

***Integrating Muldrow Glacier Topographic Maps into GIS
for Glacier Monitoring at
Denali National Park and Preserve***



Pacific Northwest CESU Task Agreement #H8W07060001

GeoSpatialServices



Muldraw Glacier

Background:

National Park Service (NPS) staff of Denali National Park and Preserve (DNA) are currently working with cooperators from the University of Alaska Fairbanks, Geophysical Institute (UAF-GI) on a project to analyze glacier change on the Muldraw Glacier. The purpose of that project is to investigate changes in overall glacier extent through comparison and analysis of historic satellite imagery and traditional hardcopy topographic mapping with recently developed LiDAR (Light Detection and Ranging) digital elevation model and laser altimetry profiles collected by UAF-GI.

One of the data sources available for the UAF-GI study is a series of five hand drafted topographical maps (Washburn study) of the Muldraw Glacier. These maps were created using traditional land survey techniques and consist of a dense network of spot elevations in and around the Muldraw Glacier with contour lines at 10m intervals interpolated from the spot heights. NPS has converted these maps into digital form using a high resolution, large format map scanner in preparation for having the elevation data captured into a digital spatial database. The purpose of this project is to have Saint Mary's University of Minnesota (SMUMN) collaborate with NPS on georeferencing these scanned topographic maps and capturing the spot elevations in order to provide critical elevation data for UAF-GI to complete the glacial change analysis research. This project will serve as one of the best available datasets for assessing rates of glacial change in Alaska.

The GeoSpatial Services Project Center (GSS) of Saint Mary's University of Minnesota has considerable experience in capturing spatial data from original scanned maps. As a result, they have a well developed workflow processes that is immediately applicable to converting the Washburn maps of the Muldraw Glacier into digital spatial databases. It is necessary for NPS staff to work closely with GSS on this project in order to interpret the historic glacier spatial data and determine how to manipulate these data to preserve their original quality while meeting the overall need of the comparison study with modern glacier monitoring data. The historic topographic maps have very limited metadata, thus requiring local NPS knowledge for use and interpretation, while the more modern monitoring data has inference limitations. As data manipulation occurs, it is important for NPS and GSS to work cooperatively to ensure that the desired level of comparison among the data sets is achieved.

The public benefits of this project include one of the only large-scale, quantitative analyses from which to determine rates and distribution of glacial change in Alaska. The inclusion of the historic data, made possible through this collaboration with SMUMN, contributes to a more accurate interpretation of the impacts of climate change in Alaska. Inclusion of the Washburn data in this project facilitates the analysis of data spanning a broad elevation gradient, which is not otherwise possible. As a result of this project, the public will have better interpretive information available for one of Alaska's most-viewed glaciers and the science community can more accurately assess the effects of climate change.

Study Area and Mapping Program:

The Muldraw Glacier is located on the north side of Mount McKinley and can be observed from a variety of locations along the Denali Park Road starting at approximately mile 50. The Muldraw represents one of the most viewed glaciers in Alaska and is one of the highlights for visitors on bus tours along the Park Road.

The Muldrow is known to be a surge-type glacier, which means it can be subjected to periods of high velocity movement (up to 100 times faster than normal) after years of relative stagnation. The Muldrow Glacier last surged in 1956 when it advanced almost 2.5 miles in one season. The elevation data developed through this project provides a valuable source of information for quantitative analysis of glacial change on the north slope of Mount McKinley.

Original data for this project was provided by NPS as a series of 5 topographic maps of the Muldrow Glacier created by Bradford Washburn using traditional manual surveying techniques circa 1975. These maps were converted into digital image form by NPS staff using a large format map scanner. Digital files of the scans were sent to GSS in non-georeferenced TIFF format.

Digital Conversion Methodology:

Digital conversion for this project consisted of georeferencing five scanned topographic maps and the capture of spot elevation data as point features from these maps. Once in digital form, these elevation points were used to generate a series of digital elevation models (DEM) in ArcGIS GRID format. From the DEM models contour line shape files were developed. There were several interpolation techniques available in ArcMap 9.3.1 for generating the DEM. For this project, five techniques were investigated and evaluated and the one that most accurately represented the spot elevation data was selected for further processing. These techniques are discussed in more detail below.

