



Glacier Monitoring in the Southwest Alaska Network

Version 1.0

Natural Resource Report NPS/SWAN/NRR—2011/293



ON THE COVER

Pederson Glacier, Kenai Fjords National Park (photograph taken on October 1, 2009)
Photograph by: Jeff Bennett, National Park Service, Alaska Regional Office

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Change History

Version numbers will be incremented by a whole number (e.g. Version 1.3 to Version 2.0) when a change is made that significantly affects requirements or procedures. Version numbers will be incremented by decimals (e.g. Version 1.6 to Version 1.7) when there are minor modifications that do not affect requirements or procedures.

The following revisions have occurred to this plan since January 2011

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Abstract

Glaciers are intricately related to climate and are indicators of regional climate change. The scientific community, the public and park visitors are becoming more aware and concerned about how regional and global climate change will impact the natural resources of parks all across the nation. Glaciers are a key component of the naturally functioning terrestrial and aquatic ecosystems of the Southwest Alaska Inventory and Monitoring Network (SWAN) parks. Together, these interrelated natural resources create the wilderness scenic beauty and quality that is the SWAN. About 50% of Kenai Fjords National Park, 20% of Lake Clark National Park and Preserve and 6% of Katmai National Park and Preserve is covered by glaciers. For these reasons, the Southwest Alaska Inventory and Monitoring Network identified Glacier Extent as a vital sign. This document presents the protocol for mapping and monitoring glacier extent in the SWAN.

Boundaries of all glacierized terrain (glacier extent) will be mapped on a park-wide scale for Kenai Fjords National Park, Lake Clark National Park and Preserve and Katmai National Park and Preserve on a repeating decadal basis. Individual glaciers (area of glacier ice within a hydrologic basin) will be extracted from park-wide glacier extent mapping effort and glaciological parameters (width, length, elevation, equilibrium line altitude, etc) will be quantified for each glacier. This glacier mapping effort utilizes Landsat imagery and established satellite imagery classification techniques, followed by careful manual editing to map glacier boundaries.

As the glacier extent dataset builds, this glacier mapping effort will allow for park-by-park and network-wide analysis of glacier status and trends – informing park managers, scientists and the public how glaciers are changing. The results of this mapping effort will add to the scientific body of knowledge documenting observations of glacier change for much broader Alaska-wide and global studies.

This SWAN glacier boundary mapping effort mirrors the glacier mapping guidelines established by the Global Land Ice Measurements from Space (GLIMS) program. The GLIMS program is a world-wide effort to map glacier extent and to provide a suite of glaciological characteristics describing the glacial geometry (width, length, elevation, equilibrium line altitude, etc).

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Background and Objectives

Background and History

The National Park Service (NPS) has implemented a strategy through “vital signs monitoring” designed to observe and understand the status and long-term trends natural resources and ecosystem function in park units. The Southwest Alaska Inventory and Monitoring Network (SWAN) has identified glacier extent as an important vital sign to monitor (Bennett et al. 2006). This protocol describes the methods to be used to map the boundaries of all individual glaciers (collectively glacier extent) within the SWAN and monitor change and identify trends on a park- and SWAN-wide basis.

There are approximately 85,000 to 90,000 km² of mountain glaciers located in Alaska and Canada, or about 13% of the mountain glaciers worldwide, with approximately 75,000 km² (18.5 million acres) occurring in Alaska (Arendt et al. 2002, Kaufman and Manley 2004, Dyurgerov and Mier 2005, Briner and Kaufman 2008, Barclay et al. 2009, Berthier et al. 2010). Glacierized areas in Alaska are most extensive in the southern portion of the State due to the interaction of maritime climate and the abrupt rugged topography proximal to the North Gulf of Alaska coast (Hamilton 1994).

The SWAN is comprised of five park units (Aniakchak National Monument and Preserve, Alagnak Wild River, Katmai National Park and Preserve, Kenai Fjords National Park, Lake Clark National Park and Preserve) encompassing over 38,000 km² (9.4 million acres) of remote Alaskan wilderness. Glaciers occur in four of the five SWAN park units (Aniakchak, Katmai, Kenai Fjords, Lake Clark) and are a significant land cover type in three of the five SWAN park units (Katmai National Park and Preserve, Kenai Fjords National Park, Lake Clark National Park and Preserve) shown in Figure 1.

Glaciers are important indicators of climate fluctuations over time (Hall et al. 1992, Raup et al. 2007). Measurements of glacier change can be used to explain changes in regional climate in many glacierized areas of the Earth (Hall et al 2000, 2003, Sapiano 1998). Valley and mountain glaciers typically respond to changes in the regional climate on a decadal scale (Hall et al. 1992, 1995, Adalgeirsdottir, 1998). Small glaciers are sensitive indicators of local climate (Sapiano 1998).

A glacier’s long term response to climate change is expressed geometrically (elevation and extent) as glacier mass is distributed through ice flow. Glacier response time ranges from decades for maritime (wet-warm), to thousands of years for continental (dry/cold) climates respectively (Raper and Braithwaite 2009). Glacier sensitivity to climate change (temperature and/or precipitation) is high for maritime glaciers and relatively low for continental glaciers (Braithwaite and Raper 2007).

Land based termini in Alaska have been receding since the end of the Little Ice Age, approximately 1880 (Barclay et al. 2009). Change in glacier extent is a long-term integrated reaction of a glacier’s response to the present as well as past climates. A retreating glacier might well have a positive mass balance today, but it is retreating in response to less favorable climate conditions in the past. Glaciers flow slowly and have a “memory” to past climates expressed in how their geometry (elevation and extent) changes.

It is important to remember that there are many glaciers, like surging glaciers and tide water glaciers that are also strongly forced by other, non-climatic factors. A change in climate may initiate a change in glacier dimensions but can't be accounted for all the change (Barclay et al. 2009).

Knowledge of how glaciers are reacting to climate change in SWAN parks and how this change may be linked with aquatic and terrestrial ecosystem function and response is lacking. This protocol establishes an approach whereby Landsat satellite data can be analyzed on a repeating decadal scale for glacier extent on a park-wide basis using a combination of automated classification techniques followed by detailed manual editing. Individual glaciers boundaries will then be extracted from the park-wide glacier extent shapefiles allowing for in-depth analysis of glacier change in the SWAN parks. The expanse and inaccessibility of much of the glacierized terrain in the SWAN preclude the use of ground-based glacier monitoring techniques.

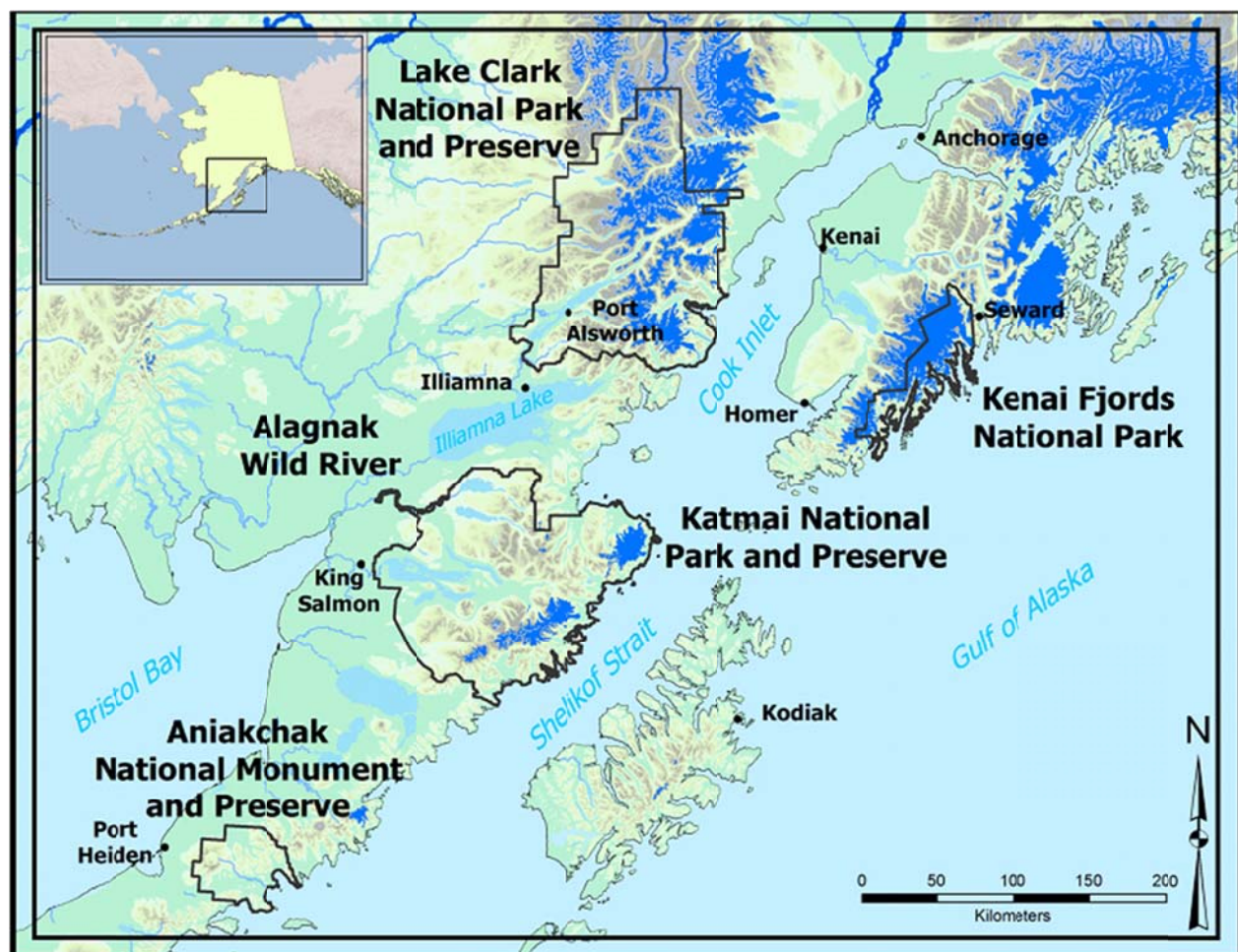


Figure 1. Southwest Alaska Inventory and Monitoring Network location map. Glacierized areas are shown in dark blue.

Geography and Climate Topographic Setting

The SWAN region is located between 57° to 61° north latitude and 149° and 158° west longitude. The SWAN parks are mountainous (rising abruptly from sea level and approaching 2,300 m) parks composed of some of the most rugged and impressive terrain in North America.

Climate and Climate Trends

Alaska can be divided into five major climatic regions: Arctic; Interior and Copper River Basin; West Coast; Bristol Bay and Cook Inlet; and the South Coast. The SWAN is primarily located in the South Coast and Cook Inlet regions (Shulski and Wendler 2007), although the northwestern portions of LACL are dominated by conditions of the Interior and Copper River Basin region. The South Coast region borders the north Gulf of Alaska is influenced by strong maritime air masses resulting in high precipitation and moderate temperatures. The Cook Inlet region is an area of transition from South Coast maritime conditions to Interior and Copper River Basin continental conditions. The interior and Copper River Basin regions experience warm summers, very cold winters, and are typically dry as a result of high pressure systems that frequently develop over interior Alaska (Shulski and Wendler 2007).

Local climatic conditions of the SWAN are largely influenced by the region's high latitude, proximity to the northern Gulf of Alaska, complex topography, and the interaction of these features with global circulation (Simpson et al. 2002). The location of the Aleutian Low during the winter months produces a high frequency of marine cyclones making landfall (Davey et al. 2007) and the presence of mountains rising directly and steeply from the Gulf of Alaska (Bennett et al. 2006, Davey et al. 2007) create maritime influences that interact with steep topography to create patterns of high precipitation on the windward side of the mountains, which in-turn leads to over 5,700 km² (1.4 million acres) of glacier ice within the SWAN parks (Table 1 and Figure 2).

Table 1. Glacier ice within the SWAN parks (circa 1960).

Park	Park Area (sq. km)	Glacier Area (sq. km)	Glacier Area (%)
Katmai	16,591	1,000	6
Kenai Fjords	2,699	1,450	53
Lake Clark	16,330	3,300	20
Total	35,620	5,750	16

Alaska's climate record is brief and there are few weather stations compared to the rest of the USA and even fewer stations that are proximal to glacierized regions. A 50-year trend analysis of 24 Alaskan weather stations indicate that annual and seasonal mean temperatures have increased throughout the State with the highest increases coming from the interior part of the State (Stafford et al. 2000, Wendler and Shulski 2008). Arendt and others (2009) found that between 1950 and 2000, winter and summer temperatures have increased $2.0^{\circ} \pm 0.8^{\circ}$ and $1.0^{\circ} \pm 0.4^{\circ}$ C, respectively. Observed summer warming is reflected in the recent summer observations of increased glacier thinning in Alaska (Arendt et al. 2002).

Based on Alaska temperature modeling (PRISM Climate Group, Oregon State University), the mean annual temperature in the SWAN area is close to zero °C (Redmond et al. 2005). A positive temperature shift of only a degree or two will increase the mean annual temperature from near to below freezing, to one that is near to above freezing throughout the SWAN parks thus directly influencing glacierized areas (Redmond et al. 2005).

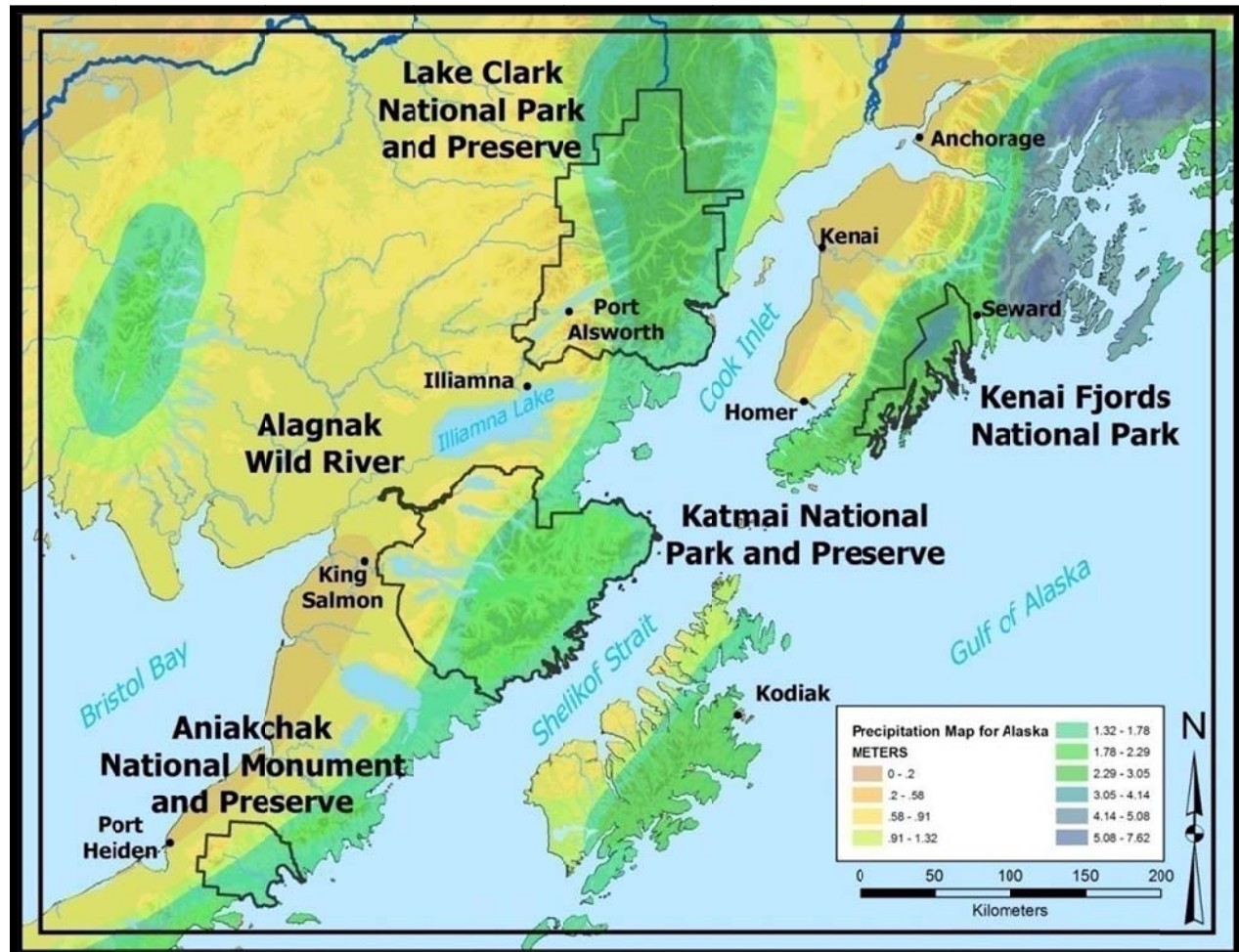


Figure 2. Generalized precipitation across Kenai Fjords NP and Katmai and Lake Clark NP&Ps (Brabets 1997).

Glaciers of the SWAN

The SWAN parks host a range in the type and size of glaciers including ice fields, large and small valley glaciers, cirque glaciers and lake and ocean terminating glaciers. The Harding Icefield (KEFJ) is the single largest glacier feature in the SWAN parks and spawns many outflow valley glaciers. Both LACL and KATM have glacier capped volcanoes (Barclay et al. 2009).

Glacier Characteristics - Kenai Fjords National Park

There are approximately 1,450 km² (360,000 acres) of glacier ice/permanent snowfields in Kenai Fjords National Park (KEFJ), comprising approximately 53% of the park area (Hydrography data set, NPS - Alaska Regional Office). The Harding Icefield is the dominate feature in the Landsat image shown in Figure 3. The administrative boundary of KEFJ was created in 1978; the western boundary of the park bisects both the Harding Icefield and the Grewingk-Yalik Glacier Complex.

The SWAN glacier monitoring effort will include mapping the entire Harding Icefield and the Grewingke-Yalik Glacier Complex. Mapping only that portion of these glacier systems occurring within the park boundary would be short sighted and not allow for a complete analysis of glacier status within and proximal to the park.

The main body of the Harding Icefield is 1,786 sq km, (approximately 80 km x 30 km in area), about 2/3rd of which occurs within the boundary of Kenai Fjords National Park. The bulk of the Harding Icefield occurs at elevations between 900 m and 1,300 m. Dozens of outflow glaciers flow down valleys and terminate on land, in lakes or in the Gulf of Alaska.

A few kilometers to the southwest of the Harding Icefield is the Grewingk-Yalik Glacier Complex (approximately 35 km by 10 km in area), about 1/3rd of which occurs within the boundary of Kenai Fjords National Park. Elevations here reach 1400 m (~4,600 ft) above sea level. This ice field spawns several outflow valley glaciers that terminate on land. There are no tidewater glaciers issuing from the Grewingk-Yalik Glacier complex.

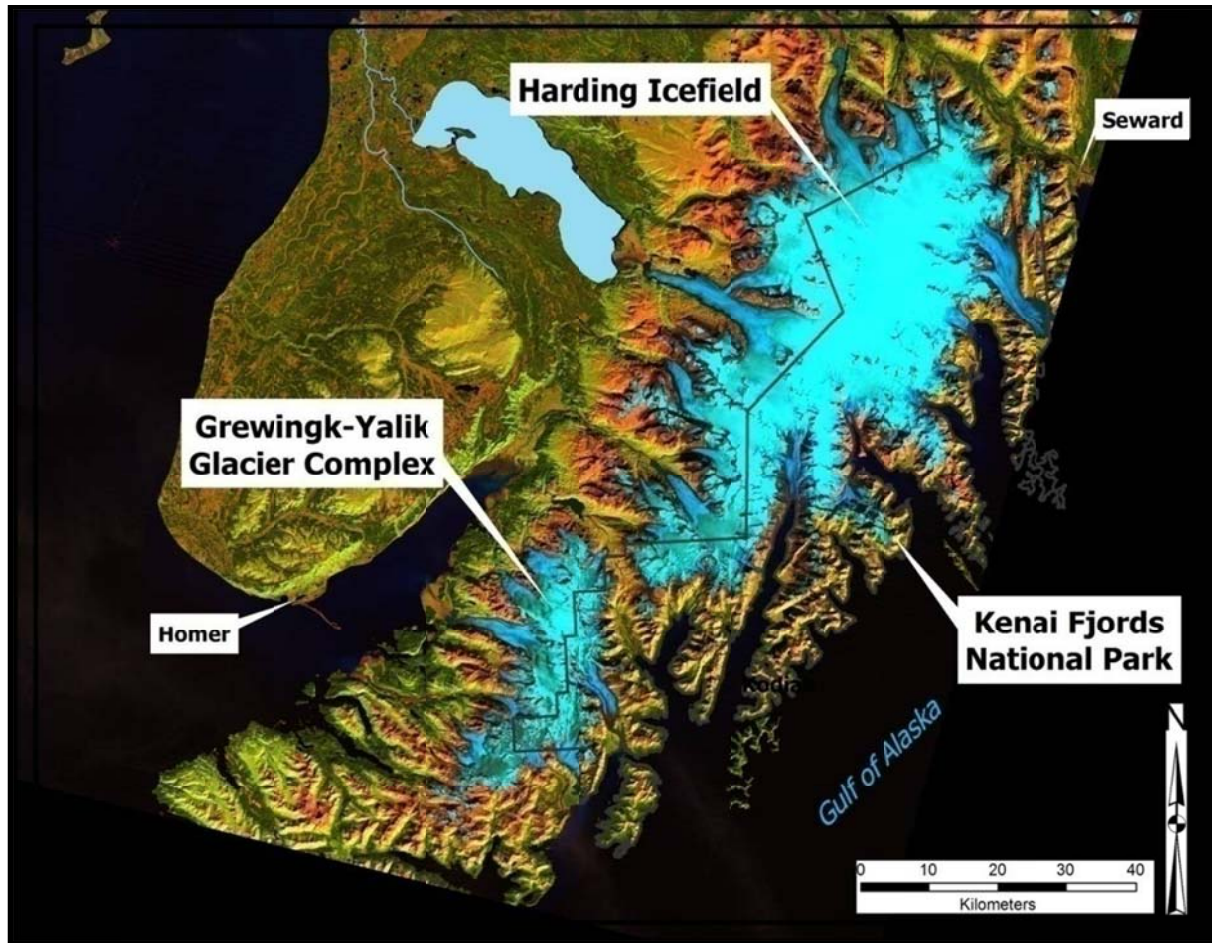


Figure 3. September 1986 Landsat image (Thematic Mapper 5) of Kenai Fjords National Park.

Glacier Characteristics - Katmai National Park and Preserve

There are over 1,000 km² (250,000 acres) of glacier ice/permanent snowfields in Katmai National Park and Preserve (KATM), comprising approximately 6% of the park area (Hydrography data set, NPS - Alaska Regional Office). Over a hundred glaciers originate from three primary areas in KATM (Figure 4). Source areas for these glaciers are volcanic mountains (approaching 2,300 m (~7500 ft) above sea level) of the northern Alaska Peninsula. Valley glaciers are the most common glacier type in KATM and most of these glaciers terminate on land, though a few terminate in lakes and flow from both simple and compound basins coalescing into larger valley glaciers. Beyond the three primary accumulation areas of glacier ice, there are small cirque glaciers and innumerable small isolated permanent snowfields.

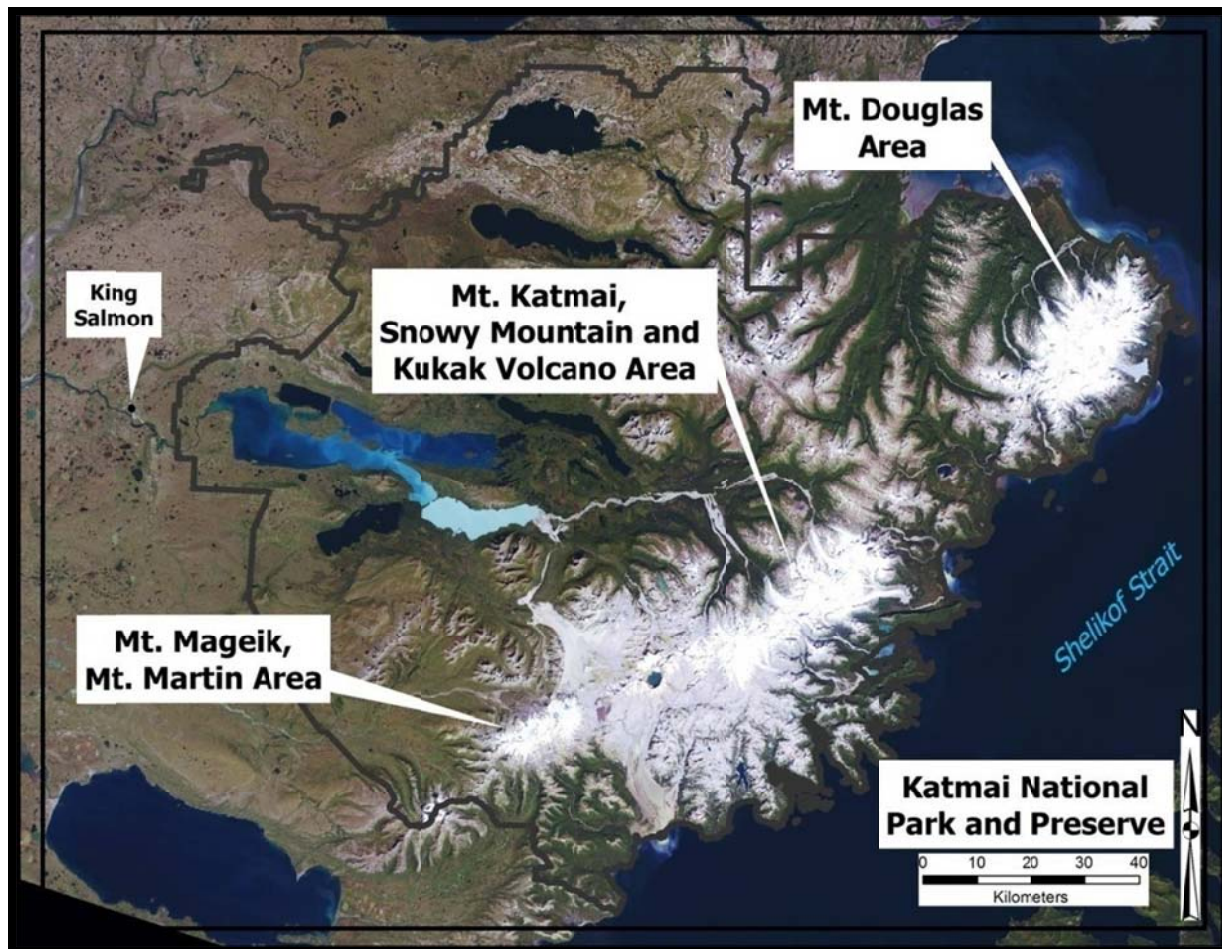


Figure 4. Landsat satellite image (composite image of August 30, 1991, September 3, 1995 and August 16, 2000) of Katmai National Park and Preserve.

Glacier Characteristics - Lake Clark National Park and Preserve

There are over 3,300 km² (820,000 acres) of glacier ice/permanent snowfields in Lake Clark National Park and Preserve (LACL), comprising approximately 20% of the park area (Hydrography data set, NPS - Alaska Regional Office). LACL hosts the convergence of two major mountain ranges, the Aleutian and Alaska Ranges, resulting in broad expanses of rugged topography approaching 3,050 m (10,000 ft). Hundreds of glaciers and small ice fields occur throughout the mountainous areas of the park (Figure 5). Large and small valley glaciers terminate on land, with a few terminating in lakes.

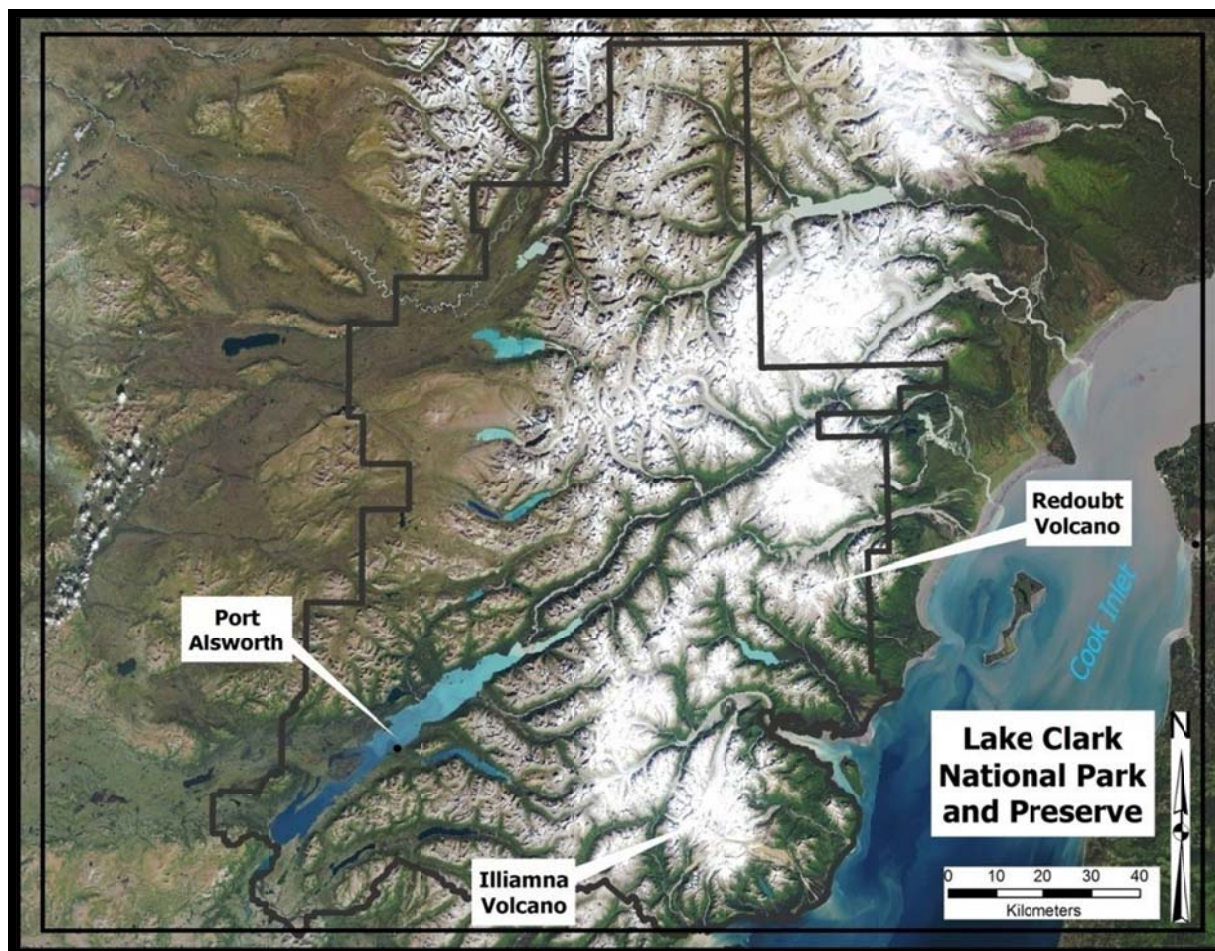


Figure 5. Landsat satellite image (composite image of August 30, 1991, September 3, 1995 and August 16, 2000) of Lake Clark National Park and Preserve.

Glacier Characteristics - Aniakchak National Monument and Preserve

Aniakchak National Monument and Preserve (ANIA) is home to a couple small hanging/cirque glaciers of very limited extent that occur inside the Aniakchak crater on the very steep north aspect of the southern portion of the crater. Glaciers of Aniakchak are not a significant feature of the landscape and will not be monitored through this protocol.

Glacier Terminus Characteristics

Glacier termini characteristics in these parks vary from clean-ice boundaries of calving tidewater or lake-terminating glaciers to ice choked fjords and lakes to debris covered termini of the many land-terminating glaciers (a characteristic of glaciers in recession). Additionally, large valley glaciers are striped with characteristic medial moraines as a result of coalescing valley glaciers; these valley glaciers also exhibit strong accumulations of lateral moraine material on the glacier boundaries. There are also isolated cirque glaciers and many small valley glaciers throughout these parks with varying degrees of debris cover. In addition, since the volcanic eruption of Novarupta in 1912, vast exposures of volcanic ash remain in KATM. Frequent wind events in the area entrain volcanic ash and continually redeposit this ash over the landscape. Many glaciers in this portion of KATM are completely blanketed with a thick layer of volcanic ash (Figure 6).

Mapping clean ice boundaries from Landsat imagery using automated classification methods is fast and effective. Mapping obscured glacier boundaries (debris covered or ice choked fjords/lakes) from Landsat imagery using automated classification methods does not accurately capture glacier boundaries and requires time consuming manual correction.

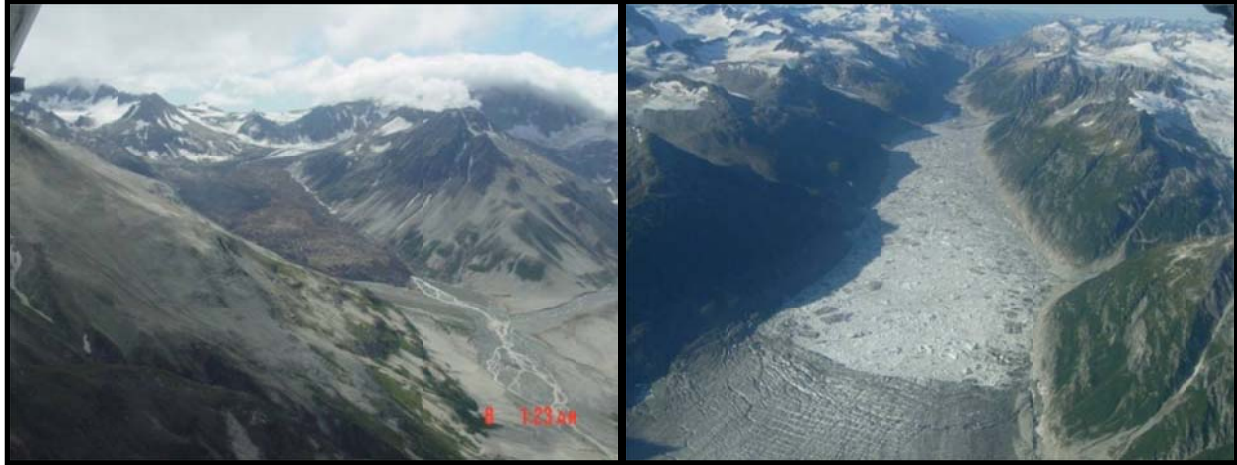


Figure 6. Two examples of glacier termini (left - volcanic ash/debris cover and right – ice choked lake) that prove to be challenging to automated classification methods.

Glaciers and Climate

A glacier that is in a steady state (datum state) is a glacier where the mass balance has remained constant for many years and glacier extent (and terminus position) remains largely unchanged. When there is a change in the mass balance of a glacier, the position of the glacier terminus will eventually respond. Glaciers adjust their geometries to respond to climate change in two ways: by change to the surface elevation and/or by change to the terminus position (Harrison et al. 2009). An increase in mass balance imparts little change in extent to the upper reaches of a glacier. The ice flux (volume of ice passing through a cross section of glacier) accumulates down-glacier and thus an increase in mass balance imparts a more dramatic change to glacier length (and extent) at the glacier terminus (Paterson 1994). This is because the lateral boundaries of valley glaciers are typically contained by steep U-shaped valley walls. This is illustrated by the fact that trim lines are distant from current terminus positions (down glacier positions) and more proximal to current glacier positions in the upper reaches of glaciers (Patterson, 1994). This observation is clearly exhibited in many glaciers in the SWAN (Figure 7). It is also important to note that some glaciers may be thinning rapidly but not expressing this as any change in extent (i.e. length); heavily debris-laden glaciers may fall into this category.

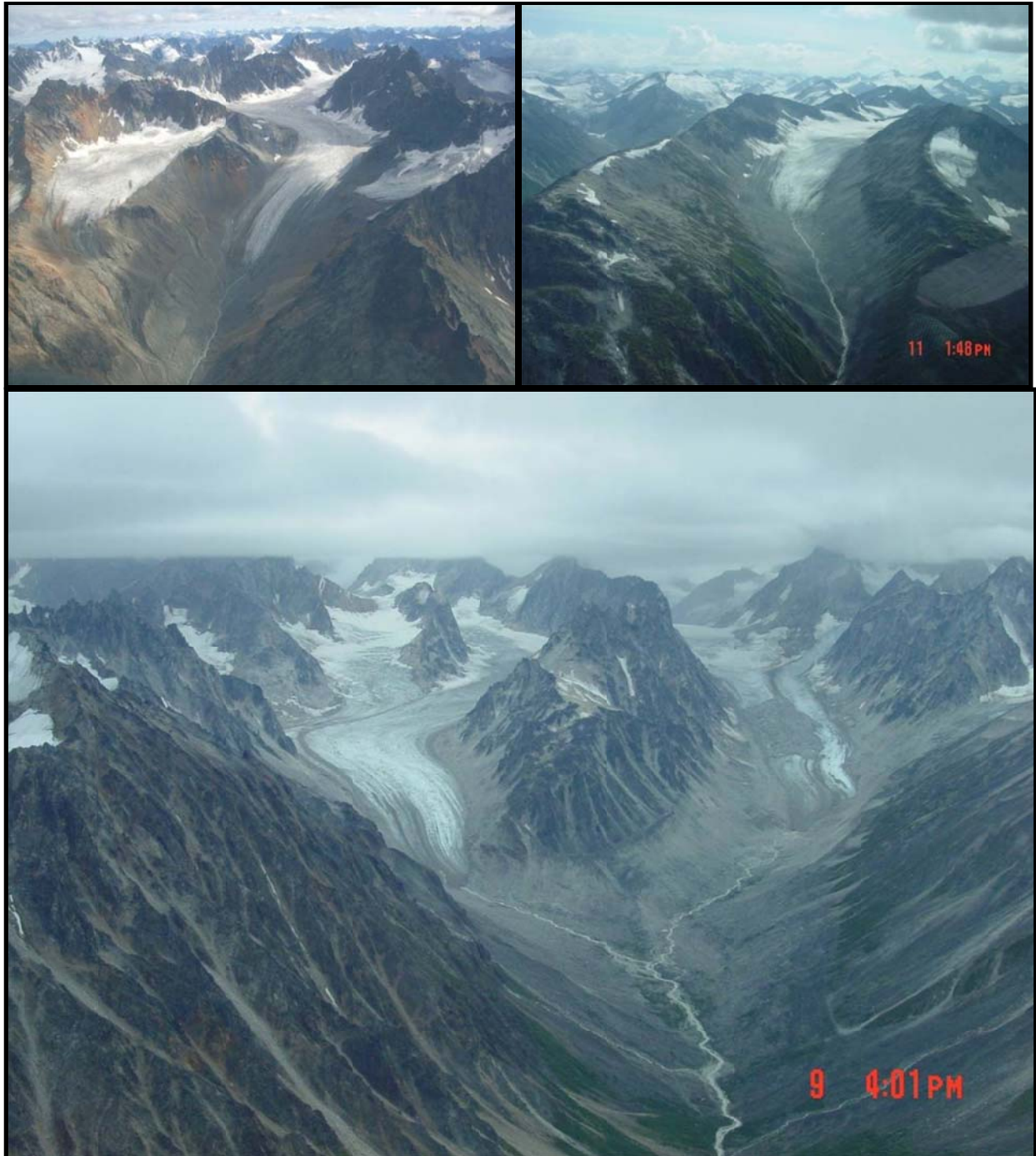


Figure 7. Examples of three unnamed glaciers in Lake Clark National Park and Preserve showing significant terminus retreat from the Little Ice Age glacier positions.

Long term fluctuations in glacier mass balance are due mainly to shifts in temperature and precipitation (Oerlemans 2005). A glacier's response to climate (temperature and precipitation) change is determined by glacier size, dynamics and thermodynamic regime of the ice, topography (slope, hypsometry) and the general climatic environment (temperature and precipitation) - all are factors governing long-term glacier response (i.e. change in glacier length and area (Marshall 2006)). Glacier termini move in response to climate change (Patterson 1994,

Molnia 2007) exhibiting a strong relationship between change in length and climate change (Paul 2010). In general, glacier length has been related to global mean temperatures (Oerlemans 2005). Glacier advance histories in southern Alaska during the First Millennium A.D. and the Little Ice Age support the inference that regional climate change was the primary control on glacier terminus movement (Barclay et al. 2009). At its very simplest, mass balance change of a glacier is propagated to the terminus with either advancement or retreat.

The time it takes for a glacier to adjust its geometry to climate change is the glacier volume response time. Glacier volume response time ranges from decades to thousands of years for maritime (warm and wet) and continental (cool and dry) glaciers, respectively (Raper et al. 2009). The SWAN has both types of glaciers and, thus changes observed today are at least in part from changes in climate that occurred tens to hundreds of years ago. Though climate change and resulting change in glacier mass balance is complex, recent studies suggest that 50-70% of a glacier's reaction to climate change is exhibited in adjustments to glacier geometry (surface extent and elevation), while 30-50% can be measured in long-term mean mass balance (Paul 2010). Most studies find that glacier volume reacts faster to climate forcing than glacier length and that temperature is more influential than precipitation and radiation (Oerlemans et al. 2007).

Recent glacier changes observed in Alaska appear to be a result of warmer summer temperatures (Josberger et al. 2007). Increased freezing level heights may cause increased melting and reduced snowfall, especially on glaciers with termini at lower elevations. (Arendt et al. 2009). Glaciers of southeast Alaska appear to be thinning rapidly due to factors of climate change, dynamics of tide water glaciers and a rise in the equilibrium line altitude (ELA) (Larsen et al. 2007). Some of these factors may be driving observed glacier change in the SWAN parks.

Rationale for Monitoring Glacier Extent

Glaciers are a significant landscape feature in the SWAN parks. Knowledge of glaciers and how they are changing is important in many aspects of park operations from resource management and planning efforts, to modeling glacier and ecosystem dynamics, to interpretive presentations, and understanding and addressing potential climate change. It is impossible to assess the effects of glacier change or to evaluate the resilience of existing habitats and plan for future management actions if there is a lack of basic understanding of the current state of park resources.

We know that glaciers are indicators of climate change (Barclay et al. 2009) and that basic information about SWAN glaciers and how these glaciers are responding to climate change is lacking. We also know that Alaska's glaciers have experienced steady recession since the close of the Little Ice Age (~mid 1800) (Molnia 2007) and that the most recent observations indicate that the rate of recession and glacier thinning has increased over the last decade (Larsen et al. 2007, Arendt et al. 2009). If modeled future climate scenarios are correct, continued glacier mass loss (and reduced extent) of many Alaska glaciers is expected and these glacial changes will impart significant changes to the aquatic and terrestrial ecosystems across the SWAN region.

Changing glacial systems in the SWAN parks are one among several important drivers (temperature, precipitation, fire, etc) that will impart change to ecosystems and landscapes of the parks. For example, melt waters from many SWAN glaciers drain directly into some of the most biologically productive waters in the world (e.g. Bristol Bay and the Northern Gulf of Alaska).

The direct and indirect effect glacier change may have on Alaska ecosystem function is not completely understood. What is understood, but not well quantified, is that glaciers store a huge amount of freshwater on the landscape. The release (melt) of this “stored water” is a factor of weather and climate, which in-turn is reflected in changes to freshwater flow through the SWAN. As glaciers in the SWAN respond to climate change, glacially fed freshwater systems will experience changes in volume, timing, temperature, turbidity, and water chemistry, which in turn will gradually impart changes to the productivity, diversity, abundance and population distributions of aquatic species. Change in glacier extent also affects landform and landcover with direct impacts to plant communities and their productivity, diversity and abundance, which in-turn will impart changes to the distribution, productivity, diversity and abundance terrestrial animal communities proximal to glaciers. These are just a few of the interlinked responses of the terrestrial and aquatic ecosystems to change in glacier extent.

Monitoring changes in glacier extent will allow scientists to identify regional and park-wide trends and to also focus on areas of significant change and study how these linked changes affect ecosystem response and productivity in the SWAN parks. Understanding landscape-scale natural processes, the resilience of these processes and how these processes are changing and interacting over time will further our knowledge of ecosystem function in the SWAN. Natural processes are largely outside the control of natural resource managers and understanding these processes provides important ecological context for interpreting change in park resources and is integral to the preservation and protection of public lands, and to determining the appropriate management strategies to employ (Reed et al. 2006).

This glacier monitoring protocol will provide valuable information for management of park resources and will allow for management decisions to be made based on knowledge rather than assumptions. This protocol will also provide valuable data and data analysis to a large global scientific community studying the change in the global cryosphere. In addition, fascinating data and information on glaciers and glacier change (extent) in the SWAN park units which will be conveyed to park visitors from all over the world who have a heightened awareness of glaciers and glacier change especially in light of global climate change.

Another important issue in monitoring the cryosphere is Global Sea Level Rise (GSLR). GSLR occurs from ocean thermal expansion (steric rise) and additions of mass to the oceans (eustatic rise). Recent glacier melting is likely the single largest contributor to eustatic rise (Arendt et al. 2006). The rate of world-wide glacier contribution to sea-level rise appears to have increased from 0.50 ± 0.18 mm/year (1963 to 2003) to 0.77 ± 0.22 mm/year (1993 to 2003) (Oerlemans et al. 2007). From the mid 1950s to mid 1990s, Alaska glaciers contributed 0.14 ± 0.04 mm/year to rising sea level (Arendt et al. 2002). Berthier and others (2010) suggests that Alaska glacier's are contributing 0.12 ± 0.02 mm/year to sea level rise over the period of 1962 to 2006. Regardless to what the exact contribution is, the decline in glacier extent in western Canada and Alaska significantly contributes to sea level rise (Bolch 2010). When compared with other glacierized areas across the globe, Alaska glaciers are the single largest contributors to sea level rise over the last 50 years (Arendt 2002), however, Alaska glaciers are some of the most poorly mapped glaciers in the world.

Measurable Objectives

The objective of this protocol is to measure and document changes in glacier ice across the SWAN parks on a park-wide basis. The specific goals are to:

- Map the extent of glacier ice in the SWAN parks on a decadal scale beginning in the early 1980s and continuing through the early 2000s and decadal thereafter.
- Extrapolate individual glacier boundaries (based on hydrologic basins) from glacier extent shapefiles based on a terrain analysis using the best available Digital Elevation Models (DEM).
- Populate a glaciological parameter geospatial dataset describing glacier characteristics (surface area, average length, width and elevation) for each individual glacier. This dataset is based on select terrain information generated from existing DEMs.
- Quantify glaciological statistics (absolutes, averages and trends) based on glacier mapping and analyze how the interrelations of the glaciological characteristics influence a glaciers response to climate.
- Quantify total glacier area, number of glaciers, average ablation zone elevation, average accumulation zone elevation, length, width, ELA and AAR.
- Provide reliable data and data analysis to parks, the public and the global glacier monitoring efforts of the Global Land Ice Measurements from Space program (GLIMS).

Sample Design

This protocol establishes a consistent automated approach whereby glacier extent will be mapped using Landsat satellite imagery beginning in the 1980s and thereafter on a repeating decadal scale (refer to Standard Operating Procedure (SOP) #1) followed by careful manual editing for the glacierized parks of the SWAN (refer to SOPs #2-4). Based on terrain and watershed analysis, individual glacier boundaries will be extracted from the glacier extent shapefiles and a dataset (attribute table) of glacier parameters will then be populated defining glaciological characteristics (surface area, average length and elevation), see SOP #6. The entire classification and editing process is completed using a Geographic Information System (GIS).

The SWAN will adopt the Global Land Ice Measurements from Space (GLIMS) methods for monitoring glaciers. The goal of GLIMS program is to map the extent and change of the world's glaciers through the use of multispectral satellite imagery and to provide a suite of glaciological characteristics describing the glacial geometry (surface area, average length and elevation). Adopting the GLIMS glacier mapping and database standards will not only meet the goals of the SWAN glacier monitoring protocol but takes advantage of glacier mapping methods and database design developed by glaciologists with expertise in monitoring the global cryosphere. The SWAN will archive its own glacier mapping data and will also provide this data to the GLIMS program for inclusion into the GLIMS world-wide glacier mapping dataset where glacier mapping data is more accessible to the public and researchers across the globe.

The SWAN will attempt to identify two other glaciological parameters that are commonly reported – the equilibrium line altitude (ELA) and the accumulation area ratio (AAR) (refer to SOP #6). Mountain glaciers are separated into two zones, an accumulation zone, where annual mass balance is positive, and an ablation zone, where annual mass balance is negative. The accumulation zone of a typical mountain glacier covers the higher elevation areas of the glacier and extends down glacier to where it meets the ablation zone. The equilibrium line, the line across the glacier where net annual mass balance is zero, distinguishes the accumulation zone from the ablation zone. The altitude (elevation) of the equilibrium line is referred to as the ELA (equilibrium line altitude). The AAR is the ratio of the accumulation area to the area of the entire glacier (Meier 1962, Khalsa et al. 2004, BIDLake et al. 2010), which can be easily determined after the equilibrium line has been established.

The approximate location of the equilibrium line is the firn line (i.e. snow line) at the end of the melt season (Khalsa et al. 2004, Braithwaite et al. 2007). The snow line altitude (SLA) is controlled by a fluctuation of climate (temperature and precipitation), glacier orientation, microclimate hypsometry and catchment area. A shift in the SLA over time indicates a change in temperature and/or precipitation (McFadden et al. 2010), though the overall control determining SLA is temperature change (McFadden et al. 2010). The snow lines can be identified on glaciers using late-season Landsat imagery and the altitude range can be extracted using the best available digital elevation model (McFadden et al. 2010; Khalsa et al. 2004).

The ELA and AAR two important features related to the glacier mass balance, which in-turn are linked to a glacier's response to a changing climate. On average, glaciers with a net mass balance of zero have an AAR of approximately 60% but the AAR can range from 50% to 70% for steady

state glaciers depending on the specific glacier characteristics (slope, elevation, aspect, length, width, etc.) (Zemp et al. 2009).

Rationale for Selecting this Sampling Design

The SWAN parks are vast, remote, wilderness parks. Access to most of the glacierized areas is expensive and difficult due to the terrain and ever-changing weather conditions. Most glaciers across the globe are studied remotely (Haeberli and Hoelzle 1995) because detailed ground-based mass balance measurements are difficult and costly to obtain. Mapping glacier boundaries using satellite imagery, is recognized as a simple and effective method for documenting change in glacier extent (Hall 2005). For glacier studies covering large remote glaciated areas, satellite imagery provides one of the most efficient means for monitoring regional glacier activity (Fountain et al. 1997).

Remote Sensing Satellite Imagery Options

Landsat, ASTER, IKONOS, MODIS and SAR are the types of satellite imagery which were evaluated for use in this protocol. Table 2 summarizes the satellite data types evaluated for use in this protocol.

The first Landsat mission was launched in 1972. Landsat imagery has a large foot print (185 km X 185 km) with 15 to 30 m resolution in 7 spectral bands, with a repeating orbit every 16 days, recovering data continuously. Thirty meter data are collected in visible and near-infrared wavelengths. Landsat satellite imagery is available from 1972 (Landsat 1) to the present (Landsat 7). The next Landsat mission (Landsat Data Continuity Mission) is scheduled for launch in 2012.

ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) is a sensor aboard the Terra satellite launched in 1999. One ASTER scene covers an area 60 km X 60 km. It takes nine ASTER images to cover same area of one Landsat image. ASTER has 15 to 90 m resolution in 14 spectral bands, with a repeating orbit every 16 days. The 15m data are collected in the visible and near-infrared wavelengths, 30m data in the shortwave infrared, and 90m data in the thermal infrared wavelengths. ASTER is an “on-demand” instrument and data will only be acquired if a request has been submitted by an authorized user (ASTER Science Team). Only the ASTER Science Team may request that the ASTER instrument acquire new data. The GLIMS program has the ability to request ASTER imagery be acquired of glaciated area. The cost to the GLIMS program is zero.

The commercial satellite IKONOS-2 was launched in 1999. IKONOS imagery has a foot print (13 km X 13 km). It takes over 200 IKONOS images to cover the same area of one Landsat image. IKONOS has 4 m resolution in 5 spectral bands. The 4 m data are collected in the visible and near-infrared wavelengths. A panchromatic band collects 1m data in the visible blue to near-infrared wavelengths. IKONOS is an on-demand instrument, acquiring data over a location only if a request has been submitted to observe that area. The expense of acquiring IKONOS images over the glacier areas of the SWAN parks is high. The NPS has acquired IKONOS imagery park-wide for KEFJ (2005) and ANIA (2005).

MODIS (Moderate Resolution Imaging Spectroradiometer) aboard NASA’s Aqua and Terra satellites has a minimum spectral resolution of 250 meters, which will not meet the objectives of the protocol.

SAR (Synthetic Aperture Radar) has many different resolutions. Landsat generally produces better contrasting data between the glacier and the surrounding debris than does SAR, though SAR is not affected by cloud cover (Hall 1995). Landsat is generally a better tool to measure glacier area than is SAR (Hall et al. 2000). There are new SAR technologies promising new glacier mapping methods using InSAR coherence mapping that can mask areas that are in motion between two SAR scenes. This provides a mask of active ice and might be a useful algorithm for glacier extent mapping. SAR technology and application to glacier mapping will be monitored and this protocol will be modified to take advantage of any advancement that improves on current methodologies.

Table 2. Potential satellite data acquisition platforms.

Data Type	Launch Date	Spectral Bands	Swath Width (km)	Resolution (m)	Ground Track - Repeat Cycle	Georectified
Landsat	1972	6	185	15 - 30	16 days	yes
ASTER	1999	14	60	15	16 days	yes
IKONOS	1999	4	11.3	1	3 days	yes
MODIS	1999	36	2,330	200, 500, 1000	1-2 days	yes
SAR	1991	1	100	30	35 days	yes
SAR	1995	1	100	30	35 days	yes

Selected Option - Landsat

Currently (2010), Landsat imagery is the best fit for the objectives of this protocol. Landsat has good resolution in the visible spectral range (15 to 30 m) and a large foot print (185 km X 185 km), which is important to cover the large glaciated areas of the SWAN parks. Even with the large foot print, multiple scenes will be required to cover the glacier areas on a park- and SWAN-wide basis. Landsat imagery can also be used for retrospective studies as there is a Landsat data archive that dates back to 1972. Landsat provides the best combination of image resolution, footprint, historic data availability, and economy.

Landsat Satellite Image Data Accuracy and Mapping Precision

Landsat scenes are composed of pixel data. Landsat MSS (Multi Spectral Scanner) resolution is 79 meters, one pixel representing the spectral reflectance of a piece of ground measuring 79 meters x 79 meters. Landsat TM (Thematic Mapper) or ETM+ (Enhanced Thematic Mapper +) resolution is 30 meters, one pixel representing an area 30 meters x 30 meters. Table 3 reviews spectral and spatial specifications of the various Landsat satellites.

Table 3. Spectral and spatial specifications for Landsat MSS, TM and ETM+.

Satellite	Spectral Resolution (μm)	Band	Spatial Resolution (m)
Landsat 1-3 MSS	Band 4: 0.50 - 0.60	Green	79
	Band 5: 0.60 – 0.70	Red	79
	Band 6: 0.70 – 0.80	Near IR	79
	Band 7: 0.80 – 1.10	Near IR	79
Landsat 4-5 TM	Band 1: 0.45 – 0.52	Blue	30
	Band 2: 0.52 – 0.60	Green	30
	Band 3: 0.63 – 0.69	Red	30
	Band 4: 0.76 – 0.90	Near IR	30
	Band 5: 1.55 – 1.75	Mid IR	30
	Band 6: 10.4 – 12.5	Thermal	120
	Band 7: 2.08 – 2.35	Mid IR	30
Landsat 7 ETM+	Band 1: 0.450 – 0.515	Blue	30
	Band 2: 0.525 – 0.605	Green	30
	Band 3: 0.630 – 0.690	Red	30
	Band 4: 0.760 – 0.900	Near IR	30
	Band 5: 1.550 – 1.750	Mid IR	30
	Band 6†: 10.40 – 12.5	Mid IR	30
	Band 7: 2.080 – 2.35	Thermal	60
	Band 8: 0.52 – 0.92	Thermal	60

The level of change that can be detected in a Landsat image is dependent on the resolution of the imagery, which is directly related to the precision with which a glacier boundary can be identified, plus any geolocation/registration error for the image (Raup and Khalsa 2010).

The geolocation/registration error of Terrain Corrected TM or ETM+ Landsat data is 30 meters between images (EROS Data Center pers. comm. 2006). For a clean glacier terminus (i.e. not debris covered), changes of terminus positions can be determined to within ± 40 meters when analyzing Landsat TM and ETM+ scenes. The accuracy decreases to ± 113 meters when analyzing data between Landsat MSS and TM or ETM+ scenes (Hall et al. 2003).

Error Estimation

Accuracy of the glacier boundaries/outlines derived from image classification using automated methods is generally estimated to be one pixel in most accuracy studies. However, the accuracy estimates may vary widely by region depending on the quality of the images, the methods used and the presence of debris-covered glaciers (Racoviteanu et al. 2009). Regional glacier boundary mapping projects using band ratio techniques indicate a $\pm 2\%$ error for clean glacier ice. Boundaries of debris covered glacier ice are more difficult to accurately map via automated techniques and are manually improved, thus adding an additional $\pm 0.5\%$ error. For regional glacier boundary mapping efforts, the cumulative glacier boundary mapping error is estimated at $\pm 2.5\%$ (Bolch et al. 2010).

Current Status – Landsat Program

Launched in 1984, the Landsat 5 Thematic Mapper is currently functioning well beyond its designed life expectancy of 3 years and has collected over 900,000 individual satellite images across the globe. Landsat 5 continues to collect imagery suitable for use in this protocol even today.

Launched in 1999, Landsat 7 ETM+ stopped functioning as designed in June 2003 and currently collects data in Scan Line Corrector (SLC)-off mode. This malfunction causes an increasing amount of data loss as you move away from the scene center towards the sides of the scene. Landsat 7 ETM+ imagery collected post June 2003 is not acceptable for use in this protocol.

NASA and the USGS are currently developing the Landsat Data Continuity Mission, scheduled for launch in December 2012. This will extend the availability of global earth observing satellite imagery to the interested public and scientific community.

Criteria for Site Selection

The area to be monitored is driven by the extent of glacier ice within each of the three major glacierized SWAN parks. Figure 1 and Table 1 summarize the extent of glacier ice within the SWAN parks and this represents the approximate size of the area to be monitored.

Sampling Frequency and Replication

Time-series glacier studies utilizing Landsat imagery produce very good results when repeated on approximately a decadal scale (Bayr et al. 1994, Hall et al. 1995, Li et al. 1998, Hall et al. 2000, Hall et al. 2003). Remote sensing using satellite imagery, in combination with a Geographic Information System provides an effective means to analyze the state of glacier cover (Khalsa et al. 2004), and as the dataset is built up over decades, trends in glacier change can be determined (Li et al. 1998).

In support of this protocol, SWAN-wide glacier extent mapping will be repeated decadal. In the context of this protocol, decadal means 10 years, $\pm$ several years, but is wholly dependent on the availability of quality late-season Landsat imagery.

Data Quality - Landsat

Landsat data will be acquired on approximately a decadal scale. Late-season, cloud-free Landsat imagery is required to support this protocol. The seasonal timing of imagery acquisition ensures that the seasonal snowpack has melted as much as possible and that the amount of new snow is minimized. Landsat imagery (historic data or future data) will meet the following standards:

Satellite imagery over glacier areas will be cloud-free or very minimal cloud cover

Satellite imagery will be acquired as late into the melt-season as possible, but prior to any seasonal snow. For the SWAN parks, this acquisition window is typically mid-August through mid-September, the later into the ablation season the better. July scenes will not meet the requirements of this protocol due to lingering of the prior season's snow fall.

Methods

Background

Automated classification of satellite imagery is a reasonable and effective method to employ to delineate glacial ice boundaries. However, heavy debris on glaciers causes the glacier to have a similar reflectance as the surrounding moraine and/or mountain material (Hall et al. 2000, 2003, Jacobs et al. 1997). Automated classification of ice that is completely covered in debris is not possible because its spectral reflectance can't be distinguished from surrounding moraine/mountain material (Sidjak and Wheate 1999). When a glacier is in recession, debris may become concentrated on the surface of part or all of the glacier tongue. Also, debris on the sides of valley glacier obscures the glacier boundaries. Automated classification techniques utilized in combination with detailed manual editing will improve the accuracy of the glacier extent boundary. Manual interpretation remains the best tool in mapping glacier extent in many situations (Raup et al. 2007).

Other challenges to automated mapping:

- Shadows obscuring glacier boundaries. Low sun angle and extreme topography produces shadows across glacier boundaries. Shadows in combination with debris covered ice create challenges for the automated glacier boundary mapping techniques. These situations are not widespread and careful manual editing of these areas will be required to accurately map glacier boundaries. See SOP#4.
- Permanent/seasonal snowfields. Snow lying on ground or on a glacier is not spectrally different, so these two feature types aren't distinguishable from one another. A process can be applied to a classified image to remove small isolated groups of pixels that are more likely to represent isolated snowfields not associated with a glacier, see SOP#3 and #4.
- Seasonal date of the satellite image. The presence of seasonal snow can impart an error as large as $\pm 3\%$ (Bolch et al. 2010). The difference between a mid-August Landsat image and a September image is noticeable in the amount of seasonal snow in the imagery. Several factors affect the amount of seasonal snow cover lingering in a image: 1) the magnitude of the winter accumulation, 2) the magnitude of the summer ablation, 3) the date of the imagery (September is best!).
- The presence of cloud cover in glaciated areas is problematic to automated mapping, however, this protocol relies on the use of cloud-free imagery.

Some of these factors can be resolved by viewing higher resolution imagery (if available) and/or local expert knowledge of the area. The availability of higher resolution imagery facilitates the interpretation of the Landsat data in areas of uncertainty.

Data Acquisition

All current and historical Landsat image data in the USGS archive are available electronically at no charge to the user community from [EarthExplorer](#) or the [USGS Global Visualization Viewer](#). All imagery ordered from EROS is Terrain Corrected (Level 1T) and includes radiometric, geometric, and precision correction, as well as the use of a digital elevation model (DEM) to correct parallax error due to local topographic relief (<http://edc.usgs.gov/products/satellite/landsat7.html#l7status>). The Landsat geoTIFF images are acquired by the NPS as describe in SOP #1. Table 4 reviews Landsat imagery delivery specifications:

Table 4. Landsat processing parameters for Terrain Corrected (Level 1T) imagery.

Parameter	Value
Output format	GeoTIFF
Resampling method	Cubic convolution (CC)
Map projection	UTM – WGS 84
Image orientation	Map north up
Distribution	FTP download only

File Naming Convention

As supplied via EROS Data Center:

Landsat Scene Identifier: LXSPPPRRRRYYYYDDDGSI VV

Where:

L = Landsat
X = Sensor (M = MSS, T = TM, E = ETM)
S = Satellite
PPP = WRS Path
RRR = WRS Row
YYYY = Year of Acquisition
DDD = Day of Acquisition Year
GSI = Ground Station Identifier
VV = Version

Example: LE70690182000238AGS02

All Landsat imagery is provide in WGS-84 UTM map projection. All imagery classification and editing will be done in the native projection and orientation of the original imagery. All glacier boundary mapping data will be provided to the GLIMS program in the original map projection of the Landsat imagery (WGS-84). Final glacier extent shapes will include a duplicate suite of files in the datum and projection required by the NPS Alaska Region (NAD-83-Alaska Albers).

Glacier Extent Mapping - Automated Satellite Image Classification Techniques

Image classification for snow and glacier ice is a process by which all pixels in the image representing snow/glacier ice are segregated from all other pixels in the image. Applying threshold values to various band ratio techniques [TM4/TM5, TM3/TM5 and (TM2-TM5)/(TM2+TM5)] are useful in automatically classifying Landsat imagery for glacier and snow cover (Andreassen et al. 2008, Bolch et al. 2010). Regional mapping of glacier extent in western Canada produced good results using the TM3/TM5 band ratio because this banding technique achieves good results in shadows and in areas of thin debris (Bolch et al. 2010). Some experimenting with the band ratio techniques and threshold values is required to achieve a glacier/snow classification that best represents glacier/snow and minimizes the amount of manual correction. Image classifications are converted to shapefiles. Polygons representing snow/glacier ice and nunataks are segregated and small isolated snow fields that aren't connected to and/or associated with a glacier are eliminated. Details of the classification technique and editing process are further described in SOP #3 and #4.

It can't be overemphasized enough how critical the use of late-season imagery is to the comparative value between mapping efforts. The further into the ablation season an image is acquired reduces the amount of error imparted into the glacier mapping effort. Seasonal snow can contribute up to $\pm 3\%$ error (Bolch et al. 2010) in regional glacier mapping efforts.

Manual Correction

The polygon shapefiles and the requisite color-composite satellite image in the background will be loaded into an ArcGIS edit session where the shapefiles are modified to correct areas of misclassification. A Landsat color composite (Landsat bands 5, 4 and 2 (RGB)) works well with glacier studies. A true color composite can also be used (bands 3, 2, 1).

Delineating the boundary where glacier ice contacts ground is not as simple as may first appear. It is a time consuming and tedious task when correcting glacier boundaries on a regional scale. As the interpreter zooms into an area of interest, the pixels representing the contact (glacier – ground contact) will trend from white (ice) to black (ground), and in many circumstances, a transition zone of grey pixels between. The spectral reflectance of the pixels represents surface conditions that contain varying proportions of ice, debris on the ice and ground. Mapping the glacier boundary in these situations is left up to the judgment of the image interpreter.

Manual editing of the polygon shapefiles will more accurately capture glacier margins in the following areas of misclassification:

- debris covered glacier ice (typically terminus areas)
- shadowed snow/glacier areas
- water bodies exhibiting higher concentrations of suspended solids (glacier flour)
- clouds

Editing of the glacier extent polygon shapefiles will be accomplished with the aid of local expert knowledge of the region's glaciology and higher resolution photography, if available. When

careful attention is maintained throughout the mapping and editing effort, accuracy and repeatability is substantially improved, especially in areas of debris covered ice. Detailed procedures for manual editing of glacier boundaries are included in SOP #4.

To help standardize glacier mapping, the definition of what falls into the category called “glacier extent” must be defined. The following definition of what a glacier is in the context of this protocol will adhere to the GLIMS definition of a glacier (Raup and Khalsa 2010).

A glacier or perennial snow mass consists of a body of ice and snow that is observed at the end of the melt season. This includes, at a minimum, all tributaries and connected feeders that contribute ice to the main glacier, plus all debris covered parts of it. Excluded is all exposed ground, including nunataks.

The following circumstances will be considered when mapping glacier boundaries:

- 1. Bodies of ice above the bergschrund that are connected to the glacier shall be considered part of the glacier, because they contribute snow (through avalanches) and ice (through creep flow) to the glacier.*
- 2. A tributary in a glacier system that has historically been treated (and named) as a separate glacier should, within the GLIMS framework, be included as part of the glacier into which it flows. The name field for the glacier should be populated with all relevant names of tributaries.*
- 3. Any steep rock walls that avalanche snow onto a glacier but do not retain snow themselves are NOT included as part of the glacier.*
- 4. A stagnant ice mass still in contact with a glacier is part of the glacier, even if it supports an old growth forest.*
- 5. All debris covered parts of the glacier must be included.*
- 6. If no flow takes place between separate parts of a continuous ice mass, they should, in general, be treated as separate units, separated at the topographic divide. However, for practical purposes, such an ice mass may be analyzed as a unit at the analyst's discretion, if delineation of the flow divides is impossible or impractical. If the same system is analyzed in the same way later, it will have the same glacier ID, and can therefore be compared. If the system is analyzed in more detail later by breaking it into its component glaciers, those pieces will get new IDs (ID of system will be “parent ice mass” ID for each part), and future analyses of those pieces, if done in the same way, will be comparable.*
- 7. It is possible that an ice body that is detached from another may still contribute mass to the latter through ice avalanches, or it may no longer do so. It is practically impossible to tell which is the case from a single satellite image. Therefore, within GLIMS, adjacent but detached ice areas should, in general, be considered as different “glaciers”, regardless of whether they contribute mass to the main glacier through snow or ice avalanches. However, at the analyst's discretion, detached ice masses may be included as*

parts of one glacier. This is similar to the situation described in 5 above. If the pieces are analyzed separately later, each piece should be given a new GLIMS ID, the old one being used as the “parent ice mass” ID for all the pieces.

8. *Regarding the lower parts of lateral snowfields, whose extent varies from year to year map only at the end of the ablation period, preferably in a year without snow outside of the glaciers, to exclude seasonal snow. Then map everything that is connected to the glacier. If snowfields are identifiable, they should be disconnected from the main glacier. For hydrological purposes they can be included in the GLIMS Glacier Database under a separate GLIMS glacier ID, but they must be marked as a snowfield. Lateral glacier outlines that might be hidden by seasonal snow or by avalanches should be labeled as preliminary, or even the entire glacier can be excluded. Ice avalanche cones below a glacier terminus (dry calving) are not a part of the glacier.*
9. *Rock glaciers and heavily debris covered glaciers tend to look similar, but their geneses are different. GLIMS does not currently deal with the former, but does include the latter.*

Extracting Individual Glacier Boundaries

There are many areas in SWAN parks where two or more glacier will flow from the same accumulation area. In these situations, individual glacier boundaries will be extracted from the larger glacier extent polygon feature using the best available DEM and terrain analysis techniques. The result will be a polygon shapefile composed of individual glaciers. Each glacier is representative of glacier ice within a hydrologic basin. When all individual glaciers have been extracted from the glacier extent shapefile, glaciological parameters describing glacier characteristics (width, length, elevation, ELA, etc) will be quantified in the accompanying attribute table. A composite of all individual glaciers is equivalent to the glacier extent, except the shapefiles containing the individual glacier boundaries and attributes will provide for a much more in-depth analysis of glacier change. SOP #5 and #6 gives general guidance in the procedures of extracting individual glacier boundaries from glacier extent shapefiles and populating attribute tables with glaciological parameters.

Developing Local Expert Knowledge - Aerial Reconnaissance

It is necessary to rely on or develop “local expert knowledge” in areas where the location of glacier margins is unclear from Landsat imagery interpretation alone (i.e. areas of debris covered ice, areas obscured by clouds, and areas of extreme topography resulting in shadowed ice). Developing “local expert knowledge” through the acquisition of oblique photography will facilitate the interpretation of Landsat imagery in areas where glacier margins are uncertain.

Acquisition of time-relevant aerial oblique photography should be scheduled within one year of the date of the satellite image and should be acquired in the August/September time frame. The acquisition of aerial oblique photography will be conducted by the PI and an assistant using the park and/or charter aircraft, see SOP #7. For over-flights to be fully effective, the draft interpretation of the glacier boundaries on satellite imagery must be finished, thus identifying those areas where fixed wing over-flights and acquisition of aerial oblique photography will facilitate the mapping of glacier boundaries. It is not always reasonable to acquire oblique imagery in the same year as the satellite imagery; however, the availability of time-relevant

aerial oblique photography will help build the “expert local knowledge” necessary to more accurately edit the glacier boundary shapefiles.

Acquisition of aerial oblique photography in support of this protocol may require the acquisition of 100s if not 1000s of photographs. Organizing this amount of data is imperative. Refer to SOP #8, “Geotagging and Organizing Oblique Aerial Digital Photographs in a GIS” for guidance in geotagging oblique aerial digital photographs and naming and organizing large numbers of photographs in a Geographic Information System (GIS).

Quality Assurance/Quality Control

Quality assurance and control is imperative in creating high quality data that is comparable between glacier mapping efforts. First, all Landsat imagery is acquired in standard format (see SOP #1) from the USGS EROS Data Center where QA/QC is a critical element in Landsat product. Image processing, and classification techniques are standardized (see SOP #2 and #3) and techniques employed for manual editing are detailed in SOP #4. By paying careful attention to processes outlined in these SOPs, baseline datasets created in support of this protocol will be of high quality and value to the park, the scientific community and the public.

Automated Data Harvest Development

Other glacier inventory projects are developing automated techniques to separate individual glaciers from the glacier extent shapefiles using the best available DEMs and terrain analysis tools. Efforts are also underway to automate the capture of individual glacier characteristics (surface area, length, elevation, slope, aspect, AAR and ELA) (Paul et al. 2010). As automated techniques are developed, the SOPs in this protocol will be updated to take advantage of these time saving efforts.

Future Plans

As more is learned about the glaciers of the SWAN, NPS will encourage future glacier studies through partnerships with other agencies and universities. This listing is meant only to identify some of the possibilities.

- Link glacier observations with past and future climate changes
- Regional and/or glacier specific ice elevation surveys (LiDAR, laser altimetry transects and survey-grade GPS)
- Link change in glacier change in the SWAN to mass balance studies at Wolverine Glacier (USGS Benchmark Glacier)
- Mass balance studies (Riedel et al. 2008)
- Repeat Photography (aerial and/or surface locations)
- Monitor the equilibrium line altitude (ELA) with imagery (Khalsa et al. 2004)
- Monitor accumulation area ratios (AAR)
- Laser/LiDAR elevation transect surveys
- Permanent snowfield inventory and monitoring

Data Management

This protocol requires the handling of numerous Landsat images for three SWAN parks for the glacier mapping effort. Many data handling steps (image classification and editing) necessarily result in numerous preliminary sequential datasets before a final glacier extent shapefiles (and accompanying data) are produced for archiving and distribution. This process necessitates the efficient and consistent management of all folders and files created in the glacier extent mapping process. Specific folder and file naming procedures are provided with the SOPs.

A time series of Landsat imagery is acquired and geospatial glacier boundary data (attributed point and polygon shapefiles) are created from data handling procedures identified in SOP #3, #4, #5 and #6. Fields in the final shapefile (PARK_YYYY_glaciers.shp and the PARK_YYYY_glacier_segments.shp) attribute tables are identified in Tables #5 and #6. Fully documented metadata will accompany all shapefiles created in support of glacier mapping.

Table 5. List of attributes for PARK_YYYY_session.shp.

Attribute	Value	Data Type	Comments
Rc_id	4	Integer	Regional center id: 4 = Alaska
Analy_time	to be determined	Integer	Time (in days) expended to complete the mapping (in days)
Data_src	i.e. Landsat 7	Text	Name of satellite data source
Anlst_surn	Giffen	Text	Surname of analyst
Anlst_givn	Bruce	Text	Given name(s) of analyst

Table 6. List of attributes for PARK_YYYY_glaciers_segments.shp.

