

Characterizing Pyroclastic Density Currents from the 1980 Mount St. Helens Eruption, WA through Analyses of Standing Trees

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Abstract: The eruption of Mount St. Helens in 1980 is characterized by a large, lateral moving pyroclastic density current. Within the blowdown zone, where trees were burnt, toppled over, and destroyed, the PDC appeared to have travelled over certain trees, leaving them standing. These trees were protected from the PDC by hills that acted as a barrier for the pyroclastic density current to overcome. Due to these standing trees, it is suggested that the PDC temporarily detached from the ground and was suspended within the air for an amount of time, flowing over the trees and thus not destroying them. Distance from the center of the volcano, hill elevation, and slope direction can play a role in hindering PDCs and thus influence their internal dynamics. Here, I look at these three factors and determine whether or not they affect PDCs.

I. Problem

The 1980 eruption of Mount St. Helens consisted of a large pyroclastic density current (PDC) that moved laterally away from the center of the volcano. Conifer trees that fell within the path of the PDC were toppled over and burnt due to the impact of the eruption. However, patches of trees remained standing since they were located behind a hill that acted as a barrier from the PDC. Trees are still standing in these patches due to the reason that the PDC left the ground for a period of time in order to travel over the hill (Gardner et al, 2018). Through analysis of these standing trees and their proximity to the center of the eruption, we can better constrain PDCs.

My hypothesis is that the PDC from the Mount St. Helens eruption can be characterized through the determining relationships between the number of standing trees and (1) distance traveled from the center of the volcano, (2) hill elevation (hills act as barriers to PDCs), and (3) hill slope azimuth. By analyzing the amount of standing trees in patches of somewhat equal areas, I can be able to determine how the above factors influence PDCs in order to better understand their properties.

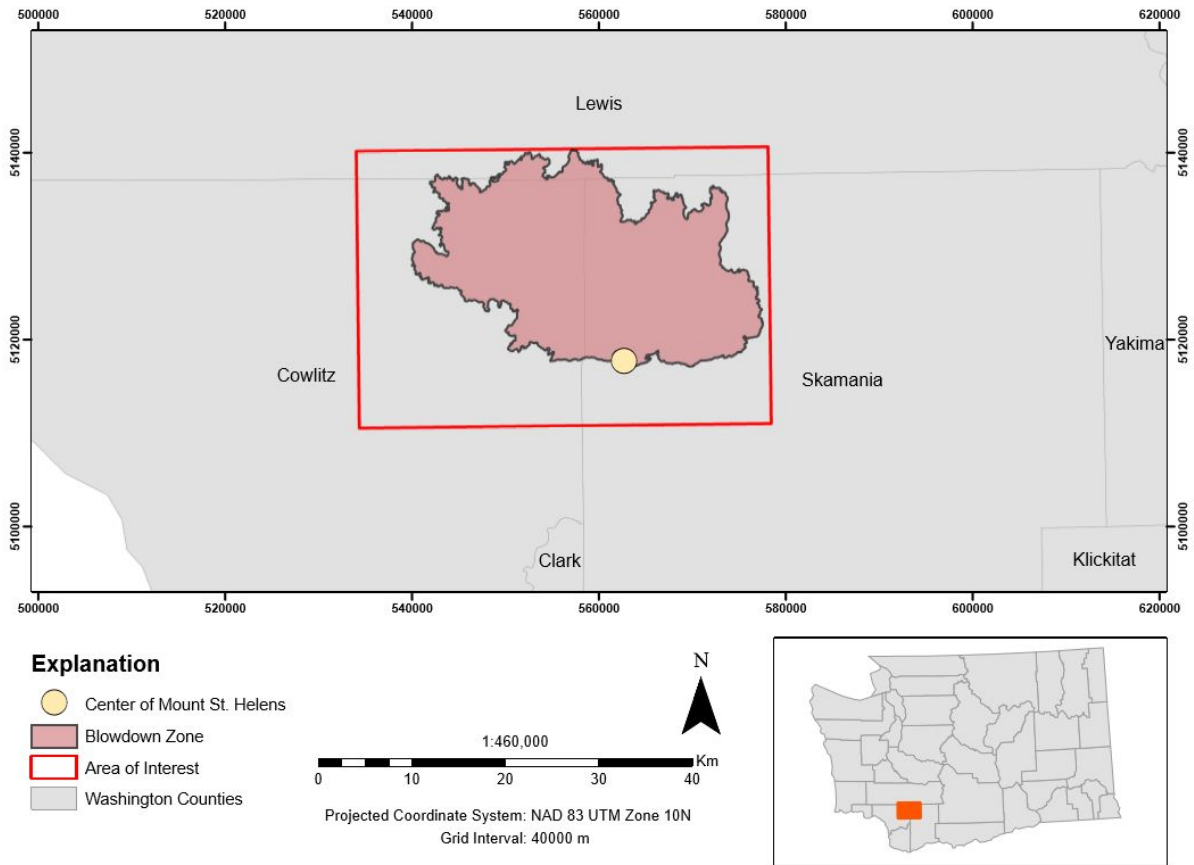


Figure 1. Location map of Mount St. Helens created using the Washington county boundaries shapefile from the Washington DNR GIS Database.

II. Data Collection

For this project, I assisted Nicole Guinn in her Master’s Thesis in analyzing the orientation of trees blown-down by the 1980 Mount St. Helens eruption and what these orientations tell us about the impact of the eruption. I was given a Data Elevation Model (DEM) of Mount St. Helens (Source: Washington 30-m DEM by USGS quad), 19 aerial images taken after the eruption (Source: USGS EarthExplorer), and data from Dr. Jim Gardner’s personal geodatabase. The files I used within Dr. Gardner’s geodatabase are the Blowdown.shp, center.shp, clipping_box.shp, and the lee_sides.shp. I obtained the Washington State Boundary Shapefile and the Washington County Boundaries Shapefile from the Washington DNR GIS Database to create the location map and inset maps.

III. Data preprocessing

To begin this project, I needed to process my data in order use them for analysis in ArcGIS. The Data Frame I created was in a projected coordinate system, most specifically NAD 1983 UTM Zone 10N. Using the DEM, I created a hillshade raster using the Hillshade tool within the Spatial Analyst Toolbox. Tree patches were located in the lee_sides.shp file within Dr. Gardner's geodatabase. I used these two layers to georeference the aerial images to the hillshade raster to accurately constrain the patches of trees. First, I would locate the aerial photo on the hillshade raster, place control points (4 at the most) from the image to the hillshade, and then update the georeferencing. I would then turn on the lee_sides.shp file to see if the tree patches actually contained standing trees and then turned on/off control points of the images within the links table located in the georeferencing toolbar to better constrain these patches (Figure 2).

I then created a personal geodatabase with matching coordinates to the Data Frame (NAD 1983 UTM Zone 10N) in order to store the feature classes I would create. Once all images were georeferenced, I created two fairways using a Polygon Feature Class within my geodatabase. The fairways were determined based on where a majority of the patches were located (NE and NW) within the blowdown zone (Figure 2). I then constrained tree patches of similar area by sorting the area of the polygons within the attribute table of the lee_sides layer. Patches 84, 92, 81, 52, 46, 69, and 28 were chosen based on similar areas (Table I). I applied a definition query to the lee_sides layer, so that I would only see the patches of the specified areas within my designated fairways. I then renamed the layer within my table of contents to "patches" to distinguish my specified patches from the rest of the group (Figure 2).

