Raster Analysis Lab Exercise

Common Analytical Functions and Surface Analysis

Table of Contents

Grading Criteria 4

Slide Notes 5

Introduction 5

Reminder of Raster Data 5

4 Common Raster Analysis Methods 6

Surface Analysis 8

Warning regarding Geographic Data 12

Neighborhood and Surface Analysis Tip: 14

Raster and Surface Analysis GIS Lab Exercises: 15

Note: The Navigation Pane 15

Regarding the DEM: 15

Exercise 1: Calculate Aspect 17

Objectives 17

Data used 17

For Homework 17

Exercise 17

Prepare your Map and Data: 17

Calculate Aspect 20

Exercise 2: Calculate Slope 25

Objectives 25

Data used 25

For Homework 25

Exercise 25

Prepare your Map and Data: 26

Calculate Slope 26

Exercise 3: Calculate Hillshade 33

Objectives 33

Data used 33

Exercise 33

Prepare your Map and Data: 33

Calculate Hillshade 34

Exercise 4: Calculate Curvature (Mean, Profile and Plan) 38

Objectives 38

Data used 38

For Homework 38

Exercise 38

Prepare your Map and Data: 38

Calculate Curvature 39

Curvature Type 1: Mean Curvature 40

Curvature Type 2: Profile Curvature 43

Curvature Type 3: Plan Curvature *45*
Exercise 5: Calculate TPI (Topographic Position Index) *49*
Objectives 49
Data used 49
For Homework 49
Additional Documentation 49
For Fun 49
Exercise 49
Prepare your Map and Data: *50*
Calculate Neighborhood Focal Mean *50*
Subtract this Nbrhood_Mean raster from your original DEM *53*
Exercise 6: Reclassify Aspect *55*
Objectives 55
Data used 55
For Homework 55
Exercise 55
Prepare your Map and Data: *55*
Reclassify Aspect *56*
Clip the Reclassified Raster to the Semester D Management Unit Polygon *60*
Exercise 7: Calculate Zonal Statistics for the Semester D Management Unit *67*
Objectives 67
Data used 67
For Homework 67
Exercise 67
Prepare your Map and Data: *67*
Calculate Zonal Statistics *68*
Exercise 8: Use Extract Values to Points Tool to Get Raster Values at Points *74*
Objectives 74
Data used 74
For Homework 74
Exercise 74
Prepare your Map and Data: *74*
Calculate Point Values *75*
Exercise 9 [Optional]: Calculating NDVI and NDWI *79*
Objectives 79
Data used 79
Background 79
For Homework 80
For Fun 80
Exercise 81
Prepare your Map and Data: *81*
Calculate NDVI *83*
Calculate NDWI *86*
Exercise 10 [Optional]: Calculate a Hillshade and apply Hypsometric Shading *88*
Objectives 88
Data used 88
For Homework 88
Exercise 88
Prepare your Map and Data: *88*

Calculate Hillshade *89*
Exercise 11 [Optional]: Calculate a Hillshade Based on Two Sun Locations *97*
Objectives 97
Data used 97
For Homework 97
For Fun 97
Exercise 97
Prepare your Map and Data: *97*
Prepare your toolbox: *98*
Create the Model: *100*
Exercise 12 [Optional]: Calculate the MDOW (Multidirectional Oblique Weighted) Hillshade *114*
Objectives 114
Data used 114
For Homework 114
For Fun 114
Exercise 114
Prepare your Map and Data: *115*
Prepare your toolbox: *115*
Create the Model: *117*
Exercise 13 [Optional]: Creating a Blurred Hillshade *146*
Objectives 146
Data used 146
For Homework 146
For Fun 146
Exercise 146
Prepare your Map and Data: *146*
Prepare your toolbox: *147*
Create the Model: *149*
Appendix: Issues with Directional Data 158
Issues with Directional Data *158*
Azimuths and Geodesic Curves *158*
Graphically Representing Directional Data *159*
Analyzing Directional Data *162*
Circular Statistics 162
Mean Direction and Mean Resultant Length *163*
Variance and Standard Deviation: *164*
Other Methods to Analyze Directional Data 166
Classification of Aspect Values *167*
Deviations from a Bearing *167*
Sine and Cosine Transformations *167*
Special Considerations for Aspect *168*
How Aspect is Calculated 168
Is this the best method to calculate aspect? *170*
Issues with Aspect 170
Solar Insolation: An alternative to Aspect 171
ESRI's Solar Radiation Tool *171*
Hillshade 173
References *173*

Grading Criteria

Your homework on this topic will be answered directly from your lab exercises. You'll need to fill in the following tables from Lab Exercises 6 and 7 and answer the questions from Lab Exercise 8.

From Lab Exercise 6:

Proportions of Semester D Management Unit Lying in Four General Directions			
Value	**Meaning**	**Count**	**Proportion**
0	Flat		
1	North		
2	East		
3	South		
4	West		

From Lab Exercise 7:

Semester D Management Unit Polygon Descriptive Statistics for Six Rasters					
Dataset	**Statistic**				
	Minimum	**Maximum**	**Range**	**Mean**	**Standard Deviation**
DEM					
Slope					
Curvature					
Plan					
Profile					
TPI					

You will need to enter 40 values to fill up the two tables above, and 10 more values to answer the questions from Lab Exercise 8, so your score will be based on the proportion of those 50 values you got right. All answers are weighted equally. If you miss any of them, I will try to explain what you might have done wrong and give you a chance to fix it.

Please contact me if you have problems or questions!

Jeff Jenness
jeffj@jennessent.com
(928) 607-4638 - Cell
(928) 526-4139 - Home

Slide Notes

Introduction

Slide 2, 3, 4, 5, 6, 7, 8, 9, 10, 11: Main topics for today

1) A reminder of what Raster data is.
2) Discuss a few common ways to analyze raster data. There are lots of ways to analyze rasters, and would take weeks to just look at them all. This lab will only look at 3 of the most common types of analysis.
    a) Reclassification
    b) Zonal Analysis
    c) Neighborhood Analysis
    d) Math with Raster Layers
3) Discuss one common use of raster data: Analyzing the shape of the landscape
    a) Slope, Aspect, Curvature, Hillshade, Insolation
    b) Discuss special issues with Geographic data.

Reminder of Raster Data

Slide 12, 13, 14, 15, 16, 17, 18: Reminder of two broad classes of spatial data. Vector data are defined by vertices.

Slide 19, 20, 21, 22, 23: Example of Vector data. An important point is that a polygon or polyline may have attributes, and these attributes apply equally over the entire vector object. Attribute values don't change over the extent of a vector object. Because of this, vector objects don't do a good job of showing gradual change over a surface. TINs may be an exception to this, but in general rasters are still a better, more efficient and easier to analyze format to represent a continuously changing surface.

Slide 24, 25, 26, 27, 28: Remember that a raster is composed of square pixels that completely cover a region. Each pixel has a value (such as a color or number) which represents the general raster value within the pixel area.

Rasters are not as precisely defined as vector data. The pixel value is a general descriptor of the cell, not the value at an exact location.

Rasters do good at showing continually changing values over the landscape.

Slide 29: Rasters can represent many things. Images are a very common example of raster data. This slide shows an example of a raster plus a close-up of the pixels.

Slide 30: All rasters are composed of either a single or multiple raster bands. Images commonly have at least three raster bands for different electromagnetic wavelengths.

Slide 31, 32, 33, 34, 35, 36: Of course, rasters do not have to show imagery. Many rasters contain some kind of numerical values that describe the landscape in some way.

- DEM: Digital Elevation Model, containing elevation or bathymetric values
- Slope, Aspect, Curvature, Surface Area rasters

- Streamflow, flow direction, contributing area
- Habitat quality

Slide 37: You saw DEMs in the wildlife lab. We will spend a lot more time today doing things with DEMs.

4 Common Raster Analysis Methods

Slide 38, 39, 40, 41, 42: Today we will look at 3 common raster analysis methods, and the lab exercises will let you experience all of them.

- Reclassification
- Zonal Statistics
- Neighborhood Focal Statistics
- Math with Raster Layers

Slide 43, 44, 45, 46, 47: Starting with Reclassification: One of the simplest analytical methods. Just means to assign a new value based on an old value. We usually do this to categorize regions that lie within some range of values.

- Reclassification produces a new **raster**.
- It is especially useful because it makes it easy to summarize an area based on the proportion of raster cells that fall within each category.

Slide 48: For example, we may think that Mexican spotted owls are usually at elevations > 7,000 feet and < 10,000 feet. Therefore we might reclassify the landscape into 3 elevation bands.

Slide 49, 50, 51, 52, 53, 54: Zonal Statistics: A very useful tool.

- Calculates general descriptive statistics (mean, minimum, maximum, etc.) on all raster cells within ***zones***. And the concept of **zone** is important here. This method generates statistics on specific regions, and those regions are defined by these zones. We'll discuss this concept more shortly.
- Produces a **Table** of statistics describing each zone (although there are variations that produce other output formats). And in fact the tool we'll use in the labs is actually called the **Zonal Statistics as Table** tool.
- Zones can be defined lots of ways.
    - Most commonly by a combination of vector objects (points, polylines, polygons) and associated attribute values.
    - Also by a categorical rasters, such as the reclassified elevation raster from last slide where we identified a region where spotted owls might be found.

Slide 55: Suppose we want to calculate elevation statistics within a home range polygon, or perhaps determine the elevation at all the animal observation points.

Remember that the vector feature itself is not a Zone! It is the vector plus an attribute value. If we had several polygons, and they all had the same Zone attribute value, then the Zonal Statistics would reflect the combined region of all the polygons. The same with points. In the example above, I treated each point as a separate zone. This gives us the elevation value at each point. Notice that the min, max and mean are all the same because there is only a single raster cell at each point. However, if I wanted I

could have set all points to the same zone by using a different attribute field. If I had done this, then I would have had only a single zone. The attribute table would show a single row of statistics that would describe elevation statistics for the entire set of points.

Slide 56: Here is another example illustrating the use of zones. We can calculate county-level statistics if we define zones using the County Name attribute field. Or we can calculate state-level statistics if we define zones using the State Name attribute field.

Slide 57: There is a problem with the Zonal Statistics tool, though! It will not handle overlapping polygons. Even worse, it won't tell you there was a problem. It just spits out a table of statistics that looks accurate.

If zones overlap, then the tool will only analyze the first one. In this example, the red polygon is the first feature in the feature class. Therefore the tool will give accurate statistics on it. However, when the tool gets to the blue polygon, it will ignore any regions it has already analyzed with the red polygon. Therefore the statistics on the blue polygon will only reflect the areas that lie inside the blue polygon and outside the red polygon.

If any features are selected, then the Zonal Statistics tool will only run on the selected features. Therefore you need to select each overlapping polygon individually before you run the tool.

Slide 58: Here's another issue with the Zonal Statistics tool when it is applied to points: The cell value at each point is not always drawn from the intersecting cell! I suspect the tool is converting the point feature class to a raster first, and that raster intersection is not working well.

Slide 59, 60, 61, 62: Neighborhood Statistics: Another very useful tool.

- Analyzes all raster cells in some neighborhood around each cell.
- Sometimes called a "Moving Window" analysis.
- Neighborhood analysis produces a **new raster**, where each raster cell value is a statistic (sum, mean, minimum, etc.) describing all cells in the neighborhood around the original cell.

Slides 63, 64, 65, 66, 67, 68, 69, 70, 71: Neighborhood Example

Slide 72: 6 basic neighborhood shape types. The Kernel Density tool uses a variation on the Weighted neighborhood type.

Slide 73, 74: Math with raster layers: When applying a mathematical operator to two rasters, the resulting raster will have cell values representing the results of the mathematical function applied to all overlapping cells.

Slide 75: For example, when adding two rasters, the new raster cell values contain the sum of the overlapping raster cells.

Slide 76: NDVI is a common and simple example of raster math. Based on two electromagnetic wavelengths that reflect Chlorophyll very differently (the Red and Near Infrared wavelengths), we can identify the regions where chlorophyll (and, presumably, forest health) really stand out.

Slide 77: The math is pretty simple. However, remember to convert the bands to floating point numeric types! Otherwise ArcGIS will produce an integer-type output, which is not helpful when values range between -1 and 1.

Slide 78: Done with 4 common raster analysis methods. Any questions before we move on to Surface Analysis?

Surface Analysis

Slide 79, 80, 81: Surface Analysis: I really enjoy working with surface analysis. I think the shape of the landscape is really interesting.

- All about describing the shape of the landscape based on a DEM.
  - Also known as "Terrain Analysis"
  - Also known as "Geomorphology"
- We will look at slope, aspect, hillshade, curvature and insolation (solar radiation).
  - Technically, insolation does not describe the shape of the landscape directly, but it is almost entirely defined by the shape of the landscape.
- There are many, many other ways to describe the shape of the landscape that we won't go into.

Slide 82, 83, 84: What we'll cover in Surface Analysis

Slide 85: Slope

I suspect we all know what slope is and why it is important. Many wildlife species seem to select habitat partly based on slope. If you're a timber beast, slope affects what kind of harvesting method you choose and even whether an area is harvestable or not. If you work in the field for any reason, slope affects how tired you are at the end of the day.

Slide 86, 87, 88, 89, 90, 91, 92: There are a few things to consider regarding slope, and a few things that people often misunderstand.

In forestry we usually measure slope in either Percent or Degrees. There is another measure used occasionally called a "gradian", "grade" or "gon", which was an attempt to apply the advantages of the metric system to angular units. One gradian is equal to 1/100th of a right angle. A full circle is 400 gradians. This system doesn't seem to have taken off here in the US, though.

Pay attention to the definitions of Percent Slope and Degrees. Lots of people have a misconception that 100% slope is a vertical cliff. It is not. 100% slope = 45°.

$$\%\,\text{Slope} = \tan\left(\frac{\pi\left(\text{Degrees Slope}\right)}{180}\right) * 100$$

$$\text{Degrees Slope} = \frac{180\left(\arctan\left(\frac{\%\,\text{Slope}}{100}\right)\right)}{\pi}$$

Slide 93, 94, 95, 96: Slope Statistics: We often want to calculate slope statistics, such as the mean and standard deviation of slope values in our study area. **You cannot do this if your slope values are in Percent!** Percent slope goes to infinity. You need to convert your slope values to degrees before you can calculate these statistics. Then, you can always convert your final mean value back to percent for your report if you want.

Slide 97: Aspect

Another thing we are all familiar with. Just the direction of steepest slope.

Slide 98: Aspect plays a major role in microclimate, vegetation density and species composition. This is Dry Lake, right near the Semester D Management Unit.

Slide 99, 100, 101, 102, 103: What do you do with Aspect? We know that it is important, but how can we describe an area in terms of aspect?

Aspect is a Circular Variable:

- The difference between 0° and 1° is the same as the difference between 0° and 359°!
- You can't use arithmetic mean and standard deviation! The **Focal Statistics** tool does not give you correct statistics. Fortunately, the **Zonal Statistics** tool has recently been upgraded to give the option for circular data like Aspect.
    - Everybody should know how to calculate the arithmetic mean. What is the average of 5, 8, and 17? It is (5 + 8 + 17) / 3 = 10. This method does not work for directional data. What is the average of 359° and 1°? It is **not** (359° + 1°) / 2 = 180°. This is exactly the opposite of the correct answer!
- There are measures of dispersion and central tendency, though…

Where: $\theta = \text{Direction in Radians}$

$$C = \sum_{i=1}^{n} \cos\theta_i \qquad S = \sum_{i=1}^{n} \sin\theta_i \qquad R^2 = C^2 + S^2 \qquad \bar{R} = \frac{R}{n}$$

$$\text{Mean Direction: } \bar{\theta} = \begin{cases} \tan^{-1}(S/C) & S > 0, C > 0 \\ \tan^{-1}(S/C) + \pi & C < 0 \\ \tan^{-1}(S/C) + 2\pi & S < 0, \ C > 0 \end{cases}$$

$$\text{Circular Variance: } V = 1 - \bar{R} \qquad \text{(Mardia \& Jupp, Fisher)}$$

$$\text{Angular Variance: } s^2 = 2\left(1 - \bar{R}\right) \qquad \text{(Batschelet)}$$

$$\text{Circular Standard Deviation: } v = \sqrt{\left(-2\ln\bar{R}\right)} \quad \text{(In Radians)} \qquad \text{(Mardia \& Jupp, Fisher)}$$

$$\text{Angular Deviation: } s = \sqrt{s^2} = \sqrt{2\left(1 - \bar{R}\right)} \quad \text{(In Radians)} \qquad \text{(Batschelet)}$$

$$\text{Radians to Degrees: } Degrees = \frac{180}{\pi}(Radians)$$

- I've included an article on issues with directional analysis as an appendix to this document for anyone who is interested.

Slide 104: How to calculate mean direction, step 1.

Slide 105: How to calculate mean direction, step 2.

Slide 106: How to calculate mean direction, step 3.

Slide 107, 108, 109: Another thing to do with Aspect: Decompose it into Eastness and Northness, or into a deviation from a direction of interest. Convert to radians first! See Beers et al. (1966) and Trimble & Weitzmann (1956) for examples on using the Sine/Cosine methods on a direction other than exactly North/South or East/West.

Beers, T. W., P. E. Dress, and **L. C. Wensel.** 1966. *Notes and Observations: Aspect Transformation in Site Productivity Research*. Journal of Forestry 64:691–692. <https://drive.google.com/file/d/1aGbmTReagOIA-78yKjUzNXSivhrMSMK2/view?usp=sharing>

Trimble, G. R., and S. Weitzman. 1956**.** *Site Index Studies of Upland Oaks in the Northern Appalachians***.** Forest Science 2:162–173. <https://drive.google.com/file/d/1DlL7s0pW-QLbxK_tuzuxNHDfNyL0zWMk/view?usp=sharing>

Slide 110: Mary Zylo, Carol and I are looking at some bald eagle aspect data. At first glance the eagles seem to like north-facing slopes when they roost at night. Daytime aspects are more random.

Slide 111: This approach might be interesting for some species. Not looking at aspect directly, but rather the difference between aspect and the direction the sun sets or rises. Does a species pick a roost location based on the direction the sun sets or rises? More complex analysis because the direction of sunrise and sunset changes with geographic location and with date.

Slide 112, 113, 114: Trivia time! Who invented this type of graph?

Slide 115: Another thing to do with Aspect: Reclassify it into general directions, then summarize your study area based on proportions of study area facing each general direction.

Note: I've included an article on issues with directional analysis as an appendix for anyone who is interested.

Slide 116, 117, 118, 119: Some food for thought regarding Aspect:

- Aspect obviously has a great influence on vegetation species composition, structure and microhabitat.
- Why does aspect have this influence?
    - Possibly because of prevailing wind direction.
    - In large part because of how much sunlight hits the area, and at what angle.
- If aspect is important because of how it influences sun exposure, then perhaps solar insolation would be a better variable to use.
    - It is also much easier to calculate summary statistics from solar insolation!

Slide 120, 121, 122, 123, 124, 125: Solar Insolation: All about how much sunlight hits the ground.

- In many cases, it may be a more direct driver for vegetation and microclimate than aspect.
- All about measuring how much sunlight hits the ground, based on topography.
    - It **does** incorporate direct sunlight from the sun, plus diffuse radiation from the sky in general.
    - It does **not** incorporate reflection from the ground.
- Lots of cool options, like calculating for a specific time, day, season or year.
- It takes a long time to calculate, though. In case anyone wants it, I made you a Solar Insolation layer summarizing cumulative annual insolation and hours of solar exposure for your Semester D Management area. It took about 20 minutes to calculate on my computer.

Slide 126: Solar Insolation: The primary output is watt hours of solar energy per square meter.

Slide 127: Solar Insolation: One optional output is the number of hours of exposure to sunlight.

Slide 128: Solar Insolation: Hours of daylight makes a cool image. Very austere and bleak to my eye.

Slide 129: Hillshade: Hillshades are usually used for graphical illustrative purposes (as in the illustration above and in the slide background). You can set the sun location to any compass direction and angle of inclination, which means that a hillshade can also be used as sort of a poor-man's insolation. We used to use them for that purpose. It is tricky figuring out the exact sun position for different times during the year, but otherwise it is a decent estimate of sun exposure. ArcGIS's specialized solar insolation tools are much better for that purpose, though.

Slide 130, 131, 132, 133: Various authors have suggested modifications to the basic hillshade. One of the more popular methods is generally referred to as the "Swiss Method", after Imhof and his contemporaries. Strictly speaking, the "Swiss Method" is a manual method where the cartographer draws the hill shading by hand. Kurt Brassel introduced some automated methods to replicate some of the best qualities of the hand-drawn Swiss method (Brassel 1974), specifically recommending three general modifications.

Introduce light sources from multiple directions: Brassel recommended setting a variable light source direction for each cell, based on a primary illumination direction ± a directional adjustment computed from the aspect of that cell. Brassel also recommended that the illumination inclination angle (i.e. how high the sun is) for each raster cell should be variable, based on the deviation of the surface normal to the primary illumination source. By Brassel's method, every cell could receive a hillshade based on a different illumination angle. Imhof (2007, p. 211) suggests a similar but simpler method, where the hillshade is calculated from two stationary light sources separated by a small amount (10° – 15°).

Atmospheric Adjustments: Brassel suggested that both the contrast and the brightness of the hillshade should decrease at lower elevations, and increase at higher elevations, in order to mimic atmospheric effects. The contrast could be adjusted by modifying the reflectance based on the elevation, such that low elevations would have relatively little reflectance. Brightness could be adjusted simply by darkening the cell according to the relative elevation.

Blur the final hillshade: Brassel felt that small topographic features (misnamed "small-scale" in his manuscript) tended to have less information to describe them, and that consequently the hillshading of such features was more likely to be "'fictive' or 'creative'". Therefore such small features should be blurred to de-emphasize them. He also was working with dot-matrix printers to print his hillshades, and he recommended photographically blurring the output to increase the aesthetic quality of the hillshade. Others advocate blurring the hillshade if you simply want it to be a little less prominent or noticeable in the map (see especially Buckley & Barnes, 2004).

Slide 134: MDOW hillshade incorporates the multiple light sources, although in an unusual way.

MDOW paper: https://pubs.usgs.gov/of/1992/of92-422/of92-422.pdf

Slide 135: Light sources are weighted according to how directly the point faces the light. Weighted at 0 if directly facing the light, increasing to 100% at right-angles.

Note: If the land faces away from the light, then it automatically gets the darkest value. These charts just show the mathematical weighting system.

Slide 136: Weighting of all 4 MDOW light sources.

Slide 137: Hypsometric shading

Slide 138, 139, 140, 141: Blurring

Slide 142: Examples of blurring; this is Walnut Canyon without blurring

Slide 143: USGS Topo maps use a blurred hillshade.

Slide 144: Interesting hillshade trivia. In the northern hemisphere, the sunlight usually shines from a southerly direction. However, a hillshade developed using that direction creates an optical illusion for most people (but not all people!). Most people see this slide as a hillshade of a mountain range.

Slide 145: This is a hillshade of the same area (Oak Creek Canyon) using a sun direction that does not happen in nature (from the northwest). Because of this optional illusion, most GIS hillshade tools default to a sun direction of 315°.

Slide 146, 147, 148: Curvature

- Infinite number of variations. ArcGIS offers 3 types of curvature.
- It can be used as a measure of exposure because it identifies hills, ridges, valleys and depressions.
- Used a lot in hydrological projects because it shows whether water will converge, diverge, accelerate or decelerate as it flows over a cell.

Slide 149, 150: Illustration of general curvature. This general curvature tells you whether the landscape is concave or convex. Values can be positive (for hills) or negative (for valleys).

Slide 151, 152: Profile Curvature: This is the curve of a line! The line is formed by the intersection of a vertical plane, in direction of aspect, with the surface.

Best understood as describing whether water will accelerate (negative, convex; red in map) or decelerate (positive, concave; blue in map) as it flows downhill. Negative areas will tend to have more exposure to the elements.

Slide 153: Warning! ArcGIS Pro offers **two** tools that calculate Curvature.

- The **original** tool (called "**Curvature**") calculates positive profile curvature if the land is concave (i.e. when water slows down), and negative curvature if land is convex (water speeds up).
- The **new** tool (called "**Surface Parameters**") **reverses the sign**. Positive values produced by the new tool mean the land is convex (water speeds up), and negative values mean the land is concave (water slows down).

Slide 154, 155: Plan Curvature: Also is the curve of a line! This line is formed by the intersection of a horizontal plane with the surface.

Best understood as describing whether water will converge (negative, concave; red in map above) or diverge (positive, convex; blue in map above) as it flows downhill. Diverging (positive) areas will tend to have more exposure to elements.

Slide 156: Curvature Units: Note that curvature units are often very small, so ArcGIS multiplies them by 100. Note also that this definition applies to profile and plan curvature, not general curvature. This definition assumes the curvature of a line, which is the intersection of a surface and a plane.

Warning regarding Geographic Data

Slide 157, 158, 159: Warning! The standard ArcGIS Surface Tools do not work correctly with geographic (lat/long) data. You must use projected rasters.

- The standard ArcGIS surface tools are only accurate with projected data. Geographic (i.e. Latitude / Longitude) data violate important assumptions of the tools.

- Assumption 1: The tools assume the raster cells are square. Geographic raster cells are actually trapezoidal when viewed on the earth's surface.
- Assumption 2: The X, Y and Z units are all the same.

Slide 160: The major problem is that the all the surface tools use the east-west and north-south gradients in the computations.

Slide 161: ArcGIS assumes that the raster cells are square, and therefore the cell size east-to-west is the same as the cell size north-to-south. This is incorrect.

As far as ArcGIS knows, a geographic raster has square cells. It looks that way on the map. But we don't live in that world. In our world, these cells actually are trapezoids on the ground. The east-west distance is not the same as the north-south distance!

Slide 162: More specifically, the east-west distance is shorter than the north-south distance (with the rare exception of working directly on the equator). The end result is that ArcGIS underestimates the east-west gradient. This causes errors with all the rest of the surface measurements (slope, aspect, curvature, insolation, hillshade). The errors get worse the farther away you are from the equator.

Just FYI, I have a tool that does correctly handle geographic data, but you can't install it in the NAU lab: http://www.jennessent.com/arcgis/surface_area.htm

Slide 163, 164, 165, 166: Another problem with units:

Remembering back to the equations: These equations also assume that the Z-units are the same as the X- and Y-units.

If your elevation units are in Feet, but your raster coordinate system uses Meters (and therefore your cell sizes are in meters), then you must remember to set a correction factor in the tool to convert Feet to Meters!

This is a common user error. ArcGIS lets you set an elevation correction factor (called a z-factor) to avoid this error, but it is up to you to remember to set it!

Slide 167, 168, 169, 170, 171, 172: Major Points to Remember regarding Surface Analysis:

- It is fine to calculate slope as either Percent Slope or Degrees Slope. However, you can't calculate descriptive statistics if your slope values are in Percent.
  - Percent slope works fine if you want to reclassify into, say, harvestable vs. non-harvestable slopes.
  - 100% Slope is not equal to a vertical cliff. It is equal to a 45° slope.
- Aspect is a circular variable and therefore you can't use traditional methods to calculate descriptive statistics.
- All these surface variables require that your DEM be projected! You cannot calculate any of them accurately with geographic (lat/long) rasters (at least not with the basic tools in ArcGIS).

Neighborhood and Surface Analysis Tip:

Slide 173, 174, 175, 176, 177:

- All Neighborhood tools require all cells in the neighborhood to accurately calculate the new cell value.
- Most surface analysis functions (slope, aspect, hillshade and curvature) are neighborhood functions that use a 3x3 cell neighborhood.
- Therefore neighborhood and surface tools cannot accurately calculate values for the outermost rows and columns, or any cells next to “No Data” cells.
- Consequently, the new raster will either be smaller (fewer rows and columns) than the original raster, or the outermost cells will not be calculated with full data.

Slide 178, 179, 180, 181, 182: Illustration of edge problem.

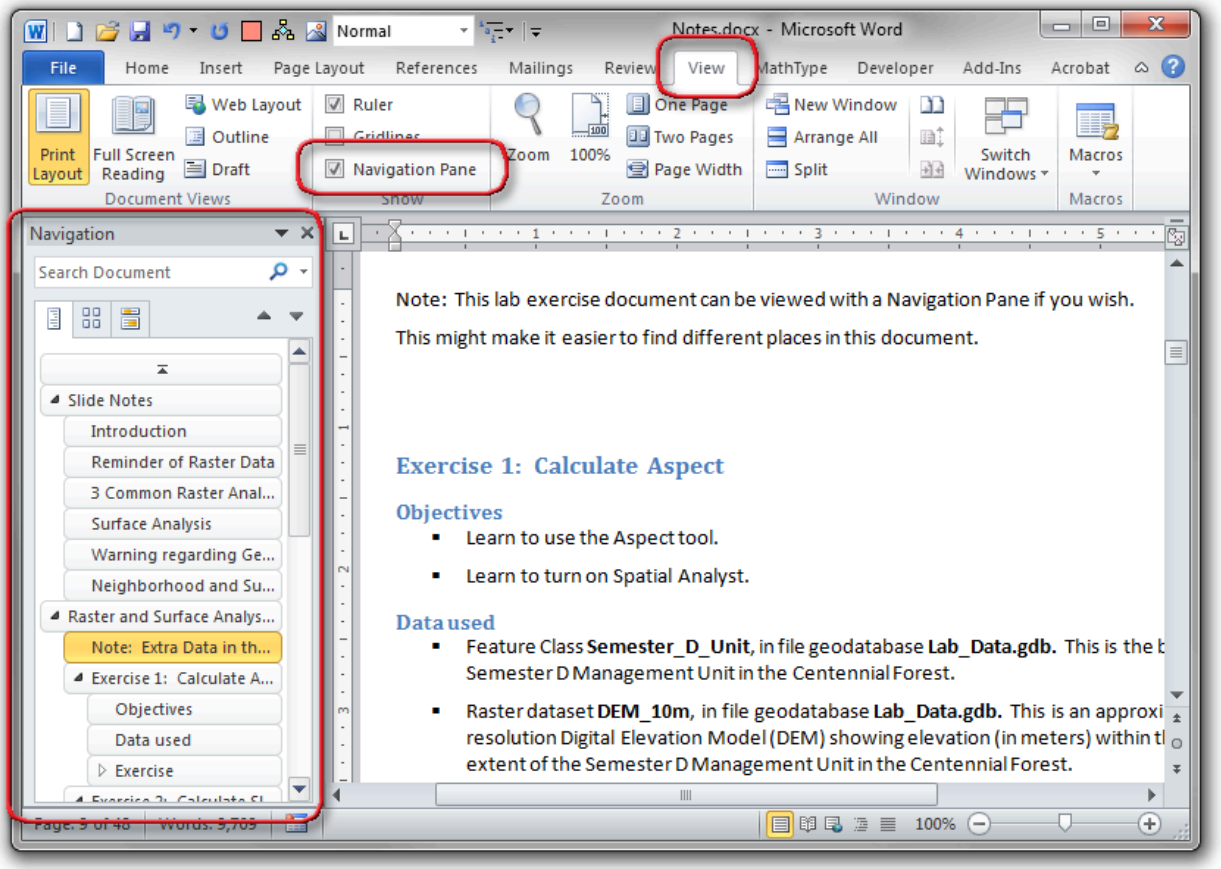
Slide 183, 184, 185, 186: Takeaway message: If you want to calculate neighborhood or surface rasters accurately within some area, make sure your original DEM or source raster is larger than that area!

- For Surface rasters (slope, aspect, hillshade, curvature), your original DEM should be at least 1 cell larger than your area.
- For other neighborhood rasters, your original raster should be larger than your area by at least ½-neighborhood size.
- Solar Insolation requires a much larger region than your area (typically about 200 cells) because it accounts for shadows from far away.

Raster and Surface Analysis GIS Lab Exercises:

Note: The Navigation Pane

If you wish, Word includes a navigation pane that might make it easier to find different places in this document.



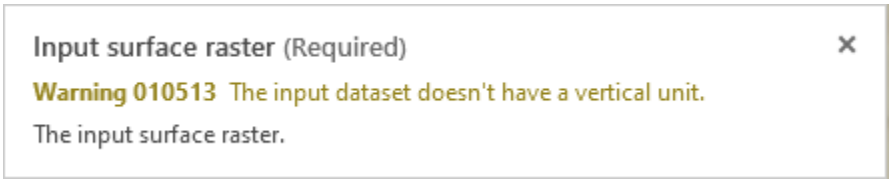
Regarding the DEM:

These lab exercises use a small 10m-resolution DEM (~ 40 km^2) located near Rogers Lake just west of Flagstaff. Keep in mind that you also have an Arizona state-wide 30m DEM to play with if you ever want to, located on Canvas in the folder **Extra Data**. You won't use it for this lab, but it might be useful for other purposes.

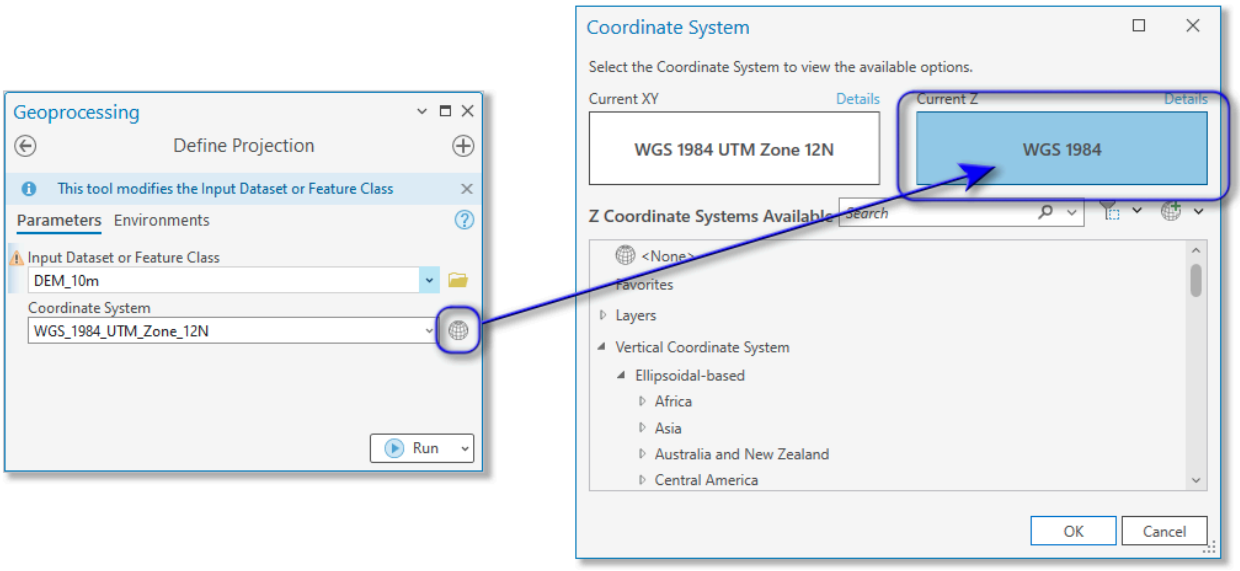
One downside of this larger DEM, though, is that it is in geographic (latitude/longitude) coordinates and some of the standard ArcGIS tools do not calculate surface characteristics of lat/long DEMs correctly. Specifically the **Slope** and **Aspect** tools are able to adjust for geographic coordinates, but the **Curvature** and **Hillshade** tools do not.

Esri has introduced geodesic functionality into a new all-purpose tool called **Surface Parameters**, so you can use that tool to calculate accurate surface descriptors of both projected and unprojected DEMs. This new tool incorporates entirely new algorithms, too, so the outputs will be different than those produced by the original tool even if using the same parameters on projected data.

Many tools will give you a warning about vertical units if they do not automatically know the vertical linear unit of the dataset.



If the tool does not know what the vertical units are, it will assume the units are meters. If you want or need to, you can set the vertical unit of a DEM using the "Current Z" section of the **Define Projection** tool.



There is also a short video on this at https://youtu.be/PXNQHnAbDFw.

Exercise 1: Calculate Aspect

Objectives

- Learn to turn on Spatial Analyst.
- Learn to use the Aspect tool.

Data used

- Layer file **Semester_D_Unit.lyr**, in folder **..\Class_GIS_Data\Raster_Functions\...** This is the boundary of the Semester D Management Unit in the Centennial Forest, and it references a feature class named **Semester_D_Unit** in the file geodatabase **Lab_Data.gdb** located in the same folder.
- Raster layer file **DEM_10m.lyr**, in folder **..\Class_GIS_Data\Raster_Functions\...** This layer file references a raster dataset named **DEM_10m** in the file geodatabase **Lab_Data.gdb**, and is an approximately 10m resolution Digital Elevation Model (DEM) showing elevation (in meters) within the general extent of the Semester D Management Unit in the Centennial Forest.
- Optionally, any online basemap layers you prefer, such as topo maps or imagery. These won't be used in the analysis but they are often useful to help orient yourself or see the analysis within a larger landscape context.

For Homework

You will calculate statistics on your aspect raster dataset in Lab Exercise 6.

Exercise

Based on the DEM (digital elevation model), you will generate a new raster showing the compass direction (aspect) of all points on the landscape.

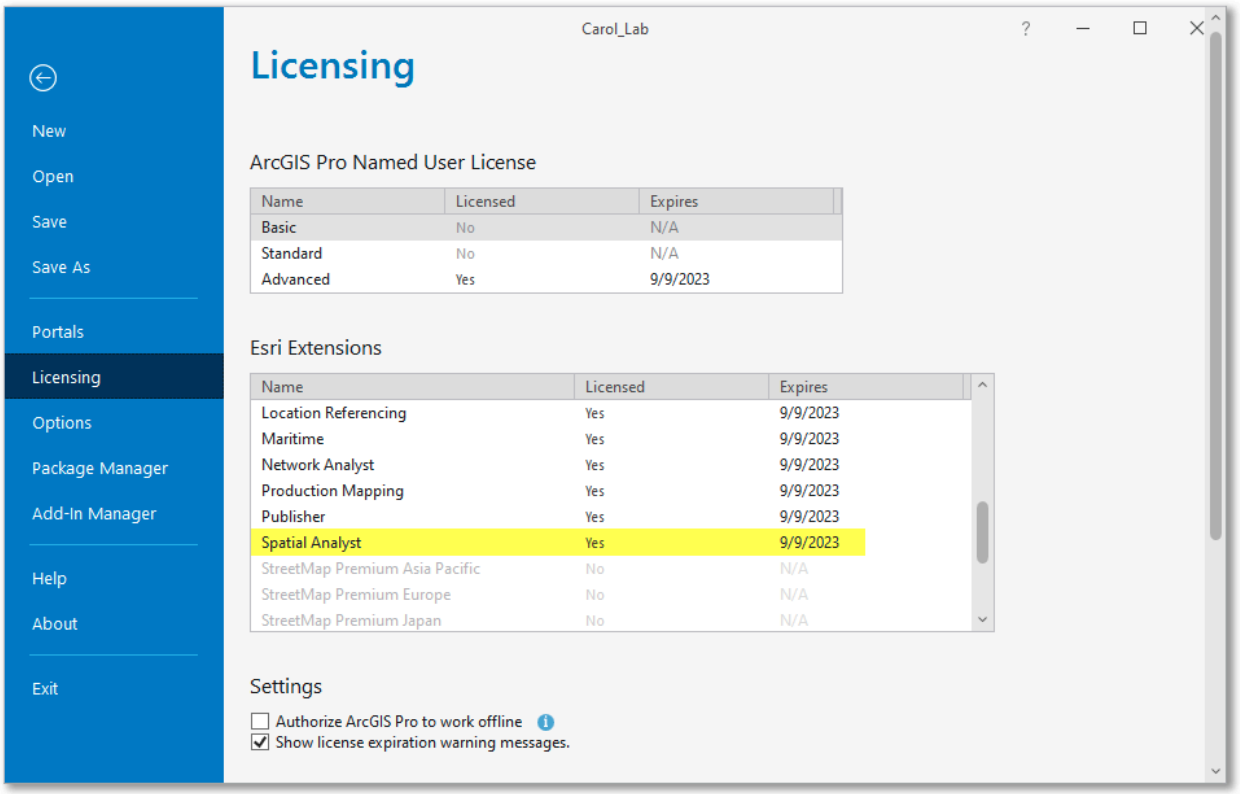
Always consider two issues before you calculate aspect!

- Currently ArcGIS Pro has two tools that calculate Aspect; the **Aspect** tool and the **Surface Parameters** tool. Depending on which tool you use, you must consider different issues:
    a. If you are using the **Aspect** tool, then you must take care if your DEM raster is in geographic (lat/long) coordinates. In this case, **you must use the geodesic option in the tool!** Otherwise you must project your DEM before calculating aspect.
    b. If you are using the **Surface Parameters** tool, then you do not need to worry about it. The **Surface Parameters** tool will automatically use geodesic methods.
- Are your DEM elevation units the same as your X/Y coordinate system units? If one is in Feet and the other in Meters, then you will have to specify the correct units when running the tool.

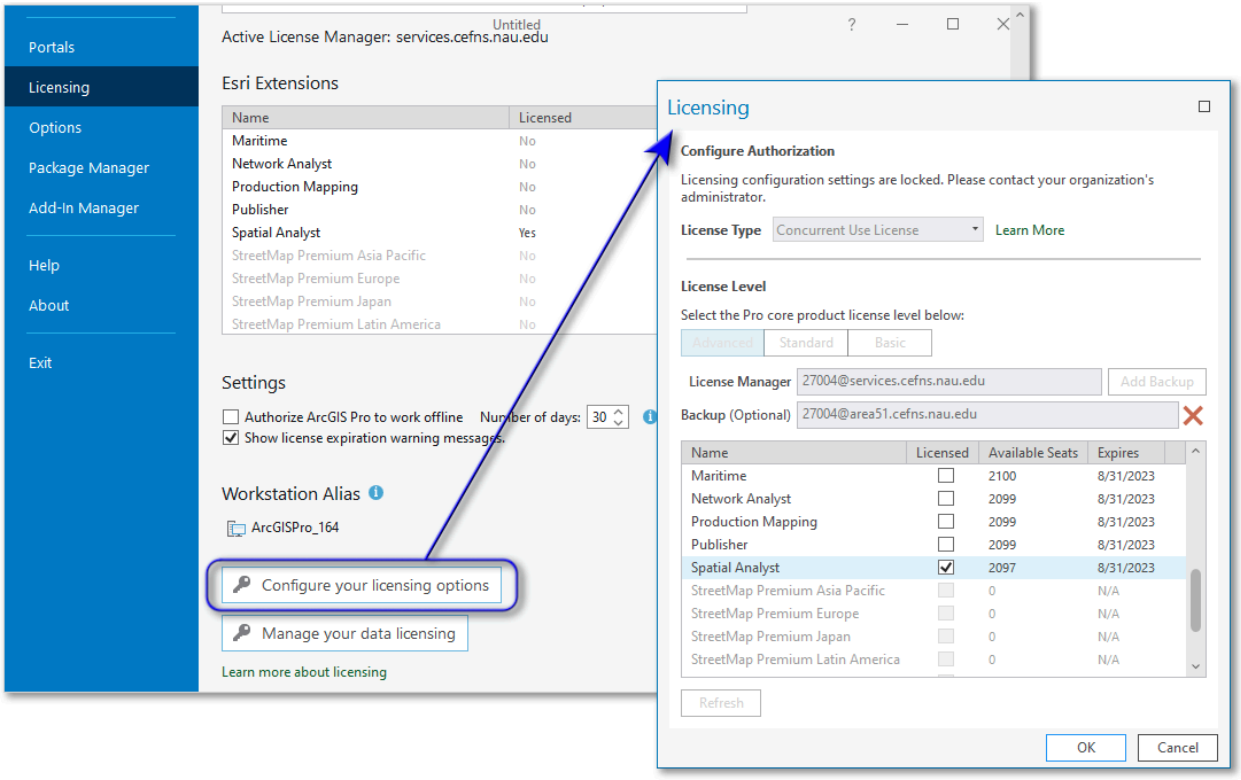
Prepare your Map and Data:

1) Open a blank map in ArcGIS Pro.
2) Make sure you have the **Spatial Analyst** extension turned on.
    a) Click the "Project" tab, then "Licensing".

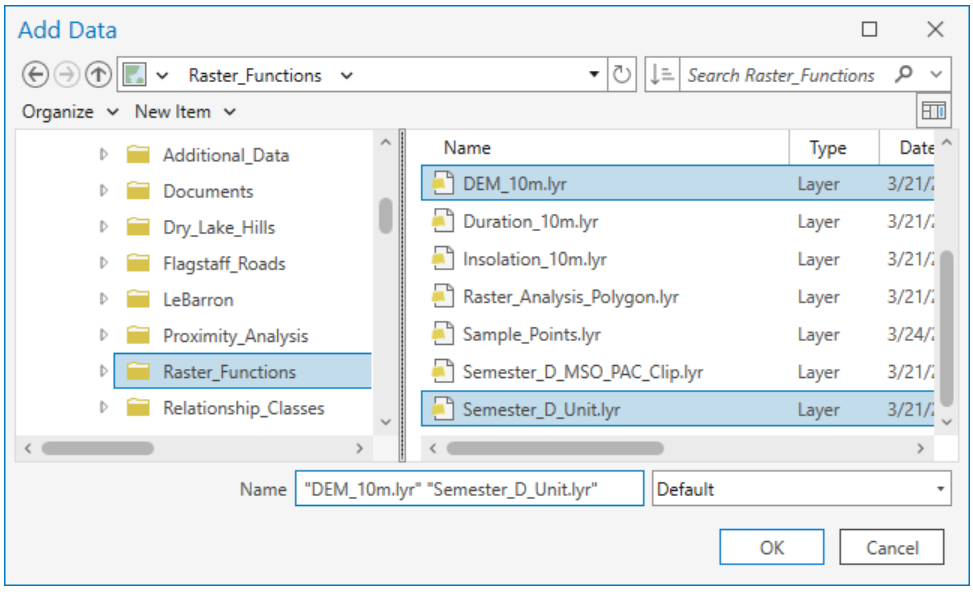
b) In the “Licensing” window, scroll down and make sure you have **Spatial Analyst** turned on (and see https://youtu.be/JHMZYkbn7PI).



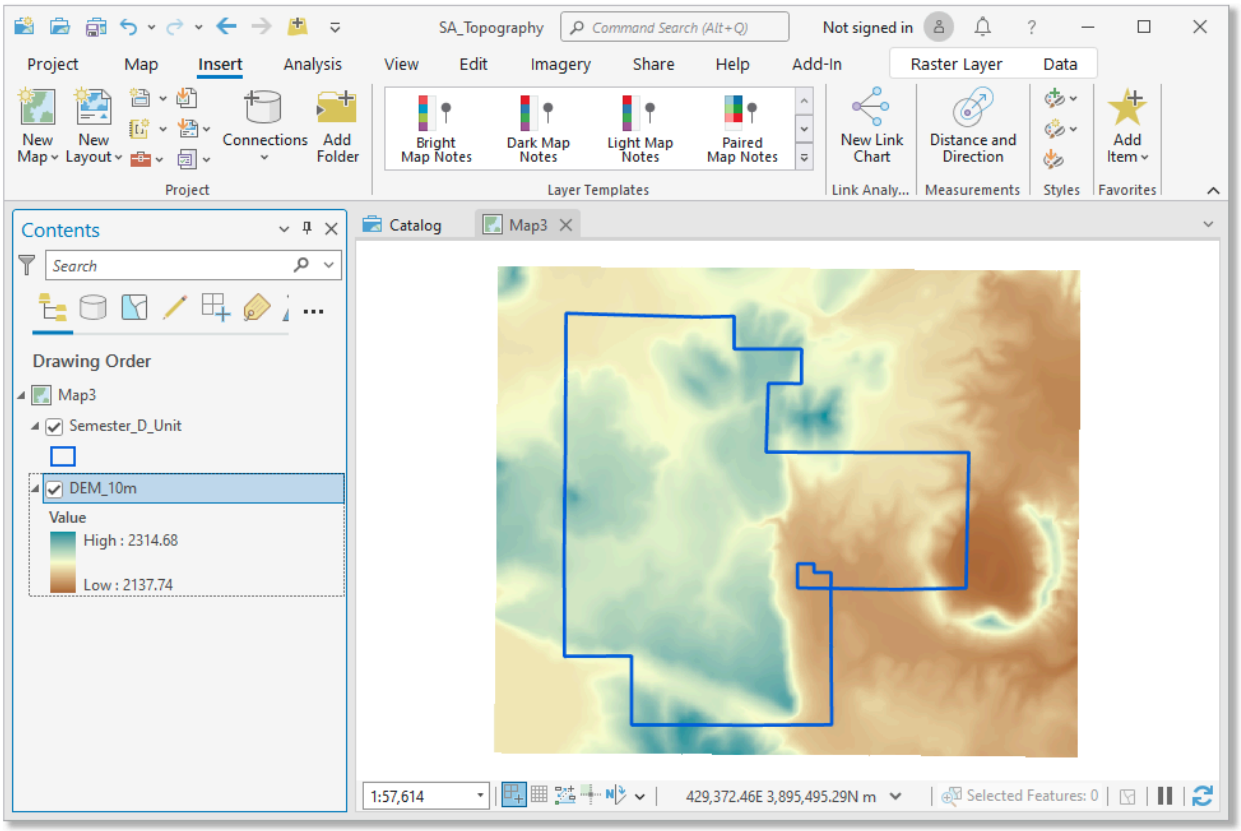
c) If **Spatial Analyst** is not licensed, then scroll down and click the button “Control your Licensing Options”, then check the box next to “Spatial Analyst” in the “Licensing” window.



3) Load the **Layer** files **DEM_10m.lyr** and **Semester_D_Unit.lyr** from the folder **..\Class_GIS_Data\Raster_Functions\...**



4) If you loaded the Layer files, you should see the following.



5) Optionally, load any online basemap layers or other background data you like.

6) The following questions are not for your homework, but are questions you should always consider when working with DEMs.

Question: What is the name of the **DEM** raster coordinate system? **Hint**: Open the Layer Properties for **DEM**, then click the "Source" tab, then scroll down until you see the "Spatial Reference" information.

Question: Is the DEM raster coordinate system **projected** or **geographic**?

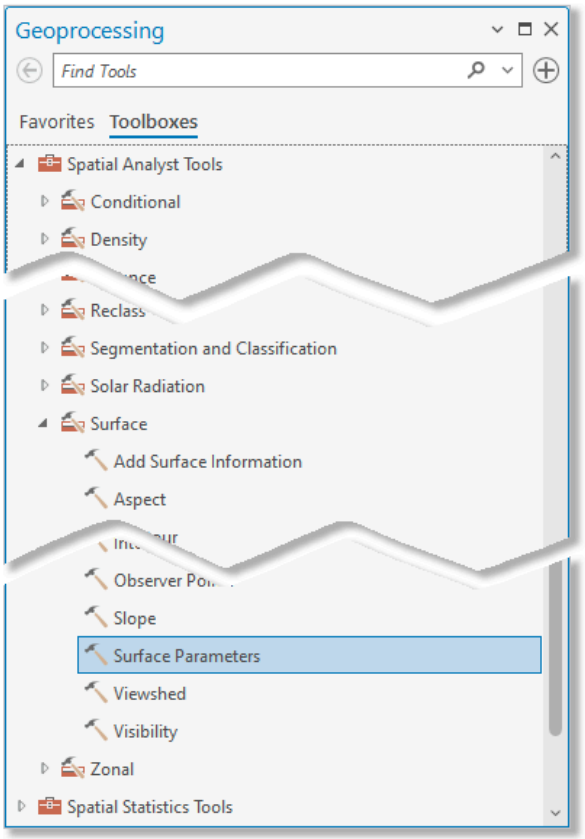
Question: What is the resolution of this raster?

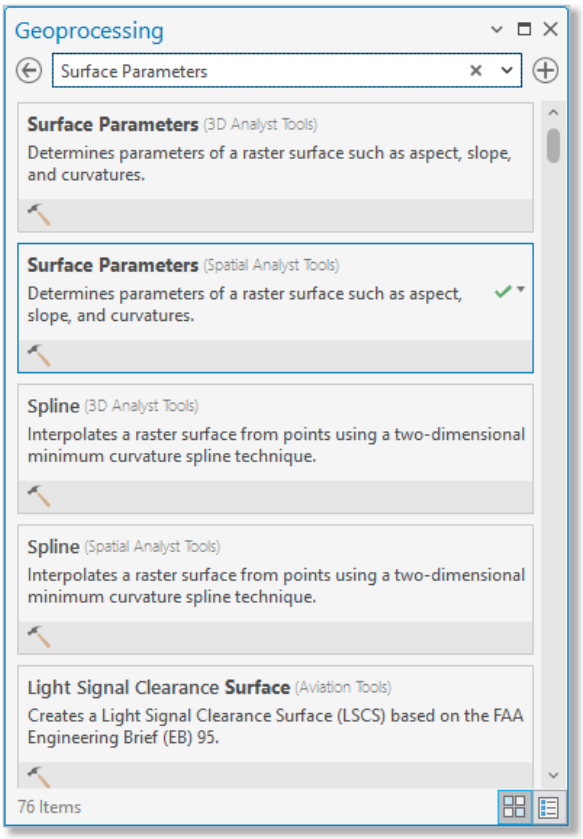
Question: What is the linear unit of the **DEM** raster coordinate system?

Calculate Aspect

ArcGIS has two tools that calculate Aspect: The **Aspect** tool, and the **Surface Parameters** tool. Esri encourages users to use the new **Surface Parameters** tool, so this lab exercise will follow their lead.