1. Base Layers:

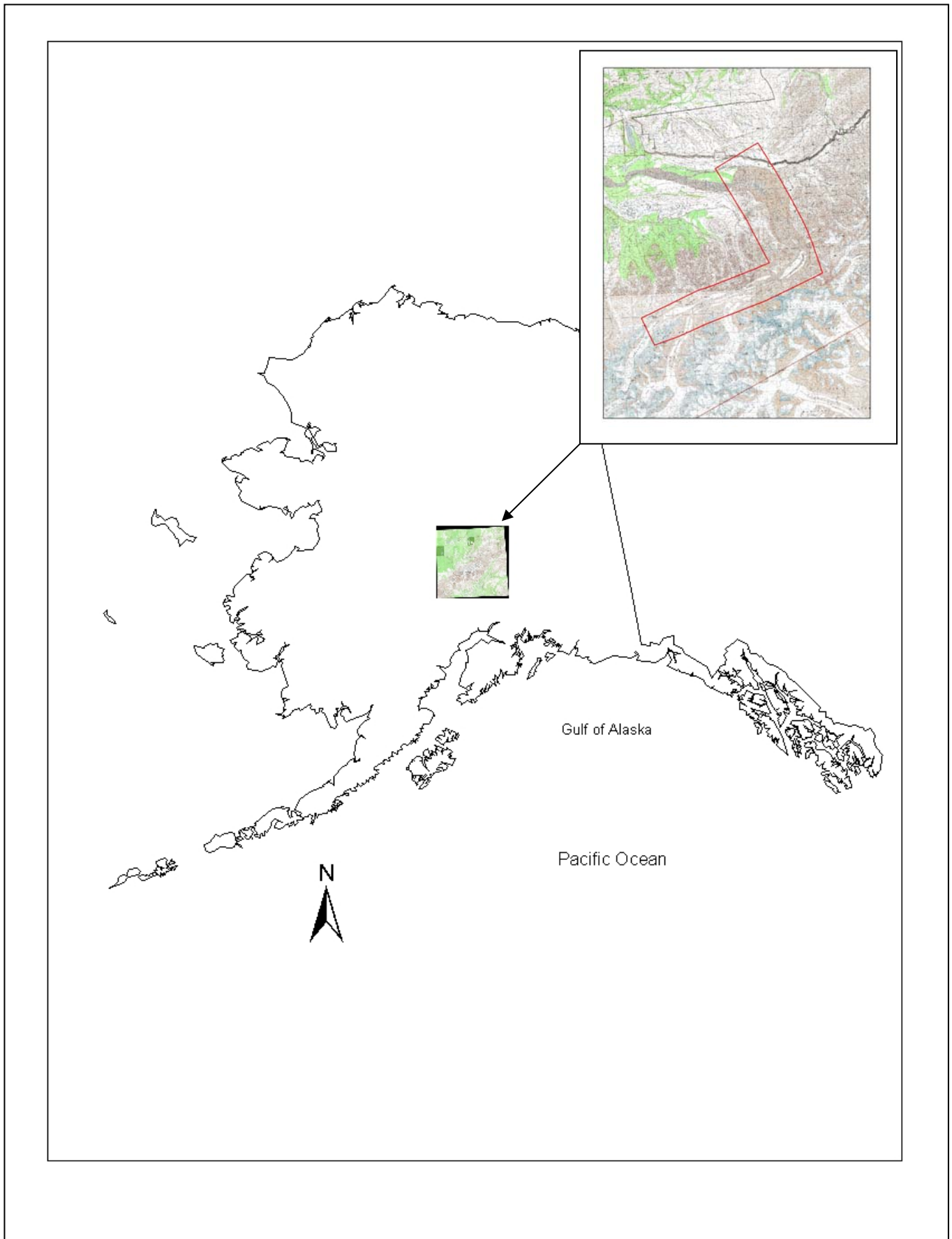
Due to the complexity of the terrain and the lack of good reference features on the scanned maps, several NPS base layers were used as collateral data sources to aid in the placement of control points for georeferencing. These datasets include:

1. Alaska GNIS
2. NHD Flowline
3. Muldrow Shaded Relief
4. Denali ITM DRG's
5. Denali IKONOS True Color Mosaic Image

2. Georeferencing:

Georeferencing is the process of defining the location of mapped data in physical space using coordinate systems or map projections. The georeferencing process typically involves selecting multiple known features on a scanned hardcopy map, assigning their correct x,y coordinate values from an accurately referenced map product and then transforming the map surface so that the error in coordinate selection is equally distributed across the entire image. For this process, it is important to use the most accurate reference dataset possible in order to minimize transformation error in the map that is being georeferenced. For the Muldrow Glacier area, NPS staff were able to provide GSS with a georeferenced and orthorectified IKONOS satellite image to support the georeferencing process. The horizontal accuracy of this image mosaic meets or exceeds the national map accuracy standard for 1:24000 scale mapping of +/- 30 meters. In addition, because the image had already been corrected for terrain aberrations through an orthorectification process, the georeferenced topographic maps also included this terrain correction.