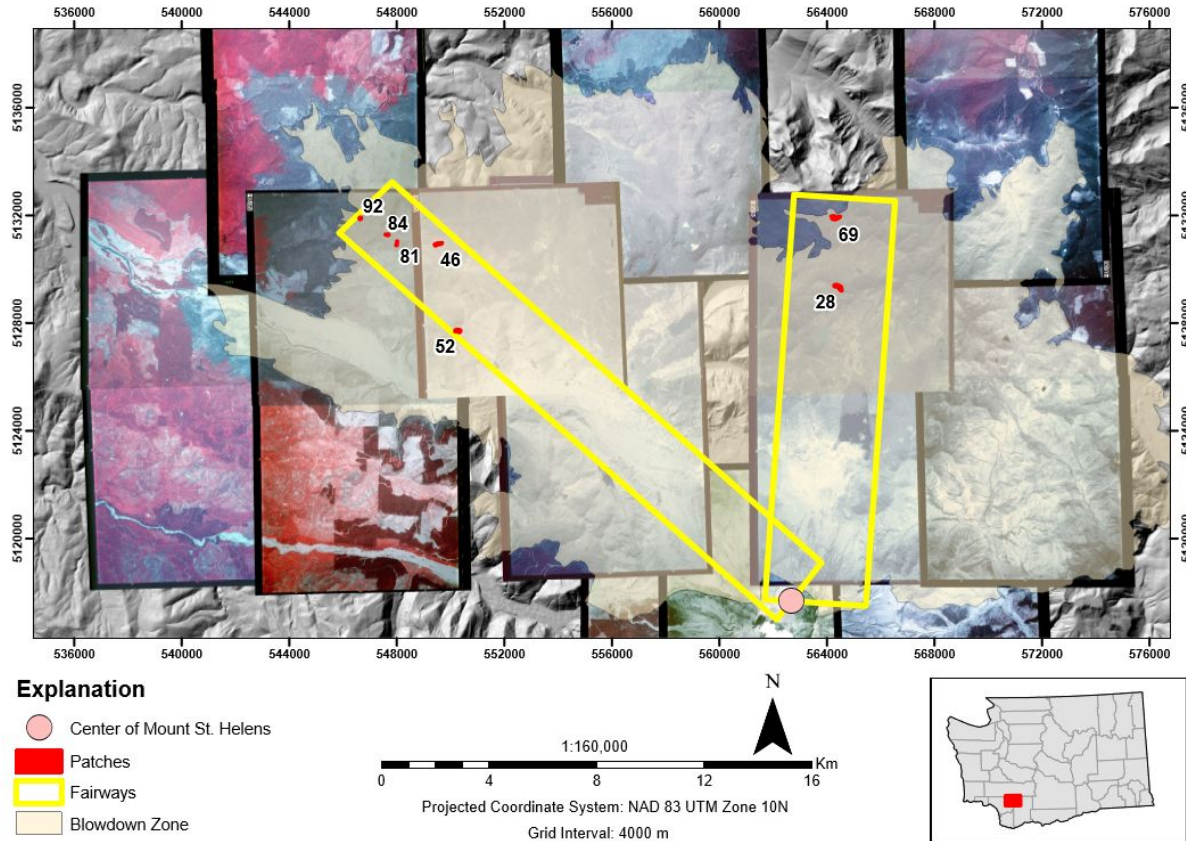


Figure 2. Aerial images (USGS EarthExplorer) georeferenced to a DEM (Washington 30-m DEM by USGS quad). Patches of similar area shown in red within designated fairways.

After the fairways and patches were designated, I began to digitize trees. I created a point feature class (“trees”) within my personal geodatabase and added one field: Patch_Number (Short Integer). To begin, I would start an editing session, select my “trees” layer and then zoom into a patch to start digitizing. To determine standing trees, I looked at the shadows within the patches and clicked to create a point in what I predicted is a standing tree (Figure 3). I then filled in the respective attribute (Patch_Number) within the trees layer attribute table for each tree by only selecting trees within a patch (i.e. Patch 52), changing the view of the attribute table to selected values, and then using the Field Calculator to input values (i.e. “Patch_number = 52”, Figure 4). I repeated this process for the remaining 6 patches.

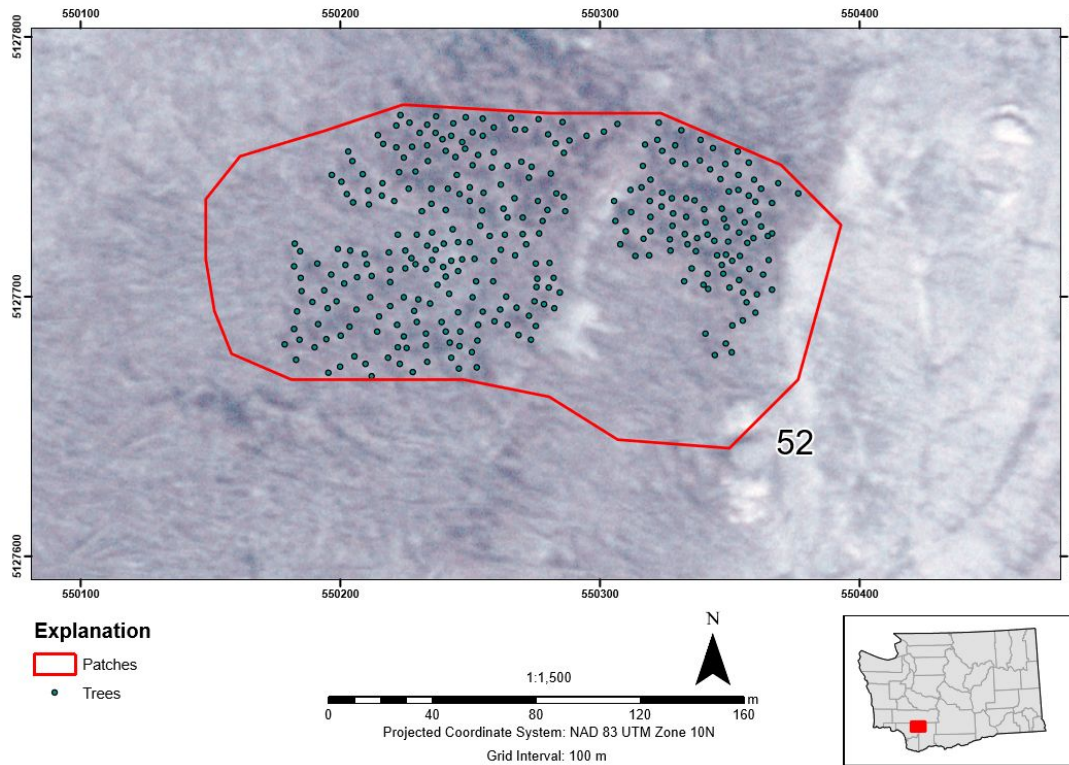


Figure 3. Standing trees shown within Patch #52. Trees were digitized based on shadows and distinguishable treetops from the aerial photos (USGS EarthExplorer).