7) Open the **Surface Parameters** tool (in Toolboxes --> Spatial Analyst Tools --> Surface --> Surface Parameters):



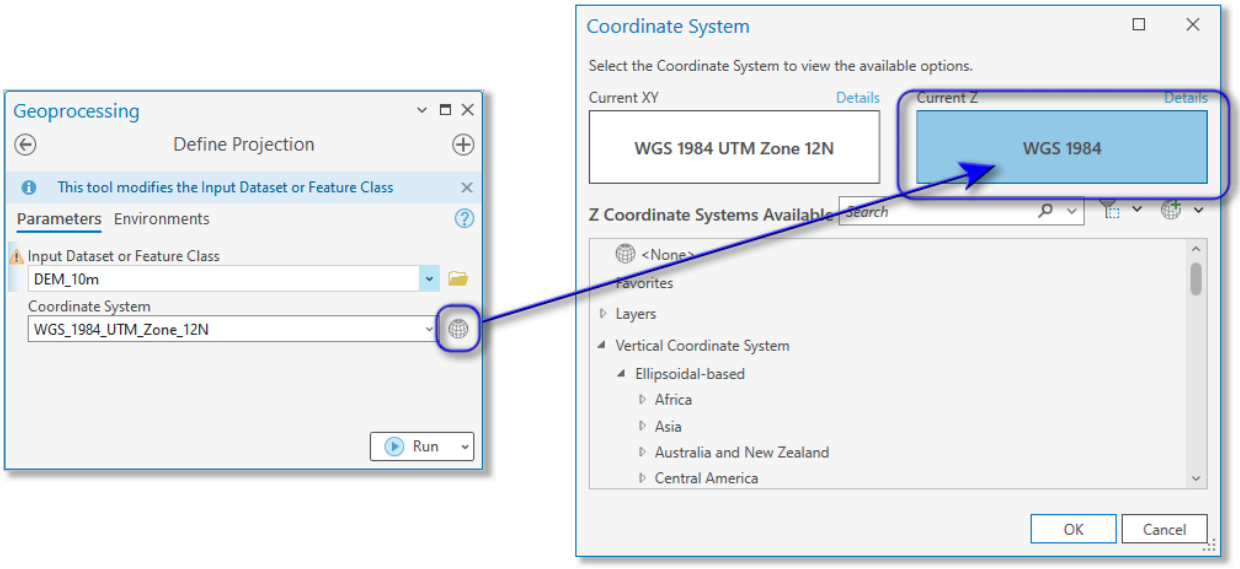


8) In the **Surface Parameters** window:

   a) Set the "Input Raster" to **DEM_10m**.

      i) You might notice a warning icon and a message stating **Warning 010513** The input dataset doesn't have a vertical unit. This is because the DEM dataset itself doesn't have any information written into it stating what the elevation units are. Because of this, we will need to set an elevation unit in the tool window (see below).

      ii) If you ever want to, you can set the dataset vertical unit using the "Current Z" section of the **Define Projection** tool. If you do this, then tools like the **Surface Parameters** tool will no longer ask you to specify the vertical unit.



There is also a short video on this at https://youtu.be/PXNQHnAbDFw.

b) Pick a name and location for your output Aspect raster. I recommend saving it to your default project file geodatabase and naming it "Aspect". This suggestion is just to help you keep organized, though. You won't turn in the actual rasters as part of your homework.

c) Leave "Input analysis mask" blank.

d) Set the "Parameter Type" to be *Aspect*.

e) Set the "Local surface type" to be *Quadratic.*

   i) Are you wondering what the difference between **Quadratic** and **Biquadratic** is? They each fit a mathematical 3D surface model to the neighborhood of elevation values around each cell, but the "Quadratic" method is a "best fit" method that is **not** forced to go exactly through all the points, while the "Biquadratic" method **is** forced to go through all points.

   According to the documentation, you should only use the **Biquadratic** method if (1) your DEM is highly accurate, and (2) you calculate your surface statistic (Aspect in this case) based on the 3 × 3 neighborhood of cells immediately surrounding each DEM cell.

   These conditions are rare, so the documentation encourages you to use the **Quadratic** method unless you have a good reason not to.

f) Leave the "Neighborhood distance" to the given value (9.33… Meters). This is the cell size of the raster **DEM_10m**, and using this value means the tool will look out exactly 1 cell in all directions and end up analyzing a 3 × 3 neighborhood of cells around each DEM cell. If you wanted, you could use a larger neighborhood. You might want to do this if you wanted your surface parameter (Aspect in this case) to describe conditions over a larger area, which in turn would make it less influenced by elevation variation right around each cell.

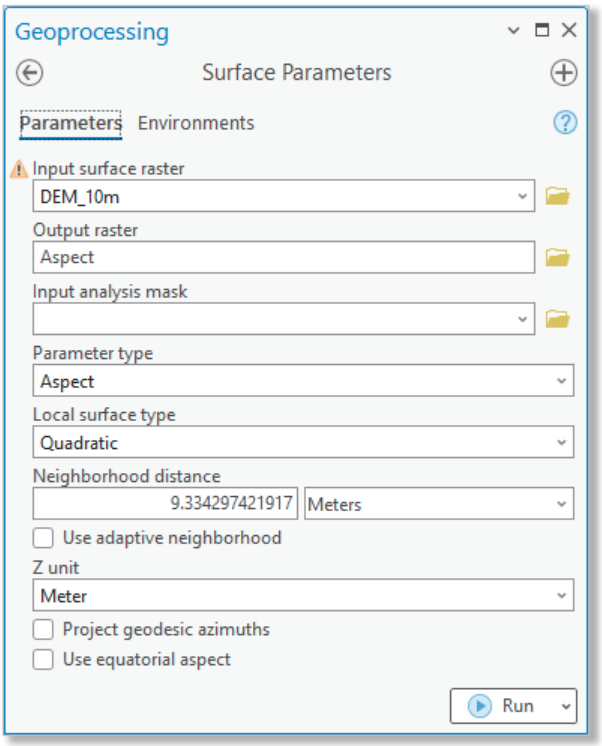
g) Leave **unchecked** "Use adaptive neighborhood". This option would cause the tool to potentially use different-sized neighborhoods for each cell. One cell might have aspect calculated from a 3 × 3 neighborhood, while the next cell might have it calculated from a 7 × 7 neighborhood. That might be useful in some cases, but not in this course.

h) Set your "Z unit" to be *Meter*, since our elevation units are in Meters.

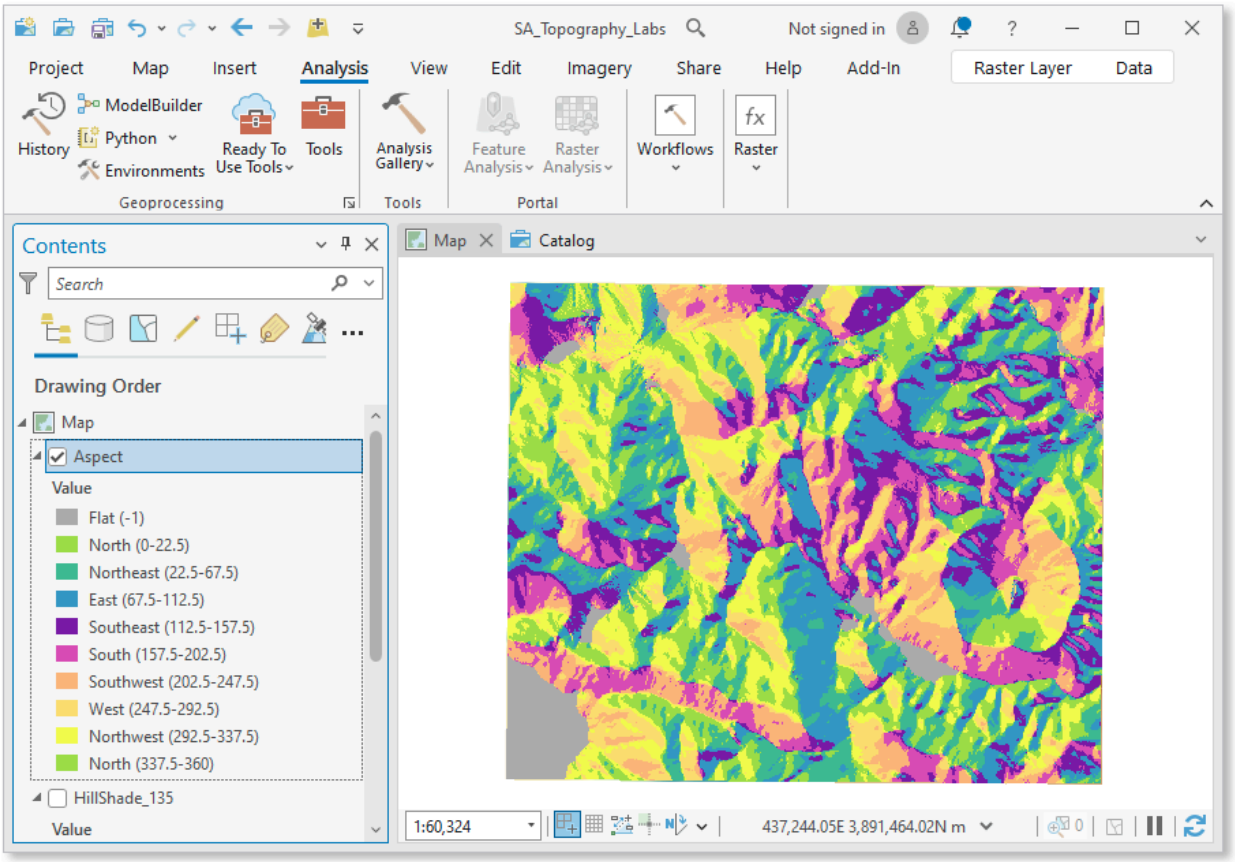
i) **Note:** You will only see this "Z unit" option if your input surface raster does not have an elevation unit set (see [a] above). If you have defined an elevation unit using the **Define Projection** tool, then this **Surface Parameters** tool will already know what the elevation units are and will not ask you to specify it here.

i) Leave **unchecked** "Project geodesic azimuths". This option adjusts the true Aspect direction to match any local projection distortion in your new Aspect raster.

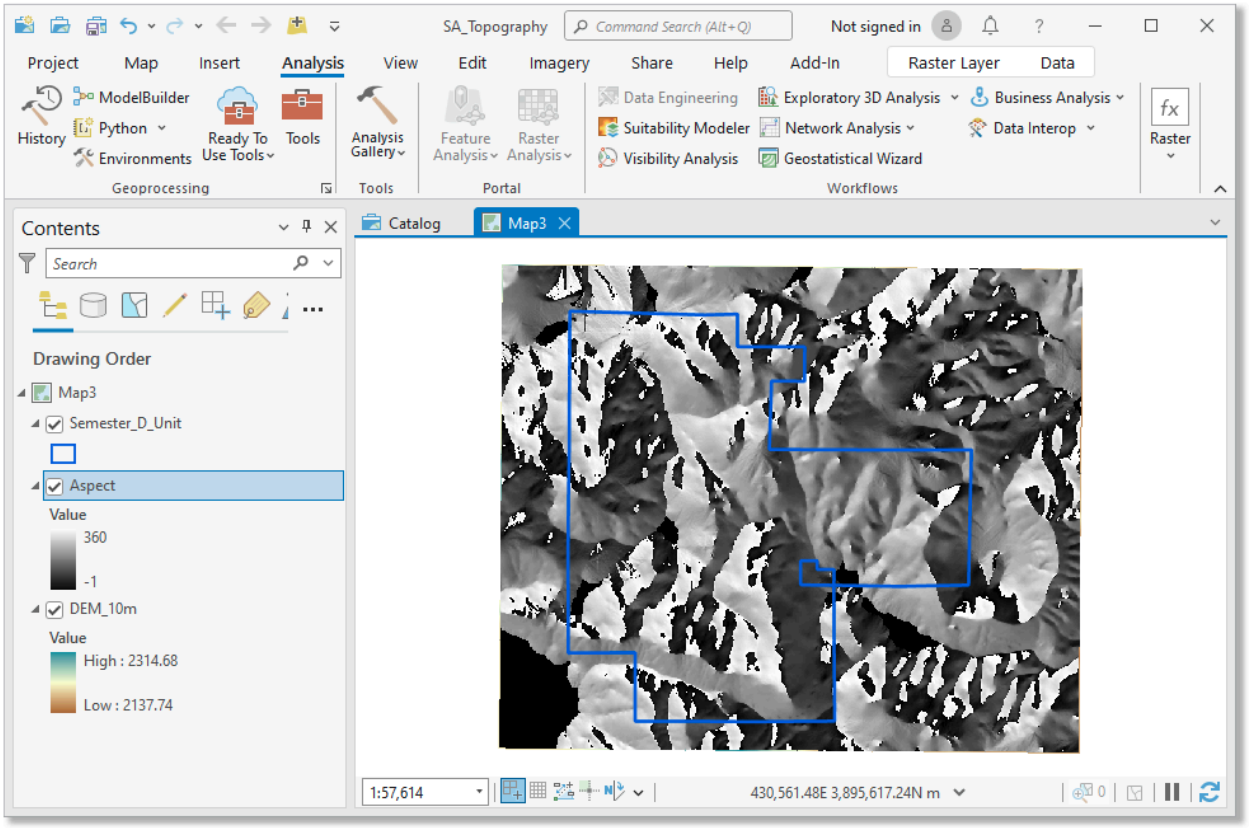
j) Leave **unchecked** "Use equatorial aspect"**.** This option is intended to be used only if you are calculating Aspect very close to either the North or South pole, where the bearing toward North can change quickly over short distances. Using this option forces the tool to pretend the point actually lies on the equator. It will make almost no difference if you are not right near a pole, so we leave it unchecked.



9) Upon completion, the tool will add a new Aspect raster to your map. ArcGIS typically symbolizes an Aspect raster using 8 directional categories, plus -1 if the landscape is flat:



10) **Note:** Despite how ArcGIS symbolizes the Aspect raster, it is **not** a categorical raster. The aspect cell values are actually compass directions ranging from 0° - 360°, or -1 if the land was flat and had no aspect. If you change the symbology type to "Stretch", you'll see this:


SA_Topography
Command Search (Alt+Q)
Not signed in
Project
Map
Insert
Analysis
View
Edit
Imagery
Share
Help
Add-In
Raster Layer
Data
History
ModelBuilder
Python
Environments
Ready To Use Tools
Tools
Analysis Gallery
Feature Analysis
Raster Analysis
Data Engineering
Exploratory 3D Analysis
Business Analysis
Suitability Modeler
Network Analysis
Data Interop
Visibility Analysis
Geostatistical Wizard
Raster
Geoprocessing
Tools
Portal
Workflows
Contents
Search
Drawing Order
Map3
Semester_D_Unit
Aspect
Value
360
-1
DEM_10m
Value
High : 2314.68
Low : 2137.74
Catalog
Map3
1:57,614
430,561.48E 3,895,617.24N m

Exercise 2: Calculate Slope

Objectives

- Learn to use the Slope tool.
- Learn how to check the metadata of a dataset to remind yourself how you set up the tool.

Data used

- Layer file **Semester_D_Unit.lyr**, in folder **..\Class_GIS_Data\Raster_Functions\...** This is the boundary of the Semester D Management Unit in the Centennial Forest, and it references a feature class named **Semester_D_Unit** in the file geodatabase **Lab_Data.gdb** located in the same folder.
- Raster layer file **DEM_10m.lyr**, in folder **..\Class_GIS_Data\Raster_Functions\...** This layer file references a raster dataset named **DEM_10m** in the file geodatabase **Lab_Data.gdb**, and is an approximately 10m resolution Digital Elevation Model (DEM) showing elevation (in meters) within the general extent of the Semester D Management Unit in the Centennial Forest.
- Optionally, any online basemap layers you prefer, such as topo maps or imagery. These won't be used in the analysis but they are often useful to help orient yourself or see the analysis within a larger landscape context.

For Homework

- You will calculate statistics on your slope raster dataset in Lab Exercise 7, and extract point values from it in Lab Exercise 8.

Exercise

Based on the DEM (digital elevation model), you will generate a new raster showing the slope steepness, in degrees, of all points on the landscape.

Always consider two issues before you calculate slope!

- Currently ArcGIS Pro has two tools that calculate Slope; the **Slope** tool and the **Surface Parameters** tool. Depending on which tool you use, you must consider different issues:
    a. If you are using the **Slope** tool, then you must take care if your DEM raster is in geographic (lat/long) coordinates. In this case, **you must use the geodesic option in the tool!** Otherwise you must project your DEM before calculating slope.
    b. If you are using the **Surface Parameters** tool, then you do not need to worry about it. The **Surface Parameters** tool will automatically use geodesic methods.
- Are your DEM elevation units the same as your X/Y coordinate system units? If one is in Feet and the other in Meters, then you will need to tell the tool to convert units. In the **Surface Parameters** tool, you only need to tell the tool what units the elevation values are in. In the **Slope** tool, you do this by specifying a conversion factor (called the "Z Factor" in the tool) to convert your elevation units to your X/Y units.
    a. If you use the geodesic method, then ArcGIS will assume your elevation units are in meters. If your units are not meters, then specify a Z-factor that converts your units to

meters. For example, if you use the geodesic method, and your elevation units are in feet, then specify a Z-factor of 0.3048 because there are that many meters in a foot.

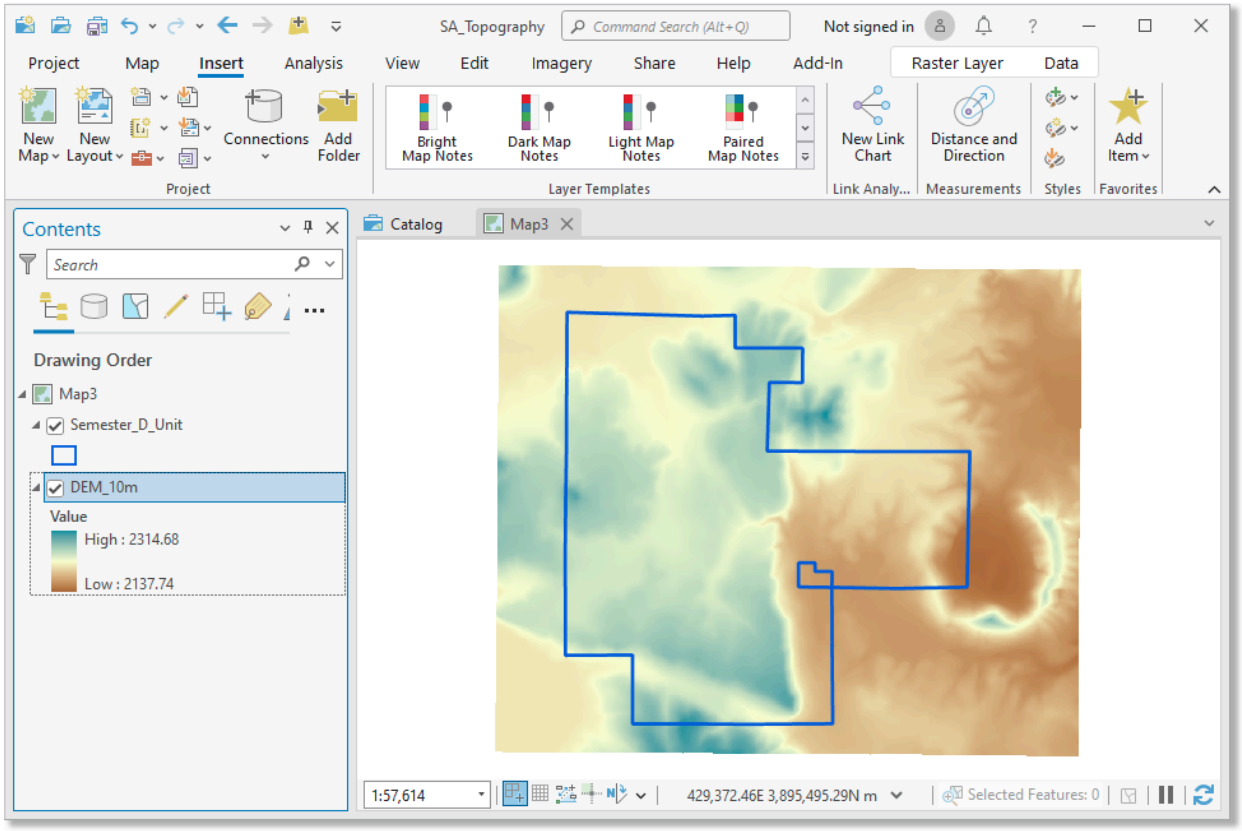
Prepare your Map and Data:

1) Open a blank map in ArcGIS Pro. If you still have ArcGIS Pro open from the previous exercise, you may simply insert a new map.

2) Make sure you have the **Spatial Analyst** extension turned on. See Exercise 1 if you have questions on this.

3) If they are not already present, then load the **Layer** files **DEM_10m.lyr** and **Semester_D_Unit.lyr** from the folder **..\Class_GIS_Data\Raster_Functions\...** as you did in Exercise 1.

4) If you loaded the Layer files, you should see the following.

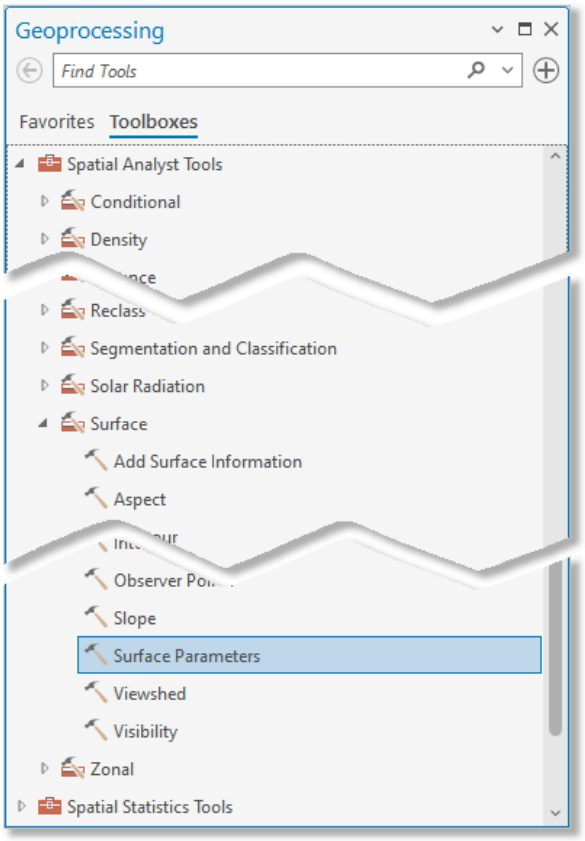


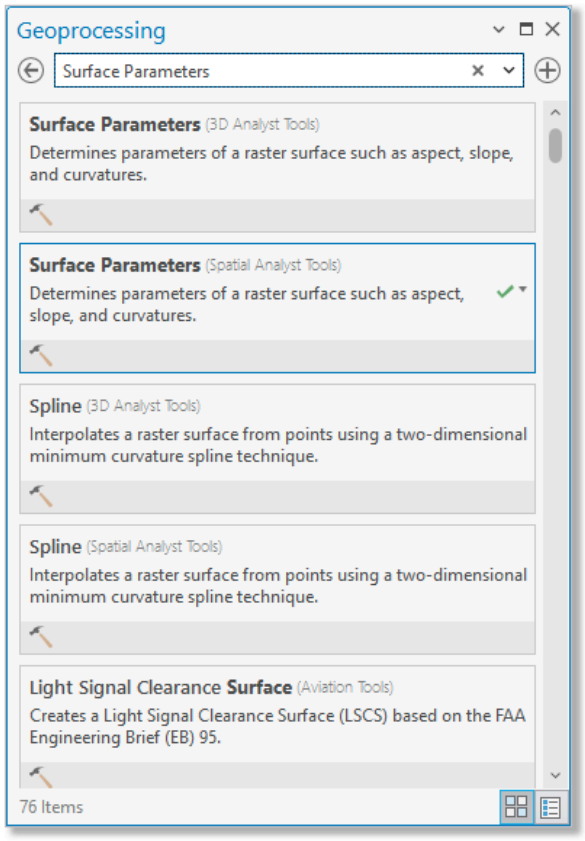
5) Optionally, load any online basemap layers or other background data you like.

Calculate Slope

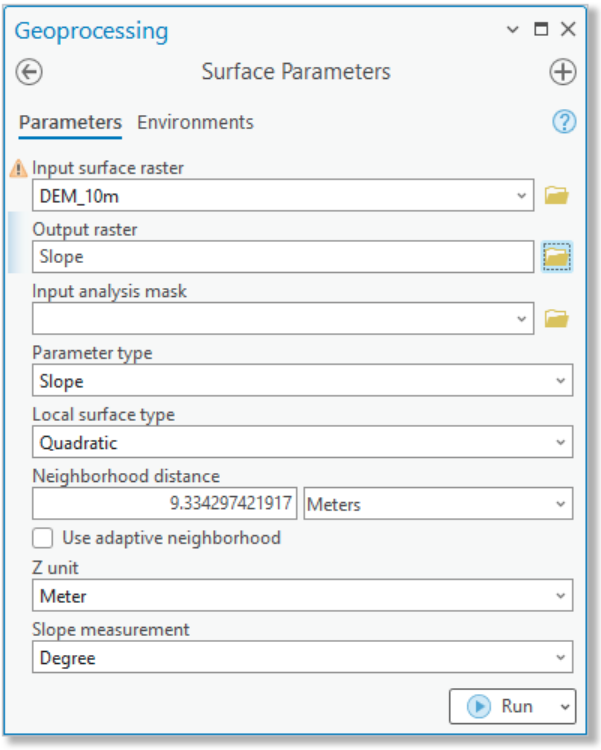
ArcGIS has two tools that calculate Slope: The **Slope** tool, and the **Surface Parameters** tool. Esri encourages users to use the new **Surface Parameters** tool, so this lab exercise will follow their lead.

6) Open the **Surface Parameters** tool (in Toolboxes --> Spatial Analyst Tools --> Surface --> Surface Parameters):

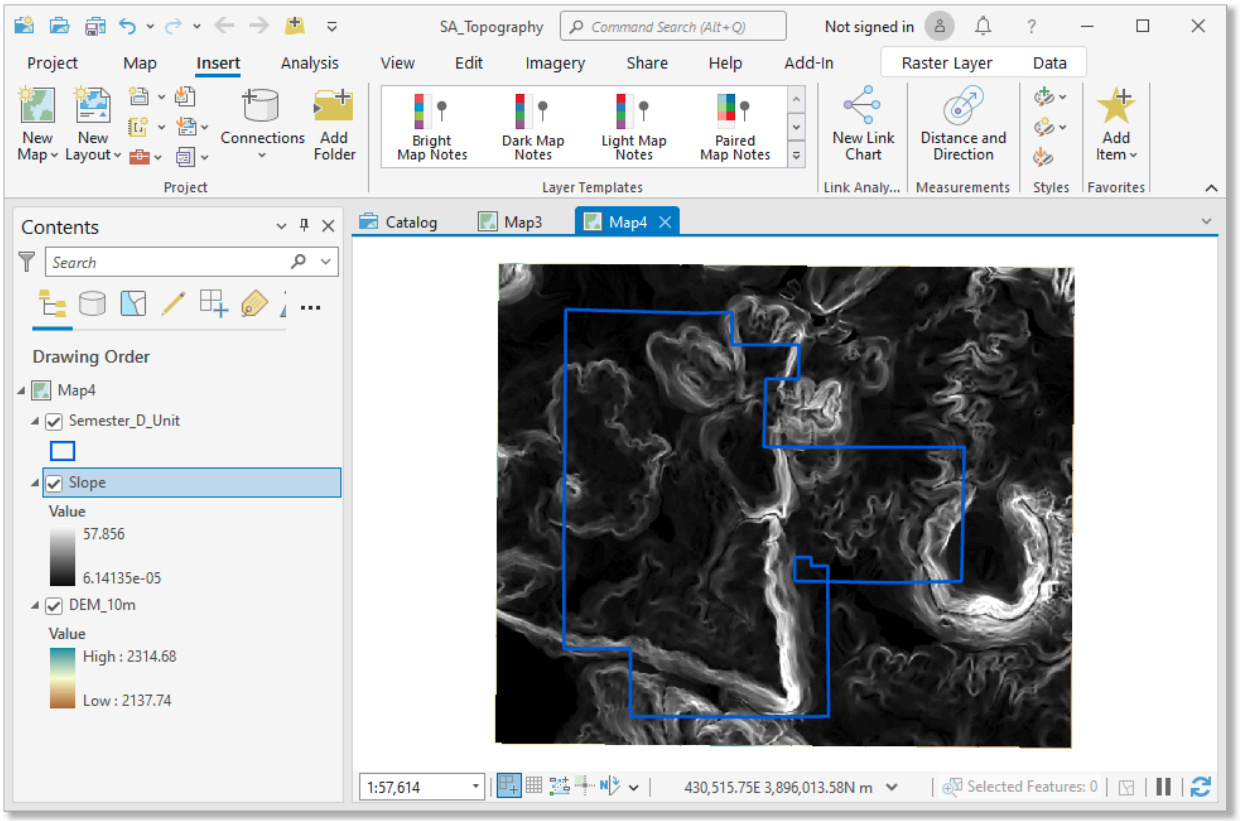




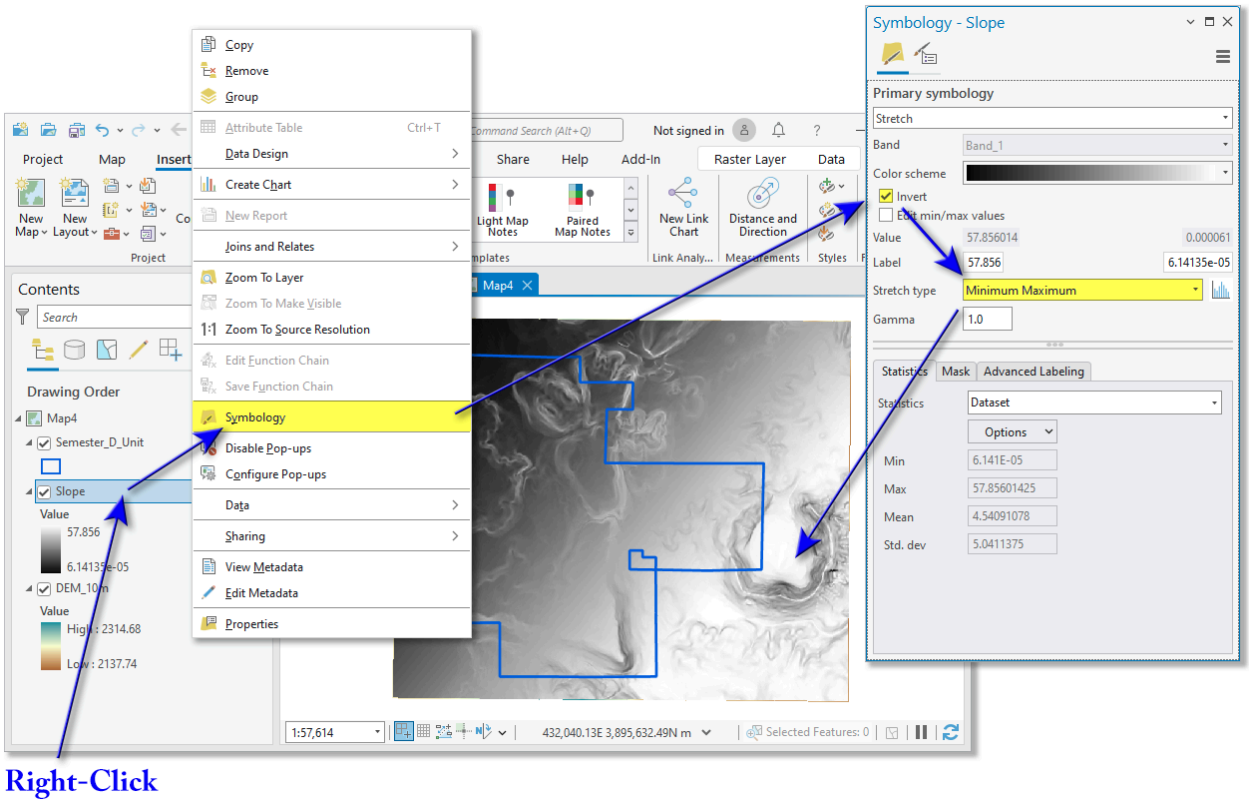
7) In the **Surface Parameters** window (and see p. – for full explanations of the options in this tool):
   a) Set the "Input Raster" to **DEM_10m**.
   b) If you see the "Input Dataset doesn't have a vertical unit" warning ⚠, and would like to know more about it, please take a look at https://youtu.be/PXNQHnAbDFw.
   c) Pick a name and location for your output Aspect raster. I recommend saving it to your default project file geodatabase and naming it "Slope". This suggestion is just to help you keep organized, though. You won't turn in the actual rasters as part of your homework.
   d) Leave "Input analysis mask" blank.
   e) Set the "Parameter Type" to be *Slope*.
   f) Set the "Local surface type" to be *Quadratic.*
   g) Leave the "Neighborhood distance" to the given value (9.33… Meters).
   h) Leave **unchecked** "Use adaptive neighborhood".
   i) Set your "Z unit" to be *Meter*, since our elevation units are in Meters.
   j) Set "Slope measurement" to *Degree*. **Important:** Refer to lecture discussing the consequences of calculating slope in *Percent*. Slopes in *Percent* are fine in and of themselves, but you can only calculate accurate slope mean and standard deviation if your slope values are in *Degrees*.



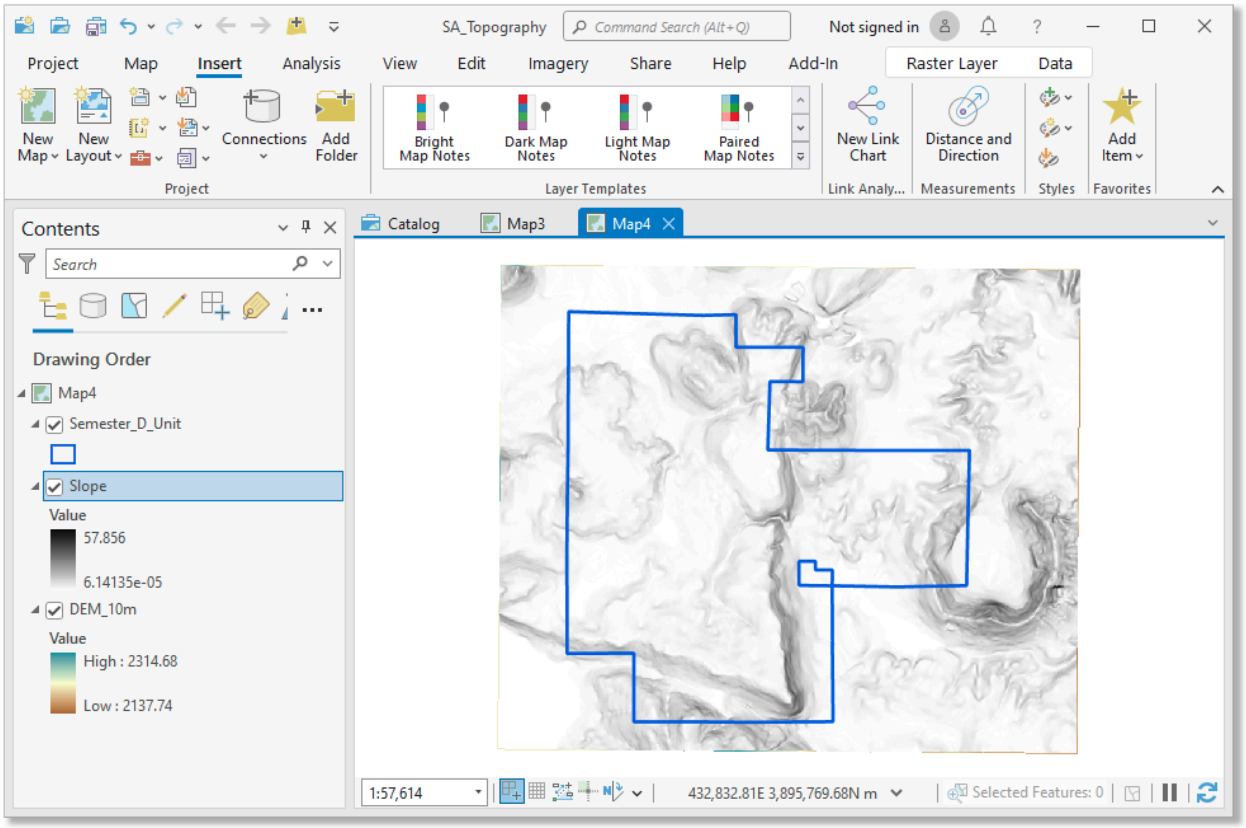
8) Upon completion, the tool will add a new Slope raster to your map. It should look something like the following:



Optional: If you get this dark-to-light color ramp, you might want to flip the colors. Personally I prefer viewing slope with "Stretched" symbology over a single color, going from light to dark, and often I'll use "Minimum-Maximum" instead of "Percent Clip". I will usually change the symbology to something like this:



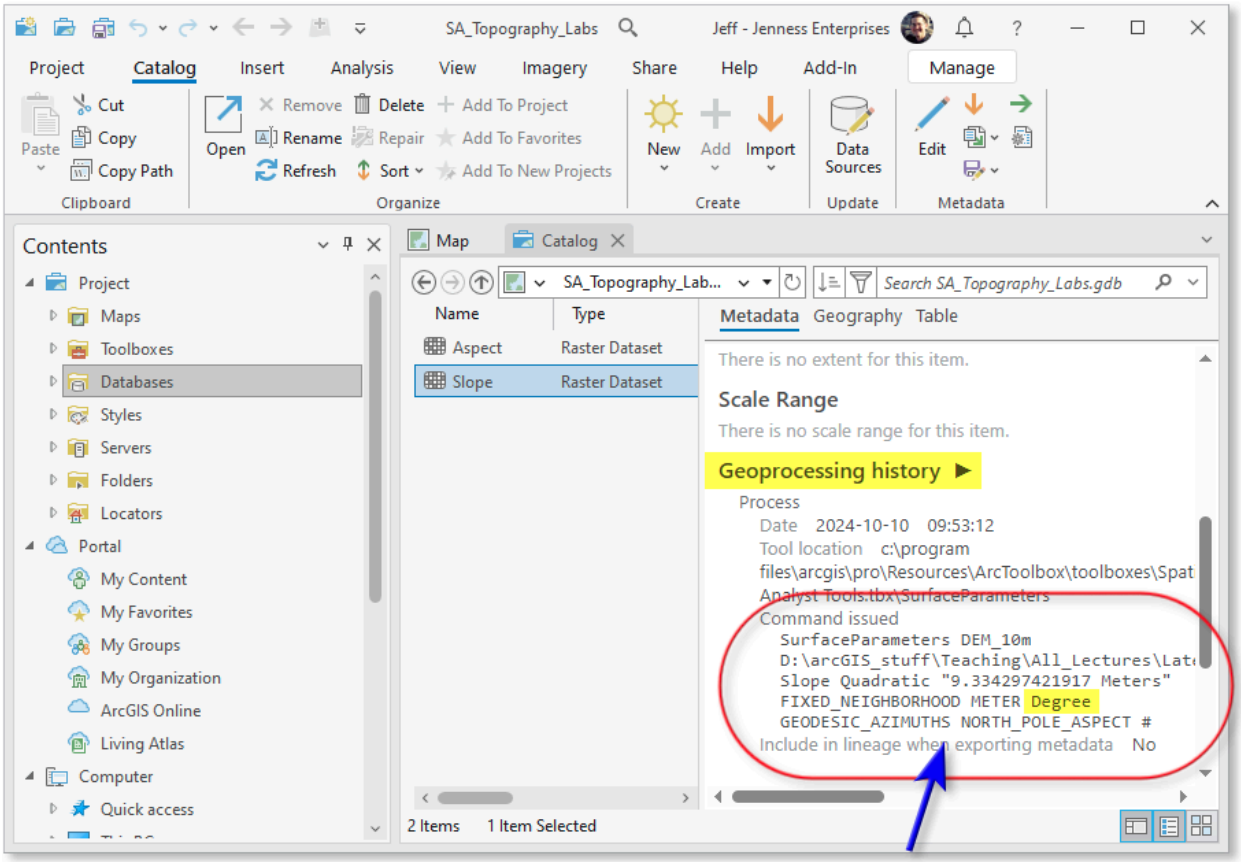
9) Which produces the following:



10) One last step: Suppose you load up this slope raster into a new map sometime in the future, but you can't remember if you created it in Degrees or in Percent? We can find out by looking at the **Geoprocessing History** in the raster metadata.

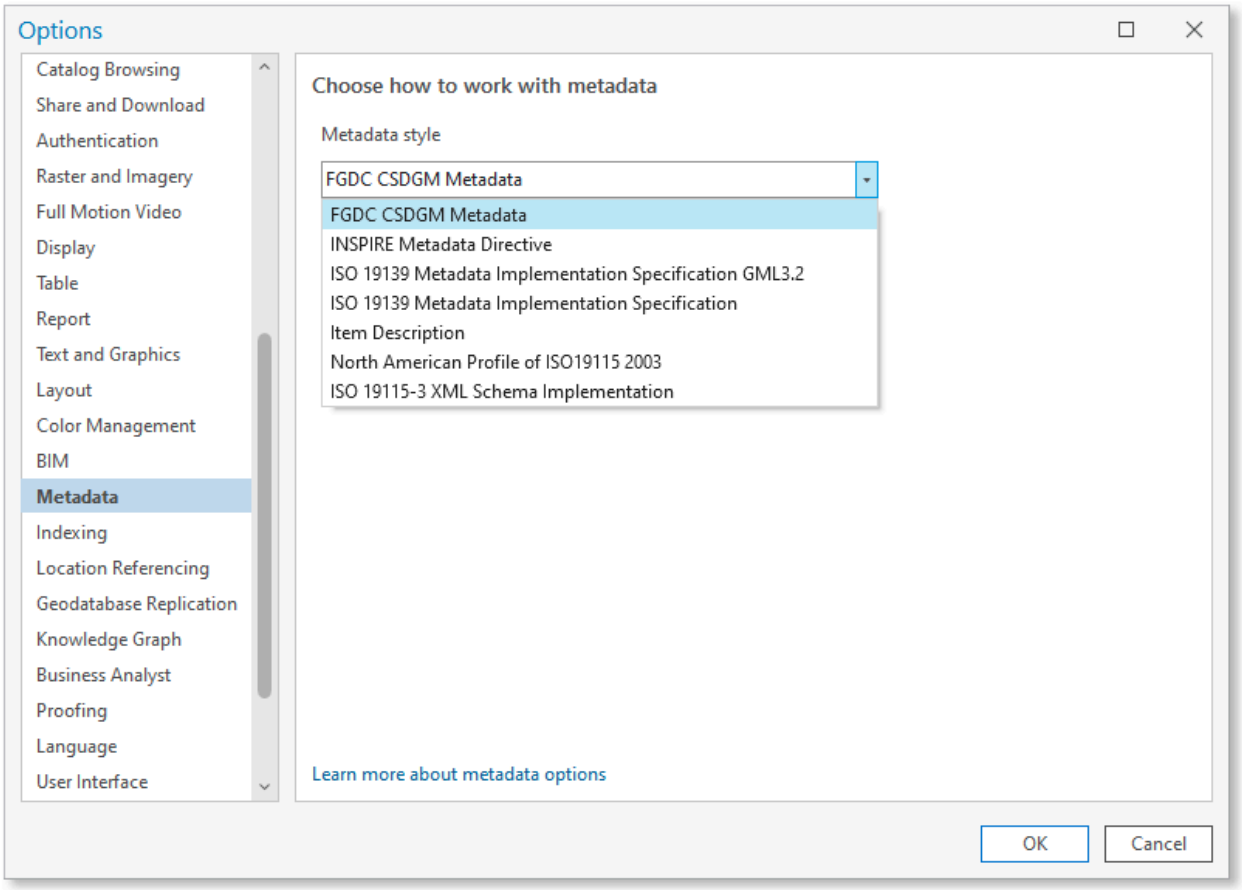
   a) Open your Catalog view and find your Slope raster.

   b) Select it and view the metadata. Scroll down to see the **Geoprocessing History** and view the settings you used when you ran the tool.



These are the settings you used when you ran the tool

c) **Note:** Do you not see your geoprocessing history? Then you probably have your **Metadata Style** set to "Item Description". This is the default style used by ArcGIS Pro, and by far the worst choice for viewing metadata. Take this opportunity to change your metadata style by opening your ArcGIS Pro "Options" window (go to the "Project" tab, then click on "Options"), scroll down to the "Metadata" tab, and change "Metadata Style" to anything other than Item Description. Then return to your Catalog view and see the full metadata for your Slope raster dataset.


Options
Catalog Browsing
Share and Download
Authentication
Raster and Imagery
Full Motion Video
Display
Table
Report
Text and Graphics
Layout
Color Management
BIM
Metadata
Indexing
Location Referencing
Geodatabase Replication
Knowledge Graph
Business Analyst
Proofing
Language
User Interface
Choose how to work with metadata
Metadata style
FGDC CSDGM Metadata
FGDC CSDGM Metadata
INSPIRE Metadata Directive
ISO 19139 Metadata Implementation Specification GML3.2
ISO 19139 Metadata Implementation Specification
Item Description
North American Profile of ISO19115 2003
ISO 19115-3 XML Schema Implementation
Learn more about metadata options
OK
Cancel

Exercise 3: Calculate Hillshade

Objectives

- Learn to use the Hillshade tool.

Data used

- Layer file **Semester_D_Unit.lyr**, in folder **..\Class_GIS_Data\Raster_Functions\...** This is the boundary of the Semester D Management Unit in the Centennial Forest, and it references a feature class named **Semester_D_Unit** in the file geodatabase **Lab_Data.gdb** located in the same folder.

- Raster layer file **DEM_10m.lyr**, in folder **..\Class_GIS_Data\Raster_Functions\...** This layer file references a raster dataset named **DEM_10m** in the file geodatabase **Lab_Data.gdb**, and is an approximately 10m resolution Digital Elevation Model (DEM) showing elevation (in meters) within the general extent of the Semester D Management Unit in the Centennial Forest.

- Optionally, any online basemap layers you prefer, such as topo maps or imagery. These won't be used in the analysis but they are often useful to help orient yourself or see the analysis within a larger landscape context.

Exercise

Based on the DEM (digital elevation model), you will generate a new raster showing the slope steepness, in degrees, of all points on the landscape.

Always consider two issues before you calculate hillshade!

- Is your DEM raster in geographic (lat/long) coordinates? If so, **you cannot accurately calculate a hillshade!** The standard ArcGIS tools will only accurately calculate a hillshade from projected data. You must project your DEM. The alternative surface tool **Surface Parameters** does not calculate hillshades.

    a. However, if your only purpose is to create something that looks cool, and accuracy is not an issue, then you can use a conversion factor (called the "Z Factor" in the tool) to convert the elevation units in such a way that the hillshade still looks good.

- Are your DEM elevation units the same as your X/Y coordinate system units? If one is in Feet and the other in Meters, then you will have to specify a conversion factor (Z Factor) to convert your elevation units to your X/Y units. For example, if your coordinate system is in meters, and your elevation units are in feet, then specify a Z-factor of 0.3048 because there are that many meters in a foot.

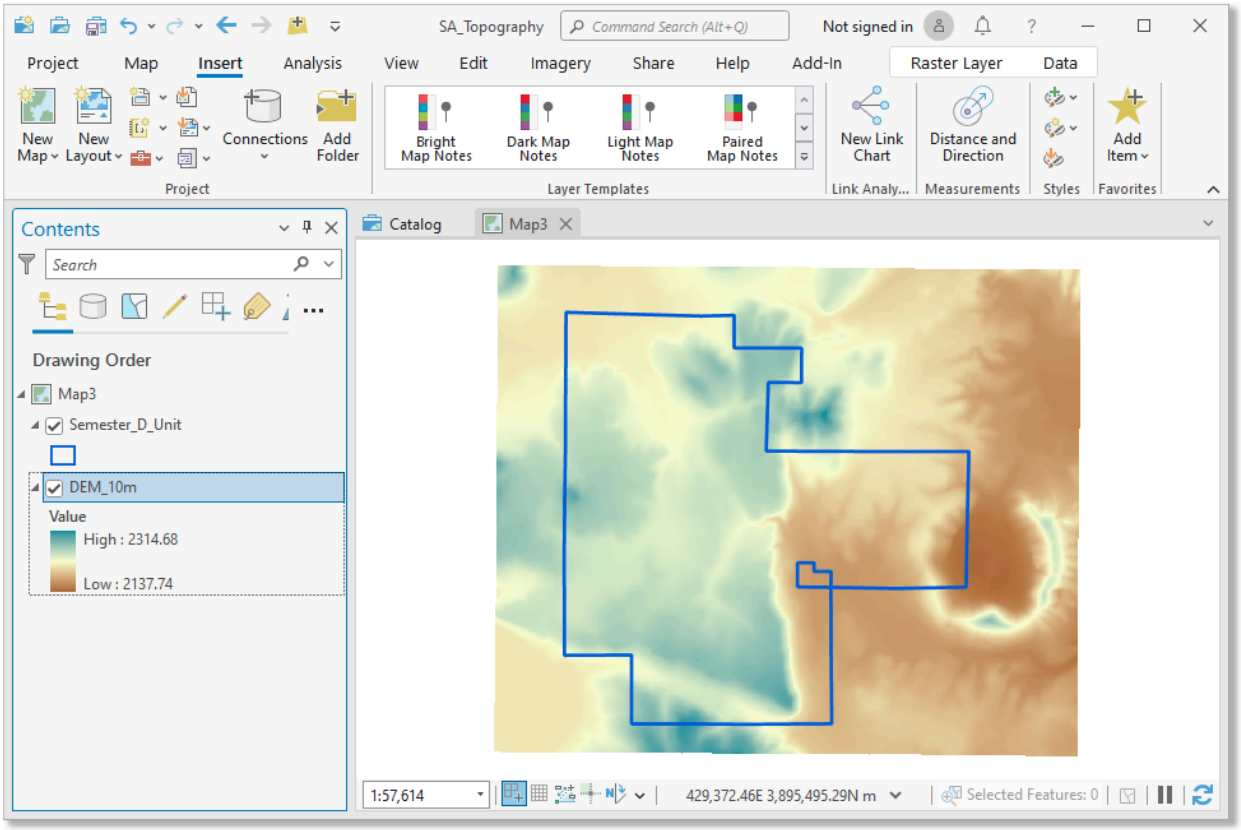
Prepare your Map and Data:

1) Open a blank map in ArcGIS Pro. If you still have ArcGIS Pro open from the previous exercise, you may simply insert a new map.

2) Make sure you have the **Spatial Analyst** extension turned on. See Exercise 1 if you have questions on this.

3) If they are not already present, then load the **Layer** files **DEM_10m.lyr** and **Semester_D_Unit.lyr** from the folder **..\Class_GIS_Data\Raster_Functions\...** as you did in Exercise 1.

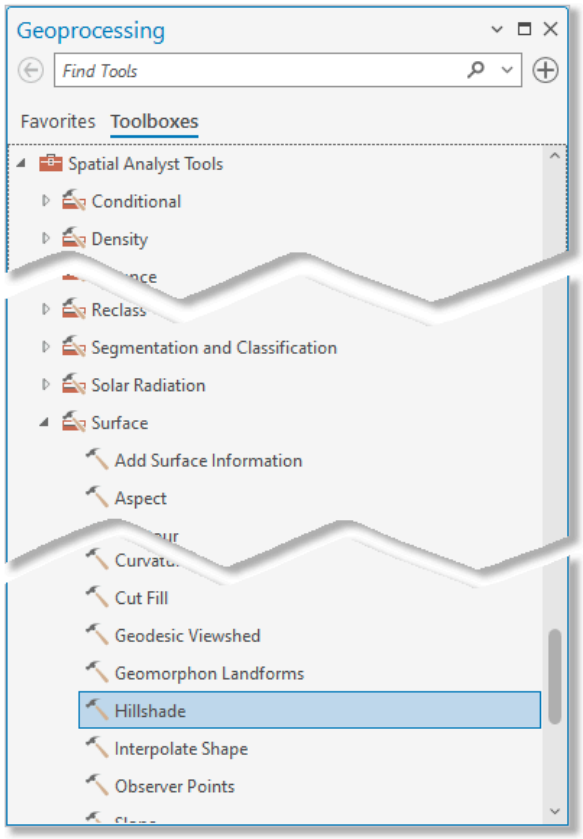
4) If you loaded the Layer files, you should see the following.

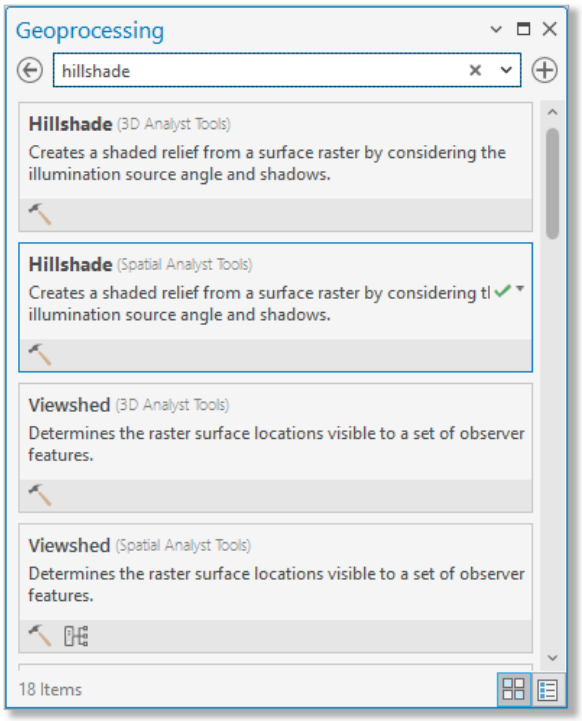


1) Optionally, load any online basemap layers or other background data you like.

Calculate Hillshade

2) Open the Hillshade tool (in Toolboxes --> Spatial Analyst Tools --> Surface --> Hillshade):



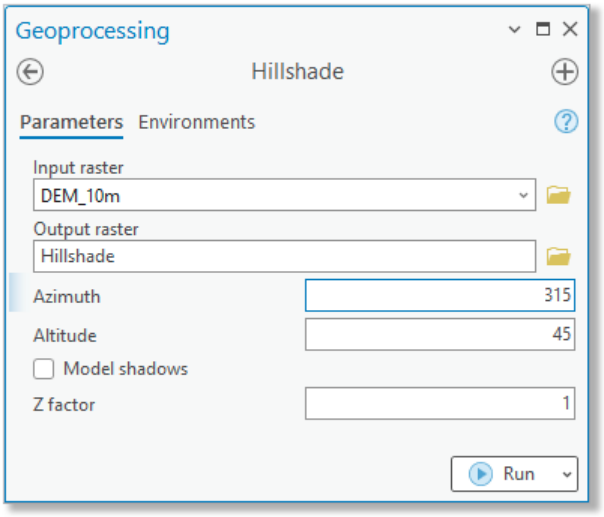


3) Set the "Input Raster" to **DEM_10m** and pick a name and location for your output Hillshade raster. I recommend saving it to your file geodatabase named "New_Data.gdb" and naming it "Hillshade". Set the "Azimuth" to **315** and the "Altitude" to **45**. You may choose to model shadows or not; your choice.