Attributes	Value	Data Type	Comments
glac_id	GxxxxxxEyyyyyN	Text	The GLIMS glacier ID based on geographic centre of glacier with 3dp. xxxxxx is longitude (000.000-359.999); yyyyy is latitude (00.000-90.000) (Eg79.894W,77.146N=G259894E77146N)
glac_name	Glacier name	Text	Name of glacier (if one exists)
width	Width in meters	Integer	Representative width in meters
length	Length in meters	Integer	Representative length in meters
area	Area in km2	Integer	Area of basin (i.e., glacier + rocks) in km2
abarea	Area in km2	Integer	Size of ablation area
snowln_elev	Elevation in meters	Integer	Elevation of snowline in imagery (i.e., not equivalent to ELA) if available
min_elev	Elevation in meters	Integer	Elevation of the lowest part of the glacier, in meters above sea level.
mean_elev	Elevation in meters	Integer	Mean elevation of the glacier, in meters above sea level.
max_elev	Elevation in meters	Integer	Elevation of the highest part of the glacier, in meters above sea level.

Data Handling

All data handling, processing, analysis is done with desktop computer. The following is a basic recommended directory structure for data management using “D:” for an example drive letter:

D:\SWAN\GLACIER_EXTENT\PARK\YYYY\ORIGINAL

D:\SWAN\GLACIER_EXTENT\PARK\YYYY\WORKING

D:\SWAN\GLACIER_EXTENT\PARK\YYYY\FINAL

Where PARK will be the four letter acronym for the subject park and YYYY is the year of the Landsat imagery. The ORIGINAL folder will be the location for the original Landsat data.

The WORKING folder will contain a folder named IMAGERY and serves as a workspace for imagery classification files and raster-to-polygon conversions shapefiles. The IMAGERY folder will also be used to store various color composite images (geoTIFF) created.

The WORKING folder will also contain two personal geodatabases. The naming convention of the first personal geodatabase is (GLACIER_Extent_PARK_YYYY), where PARK is the four letter acronym for the park, YYYY is the year of the imagery. This will be the workspace where automated classification and manual editing of the polygon shapefiles takes place during an ArcGIS edit session. The naming convention for the shapefiles will contain the park name and date of the edit session (PARK_YYYYMMDD), where MM and DD stands for the numeric

representation of the month and day. Attribute tables for the accompanying shapefiles will also be populated with appropriate data. The naming convention for the final shapefile is GLACIER_EXTENT_PARK_YYYYMMDD. All final shapefiles depicting glacier extent and the satellite image (color composite geoTIFF) upon which the shapefile is based, will be moved to archival status.

The WORKING folder will contain a second personal geodatabase. When the glacier extent file is complete, a duplicate shapefile will be copied to the (GLACIER_PARK_YYYY) personal geodatabase. This will be the workspace where individual glacier boundaries will be extracted from the final glacier extent shapefile and glaciological characteristics will be quantified in the accompanying attribute table. The naming convention for the shapefiles will contain the park name and date of the edit session (PARK_YYYYMMDD). Attribute tables describing the glaciological features of each individual glacier will be populated. The naming convention for the final shapefile is GLACIER_PARK_YYYYMMDD. All final shapefiles depicting individual glacier boundaries and the satellite image (color composite geoTIFF) upon which the shapefile is based, will be moved to archival status.

The WORKING folder will also contain a folder named ANALYSIS where charts, tables, and graphs, text documents and supporting spreadsheets where the comparative analysis with previous mapping efforts are developed.

The FINAL folder will be the depository of two personal geodatabases with the final shapefiles depicting glacier extent and the individual glacier boundaries and accompanying glaciological attribute files. The FINAL folder will also house the original Landsat data and the color composite image used to perform manual editing of the glacier extent shapefiles. Comparative analysis documentation will also be found in this folder. The naming convention for the original imagery will be that as delivered from the EROS Data Center. The naming convention for the color composite image is LANDSAT_COMPOSITE_B₁B₂B₃_IMAGE_PARK_YYYYMMDD, where B₁B₂B₃ are the corresponding Landsat bands used to produce the composite image.

The contents of the WORKING folder (preliminary work products) will be removed upon completion of the mapping effort and archival of the final data products.

SOP #9 will detail a suggested directory structure and file naming convention, though folder and file naming convention is also addressed in SOP #1, #2, #3 and #4 and #6.

Draft or interim data will be backed up to the SWAN server daily. These files will include imagery, classified imagery and preliminary shapefiles, attribute tables, and metadata.

Final Data Products

The PI is responsible for checking the accuracy of the glacier extent boundary and approving the final shapefiles for archiving.

The archive data for each park will consist of:

- A color composite satellite image for which the editing of the glacier extent is based.
- A polygon shapefile(s) outlining the glacier mapping area.
- A point shapefile(s) identifying the point location of individual glaciers.
- A polygon shapefile consisting of glacier ice extent and nunataks.
- A polygon shapefile consisting of individual glaciers with fully populated glaciological attributes.
- A polygon shapefile(s) of the imagery footprint.
- A spreadsheet presenting current glacier extent and regional glaciological statistics and a comparison analysis with previous mapping efforts.

When shapefiles are final, they will be delivered to the SWAN Data Manager for archiving. The resultant glacier extent shapefiles will be available on the NPS Alaska Regional Office Permanent Data Set (PDS) and will be available for analysis with many other related data sets maintained by the Alaska-NPS. These files will be served on the ArcGIS Theme Manager maintained by the AKRO GIS Team.

Data backups at the AKRO are managed by the AKRO Information Technology team as detailed in the SWAN Data Management Plan, Section 11.5.

Metadata Procedures - Documentation

Complete metadata records will be created for each shapefile in the archive data. Metadata will meet Federal Geographic Data Committee (FGDC) content standards for Digital Geospatial Metadata (CSDGM). See Appendix B for an example of a metadata file.

Data Distribution

There is a suite of four shapefiles (with FGDC compliant metadata) that will be produced to facilitate distribution for each glacier mapping effort to the GLIMS program. Final shapefiles will be provided to the GLIMS program for inclusion into their global cryosphere data archive. Table 7 includes a listing of the shapefiles to be provided to the GLIMS program. The names of the shapefiles track the name of the park and the date of the satellite imagery. SOP #6 describes the production of these shapefiles and their associated attributes.

Table 7. Listing of the files to be provided to the GLIMS program.

Shapefile name	Data Type	Geometry
PARK_YYYY_session.shp	Polygon	Outline of the mapping region
PARK_YYYY_glaciers.shp	Point	Point location of individual glaciers
PARK_YYYY_segments.shp	Polygon	Line segments, glacier outlines
PARK_YYYY_images.shp	Polygon	Polygon of image footprint

Analysis and Reporting

This section describes the analysis techniques, the means of reporting and presenting the time series analysis data. These data and reporting products will be useful in understanding how glaciers in the SWAN are responding to observed trends of climate and climate change.

Analysis

This analysis will quantify glacier extent and identify areas and/or regions of rapid and/or anomalous change of glacier extent in the SWAN parks (Figure 1). The richness of the glaciological parameter geospatial dataset describing individual glacier characteristics (average length, width, slope, aspect, ELA and AAR) will be fully exploited to learn how glaciers are responding to climate change. Glacier response to climate change will be quantified and trends established at various geographic scales (park-wide, region-wide, watershed-wide, individual glacier).

Data analysis will be comprehensive using decadal repeating datasets representing:

- Park-wide glacier geospatial datasets identified in Table 5.
- Regional climate data and local climate data (if available).

How glaciers respond to observed trends in climate change may allow for a determination of:

- What glaciological parameter(s) appear to exert greater influence on glacier response in light of observed changes in local/regional climate?
- What glaciological parameter(s) appear to be less important to glacier response in light of observed changes in local/regional climate?
- Are there certain interactions between glacier parameters that appear to impart more (or less) influence on glacier response in light of observed changes in local/regional climate?
- What are the regional and/or park-wide observations and expected trends of glacier extent based on current climate trends/modeling?
- How observations of climate change are being projected through observation in glacier response and extent across the SWAN parks?
- How many total glaciers are in each SWAN park and which glaciers are growing, which are receding and which are on track to disappear?
- How are the observed changes in glaciers linked to changes in ecosystem response and change in the SWAN?

As the glacier mapping dataset builds over time, time-series analysis will strengthen observations of glacier change and identify reliable trends that may be useful for forecasting and prediction. Each successive glacier extent mapping effort increases the dataset's comparative analysis

qualities. As would be expected, each successive data point adds reliability and credibility to analyses to be conducted.

Reporting

The subject of glaciers and glacier change is currently very much in the public eye. Reporting the results of work accomplished (methods, data analysis and results) through the implementation of this protocol will be of interest to glaciologists, climate change researchers, landscape ecologists, and/or park staff. Park managers, the informed public, and other generally interested parties will use data and interpretations of data to gain an accurate understanding of glacier conditions in the SWAN parks.

It is the intent of the SWAN to share data and reporting products about glacier mapping efforts widely through formal talks, presentations and casual communications with park management and staff, outside scientists and the public. As indicated earlier, all glacier mapping data will be shared with the GLIMS program where it will be widely distributed to the public and global scientific community studying change of the global cryosphere.

Report Format

An example of a report describing the details of glacier mapping efforts is found in SOP #10, Appendix D; this draft report presents methods, data analysis and results of glacier extent mapping efforts. Glacier extent statistics and trends are displayed in table form and in “difference” maps created by overlaying glacier extent shapefiles representing different time periods.

Reports will contain:

- A description of the project.
- Listing of the imagery used in the analysis (type of imagery, date of imagery, image identifier, projection, datum, pixel size, format, level of correction).
- A description of imagery enhancements/processing used (band ratioing, band composite, thresholds).
- Accuracy of the interpretation of glacier extents based in sensor resolution and imagery registration.
- Overall glacier extent change and trends on a park-by-park basis.
- Detailed statistics regarding individual glaciological characteristics by park, region and/or watershed.
- A review of climate and climate trends and how glaciers of the SWAN are responding.
- Listing of particularly active areas that are candidates for site-specific studies.
- Maps, tables, charts and graphs.

Recommended Reporting Schedule

There are three parks in the SWAN with significant glacier cover, KATM, KEFJ and LACL. The goal of this protocol is to repeat glacier mapping on a decadal scale for each of these parks. As new mapping is complete, reporting will be performed.

Personnel Requirements and Training

Glacier extent mapping and analysis described in this protocol will be accomplished by a skilled physical scientist who is familiar with glaciers and glacier processes. It is intended that this work be accomplished with NPS staff. Personnel performing tasks detailed in this protocol should receive up to date training with ESRI ArcGIS and ArcCatalog and ITT ENVI software. Key tasks and associated personnel are outlined in Table 8. Personnel experience and qualifications are outlined in Table 9.

Table 8. Tasks required for achieving the goal of glacier extent mapping.

Task	Responsible Personnel
Data Acquisition:	Physical Scientist/Technician
Review and order imagery	
ArcGIS:	Physical Scientist/Technician or Remote Sensing Specialist
Satellite imagery classification	
Convert classification to polygon shapefiles	
Extract individual glaciers from glacier extent shapefiles	
Populate attributes for individual glaciers	
Create color composites of satellite imagery	
Using color composite satellite imagery as a base, edit the polygon shapefiles in ArcGIS	
Creating and updating metadata	
Data Analysis and Interpretation:	Physical Scientist/Technician or Remote Sensing Specialist
Spatial analysis - determine park-wide/region-wide area of glacier extent	
Trend analysis (glacier area, terminus position)	
Glaciological geospatial dataset analysis	
Data summaries	
Reporting	Physical Scientist
Data Management:	Data Manager, Physical Scientist/Technician and Remote Sensing Specialist
Manage directory structure and file naming convention	
Move final shapefiles to archive	
Data backups	
Data distribution	
Protocol Revisions	Physical Scientist

Table 9. Personnel required for achieving the goal of glacier extent mapping.

Personnel	Qualifications/Experience
Data Manager	Experience with data stewardship and developing applications for data analysis
Physical Scientist/Technician	Experience with ArcGIS: - Automated classification techniques - Conversion to polygon shapefiles - Creation of color composite geoTIFFs Experience in remote sensing and manual interpretation of satellite imagery and derived products in glacierized regions Complete comparative analysis and develop reports, maps, posters to convey finding to management, staff, scientific community and the public
GIS Specialist/ Physical Scientist/Technician	Experience with ArcGIS: - Geodatabases - Feature datasets - Feature classes - Editing - Various data types (raster, line and polygon) - Map projections - Preparation of interpretive maps Experience in remote sensing and manual interpretation of glacier features using satellite imagery and other higher resolution imagery Prepare comparative analysis and summary spreadsheets

Operational Requirements

Workload and Data Acquisition

Workload associated with this protocol are on a reoccurring decadal cycle, but is dependent upon availability of late-season, cloud-free imagery. It is not realistic to think that cloud-free, late-season satellite imagery for all the SWAN parks will be available in the year 2010, 2020, 2030 and so on. With this in mind, the search for acceptable imagery for a park should begin eight years after the last glacier mapping analysis was completed and continue until acceptable late-season cloud-free imagery is acquired. Due to the fact that the next generation Landsat mission launch is scheduled for 2012, it is recommended that imagery acquisition in support of this protocol not occur until the new Landsat satellite data is available, likely 2013.

The workload associated with image preparation, automated classification and manual editing of glacier boundaries and analysis will be approximately three work-months per park. Preparation of reports and accompanying graphics will require another month for a total of .33 FTE. This will be a reoccurring workload approximately every ten years for each of the three glacierized SWAN parks (KATM, KEFJ and LACL). The work tasks will be shared among the physical scientist, GIS specialist and physical science technician.

Field Investigation

The accuracy and interpretation of glacier boundaries from imagery will be enhanced by field investigations where debris cover, shadows and/or clouds obscure glacier ice. With this in mind, following the year of imagery acquisition, it is anticipated that approximately one week of fixed wing over-flights be conducted to gain time-relevant local expert knowledge of identified areas within the SWAN parks where imagery interpretation is uncertain. See SOP #7 and #8 for flight planning and aerial oblique image handling and archiving.

Software

Currently there are four primary software packages which will be required to meet the goals of this protocol.

- Standard internet browser for evaluating and ordering satellite imagery from the EROS Data Center website
- Satellite image processing software package: ENVI is the current package used by the SWAN
- Geographic Information System software package: ArcGIS is the current package used by the NPS
- Microsoft Office (word processing, spreadsheet preparation, presentations preparation)

Hardware

The hardware requirements include a personal computer with a minimum of 2.0 GHZ processor and 2 GB or greater of memory - these are minimum requirements. To achieve maximum performance in processing and manipulation of imagery, more powerful processors and memory are preferred. A minimum hard drive capacity of 1 Tb is recommended for imagery processing.

Procedures for Revising this Protocol

There will certainly be advances in satellite technologies and advancements in image classification methodologies through the years and this protocol will be updated to take advantage of future advancements satellite imagery and classification techniques. Careful documentation of changes to the protocol, and a library of previous protocol versions are essential for maintaining consistency in within the program. SOP #11 identifies the steps necessary for changing this protocol. Each SOP contains a revision history log that should be filled out when a SOP is revised. The new version of the SOP and/or protocol narrative should then be archived in the SWAN protocol library under the appropriate folder.

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Appendix A: Standard Operating Procedures

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Standard Operating Procedure (SOP) #1

Data Search - Landsat Imagery

Version 1.0

Change History

Version numbers will be incremented by a whole number (e.g. Version 1.3 to Version 2.0) when a change is made that significantly affects requirements or procedures. Version numbers will be incremented by decimals (e.g. Version 1.6 to Version 1.7) when there are minor modifications that do not affect requirements or procedures.

The following revisions have occurred to this plan since January 2011.

Version #	Date	Revised by	Changes	Justification

This Standard Operating Procedure describes the procedures for searching the USGS [National Center for Earth Resources Observation & Science \(EROS\)](#) EarthExplorer website for Landsat images in support of the Glacier Monitoring protocol for the Southwest Alaska Network (SWAN).

Overview

Cloud-free Landsat imagery will be acquired on a decadal scale for glacierized regions of the SWAN. This is the primary dataset used to map glacier extent across the SWAN. A comparative analysis with previous mapping efforts will document change and trends in glacier ice cover in the SWAN parks. The seasonality of the Landsat imagery is critical. Imagery must be acquired late in the ablation season (mid-August to late-September) to maximize seasonal snow melt but also before the first winter snows appear across the landscape. Typically, sky conditions in the SWAN region tend to be cloudier in August and September; that combined with a 16 day repeating orbit of Landsat, it will not be uncommon to have to wait several years to acquire acceptable late-season, cloud-free imagery. The Landsat data will be archived at the NPS - Alaska Regional Office.

Landsat 7 ETM+ satellite had a hardware failure in May 2003 and is no longer operating as designed. The older Landsat 5 satellite continues operate as designed. The next generation Landsat vehicle (Landsat Data Continuity Mission) is scheduled for launch in 2011. This mission is designed to continue the acquisition, archival, and distribution of multi-spectral imagery affording global, synoptic, and repetitive coverage of the Earth's land surfaces at a scale where natural and human-induced changes can be detected, differentiated, characterized, and monitored over time. When the new Landsat satellite data becomes available, this SOP will be updated. But until then, any Landsat data acquired post May 2003 in support of this protocol must be Landsat 5 data.

Landsat Data Source

EROS Data Center is the depository and archival facility for all Landsat data acquired over the USA. Information about the Landsat program and products are found on the web at:

http://landsat.usgs.gov/products_productinformation.php

Current updates about the Landsat mission and data can be found at:

<http://landsat.usgs.gov/>

EROS Data Center

The Earth Resources Observation Systems (EROS) Data Center (EDC) is a data management, systems development, and research field center for the U.S. Geological Survey's ([USGS](http://www.usgs.gov/)) [National Mapping Division](http://www.usgs.gov/national_mapping_division/). The EDC opened in the early 1970's with a handful of employees and the largest mainframe computer in the State of South Dakota. Today the EDC has approximately 600 government and contractor employees, including employees at its [Alaska Field Office](http://www.usgs.gov/alaska/) in Anchorage, Alaska, and employees at the [NASA Ames Research Center](http://www.nasa.gov/ames/) in Moffett Field, California. And now the EDC houses one of the largest computer complexes in the Department of the Interior.

Currently, the EROS Data Center provides all Landsat imagery free of charge to all users of the data. As significant changes occur to the EROS web site, this protocol will be updated.

EROS Data Center - Landsat Data

To order Landsat data visit:

<http://edcsns17.cr.usgs.gov/EarthExplorer/>

Instructions to navigate and order imagery from the EROS web site are available by selecting a “Help” button on the EROS web page.

Below is a step-by-step procedure for searching and ordering imagery from EROS. To order or download data from the EROS website, you will need to “Sign in” if you are a registered user. If not, it is easy to register, creating your own username and password.

EROS Website - Landsat Data Search –

On-line search for Landsat imagery is conducted through the EROS website. Below are the step-by-step procedures to conduct a search for Landsat data specific to SWAN parks.

1) Access the EROS website through the following link:

<http://edcns17.cr.usgs.gov/EarthExplorer/>

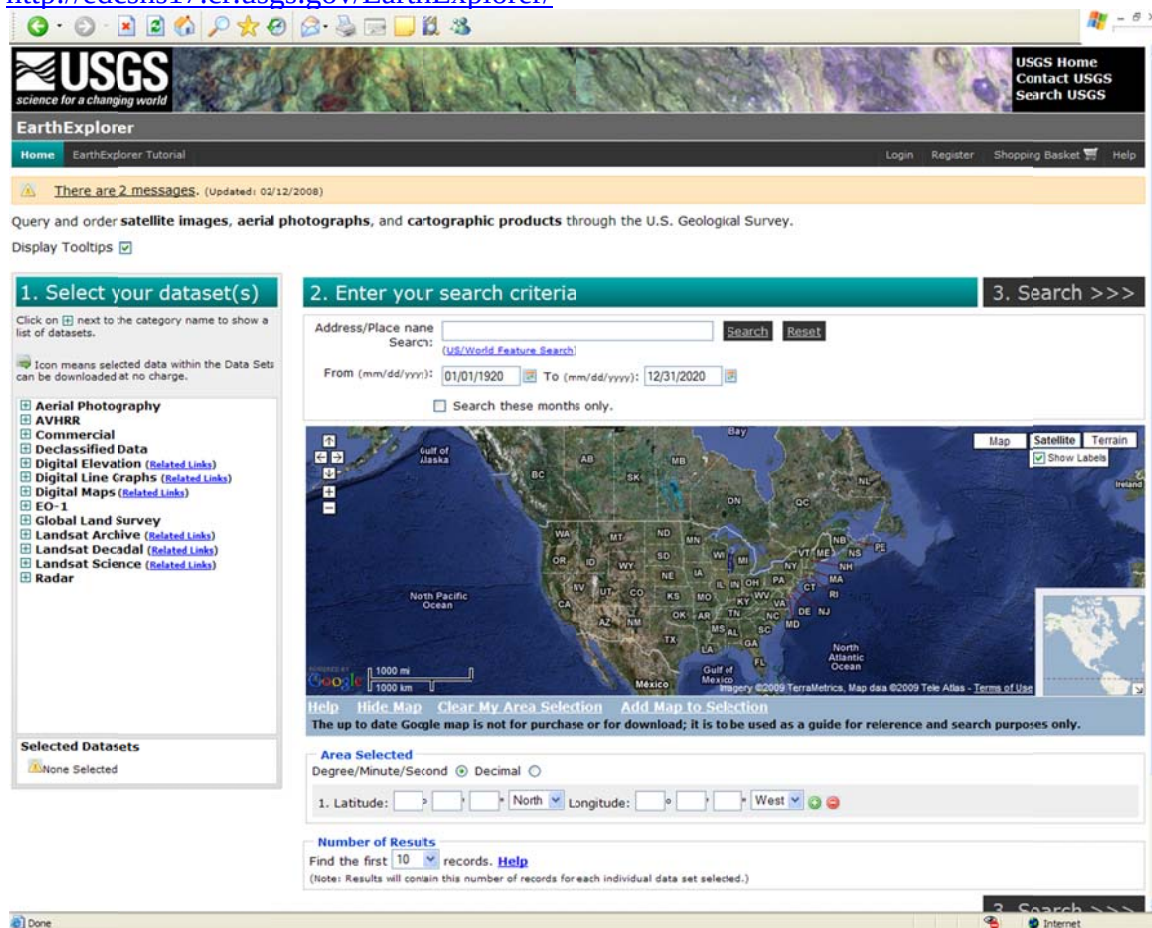


Figure 1-1. EROS website.

There are 3 steps to be completed in order to conduct a search for data:

1. Select your dataset(s)
2. Enter your search criteria
3. Search

Select your dataset(s)

In this window of the webpage, all datasets (both free and cost) served by EROS are listed. Expand the Landsat Archive by clicking on the “+” symbol.

At this point all Landsat data options appear. Click on the box next to the desired imagery (e.g. Landsat 4-5 TM is selected in the example).

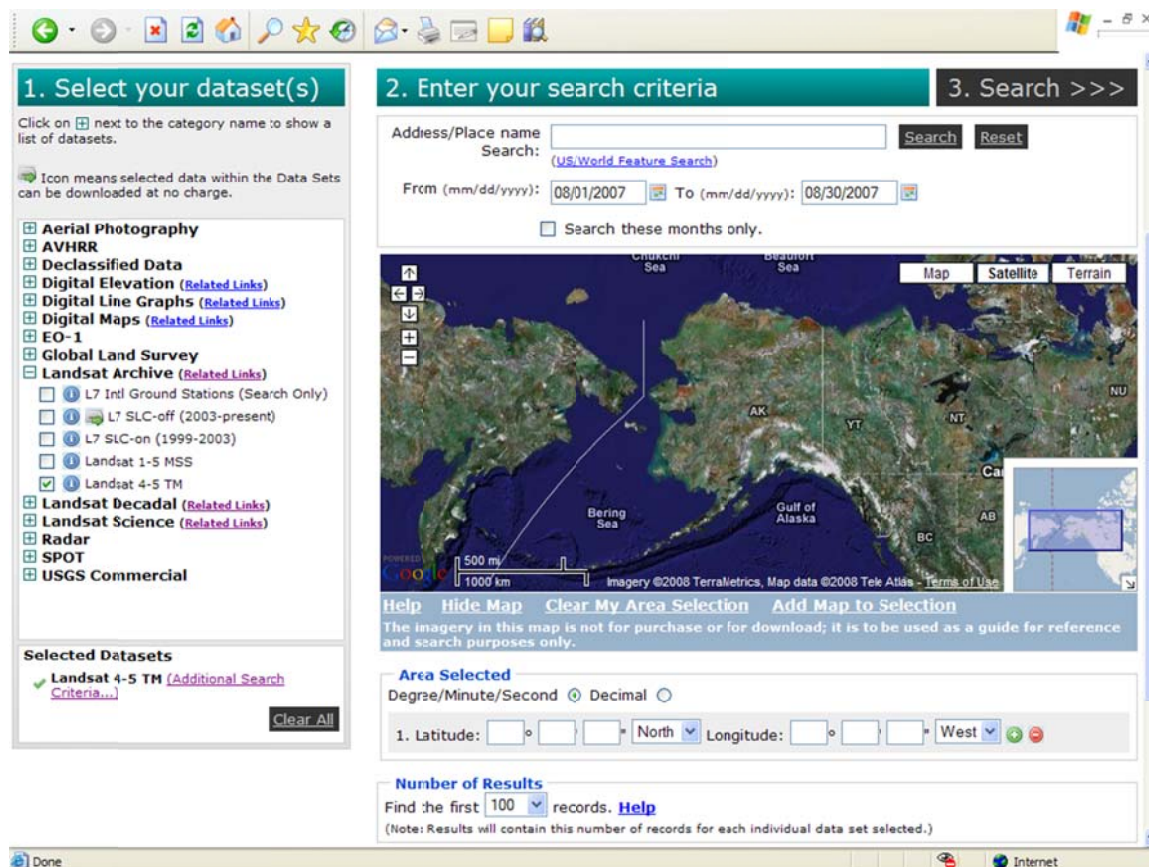


Figure 1-2. EROS website – selecting datasets.

To further refine the dataset search criteria, go to the “Selected Datasets” portion of the “Select your Dataset(s)” window and click on “Landsat 4-5 TM (Additional Search Criteria.....).”

http://edcsns17.cr.usgs.gov - EarthExplorer: Dataset-Specific Search Criteria - Microsof...

Dataset-Specific Search Criteria

Landsat 4-5 TM

Effective April 2, 2007, the radiometric calibration of Landsat 5 (L5) Thematic Mapper (TM) data will be updated. For more information, please visit http://landsat.usgs.gov/technical_details/calibration_files/l5_lut.php

International Landsat Data: For many locations outside the U.S., there may be Landsat scenes that were collected by the sensor but the data is not archived or distributed by USGS Earth Resources Observation and Science Center (EROS). These scenes may be available from other International Ground Stations. Please visit the Landsat Web site for more information [Landsat Web Site](#).

Landsat Scene Identifier

Landsat Scene Identifier:

OR

OR

OR

OR

OR

OR

OR

OR

Station Identifier

Station Identifier: All

Day Night

Day Night: Day

Browse Exits

Browse Exits: All

Path Row Search

WRS Path: to

WRS Row: to

Cloud Cover

Cloud Cover: Less than 60%

Internet

Figure 1-3. EROS website – selecting specific search criteria.

In the screen that appears, there are several criteria that can be selected to refine your search, such as: [Day Night](#), [Cloud Cover](#) and several others. To eliminate unacceptable imagery from the search results, select a couple components in this window:

- [Day Night](#) – select “Day”
- [Cloud Cover](#) – select “Less than 60%”
- Select “OK”

Based on Landsat 5 flight path and swath width, the following is a tally of the minimum number of Landsat scenes required to cover the glacier bearing parks in the SWAN:

- KEFJ – 1 scene (path 69, row 18; path 69, row 19),
- LACL – 3 scenes (path 72 row 17, path 71, row 18, path 71, row 17),
- KATM – 1 scene (path 71, row 19).

Enter your search criteria

In this window of the webpage, you can identify the search dates (to and from), geographic location and you can limit the number of results returned in the search.

Search Dates (From and to in mm/dd/yyyy format). Mid-August through September imagery should be identified in the search. Check the box “Search these months only” and your search becomes a seasonal search over the span of years identified. This eliminates all imagery outside the August-September time frame.

The next step is to toggle in the upper left of the map image to pan and zoom to the region of interest. To move the image around, click and drag. Once your region of interest is displayed, click with your mouse at the northeast corner of the region of interest and click again at the southwest corner of the region of interest. This defines the geographic limits of the search area. The glacierized region of LACL is used in the example.

The “Number of results” is the last item to fill out in this window. Limit the search to 100. This ensures that all available results will be identified.

The following example shows the EROS website with search criteria appropriate for Landsat 5 data from 1985 through 2009, seasonally for August 15 through September 30 only, returning 100 results.

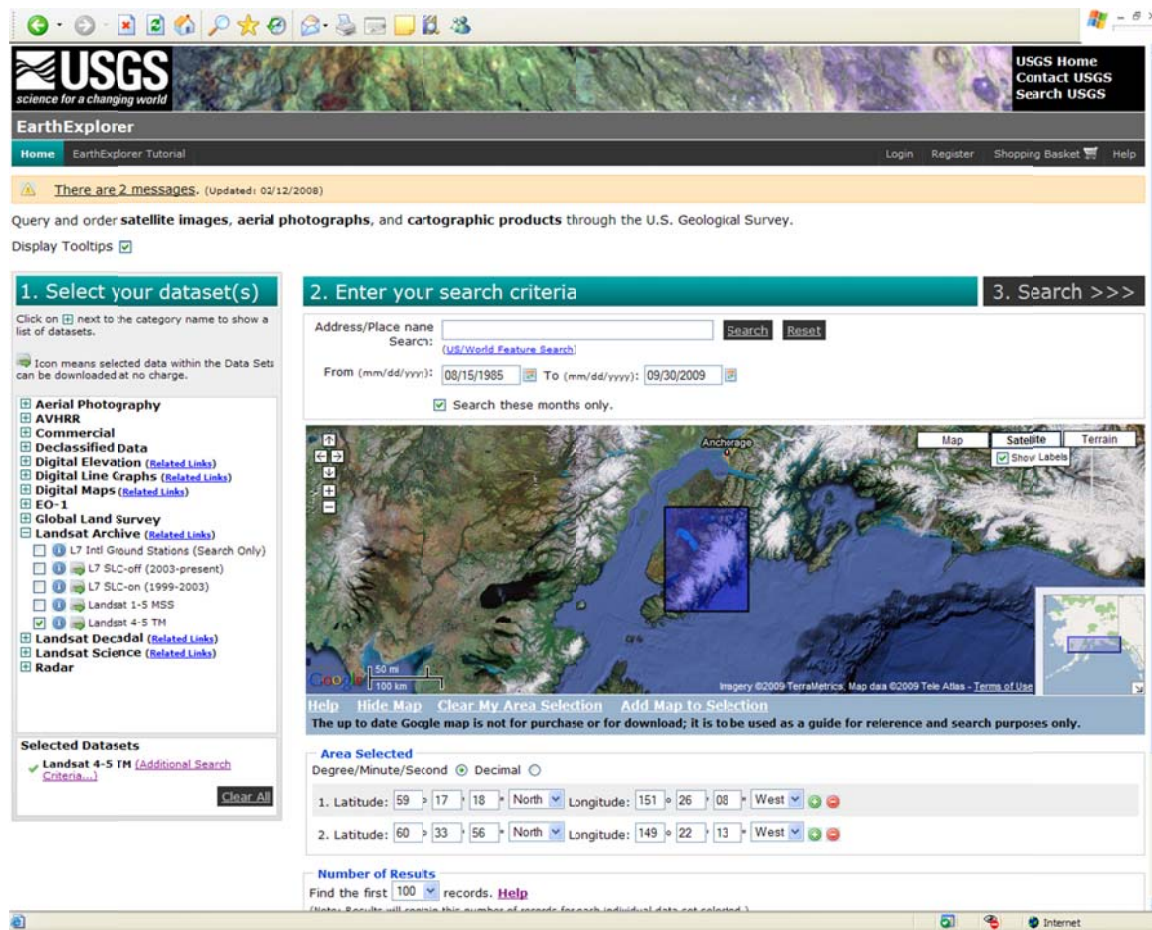


Figure 1-4. EROS website. Identifying date range, geographic extend and maximum possible or returns for meeting the search criteria.

Next, click on the “Search” button. The search may take several minutes to complete. The results screen is shown in Figure 1-5.

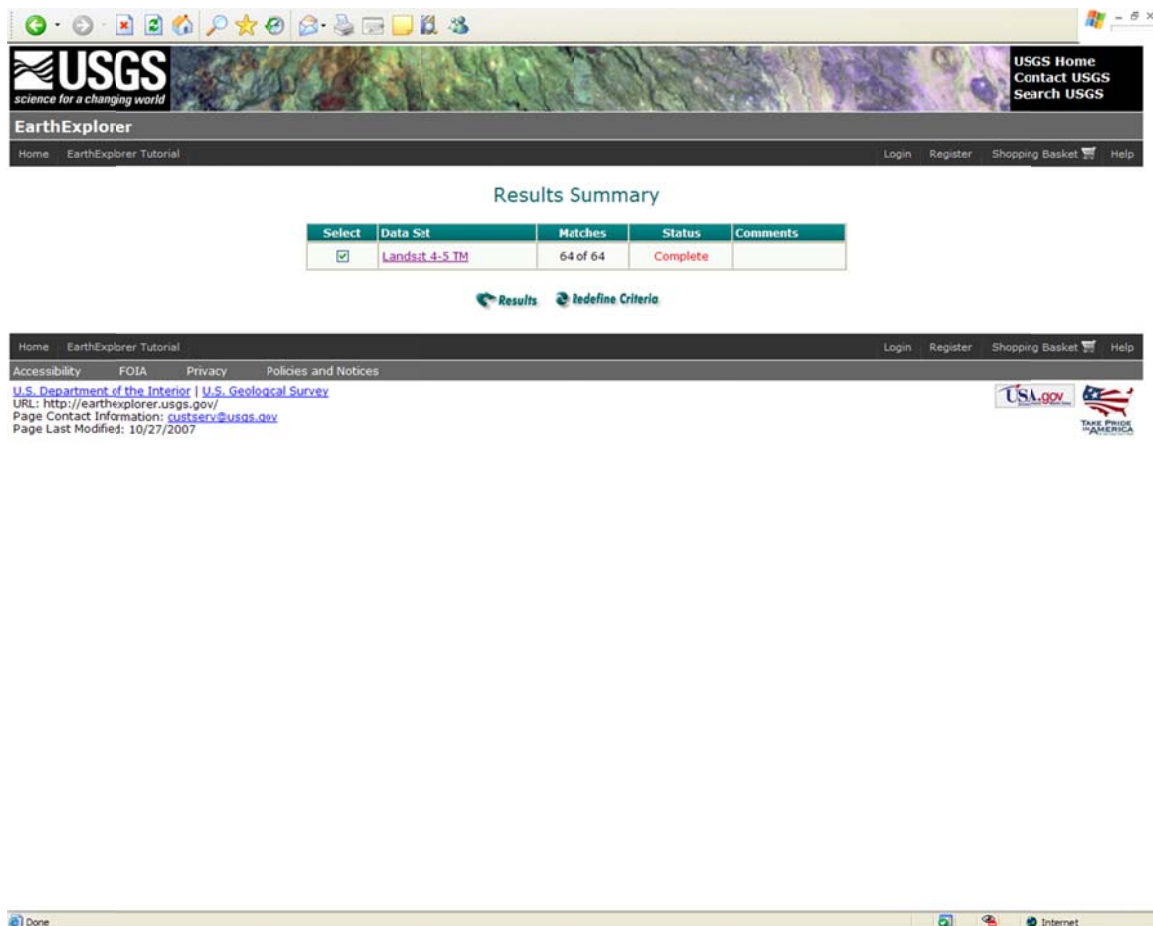


Figure 1-5. EROS website – Summary Results of the search criteria.

The data set and number of matches to the search criteria are displayed when the search is complete. Click on the data type identified under “Data Set” and the screen shown in Figure 1-6 appears.

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EarthExplorer

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Results

International Landsat Data: For many locations outside the U.S., there may be Landsat scenes that were collected by the sensor but the data is not archived or distributed by USGS EROS. These scenes may be available from other International Ground Stations. Please visit the Landsat Web site for more information [Landsat Web Site](#).

NEW! If a scene is not available for Download, add the desired scene to the Shopping Basket and proceed with the order, for which you will not be charged. An email notification will be sent to you once the data is available for download. We recommend that you save your search results using the Save Results™ feature. This allows you to easily search for your scenes after they have been processed and become available for download. *You must be logged in to use the Save Results feature.

NOTE: A maximum of twenty-five scenes can be requested for download processing at a time. Scenes added over that amount will have to be removed from the Shopping Basket before submitting the request.

Show Map Pop-out

The up to date Google map is not for purchase or for download; it is to be used as a guide for reference and search purposes only.

Landsat 4-5 TM
64 of 64 metadata records retrieved. Showing 11-20

Preview Image	Show Footprint	Show All Fields	Exclude	Order Qty	Price	Downloadable	Landsat Scene Identifier	Date Acquired	WRS Path	WRS Row	WRS Type	Cloud Cover	Sun Elevation	Sun Azimuth	On Demand
	Show	Show	☐	☐	\$0.00	Available by ordering	LT50670182103256PAC01	2003/09/13	067	018	2	0	32.1029877	159.1034325	Y
	Show	Show	☐	☐	\$0.00	Available by ordering	LT506701821052450LC00	2005/09/02	067	018	2	20	36.2752273	160.990394	Y
	Show	Show	☐	☐	\$0.00	Available by ordering	LT506701821052610LC00	2005/09/18	067	018	2	10	30.4924094	163.1309957	Y
	Show	Show	☐	☐	\$0.00	Available by ordering	LT506801821052680LC00	2005/09/25	068	018	2	20	27.877003	164.3580395	Y
	Show	Show	☐		N/A	Download now	LT506801821062390LC00	2006/08/27	068	018	2	0	38.62832525	161.43206984	N
	Show	Show	☐		N/A	Download now	LT506801821062550LC00	2006/09/12	068	018	2	0	32.98943892	164.15158599	N

Figure 1-6. EROS website – thumbnails and details for each image meeting the search criteria.

A thumbnail of each image is displayed. Scroll through the results. Click on those thumbnail images that appear to be largely cloud free. This will display the image in greater detail. Evaluate these images for their acceptability in meeting the requirements of this protocol.

Note that the image shown in Figure 1-7 is approximately 30% cloudy, but this is acceptable because the glacier area is cloud-free.

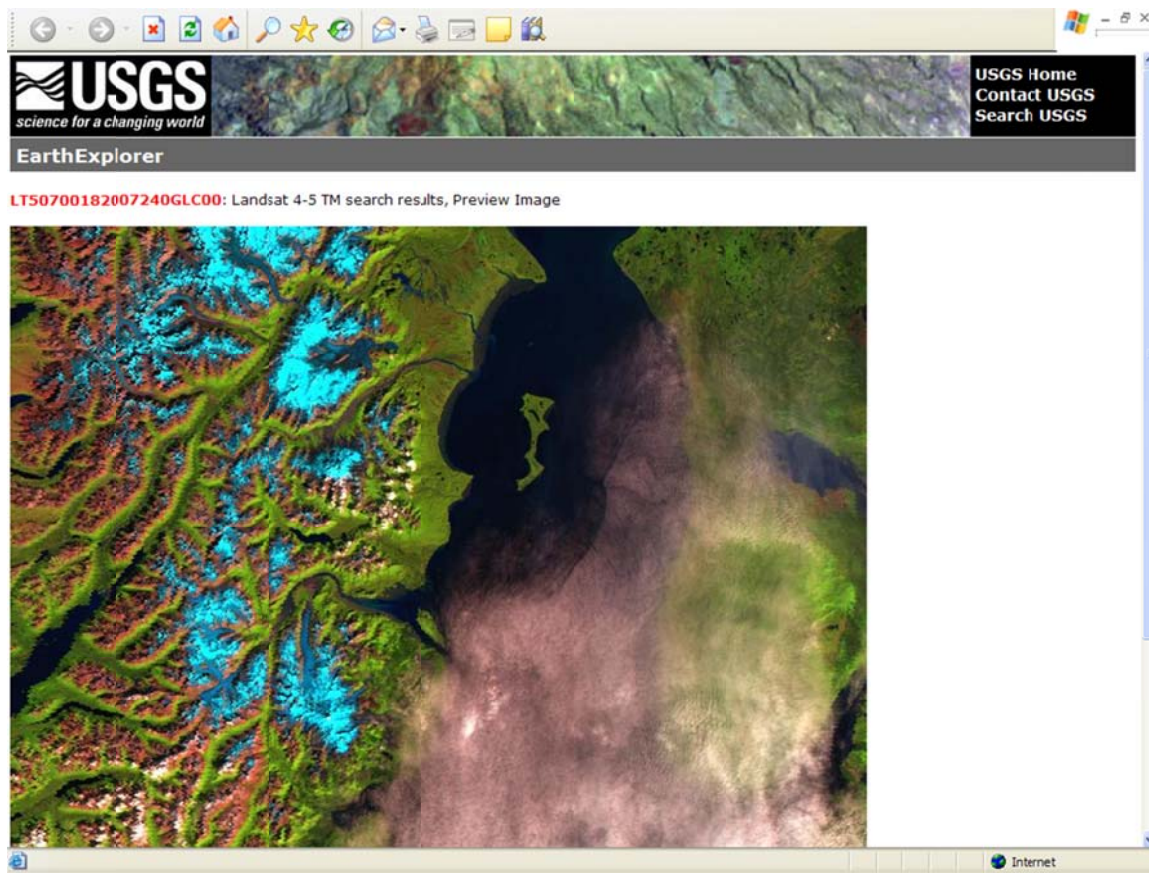


Figure 1-7. EROS website – Expanded thumbnail.

EROS Website - Landsat Data Order

When Landsat imagery is identified that meets the late-season, cloud-free requirements with little or no early-season snow requirements, it is time to order or download the image. If you are not “Signed in” on the EROS website, do so now.

From Figure 1-7, some data is available immediately if the “Download now” option is activated. Click on the “Download now” button and follow the instructions. Otherwise, select the box under the Column “Order” and then select “Add Selected Items to Shopping Basket” near the bottom of the page. Then select “View Shopping Basket” (Figure 1-8).

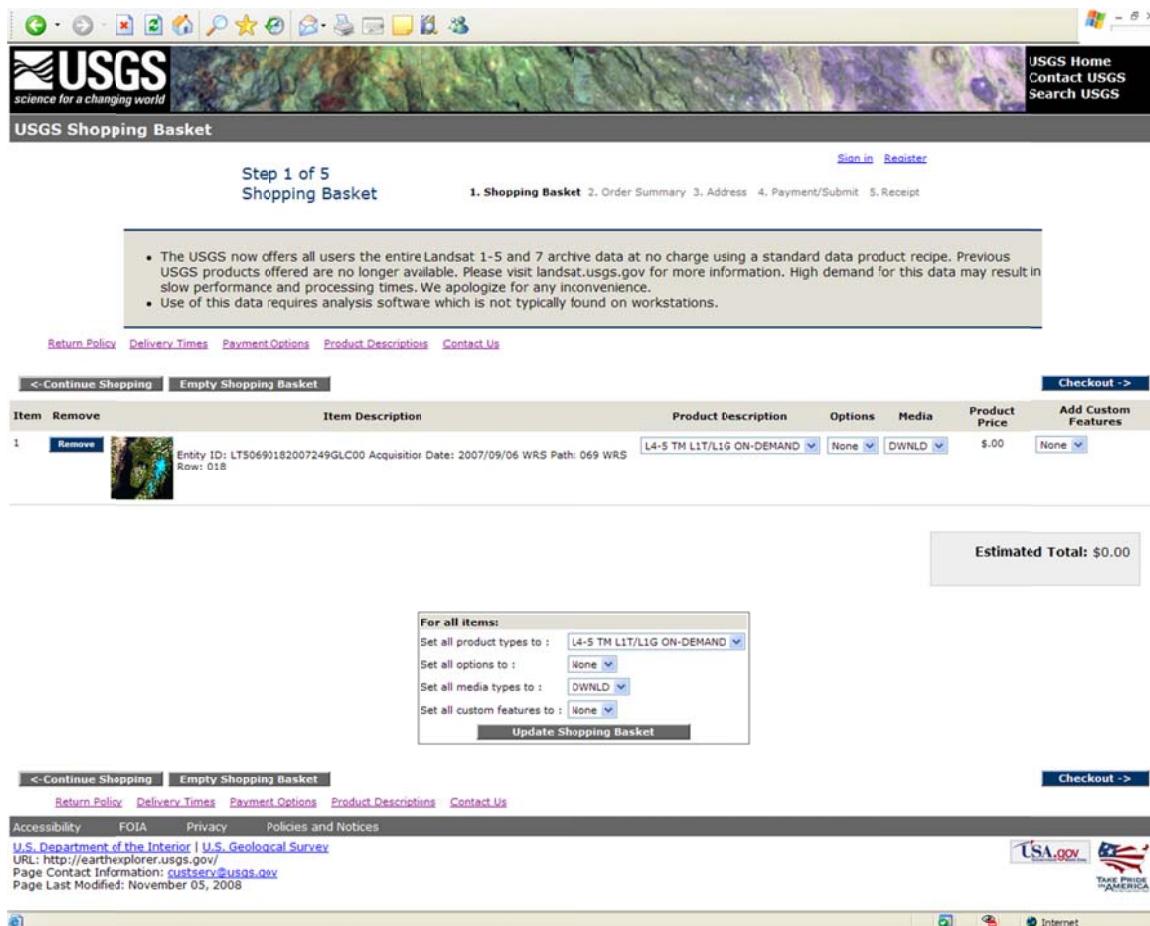


Figure 1-8. EROS website – shopping basket.

Verify that the images you need are identified in you “Shopping Basket” and select “Checkout” and the screen shown in Figure 1-9 appears, verifying that the order is being processed.

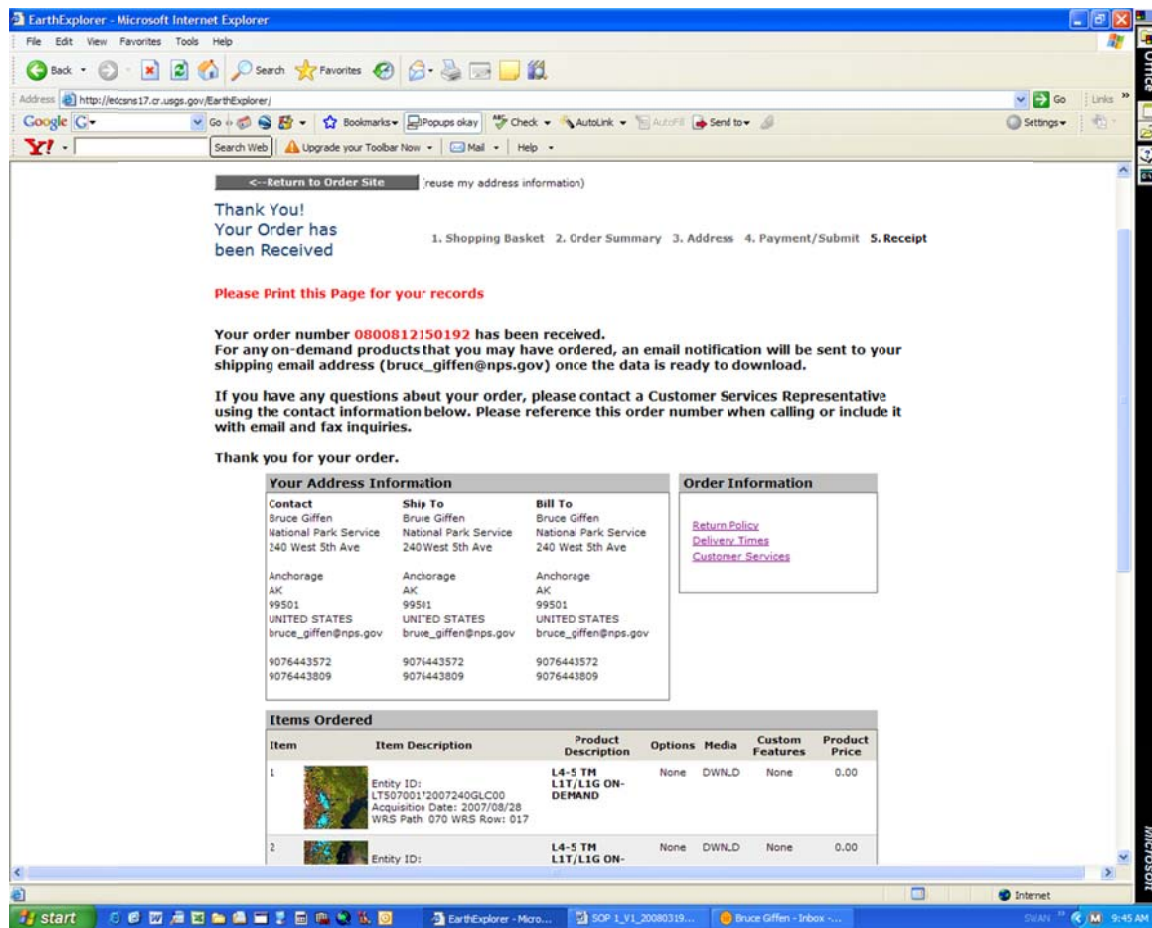


Figure 1-9. EROS website – order confirmation.

An email will be received verifying the order and when the order has been processed (Figure 1-10) and another email will be received with downloading instructions (Figure 1-11).

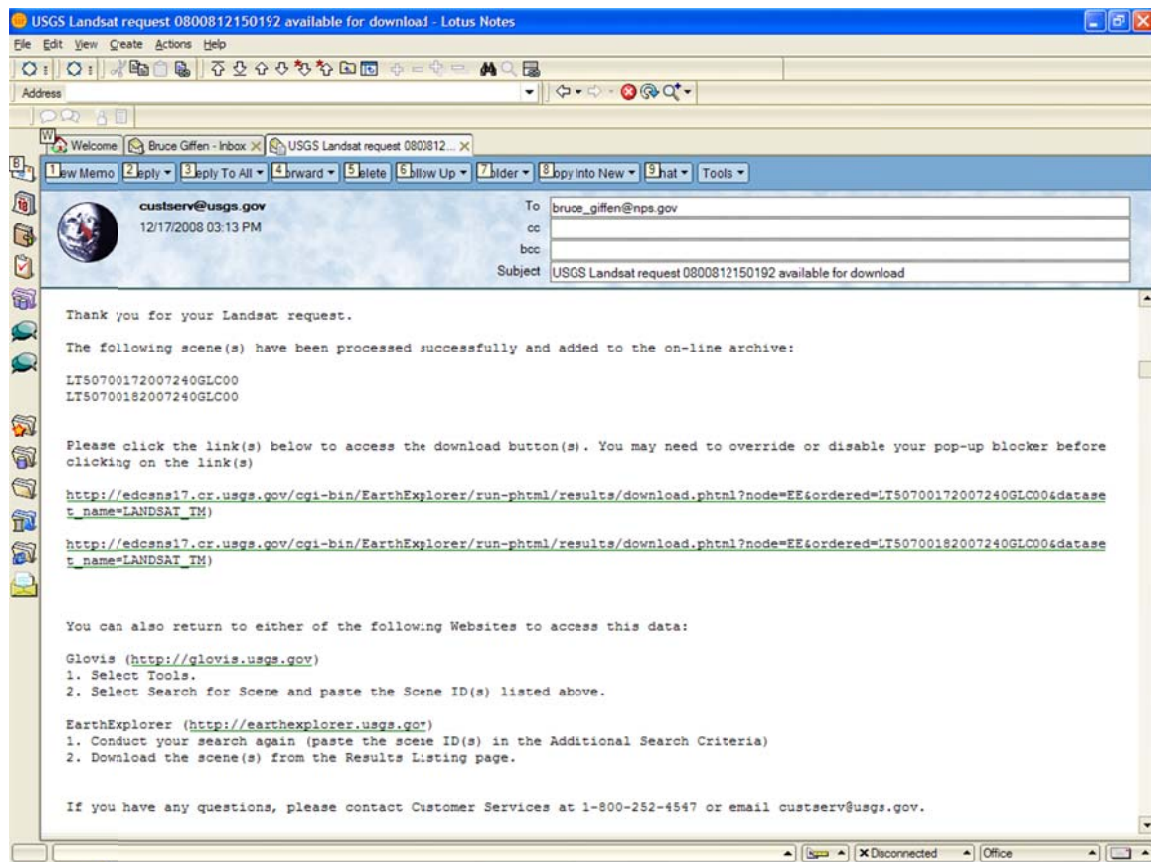


Figure 1-10. Email for the EROS Data Center – notification that ordered imagery is available for downloading.

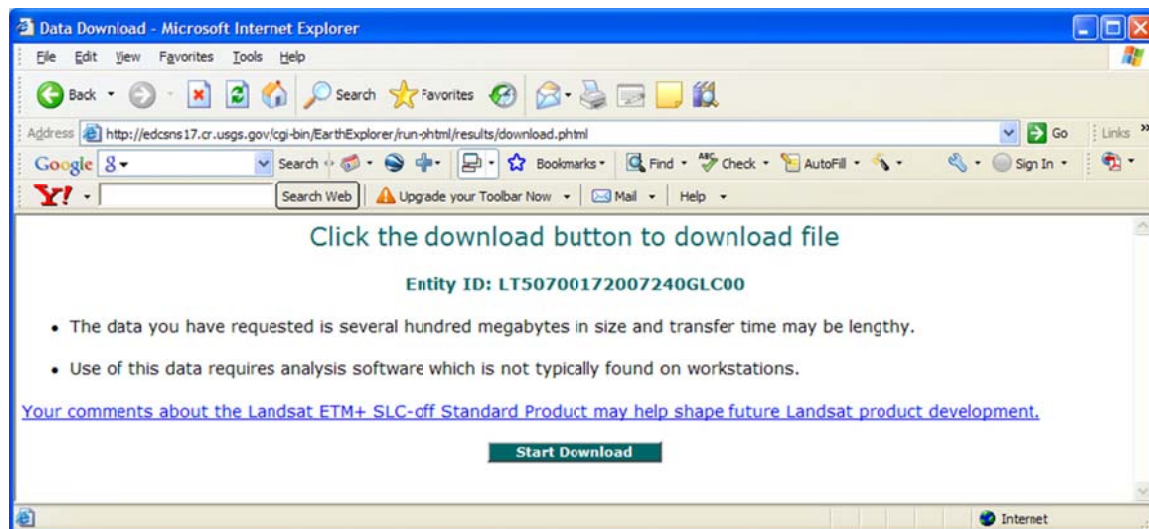


Figure 1-11. EROS website – web-link provided in email from EROS notifying that imagery is ready for download.

The downloading instructions in the email are clear. When you click the download button, a Windows message appears asking to “open” or “save” the file – select “save” and “ok.” Navigate to a previously created folder (see Figure 1-12) where the file should be saved. The folder naming convention for the Landsat imagery is: Landsat_YYYYMMDD

Where:

- Landsat = self explanatory
- YYYYMMDD = year, month and day of the Landsat imagery.

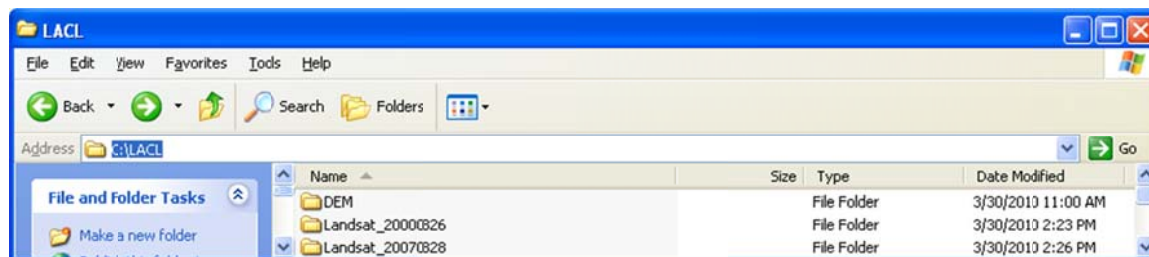


Figure 1-12. Landsat imagery download as a Win Zip file in appropriate folder which you have created.

For each Landsat image downloaded from EROS, there will be one Winzip file in the each folder that was created with the standard naming convention for Landsat imagery (Figure 1-13).

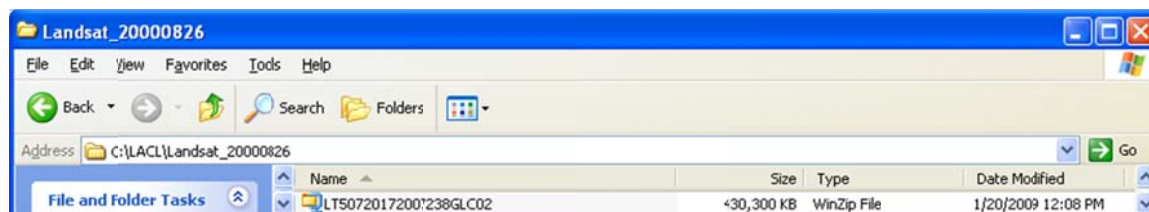


Figure 1-13. WinZip file holding the Landsat imagery downloaded from EROS.

Double click on the each zip file. WinZip will launch and decompress the Zip file into a group of files including Landsat imagery bands and text and “readme” files (Figure 1-14).

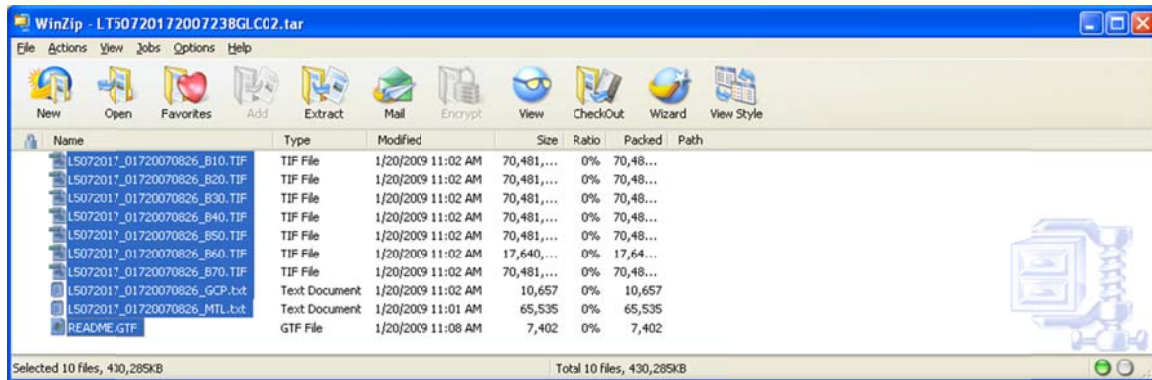


Figure 1-14. Decompressed WinZip file.

Select all files and “Extract” them to the appropriate folder (“Landsat_20700826”) you already created (Figure 1-15).

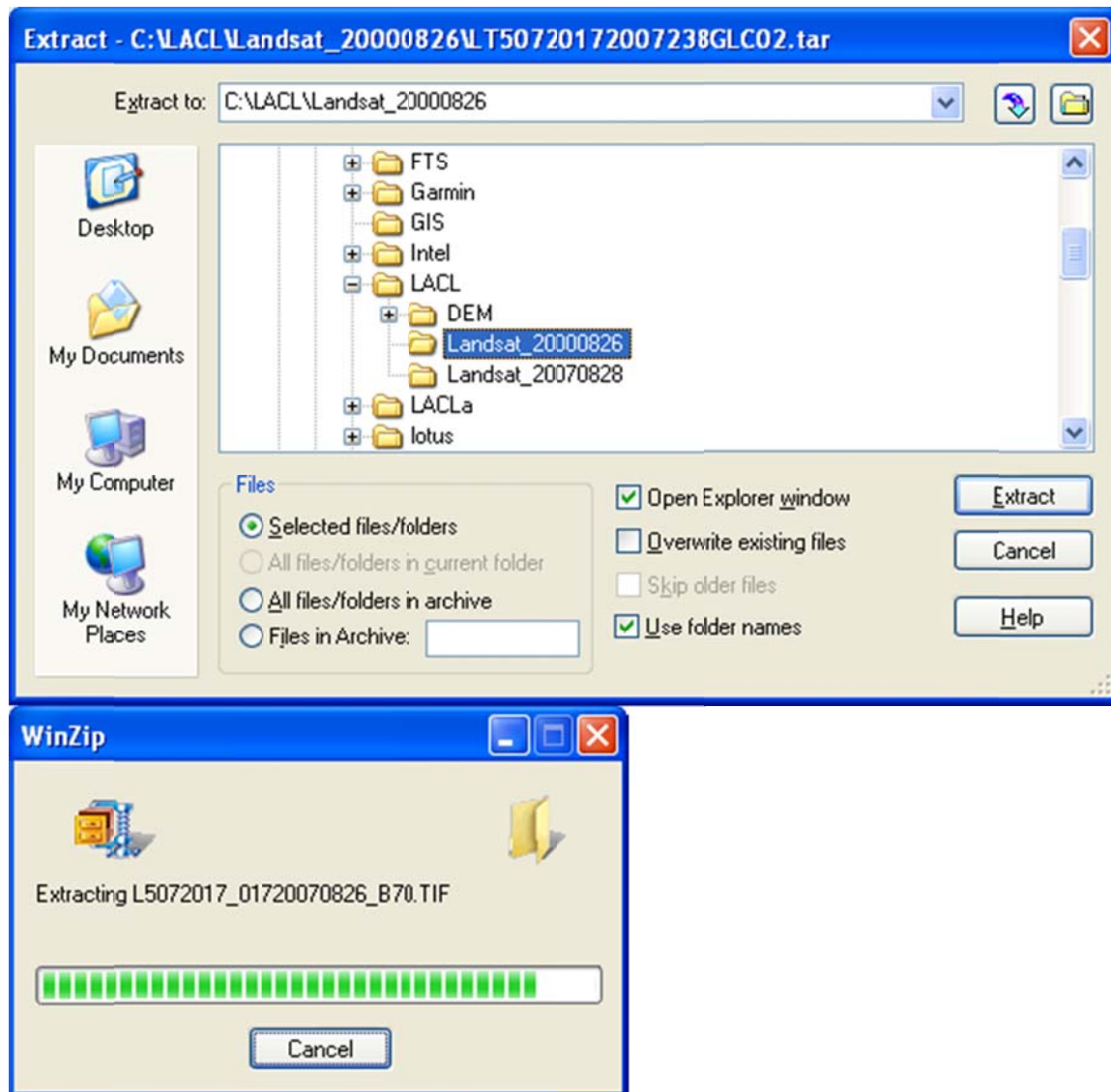


Figure 1-15. Extracting the decompressed Landsat image files to the “Landsat_20700826” folder.

The Landsat geoTIFF bands are located in a folder using the standard naming convention for Landsat imagery as received from EROS (Figure 1- 16).

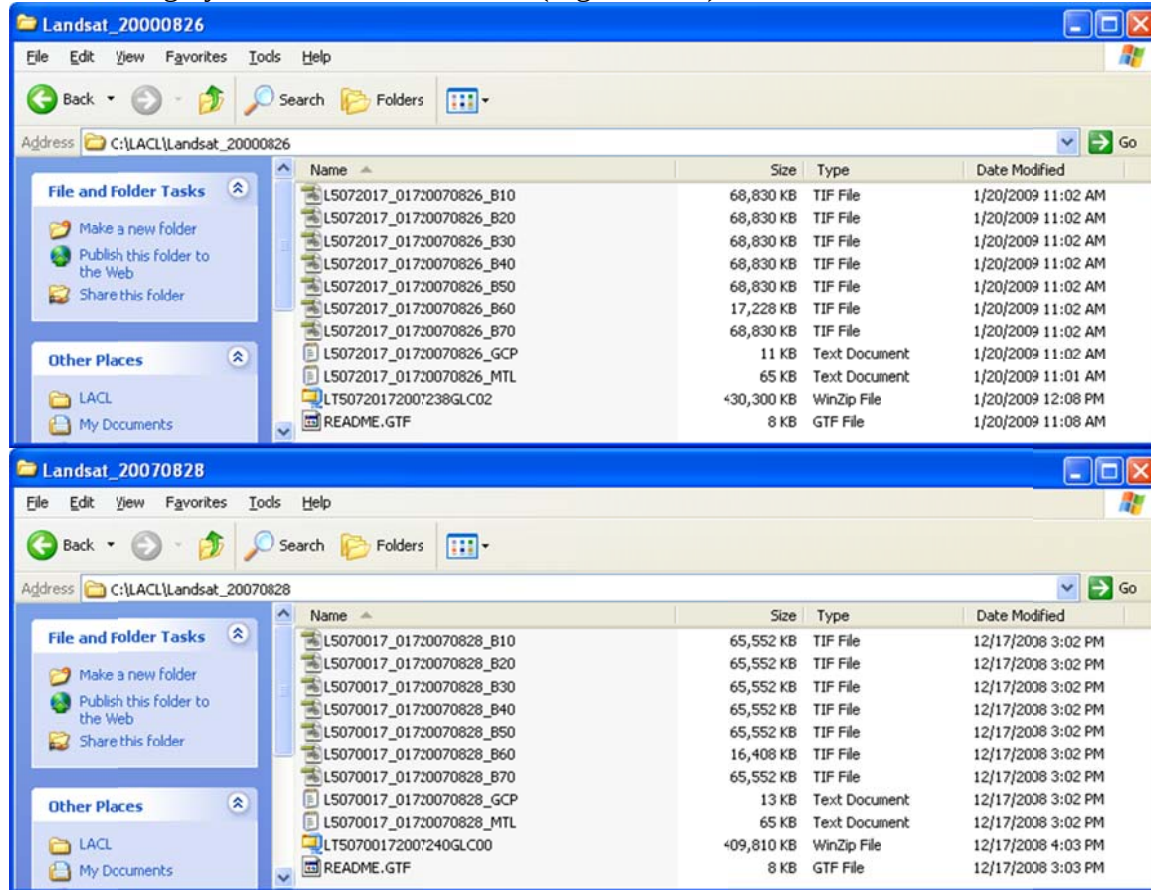


Figure 1-16. A look at the folder and the extracted Landsat geoTIFF files and text files. Note that there are two Landsat folders (“Landsat_20700826” and “Landsat_20700828”) here with two sets of imagery and text files.

The Landsat image is now ready to load into image processing software.

The Alaska Landsat data is delivered with the following parameters:

Map projection: UTM, Zone 5 or Zone 6
Pixel: 28.5 or 30 meters
Datum: WSG84
Image orientation: Map (north up)
Correction (Level L1T/L1G)
GeoTIFF

Standard Operating Procedure (SOP) #2

Landsat Image Analysis in a GIS – Part 1

Version 1.0

Change History

Version numbers will be incremented by a whole number (e.g. Version 1.3 to Version 2.0) when a change is made that significantly affects requirements or procedures. Version numbers will be incremented by decimals (e.g. Version 1.6 to Version 1.7) when there are minor modifications that do not affect requirements or procedures.

The following revisions have occurred to this plan since January 2011.

Version #	Date	Revised by	Changes	Justification

This Standard Operating Procedure describes the procedures to perform simple band math (band ratio techniques) and determine threshold values used to automatically classify Landsat imagery for snow and glaciers in support of the Glacier Monitoring protocol in Southwest Alaska Network (SWAN) parks.

Overview

This Standard Operating Procedure explains the steps to take in initiating glacier ice mapping using Landsat satellite imagery. Simple band math techniques are used to manipulate the Landsat data, which in-turn allows for the automated classification of snow and glacier ice pixels from all other pixels in the Landsat image. Band math technique and threshold values are evaluated using ArcGIS software.

Attempts over the years to develop an automated classification technique to accurately define glacier ice extent have not proved entirely successful. Debris covered ice is likely the single largest obstacle to success because the reflectance of debris covered ice is the same as the surrounding moraine material. Manual interpretation of the Landsat data will necessarily be a large part of the process in areas of debris cover.

The goal of this SOP is to identify an appropriate band ratio technique and threshold value(s) that will be used to automate the classification of permanent snowfields and glacier ice as much as possible and remove as much of the human interpretation component as possible from the mapping effort. Not only will this enhance un-biased repeatability of this protocol, but it will significantly reduce the workload burden for the SWAN parks. Accuracy and repeatability is critical to this protocol and therefore relies on the following:

- Landsat satellite imagery must meet the criteria specified in SOP #1 for cloud-free, late-season imagery.
- Imagery classification techniques to automate as much of the glacier extent mapping effort as possible (refer to SOP #3).
- Manual editing techniques of the glacier extent boundary in a GIS (refer to SOP #4) primarily in areas of heavy debris cover.

When careful attention is maintained throughout the mapping effort, accuracy and repeatability is substantially increased.

Procedures - Mapping Glacier Extent

What is a Glacier?

To help standardize glacier mapping, the definition of what falls into the category called “glacier extent” must be clearly defined. The following is from the GLIMS definition of a glacier and is used for this protocol (Raup and Khalsa 2010).

A glacier or perennial snow mass consists of a body of ice and snow that is observed at the end of the melt season. This includes, at a minimum, all tributaries and connected feeders that contribute ice to the main glacier, plus all debris covered parts of it. Excluded is all exposed ground, including nunataks.

The following circumstances will be considered when mapping glacier boundaries:

- 1. Bodies of ice above the bergschrund that are connected to the glacier shall be considered part of the glacier, because they contribute snow (through avalanches) and ice (through creep flow) to the glacier.*
- 2. A tributary in a glacier system that has historically been treated (and named) as a separate glacier should, within the GLIMS framework, be included as part of the glacier into which it flows. The name field for the glacier should be populated with all relevant names of tributaries.*
- 3. Any steep rock walls that avalanche snow onto a glacier but do not retain snow themselves are NOT included as part of the glacier.*
- 4. A stagnant ice mass still in contact with a glacier is part of the glacier, even if it supports an old growth forest.*
- 5. All debris covered parts of the glacier must be included.*
- 6. If no flow takes place between separate parts of a continuous ice mass, they should, in general, be treated as separate units, separated at the topographic divide. However, for practical purposes, such an ice mass may be analyzed as a unit at the analyst's discretion, if delineation of the flow divides is impossible or impractical. If the same system is analyzed in the same way later, it will have the same glacier ID, and can therefore be compared. If the system is analyzed in more detail later by breaking it into its component glaciers, those pieces will get new IDs (ID of system will be “parent ice mass” ID for each part), and future analyses of those pieces, if done in the same way, will be comparable.*
- 7. It is possible that an ice body that is detached from another may still contribute mass to the latter through ice avalanches, or it may no longer do so. It is practically impossible to tell which is the case from a single satellite image. Therefore, within GLIMS, adjacent but detached ice areas should, in general, be considered as different “glaciers”, regardless of whether they contribute mass to the main glacier through snow or ice avalanches. However, at the analyst's discretion, detached ice masses may be included as*

parts of one glacier. This is similar to the situation described in 5 above. If the pieces are analyzed separately later, each piece should be given a new GLIMS ID, the old one being used as the “parent ice mass” ID for all the pieces.

- 8. Regarding the lower parts of lateral snowfields, whose extent varies from year to year map only at the end of the ablation period, preferably in a year without snow outside of the glaciers, to exclude seasonal snow. Then map everything that is connected to the glacier. If snowfields are identifiable, they should be disconnected from the main glacier. For hydrological purposes they can be included in the GLIMS Glacier Database under a separate GLIMS glacier ID, but they must be marked as a snowfield. Lateral glacier outlines that might be hidden by seasonal snow or by avalanches should be labeled as preliminary, or even the entire glacier can be excluded. Ice avalanche cones below a glacier terminus (dry calving) are not a part of the glacier.*

Rock glaciers and heavily debris covered glaciers tend to look similar, but their geneses are different. GLIMS does not currently deal with the former, but does include the latter.

Software Selection

There are several satellite image processing software packages that can be used to view, analyze, enhance and process Landsat imagery data: ERDAS, ENVI and PCI are just a few. Recently, ESRI has incorporated image classification tools into their ArcGIS software package. Each of these software packages can perform the simple band math and threshold analyses required by this SOP. However, to simplify the protocol and reduce the software packages employed, the process will be presented here using ArcGIS.

Landsat Imagery Processing and Analysis

ArcGIS has many spatial analysis tools available for imagery analysis. A general overview of the tools used in support of this SOP is presented below.

Multi-spectral Classification Methods

Several classification techniques using simple band math and the identification of appropriate threshold values can be used to classify Landsat imagery for permanent snow and glacier ice. The techniques are similar regardless of the specific band-math formula being used.

Four simple band math techniques have been tested for glacier mapping:

- $\text{NDSI} ((\text{TM2}-\text{TM5})/(\text{TM2}+\text{TM5}))$
- $\text{NDVI} ((\text{TM3}-\text{TM5})/(\text{TM3}+\text{TM5}))$
- $\text{TM3}/\text{TM5}$
- $\text{TM2}/\text{TM5}$

Where:

NDSI is the Normalized Difference Snow Index,

NDVI is the Normalized Difference Vegetation Index and

TM2 refers to Landsat Thematic Mapper Band 2 and so forth.

For the most part, each of these techniques (with appropriate threshold value(s)) produces good results for clean glacier boundaries. Each of these techniques is sensitive to the threshold value(s) applied and will produce varying results in areas of shadows and/or debris covered ice. A range of threshold values should be tested to identify the threshold value that best classifies the Landsat image for snow and glacier ice. These classification techniques are fast and accurate for clean glacier and snow boundaries, but require substantial manual editing for areas of debris covered boundaries.

The best band math technique appears to be TM3/TM5 ratio, with appropriate threshold value(s). TM3/TM5 ratio appears to isolate snow and glacier ice pixels across the entire image better than other techniques, especially in shadow areas and areas of light debris cover.

None of the techniques produce acceptable results in areas of heavy debris covered ice. These areas will require manual interpretation to correct the glacier margin.

Time spent on the process of identifying the most effective threshold will result in an accurate automated mapping effort, while at the same time minimize the amount of manual editing required to complete the glacier mapping effort.

Outlining the steps and procedures of band math and determining threshold value(s) using ArcGIS are presented below. The person performing these duties should be well versed in ArcGIS, as good results are based on a series of trial and error efforts until satisfactory results are achieved.

Once the threshold value is identified, this information is then used to classify the Landsat data and produce shapefiles based on the classification (SOP #3). These shapefiles are then manually edited to correct areas of misclassification (SOP #4).

The general instructions that follow describe how to navigate ArcGIS software to perform simple band math using raster data (Landsat) and determining appropriate threshold value(s).

Step 1 Landsat Raster Data in the Landsat_YYYYMMDD Folder

From SOP #1, the Landsat_YYYYMMDD folder(s) contain Landsat data necessary for the image classification and color composite image preparation.

Before classification of the imagery can begin, there is one step that needs to be accomplished so that the original Landsat image files are not modified in any way. EROS provides Landsat data in the following format:

Map projection: UTM, Zone 5 or Zone 6
Pixel: 28.5 or 30 meters
Datum: WSG84
Image orientation: Map (north up)
Correction (Level L1T/L1G)
GeoTIFF

The first step is to create a copy of the original Landsat raster TIFF files as delivered by EROS (WGS84, UTM Zone 5 or 6). It is important to complete the following procedure in ArcCatalog. Figure 2-1 displays the command in ArcCatalog. You will need to complete command six times, one time for each of the Landsat bands.

