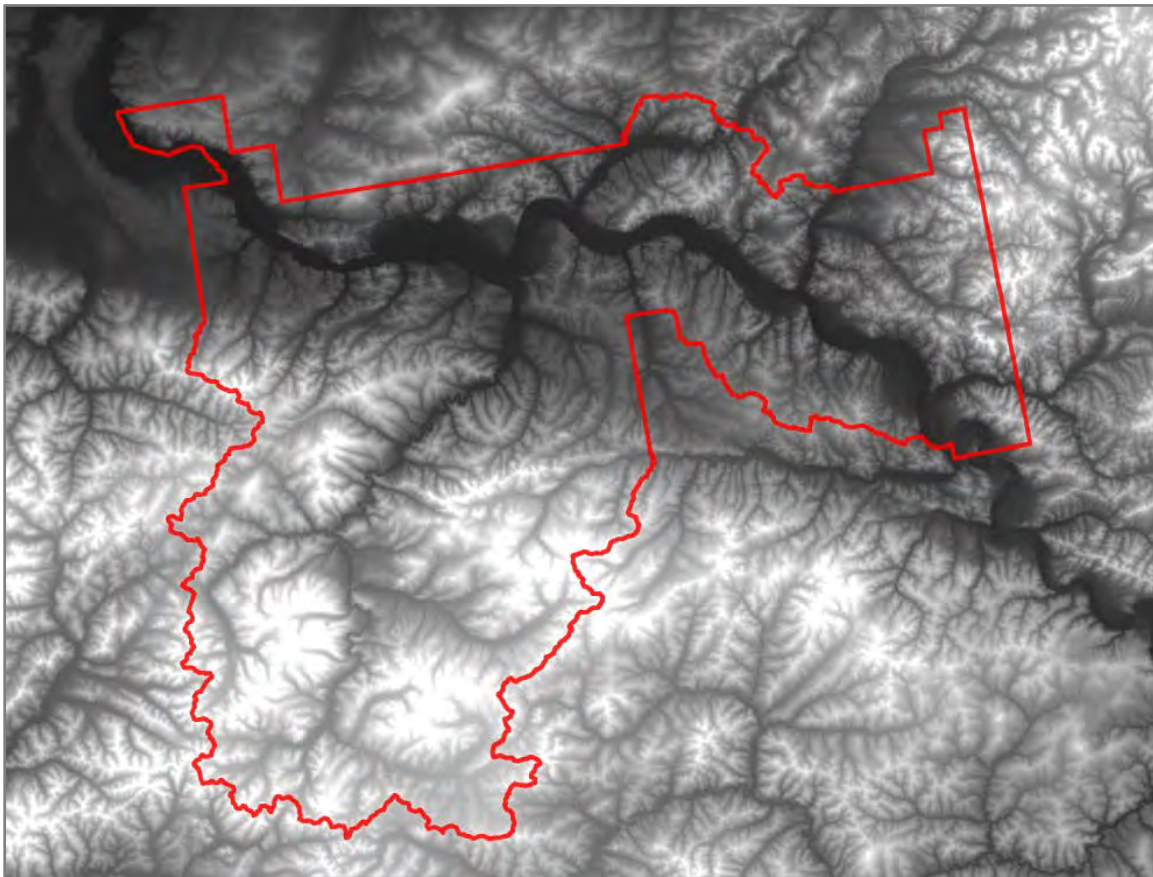
### Orthorectification

The final step in the digital conversion process was to orthorectify the scanned and georeferenced aerial photographs. Orthorectification was the process by which a digital elevation model (DEM) and camera calibration reports were used to correct image displacement caused by terrain 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 was a digital elevation model (**Figure 5**). 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 2006-2007 CIR orthomosaic imagery provided by NPS, there was also a high resolution DEM that was built by Aerometric Inc. for the orthorectification of the 2006-2007 color infrared (CIR) orthomosaic imagery. The 2007 YUCH DEM had a resolution of 10 meters and was also clipped tightly to the park boundary. Given that the 2007 YUCH DEM was limited in its coverage to a tightly clipped boundary along the park administrative boundary, other DEM products were required to orthorectify photos that fell outside of the park. The secondary digital elevation model used was a 30 meter resolution model derived from NASA's Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) satellite.