Figure 1: Muldrow Glacier Location



One of the challenges of the georeferencing process was that it was very difficult to locate features on the scanned topographic maps that corresponded to identifiable locations on the IKONOS image. This issue was resolved by using other, less accurate maps to initially locate the topographic maps in space and then use the IKONOS image to refine the georeferencing. Base layer datasets 1-4 above, were used to get the scanned images into the best possible alignment with the IKONOS mosaic usually utilizing around 10 points so that a 3rd order or spline polynomial transformation could be applied. From this point all additional control points were placed referencing the IKONOS mosaic. After 10 control points were established using the IKONOS mosaic all the previous less accurate control points from the preliminary referencing were deleted and further points were added to match locations on the IKONOS image. In many cases, more than 24 georeferencing points were used in order to achieve the best match possible between the topographic maps and the image.

Unfortunately, the IKONOS image did not fully cover the entire extent of all five topographic maps. The southwestern most scan did not have IKONOS coverage for its lower left corner, approximately one fourth of the map sheet. This area was georeference using points from the 1:63,360 scale USGS DRGs and, as a result, georeferencing accuracy in this area is not equivalent to other portions of the scans.

3. Point Extraction:

Once georeferencing was complete, empty point feature classes were created for each georeferenced image in order to capture of spot elevations from the scans. The geodatabase fields created for collection were Elevation (text), Comments (text), and Elev_Number (double). Some of the spot elevations were represented as whole numbers and some were labeled with decimal values. As a result, GSS created a double precision number field and used the ArcGIS Field Calculator tool in order to capture each elevation exactly as it was originally mapped. In cases where there were anomalies associated with the interpretation or location of point values, notes were added to the comment field of the feature class to document the issue(s).

Points were extracted from each of the five georeferenced images at an on-screen zoom scale 1:3000. Each point was captured twice by separate GIS Analysts and then each dataset was compared to the original maps in order to minimize or eliminate the possibility of errors of transcription or omission. A separate point feature class was created for each scanned map (5 in total) and, upon completion of the QA/QC process these features were appended together into a single, final point feature class.

As mentioned above, the southwestern most topographic map in the collection did not have IKONOS coverage for its lower left corner. There were 40 spot elevations captured in this area and notes were added to the geodatabase to indicate that these points likely have lower positional accuracy than points in the surrounding areas.

4. Digital Elevation Models:

A Digital Elevation Model (DEM) is a mathematically defined approximation of the spatial distribution of elevations across a continuous smooth surface. These models approximate variations in the earth's terrain within a defined map extent using input elevations such as spot heights or isolines (contours). ArcMap 9.3.1 includes a variety of mathematical techniques for the creation of DEMs through its Spatial Analysis extension. Each technique statistically

evaluates and transforms the input data in different ways. The five techniques utilized in this project were:

1. Spline;
2. Inverse Distance Weighted;
3. Kriging;
4. Kriging with information extrapolated from the Geostatistical Wizard; and,
5. The Topo to Raster tool.

Each of these processing techniques produced an output DEM with different characteristics and contributed to the knowledge gained and the quality of the final product. Part of the purpose of this project was to explore these different techniques and present them to the NPS for information. Methodologies assessed and applied in this project will contribute to the workflow processes of similar future projects.

Spline:

Documentation for ArcMap 9.3.1 recommends the use of the spline technique (Figure 2) for the creation of elevation datasets. Spline methods use a mathematical calculation that fits a minimum curvature surface through the range of input spot elevations. This interpolation method ensures a continuous and differentiable (smooth) surface; however, rapid changes in gradient or slope may occur in vicinity of the data points.