- Copy Raster Management: Copy all six Landsat bands one at a time and name the copies “b1,” “b2,” “b3,” “b4,” “b5,” “b6”. (i.e. “L5070017_01720070828_B10” copy to “b1”) (Don’t change any of the environmental settings.)

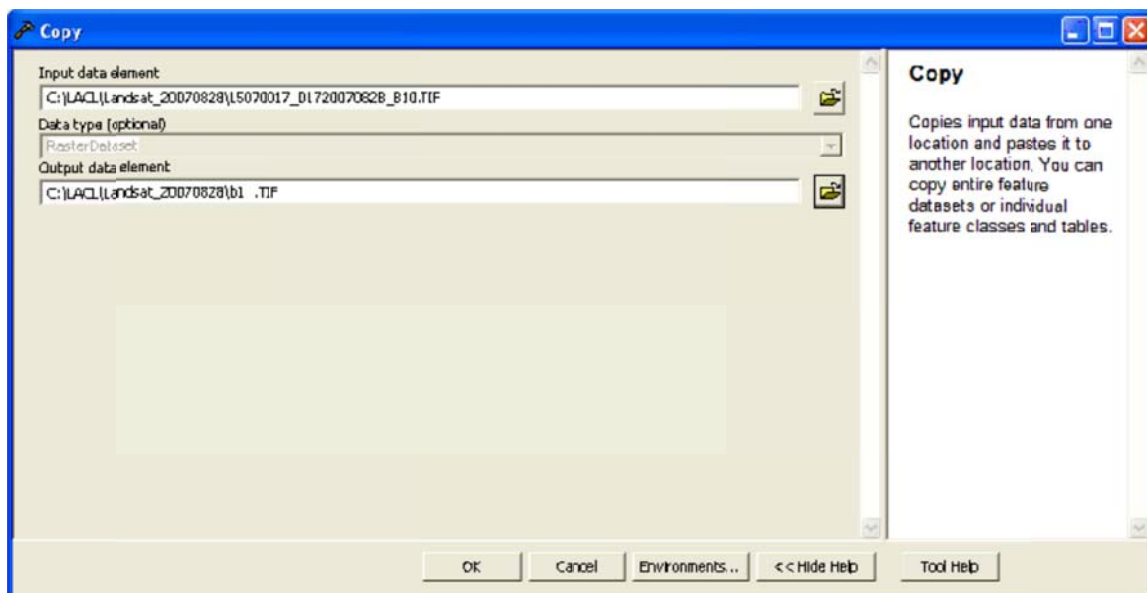


Figure 2-1. Copy raster command in ArcCatalog.

Verify for each new raster TIFF file created that the datum and projection is that of the original raster data (Figure 2-2).

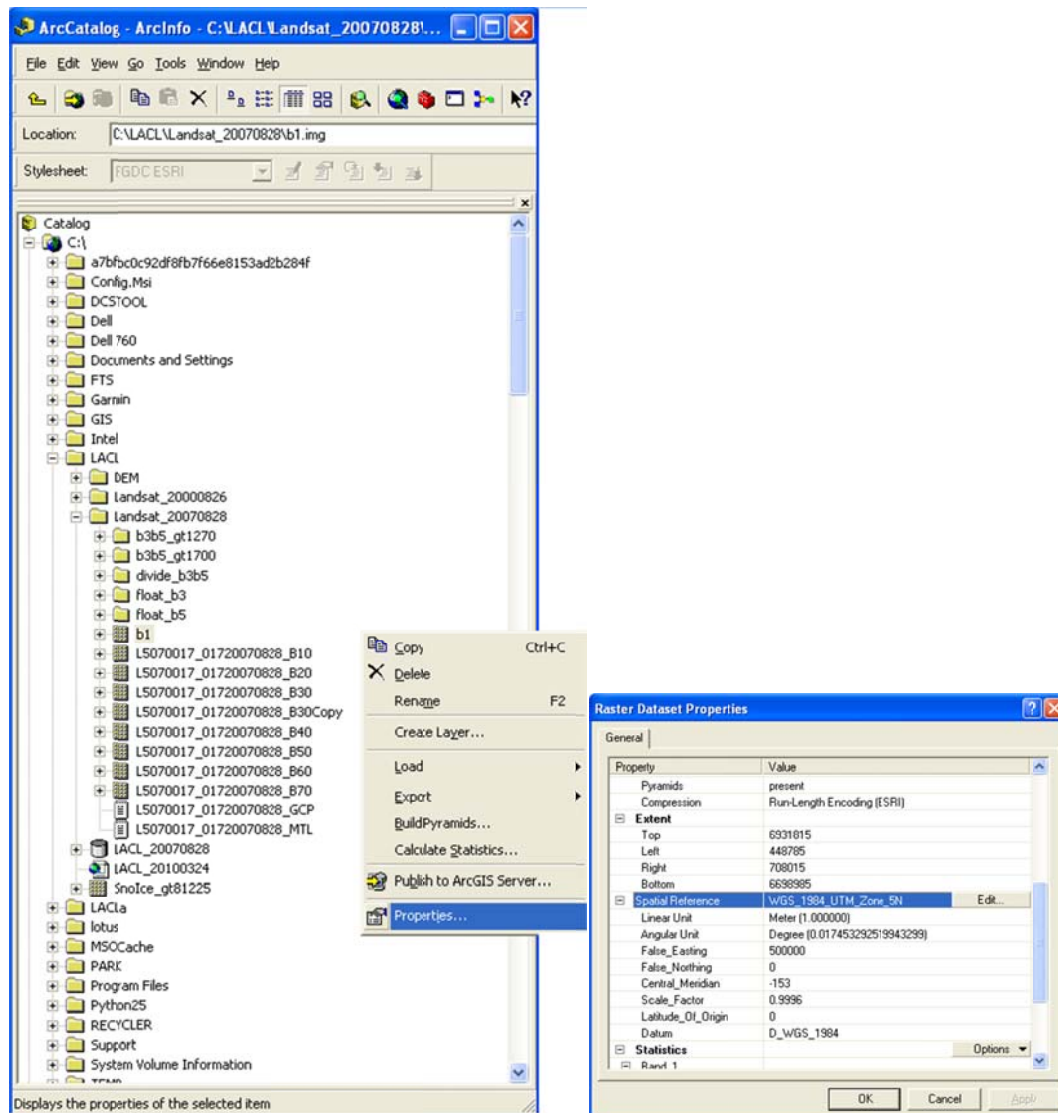


Figure 2-2. Verifying datum and projection of raster data. Right click on the raster file of interest and then click on “Properties.” The “Raster Dataset Properties” dialog box appears – scroll down to “Spatial Reference” to verify the datum and projection.

Figure 2-3 shows the basic folder and file naming convention in a “Landsat_YYYYMMDD” folder prior to any imagery analysis or imagery classification. Note that there are other files in this folder, their creation is described below.

Subsequent interim raster classification files and ArcGIS shapefiles will be produced in the native datum and projection of the Landsat imagery.

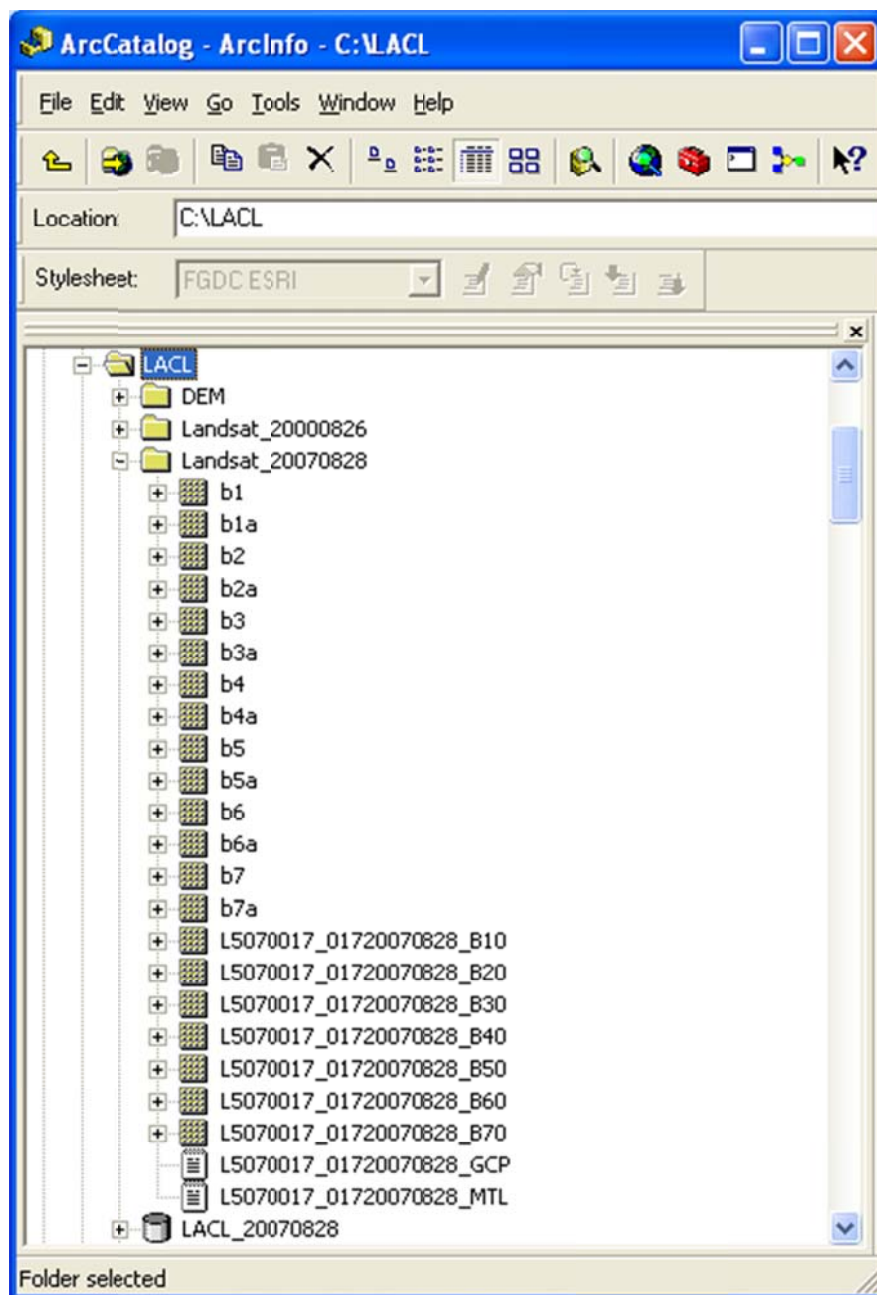


Figure 2-3. File naming convention within the LACL/Landsat_20070828 folder.

Step 2 Create a Color Composite Image

Create a false color composite image using B5 (Landsat Band 5, red), B4 (Landsat Band 4, green), and B2 (Landsat Band 2, blue) (Figure 2-4). This Landsat band combination is very affective for glacier mapping purposes; see Figures 8, 9 and 10. The color composite image file (b5b4b2_composite) is seen in Figure 2-4. A true color composite can be created in the same way using bands B3, B2 and B1.

- Composite Bands (management): Landsat Band 5 (b5), Landsat Band 4 (b4), Landsat Band 2 (b2).

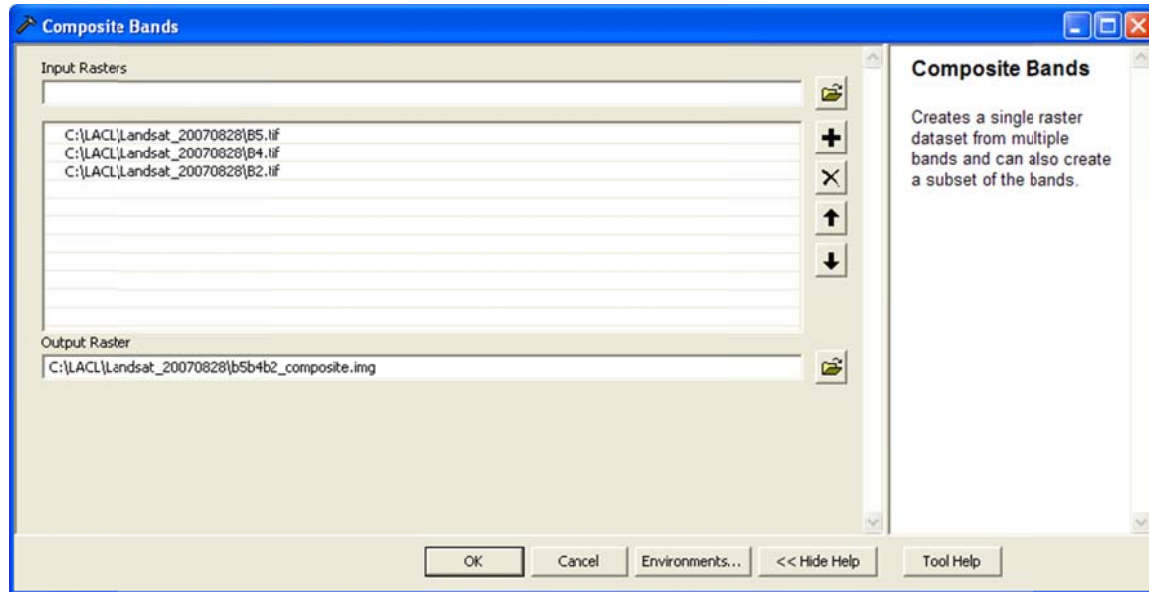


Figure 2-4. Creating a color composite Landsat image using the “Composite Bands” command in ArcCatalog.

Step 3 Band Ratio Techniques

From testing and analysis, it has been determined that a simple band math ration B3/B5 (B3 divided by B5) produces the best results for isolating snow and glacier ice pixels.

The following steps will proceed with an example using B3/B5 ratio and followed by a review of the resultant raster to identify threshold of value(s) that best isolate snow and glacier ice pixels from all other pixels in the image.

Float Appropriate Landsat Bands

In this step, “float” **all** the appropriate Landsat bands to be used in the band math calculations. In this example, Landsat band 3 and band 5 are floated. The following example (Figure 2-5) shows the procedure to float Landsat band 3 and 5. Place the resultant bands in the Landsat_YYYYMMDD folder:

- Float (sa): Float Landsat band 3 and 5 and name the resultant raster files “float_b3” and “float_b5”.

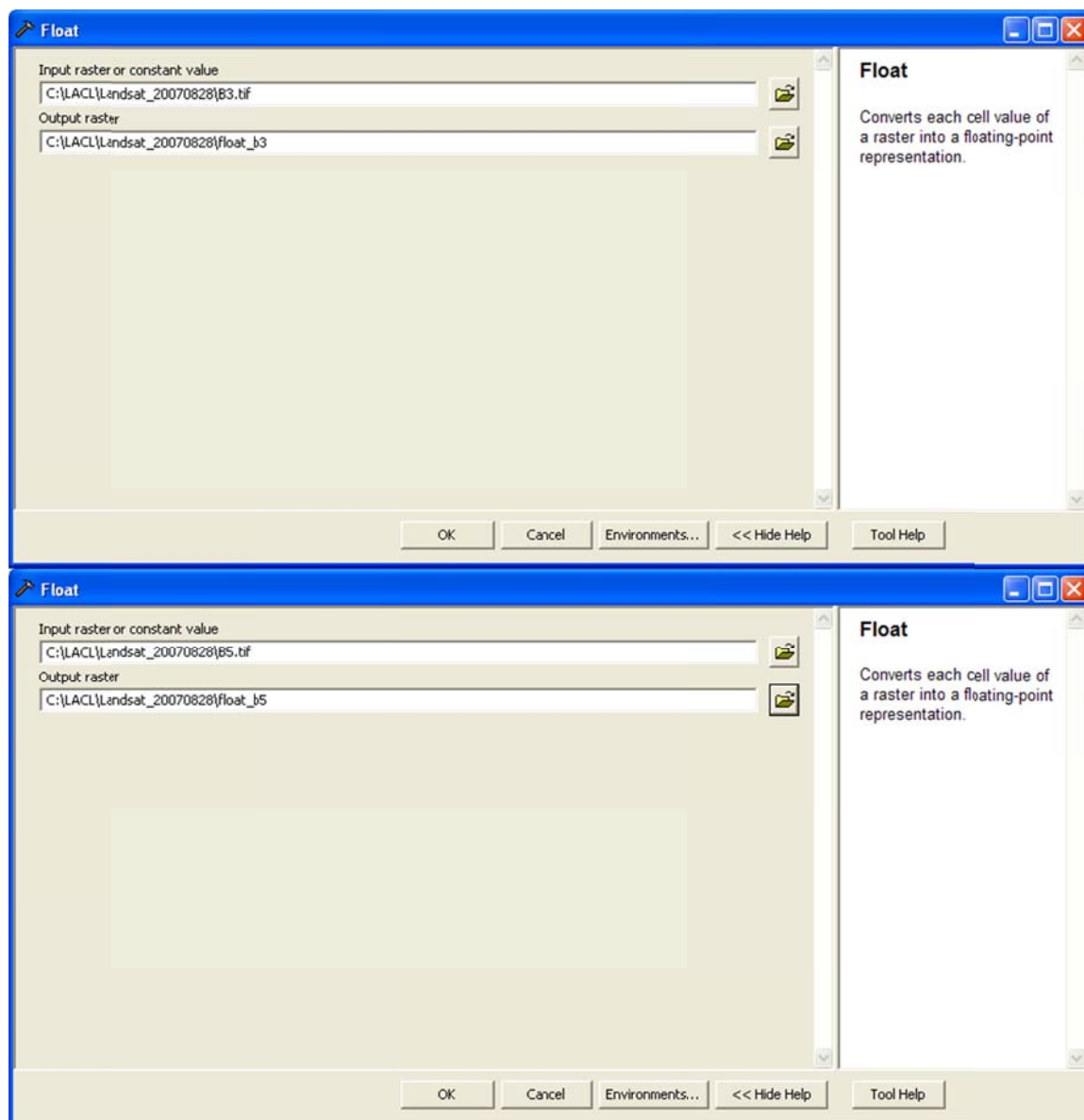


Figure 2-5. “Float” command in ArcCatalog.

Band Math

Next, perform the math expression using the “Floated” bands created in above step.

- Divide (sa): Using the Spatial Analyst Tools>Math>Divide; divide the floated bands “float_b3” by “float_b5”. Name the output raster file “divide_b3b5” (Figure 2-6).

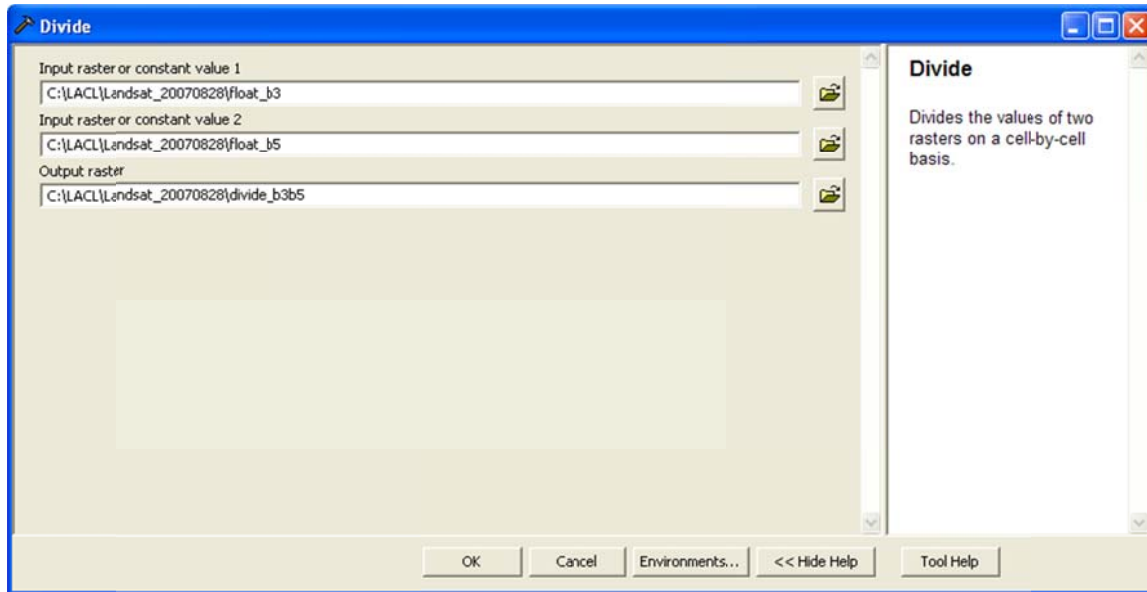


Figure 2-6. “Divide” command in ArcCatalog.

Step 4 Determining Threshold Value(s)

Load the color composite raster image (from Step 2) and the raster created in Step 3 above (divide_b3b5) into an ArcGIS session (Figure 2-7). The “b5b4b2_composite” layer must be the visible layer displayed in the ArcGIS session. Next, select the “Identify” button in ArcGIS and select “divide_b3b5” from the drop-down menu of the “Identify” window pane.

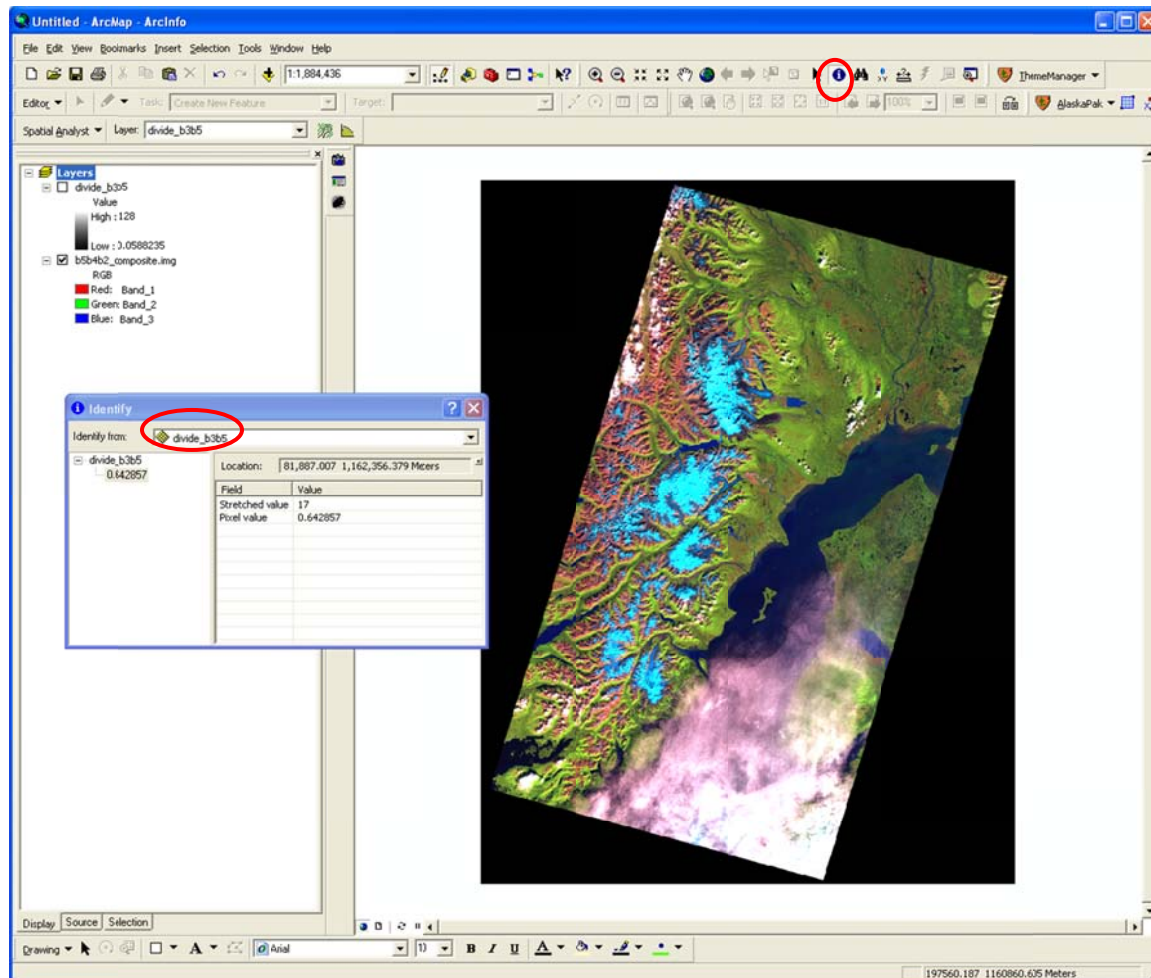


Figure 2-7. ArcGIS work session with a Landsat 542 false color composite displayed. The “Identify” button is active and the “Identify” dialog box is on the screen.

Next, navigate to and zoom into (1:24,000) an area of glacier ice. Select the “Identify” button and start clicking on pixels representing glacier ice. Click on pixels as you move from glacier ice across the boundary and onto ground, note how the pixel values are changing in the “Identify” dialog box. From a quick test, you can tell that the pixel value at the glacier boundary is close to 1.000 at lower elevation sites (Figure 2-8). Zoom into (1:10,000) a glacier boundary area so you can select individual pixels and see what the values are doing across the boundary area. You will want to do this in several areas of the image, both at low elevation sites and high elevation shadowed sites.

Figure 2-9 (lower Shamrock Glacier) shows that a pixel value of greater than 1.270 appears to accurately capture snow and glacier ice pixels in these lower elevation areas. A little time must be dedicated to this step, because you want to push the limit of the threshold value to capture as much debris covered ice as possible without capturing barren ground. In this case, a threshold value of less than 1.270 will classify areas as glacier that is really ground. A threshold value greater than 1.270 will not classify areas of light moraine covered glacier as glacier but rather capture those areas as ground. So there is a fine line in selecting the most effective threshold value to maximize the accuracy of the automated classification.

At higher elevations, the threshold value of >1.270 identifies pixels that are clearly not glacier ice or snow. Thus, a corresponding pixel value should be identified for snow and glacier ice at shadowed high elevation sites as well in the same manner as described above.

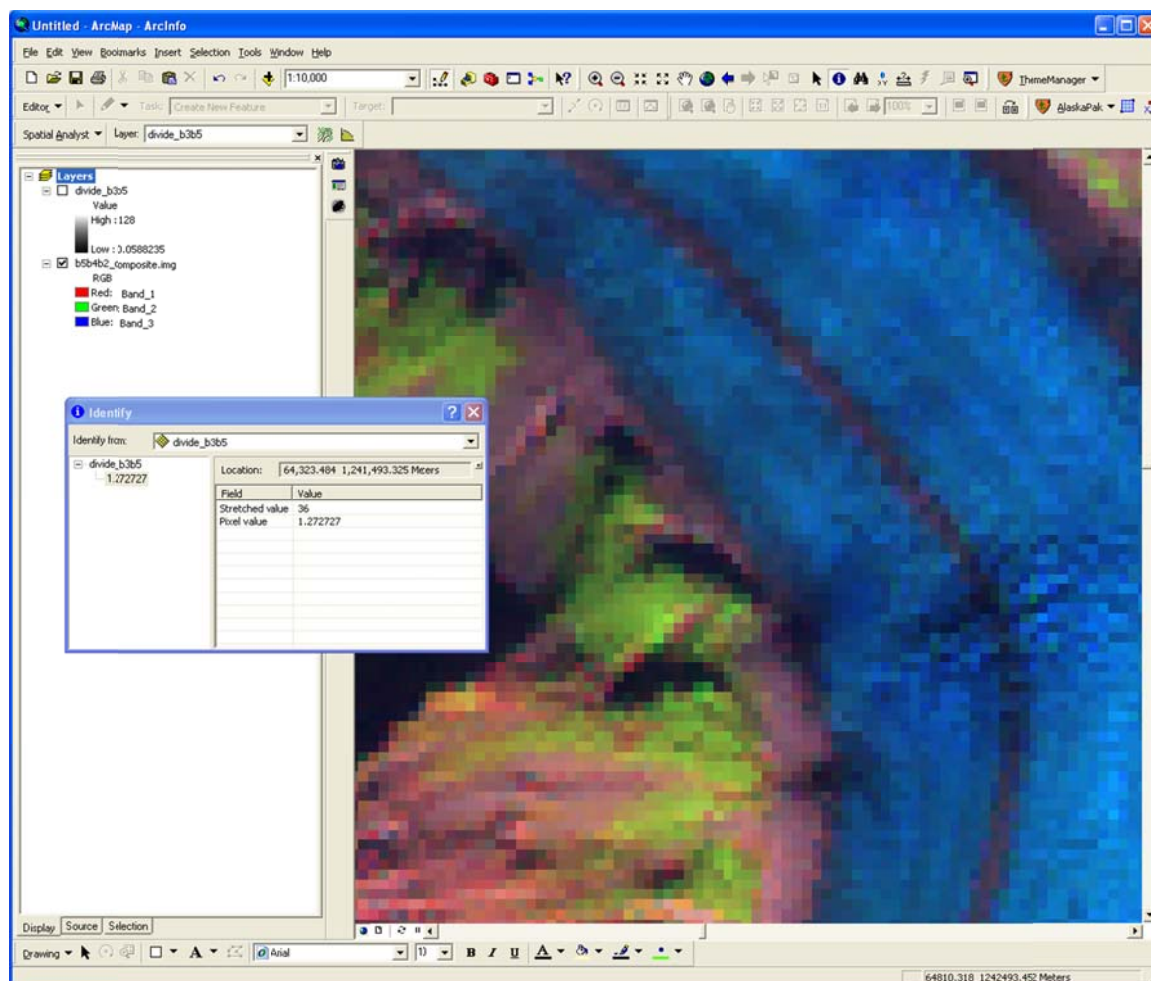


Figure 2-8. A Landsat false color (bands 5,4,2) composite of the lower Shamrock Glacier near Lake Clark NP&P. Note the glacier ice/ground boundary is easily recognizable. A bit of effort will be required to identify the value of pixels representing ground versus the glacier.

Moving to an area of high elevation and shadows, repeat the process above identifying the pixel values that most accurately represent snow and glacier ice. Again, click on pixels as you move from glacier ice to shadowed glacier ice and onto ground, note how the pixel values are changing

in the “Identify” dialog box. From a quick test, you can tell that the pixel values at the shadowed ice/ground boundary are between 1.500 to 2.000. Zoom into (1:10,000) a glacier boundary area so you can select individual pixels and see what the values are doing across the shadowed boundary area. A pixel value of greater than 1.700 appears to accurately capture snow and glacier ice pixels at these higher elevations, especially in shadowed areas. A lower threshold value will result in over-classification and a higher threshold value will result in under-classification of glacier ice and snow at high elevations.

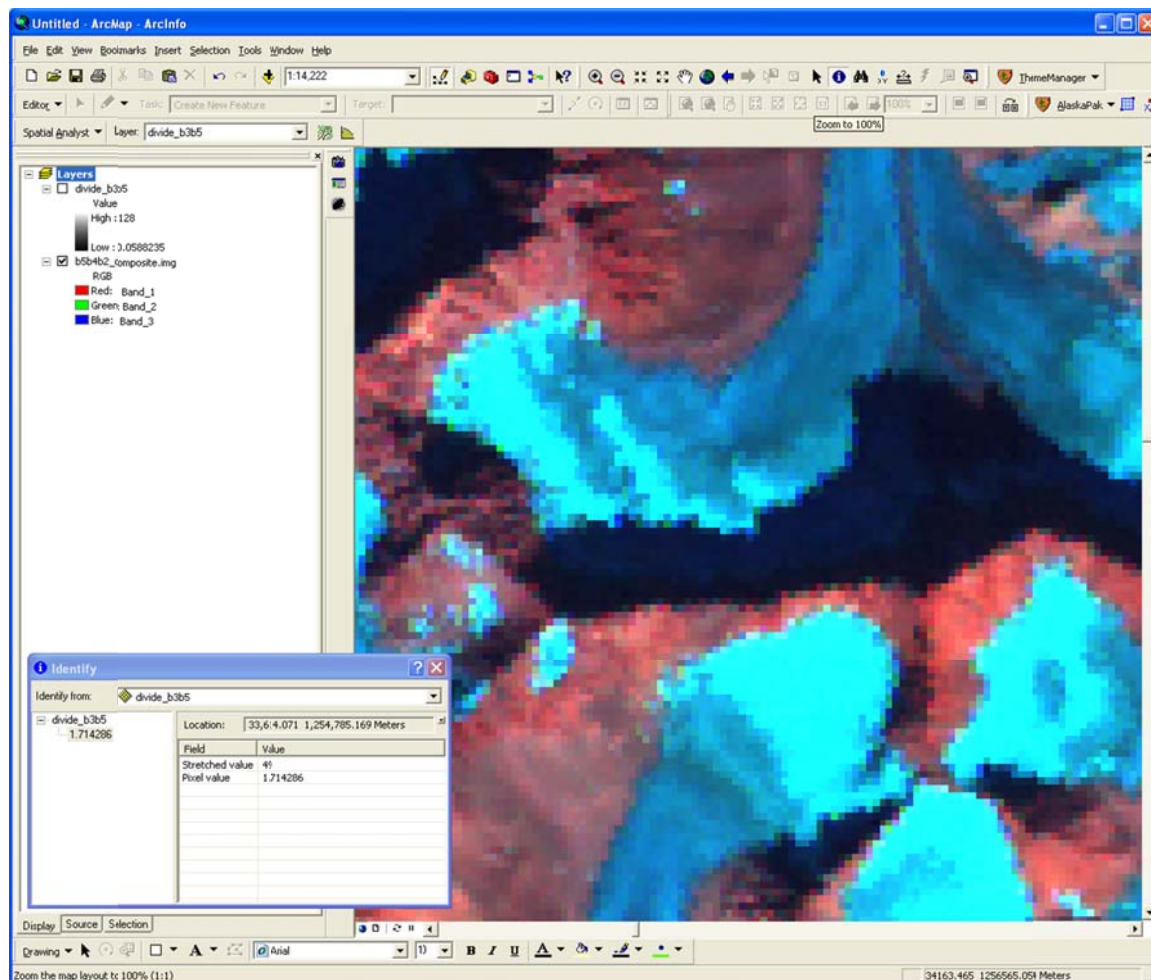


Figure 2-9. A Landsat false color (bands 5,4,2) composite of an unnamed glacier in Lake Clark NP&P. Note the glacier ice and the glacier ice obscured by shadow. With a bit of effort it is possible to identify a threshold value that is representative of the shadowed ice/ground boundary.

You will want to test several areas throughout the image in both high and low elevation areas in an effort to identify a threshold value(s) that will accurately isolate snow and glacier ice from all other pixels. The more time spent identifying an accurate threshold value(s) will mean less manual editing of resultant shapefiles that are created in SOP #3. Accurate threshold values will also allow for improved repeatability and comparability with future glacier mapping efforts.

In the example above, ArcGIS was used to perform simple band math ratio of Landsat B3 divided by B5 (B3/B5), and identify the threshold value(s) of >1.270 (for lower elevation areas) and >1.700 (for higher elevation areas) that are effective in mapping glacier margins. ArcGIS will be used to classify Landsat data for snow and glacier ice, shapefiles will be created and editing of the shapefiles completed in an ArcGIS work sessions as described in SOP#3 and #4.

Literature Cited

Raup, B., and S. Khalsa. 2010. GLIMS analysis tutorial. Global Land and Ice Measurements from Space Program. Available at http://www.glims.org/MapsAndDocs/assets/GLIMS_Analysis_Tutorial_letter.pdf (accessed 17 January 2011).

Standard Operating Procedure (SOP) #3

Landsat Image Analysis in a GIS – Part 2

Version 1.0

Change History

Version numbers will be incremented by a whole number (e.g. Version 1.3 to Version 2.0) when a change is made that significantly affects requirements or procedures. Version numbers will be incremented by decimals (e.g. Version 1.6 to Version 1.7) when there are minor modifications that do not affect requirements or procedures.

The following revisions have occurred to this plan since January 2011.

Version #	Date	Revised by	Changes	Justification

This Standard Operating Procedure describes the procedures process of classifying Landsat imagery for snow and glacier ice in support of the Glacier Monitoring protocol for the Southwest Alaska Network (SWAN).

Overview

This Standard Operating Procedure describes the process of classifying Landsat imagery for snow and glacier ice. This is a process by which all pixels in the image representing snow/glacier ice are segregated from all other pixels in the Landsat image. The great majority of the glacier margins are captured through the classification of the Landsat imagery described in this SOP. The classified raster files are converted to polygon shapefiles. Polygons representing snow/glacier ice and nunataks are segregated and small isolated snow fields that aren't connected to and/or associated with a glacier are eliminated. The steps outlined in this SOP are performed entirely in ArcCatalog and/or ArcGIS.

The final polygon shapefiles created in this SOP will require significant manual editing using ArcGIS. Manual editing of the polygon shapefiles will be detailed in SOP #4 to more accurately capture glacier margins. Areas of misclassification are associated with:

- debris covered glacier ice (typically terminus areas),
- shadowed snow/glacier areas,
- water bodies exhibiting higher concentrations of suspended solids (glacier flour),
- clouds

This SOP is not a comprehensive guide to using ArcGIS; a working knowledge of ArcGIS is necessary.

Procedures - Mapping Glacier Extent using ArcGIS and ArcCatalog

Mapping glacier extent requires several steps ranging from creating a color composite image to spatial analysis using simple math, conditional statements using threshold values, conversion of these results to shapefiles, manipulation of shapefiles to extract the most accurate representation of glacier margins and finishing up with manual editing of the shapefiles (as described in SOP #4).

The procedures outlined here involve the creation of numerous folders and files. Care must be exercised in developing a rational folder and file naming structure/plan. SOP #9 (Data Management) presents a thorough description of the recommended folder structure and file naming convention.

Step 1 Setup Folder and File Structure

The basic folder and file structure is presented in SOP #1 and #2. The folder structure and naming convention, is further described here. The creation and naming of Personal Geodatabases and Feature Datasets are presented in SOP #9. Detailed file naming convention is presented throughout this SOP as appropriate.

PARK

The PARK folder will be that of the four letter park acronym, in the case of the SWAN parks either: KEFJ or KATM, or LACL. In this PARK folder, set up the additional folders as follows: DEM, Landsat_YYYYMMDD and a Personal Geodatabase with the following naming convention “PARK_YYYYMMDD”, where YYYYMMDD is the year, month and day of the Landsat imagery for which the glacier mapping is based. Within the Personal Geodatabase are Feature Datasets named “Processing_1270” and “Processing_1700” and Processing_Union_1270_1700.” (Figure 3-1). These Feature Datasets hold all the working shapefiles for the glacier extent mapping. The “1270” and “1700” represent the threshold value of the snow and ice pixels that was established in SOP #2 (i.e. 1.270 and 1.700). All data processing relevant to threshold value 1.270 occurs in the Feature Datasets named “Processing_1270” and so forth.

In creating Feature Datasets in ArcCatalog, be sure to define the datum and projection consistent with the datum and projection of the Landsat imagery.

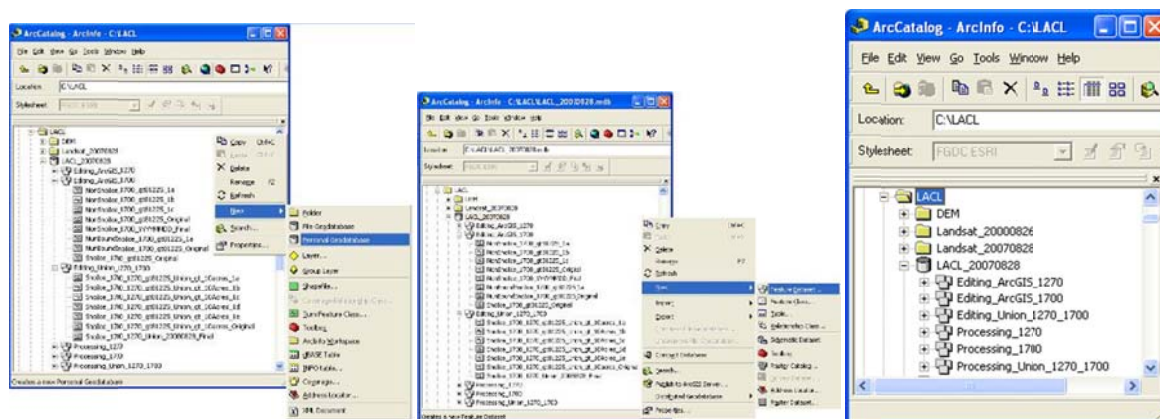


Figure 3-1. Creating a Personal Geodatabase (left), and a Feature Dataset (middle) using ArcCatalog. Basic folder structure for glacier extent mapping (right). Note that creating a new folder is also an option using ArcCatalog (left).

Step 2 Place Landsat Raster Data in the Landsat_YYYYMMDD Folder

In SOP #1 Landsat imagery was downloaded and placed into an appropriate Landsat_YYYYMMDD folder. In SOP #2, working raster files were created and were converted from WGS84 UTM 5 to NAD83 Alaska Albers; also some processing and analysis of Landsat data occurred – these products were placed into the appropriate Landsat_YYYYMMDD folder.

In Figure 3-2 the original Landsat bands 1, 2, 3 4 and 5 are shown in the Landsat_YYYYMMDD folder. The other raster files that are also shown in Figure 3-2 (located in the Landsat_YYYYMMDD folder) are the resultant raster files from processes (ArcGIS/ArcCatalog commands) completed in SOP #2 (i.e. b5b4b2_composite, divide_b3b5, float_b3, float_b5).

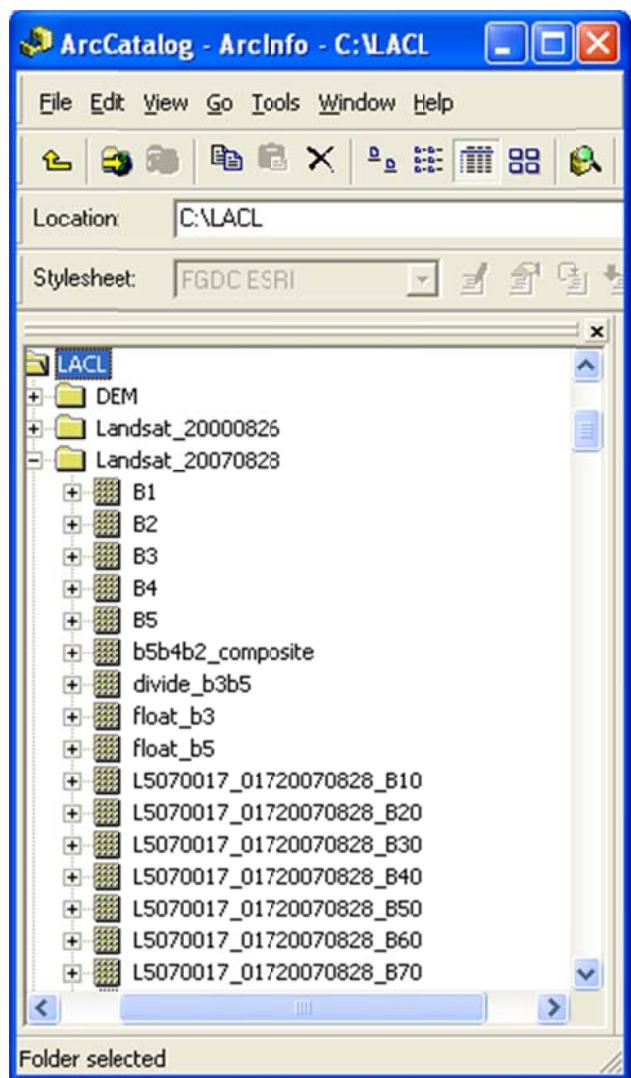


Figure 3-2. File naming convention within the LACL/Landsat_20070828 folder.

Step 3 Create a Color Composite Image

A color composite image using Landsat Band 5 (red), Landsat Band 4 (green), and Landsat Band 2 (blue) was created in SOP #2. This Landsat band combination is very effective for glacier mapping purposes. A true color composite can be created in the same way using bands 3,2 and 1.

Step 4 Band Ratio Technique and Threshold Value(s)

The band math and threshold information determined from SOP #2 are essential for successful implementation of SOP #3. In SOP #2 ArcGIS was used to determine the most appropriate threshold value(s) to apply to the B3/B5 band ratio technique.

There may be more than one threshold value - one threshold value may produce good results in areas of shadowed ice and /or lower elevation and vice versa.

The following example steps proceed using the B3/B5 ratio with a threshold value of 1.700. Note that a second set of files, a geodatabase and a feature dataset was created in this example facilitating the processing of the Landsat data using a threshold value of 1.270.

Step 5 Band Ratio Technique and Threshold Determination

Both the “Band Ratio Techniques” and “Threshold Determination” were covered in SOP #2, Steps 3 and 4. If necessary refer to SOP #2.

Step 6 Conditional Statement

Using the “divide_b3b5” raster created in SOP #2 (Step 3), apply the threshold value(s) determined in SOP #2 (Step 4) that best segregates snow/glacier pixels from all other pixels. In this case, the threshold value is 1.700.

- Con (sa): Use the Spatial Analyst Tools>Conditional>Con; Use “divide_b3b5” as the input raster, the expression is the threshold value determined in SOP #2. True = 1 False = 2. And name the output raster: “b3b5_gt1700” (Figure 3-3).

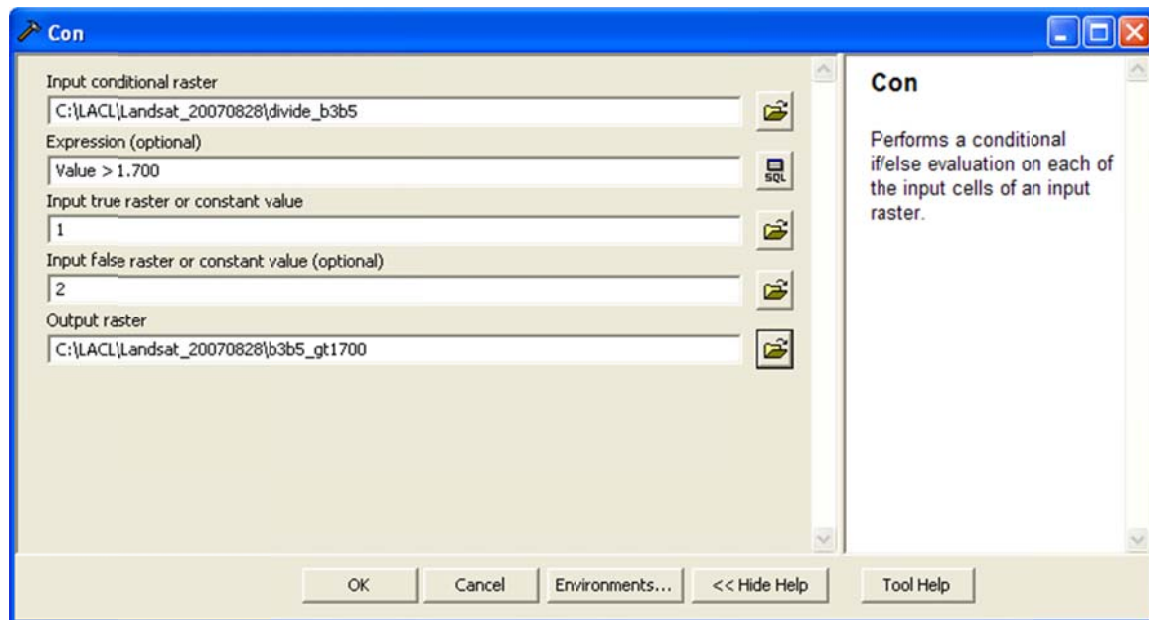


Figure 3-3. Creating a raster image using the “Con” command in ArcCatalog.

Step 7 Raster To Polygon Conversion

Convert the raster created in Step 6 to a polygon shapefile.

- Raster-To-Polygon: Convert raster “b3b5_gt1700” to a polygon shapefile: “RstrToPoly_b3b5_gt1700a” and save to the Processing_1700 feature dataset within the PARK_YYYYMMDD personal geodatabase. Make sure the “Simplify polygons” box is unchecked (Figure 3-4).

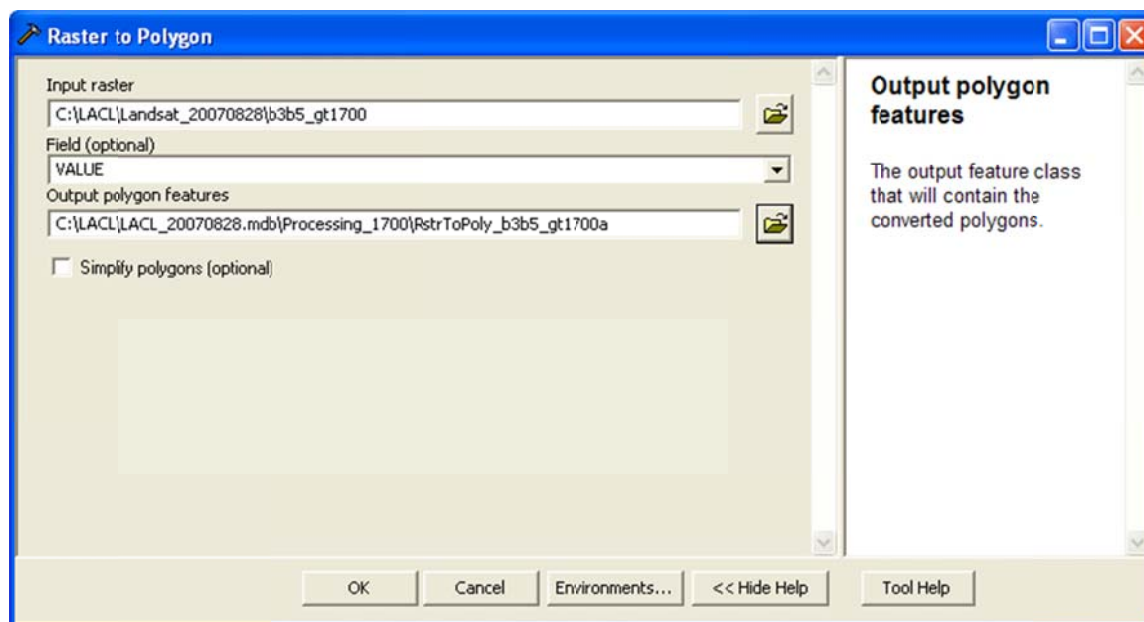


Figure 3-4. Converting the raster created in Step 6 to a polygon shapefile using the “Raster to Polygon” command in ArcCatalog.

Step 8 Select Analysis

The “Raster to Polygon” process (Step 7) creates several large polygons – artifacts from the Landsat image foot print, Cook Inlet, and large river systems (e.g. Susitna River) – that aren’t related to glacier systems. View the “RstrToPoly_b3b5_gt1700a” shapefile in ArcGIS and determine the minimum size of the largest artifacts (not all large polygons, just the largest 2 to 4 polygons not associated with glacier ice in the shapefile). From this process, it was determined to remove all polygons greater than 2,000,000,000 m² from the shapefile.

- Select (analysis): Using the Analyst Tools>Extract>Select; Using file “RstrToPoly_b3b5_gt1700a” select for Shape_Area < 2,000,000,000. Resultant file: “RstrToPoly_b3b5_gt1700b” (Figure 3-5).

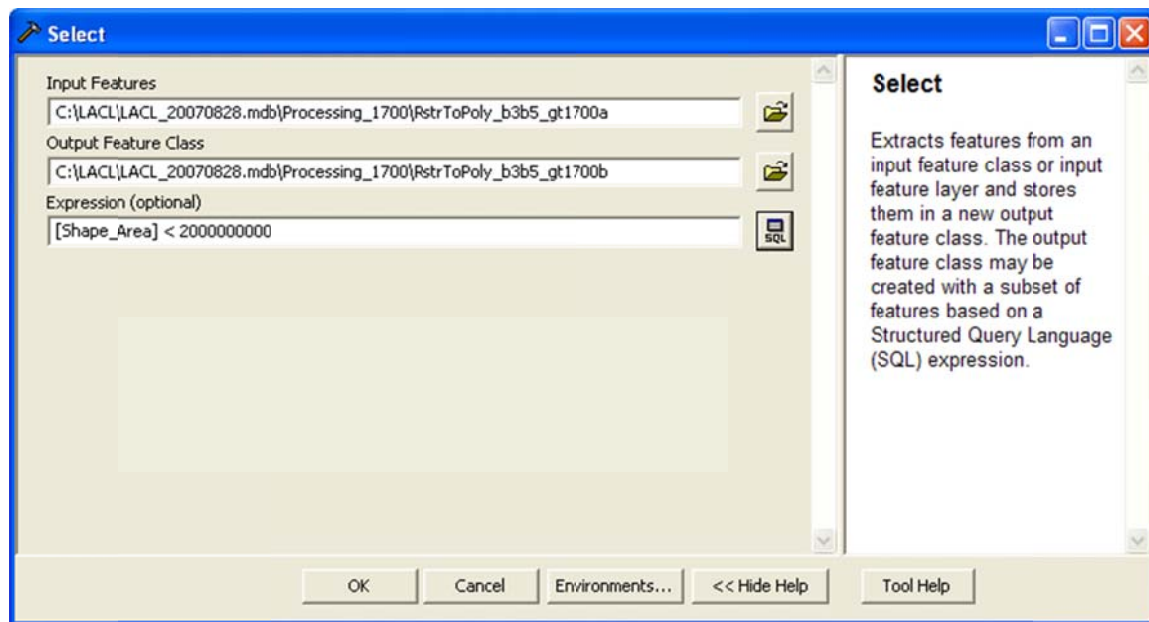


Figure 3-5. This Select Analysis removes large polygon artifacts not associated with glaciers from the “RstrToPoly_b3b5_gt1700b” polygon shapefile.

Step 9 Select Analysis of the Polygon Shapefiles - Snolce and NonSnolce

The polygon shapefile created in Step 8 above “RstrToPoly_b3b5_gt1700b” has two types of features, snow and/or glacier features (GRIDCODE=1) or all other features (GRIDCODE=2). Also, because the “RstrToPoly_b3b5_gt1700b” was created in Feature Dataset within a Personal Geodatabase, a field labeled “Shape_Area” was created; the data is presented in square meters. Figure 3-6 shows a portion of the attribute table for the polygon shapefile.

Attributes of RstrToPoly_b3b5_gt1700b

OBJECTID	Shape	ID	GRIDCODE	Shape_Length	Shape_Area
1	Polygon	1	2	285	3249
2	Polygon	2	2	114	812.25
3	Polygon	3	2	171	1624.5
4	Polygon	4	1	114	812.25
5	Polygon	5	2	114	812.25
6	Polygon	6	1	171	1624.5
7	Polygon	7	1	114	812.25
8	Polygon	8	1	342	4873.5
9	Polygon	9	2	171	1624.5
10	Polygon	10	1	228	3249
11	Polygon	11	2	114	812.25
12	Polygon	12	2	285	4061.25
13	Polygon	13	2	114	812.25
14	Polygon	14	1	171	1624.5
15	Polygon	15	2	114	812.25
16	Polygon	16	1	114	812.25
17	Polygon	17	1	114	812.25
18	Polygon	18	1	114	812.25
19	Polygon	19	1	171	1624.5
20	Polygon	20	1	342	4873.5
21	Polygon	21	1	114	812.25
22	Polygon	22	2	399	4873.5
23	Polygon	23	1	114	812.25
24	Polygon	24	1	114	812.25
25	Polygon	25	1	114	812.25

Record: 1 Show: All Selected Records (0 out)

Figure 3-6. Attribute table for “RstrToPoly_b3b5_gt1700b” shapefile.

The goal in this step is to isolate larger snow and/or ice features from smaller snow and/or ice features. For this particular example, 8122.5 m² is the threshold for size.

- Select (analysis): Using the Analyst Tools>Extract>Select; Using file “RstrToPoly_b3b5_gt1700b” Select for GRIDCODE = 1 AND Shape_Area >= 8122.5 and save as “SnoIce_1700_gt81225a” (Figure 3-7).

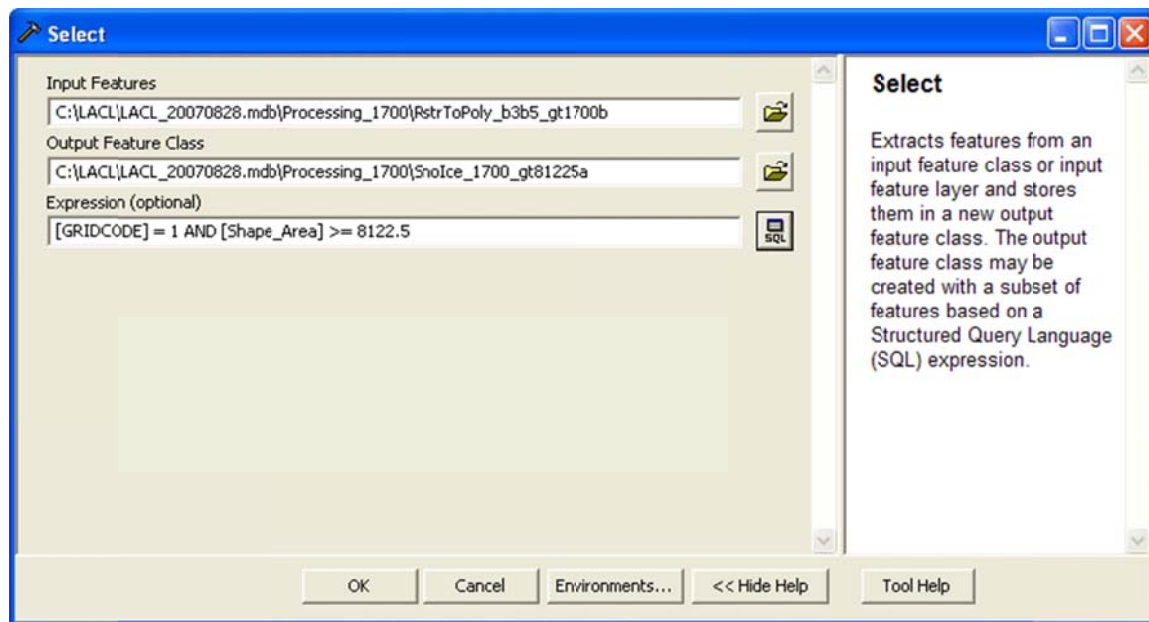


Figure 3-7. Selecting polygons within the “RstrToPoly_b3b5_1700_gt1700b” shapefile that represent snow and ice features (GRIDCODE = 1) and that are equal to or greater than 8,122.5 m² (Shape_Area >= 8122.5) using the “Select” command in ArcCatalog.

Note: The threshold value for “Shape_Area” may seem low in this instance; however, in Lake Clark National Park and Preserve, a larger threshold value eliminates the ability to capture the many linear and narrow nunatak features in the region.

Repeat the previous “Select” command, except the target data is large non-snow and -ice features. The goal in this command is to isolate large non-snow and/or -ice features from all others (Figure 3-8). For this particular example, 8122.5 sq m is the threshold for size.

- Select: Using the Analyst Tools>Extract>Select; Using file “RstrToPoly_b3b5_gt1700b”, Select for GRIDCODE = 2 AND Shape_Area >= 8122.5 and save as “NonSnoIce_1700_gt81225a”.

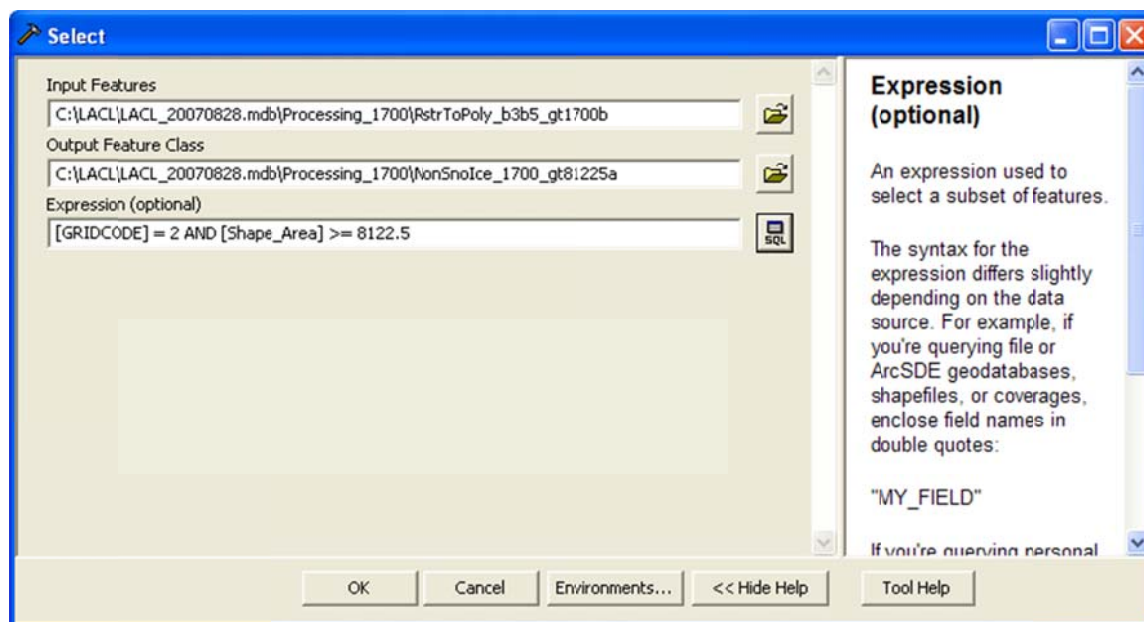


Figure 3-8. Selecting polygons within the “RstrToPoly_b3b5_gt1700b” shapefile that represent non snow and ice features (GRIDCODE = 2) and that are equal to or greater than 8,122.5 m² (Shape_Area >= 8122.5) using the “Select” command in ArcCatalog.

Note: 8,122.5 m² is equivalent to 10 pixels or approximately 2 acres. So the goal of Steps 8 and 9 is to isolate all snow/ice polygons greater than 8,122.5 sq m (10 pixels) and isolate all non-snow and/or -ice polygons greater than 8,122.5 sq m.

Before proceeding further, view the “SnoIce_1700_gt81225a” and “NonSnoIce_1700_gt81225a” polygon shapefiles with the “b5b4b2_composite” image in the background. Be sure to adjust the polygons to be hollow with an outline color that is easily seen against the color composite image. If you think the classification can be improved, adjust the threshold value (refer to SOP #2, Step 4) and repeat Step 6 through Step 9. If you are satisfied with the accuracy of the glacier boundary, proceed to Step 10.

Step 10 Cleaning Polygon Shapefiles - Snoise

The next step is to clean the polygon shapefiles “SnoIce_1700_gt81225a” and “NonSnoIce_1700_gt81225a” through the following process. The next couple commands will remove small unwanted artifacts in the shapefiles.

- Feature-To-Line (management): Convert “SnoIce_1700_gt81225a” polygon shapefile to a line shapefile and name the resultant file “SnoIce_1700_gt81225_Clean1a” (Figure 3-9).

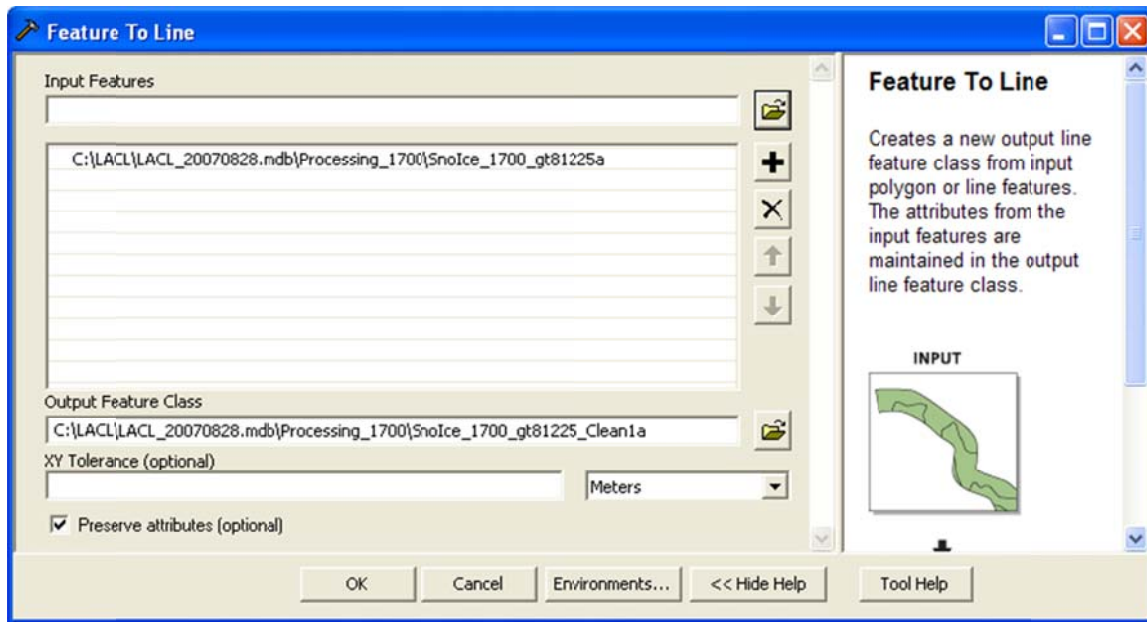


Figure 3-9. Converting “SnoIce_1700_gt81225a” polygon shapefile to a line shapefile using the “Feature to Line” command in ArcCatalog.

And:

- Feature-To-Polygon (management): Convert “SnoIce_1700_gt81225_Clean1a” line shapefile to a polygon shapefile and name it “SnoIce_1700_gt81225_Clean1b” (Figure 3-10).

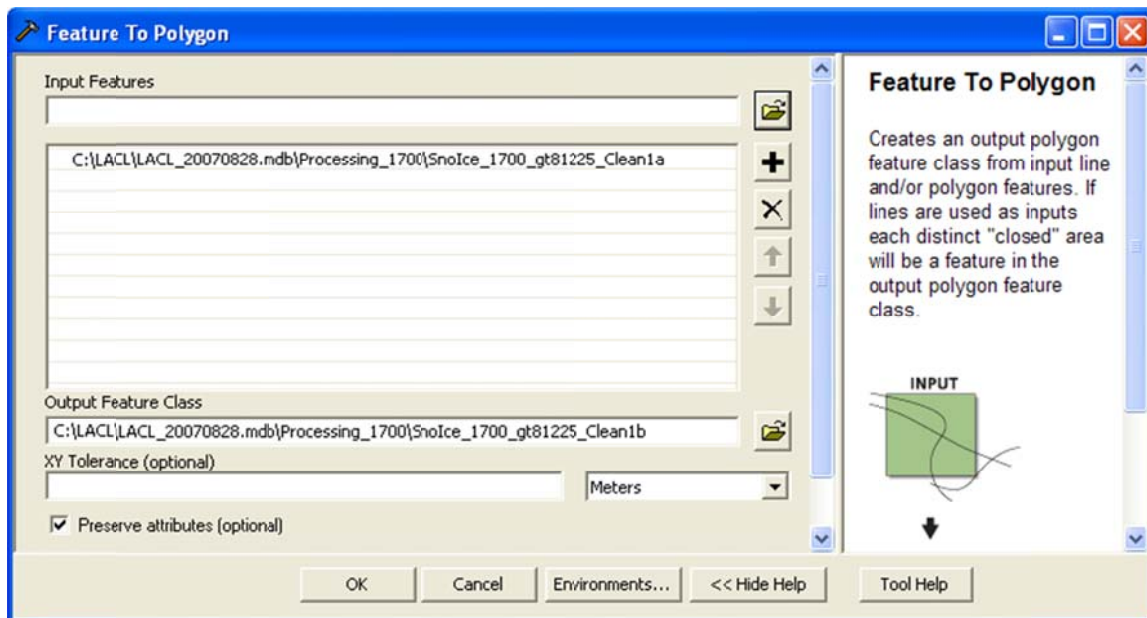


Figure 3-10. Converting “SnoIce_1700_gt81225_Clean1a” line shapefile to a polygon shapefile using the “Feature to Polygon” command in ArcCatalog.

Step 11 Cleaning Polygon Shapefiles - NonSnoIce

Repeat the two commands outlined in Step 10, this time using the “NonSnoIce_1700_gt81225” polygon shapefile.

- Feature-To-Line (management): Convert “NonSnoIce_1700_gt81225” polygon shapefile to a line shapefile and name the resultant file “NonSnoIce_1700_gt81225_Clean1a”.
- Feature-To-Polygon (management): Convert “NonSnoIce_1700_gt81225_Clean1a” line shapefile to a polygon shapefile and name it “NonSnoIce_1700_gt81225_Clean1b”.

Step 12 Edit Snow/Ice polygons

Large lakes (e.g. Chakachamna Lake) may be classified as snow/ice polygons and/or connected to larger snow/ice polygons. If this is the case, these large polygon features (i.e. Chakachamna Lake) should be modified and deleted from the SnoIce shapefile at this point. Use the “cut polygon feature” found in the ArcGIS task bar and then delete the misclassified polygon.

Step 13 Attribute Tables Management - SnoIce and NonSnoIce

Add a field (Figure 3-11) to the attribute tables and calculate field values (Figure 3-12) for the polygon shapefiles created in Step 10 “SnoIce_1700_gt81225_Clean1b” (Figure 3-9) and Step 11 “NonSnoIce_1700_gt81225_Clean1b”.

- Add Field (management): Add a “field” called RASTER to each of the polygon shapefiles “SnoIce_1700_gt81225_Clean1b” and “NonSnoIce_1700_gt81225_Clean1b”

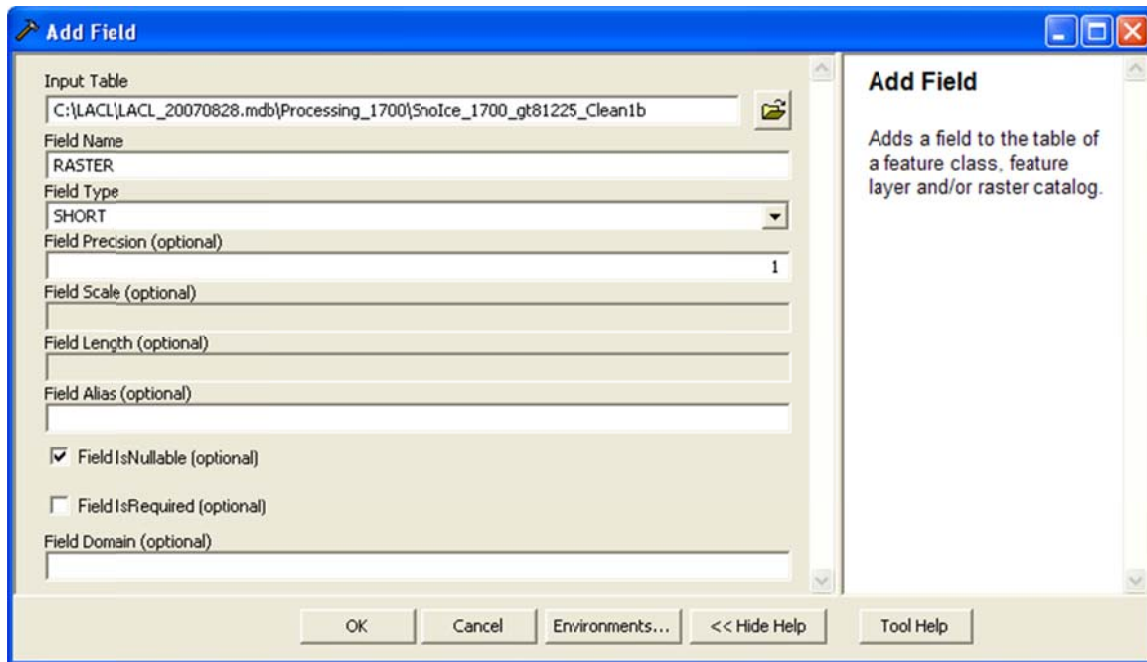


Figure 3-11. Adding a “field” to the attribute table of “SnoIce_1700_gt81225_Clean1b” polygon shapefile using the “Add Field” command in ArcCatalog.

- Calculate Field (management): Assign a value of “1” to the RASTER field for each of the polygon shapefiles created above:
- “SnoIce_1700_gt81225_Clean1b”
- “NonSnoIce_1700_gt81225_Clean1b”

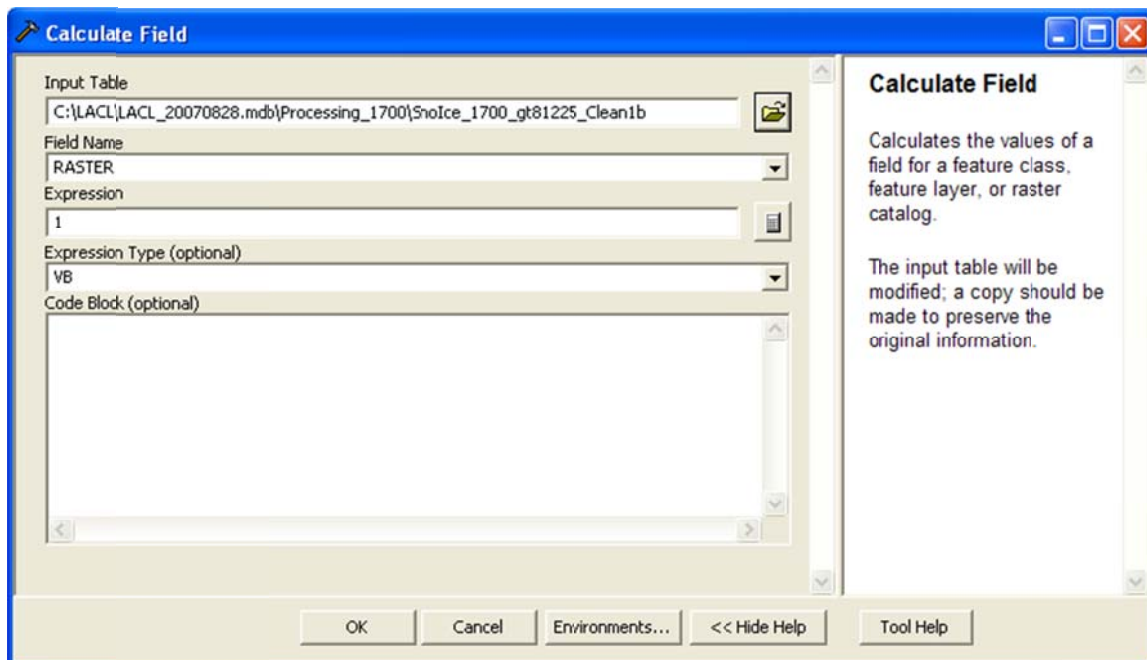


Figure 3-12. Calculating RASTER “field” value equal to “1” for all records “SnoIce_1700_gt81225_Clean1b” polygon shapefile using the “Calculate Field” command in ArcCatalog.