Where aerial photos extended beyond the high resolution 2007 YUCH DEM a no data strip (clipping) occurred at the DEM edge during the orthorectification process. To resolve missing DEM coverage issues SMUMN merged together ASTER (re-sampled to 10 meter using nearest neighbor processing) with the 2007 YUCH DEM to create the composite DEM and extend the elevation data beyond the edge of the project boundary. The high resolution 2007 YUCH DEM, where present, took precedence over the lower accuracy ASTER DEM. All of the calculations and processes used to create this composite DEM were executed in ArcGIS 10.0 using the Spatial Analyst extension. As a final step, the composite DEM was converted to TIFF format, projected to Alaska Albers (using the projection definition above) and then converted to a DEM format for use in the orthorectification software.



**Figure 5.** Composite DEM used to orthorectify photos extending over the YUCH park boundary.

The software package used for orthorectification on this project was OrthoMapper ver. 5.1.9 from Image Processing Software Inc. OrthoMapper has shown that, for processing large amounts of data (e.g. hundreds of scanned aerial photos); OrthoMapper provided a more appropriate environment for larger production work flows.

With OrthoMapper, individual project folders were created for each photo. When camera calibration information was used it only needs to be entered once and the camera report file generated was used for every photo associated with it. Whereas in other software camera report information needed to be entered for each photo. There were several benefits to using OrthoMapper including:

- 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. Senior staff educated student technicians on all quality control procedures. During the georeferencing phase, the amount of error associated with the selection of individual control points was monitored. Points that had too much error were eliminated from the final rectification. An average of 15 to 20 control points were chosen per photo in order to ensure that spatial correlation was representative of the image base.

A second, quality control review was conducted by senior staff on every photo following the orthorectification process. This review was completed in digital form using GIS software to display the orthorectified photo on top of the base layer that was used for deriving the control points that were applied 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 orthorectified photo. These shifts typically ranged from 2 to 35 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.

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 2007 YUCH DEM. If photos were completely within the boundaries of the 2007 YUCH DEM then only the high quality DEM was used for orthorectification. Student technicians, with staff oversight, had the opportunity to conduct post processing on orthorectified images. This expanded student's knowledge to include processes and tools for creating spatial information and metadata.

## Results and Discussion

Final products completed for the YUCH orthorectification project include the following:

- 456 scanned aerial photos per above-mentioned specifications;
- Orthorectified aerial photos delivered as 8 bit pixel depth, 1 meter pixel resolution, TIFF format files. These files all included OGC compliant metadata created with the Environmental Systems Research Institute (ESRI) ArcGIS 10.0 metadata editor following the Federal Geographic Data Committee (FGDC) STD-001-1998 standard;
- Text reports for each orthorectified photograph summarizing the average horizontal RMS error inherent in the rectification process (**Appendix A**);
- The orthorectification products include: OGC compliant metadata created with the ESRI ArcGIS 10.0 metadata editor employing FGDC-STD-001-1998 (**Appendix B**).

The intention of this project was to develop a digital library of historic aerial photographs that were georeferenced, orthorectified, and available for comparison and evaluation with current imagery. SMUMN senior staff and student geospatial technicians developed 456 scanned black and white photos for YUCH. The digital product meets the 1:63,360 National Map Accuracy Standard of  $\pm 32$  meters horizontal accuracy for areas where the 2007 YUCH DEM and 2006-2007 color infrared (CIR) orthomosaic imagery was available.

The use of a higher quality DEM in the orthorectification process generally led to horizontal RMS errors of between 6 and 15 meters. Additionally, 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 YUCH where the Landsat image was used for georeferencing, and in areas where the composite DEM was used for orthorectification, horizontal accuracy ranged between 15 and 40 meters.

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

- The number of control points used,
- The displacement of the control points over the surface of the image, or RMS,
- The resolution of the DEM,
- The extent of the DEM,
- The quality of the composite DEM (where it was used),
- The accuracy and quality of the base layer imagery,
- The quality of the input aerial photo (e.g., cloud covered, shadows, scratches, and warp),
- Deviations from ideal flight lines and non-addressable variations caused by the roll, pitch, and yaw of the aircraft and or camera platform,
- The topographic variation of the photo (i.e. significant change in topographic relief and landscape characteristics over short distances),
- The ability of computer software to perform increasingly complex transformations,
- The non-existence of camera calibration reports,
- 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. Issues appeared to occur most commonly towards the outer edges and corners of orthorectified photos and in areas of significant topographic relief. Speculation suggested that these photos probably contained a significant amount of radial displacement and lens aberration caused by the older camera technology employed during photo acquisition. Additionally, having no camera calibration reports available for camera lens adjustment during orthorectification added to the smearing effect.

Other challenges experienced in the orthorectification process included: the ability of computer software to perform complex spatial transformations; the existence and completeness of camera calibration reports; and anomalies present within individual aerial photographs such as: lens aberrations; lack of fiducials; and tilt displacement.