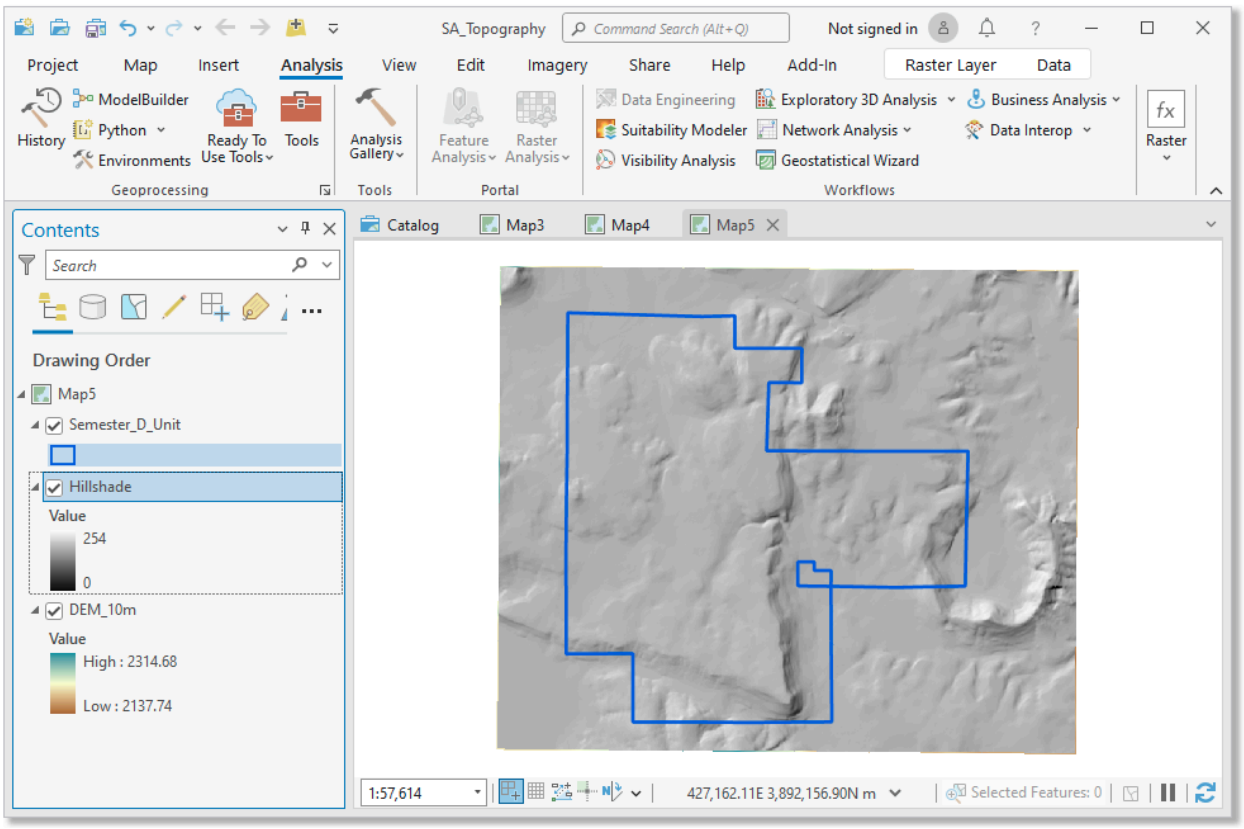
   a) **Note:** "Azimuth" and "Altitude" refer to the sun position. These default values usually produce a good-looking raster that brings out the shape of the landscape very well. However, remember that the sun is rarely in that position (exactly Northwest [315°], and 45° up) in the northern hemisphere! You can change the sun position to any location you want. There are online tools available (such as http://www.esrl.noaa.gov/gmd/grad/solcalc/) to help you determine sun position for a particular place and time.

   b) **Note:** The option to "Model Shadows" means to check for places that might directly face the sun, but would be in the shadow of a larger feature. Modeling shadows would set these areas to black (or a hillshade value of 0) regardless of their orientation.

4) If your elevation units are different than your coordinate system linear units, then set the appropriate conversion factor in the "Z factor" box. For example, if your coordinate system is in meters, and your elevation units are in feet, then specify a Z-factor of 0.3048 because there are that many meters in a foot. Otherwise, leave this conversion factor equal to 1.

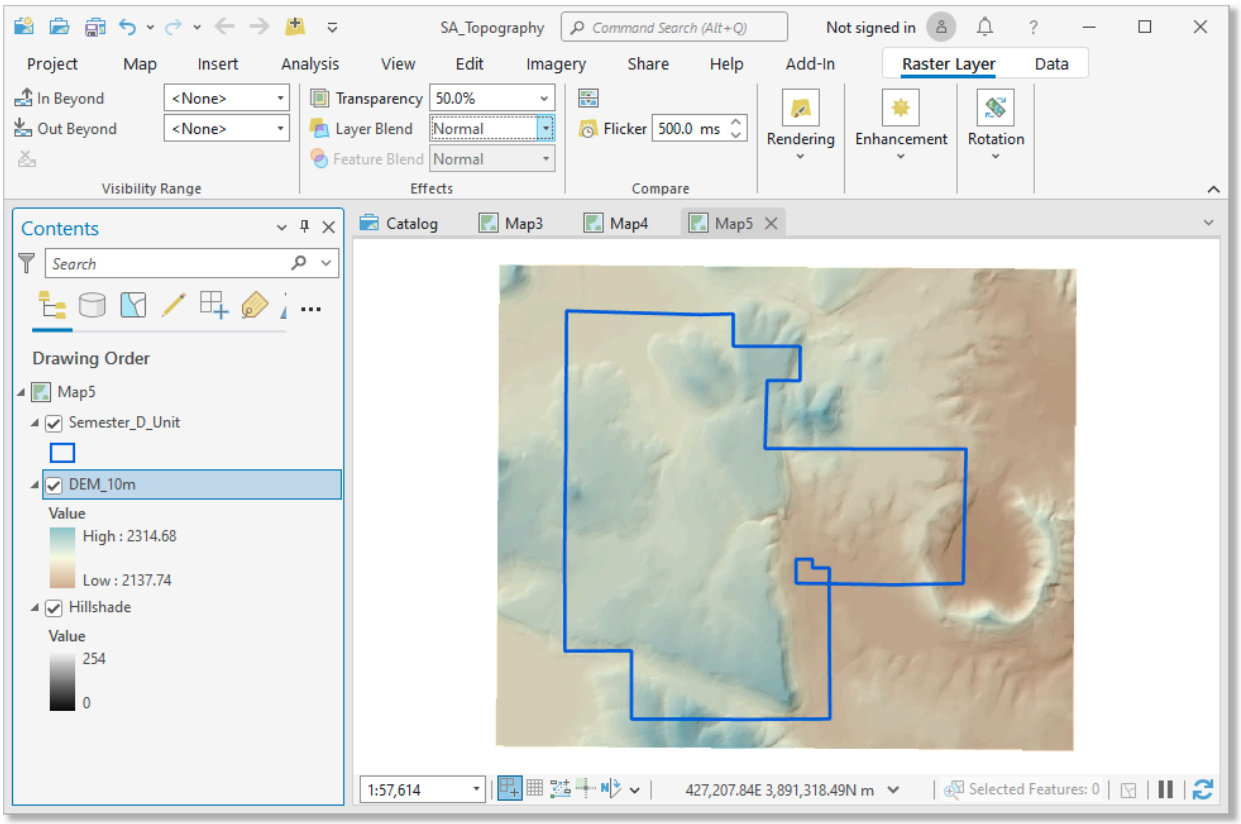


5) Upon completion, the tool will add a new Hillshade raster to your map. It should look something like the following:



6) **Optional:** I often like to set the DEM over the hillshade (or any layer over the hillshade) and make it partially transparent. This lets me see the shape of the landscape underneath whatever I am mapping.

For example, dragging the Hillshade to the bottom and setting the DEM to 50% transparent produces the following:


SA_Topography
Command Search (Alt+Q)
Not signed in
Project
Map
Insert
Analysis
View
Edit
Imagery
Share
Help
Add-In
Raster Layer
Data
In Beyond
<None>
Out Beyond
<None>
Visibility Range
Transparency
50.0%
Layer Blend
Normal
Feature Blend
Normal
Effects
Flicker
500.0 ms
Compare
Rendering
Enhancement
Rotation
Contents
Search
Drawing Order
Map5
Semester_D_Unit
DEM_10m
Value
High : 2314.68
Low : 2137.74
Hillshade
Value
254
0
Catalog
Map3
Map4
Map5
1:57,614
427,207.84E 3,891,318.49N m
Selected Features: 0

Exercise 4: Calculate Curvature (Mean, Profile and Plan)

Objectives

- Learn to use the Curvature tools to calculate three common types of curvature.

Data used

- Layer file **Semester_D_Unit.lyr**, in folder **..\Class_GIS_Data\Raster_Functions\...** This is the boundary of the Semester D Management Unit in the Centennial Forest, and it references a feature class named **Semester_D_Unit** in the file geodatabase **Lab_Data.gdb** located in the same folder.

- Raster layer file **DEM_10m.lyr**, in folder **..\Class_GIS_Data\Raster_Functions\...** This layer file references a raster dataset named **DEM_10m** in the file geodatabase **Lab_Data.gdb**, and is an approximately 10m resolution Digital Elevation Model (DEM) showing elevation (in meters) within the general extent of the Semester D Management Unit in the Centennial Forest.

- Raster dataset **Hillshade**, which you created in Exercise 3 above.

- Optionally, any online basemap layers you prefer, such as topo maps or imagery. These won't be used in the analysis but they are often useful to help orient yourself or see the analysis within a larger landscape context.

For Homework

You will calculate statistics on your curvature raster datasets in Lab Exercise 7.

Exercise

Based on the DEM (digital elevation model), you will generate a new raster showing general curvature, plan curvature and profile curvature, of all points on the landscape.

Always consider two issues before you calculate curvature!

- There are two tools that calculate surface curvature: The **Curvature** tool and the **Surface Parameters** tool. Is your DEM raster in geographic (lat/long) coordinates? If so, you must use the **Surface Parameters** tool to calculate curvature! The **Curvature** tool will only accurately calculate curvature from projected data. You must project your DEM if you want to use the **Curvature** tool.
- Are your DEM elevation units the same as your X/Y coordinate system units? If one is in Feet and the other in Meters, then you will have to apply a correction factor when running the tool.
    a. In the **Surface Parameters** tool, you set this by specifying exactly what units the elevation values are.
    b. In the **Curvature** tool, you set this by entering a conversion factor into the "Z-Factor" box.

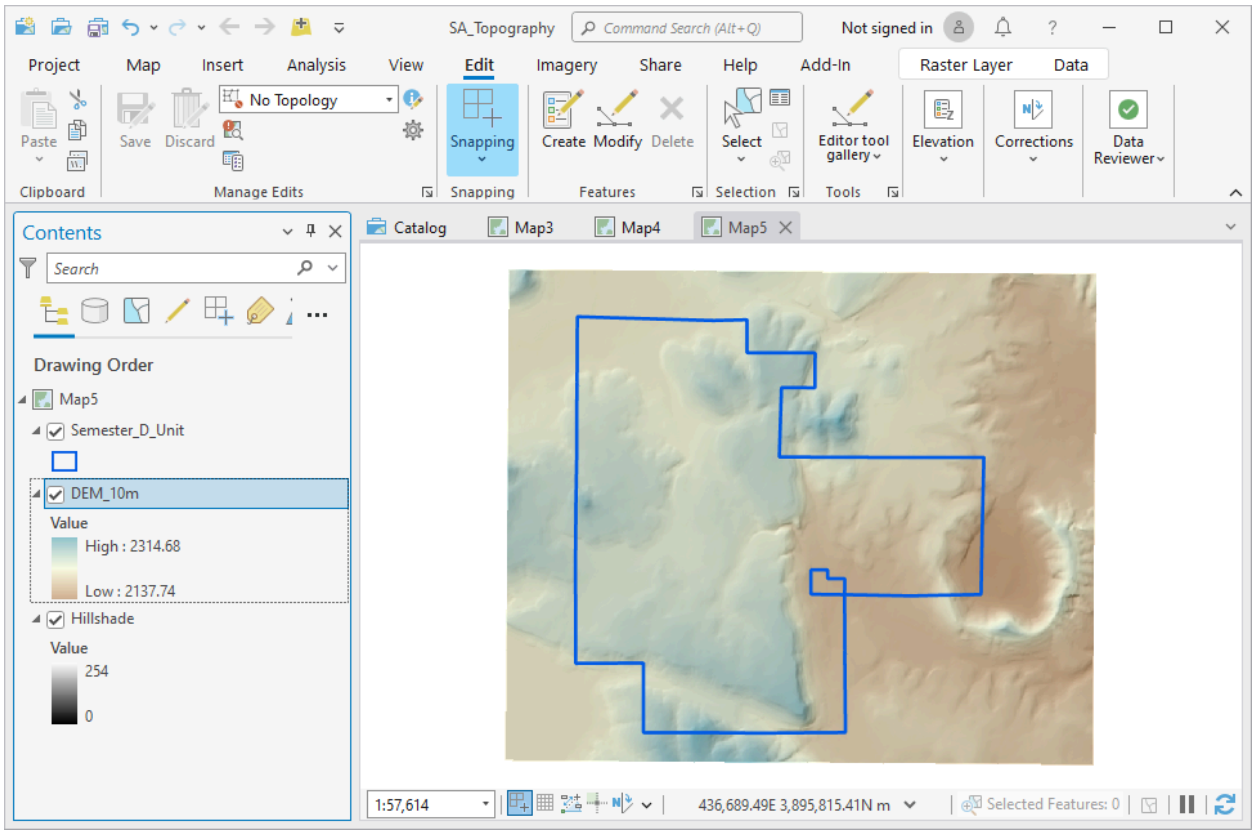
Prepare your Map and Data:

1) If your map and data from the previous exercise are still open, you may work directly in that map. You will use the Hillshade layer you just created. Otherwise, open a blank map in ArcGIS Pro.

2) Make sure you have the **Spatial Analyst** extension turned on. See Exercise 1 if you have questions on this.

3) If they are not already present, then load the **Layer** files **DEM_10m.lyr** and **Semester_D_Unit.lyr** from the folder **..\Class_GIS_Data\Raster_Functions\...** as you did in Exercise 1, and add your **Hillshade** layer from Exercise 3 above.

4) If you set **DEM_10m** as partially transparent, and your hillshade on the underneath the DEM, you should see the following.

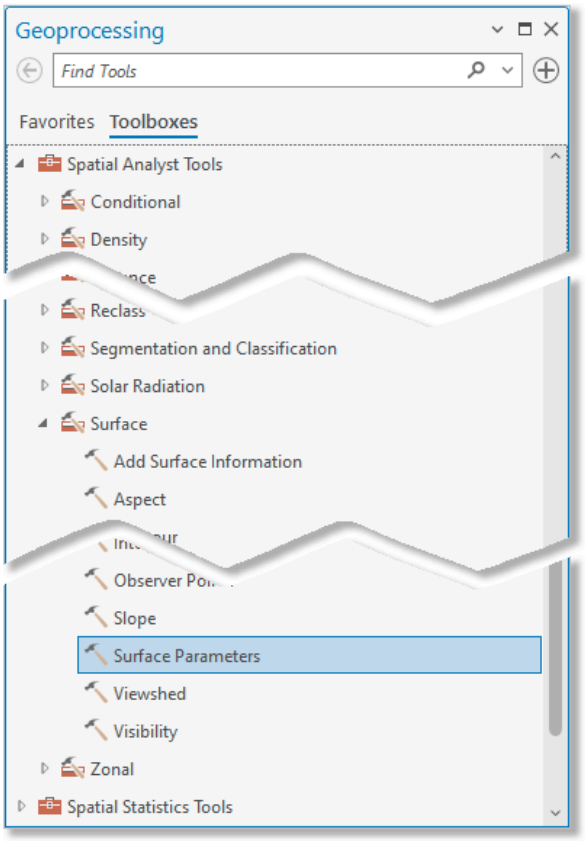


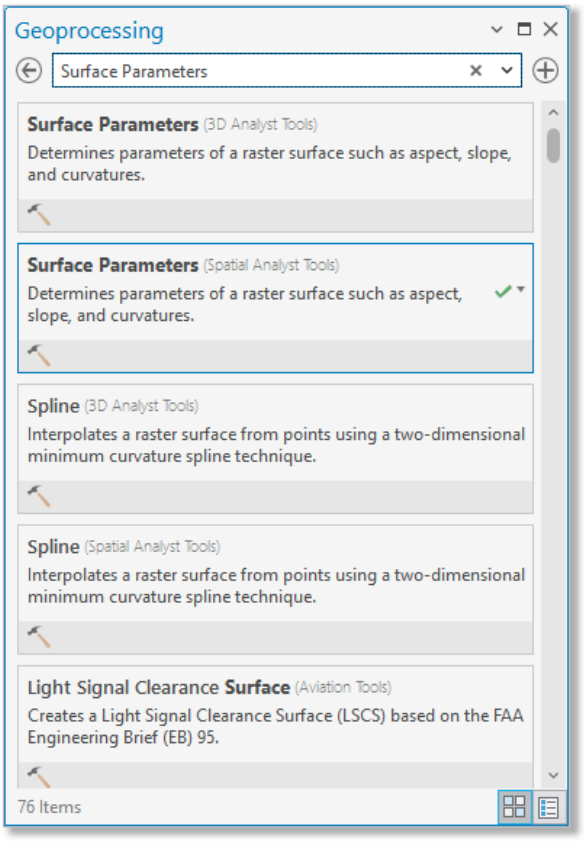
5) Optionally, load any online basemap layers or other background data you like.

Calculate Curvature

ArcGIS has two tools that calculate Curvature: The **Curvature** tool, and the **Surface Parameters** tool. The **Curvature** tool has the advantage that it allows you to calculate three types of curvature simultaneously, while the **Surface Parameters** tool will only calculate one type at a time. The **Surface Parameters** tool has the advantage that it will work on projected and unprojected DEMs, and it offers a few more types of curvature than the standard tool. Esri encourages users to use the new **Surface Parameters** tool, so this lab exercise will follow their lead.

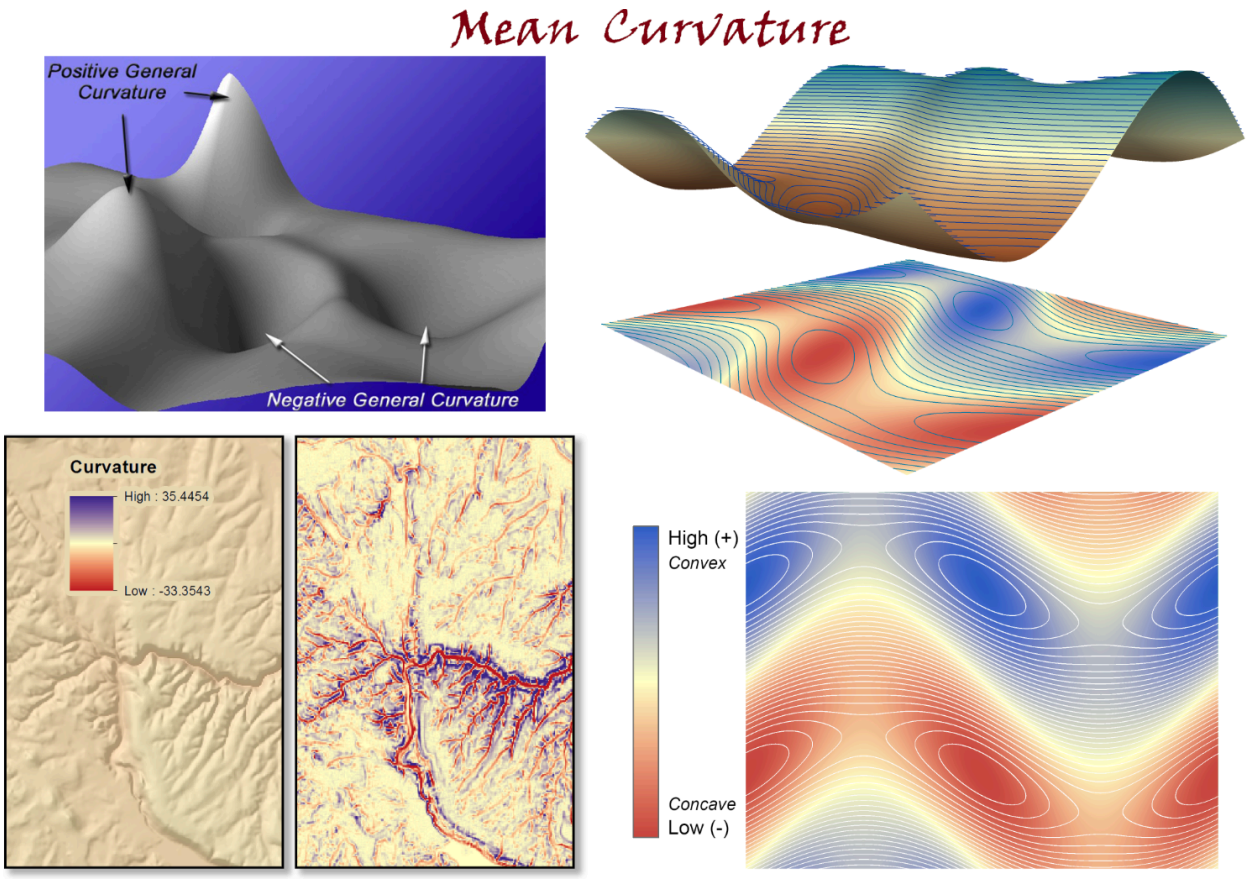
6) Open the **Surface Parameters** tool (in Toolboxes --> Spatial Analyst Tools --> Surface --> Surface Parameters):





Curvature Type 1: Mean Curvature

Mean curvature is the general convexity or concavity of the landscape, where concave surfaces (dips or valleys) have negative values and convex surfaces (hills or ridges) have positive values.



7) In the **Surface Parameters** window (and see p. – for full explanations of the options in this tool):

   a) Set the "Input Raster" to **DEM_10m**.

   b) If you see the "Input Dataset doesn't have a vertical unit" warning ⚠, and would like to know more about it, please take a look at https://youtu.be/PXNQHnAbDFw.

   c) Pick a name and location for your output Mean Curvature raster. I recommend saving it to your default project file geodatabase and naming it "Mean_Curvature". This suggestion is just to help you keep organized, though. You won't turn in the actual rasters as part of your homework.

   d) Leave "Input analysis mask" blank.

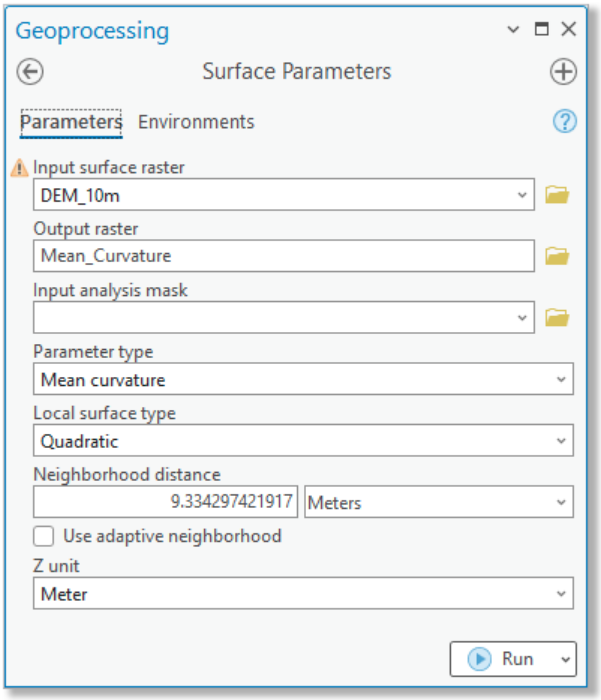
   e) Set the "Parameter Type" to be *Mean Curvature*.

   f) Set the "Local surface type" to be *Quadratic.*

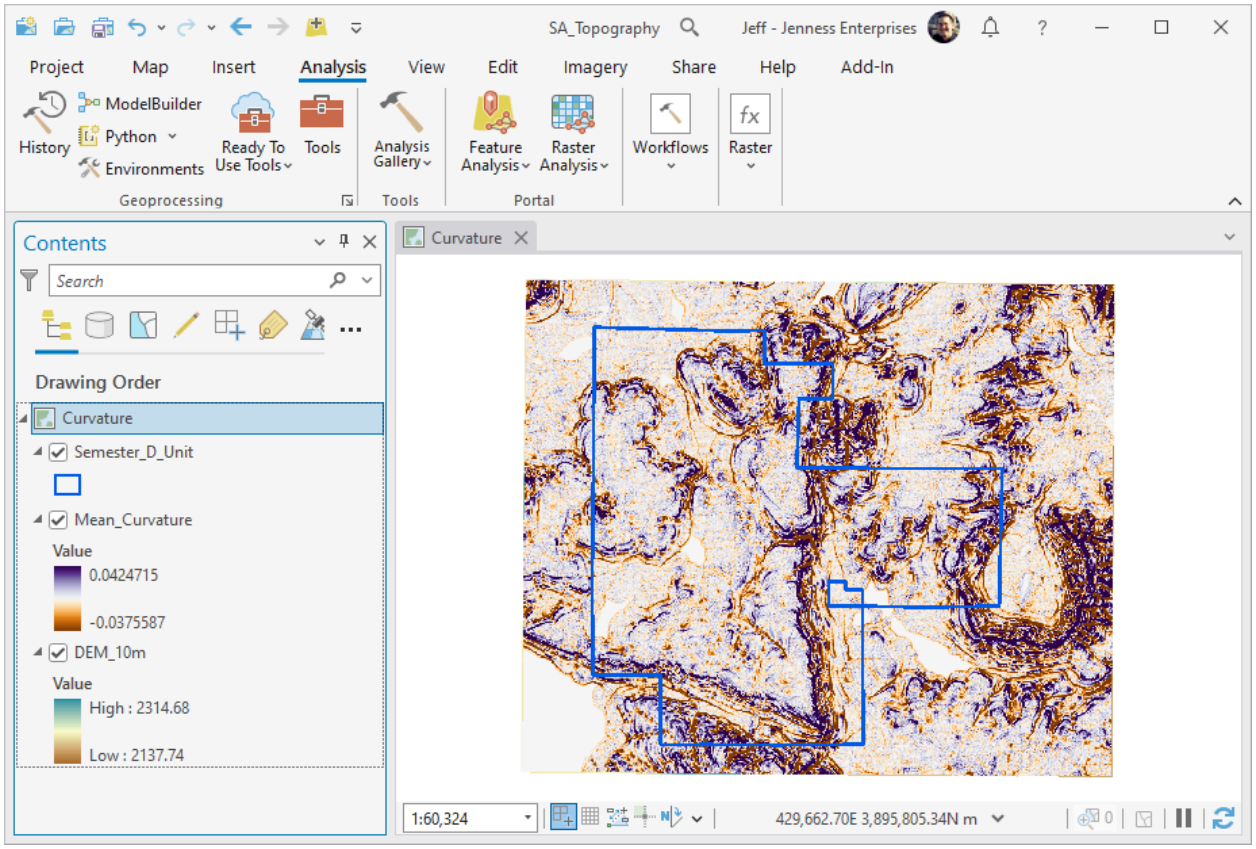
   g) Leave the "Neighborhood distance" to the given value (9.33… Meters).

   h) Leave **unchecked** "Use adaptive neighborhood".

   i) Set your "Z unit" to be *Meter*, since our elevation units are in Meters.



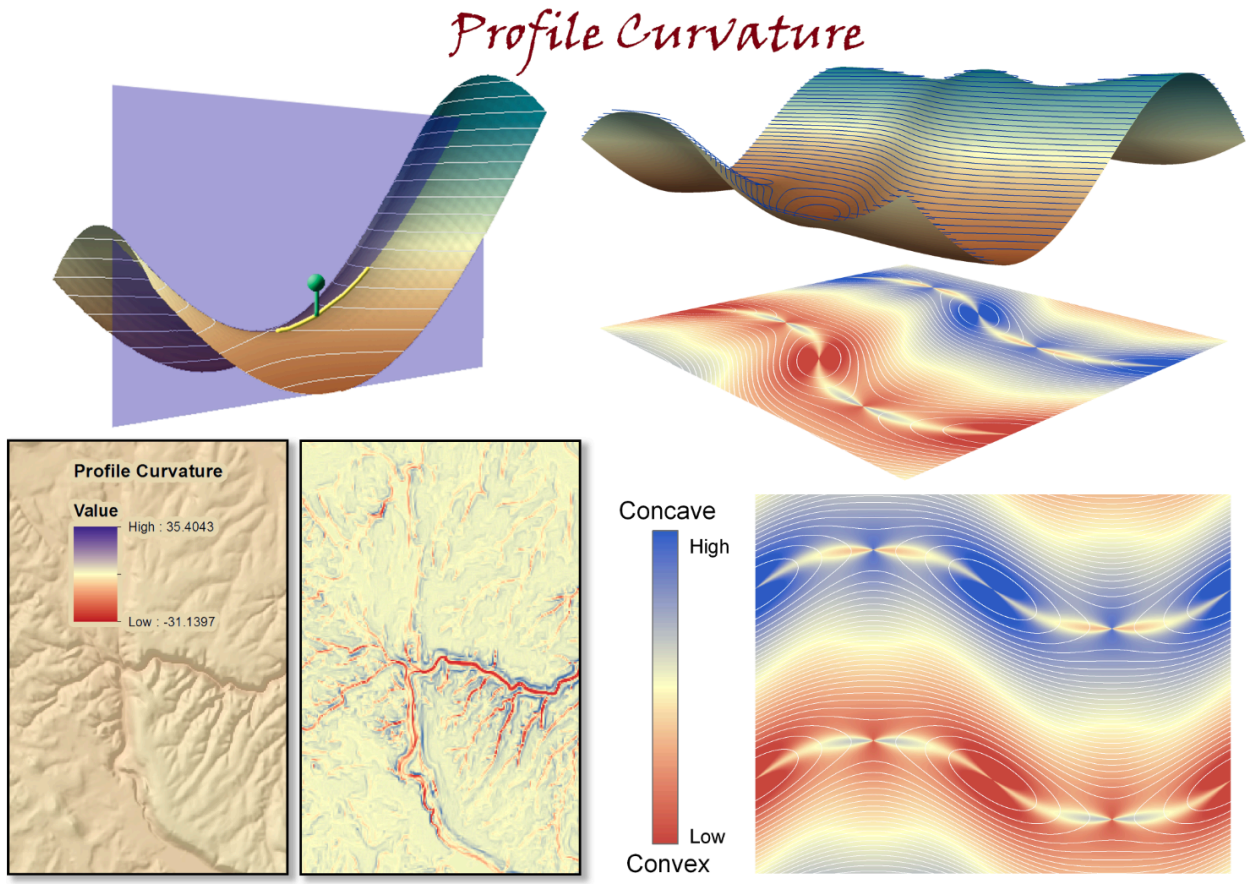
8) Upon completion, the tool will add a new Slope raster to your map. It should look something like the following:



Curvature Type 2: Profile Curvature

Profile curvature tells you whether water would speed up or slow down as it flows over the surface. It is the curvature at a point on the line of intersection, where a vertical plan intersects the landscape in the direction of steepest slope.

Curvature Trivia! When Esri rewrote the *Profile Curvature* function for the new **Surface Parameters** tool, they actually flipped the output so that positive values in the original tool show up as negative values in the new tool, and vice versa. Be careful of this if you are comparing your profile curvature outputs to other people's calculations!



9) In the **Surface Parameters** window (and see p. – for full explanations of the options in this tool):

   a) Set the "Input Raster" to **DEM_10m**.

   b) If you see the "Input Dataset doesn't have a vertical unit" warning ⚠, and would like to know more about it, please take a look at https://youtu.be/PXNQHnAbDFw.

   c) Pick a name and location for your output Profile Curvature raster. I recommend saving it to your default project file geodatabase and naming it "Profile_Curvature". This suggestion is just to help you keep organized, though. You won't turn in the actual rasters as part of your homework.

   d) Leave "Input analysis mask" blank.

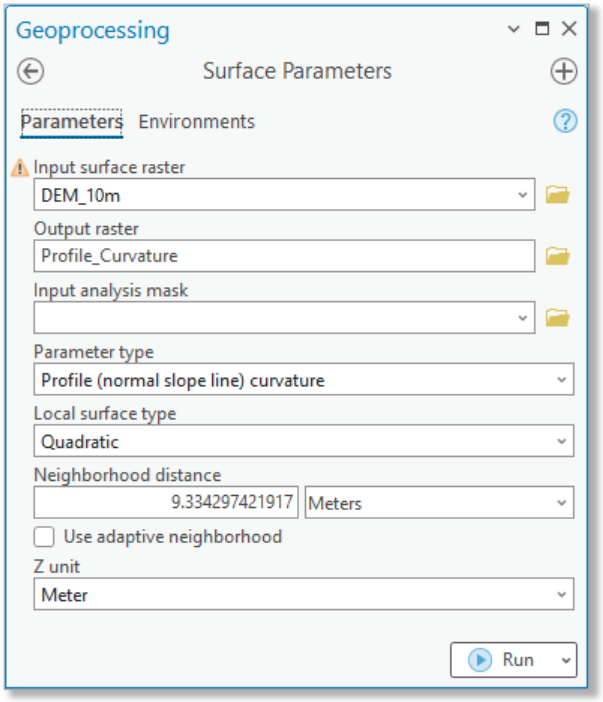
   e) Set the "Parameter Type" to be *Profile (normal slope line) curvature*.

   f) Set the "Local surface type" to be *Quadratic.*

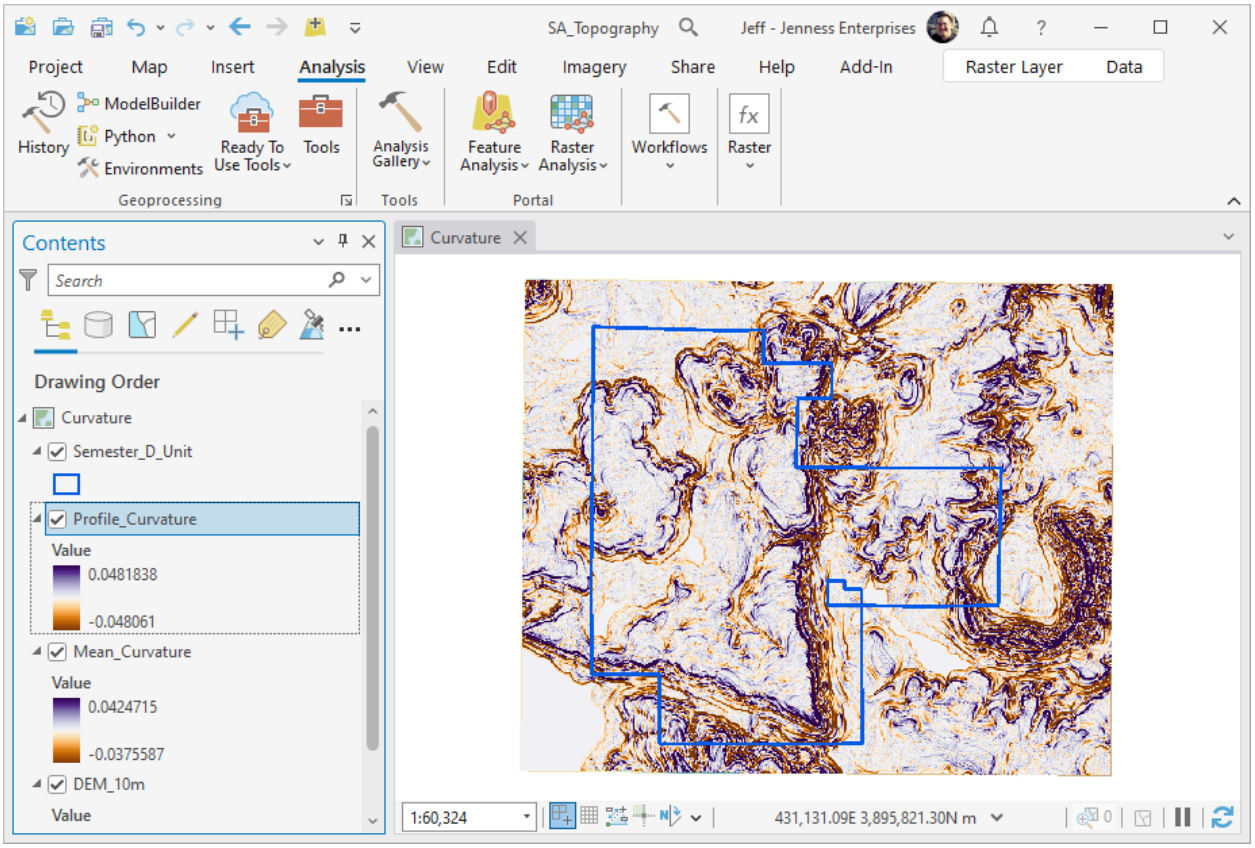
g) Leave the “Neighborhood distance” to the given value (9.33… Meters).

h) Leave **unchecked** “Use adaptive neighborhood”.

i) Set your “Z unit” to be *Meter*, since our elevation units are in Meters.

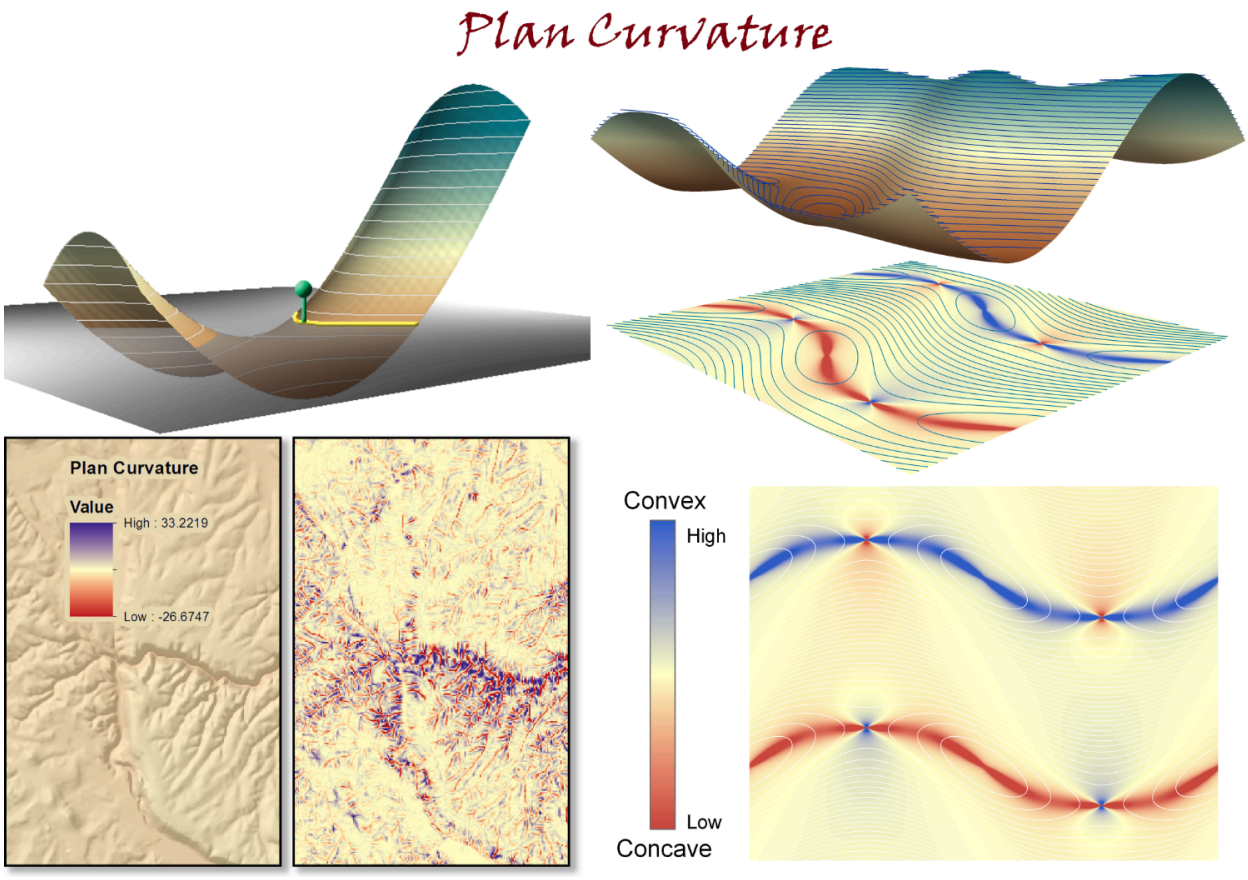


10) Upon completion, the tool will add a new Slope raster to your map. It should look something like the following:



Curvature Type 3: Plan Curvature

Plan curvature tells you whether water will diverge or converge as it flows over a point. It is the curvature of a point on the line of intersection between a horizontal plane and the landscape (essentially the curvature of a contour line).



11) In the **Surface Parameters** window (and see p. – for full explanations of the options in this tool):

a) Set the "Input Raster" to **DEM_10m**.

b) If you see the "Input Dataset doesn't have a vertical unit" warning , and would like to know more about it, please take a look at https://youtu.be/PXNQHnAbDFw.

c) Pick a name and location for your output Plan Curvature raster. I recommend saving it to your default project file geodatabase and naming it "Plan_Curvature". This suggestion is just to help you keep organized, though. You won't turn in the actual rasters as part of your homework.

d) Leave "Input analysis mask" blank.

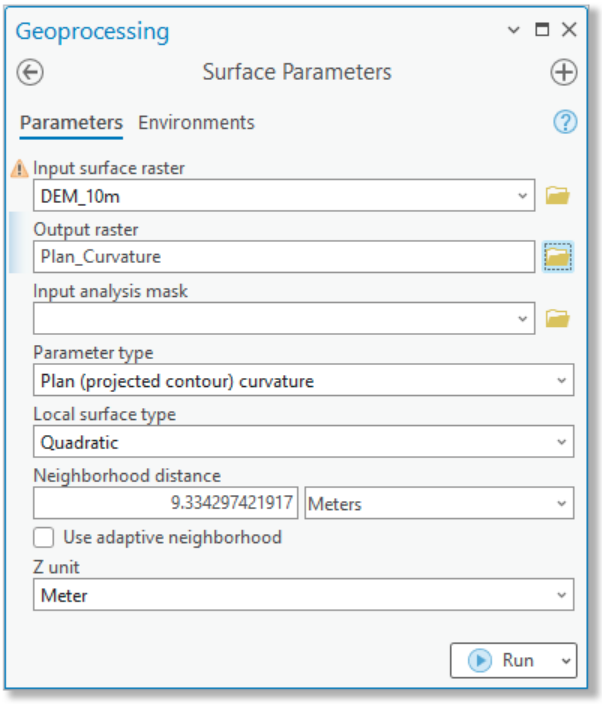
e) Set the "Parameter Type" to be *Plan (projected contour) curvature*.

f) Set the "Local surface type" to be *Quadratic.*

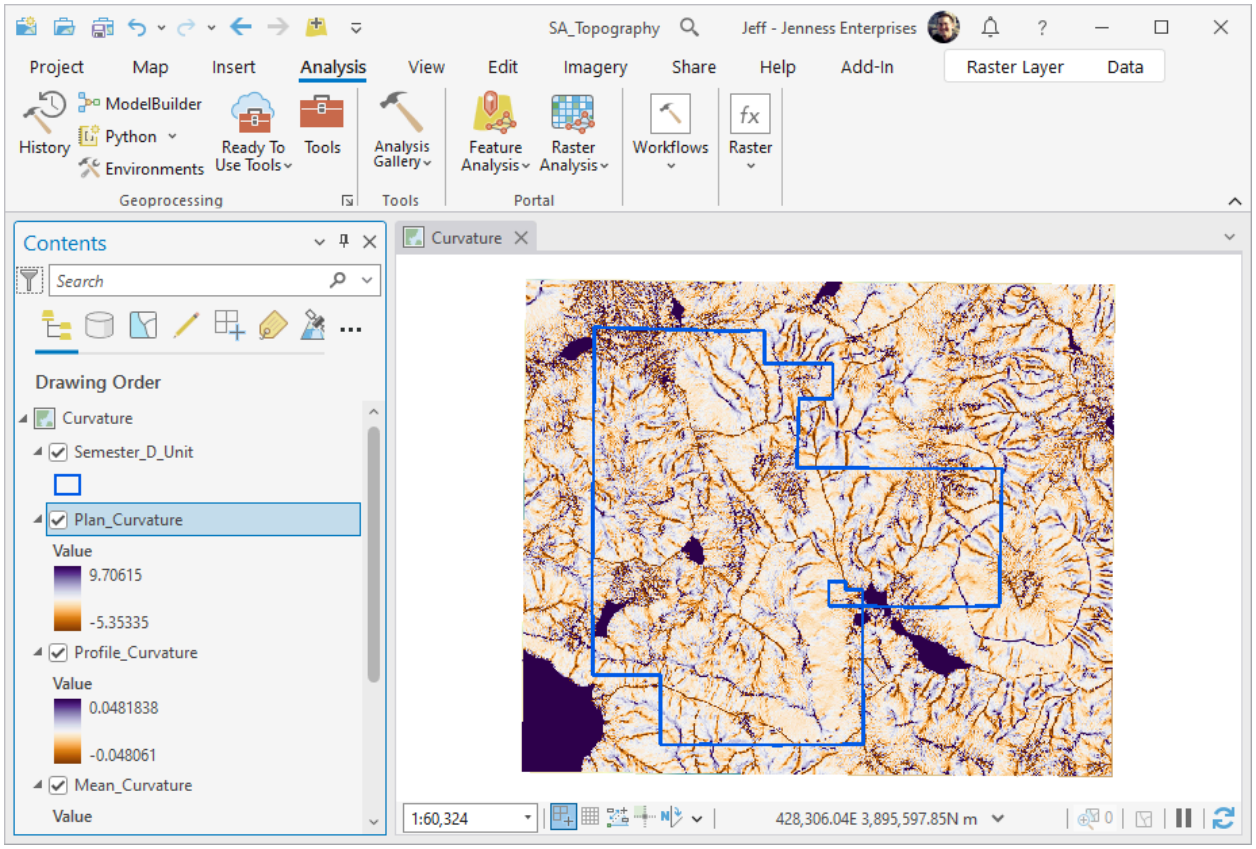
g) Leave the "Neighborhood distance" to the given value (9.33… Meters).

h) Leave **unchecked** "Use adaptive neighborhood".

i) Set your "Z unit" to be *Meter*, since our elevation units are in Meters.



12) Upon completion, the tool will add a new Slope raster to your map. It should look something like the following:



13) Look closely at your curvature rasters and compare them with your hillshade. **Note: You do not have to look only within your analysis area!** Study different landscape features until you understand exactly what each curvature dataset is telling you. For example:

   a) Find a ridgeline on your hillshade and zoom in to it. If water was running over this ridgeline, where do you think it would speed up (because the ground is getting steeper as you go downhill)? Where would it slow down? Then look at your **Profile** Curvature raster on this same area. Does it show values you expect?

   b) Find another ridgeline on your hillshade. If water was running over this ridge, where do you think it would diverge (because it is running along the top of a ridge or saddle)? Where would it converge (because it is inside a drainage)? Then look at your **Plan** Curvature raster. Does it show values you expect?

   c) Find a hill or valley on your hillshade. Hills are convex with respect to the earth, and valleys are concave. Then look at your **General** curvature raster. Does it show values you expect?

Exercise 5: Calculate TPI (Topographic Position Index)

Objectives

- Learn to use the Neighborhood Focal Statistics tool.
- Learn the Raster Math Tools using the "Minus" tool as an example.
- Learn how to calculate Topographic Position Index, which is a cool and informative statistic that helps you classify the landscape into Hills and Valleys.

Data used

- Layer file **Semester_D_Unit.lyr**, in folder **..\Class_GIS_Data\Raster_Functions\...** This is the boundary of the Semester D Management Unit in the Centennial Forest, and it references a feature class named **Semester_D_Unit** in the file geodatabase **Lab_Data.gdb** located in the same folder.
- Raster layer file **DEM_10m.lyr**, in folder **..\Class_GIS_Data\Raster_Functions\...** This layer file references a raster dataset named **DEM_10m** in the file geodatabase **Lab_Data.gdb**, and is an approximately 10m resolution Digital Elevation Model (DEM) showing elevation (in meters) within the general extent of the Semester D Management Unit in the Centennial Forest.
- Optionally, any additional data or online basemap layers you prefer, such as your hillshade, topo maps or imagery. These won't be used in the analysis but they are often useful to help orient yourself or see the analysis within a larger landscape context.

For Homework

You will calculate statistics on your TPI raster dataset in Lab Exercise 7.

Additional Documentation

Original TPI poster by Andrew Weiss: https://www.jennessent.com/arcview/TPI_Weiss_poster.htm

Poster for a TPI tool I wrote many years ago: https://www.jennessent.com/arcview/TPI_jen_poster.htm

TPI Documentation: https://www.jennessent.com/downloads/TPI_Documentation_online.pdf

For Fun

I have created a sample model named **TPI** that will calculate TPI from a DEM, as well as models that do a few other things we describe in these labs, that you are welcome to download and play with. The toolbox is saved in a geodatabase you can download from here:

https://drive.google.com/file/d/1MDMLqwZolsCLVpKiy9i75aQceRI-gIPw/view?usp=sharing

Exercise

Based on the DEM (digital elevation model), you will generate a new raster showing whether raster cells are higher than their neighbors (hills) or lower than their neighbors (valleys).

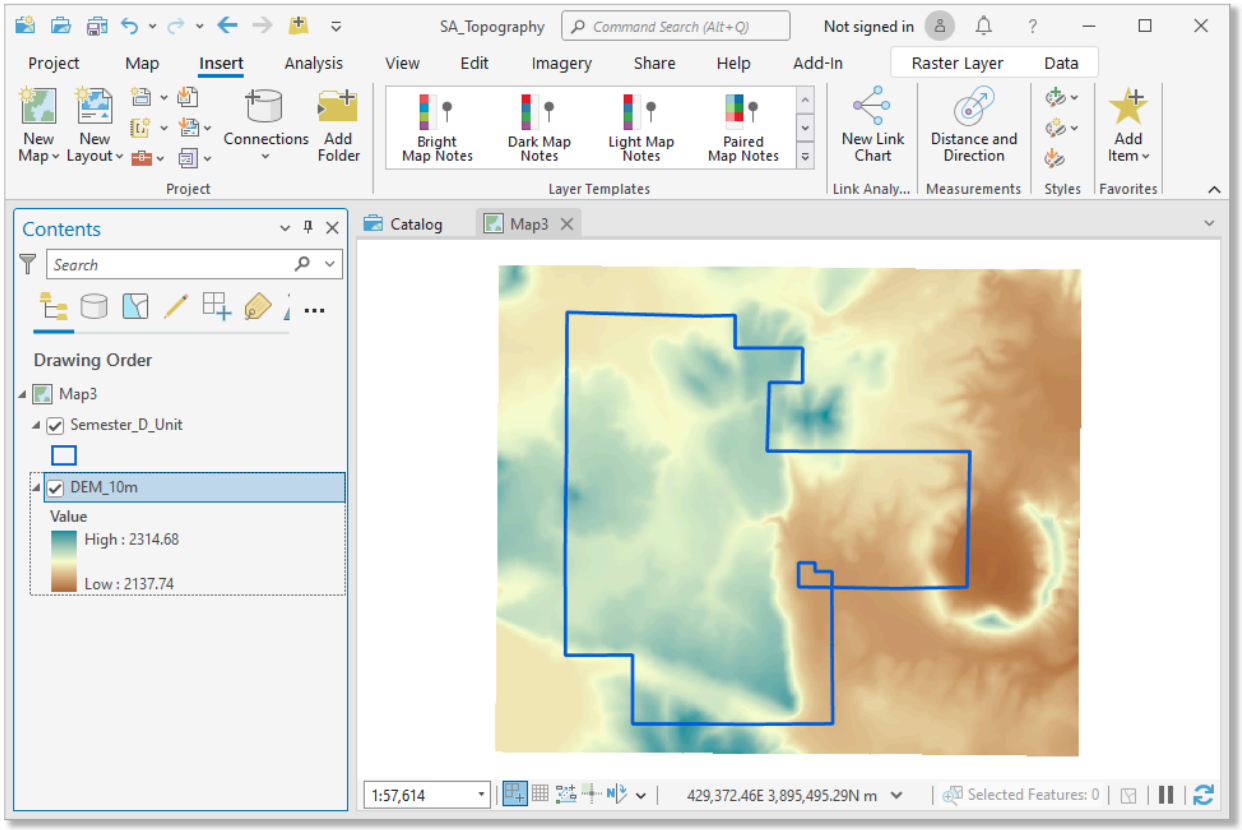
TPI (Topographic Position Index) is a measure of how much a raster cell differs in elevation from the average elevation of its neighbors. You calculate it by first calculating the average elevation in the neighborhood, which gives you a new raster of "Neighborhood Average" values. You then subtract that new raster from your original DEM, which gives you a raster of "Elevation – Mean Elevation" values. If

the value is negative, then the focal (central) cell is lower than its neighbors. If the value is positive, then clearly it is higher than its neighbors.

One cool thing about this method is that you can set your neighborhood size to an appropriate scale for the phenomenon you are analyzing. Remember that the terms "hill", "ridge", or "valley" are pretty subjective. What is a hill to a mouse might not even be noticeable to you, and a mountain goat wouldn't even blink at a hill that stops us cold. Having a flexible neighborhood size allows you to analyze different scales of topographic features.

Prepare your Map and Data:

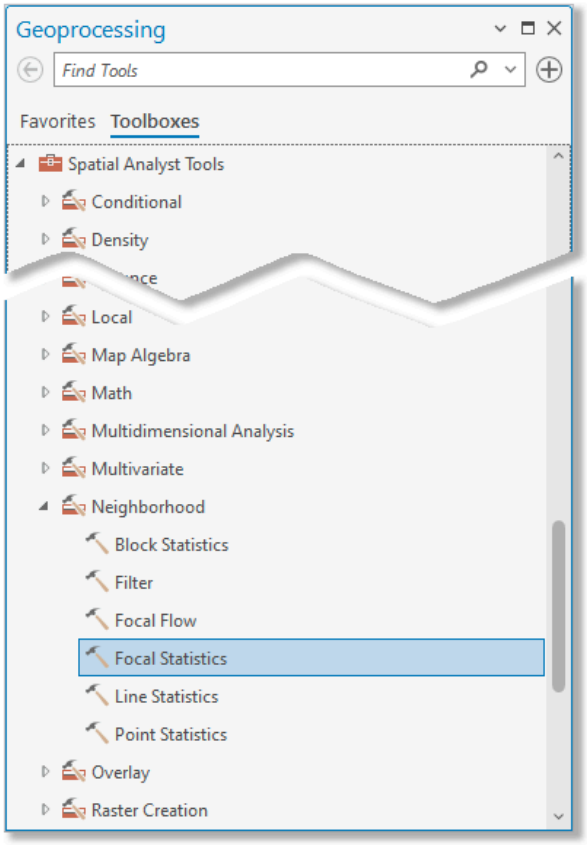
1) Open a blank map in ArcGIS Pro. If you still have ArcGIS Pro open from the previous exercise, you may simply insert a new map.
2) Make sure you have the **Spatial Analyst** extension turned on. See Exercise 1 if you have questions on this.
3) If they are not already present, then load the **Layer** files **DEM_10m.lyr** and **Semester_D_Unit.lyr** from the folder **..\Class_GIS_Data\Raster_Functions\...** as you did in Exercise 1.
4) If you loaded the Layer files, you should see the following.

