Investigation of the Permafrost Table through Multi-resolution Object Oriented Fuzzy Analysis, North Slope, Alaska

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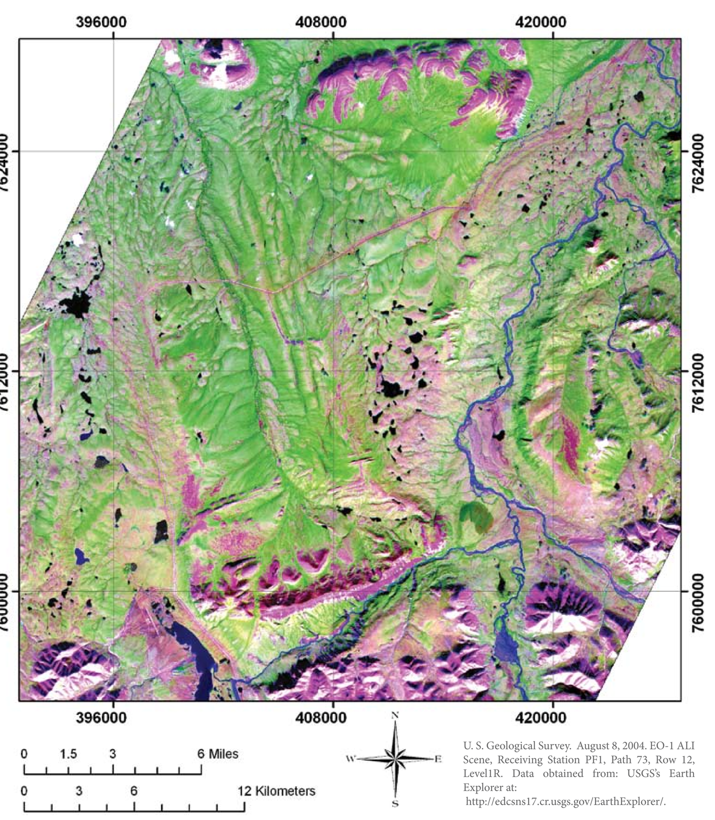
Photo looking south across Galbraith Lake toward Atigun Pass

Project

This investigation examined the changing surface conditions of a study area near Toolik Lake, Alaska (see below) and sought to differentiate the surficial geology and geomorphology, largely influenced by glacial activity, as well as ecology of the region, in order to characterize the state of the permafrost table. The study was conducted utilizing remotely sensed images and datasets; as well as, field data, in order to conduct analysis of the landscape over multiple years. This information was subsequently used as proxy data to make observations of the state of the permafrost table which underlies this landscape. This type of study yielded continuous estimates of the ground conditions without the need for a lengthy ground campaigns that could have proved difficult in a region such as this.

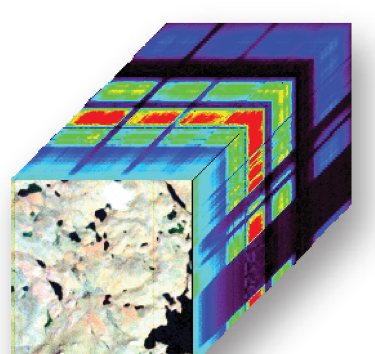


Advanced Land Imager[1] (ALI)
Map of the Study Area (left):

Band	Spectral Range (μm)	Resolution (m)	ETM+
Pan	0.048 - 0.690	10	
1	0.433 - 0.453	30	
2	0.450 - 0.515	30	1
3	0.525 - 0.605	30	2
4	0.630 - 0.690	30	3
5	0.775 - 0.805	30	4
6	0.845 - 0.890	30	
7	1.200 - 1.300	30	
8	1.550 - 1.750	30	5
9	2.080 - 2.350	30	7

Data

Data implemented for this project included an Advanced Land Imager and Landsat TM scene; as well as, a Digital Elevation Model with its derivative data. Hyperion hyperspectral data was also utilized for this project to obtain spectral characteristics of the ground surface along with field data collected with an ASD spectral radiometer. Destriping of the Hyperion image was conducted within ENVI and the Eclipse development platform utilizing the Java IDE. All images were atmospherically corrected to retrieve at-surface-reflectance values by using Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes or Empirical Line Calibration where appropriate in order to facilitate cross scene analysis of the images.

