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Trying to Quantify Elevation Change in Relation to Permafrost in Northern Alaska

(http://permafrost.gi.alaska.edu/photos/image/490)

Introduction / Background

News stories dealing with the sinking of land in Alaska have been cropping up for almost the past decade (http://www.nbcnews.com/id/32734325/ns/us_news-environment/t/arctic-villagers-have-sinking-feeling/#.WEuvN-YrKM8 http://news.nationalgeographic.com/news/2014/04/140417-drunken-trees-melting-permafrost-global-warming-science/) and almost all of them cite the thawing of Alaskan permafrost as the cause of land subsidence. Permafrost is a layer of ground that remains frozen regardless of season, occurring in some instances in subsurface layers tens of thousands of years old, endemic mostly to the Arctic and Antarctic regions with some associated in conjunction with high altitudes in lower latitudes. In the case of Alaska permafrost underlies some 80% of the surface and is a growing concern given the continued effects of anthropogenic climate forcing.

Additionally, permafrost is widely recognized as a significant sink in the world CO_2 budget, containing an estimated 1500 Pg worldwide.

Earlier this year the ArcticDEM project began releasing high quality (2 m and 5 m resolution) DEMs of the Arctic Circle in batches, starting first with most of Alaska. These data represent the most recent, highest resolution coverage of Alaska widely available – sourced from the DigitalGlobe family of imaging satellites through images taken starting in the summer of 2015 through the summer of 2016.

Through the use of this dataset and another, older set of DEMs it was hoped that an overall picture of Alaskan land subsidence related to permafrost thawing might be gleamed.

Data Collection

To attempt this analysis several collections of data were needed:

A map of Alaskan permafrost extent and ground distribution was retrieved through the ArcGIS online content portal, originally made by Jorgenson et al., 2008 at the University of Alaska Fairbanks:
http://www.arcgis.com/home/item.html?id=bd72102091e04e8bb70075c8776e513b
This map was chosen because of relative newness and the useful separation of permafrost into areas of distribution underground (continuous, discontinuous, sporadic, isolated, and absent) as represented through many feature polygons.

A high quality shapefile for Alaska's boundaries was downloaded as part of a set of United States state boundaries from the U.S. Census Bureau.
http://www2.census.gov/geo/tiger/GENZ2015/shp/cb_2015_us_state_5m.zip
This shapefile was used because of its stated purpose of being a Cartographic Boundary file meant for thematic mapping and adequate resolution of 1:5,000,000.

A feature class of Alaskan population centers was found through the U.S. Geological Survey's data portal, which in turn linked to data.gov, providing a feature class of all cities and towns within the United States.
https://catalog.data.gov/dataset/usgs-small-scale-dataset-cities-and-towns-of-the-united-states-201403-shapefile
This was downloaded with the intent to produce a zone of exclusion around human inhabitation in permafrost-underlain areas for any results generated, as localized heat from human activity or buildings could skew results. This ended up not being prominent for reasons discussed later.

The relevant ArcticDEM rasters that cover areas of extensive permafrost were needed to establish most-recent elevations in areas of interest.
http://pgc.umn.edu/arcticdem
http://elevation2.arcgis.com/arcgis/rest/services/Polar/ArcticDEM/ImageServer
The ArcticDEM raster product can be accessed in a few ways, but in this instance the ArcGIS Image Server file for the ArcticDEM data were downloaded for use with desktop ArcMap such that areas of interest could be easily identified relative to the extent of Alaskan permafrost.

Another set of rasters of comparable quality, older age, and of the same region was initially hard to come by – but was found on the Alaskan state government's Alaska Division of Geological & Geophysical Surveys website. There they host an IfSAR (Interferometric synthetic aperture radar) DEM dataset.
http://maps.dggs.alaska.gov/lidar/#-16000000:9338001:4

Although acquired by an airplane mounted radar, the DEM offered is 5 meters in resolution – which matches the resolution of one of the ArcticDEM products, eliminating the need to arbitrarily interpolate or aggregate down the ArcticDEM 2 meter DEMs to a lower resolution. Additionally, the IfSAR data was acquired in batches dating as far back as 2010, giving a good temporal envelope between the more contemporary and up to date ArcticDEM data. Happily, the IfSAR DEM was also served through an ArcGIS Image Server, which made finding areas of common coverage between the two sets of DEMs straightforward.

ArcGIS Data Processing / Methods
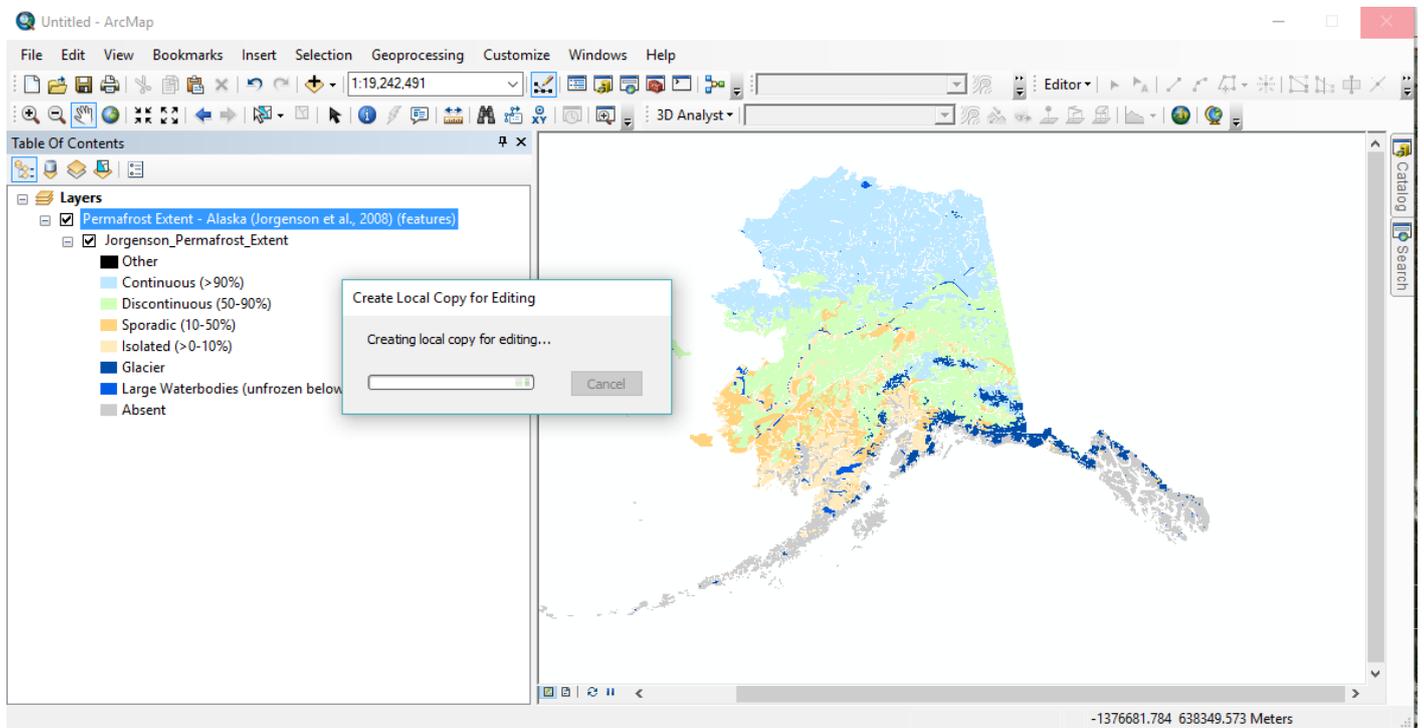
Fig. 1

After downloading the Permafrost Extent map from the ArcGIS website it is necessary to make a local copy of it, as it is an online object initially downloaded as a ".pitem" (ArcGIS Portal Item) and can't initially be edited.
To do so right-click on it in the table of contents -> Edit Features -> Create Local Copy For Editing. Additionally, under Edit Features, disconnect the Local Copy from Server, and finally right click Data -> Export Data, exporting all features and naming it accordingly as a separate item on the table of contents.

It is important to note that this map is projected in NAD_1927_Alaska_Albers_Meters, and that everything added to the map after this is likewise projected in that system.
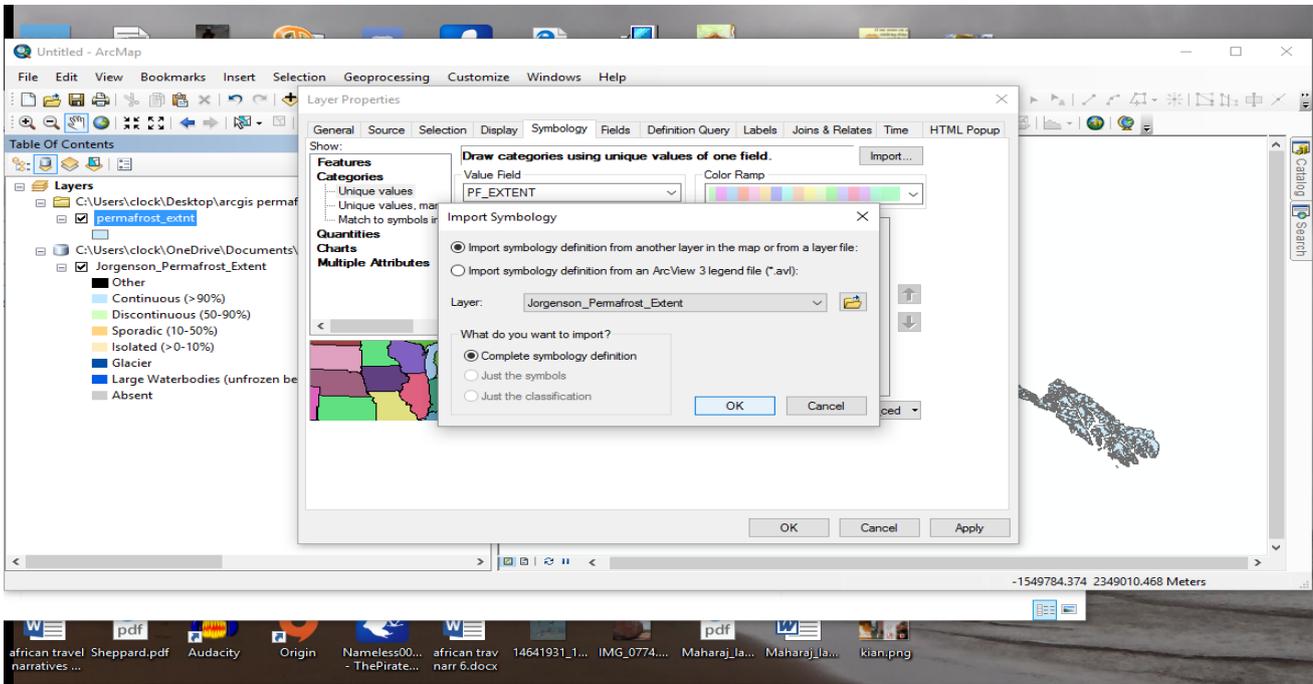
Fig. 2