Step 14 Polygon To Raster Conversion - Snolce and NonSnolce

Create raster files (Figure 3-13 and 3-14) from the polygon shapefiles created in Steps 10 and 11 (Figure 3-10). Set the “Cell Size” equivalent to the original resolution of the Landsat data, in this case, 28.5.

- Polygon-To-Raster (conversion): Convert Polygon to Raster for the two files: “SnoIce_1700_gt81225_Clean1b” and “NonSnoIce_1700_gt81225_Clean1b”. The resultant files “SnoIce_1700_gt81225.img” and “NonSnoIce_1700_gt81225.img” are located in the PARK/Landsat folder.

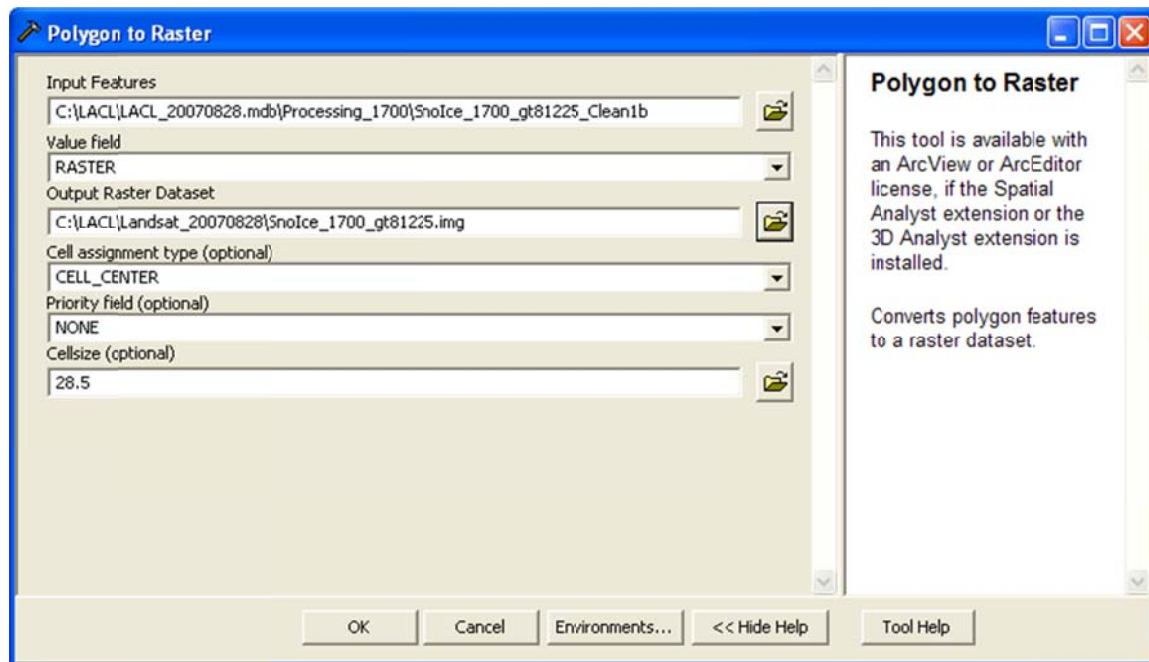


Figure 3-13. Converting “SnoIce_1700_gt81225_Clean1b” polygon shapefile to a raster file using the “Polygon to Raster” command in ArcCatalog.

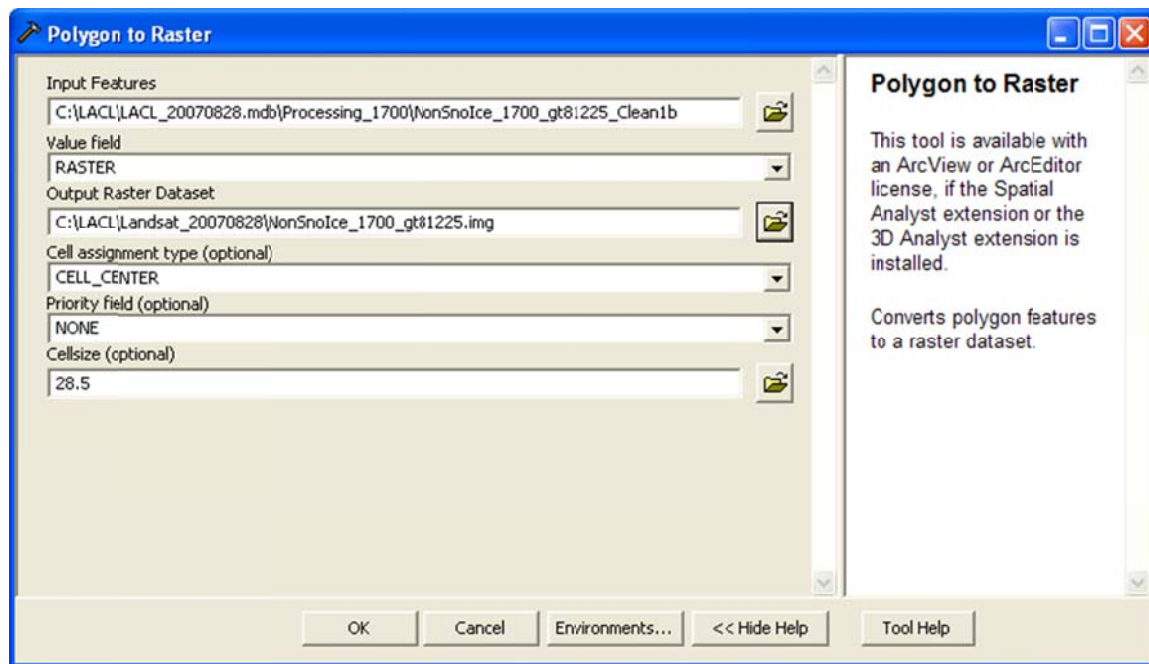


Figure 3-14. Converting “NonSnoIce_1700_gt81225_Clean1b” polygon shapefile to a raster file using the “Polygon to Raster” command in ArcCatalog.

Step 15 Raster To Polygon Conversion – SnoIce and NonSnoIce

Create polygon shapefiles (Figure 3-15 and 3-16) from the raster files created in Step 14. Be sure that the “Simplify Polygons” box is not checked.

- Raster-To-Polygon (conversion): Convert Raster to Polygon for the two files: “SnoIce_1700_gt81225.img” and “NonSnoIce_1700_gt81225.img”. The resultant files are: “SnoIce_1700_gt81225_Clean1c” and “NonSnoIce_1700_gt81225_Clean1c”.

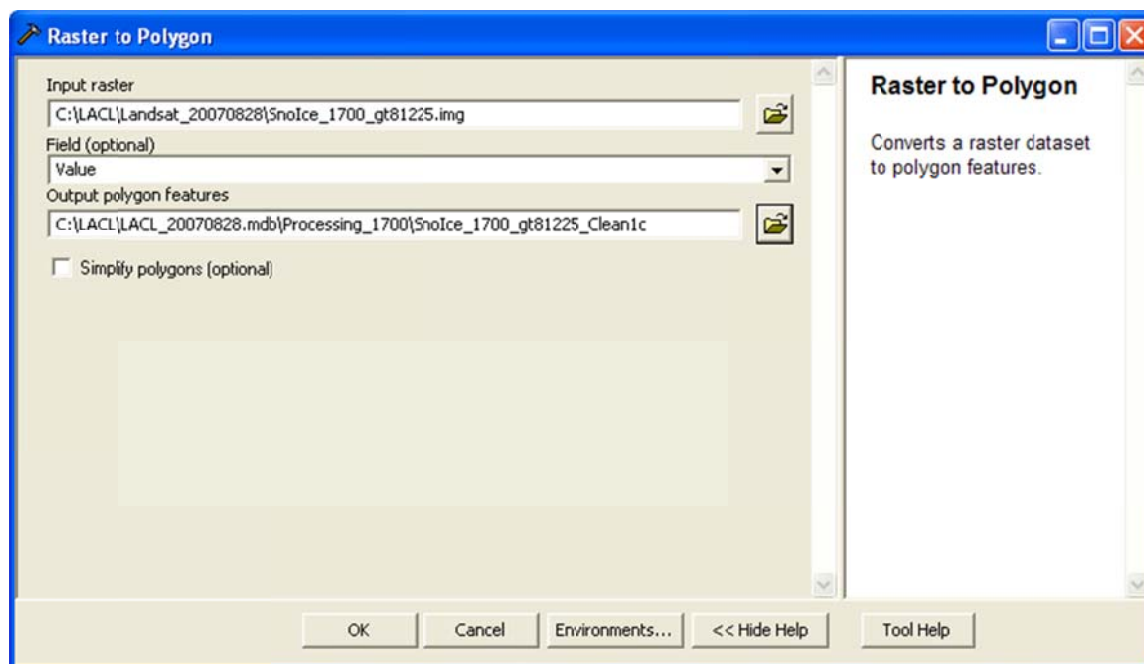


Figure 3-15. Converting “SnoIce_1700_gt81225.img” raster file to a polygon shapefile using the “Raster to Polygon” command in ArcCatalog.

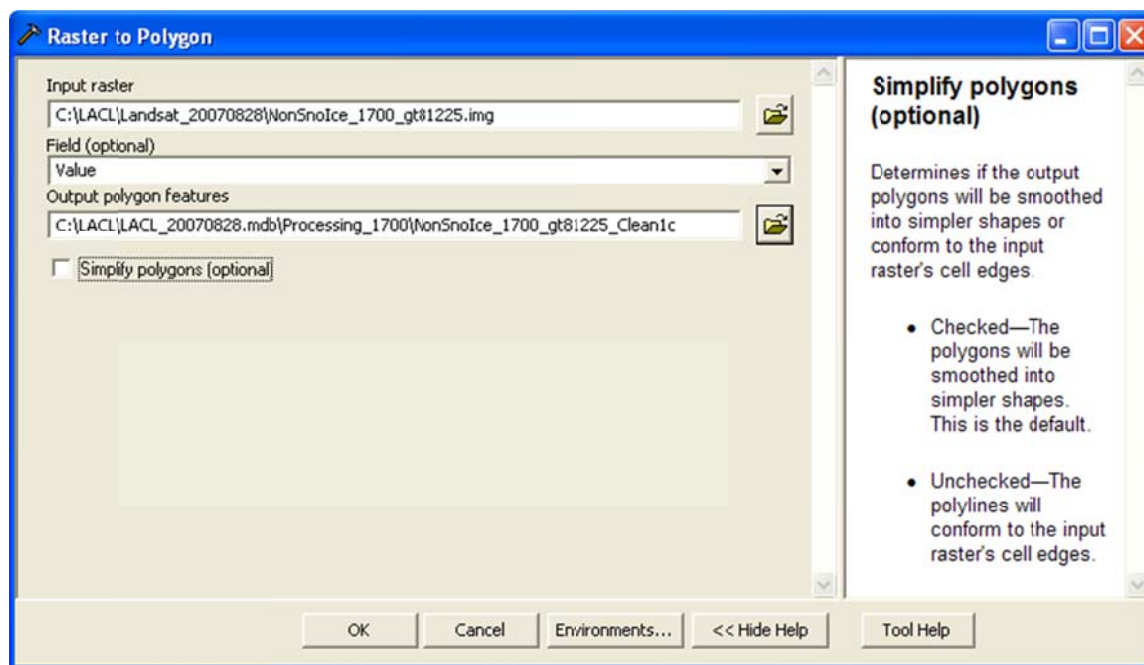


Figure 3-16. Converting “NonSnoIce_1700_gt81225.img” raster file to a polygon shapefile using the “Raster to Polygon” command in ArcCatalog.

Step 16 Select Analysis

This Select Analysis isolates snow and ice features from other features and creates a new file containing only these snow and ice features in a polygon shapefile.

- Select (analysis): Using the Analyst Tools>Extract>Select with file “SnoIce_gt81225_Clean1c”. Select for GRIDCODE > 1. The resultant file is “SnoIce_gt81225_Clean1d” (Figure 3-17).

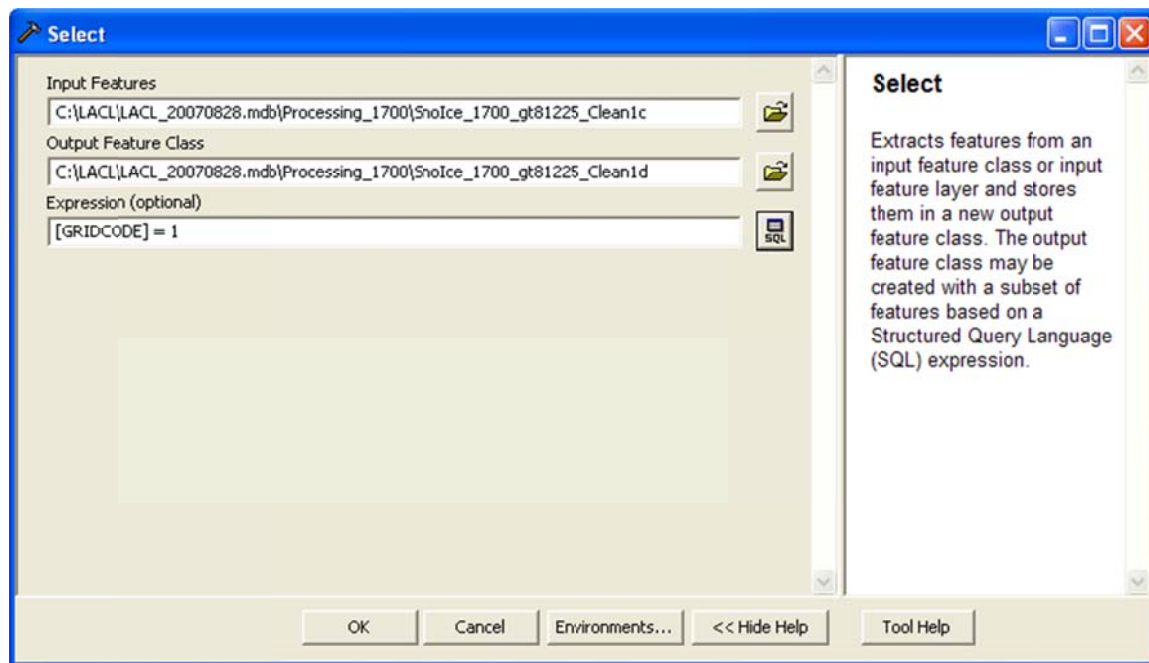


Figure 3-17. The Select Analysis isolates snow and ice features from other features and creates a new file containing only these features in a polygon shapefile - “SnoIce_1700_gt81225_Clean_1c”.

Step 17 Select Analysis

This Select Analysis isolates non-snow and ice features from other features and creates a new file containing only these non-snow and ice features in a polygon shapefile.

- Select (analysis): Using the Analyst Tools>Extract>Select with file “NonSnoIce_gt81225_Clean1c”. Select for GRIDCODE > 1. The resultant file is “NonSnoIce_gt81225_Clean1d” (Figure 3-18).

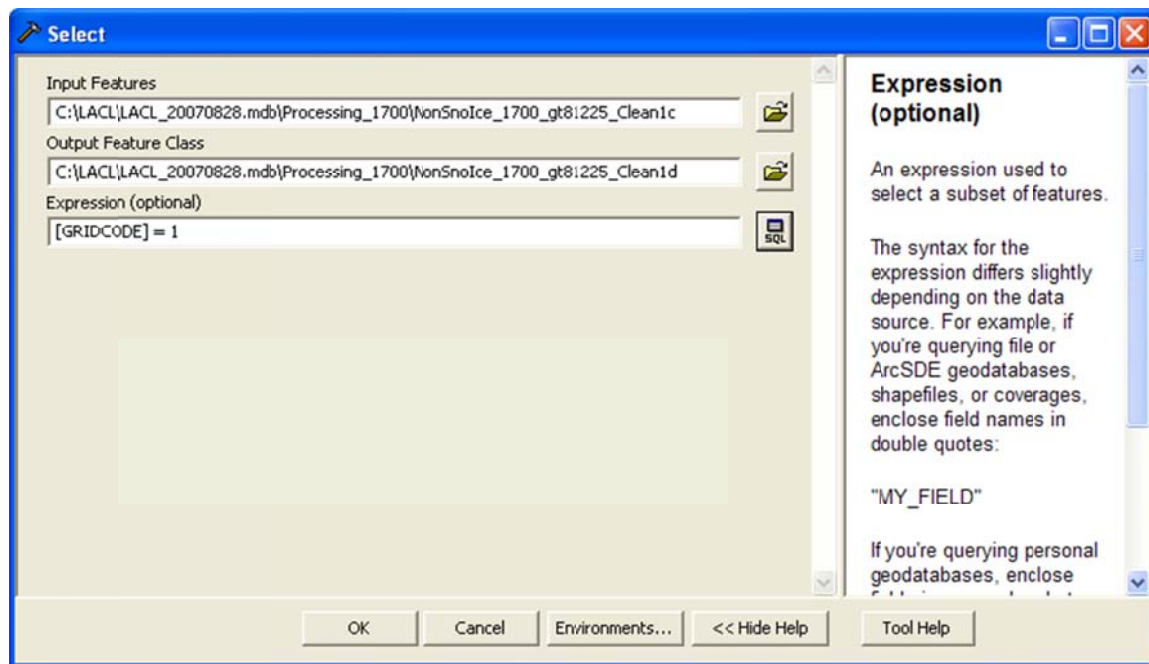


Figure 3-18. This Select Analysis isolates non-snow and ice features from other features and creates a new file containing only these features in a polygon shapefile - “NonSnoIce_1700_gt81225_Clean_1c”.

Step 18 Cleaning up Nunatak Boundaries

The purpose of the following steps is to cleanup nunatak boundaries (Figure 3-19 and 3-20).

- Erase (analysis): “SnoIce_1700_gt81225_Clean1d” minus “NonSnoIce_1700_gt81225_Clean1d” = “NonSnoIce_1700_gt81225_XX”.

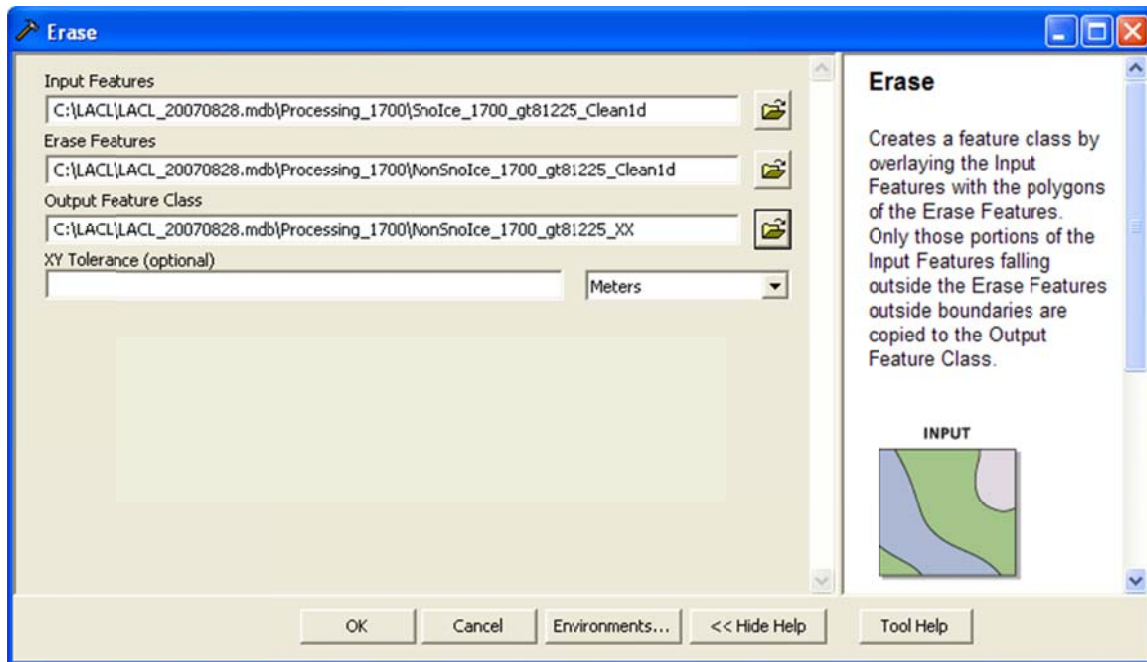


Figure 3-19. Erase polygons of the “NonSnoIce_1700_gt81225_Clean1d” polygon shapefile from the “SnoIce_1700_gt81225_Clean1d” polygon shapefile using the “Erase” command in ArcCatalog.

- Erase (analysis): “SnoIce_1700_gt81225_Clean1d” minus “NonSnoIce_1700_gt81225_XX” = “NonSnoIce_1700_gt81225_Clean1e”.

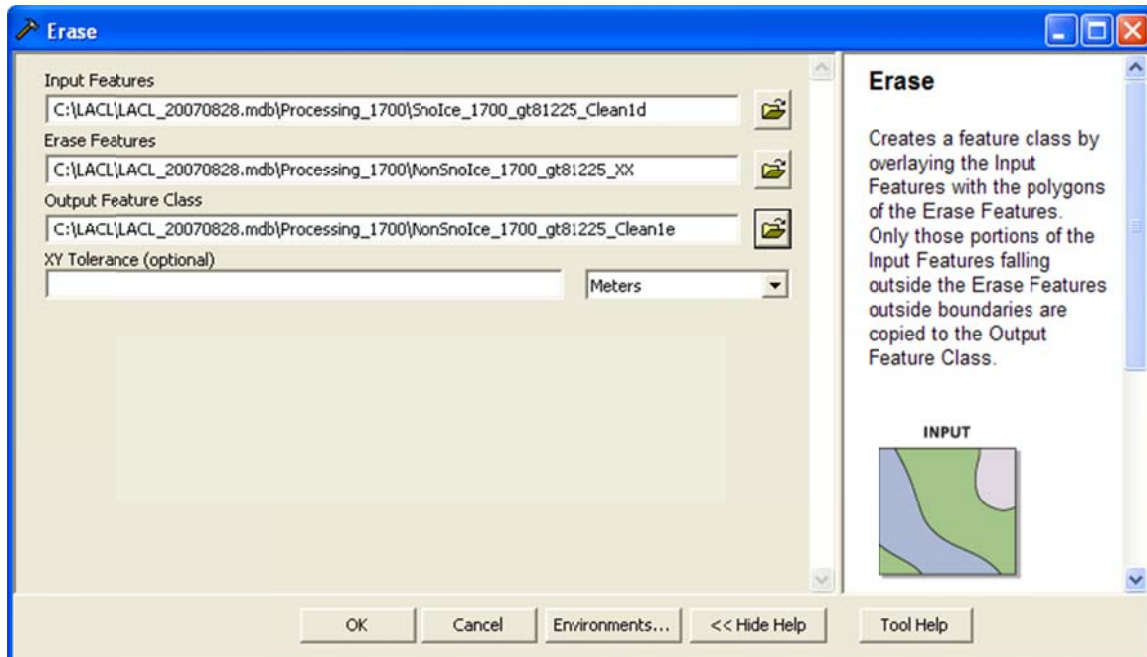


Figure 3-20. Erase polygons of the “NonSnoIce_1700_gt81225_XX” polygon shapefile from the “SnoIce_1700_gt81225_Clean1d” polygon shapefile using the “Erase” command in ArcCatalog.

Step 19 Cleaning up Nunatak-Bound Glacier Boundaries

The following commands are designed to clean up the boundaries of nunatak-bound glaciers (Figures 3-21 and 3-22). These are smaller glaciers occurring completely within the bounds of nunataks.

- Erase (analysis): “NonSnoIce_1700_gt81225_Clean1e” minus “SnoIce_1700_gt81225a” = “NunBoundSnoIce_1700_gt81225_Clean1a”.

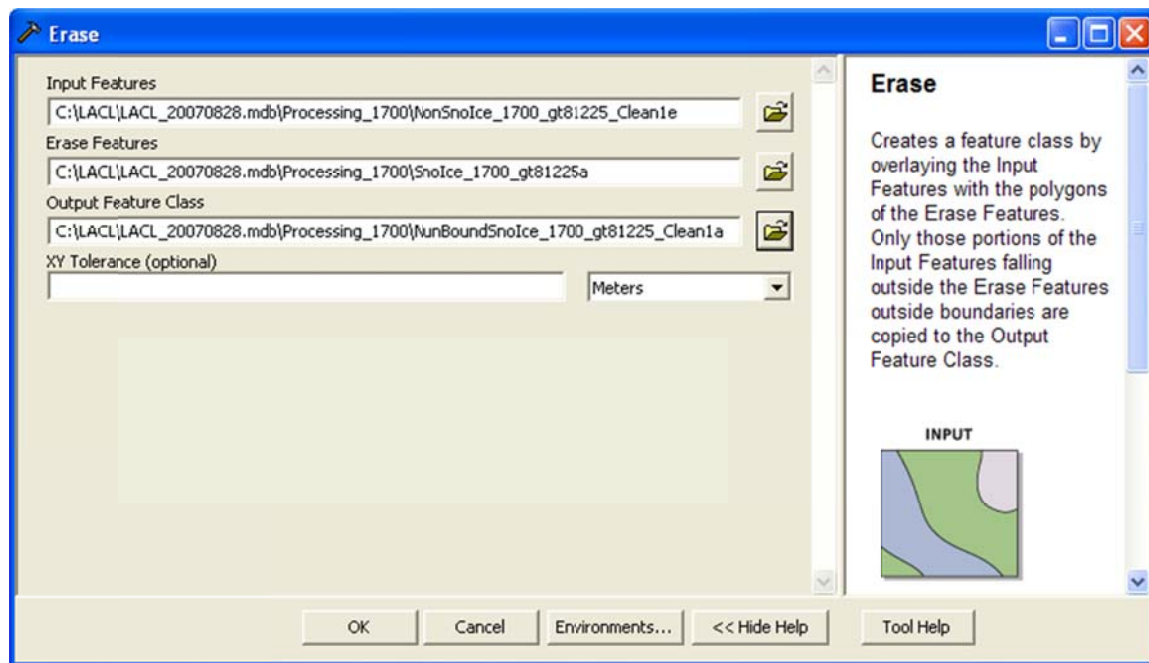


Figure 3-21. Erase polygons of “SnoIce_1700_gt81225” polygon shapefile from the “NonSnoIce_1700_gt81225_Clean1e” polygon shapefile using the “Erase” command in ArcCatalog.

- Erase (analysis): “NonSnoIce_1700_gt81225_Clean1e” minus “NunBound_SnoIce_1700_gt81225_Clean1a” = “NunBound_SnoIce_1700_gt81225_Clean1b”.

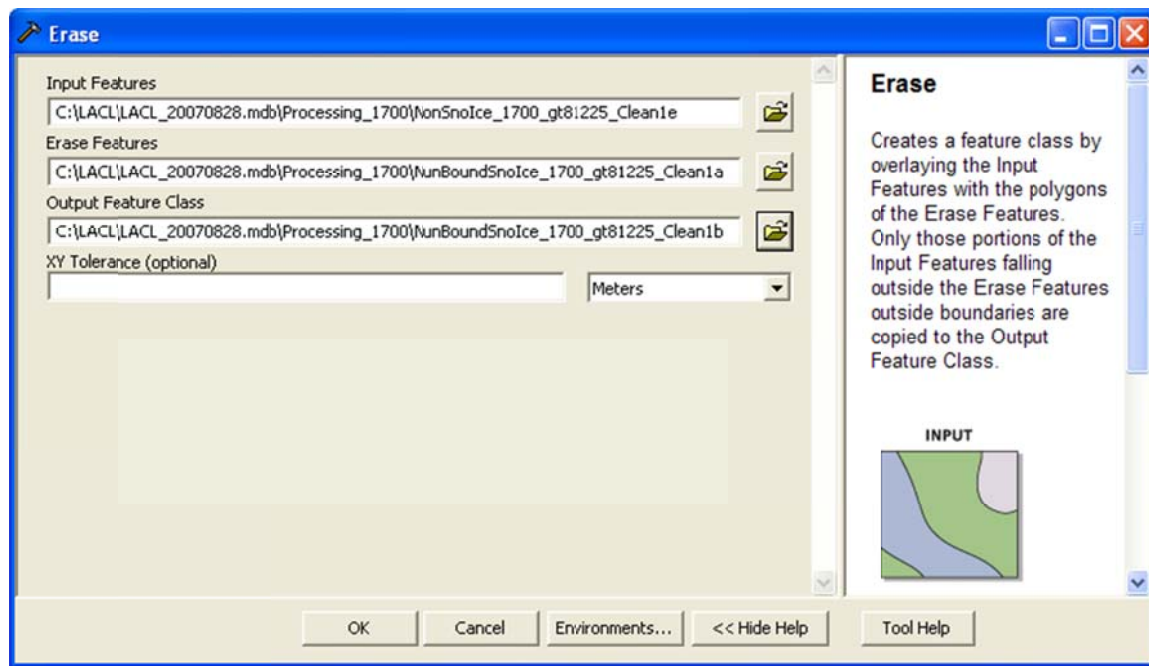


Figure 3-22. Erase polygons of the “NunBound_SnoIce_1700_gt81225_Clean1a” polygon shapefile from the “NonSnoIce_1700_gt81225_Clean1e” polygon shapefile using the “Erase” command in ArcCatalog.

- Feature-To-Line (management): “NunBoundSnoIce_1700_gt81225_Clean_1b” polygon shapefile = “NunBoundSnoIce_1700_gt81225_Clean_1c” to line shapefile (Figure 3-23).

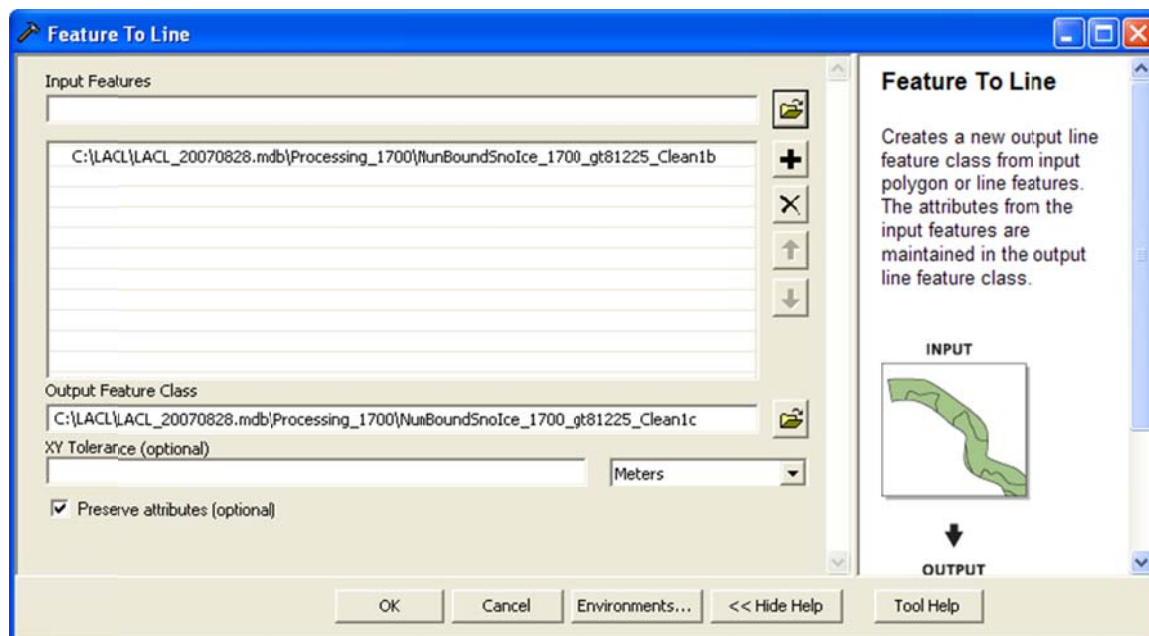


Figure 3-23. Converting “NunBoundSnoIce_1700_gt81225_Clean_1b” polygon shapefile to a line shapefile using the “Feature to Line” command in ArcCatalog.

- Feature-To-Polygon (management):
 “NunBoundSnoIce_1700_gt81225_Clean_1c” to polygon shapefile =
 “NunBoundSnoIce_1700_gt81225_Clean_1d” (Figure 3-24).

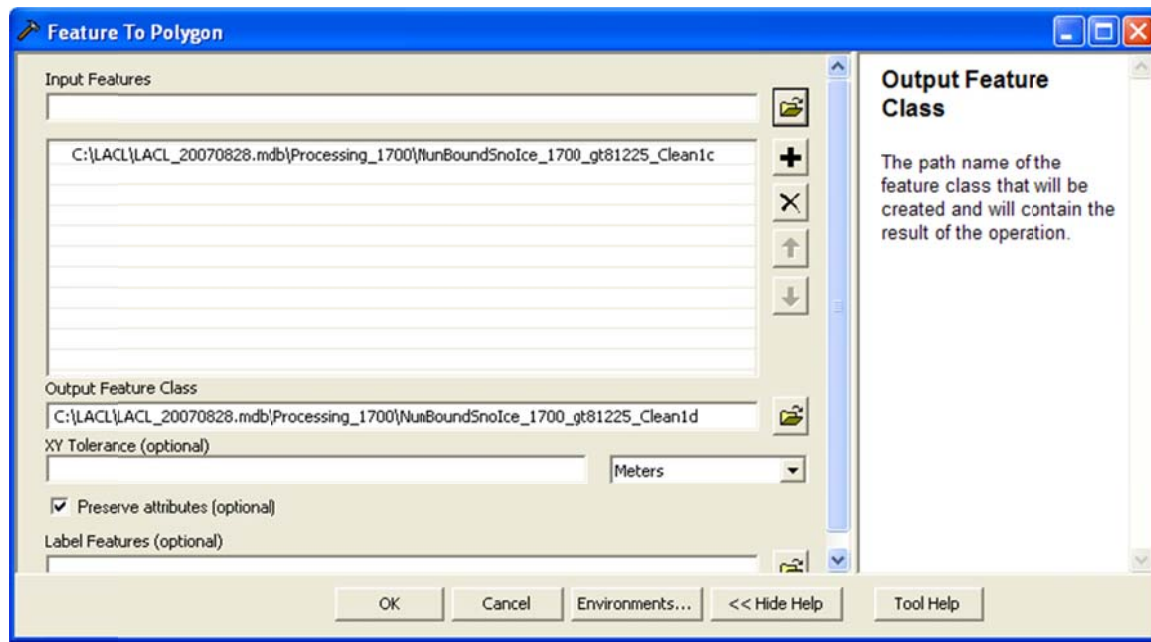


Figure 3-24. Converting “NunBoundSnoIce_1700_gt81225_Clean_1c” line shapefile to a polygon shapefile using the “Feature to Polygon” command in ArcCatalog.

- Add Field (management): Add a Field named RASTER to the attribute table of
 “NunBoundSnoIce_1700_gt81225_Clean_1d” (Figure 3-25).

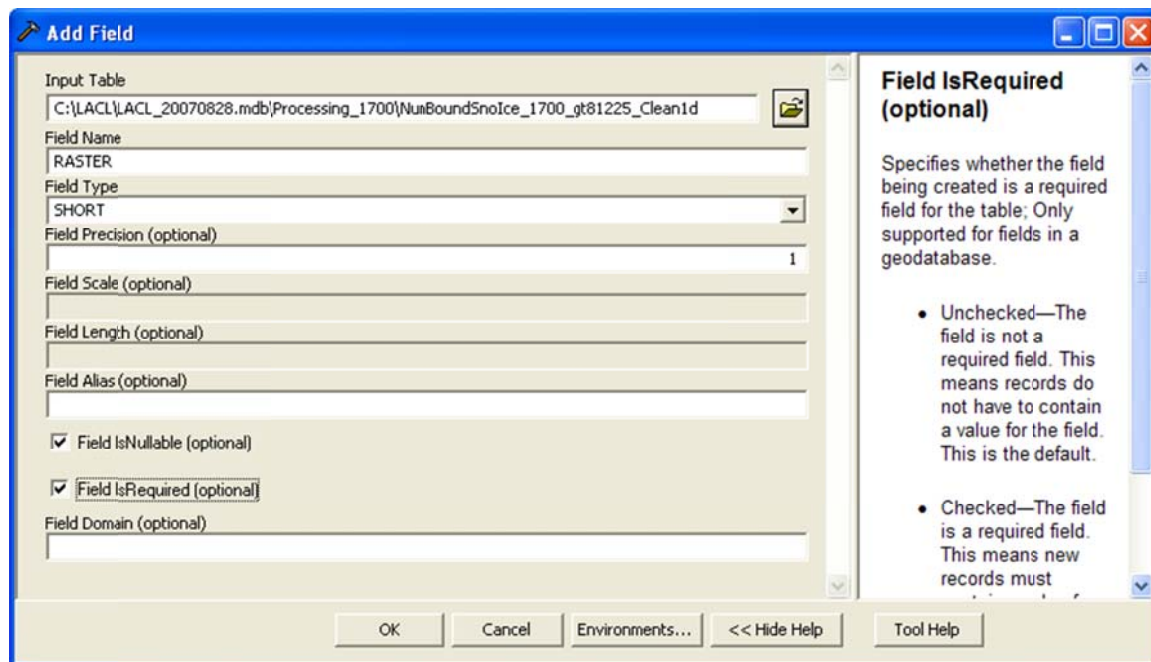


Figure 3-25. Adding a Field called “RASTER” to the attribute table of “NunBoundSnoIce_1700_gt81225_Clean_1d” polygon shapefile using the “Add Field” command in ArcCatalog.

- Calculate Field (management): Calculate to “1” the RASTER field for the polygon shapefiles created above (Figure 3-26).

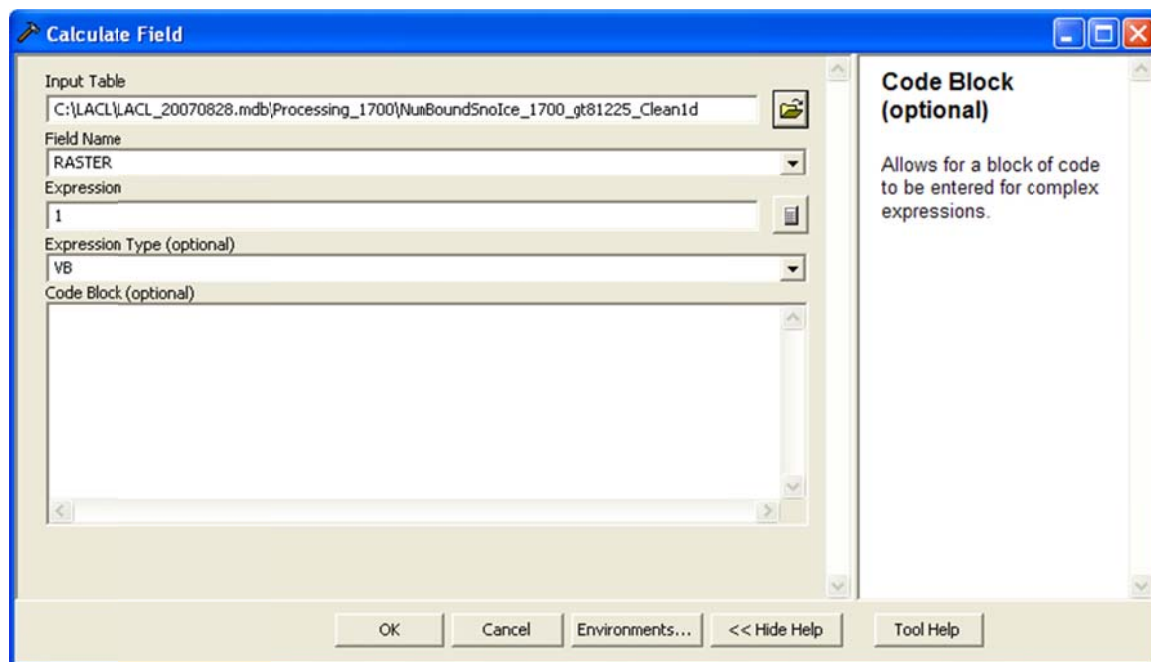


Figure 3-26. Calculating RASTER field value equal to “1” for all records “NunBoundSnoIce_1700_gt81225_Clean_1d” polygon shapefile using the “Calculate Field” command in ArcCatalog.

Step 20 Polygon To Raster Conversion

Create a raster file (Figure 3-27) from the polygon shapefile created in Step 19 (Figure 3-24). Set the “Cell Size” equivalent to the original resolution of the Landsat data, in this case, 28.5.

- Polygon-To-Raster (conversion): “NunBoundSnoIce_1700_gt81225_Clean_1d” to “NunBoundSnoIce_1700_gt81225.img” (Figure 3-27).

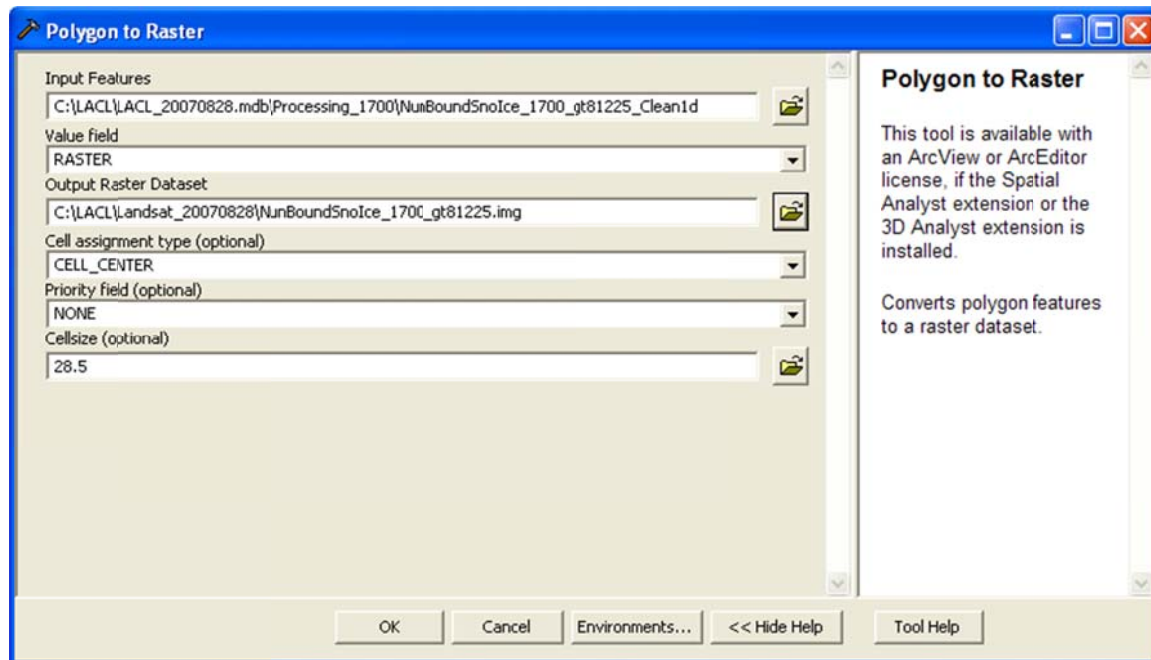


Figure 3-27. Converting “NunBoundSnoIce_1700_gt81225_Clean_1d” polygon shapefile to a raster file using the “Polygon to Raster” command in ArcCatalog.

Step 21 Raster To Polygon Conversion

Convert the raster created in Step 20 to a polygon shapefile.

- Raster-To-Polygon (conversion): “NunBoundSnoIce_1700 gt81225.img” to “NunBoundSnoIce_1700_gt81225_Clean_1e” (Figure 3-28).

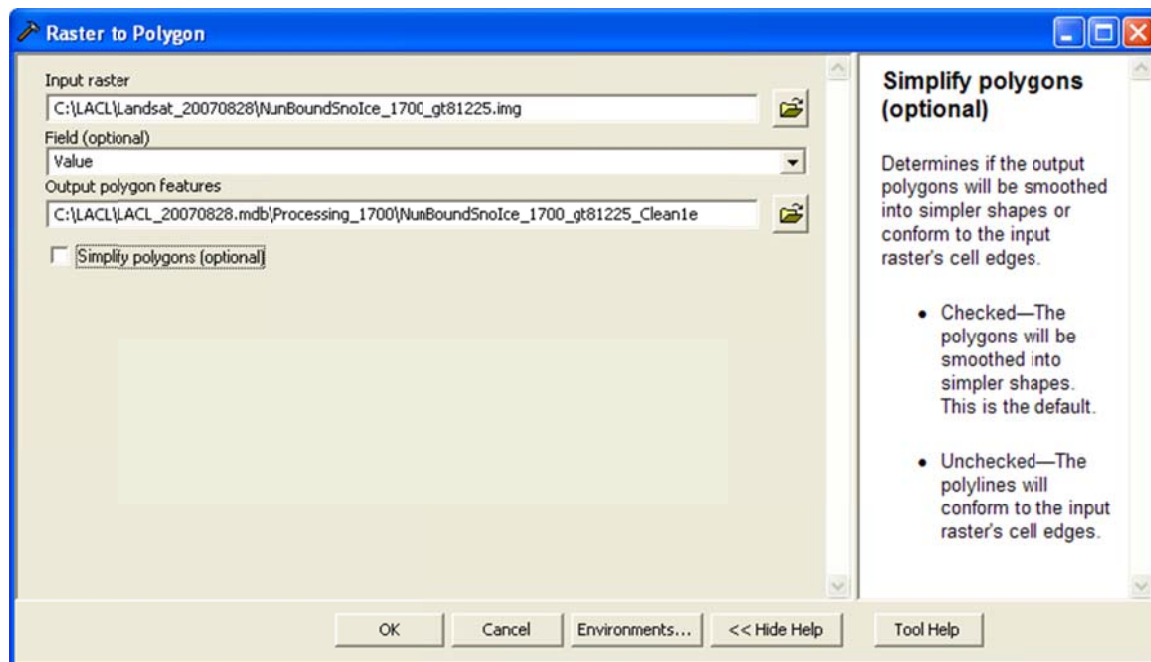


Figure 3-28. Converting “NunBoundSnoIce_1700_gt81225.img” raster file to a polygon shapefile using the “Raster to Polygon” command in ArcCatalog.

Step 22 Select Analysis

This Select Analysis isolates nunatak-bound snow and ice features from other features and creates a new file containing only these nunatak-bound snow and ice features in a polygon shapefile.

- Select (analysis): Using the Analyst Tools>Extract>Select: Using file “NunBoundSnoIce_1700_gt81225_Clean_1e”: Select for GRIDCODE > “1”. Resultant file “NunBoundSnoIce_1700_gt81225_Clean_1f” (Figure 3-29).

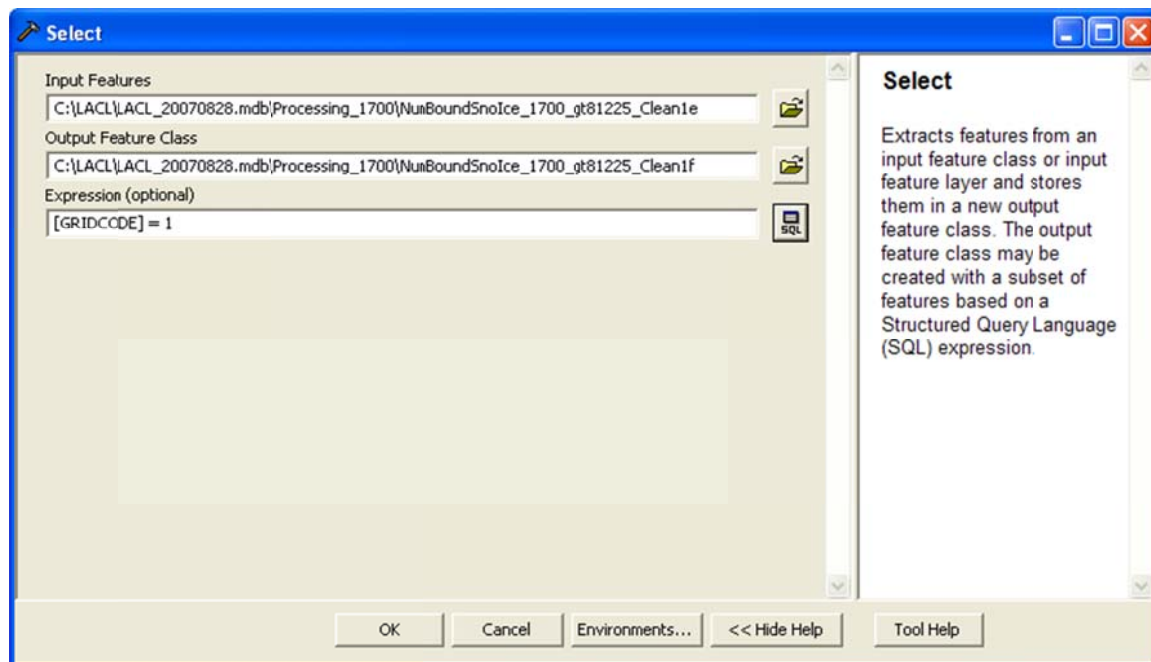


Figure 3-29. Select analysis isolates nunatak-bound snow and ice from other features and creates a new file containing only these features in a polygon shapefile - “NunBoundSnoIce_1700_gt81225_Clean_1e”.

Step 23 Second Threshold Analysis

As noted above, there are two thresholds values appropriate for glacier mapping. In this example, using the B3/B5 band math the two thresholds are 1.250 and 1.700. In steps above, shapefiles using the 1.700 threshold were produced – these shapefiles produce good results for glacier/snow at higher elevations. Also seems to produce good results in shadowed areas. However, this threshold doesn’t produce good results at lower elevations where debris cover is more predominate. To improve the classification at lower elevations (and debris cover) an additional classification is created using a different threshold, in this case, the second threshold is 1.270.

Repeat Steps 6 through 22 using threshold 1.270 beginning with Step 6. Mirror the folder and file naming convention used in the first classification effort.

The resulting “SnoIce” shapefiles are:

- “SnoIce_1270_gt81225_Clean1d”: maps glacier extent at lower elevations and
- “SnoIce_1700_gt81225_Clean1d”: maps glacier extent at higher elevations.

Step 24 DEM Analysis

As noted above the “SnoIce_1270_gt81225_Clean1d” shapefile better maps glacier extent at lower elevations and the “SnoIce_1700_gt81225_Clean1d” shapefile better maps glacier extent at higher elevations.

- Load the National Elevation Dataset (NED) raster file for Lake Clark National Park and Preserve, the “SnoIce_1270_gt81225_Clean1d” and the “SnoIce_1700_gt81225_Clean1d” shapefiles into ArcGIS. Visually identify the elevation break where the two thresholds (.1270 and .1700) merge and then diverge. Make note of the elevation. For LACL 2007 Landsat image, the b3b5 thresholds of .1270 and .1700 the elevation break is 4600 to 4750ft. A threshold of 4,650 was selected in this example.

Step 25 Conditional Statement

Using the National Elevation Dataset (NED) raster file for Lake Clark National Park and Preserve (LACL), apply the threshold value determined in Step 24 that segregates elevation pixels greater than or equal to 4,650 feet elevation from pixels less than 4,650 feet elevation.

- Con (sa): Use the Spatial Analyst Tools>Conditional>Con; Use National Elevation Dataset (NED) raster file LACL as the input raster, the expression is the threshold value determined in Step 24. True = 1 False = 2. Name the output raster: “LACL_gt_4650” and place this file in the “DEM” folder (Figure 3-30).

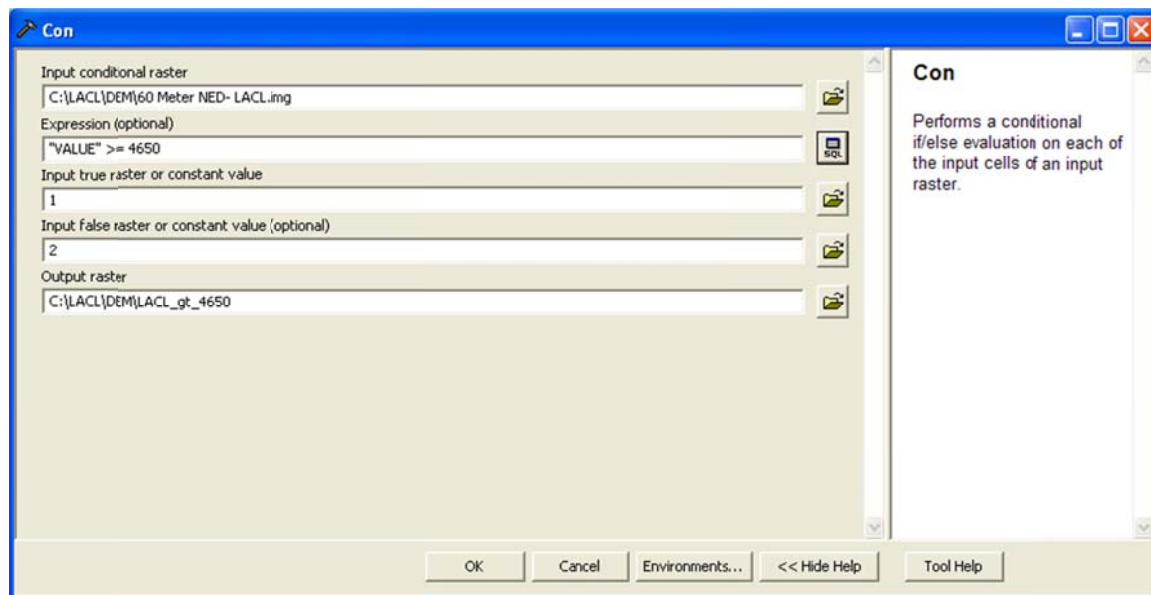


Figure 3-30. Creating a raster image using the “Con” command in ArcCatalog. In this case, the NED in the Lake Clark NP&P region classified into pixels greater than or equal to 4,650 feet elevation and those less than 4,650 feet elevation.

Step 26 Raster to Polygon

Convert the raster created in Step 25 to a polygon shapefile.

- Raster-To-Polygon: Convert raster “LACL_gt_4650” to a polygon shapefile: “LACL_DEM_gt_4650.shp”) and save to the DEM folder. Make sure the “Simplify polygons” box is unchecked (Figure 3-31).

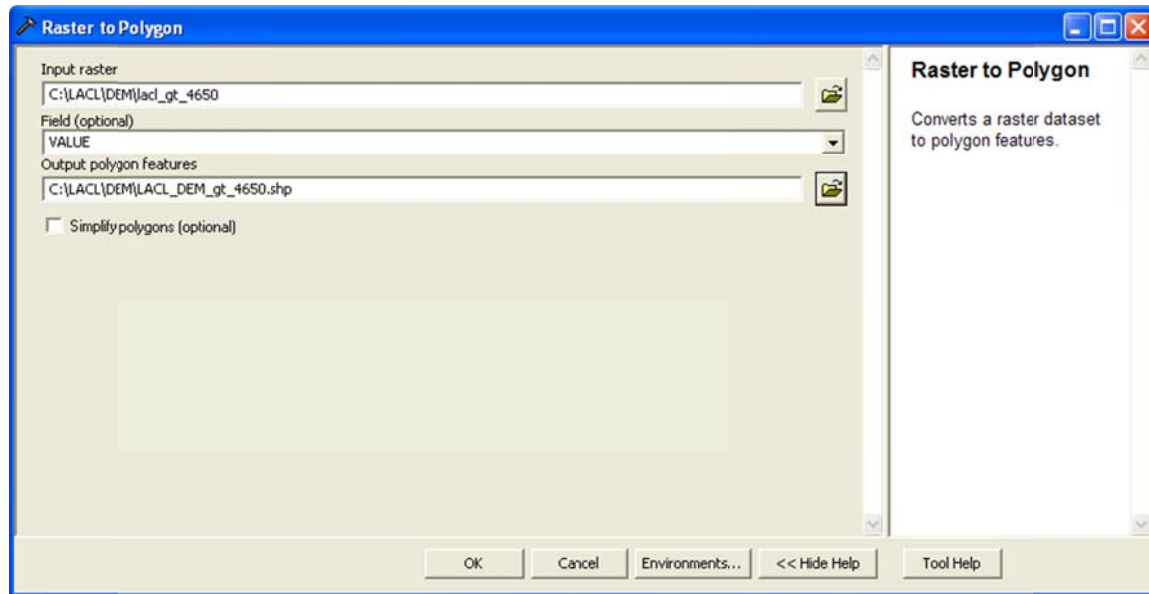


Figure 3-31. Converting the raster created in Step 25 to a polygon shapefile using the “Raster to Polygon” command in ArcCatalog.

Step 27 Select Analysis

Segregates the two classes of polygons created in Step 26 into two separate shapefiles, one representing areas greater than/equal to 4,650 feet elevation and one representing areas less than 4,650 feet elevation.

- Select (analysis): Using the Analyst Tools>Extract>Select; Using file “LACL_DEM_gt_4650”, select for GRIDCODE = “1”. Resultant file: “LACL_DEM_gt_4650_1a” (Figure 3-32).

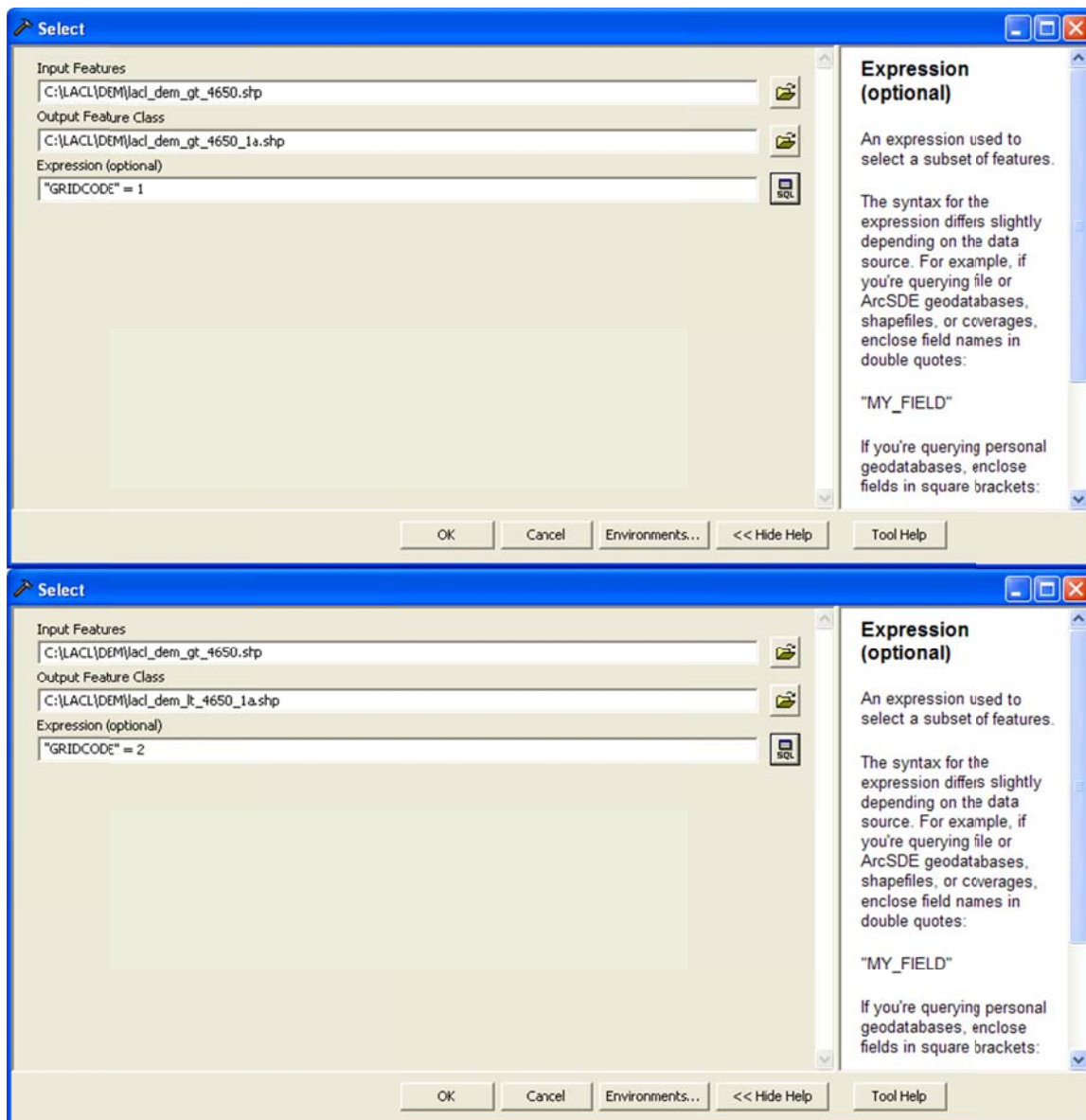


Figure 3-32. This Select Analysis effectively removes polygons representing regions with elevations below 4,650 feet in elevation from the "dem_gt_4650" polygon shapefile.

And:

- Select (analysis): Using the Analyst Tools>Extract>Select; Using file "LACL_DEM_gt_4650", select for GRIDCODE = "2". Resultant file: "LACL_DEM_lt_4650_1a" (Figure 3-33).

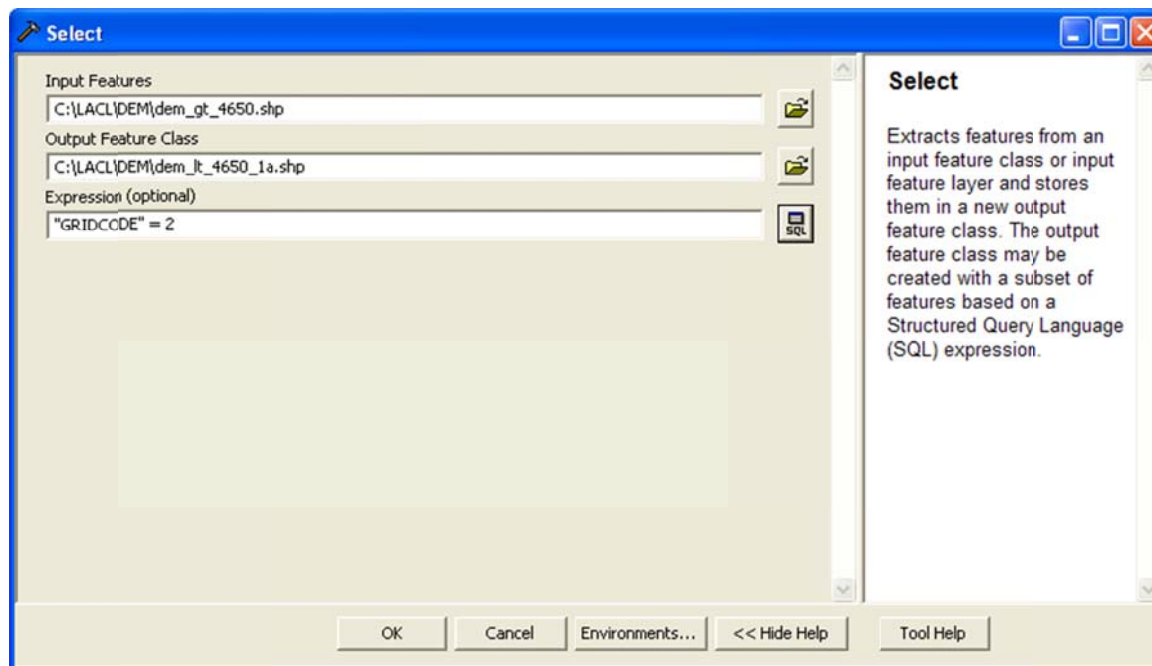


Figure 3-33. This Select Analysis effectively removes polygons representing regions with elevations above 4,650 feet in elevation from the “LACL_dem_gt_4650” polygon shapefile.

Step 28 Erase Analysis

As noted above, the “SnoIce_1270_gt81225_Clean1d” shapefile better maps glacier extent at lower elevations and the “SnoIce_1700_gt81225_Clean1d” shapefile better maps glacier extent at higher elevations. This step will remove the polygons (or those portions of polygons) from the “SnoIce_1270_gt81225_Clean1d” shapefile occurring above the 4,650 foot elevation threshold determined above.

- Erase (analysis): “SnoIce_1270_gt81225_Clean1d” minus “dem_gt_4650_1a” = “SnoIce_1270_gt81225_Clean1e” (Figure 3-34).

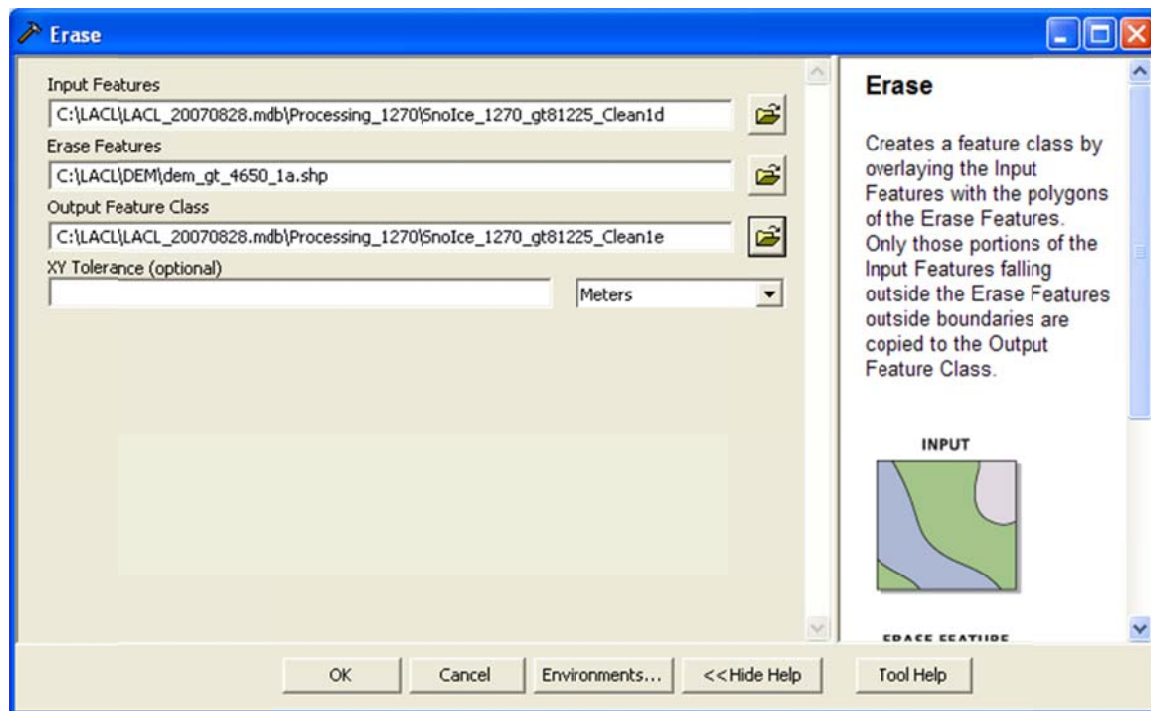


Figure 3-34. Erase polygons of the “SnoIce_1270_gt81225_Clean1d” polygon shapefile from the “DEM_gt_4650_1a” polygon shapefile using the “Erase” command in ArcCatalog.

The same erase analysis is conducted on “SnoIce_1700_gt81225_Clean1d” shapefile, where polygons (or those portions of polygons) will remove from the “SnoIce_1700_gt81225_Clean1d” shapefile occurring below the 4,650 foot elevation threshold determined above.

- Erase (analysis): “SnoIce_1700_gt81225_Clean1d” minus “dem_lt_4650_1a” = “SnoIce_1700_gt81225_Clean1e” (Figure 3-35).

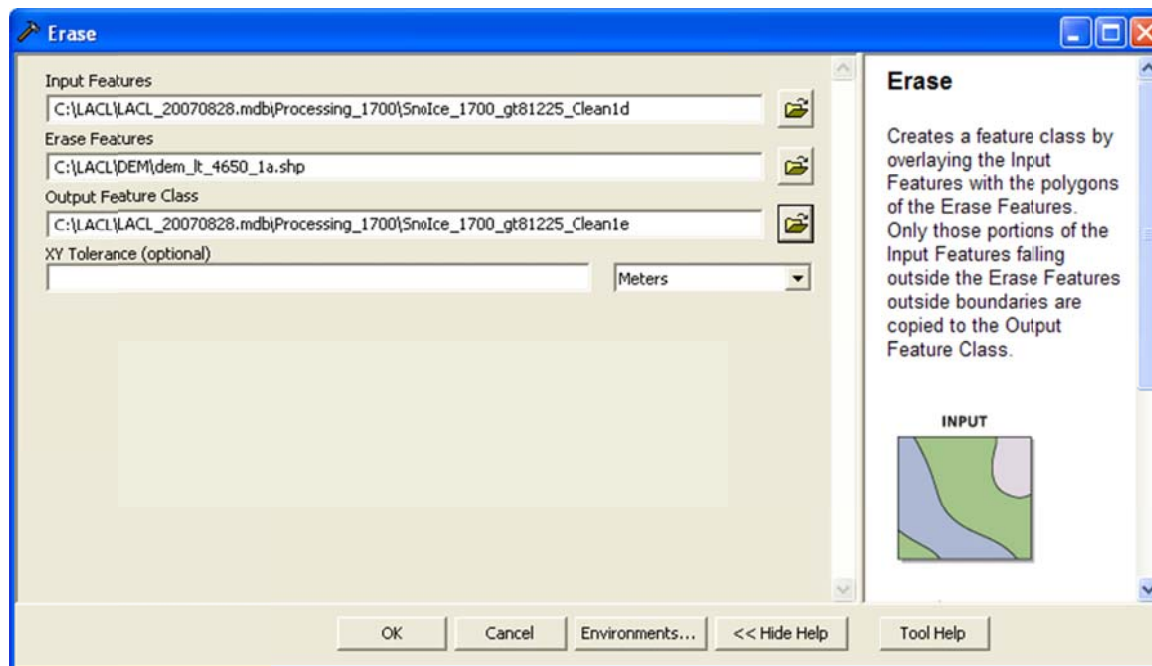


Figure 3-35. Erase polygons of the “SnoIce_1700_gt81225_Clean1d” polygon shapefile from the “DEM_lt_4650_1a” polygon shapefile using the “Erase” command in ArcCatalog.

Step 29 Union

The next step is to “union” the two shapefiles created in Step 28 above. The “union” of these two shapefiles creates one polygon shapefile that best represents glacier ice and permanent snow boundaries at high and low elevations.

- Union (analysis): Using file “SnoIce_1700_gt81225_Clean1e” and “SnoIce_1270_gt81225_Clean1e”, Resultant file: “SnoIce_1700_1270_gt81225_Union1a” saved to the “Processing_Union_1270_1700” folder, a feature dataset within the PARK_YYYYMMDD personal geodatabase (Figure 3-36).

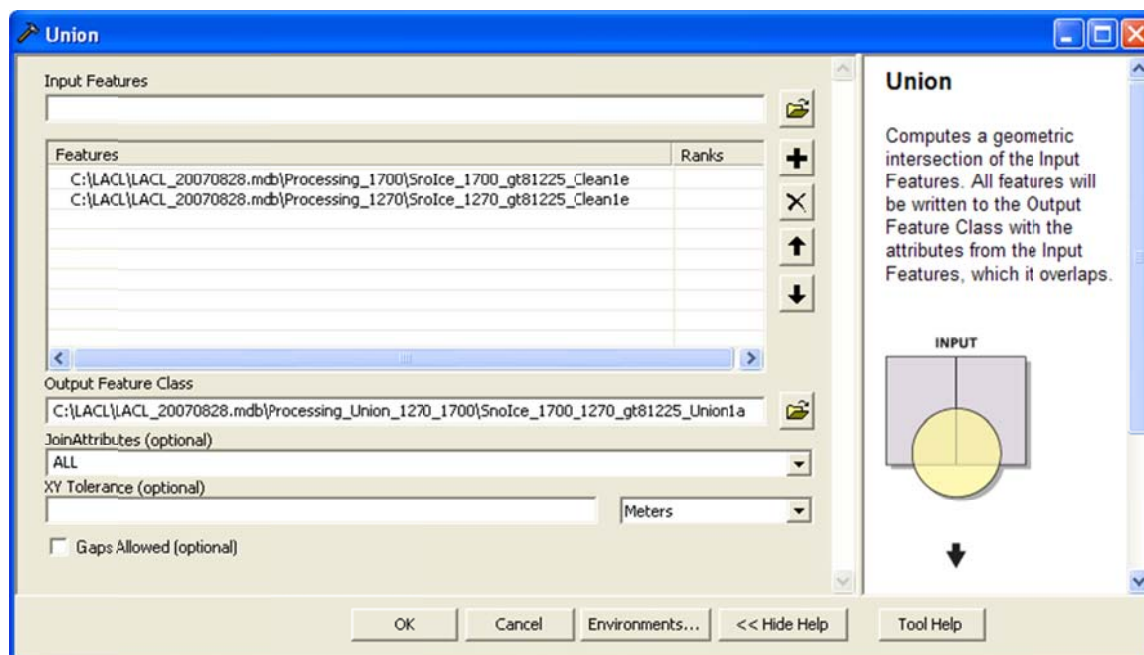


Figure 3-36. “Union” of two shapefiles creates one polygon shapefile that represents glacier ice and permanent snow boundaries at high and low elevations.

Step 30 Attribute Tables Management - SnoIce

Add a “Field” to the attribute table and “Calculate” field values for the polygon shapefile created in Step 29 “SnoIce_1700_1270_gt81225_Union1a” (Figures 3-37 and 38).

- Add Field (management): Add a “Field” called RASTER to the polygon shapefile: “SnoIce_1700_1270_gt81225_Union1a”.

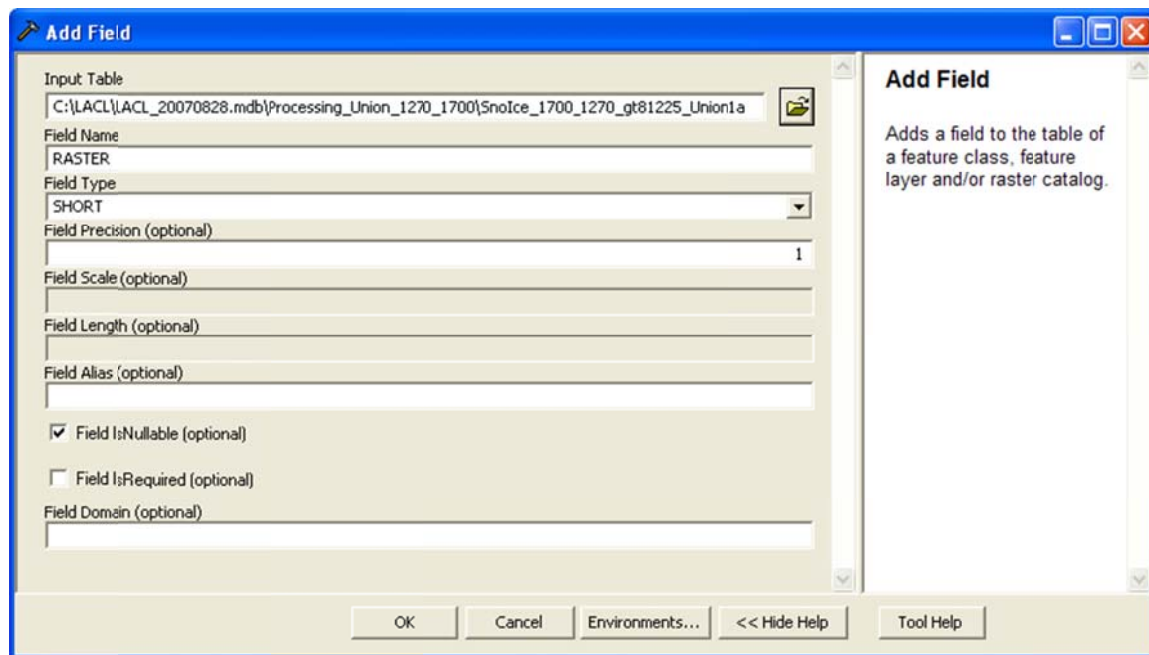


Figure 3-37. Adding a Field called “RASTER” to the attribute table of “SnoIce_1700_1270_gt81225_Union_1a” polygon shapefile using the “Add Field” command in ArcCatalog.