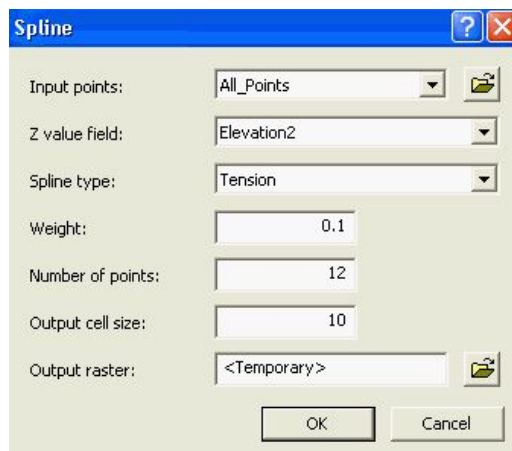


Figure 2: ArcGIS 9.3.1 Spline interface

There were not many options to set with this technique. Spline type offers two different approaches to the interpolation of the elevation data. Regularized creates a surface with data values that lay outside the data range. The use of this option expanded the range of values far beyond the range of data input values; which was limited to between 735 and 3305 meters. The tension option generates a less smooth surface, but the range is controlled more closely to that of the input data source values (Figure 3).

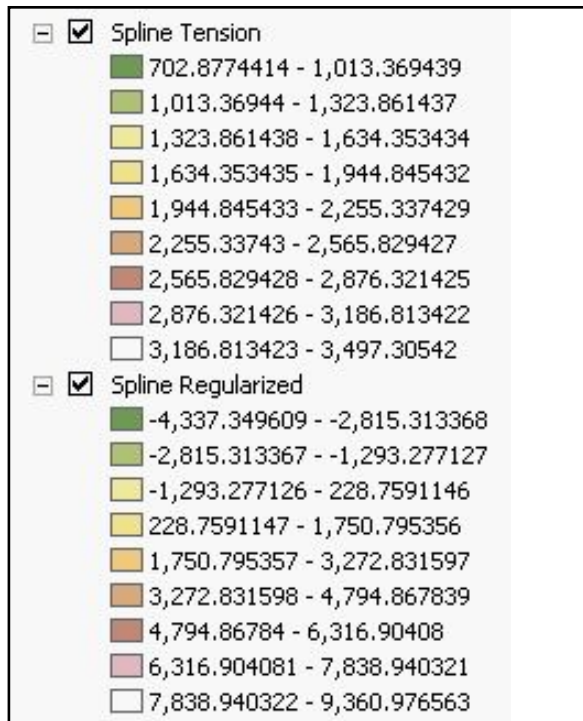


Figure 3: Data ranges with spline type options

Weight parameters were used to define the coarseness of the surface and variations in the value of this parameter did not seem to have a large impact on the “smoothness” of the DEM. The next option, however, defining the number of points used for the interpolation, proved to be very important for the final model. Testing revealed that using a value over 12 for this parameter would start to push the range values in the DEM surface outside of the range defined by the input spot elevations. This was similar to what happened when a spline type of regularized was selected for processing. As a result, a value of 12 or less was used for the number of points that defined the spline so that the output surface more closely represented the values of the input data.

Inverse Distance Weighted:

The Inverse Distance Weighted (IDW) technique assumes that points that are closer together on the elevation surface have a greater probability of being similar in value than points that are farther apart. As a result, as it calculates the elevation value of a cell, the algorithm places more influence or weight on the points closest to the cell than those farther away (Figure 4).

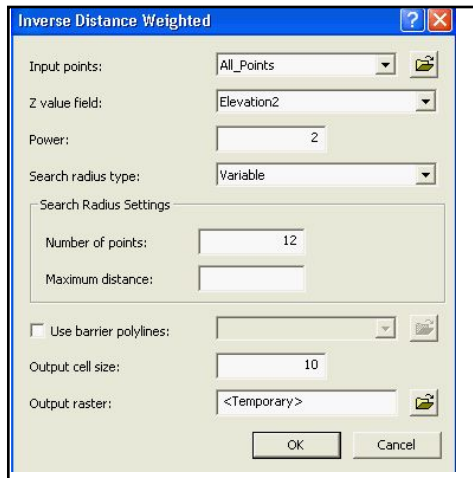


Figure 4: ArcGIS 9.3.1 Inverse Distance Weighted interface

The Power function places value on how much weight to apply to near and far points. A smaller number will incorporate points further away and be smoother than a higher power value. After evaluating different model results, the default value of 2 was maintained for this project. Other parameters such as, search radius and number of points to constrain the amount of influence placed on each cell by point values proved to have more influence on the quality of the output DEM.