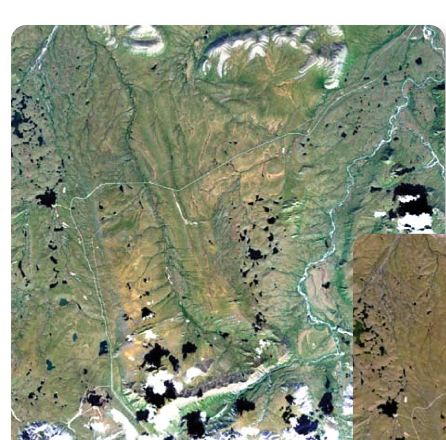


Spectral Data Cube (above)
Generated from the Hyperion image near Toolik Lake, Alaska

Hyperion Hyperspectral Swath[2] (left):
Red: 32 Green: 22 Blue: 16

VNIR (bands 8 - 57) 0.427 - 0.925 μm
SWIR (bands 77 - 224 0.912 - 2.395 μm

Spect. Resolution ~10 nm
Resolution (m) 30.38 m
Scene Width 7.7 km

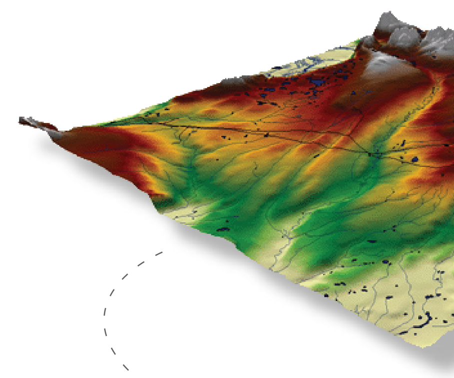


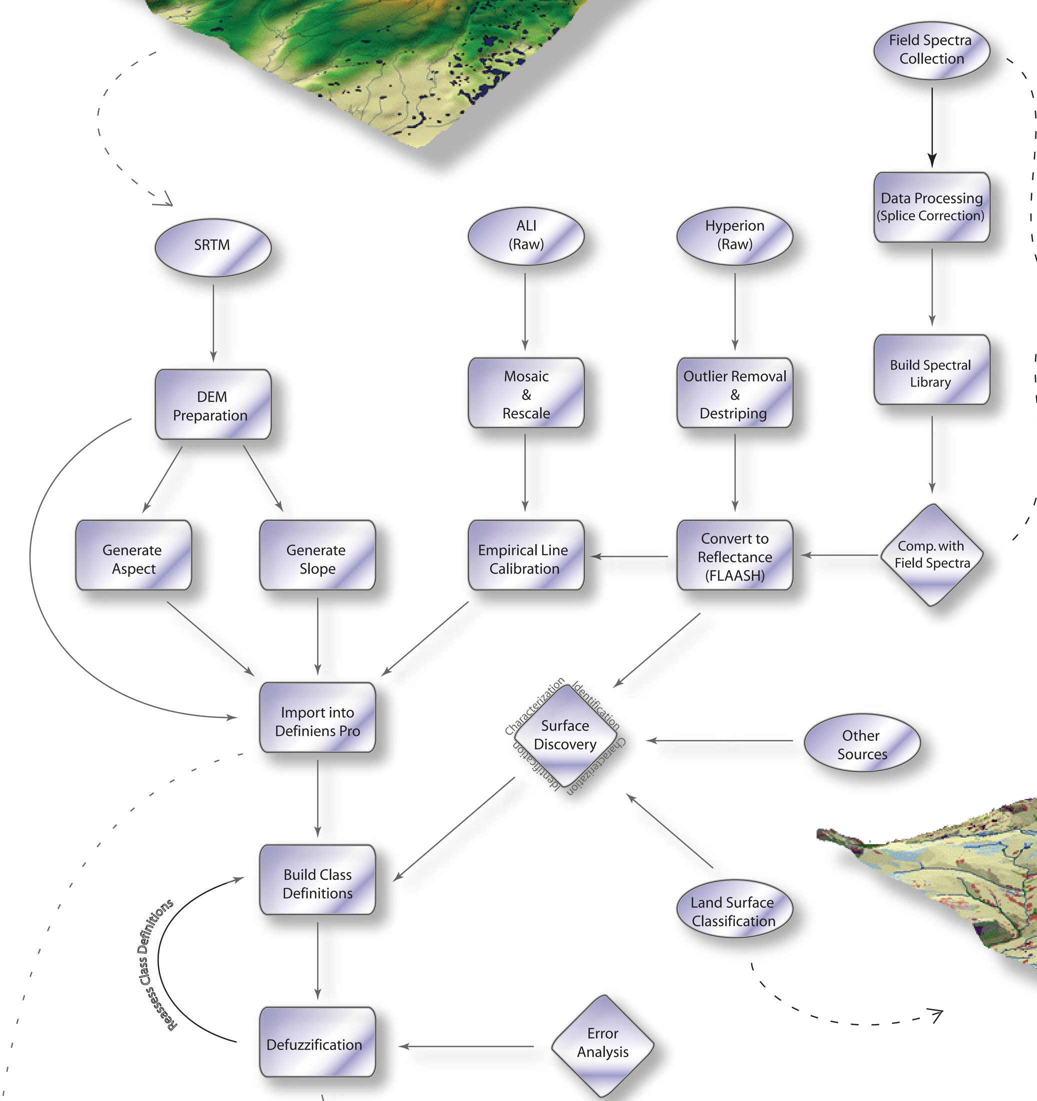
Landsat TM[3] (left)
True Color Composite: R3: G2: B1
Landsat Thematic Mapper image of the study area captured in August of 1985