Initially, the exported version will have no associated symbology, so it is necessary to import symbology from the Jorgenson Permafrost Extent map as shown in Fig. 2. Then the original Jorgenson Permafrost Extent map can be removed.
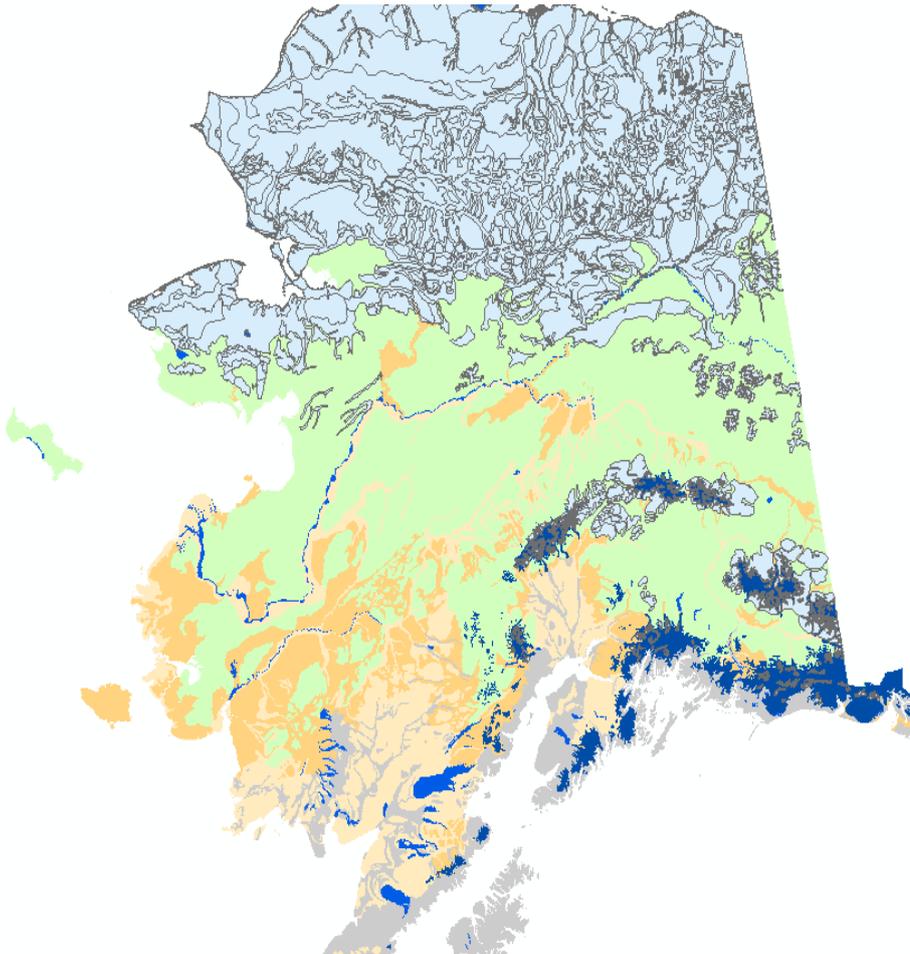
Right clicking on the new permafrost map, opening the attribute table and seeing what polygons conform to what reveals that "Continuous" permafrost is marked "C" under the PF_TYPE column. By selecting all "C" PF_TYPE polygons it is then possible to create a layer of continuous extent permafrost only by right clicking in the ToC -> Selection -> Create Layer From Selected Features – in doing so this project's area of focus shrinks to what is essentially northern Alaska, where permafrost is the most continuous and likely contains the most trapped CO_2. By doing this, also, it later becomes easier to figure out what rasters are relevant to analysis. This new layer of continuous permafrost is in light blue in Fig. 3, in addition to the new permafrost extent map.