With IDW processing, those points that are further from the cell being processed have little or no spatial correlation. The Search Radius options available in the interface are fixed and variable and they are used to place more weight on those points with spatial correlation to each cell. The fixed radius option does not function consistently, even with the “Number of Points” value set. This option sets a radius distance and all points falling within that radius are used to calculate the value of the cell being processed causing different numbers of measured points per neighborhood. There is no option to have a distance value of zero with fixed radius so that only a specified amount of points will be calculated. In addition if the minimum number of points is not found within the specified radius the radius is then automatically expanded to capture at least the minimum number of sample points. With variable radius the desired number of points to use in the calculation can be set and the distance value can be zero.

Kriging:

Kriging (Figure 5) differs from spline and IDW in its approach to predicting a surface. Whereas spline and IDW function directly from the neighboring measured values, kriging uses statistical models to define the relationships between points. In practice, kriging methods take into consideration autocorrelation structures of elevations in order to define optimal weights for different distances from a point and then automatically evaluate the results. The method, however, requires a skilled user with geostatistical knowledge.

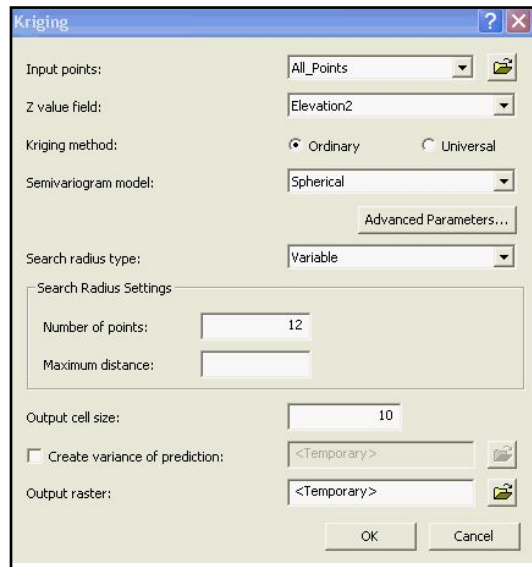


Figure 5: ArcGIS 9.3.1 Kriging interface

The kriging methods available in ArcGIS 9.3.1 are ordinary and universal. Ordinary is the most commonly used. Universal is used when there is a known trend in the data and the user would like to incorporate this trend in the development of the elevation surface. Trends must be identified and defined through geostatistical analysis prior to processing the elevation surface through kriging.

Kriging uses a semivariogram function that describes the degree of spatial dependence between a random field of elevation points. There are two options in the Kriging interface for semivariogram modeling and these are spherical and exponential. Of these two options spherical was used in this project to determine the correlation between disparate point values. Spherical processing decreases progressively in correlation with increases in distance from the cell. The exponential model does the same, however, in dealing with different spaced points with varying, increasing and decreasing values there did not appear to be any identifiable trend in the point values.

The Kriging process also includes a search radius function similar to the IDW process. This function operated in the same manners as with IDW. Kriging also has advanced parameters that coincide with the semivariogram models. The kriging process used for this project did not utilize these parameters. A later kriging DEM was created with input values extrapolated from the ArcMap Geostatistical Wizard and is discussed below.

The Kriging interface also allows for the input of advanced variogram parameters such as lag size, major range, partial sill, and nugget (Figure 6). To extrapolate this information from the spot elevation database used for this project, the ArcMap Geostatistical Wizard was used. The resulting values were entered as input to a separate run of the kriging DEM development process.

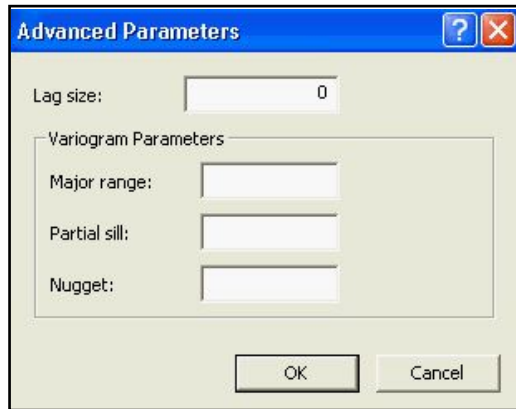


Figure 6: Kriging Advanced Parameters

In order to utilize advanced parameters in the kriging process, once elevation points are added to the model and ordinary is chosen for the semivariogram model, the application opens the Geostatistical wizard interface (Figure 7). This wizard analyzes the point data and presents values for lag size, major range, partial sill and nugget that can then be input into the Advanced Parameters interface in the kriging process.