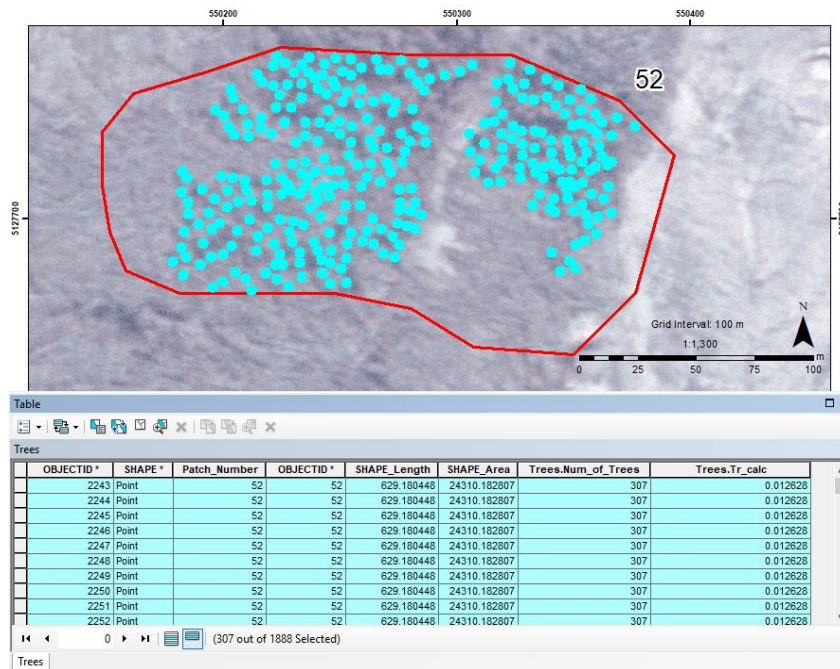


Figure 4. Selection of all trees within Patch 52 and their related attributes.

IV. ArcGIS Processing

With the trees digitized in their respective patches, I was now able to process my data through ArcGIS. First, I wanted to determine the amount of trees within an area of 1 square meter. To do this, I joined the attribute table of the patches layer with the attribute table of the trees layer basing the common value on the patch number (Figure 4) using the Join process within the Joins and Relates menu. Now, in one attribute table (within the trees layer), I created two new data fields: Num_of_Trees (long integer) and Tr_calc (long integer) (Figure 4). I then selected all of the trees within one patch (i.e. Patch 52), switched the view to only selected values within the attribute table, and saw how many values were selected to determine the number of trees within that patch (i.e. 307 out of 1888 selected values for Patch 52, Figure 4). I then used the Field Calculator to input this value (307) for all selected trees within Patch 52 (Figure 4). I repeated this process for the remaining 6 patches. With the number of trees quantified, I was now able to calculate the number of trees per 1 m². In the Tr_calc data field, I used the Field Calculator once again and used the formula: $Trees.Tr_calc = Trees.Num_of_Trees/lee_sides.SHAPE_Area$ to get the number of trees per 1 m² (Figure 4). All values were filled in for every data point (Table 1).

For the factors that would influence PDCs, I wanted to look at the distance between a patch and the center of Mount St. Helens, hill elevation that the patch was located next to or behind, and slope (azimuth). To measure the distance, I used the measuring tool with the units set to km and clipped the first endpoint to the edge of a patch closest to the center and then clipped the second endpoint to the marked center of the volcano (center.shp), double clicking at the center to release the line. I then recorded the distance for all seven patches. In order to simplify the hill elevation so I could be as precise as possible, I created a mask for all seven patches using the Feature Outline Masks tool in the Cartography Toolbox¹. The created masks had around a 30 m perimeter from the patches themselves. These masks were then used to extract raster layers within that 30 m perimeter of the patches. I used the Extract by Mask tool in the Spatial Analyst Toolbox with the hillshade raster as the input raster and “mask_patches” as the feature mask data². This then created a raster of the hillshade within a 30 m perimeter to the original patches. To gather data on the azimuth for the slopes, I created an Aspect from the original DEM using the Aspect tool in Spatial Analyst Toolbox³. I repeated the same process to create a mask as described above for the hillshade, but instead using the aspect raster as the input raster and “mask_patches” as the feature mask data (Figure 6).

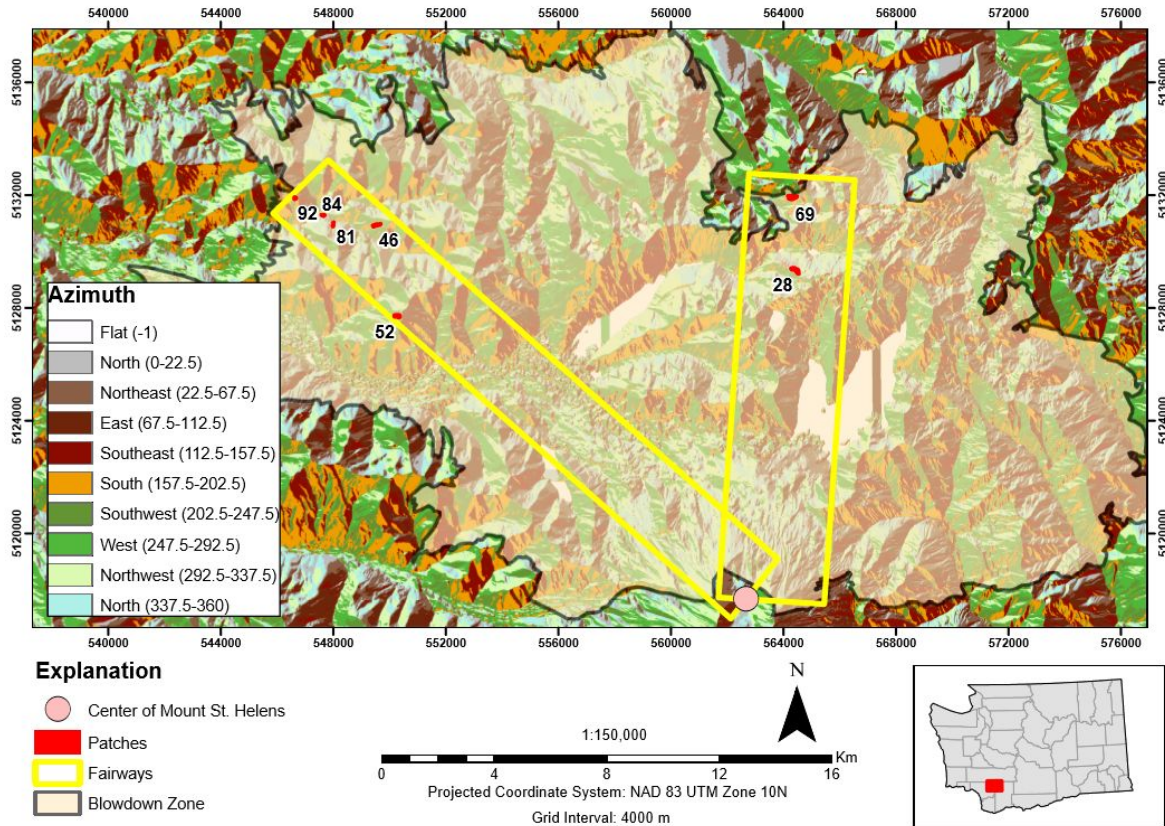


Figure 5. Aspect raster created from the DEM (Washington 30-m DEM by USGS quad).