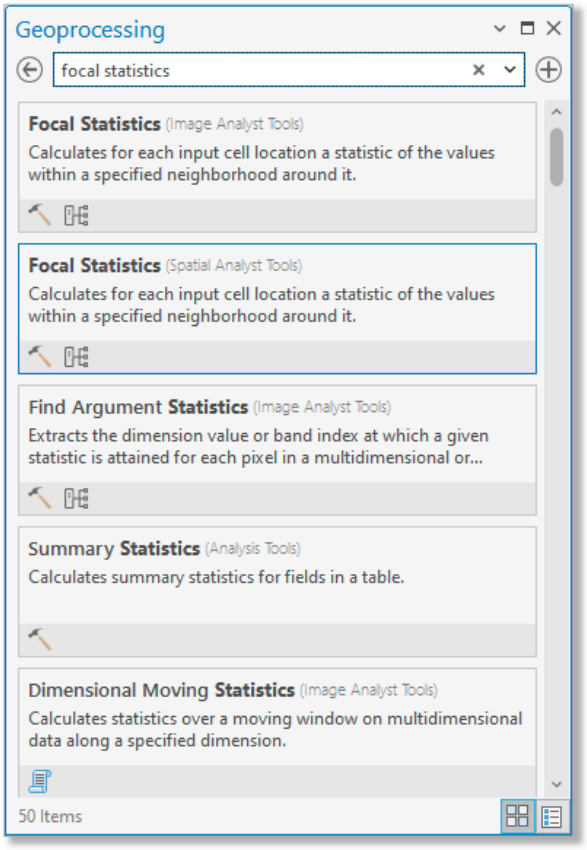


5) Optionally, load any online basemap layers or other background data you like.

Calculate Neighborhood Focal Mean

6) Open the Focal Statistics tool (in Toolboxes --> Spatial Analyst Tools --> Neighborhood --> Focal Statistics):





7) In the **Focal Statistics** window:

   a) Set the "Input Raster" to **DEM_10m**.

   b) Pick a name and location for your output Neighborhood Mean raster. I recommend saving it to your default project file geodatabase and naming it "Nbrhood_Mean". This suggestion is just to help you keep organized, though. You won't turn in the actual rasters as part of your homework.

   c) Set your "Neighborhood" to a *Circle*, with a radius of 200 map units (which means 200 meters, because our DEM is in a coordinate system that uses meters as the linear unit. Just FYI, when this tool says "map units", it actually means the linear units of your raster coordinate system. It has nothing to do with the coordinate system of the map itself.)

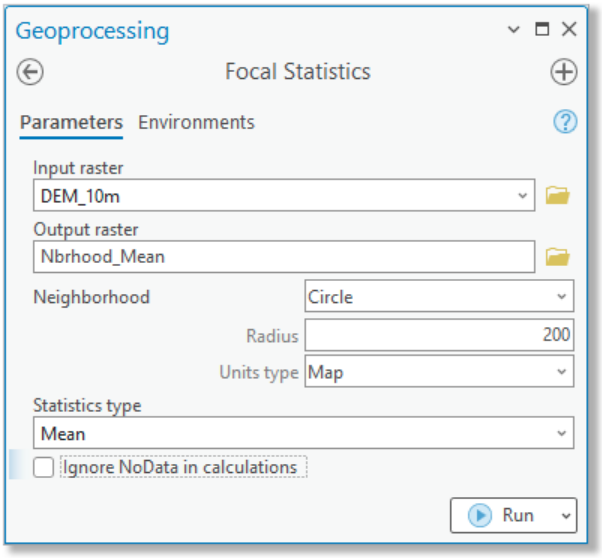
   d) Set "Statistics Type" to **Mean.**

   e) Set "Ignore NoData in calculations" = **False**

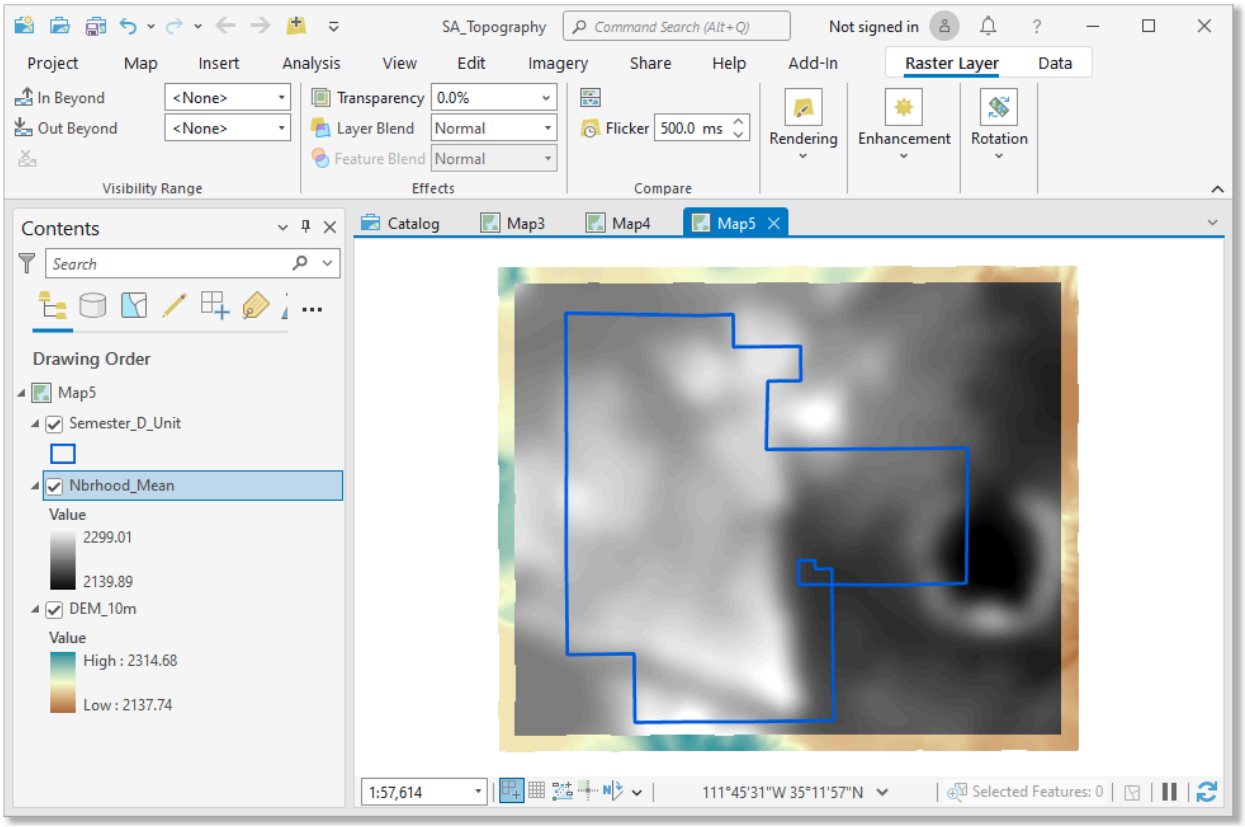
      i) This means that, if any NoData cells are found inside the neighborhood, then the new raster cell will also be set to **NoData**. This guarantees that the mean value calculated for all the raster cells in our new raster will be calculated from the same number of neighborhood cells.

      ii) If we set this value to "True", then the tool would just skip over any NoData cells in the DEM, including the regions outside the edge of the raster. Cells at the edge of the raster may have mean values calculated from half or less of the number of elevation cells as interior cells.

      iii) Please ask me if you are confused on this point.



8) Upon completion ArcGIS Pro will add your new Neighborhood Mean raster to your map. Notice that it looks a lot like your original DEM, but blurrier. Which is what you'd expect.



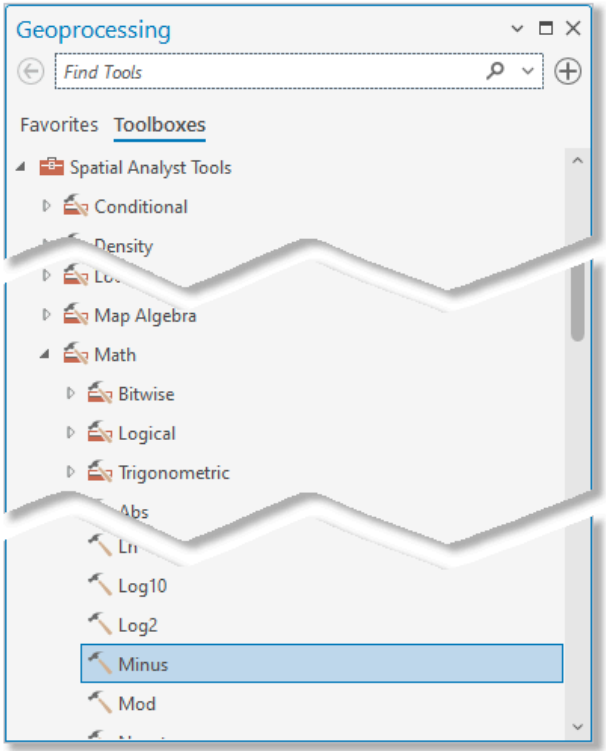
Stop and check your values! Your minimum and maximum values should be something like those pictured above (Minimum = 2139.89, Maximum = 2299.01). Did you get different values than these?

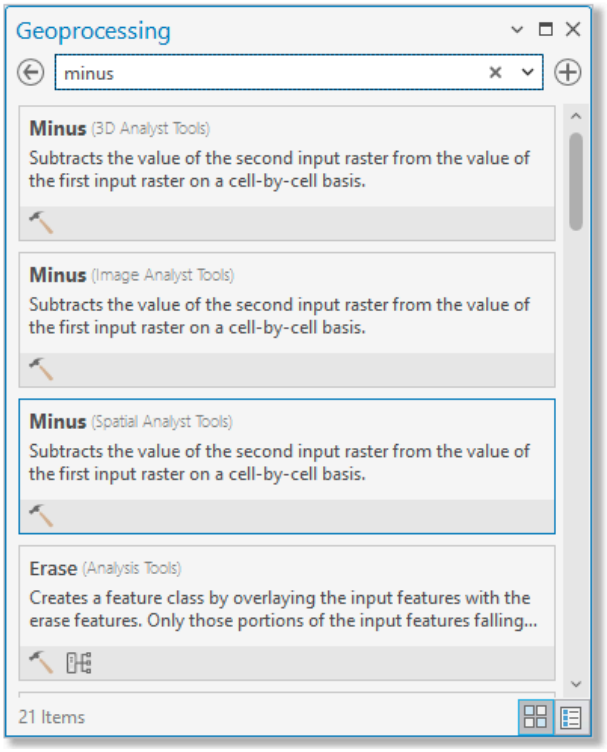
- **If you got** different values, then double-check that you set a neighborhood of 200 map units. You may also have failed to set "Ignore NoData in calculations" = **False**. If necessary rerun the tool with the correct settings.

9) If you zoom out to the full extent of your Neighborhood raster, you may observe that it is smaller than your original DEM. This is because ArcGIS only calculated neighborhood means for cells ≥ 200m from the edge (this is what setting "Ignore NoData in calculations" = **False** did).

Subtract this Nbrhood_Mean raster from your original DEM.

10) Open the "Minus" tool (in Toolboxes --> Spatial Analyst Tools --> Math --> Minus):



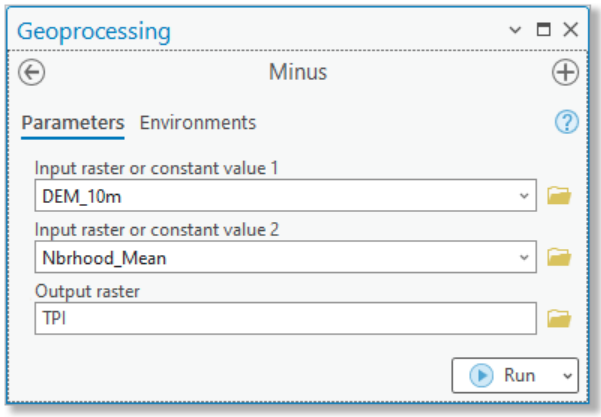


11) In the **Minus** window:

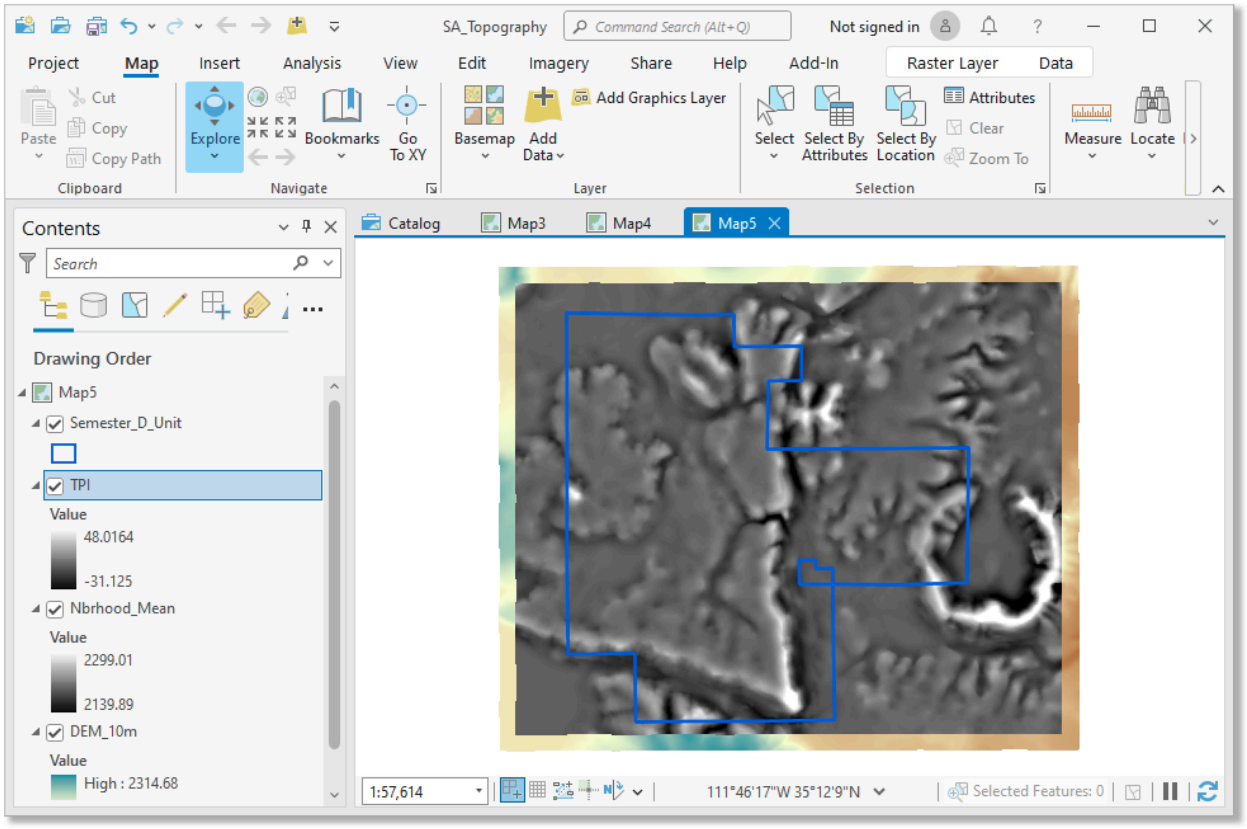
a) Set the "Input Raster or constant value 1" to **DEM_10m**.

b) Set the "Input Raster or constant value 2" to **Nbrhood_Mean.**

c) Pick a name and location for your output Topographic Position Index raster. I recommend saving it to your default project file geodatabase and naming it "TPI". This suggestion is just to help you keep organized, though. You won't turn in the actual rasters as part of your homework.



12) Upon completion, you will have a new TPI raster which displays hills and valleys based on a 200m radius window. Positive values are hills or ridges, and negative values are drainages or sinks.



13) Often, a next step is to classify the TPI values as either ridges, valleys or flat areas based on some threshold TPI value. We won't do this in this lab, but keep it in mind for your future work. It can be difficult to pick a good threshold value.

Also, consider that a TPI value near Zero only means that the elevation at the central cell was close to the average elevation in its neighborhood, and this can mean either a flat area (where all cells are near the same elevation) or midslope on a hill (where half the neighborhood is above the focal cell, and half the neighborhood below). To distinguish between these two possibilities, we often check the slope at the cell. If the slope is near zero, we'll call it flat. Otherwise we'll call it a midslope area.

Exercise 6: Reclassify Aspect

Objectives

- Learn to use the Reclassify tool.
- Learn to use the "Extract by Mask" tool.
- Learn to calculate the proportion of raster classes within a polygon.

Data used

- Layer file **Semester_D_Unit.lyr**, in folder **..\Class_GIS_Data\Raster_Functions\...** This is the boundary of the Semester D Management Unit in the Centennial Forest, and it references a feature class named **Semester_D_Unit** in the file geodatabase **Lab_Data.gdb** located in the same folder.
- Raster dataset **Aspect**, which you created in Exercise 1 above.
- Optionally, any online basemap layers you prefer, such as topo maps or imagery. These won't be used in the analysis but they are often useful to help orient yourself or see the analysis within a larger landscape context.

For Homework

You will find the cell counts and proportions of the management unit that face the 5 directions listed below.

Exercise

Based on the Aspect raster you generated earlier, you will **reclassify** the aspect compass direction values into 5 classes:

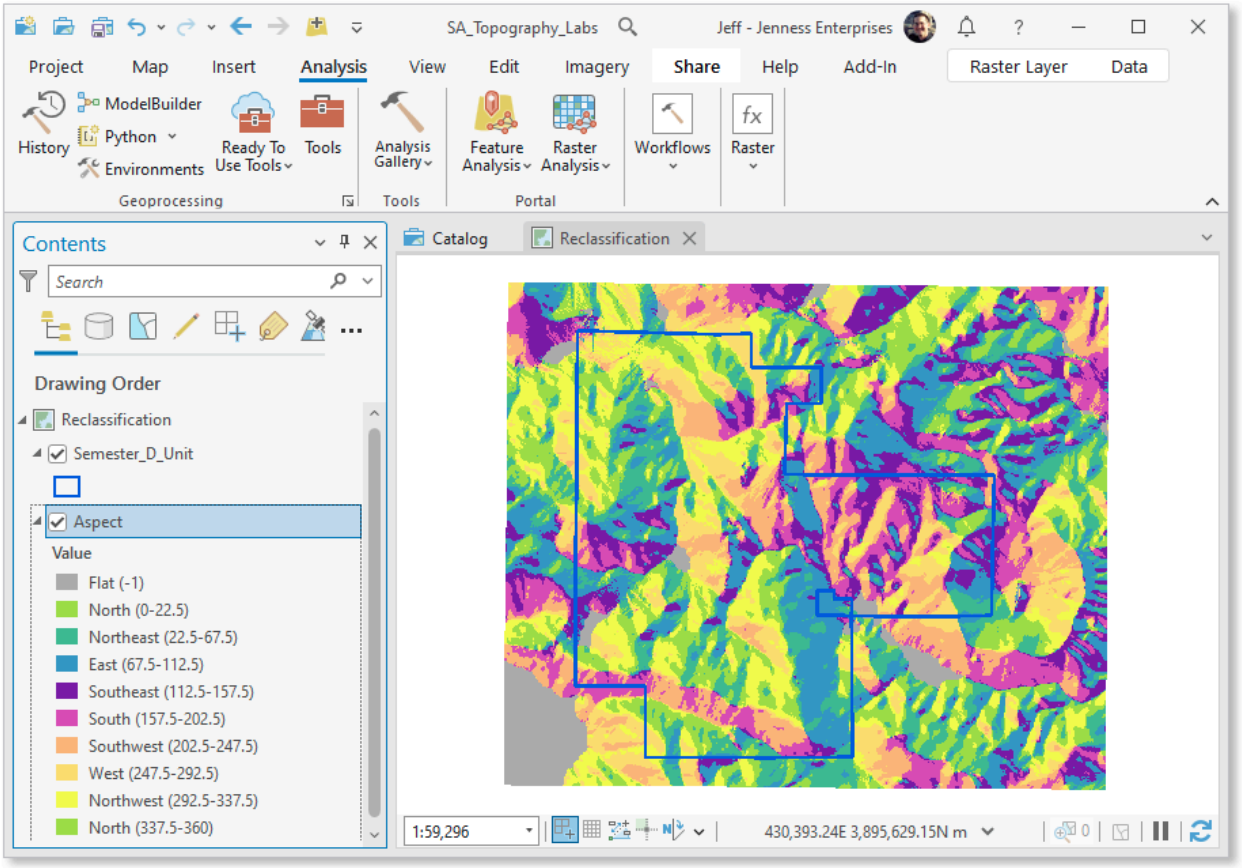
- Flat areas, with no aspect
- North-facing areas, with Aspect values ≥ 315° or < 45°
- East-facing areas, with Aspect values between 45° and 135°
- South-facing areas, with Aspect values between 135° and 225°
- West-facing areas, with Aspect values between 225° and 315°.

Prepare your Map and Data:

1) Open a new map in ArcGIS Pro.
2) Make sure you have the **Spatial Analyst** extension turned on. See Exercise 1 if you have questions on this.
3) If it is not already present, then load the **Layer** files **Semester_D_Unit.lyr** from the folder **..\Class_GIS_Data\Raster_Functions\...** as you did in Exercise 1.
4) Add your Aspect raster from Exercise 1 above.
   a) **Note:** At this point you **might** be asked whether you want to generate pyramids and/or statistics for Aspect. This just gives ArcGIS a way to draw it faster, and you may do it if you like. It won't

change the actual Aspect data so it really doesn't matter too much whether you do or not. IF you do, I like "Bilinear Interpolation" for continuous data like Aspect:

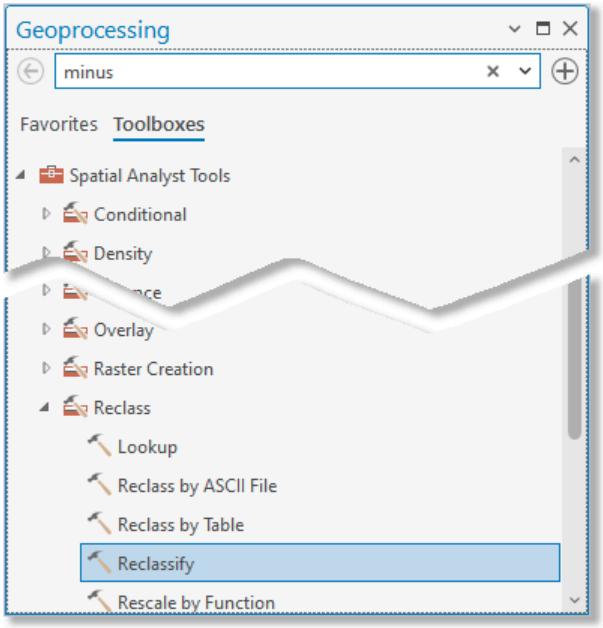
5) After it loads, you should see something like the following. Notice that the Aspect raster sometimes loads up looking like it is classified into directional ranges, but the actual aspect values are compass directions ranging between 0 and 360, plus a special value of -1 meaning the area is flat and has no compass direction.

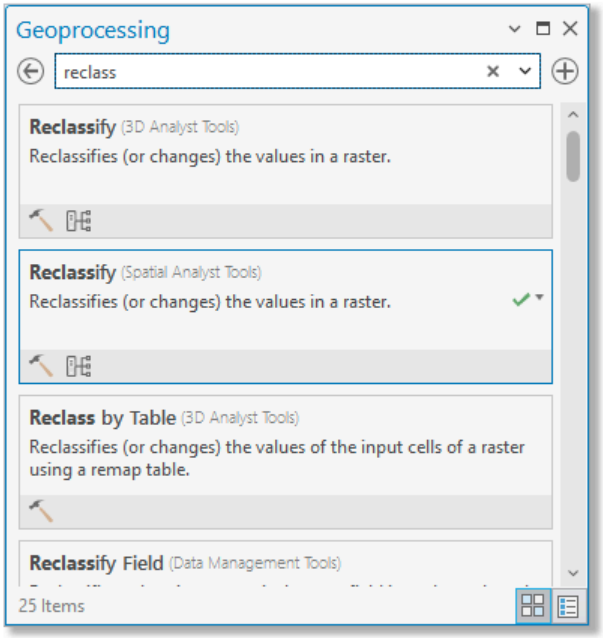


6) Optionally, load any online basemap layers or other background data you like.

Reclassify Aspect

7) Open the Reclassify tool (in Toolboxes --> Spatial Analyst Tools --> Reclass --> Reclassify):



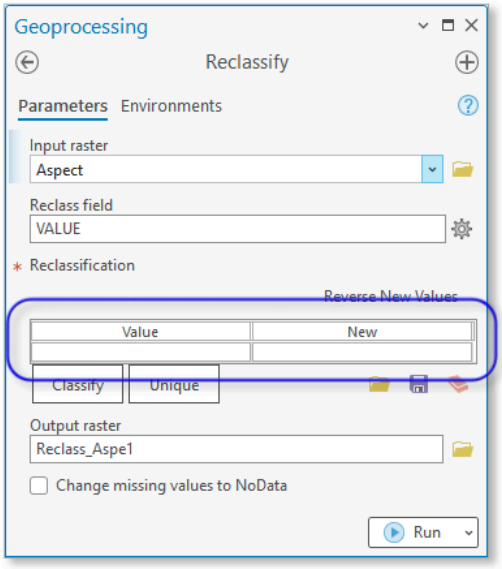


8) In the **Reclassify** window:

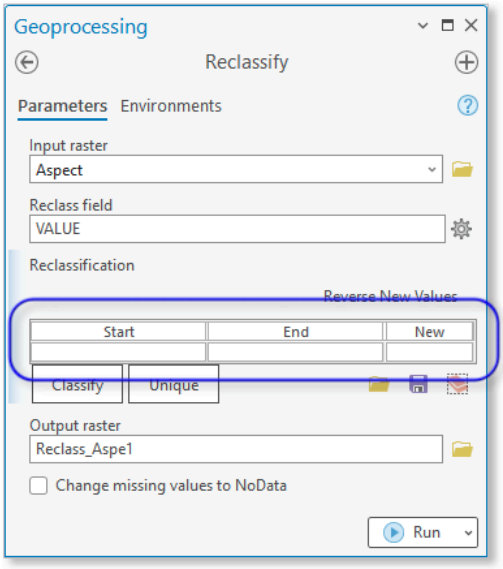
   a) Set the "Input Raster" to **Aspect**

   b) Set the "Reclass Field" to **VALUE**. Since the **Aspect** raster doesn't have an attribute table, this means the tool will just use the cell values.

   c) **Question:** Doe the reclassification table in your **Reclassify** tool have 2 columns or 3 columns?



Two Columns



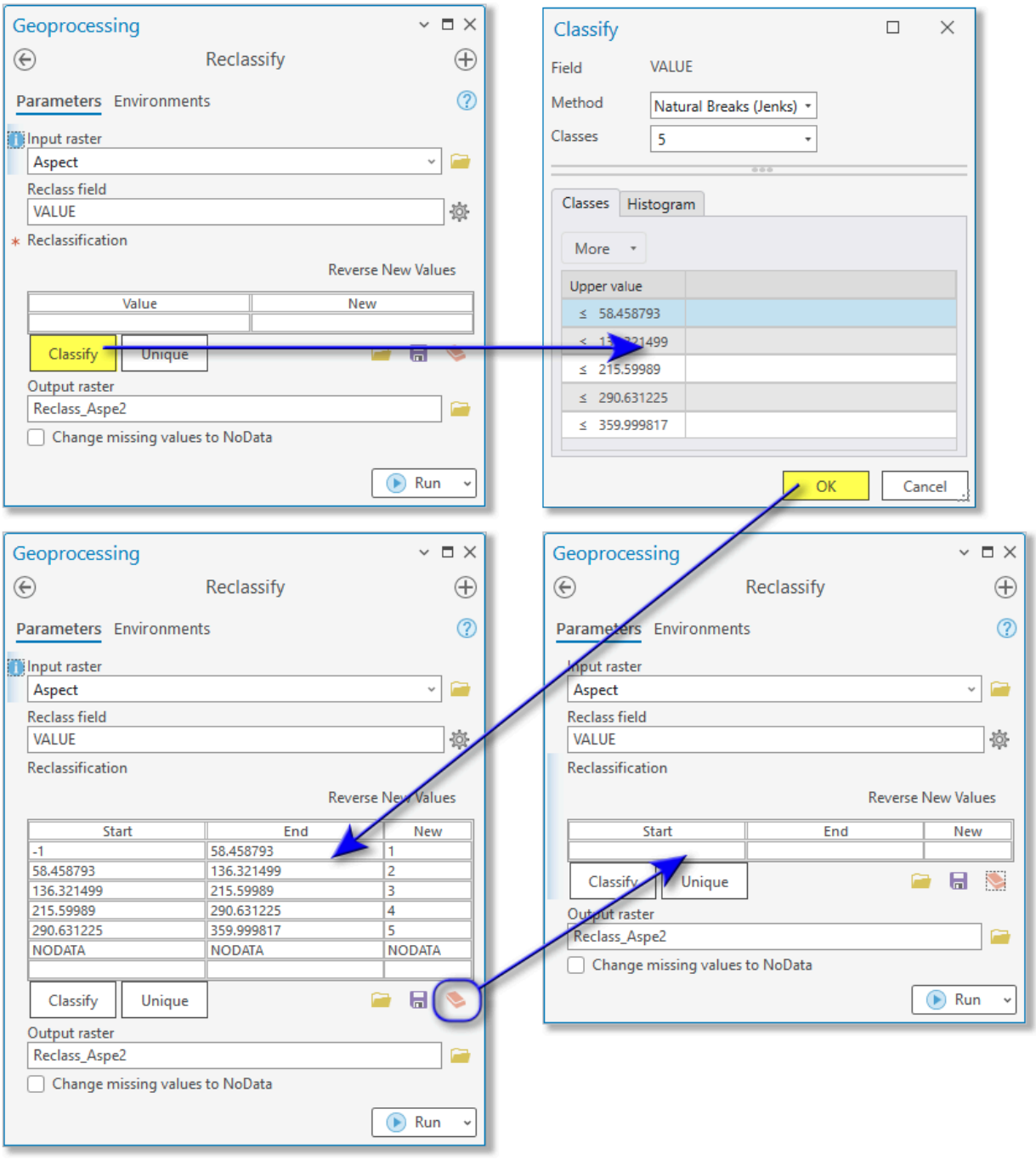
Three Columns

   i) If your tool has 3 columns visible, then skip to Step 9 below.

   ii) **Only** do the following if your **Reclassify** window has a 2-column table for "Value" and "New": These two columns are not the most efficient way to specify new values for a range of original values. We want to force the tool to show us a 3-column table with fields for

"Start" and "End" (to give the beginning and end of the range of values) and "New" (to give the new value that will be assigned to that range). Take a look at the 3-column table in the illustration above for an example.

- To fix this, click the "Classify" button, and then accept whatever default classification system shows up. The tool will recreate itself with a 3-column table. Then, just click the *Remove all remap records* icon  to empty the table. You should now have a table with 3 columns that you can use to easily enter the beginning and ending values of each range of Aspect values.



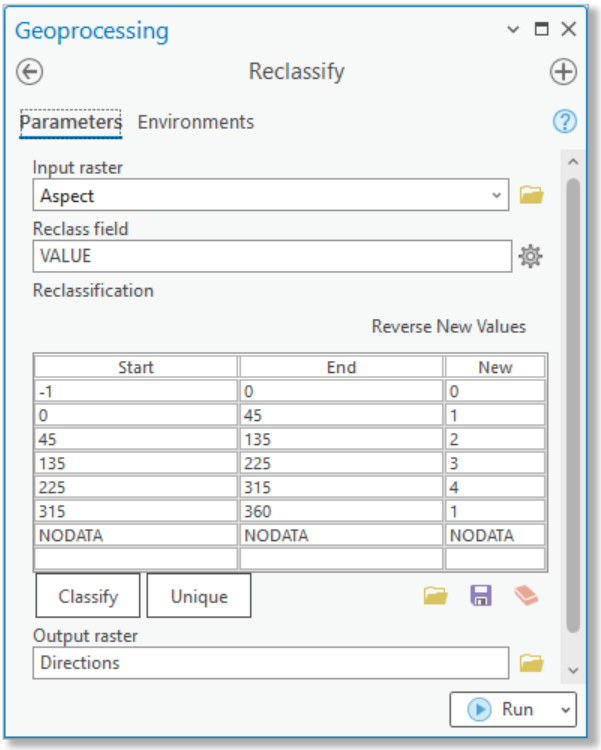
9) If you see 3 columns in your **Reclassify** tool, and those 3 columns are already filled up with data, then click the *Remove all remap records* icon  to empty the table (and see illustration immediately above for an example). You should now have an empty table with 3 columns that you can use to easily enter the beginning and ending values of each range of Aspect values.

10) Reclassify your Aspect values as follows. First type **-1** in the "Start" column, **0** in the "End" column, and **0** in the "New" column. Then hit the Enter key to add a new row, and enter the rest of the values you see below.

Start	End	New	Interpretation
-1	0	0	All Flat areas will be classified as 0
0	45	1	All areas between 0° and 45° will be classified as 1, for "North"
45	135	2	All areas between 45° and 135° will be classified as 2, for "East"
135	225	3	All areas between 135° and 225° will be classified as 3, for "South"
225	315	4	All areas between 225° and 315° will be classified as 4, for "West"
315	360	1	All areas between 315° and 0° will be classified as 1, for "North"
NoData	NoData		All original NoData cells will still be classified as NoData in the new raster.

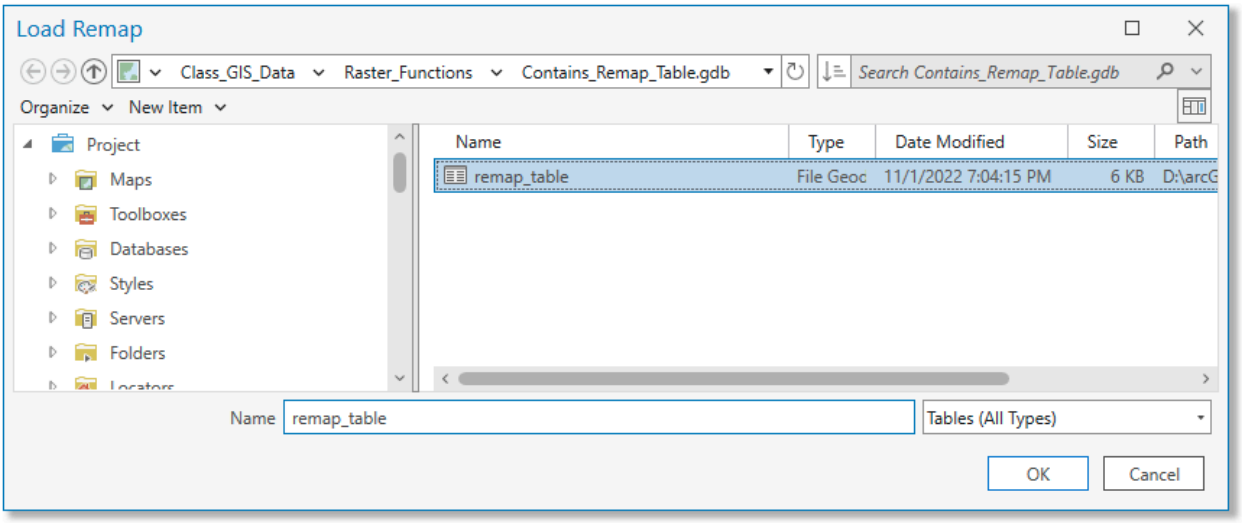
11) Pick a name and location for your reclassification raster. I recommend saving it to your default geodatabase and naming "Directions".

12) Upon completion, your **Reclassify** window should look like this.

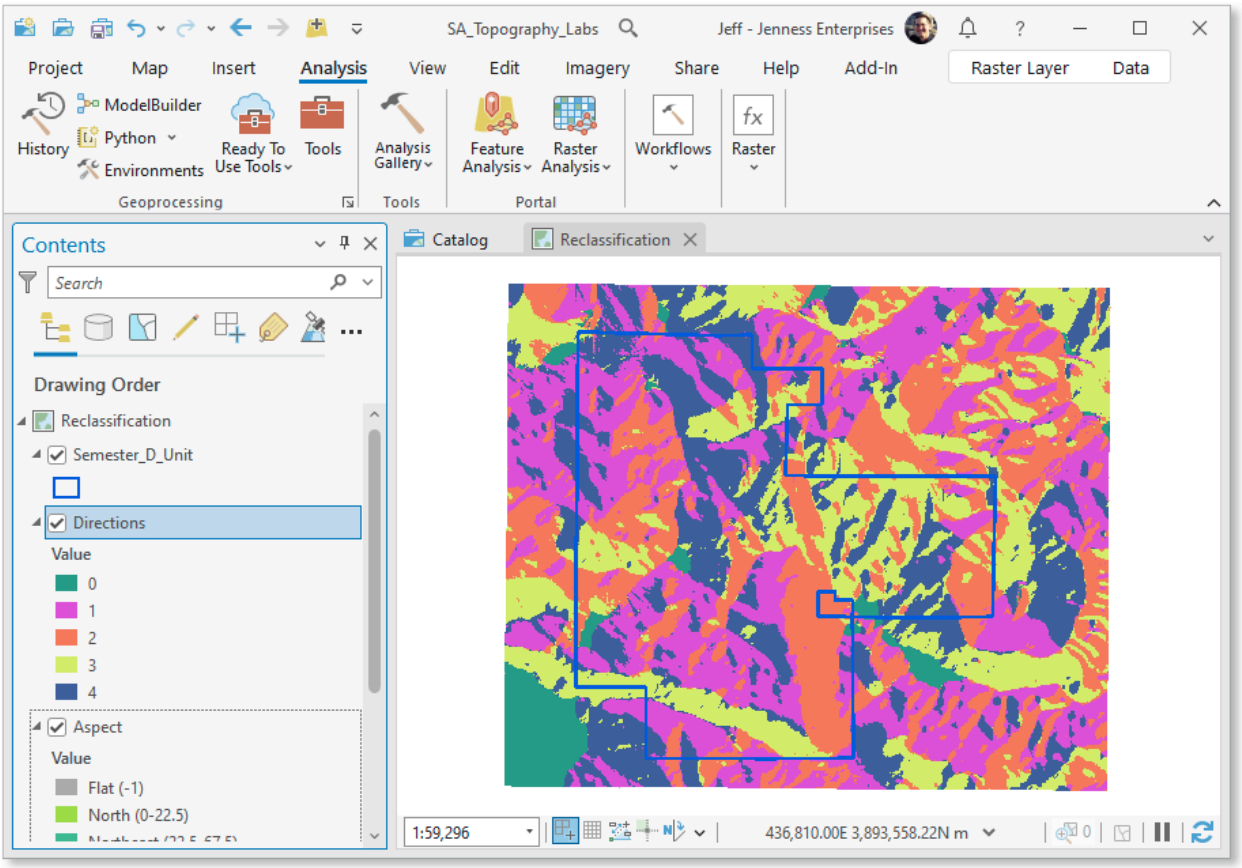


13) **If you have trouble entering values or getting the tool to work:** This tool can be tricky to use sometimes. If you have trouble manually entering these values, then I have made a reclassification table you can use to load the data directly.

   a) Click the *Load remap from table* button and locate the geodatabase **..\Class_GIS_Data\Raster_Functions\Contains_Remap_Table.gdb\...** and load the table named "remap_table". This will fill the table with the correct values.



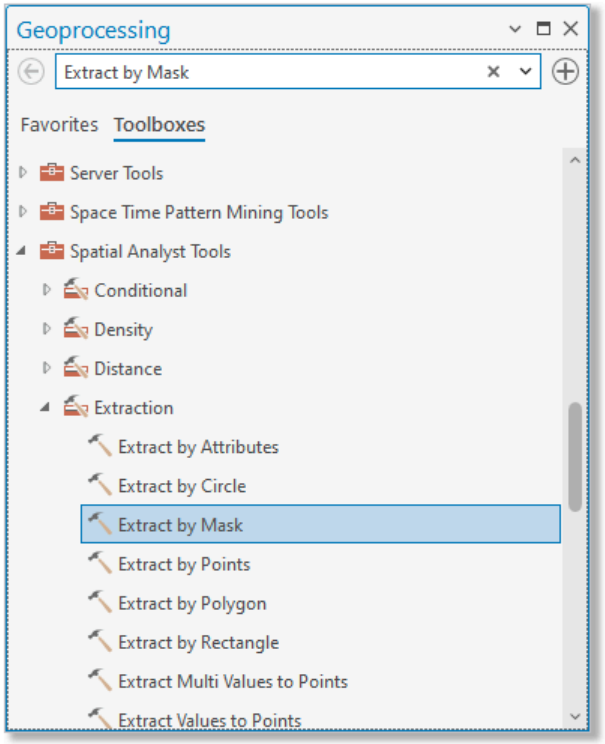
14) Click "OK" to run the tool. Upon completion, you will have a Reclassified raster layer like this:

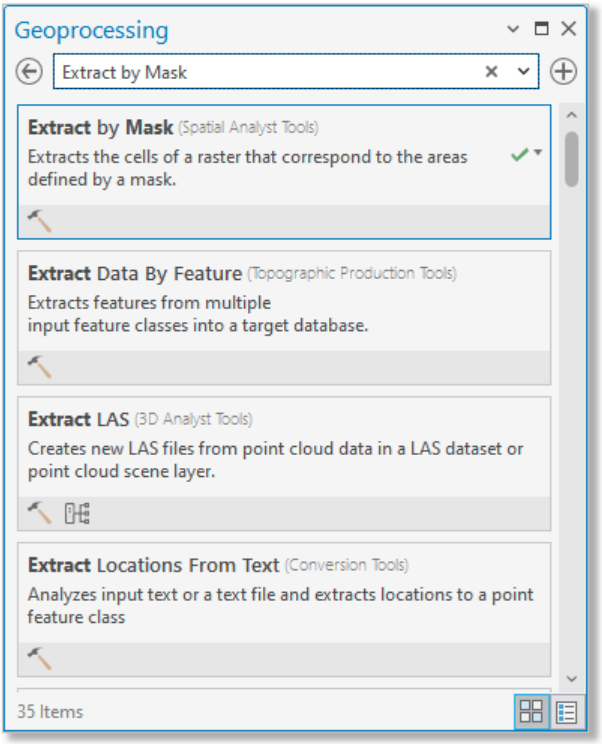


Clip the Reclassified Raster to the Semester D Management Unit Polygon

For this analysis, we only care about the Aspect values within our study area. We will use the **Extract by Mask** tool to clip out the portion of the reclassified aspect raster that lies within the Semester D Management Unit Polygon. Then we can use the Raster Attribute table to determine the proportions of each slope direction that lie within this polygon.

15) Open the "Extract By Mask" tool (in Toolboxes --> Spatial Analyst Tools --> Extraction --> Extract by Mask)





16) In the **Extract by Mask** window:

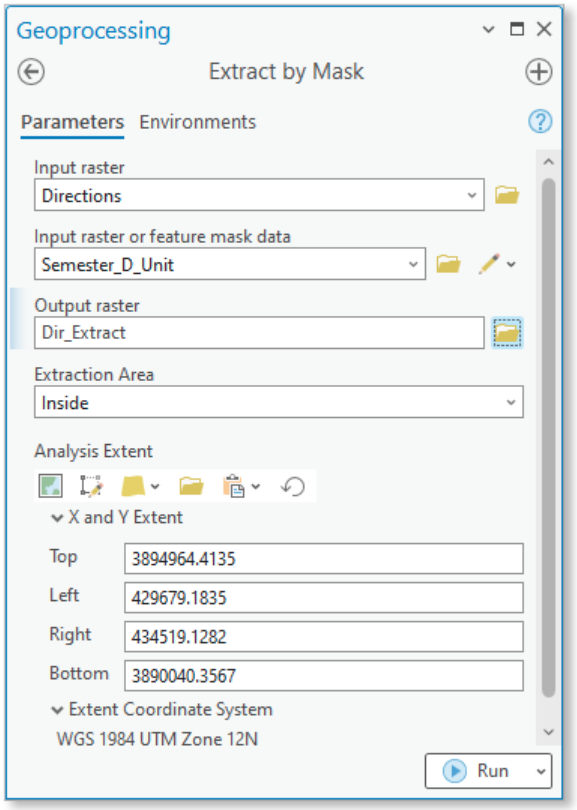
a) Set the "Input Raster" to be **Directions**

b) Set the "Input Raster or feature mask data" to be **Semester_D_Unit**

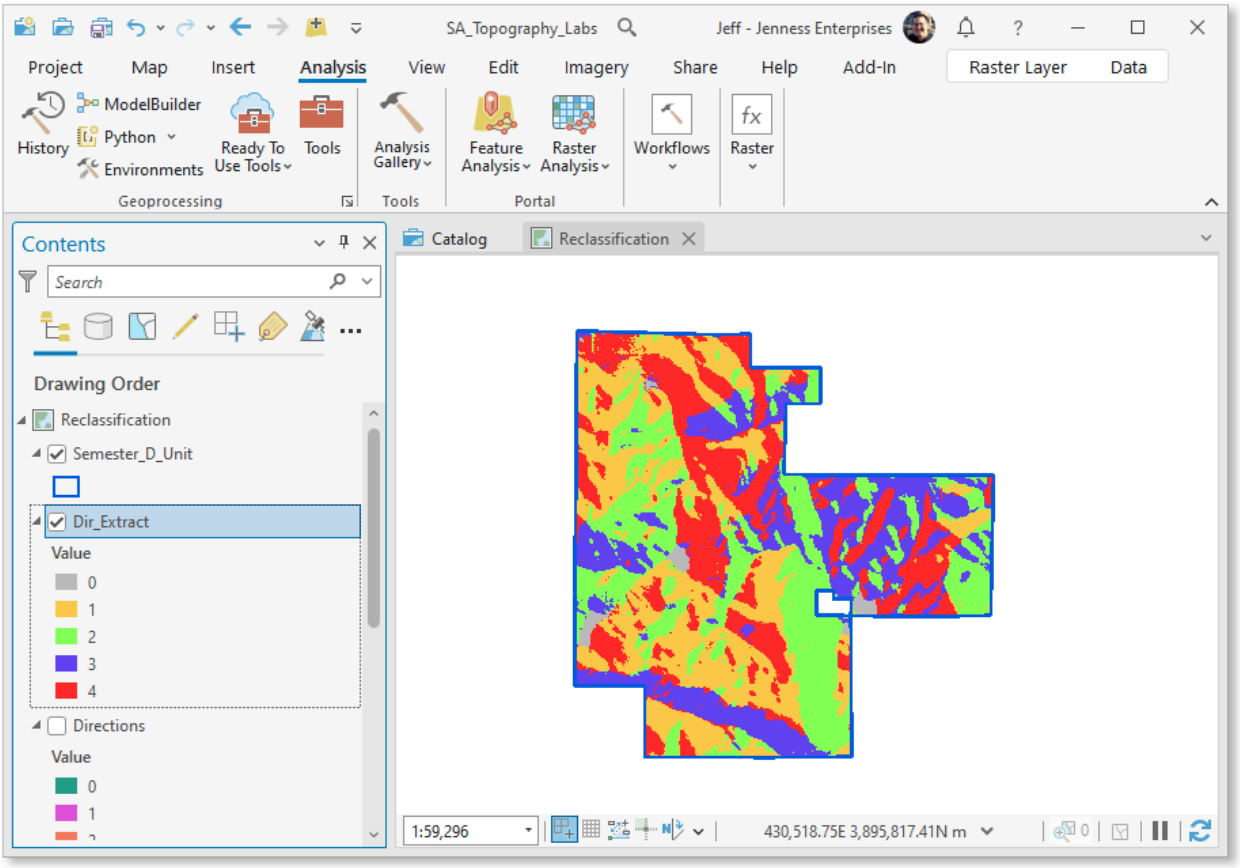
c) Pick a name and location for your clipped reclassification raster. I recommend saving it to your default file geodatabase and naming "Dir_Extract".

d) Set the "Extraction Area" to be *Inside*

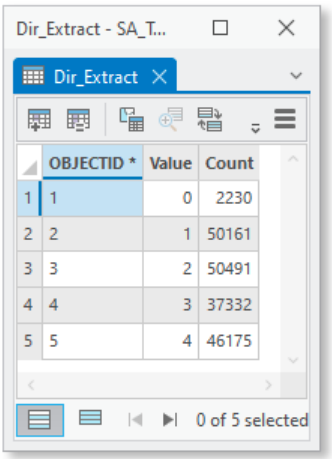
e) Leave "Analysis Extent" alone. It defaults to the extent of your "Input raster or feature mask data", which in this example is the **Semester_D_Unit** feature class.



17) You should now see a new raster that is identical to your **Directions** raster, but clipped to the Semester D Management Unit.



18) Open the attribute table for **Dir_Extract.** You should see the following numbers:



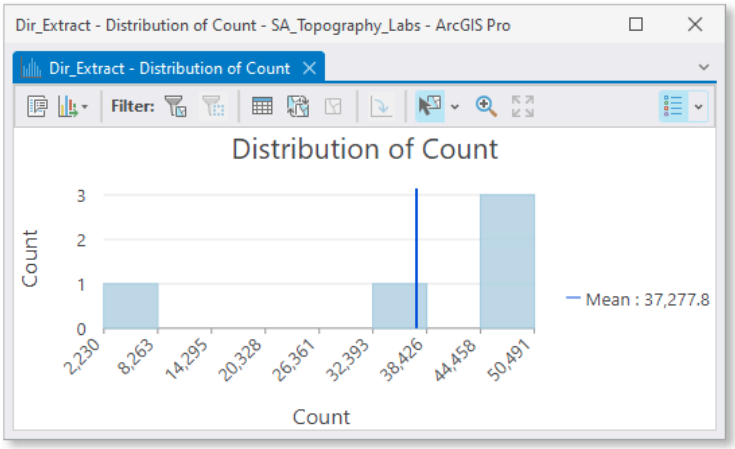
19) Do you see different numbers from either example above, but the numbers are pretty close? It could be you've done everything correctly, but we are using different versions of ArcGIS Pro and the algorithm may have been updated between versions. Or maybe you used a different tool to calculate aspect. **I will be flexible with the grading.**

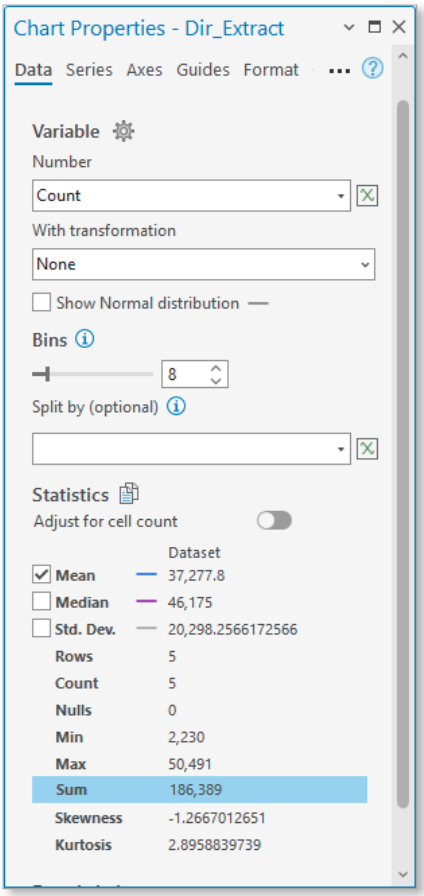
20) Observe that the [COUNT] attribute field contains the number of raster cells in each category. Also, remember that the [VALUE] values mean the following:

- 0 = Flat, No Aspect

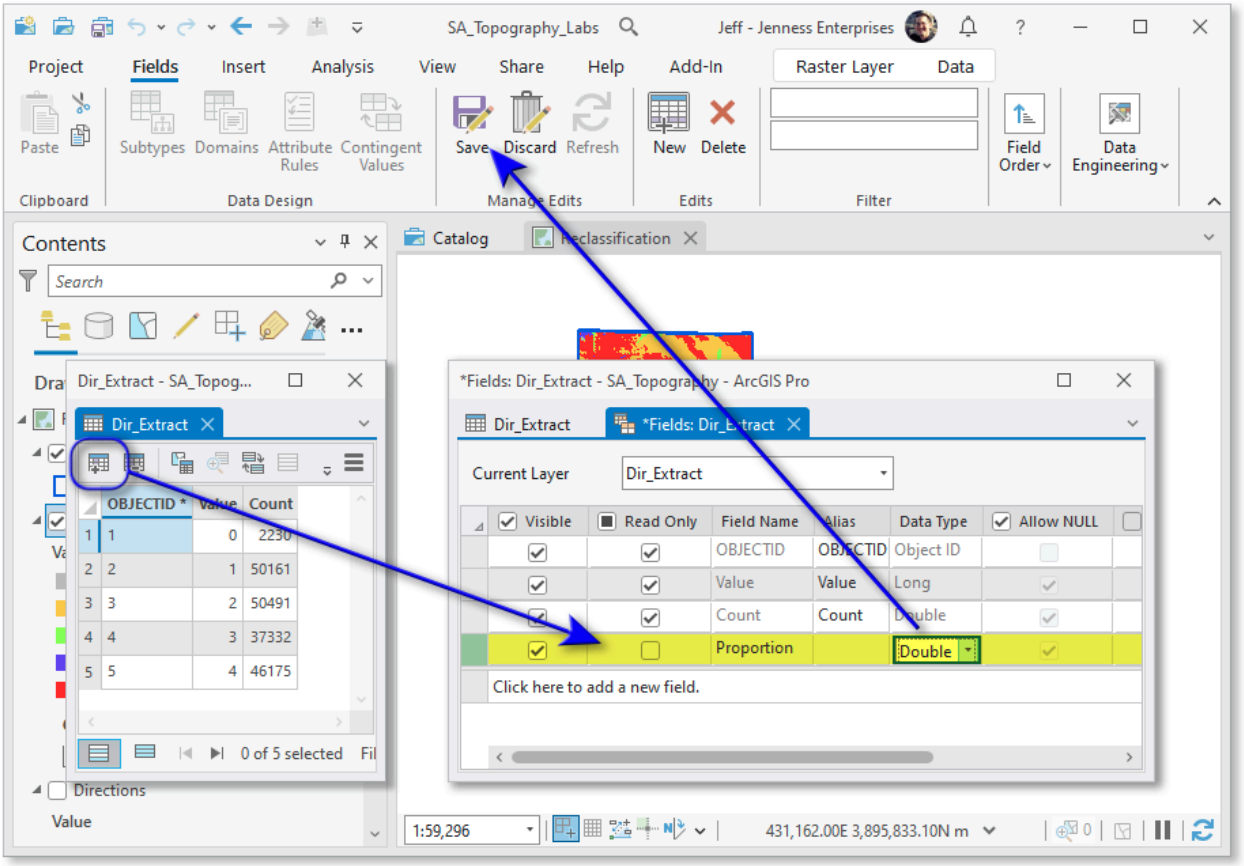
- 1 = North
- 2 = East
- 3 = South
- 4 = West

21) **Question:** What is the total number of **Dir_Extract** raster cells in the Semester D Management Unit polygon? **Hint:** Right-click the "Count" attribute field name and click "Visualize Statistics" to open the "Chart Properties" pane, and look for the **Sum**. Remember this number because you will use it below.