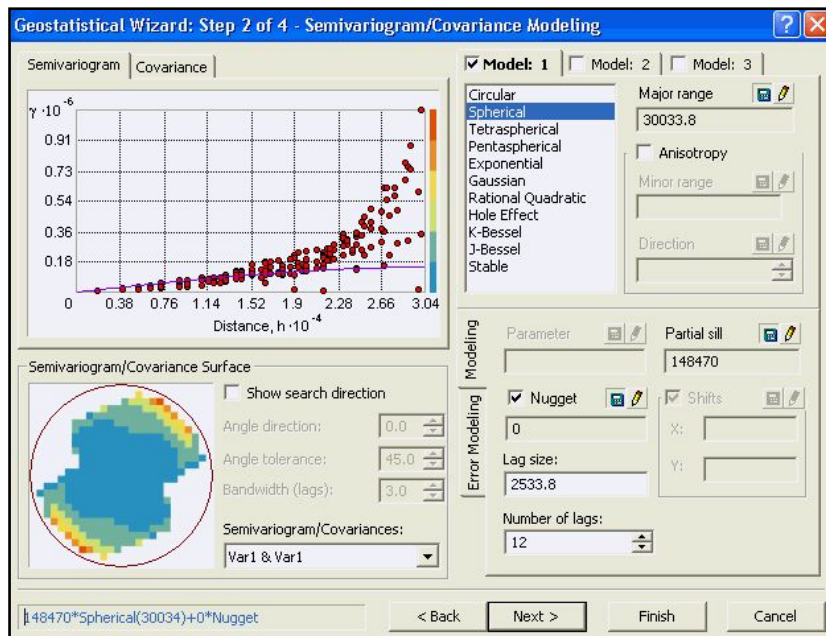


Figure 7: ArcGIS 9.3.1 - Semivariogram parameters

A second kriging DEM was created with these advanced parameters added so that they would, in theory, better define the criteria for interpolation of cell values. The geostatistical wizard findings were input into the advanced parameters interface and the other parameters were kept the same as the initial kriging DEM.

Topo to Raster:

The Topo to Raster tool is designed to create hydrologically correct DEM's. There are several parameters within this interface to set prior to interpolation (Figure 8).

The screenshot shows the 'Topo to Raster' tool interface. It features a table for 'Input feature data' with columns for 'Feature Layer', 'Field', and 'Type'. Below the table are several input fields and dropdown menus for configuring the tool's output and processing parameters.

Feature Layer	Field	Type
All_Points	Elevation2	PointElevation

Output surface raster: P:\NPS\DNA\Add_Projects\Working\Final_GRIDS\Topo_to_Raster\TopoRaster

Output cell size (optional): 10

Output extent (optional): Same as layer All_Points

Margin in cells (optional): 10

Smallest z value to be used in interpolation (optional): 700

Largest z value to be used in interpolation (optional): 3500

Drainage enforcement (optional): ENFORCE

Primary type of input data (optional): SPOT

Maximum number of iterations (optional): 40

Roughness penalty (optional): 0.5

Discretisation error factor (optional): 1

Vertical standard error (optional): 0

Tolerance 1 (optional):

Tolerance 2 (optional):

Figure 8: Topo to Raster interface

These parameters include:

1. Feature layer: for this project the input spot elevation points from the topographic maps;
2. Output surface: the name of the DEM to be created;
3. Output extent: should be set as the same extent as the input layer;
4. Margin in cells: specifies a margin around the input data which the model will search for additional input elevations;
5. Smallest z-value: for this project set to 700 because the lowest elevation in the spot height dataset was known to be 735;
6. Largest z-value: for this project set to 3400 because the lowest elevation in the spot height dataset was known to be 3305;
7. Primary type of input: set as spot for the input elevation data used on this project;
8. Drainage enforcement: left as default;
9. Roughness penalty: left as default;
10. Discretisation error factor: left as default; and,
11. Vertical standard error: left as default

5. Contour Generation:

The original topographic maps used for this project included both spot elevations and contours created through traditional survey techniques and hand drafting. The contour interval used on these maps was 10 meters as stated in the NPS project task agreement. To maintain consistency with the original data contours with a 10 meter interval were generated from the DEM using the ArcMap Spatial Analyst surface analysis tool (Figure 9).