Landsat ETM+[4] (right)
True Color Composite: R3: G2: B1
Landsat Enhanced Thematic Mapper image of the study area captured in July of 1999

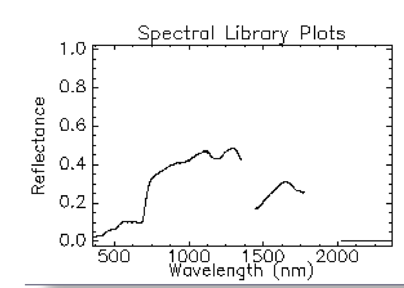
Process Flow

Digital Elevation Model[5] (below):
Shuttle Radar Topography Mission (SRTM) data has been used for this project with spatial resolutions of 2 arc seconds. This model has been oriented with north toward the lower left of the scene, also displays the Dalton Highway, Alaska Pipeline and water features for reference. (Note: this is not SRTM data and has only been used in this figure)

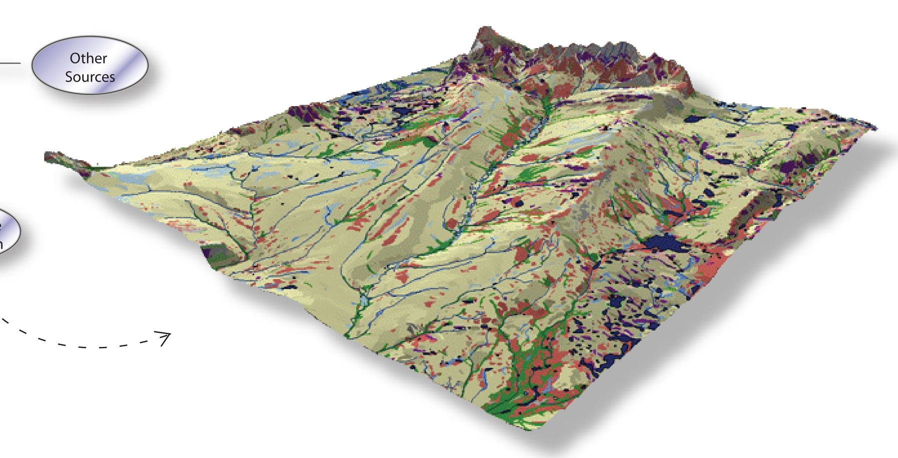




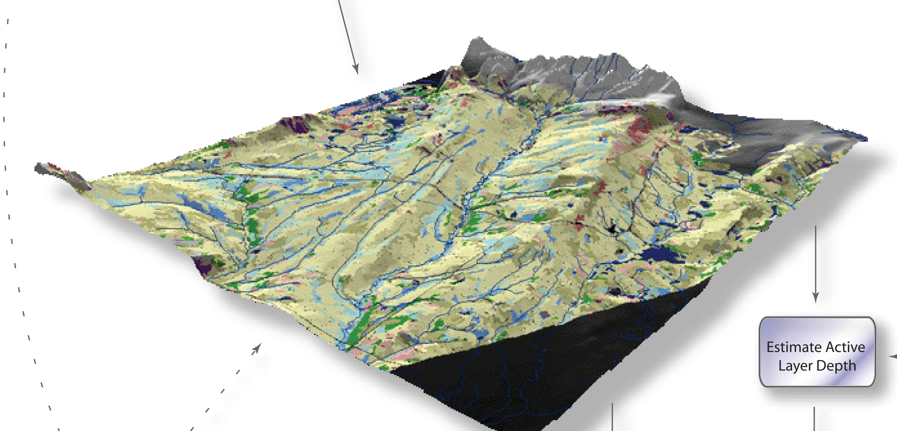
Field Data Collection (below):
Photo of data collection using the ASD Spectral Radiometer take July 2007 near Galbraith Lake.