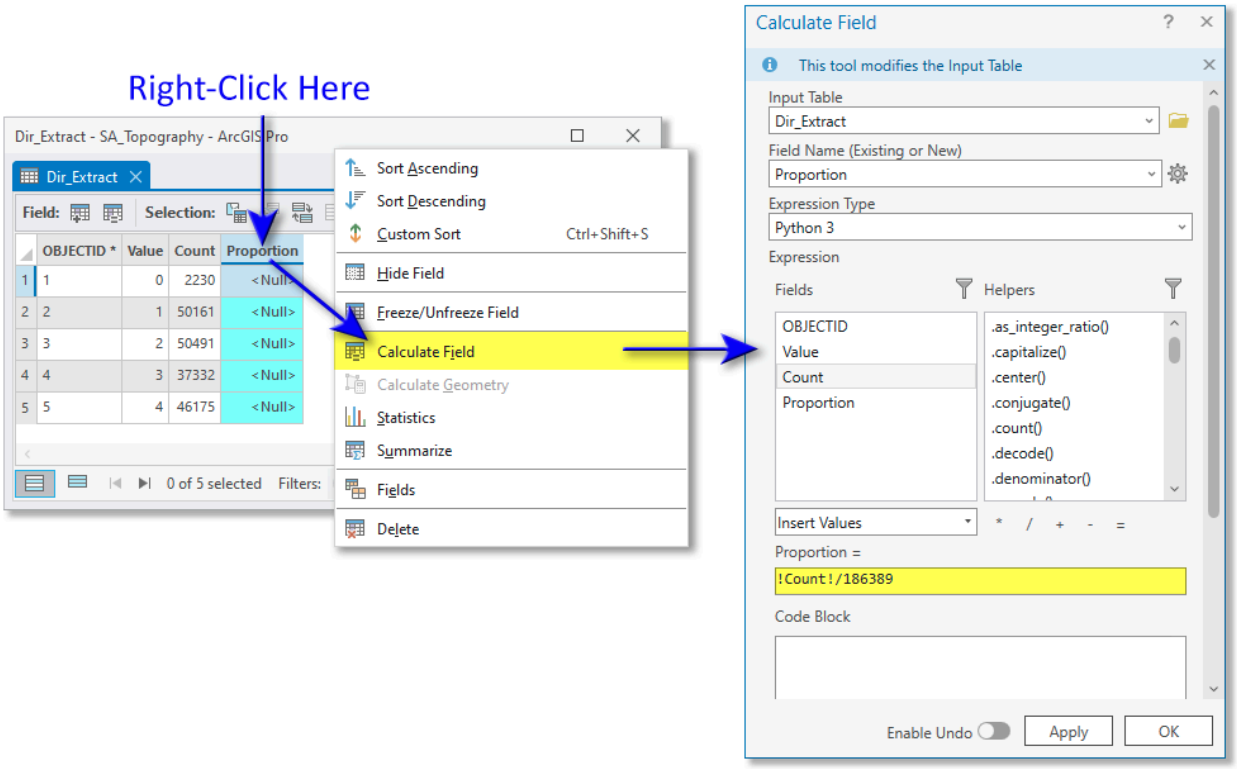


22) Add a new attribute field to your **Dir_Extract** attribute table. Make it a Double-precision field named "Proportion". Make sure to save your edits after you've added the field.



23) Right-click your new "Proportion" field, open the "Field Calculator" and calculate the proportion of each direction category value. In my example there are 186,389 total cells in the management unit area. The number of cells in each direction category are in the attribute field named **Count**. Therefore, in my example, the calculate string should be: **Note: Don't put a comma in the number!** The value should be **186389,** not **186,389**

```
!Count!/186389
```



In the **Calculate Field** window, in the listbox showing the attribute fields, you can double-click on the attribute field name **Count** and you will see **`!Count!`** appear in the text box where you enter your calculation string. Then, just click down in that box and type **/** and then your total number of cells at the end, and then click "OK".

Note: Are you wondering why the attribute field **Count** has exclamation marks around it? This is just how attribute fields are identified in Python code. The exclamation marks around the word "Count" tell the Python engine that "Count" is the name of an attribute field in an attribute table.

24) Fill in the following table with your Count and Proportion values. **Note:** This table will be part of your homework.

a) **Tip:** You can copy values out of your table by right-clicking on the cell and choosing "Copy". You can then paste the values into the table using the "Paste" tool in Word, or by just clicking [CONTROL]-V. This might save you from making errors typing in the values.

Proportions of Semester D Management Unit Lying in Four General Directions			
Value	**Meaning**	**Count**	**Proportion**
0	Flat		
1	North		
2	East		
3	South		
4	West		

Exercise 7: Calculate Zonal Statistics for the Semester D Management Unit

Objectives

- Learn to use the **Zonal Statistics as Table** tool to calculate descriptive statistics of the various datasets you have calculated over the course of this lab.
- Learn how the **Zonal Statistics as Table** tool can be used to calculate descriptive statistics from circular variables like Aspect.

Data used

- Layer file **Semester_D_Unit.lyr**, in folder **..\Class_GIS_Data\Raster_Functions\...** This is the boundary of the Semester D Management Unit in the Centennial Forest, and it references a feature class named **Semester_D_Unit** in the file geodatabase **Lab_Data.gdb** located in the same folder.
- Raster layer file **DEM_10m.lyr**, in folder **..\Class_GIS_Data\Raster_Functions\...** This layer file references a raster dataset named **DEM_10m** in the file geodatabase **Lab_Data.gdb**, and is an approximately 10m resolution Digital Elevation Model (DEM) showing elevation (in meters) within the general extent of the Semester D Management Unit in the Centennial Forest.
- Raster dataset **Aspect**, which you created in Exercise 1 above.
- Raster dataset **Slope**, which you created in Exercise 2 above.
- Raster datasets **Mean_Curvature, Plan_Curvature** and **Profile_Curvature** you created in Exercise 4 above.
- Raster dataset **TPI**, which you created in Exercise 5 above.
- Optionally, any online basemap layers you prefer, such as topo maps or imagery. These won't be used in the analysis but they are often useful to help orient yourself or see the analysis within a larger landscape context.

For Homework

You will calculate a variety of statistics describing elevation, slope, curvature and TPI inside the Semester D Management Unit polygon.

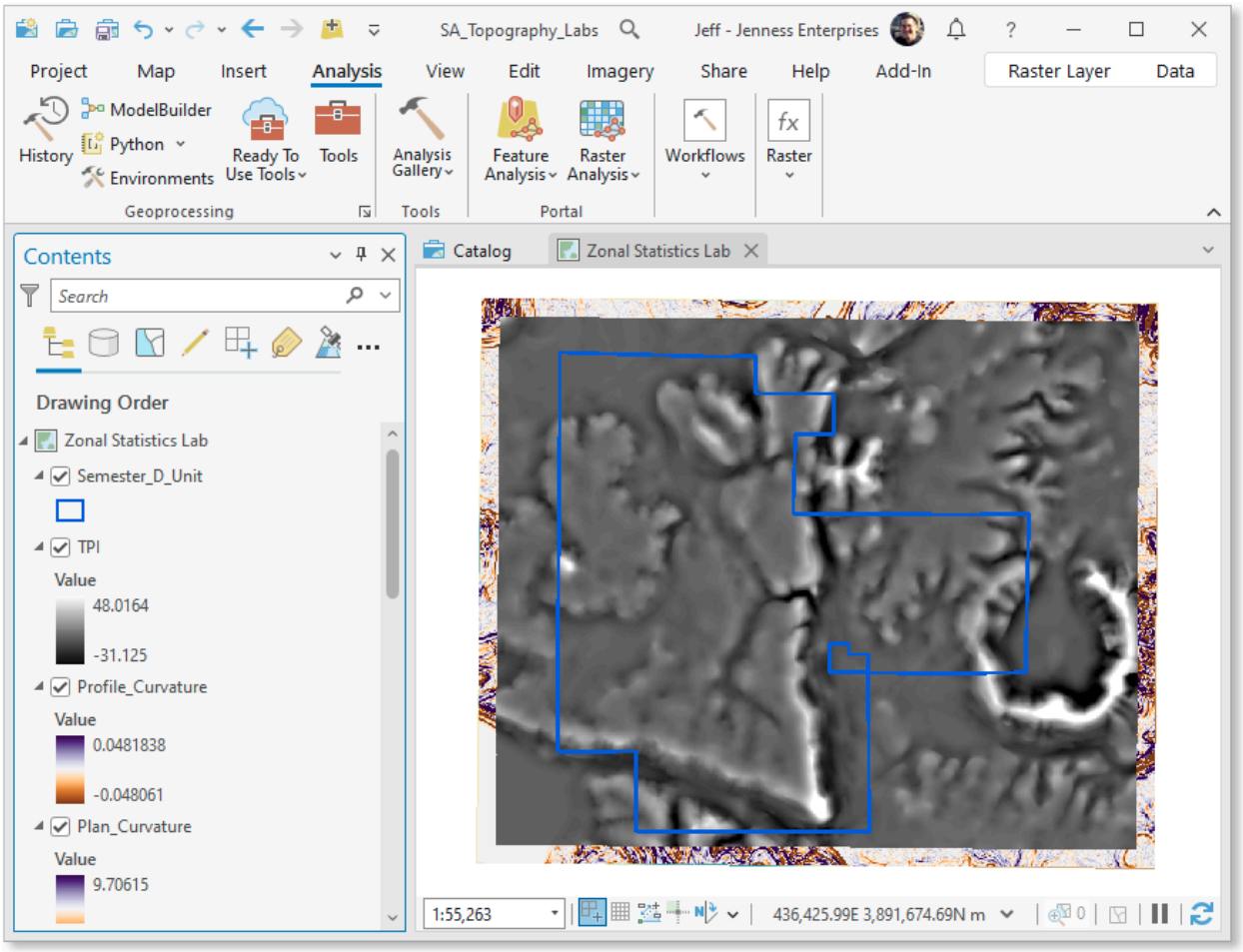
Exercise

Prepare your Map and Data:

1) Open a blank map in ArcGIS Pro. If you still have ArcGIS Pro open from the previous exercise, you may simply insert a new map.
2) Make sure you have the **Spatial Analyst** extension turned on. See Exercise 1 if you have questions on this.
3) If they are not already present, then load the **Layer** files **DEM_10m.lyr** and **Semester_D_Unit.lyr** from the folder **..\Class_GIS_Data\Raster_Functions\...** as you did in Exercise 1.

4) Add your **Aspect, Slope**, **Mean_Curvature**, **Plan_Curvature**, **Profile_Curvature** and **TPI** rasters from Exercises 1, 2, 4 and 5 above.

5) You should see something like the following.



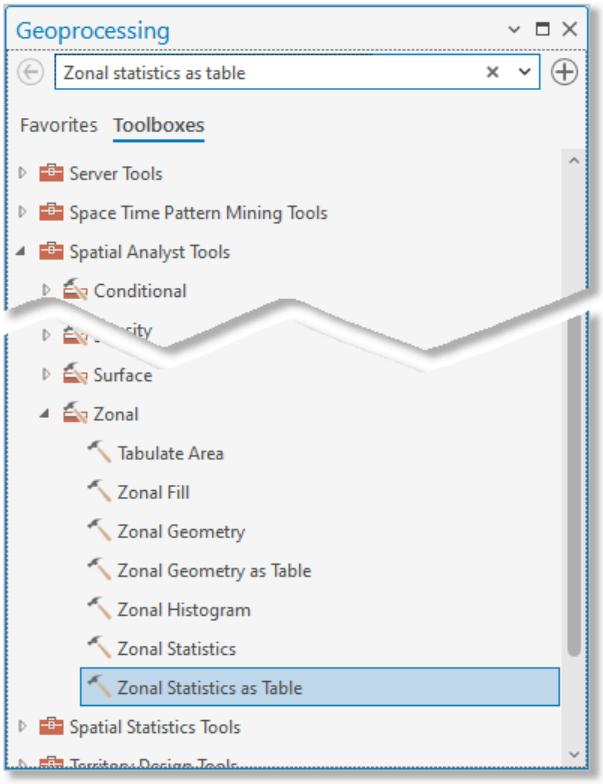
6) Optionally, load any online basemap layers or other background data you like.

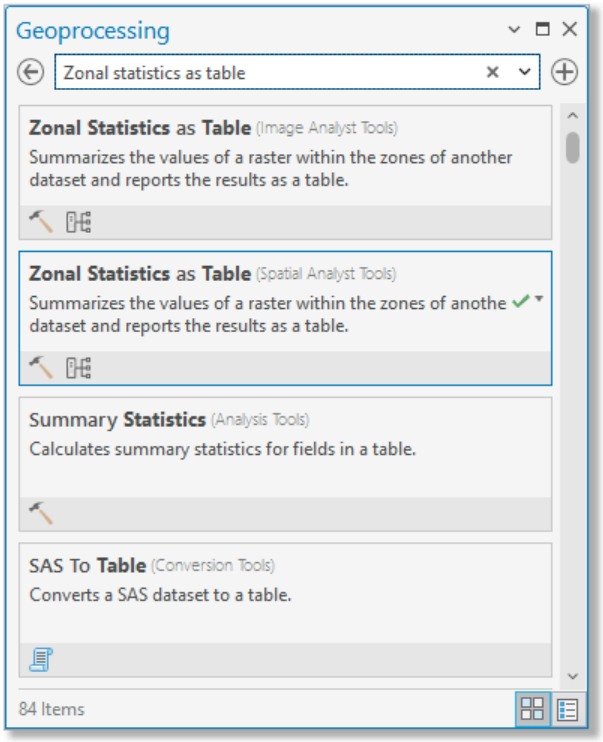
Calculate Zonal Statistics

This exercise will illustrate exactly how to generate zonal statistics for Elevation values inside the NAU Management Unit polygon. You will then repeat these steps for the Slope, Mean_Curvature, Plan_Curvature, Profile_Curvature and TPI rasters and fill in the values in the table. **Note: Read special instructions below for calculating zonal statistics for Aspect!**

7) Open the **Zonal Statistics as Table** tool (in Toolboxes --> Spatial Analyst Tools --> Zonal --> Zonal Statistics as table):

   a) **Note:** Be sure to get the correct tool! There is another tool with a similar name ("Zonal Statistics"), but this is **not** the correct tool. You want the **Zonal Statistics as Table** tool.





8) In the **Zonal Statistics as Table** window:

   a) Set the "Input raster or feature zone data" to **Semester_D_Unit** and set the "Zone field" = **OBJECTID.**

      i) **Note:** This is how you set your Zone! If you like, you can refer to Slides 49 – 58 to remind yourself. It is important that you understand this concept.

   b) Set your "Input Value Raster" to **DEM_10m**.

   c) Pick a name and location for your output statistics table. I recommend saving it to your default file geodatabase and naming it "DEM_Stats"

   d) Leave **checked** "Ignore NoData in Calculations". This just means it won't report the counts of NoData cells in the Semester D Polygon. You shouldn't have any, so this option wouldn't give you any useful information.

   e) Set "Statistics type" = **ALL**. This means that all the standard descriptive statistics will be calculated.

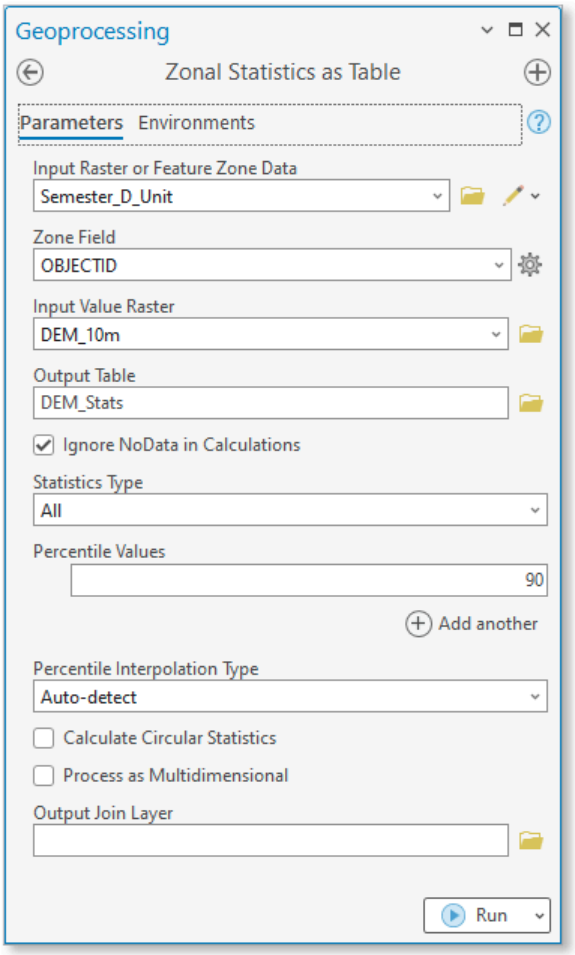
   f) Set "Percentile Values" = 90. This means it will also calculate the 90th percentile value.

   g) Leave "Percentile Interpolation Type" as *Auto-detect*.

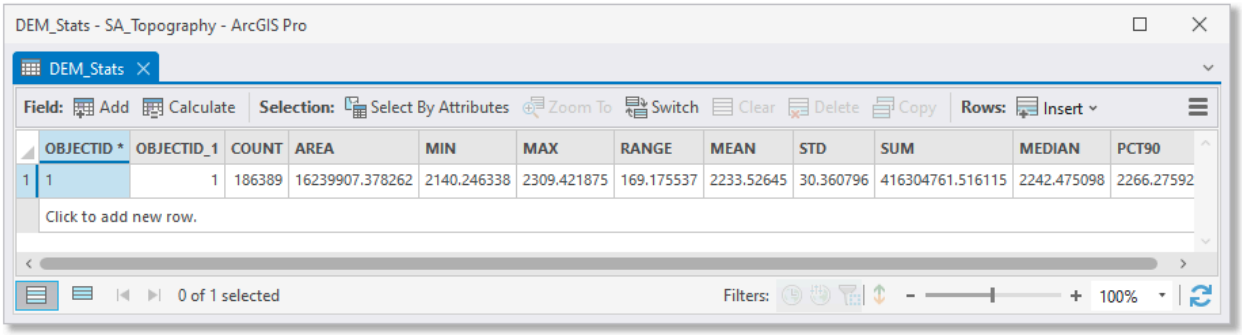
   h) Leave **Unchecked** "Calculate Circular Statistics" and "Process as Multidimensional"

   i) Leave **Output Join Layer** empty. This tool produces a table of raster statistics (elevation statistics in this example), and if we wanted we could join this table back to our **Semester_D_Unit** if we wanted. That would be useful if we had a lot of extra data in the **Semester_D_Unit** feature class about each polygon, and we wanted to have the elevation statistics in the same table, but it is not necessary for this particular lab. Here we are only interested in the raster statistics in the

polygon, and we don't need the data from the **Semester_D_Unit** feature class, so we don't need to go to the extra step of joining those statistics back to that feature class.



9) Upon completion, the tool will add a new table to your map. Open it to see the results. It should look something like the following:



10) **Note**: Does your table look very close to the example above, but with slightly different numbers? As in Exercise 6 above, it could be you've done everything correctly but we are using different versions of ArcGIS Pro and the algorithm may have been updated between versions. **I will be flexible with the grading.**

11) So what did you get?

a) The statistical fields ([MIN], [MAX], [RANGE], [MEAN], [STD], [SUM], [MEDIAN] and [PCT90].) are all basic descriptive statistics describing elevation values in the Semester D Management Unit polygon. Please ask me if you do not know what any of these mean.

b) The field [OBJECTID_1] is the Zone field you selected from your **Semester_D_Unit** feature class. Basically the tool combined all polygons with identical OBJECTID values and developed statistics for each unique OBJECTID value it found. In this case it was easy because there was only one polygon. **Note:** It changed the name of the zone field to OBJECTID_1 in this table because there was already an OBJECTID field and you can't have multiple fields with the same name.

c) The field "Count" is the number of elevation raster cells in the Semester D Management Unit polygon. Observe that this is the same number of cells we got when we extracted the Aspect values in Lab Exercise 6.

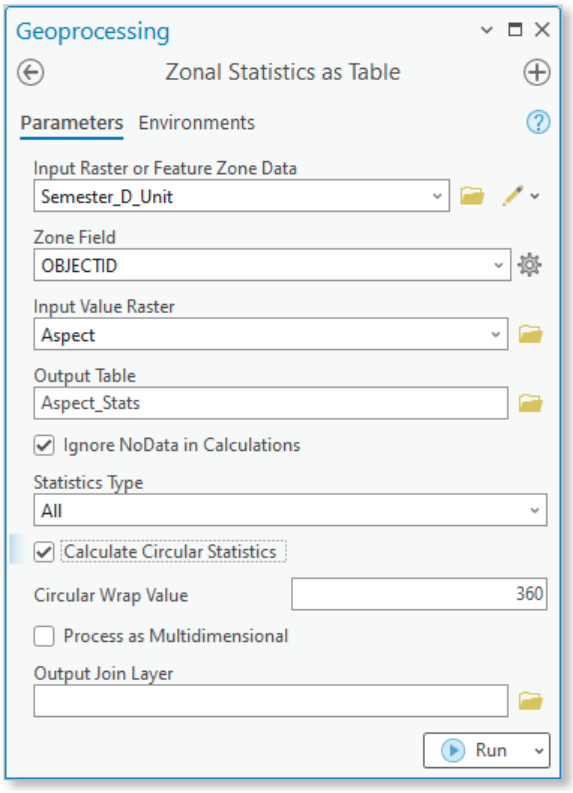
d) The field "AREA" is the **DEM** raster cell size (9.3342974^2 = 87.13 square meters) times the number of cells (186,389, in my example).

12) Add the appropriate Elevation Statistic values to the table below:

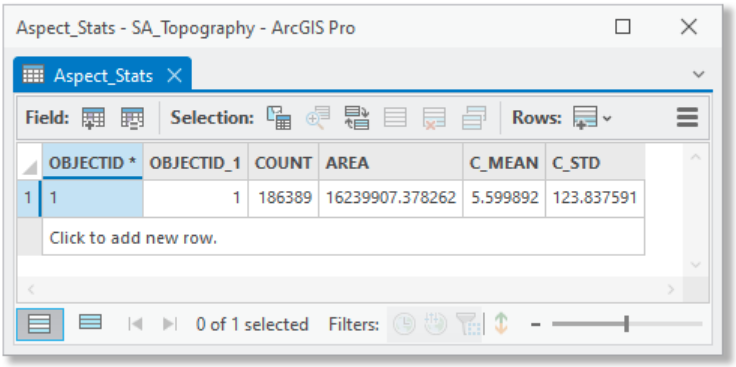
Semester D Management Unit Polygon Descriptive Statistics for Six Rasters					
Dataset	**Statistic**				
	Minimum	**Maximum**	**Range**	**Mean**	**Standard Deviation**
DEM					
Slope					
Curvature					
Plan					
Profile					
TPI					

13) Repeat the steps above for your Slope, Curvature, Plan, Profile and TPI rasters. **Note:** You will turn this table in as part of your homework.

14) Repeat the steps above for your **Aspect** raster. This time fill out the **Zonal Statistics as Table** window with the *Calculate Circular Statistics* option **checked.** Also, set the *Circular Wrap Value* to **360** (because that's when Aspect is due North, and switches back to 0). **Note:** There are no homework questions from this step.



15) Because Aspect was analyzed as a **circular** variable, the tool produces different statistics for it:



16) The field **C_Mean** contains the Circular Mean, which is the mean direction that the Semester D Polygon faces. A mean direction of 5.6° means this is predominately a north-facing management unit.

17) The field **C_STD** contains the circular standard deviation, and indicates that there is a lot of variation in direction within the Semester D management unit.

Exercise 8: Use Extract Values to Points Tool to Get Raster Values at Points

Objectives

- Learn to use the **Extract Values to Points** tool to extract raster cell values for each point in a point feature class.
- **Note:** You could also use the **Zonal Statistics** tool for this, but the **Extract Values to Points** tool is more accurate and better suited to getting raster values at individual point locations.

Data used

- Layer file **Semester_D_Unit.lyr**, in folder **..\Class_GIS_Data\Raster_Functions\...** This is the boundary of the Semester D Management Unit in the Centennial Forest, and it references a feature class named **Semester_D_Unit** in the file geodatabase **Lab_Data.gdb** located in the same folder.
- Layer file **Sample_Points.lyr**, in folder **..\Class_GIS_Data\Raster_Functions\...** These are sample survey points distributed across the Semester D Management Unit in the Centennial Forest, and the layer file references a feature class named **Sample_Points** in the file geodatabase **Lab_Data.gdb** located in the same folder.
- Raster layer file **DEM_10m.lyr**, in folder **..\Class_GIS_Data\Raster_Functions\...** This layer file references a raster dataset named **DEM_10m** in the file geodatabase **Lab_Data.gdb**, and is an approximately 10m resolution Digital Elevation Model (DEM) showing elevation (in meters) within the general extent of the Semester D Management Unit in the Centennial Forest.
- Raster dataset **Slope**, which you created in Exercise 2 above.
- Optionally, any online basemap layers you prefer, such as topo maps or imagery. These won't be used in the analysis but they are often useful to help orient yourself or see the analysis within a larger landscape context.

For Homework

At the end of this exercise, you will answer 10 questions on elevation and slope statistics among the survey points.

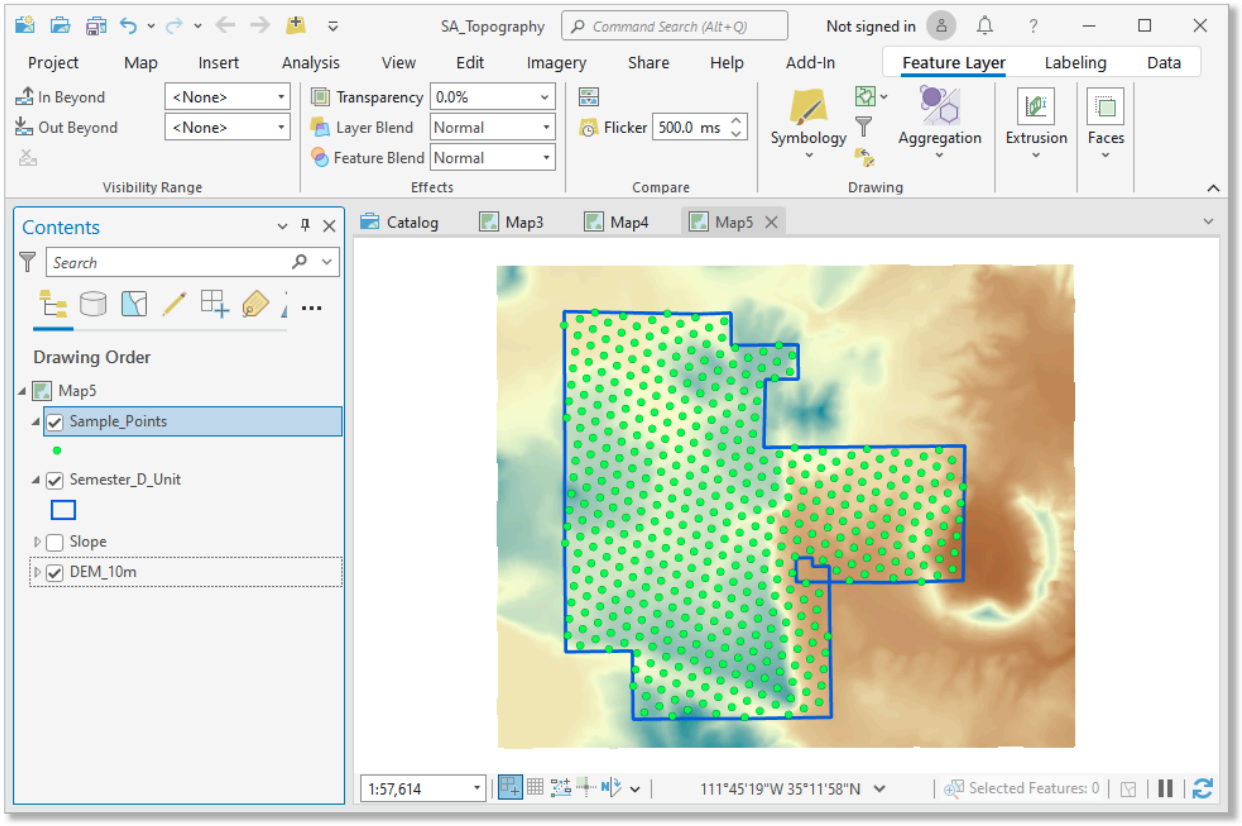
Exercise

You will calculate summary statistics on survey plots.

Prepare your Map and Data:

1) Open a new map in ArcGIS Pro.
2) Make sure you have the **Spatial Analyst** extension turned on. See Exercise 1 if you have questions on this.
3) If they are not already present, then load the **Layer** files **DEM_10m.lyr**, **Semester_D_Unit.lyr** and **Sample_Points.lyr** from the folder **..\Class_GIS_Data\Raster_Functions\...** as you did in Exercise 1.
4) Add your **Slope** raster from Exercises 2 above.

5) You should see something like the following (note that the Slope layer has the visibility turned off).

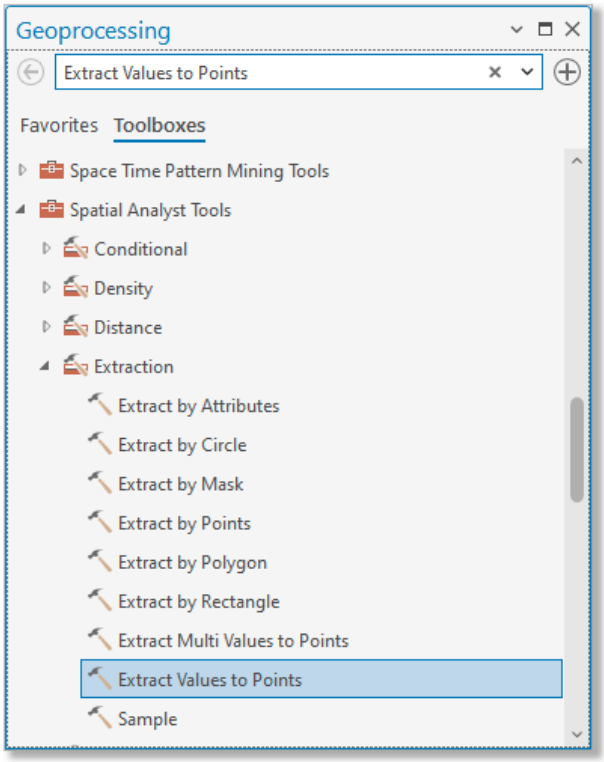


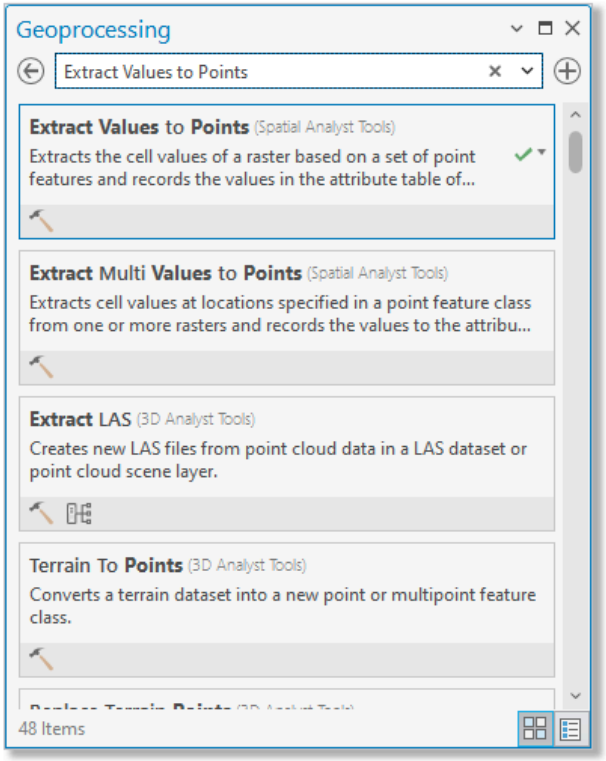
6) Optionally, load any online basemap layers or other background data you like.

Calculate Point Values

This exercise will illustrate how to extract Elevation and Slope values at each point in the **Sample_Points** feature class.

7) Open the **Extract Values to Points** tool (in Toolboxes --> Spatial Analyst Tools --> Extraction --> Extract Values to Points):





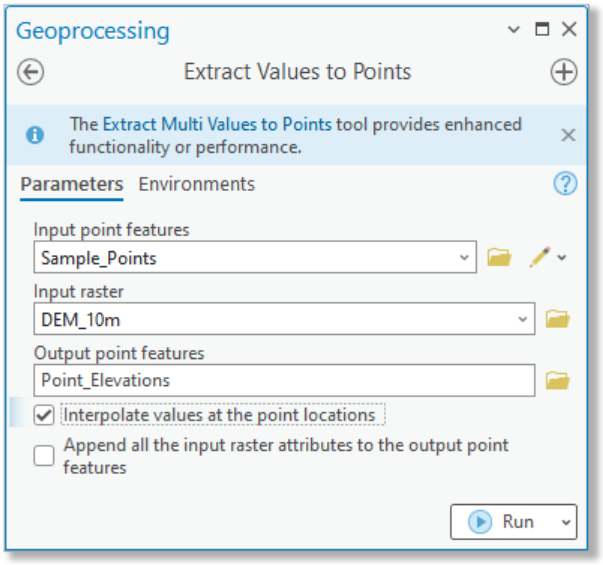
8) In the **Extract Values to Points** window:

   a) Set the "Input point features" to **Sample_Points.**

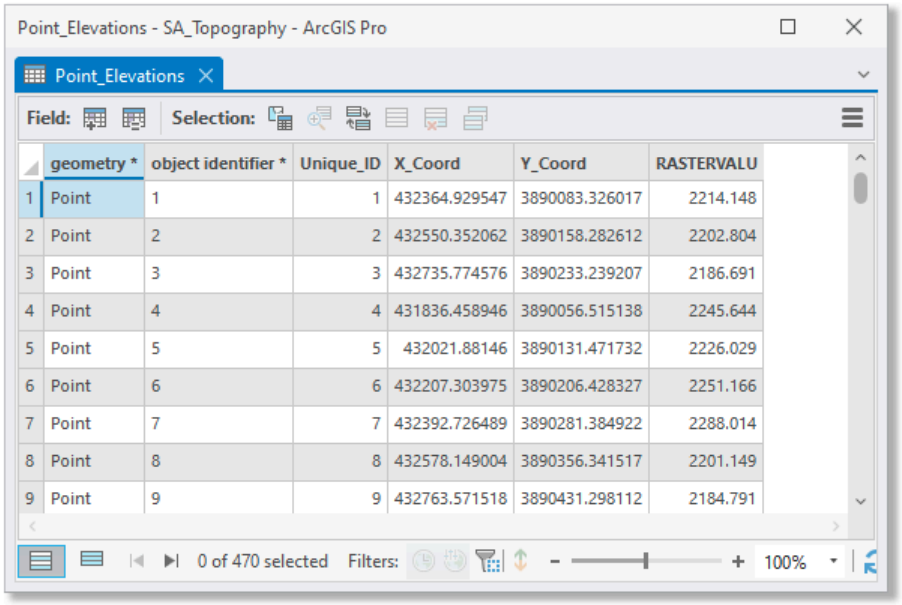
   b) Set your "Input raster" to **DEM_10m**.

   c) Pick a name and location for your output statistics table. I recommend saving it to your default file geodatabase and naming it "Point_Elevations"

   d) Set "Interpolate values at the point locations" = **True**.



9) Upon completion, the tool will add a new point feature class to your map. Open the attribute table to see the results. It should look something like the following:



	geometry *	object identifier *	Unique_ID	X_Coord	Y_Coord	RASTERVALU
1	Point	1	1	432364.929547	3890083.326017	2214.148
2	Point	2	2	432550.352062	3890158.282612	2202.804
3	Point	3	3	432735.774576	3890233.239207	2186.691
4	Point	4	4	431836.458946	3890056.515138	2245.644
5	Point	5	5	432021.88146	3890131.471732	2226.029
6	Point	6	6	432207.303975	3890206.428327	2251.166
7	Point	7	7	432392.726489	3890281.384922	2288.014
8	Point	8	8	432578.149004	3890356.341517	2201.149
9	Point	9	9	432763.571518	3890431.298112	2184.791

10) **Note**: Does your table look very close to the example above, but with slightly different numbers? As in the exercises above, it could be you've done everything correctly but we are using different versions of ArcGIS Pro and the algorithm may have been updated between versions. **I will be flexible with the grading.**

11) You now have elevation values at each sample point, stored in the attribute field **RASTERVALU**. Note that you also have all the original attribute values from **Sample_Points**.

12) **Questions:** For your homework:

   a) What was the **maximum elevation** encountered at a survey point?

   b) What is the **Unique_ID** value of the point with the **maximum** elevation?

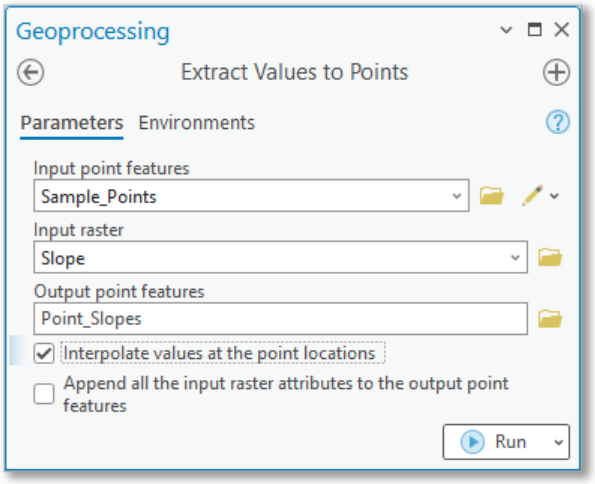
   c) What was the **minimum elevation** encountered at a survey point?

   d) What is the **Unique_ID** value of the point with the **minimum** elevation?

   e) What was the **average elevation** of all the survey points?

   - **Hint:** You can easily find descriptive statistics like minimum, maximum and mean by right-clicking on the field names and then opening the "Statistics" window.
   - **Additional Hint:** You can also double-click the attribute field name **RASTERVALU** to sort the elevation values in ascending order. Then you can quickly find the point with the highest and lowest elevation by simply looking at the first and last numbers in the list. This option also gives you an easy way to find the **Unique_ID** for those high and low values by just looking at the corresponding **Unique_ID** attribute value in the first or last row. **Note:** Make sure you are looking at the attribute field named **Unique_ID**, not **Object_ID**!

13) **Question:** Redo the steps above to find the **slopes** at each **Sample_Points** point (Hint: Rerun the **Extract Values to Points** tool, but this time extract values from your **Slope** raster).



a) What was the **maximum slope** encountered at a survey point?

b) What is the **Unique_ID** value of the point with the **maximum** slope?

c) What was the **minimum slope** encountered at a survey point?

d) What is the **Unique_ID** value of the point with the **minimum** slope?

e) What was the **average slope** of all the survey points?

Exercise 9 [Optional]: Calculating NDVI and NDWI

Objectives

- Learn to use the **Raster Calculator** tool to calculate the *Normalized Difference Vegetation Index* (**NDVI**; see Huang et al. [2021] and Pettorelli [2013] for review) and the *Normalized Difference Water Index* (**NDWI**; McFeeters 1996) from multiband imagery containing reflectance in the Red, Green and Near Infrared bands.
- Learn how to force the **Raster Calculator** tool to produce a floating-point raster (i.e. a raster whose cells contain decimal numbers rather than integers) when the input rasters are integer.
- Learn how to load individual bands from a multipoint raster.

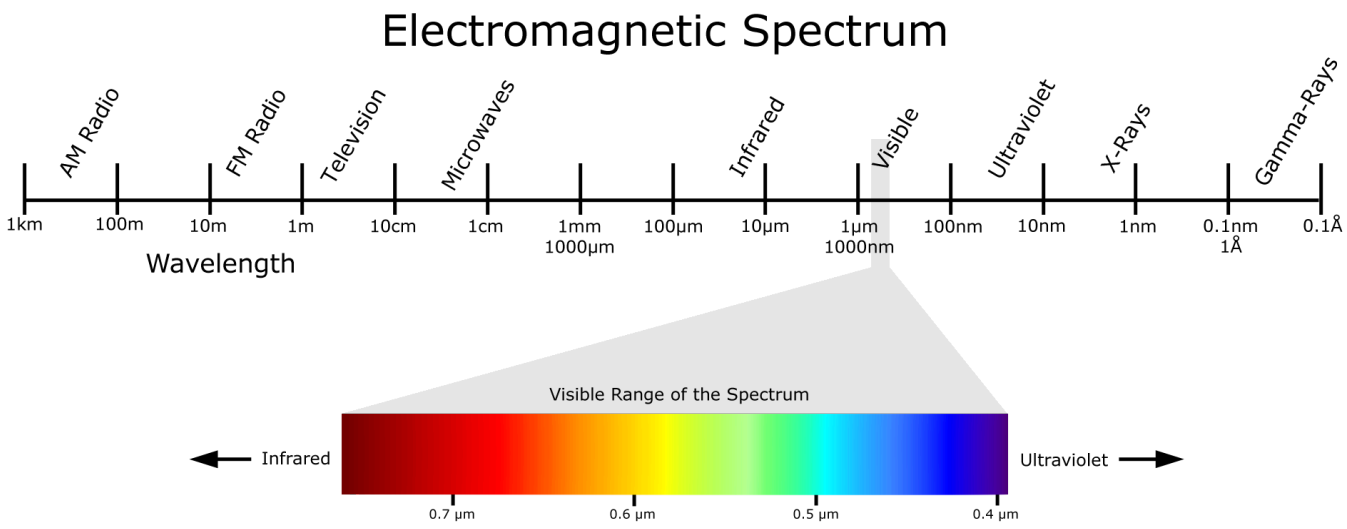
Data used

- Landsat image of the Grand Canyon area. File is named **Landsat_GC.tif** in folder "**..\Class_GIS_Data\Additional_Data\..**"

Background

This lab exercise will use a **Landsat Enhanced Thematic Mapper** Landsat image of the Grand Canyon region taken back in 2012. However, the methods illustrated apply equally well to any multiband image that includes reflectance in the **Red**, **Green** and **Near Infrared** spectral bands. Most multiband imagery datasets include these bands and many more.

The image and table below show the electromagnetic wavelengths corresponding to Landsat Enhanced Thematic Mapper bands. For this lab exercise, we are most interested in Bands 2 (Green), 3 (Red) and 4 (Near Infrared). For your reference, the electromagnetic spectrum is displayed below.



Landsat Image Example	Wavelength	Landsat ETM Band Name

	(µm)	
Band_1	0.45-0.52	Landsat ETM Band 1 (Blue-Green)
Band_2	0.52-0.60	Landsat ETM Band 2 (Green)
Band_3	0.63-0.69	Landsat ETM Band 3 (Red)
Band_4	0.76-0.90	Landsat ETM Band 4 (Near Infrared)
Band_5	1.55-1.75	Landsat ETM Band 5 (Mid Infrared)
Band_6	10.40-12.50	Landsat ETM Band 6H (Thermal Infrared, High)
Band_7	2.08-2.35	Landsat ETM Band 7 (Mid Infrared)
Band_8	0.52 – 0.9	Landsat ETM Band Panchromatic

Both NDVI and NDWI are very simple to calculate, using short equations with few variables.

$$NDVI = \frac{(NIR - Red)}{(NIR + Red)} \qquad NDWI = \frac{(Green - NIR)}{(Green + NIR)}$$

Both equations produce a raster dataset with values ranging from -1 to 1. NDVI values near 1 indicate higher concentrations of chlorophyll, and therefore provide an estimate of vegetation density and health. Comparing NDVI over time can show how a landscape is either recovering or deteriorating. NDWI values near 1 indicate open water, and are a good way to locate water sources from images.

Note: NDVI is a very common vegetation index, and easy to calculate. However, there are others available. EVI (Enhanced Vegetation Index) is uses the Red, Near Infrared and Blue bands, and is supposed to work better in areas with high biomass (Huete et al. 2002). There is also a variation on NDWI that uses the Short-Wave Infrared and the Near Infrared bands, which helps bring out water content in vegetation (Gao 1996).

Gao, B.-C. 1996. NDWI—A normalized difference water index for remote sensing of vegetation liquid water from space. Remote sensing of environment 58:257–266.

Huete, A., K. Didan, T. Miura, E. P. Rodriguez, X. Gao, and L. G. Ferreira. 2002. Overview of the radiometric and biophysical performance of the MODIS vegetation indices. Remote sensing of environment 83:195–213.

Huang, S., L. Tang, J. P. Hupy, Y. Wang, and G. Shao. 2021. A commentary review on the use of normalized difference vegetation index (NDVI) in the era of popular remote sensing. Journal of Forestry Research 32:1–6.

McFeeters, S. K. 1996. The use of the Normalized Difference Water Index (NDWI) in the delineation of open water features. International journal of remote sensing 17:1425–1432.

Pettorelli, N. 2013. The normalized difference vegetation index. Oxford University Press, USA.

For Homework

There is no homework due from this lab exercise.

For Fun

I have created two sample models named **NDVI** and **NDWI** that will calculate NDVI and NDWI from a multiband image, provided you know which bands are from the Red, Green and Near Infrared

wavelengths. There are also models that do a few other things we describe in these labs, that you are welcome to download and play with. The toolbox is saved in a geodatabase you can download from here:

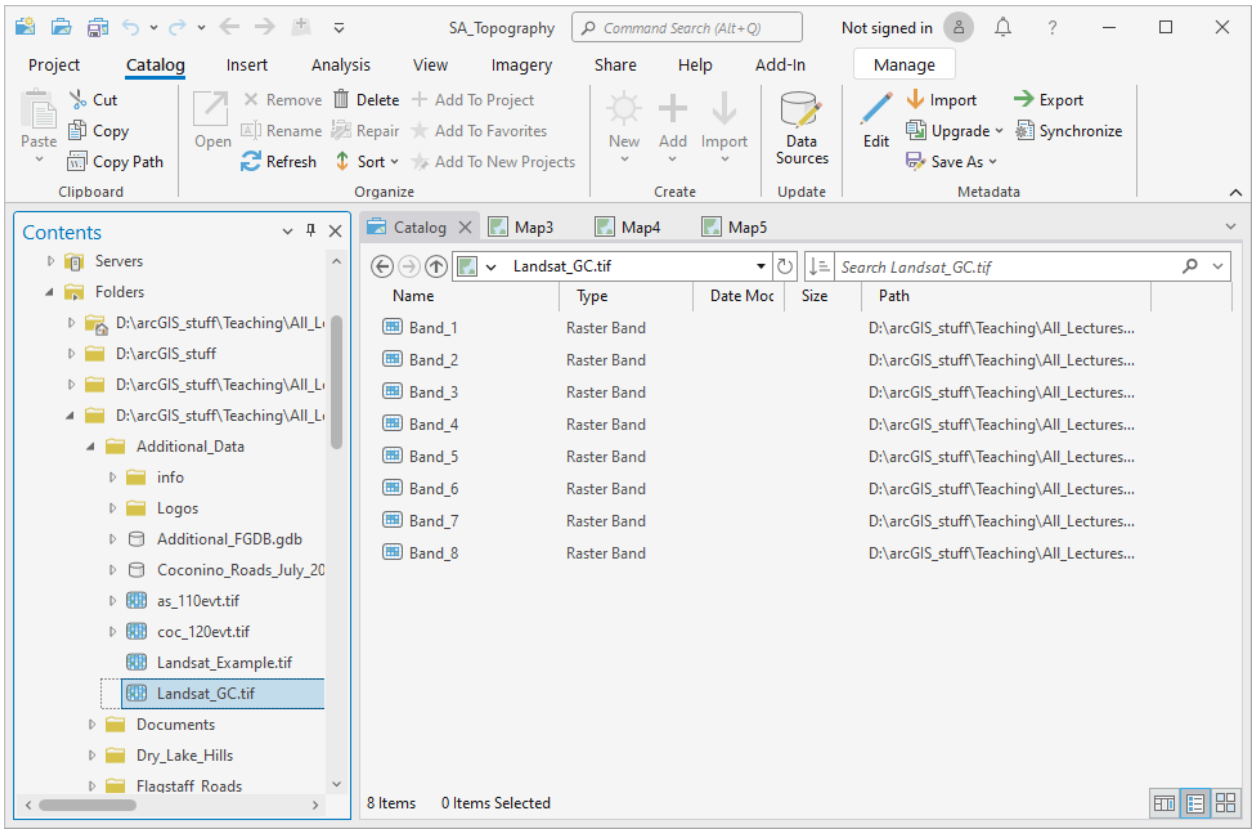
https://drive.google.com/file/d/1MDMLqwZolsCLVpKiy9i75aQceRI-gIPw/view?usp=sharing

Exercise

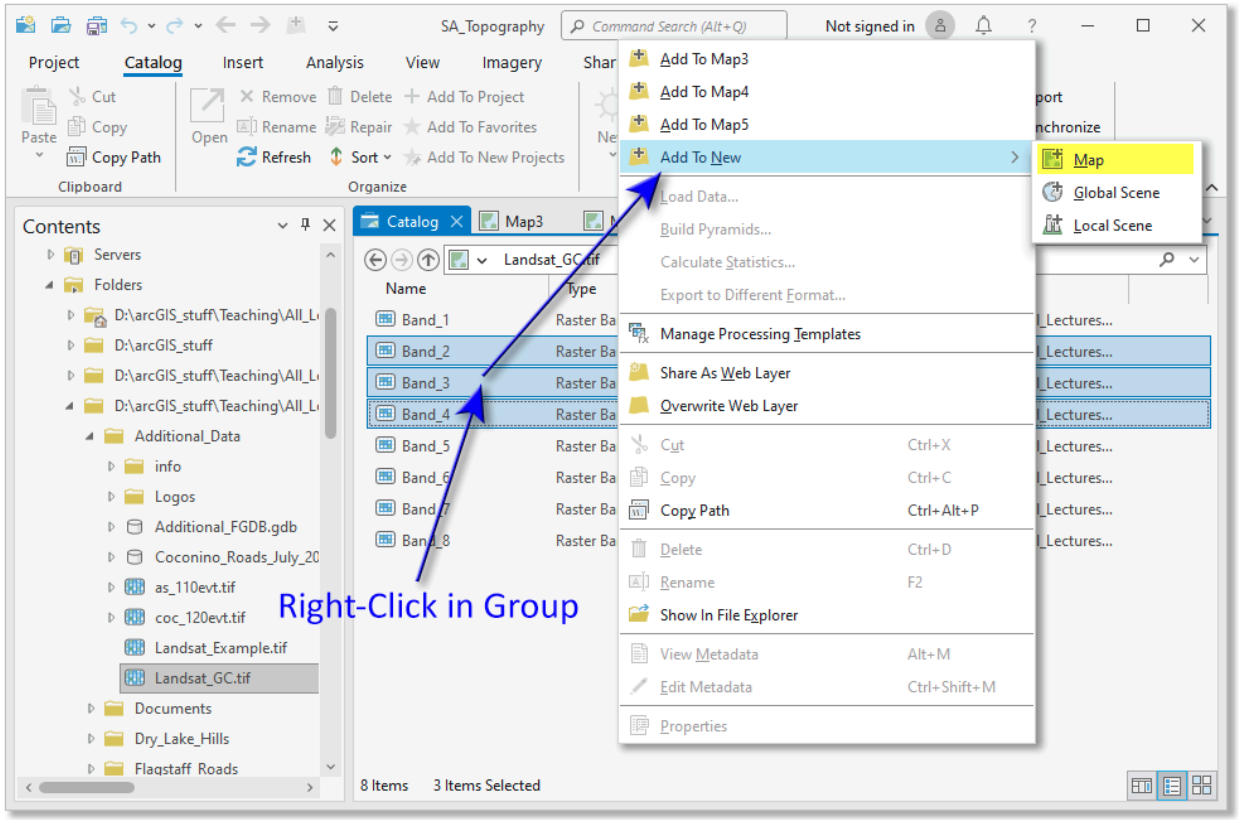
You will generate an NDVI raster showing where Chlorophyll is most abundant on the landscape, and an NDWI raster highlighting open water.