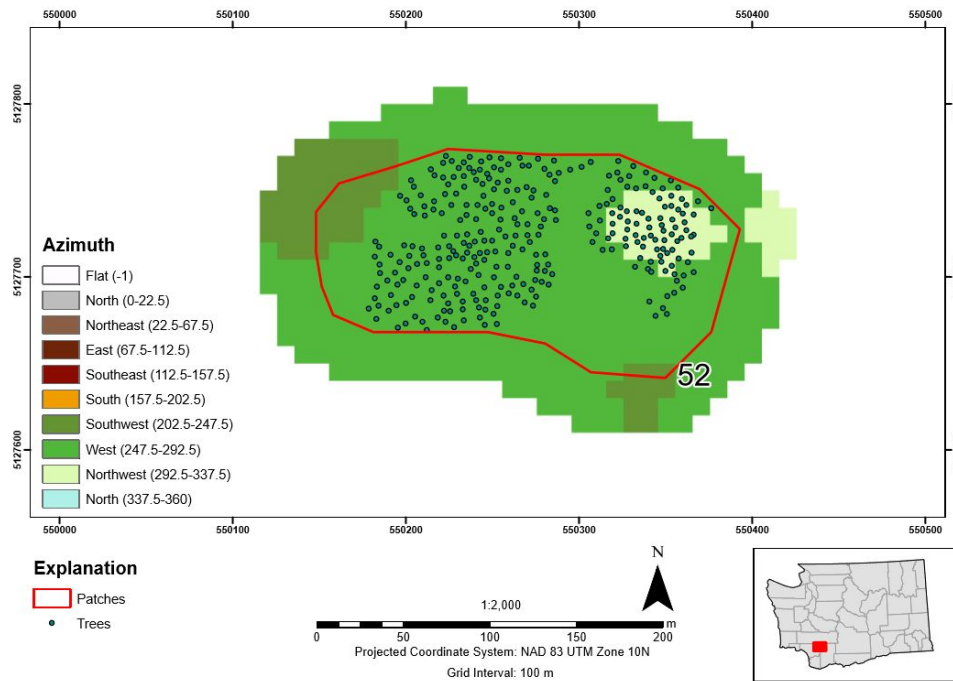


Figure 6. Aspect raster mask extracted within a 30 m perimeter from the original patch.

Now, with all of my created rasters, I could record values for hill elevation and azimuth. For hill elevation, I would center in on a patch with the extracted mask of the hillshade raster behind the patch and the trees, and record the cells with the highest values, focusing on the white cells as these represented the highest elevation, and thus the hilltop. I repeated the same process for the extracted aspect raster, focusing on the slopes that were located right on the lee side of the hills (Figure 6). However, I quickly noticed that all patches had various azimuth values that would equate to different directions. In focusing on the side of the patch closest to the lee side of the hills, I was able to narrow the azimuths to two directions at the most, and typically, the azimuths would fall within a similar range of directions (i.e. Patch 92 had a slope direction of SW and S, Table II). Since I was able to narrow down the azimuths to two directions for all patches, I then took the average using the lowest degree value and adding it to the highest degree value. This way, I was able to get a value that fell in the general orientation of the range of azimuths.

V. Data

The number of trees/m² for all seven patches is seen below in Table I. The trees were digitized within each patch based on shadows and aerial imagery. To get the number of trees/m², the total number of trees was divided by the area of the patch. Table II shows the three factors that were taken into account when attempting to constrain PDCs.

Patch Number	Fairway Direction	Total Number of Trees	Area (m ²)	Trees/m ²
92	NW	191	8632.748716	0.022125
84	NW	348	8518.685701	0.021013
81	NW	138	8931.326661	0.015451
52	NW	307	24310.18281	0.012628
46	NW	413	24534.25673	0.016834
28	NE	442	38885.38098	0.006763
69	NE	397	38856.89626	0.010217

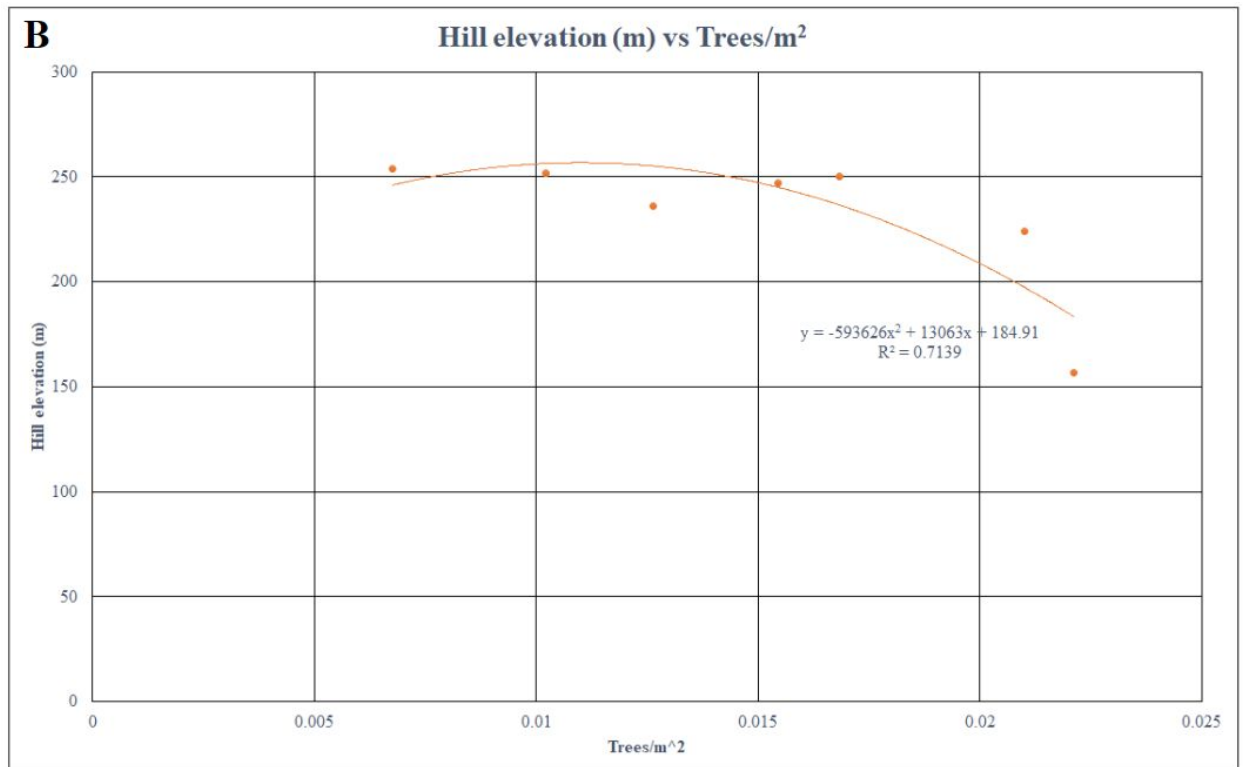
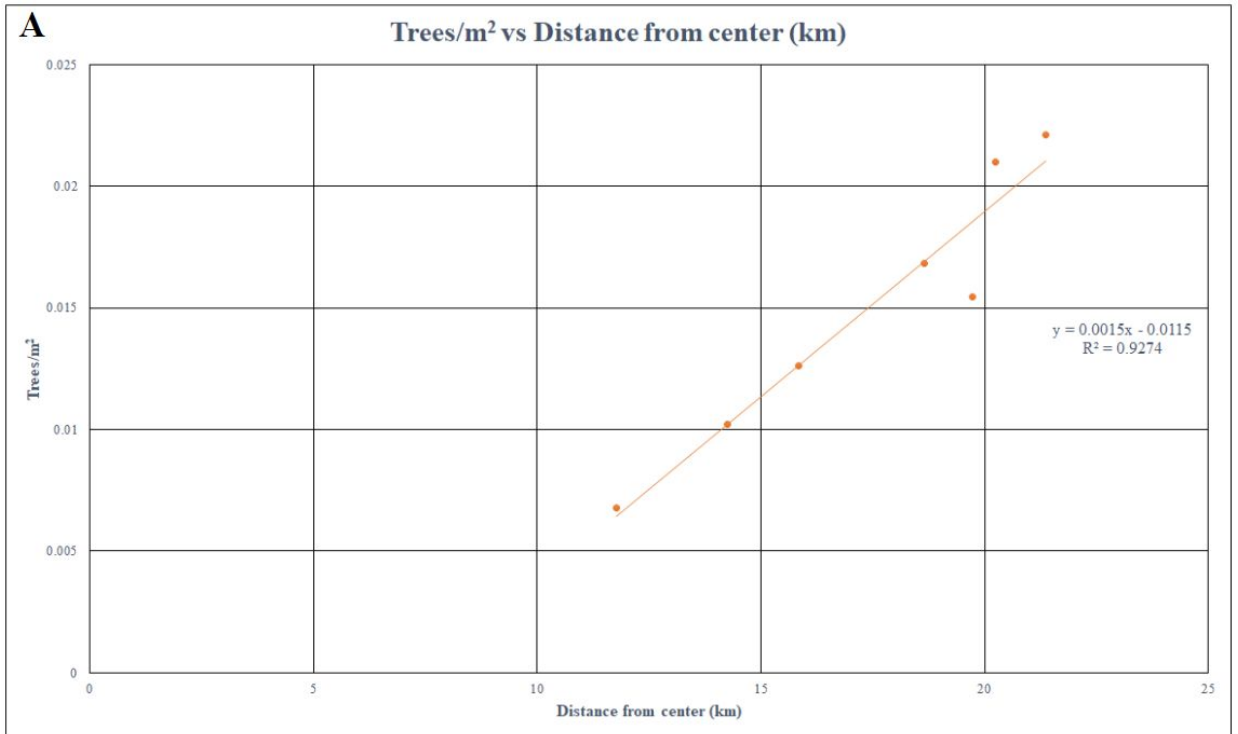
Table I. Table shows values used to calculate the number of Trees/m².