Fig. 3
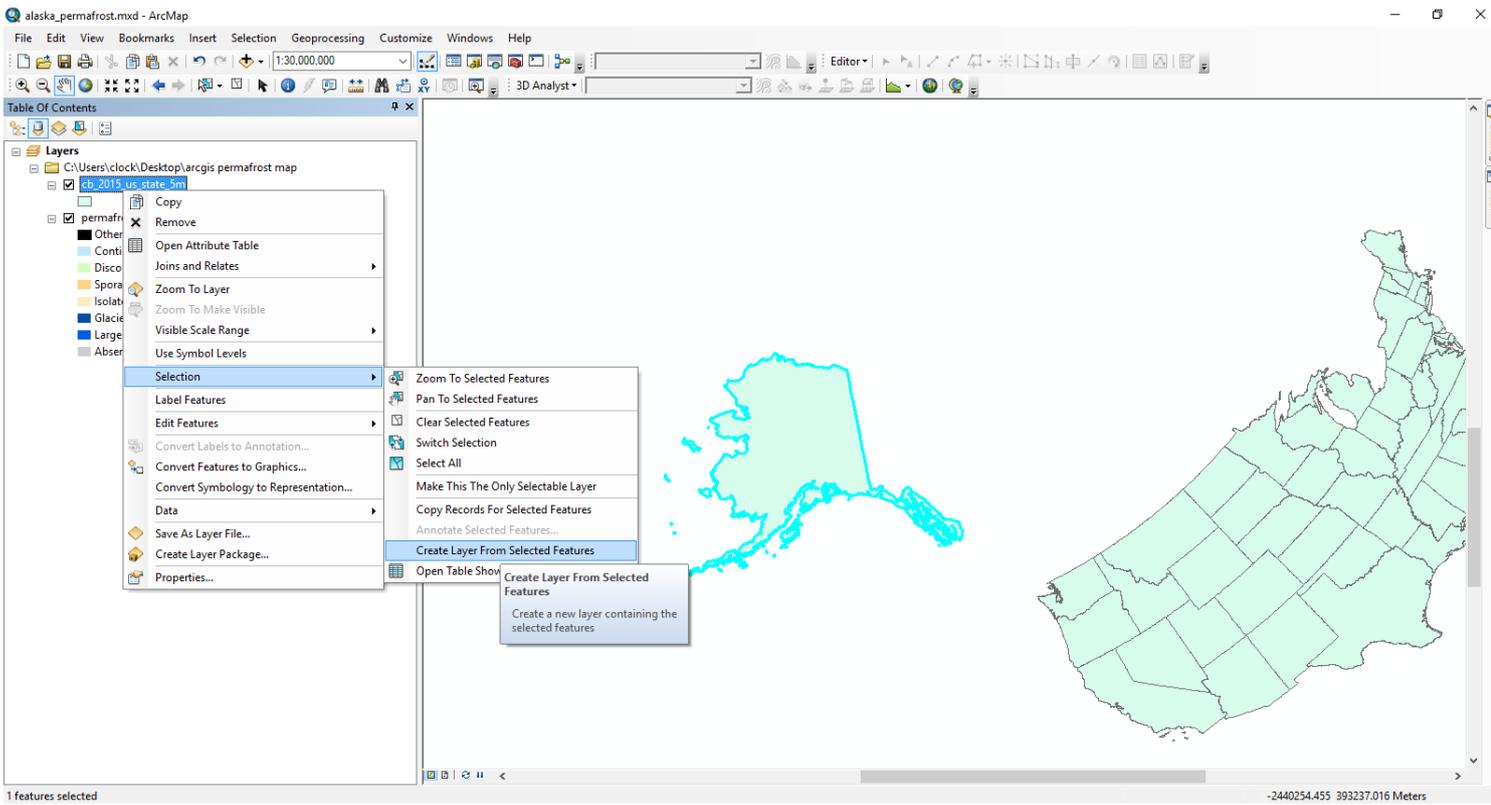
Fig. 4

Next, it is necessary to add the Census Bureau's United States CBF shapefile and isolate Alaska's boundaries. This was done by selecting the Alaska feature and right clicking the shapefile in the ToC, Selection -> Create Layer From Selected Features as in Fig. 4. By doing so, rather than relying on the permafrost map's edges (which may end up edited or have small gaps in coverage) clipping items to the state's boundary stays uniform.
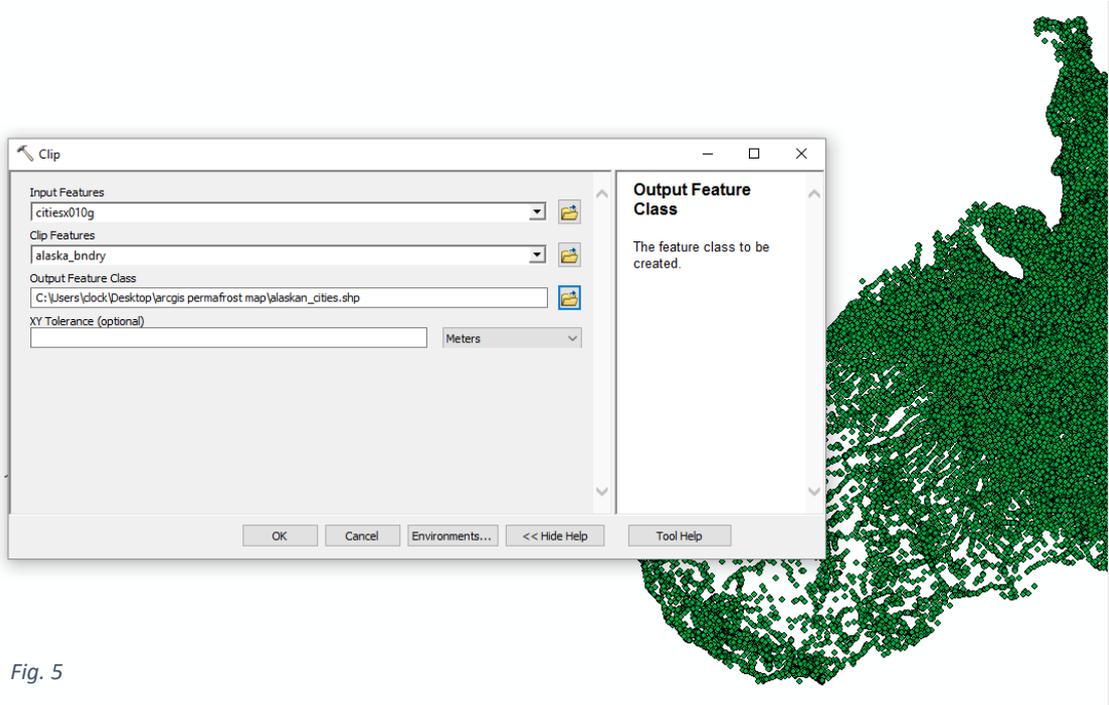
Fig. 5

At this point it is necessary to add the USGS city and town feature class shapefile. As it covers the entirety of the United States it is necessary to reduce it – handily accomplished by clipping the file to the new Alaska boundary shapefile as in Fig. 5.
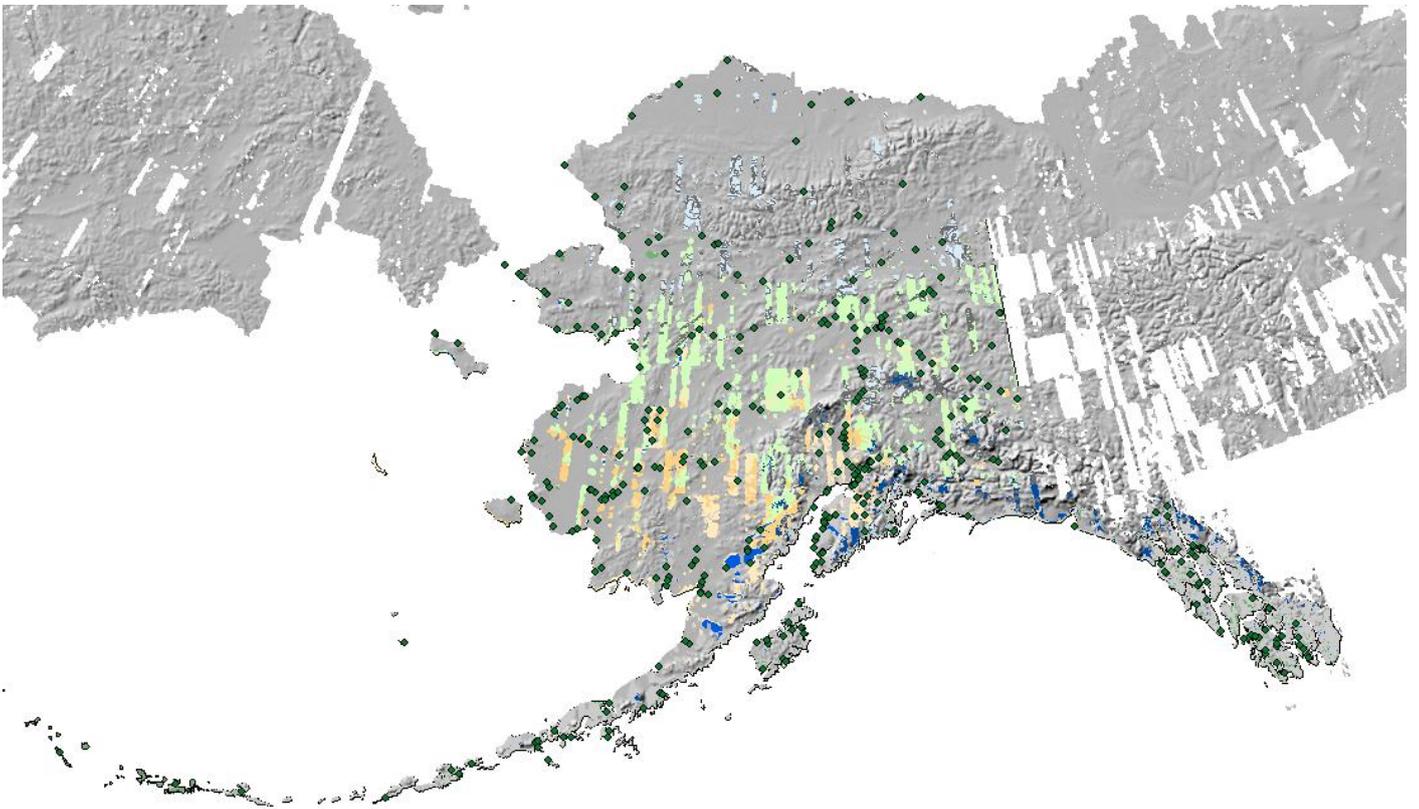
Next, the ArcticDEM Image tile index service layer is added, showing up as pictured in Fig. 6. By itself, this view is cool, but isn't useful for figuring out what raster files coincide with what areas. This view also reveals the spottiness of the current release of ArcticDEM. So, in the ToC, right click the Polar\ArcticDEM item, -> Properties -> Display and check the "Display footprints with this symbol" box. The wait for the map to redraw goes way up (see Fig. 6a) – so it is necessary to reduce what is drawn.
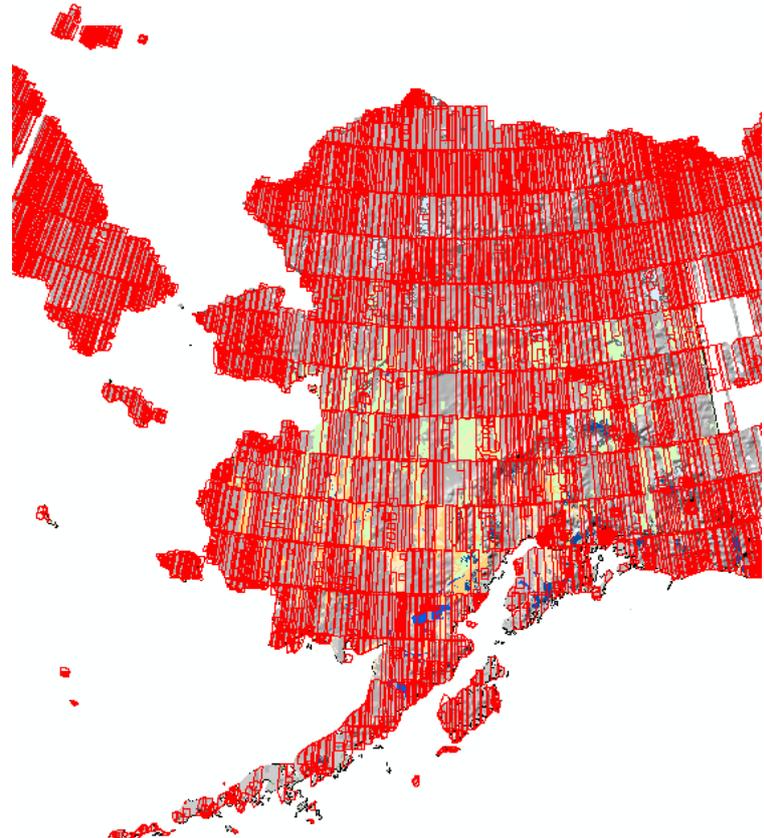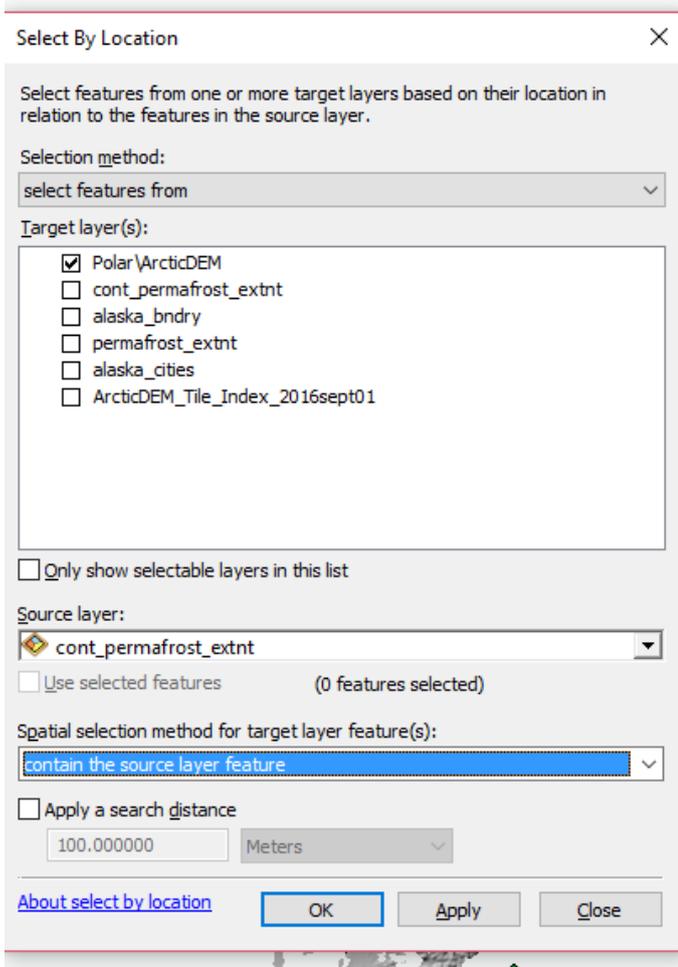
Fig. 7