Unfortunately camera calibration reports were not available for the YUCH 1950's historical photos. These reports, created by the USGS as part of the pre-mission quality assurance process, contain correction information that is 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. These reports also help limit distortion caused by topographic and landscape variations, aircraft anomalies caused by shifts in the roll, pitch, and yaw, as well as aberrations such as dust, haze, and glare present in the camera's lens at time of acquisition.

Another consideration for shifting in the orthorectification was the topography of YUCH Preserve. For YUCH, topographic impacts were relatively minimal as changes in elevation occurred more gradually than in some other Alaskan parks such as Lake Clark National Park and Preserve (LACL), Katmai National Park and Preserve (KATM), Kenai Fjords National Park (KEFJ), and Denali National Park and Preserve (DENA). In general, increased topographic variation within short horizontal distances equates to reduced horizontal accuracy on the orthorectified image product because of the variety of adjustments that are necessary to stretch a flat aerial image over an undulating surface. Shifting due to topography in YUCH was minimal as a result of the rolling nature of the terrain (**Figure 6, Figure 7**).

In a minimal number of areas, there were photos in this project that extended beyond the high resolution DEM coverage. Where this occurred, the photos were clipped at the edge of the DEM boundary and any portion of the image data that extended beyond the DEM was dropped. As a result, these photos appear either reduced in size or incomplete and required that a composite DEM be created from lower resolution sources in order to extend the project study area. For future projects this issue may be resolved by limiting the size of the project study area to only those areas with complete DEM coverage, unless there is acceptance that these orthorectified photos will be less accurate. Preference should be given to project areas where complete base imagery and a corresponding DEM are available. This will ensure accuracy in the final orthorectified product.

Student technicians contributed to the many aspects of the project. Typically the main role for student 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 6.** Sample orthorectified image of areas with larger changes in topographic relief.