Calculate Field (management): Assign a value of “1” to the “RASTER” field created above: “SnoIce_1700_1270_gt81225_Union1a” (Figure 3-38).

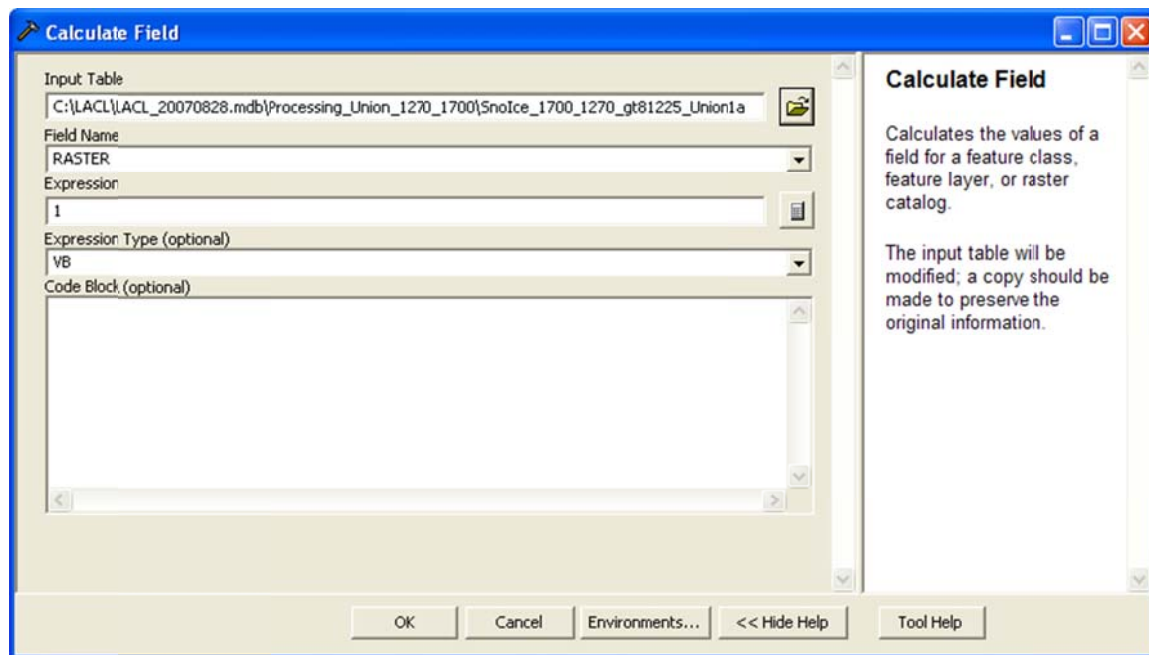


Figure 3-38. Calculating “RASTER” field value equal to “1” for all records “SnoIce_1700_1270_gt81225_Union1a” polygon shapefile using the “Calculate Field” command in ArcCatalog.

Step 31 Polygon To Raster Conversion

Create a raster file from the polygon shapefile created in Step 30. Set the “Cell Size” equivalent to the original resolution of the Landsat data, in this case, 28.5(Figure 3-39).

- Polygon-To-Raster (conversion): Convert Polygon to Raster for file: “SnoIce_1700_1270_gt81225_Union1a”. The resultant file “SnoIce_1700_1270_Union.img” is located in the Landsat folder.

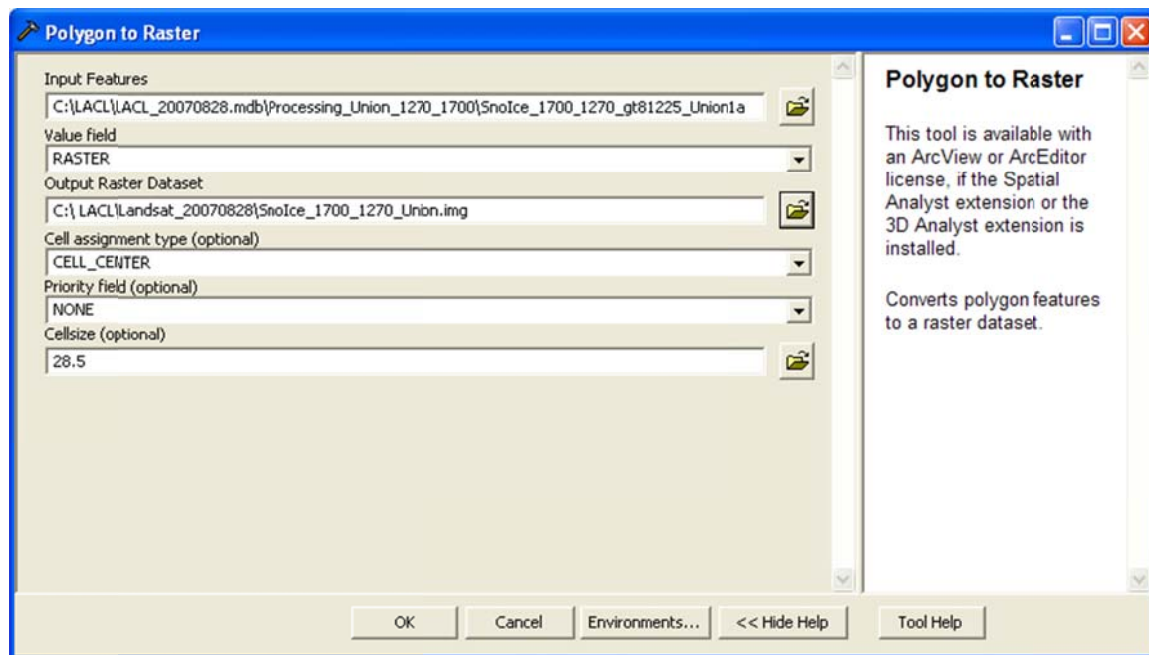


Figure 3-39. Converting the raster created in Step 30 to a polygon shapefile using the “Raster to Polygon” command in ArcCatalog.

Step 32 Raster to Polygon Conversion

Convert the raster created in Step 31 to a polygon shapefile.

- Raster-To-Polygon: Convert raster “SnoIce_1700_1270_Union.img” to a polygon shapefile: “SnoIce_1700_1270_gt81225_Union1b” and save to the “Processing_Union_1270_1700” feature dataset within the PARK_YYYYMMDD personal geodatabase. Make sure the “Simplify polygons” box is unchecked (Figure 3-40).

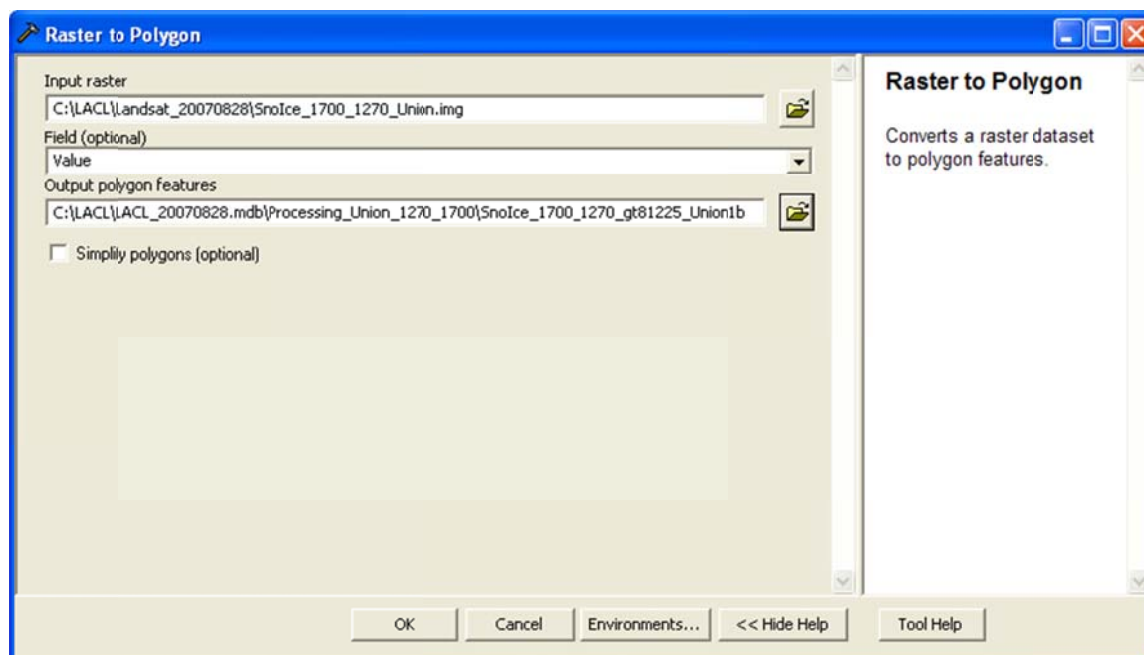


Figure 3-40. Converting “NunBound_SnoIce_1d_Raster” raster file to a polygon shapefile using the “SnoIce_1700_1270_gt81225_Union1b” command in ArcCatalog.

Step 33 Select Analysis

This step removes are features less than ten (10) acres from the “SnoIce_1700_1270_gt81225_Union1b” shapefile. It is assumed that features smaller than 10 acres are primarily lingering snowfields.

- Select (analysis): Using the Analyst Tools>Extract>Select: Using file “SnoIce_1700_1270_gt81225_Union1b” Select for Shape_Area > 40,468 m². Resultant file: “SnoIce_1700_1700_gt81225_Union_gt_10acres” (Figure 3-41).

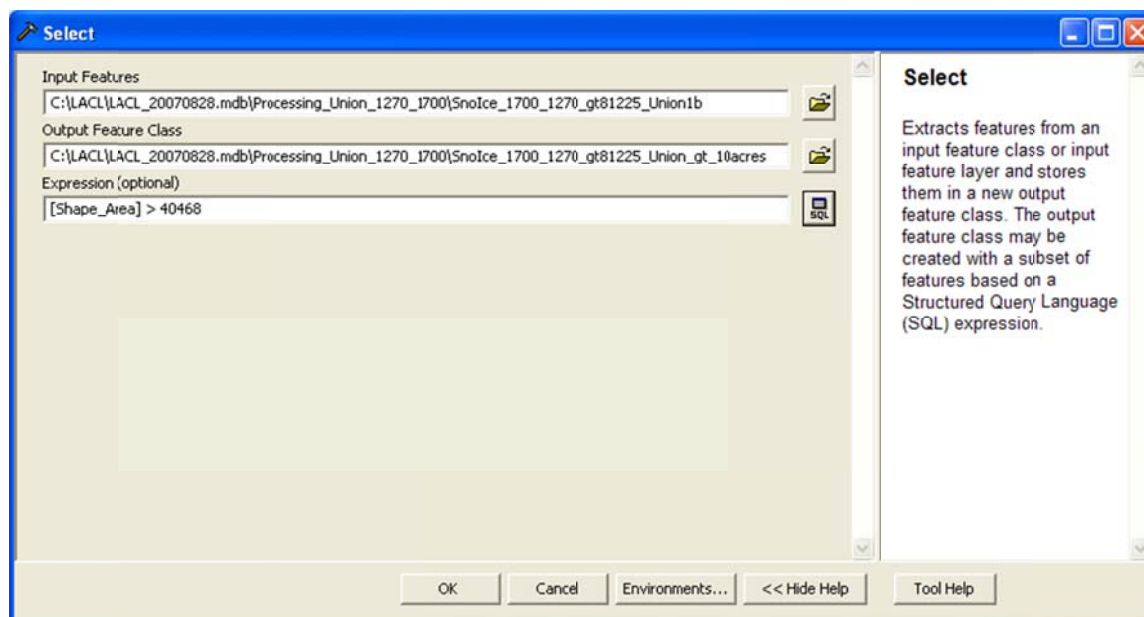


Figure 3-41. Select analysis removes polygons less than 40,468 m² (10 acres) from “SnoIce_1700_1270_gt81225_Union1b” polygon shapefile.

Note: Depending on the elevation where the majority of nunataks (ice free ground surrounded by glacier) occur, it may or may not be necessary to repeat Steps 28-33 using “NonSnoIce_1270_gt81225_Clean1d” and the “NonSnoIce_1700_gt81225_Clean1d” shapefiles.

Conclusions

Phewf! If you are thinking that was fun, SOP #4 is even more fun! Before moving on to SOP #4 identify the shapefiles created in SOP #3 that will be needed for SOP #4.

Selecting shapefiles for final ArcGIS Editing

The next step is to move to complete the final editing of the polygon shapefiles created in SOP #3.

Snow/Glacier Ice

For snow/glacier ice extent, the following shapefile will be edited as outlined in SOP #4:

“SnoIce_1700_1700_gt81225_Union_gt_10acres”

Nunataks

For nunatak features, the following shapefile will be edited as outlined in SOP #4:

“NonSnoIce_1700_gt81225_Clean1e”

Nunatak Bound Snow/Glacier

For snow/glacier features of limited extent and occurring only within the boundaries of nunataks, the following shapefile will be edited as outlined in SOP #4:

“NunBoundSnoIce_1700_gt81225_Clean1f”

The resulting folder and file Structure is shown in Figure 3-42.

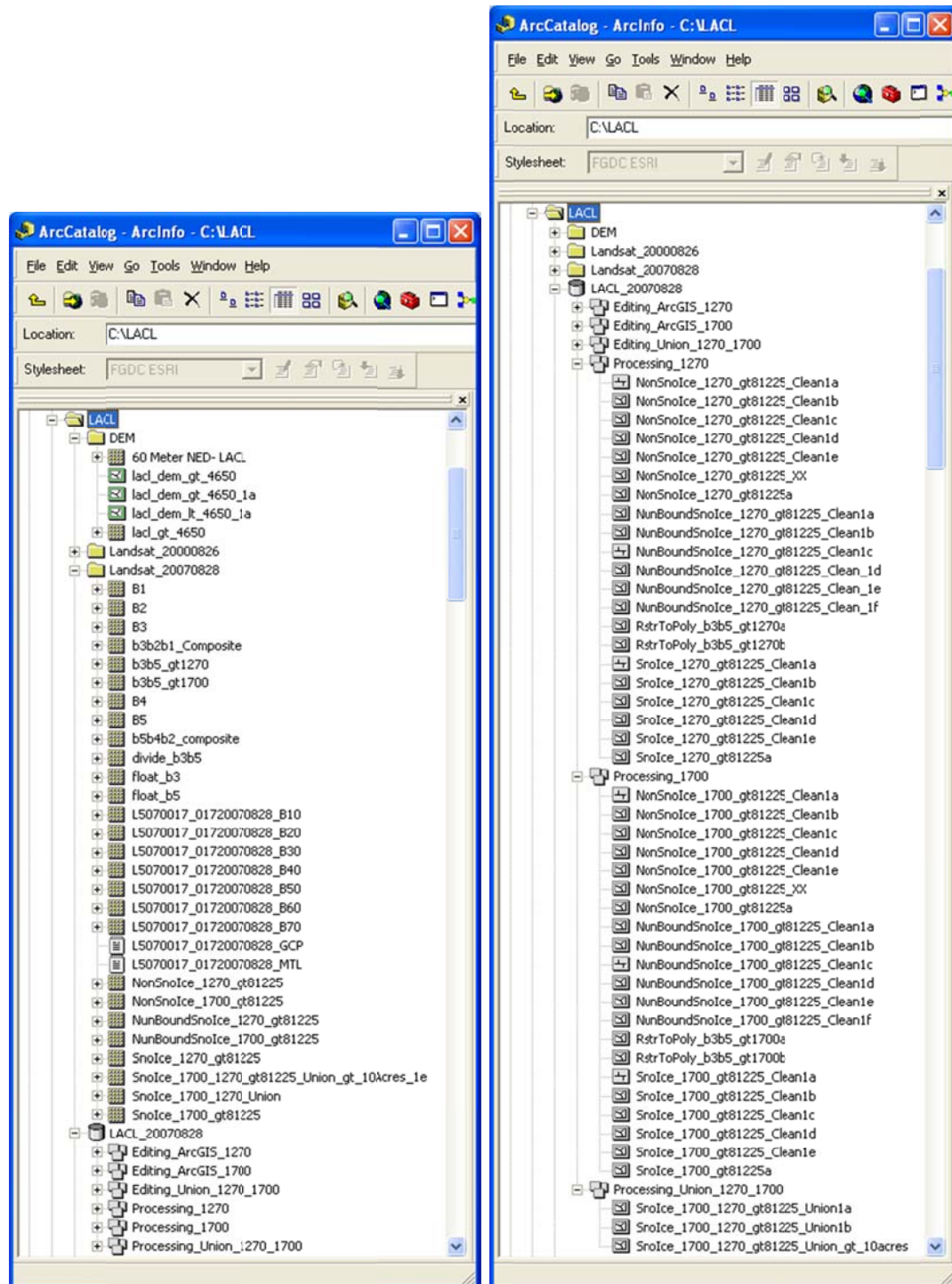


Figure 3-42. Folder and file structure and naming.

The resulting classification of a portion of LACL is shown in Figure 3-43.

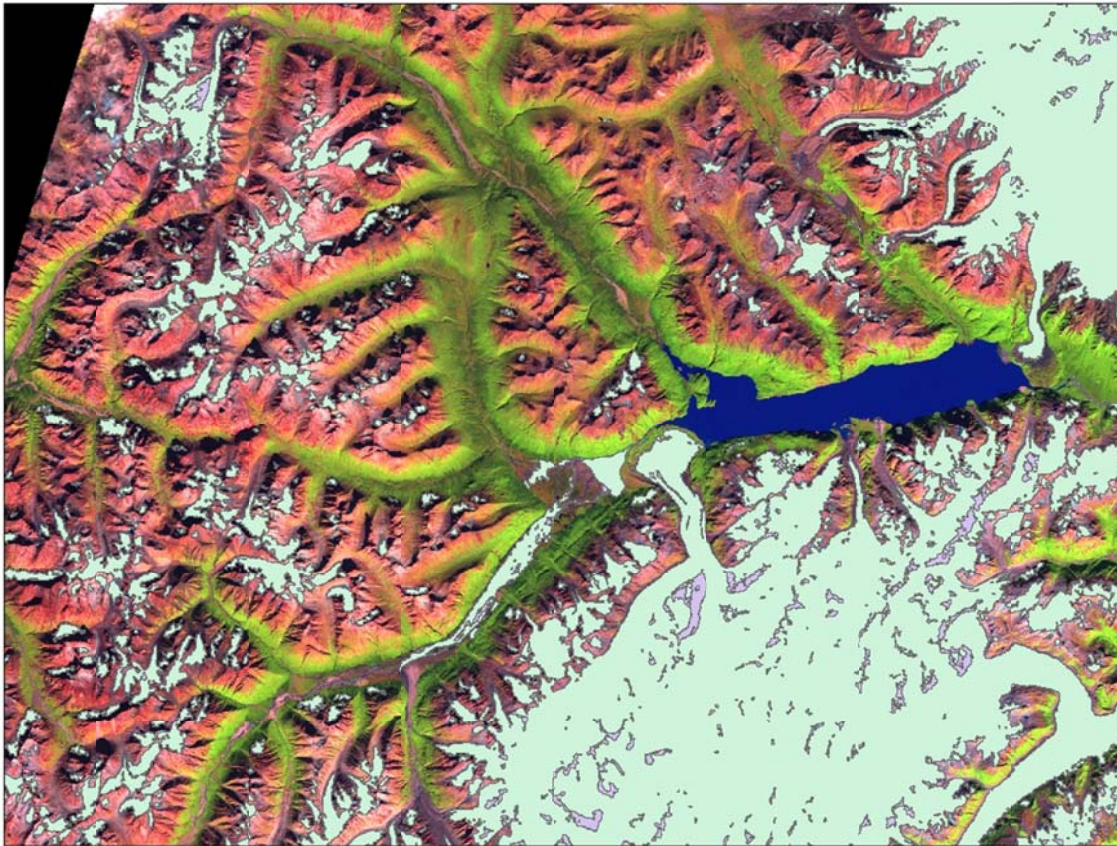


Figure 3-43. A portion of Lake Clark National Park and Preserve (and nearby areas) showing final polygon shapefiles prior to manual editing. Three classes of shapefiles are depicted here: glacier extent, nunataks and nunatak-bound glaciers. Note: obvious areas of misclassification in this Figure 3-include large lakes and rivers (over classification) and debris covered glacier termini (under classification). Landsat 5 image from Sept 28, 2007 (bands 5,4,2) forms the background.

Standard Operating Procedure (SOP) #4

Glacier Boundary Editing - ArcGIS GIS

Version 1.0

Change History

Version numbers will be incremented by a whole number (e.g. Version 1.3 to Version 2.0) when a change is made that significantly affects requirements or procedures. Version numbers will be incremented by decimals (e.g. Version 1.6 to Version 1.7) when there are minor modifications that do not affect requirements or procedures.

The following revisions have occurred to this plan since January 2011

Version #	Date	Revised by	Changes	Justification

This Standard Operating Procedure describes the process of editing automated classifications of glacier extent using ArcGIS and ArcCatalog software supplemented with high resolution oblique aerial photography (if available) in support of the Glacier Monitoring protocol for the Southwest Alaska Network (SWAN).

Overview

This Standard Operating Procedure editing automated classifications of glacier extent using ArcGIS and ArcCatalog software supplemented with high resolution oblique aerial photography (if available). This SOP is not a comprehensive guide to ArcGIS or ArcCatalog; a working knowledge of this software is necessary.

This SOP is an exercise in editing polygon shapefiles in GIS. Raster classifications were created and converted to polygon shapefiles via several processing steps as outlined in SOP #3. These shapefile accurately capture snow and glacier boundaries in all areas except in areas debris covered termini and these are the areas where glacier boundaries will be edited using the techniques outlined in this SOP.

A true-color composite satellite image (Landsat bands 5, 4, and 2) was created in SOP #2 using the same Landsat scene data from which the glacier extent classification is based. The polygon shapefiles and color-composite satellite image will be loaded into ArcGIS where the shapefiles will be modified to correct areas of miss-classification.

Editing the glacier extent polygon shapefiles will be accomplished with the aid of expert knowledge of the region's glaciology and high resolution oblique aerial photography (if available). The accuracy and repeatability of this editing is substantially increased if careful attention is maintained throughout the mapping and editing effort, especially in areas of debris covered ice.

Editing Glacier Extent Boundaries - Overview

The polygon shapefiles created from the raster classification (from SOP #3) will be edited in ArcGIS to correct for areas of miss-classification. In order to create and maintain as much consistency in this glacier extent mapping effort, an understanding of what qualifies as a glacier must be defined.

Delineating the boundary where glacier ice contacts ground is not as simple as it may first appear. As the interpreter zooms in to an area of interest, the pixels representing the contact will trend from white (ice) to black (ground), and in many circumstances, a transition zone of grey pixels between. The spectral reflectance of the pixels represents surface conditions that contain varying proportions of ice, debris on the ice and ground. Mapping the glacier boundary in these situations is left up to the judgment of the image interpreter.

To help standardize glacier mapping, the definition of what falls into the category called "glacier extent" must be defined. This may seem simple, but it is more complicated than first appears. With this in mind, the following is from the GLIMS definition of a glacier to better define a glacier for this protocol (Raup and Khalsa 2010).

A glacier or perennial snow mass consists of a body of ice and snow that is observed at the end of the melt season. This includes, at a minimum, all tributaries and connected feeders that contribute ice to the main glacier, plus all debris covered parts of it. Excluded is all exposed ground, including nunataks.

The following circumstances will be considered when mapping glacier boundaries.

- 1. Bodies of ice above the bergschrund that are connected to the glacier shall be considered part of the glacier, because they contribute snow (through avalanches) and ice (through creep flow) to the glacier.*
- 2. A tributary in a glacier system that has historically been treated (and named) as a separate glacier should, within the GLIMS framework, be included as part of the glacier into which it flows. The name field for the glacier should be populated with all relevant names of tributaries.*
- 3. Any steep rock walls that avalanche snow onto a glacier but do not retain snow themselves are NOT included as part of the glacier.*
- 4. A stagnant ice mass still in contact with a glacier is part of the glacier, even if it supports an old growth forest.*
- 5. All debris covered parts of the glacier must be included.*
- 6. If no flow takes place between separate parts of a continuous ice mass, they should, in general, be treated as separate units, separated at the topographic divide. However, for practical purposes, such an ice mass may be analyzed as a unit at the analyst's discretion, if delineation of the flow divides is impossible or impractical. If the same system is analyzed in the same way later, it will have the same glacier ID, and can therefore be compared. If the system is analyzed in more detail later by breaking it into its component glaciers, those pieces will get new IDs (ID of system will be "parent ice mass" ID for each part), and future analyses of those pieces, if done in the same way, will be comparable.*
- 7. It is possible that an ice body that is detached from another may still contribute mass to the latter through ice avalanches, or it may no longer do so. It is practically impossible to tell which is the case from a single satellite image. Therefore, within GLIMS, adjacent but detached ice areas should, in general, be considered as different "glaciers", regardless of whether they contribute mass to the main glacier through snow or ice avalanches. However, at the analyst's discretion, detached ice masses may be included as parts of one glacier. This is similar to the situation described in 5 above. If the pieces are analyzed separately later, each piece should be given a new GLIMS ID, the old one being used as the "parent ice mass" ID for all the pieces.*
- 8. Regarding the lower parts of lateral snowfields, whose extent varies from year to year map only at the end of the ablation period, preferably in a year without snow outside of the glaciers, to exclude seasonal snow. Then map everything that is connected to the glacier. If snowfields are identifiable, they should be disconnected from the main glacier.*

For hydrological purposes they can be included in the GLIMS Glacier Database under a separate GLIMS glacier ID, but they must be marked as a snowfield. Lateral glacier outlines that might be hidden by seasonal snow or by avalanches should be labeled as preliminary, or even the entire glacier can be excluded. Ice avalanche cones below a glacier terminus (dry calving) are not a part of the glacier.

9. *Rock glaciers and heavily debris covered glaciers tend to look similar, but their geneses are different. GLIMS does not currently deal with the former, but does include the latter*

ArcGIS/ArcCatalog – Editing Glacier and Nunatak Boundaries

ArcGIS/ArcCatalog – Folder and File Naming Convention and Data Handling

Folder structure and naming convention, the creation and naming of Personal Geodatabases and Feature Datasets are presented in SOP#9. Detailed file naming convention is presented throughout this SOP as appropriate.

The first step will be to set up a folder and file naming system as identified in SOP #9 and already initiated in SOP #3. Within the “PARK” folder, a Personal Geodatabase “PARK_YYYYMMDD” was created in SOP #3. Within the Personal Geodatabase, create a new Feature Dataset and name it “Editing_ArcGIS_1270,” “Editing_ArcGIS_1700” and “Editing_Union_1270_1700.” This is where all the editing of the polygon shapefiles created in SOP #3 will occur (Figure 1).

The Datum and Projection of the Feature Datasets created will be equivalent to that of the Landsat data being processed. As indicated in SOP #1, Landsat imagery is currently delivered from EROS Data Center in WGS84, UTM zone 5 or 6, for the SWAN parks.

Frequent file saving during this process is critically important. It will save time in the long run. Also be sure to backup you work files to a separate server. These procedures are outlined in SOP #9.

Copy Polygon Shapefiles into Editing_ArcGIS_XXXX Folder

The final polygon shapefiles that were created in SOP #3 are copied to the “Editing_ArcGIS_1270” and “Editing_ArcGIS_1700” and “Editing_Union_1270_1700” feature datasets. Rename these files using the following format:

<u>“Processing_1700”</u>	→	<u>“Editing_ArcGIS_1700”</u>
SnoIce_1700_gt81225_Clean1e	→	SnowIce_1700_Original
NonSnoIce_1700_gt81225_Clean1e	→	Nunataks_1700_Original
NunBoundSnoIce_1700_gt81225_Clean1f	→	NunatakBound_SnowIce_1700_Original
 <u>“Processing_1270”</u>	 →	 <u>“Editing_ArcGIS_1270”</u>
SnoIce_1270_gt81225_Clean1e	→	SnowIce_1270_Original
NonSnoIce_1270_gt81225_Clean1e	→	Nunataks_1270_Original
NunBoundSnoIce_1270_gt81225_Clean1f	→	NunatakBound_SnowIce_1270_Original
 <u>“Processing_Union_1270_1700”</u>	 →	 <u>“Editing_Union_1270_1700”</u>

SnoIce_1700_1270_gt81225_Union_gt_10acres
 → SnoIce_1700_1270_gt81225_Union_gt_10acres_Original

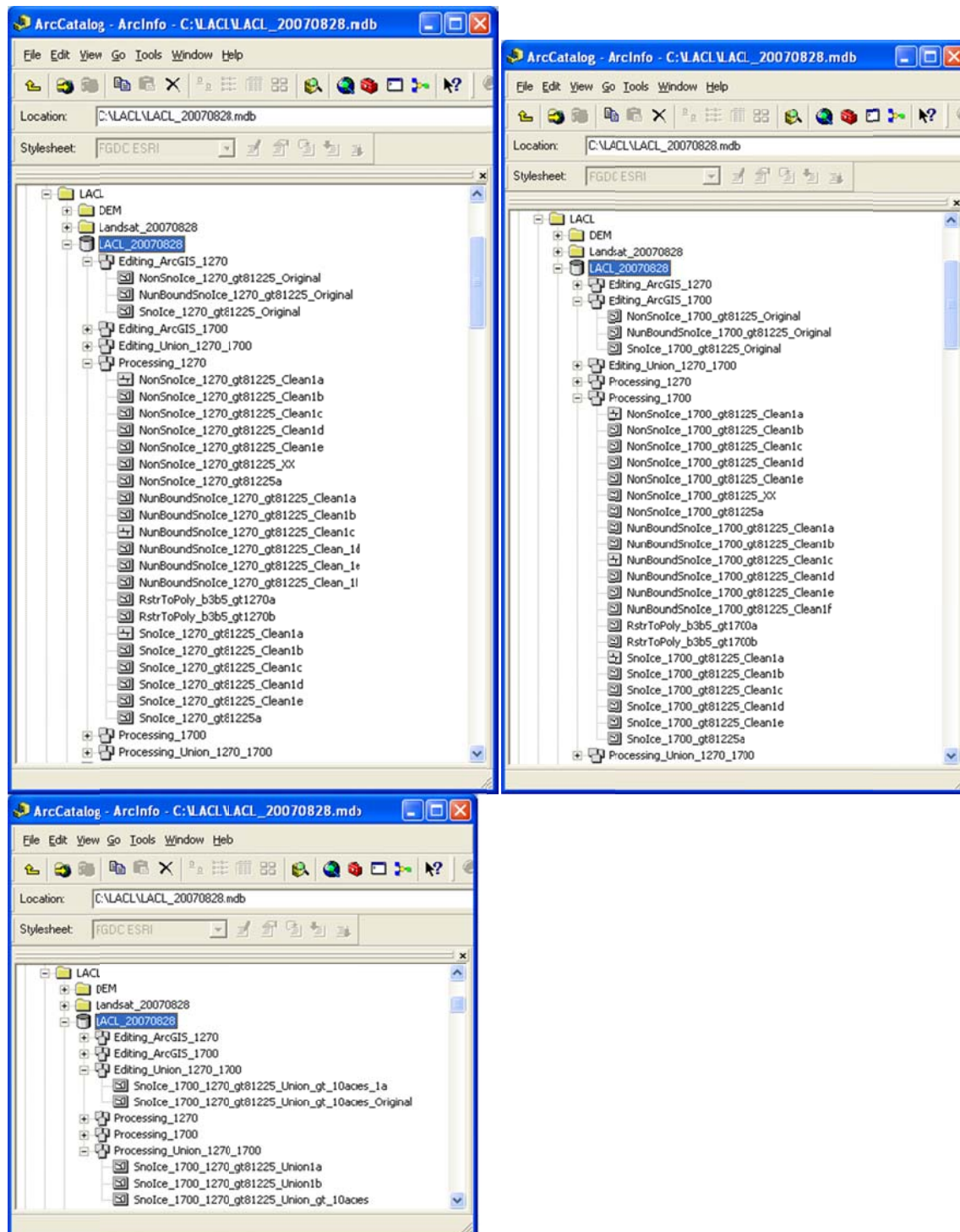


Figure 4-1. Folder, file and personal geodatabase and feature dataset organization.

Load Raster and Shapefiles into ArcGIS

In ArcGIS:

- Load the color-composite Landsat image that was created in SOP #2 (which is located in the “Landsat” folder) into ArcMap. This is the Landsat scene data for which the glacier extent classification is based.
- Using ArcCatalog, make a copy of the “SnoIce_1700_1270_gt81225_Union_gt_10acres_Original” polygon shapefile and name it “SnoIce_1700_1270_gt81225_Union_gt_10acres_XX” and place it in the “Editing_ArcGIS_1270_1700” feature dataset, where XX is a number/alpha character progressing by one for each editing session (e.i. 1a, 1b, 1c, ...). Load “SnoIce_1700_1270_gt81225_Union_gt_10acres_1a” shapefile into ArcMap.
- Adjust the symbology representing “SnoIce_1700_1270_gt81225_Union_gt_10acres_1a” shapefile. Select “Hollow” and then select the “Outline” color you prefer. This will enhance your ability to see the “SnoIce_1700_1270_gt81225_Union_gt_10acres_1a” shapefile on the base image (Figure 4-2).

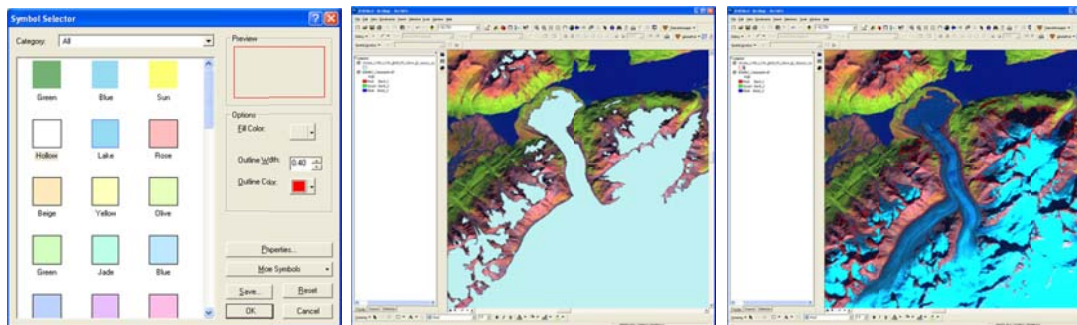


Figure 4-2. “SnoIce_1700_1270_gt81225_Union_gt_10acres_1a” shapefile before and after symbology is modified.

Delete Misclassified Polygons

There are hundreds and possibly thousands of polygons in the “SnoIce_1700_1270_gt81225_Union_gt_10acres_1a” shapefile that are a result of over-classification. Start editing in ArcGIS and begin deleting the polygons that are obvious errors. These areas of over-classification are typically water bodies (lakes and rivers) and shadowed areas (Figure 4.3).

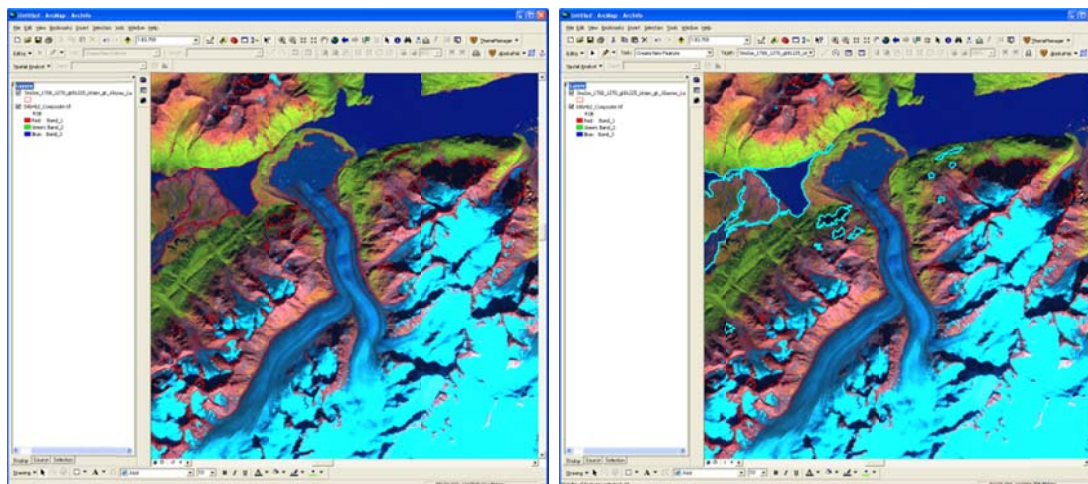


Figure 4-3. The original “SnoIce_1700_1270_gt81225_Union_gt_10acres_1a” shapefile on the left with polygons representing areas of obvious over classification (lakes, rivers, shadows). The image on the right shows the highlighted polygons to be deleted from the “SnoIce_1700_1270_gt81225_Union_gt_10acres_1a” shapefile.

As the larger (easiest) polygons are identified and deleted from the “SnoIce_1700_1270_gt81225_Union_gt_10acres_1a” shapefile, zoom in to a scale not smaller than 1:24,000. Systematically pan across the entire glacier mapping region deleting all polygons of over-classification (misclassification). If a polygon can’t be deleted in its entirety (i.e. there is snow/glacier ice within its boundary) leave it for now, don’t begin polygon boundary modifications at this point.

This process of deleting polygons of misclassification will take a lot of time and effort (it may span several days). Frequent file saving will reduce frustration and save time. Create a new polygon shapefile at the beginning of each new day of editing from the most recent edited shapefile. The following screen captures (Figures 4-4 and 4-5) further illustrate the editing procedure.

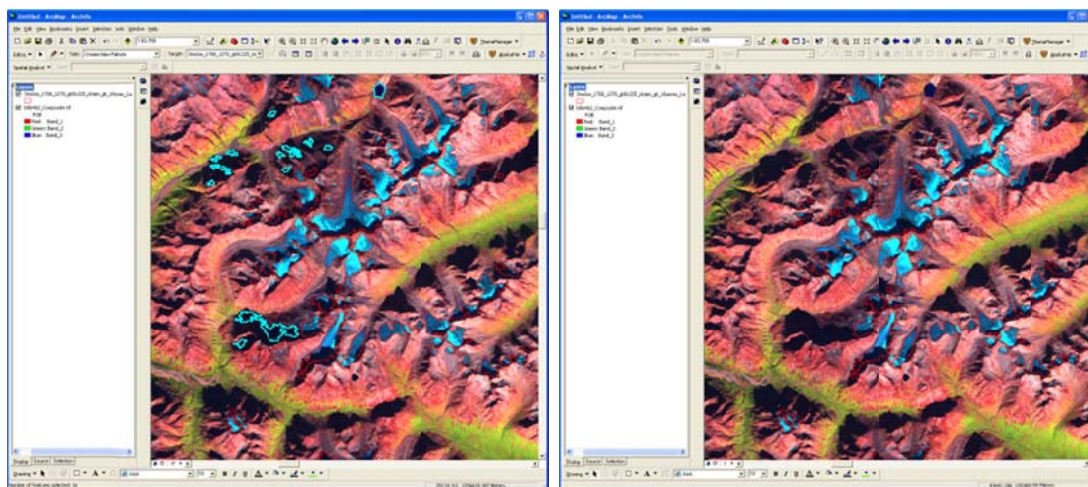


Figure 4-4. The highlighted polygons in the left image (SnoIce_1700_1270_gt81225_Union_gt_10acres_1a shapefile) represent shadow, not snow or glacier ice. These polygons are deleted from the shapefile in the image on the right.

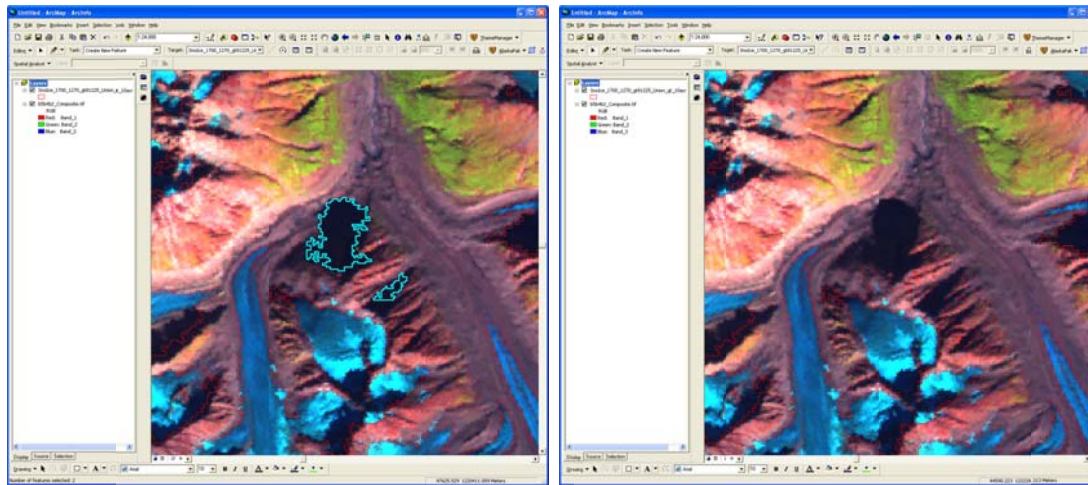


Figure 4-5. A couple shadow polygons are present in the center portion of the left image (“SnoIce_1700_1270_gt81225_Union_gt_10acres_1a” shapefile). These polygons are deleted from the shapefile in the image on the right.

Continue systematically traversing the entire glacier mapping area deleting these polygons of misclassification. Zooming in and out and looking at higher resolution imagery (if available) will aid this editing process.

Repeat the process of removing polygons of misclassification with the Nunataks shapefile. Begin by making a copy of the “NonSnoIce_1700_gt81225_Original” shapefile, and name the copy “NonSnoIce_1700_gt81225_XX” where XX is a number/alpha character progressing by one for each editing session (e.i. 1a, 1b, 1c, ...). Load the latest “SnoIce_1700_1270_gt81225_Union_gt_10acres_XX” shapefile into ArcMap. Next, convert “NonSnoIce_1700_gt81225_1a” shapefile to a line file “NonSnoIce_1700_gt81225_1b” and then back to a polygon shapefile “NonSnoIce_1700_gt81225_1c.” Begin deleting misclassified polygons using the “NonSnoIce_1700_gt81225_1c” shapefile, eliminating all polygons captured erroneously as nunataks (Figures 4-6 and 4-7). Again, this process should also be carried out with the composite image and the most recent “SnoIce_1700_1270_gt81225_Union_gt_10acres_XX” shapefile as a backdrop during the editing process. By definition, nunataks are bare ground surrounded by glacier ice.

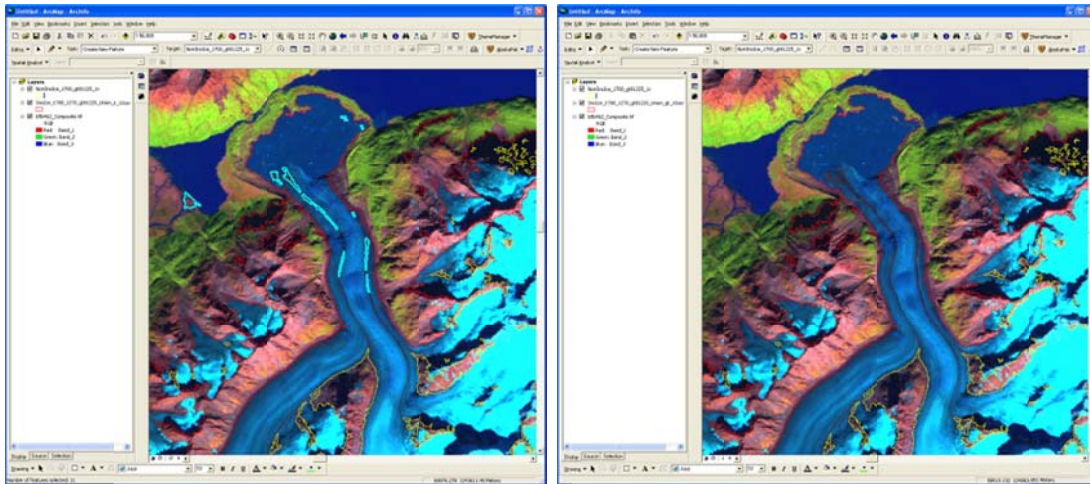


Figure 4-6. A few nunatak polygons (selected light blue color) in the “NonSnoIce_1700_gt81225_1c” shapefile (left image) are clearly not nunataks but are moraine features on the glacier and deltaic feature (left of left image). These polygons are deleted from the “NonSnoIce_1700_gt81225_1c” shapefile in the image on the right.

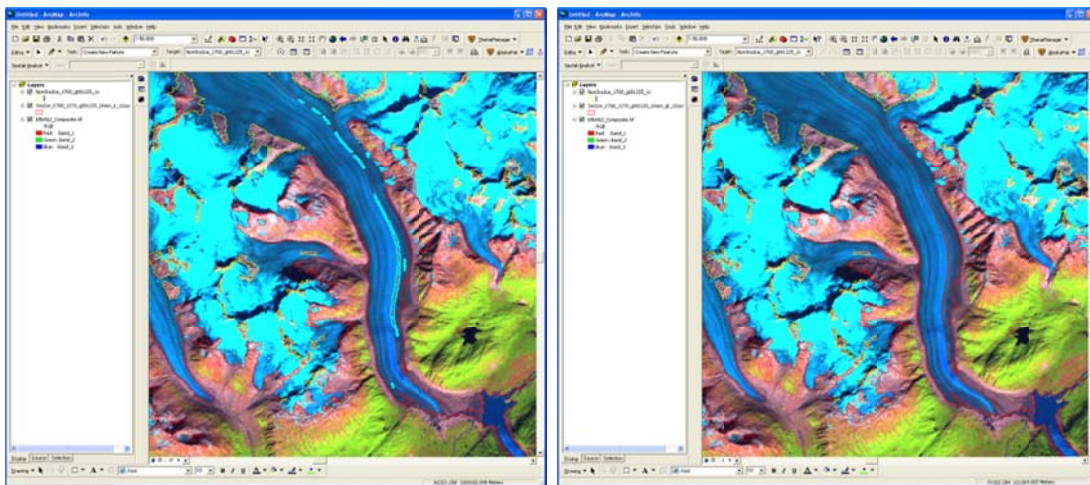


Figure 4-7. Again, a few nunatak polygons (light blue color - selected) in the “NonSnoIce_1700_gt81225_1c” shapefile (left image) are clearly not nunataks but are moraine features on the glacier. These polygons are deleted from the shapefile in the image on the right.

Editing Glacier Boundaries

When all extraneous polygons representing miss-classification (both “SnoIce_1700_1270_gt81225_Union_gt_10acres_XX” and “NonSnoIce_1700_gt81225_XX” shapefiles) have been eliminated, it is time to begin to modifying polygon boundaries to capture areas of partial miss-classification, typically these are areas of under-classification. This step will be performed at a scale of not smaller than 1:24,000 and 1:15,000 is better. Frequently zooming in and out is useful, though actual line modification should occur zoomed to at a scale of least 1:24,000.

For this step in the boundary modification process, there are essentially two classes of glaciers:

- Individual debris covered glacier termini
- Coalescing debris covered glacier termini (two or more coalescing glaciers)

Editing Glacier Boundaries - Individual Debris Covered Glacier Termini

For individual debris covered glaciers, this step is a simple editing task in ArcGIS. Some of the editing features that will be important are:

- Create Tasks
- Modify Tasks
- Snapping

In areas of coalescing debris covered glaciers, the process becomes more complicated, requiring several additional steps be accomplished to facilitate the editing process. This process will be described in the next section of this SOP.

Start with the polygon shapefiles that have been cleaned of all polygons representing misclassification/over classification (“SnoIce_1700_1270_gt81225_Union_gt_10acres_XX” and “NonSnoIce_1700_gt81225_XX”). Make a copy of these shapefiles prior to conducting the following steps in the editing process and name the file appropriately (next in the numbering sequence). This ensures that you can step back to the latest version shapefile if the work becomes corrupt.

NOTE: At this stage, the “SnoIce_1700_1270_gt81225_Union_gt_10acres_XX” is the best representation of clean glacier ice boundaries created in the process.

The following process/example will be presented using the latest version of the “SnoIce_1700_1270_gt81225_Union_gt_10acres_XX” shapefile. This editing will also necessarily create some new polygons representing nunataks and thus these new nunatak polygons will be added to the most recent nunatak shapefile.

ArcGIS/ArcCatalog Commands

- Feature To Line (management): Convert the “SnoIce_1700_1270_gt81225_Union_gt_10acres_XX” shapefile to a line shapefile and name the file appropriately (next in the file naming sequence) (Figure 4-8).

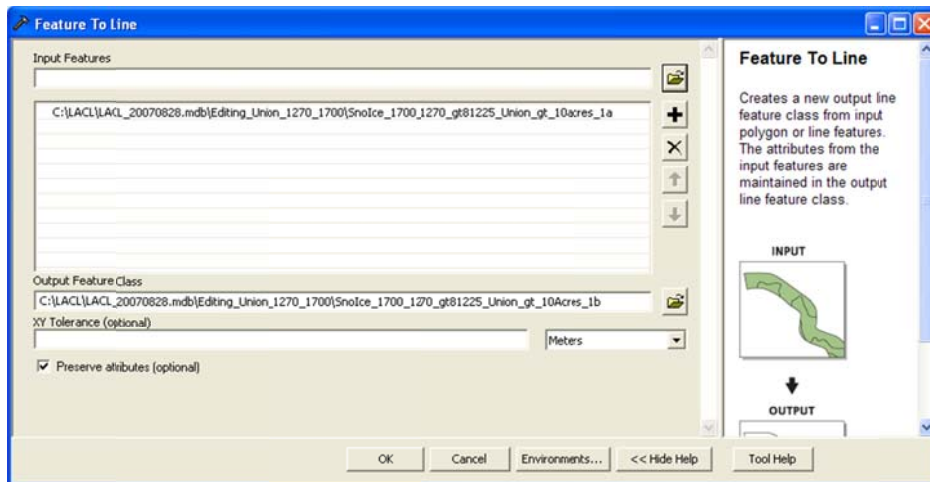


Figure 4-8. “Feature To Line” command.

- Split Line At Vertices (management): Split the “SnoIce_1700_1270_gt81225_Union_gt_10acres_XX” shapefile created above at the vertices and name the file appropriately (next in the file naming sequence) (Figure 4-9).

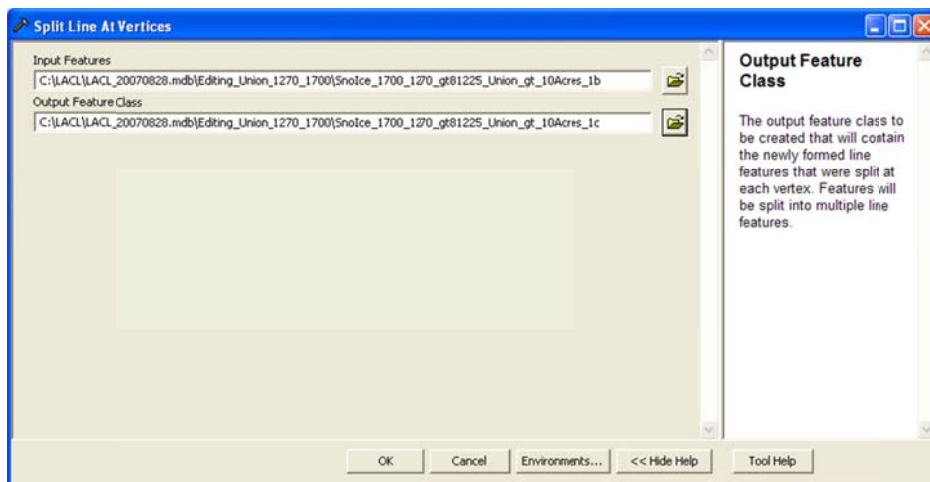


Figure 4-9. “Split Line At Vertices” command.

- At this point begin editing the newest “SnoIce_1700_1270_gt81225_Union_gt_10acres_XX” line shapefile in a standard ArcGIS edit session. Start an Edit session in ArcGIS and select “Create New Feature” and indentify the “Target” as the “SnoIce_1700_1270_gt81225_Union_gt_10acres_XX” line shapefile.
- Begin to capture areas of debris covered termini digitizing their boundaries using on-the-fly digitizing with your mouse. Be sure to use the snapping feature in the edit session to initiate and terminate the new feature at an appropriate vertex of the “SnoIce_1700_1270_gt81225_Union_gt_10acres_XX” line shapefile. Using the “snapping” feature to initiate and terminate lines will ensure that polygons will be created when this line shapefile is converted to a polygon shapefile.

The following figures (Figures 4-10 through 4-18) illustrate editing of individual glacier termini that are debris covered.

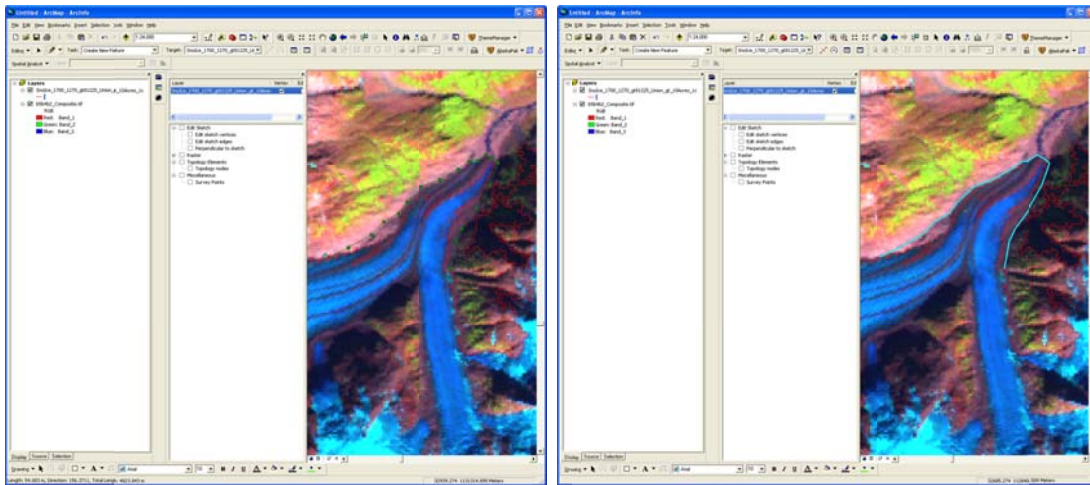


Figure 4-10. Simple glacier boundary extension in areas of one debris covered glacier terminus: initial classification and editing in progress (left) and the corrected classification (right).

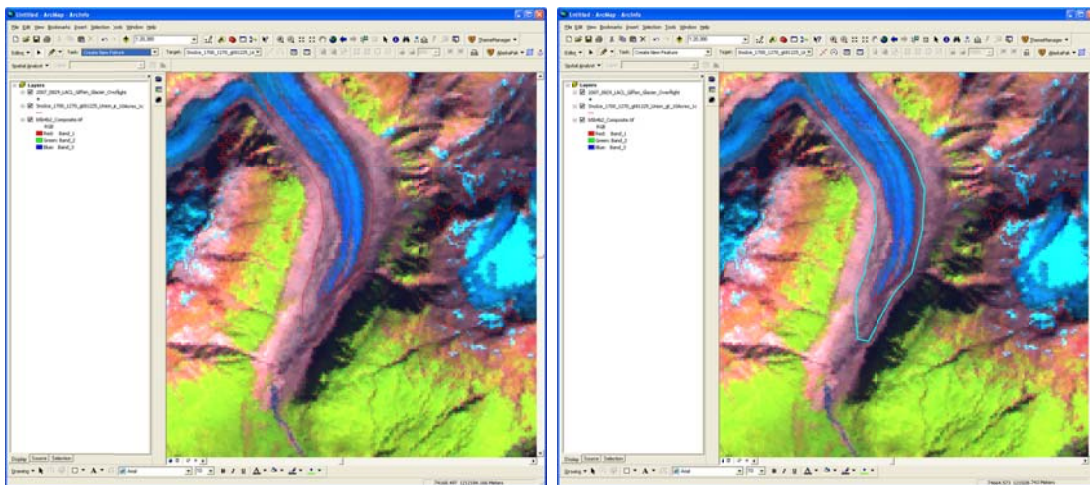


Figure 4-11. Landsat image and the initial classification (left) and the corrected classification (right).

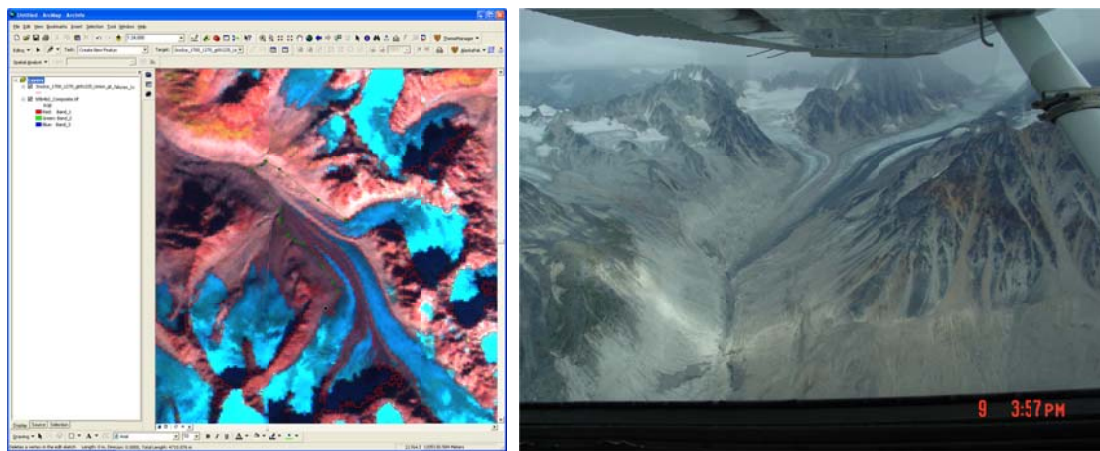


Figure 4-12. In this situation, an aerial oblique photo is available to aid in the glacier boundary modification. Landsat image (left), the initial classification and the corrected classification based on information gained from the aerial oblique photo of the glacier. The Landsat image and the aerial oblique photo were both captured in August 2007.

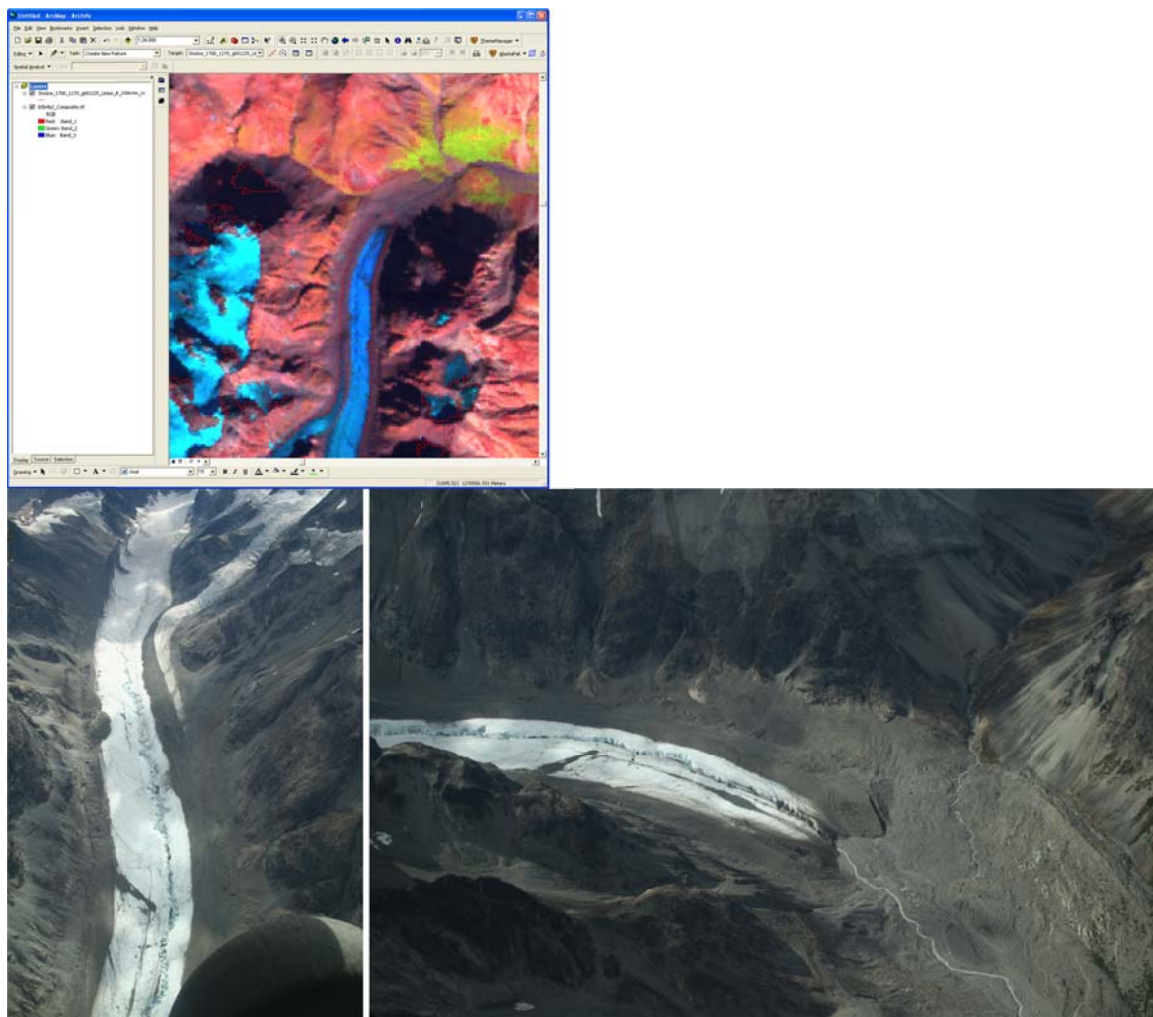


Figure 4-13. Another example of the corrected classification based on aerial oblique photography.

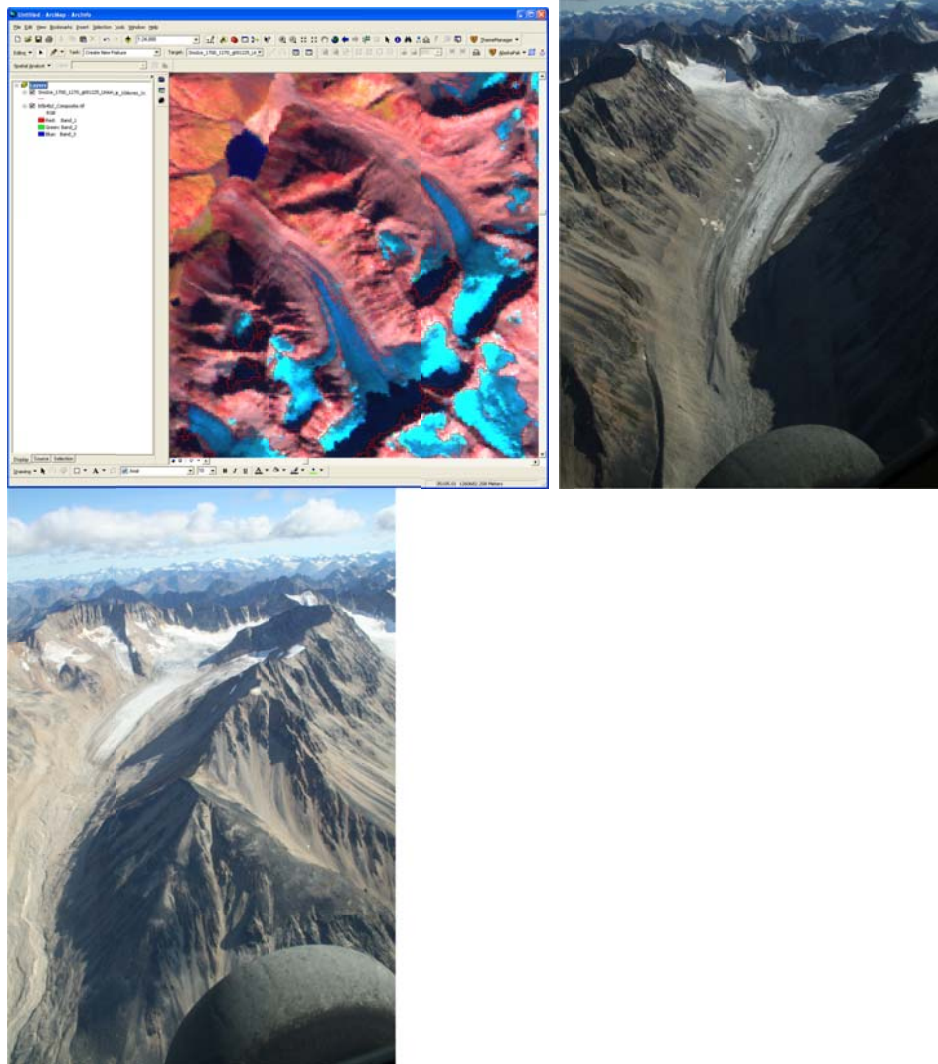


Figure 4-14. Another example of the initial classification and corrected classification based on aerial oblique photography. The aerial oblique on the left is of the glacier on the left of the Landsat image. The aerial oblique on the right is of the glacier on the right of the Landsat image.

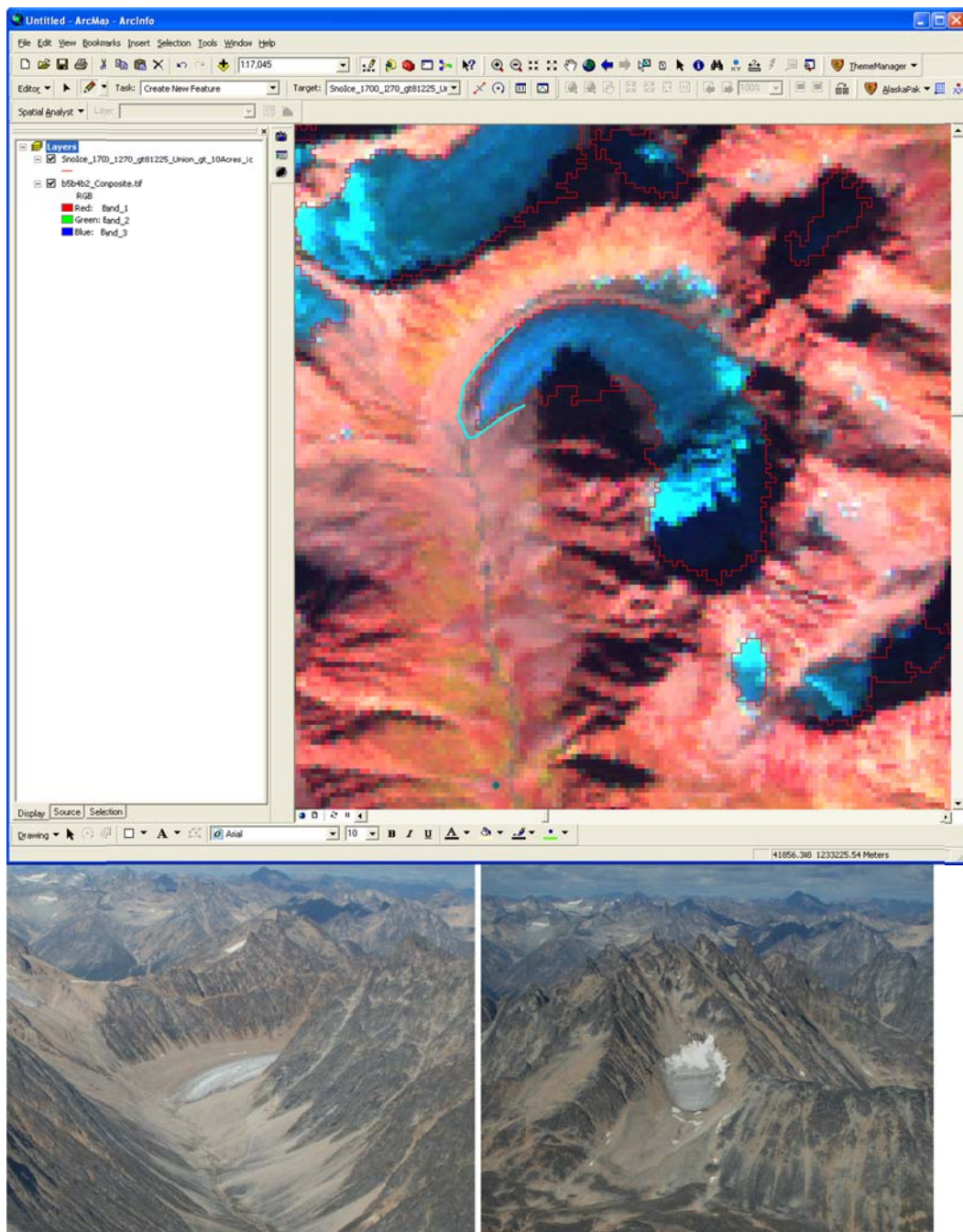


Figure 4-15. Another example of the initial classification and corrected classification based on aerial oblique photography. The aerial oblique on the left is of the glacier on the left of the Landsat image. The aerial oblique on the right is of the small glacier on the right of the Landsat image. Correction shown in blue. Note no correction was made to the small glacier on the right.

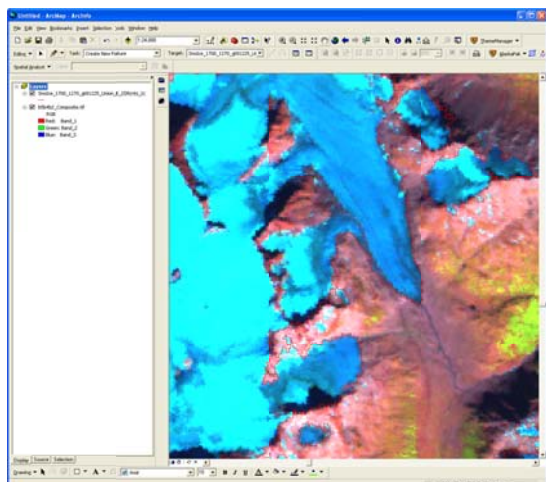


Figure 4-16. An example of the initial classification. No correction is required here. The glacier in the center of the aerial oblique is the main valley glacier in the Landsat image.

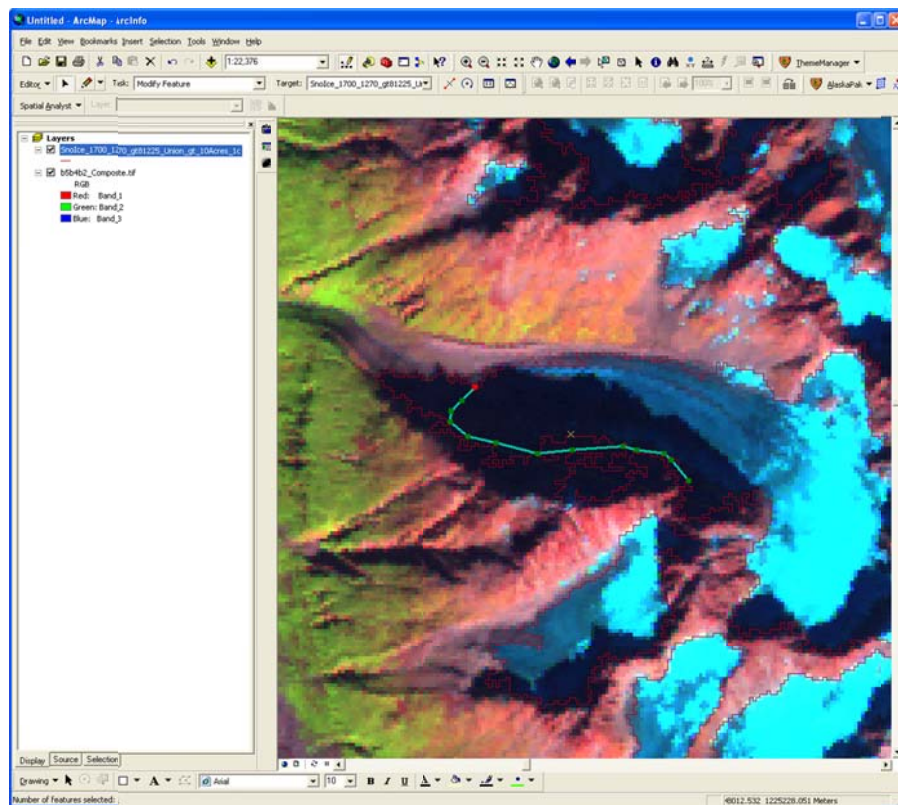


Figure 4-17. Another example of the initial classification and corrected classification based on aerial oblique photography. The initial classification is challenged by shadowed ice. Correction shown in blue.



Figure 4-18. An example of the classification correction in progress based on aerial oblique photography. The aerial oblique imagery shows both the terminus and the boundaries of the Shamrock Glacier. In this situation, aerial oblique imagery is helpful but not critical as the terminus position shows up very nicely in the Landsat imagery.

Editing Glacier Boundaries - Coalescing Debris Covered Glacier Termini

At this stage of the editing process, the boundaries of all the individual debris covered glaciers have been edited. Phewf! The next step is to edit glacier boundaries in areas of coalescing debris covered glaciers. In these circumstances, not only will glacier termini boundaries be adjusted to encompass a larger area but the process will create features representing ground (nunataks) that were not captured in the original Nunatak shapefile. Care must be taken to copy these “new” nunatak features to the current Nunatak shapefile. The process of editing glacier boundaries in these areas gets complex and confusing, so each of these areas will be addressed one at a time as editing progresses through the mapping region. The processing/editing steps will be repeated in each of the coalescing glacier areas and will seem repetitive. However, it is best to proceed in this fashion, because as glacier boundaries are corrected through an area of coalescing glaciers, you will see that boundaries of features representing barren ground (nunataks) have also been delineated. These new bare-ground features will need to be added to the “NonSnoIce_1700_gt81225_XX” shapefile where XX is a number/alpha character progressing by one for each editing session (e.i. 1a, 1b, 1c, ...). When adding these newly created “Non Snow and Ice” features, be sure to copy them to the most current

“NonSnoIce_1700_gt81225_XX” shapefile. Again, editing glacier margin boundaries will occur at a scale of not less than 1:24,000.