The next step is to zoom to the independent layer of continuous permafrost and open the Selection -> Select By Location menu, setting it up as in Fig. 7, so that only rasters that are contained within the region of greatest permafrost extent are selected. By doing so when rasters are later downloaded extraneous data doesn't take up space. That said, selecting rasters this way leads to 1800 returns! These 1800 results include many 2 meter resolution strips, and several polygons that are likely leftover from the ArcticDEM workflow and entirely unimportant. The way to amend things further is to go into the Polar\ArcticDEM attribute table and select only 5 meter resolution tiles. These number a much more manageable 185, although consequently coverage is now much reduced – see Fig. 8.

In theory, at this point one could right click on Polar\ArcticDEM -> Data -> Download Selected Rasters, but that option remained greyed out for whatever reason. The workaround is to create a new layer from selection, go into the attribute table, copy the 185 URLs to the rasters in question, and to use a program like uGet (a batch downloader) to download the data.
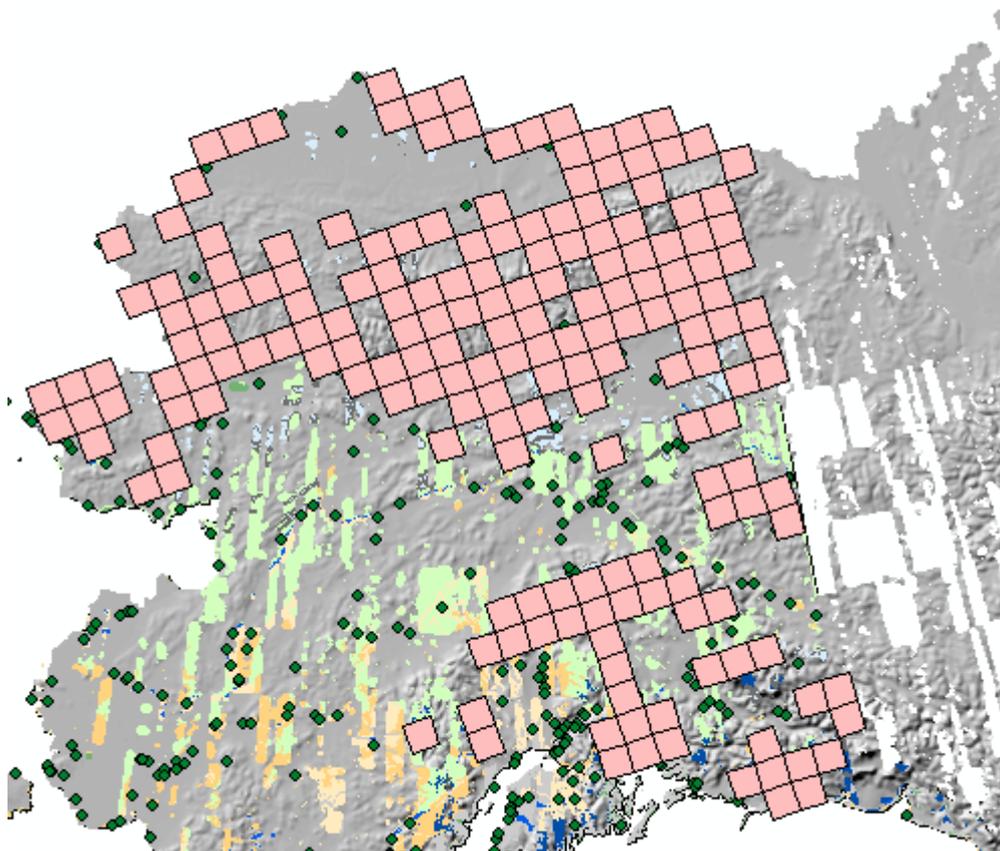
Fig. 8

Once uGet finishes and the rasters are extracted from their .tar files (in this instance all through WinRAR) rather than add each raster to ArcMap the easy alternative is to make a Mosaic Dataset (Fig. 9a) to display and work with the large number of rasters. To do so requires launching ArcCatalog, right clicking in the geodatabase where work is being done, -> New -> Mosaic Dataset. Once that's done, it's necessary to right click the new Mosaic Database and select
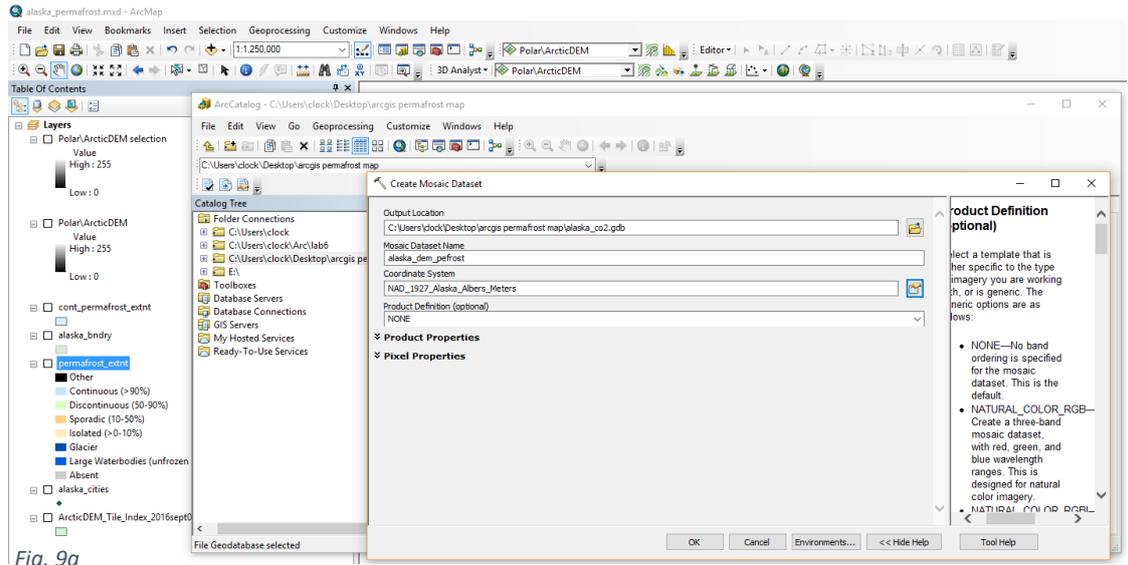
Fig. 9a