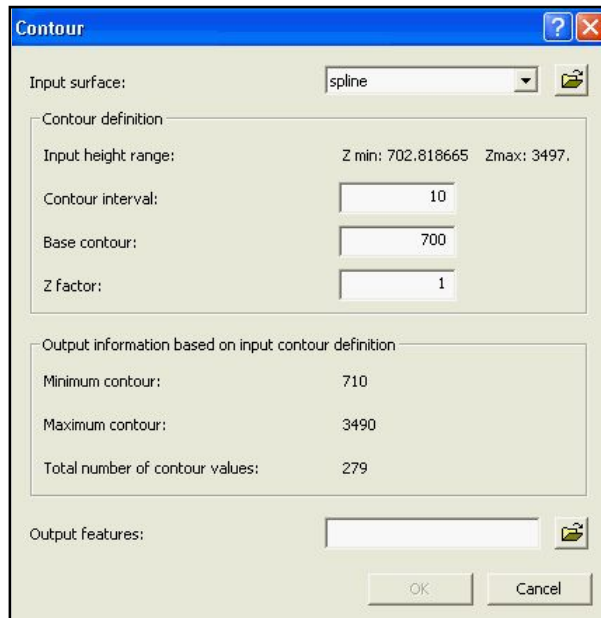


Figure 9: ArcGIS 9.3.1 Contour Generation Settings

A base contour value of 700 was chosen even though the lowest point elevation value was 735. This was because surface interpolation in the DEM development process generated grid cells with values lower than 735 meters and these areas needed to be accounted for in the contour map. A default Z Factor of 1 was chosen so as not to vertically exaggerate the final contour data.

Final Products:

Final products for the Muldrow Glacier project included the following:

1. Five digital georeferenced topographic maps of the Muldrow Glacier area
2. ArcGIS point feature class of spot elevations
3. Five DEM surfaces in GRID format interpolated from spot elevations
4. Five contour shapefiles created from each of the DEMs
5. A series of maps in PDF format presenting the project data

Results and Discussion:

Quality Control:

Quality control of the final product was managed in several different ways:

1. During the georeferencing phase, the amount of error associated with the selection of individual georeferencing control points was monitored and points that had too much error were eliminated from the final rectification. Points that were used for reference with less accurate data were removed and replaced with higher accuracy points attained from IKONOS imagery.
2. As many control points as possible were collected to ensure the best spatial accuracy.
3. Point elevation data was collected at a scale of 1:3000 for all five topographic map sheets. This was done to ensure consistency between all points collected.
4. The final merged data was reviewed by a different GIS Analyst for any additional errors of omission.
5. An additional check for point attribute consistency was performed following the generation of contours. This was undertaken through a detailed examination of the contours for elevation anomalies (e.g. spikes, sinks, isolated, abrupt changes in elevation).
6. Limited information on the topographic maps made it difficult to select georeferencing points from the base layers. Using multiple base layers with different features and multiple levels of accuracy led to an effective process.
7. Capturing points at the same scale made for consistency and reduced possible error due to legibility of the topographic maps. When closer examination of points was required Analysts had free rein to zoom and pan as necessary.

DEM generation was assessed using five different interpolation techniques in ArcGIS. In the end the spline technique appeared to be the most consistent with the spot elevations (through visual examination) and produced the smoothest contours. ESRI documentation suggested that the spline technique is the optimum method for generation of an elevation surface. There is considerable room for further examination of DEM generation techniques in future studies. For example, a deeper understanding of the functions of the Geostatistical Wizard may produce more applicable advanced parameter values for the kriging technique. Due to scope and budget limitations in the current project, statistical assessment of different DEM generation techniques was not undertaken.

Cell resolution for all five DEM grids produced for this project was 10 meters. This resolution was agreed upon in original project scoping sessions between GSS and NPS and was considered to be suitable given the density of spot elevations on the original topographic maps. This cell size produced final output grids of manageable size and details for the project study area.

Contour creation was straight forward and a 10 meter contour interval was chosen in order to readily permit comparison with the original topographic maps. Each contour shapefile was clipped with a mask created from the extents of the rectified maps. This was done in order to avoid the creation of contours outside of the areas where there was no valid elevation data to support interpolation.

All the final datasets were delivered in the Alaska Albers NAD 83 projection. This is the NPS standard projection for GIS data in the Alaska Region.