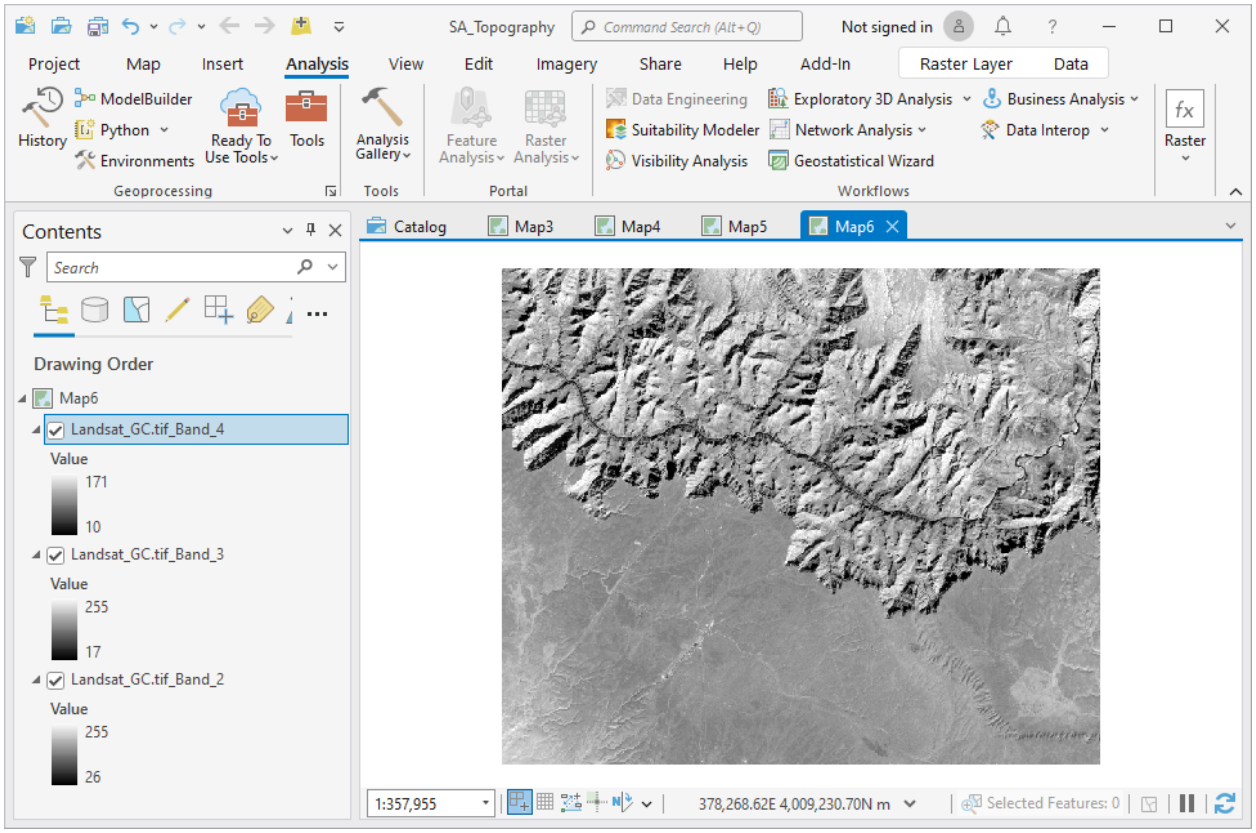
Prepare your Map and Data:

1) Open a new map in ArcGIS Pro.
2) Make sure you have the **Spatial Analyst** extension turned on. See Exercise 1 if you have questions on this.
3) Open a Catalog view and Find **Landsat_GC.tif**.
4) Notice that, in the **Catalog** view, you can expand **Landsat_GC.tif** and view each band individually.



5) Select bands 2, 3 and 4, then right-click on them and click “Add to New Map”.


Right-Click in Group



Calculate NDVI

NDVI (Normalized Difference Vegetation Index) is a simple equation using only the Red and Near Infrared bands of your multiband image. In this example, using Landsat Thematic Mapper, the Red band is Band 3, and the Near Infrared band is Band 4 (see p.).

$$NDVI = \frac{(NIR - Red)}{(NIR + Red)} = \frac{(Band\ 4 - Band\ 3)}{(Band\ 4 + Band\ 3)}$$

Important Note Read This: The raster bands in Landsat Thematic Mapper images (and in most remote sensing images) store the reflectance values as **integers**. This means that the reflectance has no decimal value. This is to help reduce the file size (and anyone who has downloaded many remote sensing images knows that they can be huge files). And generally we don't need more precision than integers offer.

Unfortunately this raises a problem with the **Raster Calculator** tool. If you give the **Raster Calculator** tool integer rasters to work with, it will produce an integer raster when it is done.

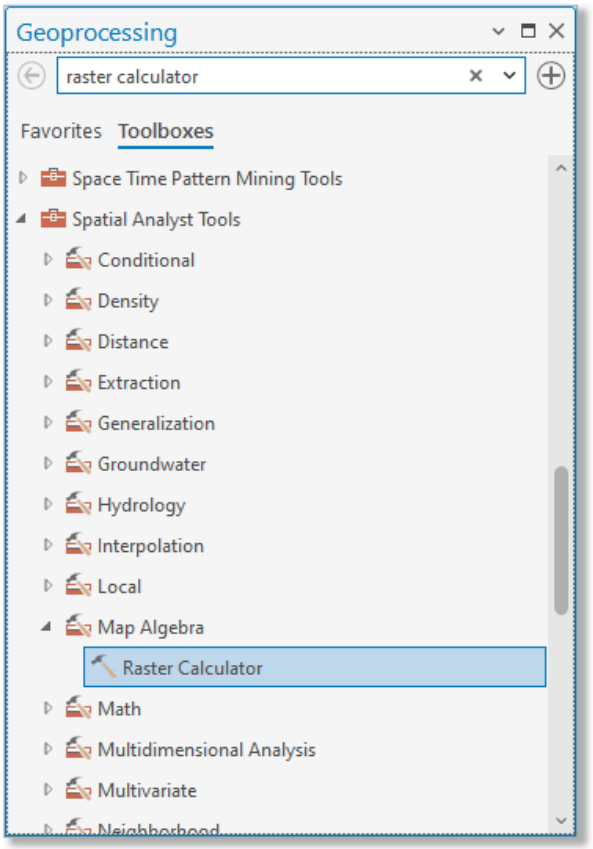
We are using integer rasters as inputs, but we want a **decimal** raster as output. This is because NDVI values range from -1 to 1. If we don't take steps to force our output to be decimal, we will end up with a raster containing, at most, 3 values (-1, 0 and 1).

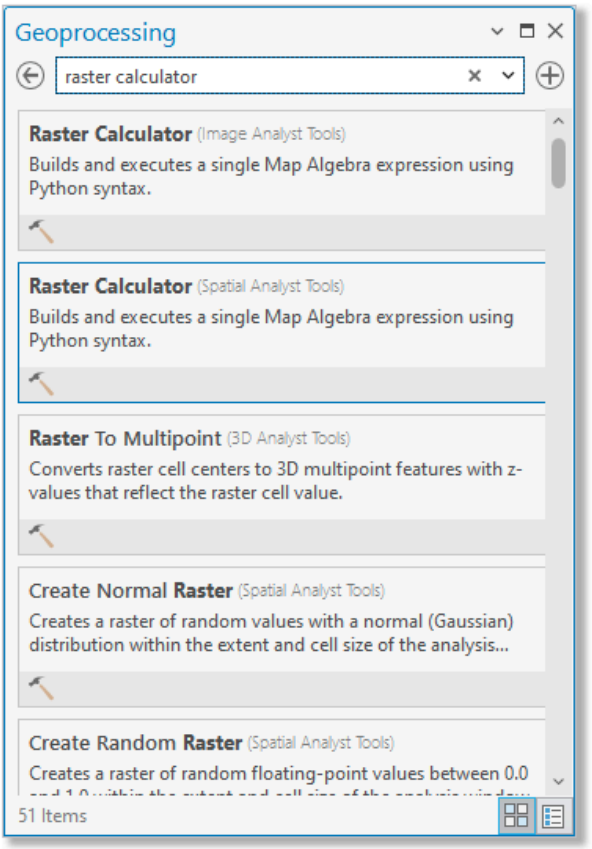
Less Important: Only read if you're interested Moreover, some images only store reflectance values ranging from 0 to 255, while others store reflectance values ranging from 0 to 65535. This again has to do with file size. Values ranging from 0 to 255 only require 8 binary digits to store the number, while values ranging from 0 to 65535 require 16 binary digits. Therefore an image with the same number of pixels will take twice as much space on the hard drive if it stores 16-bit numbers than if it stores 8-bit numbers. Decimal numbers usually take either 32 or 64 binary digits to store, so require much more hard drive space.

The Landsat Thematic Mapper image we're using in this exercise stores reflectance values as 8-bit numbers, ranging from 0 to 255. Newer Landsat images store 16-bit numbers, and so offer more precision and require larger files.

Exercise

6) Open the **Raster Calculator** tool (in Toolboxes --> Spatial Analyst Tools --> Map Algebra --> Raster Calculator):





7) In the **Raster Calculator** window:

   a) You can double-click on the raster names to make them appear in the raster equation box.

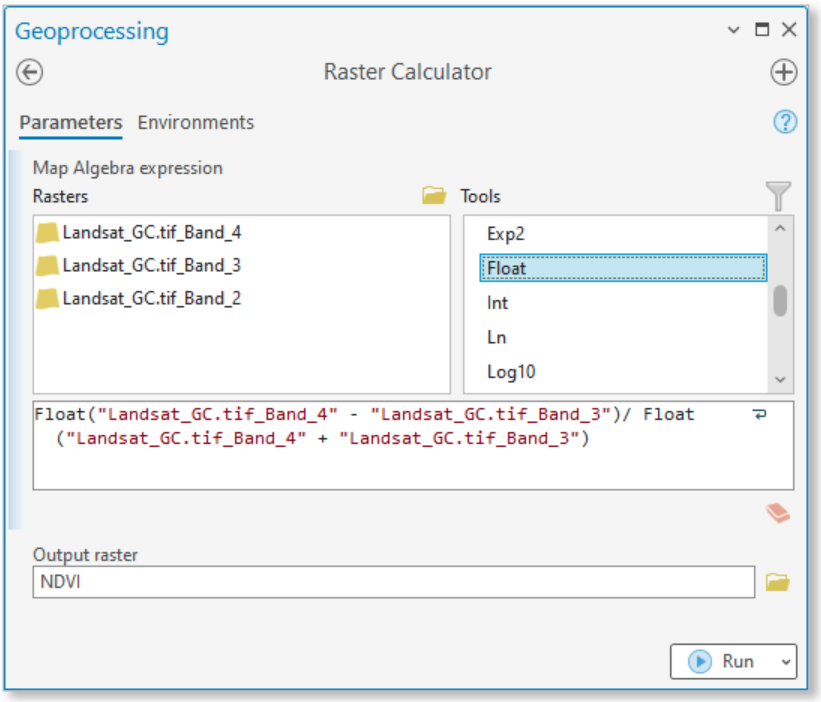
   b) **Important:** In order to avoid producing an integer raster output, you need to convert the numerator and denominator raster to floating point in the raster equation box! You do this with the `Float()` command (which is in the list of operators).

   c) **Important:** Make sure to use parentheses as illustrated! This tool is finicky, and easy to crash.

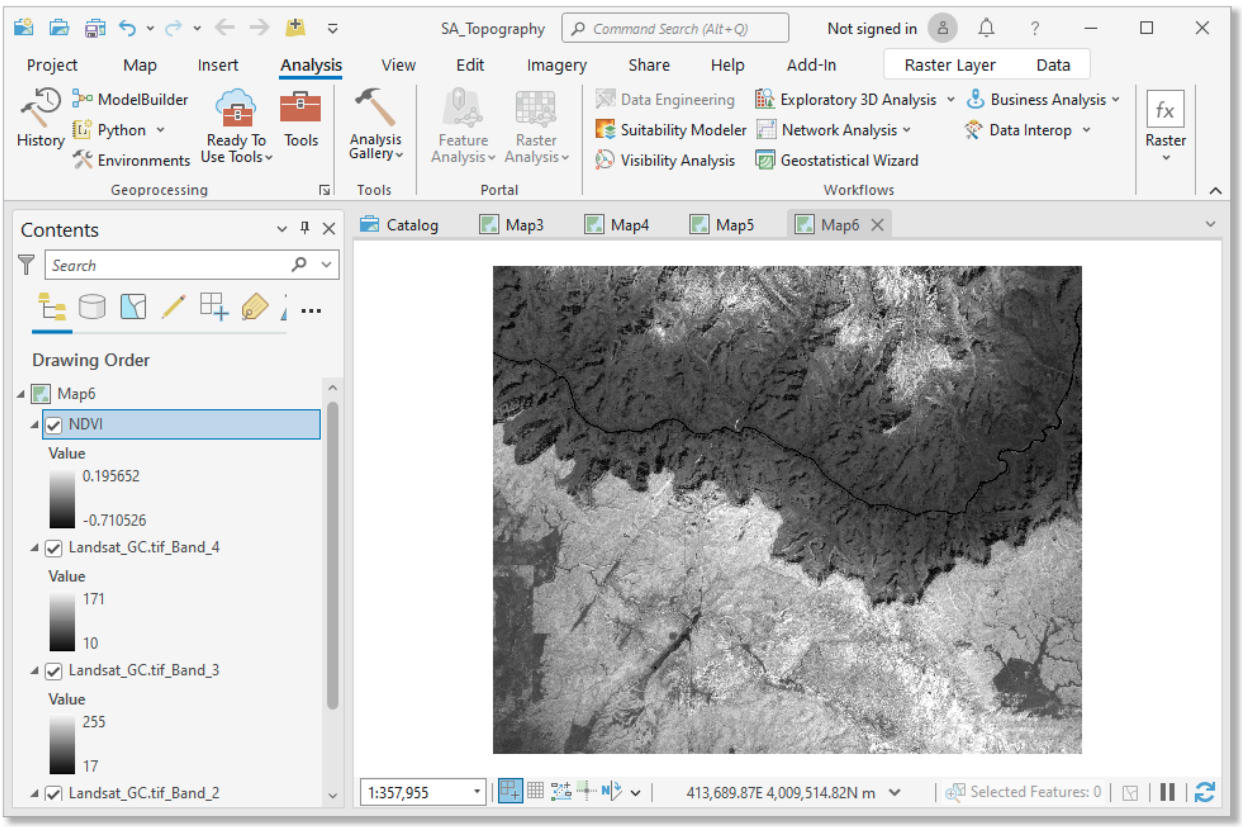
   d) Please try to construct the equation yourself in the tool, just to get the hang of it. The actual equation should be this:

```
Float("Landsat_GC.tif_Band_4" - "Landsat_GC.tif_Band_3")/
Float("Landsat_GC.tif_Band_4" + "Landsat_GC.tif_Band_3")
```

   e) Pick a name and location for your NDVI raster. I recommend saving it to your default file geodatabase and naming it “NDVI”



8) Upon completion, the tool will add your NDVI raster to your map. Notice how all values are inside the range -1 to 1, and the higher values correspond with vegetated areas.



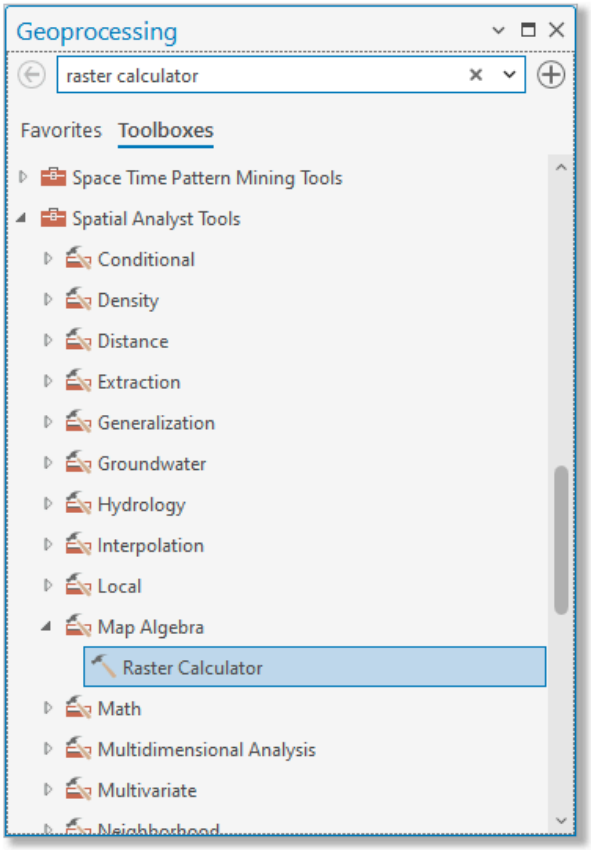
Calculate NDWI

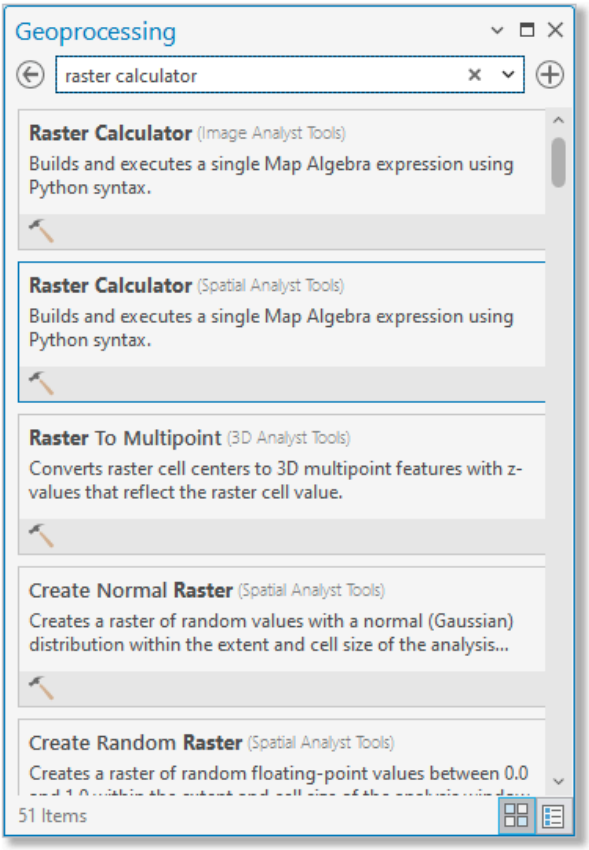
NDVI (Normalized Difference Water Index) is also a simple equation using only the Green and Near Infrared bands of your multiband image. In this example, using Landsat Thematic Mapper, the Green band is Band 2, and the Near Infrared band is Band 4 (see p.).

$$\text{NDWI} = \frac{(\text{Green} - \text{NIR})}{(\text{Green} + \text{NIR})} = \frac{(\text{Band 2} - \text{Band 4})}{(\text{Band 2} + \text{Band 4})}$$

Exercise

9) If it is not still open from the previous exercise, open the **Raster Calculator** tool (in Toolboxes --> Spatial Analyst Tools --> Map Algebra --> Raster Calculator):



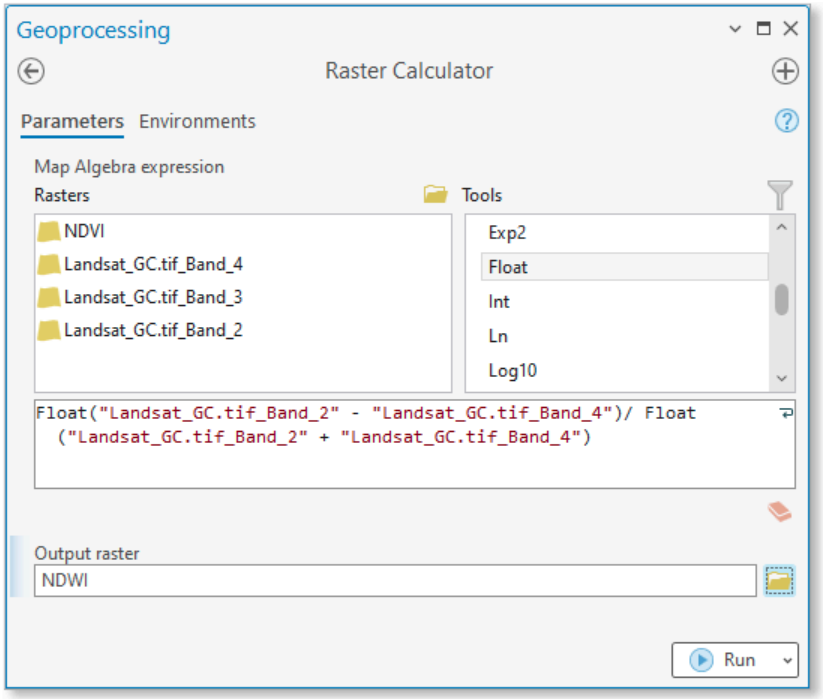


10) In the **Raster Calculator** window:

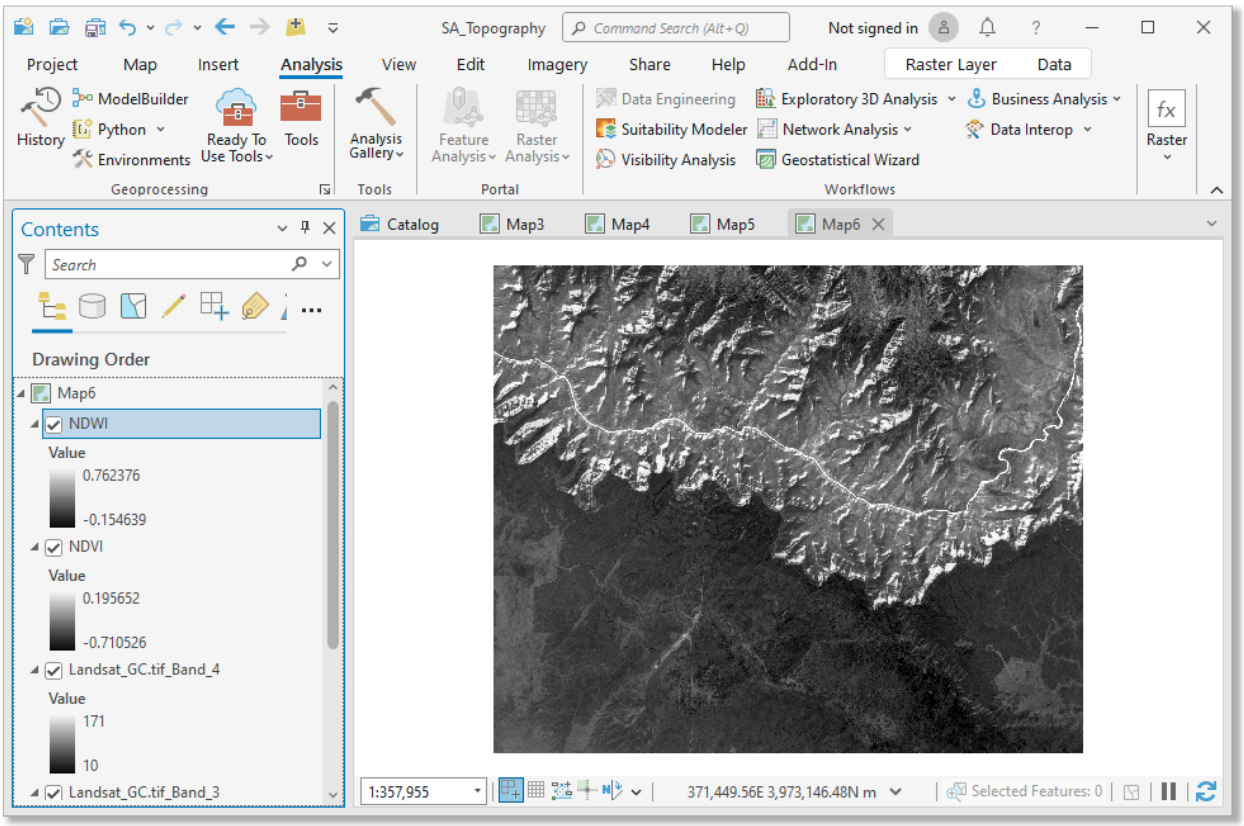
a) Again, be careful to use the `Float()` command, be liberal with your parentheses, and please try to construct the equation yourself in the tool, just to get the hang of it. The actual equation should be this:

```
Float("Landsat_GC.tif_Band_2" - "Landsat_GC.tif_Band_4")/
Float("Landsat_GC.tif_Band_2" + "Landsat_GC.tif_Band_4")
```

b) Pick a name and location for your NDWI raster. I recommend saving it to your default file geodatabase and naming it "NDWI"



11) Upon completion, the tool will add your NDWI raster to your map. Again, notice how all values are inside the range -1 to 1, and that the Colorado River is very apparent at the bottom of the canyon.



Exercise 10 [Optional]: Calculate a Hillshade and apply Hypsometric Shading

Objectives

- Learn to apply Hypsometric Shading to a hillshade, which is one of the Swiss Method strategies for making hillshades more attractive.
- Practice setting layer transparency.

Data used

- Raster layer file **DEM_10m.lyr**, in folder **..\Class_GIS_Data\Raster_Functions\...** This layer file references a raster dataset named **DEM_10m** in the file geodatabase **Lab_Data.gdb**, and is an approximately 10m resolution Digital Elevation Model (DEM) showing elevation (in meters) within the general extent of the Semester D Management Unit in the Centennial Forest.
- Optionally, any additional data or online basemap layers you prefer, such as topo maps or imagery. These won't be used in the analysis but they are often useful to help orient yourself or see the analysis within a larger landscape context.

For Homework

There is no homework due from this lab exercise.

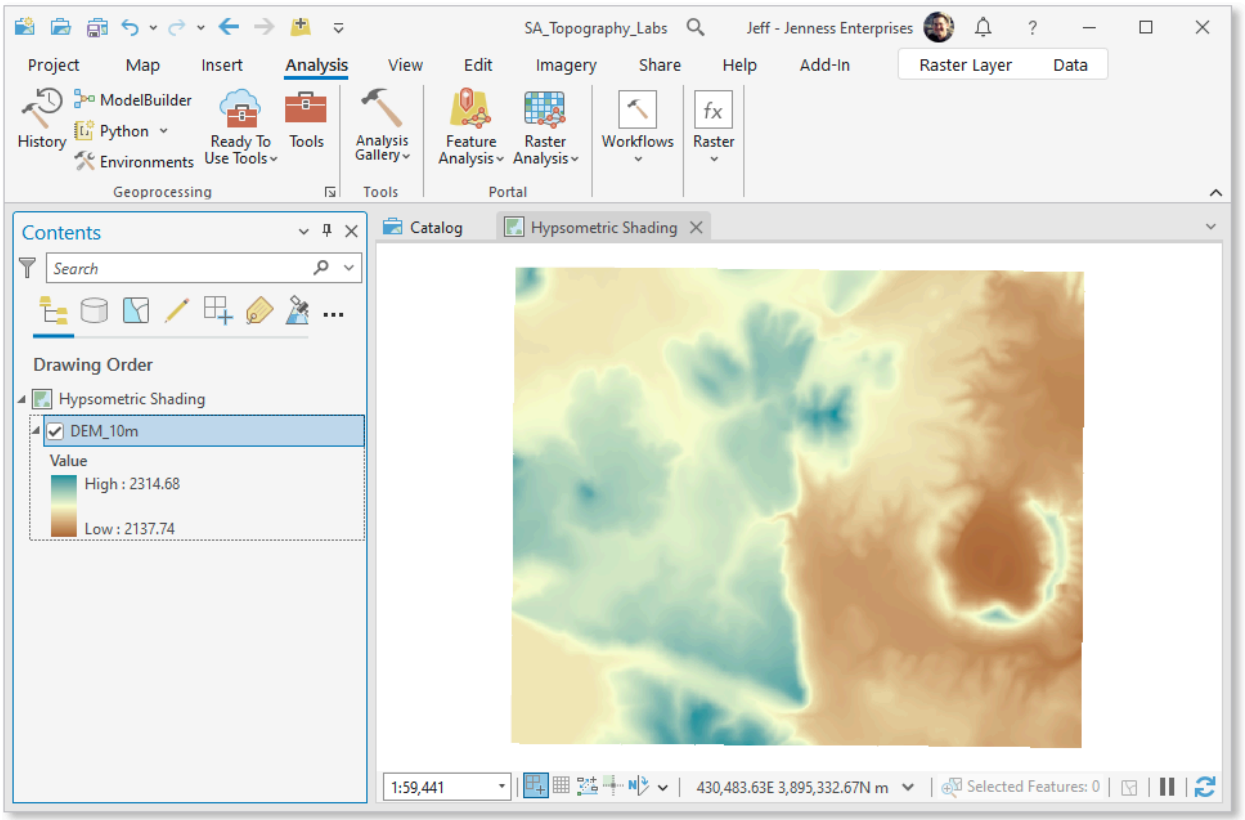
Exercise

Based on the DEM (digital elevation model), you will generate a new hillshade raster as you did in Lab Exercise 3 (p.), and then you will use to source DEM to shade the lower elevations in a darker color than higher elevations. This gives a sense of depth to the lower elevations that can make the hillshades more interesting aesthetically.

Take a look back at Lab Exercise 3 if you want to review the discussion on hillshades from geographic (Latitude/Longitude) DEMs, and for resolving differences between elevation units and X/Y coordinate system units.

Prepare your Map and Data:

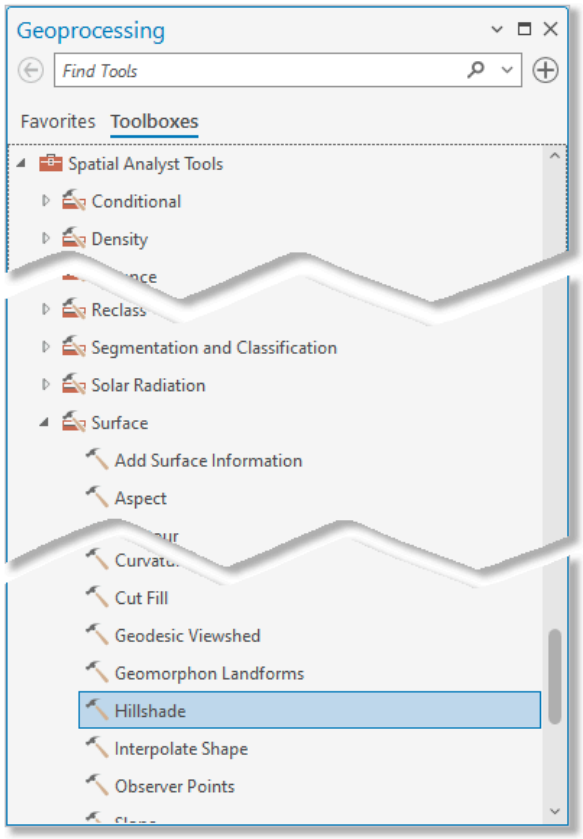
5) Open a blank map in ArcGIS Pro. If you still have ArcGIS Pro open from the previous exercise, you may simply insert a new map.
6) Make sure you have the **Spatial Analyst** extension turned on. See Exercise 1 if you have questions on this.
7) If it is not already present, then load the **Layer** file **DEM_10m.lyr** from the folder **..\Class_GIS_Data\Raster_Functions\...** as you did in Exercise 1.
8) If you loaded the Layer file, you should see the following.

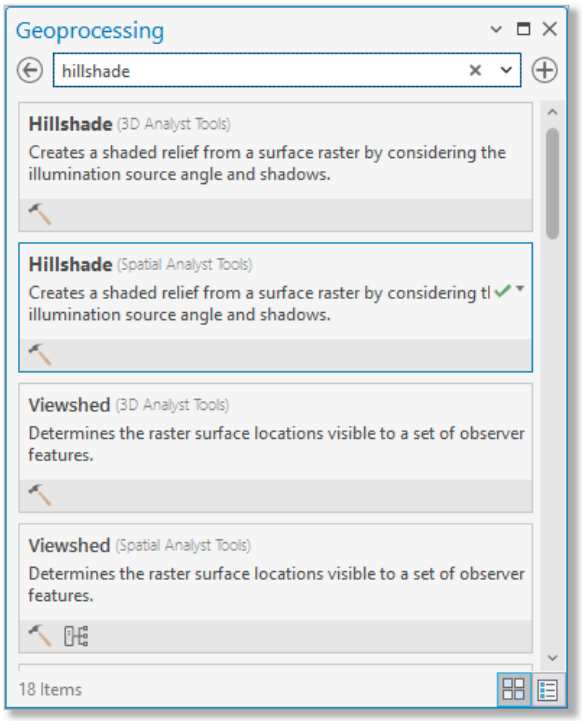


7) Optionally, load any online basemap layers or other background data you like.

Calculate Hillshade

8) Open the Hillshade tool (in Toolboxes --> Spatial Analyst Tools --> Surface --> Hillshade):



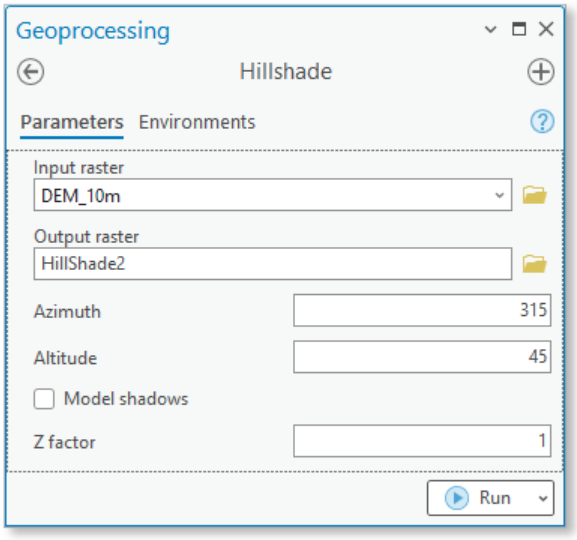


9) Set the "Input Raster" to **DEM_10m** and pick a name and location for your output Hillshade raster. I recommend saving it to your file geodatabase named "New_Data.gdb" and naming it "Hillshade2". Set the "Azimuth" to **315** and the "Altitude" to **45**. You may choose to model shadows or not; your choice.

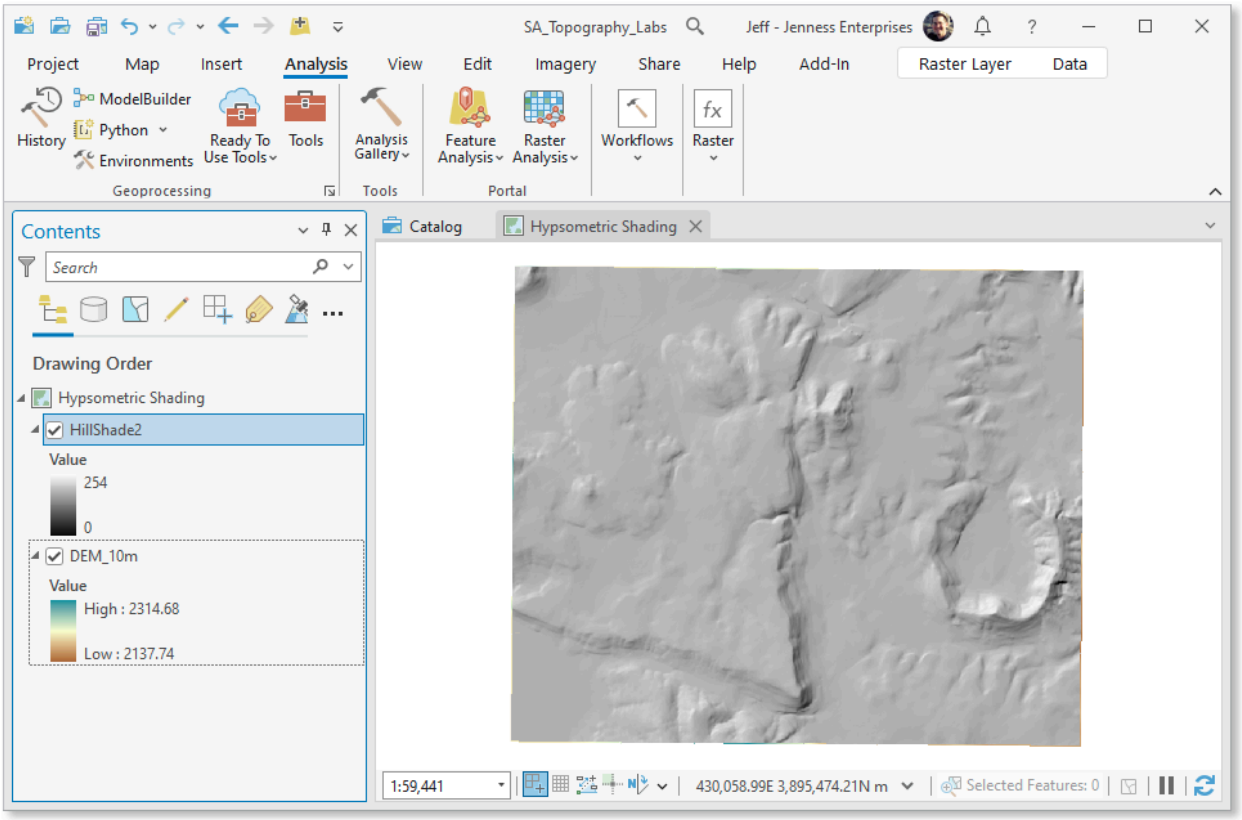
   a) **Note:** "Azimuth" and "Altitude" refer to the sun position. These default values usually produce a good-looking raster that brings out the shape of the landscape very well. However, remember that the sun is rarely in that position (exactly Northwest [315°], and 45° up) in the northern hemisphere! You can change the sun position to any location you want. There are online tools available (such as http://www.esrl.noaa.gov/gmd/grad/solcalc/) to help you determine sun position for a particular place and time.

   b) **Note:** The option to "Model Shadows" means to check for places that might directly face the sun, but would be in the shadow of a larger feature. Modeling shadows would set these areas to black (or a hillshade value of 0) regardless of their orientation.

10) If your elevation units are different than your coordinate system linear units, then set the appropriate conversion factor in the "Z factor" box. For example, if your coordinate system is in meters, and your elevation units are in feet, then specify a Z-factor of 0.3048 because there are that many meters in a foot. Otherwise, leave this conversion factor equal to 1.

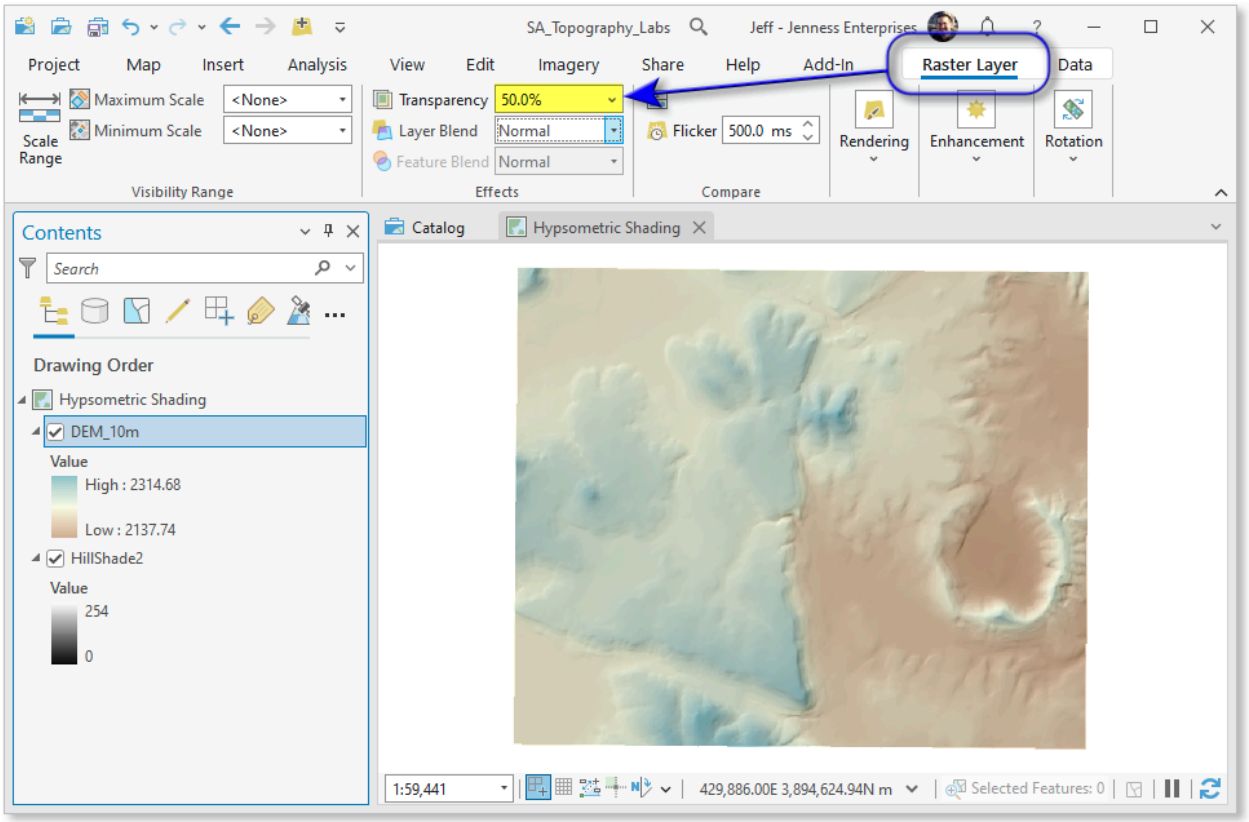


11) Upon completion, the tool will add a new Hillshade raster to your map. It should look something like the following:



12) Drag the hillshade underneath your DEM, and set your DEM transparency to 50%.

a) Select your DEM layer in your Contents pane, then click the **Raster Layer** tab above the ribbon to see the **Transparency** option.

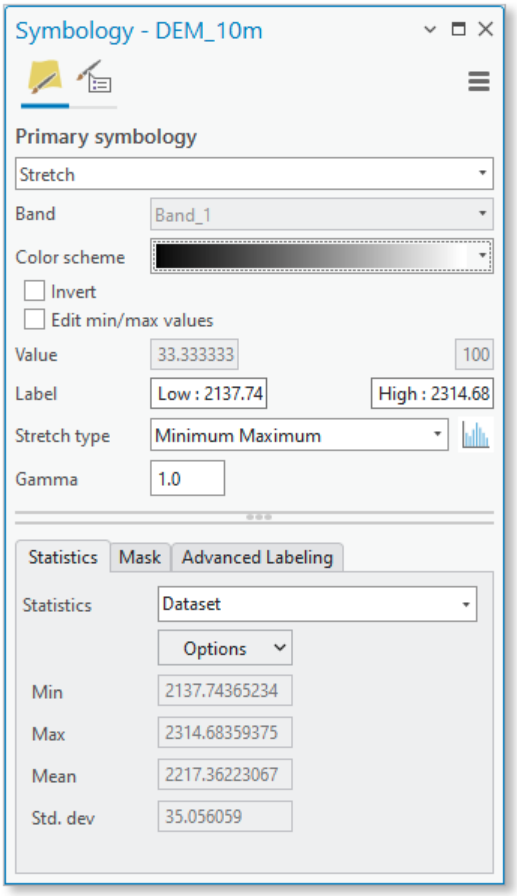


13) Set your DEM symbology to a black-to-white color ramp.

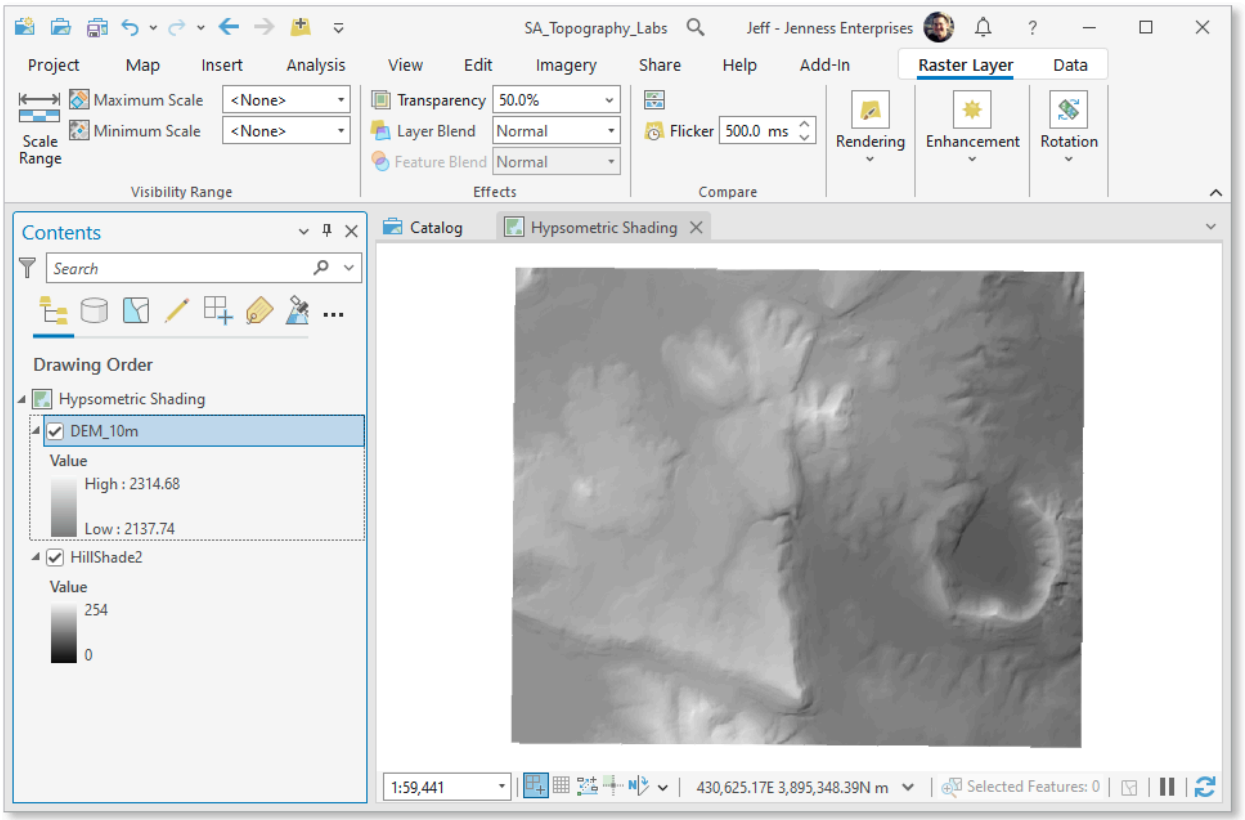
a) Right-click on your **DEM_10m** layer, and choose **Symbology** to open the **Symbology** pane.

b) Leave the Primary Symbology type as **Stretch**, and select a Black-to-White color ramp.

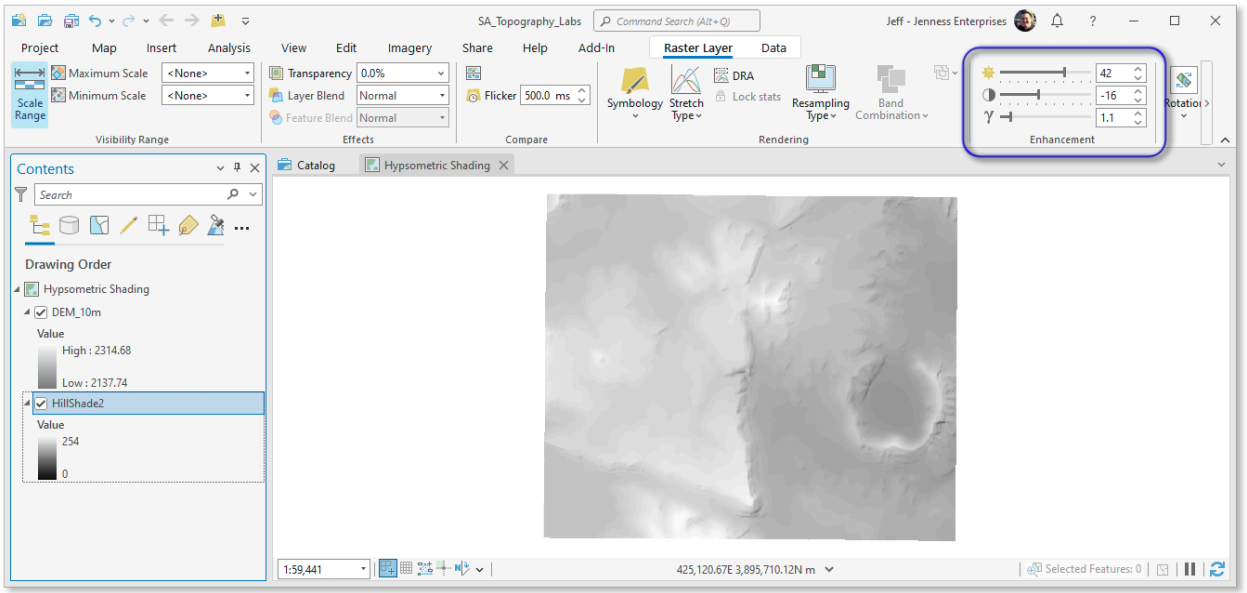
c) Set stretch type as **Minimum Maximum**



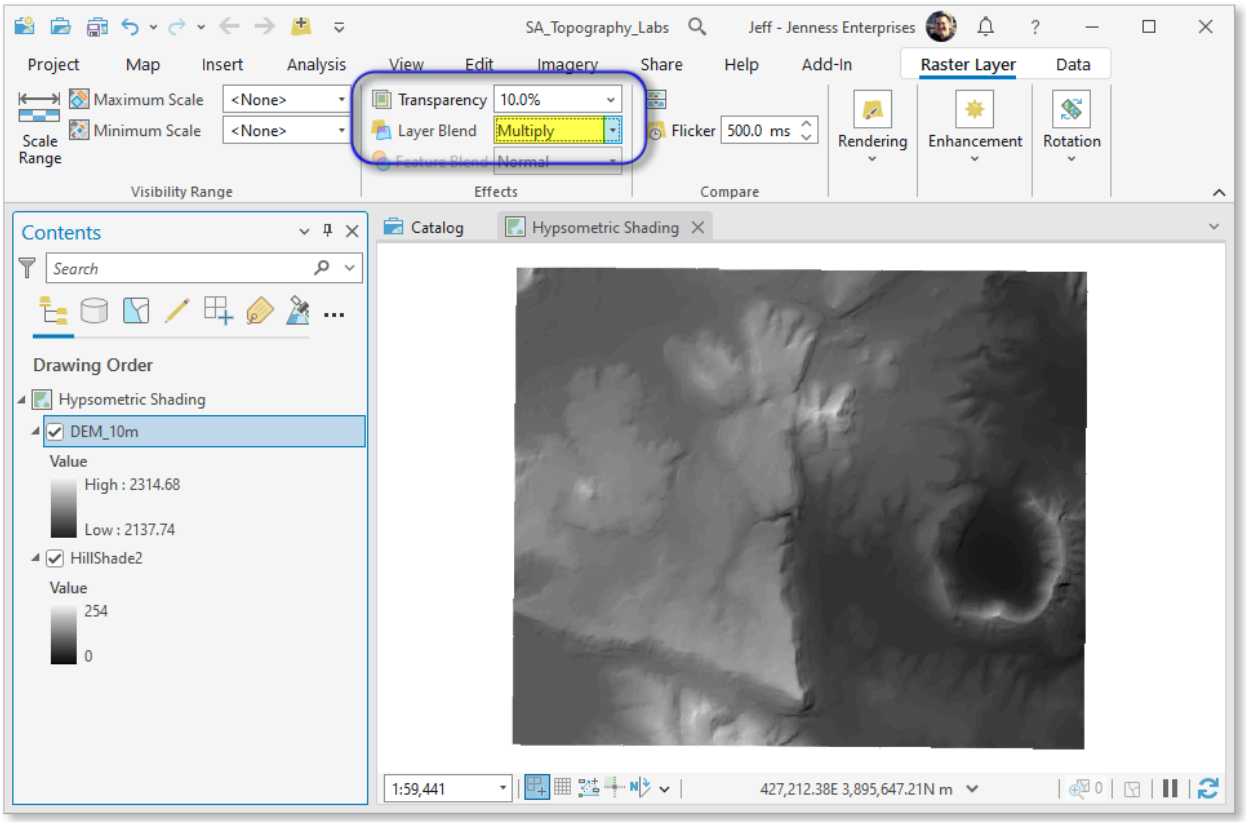
14) You should now see your DEM with Hypsometric Shading applied:



15) **Optional:** If you like, you can brighten up your underlying hillshade and/or DEM, or change the contrast, by selecting the layer in the Contents pane, then clicking the **Raster Layer** tab, and then going to the **Enhancement** box. For example, if I set the **Hillshade2 Brightness = 42**, the **Contrast = -16**, and the Layer Gamma = 1.1, then reset the **DEM_10m** transparency to 60%, then I get the following:

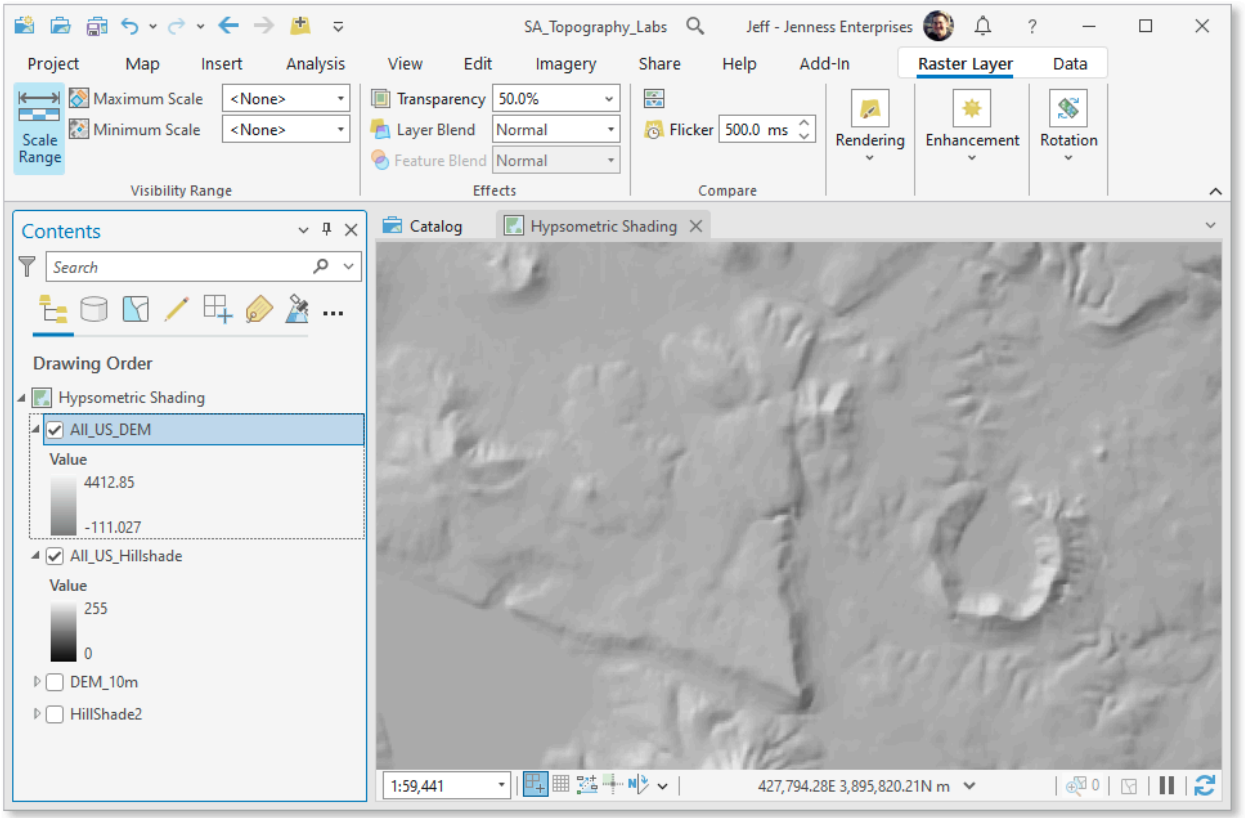


16) You can also get an enhanced effect by setting the DEM transparency to a very low number, or even Zero, and setting the **Layer Blend** type to **Multiply**. This has the effect of showing whichever layer is darker at each cell:

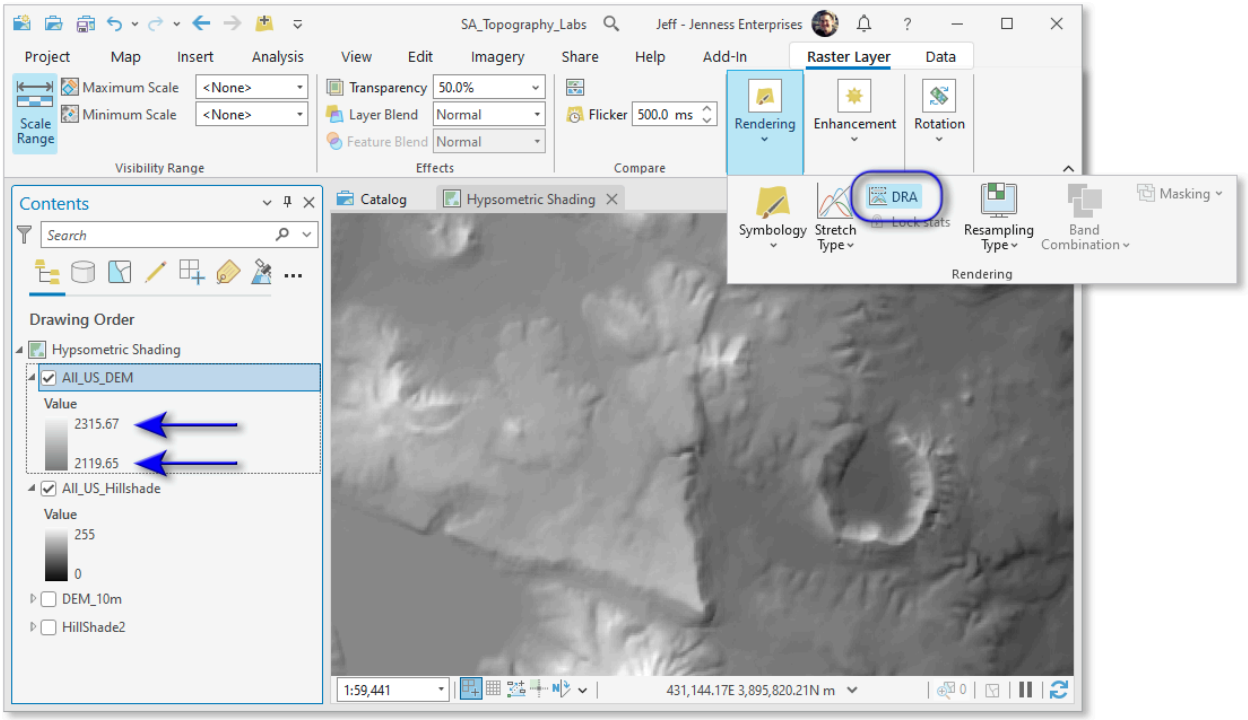


17) **A Problem you Might Encounter:** If your DEM extends far outside your visual map, then the hypsometric color range may be very narrow in your map and you may be missing the effect. For example, in the map below I am showing a DEM and hillshade that covers the entire continental United States, with elevations ranging from -111m to 4,412m, but I am zoomed into the same region as the image above.