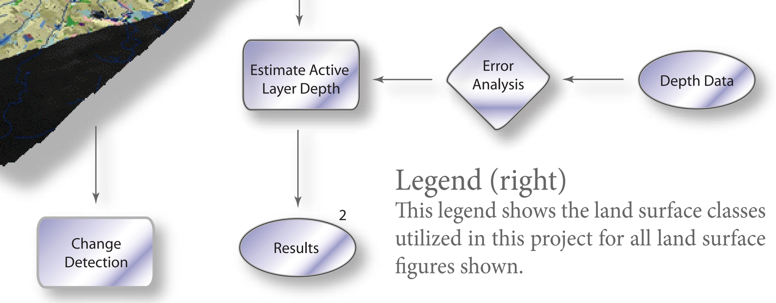


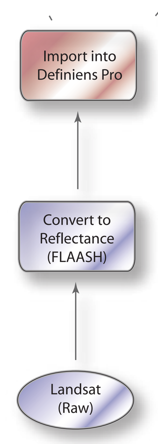
Spectral Profile (above)
Sample spectral profile derived from data collected in the field after processing.



Land Cover[6] (above)
Previously constructed land cover classification of a portion of the study area which has been included in the discovery portion of the classification. Known surfaces are compared to spectral profiles in order to catalogue the properties of materials.

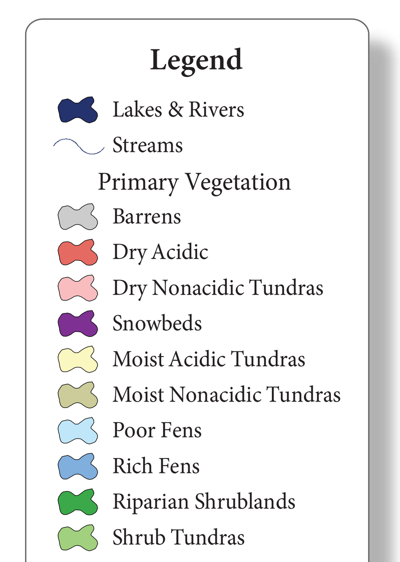






Derived Land Cover Classification (above)
This image shows the land cover distribution of the region from an object-oriented classification of the ALI image and SRTM. Since classes are only partially defined at this point, the model had difficulty distinguishing between some of the unit types. Note that this classification is only partially completed.

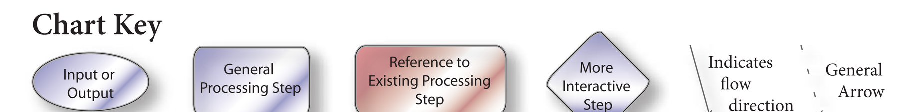
Legend (right)
This legend shows the land surface classes utilized in this project for all land surface figures shown.