Add Rasters to Mosaic Dataset and to select the newly extracted rasters. At first, if the "Update Overviews (Optional)" box isn't ticked (as in Fig. 9b) no rasters will display. It's necessary to use the Build Overviews tool on the Mosaic Dataset such that it will display what
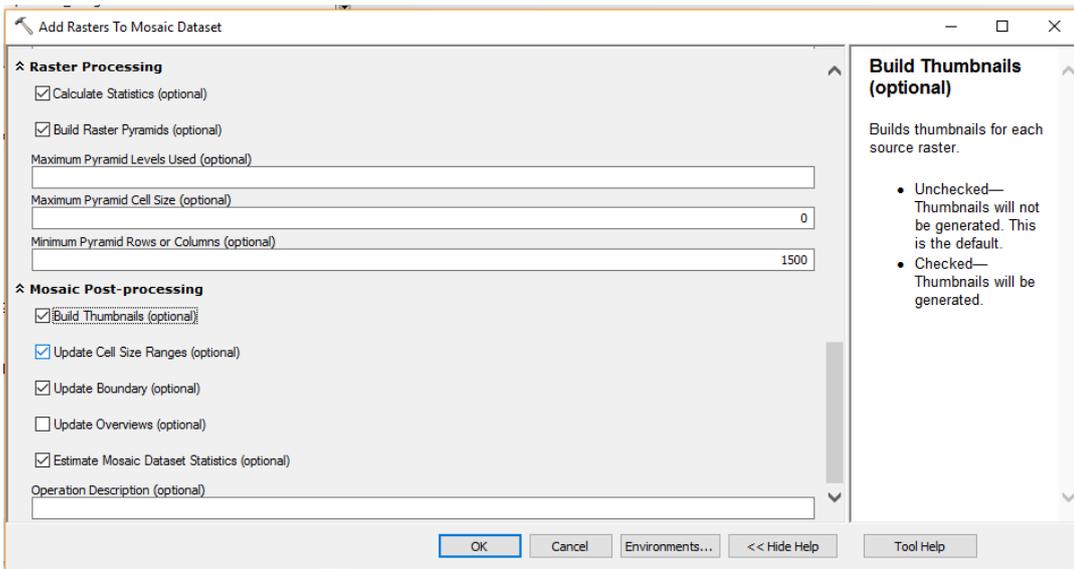
Fig. 9b
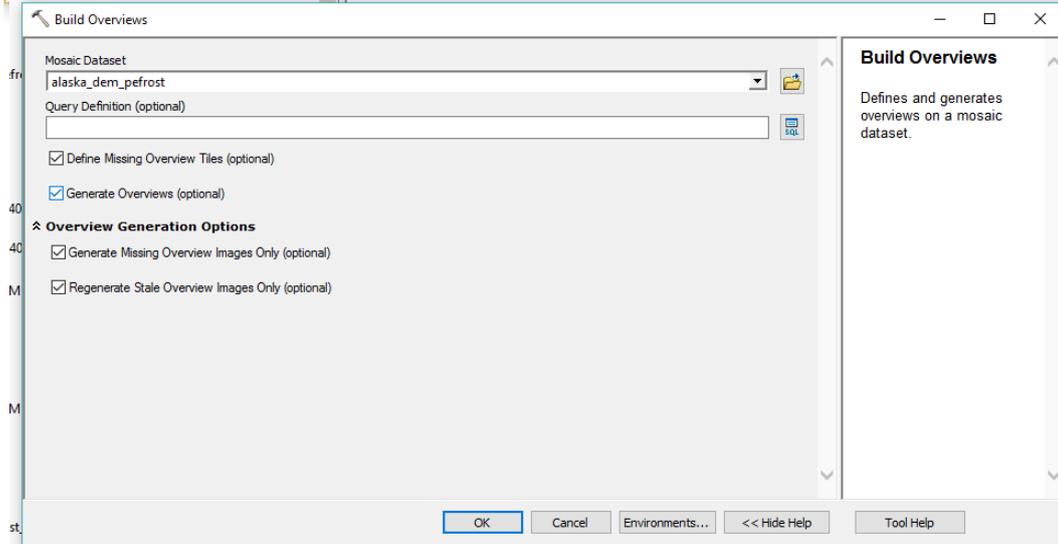
Fig. 9c

are essentially thumbnails in ArcMap (Fig. 9c).
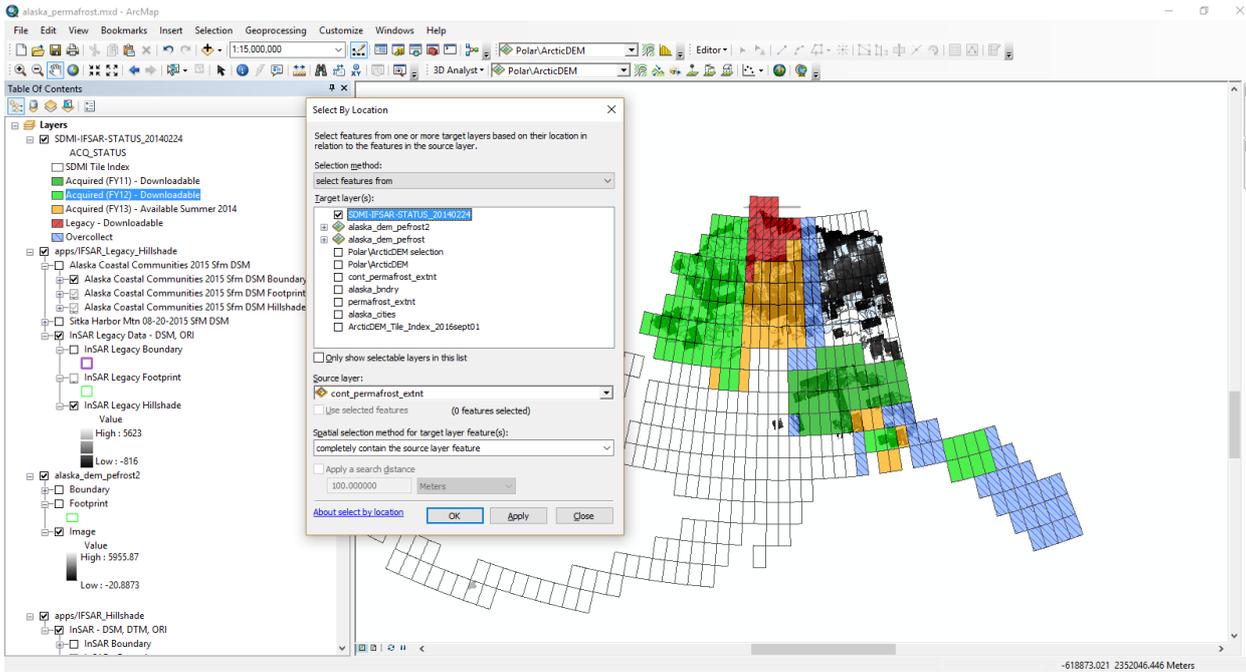
Fig. 10a

Next, it is necessary to add the IfSAR ArcGIS Image Server file and to essentially repeat the previous process. The IfSAR data is much smaller in scope and is presented as a series of DEM footprints (Fig. 10a). The color coding corresponds roughly to an area's year of collection (Fig. 10b). Going into the Selection menu, and repeating the

Fig. 10b

setup as in Fig. 7 with the continuous permafrost extent but for the IfSAR raster tiles, gives a return of 30 rasters collected in 2012 – 3 to 4 years separate from the ArcticDEM collection dates in 2015 and 2016. Tiles in red and orange in Fig. 10a were not available for download. Again, the option to download rasters from selection seems to be nonfunctional, so it's necessary to copy the URLs to the files needed (Fig. 10c) and feed them into a batch downloaded (in this instance uGet again).

Once downloaded, the process of extracting and then producing a Mosaic Dataset, generating Overviews, and adding the Mosaic Dataset to ArcMap are the same.
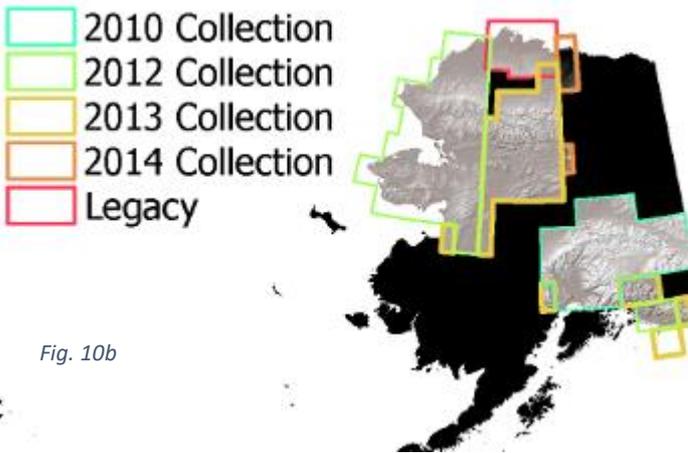
Both sets of rasters (ArcticDEM and Alaska IfSAR) are 5 meter resolution, and running several random pairs through Raster Compare from the Data Management toolbox finds no differences. Prior to attempting any raster operations (which is possible with Mosaic Datasets) the IfSAR and ArcticDEM Mosaics were clipped to each

Fig. 10c

other (Fig. 11a) to clean up the map and reduce the number of extraneous raster overviews being rendered. At this point the plan was to generate a mosaic from the subtraction of the 2012 IfSAR rasters from the 2015-2016