Patch Number	Distance from center (km)	Hill elevation in meters (DEM)	Slope direction (taken from Aspect raster)	Slope direction (averaged)
92	21.372053	157	Southwest, South	202.5
84	20.248572	224	North, Northeast	33.75
81	19.717424	247	Northwest, North	326.25
52	15.854978	236	West	270
46	18.650203	250	Northwest, West	292.5
28	11.76572	254	North, Northeast	33.75
69	14.252397	252	Northwest, West	292.5

Table II. Distance from the center of the volcano (km), hill elevation (m), and slope direction were used to determine if a relationship existed between these factors and the number of trees/m².

V. Analysis

The following plots show the three factors plotted against trees/m² in order to determine if a relationship exists to characterize PDCs. In Figure 7A, the relationship between trees/m² and the distance from the center of the volcano is linear ($R^2 = 0.9274$). This is to be expected as PDCs weaken as they move further away from their source; therefore, more standing trees are to be expected further away from the volcano. A second order polynomial relationship ($R^2 = 0.7139$) somewhat exists between hill elevation (m) and the number of trees/m² (Figure 7B) where the number of trees/m² decreases with a decrease in hill elevation. A decrease in hill elevation would provide less of a barrier for the PDC to encounter, and thus more trees have the potential to be knocked down and burned. No relationship appears to exist between the azimuth and the number of trees/m² (Figure 7C).



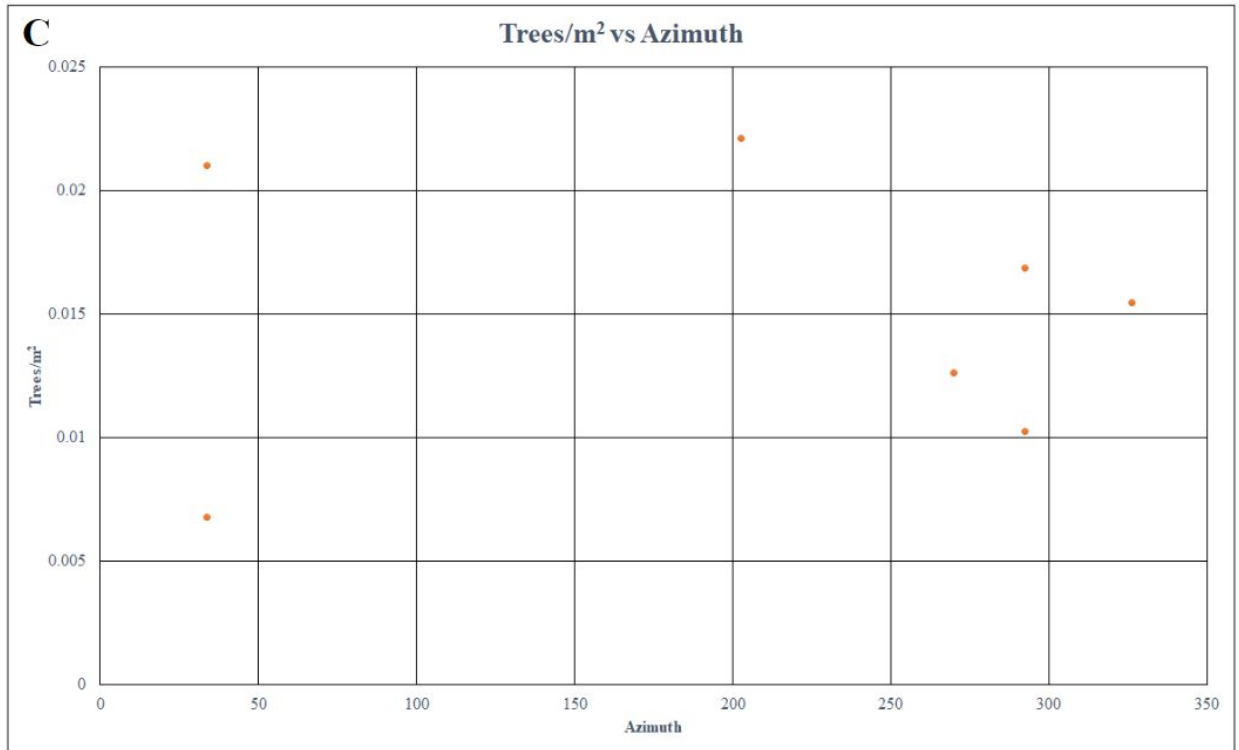


Figure 7. (A) Plot of Trees/m² vs Distance from center (km) shows a linear relationship ($R^2 = 0.9274$). (B) Plot of Hill elevation (m) vs Trees/m² shows a second order polynomial relationship ($R^2 = 0.7139$). (C) Plot of Trees/m² vs Azimuth shows no relationship.

VI. Conclusion

There is still a lot more work to be done to constrain pyroclastic density currents. Through analysis of what they destroyed, we can better understand their characteristics. Likewise, we can analyze what PDCs did not destroy - standing trees - to further focus in on how they behave. Through ArcGIS, I was able to determine whether or not certain relationships existed that would influence PDCs: (1) PDCs weaken as they move further away from the source due to the fact that most of their volume was deposited at beginning of the eruption - closest to the center of the volcano, (2) PDCs lose contact with the ground when overcoming barriers such as hills - the steeper the hill, the longer the PDC is suspended strictly within the air, and (3) there is no relationship between the azimuth of hillslopes and PDCs.