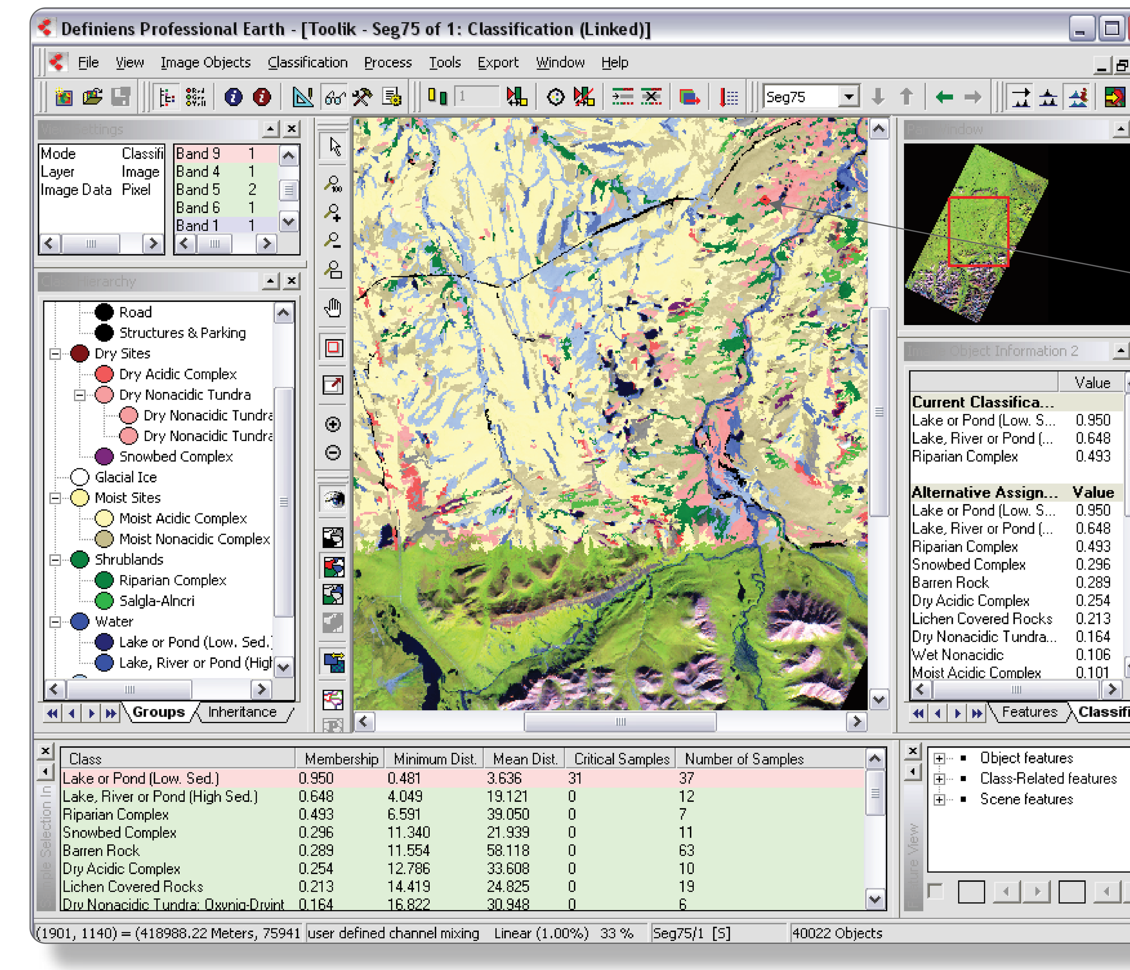
Results
By using object-based classification of multisensor and multitemporal data we utilize contextual information in addition to spectral properties for identifying surface units. We expect that this approach will yield more reliable results than pixel-based classification for mapping land cover and other surface properties resulting in improved accuracy in change detection. With respect to "Result 2", using processing steps such as those employed by Leverington and Duguay (1997)[7] or Nelson et al. (1997)[8], who achieved average errors less then 10%, results with a high degree of accuracy will hopefully be produced on a much smaller scale.

Landsat Processing Step (above)
Landsat derived classifications are not represented on this poster; however, it will be used in the same manner as ALI. The processing step "Import into Definiens Pro" displayed in red, is the same processing step as the one above and is displayed here to demonstrate where Landsat will splice into the data flow process in place of ALI.

Chart Key



Using an object oriented multi-scale segmentation approach, this study employed Definiens Professional, an image analysis application that, among other things, allowed fuzzy analysis of data and integration of multiple data types within the same project. Working in conjunction with ENVI (Environment for Visualizing Images), a model based on spectral properties of the surface materials yielded more robust results than a standard pixel based classification derived from a training set.

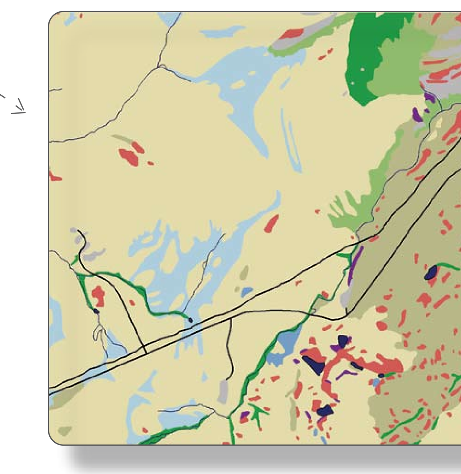


Definiens (left)
A screen capture of an ongoing surface classification within Definiens Professional 5 (Definiens AG). This classification was conducted as a test in the surface exploration phase using a basic training set and a nearest neighbor classification that took into consideration ALI bands 1-9, Elevation, Slope and Aspect.