Fig. 11a

through a simple Raster Calculator function (Fig. 11b). However, this failed, persistently (Fig. 11c), and resisted attempts at trouble shooting – such as forcing geoprocessing to run in the foreground.
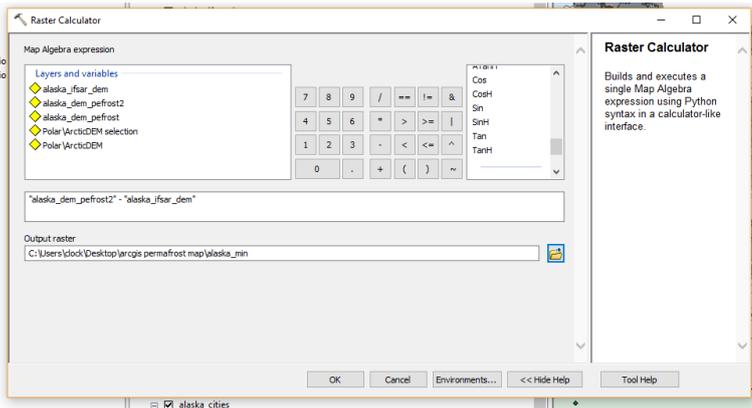
Fig. 11b
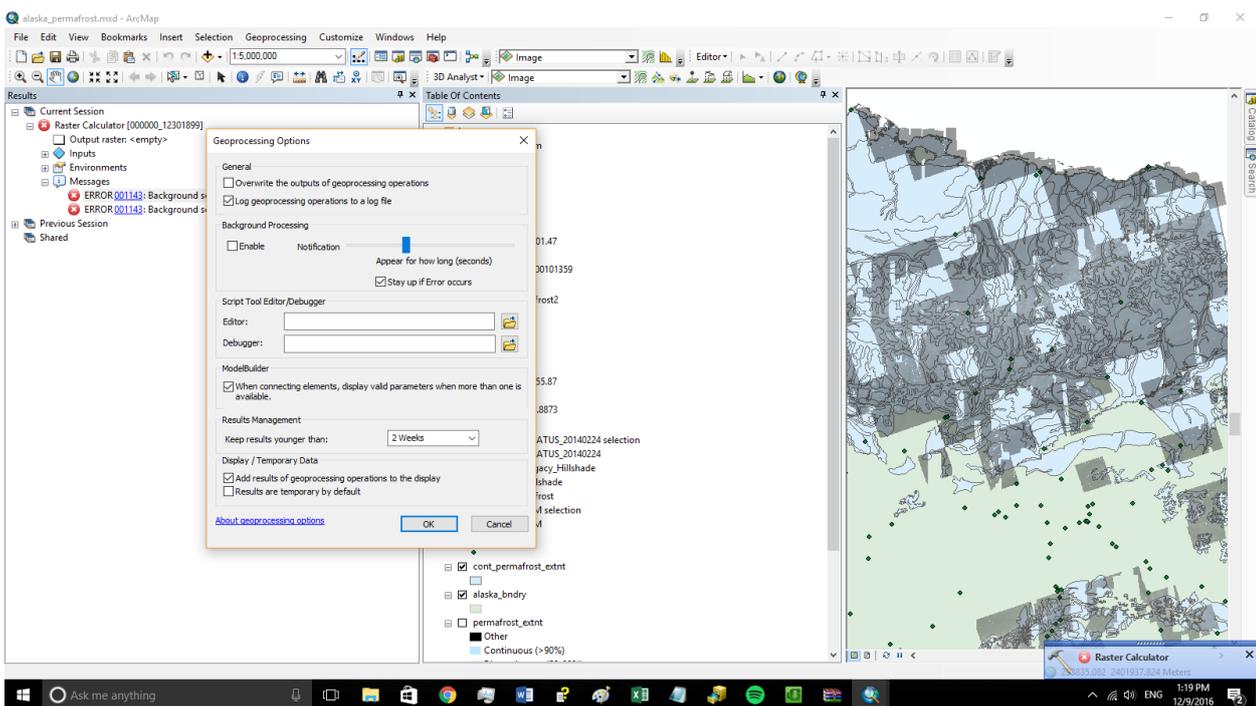
Fig. 11c

Having hit such a roadblock, the project again changed scope. Rather than quantifying the entirety of overlap between IfSAR and ArcticDEM data in northwestern Alaska an overlapping set of 4 IfSAR and 5 ArcticDEM rasters were chosen for closer analysis (Fig. 12 – IfSAR in lavender boxes, ArcticDEM in green wireframe). These rasters were chosen for a few reasons: they were at least 20 km away from any human settlement (hopefully outside any dense human population center), 300 km from the coast (away from the ocean's direct influence on ground temperature), and were in general one of few large patches that represented a coincidence of IfSAR and ArcticDEM data.
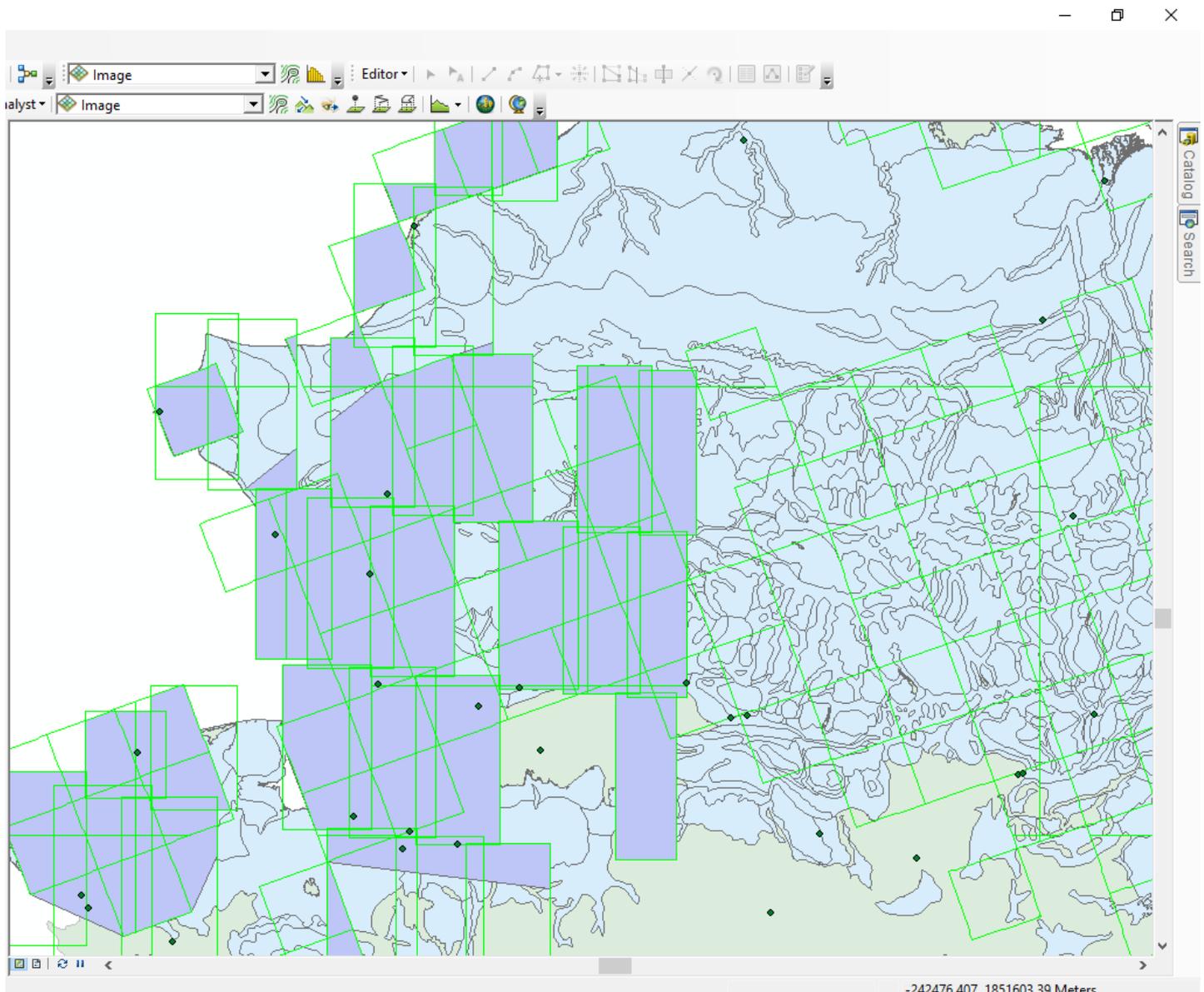
Fig. 12 IfSAR in lavender boxes, ArcticDEM in green wireframe, dark green dots are cities and towns

Fig. 13 ArcticDEM in red, IfSAR in blue
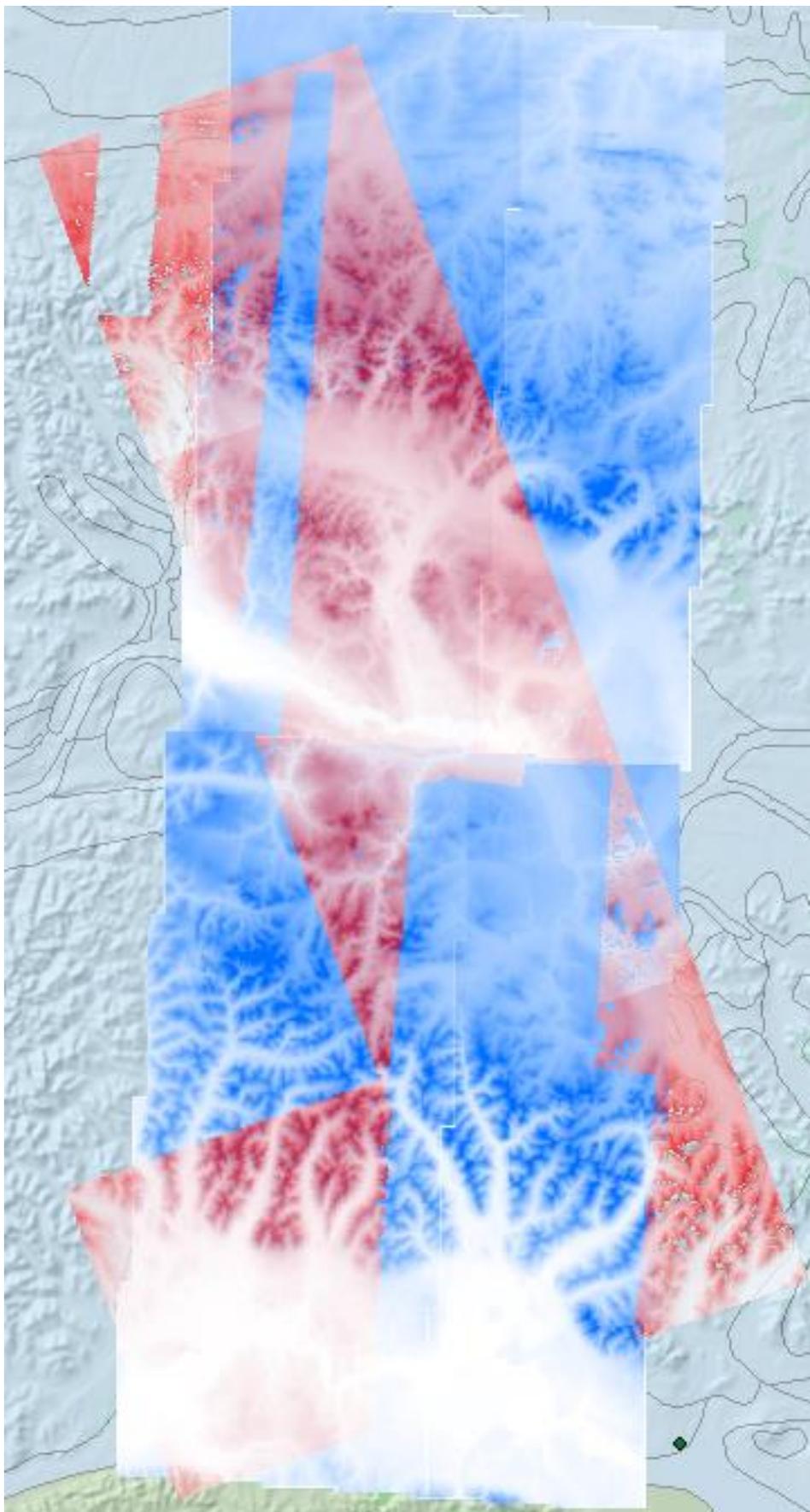
So identified, the rasters were added individually into ArcMap and symbolized (Fig. 13).