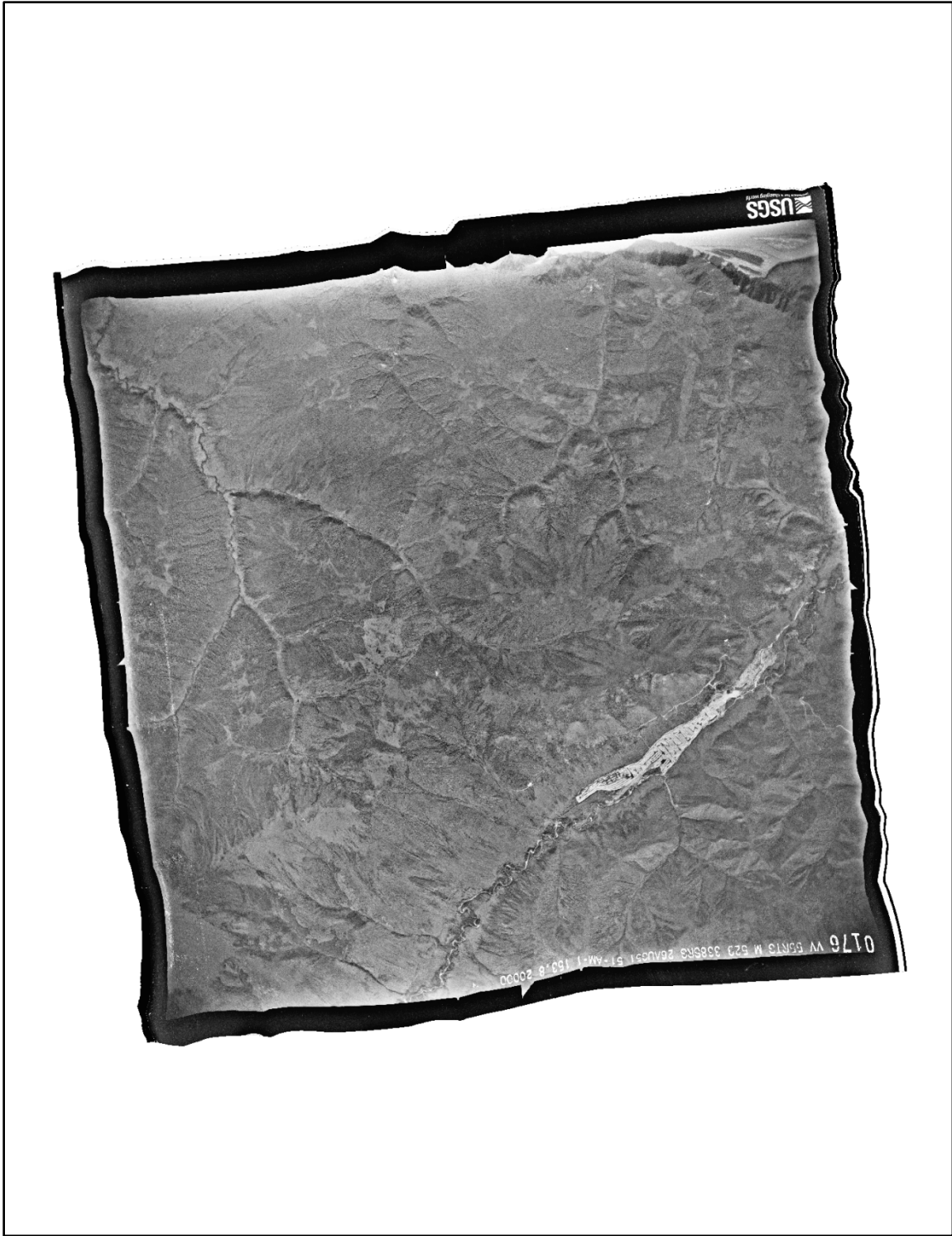


Figure 7. Sample of a typical 1950's black and white orthorectified image.



If mosaicing of the orthorectified photos is a consideration for the future project work, attention related to photo overlap must be measured as 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; this will create holes in the final composite mosaic (**Figure 8**).



**Figure 8.** Missing data (shown in white) resulting from poor overlap between adjacent photographs.

## **Literature Cited**

Alaska National Interest Lands Conservation Acts, Public Law 96-487, USC Title XIII, Sec. 201  
Subchapter Title II, Sec. 10, 94 Stat. 2371 (1980).

## Appendix A: Sample Root Mean Square (RMS) Error Report

Single Space Resection for

C:\SECTION\_2\ARBM4G100010045\_A\ARBM4G100010045\_A.LAN

Number of points processed: 22

Ground Control Coordinates

Point Name	X	Y	Z
VC1	501264.50	1701590.50	641.90
VC2	498751.50	1701151.50	649.58
VC3	501848.50	1704946.50	727.36
VC4	501123.50	1706385.50	790.86
VC5	501132.00	1708013.00	705.18
VC6	493699.00	1705209.00	517.30
VC8	496450.00	1708496.00	489.31
VC9	494666.00	1704103.00	526.09
VC10	496087.00	1699595.00	574.25
VC11	494288.00	1700858.00	630.41
VC12	495869.00	1701088.00	549.05
VC14	502215.00	1700029.00	691.79
VC15	502575.00	1702245.00	640.48
VC16	500342.00	1700937.00	667.38
VC17	497935.00	1700252.00	660.57
VC18	497826.50	1704832.50	809.55
VC19	499838.50	1705748.50	633.14
VC20	499429.50	1703301.50	599.41
VC21	498613.00	1708309.00	517.09
VC22	493529.00	1707573.00	613.88
VC23	495489.00	1706630.00	721.60
VC24	501947.00	1707977.00	746.34

Photo Control Coordinates

Point Name	Column	Row	x	y	dR	dX	dY
VC1	12720.0	13443.0	57.467	-62.361	0.0000	-0.0000	0.0000
VC2	8863.0	13640.0	3.044	-65.070	0.0000	-0.0000	0.0000
VC3	14233.0	8496.0	78.739	7.419	0.0000	-0.0000	-0.0000
VC4	13449.0	6140.0	67.639	40.679	0.0000	-0.0000	-0.0000
VC5	13688.0	3757.0	70.974	74.301	0.0000	-0.0000	-0.0000
VC6	2136.0	6693.0	-91.991	33.083	0.0000	0.0000	-0.0000
VC8	6779.0	2406.0	-26.541	93.492	0.0000	0.0000	-0.0000
VC9	3356.0	8490.0	-74.747	7.703	0.0000	0.0000	-0.0000
VC10	4607.0	15450.0	-56.984	-90.532	0.0000	0.0000	0.0000
VC11	2097.0	13254.0	-92.438	-59.498	0.0000	0.0000	0.0000
VC12	4544.0	13150.0	-57.910	-58.076	0.0000	0.0000	0.0000
VC14	13916.0	16007.0	74.384	-98.563	0.0000	-0.0000	0.0000
VC15	14796.0	12679.0	86.749	-51.618	0.0000	-0.0000	0.0000