Further work can include focusing in on the relationship between hill elevation and PDCs to determine a time constraint that PDCs leave the ground locally to see if the amount of time that PDCs are suspended affects the strength of the flow as it moves away from its source.

References:

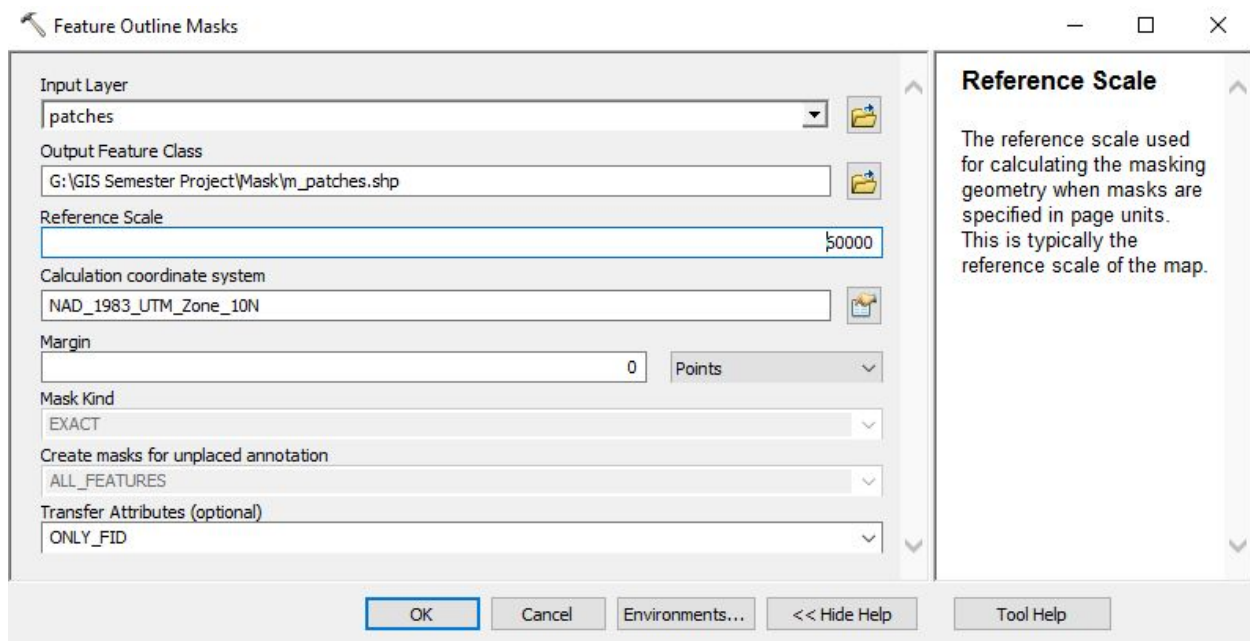
Gardner, J. E., C. Nazworth, M. A. Helper, and B. J. Andrews, 2018, Inferring the nature of pyroclastic density currents from tree damage: The 18 May 1980 blast surge of Mount St. Helens, USA: *Geology*, 46 (9): 795-798. doi: <https://doi.org/10.1130/G45353.1>

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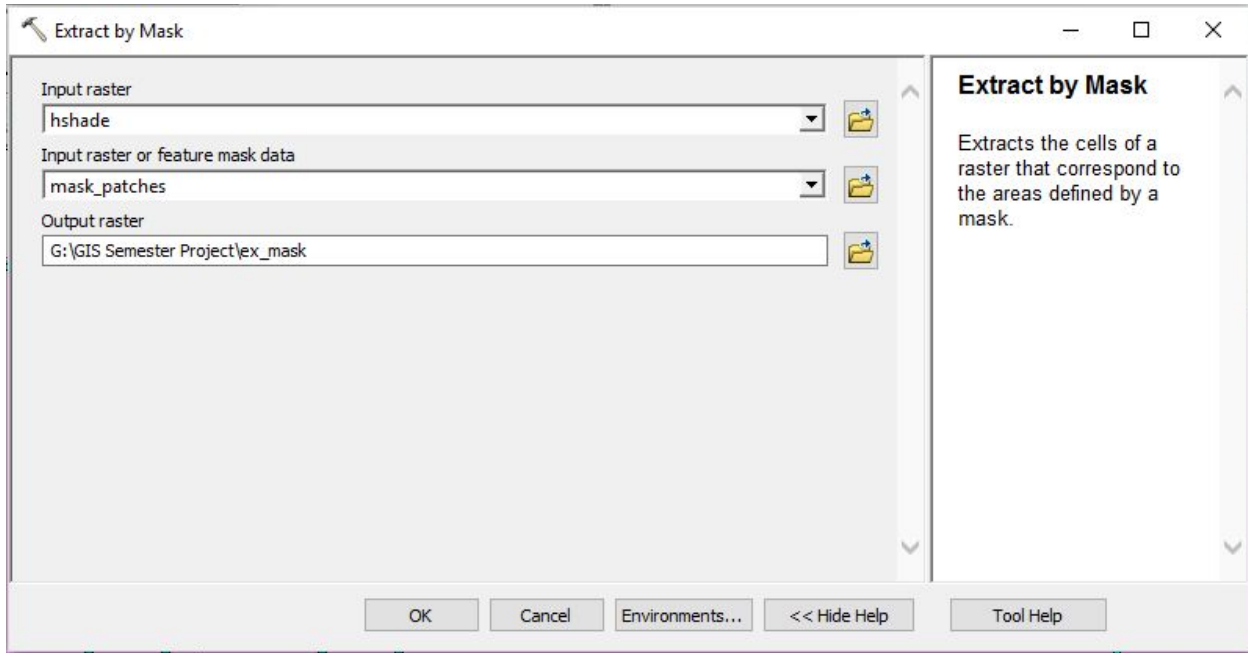
USGS EarthExplorer, Aerial photos of Mount St. Helens, Accessed 24 November 2018.

Washington State Department of Natural Resources, CADASTRE.JURISDICTION, 16 July 2018. <http://data-wadnr.opendata.arcgis.com/datasets/wa-county-boundaries?geometry=-134.692%2C44.623%2C-106.985%2C49.839>