From there, using the Raster Calculator on pairs of overlapping rasters to subtract IfSAR elevation data from ArcticDEM data where the two overlapped, 5 rasters were generated (Fig. 14) and symbolized according to geometric intervals (Fig. 14b). Positive values (in dark green) corresponding to increased elevation, and negative (in purple) corresponding to decreased elevation.
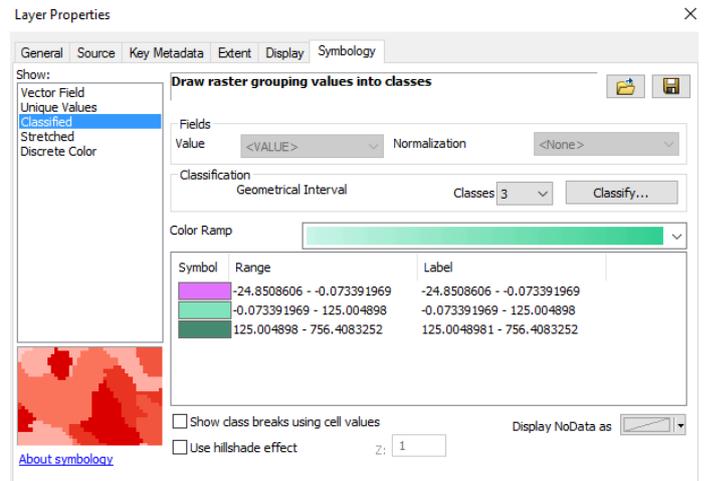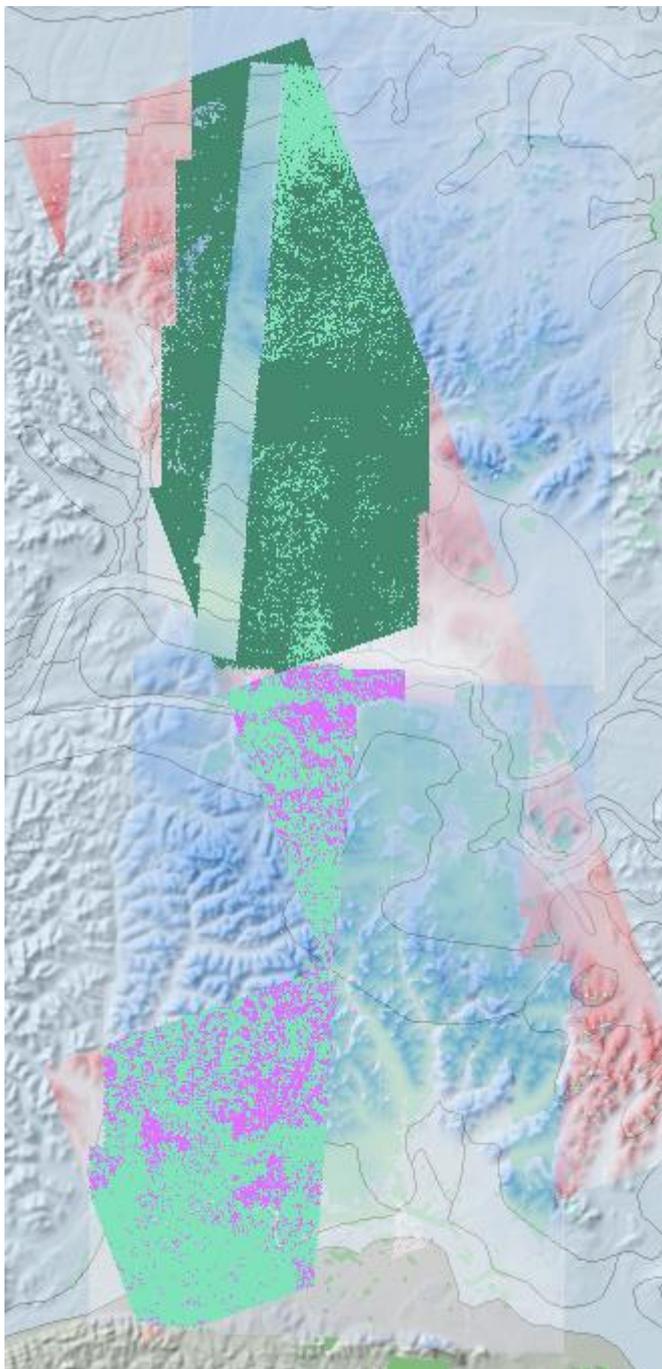
Fig. 14b

Fig. 14a ArcticDEM in red, IfSAR in blue, calculated DEMs in dark green, light green, and purple

The 3D Analyst Tool Stack Profile (which generates a profile from multiple 3D segments across multiple topographies) was used in conjunction with a new feature class called profile_line (Fig. 15a) drawn through areas of ArcticDEM and IfSAR overlap to generate Fig. 15b.
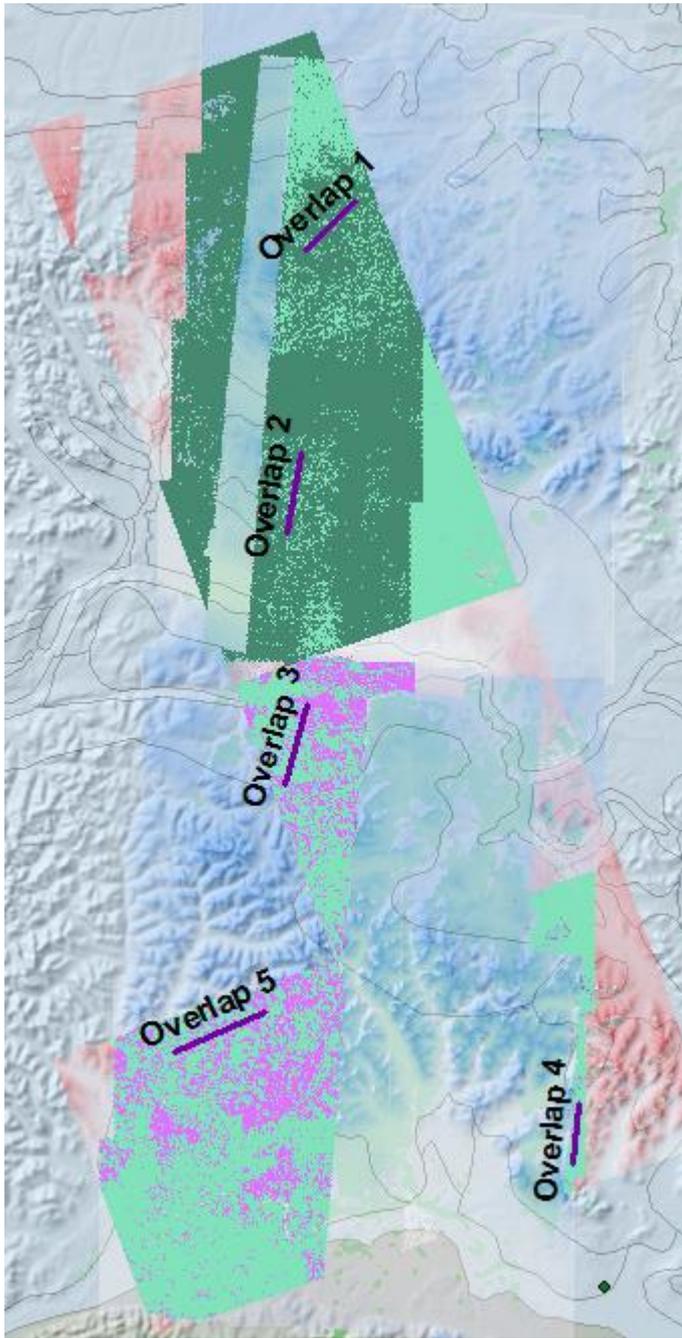
Fig. 15a
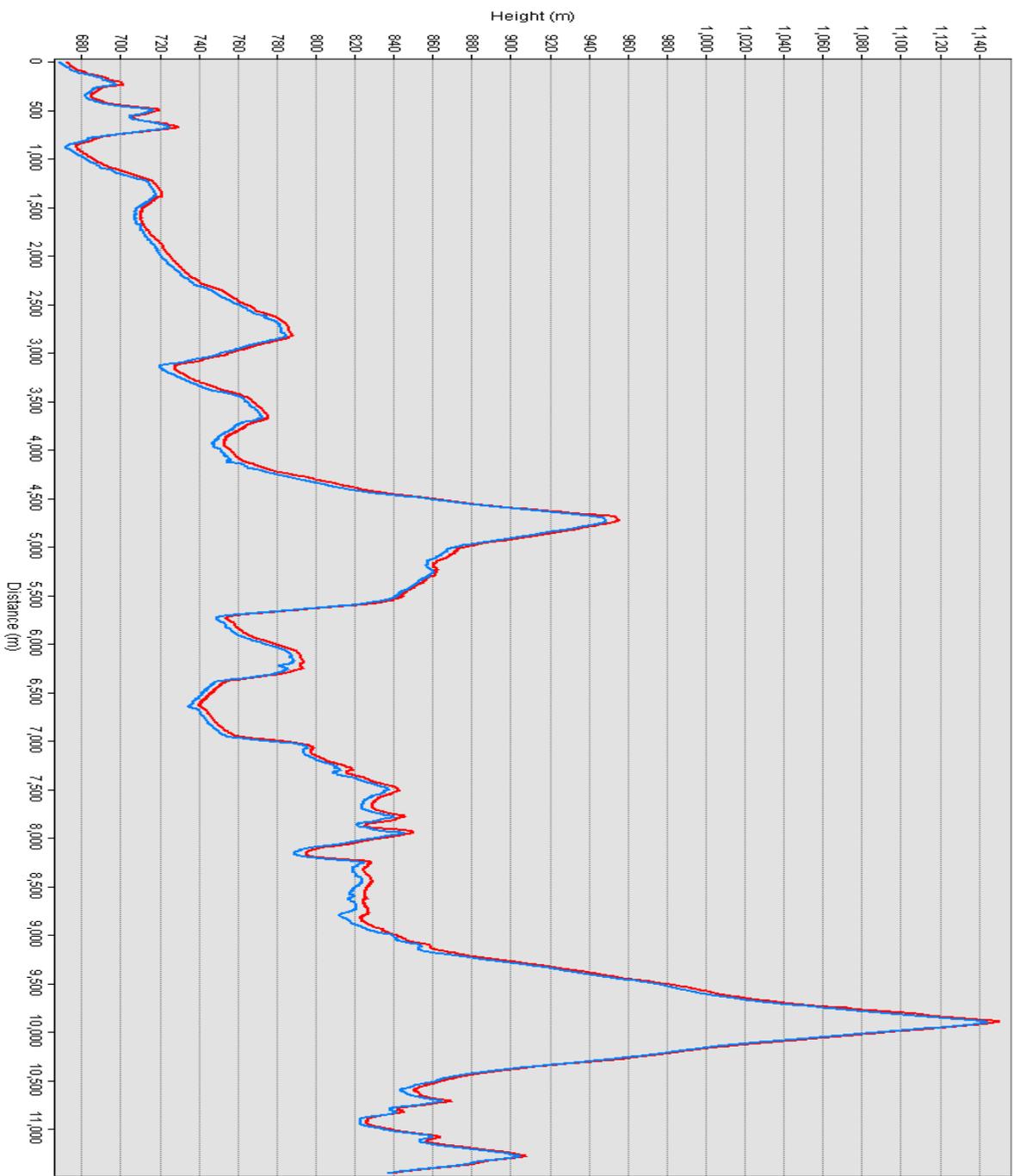
Fig. 15b – Elevation profile over ArcticDEM in red, elevation profile over IfSAR in blue.