Start with the most recent “SnoIce_1700_1270_gt81225_Union_gt_10acres_XX” shapefile. Be sure this is a polyline shapefile, if it is not, convert shapefile to a polyline shapefile using the “Feature-to-Line” command in ArcGIS and the naming convention (numbering system) established. The Figure 4-19 shows an area of debris covered coalescing glaciers before editing and after new glacier boundaries were added to the “SnoIce_1700_1270_gt81225_Union_gt_10acres_XX” shapefile (blue lines).

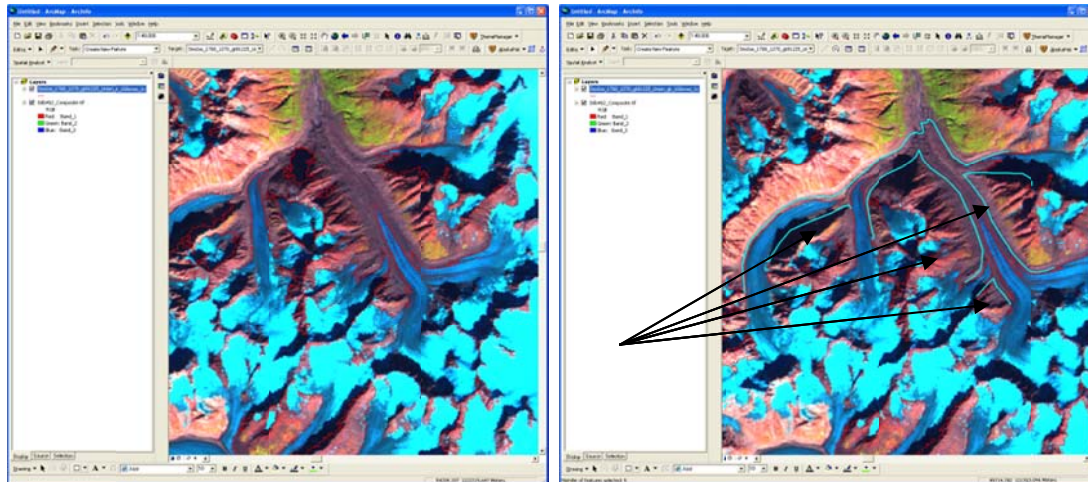


Figure 4-19. Landsat image and the initial classification of snow and glacier ice (left) and the corrected classification (right). Blue lines (left) indicate corrections. Note the addition of four nunatak (barren ground surrounded by ice) features that must be copied to the most current nunatak shape file.

Because the glaciers in the area are heavily debris covered, aerial oblique images were used as an aid in interpreting the Landsat data. Looking at the oblique images (e.g. Figures 4-20a and 4-20b) simultaneously with the Landsat image helps more accurately interpret the Landsat imagery and thus create an accurate glacier boundary.

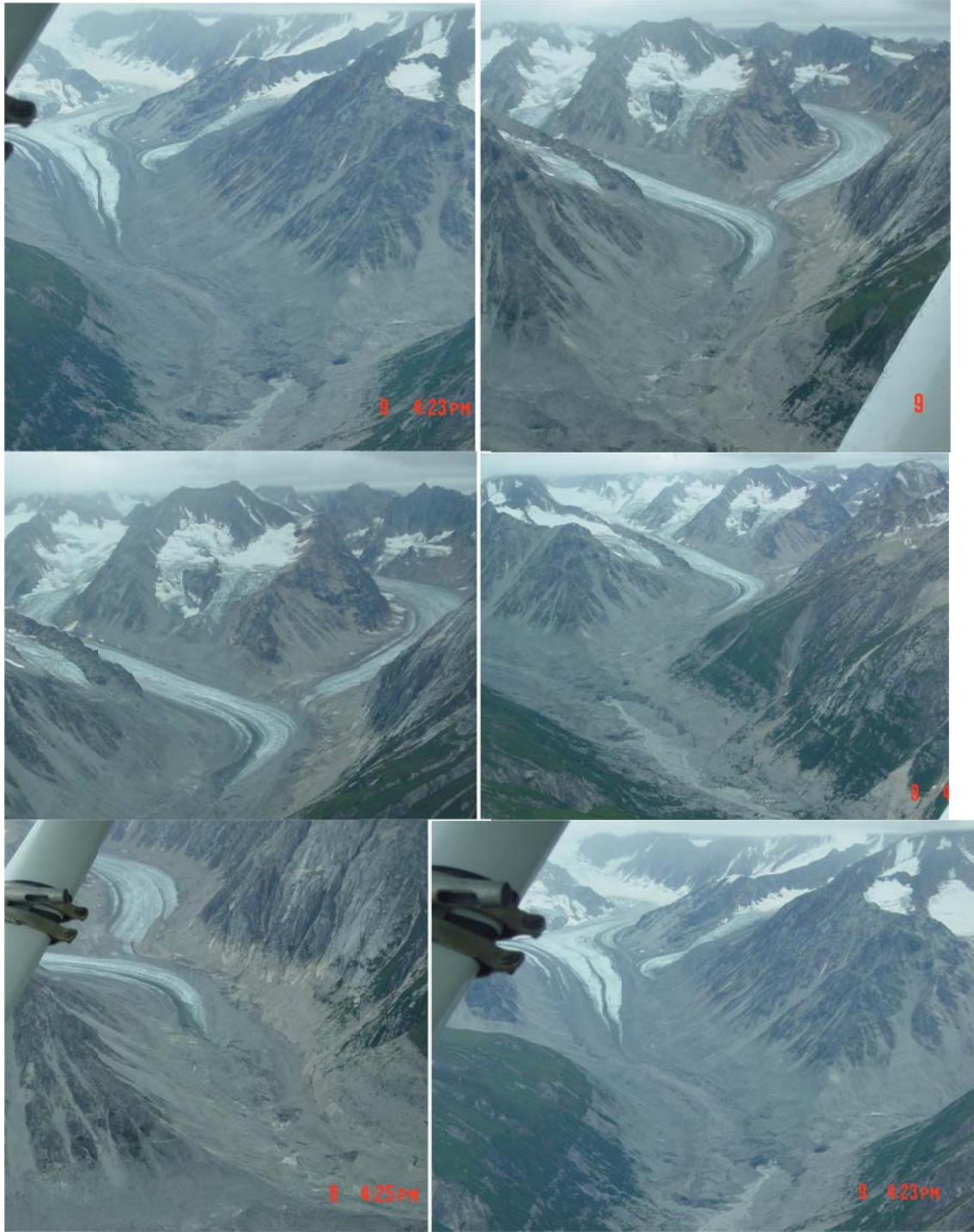


Figure 4-20a. A series of 6 aerial oblique images used in the process of modifying glacier boundaries in areas of debris covered coalescing glacier termini.

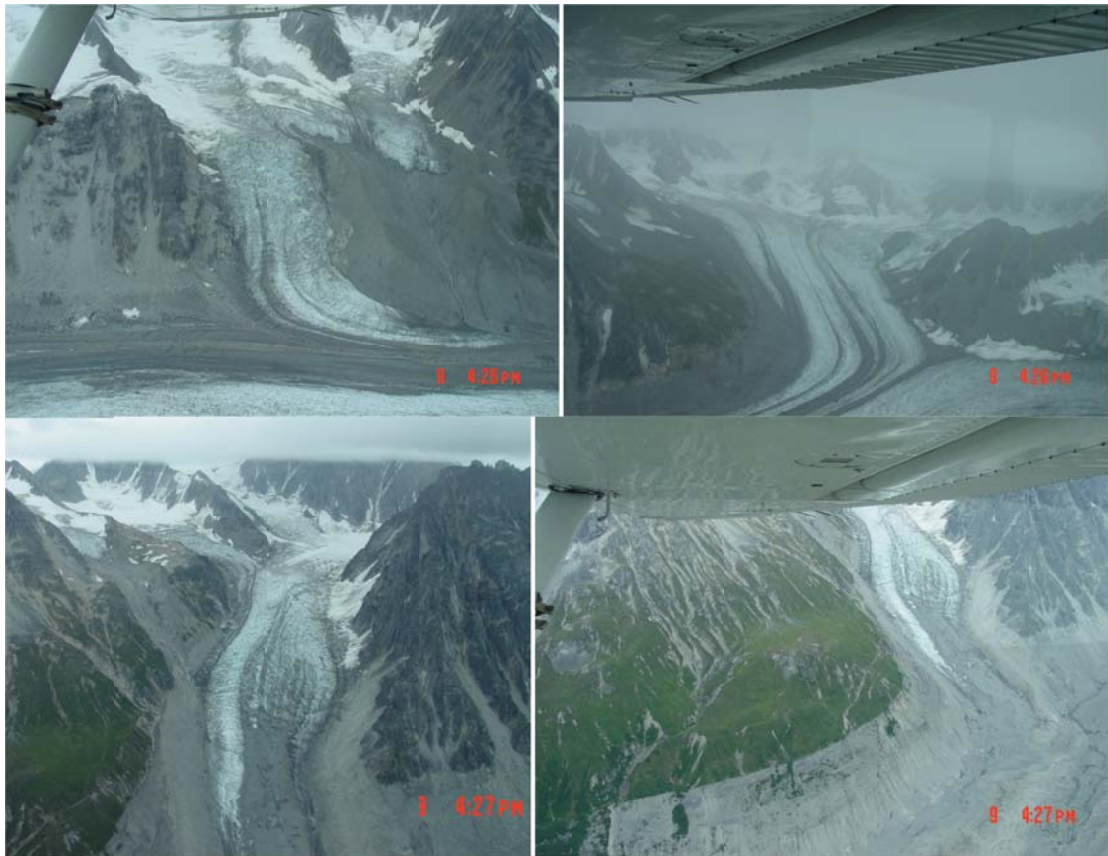


Figure 4-20b. A series of 4 aerial oblique images used in the process of modifying glacier boundaries in areas of debris covered coalescing glacier termini.

The example shown in Figure 4-21 illustrates the original snow/glacier and nunatak classification and the final snow/glacier and nunatak classification after modification of boundaries and the addition of several bare-ground (nunatak) polygons. These bare-ground (nunatak) features are added to the most recent “NonSnoIce_1700_gt81225_XX” shapefile.

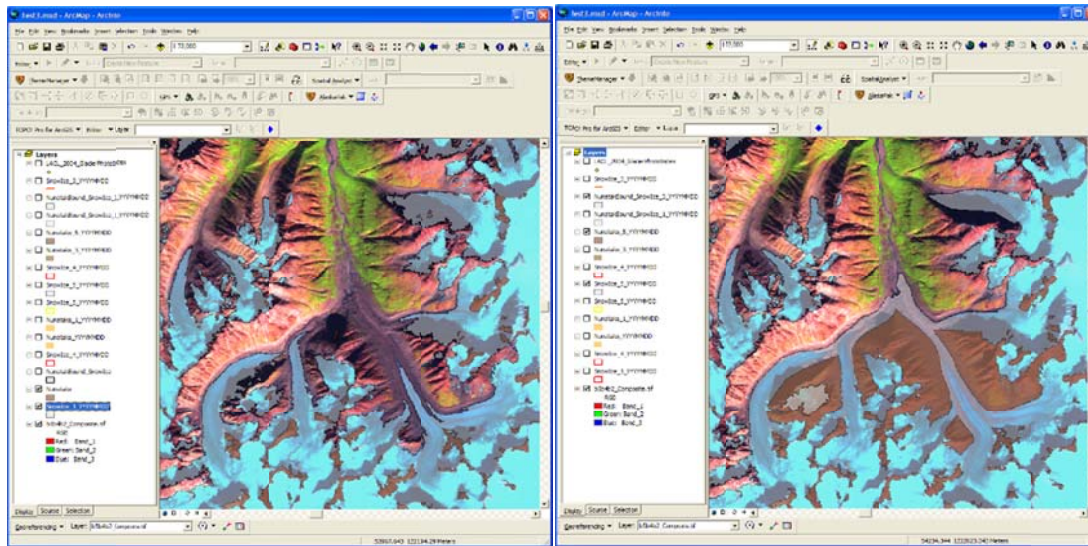


Figure 4-21. Landsat image and the initial classification of snow/glacier and nunataks (left) and the corrected classification (right). Note the expanded glacier boundaries (light blue) and the addition of four barren ground features (light brown). This area corresponds to that shown in the oblique aerial photographs in Figures 4-20a and 4-20b.

Remember, all boundaries (snow/Ice and/or nunataks) being edited are being edited as line shapefiles. When you are satisfied that the glacier boundaries have been accurately captured in an area of debris covered coalescing glaciers the next few ArcGIS commands must be completed to properly update the “SnoIce_1700_1270_gt81225_Union_gt_10acres_XX” and the “NonSnoIce_1700_gt81225_XX” shapefiles.

ArcGIS/ArcCatalog Commands

Beginning with the most recent “SnoIce_1700_1270_gt81225_Union_gt_10acres_XX” shapefile (this should be a line shapefile), proceed with the following commands.

- Feature to Polygon (management): Load the new “SnoIce_1700_1270_gt81225_Union_gt_10acres_XX” polygon shapefile into ArcGIS along with the most recent “NonSnoIce_1700_gt81225_XX” shapefile (this should also be a polygon shapefile) (Figure 4-22).

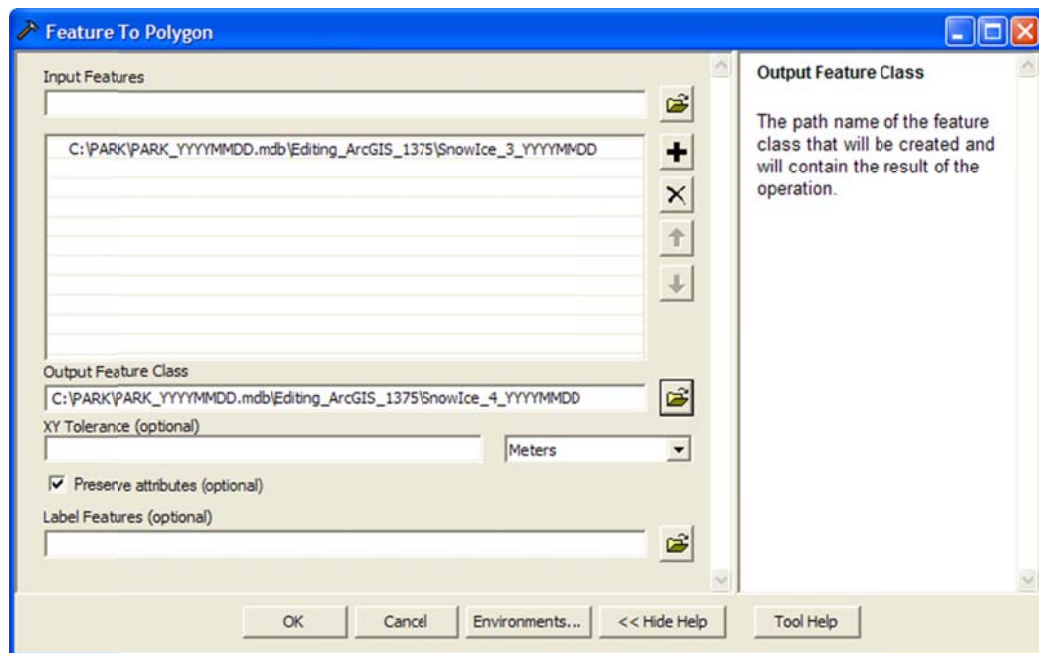


Figure 4-22. “Feature to Polygon” command in ArcCatalog.

- Load the Landsat color composite image into ArcGIS.
- Verify that the modifications to the glacier boundaries have been accurately captured as polygons in the most recent “SnoIce_1700_1270_gt81225_Union_gt_10acres_XX” polygon shapefile.
- Start editing in ArcGIS and select “Create New Feature” and identify the “Target” as the “NonSnoIce_1700_gt81225_XX” shapefile.
- Select features in the new “SnoIce_1700_1270_gt81225_Union_gt_10acres_XX” polygon shapefile that represent bare ground (nunataks) and copy these new features to the “NonSnoIce_1700_gt81225_XX” polygon shapefile. Double check that the boundaries between the “SnoIce_1700_1270_gt81225_Union_gt_10acres_XX” and the “NonSnoIce_1700_gt81225_XX” are coincident. Don’t delete polygons from the “SnoIce_1700_1270_gt81225_Union_gt_10acres_XX” polygon shapefile as you copy them to the “NonSnoIce_1700_gt81225_XX” shapefile (Figures 4-23 and 4-24).
- Note: In some cases, you may also need to add polygon features to the “NunBoundSnoIce_1700_gt81225_XX” shapefile from the “SnoIce_1700_1270_gt81225_Union_gt_10acres_XX” polygon shapefile if these types of features were created in the editing process.

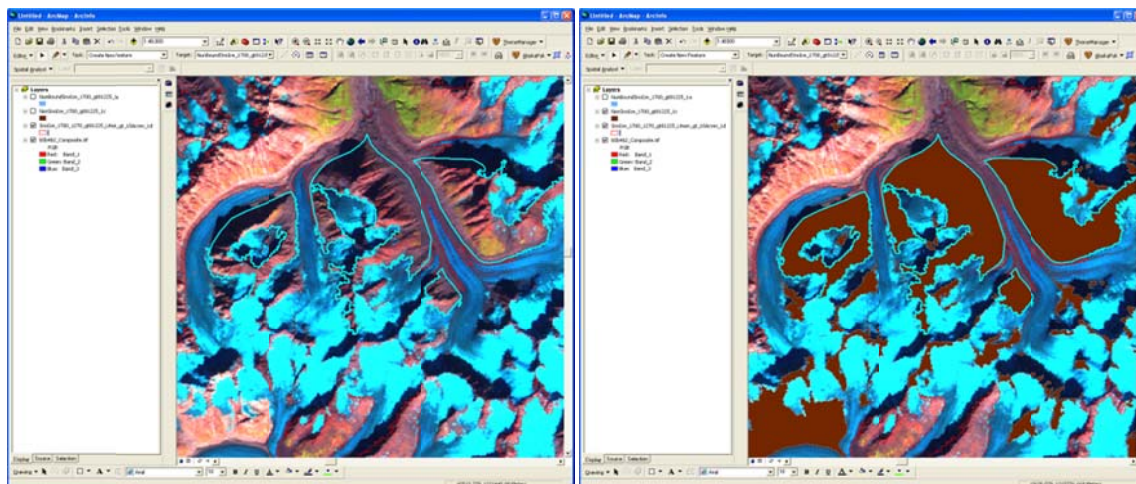


Figure 4-23. Selecting polygon features representing nunataks created in the editing process from the “SnoIce_1700_1270_gt81225_Union_gt_10acres_XX” polygon shapefile (left) and copying those features to the “NonSnoIce_1700_gt81225_XX” polygon shapefile (right).

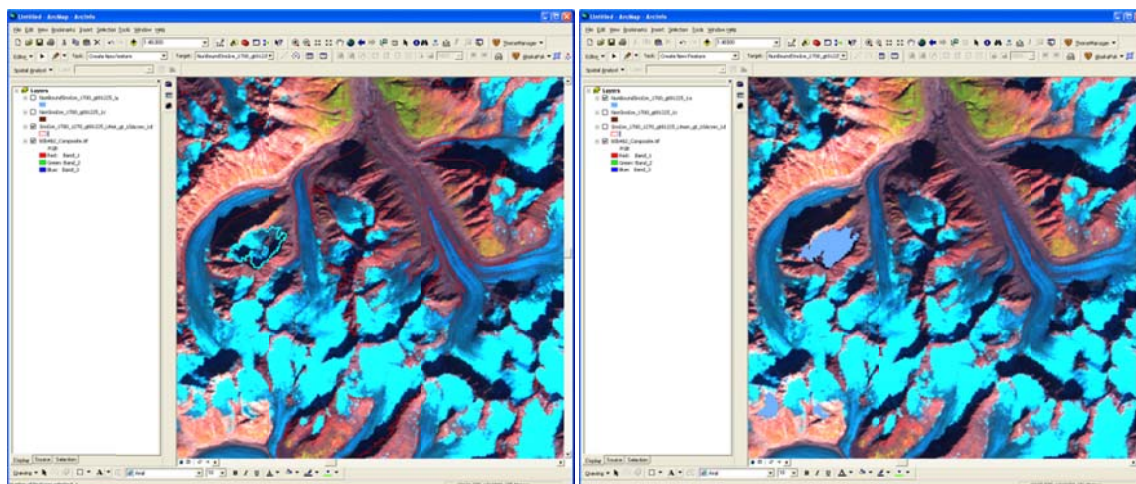


Figure 4-24. Selecting polygon features representing nunatak-bound glaciers created in the editing process from the “SnoIce_1700_1270_gt81225_Union_gt_10acres_XX” polygon shapefile (left) and copying those features to the “NunBoundSnoIce_1700_gt81225_XX” polygon shapefile (right).

Complete the task of updating the most recent “NonSnoIce_1700_gt81225_XX” polygon shapefile with the new features created from the process of modifying glacier boundaries of the “SnoIce_1700_1270_gt81225_Union_gt_10acres_XX.” Be sure not to delete any polygons from the “SnoIce_1700_1270_gt81225_Union_gt_10acres_XX” polygon shapefile in this process.

Complete the task of updating the most recent NunBoundSnoIce_1700_gt81225_XX” polygon shapefile with the new features created from the process of modifying glacier boundaries of the “SnoIce_1700_1270_gt81225_Union_gt_10acres_XX.” Be sure not to delete any polygons from the “SnoIce_1700_1270_gt81225_Union_gt_10acres_XX” polygon shapefile in this process.

Convert the “SnoIce_1700_1270_gt81225_Union_gt_10acres_XX” polygon shapefile to a raster file when the Nunatak and NunatakBound polygon shapefiles are updated. First “Add Field” called RASTER to the Attribute table (Figure 4-25). Then “Calculate Field” for RASTER equal to “1” (Figure 4-26).

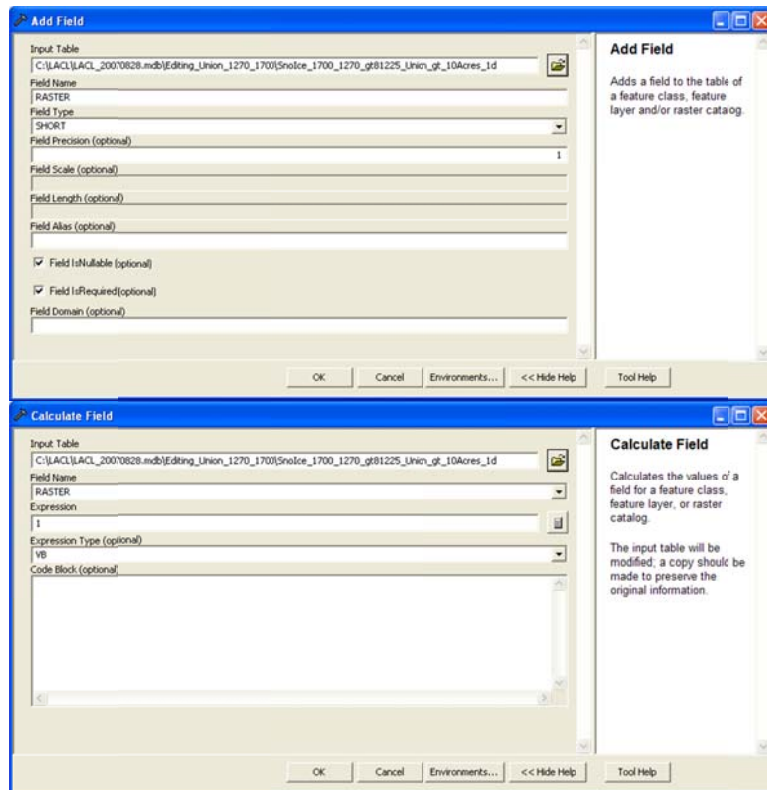


Figure 4-25. Adding a “Field” in an attribute table and “Calculating” a value for that “Field.”

The “SnoIce_1700_1270_gt81225_Union_gt_10acres_XX” polygon shapefile is now ready to convert to a raster file. Be sure to define the “Cellsize” equivalent to the original Landsat data resolution, in this case, 28.5. Next, convert the raster back to a polygon shapefile and name it appropriately in the successively increasing sequence. Be sure the “Simplify polygons” box is not checked.

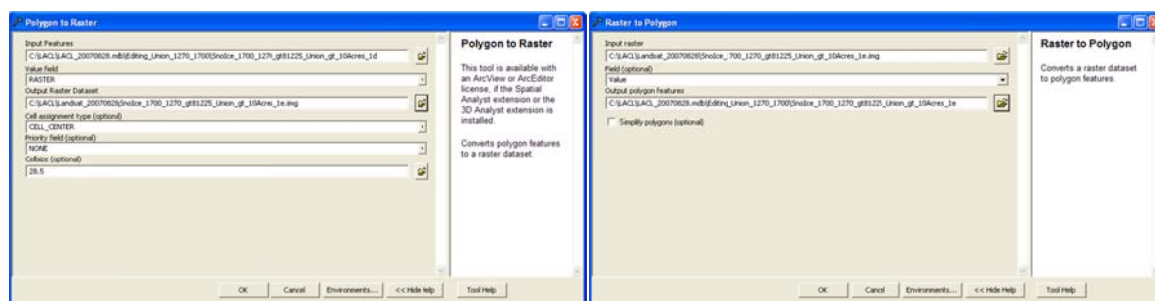


Figure 4-26. Converting a polygon shapefile to a Raster file (top) and converting a raster file to a polygon shapefile (bottom).

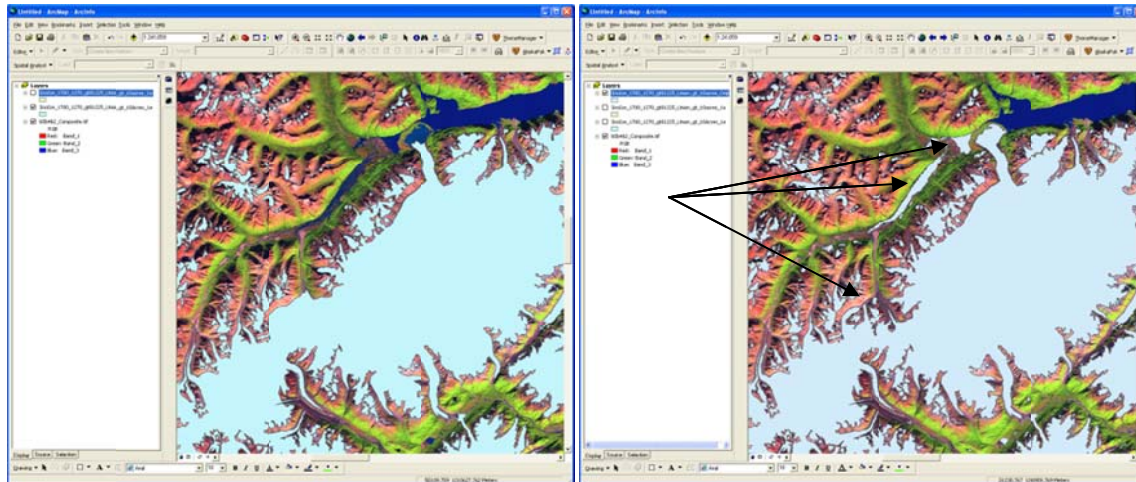


Figure 4-27. The left image is the most recent “SnoIce_1700_1270_gt81225_Union_gt_10acres_XX” polygon shapefile. Note the changes as compared to the original classification (arrows).

Move to another area of the mapping region that contains coalescing debris covered glaciers and repeat the boundary editing steps outlined above. Repeat this process, one-by-one, for all areas of coalescing debris covered glaciers in the mapping region (e.g. Figure 4-27). This is a repetitive, but is necessary to be sure all nunatak features and nunatak-bound glacier features created during the editing process are captured to the “NonSnoIce_1700_gt81225_XX” and the “NunBoundSnoIce_1700_gt81225_XX” shapefiles before too much time passes and memories fade.

Note: Remember that frequent file saving will save the day!

Creating Final Polygon Shapefiles

At the conclusion of the glacier boundary editing process, create the final shapefiles, add fields to the attribute tables, and populate these fields as directed below.

One of the last commands (Erase) will create a near-final Glacier Extent Shapefile. The process of creating the last in the sequence of the “SnoIce_1700_1270_gt81225_Union_gt_10acres_XX” shapefiles represents glacier extent without accounting for nunataks or barren ground that occur within the glacier extent boundary. Now is the time to erase the most recent “NonSnoIce_1700_gt81225_XX” shapefile from the most recent “SnoIce_1700_1270_gt81225_Union_gt_10acres_XX” shapefile.

- Erase (analysis): “SnoIce_1700_1270_gt81225_Union_gt_10acres_XX” minus “NonSnoIce_1700_gt81225_XX” = “SnoIce_1700_1270_gt81225_Union_gt_10acres_XX”.

One more command (Merge) will create the near final Glacier Extent Shapefile. Merge “SnoIce_1700_1270_gt81225_Union_gt_10acres_XX” and “NunBoundSnoIce_1700_gt81225_XX” into the final shapefile representing glacier extent.

- Merge (management): “SnoIce_1700_1270_gt81225_Union_gt_10acres_XX” and “NunBoundSnoIce_1700_gt81225_XX” = “SnoIce_1700_1270_ Union_YYYYMMDD_XX”

Now create the near final shapefiles for nunataks. This is a simple copy and naming procedure in ArcCatalog. This final shapefile is created from the last file in the numerical sequence for of the nunatak shapefiles below:

- “NonSnoIce_1700_gt81225_XX”: Copy and name the file:
“NonSnoIce_1700_YYYYMMDD_XX”

The next step is to add a “field” called “ICE” to the attribute tables of the last two shapefiles using the command “Add Field.” Next, calculate the “ICE” field using the “Calculate Field” for ICE equal to “1” (glacier features) or “0” (nunataks/barren ground features) in the final two shapefiles.

The final step is to “Merge” the latest “SnoIce_1700_1270_ Union_ YYYYYMMDD_XX” and “NonSnoIce_1700_ YYYYYMMDD_XX” into one shapefile representing the park-wide glacier extent (Figure 4-28). Name the shapefile: PARK_GlacierExtent_YYYYMMDD_FinalXX1

Where:

- PARK is the park acronym
- GlacierExtent is self explanatory
- YYYYYMMDD is the year, month and day that the glacier extent mapping is based
- Final is the version and
- XX are the initials of the author and
- 1 is the version.

Folder and file structure is shown in Figures 4-29a and 29b.

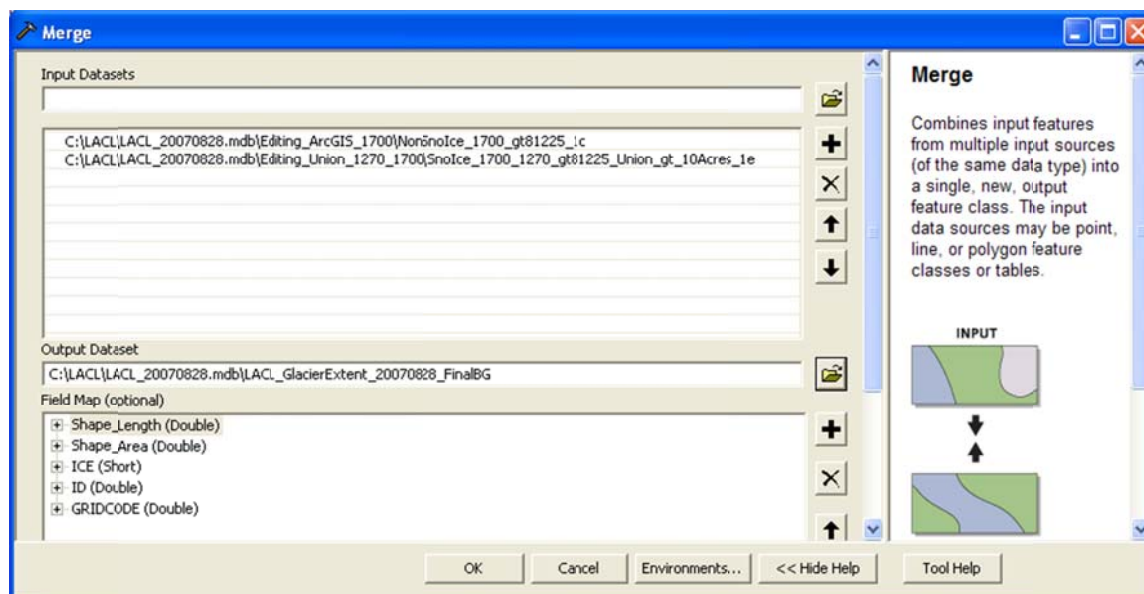


Figure 4-28. “Merge” operation to create the final park-wide glacier extent shape file.

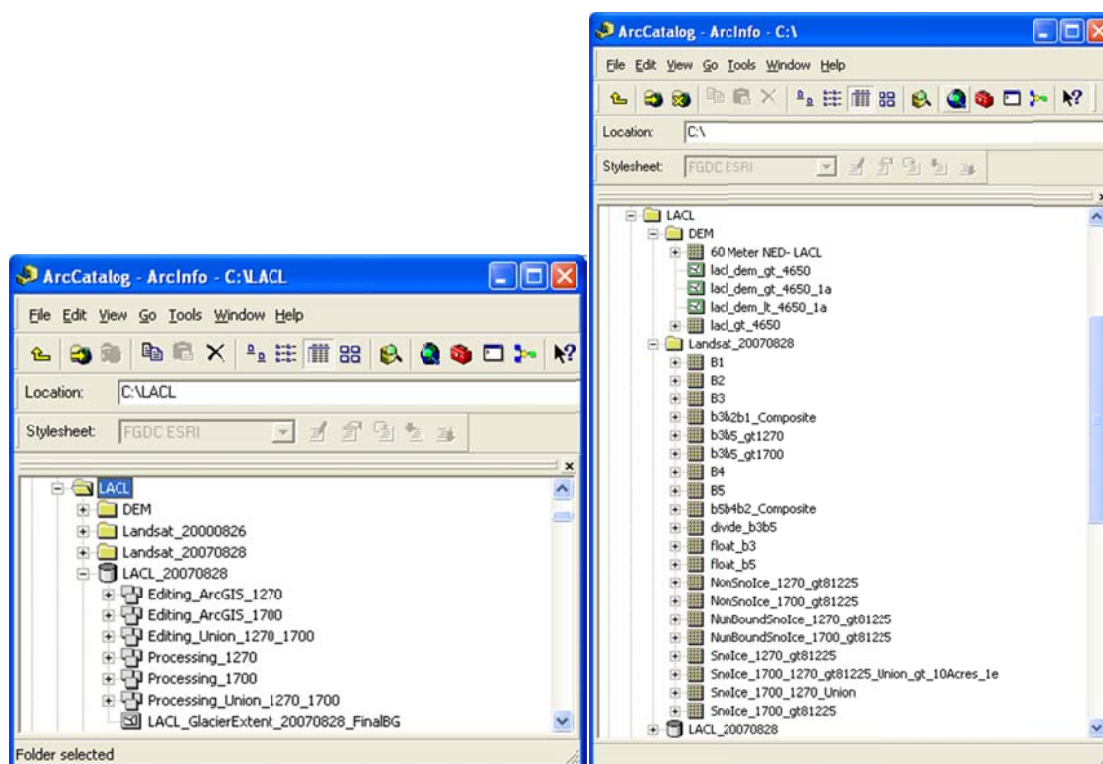


Figure 4-29a. Glacier extent mapping folder and file structure.

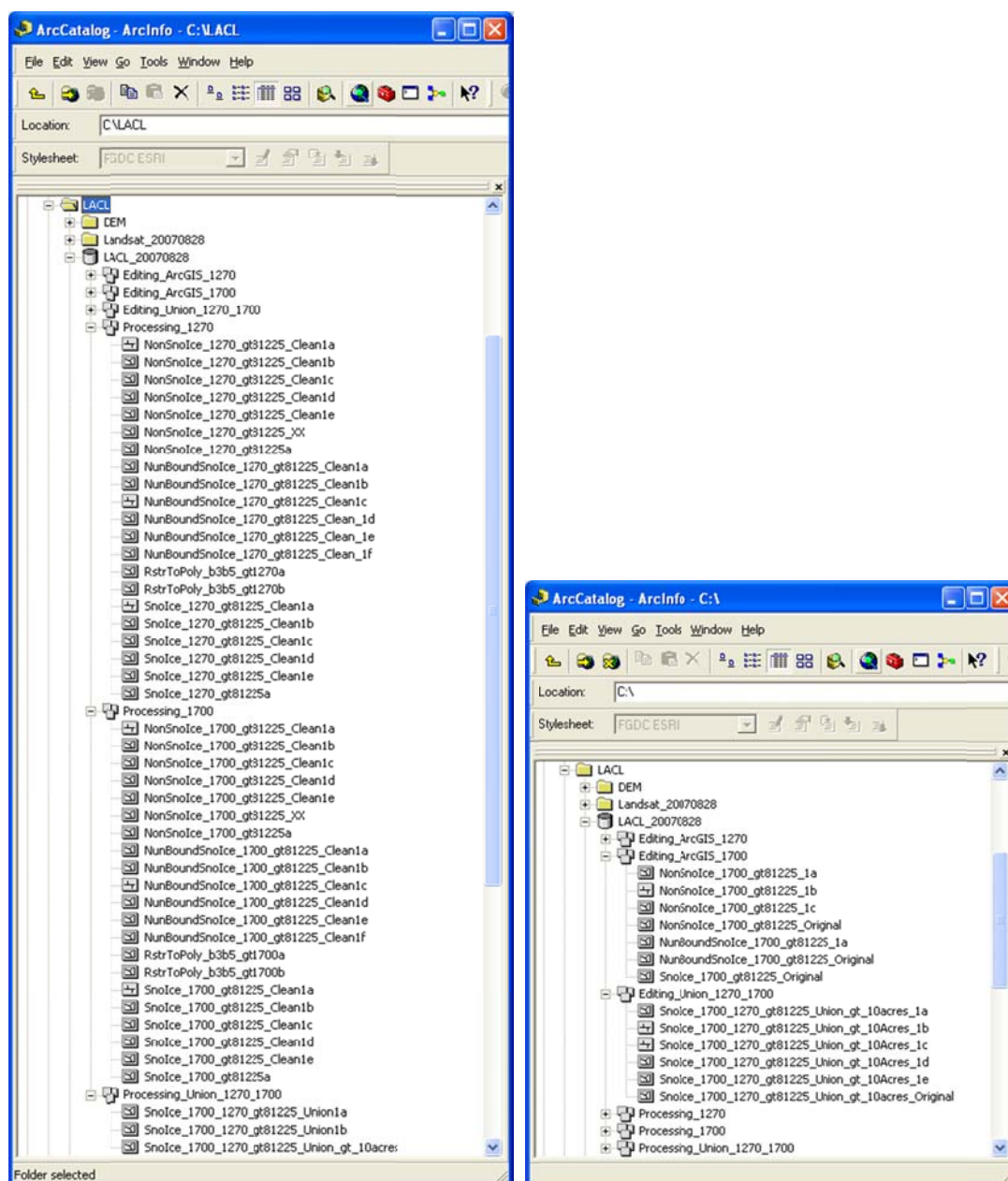


Figure 4-29b. Glacier extent mapping folder and file structure.

Literature Cited

Raup, B., and S. Khalsa. 2010. GLIMS analysis tutorial. Global Land and Ice Measurements from Space Program. Available at http://www.glims.org/MapsAndDocs/assets/GLIMS_Analysis_Tutorial_letter.pdf (accessed 17 January 2011).

Standard Operating Procedure (SOP) #5

Individual Glacier Boundary Extractions in ArcGIS

Version 1.0

Change History

Version numbers will be incremented by a whole number (e.g. Version 1.3 to Version 2.0) when a change is made that significantly affects requirements or procedures. Version numbers will be incremented by decimals (e.g. Version 1.6 to Version 1.7) when there are minor modifications that do not affect requirements or procedures.

The following revisions have occurred to this plan since January 2011.

Version #	Date	Revised by	Changes	Justification

This Standard Operating Procedure describes the process of extracting individual glacier boundaries from the Glacier Extent shapefile (that was created following the methods outlined in SOP #4) in areas where two or more glaciers share the same accumulation zone. The resulting glacier shapefile will contain all individual glaciers within a SWAN park unit, which in aggregate is equivalent to the Glacier Extent shapefile in total glacier area. This SOP supports the Glacier Monitoring protocol for the Southwest Alaska Network.

Overview

The objectives of this SOP are to identify the boundaries of all individual glaciers on a park-wide basis and to define hydrologic basins for each glacier. This SOP presents an outline of the GIS procedures that are used to accomplish these goals. There is currently much work being dedicated to this field of study and there is an effort underway to automate this procedure. When completed, these automated procedures will be adopted by this protocol. This will significantly reduce the required staff time necessary to complete the work requirement of this SOP.

Individual Glacier Extraction

Creating Watershed Boundaries

A glacier extent shapefile was created using the methods outlined in SOP #4. This shapefile contains many individual glaciers but also contains ice masses that are composed of two or more glaciers that flow from the same accumulation zone – these ice masses must be separated into their individual glacier components based on hydrologic basin analysis. The resulting shapefile produced from the guidance in this SOP will be a glacier shapefile that is composed of individual glaciers that when looked at in aggregate is equivalent to the area of the glacier extent shapefile created in SOP #4.

To accomplish this task, a watershed analysis will be performed using the best available digital elevation model (DEM). The purpose is to identify the ice divides for glacier masses where two or more glaciers originate from the same accumulation zone. The following steps guide the delineation of watersheds using ArcGIS.

Directory Structure

Use Arc Catalog to create a folder in the base PARK folder and name it PARK_XXXX_DEM_YYYY, where:

- PARK is the four letter acronym for the NPS park unit.
- XXXX variable in length and describes the type of DEM (NED, LIDAR, ASTER, IKONOS).
- DEM identifies the file as a digital elevation file.
- YYYY represents the year of the DEM data.

Example: C:\LACL\PARK_XXXX_DEM_YYYY\

Place a copy of the best available DEM into the PARK_XXXX_DEM_YYYY folder for the subject study area. Be sure the DEM is of the same datum and projection as the glacier extent shapefile that was created in SOP #4 (WGS-84 UTM Zone 5 or 6).

Also create a Personal Geodatabase within the PARK_XXXX_DEM_YYYY folder and name it PARK_WATERSHED_YYYY, where:

- PARK is the four letter acronym for the NPS park unit
- WATERSHED identifies the file as a watershed file
- YYYY represents the year of the DEM data was created

In the PARK_WATERSHED_YYYY Personal Geodatabase, create a Feature Dataset and name it PARK_Glacier_YYYY, where:

- PARK is the four letter acronym for the NPS park unit
- YYYY is the year of the Landsat imagery for which the glacier mapping is based
- Glacier is self explanatory

Example:

C:\LACL\PARK_XXXX_DEM_YYYY\PARK_WATERSHED_YYYY.mdb\PARK_Glacier_YYYY

ArcGIS/ArcCatalog

Load the following shapefiles and raster files into ArcGIS:

- Color composite Landsat image of region of study
- Glacier extent shapefile created in SOP #4
- Topography maps of the project area
- Best available DEM

Complete the following:

- Load the Spatial Analyst extension
- Be sure the Spatial Analyst toolbar is visible
- Verify that the geoprocessing environment is the same spatial reference system and cell size as the DEM layer.
- Set the processing extents in the geoprocessing environment by using the glacier extent shapefile layer and zooming into an area that is slightly larger than the area of the glacier extent mapping. Set the raster processing extent to “same as display.”

Creating Watershed Boundaries

The following steps describe the ArcGIS process utilized to create individual watersheds where two or more glaciers flow from the same accumulation zone. All raster files are to be saved to the PARK_XXXX_DEM_YYYY folder that was created above and all shapefiles created are to be saved to the PARK_WATERSHED_YYYY Personal Geodatabase created above.

Create *Flow Direction* and *Flow Accumulation* layers from the DEM

1. Run “Fill” tool:
 - a. Input file: (the DEM of the study area - PARK_XXXX_DEM_YYYY).
 - b. Output file: PARK_Fill1:
 - i. Where: PARK is the four letter acronym for the NPS park unit.
 - ii. Fill1 identifies the file as and ArcGIS *Fill* file.
2. Run “Flow Direction” tool:
 - a. Input: PARK_Fill1.
 - b. Output: PARK_FlowDir1:
 - i. Note: be sure the to check the box: “Force all edge cells to flow outward.”
3. Run “Flow Accumulation” tool:
 - a. Input: PARK_FlowDir1.
 - b. Output: PARK_FlowAcc1.
4. Use the Spatial Analyst raster calculator - determine the actual flow lines from the flow accumulation layer:
 - a. Confirm that the PARK_FlowAcc1 layer is showing in the Spatial Analyst toolbar “layer” field.
 - b. Use Raster Calculator to evaluate “FlowAcc1 > 750”. (Note the threshold value of 750 is just a starting point). The resulting “Calculation” layer, a raster layer, shows the river courses. For accumulation zones that is a source area for two or more glaciers, confirm that a string of raster cells (flow line) is present for each individual glacier flowing from that accumulation zone. Using the Raster Calculator, adjust the number upward or downward as necessary.

Create a *Pour-Point* point shapefile in the PARK_WATERSHED_YYYY Personal Geodatabase

1. Name the pour-point point shapefile PARK_PourPointX:
 - a. Where: X is the sequential numbering of pour point shapefiles if more than one pour point shape file is to be created, which is likely for a regional analysis.
2. Be sure the shapefile’s coordinate system is the same as the DEM used in this analysis.
3. Create a field in the attribute table of the PARK_PourPointX shapefile and name it BASIN (short integer, precision = 4).

Identify pour points in the PARK_PourPointX shapefile

1. Adjust the view of the data in ArcGIS:
2. Put the PARK_PourPoint1 point shapefile on top of the map’s table of contents.
3. Place the “Calculation” layer (created above that shows the flow lines) directly below the PARK_PourPoint1 shapefile. Adjust the transparency so you can see the layers below – start at 50%.
4. Next, place the final glacier extent shapefile created in SOP #4 in the map’s table of contents. Adjust the transparency so you can see the layers below – start at 50%.

5. Next, place the topographic quadrangle in the map's table of contents.
6. The DEM and the color composite Landsat image should be the last two features in the map's table of contents.

It is suggested to begin this exercise in a particular area (say the northwest corner of the mapping area) and progress systematically across the entire mapping region of the glacier extent shapefile until all accumulation areas that produce two or more glaciers have been addressed as described below.

With the "Calculation" layer in the background and the glacier extent shapefile and the topographic map layers as visual guides, zoom into an accumulation zone that is the source areas of two or more glaciers. Every glacier that flows from this accumulation zone should display a "flow line" from the "Calculation" layer. Zoom into a glacier terminus area and create a point in the PARK_PourPointX shapefile directly on a pixel that represents the flow line in the "Calculation" layer. This point should be located about 100 meters below the glacier terminus, but this may vary based on the situation, experimentation will be required.

Many hydrologic basins that contain glaciers may have two or more flow lines because many glaciers are convex in shape and typically have a flow line on either side of the glacier. If this is the case, place a pour point on all flow lines that occur below the terminus of the glacier. As pour points are created, be sure to add BASIN values to the attribute table. Start with the number 1. Assign a basin number for each pour point created. All pour points associated with a single glacier (hydrologic basin) will be assigned the same basin number. For each hydrologic basin containing a glacier, assign a basin number to all pour points created. So, for the first hydrologic basin, assign BASIN number "1" to each pour point created, and incrementally increase the basin number as you move from basin to basin.

Move systematically around the accumulation zone identifying pour points for each hydrologic basin being sure to sequentially attribute the BASIN field for each pour point in the attribute table.

Progress through the glacier extent mapping region until all accumulation zones producing two or more glaciers have all their hydrologic basin pour points created and attributed.

Note that BASIN values assigned to a hydrologic basin attribute table should be unique and not repeated.

Run “Watershed” Tool

1. Input raster: PARK_FlowDir1
2. Input Pour Point: PARK_PourPointX
 - a. Note: Select BASIN as the Pour Point field.
3. Output: PARK_WatershedX and place this raster file in the PARK_XXXX_DEM_YYYY folder.

Note that only those watersheds that were defined by pour points (and unique BASIN attribute number) have values and each watershed basin has its own raster value.

Create a polygon shapefile from the PARK_WatershedX raster file

1. ArcGIS tool: Raster to Polygon.
2. Output file: PARK_WatershedX, where X is sequential numbering beginning with the number 1. Place the polygon shapefile in the PARK_WATERSHED_YYYY Feature Dataset created earlier.

Create a polyline shapefile from the polygon shapefile

1. ArcGIS tool: Feature to Polyline.
2. Output file: PARK_WatershedX, where X is the next watershed file in the sequence. Place the polyline shapefile in the PARK_WATERSHED_YYYY Feature Dataset.

Extracting Individual Glacier Boundaries

The following steps describe the ArcGIS process utilized to identify individual glacier boundaries from accumulation zones that are source areas for two or more glaciers. All shapefiles created and modified are to be saved to the PARK_Glacier_YYYY Feature Dataset that resides in the base Personal Geodatabase that was created above.

Necessary Files

Place a copy of the final glacier extent shapefile created in SOP #4 into the PARK_Glacier_YYYY Feature Dataset created above. Name this shapefile the next in the sequence: PARK_GlacierExtent_YYYYMMDD_FinalXX2, where:

- PARK is the park acronym
- GlacierExtent is self explanatory
- YYYYMMDD is the year, month and day that the glacier extent mapping is based
- Final is the version and
- XX are the initials of the author and
- 2 is the version.

Example:

C:\LACL\PARK_XXXX_DEM_YYYY\PARK_WATERSHED_YYYY.mdb\PARK_Glacier_YYYY\PARK_GlacierExtent_YYYYMMDD_FinalXX2

Place a copy of the latest PARK_WatershedX polyline shapefile into the PARK_Glacier_YYYY Feature Dataset created above, where X is the latest version of the watershed file in the sequence.

Example:

C:\LACL\LACL_20070828.mdb\PARK_Glacier_YYYY \ PARK_WatershedX

ArcGIS/ArcCatalog

Load the following shapefiles and raster files into ArcGIS:

- Color composite Landsat image of region of study.
- The PARK_GlacierExtent_YYYYMMDD_FinalXX2 that was just copied into the PARK_YYYY_Glaciers Feature Dataset.
- PARK_WatershedX that was just copied into the PARK_Glacier_YYYY Feature Dataset.
- Topography maps layers of the project area.
- Best available DEM.

Extracting Glacier Boundaries in ArcGIS

At present, this is a tedious process whereby the ice divides that were created from the watershed analysis above are copied and pasted to each glacier emanating from an accumulation zone, one at a time. The process necessarily creates a shapefile for each glacier emanating from an accumulation zone. The final step in the process is to merge all the individual glacier shapefiles into one PARK_Glacier_YYYY shapefile.

At this point in this protocol, the steps of this process will not be described in detail. It will suffice to identify the useful ArcGIS commands necessary to complete this task.

ArcGIS commands that will be useful include:

- Feature to Line
- Feature to Polygon
- Copying shapefiles and naming shapefiles
- Merge
- Editing Features including:
 - Create New Feature
 - Extend/Trim Feature
 - Modify Feature
 - Selecting a feature
 - Snapping Modes

As mentioned above, for accumulation zones where from two or more glaciers are flowing. One shapefile will be created for each glacier. Care will need to be taken in the shapefile naming convention to keep thing straight as this process may take many days.

Individual glacier shapefiles will be created and edited in the PARK_Glacier_YYYY Feature Dataset that was created above. After all individual glacier boundaries have been extracted from the glacier extent shapefile, all individual glacier shapefiles will be merged into one shapefile. This file will contain all glacier ice represented by the Glacier Extent shapefile produced in SOP #4 with the only difference being that each individual glacier boundary is mapped. Continue to utilize the file naming convention for this file that was established above (e.g. PARK_GlacierExtent_YYYYMMDD_FinalXX2, where:

- PARK is the park acronym
- GlacierExtent is self explanatory
- YYYYMMDD is the year, month and day that the glacier extent mapping is based
- Final is the version and
- XX are the initials of the author and
- 2 is the version.

Example:

C:\LACL\LACL_20070828.mdb\PARK_Glacier_YYYY\PARK_GlacierExtent_YYYY
MMDD_FinalXX2

The next step is to define fields and populate fields in the latest glacier shapefile that was just created above (PARK_GlacierExtent_YYYYMMDD_FinalXX2 shapefile). This procedure will be described in SOP #6.

Standard Operating Procedure (SOP) #6

Glaciological Characteristics – Attribute Table Population in ArcGIS

Version 1.0

Change History

Version numbers will be incremented by a whole number (e.g. Version 1.3 to Version 2.0) when a change is made that significantly affects requirements or procedures. Version numbers will be incremented by decimals (e.g. Version 1.6 to Version 1.7) when there are minor modifications that do not affect requirements or procedures.

The following revisions have occurred to this plan since January 2011.

Version #	Date	Revised by	Changes	Justification

This Standard Operating Procedure describes the process of populating the attribute table for the glacier extent shapefile. Fields in the attribute table are created and populated with glaciological parameters that quantify geometric characteristics of each individual glacier in the mapping area. This process is completed using ArcGIS and ArcCatalog. This SOP supports the Glacier Monitoring protocol for the Southwest Alaska Network.

Overview

Every glacier is represented by a suite of glaciological characteristics that quantify the geometric characteristics that are unique to that glacier. In addition to assigning a unique identification number to each glacier, each glacier will have a suite of glaciological parameters that will quantify its geometric characteristics. The four shapefiles that are created are described in Table 6-1. Each of the shapefile attributes as described in Tables 6-2 to 6-5.

Shapefiles and Attributes

There are four shapefiles that will be utilized in this SOP, three are newly created and one is copied from output generated in SOP #5. Tables 6-1 through 6-5 list the shapefiles and attributes for each shapefile:

Table 6-1. List of shapefiles.

Shapefile name	Data Type	Geometry
PARK_glaciernmappingregion_YYYYMMDD_XX#.shp	Polygon	Outline of the mapping region
PARK_glacier_id_YYYY_YYYYMMDD_XX#.shp	Point	Point location of glaciers
PARK_glacier_segments_YYYY_YYYYMMDD_XX#.shp	Polygon	Glacier boundaries
PARK_imageryfootprint_YYYY_YYYYMMDD_XX#.shp	Polygon	Polygon of image footprint

Shapefile Descriptions

PARK_glaciernmappingregion_YYYYMMDD_XX#.shp

A polygon shapefile outlining the glacier mapping region.

PARK_glacier_id_YYYY_YYYYMMDD_XX#.shp

A point shapefile with one unique point locator per glacier. This shapefile also contains glaciological characteristics of each glacier.

PARK_glacier_segments_YYYY_YYYYMMDD_XX#.shp

A polygon shapefile depicting all individual glacier boundaries on a park-wide basis. This file is a result of the automated classification techniques detailed in SOP #2 and #3 and the manual editing detailed in SOP #4, watershed delineation on SOP #5 and glaciological attribute population in SOP #6.

PARK_imageryfootprint_YYYY_YYYYMMDD_XX#.shp

A polygon shapefile depicting the footprint of the satellite imagery that was used in the glacier mapping effort.

File Naming - ArcGIS Files

File names should follow the format:

ParkCode_ShortDescription_YYYYMMDD_InitialsVersion, where:

- ParkCode = Four-letter park or network code (e.g. ALAG, ANIA, KATM, KEFJ, LACL, SWAN). Can contain multiple four-letter park codes if necessary.
- ShortDescription = A descriptive, but brief description of the data file. Concatenate with capital letters and no spaces.
- YYYYMMDD = Date of most recent modification. Year (Y), Month (M), Day (D).
- Initials = Two or three letter initials of person performing the edits and or final shapefile.
- Version [1, 2, 3, ...] = Should be a single whole number, 1, 2, 3,... that indicates subsequent versioning for a given set of initials.

Example: PARK_glacierid_2007_YYYYMMDD_BG1.shp

Shapefile Attributes

Table 6-2. List of attributes for PARK_glaciermappingregion_YYYYMMDD_XX#.shp

Attribute	Value	Data Type	Comments
Rc_id	4	Integer	Regional center id: 4 = Alaska
Analy_time	to be determined	Integer	Time (in days) expended to complete the mapping (in days)
Data_src	i.e. Landsat 7	Text	Name of satellite data source
Anlst_surn	Giffen	Text	Surname of analyst
Anlst_givn	Bruce	Text	Given name(s) of analyst

Table 6-3. List of attributes for PARK_glacier_id_YYYY_YYYYMMDD_XX#.shp

Attributes	Value	Data Type	Comments
glac_id	GxxxxxxEyyyyyN	Text	The GLIMS glacier ID based on geographic centre of glacier with 3dp. xxxxxx is longitude (000.000-359.999); yyyyy is latitude (00.000-90.000) (Eg79.894W,77.146N=G259894E77146N)
glac_name	Glacier name	Text	Name of glacier (if one exists)
width	Width in meters	Integer	Representative width in meters
length	Length in meters	Integer	Representative length in meters
area	Area in km2	Integer	Area of basin (i.e., glacier + rocks) in km ²
abarea	Area in km2	Integer	Size of ablation area
snowln_elev	Elevation in meters	Integer	Elevation of snowline in imagery (i.e., not equivalent to ELA) if available
min_elev	Elevation in meters	Integer	Elevation of the lowest part of the glacier, in meters above sea level.
mean_elev	Elevation in meters	Integer	Mean elevation of the glacier, in meters above sea level.
max_elev	Elevation in meters	Integer	Elevation of the highest part of the glacier, in meters above sea level.

Table 6-4. List of attributes for PARK_glacier_segments_YYYY_YYYYMMDD_XX#.shp

Attributes	Value	Data Type	Comments
line_type	"glac_bound" (glacier boundary), "intrnl_rock" (internal rock outcrop, or nunatak), "snowline", "centerline" (center flowline of the glacier), debris_bound, intrnl_water.	Text	Description of the feature that the polygon encloses. Can be one of: glac_bound, centerline, snow_line, intrnl_rock, pro_lake, supra_lake, debris_cov
glac_id	GxxxxxxEyyyyyN	Text	The GLIMS glacier ID
segment_type	Measured – "m" or "a"	Text	"m" (measured) or "a" (arbitrary).

Table 6-5. List of attributes for PARK_imageryfootprint_YYYY_YYYYMMDD_XX#.shp

Attributes	Value	Data Type	Comments
inst_id	Landsat	integer	Instrument ID (valid IDs: ASTER=1, SPOT5=2, Landsat7=3, SPOT4=4, SPOT3=5, TM5=6, ERS-1 SAR=7, ERS-2 SAR=8, Ikonos1=9,
inst_name	Dependent	Text	Instrument name (TM5, ETM+)
orig_id	Dependent	Text	Original ID of image (e.g. EROS Data Center granule ID)
acq_time	YYYYMMDD	Text	Time of image acquisition, in YYYYMMDD

Creating Attribute Data

This SOP presents an outline of the GIS procedures that are used to populate attributes describing characteristics of individual glaciers. There is currently much work being dedicated to this field of study and there is an effort underway to automate this procedure. When completed, these automated procedures will be adopted by this protocol. This will significantly reduce the required staff time necessary to complete the work requirement of this SOP.

Necessary Files

Create new shapefiles with the following file names:

- PARK_glacierrmappingregion_YYYYMMDD_XX#.shp
- PARK_glacier_id_YYYY_YYYYMMDD_XX#.shp
- PARK_imageryfootprint_YYYY_YYYYMMDD_XX#.shp

Make a copy of the final shapefile created in SOP #5 (PARK_GlacierExtent_YYYYMMDD_FinalXX2 shapefile) and name the copy PARK_glacier_segments_YYYY_YYYYMMDD_XX#.shp.

Directory Structure

Use ArcCatalog to create a Personal Geodatabase in the base PARK folder and name it: PARK_Glacier_YYYY, where:

- PARK is the four letter acronym for the NPS park unit
- Glacier is self explanatory
- YYYY represents the year that the glacier mapping is based

Example: C:\LACL\PARK_Glacier_YYYY.mdb

In the PARK_Glacier_YYYY.mdb Personal Geodatabase, create a new Feature Dataset and name it: PARK_Glacier_YYYY, where:

- PARK is the four letter acronym for the NPS park unit.
- Glacier is self explanatory.
- YYYY is the year of the Landsat imagery for which the glacier mapping is based.

Example: C:\LACL\PARK_Glacier_YYYY.mdb\PARK_Glacier_YYYY

Place a copy of copy of the final shapefile created in the preceding SOP (PARK_GlacierExtent_YYYYMMDD_FinalXX2 shapefile) into the PARK_Glacier_YYYY Feature Dataset and rename the shapefile:

PARK_glacier_segments_YYYY_YYYYMMDD_XX#.shp.

Create three new shapefiles in the PARK_Glacier_YYYY Feature Dataset. Be sure the new shapefiles are created in the same map datum and projection as the rest of the data (WGS-84 UTM Zone 5 or 6). Refer to Table 6-1 which identifies the shapefiles as being point or polygon shapefiles. There should be five shapefiles in the PARK_Glacier_YYYY Feature Dataset:

- PARK_glacierrmappingregion_YYYYMMDD_XX#.shp,
- PARK_glacier_id_YYYY_YYYYMMDD_XX#.shp,
- PARK_imageryfootprint_YYYY_YYYYMMDD_XX#.shp
- PARK_glacier_segments_YYYY_YYYYMMDD_XX#.shp
- PARK_GlacierExtent_YYYYMMDD_FinalXX2.shp

Attributing PARK_glacierrmappingregion_YYYYMMDD_XX#.shp

This is a polygon shapefile. Create the fields in the attribute table specified in Table 6-2 and begin the process of adding data to the attribute table. The attributes are:

- Rc_id = 4
- Analy_time = number of days expended to complete mapping
- Data_src = Spacecraft name, i.e. Landsat TM5
- Anlst_surn = Surname of analyst
- Anlst_givn = Given name(s) of analyst

Attributing PARK_glacier_id_YYYY_YYYYMMDD_XX#.shp

This is a point shapefile. Load the following shapefiles and raster files into ArcGIS:

- PARK_glacier_id_YYYY_YYYYMMDD_XX#.shp,
- PARK_glacier_segments_YYYY_YYYYMMDD_XX#.shp,
- Color composite Landsat image of region of study,
- Best available DEM.

Attribute fields and descriptions follow:

Attribute “glac_id”

Place the PARK_glacier_id_YYYY_YYYYMMDD_XX#.shp at the top of the Table of Contents and start identifying central point locations for every glacier polygon represented in the PARK_glacier_segments_YYYY_YYYYMMDD_XX#.shp. The guidance for locating these point locations has been established by GLIMS (e.g. Raup and Khalsa 2010). The quickest way to locate a central point for all mapped glaciers is to use the “Feature to Point” tool in ArcGIS. It would be best to locate the ID point in the accumulation zone, on the approximate centerline. Review the results and edit the locations of the ID points as necessary.

Once a satisfactory point shapefile has been produced that locates the ID points in an acceptable location, follow the following procedure to produce a GLIMS ID for each glacier polygon.

Note: In order to conform to the GLIMS database guidelines make sure the projection of all open shapefiles (Glacier polygons and Point ID files) are projected to WGS-84 datum UTM Zone 5 or 6) and location units are set to decimal degrees.

- Create two new fields in the point file attribute table (e.g. LAT and LONG_) with data types *float* or *double* with 3 decimal places. Use the *Calculate Geometry* dialog box in these fields (right click on the field header to open this dialog box) to calculate *y-location* and *x-location* in decimal degrees from the *latitude* (LAT) and *longitude* (LONG_) respectively.
- Create two new fields in the point file attribute table (e.g. GLIMS_E and GLIMS_N) with data type *long integer*.
- Calculate GLIMS_E in the field calculator as: $GLIMS_E = (360 + ([LONG_])) * 1000$
- Calculate GLIMS_N in the field calculator as: $GLIMS_N = [Lat] * 1000$
- Create a new field in the point file attribute table (e.g. GLIMSID) with data type *text*, length 20.
- Calculate glac_id in field calculator as: $glac_id = "G" \& [GLIMS_E] \& "E" \& [GLIMS_N] \& "N"$

The preceding steps will populate the attribute glac_id for all individual glaciers mapped.

After the glac_id has been calculated for each glacier polygon, clean up the attribute table by removing the following attributes:

- LAT
- LONG_
- GLIMS_E
- GLIMS_N

Attribute “glac_name”

There are few glaciers that have formal names in the SWAN region, however, for those glaciers that have formal names, begin the process of adding glacier name data to the *glac_name* field in the attribute table.

Attribute “width”

At this point, width measurements are manually determined by clicking on the *measure* icon in ArcGIS. For each glacier polygon, measure and record a representative glacier width in the *width* field of the attribute table.

Attribute “length”

At this point, length measurements are manually determined by clicking on the *measure* icon in ArcGIS. For each glacier polygon, measure and record a representative glacier length in the *length* field of the attribute table.

Remaining Attribute Fields

The remainder of the fields in the attribute table (refer to Table 6-3) will be populated from data contained in the PARK_glacier_segments_YYYY_YYYYMMDD_XX#.shp shapefile. This will require a very good understanding of ArcGIS in order to tease these attributes from the PARK_glacier_id_YYYY_YYYYMMDD_XX#.shp shapefile.

1. Prior to populating the area, min_elev, mean_elev and max_elev fields, add these fields to the attribute table of the PARK_glacier_id_YYYY_YYYYMMDD_XX#.shp and PARK_glacier_segments_YYYY_YYYYMMDD_XX#.shp shapefile and then conduct Zonal Statistics for the PARK_glacier_segments_YYYY_YYYYMMDD_XX#.shp shapefile.
2. Run the Clip tool in Tool Box (Data Management Tools>Raster>Raster Processing>Clip) with the PARK_glacier_segments_YYYY_YYYYMMDD_XX#.shp shapefile (as the Output Extent) and the best available DEM (as the Input Raster). Be sure to identify a file name and location for the Output Raster Dataset (Figure 6-1).

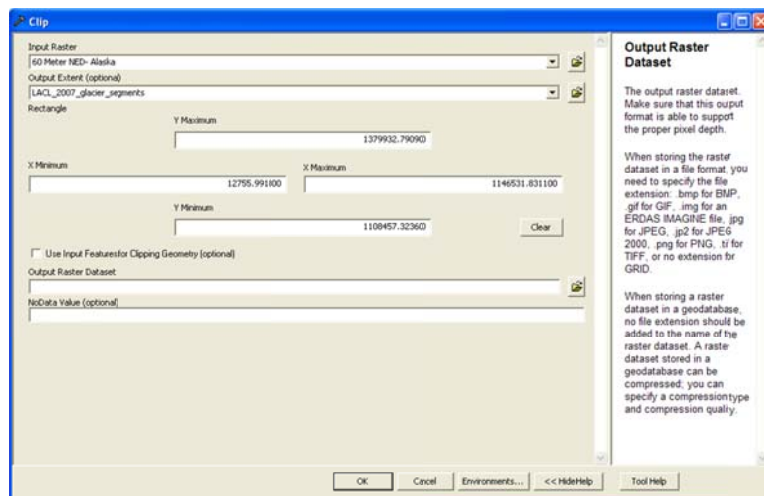


Figure 6-1. Clip tool dialogue.

3. Run the Zonal Statistics in the Spatial Analyst tool with the PARK_glacier_segments_YYYY_YYYYMMDD_XX#.shp shapefile as the Zone dataset, GLIMSID as the Zone field and the clipped DEM as the Value Raster (Figure 6-2).

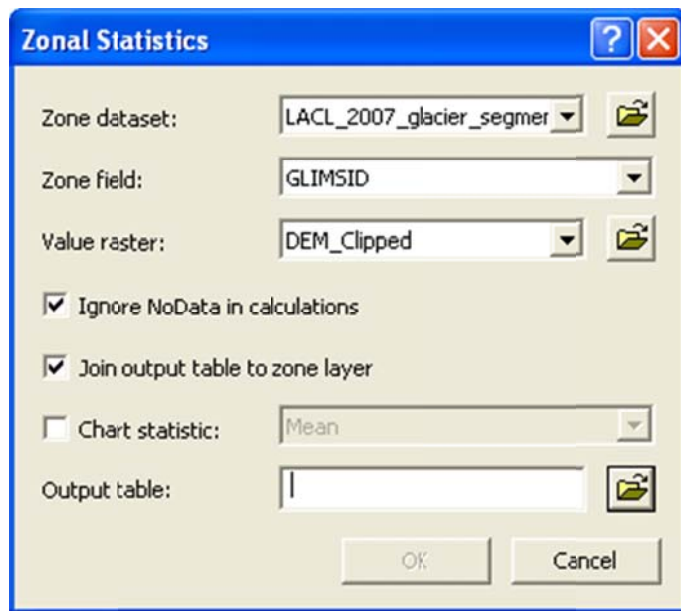


Figure 6-2. Zonal statistics dialogue.

4. With the PARK_glacier_segments_YYYY_YYYYMMDD_XX#.shp attribute table open, use the Field Calculator in the Attribute Options button to calculate the values of the area (km2), min_elev (m), mean_elev (m) and max_elev (m) fields from the equivalent fields in the joined attribute table.
5. Remove the Join created in the Attribute table by selecting the Options button in the attribute table and select Joins and Relates and then select Remove Joins.
6. With the PARK_glacier_id_YYYY_YYYYMMDD_XX#.shp attribute table open, join the PARK_glacier_segments_YYYY_YYYYMMDD_XX#.shp by selecting the Options button in the attribute table, selecting Joins and Relates, and then selecting Join and select the options as shown in Figure 6-3.

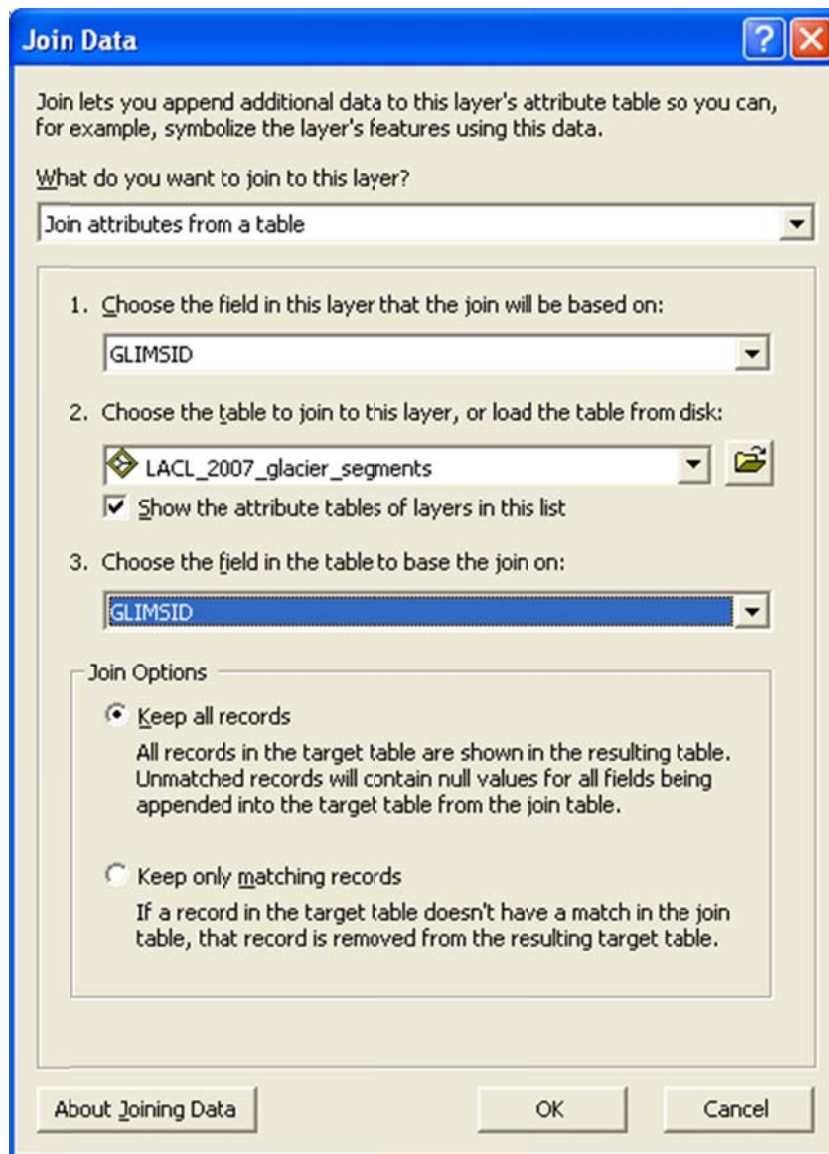


Figure 6-3. The Join Data dialogue.

7. With the PARK_glacier_id_YYYY_YYYYMMDD_XX#.shp attribute table open, use the Field Calculator in the Attribute Options button to calculate the values of the area (km²), min_elev (m), mean_elev (m) and max_elev (m) fields from the equivalent fields in the joined attribute table.
8. Remove the Join created in the Attribute table by selecting the Options button in the attribute table and select Joins and Relates and then select Remove Joins.

Two fields remain to be calculated, *abarea* and *snowln_elev*. The *snowln_elev* attribute will require a combination of manual editing and automated classification of the parent satellite imagery to map the snowline boundary on the glaciers – the process of which is fully described in SOP #2, #3, and #4. The ability to accurately indentify this feature from late-season satellite imagery may vary from region to region and year to year. The imagery classification skills developed in SOP #2 can be utilized to help identify the snowline in an automated fashion. If the snowline can be identified, individual glaciers can then be divided into their respective ablation and accumulation zones and the *snowln_elev* can be determined. With the respective ablation and accumulation zones being identified, glaciological characteristics like the mean elevation for the accumulation and ablation zones, the ELA and AAR can be determined using the similar techniques as described above.

This SOP will be updated as techniques for automatically deriving and populating attributes for these glaciological characteristics are developed and tested.

Attributing PARK_glacier_segments_YYYY_YYYYMMDD_XX#.shp

This is a polygon shapefile. Create attribute fields as specified in Table 4.