VC16	11221.0	14277.0	36.328	-74.102	0.0000	-0.0000	0.0000
VC17	7459.0	14866.0	-16.749	-82.344	0.0000	0.0000	0.0000
VC18	8104.0	7912.0	-7.757	15.772	0.0000	0.0000	-0.0000
VC19	11293.0	6938.0	37.228	29.458	0.0000	-0.0000	-0.0000
VC20	10248.0	10523.0	22.538	-21.111	0.0000	-0.0000	0.0000
VC21	9896.0	3015.0	17.453	84.841	0.0000	-0.0000	-0.0000
VC22	2262.0	3152.0	-90.269	83.048	0.0000	0.0000	-0.0000
VC23	4914.0	4804.0	-52.820	59.688	0.0000	0.0000	-0.0000
VC24	14945.0	3902.0	88.713	72.232	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 = 6.829

XL = 498405.4

YL = 1704057.8

ZL = 7793.4

A solution has been found after 3 iterations

Standard Deviation of unit weight = 0.1476880

Omega = 0.53 (Degrees)

Phi = 0.22 (Degrees)

Kappa = 6.83 (Degrees)

XL = 498285.6

YL = 1704093.5

ZL = 7801.1

The Covariance Matrix (omega phi kappa X Y Z)

(Angles in radians multiplied by 1000)

0.99219							
-0.08406	0.95797						
0.02031	-0.01296	0.12614					
-0.66474	8.00034	-0.12279	69.008				
-8.33409	0.66884	-0.19448	5.274	72.197			
-0.05333	-0.09697	-0.00001	-0.992	0.531	6.466		

Standard Deviation for Omega: 205.46 (Seconds)  
Standard Deviation for Phi: 201.88 (Seconds)  
Standard Deviation for Kappa: 73.26 (Seconds)  
Standard Deviation for XL: 8.31 (Meters)  
Standard Deviation for YL: 8.50 (Meters)  
Standard Deviation for ZL: 2.54 (Meters)

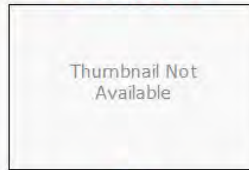
Residuals for the points entered

Point ID	Cols	Rows
VC1	10.89	10.67
VC2	15.71	-6.60
VC3	-9.62	17.15
VC4	10.49	-4.75
VC5	7.80	19.81
VC6	-16.45	-6.74
VC8	-2.90	6.28
VC9	-2.05	1.74
VC10	13.39	-2.39
VC11	-8.16	-19.17
VC12	-16.44	-15.39
VC14	10.59	-11.25
VC15	-2.29	-0.39
VC16	9.15	5.10
VC17	7.36	-2.64
VC18	-10.72	-5.36
VC19	-6.91	3.46
VC20	3.66	6.38
VC21	-10.71	0.77
VC22	4.96	10.52
VC23	-13.77	-5.01
VC24	5.02	-2.04
Col RMS =	10.03	
Row RMS =	9.41	

## Appendix B: Sample 1950's orthorectified image FGDC compliant metadata

### ARBM05290300125\_A\_ORTHO.TIF

Raster Dataset



Tags

Georeferenced Image, Orthorectified Image, Yukon Charlie National Park, Alaska, Color Infrared Photography, Yukon Charlie National Park, Orthorectification, Land Cover, Digital Georectified Image

#### Summary

The orthorectified aerial photo imagery for Yukon Charlie National Park is a multi-purpose georeferenced 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 Yukon Charlie National Park in Alaska. The imagery was procured from air photo flying missions conducted by the U.S. Air Force, USFWS and Miscellaneous in 1951 and 1953 through 1955 (Source: USGS EarthExplorer). The photo immersion is black and white and the scale of the final hardcopy photo print products is 1:40000. Scanned digital imagery at a resolution of 1800 dpi was provided by EROS Data Center to Saint Mary's University of Minnesota GeoSpatial Services. The scanned images were georeferenced and orthorectified using NPS supplied Digital CIR Orthomosaic tiles and a digital elevation relief model, both created by AeroMetric. Digital CIR Orthomosaic tiles of the Yukon-Charley Rivers National Preserve based on 2006 & 2007 aerial photography with a pixel ground resolution of 1 meter. Digital Elevation Model of the Yukon-Charley Rivers National Preserve based on 2006 & 2007 aerial photography with a ground sampling distance of 10 meters. The Digital CIR Orthomosaic tiles and DEM 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 ASTER 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.

#### Credits

Saint Mary's University of Minnesota, GeoSpatial Services.

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**National Park Service**  
**U.S. Department of the Interior**



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