Conclusions
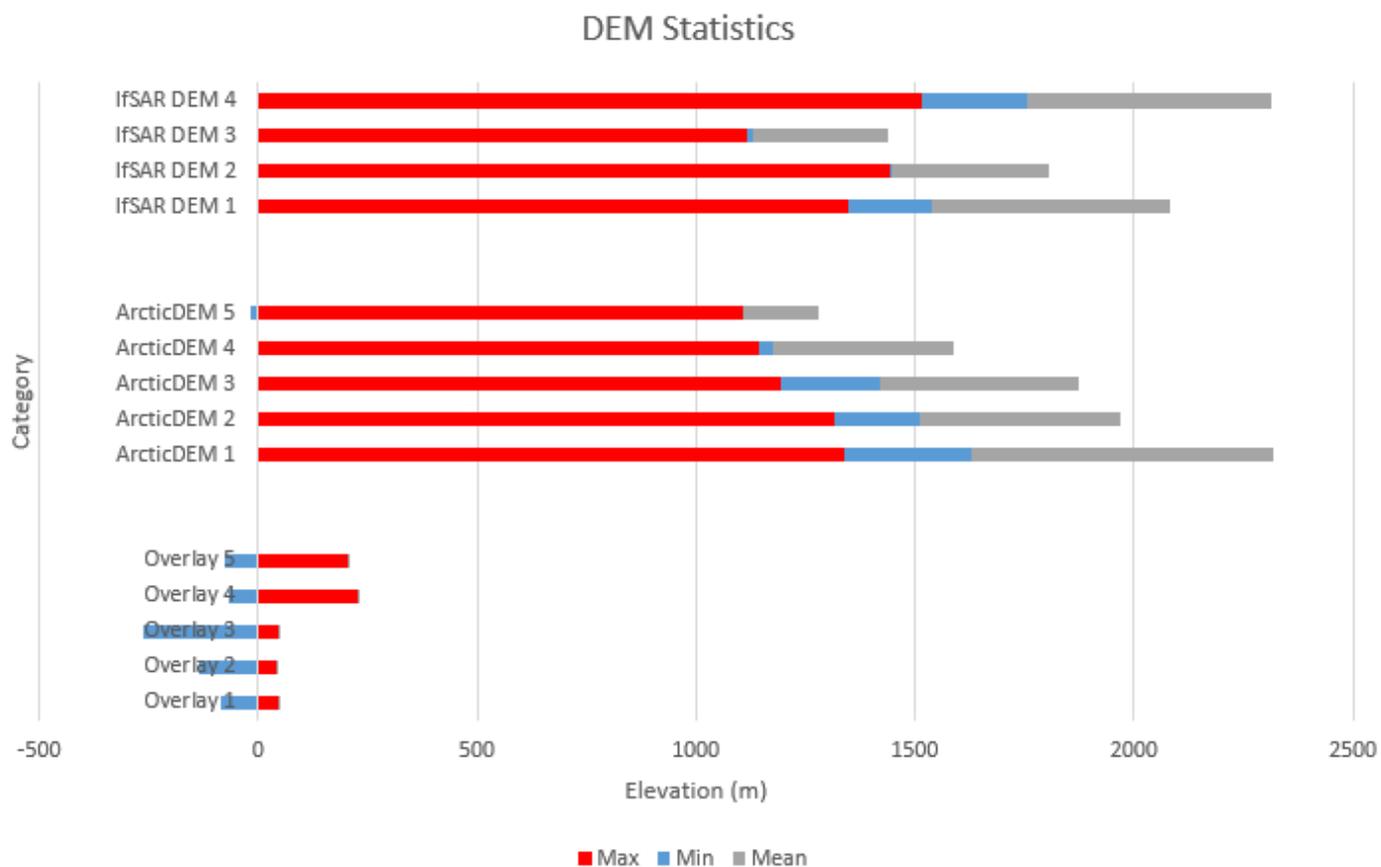
Fig. 16a

Overlay 1-	Max	Min	Mean
Overlay 1	46.39	-83.03	4.22
Overlay 2	41.82	-136.76	3.04
Overlay 3	44.7	-259.67	3.68
Overlay 4	227.09	-64.8	3.88
Overlay 5	206.42	-76.27	3.93
2015-2016 ArcticDEM			
ArcticDEM	1340.72	287.38	689.51
ArcticDEM	1316.187	195.66	456.81
ArcticDEM	1191.65	229.52	453.71
ArcticDEM	1142.78	31.1	413.7
ArcticDEM	1107.33	-16.09	173.06
2012 IfSAR DEM			
IfSAR DEM	1347.43	190.1	543
IfSAR DEM	1442.08	4.83	360.12
IfSAR DEM	1117.04	11.46	307.95
IfSAR DEM	1513.81	240.11	560.56

Fig. 16b

The resultant rasters derived from subtracting 2012 data from 2016 data indicate a general trend of increasing elevation in this locality – of around 3.75 meters. However, there exist several avenues through which this could be erroneous. It could be that Interferometric synthetic aperture radar by its nature is more prone to getting slightly higher elevation returns when processed than satellite-derived elevation data, or that one method used a different

geoid to arrive at elevation. Differences in season of imaging could also be a culprit, increased elevation being because of tress or heavy snow, although IfSAR documentation says data were collected in the summer of 2012.

Another possibility is human error in importing DEMs - that an error was made in the vertical scaling somewhere, although Raster Compare found rasters from both datasets identical in resolution and units.

In terms of this result being legitimate, it could be that areas of continuous permafrost that aren't being directly influenced by ocean currents are relatively hardy and foster snowpack growth to some extent. It could also be that northern Alaska is faring better than the more heavily populated south in terms of permafrost-driven subsidence, as the south is also in general where permafrost is less continuous in the subsurface. There are many variables to explore in this complex problem, and further examination of data (perhaps culling extraneous values or starting from raw data) could lead more precise results.

References

Permafrost Characteristics of Alaska , Jorgenson et al, 2008.
http://permafrost.gi.alaska.edu/sites/default/files/AlaskaPermafrostMap_Front_Dec2008_Jorgenson_etal_2008.pdf

ArcticDEM Documentation and User Guidance
http://www.pgc.umn.edu/system/files/ArcticDEM%20Documentation%20and%20User%20Guidance%20-%20Latest.pdf

Permafrost | Weather Underground https://www.wunderground.com/climate/permafrost.asp?MR=1