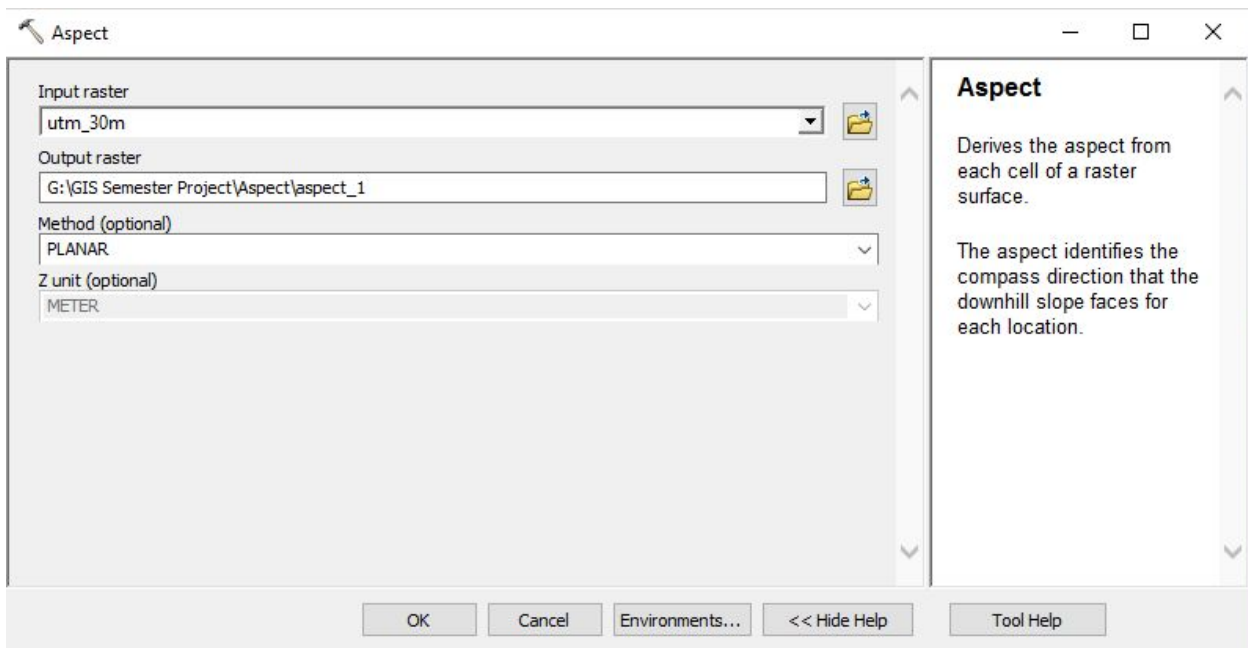
Appendix Images:



1. Feature Outline Mask tool used to create masks of the patches to be used for extracting the hillshade and aspect raster layers.



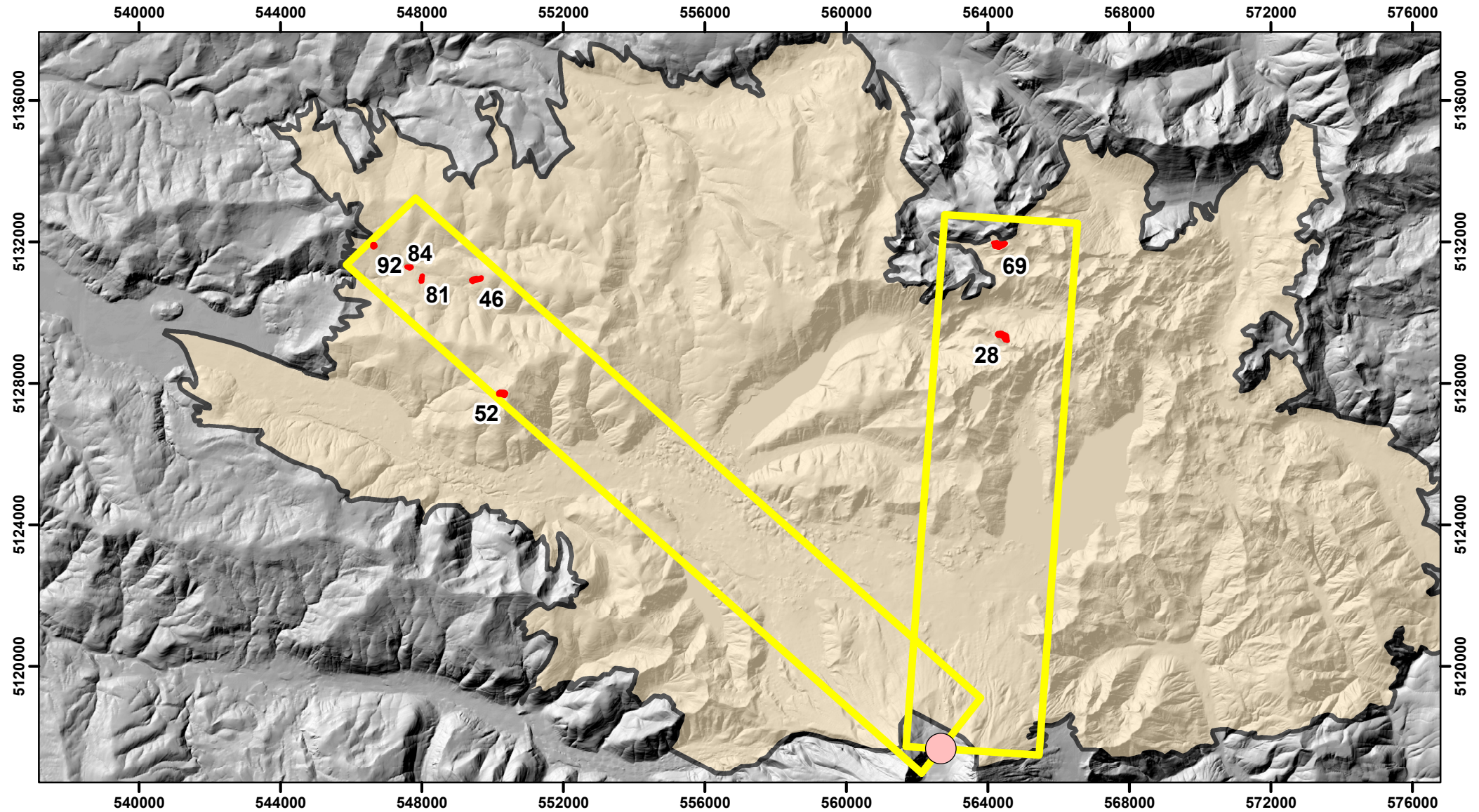
2. Extract by Mask tool used to extract hillshade values within a 30 m perimeter of the patches.







3. Aspect tool used to create an aspect raster to get values for slope azimuth.

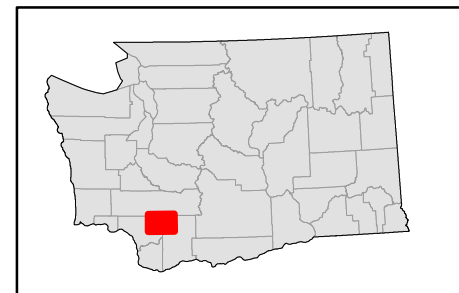
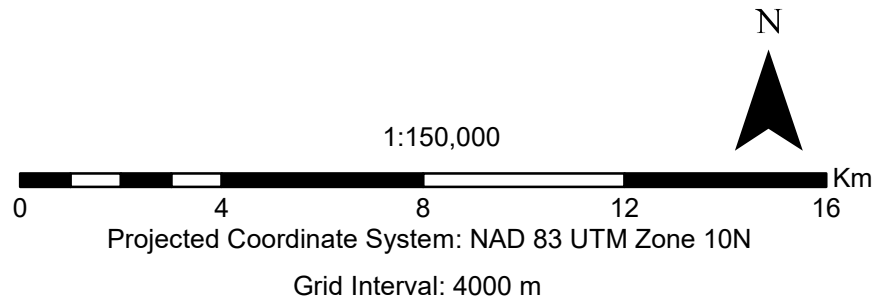
Standing tree patches of similar area within the Blowdown Zone of the 1980 Mount St. Helens Eruption, WA