Note that the hypsometric shading is still being applied, but in this case it is shading from **black** at -111m up to **white** at 4,412m. The visible region in the map only extends from 2,119m to 2,315m, so the hypsometric effect is completely washed out.



a) **The Solution!** Apply **Dynamic Range Adjustment (DRA)**. We can change the DEM layer symbology so it uses the entire black-to-white color ramp, but applies it only to the range of data visible in the map. Just select the layer you want DRA applied to (our DEM in this example), go to the **Raster Layer** tab in the Ribbon, look in the **Rendering** section, and click **DRA**:


SA_Topography_Labs
Jeff - Jenness Enterprises
Project
Map
Insert
Analysis
View
Edit
Imagery
Share
Help
Add-In
Raster Layer
Data
Scale Range
Maximum Scale
<None>
Minimum Scale
<None>
Visibility Range
Transparency
50.0%
Layer Blend
Normal
Feature Blend
Normal
Effects
Flicker
500.0 ms
Compare
Rendering
Enhancement
Rotation
Symbology
Stretch Type
DRA
Lock stats
Resampling Type
Band Combination
Masking
Rendering
Contents
Search
Drawing Order
Hypsometric Shading
All_US_DEM
Value
2315.67
2119.65
All_US_Hillshade
Value
255
0
DEM_10m
HillShade2
Catalog
Hypsometric Shading
1:59,441
431,144.17E 3,895,820.21N m

Exercise 11 [Optional]: Calculate a Hillshade Based on Two Sun Locations

Objectives

- Learn to generate a hillshade based on multiple sun locations, which is one of the Swiss Method strategies for making hillshades more attractive.
- Practice connecting up tools in a Model in ModelBuilder, so all the steps can easily be rerun in the future on a different DEM.

Data used

- Raster layer file **DEM_10m.lyr**, in folder **..\Class_GIS_Data\Raster_Functions\...** This layer file references a raster dataset named **DEM_10m** in the file geodatabase **Lab_Data.gdb**, and is an approximately 10m resolution Digital Elevation Model (DEM) showing elevation (in meters) within the general extent of the Semester D Management Unit in the Centennial Forest.
- Optionally, any additional data or online basemap layers you prefer, such as topo maps or imagery. These won't be used in the analysis but they are often useful to help orient yourself or see the analysis within a larger landscape context.

For Homework

There is no homework due from this lab exercise.

For Fun

I have created a sample model name **Dual Hillshade** that will calculate a hillshade from two specified sun locations, similar to what you'll do in this lab exercise. I've also added models that do a few other things we describe in these labs, that you are welcome to download and play with. The toolbox is saved in a geodatabase you can download from here:

https://drive.google.com/file/d/1MDMLqwZolsCLVpKiy9i75aQceRI-gIPw/view?usp=sharing

Exercise

Based on the DEM (digital elevation model), you will generate a new hillshade raster similar to what you did in Lab Exercise 3 (p.), except that you will specify two sun locations and add them together. This can sometimes help to bring out subtle variations in the landscape that are washed out in a traditional hillshade.

You will also see how to construct the steps in ModelBuilder, so you can easily apply the steps to different DEMs in the future.

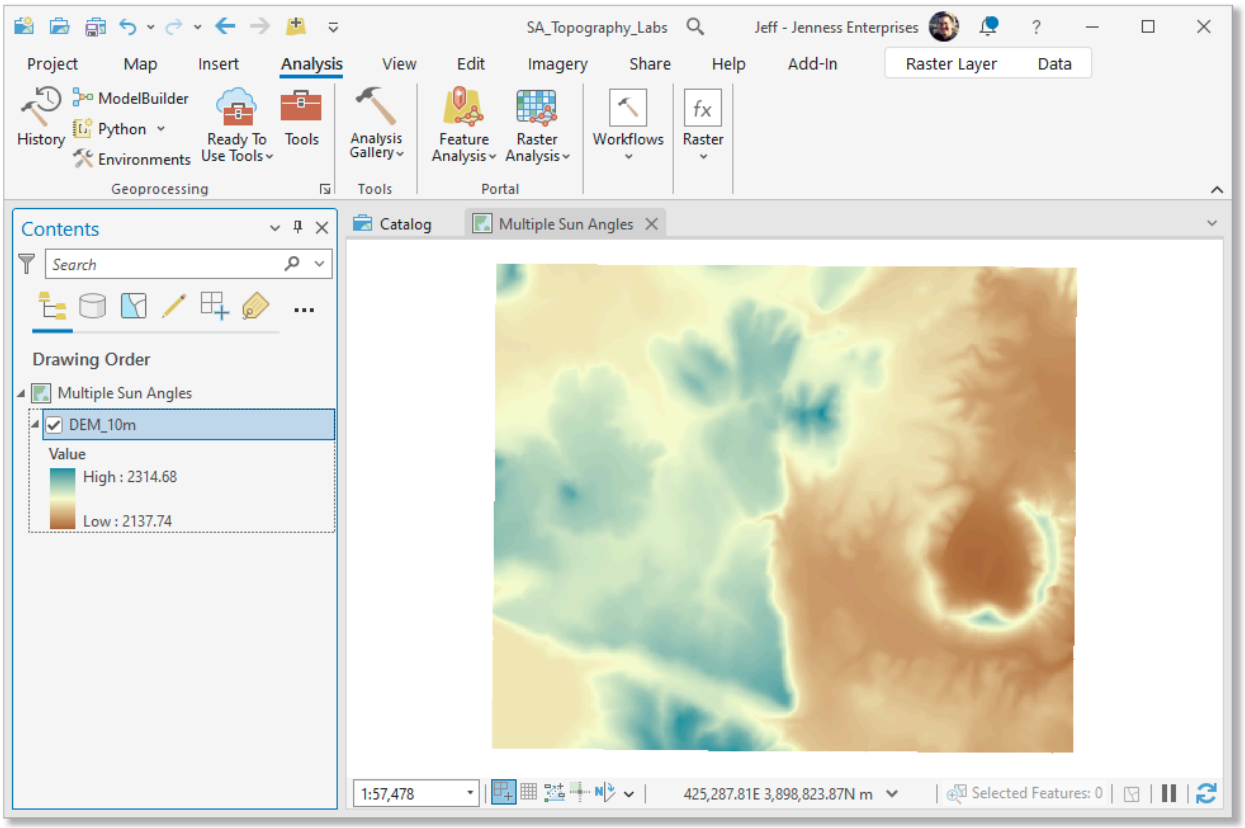
Take a look back at Lab Exercise 3 if you want to review the discussion on hillshades from geographic (Latitude/Longitude) DEMs, and for resolving differences between elevation units and X/Y coordinate system units.

Prepare your Map and Data:

1) Open a blank map in ArcGIS Pro. If you still have ArcGIS Pro open from the previous exercise, you may simply insert a new map.
2) Make sure you have the **Spatial Analyst** extension turned on. See Exercise 1 if you have questions on this.

3) If it is not already present, then load the **Layer** file **DEM_10m.lyr** from the folder **..\Class_GIS_Data\Raster_Functions\...** as you did in Exercise 1.

4) If you loaded the Layer file, you should see the following.



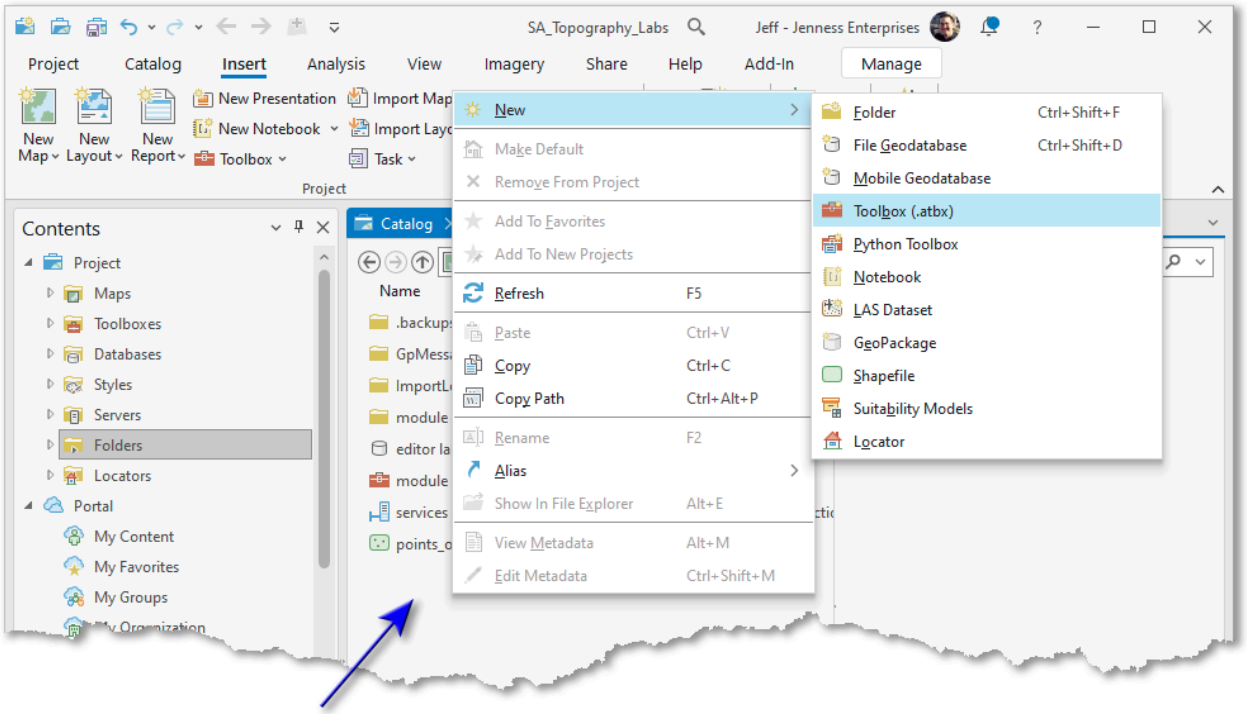
5) Optionally, load any online basemap layers or other background data you like.

Prepare your toolbox:

This exercise will construct a model which will let you easily run this process again in the future. To do this we will need to have a toolbox available to hold the model. ArcGIS Pro models have to be stored in toolboxes.

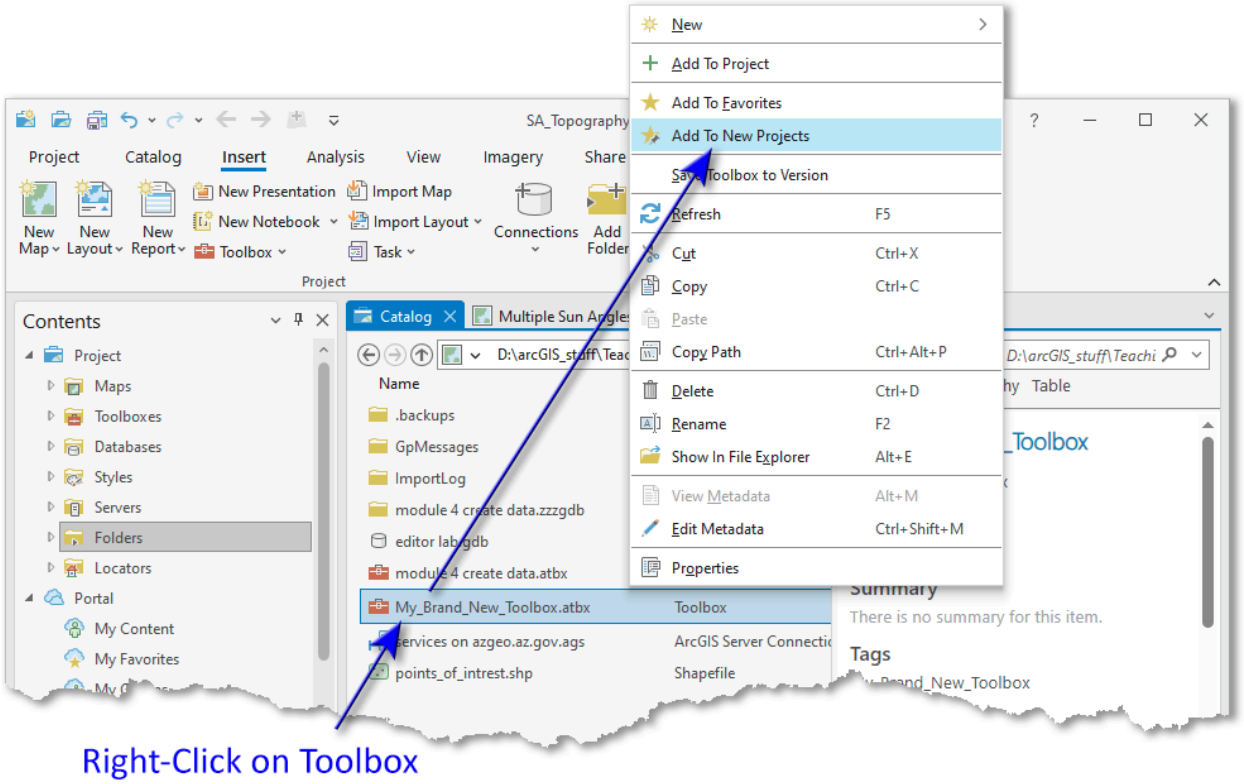
Your ArcGIS Pro project comes with its own toolbox, which we will use in this lab exercise.

If you wish, though, please feel free to create a new toolbox. It's easy to do. Just use your Catalog view to navigate to either a folder or geodatabase where you want to create it, then click "New" and then "Toolbox":

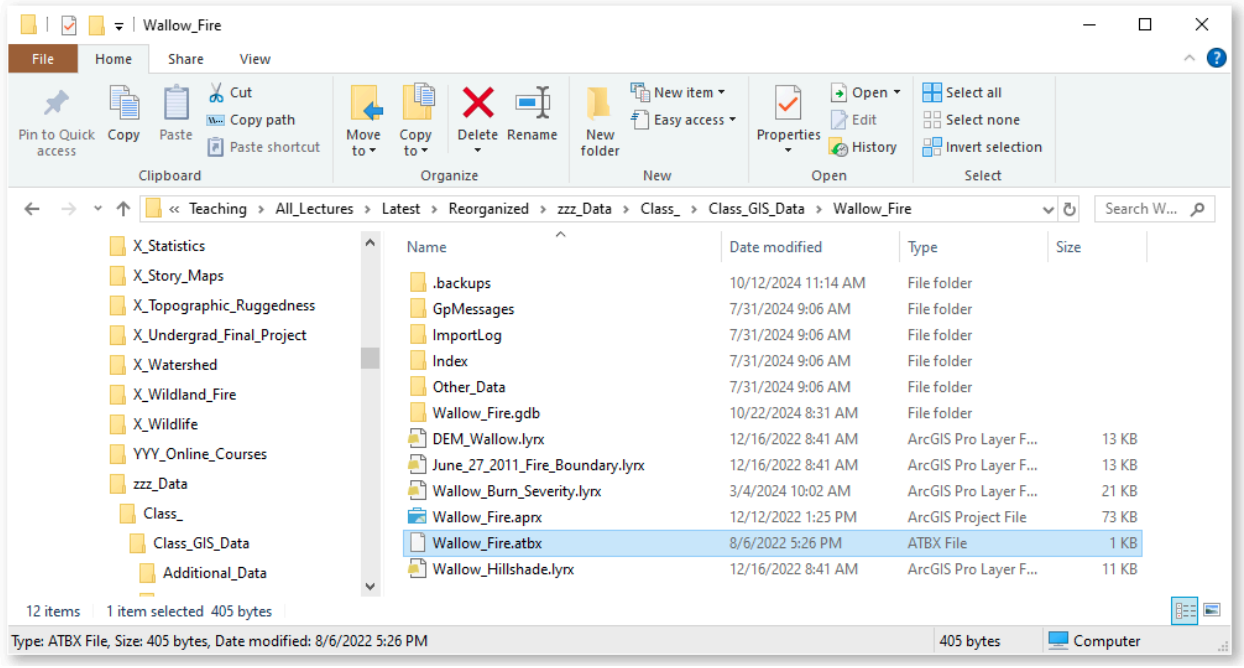


Right-Click in Folder or Geodatabase, then click “New”, then “Toolbox”

And remember that, regardless of whether you create a new toolbox or use the current ArcGIS Pro Project toolbox, you can always access that toolbox from new ArcGIS Pro projects. If you have a toolbox you want to always be available in any new ArcGIS Pro project you create, just right-click on it in Catalog view, and choose “Add to New Projects”:

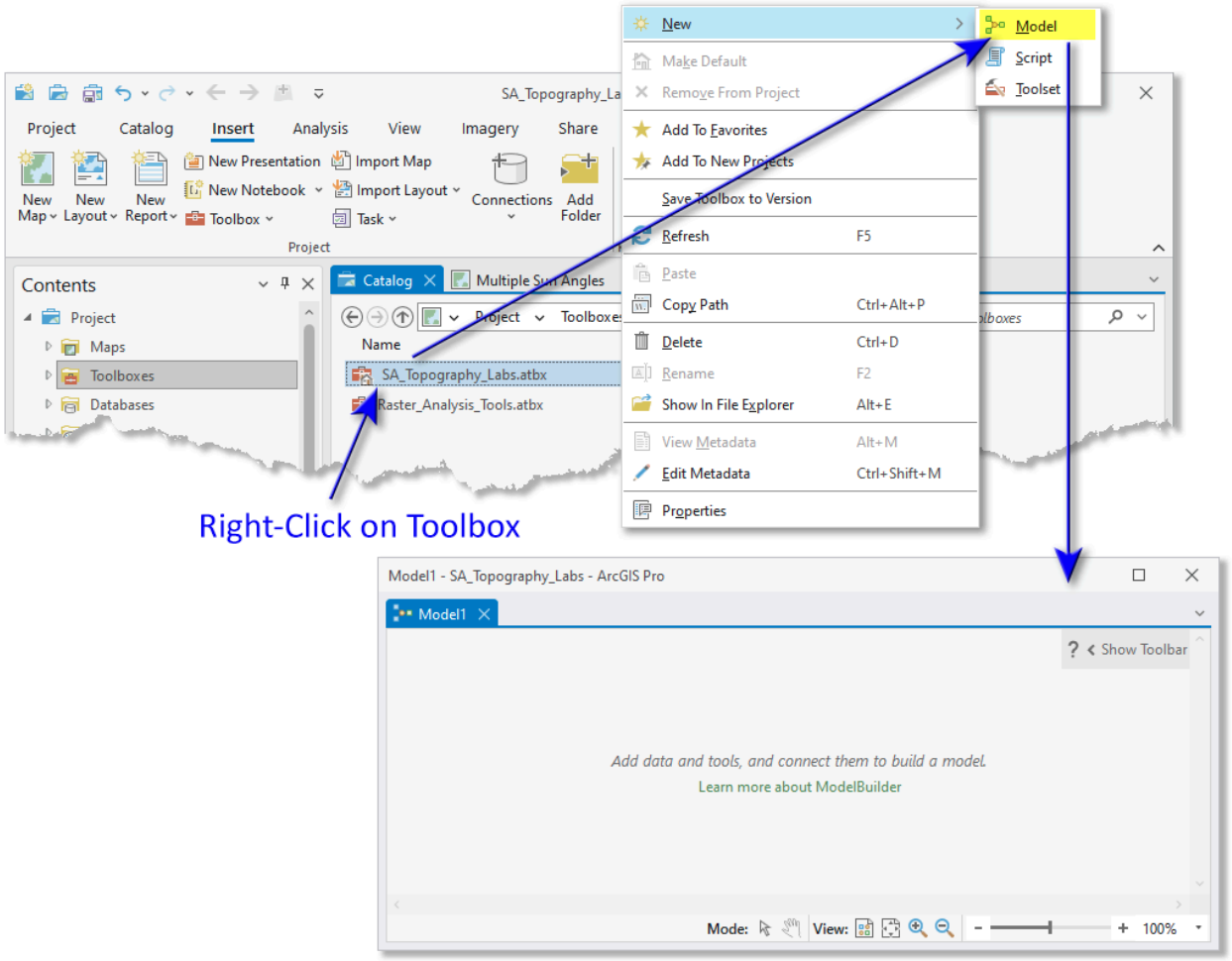


And you can easily share ArcGIS Pro toolboxes with colleagues simply by sending them the ATBX file:



Create the Model:

6) Right-click on your preferred toolbox, click “New”, then “Model”

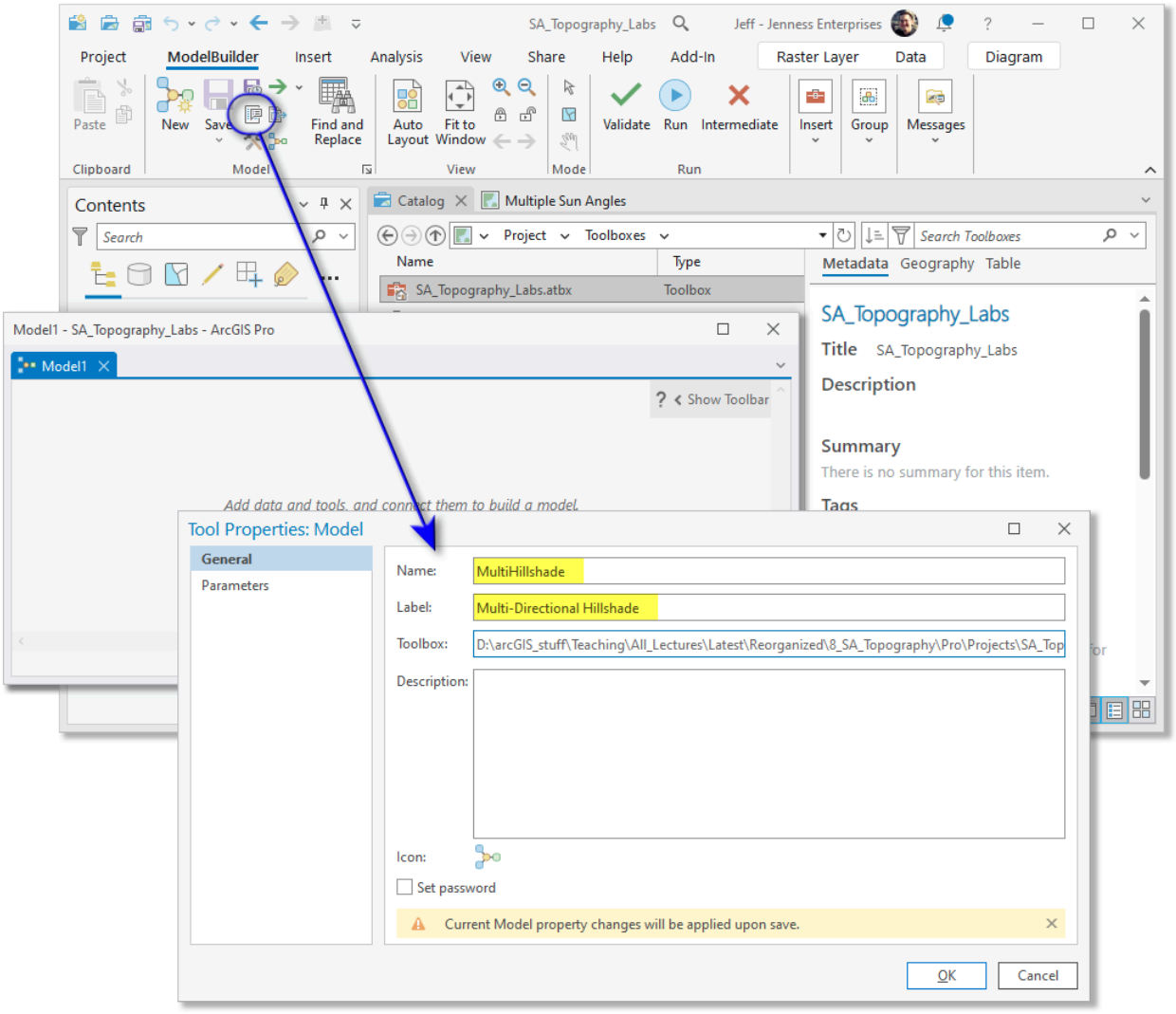


7) Change the Name and Label of your model.

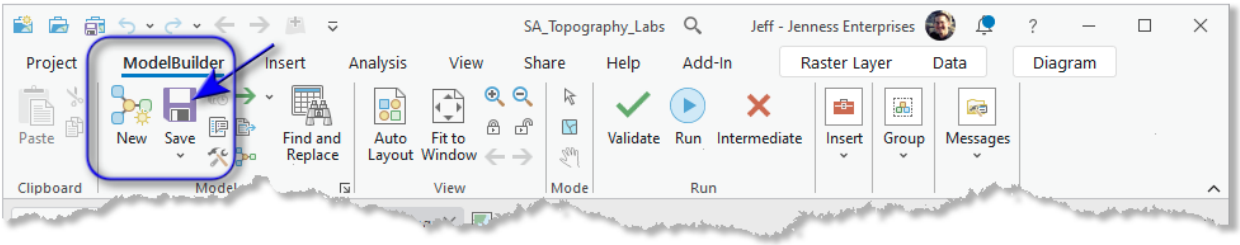
   a) In the ArcGIS Pro Ribbon, click the "ModelBuilder" tab, then the Properties icon  to open the Tool Properties window.

   b) Set the **Name** to "MultiHillshade". Note that the name cannot have any non-alphanumeric characters in it, so no spaces, periods or underscores.

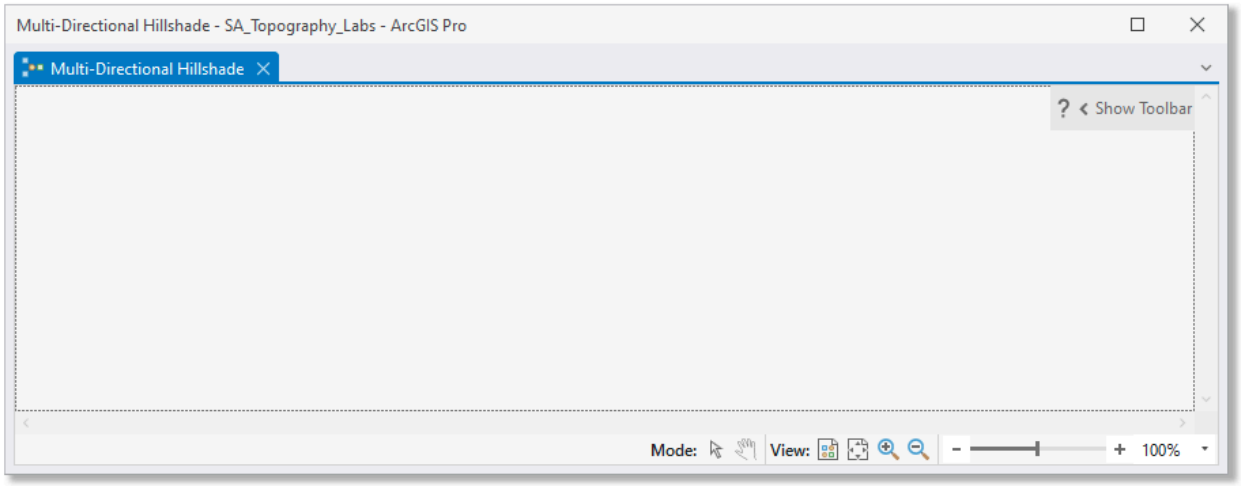
   c) Set the **Label** to "Multi-Directional Hillshade". There are no restrictions on the text you use for your label.



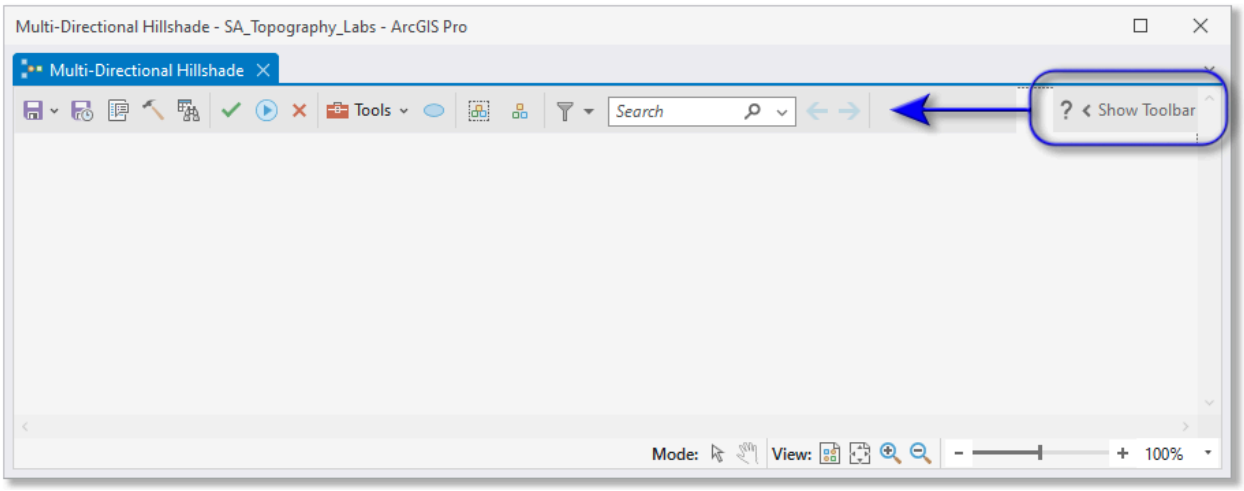
8) In the ArcGIS Pro Ribbon, click the **ModelBuilder** tab and then the **Save** icon to save your changes.



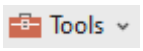
9) You should now have an empty model window that looks like the following:



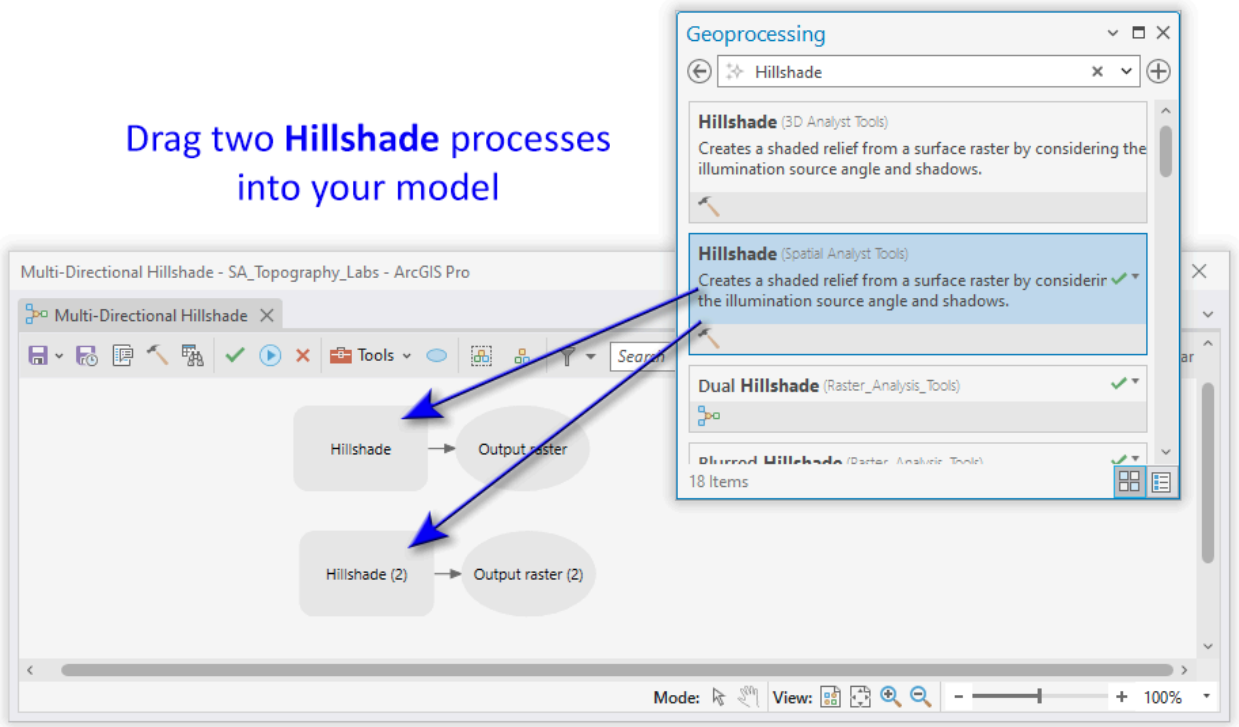
10) Click the "< Show Toolbar" to add a toolbar with handy tools in the window:



11) Add two **Hillshade** processes to your model.

a) Click the Tools icon  to open your **Geoprocessing** pane.

b) Search for **Hillshade**, then drag the Spatial Analyst version down into your model. Do this twice, so you have two processes in your model.



12) Set the parameters for your two **Hillshade** processes.

a) For the first hillshade, set the:

i) Input Raster = **DEM_10m** raster from your map.

ii) Output raster = **HillSha_DEM_1**

iii) Azimuth = **280**

iv) Altitude = **35**

v) Leave "Model Shadows" **unchecked**

vi) Set the Z-factor = **1** (this is because our DEM is a projected raster, projected into a meter-based projection, and the elevation units are in meters. Please see Lecture Videos #3 and #4 if you are unclear on why this is important).

b) For the second hillshade, set the:

i) Input Raster = **DEM_10m** raster from your map.

ii) Output raster = **HillSha_DEM_2**

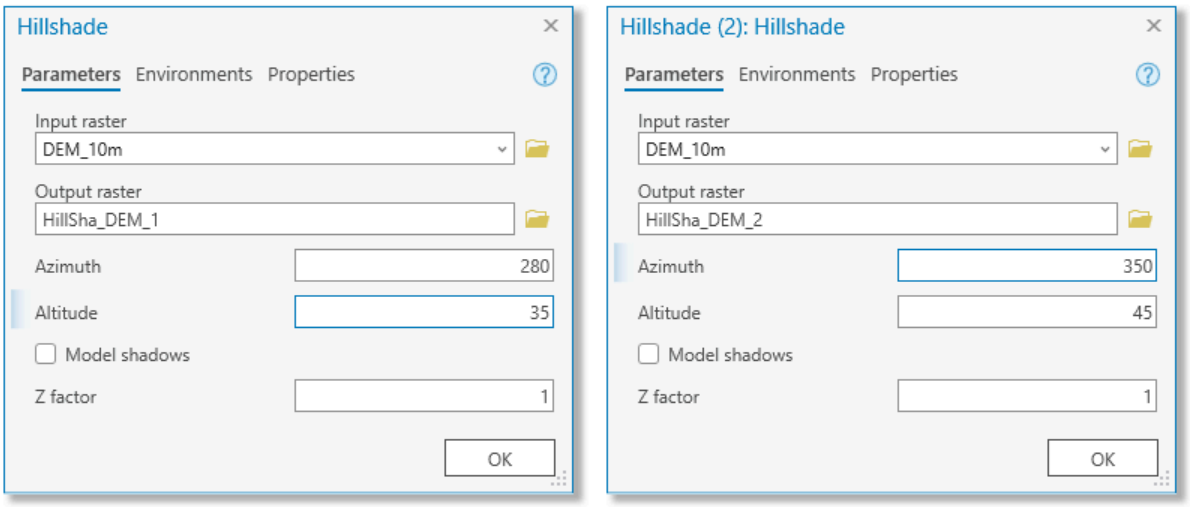
iii) Azimuth = **350**

iv) Altitude = **45**

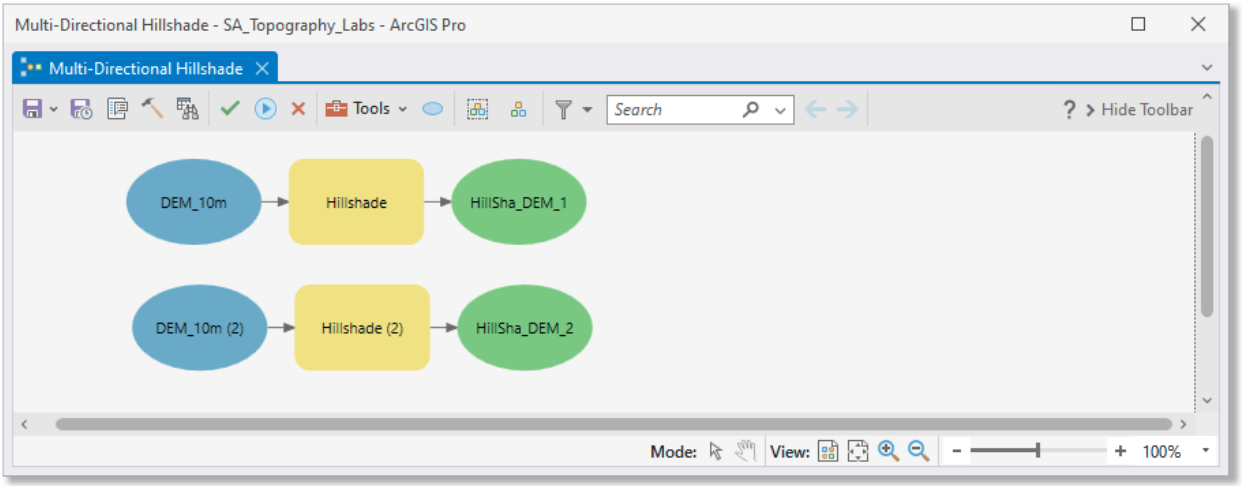
v) Leave "Model Shadows" **unchecked**

vi) Set the Z-factor = **1**

c) **Note:** For both hillshades, please feel free to try different azimuths and altitudes if you wish! You might find some combination you really like.

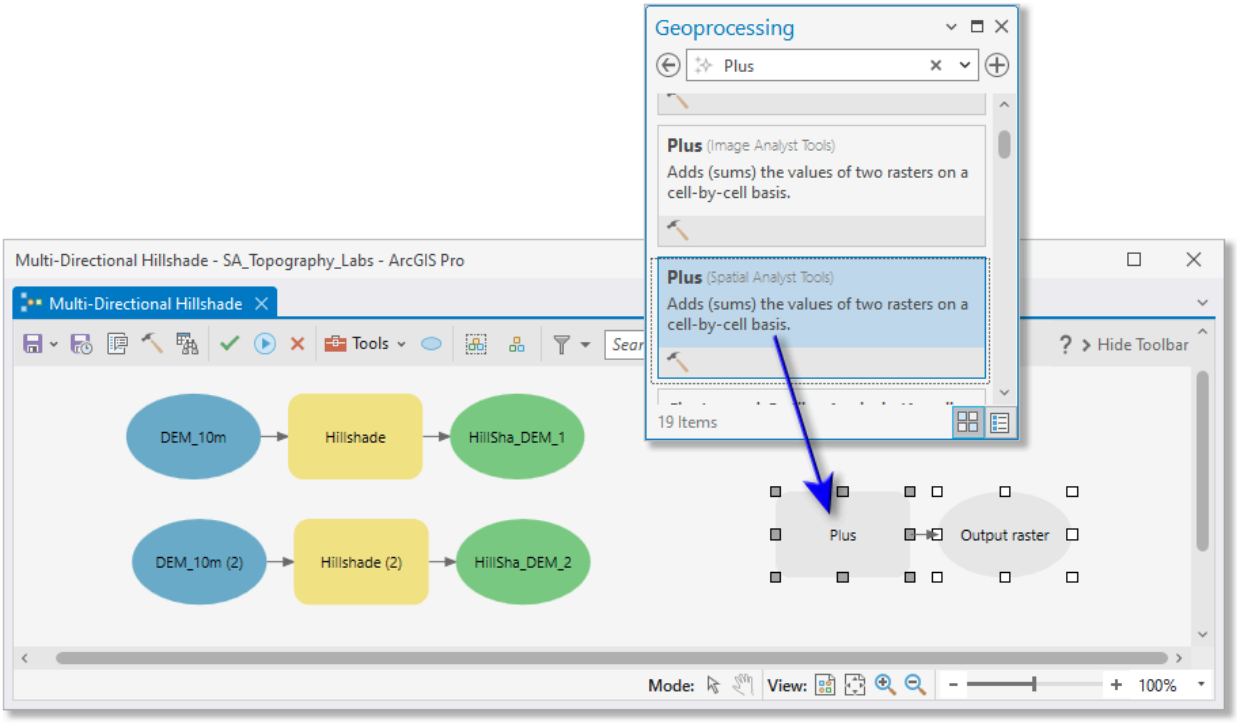


d) Both Hillshade processes should now be ready to run (but don't run them yet!)

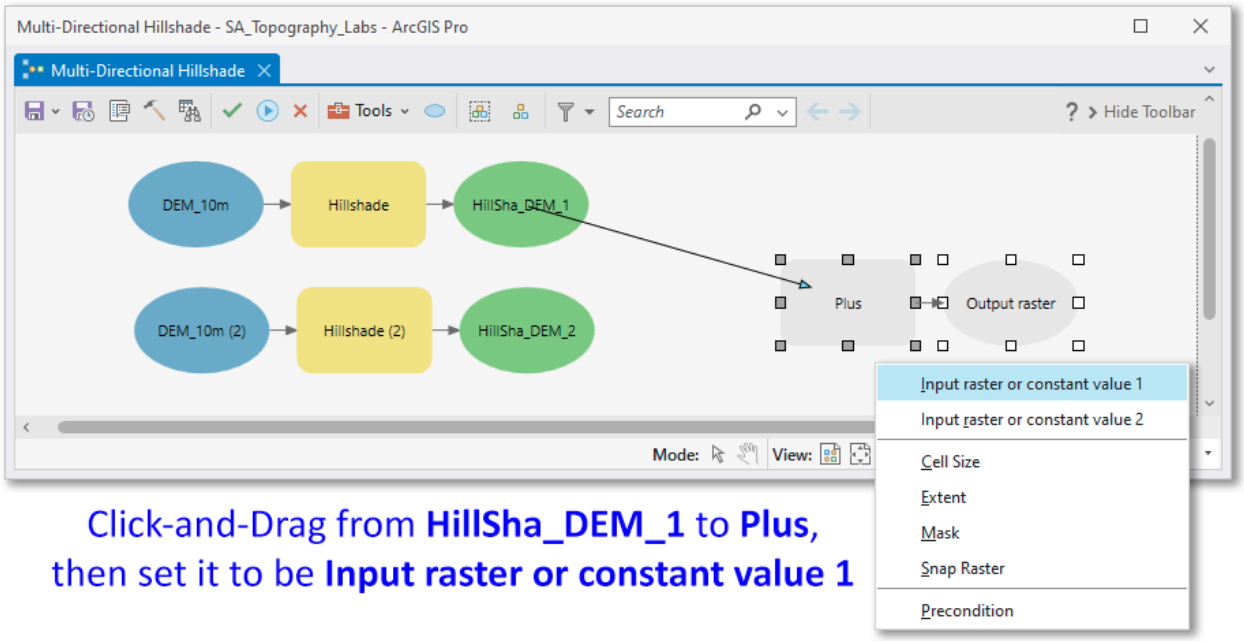


13) Add the two hillshades together:

a) Search your **Geoprocessing** pane for the tool named **Plus**, then drag the Spatial Analyst version down into your model.

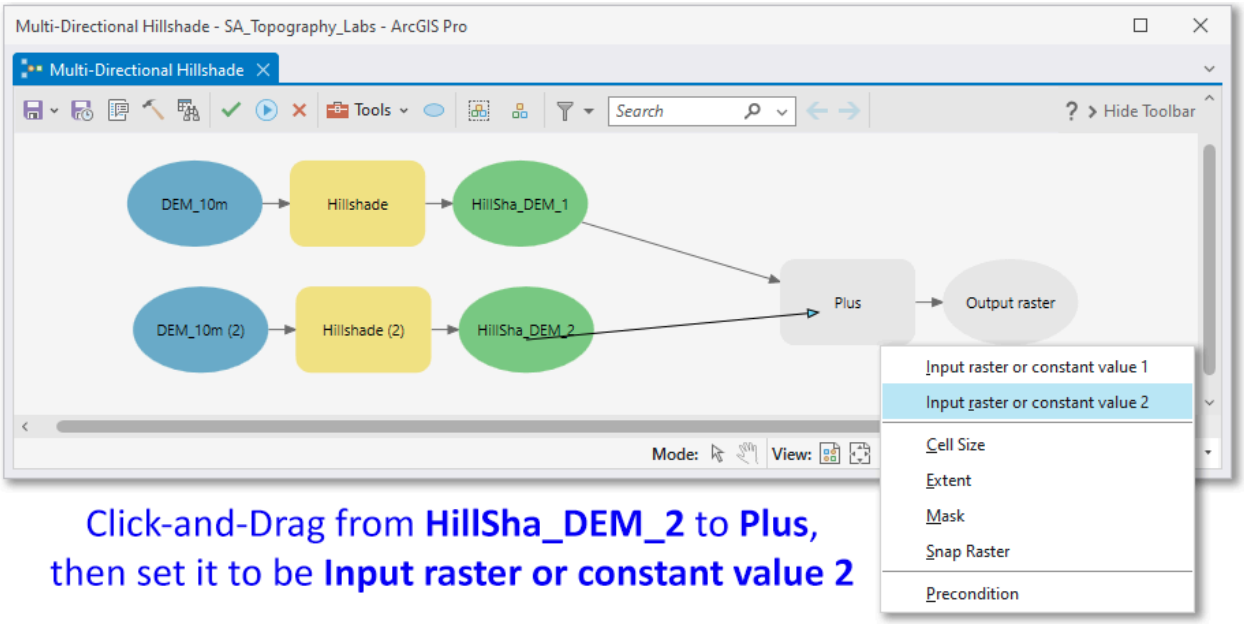


b) Draw a line from your green **Hillsha_DEM_1** oval to your new **Plus** process (just position the mouse over **Hillsha_DEM_1**, then click-and-drag over to **Plus**), and set it to be **Input raster or constant value 1**.



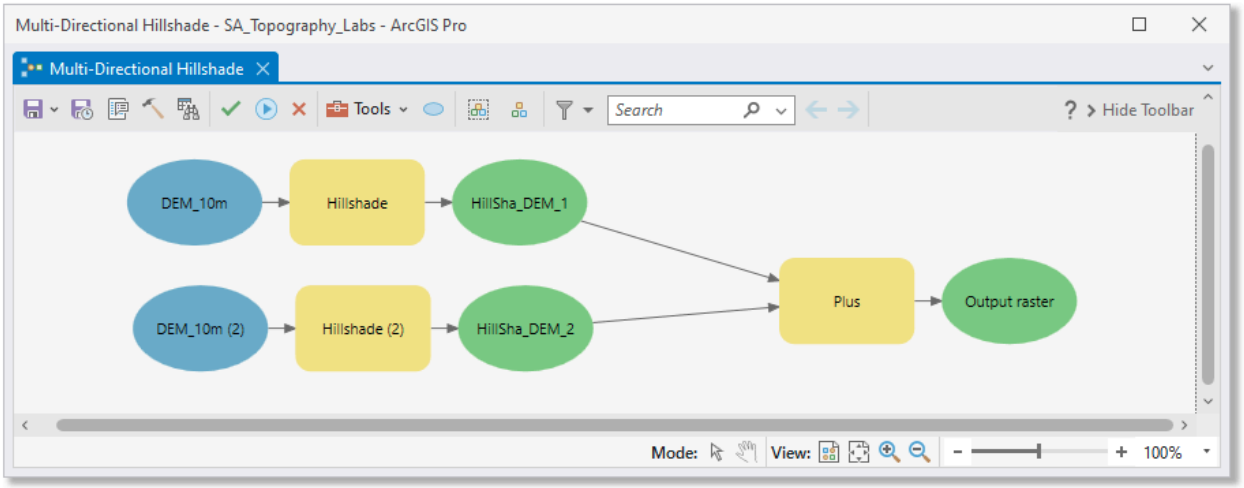
Click-and-Drag from **HillSha_DEM_1** to **Plus**, then set it to be **Input raster or constant value 1**

c) Draw a line from your green **Hillsha_DEM_2** oval to your new **Plus** process, and set it to be **Input raster or constant value 2**.

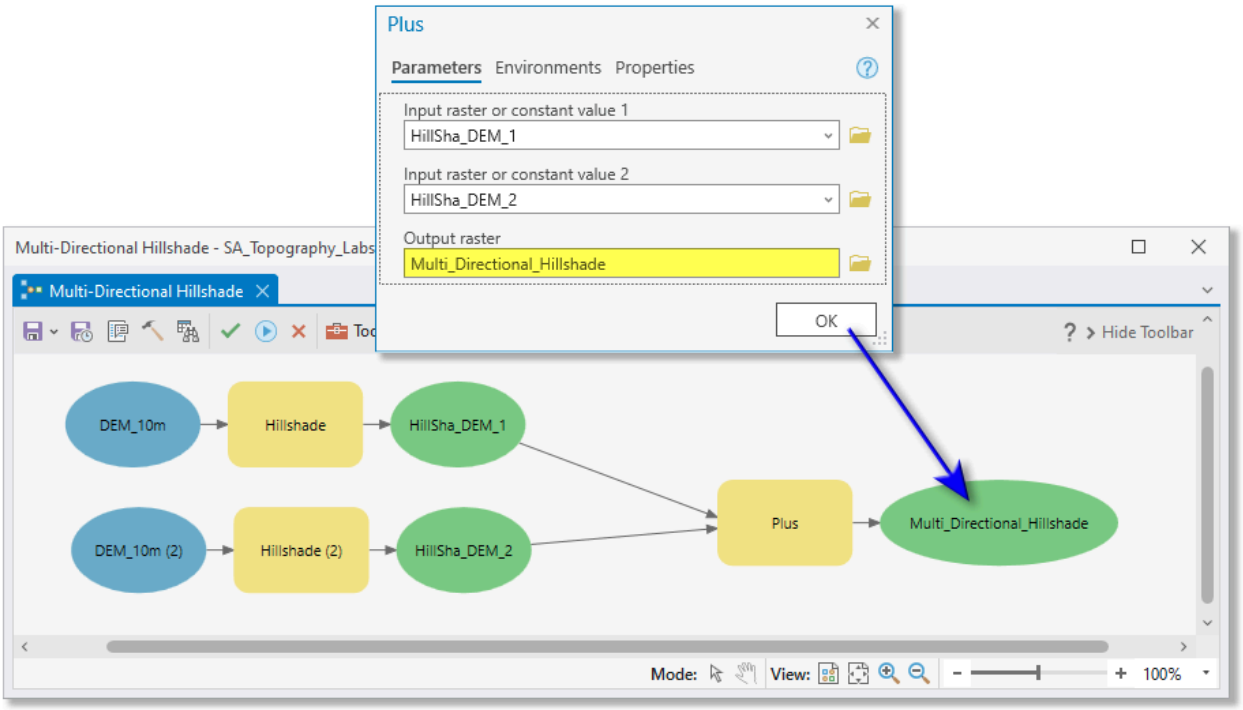


Click-and-Drag from **HillSha_DEM_2** to **Plus**, then set it to be **Input raster or constant value 2**

d) Your model will now create a hillshade based on two solar positions; one at 280° compass bearing and 35° inclination, and the second at 250° compass bearing and 45° inclination.