Fuzzy Classification
This example shows a lake with low concentrations of suspended sediment in the water column. Note that using the current class definitions and training set the classification identified this lake correctly as a lake or pond with low sediment with a membership value of 0.950 (scale 0.000-1.000). Alternative assignments for this class include lake, river or pond with high suspended sediment in the water column with a membership value of 0.648 and Riparian Complex with a membership value of 0.493.

Class Definitions
For this example, class definitions and regions selected for training where not adequate in all cases to fully distinguish between all classes. In particular, more information and/ or parameters are needed to separate out units such as "Moist Acidic Tundras" and "Moist Nonacidic Tundras".

Original Land Cover Classification[6] (above)
Vegetation map featuring primary vegetation for a portion of the study region. (*see Legend*)



Comparison of the Original Classification and the Derived Test Classification
An enlarged comparison of the original primary vegetation classification (top left) with the test classification of the data set consisting of the ALI image and the topographic information from the SRTM DEM. (below left). Points of note:

1 – While it is clear that continued work on defining units needs to be conducted, it is promising to see that with only limited effort it is possible to start pulling some surfaces cover types out of the data. Most notably in this example, Barrens and Fens.

2 – Classes need to be more defined to yield results that allow for more confidence in the model. In particular for this example, "Moist Acidic Tundras" and "Moist Nonacidic Tundras" need more work.

3 – While not all materials were identified correctly the general shape of many units has been extracted relatively well.

A Source of Error
There are several factors that should be mentioned as possible error sources for this particular example. While the main goal of the classification was vegetation mapping, we haven't examined yet how much the spectral signatures of the underlying soils influenced the classification. Moreover, the elapsed time between the compilation of the original land cover map and the ALI image acquisition is great enough to cause actual surface changes.

Previous studies conducted have utilized datasets that were largely moderate spatial and low spectra resolution. This study employed datasets that are also moderate spatial resolution but were reinforced with high spectral resolution data provided by Hyperion, resulting in a more accurate assessment of the surface materials and increased confidence in the model. Additionally, by first segmenting the datasets it was possible to utilize textual and contextual information that is typically lost in a pixel based classifications. This type of processing also allowed for automated processing of other datasets which facilitated an efficient temporal study and produced datasets that have undergone the same processing steps. This reduced the possibility of processing mistakes, increased confidence in the resulting surface classifications and subsequently, increased confidence in the resulting subsurface characterization of the permafrost table located, in most cases, at shallow depths below.

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Data Citation

1 - U. S. Geological Survey. August 8, 2004. EO-1 ALI Scene, Receiving Station PF1, Path 73, Row 12, Level1R. Data obtained from: USGS's Earth Explorer at: http://edcsns17.cr.usgs.gov/EarthExplorer/.
2 - U. S. Geological Survey. August 8, 2004. EO-1 Hyperion Scene, Receiving Station PF1, Path 73, Row 12, Level1R. Data obtained from: USGS's Earth Explorer at: http://edcsns17.cr.usgs.gov/EarthExplorer/.
3 - NASA Landsat Program, Landsat TM scene p073r12_5t850804, SLC-Off, USGS, Sioux Falls, 08/04/1985. Source for this data set was the Global Land Cover Facility, www.landcover.org.
4 - NASA Landsat Program, 2004, Landsat ETM+ scene p073r012_7k19990702_z06, SLC-Off, USGS, Sioux Falls, 07/02/1999. Source for this data set was the Global Land Cover Facility, www.landcover.org.
5 - U.S. Geological Survey (USGS), EROS Data Center. 1999. National Elevation Dataset, Shuttle Radar Topography Mission (SRTM) 2 Arc Second Data. Data obtained from the National map seamless Server at: http://ned.usgs.gov/.
6 - Walker, D.A. and N.C. Barry. 1991. Toolik Lake permanent vegetation plots: Site factors, soil physical and chemical properties, plant species cover, photographs, and soil descriptions. Department of Energy R4D Program Data report, Joint Facility for Regional Ecosystem Analysis, Institute of Arctic and Alpine Research, Boulder, CO. Boulder, CO: National Snow and Ice Data Center. Identifier no. ARCSS018. Digital media and paper copy.

References

7 - Leverington, D. W. and Duguay, C. R. (1997). "A Neural Network Method to Determine the Presence or Absence of Permafrost near Mayo, Yukon Territory, Canada." Permafrost and Periglacial Processes 8: 205-215.
8- Nelson, F. E., et al. (1997). "Estimating Active-Layer Thickness over a Large Region: Kuparuk River Basin, Alaska, U.S.A." Arctic and Alpine Research 29(4): 367-378

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RSL Home: rsl.geology.buffalo.edu
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