Attribute fields and descriptions follow:

Attribute “line_type”

Attribute is a text string. Notice the attribute field titled ICE. It is populated with either a 1 (designating ice) or a 0 (designating non ice feature). For the Line_type field populate the field as follows using the Field Calculator:

- Open the Field Calculator for the *line_type* field
- Select the advance box
- In the Pre-Logic VBA Scrip Code box (Figure 6-4) type the following:

```
If [ICE] =1 then  
x ="glac_bound"  
Else  
x = "internal_rock"  
End If
```

And in the lower text box where it says “line_type =”, type: X

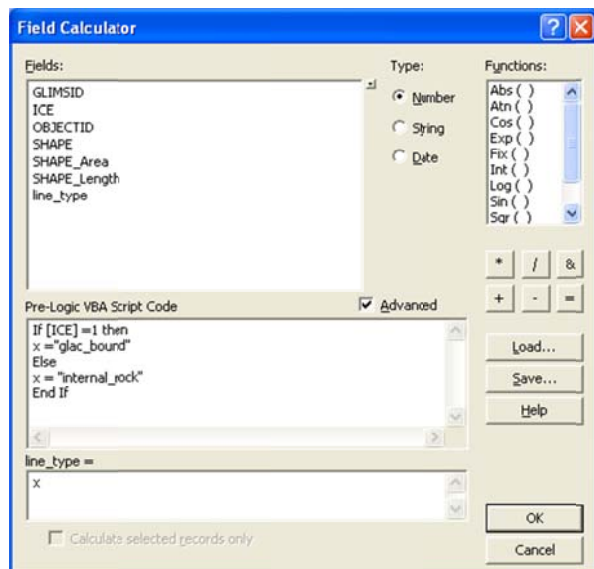


Figure 6-4. Field Calculator dialogue.

Attribute “glac_id”

Spatially join the PARK_glacier_segments_YYYY_YYYYMMDD_XX#.shp *shapefile* and the PARK_glacier_id_YYYY_YYYYMMDD_XX#.shp retaining the field GLIMSID in the PARK_glacier_segments_YYYY_YYYYMMDD_XX#.shp *shapefile*. The GLIMSID is now an attribute in the of the PARK_glacier_segments_YYYY_YYYYMMDD_XX#.shp *shapefile*.

Attribute “segment_type”

This is the last field to populate. The value of the type field is “m” for measured.

Attributing PARK_imageryfootprint_YYYY_YYYYMMDD_XX#.shp:

This is a polygon *shapefile*. Create the attribute fields specified in Table 6-5.

Attribute fields and descriptions follow:

- inst_id = Spacecraft name (i.e. Landsat)
- inst_name = Instrument name (TM5, ETM+)
- orig_id = Original id: same as image id
- acq_time = Time of image acquisition (YYYYMMDD)

Metadata

Compile metadata for these files will be completed as described in SOP #9 (Data Management). Upon completion of the metadata, these *shapefiles* are distributed to the GLIMS program.

Literature Cited

Raup, B., and S. Khalsa. 2010. GLIMS analysis tutorial. Global Land and Ice Measurements from Space Program. Available at http://www.glims.org/MapsAndDocs/assets/GLIMS_Analysis_Tutorial_letter.pdf (accessed 17 January 2011).

Standard Operating Procedure (SOP) #7

Field Investigation

Version 1.0

Change History

Version numbers will be incremented by a whole number (e.g. Version 1.3 to Version 2.0) when a change is made that significantly affects requirements or procedures. Version numbers will be incremented by decimals (e.g. Version 1.6 to Version 1.7) when there are minor modifications that do not affect requirements or procedures.

The following revisions have occurred to this plan since January 2011

Version #	Date	Revised by	Changes	Justification

This Standard Operating Procedure describes how “local expert knowledge” of glaciers margins is acquired and/or enhanced in support of the Glacier Monitoring protocol for the Southwest Alaska Network (SWAN).

Overview

This Standard Operating Procedure describes how “local expert knowledge” of glaciers margins is acquired and/or enhanced. It will be necessary to rely on or develop “local expert knowledge” in areas where the location of glacier margins is unclear from interpretation of Landsat imagery alone. Areas that will present challenges to the interpretation of Landsat imagery will be primarily those areas of debris covered ice, areas obscured by clouds, and areas of extreme topography resulting in shadowed ice. Acquisition of this aerial oblique photography will facilitate the interpretation of Landsat imagery in these challenging areas.

After working through SOP #4, there should now a clear understanding of where developing “local expert knowledge” through the acquisition of oblique photography will facilitate the interpretation of Landsat imagery in areas where glacier margins are uncertain. Beyond identifying target areas, this SOP speaks to mission planning (flight routes, aircraft selection, time of year, weather requirements).

Acquisition of aerial oblique photography in support of this SOP will necessarily require the acquisition of 100s if not 1000s of photographs. Organizing this amount of data is imperative. Refer to SOP #8, which explains the process for geotagging oblique aerial digital photographs and organizing large numbers of photographs in a Geographic Information System (GIS).

Identification of Areas for Further Investigation

The repeat cycle for this protocol is on a decadal scale with the next series of Landsat imagery to be acquired in 2010+. Presuming that good quality Landsat imagery (late-season, cloud-free) is available in the target year, interpretation of that imagery will occur during the following winter months. By the following spring, the interpretation will have identified those areas where the interpretation of the Landsat imagery is questionable. Areas that will be identified will include:

- Debris cover glacier termini
- Side moraine areas of large glaciers
- Shadowed snow and ice
- Clouds

Prepare a map (1:250,000) with specific targets identified locating all features where aerial oblique photos should be acquired. Depending on the number of targets, it may be necessary to prioritize targets.

Developing a Flight Plan

The map that identifies and prioritizes target areas will be used for navigation during a reconnaissance flight. Prioritized flight routes should be marked on the map. Note that weather conditions in the field will dictate actual flight paths.

Aerial oblique photography will be acquired of each of these priority target areas. Flights routes to and from the priority areas will be planned in such a way as to pass by other glaciers and glacier features where by aerial oblique photographs can be acquired opportunistically of these features of interest.

Preferred Aircraft and Flight Characteristics

Aircraft

The preferred aircraft is a Cesnsa 185/206 or equivalent. This aircraft has a reasonable cruising speed and is capable of carrying several passengers. The Department of Interior - National Business Center (NBC) Aviation Management assign aircraft of this type to National Parks to be used in support of park operations. If available, this aircraft should be used to fulfill this SOP. If a park aircraft is not available, this type of aircraft is readily available in the private rental market in Alaska.

Scheduling

The purpose of this SOP is to enhance the accuracy of Landsat imagery interpretation acquired in the previous year. There are two primary considerations affecting the scheduling of the mission: weather and the desire to acquire late-season photography. Mid- to late-August would be the preferred scheduling window to conduct these flight operations to maximize the loss of seasonal snow across the landscape but acquire the oblique photos prior to any new snowfall.

Flight Conditions

It is best to conduct the flight under clear, sunny, smoke-free conditions. Contrast between the debris covered glacier surface and surrounding moraine material will be more evident under these conditions.

Flight Characteristics

A safe flight operation is the priority.

The preferred elevation above ground level is 2000 to 3000 feet. This flight elevation may vary depending on sun angle (morning, evening, mid-day), turbulence, and other factors at the time of the flight.

The elevation of the targets identified may range from a few hundred feet up to 5,000 feet. Capturing photography at targets at an elevation of 5,000 feet will require different flight conditions than those at lower elevations. For example, flights at low elevations could be conducted under cloudy conditions as long as the ceiling is high enough for safe flight operations.

GPS tracking of Aircraft Flight Path

All flights will be tracked by via the tracking feature on most hand-held GPS units. Refer to the NPS Alaska Region GIS website (<http://inpakroms03web/rgr/akgis/index.cfm>) for a quick guide to collecting positional information using a Global Positioning System (GPS) while taking digital photographs from a small aircraft. This will insure that the GPS tracks and digital photographs can be properly geotagged with GPS PhotoLink software.

Digital Photography

High resolution digital photography will be used to collect oblique aerial photographs of all glacierized areas. Digital photography will subsequently be linked to the GPS tracking feature. This will allow accurate geographic locations for each photograph. Refer to SOP #8 for detailed information on suggested camera types, focal lengths, and camera orientation.

Standard Operating Procedure (SOP) #8

Geotagging and Organizing Oblique Aerial Digital Photographs in a GIS

Version 1.0

Change History

Version numbers will be incremented by a whole number (e.g. Version 1.3 to Version 2.0) when a change is made that significantly affects requirements or procedures. Version numbers will be incremented by decimals (e.g. Version 1.6 to Version 1.7) when there are minor modifications that do not affect requirements or procedures.

The following revisions have occurred to this plan since January 2011.

Version #	Date	Revised by	Changes	Justification

This Standard Operating Procedure explains the process for geotagging (adding geographic locations to media) oblique aerial digital photographs and organizing large numbers (100s-1000s) of these photographs in a Geographic Information System (GIS) in support of the Glacier Monitoring protocol for the Southwest Alaska Network (SWAN).

Overview

This Standard Operating Procedure explains the process for geotagging (adding geographic locations to media) oblique aerial digital photographs and organizing large numbers (100s-1000s) of these photographs in a Geographic Information System (GIS). Detailed procedures describe how to: 1) collect positional information using a Global Positioning System (GPS) while taking digital photographs from a small aircraft; 2) store the positional information within a digital photograph's metadata file (EXIF); 3) store, edit, and name photographs using SWAN digital photograph management strategy; 4) create a GIS shapefile with photograph locations and attributes; and 5) create a Google Earth file in Keyhole Markup Language (KML) with photograph locations and descriptions.

Necessary Equipment and Software

Acquiring, geotagging, and managing digital photographs in a GIS requires the following equipment and software. The detailed procedures that follow are specific to the recommended equipment and software that are listed.

Digital Camera

A digital single-lens reflex (DSLR) camera is recommended for use in oblique aerial photography because it is faster than a digital point-and-shoot camera, uses precise optical viewfinders, and is very battery-efficient. Resolution should be 5 megapixels or better. Memory cards should be capable of holding approximately 400 images at >5 megapixels (2GB cards work well). A relatively wide-angle lens is recommended (24-35 mm).

Recommended Digital Camera:

Cannon Digital Rebel XT (8.0 megapixel), 18-55 mm lens, and 2GB CompactFlash storage card.

GPS Receiver

A recreational-grade handheld GPS receiver is suitable for this work. The NPS Alaska Region GIS team recommends and supports Garmin handheld GPS receivers that allow waypoint averaging, external GPS antenna capability, and support with DNRGarmin software for downloading. Currently, these units include the GPSMap60 and GPSMap76 series. Although the GPS receiver can be placed on top of an aircraft instrument panel, use of an external antenna will improve accuracy.

Recommended GPS Receiver:

Garmin GPSMap60Csx with magnetic external antenna (this unit stores time to the second, which improves positional accuracy of photographs taken in rapid succession).

GPS Software

Software is necessary to transfer data from the GPS receiver to a computer. The NPS Alaska Region GIS team recommends and supports both Garmin MapSource and DNRGarmin (Minnesota Dept. of Natural Resources). Garmin MapSource is necessary in order to download and archive GPS data. DNRGarmin is recommended to transfer GPS data into GIS.

Recommended GPS Software:

Garmin MapSource v6.15.3 and DNRGarmin v5.4.0 (free).

File Renaming Software

Software is necessary to rename large numbers of digital photographs. File naming software must be capable of batch file renaming without changing the EXIF date/time. Many file naming programs are commercially available.

Recommended File Renaming Software:

FineBytes Magic File Renamer (Professional Edition) v6.12 (\$30).

Photograph Viewing and Editing Software

Software is necessary to view and edit large numbers of digital photographs. Photograph viewing software must be capable of lossless JPEG rotation (rotating and saving JPEG files without compressing image), batch photo resizing without changing EXIF date/time, and showing the EXIF information. Many photograph viewing and editing programs are commercially available.

Recommended Photograph Viewing and Editing Software:

IrfanView v4.23 with Graphic Viewer PlugIns (free).

Geotagging Software

Software is necessary to store positional information from a GPS in the digital photograph's metadata file (EXIF). The software should be capable of geotagging using locations interpolated from a GPS track log, storing this information in the EXIF, and creating a GIS shapefile with photograph locations and attributes.

Recommended Geotagging Software:

GeoSpatial Experts GPS-Photo Link Ricoh Edition v4.2 (\$329)

GIS Software

Software is necessary to organize and index large numbers (100s-1000s) of geotagged photos. Photograph locations can be plotted on maps or satellite imagery using a GIS. Information about each photograph (location, orientation, subject matter, caption, etc.) can be stored in a spatially referenced database. This allows oblique aerial photographs to be searched based on location or subject (or combination thereof)

Recommended GIS Software:

ESRI ArcGIS v9.3 (ArcInfo)

GIS to KML software extension

A software extension is necessary to export GIS data in a format that can be viewed by non-GIS users in Google Earth. This extension must be capable of exporting point, polyline, or polygon datasets in any defined projection into Keyhole Markup Language (KML). The extension should be able to incorporate GIS symbology, labeling, and database attributes into KML.

Recommended GIS to KML software extension:
Export to KML v2.5.3 (free)

File compression software

A file compression utility is necessary in order to create a compressed KML archive, also known as a KMZ file for use in Google Earth. A number of open-source file compression utilities are freely available.

Recommended file compression utility:
7-Zip v4.65 (free)

3D Geobrowser Software

Software is necessary so that non-GIS users can explore large numbers of geotagged photos. Geotagged photographs can be located and viewed using geobrowser software. Indexes in KML format can include information about each photograph (location, orientation, subject matter, caption, etc). A number of 3D geobrowser software programs are available.

Recommended 3D Geobrowser Software:
Google Earth v5.0 (free)

Pre-Flight Preparations

The GPS and camera need to be prepared prior to flying and taking photographs. The pilot should be asked about cleaning aircraft windows or flying with side windows open. The photographer should verify that the GPS receiver is on, receiving adequate satellite information, and collecting an active tracklog before takeoff.

Digital Camera

Accurate camera date and time is critical because it is recorded in the EXIF and will be used for geotagging the photographs. The camera clock should be synchronized to an active GPS to within 1 or 2 seconds (use local time and pay attention to daylight saving time). Digital cameras name photos differently. Typically cameras will have several file naming options. The most useful setting is sequential numbering (00001-99999). In general, it is recommended that the sequential numbering be reset each day that photographs are taken. Most digital cameras can digitally imprint the date and time onto the photo image. In general, it is recommended that this feature not be used because this information will automatically be stored in each photograph's metadata (EXIF) file. Any existing photographs should be deleted from the camera. Make sure the batteries are new or freshly charged. Image resolution should be set to the highest setting.

GPS Receiver

Turn on the GPS outside and let it initialize for 20 minutes to collect current satellite almanac. Set GPS to local time zone (pay attention to daylight saving time). Clear all tracks and waypoints. Set up the track log to record at 1 second intervals and to stop recording when full. Make sure the batteries are new or freshly charged. GPS receiver or external antenna should be placed on top of the instrument panel close to the windshield. With pilot's approval and direction, a magnetic external GPS antenna can be placed outside (and on top) of the aircraft. The wire may need to be taped in place to reduce vibration and prevent damage to the aircraft. Take a picture of the GPS screen showing local time before take off and collecting photographs. Hold the GPS at arm's length from the GPS and tilt the screen slightly. Verify that the time is visible in the photograph.

Aircraft

Ask the pilot if the windows (inside and outside) can be washed. The photographer can volunteer to do this with the pilot's approval and direction. If the windows are heavily scratched it may be possible to fly with the side window propped open (this will be very windy and cold).

Camera Orientation

The photographer should sit in the copilot's seat and photograph out of the side windows. Photographs taken straight ahead through the front windshield will be blurred by the propeller and should be avoided. In general, it is recommended that the camera angle relative to aircraft heading remain constant (45-135 degrees to the left or right of aircraft heading works well). Focal length (zoom) should not vary while photographs are taken (24-35 mm) works well. If there are two photographers and cameras, each should photograph from opposite sides of the aircraft (one GPS receiver will suffice, although a second GPS may be used for backup). Try not to photograph the aircraft's wings or wheels/floats/skis as much as possible.

Post-Flight Tasks

After the flight the GPS track log needs to be stopped (do not save the track log) and the GPS should be turned off. If possible, digital photographs and GPS data should be transferred to a computer as soon as possible (especially if multiple days of flying and photography will take place).

GPS Track Log

Stop the track log, but do not save it! A track log is made up of many points (one point stored each second). Saving a track log on a Garmin GPS receiver greatly simplifies the track log by deleting points. A saved track log will not work for geotagging oblique aerial photographs.

Transferring Photographs

Refer to Attachment A for a detailed description of the file management structure necessary for geotagging and managing oblique aerial photographs in a GIS. Even if the files are first transferred to a field laptop or a computer that won't be used for managing the photographs and GIS the same file management structure should be used.

Transfer the photographs from the camera to a computer. Copy them to the folder:

/Oblique_Aerial_Photos/Original_Photos/pppp_yyyymmdd_iii/

Do not rename or alter these photographs in any way. Then copy the photographs to the folder:

/Oblique_Aerial_Photos/Working_Photos/pppp_yyyymmdd_iii/

Transferring GPS Data

Use Garmin MapSource to transfer the GPS track log. Open Garmin MapSource and connect to the GPS receiver. Select **Transfer** then **Receive from device** then **Tracks**. Then save the track log using three different file types: **Garmin GPS Database Version 3 (*.gdb)**, **GPS eXchange Format (*.gpx)**, and **Text (Tab delimited) (*.txt)**. These files should be named as shown below (see Attachment A) and stored in the folder:

Oblique_Aerial_Photos/Original_GPS/pppp_yyyymmdd_iii/
pppp_yyyymmdd_iii.gdb
pppp_yyyymmdd_iii.gpx
pppp_yyyymmdd_iii.txt

Creating Flight Line and Track Log Shapefiles

Use DNRGarmin to create a line and point shapefile from the GPS data. Open DNRGarmin. Select **File** then **Set Projection** and make sure that the datum and projection listed are NAD83 and Alaska Albers Equal Area Conic. Make sure that the PRJ Definition is loaded and matches the datum and projection listed above. Connect to the GPS receiver and select **Track** then **Download**. This will take some time. Editing may be necessary if the GPS receiver was turned off or if more than one flight was captured by the track log. The **new_seg** field displays **True** anytime the track log was restarted. Double-click on that cell to modify the value and change it to **False** if the track log should be continuous but isn't. Convert the track log to a line shapefile that represents the flight line by saving the data as an **ArcView Shapefile (Projected) (*.shp)**. Name the file as shown below (see Attachment A) and select **Line** when prompted to define the output shape. Then convert the track log to a point shapefile that represents the flight line by saving the data as an **ArcView Shapefile (Projected) (*.shp)**. Name the file as shown below (see Attachment A) and select **Point** when prompted to define the output shape. These files should be stored in the folder labeled:

/Oblique_Aerial_Photos/Working_GPS/pppp_yyyymmdd_iii

/pppp_yyyymmdd_iii_Flightline.xxx **(line)**
/pppp_yyyymmdd_iii_Tracklog.xxx **(point)**

Editing and Rotating Working Photographs

Make sure that you are not making changes to the original photographs. Make changes only to the photographs stored in the folder:

/Oblique_Aerial_Photos/Working_Photos/pppp_yyyymmdd_iii/ **(here)**

Look through each of the working photographs and carefully delete any photographs that are poor quality (blurred or out of focus), duplicate, or not relevant (people photos).

Use IrfanView to rotate photographs so that they are oriented correctly. This should be done so that when the file is overwritten the image quality and the file creation date/time stored in the EXIF are not changed. The Graphic Viewer PlugIns must be installed in IrfanView. Select **Options** then **JPG Lossless Rotation...(Plugin)**. Under **Transformation** select the correct rotation angle so that the photograph will be oriented correctly. Make sure to select **Apply original EXIF date/time to new file**. This will overwrite the existing image file.

Renaming Working Photographs

Make sure that you are not making changes to the original photographs and that the renaming process does not change the file date/time stored in the EXIF (DateTimeOriginal) and that the sequential numbering in the file name (e.g. img_00135.jpg) is preserved. The sequential numbering in the working photograph's file name can be used to reference the original photograph if necessary. Use Magic File Renamer to batch rename all the photographs. Browse to the working photographs stored in the folder labeled:

/Oblique_Aerial_Photos/Working_Photos/pppp_yyyymmdd_iii/ **(here)**

Select the **#AddAll** button (it looks like this: >>>) to change the photograph's file names in that folder. The window at the bottom of the screen shows the original file name (**Full File Name** – black type) and the draft modified file name (**Full File Name** – red type). The file names aren't actually changed until the **#GO** button (the round button with a lightening bolt symbol) is selected. Make changes to the file names using the **Insert** and **Replacer** filters. When the modified photograph file names match the example shown below, select the **#GO** button (or **Ctrl+G**).

Example: Rename **Img_0234.jpg** to **pppp_yyyymmdd_iii_00234.jpg**

Geotagging

GPS-Photo Link is used for geotagging. The software matches interpolated positions from the GPS track log to the file date/time saved in the photograph EXIF. Identify the photographs to be used for geotagging. Select the **Camera Folder** option under **Photo Source**. The **Camera Folder** under **Load Photographs from Camera Folder** should match the working photograph folder:

/Oblique_Aerial_Photos/Working_Photos/pppp_yyyymmdd_iii/

The **Photo Root Folder** under **Save Output To** should match the Geotagged Photographs folder:

/Oblique_Aerial_Photos/Geotagged_Photos/

Name the new folder under **New Folder to be created under Photo Root Folder**:

pppp_yyyymmdd_iii

Select **No action** under the **Original Photo Action** option.

Next, select the GPS data source. Select **Use GPS data in file** and select the GPS eXchange Format (*.gpx) file in the Original GPS data folder:

Oblique_Aerial_Photos/Original_GPS/pppp_yyyymmdd_iii/
pppp_yyyymmdd_iii.gpx

Select the **(GMT-09:00) Alaska** time zone and make sure that **Auto adjust for daylight saving time, if needed** is selected. Select **Lat /Lon** and **WGS 84** for the **Datum/Position Format**. Select **Next >**.

Next, select the method of time synchronization. Select **Use photo of GPS receiver**. Make sure that **Use GPS position only if within 60 seconds** is selected. Select **Interpolate between closest GPS points** under **Matching**.

In the “Time Offset Entry” window scroll to view the photo of the GPS screen showing GPS time. Select **Use this photo for time entry** and enter the date and time shown on the GPS screen. If the pre-flight setup was carefully done the calculated offset should only be a few seconds.

The photographs can be further edited and a title and comments can be added in the “Data Entry / Photo Edit” window. Although useful in other applications, these options are not used in this protocol. Scroll to the photograph of the GPS unit and select **Do not include photo in output**.

Next, the desired output formats are selected. Select **Watermarked Photo, Text File (CSV), GPS Exchange (GPX), and ESRI Shape File (SHP)** under **Select output formats**. Select the **Watermarks** tab. Make sure that **Resize photo** is not selected and that nothing is selected under the **Items to Show and Placement** options. Although useful in other applications, these options

are not used in this protocol. Select **Best** under **JPEG Quality**. Select the **Heading / Distance** tab. Select **GPS Track** under **Heading (Picture Direction)**. Make sure that **Calculate new position from heading and distance** and **Adjust Heading** are not selected. (Note, this option is very useful if the camera orientation relative to aircraft heading was fixed). Select **None** under **Distance to Object**. Default settings under the **Misc** tab are acceptable because they only apply to the watermark and html settings, which are not used in this protocol. Batch geotagging and shapefile creation happens when **Finish** is selected. This process will take a while if a large number (100s) of photographs are being processed.

GPS-Photo Link creates five different output file-types in the folder:

/Oblique_Aerial_Photos/Geotagged_Photos/pppp_yyyymmdd_iii/

where:

GPS-Photo Link.txt

is the configuration settings used by GPS-Photo Link

pppp_yyyymmdd_iii_12345_small.jpg

thumbnails of the photographs with Lat / Lon stored in EXIF

pppp_yyyymmdd_iii_12345_tag.jpg

somewhat compressed photographs with Lat / Lon stored in EXIF

picture.xxx

are shapefiles that will be used in the GIS

track.xxx

are shapefiles containing all track log points

Creating GIS Photograph Index

Copy the shapefile generated by GPS-Photo Link using ArcCatalog (ArcGIS)

Copy the shapefile from:

/Oblique_Aerial_Photos/Geotagged_Photos/pppp_yyyymmdd_iii/picture.shp

to:

/Oblique_Aerial_Photos/Working_GIS/pppp_yyyymmdd_iii/picture.shp

Define the shapefile's map projection using the **Project** tool in ArcToolbox (ArcGIS). Select:

/Oblique_Aerial_Photos/Working_GIS/pppp_yyyymmdd_iii/picture.shp

as the **Input dataset**. Define and rename the **Output Dataset**:

/Oblique_Aerial_Photos/Working_GIS/pppp_yyyymmdd_iii/

pppp_yyyymmdd_iii_Origin

Select the **Alaska Albers Equal Area Conic** projected coordinate system for the **Output Coordinate System**.

Copy the line shapefile generated by DNRGarmin using ArcCatalog (ArcGIS). Copy the shapefile from:

/Oblique_Aerial_Photos/Working_GPS/pppp_yyyymmdd_iii/
pppp_yyyymmdd_iii_Flightline.xxx

to:

/Oblique_Aerial_Photos/Working_GIS/pppp_yyyymmdd_iii/
pppp_yyyymmdd_iii_Flightline.xxx

Verify that the line shapefile is in the **Alaska Albers Equal Area Conic** projected coordinate system using ArcCatalog (ArcGIS).

Open ArcMap (ArcGIS) and create a new map document. Name and save the map document:

/Oblique_Aerial_Photos/Working_GIS/pppp_yyyymmdd_iii/
pppp_yyyymmdd_Map.mxd

Load the corresponding digital raster graphic (DRG) mosaic of topographic maps at the 1:63,360 scale and the working point and line shapefiles:

/Oblique_Aerial_Photos/Working_GIS/pppp_yyyymmdd_iii/
pppp_yyyymmdd_iii_Origin.shp

and

/Oblique_Aerial_Photos/Working_GIS/pppp_yyyymmdd_iii/
pppp_yyyymmdd_iii_Flightline.shp

Open the attribute field for the Origin feature class. Delete (or turn off) the following attribute fields:

- East
- North
- Zone
- Direction
- Title
- Comment
- Internal
- Timestamp
- Webpage
- Wptname
- Track
- DOP
- FixType
- GPSValid
- Camera
- FOCLen
- FNumber
- Exposure
- ISO
- FOV

These attribute fields are either not populated by GPS-Photo Link, also preserved in the digital photographs EXIF, or not useful for this application.

Add the following attribute fields to the Origin feature class using the field types and properties listed below:

1. PARK_CODE
 - a. Text, Width=4
2. DATE_
 - a. Date, Width=8
3. PHTO_DIR
 - a. Short Integer, Precision=4
4. PHTOGRAPHR
 - a. Text, Width=25
5. LOC_1
 - a. Text, Width=25
6. LOC_2
 - a. Text, Width=25
7. GLAC_NAME
 - a. Text, Width=25
8. DIST_RSTR
 - a. Text, Width=10
9. ARCHIV_LOC
 - a. Text, Width=50
10. COLL_NAME
 - a. Text, Width=50
11. PUBLISHER
 - a. Text, Width=50
12. GEOG_NAME
 - a. Text, Width=50
13. CAPTION
 - a. Text, Width=200
14. PICT_GE
 - a. Text, Width=50
15. KEYWORDS
 - a. Text, Width=100

Populate the following attribute fields for all features within the Origin feature class with the same values using the attributes dialog box. Start editing, select all features within the Origin feature class, activate the **Attributes dialog box**, select the feature class name (not individual features), select the **Value** for a field, and enter the new value. This will change the value for all selected features within the feature class.

1. PARK_CODE
2. Four-letter park code (ex. LACL)
3. DATE_
 - a. Date picture was taken (ex. mm/dd/yyyy)
4. PHOTOGRAPHR
 - a. Photographer's name (first last)
5. DIST_RSTR
 - a. None (if taken by NPS or permission granted)
 - b. Restricted (if otherwise)
6. ARCHIV_LOC
 - a. NPS, SWAN Electronic Library
7. COLL_NAME
 - a. Last name, year (ex. Schmidt, 2009)
 - (i) or
 - b. NPS, SWAN Glacier Photo Index
8. PUBLISHER
 - a. NPS, SWAN Inventory and Monitoring Program

Populating the remaining attribute fields for features within the Origin feature class involves viewing the corresponding digital photograph, examining a topographic map (1:63,360 DRG), and editing the feature's attribute fields. It is helpful to have two computer screens – one showing ArcMap (ArcGIS) with feature class, topographic map (1:63,360 DRG), and attribute fields visible, the other showing the corresponding digital photograph using photograph viewing software (IrfanView) (Figure 8-1).

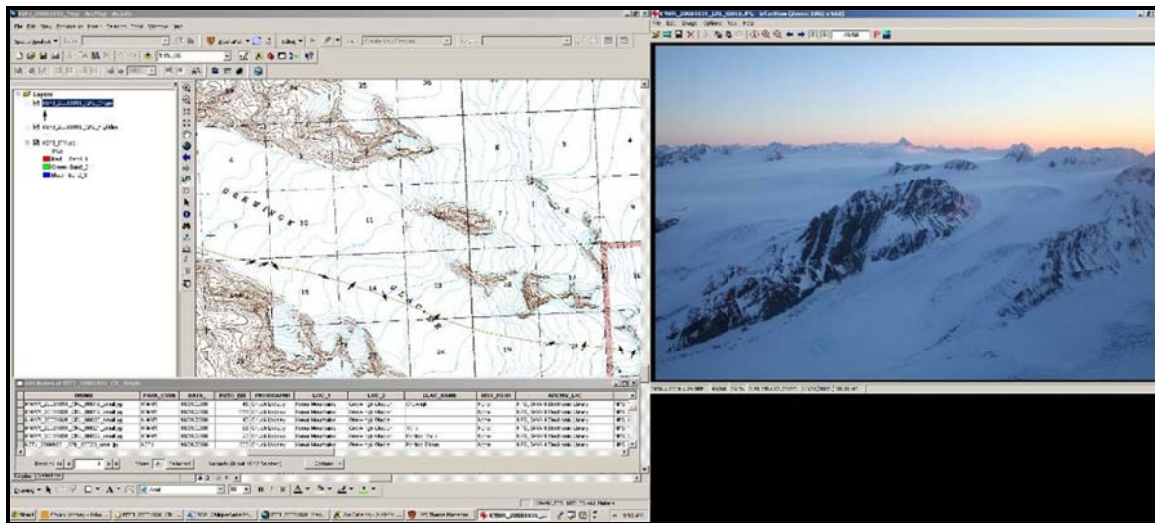


Figure 8-1. GIS and photograph viewing software running on two computer screens. The feature class, topographic map, attribute table, and corresponding digital photograph are viewed simultaneously.

Incrementally work through each feature and corresponding digital photograph, populating the remaining attribute fields for each feature. Select the first point in the feature class, pan to its location on the topographic map (1:63,360 DRG), and view the corresponding digital

photograph. Use the photograph file name from [Original] (use of “[xxxx]” describes an attribute field name) and open the file from:

/Oblique_Aerial_Photos/Working_Photos/pppp_yyyymmdd_iii/

Start editing the target layer: /pppp_yyyymmdd_iii_Origin and enter values for the following attribute fields:

1. **PHTO_DIR** (Azimuth of photograph). This is the angle (from true north) from the location where the photograph was taken to the center of the field of view of the photograph. This should be determined by examining the feature location and the area represented by the corresponding digital photograph on the topographic map (1:63,360 DRG). Values for [PHTO_DIR] correspond to the angle in degrees for 16 compass directions: 23, 45, 68, 90, 113, 135, 158, 180, 203, 225, 248, 270, 293, 315, 228, 360. The closest direction is entered.
 - a. Attribute field properties will need to be changed. Select **Field Properties** for the entire attribute field. Select the “...” button under **Display > Number Format**, select **Angle** under **Category**, select **Degrees** under both options.
 - b. The symbology can be changed to display camera azimuth if desired. To change the symbology for the Origin feature class, right-click the Origin feature class name in the **Table of Contents** and select **Properties**. Select the **Symbology** tab. Change the default symbol to **Cutting Plane Arrow** from the **Dimension Symbols** under **More Symbols**. Select symbology **Properties** and change the **Angle** to **180**. Select **Rotation** under the **Advanced** pull-down menu. Select **PHTO_DIR** under **Rotate Points by Angle in this field:** and select **Geographic** for the **Rotation Style:**.
2. **LOC_1** (Primary Geographic Location). This is the name of the mountain range where the photograph was taken. Polygon shapefiles for each park identify values to be used for [LOC_1] and this attribute field can be populated by spatial relationship. Primary geographic locations are described in Attachment A. Note: values for [LOC_1] are the same primary geographic locations that are used in the modified photograph naming format for the SWAN Glacier Photo Index (e.g. pppp_yyyymmdd_xxxxxx_iii_12345.jpg where “xxxxxx” is the same as [LOC_1]).
3. **LOC_2** (Secondary Geographic Location). This is the name of closest water body (river, creek, lake) in the drainage from which the photograph was taken. If tributaries to the drainage are named, use the name for the corresponding lowest-order stream tributary (e.g. North Fork Tlikakila River in LACL). Sometimes it makes more sense to use a glacier name for [LOC_2] (this occurs when a large, named glacier melts into a relatively small, often unnamed drainage that’s close to the ocean. Examples include Fourpeaked Glacier in KATM, and Bear Glacier in KEFJ).
4. **GLAC_NAME** (Glacier Name). This is the formal or local name of a glacier(s) visible in the digital photograph. The word “glacier” is omitted.
5. **GEOG_NAME** (Named Geographic Features). This is the name of readily identified geographic features visible in the digital photograph. Use names published on USGS topographic maps (1:63,360 or smaller scale). Include glacier names (and the word

“glacier”). Don’t use any geographic name if it’s already used for that feature in [LOC_2]. The reason for these nuances is because attribute fields are later concatenated (combined) to automatically generate photograph captions and keywords. If named geographic features are not visible in the digital photograph enter **Glaciated Landscape** if glacier ice is present and **Landscape** if no glacier ice is present.

6. **PICT_GE** (Google Earth KML file name). This is the file name of the photograph used to generate Google Earth KML files. Entry should be the same as [ORIGINAL], except no underscores are used (because they create errors in the KML). Use the Field Calculator to automatically populate this field for all features.
 - a. Start editing. Select (highlight) [PICT_GE] and activate the Field Calculator. Under **PICT_GE=** type in: **Replace([ORIGINAL],”_”,””)**
 - b. If the primary geographic location is used in the photograph naming format (as in the case of the SWAN Glacier Photo Index, e.g. pppp_yyyymmdd_xxxxxx_iii_12345.jpg where xxxxxx is the same as the primary geographic location, select (or highlight) [PICT_GE] and activate the Field Calculator. Under **PICT_GE=** type in **REPLACE([PICT_GE],”xxxxxx”,””) where xxxxxx is the geographic location.**
7. **CAPTION** (Photograph caption). This is the caption that will be used for the digital photographs in documents, reports, websites, and Google Earth KML. Use the Field Calculator to automatically populate this field for all features (once all the other attribute fields have been populated).
 - a. Start editing. Select (highlight) [CAPTION] and activate the Field Calculator. Under **CAPTION=** type in **[GEOG_NAME]&”_from_”&[LOC_2]&”_Watershed”&”,_”&[LOC_1]&”,_”&”Full_Park_Name”** where “_” is a space.
8. **KEYWORDS** (Photograph keywords). These are keywords that will be used to search any database that contains the digital photographs. Use the Field Calculator to automatically populate this field for all features (once all other attribute fields have been populated).
 - a. Start editing. Select (highlight) [KEYWORDS] and activate the Field Calculator. Under **KEYWORDS=** type in **[LOC_1]&”,_”&[LOC_2]&”,_”&[GEOG_NAME]** where “_” is a space.

An example of completed attributes for a photograph from Lake Clark is shown in Figure 8-2.

Field	Value
ALTITUDE	7841.109
ARCHIV_LOC	NPS, SWAN Electronic Library
CAPTION	Neacola Glacier from Neacola River, Neacola Mountains, Lake Clark National Park and Pres...
COLL_NAME	NPS, SWAN Glacier Photo Index
DATE_	8/28/2007
DATUM	NAD 83
DIST_RSTR	None
FID	264
GEOG_NAME	Neacola Glacier
GLAC_NAME	Neacola
HEADING	172
KEYWORDS	Neacola Mountains, Neacola River, Neacola Glacier
LAT	60.87299
LOC_1	Neacola Mountains
LOC_2	Neacola River
LOCALTIME	28-Aug-2007 16:05:27
LON	-153.375754
ORIGINAL	LACL_20070828_Neacola_CRL_00268.JPG
PARK_CODE	LACL
PHTO_DIR	293
PHTOGRAPHR	Chuck Lindsay
PICT_GE	LACL20070828CRL00268.JPG
PICTURE	LACL_20070828_Neacola_CRL_00268_tag.jpg
PUBLISHER	NPS, SWAN Inventory and Monitoring Program
SPEED	154.4
THUMB	LACL_20070828_Neacola_CRL_00268_small.jpg

Figure 8-2. Completed attribute fields for photograph from Lake Clark.

Finalized Photographs

Copy photographs to the Final_Photos folder:

Copy the full-size photographs from:

/Oblique_Aerial_Photos/Working_Photos/pppp_yyyymmdd_iii/

To:

/Oblique_Aerial_Photos/Final_Photos/Full_Size/

Copy the geotagged photographs (files that end with “_tag”) from:

/Oblique_Aerial_Photos/Geotagged_Photos/

To:

/Oblique_Aerial_Photos/Final_Photos/Geotagged/

Copy the thumbnail-sized photographs (files that end with “_small”) from:

/Oblique_Aerial_Photos/Geotagged_Photos/

To:

/Oblique_Aerial_Photos/Final_Photos/Thumbnails/

Finalized GIS Photograph Index

After all attribute fields have been populated and feature editing is complete, use ArcCatalog (ArcGIS) to copy the shapefiles to the Final_GIS folder.

Copy the line feature class from:

/Oblique_Aerial_Photos/Working_GIS/pppp_yyyymmdd_iii/
pppp_yyyymmdd_iii_Flightline.xxx

to:

/Oblique_Aerial_Photos/Final_GIS/Shapefiles/pppp_yyyymmdd_iii_Flightline.xxx

Copy the point feature class from:

/Oblique_Aerial_Photos/Working_GIS/pppp_yyyymmdd_iii/
pppp_yyyymmdd_iii-Origin.xxx

to:

/Oblique_Aerial_Photos/Final_GIS/Shapefiles/pppp_yyyymmdd_iii-Origin.xxx

Create an ArcMap (ArcGIS) map document for each park with the following layers, symbology, and field-based hyperlinks:

1. **Layers** Add layers for the point feature class “Origin”, the line feature class “Flightline”, the USGS 1:63,360 topographic map (DRG) and the true-color Landsat image mosaic. Layers should be ordered: Origin, Flightline, Topography, and Landsat Image with the Origin layer at the top of the Table of Contents.
2. Select **Layer Properties** for the Topography layer. Select the **Display** tab. Enter **50** under **Transparency**.
3. **Symbology** Use rotated symbology for the “Origin” feature class (as described above). Symbol colors for the point and line feature classes should match.
4. **Hyperlinks** Create field-based hyperlinks for the Origin layer:
 - a. Select **Layer Properties** for the Origin layer. Select the **Display** tab. Activate **Support Hyperlinks using field:** and select [PICTURE] in the pull-down menu.
 - b. Identify the hyperlink base. Click on **File** and select **Document Properties**. Copy and paste the complete pathname for the folder containing the geotagged photographs:
/Oblique_Aerial_Photos/Final_Photos/Geotagged/
 - (i) This folder must contain digital photographs with file names which match the entries in the attribute field [PICTURE].

An example data frame view from a map document created following this procedure is shown in Figure 8-3.

Name and save the map document:

/Oblique_Aerial_Photos/Final_GIS/Photo_Index/
pppp-Oblique_Aerial_Photos.mxd

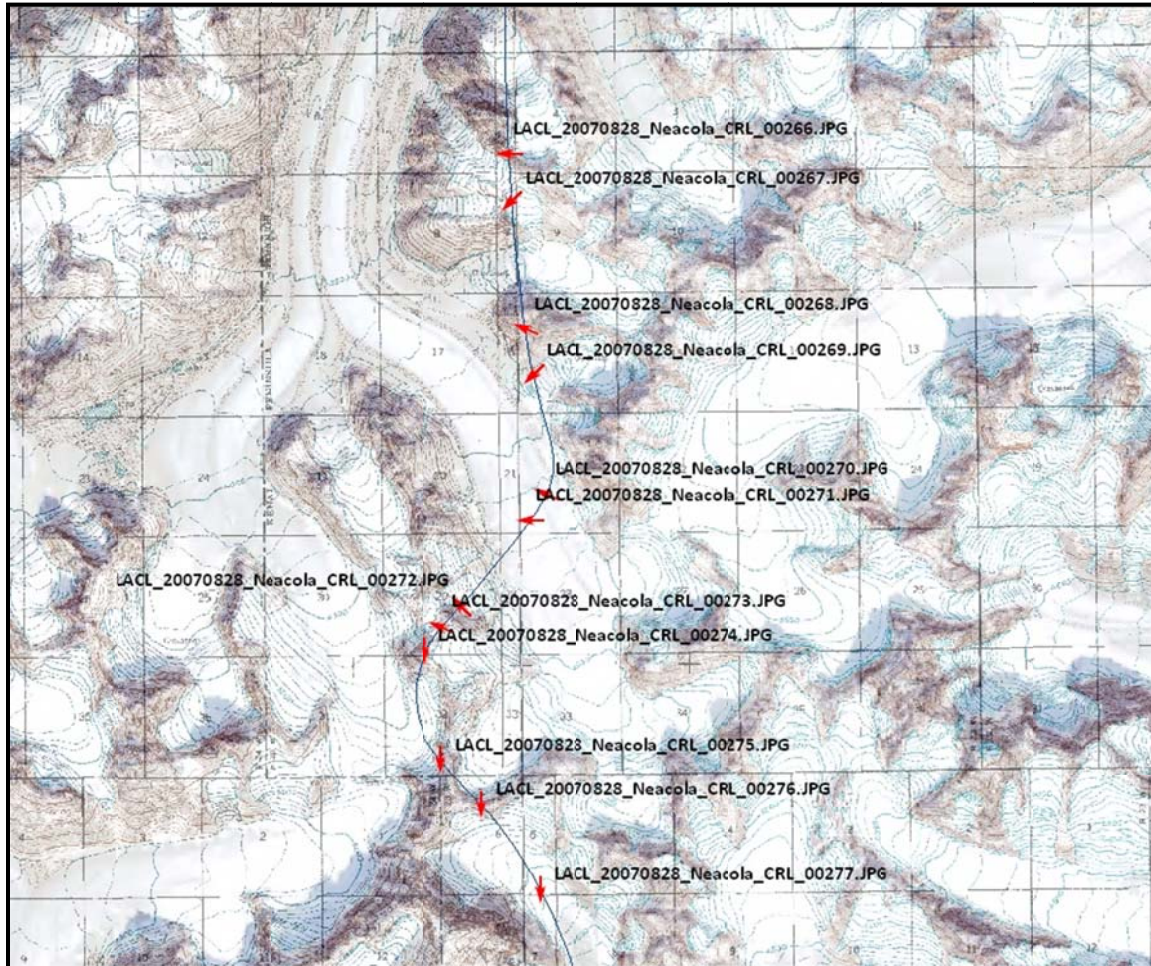


Figure 8-3. Data frame view of GIS photograph index for Lake Clark.

Batch processing photographs for Google Earth KML

Copies of working photographs are resized and renamed for use in Google Earth KML. This procedure results in a folder of photographs that are sized 400 x 350 pixels with file names that follow the naming format: ppppyyyymmddiii.jpg.

Use IrfanView to batch resize photographs. Select **File > Batch Conversion/Rename**. Identify the folder with photographs to use:
 /Oblique_Aerial_Photos/Working_Photos/pppp_yyyymmdd_iii/
 Click the **Add all** button to select all photographs for resizing.
 Select **Batch Conversion – Rename result files** and **JPG/JPEG Format**. Activate **Use advanced options**. Click the **Advanced** button and activate **Resize**. Select **Set new size:** and **Set one or both sides to: 400 Width by 350 Height (pixels)**. Select **Preserve aspect ratio (proportional)**. Activate **Save files with original date/time**. Select **OK**. Click the **Options** button under **Batch rename settings**. Type \$N for **Name pattern:** and type “_” after **Replace text (1):** and “” after **with**. Identify the **Output directory for result files:**

/Oblique_Aerial_Photos/Google_Earth/pppp_yyyymmdd_iii/files
Click **Start Batch**. Batch processing may take some time.

If primary geographic locations ([LOC_1]) are included in the photograph naming format (e.g. SWAN Glacier Photo Index) use file renaming software to remove this text from the file name. Refer to the section titled **Rename Working Photographs** above and use Magic File Renamer. The **Replacer** filter is used to delete text in a file name by replacing selected text with nothing.

Exporting GIS to KML

Download and install the Export to KML extension for ArcGIS from the ESRI Support Center. Detailed instructions for installation are included in the download package.

Open the final GIS map document. Make sure that the photograph directions ([PHTO_DIR]) in the attribute table are in numeric (not angle) format. Select **View > Toolbars** and activate the Export to KML toolbar. Click on the **Export to KML** button (it looks like the Google Earth program icon – a small blue globe with white stripes).

Select the layer to export. Select the point feature class by using the pull-down menu to select **pppp_yyyymmdd_iii_Origin**. Don't activate **Group and color features using the layer's symbology** (it doesn't recognize symbology based on field attributes like the rotated arrow used). Select **<None>** for both **Select an attribute for labeling features** and **Select an attribute that represents the height**. Browse to:

/Oblique_Aerial_Photos/Google_Earth/pppp_yyyymmdd_iii/
and name the output KML:
pppp_yyyymmdd_iii

Click the **Options** button. Select the **Export Options** tab. Type a description like: **Oblique aerial photographs taken in PARK on MONTH DAY, YEAR.** under **KML Layer Description**.

Click the **Labeling and Description Options** tab. Use the pull-down menu to select **Original** under **Select an attribute for naming each feature:**. Copy and paste the following HTML code under **Feature description expression**:

```
<b>[ORIGINAL]</b><br>
<br><b>[CAPTION]</b><br><br>Date: [DATE_]<br>Taken
from: Lat [LAT], Lon [LON], Alt [ALTITUDE] (ft)<br>Datum: [DATUM]<br>Photo
Orientation: [PHTO_DIR] deg<br>Aircraft heading: [HEADING] deg<br>Aircraft speed:
[SPEED] mph<br>Photographer: [PHTOGRAPHR]<br>Collection name:
[COLL_NAME]<br>Publisher: [PUBLISHER]<br>Archive location:
[ARCHIV_LOC]<br>Distribution restrictions: [DIST_RSTR]<br>
```

Click **OK** twice to create the KML.

Now, export the line feature class. Click on the **Export to KML** button. Select the layer to export. Select the line feature class by using the pull-down menu to select **pppp_yyyymmdd_iii_Flightline**. Don't activate **Group and color features using the layer's symbology**. Select <None> for both **Select an attribute for labeling features** and **Select an attribute that represents the height**. Browse to:

/Oblique_Aerial_Photos/Google_Earth/pppp_yyyymmdd_iii/
and name the output KML:
pppp_yyyymmdd_Flightline

Click the **Options** button. Select the **Export Options** tab. Type a description like: **Flightline for oblique aerial photography in PARK on MONTH DAY, YEAR.** under **KML Layer Description**.

Click **OK** twice to create the KML.

An example of the Google Earth output files is shown in Figure 4.

The folder for Google Earth file must follow this file structure:

```
/pppp_yyyymmdd_iii/  
  /.kml  
  /.kml  
  /files  
  /resized, renamed photographs (400 x 350 pixel, no “_” in name)
```

It may be useful to create a compressed KMZ archive that contains the point feature class and the resized, renamed photographs. Use a file compression utility (e.g. WinZip) to create a file archive containing:

```
/pppp_yyyymmdd_iii_Origin.kml  
/files
```

and rename the archive extension **.kmz**. Sometimes Google Earth doesn't recognize .kmz archives created with WinZip. The open source file compression utility 7-Zip works well.



Figure 8-4. Screenshot from Google Earth showing point and line feature class and feature description with embedded photograph exported from ArcGIS.

Attachment A. File Organization

The following steps provide guidance on naming and organizing the large number of files that will be created during geotagging and managing oblique aerial photographs in a GIS. It is important to carefully organize these files and keep original, working, and final copies of the photographs, GPS data, and GIS data.

Explanation

/ = denotes directory, subfolder

pppp = four letter park code (e.g. KEFJ)

yyyymmdd = Year, Month, Day code

iii = photographers initials (first, middle, last)

xxx = various ArcGIS shapefile extensions

12345 = sequential numbering assigned to photograph by camera

example = KEFJ_20090212_CRL.shp (use underscore in file name)

Photograph Naming Format

pppp_yyyymmdd_iii_12345.jpg

(example: KEFJ_20090212_CRL_0234.jpg)

Note: The SWAN Glacier Photo Index uses a modified photograph naming format:

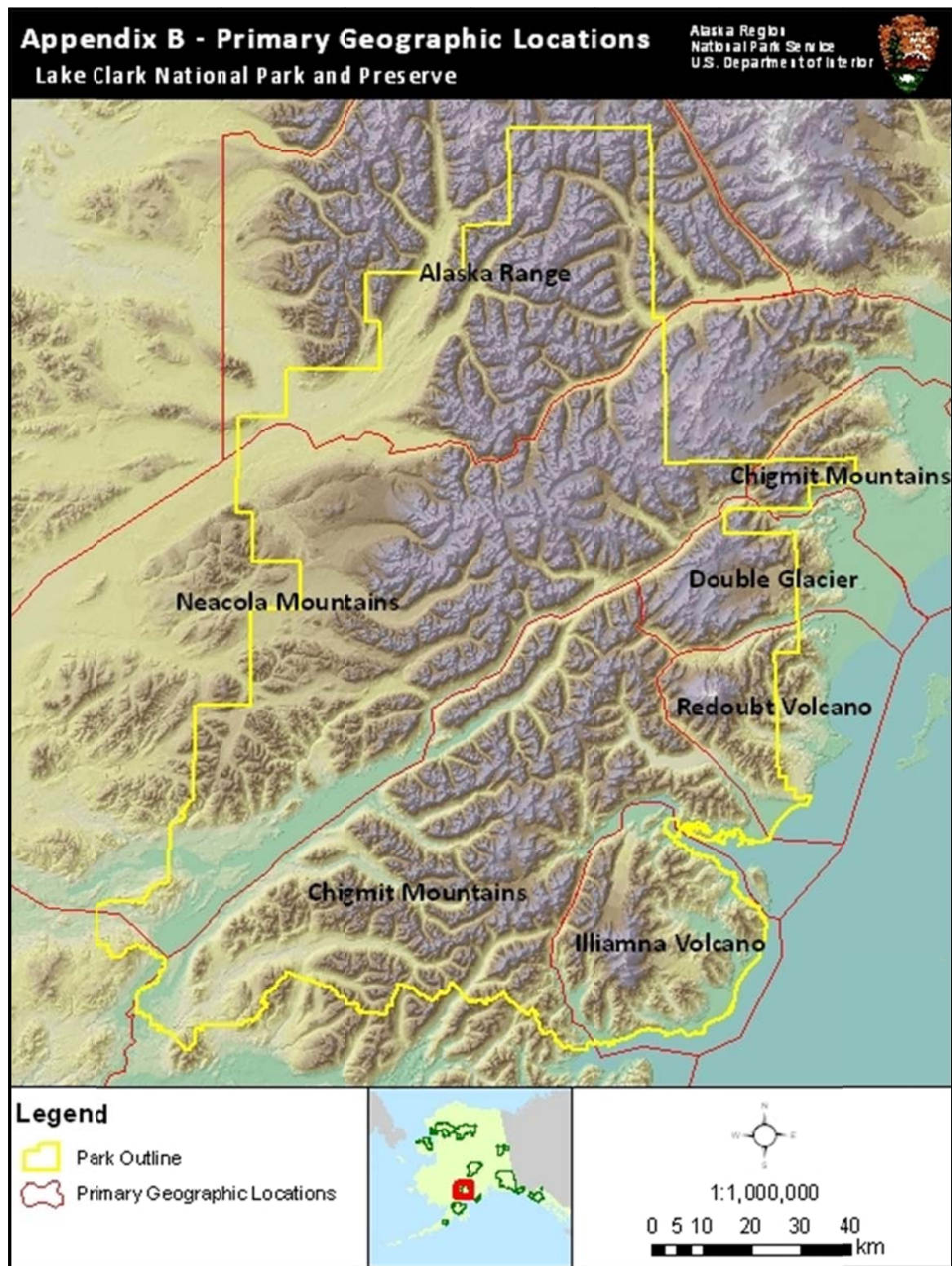
pppp_yyyymmdd_[LOC_1]_iii_12345.jpg where [LOC_1] is the primary geographic location where the photograph was taken from. This value is the same as the field attribute [LOC_1] used in the GIS shapefile (pppp_yyyymmdd_iii_Origin.xxx) and these values are described in Attachment B. This naming format is somewhat redundant and not necessary, but it was specifically requested.

Example File Organization

```
/Oblique_Aerial_Photos
    /Geotagged_Photos
        /pppp_yyyymmdd_iii
    /Google_Earth
        /pppp_yyyymmdd_iii
            /files
                /pppp_yyyymmdd_iii_Flightline.kml
                /pppp_yyyymmdd_iii_Origin.kml
                /pppp_yyyymmdd_iii.kmz
    /Final_GIS
        /Photo_Index
            /pppp_Oblique_Aerial_Photos.mxd
    /Shapefiles
        /pppp_yyyymmdd_iii_Origin.xxx
        /pppp_yyyymmdd_iii_Flightline.xxx
    /Final_Photos
        /Full_Size
            /pppp_yyyymmdd_iii
```

```
/Geotagged
    /pppp_yyyymmdd_iii_tag
/Thumbnails
    /pppp_yyyymmdd_iii_small
/Original_GPS
    /pppp_yyyymmdd_iii
    /pppp_yyyymmdd_iii.gdb
    /pppp_yyyymmdd_iii.gpx
    /pppp_yyyymmdd_iii.txt
/Original_Photos
    /pppp_yyyymmdd_iii
/Working_GIS
    /pppp_yyyymmdd_iii
    /pppp_yyyymmdd_iii_Flightline.xxx
    /pppp_yyyymmdd_iii_Origin.xxx
    /pppp_yyyymmdd_iii_Working.mxd
/Working_GPS
    /pppp_yyyymmdd_iii
    /pppp_yyyymmdd_iii_Flightline.xxx
    /pppp_yyyymmdd_iii_Tracklog.xxx
/Working_Photos
    /pppp_yyyymmdd_iii
```

Attachment B. Primary geographic locations for Lake Clark National Park and Preserve.



Standard Operating Procedure (SOP) #9

Data Management

Version 1.0

Change History

Version numbers will be incremented by a whole number (e.g. Version 1.3 to Version 2.0) when a change is made that significantly affects requirements or procedures. Version numbers will be incremented by decimals (e.g. Version 1.6 to Version 1.7) when there are minor modifications that do not affect requirements or procedures.

The following revisions have occurred to this plan since January 2011.

Version #	Date	Revised by	Changes	Justification

This Standard Operating Procedure describes the strategy for folder and file management (folder/file structure and naming convention) and backup procedures critical to the efficient data management in support of the Glacier Monitoring protocol for the Southwest Alaska Network (SWAN).

Background

Mapping glacier extent as described in this protocol requires a significant effort and investment in personnel time spread out over a period of a couple months for each mapping effort. This being the case, significant attention to folder and file management (folder/file structure and naming convention) and backup procedures is critical to the efficient management of this glacier boundary mapping protocol.

Landsat Data Acquisition

Acceptable Landsat imagery is ordered and received from the EROS Data Center (See SOP #1 for direction). This Landsat data is currently stored on the X drive (NPS Alaska Region GIS Data) maintained by the NPS, Alaska Regional Office – GIS group with the following directory structure and file naming convention.

X:\Source_Data\Satellite_Imagery\

The Landsat image file naming convention on the X drive is:

Example: TM5_7118_03Sep1995_Albers_NAD27

Sensor: “TM5” means Landsat 5 Thematic Mapper

PathRow identifier: Path 71, Row 18

Date of Acquisition: 03Sep1995

Projection: Albers

Datum: NAD27

Directory Structure and File Naming

The following is the suggested folder and file naming convention. The SWAN Data Management Plan recommends that there be no periods (.) in the path or filename. Use the underscore (_) in file and folder names. This is particularly important for ArcGIS and ArcCatalog software operations. All the data processing is completed in the ArcGIS/ArcCatalog environment, thus all folders, files, Personal Geodatabases and Feature Datasets will all be created using ArcCatalog. Figure 9-1 shows the primary folder structure where data processing occurs. From past experience, it seems that ArcGIS/ArcCatalog performs best when the folder location is located as close to the root of the “C” drive as possible.

The standard datum and projection for all geospatial data products will be that of the satellite imagery as provided by EROS Data Center. Landsat satellite imagery provided by EROS is WGS-84, UTM, Zone 5 or 6 for the SWAN parks. All data to be hosted by the Alaska Regional Office GIS Team (on the GIS Theme Manager) will be converted to NAD83, Alaska Albers projection.

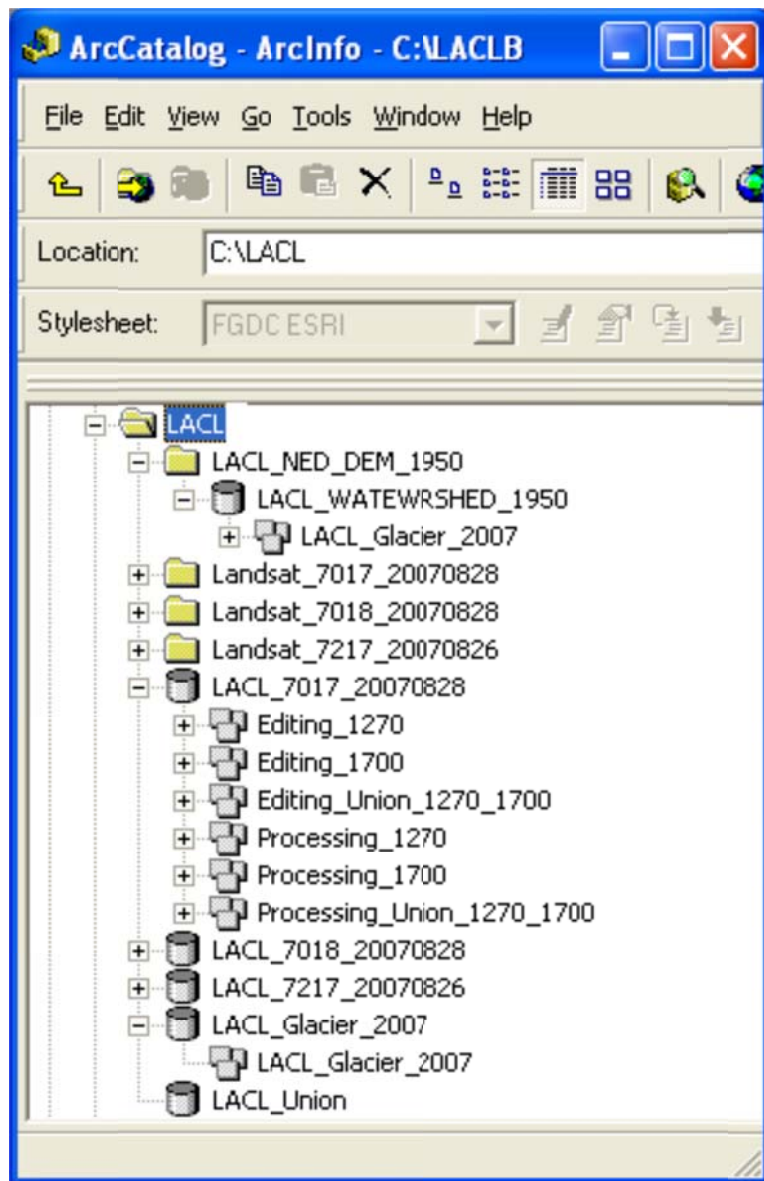


Figure 9-1. Primary folder structure. Note that in this Figure 9-“PARK” acronym has been replaced by LACL (i.e. Lake Clark NP&P). Also note that the YYYYMMDD have been replaced with the appropriate dates.

A few definitions are in order:

“C” is the C drive on the computer.

“PARK” is the primary folder in which all folders and files are located. The “PARK” acronym should name this folder, i.e. KATM, KEFJ, LACL.

“PARK_NED_DEM_1950” is a subordinate folder in the “PARK” folder that contains digital elevation model data of the mapping region.

“LACL_WATEWRSHED_1950” is a personal Geodatabase created using ArcCatalog where watershed boundary extraction is accomplished.

“LACL_Glacier_2007” is a feature dataset within the “LACL_WATEWRSHED_1950” personal Geodatabase where individual glacier polygons are created from ice divides.

“Landsat_7017_YYYYMMDD” is a subordinate folder in the “PARK” folder that contains Landsat data of the mapping region.

Where 7017 is the path and row identifier for the satellite image and YYYY, MM and DD is the year, month and day of the satellite imagery.

“PARK_7017_YYYYMMDD.mdb” is a Personal Geodatabase created using ArcCatalog. Replace “PARK” with the appropriate park acronym.

Where 7017 is the path and row identifier for the satellite image and YYYY, MM and DD is the year, month and day of the satellite imagery.

“Editing_ArcGIS_1270” is a Feature Dataset where shapefiles are edited in ArcGIS/ArcCatalog. The 1270 represents a threshold value determined in SOP #2. In this case “1270” represents a threshold value of 1.270.

“Editing_ArcGIS_1700” is a Feature Dataset where shapefiles are edited in ArcGIS/ArcCatalog. The 1700 represents a threshold value determined in SOP #2. In this case “1700” represents a threshold value of 1.700.

“Editing_Union_1270_1700” is a Feature Dataset where shapefiles are edited in ArcGIS/ArcCatalog. The shapefiles here represent the “Union” of portions of shapefiles from:

“Processing_1270”

“Processing_1700”

“Processing_1270” is a Feature Dataset where all the processing occurs. The 1270 represents a threshold value determined in SOP #2. In this case “1270” represents a threshold value of 1.270.

“Processing_1700” is a Feature Dataset where all the processing occurs. The 1700 represents a threshold value determined in SOP #2. In this case “1750” represents a threshold value of 1.700.

“Processing_Union_1270_1700” is a Feature Dataset where all the processing occurs for the union of the two classification efforts carried out in two Feature Datasets:

“Processing_1270”

“Processing_1700”

“LACL_Glacier_2007” is a personal Geodatabase created using ArcCatalog where final geospatial glacier boundary data and supporting files created and stored.

“LACL_Glacier_2007” is a feature dataset within the “LACL_Glacier_2007” personal Geodatabase where final glacier boundaries shapefiles and other supporting geospatial data are created and stored.

Creating folders, Personal Geodatabases and Feature Datasets in ArcCatalog is simply done by right clicking the mouse button on the intended location. Figure 9-2 illustrates the process of creating a Personal Geodatabase within the PARK folder. Figure 9-3 illustrates the process of creating a Feature Dataset within the PARK_YYYYMMDD.mdb Personal Geodatabase.

Note: The directory structure shown in Figure 9-1 assumes two or more satellite images are required to complete the glacier boundary mapping project – therefore, satellite image path and row identifiers are used in the folder naming convention. From this point on in this SOP, folder naming convention assumes only one satellite image is required to complete the glacier boundary mapping project – therefore, satellite image path and row identifiers are not used in the folder naming convention beyond this point in this SOP.

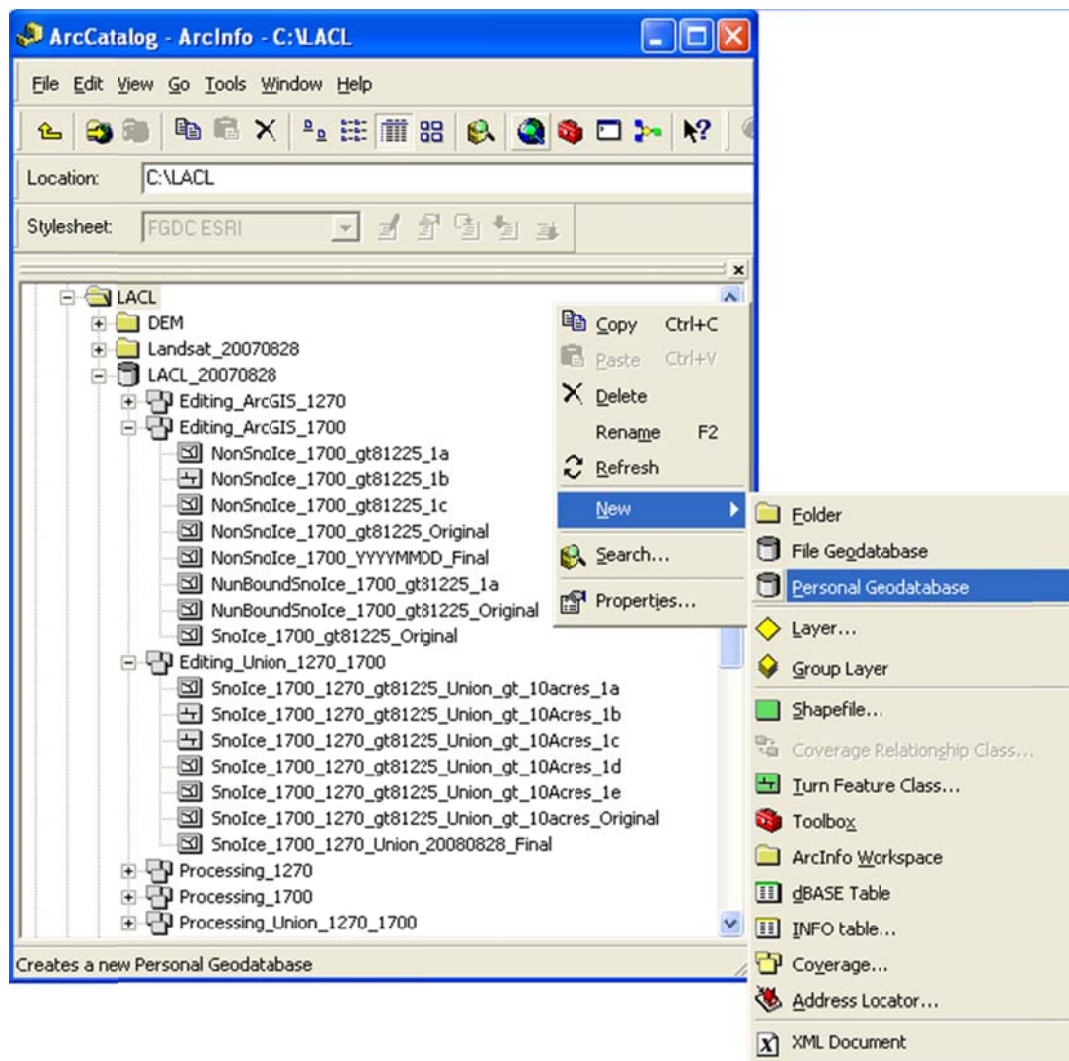


Figure 9-2. Creating a Personal Geodatabase using ArcCatalog.

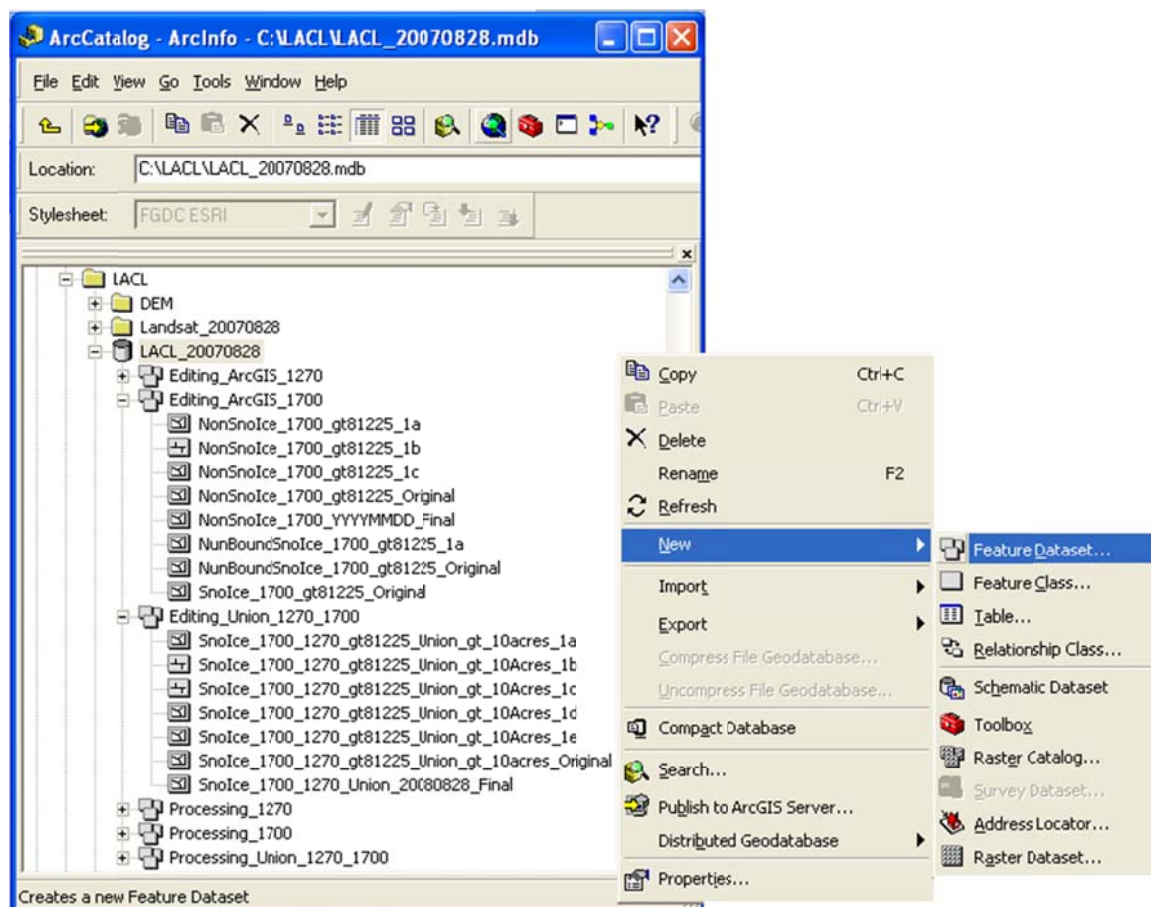


Figure 9-3. Creating a Feature Dataset within a Personal Geodatabase using ArcCatalog.

DEM Folder Contents

The “DEM” folder contains raster and shapefiles (Figure 9-4). Rasters include the best available DEM (typically the USGS NED for the SWAN parks) and a resultant raster file after a conditional statement (Con(sa)) is applied to the DEM (laci_gt_4650) (Figure 9-5).

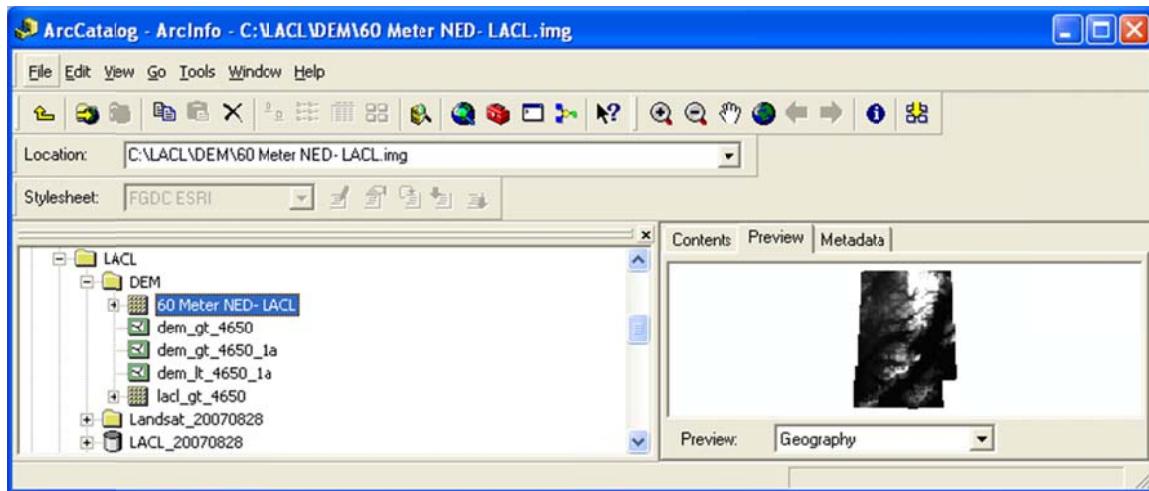


Figure 9-4. DEM folder contents.

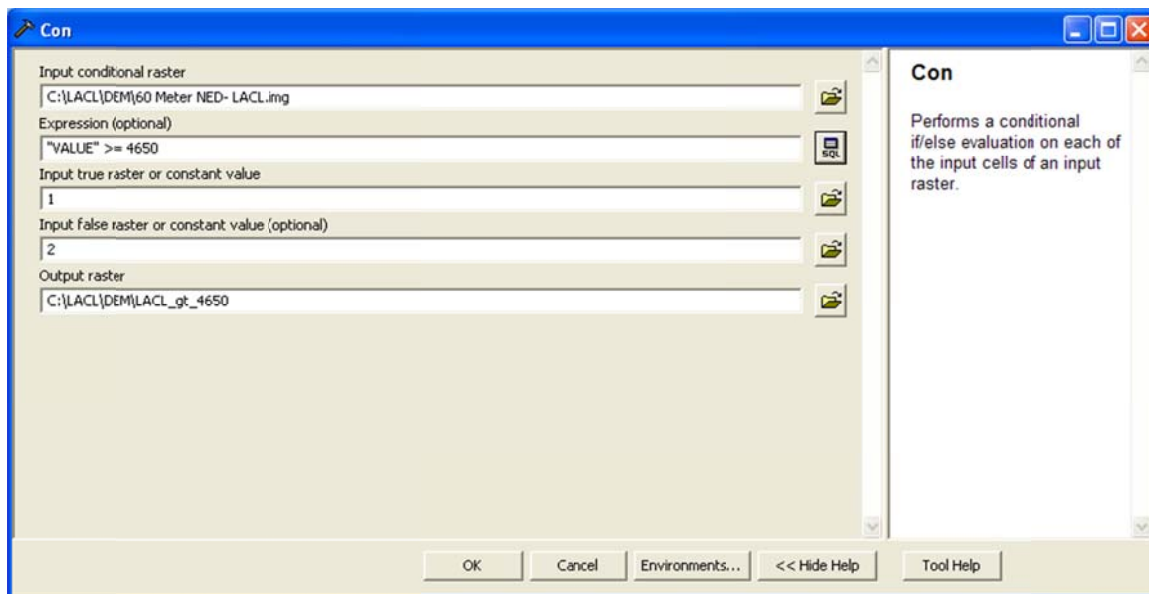


Figure 9-5. Conditional statement (Con (sa)) command in ArcCatalog.