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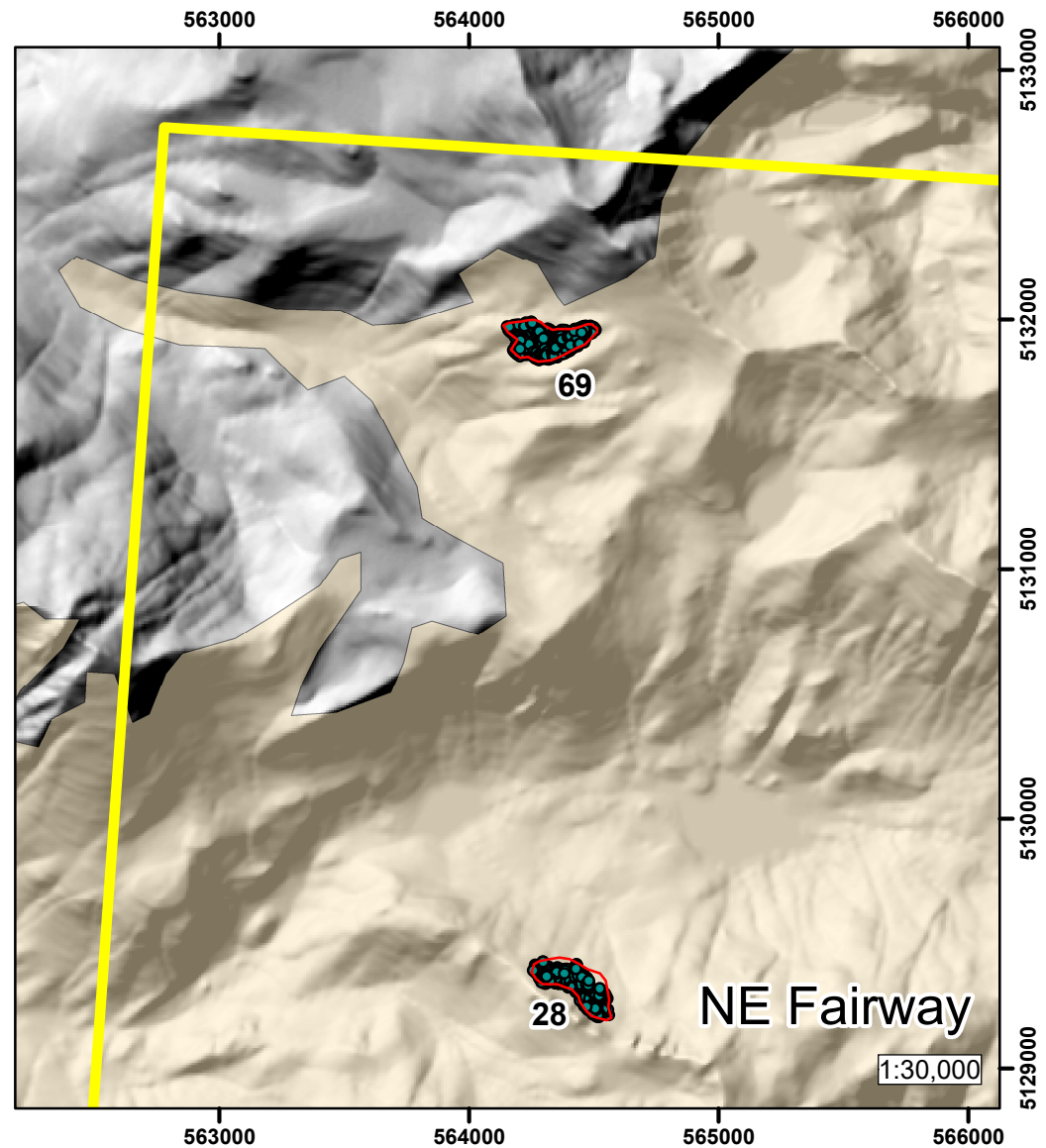
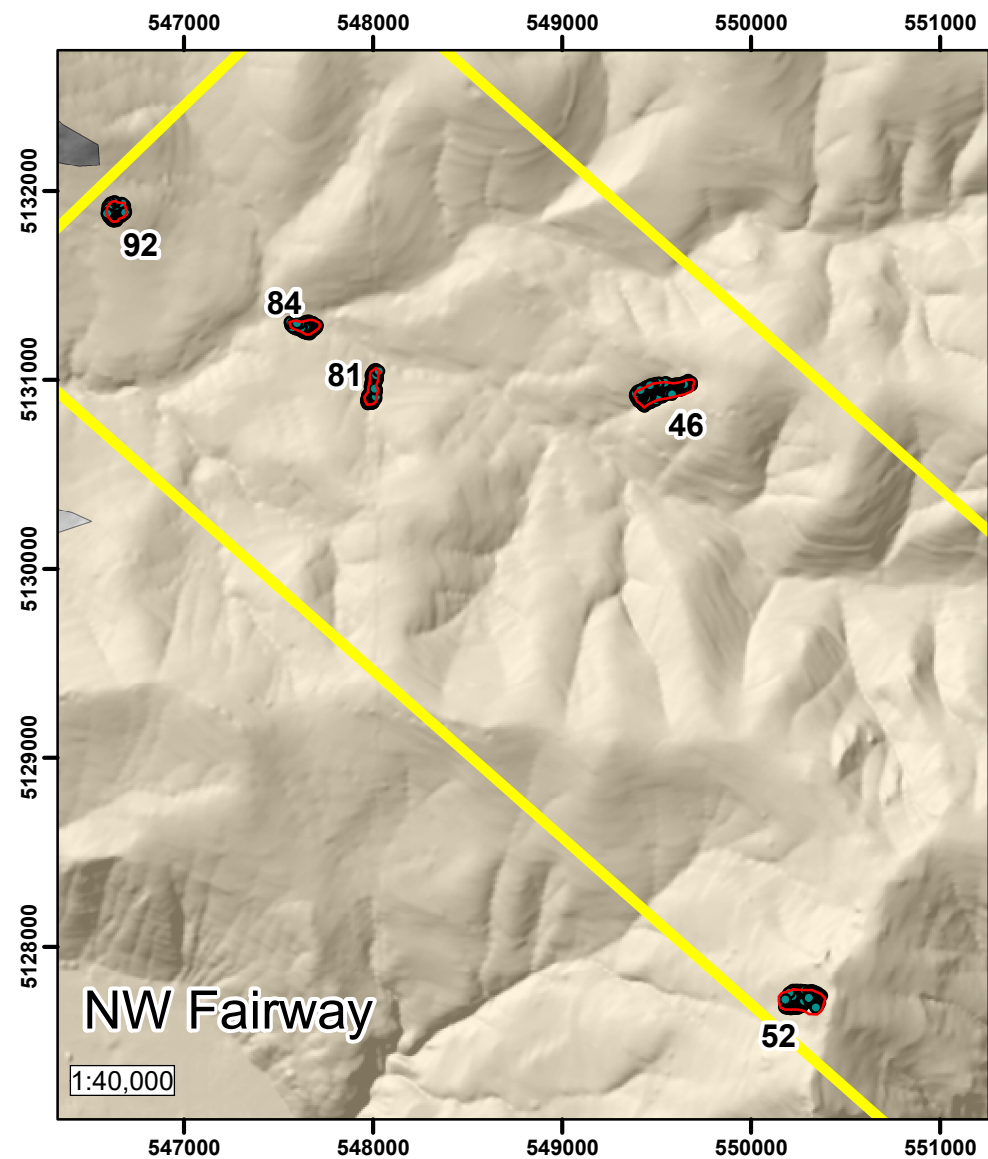
Explanation

-  Center of Mount St. Helens
-  Patches
-  Fairways
-  Blowdown Zone








Standing trees within patches of similar area within the Blowdown Zone, NW and NE Fairways, 1980 Mount St. Helens Eruption, WA

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6 December 2018



Explanation

-  Center of Mount St. Helens
-  Patches
-  Trees
-  Fairways
-  Blowdown Zone