Shapefiles are the result of a Raster-To-Polygon conversion (Figure 9-6) and a select (analysis) of the first polygon shapefile (Figure 9-7):

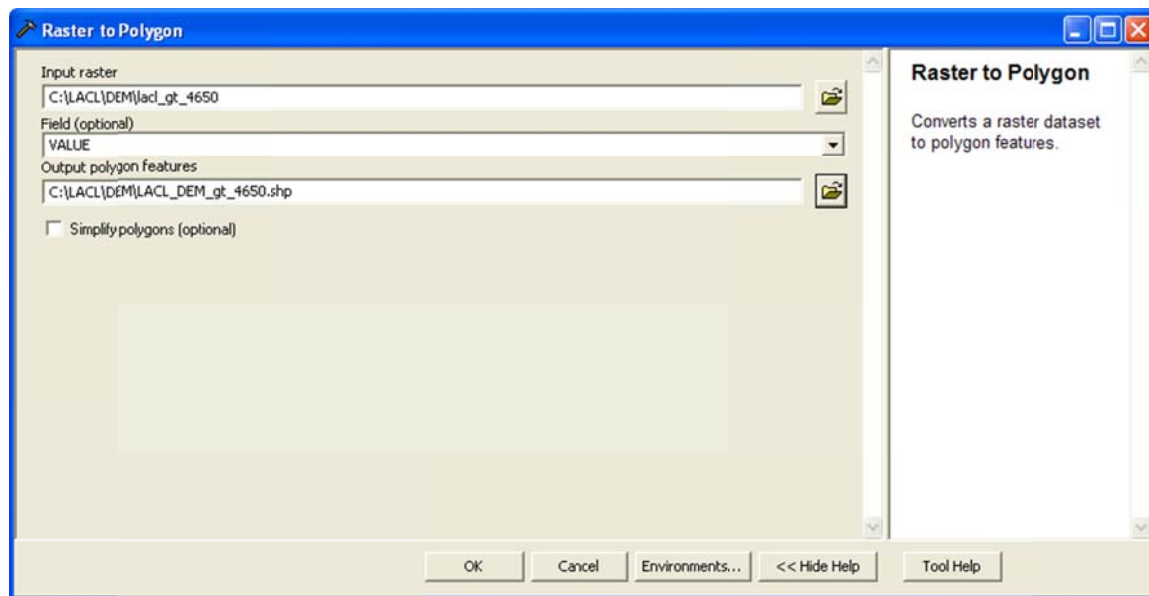


Figure 9-6. Raster to polygon conversion command in ArcCatalog.

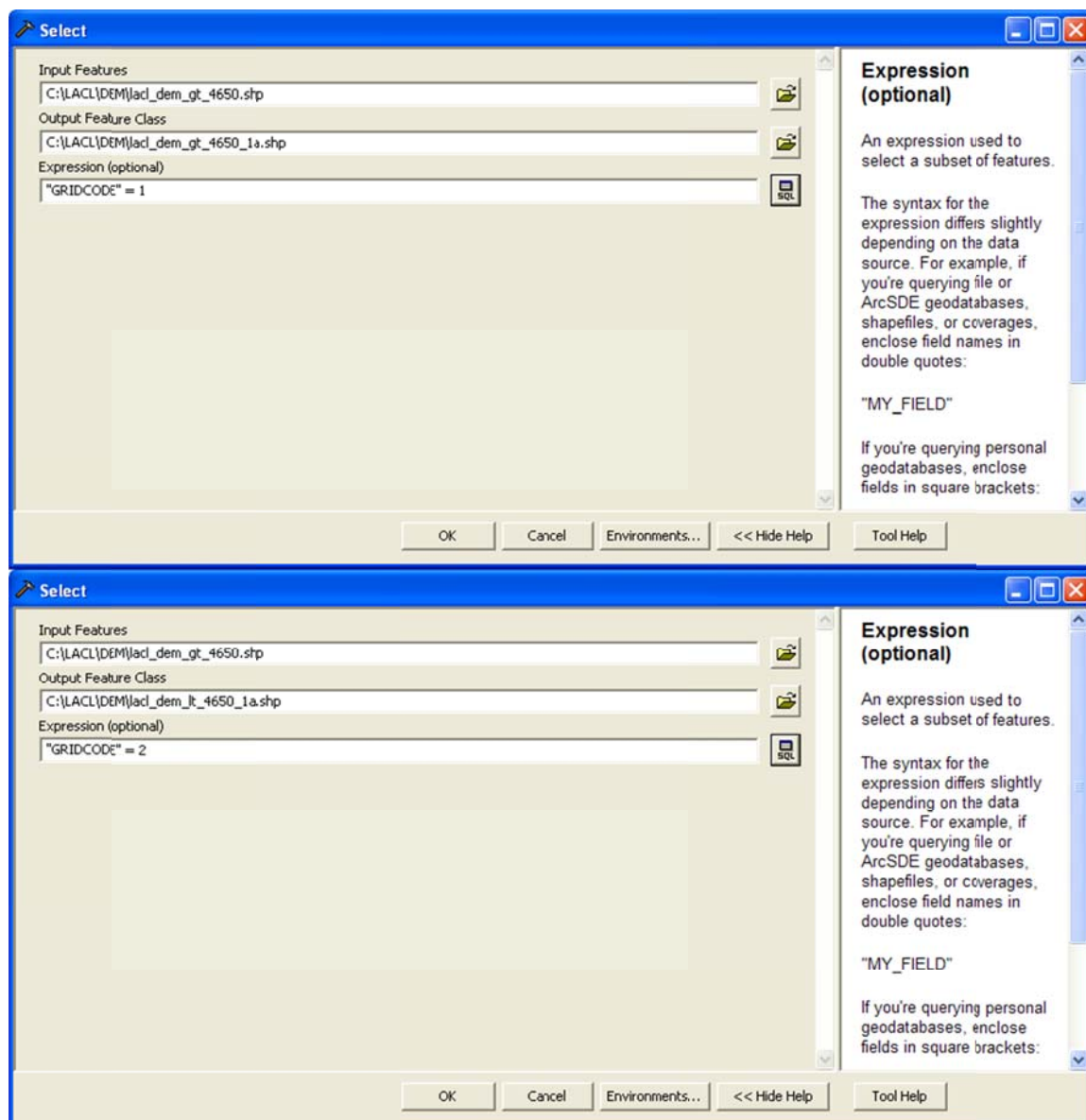


Figure 9-7. "Select" command in ArcCatalog.

Landsat_YYYY Folder Contents

The “Landsat_YYYYMMDD” folder contains raster files (Figure 9-8). Rasters include Landsat bands and resultant raster files after various processing steps. The raster files seen in Figure 9-8 have been fully described in SOP #3 and SOP #4, so only a few explanations are offered here to reduce redundancy. For example:

- b2 is the original Landsat Band 2
- b3 is the original Landsat Band 3
- b4 is the original Landsat Band 4
- b5 is the original Landsat Band 5
- float_b3 is the resultant band after applying the “Float” command
- float_b5 is the resultant band after applying the “Float” command
- divide_b3_b5 is the resultant raster after the dividing band 3 by band 5
- b5b4b2_Composite is the color composite Landsat image
- b3b5_gt1270 is a resultant raster file representing pixel value greater than 1.270 from the “divide b3b5” raster.
- b3b5_gt1700 is a resultant raster file representing pixel value greater than 1.700 from the “divide b3b5” raster.

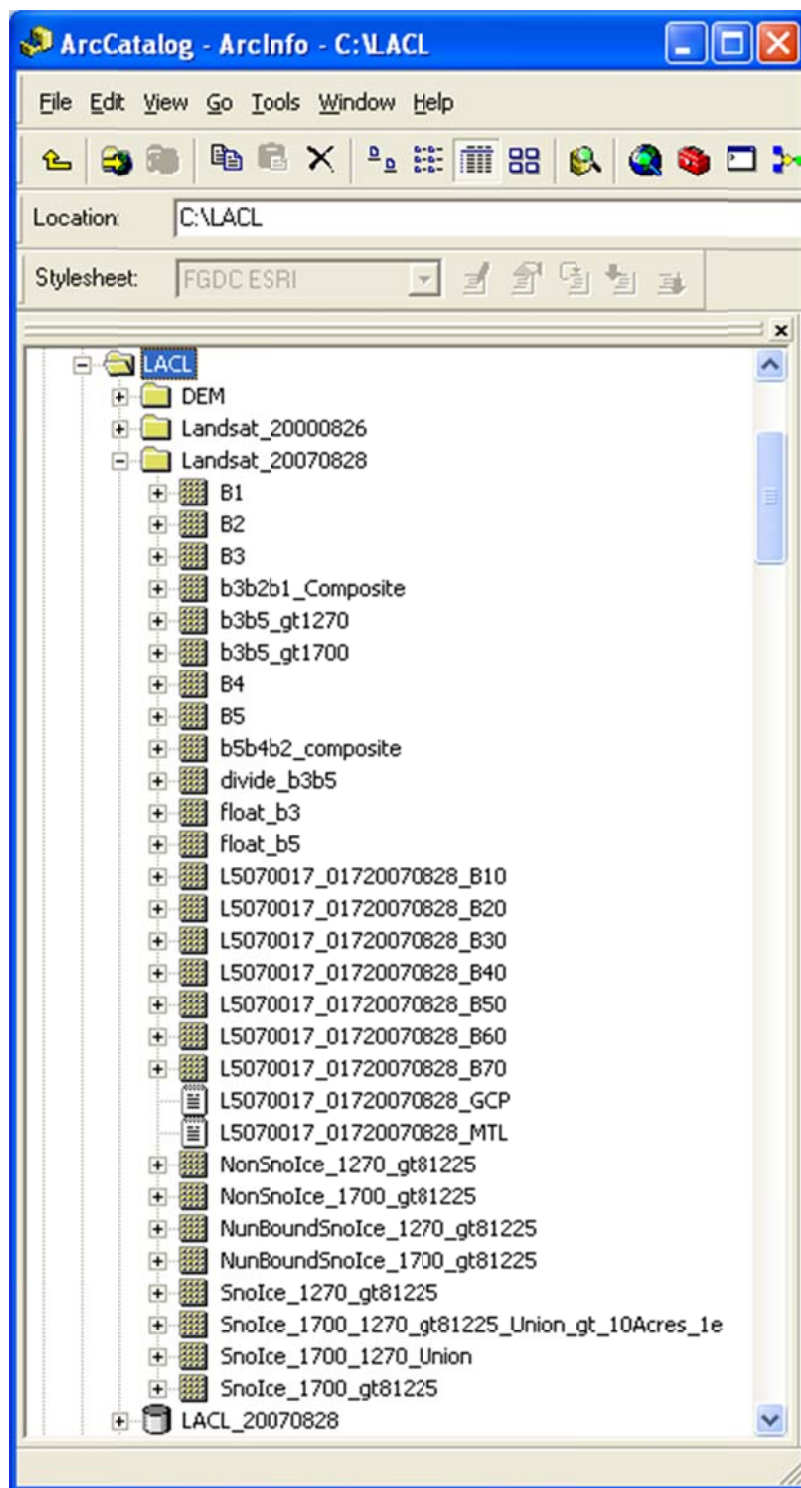


Figure 9-8. Landsat folder and file naming.

PARK_YYYYMMDD.mdb Personal Geodatabase

This Personal Geodatabase contains only Feature Datasets; no folders or files are found directly in this Personal Geodatabase. Figure 9-9 shows six Feature Datasets, three “Editing_” and three “Processing_”. Each representing mapping efforts using different threshold values (threshold values are described in SOPs #2-4, where data processing and editing are described).

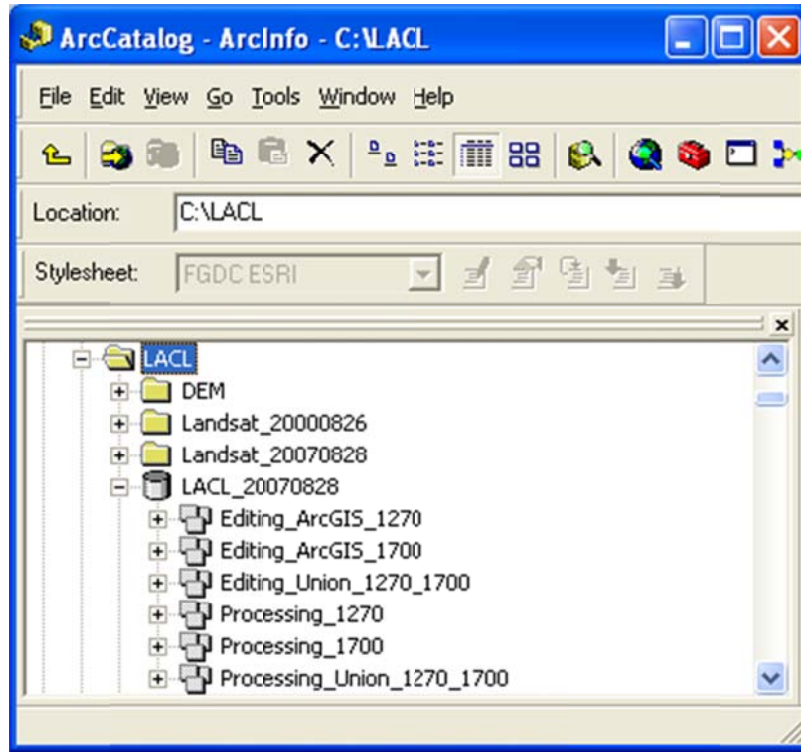


Figure 9-9. Personal Geodatabase and Feature Dataset structure.

Processing_1700 and 1270 Feature Datasets

Figure 9-10 illustrates the file naming convention used in this Feature Dataset. The file naming convention was already covered in SOP #3 and SOP #4.

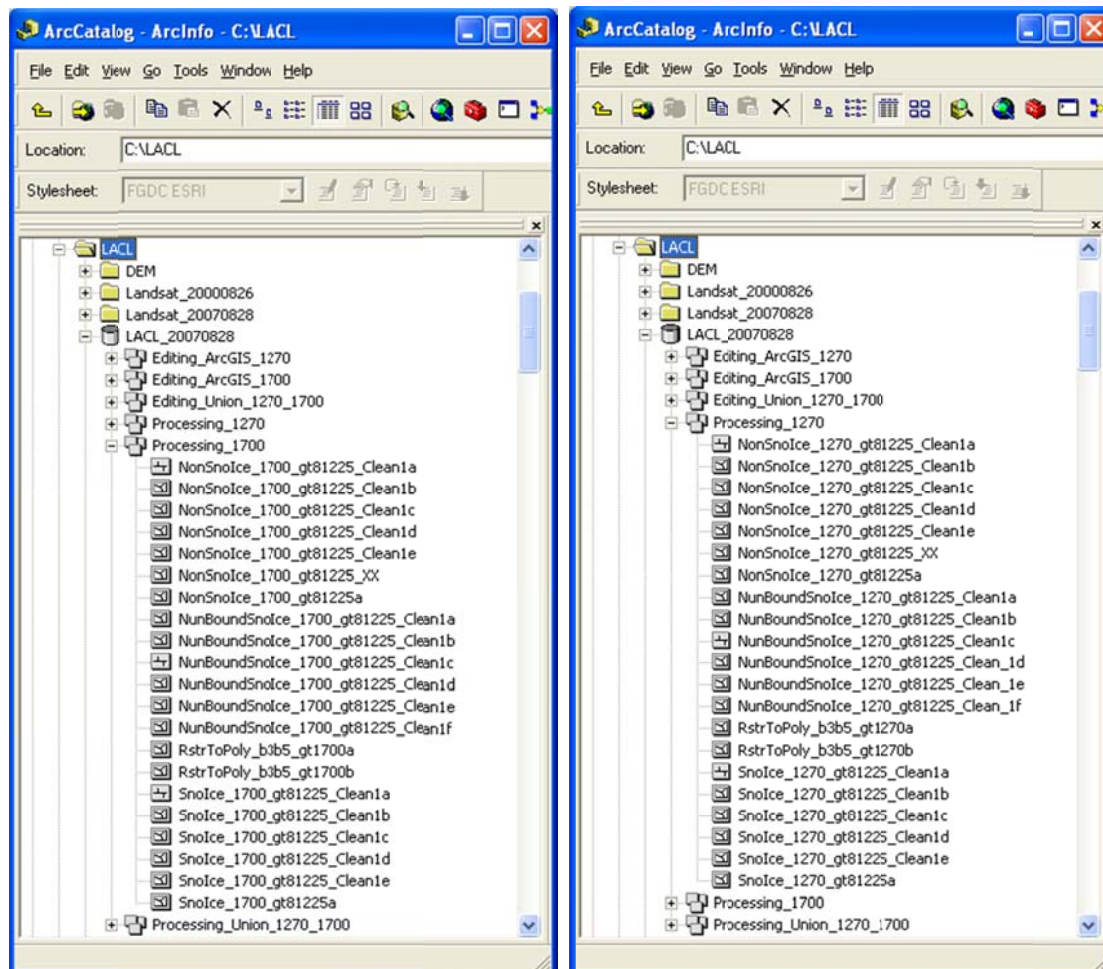


Figure 9-10. File naming convention for a "Processing_" Feature Datasets.

Processing_Union_1270_1700 Feature Datasets

Figure 9-11 illustrates the file naming convention used in this Feature Dataset. The file naming convention was already covered in SOP #3 and SOP #4.

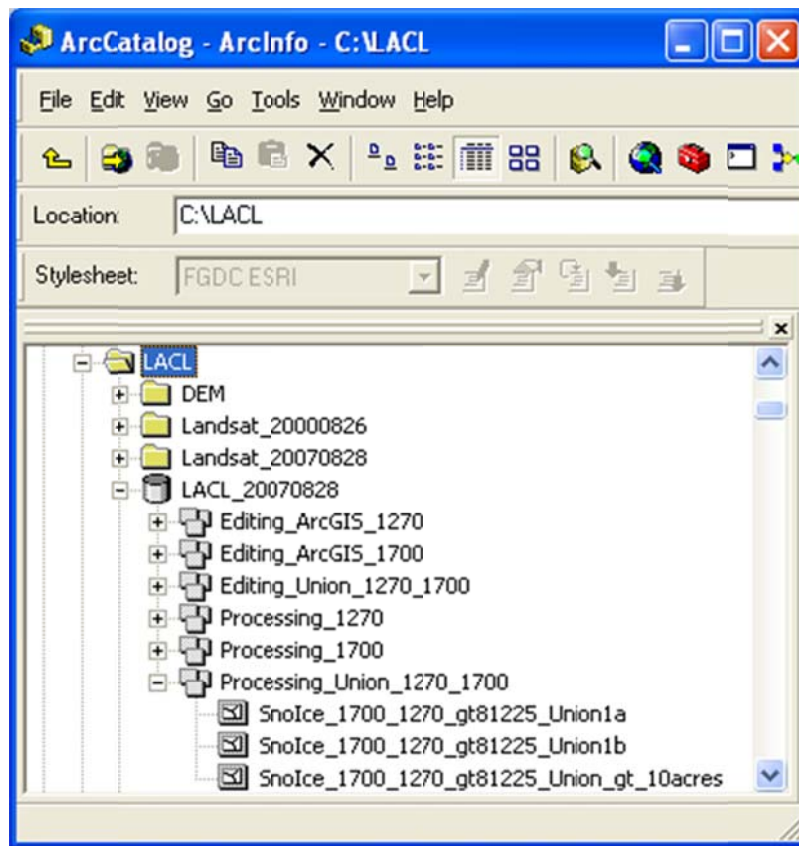


Figure 9-11. File naming convention for a "Processing_Union_1270_1700" Feature Dataset.

Editing_ArcGIS_1700 and Union_1270_1700 Feature Dataset

Figure 9-12 illustrates the file naming convention used in this Feature Dataset. The file naming convention was already covered in SOP #3 and SOP #4.

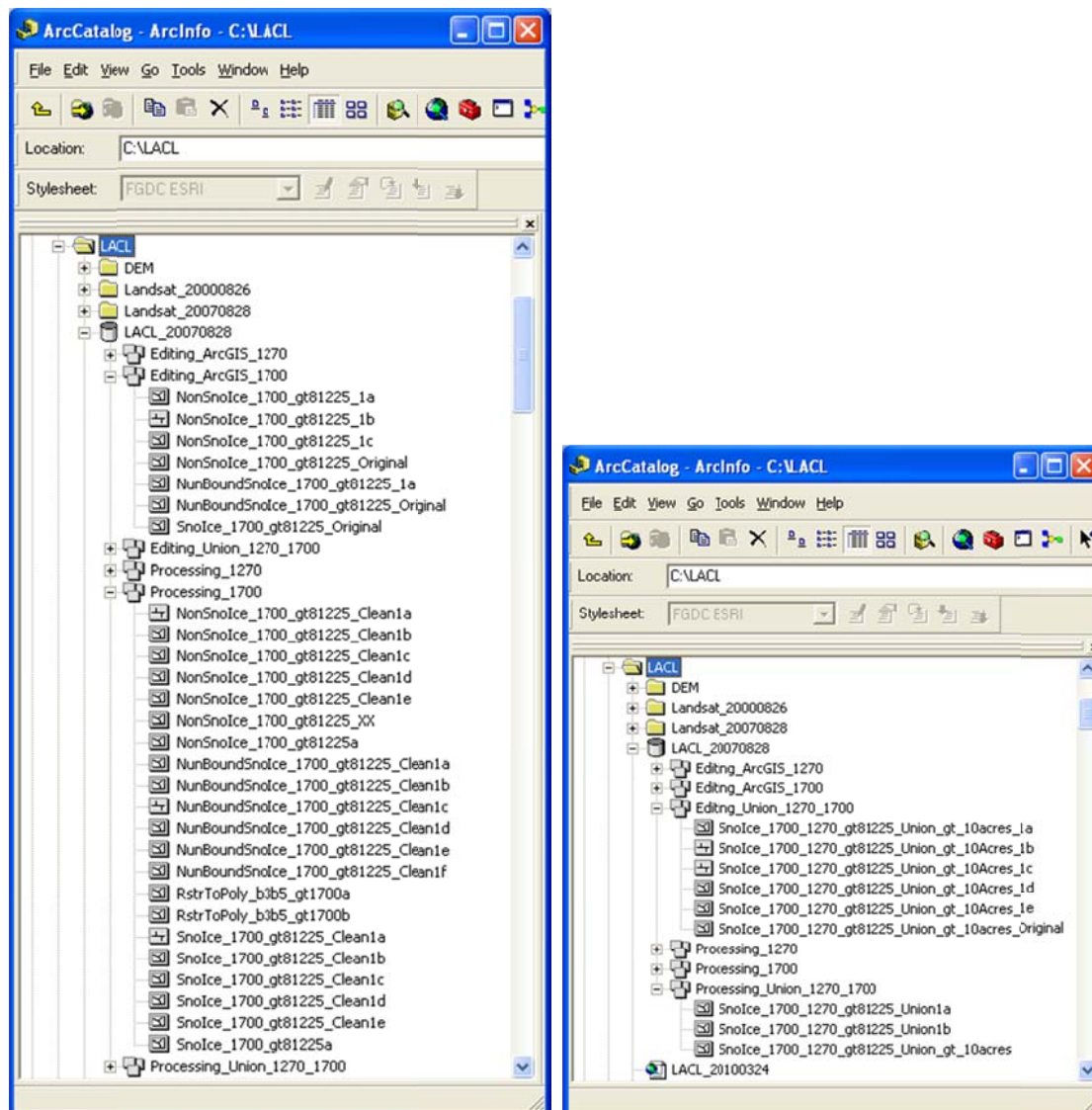


Figure 9-12. File naming convention for a "Editing_" and "PROCESSING_" Feature Dataset.

Archival File Naming

Many of the files created in this glacier mapping effort are temporary working files leading to interim and final products. Upon completion of the mapping effort, most of these temporary files will not be saved or archived. The following is a listing of the files that will be saved to the PARK_Glacier_YYYY feature dataset in the PARK_Glacier_YYYY.mdb (personal geodatabase). These files were created in SOP #6:

Table 9-1. List of shapefiles.

Shapefile name	Data Type	Geometry
PARK_glaciernmappingregion_YYYYMMDD_XX#.shp	Polygon	Outline of the mapping region
PARK_glacier_id_YYYY_YYYYMMDD_XX#.shp	Point	Point location of glaciers
PARK_glacier_segments_YYYY_YYYYMMDD_XX#.shp	Polygon	Glacier boundaries
PARK_imageryfootprint_YYYY_YYYYMMDD_XX#.shp	Polygon	Polygon of image footprint

- PARK_glaciernmappingregion_YYYYMMDD_XX#.shp is a polygon shapefile outlining the glacier mapping region.
- PARK_glacier_id_YYYY_YYYYMMDD_XX#.shp is a point shapefile with one unique point locator per glacier. This file also contains glaciological characteristics of each glacier.
- PARK_glacier_segments_YYYY_YYYYMMDD_XX#.shp is polygon shapefile depicting all individual glacier boundaries on a park-wide basis. This file is a result of the automated classification techniques detailed in SOP #2 and #3 and the manual editing detailed in SOP #4, watershed delineation on SOP #5 and glaciological attribute population in SOP #6.
- PARK_imageryfootprint_YYYY_YYYYMMDD_XX#.shp is polygon shapefile depicting the footprint of the satellite imagery that was used in the glacier mapping effort.

File Naming - ArcGIS Files

File naming should be based on the following format:

ParkCode_ShortDescription_YYYYMMDD_InitialsVersion

where:

ParkCode = Four-letter park or network code (e.g. ALAG, ANIA, KATM, KEFJ, LACL, SWAN). Can contain multiple four-letter park codes if necessary.

ShortDescription = Provide a descriptive, but brief description of the data file.

Concatenate with capital letters and no spaces.

YYYYMMDD = Date of most recent modification. Year (Y), Month (M), Day (D).

Initials = Two or three letter initials of person performing the edits and or final shapefile.

Version [1, 2, 3, ...] = Should be a single whole number, 1, 2, 3,... that indicates subsequent versioning for a given set of initials.

Example: PARK_glacierid_2007_YYYYMMDD_BG1.shp

File Naming – Landsat Imagery Files

All original Landsat data is archived on the ARO-GIS server and stored in a folder/file naming convention as follows:

X:\Source_Data\Satellite_Imagery

Each Landsat scene is stored in a separate folder in the above directory with the following naming convention:

TM5_6918_12sep1986_Albers_NAD27

where:

- TM5 = Landsat satellite (TM5 = Thematic Mapper 5)
- 6918 = path and row number for the satellite image
- 12sep1986 = day, month and year of the imagery
- Albers = projection
- NAD27 = datum

Metadata

Metadata will be FGDC (Federal Geographic Data Committee) compliant. A complete metadata file will be prepared for each of the final data products produced (i.e. those listed in Table 9-1). An example of an acceptable metadata file is included as Appendix B.

Operational and Archiving File Management

The data acquisition, processing and interpretation of Landsat data will be conducted on NPS desktop computers. This protocol has a repeat cycle of every ten years. Filenames will follow the conventions previously outlined. This naming convention will allow for easier transfer to the SWAN server. Upon final completion of imagery classification and generation of final shapefiles, the files will be transferred to the SWAN server and the GIS Permanent Dataset (PDS) maintained by the NPS Alaska Region GIS Team.

Data processing steps will require the creation of temporary working files that will not be needed for long-term monitoring in the SWAN. These temporary files will remain on the desktop computer until the glacier extent mapping is complete for the subject Landsat image. Upon acceptance of the final glacier boundary geospatial data (Table 1, above) in to Alaska Regional Office - GIS Theme Manager, a thoughtful review of the preliminary files created throughout the glacier boundary mapping process should identify any files that should be saved. This could be a suite of imagery classification, DEMs and/or shapefiles. One shapefile that maybe of particular important would be the “SnoIce_1700_1270_gt81225_Union_gt_10acres_Original” shapefile created after over-classification polygons are completely removed but before glacier boundary modifications are made in the last step in SOP #4. This shapefile is representative of clean-ice glacier extent in the mapping region and this shapefile is the file located in the “Editing_Union_1270_1700” Feature Dataset. Differencing these shapefiles with the final glacier boundary shapefiles might be valuable in determining the amount of debris covered ice and also provides a measure of how much manual editing is required. Any other unimportant files should be deleted.

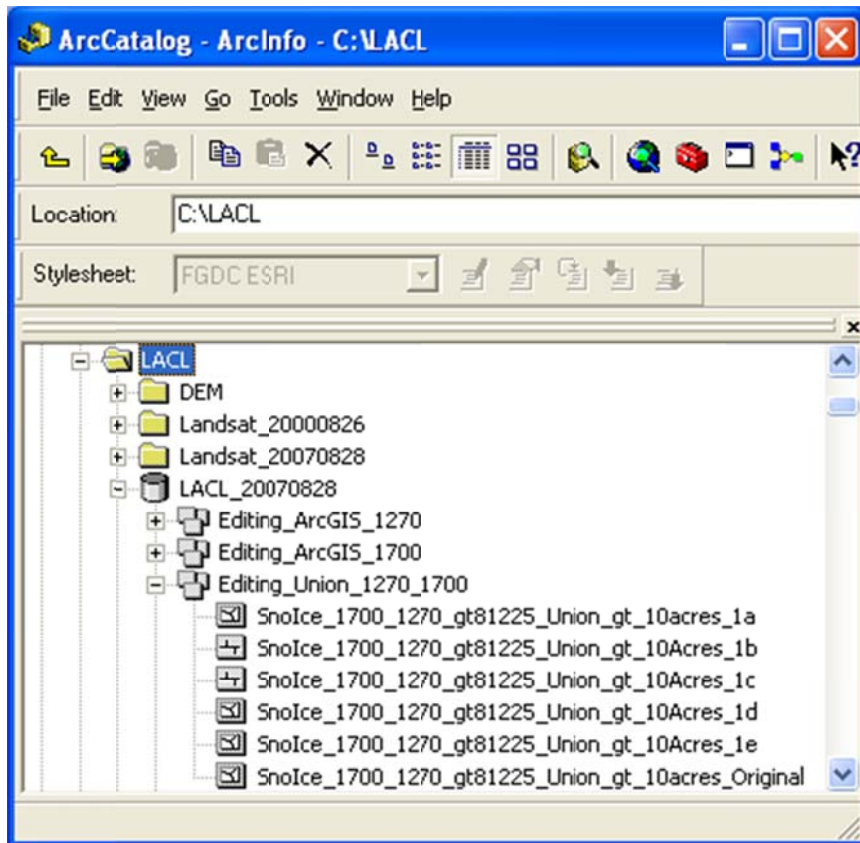


Figure 9-13. Location of the original snow and ice classification shapefile after areas of obvious over classification (i.e. shadows, water) have been removed but before any boundary modifications adjusting debris covered ice has occurred.

Final glacier extent and the associated color composite Landsat images will be archived on the SWAN data file server in their appropriate product type directories.

Backup Procedures

System backups are managed by the Alaska Regional Information Technology staff as described in the SWAN Data Management Plan. Additional backups of working documents will be performed by SWAN staff. Interim and final work products are completed on a desktop PC and these products will be backed up to the SWAN server on a daily basis when mapping work is being accomplished.

Standard Operating Procedure (SOP) #10

Data Analysis and Reporting

Version 1.0

Change History

Version numbers will be incremented by a whole number (e.g. Version 1.3 to Version 2.0) when a change is made that significantly affects requirements or procedures. Version numbers will be incremented by decimals (e.g. Version 1.6 to Version 1.7) when there are minor modifications that do not affect requirements or procedures.

The following revisions have occurred to this plan since January 2011.

Version #	Date	Revised by	Changes	Justification

This Standard Operating Procedure describes the procedures for preparing reports and accompanying products in order to broadly share the results of glacier mapping efforts in support of the Glacier Monitoring protocol for the Southwest Alaska Network (SWAN).

Overview

Glacier extent mapping efforts are repeated approximately every decade for each of the glaciated SWAN parks. Data analysis, reporting and updates will occur as glacier mapping efforts are initiated and completed. Reporting will be completed through annual SWAN reporting requirements, annual updates to the SWAN Technical Committee and through public presentations.

The subject of glaciers and glacier change is currently very much in the public eye. It is the intent of the SWAN to share these data and information widely with other government agencies, universities and the general public by presenting formal talks/presentations, through casual communications and sharing of data with colleagues and the public.

Generating Statistical Information and Decadal Comparisons

Final GIS shapefiles are created delineating all individual glaciers (glacier extent in aggregate) occurring within each glacier-bearing SWAN park. Using GIS, these shapefiles will be analyzed to determine where, how much and identify trends about how glacier extent is changing. Glaciological characteristics will be analyzed to determine what types of characteristics are more important (or less important) to the observed change in glaciers in response to climate. The amount of debris covered ice can be determined by differencing initial snow/ice classifications with the final glacier shapefiles – this may prove to be a valuable metric to track as glaciers respond to climate change.

Glacier ice extent will be described by total-area (sq units) and change in total-area (sq units) from the previous temporal data points. Further analysis can be carried out on a watershed-by-watershed basis, thus identifying specific areas within SWAN parks that are experiencing change beyond the park- and SWAN-wide averages. Areas of unusually rapid change will be identified as potential areas for site specific studies.

Reports and Publications

Reporting is relatively simple and can be achieved by presenting metrics in table form identifying SWAN- or Park-wide glacier extent (sq km), change and trends. As the glacier extent data is built up over several decades, rates of change and trends can be identified (refer to Appendices C, D, E, and F for examples of reporting).

A measurement being captured, beyond that of SWAN- and Park-wide glacier extent, is change in glacier terminus position. A suite of representative glaciers has been selected in each of the SWAN parks and measurements documenting change in terminus position over time are determined. Glacier terminus change measurement techniques and tables presenting the data are presented in Appendix D.

The results of this repeating decadal glacier extent mapping effort will be shared to broad audiences through publication of the data. Glacier extent boundary mapping results have been published through the “Eastern Snow Conference” (Appendix E) and in a book (currently in press) produced by the Global Land and Ice Measurements from Space program.

Presentations

The scientific community, the public and park visitors are becoming more aware and concerned about how regional and global climate change will impact the natural resources of parks all across the nation. The results of this mapping effort will add to the scientific body of knowledge and provide interpretive information to park management, visitors, and the global community interested in the effects of climate change.

Both formal and informal presentations will take the form of talks and poster sessions. Some example presentation products are included in Appendix F.

Data Sharing

Glacier extent shapefiles created as a result of this protocol will be shared with the GLIMS (Global Land Ice Measurements from Space) program, a project designed to monitor the world's glaciers primarily using data from optical satellite instruments. Being the recognized archival facility for worldwide glacier mapping data, the GLIMS program is much better positioned to share the SWAN glacier mapping data to the global community interested in the topic. Data will also be hosted on the NPS Alaska Regional Office GIS Team and thus will be available locally to NPS employees.

The shapefiles that were produced following the methods outlined in SOP #6 (Table 10-1) meet the data requirements of the GLIMS program and will be provided to the GLIMS - Alaska Region. The SWAN and the GLIMS programs have slightly differing file naming conventions. To meet the GLIMS file naming convention, the names of the files have been changed, as shown in Table 10-1.

Table 10-1. List of shapefiles.

Shapefile name	Data Type	Geometry
PARK_YYYY_session.shp	Polygon	Outline of the mapping region
PARK_YYYY_glaciers.shp	Point	Point location of glaciers
PARK_YYYY_segments.shp	Polygon	Line segments
PARK_YYYY_images.shp	Polygon	Polygon of image footprint

The GLIMS Alaska Region contact is currently Dr. Anthony Arendt.

Dr. Anthony Arendt, Research Professor	
University of Alaska Fairbanks	arendta@gi.alaska.edu
401 E, Geophysical Institute	
903 Koyukuk Drive	Phone: 907- 474-7427
PO Box 757320	Fax: 907-474-7290
Fairbanks AK 99775-7320	

Standard Operating Procedure (SOP) #11

Changes to the Glacier Monitoring Protocol

Version 1.0

Change History

Version numbers will be incremented by a whole number (e.g. Version 1.3 to Version 2.0) when a change is made that significantly affects requirements or procedures. Version numbers will be incremented by decimals (e.g. Version 1.6 to Version 1.7) when there are minor modifications that do not affect requirements or procedures.

The following revisions have occurred to this plan since January 2011.

Version #	Date	Revised by	Changes	Justification

This Standard Operating Procedure outlines the documentation of changes to the protocol narrative and accompanying SOPs. These procedures are based on the recommendations of Oakely and others (2003).

Revision Procedures

1. All edits will require review for clarity and technical soundness. Small changes or additions to existing methods will be reviewed by SWAN staff. However, if a complete change in methods becomes necessary, an outside review will be required. Regional and national staff of the National Park Service with expertise in remote sensing and data analysis, and/or external specialists, will be utilized as reviewers.
2. Edits will be tracked in the Revision History Logs that accompany the protocol narrative and each SOP. Version numbers assigned to each edited draft should reflect the magnitude of changes therein. Major changes will be designated by whole number increases (e.g., Version 1.0 to Version 2.0, etc.) and minor changes by tenths (e.g., Version 1.1 to Version 1.2, etc.). With each round of changes to the protocol narrative or SOPs, the following information should be recorded in the associated Revision History Log: the previous version number, new version number, date of revision, author of the revision, paragraph(s) and page(s) where changes appear, and the rationale for each change.
3. Changes to the protocol narrative and SOPs that are recorded in the Revision History Log that accompanies both the protocol narrative and SOPs will also be documented in the master version table, which is part of this SOP (Table 11-1). The master version number is clearly documented on the cover of the combined protocol narrative and SOPs (e.g. Version 1.0). The master version will be incremented by a whole number (e.g. Version 1.3 to Version 2.0) when a change is made that significantly affects requirements or procedures. Version numbers will be incremented by decimals (e.g. Version 1.6 to 1.7) when there are minor modifications that do not affect requirements or procedures. Previous versions of the protocol narrative and SOPs will be archived.
4. The Data Manager will be informed regarding changes to the protocol narrative or SOP so that the new version number can be incorporated in the metadata of the project database. The database may have to be edited by the Data Manager to accompany changes in the protocol narrative and SOPs.
5. The Data Manager will post new versions of the protocol on the internet and forward copies to all individuals known to have a previous version.

Table 11-1. Master version table for the Glacier Monitoring protocol for the Southwest Alaska Network (protocol narrative and SOPs).

Master version number (v. #)	Date of change (mm/dd/yyyy)	Narrative (v. #)	SOP # 1 (v. #)	SOP # 2 (v. #)	SOP # 3 (v. #)	SOP # 4 (v. #)	SOP # 5 (v. #)	SOP # 6 (v. #)	SOP # 7 (v. #)	SOP # 8 (v. #)	SOP # 9 (v. #)	SOP # 10 (v. #)	SOP # 11 (v. #)
1.0	01/18/2011	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

Literature Cited

Oakley, K.L., L.P. Thomas, and S.G. Fancy. 2003. Guidelines for long-term monitoring protocols. *Wildlife Society Bulletin* 31(4)1000-1003.

Appendix B: Metadata Example

KEFJ_GLACIER_EXTENT_ALL_2000

Metadata:

- [Identification Information](#)
- [Data Quality Information](#)
- [Spatial Data Organization Information](#)
- [Spatial Reference Information](#)
- [Entity and Attribute Information](#)
- [Distribution Information](#)
- [Metadata Reference Information](#)

Identification_Information:

Citation:

Citation_Information:

Originator: National Park Service, Alaska Regional Office

Publication_Date: 2008

Title:

KEFJ_GLACIER_EXTENT_ALL_2000

Geospatial_Data_Presentation_Form: vector digital data

Publication_Information:

Publication_Place: Anchorage, Alaska

Publisher: National Park Service, Alaska Regional Office

Online_Linkage: <http://science.nature.nps.gov/nrdata/>

Online_Linkage:

[\\165.83.60.63\GisData\Albers\parks\swan\base\physical\statewid\GlacExtKEFJ.gdb](http://165.83.60.63/GisData/Albers/parks/swan/base/physical/statewid/GlacExtKEFJ.gdb)

Description:

Abstract:

This dataset delineates glacial extents for Kenai Fjords National Park over a 30 year period. It contains polygon areas of Glacial and non-glacial areas (i.e. Nunataks) and Linear glacial terminus features for 3 time periods from the 1970s to 2000s.

Purpose:

The purpose of this effort was to map the glacier extent on a park-wide basis using Landsat imagery over a 30 year period, identifying changes in extent. This glacier extent data set was created through a joint effort between the NPS and NASA-Goddard Space Flight Center. This data set is the result of extensive manual editing of shapefiles created from supervised classification of the Landsat imagery. This mapping effort was repeated on a decadal scale to quantify trends and changes in glacial extent from the 1970s to 2000.

Time_Period_of_Content:

Time_Period_Information:

Single_Date/Time:

Calendar_Date: 2000
Currentness_Reference:
 ground condition
Status:
Progress: Complete
Maintenance_and_Update_Frequency: As needed
Spatial_Domain:
Bounding_Coordinates:
West_Bounding_Coordinate: -151.137404
East_Bounding_Coordinate: -149.464285
North_Bounding_Coordinate: 60.308669
South_Bounding_Coordinate: 59.340381
Keywords:
Theme:
Theme_Keyword_Thesaurus: National Park Service Theme Category Thesaurus
Theme_Keyword: Landform
Theme_Keyword: Monitoring
Theme:
Theme_Keyword_Thesaurus: ISO 19115 Topic Category
Theme_Keyword: geoscientificInformation
Theme:
Theme_Keyword: glacier
Theme_Keyword: snow
Place:
Place_Keyword_Thesaurus: National Park System Unit Name Thesaurus
Place_Keyword: Kenai Fjords National Park
Place:
Place_Keyword_Thesaurus: National Park System Unit Code Thesaurus
Place_Keyword: KEFJ
Place:
Place_Keyword: Alaska
Access_Constraints: none
Use_Constraints:
 none
Point_of_Contact:
Contact_Information:
Contact_Organization_Primary:
Contact_Organization: National Park Service, Alaska Regional Office
Contact_Person: GIS Team
Contact_Position: GIS Specialist
Contact_Address:
Address_Type: mailing and physical address
Address:
 240 W 5th Ave.
 City: ANCHORAGE
 State_or_Province: AK

Postal_Code: 99501

Country: USA

Contact_Voice_Telephone: Please contact us via email.

Contact_Electronic_Mail_Address: AKRO_Internet_Contact@nps.gov

Hours_of_Service: 8:00am- 5:00pm AST

Native_Data_Set_Environment:

Microsoft Windows XP Version 5.1 (Build 2600) Service Pack 3; ESRI ArcCatalog

9.2.5.1450

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Data_Quality_Information:

Attribute_Accuracy:

Attribute_Accuracy_Report:

All attributes were verified by visually comparing the attributes in the digital coverage against the original source material, but no formal tests were performed.

Logical_Consistency_Report:

Topologically clean as verified by ArcGIS version 8.x/9x

Completeness_Report:

Data set complete

Positional_Accuracy:

Horizontal_Positional_Accuracy:

Horizontal_Positional_Accuracy_Report:

Horizontal positional accuracy for the digital data is tested by visual comparison of the source with hard copy plots at intended scale.

Lineage:

Process_Step:

Process_Description:

Landsat imagery was acquired that met the following standards:

Cloud-free or minimal cloud cover;

Late-season imagery (to maximize seasonal snow melt and minimize new seasonal snow (August and September)).

Landsat imagery was classified for glacier ice and snow using PCI image-processing software where training sites were defined and a "maximum likelihood" algorithm was used to classify the imagery. The classification was converted to GIS shapefiles and edited in ArcGIS. If available, higher-resolution aerial photography was used as a tool to help interpret the Landsat data. Very small glaciers, and areas that appeared to be snowfields (not glacier ice) were generally not captured.

Complicating Issues

Several factors influence the accuracy of the initial supervised classification of glacier extent:

Debris-covered ice (moraine and/or volcanic ash)

Shadows

Seasonal snow cover and /or new snow cover

Permanent snowfields outside of the accumulation area

Each of these factors influence the spectral reflectance of the terrain which in-turn affects the accuracy of the supervised classification.

Manual Editing

The supervised classification was converted to a GIS shapefile. Areas that were misclassified in the original classification were captured manually (debris-covered ice, shadowed ice) or removed (isolated small snowfields) during an edit session in ArcGIS. Editing of the shapefile is based on the judgment of the person doing the satellite image interpretation. The human eye can perceive textural differences in debris-covered ice that were typically missed in the original supervised classification. In addition, local knowledge and the use of high-resolution imagery can aid in the interpretation of Landsat data. Careful manual interpretation of these areas is required to optimize the accuracy of the mapping effort.

SATELLITE IMAGERY INTERPRETATION ACCURACY

The amount of change that can be detected in a Landsat image is dependent on the resolution of the imagery plus any registration error. The spatial accuracy of Terrain Corrected TM or ETM+ Landsat data is 30 meters between images (EROS Data Center, personal comm., 2006). If the registration between images is perfect, changes of terminus positions can be determined to within ± 42.4 meters when analyzing Landsat TM and ETM+ scenes; the accuracy decreases to ± 113 meters when analyzing data between Landsat MSS and TM or ETM+ scenes (Hall et al., 2003).

Worker Bees:

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BRUCE A. GIFFEN, Alaska Regional Office, National Park Service, 240 West 5th Ave., Anchorage, Alaska 99501, USA, bruce_giffen@nps.gov.

Source_Used_Citation_Abbreviation:

Landsat scene 17-Aug-73 MSS LM1074018007322990

Source_Used_Citation_Abbreviation:

Landsat Scene 12-Sep-86 TM LT5069018008625510

Source_Used_Citation_Abbreviation:

Landsat Scene 9-Aug-00 ETM+ NZT070690180809200000

Source_Produced_Citation_Abbreviation:

Bruce Giffen

Process_Contact:

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Contact_Organization_Primary:

Contact_Organization: National Park Service, Alaska Regional Office

Contact_Person: GIS Team

Contact_Position: GIS Specialist

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State_or_Province: AK

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Contact_Voice_Telephone: Please contact us via email.

Contact_Electronic_Mail_Address: AKRO_Internet_Contact@nps.gov

Hours_of_Service: 8:00am- 5:00pm AST

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Spatial_Data_Organization_Information:

Direct_Spatial_Reference_Method: Vector

Point_and_Vector_Object_Information:

SDTS_Terms_Description:

SDTS_Point_and_Vector_Object_Type: G-polygon

Point_and_Vector_Object_Count: 350

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Spatial_Reference_Information:

Horizontal_Coordinate_System_Definition:

Planar:

Map_Projection:

Map_Projection_Name: Albers Conical Equal Area

Albers_Conical_Equal_Area:

Standard_Parallel: 55.000000

Standard_Parallel: 65.000000

Longitude_of_Central_Meridian: -154.000000

Latitude_of_Projection_Origin: 50.000000

False_Easting: 0.000000

False_Northing: 0.000000

Planar_Coordinate_Information:

Planar_Coordinate_Encoding_Method: coordinate pair

Coordinate_Representation:

Abscissa_Resolution: 0.000100

Ordinate_Resolution: 0.000100

Planar_Distance_Units: meters

Geodetic_Model:

Horizontal_Datum_Name: North American Datum of 1983

Ellipsoid_Name: Geodetic Reference System 80

Semi-major_Axis: 6378137.000000

Denominator_of_Flattening_Ratio: 298.257222
Vertical_Coordinate_System_Definition:
Altitude_System_Definition:
Altitude_Resolution: 0.000003
Altitude_Encoding_Method: Explicit elevation coordinate included with horizontal coordinates

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Entity_and_Attribute_Information:

Detailed_Description:

Entity_Type:

Entity_Type_Label: KEFJ_GLACIER_EXTENT_ALL_2000

Attribute:

Attribute_Label: OBJECTID

Attribute_Definition:

Internal feature number.

Attribute_Definition_Source:

ESRI

Attribute_Domain_Values:

Unrepresentable_Domain:

Sequential unique whole numbers that are automatically generated.

Attribute:

Attribute_Label: Shape

Attribute_Definition:

Feature geometry.

Attribute_Definition_Source:

ESRI

Attribute_Domain_Values:

Unrepresentable_Domain:

Coordinates defining the features.

Attribute:

Attribute_Label: ACRES

Attribute:

Attribute_Label: SQ_KILOMETERS

Attribute:

Attribute_Label: ICE

Attribute_Definition:

Contains Ice

Attribute_Domain_Values:

Enumerated_Domain:

Enumerated_Domain_Value: 0

Enumerated_Domain_Value_Definition:

No Ice i.e. Nunataks

Enumerated_Domain:

Enumerated_Domain_Value: 1

Enumerated_Domain_Value_Definition:

Ice - i.e. Glacier

Attribute:

Attribute_Label: Shape_Length

Attribute_Definition:

Length of feature in internal units.

Attribute_Definition_Source:

ESRI

Attribute_Domain_Values:

Unrepresentable_Domain:

Positive real numbers that are automatically generated.

Attribute:

Attribute_Label: Shape_Area

Attribute_Definition:

Area of feature in internal units squared.

Attribute_Definition_Source:

ESRI

Attribute_Domain_Values:

Unrepresentable_Domain:

Positive real numbers that are automatically generated.

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Distribution_Information:

Distributor:

Contact_Information:

Contact_Organization_Primary:

Contact_Organization: National Park Service, Alaska Regional Office

Contact_Person: GIS Team

Contact_Position: GIS Specialist

Contact_Address:

Address_Type: mailing and physical address

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240 W 5th Ave.

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State_or_Province: AK

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Country: USA

Contact_Voice_Telephone: Please contact us via email.

Contact_Electronic_Mail_Address: AKRO_Internet_Contact@nps.gov

Hours_of_Service: 8:00am- 5:00pm AST

Resource_Description: GlacExtKEFJ.gdb

Distribution_Liability:

The National Park Service shall not be held liable for improper or incorrect use of the data described and/or contained herein. These data and related graphics (i.e. GIF or JPG format files) are not legal documents and are not intended to be used as such. The information contained in these data is dynamic and may change over time. The data are not better than the original sources from which they were derived. It is the responsibility

of the data user to use the data appropriately and consistent within the limitations of geospatial data in general and these data in particular. The related graphics are intended to aid the data user in acquiring relevant data; it is not appropriate to use the related graphics as data. The National Park Service gives no warranty, expressed or implied, as to the accuracy, reliability, or completeness of these data. It is strongly recommended that these data are directly acquired from an NPS server and not indirectly through other sources which may have changed the data in some way. Although these data have been processed successfully on computer systems at the National Park Service, no warranty expressed or implied is made regarding the utility of the data on other systems for general or scientific purposes, nor shall the act of distribution constitute any such warranty. This disclaimer applies both to individual use of the data and aggregate use with other data.

Standard_Order_Process:

Fees: none

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Metadata_Reference_Information:

Metadata_Date: 20080512

Metadata_Contact:

Contact_Information:

Contact_Organization_Primary:

Contact_Organization: National Park Service, Alaska Regional Office

Contact_Person: GIS Team

Contact_Position: GIS Specialist

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Country: USA

Contact_Voice_Telephone: Please contact us via email.

Contact_Electronic_Mail_Address: AKRO_Internet_Contact@nps.gov

Hours_of_Service: 8:00am- 5:00pm AST

Metadata_Standard_Name: FGDC Content Standards for Digital Geospatial Metadata

Metadata_Standard_Version: FGDC-STD-001-1998

Metadata_Time_Convention: local time

Metadata_Extensions:

Online_Linkage: <http://www.esri.com/metadata/esriprof80.html>

Profile_Name: ESRI Metadata Profile

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Appendix C: Reporting Example – Charts and Tables

Glacier Extent Change -Sample Tables

Katmai National Park and Preserve														
Glacier Area	Glacier Extent, sq km			Change in Glacier Extent, sq km (total annual rate)						% Change in Glacier Extent (total annual rate)				
	1974	1987	2000	1974 to 1987		1987 to 2000		1974 to 2000		1974 to 1987		1987 to 2000		1974 to 2000
Mt Douglas Area	377	348	330	-30	-2.3	-17.6	-1.4	-47.2	-1.8	-7.8%	-0.6%	-5.1%	-0.4%	-12.5%
Mt Katmai Area	543	563	510	21	1.6	-53.6	-4.1	-32.9	-1.3	3.8%	0.3%	-9.5%	-0.7%	-6.1%
Mt Mageik Area	72	74	70	2	0.2	-4.6	-0.4	-2.5	-0.1	2.9%	0.2%	-6.2%	-0.5%	-3.5%
Katmai NPP	992	985	910	-7	-0.5	-75.8	-5.8	-82.6	-3.2	-0.7%	-0.1%	-7.7%	-0.6%	-8.3%

Kenai Fjords National Park														
Glacier Area	Glacier Extent, sq km			Change in Glacier Extent, sq km (total annual rate)						% Change in Glacier Extent (total annual rate)				
	1974	1987	2000	1974 to 1986		1986 to 2000		1974 to 2000		1974 to 1986		1986 to 2000		1974 to 2000
Harding Icefield and surrounding glaciers	2043	1935	1903	-108	-9.0	-32.3	-2.3	-140.7	-5.4	-5.3%	-0.4%	-1.7%	-0.1%	-6.9%
Grewingk Yalik Glacier Complex	514	445	424	-69	-5.8	-20.5	-1.5	-89.5	-3.4	-13.4%	-1.1%	-4.6%	-0.3%	-17.4%
	2557	2380	2327	-177	-14.8	-52.8	-3.8	-230.2	-8.9	-6.9%	-0.6%	-2.2%	-0.2%	-9.0%

Glacier Terminus Change -Sample Tables

Glacier Terminus Movement in Katmai NP&P						
	Average Change (in m) from 1951-1987; Second number is average annual rate of change (m/yr)		Average Change (in m) from 1987-2000; Second number is average annual rate of change (m/yr)		Average Change (in m) from 1951-2000; Second number is average annual rate of change (m/yr)	
North and west flowing (Interior) *	-647	-18	-243	-19	-890	-18
South and East Flowing (Coastal) **	-706	-20	-116	-9	-822	-17

* data based on 9 northwest flowing glacier; ** data based on 11 southeast flowing glaciers

Kenai Fjords National Park														
Glacier Area	Glacier Extent, sq km			Change in Glacier Extent, sq km (total annual rate)						% Change in Glacier Extent (total annual rate)				
	1974	1987	2000	1974 to 1986		1986 to 2000		1974 to 2000		1974 to 1986		1986 to 2000		1974 to 2000
Harding Icefield and surrounding glaciers	2043	1935	1903	-108	-9.0	-32.3	-2.3	-140.7	-5.4	-5.3%	-0.4%	-1.7%	-0.1%	-6.9%
Grewingk Yalik Glacier Complex	514	445	424	-69	-5.8	-20.5	-1.5	-89.5	-3.4	-13.4%	-1.1%	-4.6%	-0.3%	-17.4%
	2557	2380	2327	-177	-14.8	-52.8	-3.8	-230.2	-8.9	-6.9%	-0.6%	-2.2%	-0.2%	-9.0%

Appendix D: Reporting Example – Glacier Terminus Measurements

Terminus Position Measurements

Methodology

The terminus “position” can be measured at various points along the terminus of the glacier. Changes in the terminus positions and rates of recession are approximate because they are highly dependent on the exact spot on the terminus that was selected to make the measurement. For this protocol, a standard method was developed to select a point on a glacier terminus for each terminus measurement. First, a down-valley vector parallel to the direction of glacier flow was determined for each glacier terminus to be measured. Then the farthest down-valley point on the terminus was identified and a line was projected from this point, and then a line projected normal to the down-valley flow vector was drawn. The result is a series of parallel lines intersecting the down-valley flow vector, see Figure D-1. The distance between these parallel lines is the distance assigned to the terminus movement. Change in terminus position was determined using ArcGIS software.

This analysis shows rates and trends of glacier terminus movement, and also identifies which glaciers are most active. The 1951/1952 terminus positions were determined from the USGS 1:63,360 quadrangle maps produced from high quality aerial photography (approximately 1:40,000). Terminus positions were determined using Landsat imagery from 1986, 1987, 2000 and 2006. A 2005 Ikonos image was used to map 2005 terminus positions (KEFJ only).

Kenai Fjords National Park

The terminus positions were mapped for 27 glaciers emanating from the Harding Icefield and the Grewingk-Yalik Glacier Complex (Figure D-2); 10 of these glaciers terminate within the KEFJ. Figure D-2 identifies these glaciers on a Landsat image (2000) by name (or alpha code) which corresponds with Table D-1.

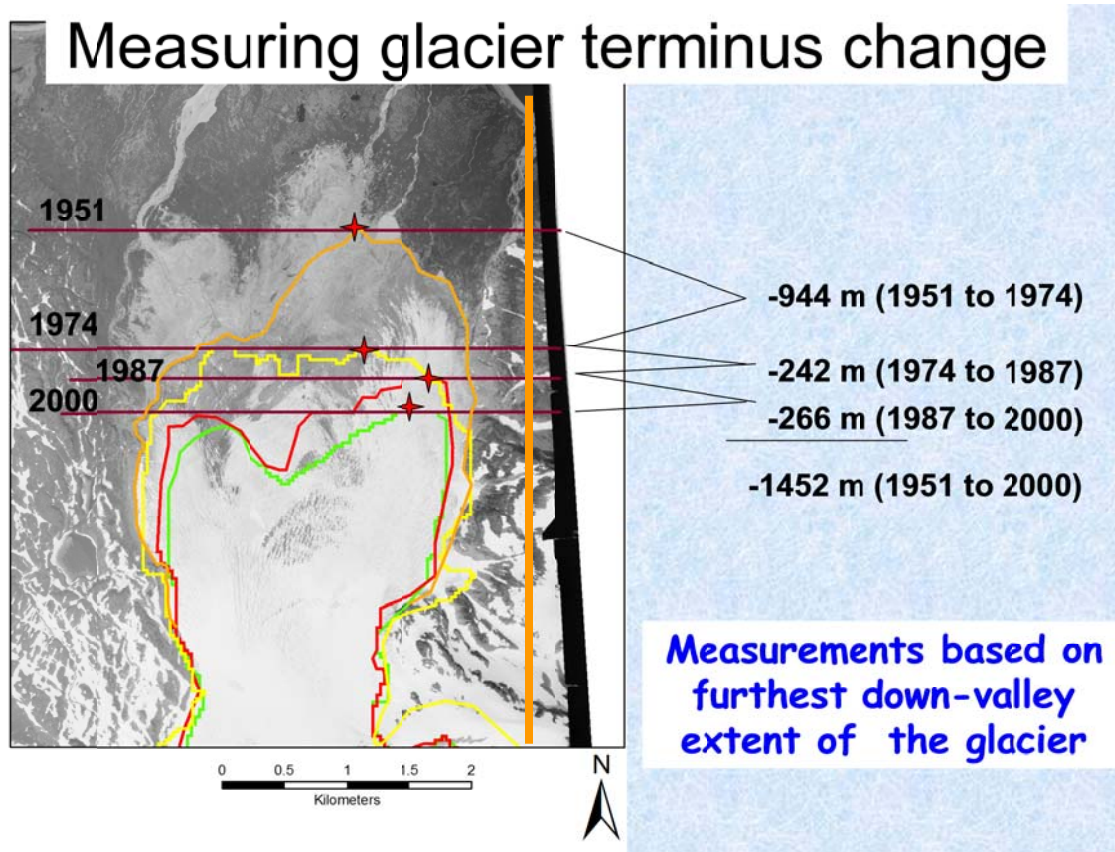


Figure D-1. Measurement of glacier terminus position. Vertical orange line is parallel to the direction of glacier flow.



Figure D-2. This is a true-color September 12, 1986, TM Landsat-5 image of the glaciated portion of KEFJ. The glacier names in this Figure 1 identify which glacier termini were measured and correspond to data presented in Table 1.

Table D-1. Glacier Terminus Movement in KEFJ.

Glacier Terminus Movement in KEFJ - Sample Table

Glacier Name	Change (in m) from 1950(51) - 1986; Second number is average annual rate of change (in m/yr)		Change (in m) from 1950(51) - 2000; Second number is average annual rate of change (in m/yr)		Change (in m) from 1950(51) - 2005(06); Second number is average annual rate of change (in m/yr)		Change (in m) from 1986 - 2000; Second number is average annual rate of change (in m/yr)		Change (in m) from 1986 - 2005(06); Second number is average annual rate of change (in m/yr)		Change (in m) from 2000 - 2005(06); Second number is average annual rate of change (in m/yr)	
Lowell	-741	-21	-1375	-28	-1505	-28	-634	-45	-764	-40	-130	-26
A	-586	-17	-906	-18	-1055	-19	-320	-23	-469	-23	-149	-25
Skilak	-2267	-65	-4053	-83	-4032	-73	-1786	-128	-1765	-88	21	4
Killey	-798	-23	-1229	-25	-1589	-29	-431	-31	-791	-40	-360	-60
Indian	-692	-20	-973	-20	-1257	-23	-281	-20	-565	-28	-284	-47
Tustumena	-324	-9	-712	-15	-744	-14	-388	-28	-420	-21	-32	-5
Truuli	-1065	-30	-971	-20	-1118	-20	94	7	-53	-3	-147	-25
Chernof	-1366	-39	-1461	-30	-1914	-35	-95	-7	-548	-27	-453	-76
Dinglestadt (West)	-2823	-81	-3052	-62	-3408	-62	-229	-16	-585	-29	-356	-59
Kachemak	-801	-23	-989	-20	-1145	-21	-188	-13	-344	-17	-156	-26
Nuka	-226	-6	-189	-4	-342	-6	37	3	-116	-6	-153	-26
B	-728	-21	-997	-20	-1115	-20	-269	-19	-387	-19	-118	-20
Dixon	-422	-12	-589	-12	-746	-14	-167	-12	-324	-16	-157	-26
Portlock	-1188	-34	-1322	-27	-1563	-28	-134	-10	-375	-19	-241	-40
Grewingk	-1350	-39	-2298	-47	-2502	-45	-948	-68	-1152	-58	-204	-34
Wosnesenski	-1268	-36	-1436	-29	-1982	-36	-168	-12	-714	-36	-546	-91
Doroshin	-751	-21	-1495	-31	-1644	-30	-744	-53	-893	-45	-149	-25
Petrof	-1261	-36	-1576	-32	-1696	-31	-315	-23	-435	-22	-120	-20
Yalik	-1057	-30	-1854	-38	-2160	-40	-797	-57	-1103	-58	-306	-61
Dinglestadt (East)	-347	-10	-446	-9	-521	-10	-99	-7	-174	-9	-75	-15
McCarty	-1599	-46	-1730	-35	-2248	-42	-131	-9	-649	-34	-518	-104
Northwestern	-5198	-149	-6553	-134	-6367	-118	-1355	-97	-1169	-62	186	37
Holgate	-245	-7	-349	-7	-359	-7	-104	-7	-114	-6	-10	-2
Pederson	-706	-20	-860	-18	-1140	-21	-154	-11	-434	-23	-280	-56
Aialik	186	5	183	4	-105	-2	-3	0	-291	-15	-288	-58
Bear	-158	-5	-1123	-23	-2968	-55	-965	-69	-2810	-148	-1845	-369
Exit	-488	-14	-481	-10	-621	-12	7	1	-133	-7	-140	-28
Average Rate of Terminus Change (m/yr)	-1047.0	-29.9	-1438.4	-29.4	-1698.0	-31.1	-391.4	-28.0	-651.0	-33.3	-259.6	-47.5
North and West flowing (Interior)	-993.6	-28.4	-1362.7	-27.8	-1571.2	-28.6	-369.1	-26.4	-577.7	-29.0	-208.6	-35.3
South and East Flowing (Coastal)	-1153.9	-33.0	-1589.8	-32.4	-1951.6	-36.1	-435.9	-31.1	-797.7	-41.9	-361.8	-71.9

Appendix E: Reporting Example – Report/Paper

Note: The following is an abstract of a paper produce by Dr. Dorothy Hall (et al. 2005). The report is available on-line at: <http://www.easternsnow.org/proceedings/2005/hall.pdf>

62nd EASTERN SNOW CONFERENCE
Waterloo, ON, Canada 2005

Changes in the Harding Icefield and the Grewingk-Yalik Glacier Complex

DOROTHY K. HALL,¹ BRUCE A. GIFFEN,² AND JANET Y.L. CHIEN³

ABSTRACT

Glacier changes in the mountains of the Kenai Peninsula, Alaska, have been analyzed in the Harding Icefield and the Grewingk-Yalik Glacier Complex, many of which originate in Kenai Fjords National Park (KEFJ). The Harding Icefield spawns more than 38 glaciers of which some are tidewater and others are land-based, or wholly or partially terminate in lakes. We used Landsat Multispectral Scanner (MSS), Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) scenes to outline glacier areas and terminus positions on four scenes. Glacier outlines were done using vector segments to produce shape files for the Geographic Information System (GIS) analysis. Results show that most of the glaciers in the Harding Icefield have receded since 1973, some dramatically. These results are generally consistent with results from extensive work done in the 1990s on the Harding Icefield by previous researchers. For this project, we derived GIS shape files, and from those we can calculate glacier area and terminus changes from 1973 to 2002. We also did a classification of the 1986 and 2002 Landsat scenes to measure the areal extent of the two ice masses, and found that there was a reduction of 3.62%, or approximately 78 km² from 1986 to 2002, with most of the changes occurring in the Harding Icefield. Some issues that complicate the analysis include: fresh snow cover and spatial resolution differences between images.

Appendix F: Reporting Example –Poster

Appendix F: Reporting Example

Abstract

Glaciers have experienced measurable recession in Katmai National Park and Preserve and Kenai Fjords National Park largely in response to regional climate warming. Glacier-extent mapping using Landsat satellite imagery indicates a glacier ice loss of 75 sq km (7.7%) in Katmai NPP and a loss of 52 sq km (2.2%) in Kenai Fjords NP and the adjacent Kenai National Wildlife Refuge and Kachemak Bay State Park between 1986/87 and 2000.

Introduction

Glaciers dominate the landscape in Katmai NPP and Kenai Fjords NP. Most of Alaska's glaciers have been experiencing net recession and thinning since the end of the Little Ice Age (~1850). Because glaciers cover many hundreds of sq km in these parks, even modest changes to this landscape type will influence terrestrial and aquatic plant and animal communities.

Aside from the USGS topographic maps (circa 1950s), very little if any glacier mapping had occurred in these parks until the National Park Service, in partnership with NASA-Goddard Space Flight Center, initiated a project to map glacier extent on a park-wide basis for Katmai NPP, Kenai Fjords NP and Lake Clark NPP using Landsat satellite imagery on a decadal time frame.

Using Landsat Multispectral Scanner (MSS), Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) imagery, mapping of glacier margins has been completed in Katmai NPP and Kenai Fjords NP for the years 1974, 1986/87 and 2000. Mapping efforts in Lake Clark NPP are ongoing.

We also used USGS black and white aerial photographs from the 1950s to map glacier terminus positions of selected glaciers in Katmai NPP and Kenai Fjords NP. This allows us to evaluate how individual termini have changed since the 1950s when compared with more recent satellite-derived measurements.

Methodology

Cloud-free, late-season Landsat imagery was obtained from the EROS Data Center in Sioux Falls, South Dakota. The orthorectified satellite imagery was classified to separate snow and glacier ice from surrounding terrain features using image processing software as described in detail in Giffen, et al., in press. Two different band ratios were used with varying success in the classification process: Normalized Difference Snow Index or NDSI = (TM2-TM5)/(TM2+TM5), and TM3/TM5. Threshold values were defined for classifying the image. The classification was further refined in a sieving process to remove small, isolated snowfields that were confused with glacier ice. The resultant raster classifications were exported as polygon shapefiles.

Automated classification techniques resulted in many areas of misclassification, particularly in areas where moraine and/or volcanic ash cover the ice. Thus, shapefiles produced in the classification process required extensive editing in a GIS edit session to increase the accuracy of the glacier-extent mapping.

Clean glacier margins can be mapped to an accuracy of ± 40 m when using TM or ETM+ (Hall et al., 2003). Landsat image registration error (± 1 pixel or 30 meters for TM and ETM+) in combination with the imagery resolution contributes to this error.

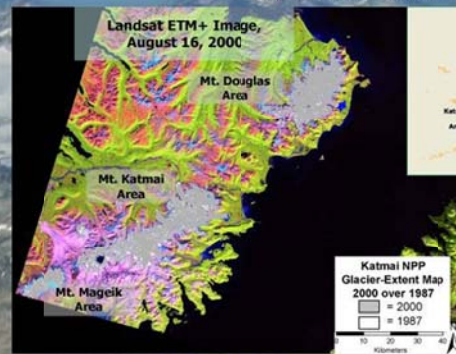
Challenges to Automated Classification Techniques

To enhance the accuracy and repeatability of the glacier mapping effort, late-season, cloud-free imagery is essential to minimize the amount of snow in the imagery. For Katmai NPP and Kenai Fjords NP, this means using mid-August to mid-September imagery when available, however fresh snow can fall anytime of the year in these parks, especially at higher elevations. If possible, imagery with large amounts of persistent snowpack and/or fresh snowfall should be avoided.

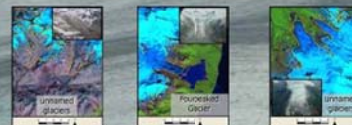
There are several substantial challenges to automated classification of snow and ice. These are: the existence of numerous small, isolated snowfields that have a spectral signature identical to glacier ice; shadows in areas of extreme topography; moraine debris and volcanic ash on the glacier surface; lingering snowpack, early snowfall and differences in imagery resolution. Each of these characteristics causes errors in the automated classification process.

MONITORING CHANGE IN GLACIER EXTENT AT KENAI FJORDS NP AND KATMAI NPP USING SATELLITE IMAGERY

Bruce A. Giffen*, Dorothy K. Hall** and Janet Y.L. Chien+
*National Park Service, Anchorage, AK 99501 USA, bruce.giffen@nps.gov, **NASA / Goddard Space Flight Center, Cryospheric Sciences Branch, Code 614.1 Greenbelt, MD 20771 USA, dorothy.k.hall@nasa.gov, +earthremote@bvi.com, bvi.com, Alaska, CA 95603 USA, janet.y.chien@gmail.com

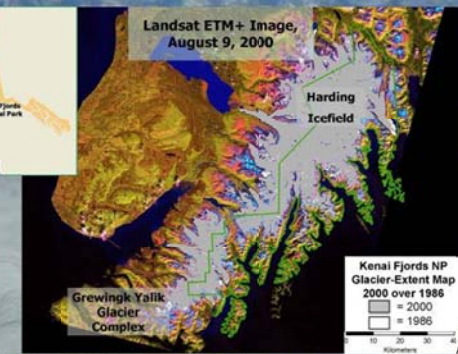


Glacier Area	Glacier Extent, sq km	Change in Glacier Extent, sq km (total annual rate)		% Change in Glacier Extent (total annual rate)	
		1974 to 1987	1987 to 2000	1974 to 1987	1987 to 2000
Total Area	777 548 335	19 123 137	-47 211 13	2.5%	-0.03%
Unnamed Area	543 563 512	18 138 41	-32 93 13	3.3%	-0.03%
Named Area	234 985 823	1 785 726	-15 218 0	0.8%	-0.01%



Glacier	Average Change (in m) from 1987-1989		Average Change (in m) from 1989-2000		Average Change (in m) from 1987-2000	
	Second number is average annual rate of change (in m/yr)	Second number is average annual rate of change (in m/yr)	Second number is average annual rate of change (in m/yr)	Second number is average annual rate of change (in m/yr)	Second number is average annual rate of change (in m/yr)	Second number is average annual rate of change (in m/yr)
North and West Flowing (Unnamed)**	-607	-18	-243	-19	-890	-18
South and East Flowing (Unnamed)**	-706	-20	-116	-9	-822	-17

** Data based on 8 northwest flowing glacier; ** Data based on 11 southeast flowing glaciers



Glacier Area	Glacier Extent, sq km	Change in Glacier Extent, sq km (total annual rate)		% Change in Glacier Extent (total annual rate)	
		1974 to 1986	1986 to 2000	1974 to 1986	1986 to 2000
Total Area	2943 1935 1903	-108 49 0	-32 3 3	-3.7%	-0.01%
Unnamed Area	2943 1935 1903	-108 49 0	-32 3 3	-3.7%	-0.01%
Named Area	514 445 424	-49 49 0	-20 5 1	-9.5%	-0.04%



Glacier	Average Change (in m) from 1986-1988		Average Change (in m) from 1988-2000		Average Change (in m) from 1986-2000	
	Second number is average annual rate of change (in m/yr)	Second number is average annual rate of change (in m/yr)	Second number is average annual rate of change (in m/yr)	Second number is average annual rate of change (in m/yr)	Second number is average annual rate of change (in m/yr)	Second number is average annual rate of change (in m/yr)
North and West Flowing (Unnamed)**	-594	-28	-389	-20	-578	-28
South and East Flowing (Unnamed)**	-1104	-33	-430	-31	-708	-32

** Data based on 18 northwest flowing glacier; ** Data based on 9 southeast flowing glaciers

Conclusions

Glacier-extent mapping clearly shows a net reduction of glacier extent in both Kenai Fjords NP and Katmai NPP over the study period (1974 through 2000) (Giffen et al., in press). On a percentage basis, glacier extent in Katmai NPP shows higher losses than observed at Kenai Fjords NP. This is due, in part, to a persistent lingering snowpack observed in the 1974 and 1987 Landsat imagery of Katmai NPP as compared to more extensive snowmelt observed in the 2000 image. In comparison, Landsat images used in the Kenai Fjords NP study (1974, 1986 and 2000) show more advanced snowmelt across the images. This verifies the absolute necessity of using only late season imagery for glacier extent mapping.

Most glacier termini in Kenai Fjords NP and Katmai NPP exhibited recession between 1986 and 2000, some more dramatic than others. The majority of glaciers in these parks can be described as northwest flowing or southeast flowing glaciers. Southeast flowing glaciers in Kenai Fjords NP display markedly higher rates of recession than do southeast flowing glaciers in Katmai NPP over the study period. Northwest flowing glaciers in Kenai Fjords NP also exhibit higher rates of recession than do northwest flowing glaciers in Katmai NPP over the study period.

The result of this careful mapping study is that glacier extent changes in Kenai Fjords NP and Katmai NPP have been documented to the greatest extent possible given the limitations of the satellite mapping techniques. As a result, it will be possible to conduct future studies of glacier ice extent in these parks with the highest level of accuracy possible. The shapefiles developed for this mapping effort will be provided to the Global Land Ice Measurements from Space (GLIMS) mapping project which is a NASA-funded project that is compiling a database of global glacier ice extent.

References

Giffen, B.A., D.K. Hall and J.Y.L. Chien, in press: Glaciers of Kenai Fjords National Park and Katmai National Park and Preserve, J. Kargel (ed.) Title of book has not yet been decided. Praxis-Springer
Hall, D.K., K.J. Bay, W. Schöner, R.A. Bindschadler and J.Y.L. Chien, 2003: Consideration of the errors inherent in mapping historical glacier positions in Austria from the ground and space (1893-2001), *Remote Sensing of Environment*, 86:566-577.

Background Image: Unnamed glacier in the Olgren Mountains, Lake Clark National Park and Preserve

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