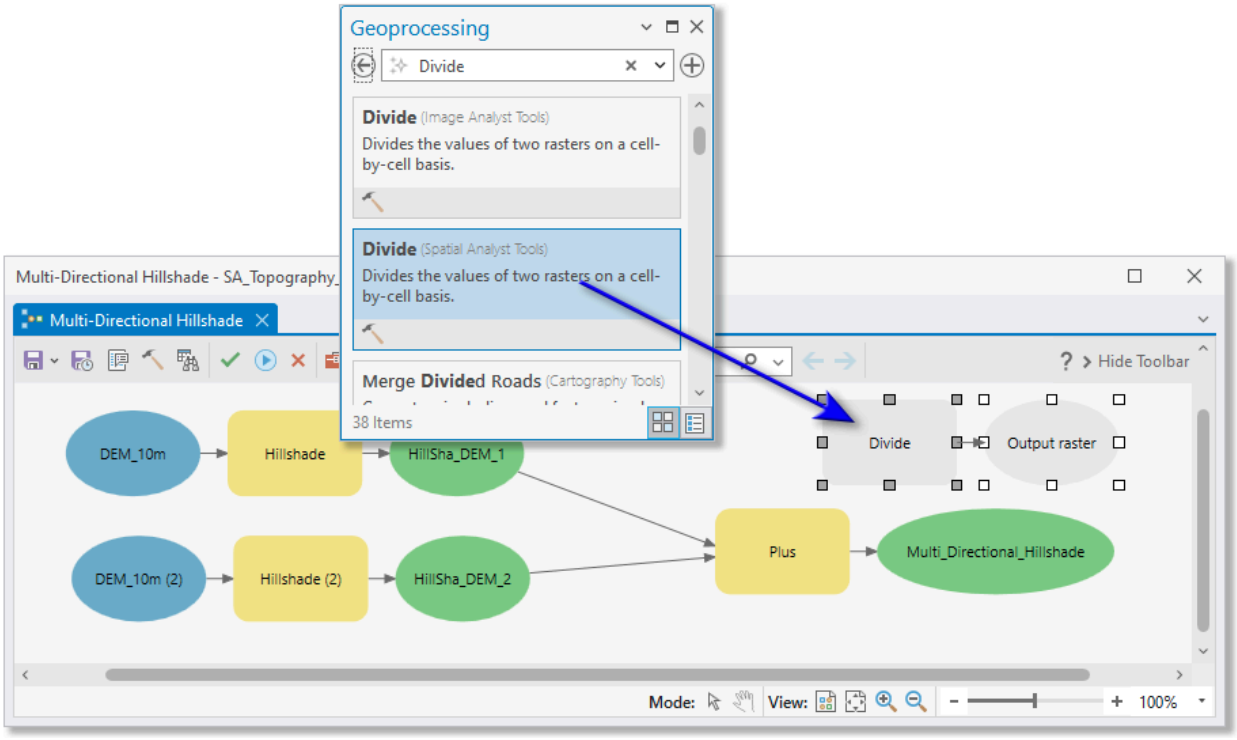
e) Double-click on your **Plus** process and change the **Output Raster** name to **Multi_Directional_Hillshade**



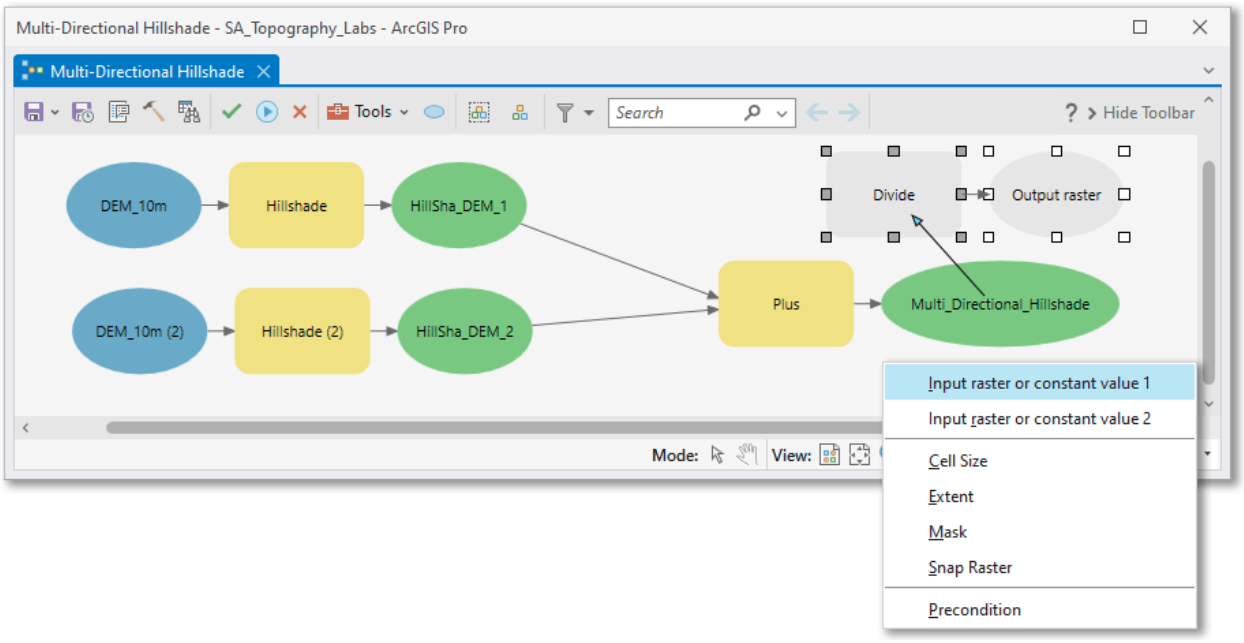
14) If you run the model now, it will produce a hillshade generated from both sun positions. Aesthetically, this is all you need to do. **If you wish to stop at this point, you can do so!** However, I will demonstrate one more step just to make the hillshade more consistent with typical hillshades.

    Remember that the standard hillshade tool produces a raster with values ranging from 0 to 255. Because we are adding two hillshades, we could potentially have values ranging from 0 to 510. Just for consistency, we'll divide this new multidirectional hillshade by 2 so the hillshade values will also range between 0 and 255.

    a) Search your **Geoprocessing** pane for the tool named **Divide**, then drag the Spatial Analyst version down into your model.



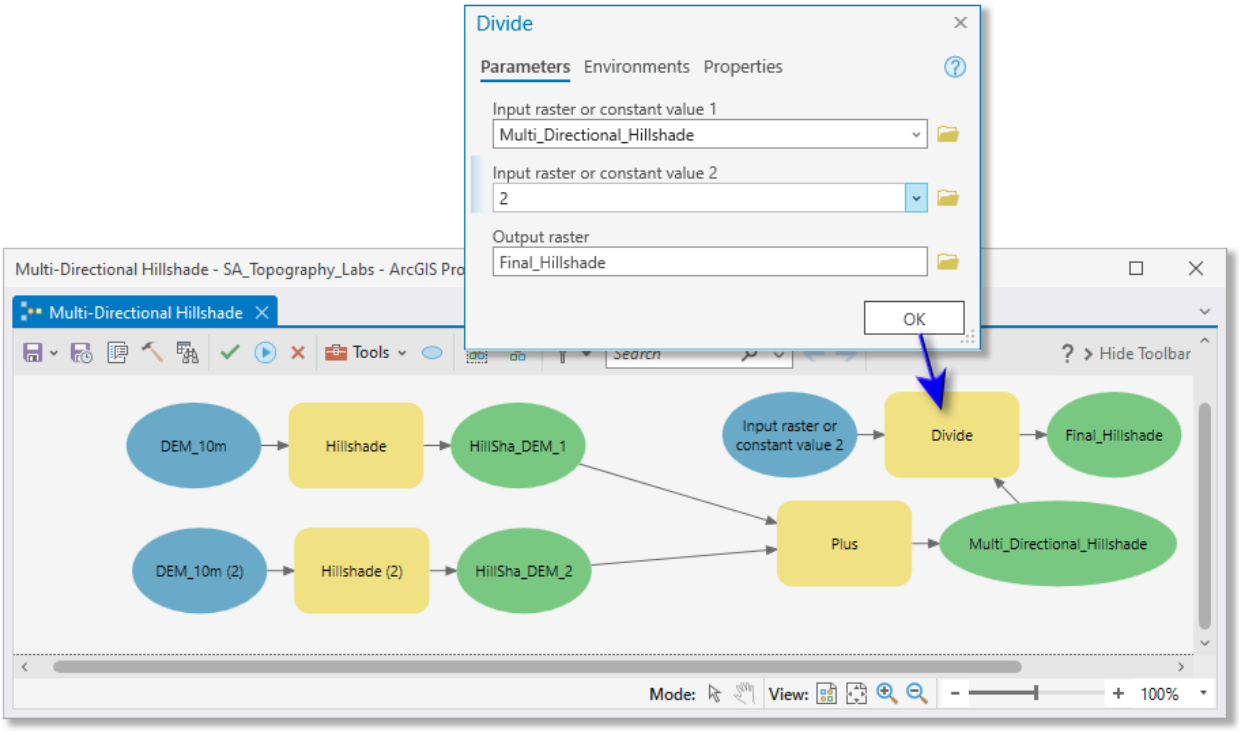
b) Draw a line from your green **Multi_Directional_Hillshade** oval to your new **Divide** process, and set it to be **Input raster or constant value 1**.



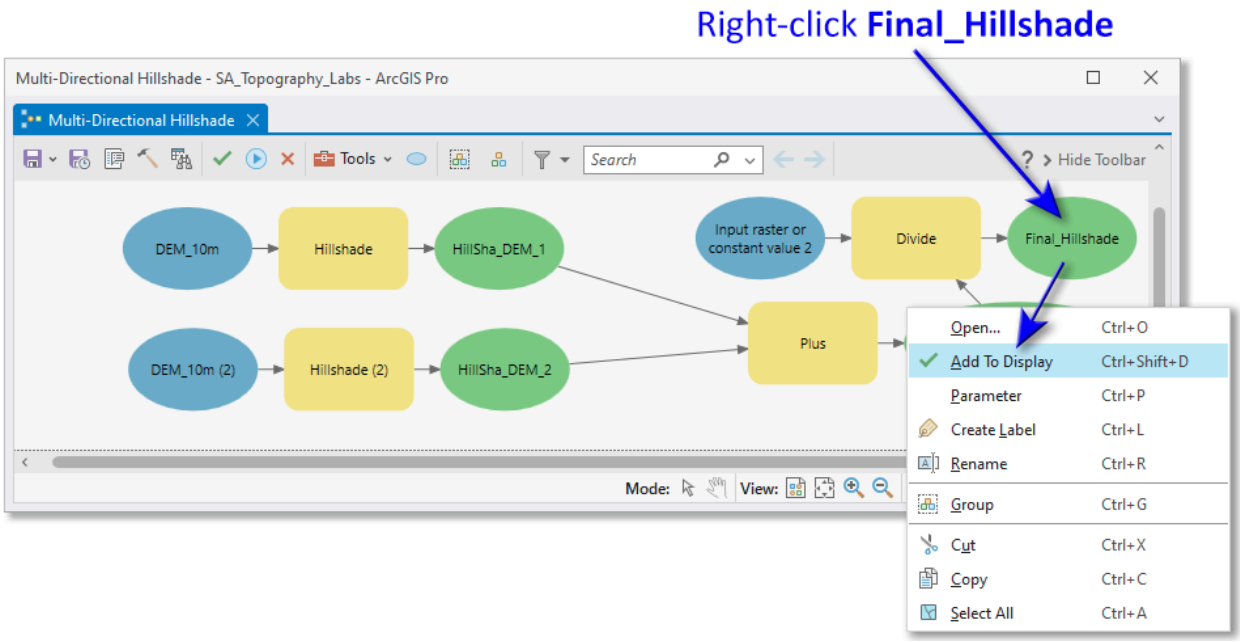
c) Double-click on your new **Divide** process and set:

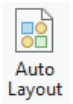
i) Input raster or constant value 2 = 2

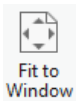
ii) Output raster = **Final_Hillshade**



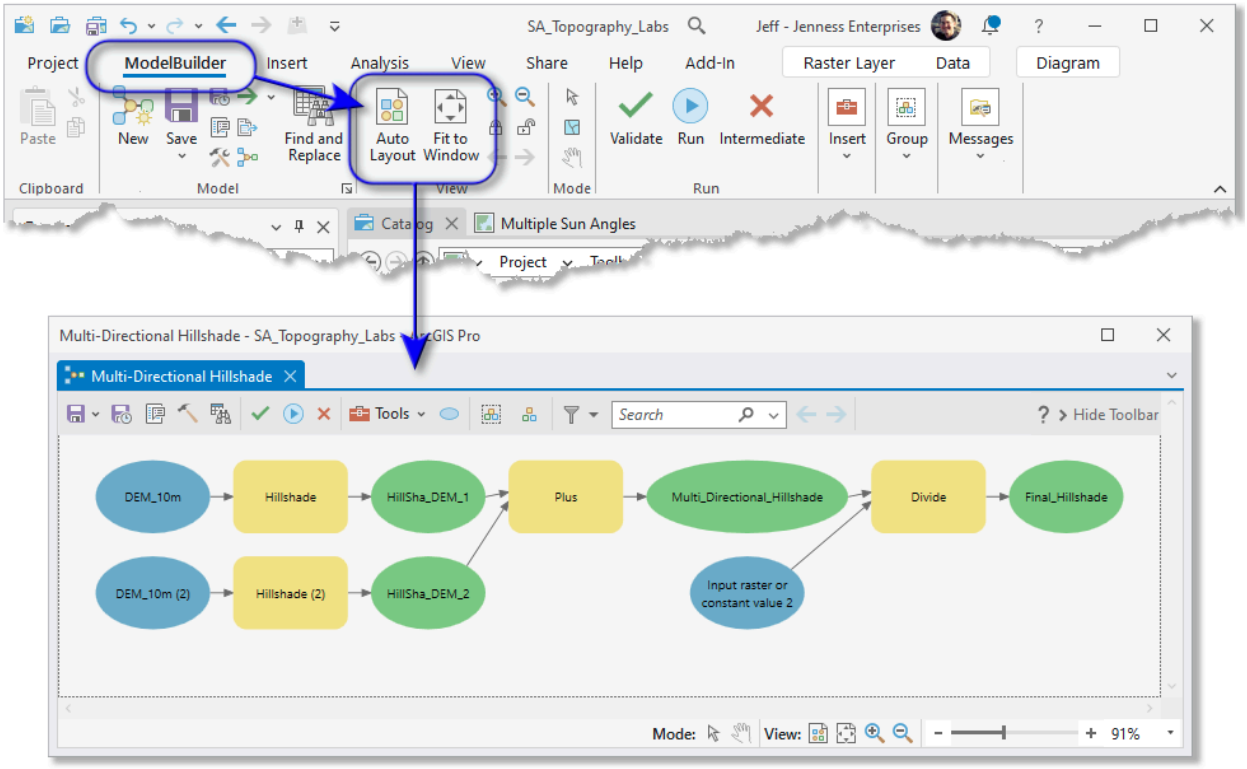
d) Right-click on your green **Final_Hillshade** oval and set it to be added to your display:



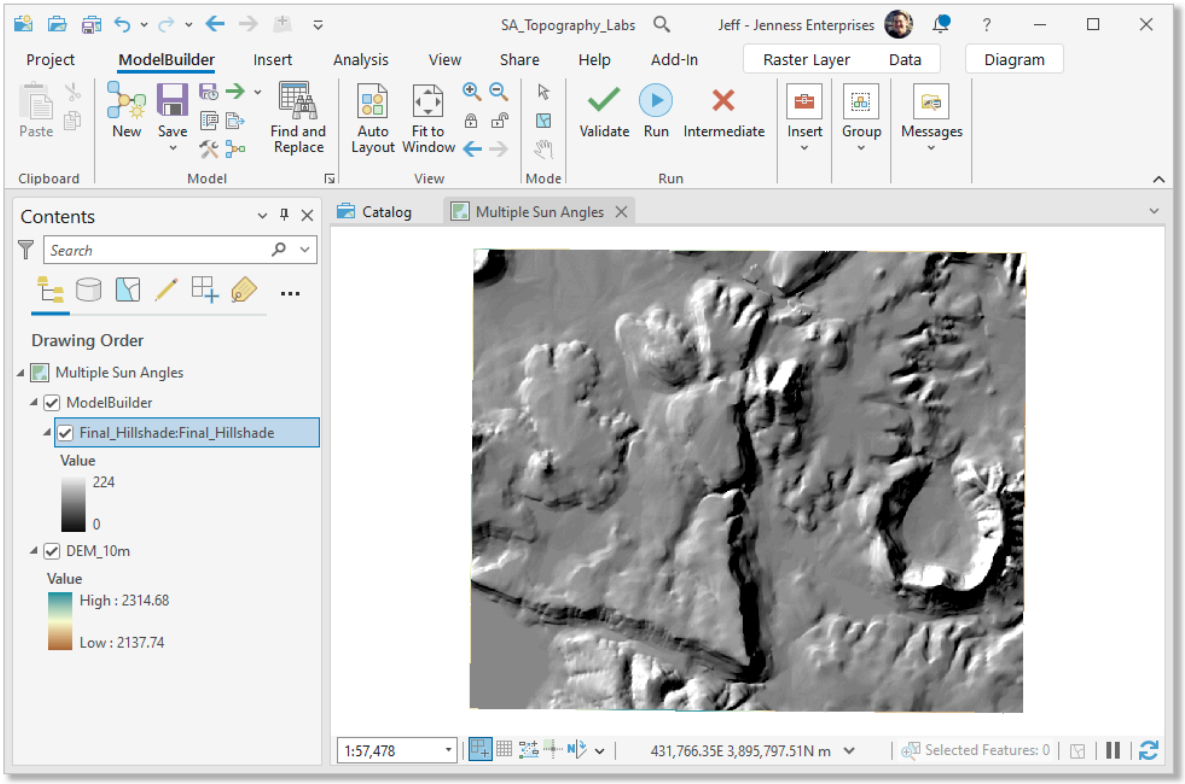
15) Just to clean up the model window a bit, go back to your ArcGIS Pro ribbon, click the **ModelBuilder** tab, then click the **Auto Layout** icon 

, and then the **Fit to Window** icon 

.

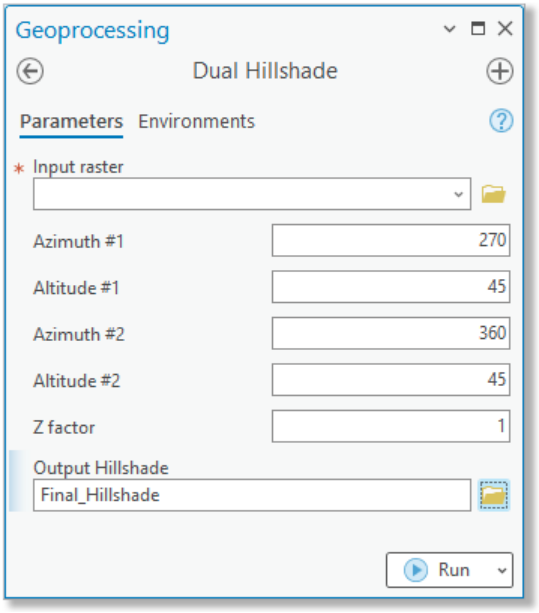


16) Your model is now ready to run. Save your edits by clicking the **Save** command, then click the **Checkmark** to validate your model, and finally the **Run** button to run it. You should get your new multi-directional hillshade added to your map.

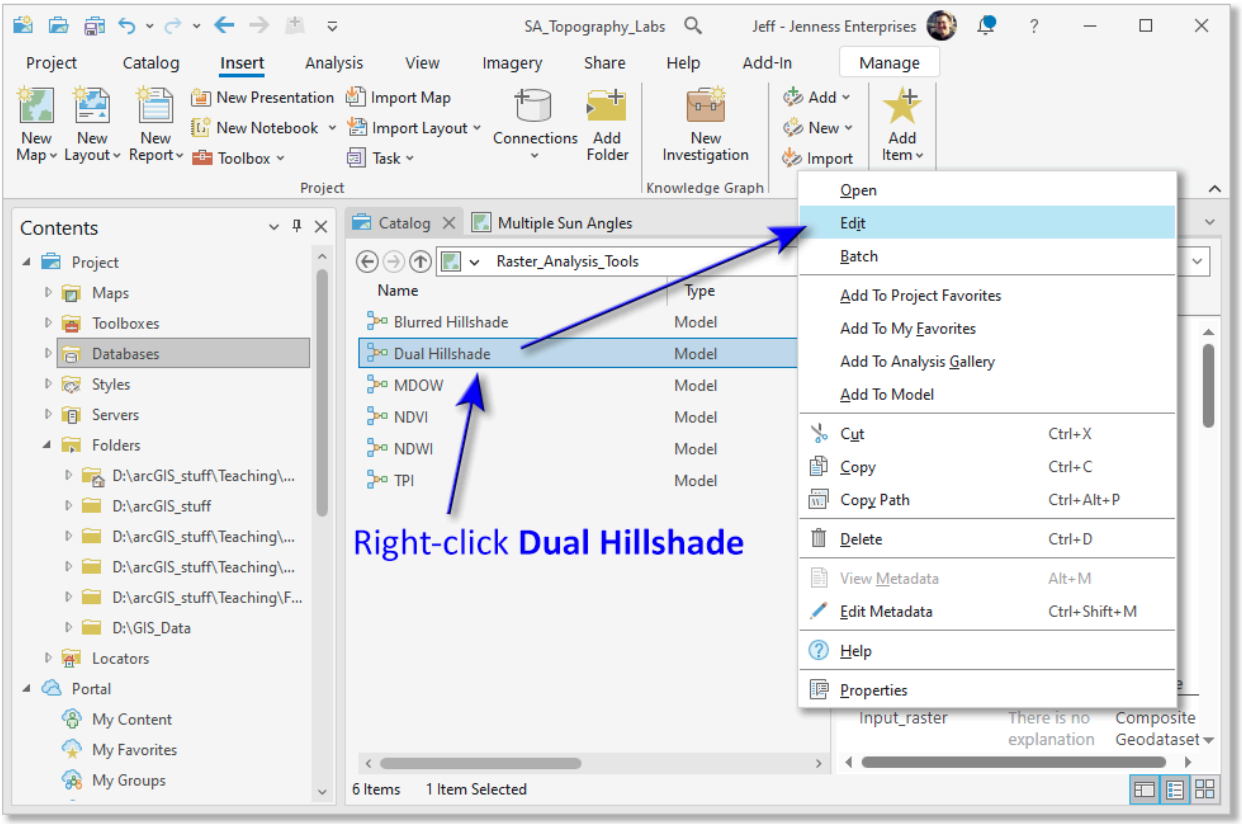


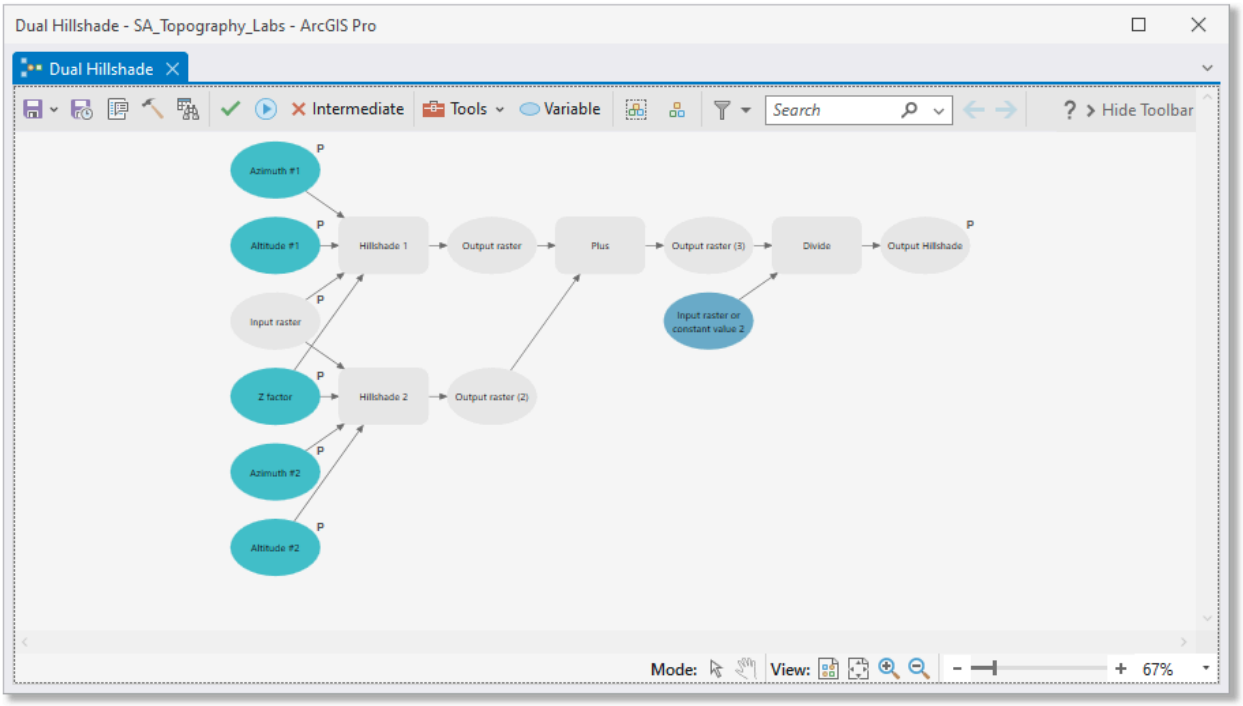
17) Finally, click the **Delete Intermediate** icon to delete the intermediate datasets created by this model (**HillSha_DEM_1**, **HillSha_DEM_2**, and **Multi_Directional_Hillshade**).

Note: The sample **Dual Hillshade** model available for download at the link above (see **For Fun** at the beginning of this lab exercise) is very similar to the exercise you just completed, except that I set several of the operating parameters to be model parameters. Doing this allows you to run the model by double-clicking on it in the toolbox and setting such parameters as the DEM, sun positions, and output dataset manually.



Setting these parameters to be model parameters makes the tool much more flexible and easier to run with different sun locations or on different data. Please take a look at that sample if you'd like to see how to set the model up to run this way. Just open the downloaded toolbox **Raster_Analysis_Tools**, right-click on the model named **Dual Hillshade** and click "Edit" to open the model window.




Dual Hillshade - SA_Topography_Labs - ArcGIS Pro
Dual Hillshade
Intermediate
Tools
Variable
Search
Hide Toolbar
Azimuth #1
Altitude #1
Hillshade 1
Output raster
Plus
Output raster (3)
Divide
Output Hillshade
Input raster
Input raster or constant value 2
Z factor
Hillshade 2
Output raster (2)
Azimuth #2
Altitude #2
Mode:
View:
67%

Exercise 12 [Optional]: Calculate the MDOW (Multidirectional Oblique Weighted) Hillshade

Objectives

- Learn to generate a hillshade using a method invented by Robert Mark with the USGS back in 1992 < https://pubs.usgs.gov/of/1992/of92-422/of92-422.pdf>. This is another example of the Swiss Method effect of using multiple sun locations for the hillshade. It creates an interesting effect, and does a better job at bringing out details in the landscape surface than a simple hillshade. To me, it make the landscape look kind of glossy somehow.

- Practice **ModelBuilder**, because there are too many steps here to try and do it as a series of individual tools.

Data used

- Raster layer file **DEM_10m.lyr**, in folder **..\Class_GIS_Data\Raster_Functions\...** This layer file references a raster dataset named **DEM_10m** in the file geodatabase **Lab_Data.gdb**, and is an approximately 10m resolution Digital Elevation Model (DEM) showing elevation (in meters) within the general extent of the Semester D Management Unit in the Centennial Forest.

- Optionally, any additional data or online basemap layers you prefer, such as topo maps or imagery. These won't be used in the analysis but they are often useful to help orient yourself or see the analysis within a larger landscape context.

For Homework

There is no homework due from this lab exercise.

For Fun

I have created a model named **MDOW** that will calculate the MDOW hillshade from a DEM, similar to what you'll do in this lab exercise. I've also added models that do a few other things we describe in these labs, that you are welcome to download and play with. The toolbox is saved in a geodatabase you can download from here:

https://drive.google.com/file/d/1MDMLqwZolsCLVpKiy9i75aQceRI-gIPw/view?usp=sharing

Exercise

Based on the DEM (digital elevation model), you will generate a new hillshade raster based on Robert Mark's Multidirectional Oblique Weighted method (Mark 1992). As with the multidirectional hillshade you saw in Lab Exercise 11 (p.), this MDOW method can sometimes help to bring out subtle variations in the landscape that are washed out in a traditional hillshade. For details on how this method works, please review Lecture Video 3 in this module, "More Analysis of Topographic Surfaces", at https://youtu.be/shU_m4T3XcQ.

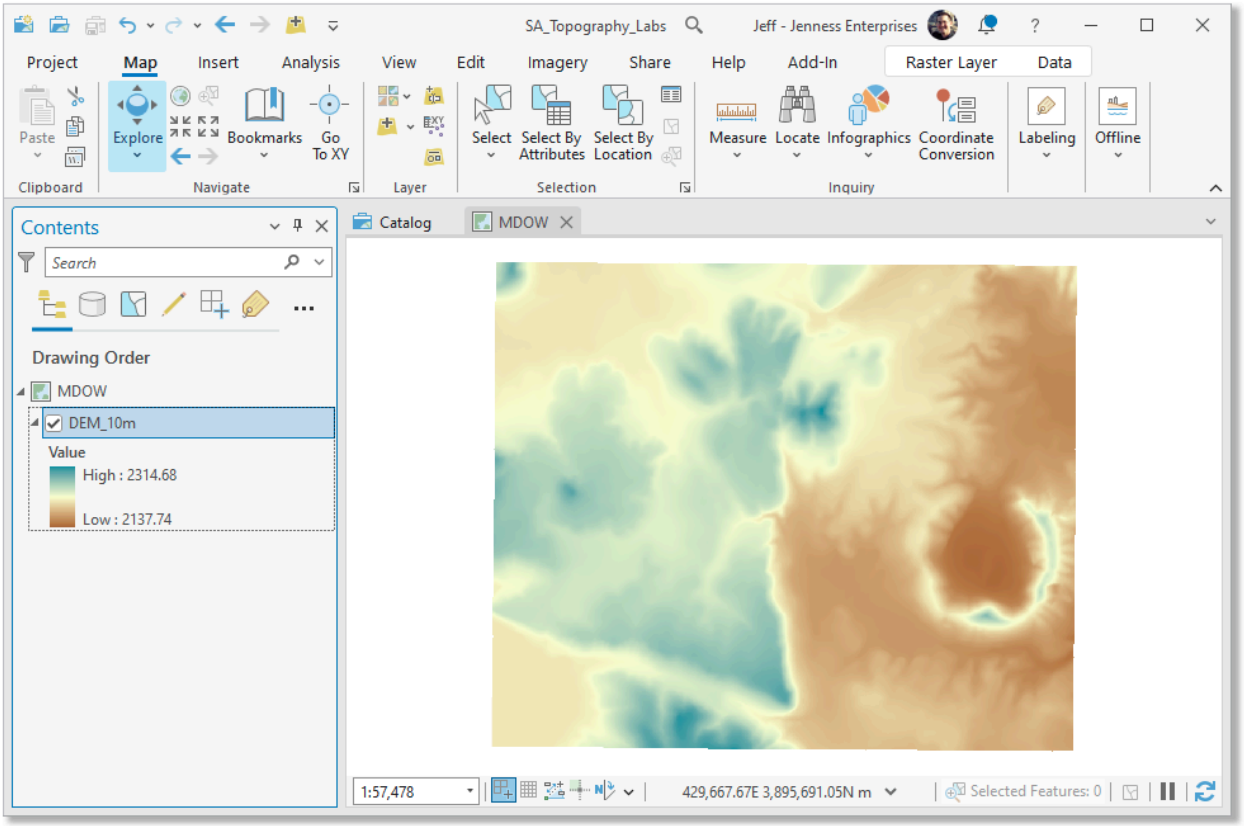
Mark, R. K. 1992. A multidirectional, oblique-weighted, shaded-relief image of the Island of Hawaii. US Dept. of the Interior, US Geological Survey, https://pubs.usgs.gov/of/1992/of92-422/

You will also see how to construct the steps in ModelBuilder, so you can easily apply the steps to different DEMs in the future.

Take a look back at Lab Exercise 3 (p.) if you would like to review the discussion on hillshades from geographic (Latitude/Longitude) DEMs, and for resolving differences between elevation units and X/Y coordinate system units.

Prepare your Map and Data:

1) Open a blank map in ArcGIS Pro. If you still have ArcGIS Pro open from the previous exercise, you may simply insert a new map. In the illustrations below, I have named the map "MDOW".
2) Make sure you have the **Spatial Analyst** extension turned on. See Exercise 1 if you have questions on this.
3) If it is not already present, then load the **Layer** file **DEM_10m.lyr** from the folder **..\Class_GIS_Data\Raster_Functions\...** as you did in Exercise 1.
4) If you loaded the Layer file, you should see the following.

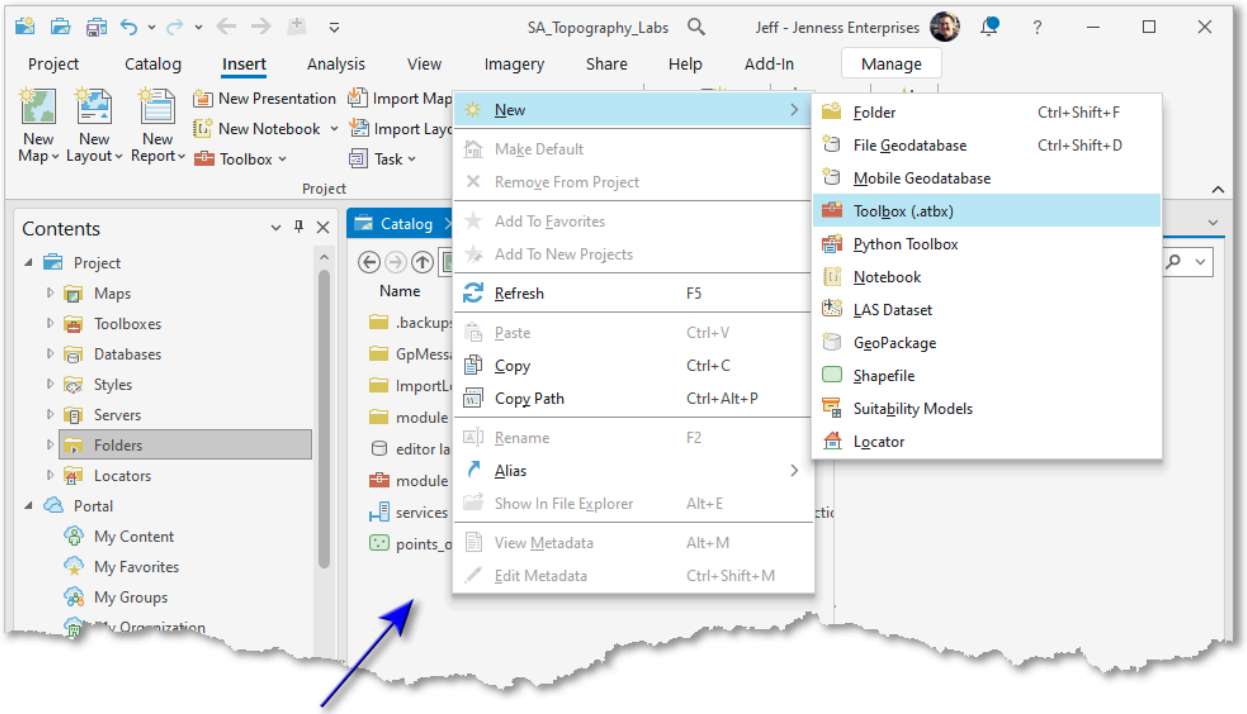


Prepare your toolbox:

This exercise will construct a model which will let you easily run this process again in the future. To do this we will need to have a toolbox available to hold the model. ArcGIS Pro models have to be stored in toolboxes.

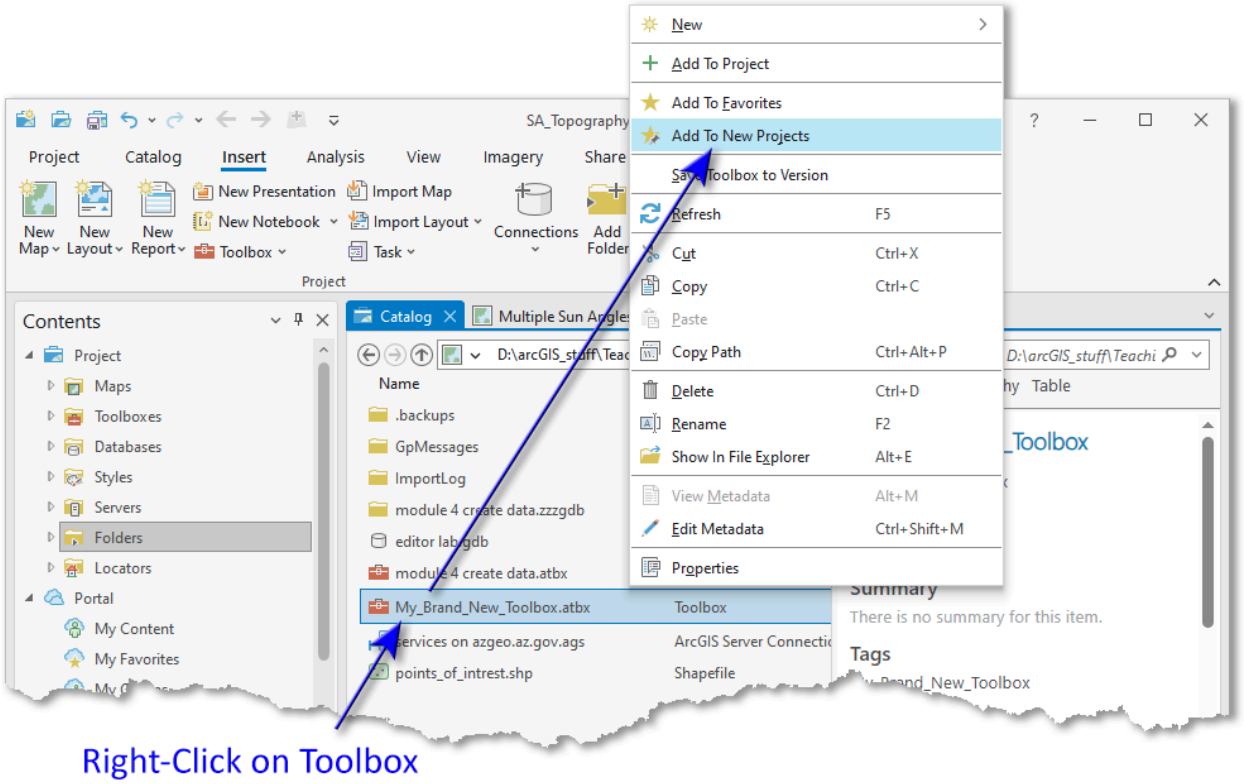
Your ArcGIS Pro project comes with its own toolbox, which we will use in this lab exercise.

If you wish, though, please feel free to create a new toolbox. It's easy to do. Just use your Catalog view to navigate to either a folder or geodatabase where you want to create it, then click "New" and then "Toolbox":

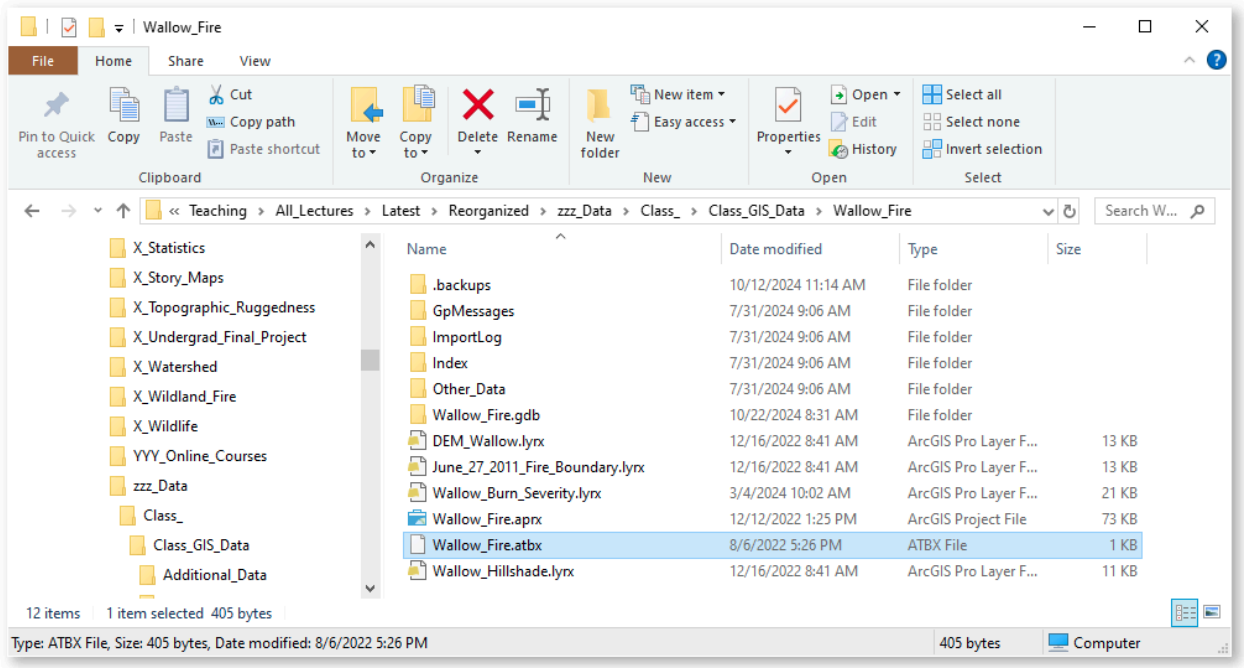


Right-Click in Folder or Geodatabase, then click “New”, then “Toolbox”

And remember that, regardless of whether you create a new toolbox or use the current ArcGIS Pro Project toolbox, you can always access that toolbox from new ArcGIS Pro projects. If you have a toolbox you want to always be available in any new ArcGIS Pro project you create, just right-click on it in Catalog view, and choose “Add to New Projects”:

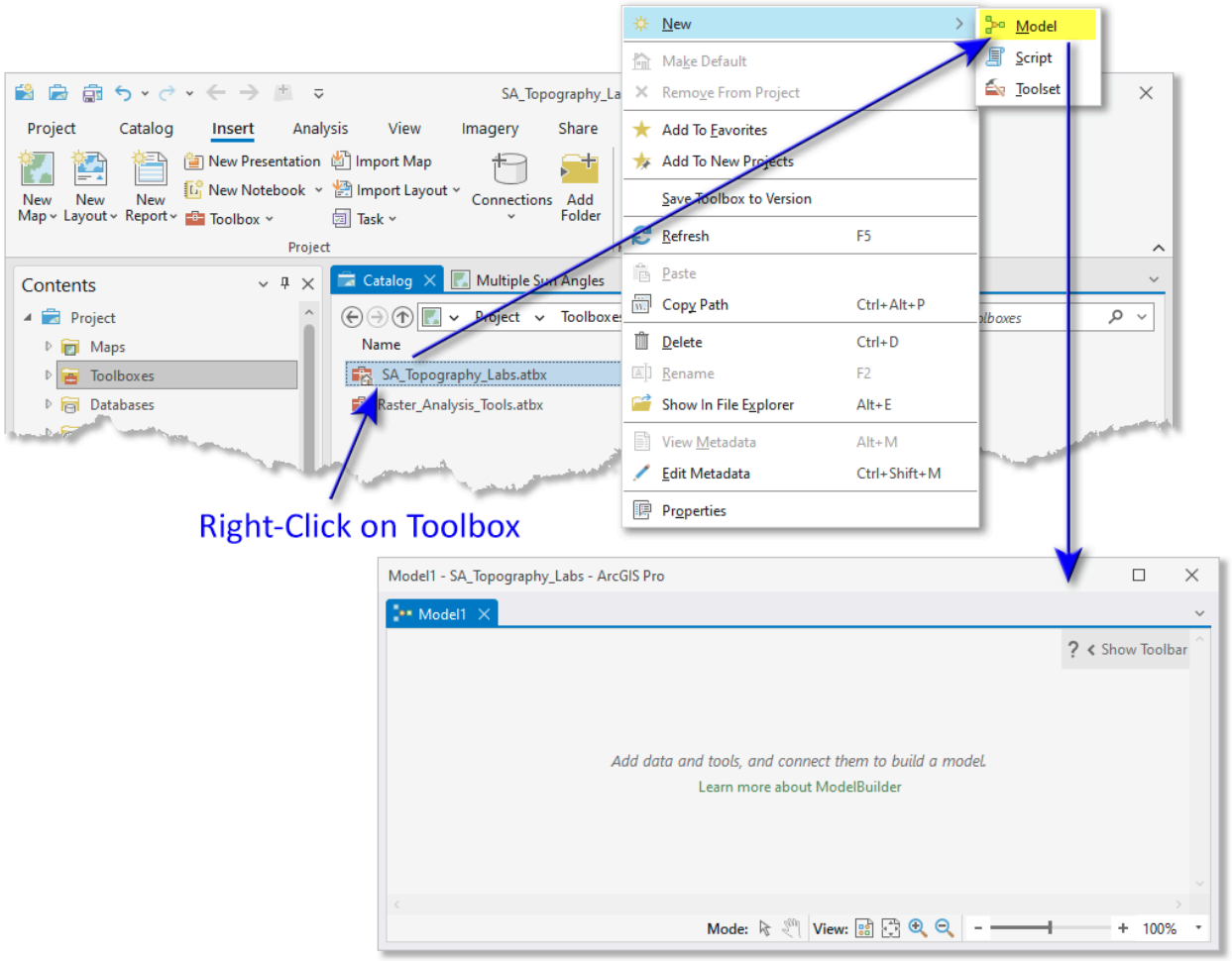


And you can easily share ArcGIS Pro toolboxes with colleagues simply by sending them the ATBX file:



Create the Model:

5) Right-click on your preferred toolbox, click “New”, then “Model”

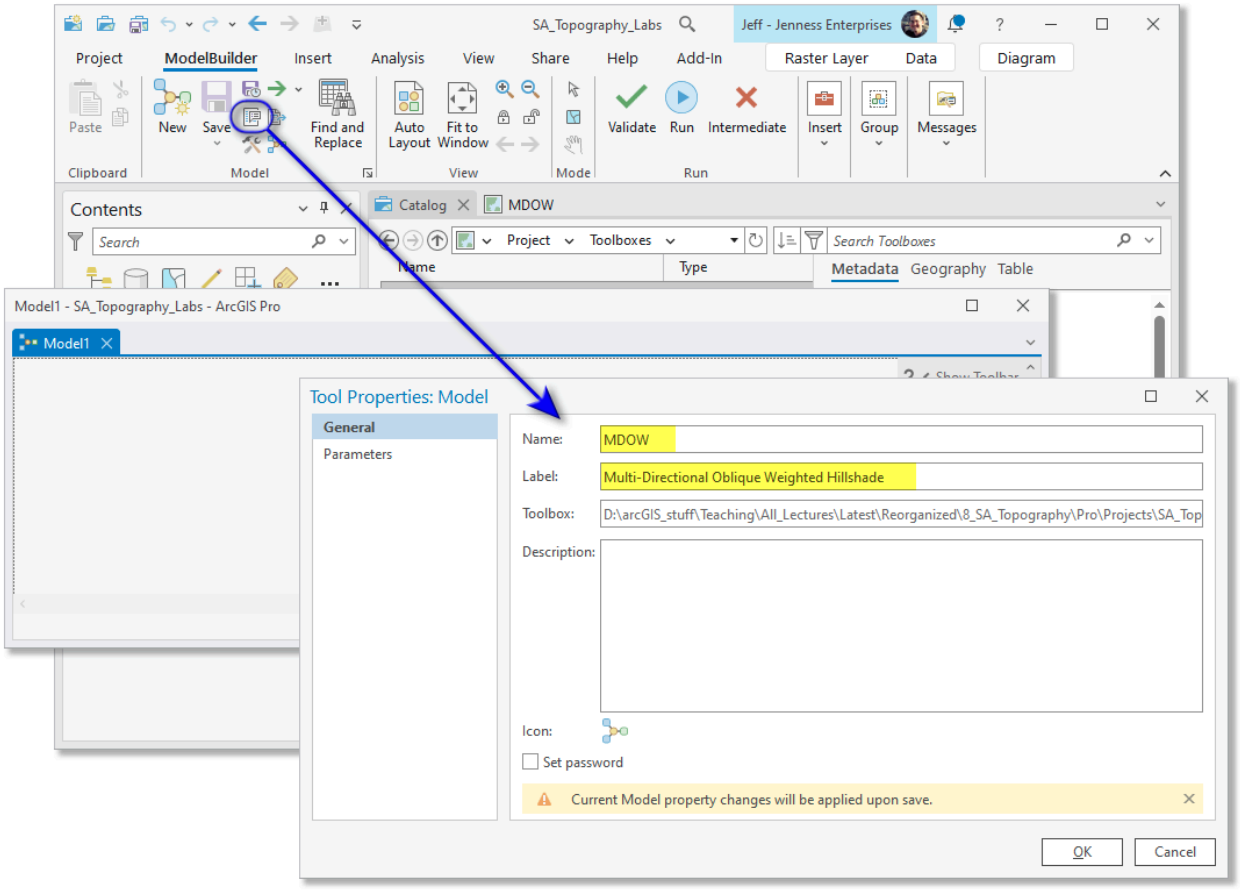


6) Change the Name and Label of your model.

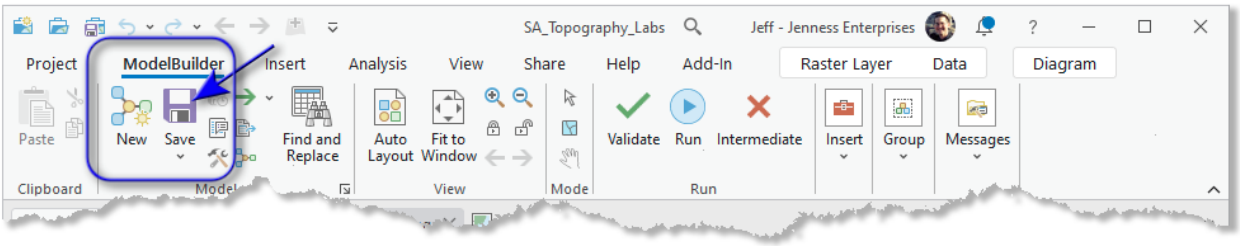
   a) In the ArcGIS Pro Ribbon, click the "ModelBuilder" tab, then the Properties icon  to open the Tool Properties window.

   b) Set the **Name** to "MDOW". Note that the name cannot have any non-alphanumeric characters in it, so no spaces, periods or underscores.

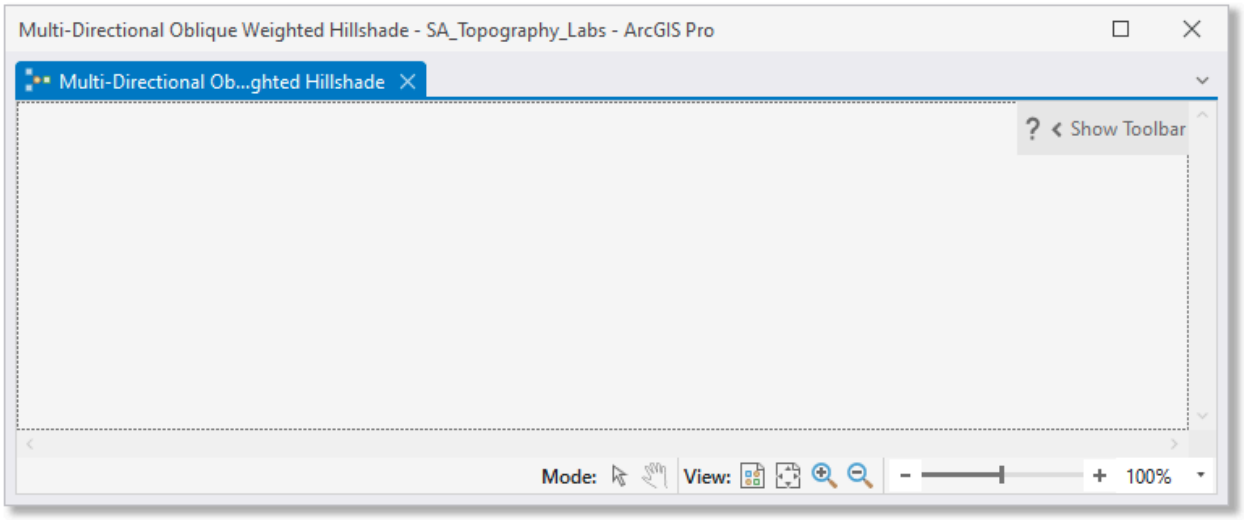
   c) Set the **Label** to "Multi-Directional Oblique Weighted Hillshade". There are no restrictions on the text you use for your label.



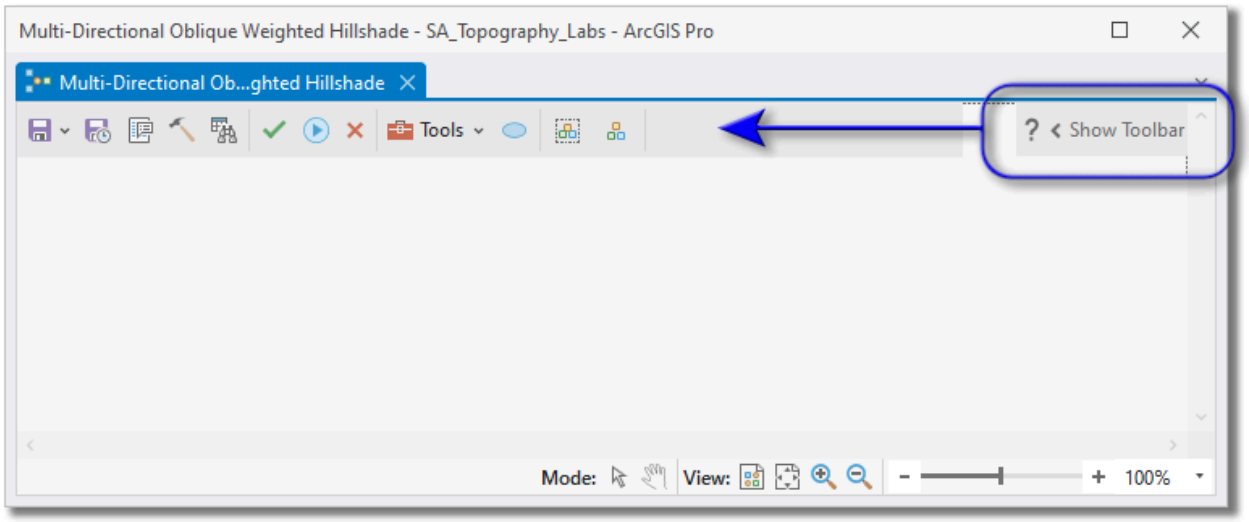
7) In the ArcGIS Pro Ribbon, click the **ModelBuilder** tab and then the **Save** icon to save your changes.



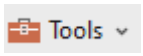
8) You should now have an empty model window that looks like the following:



9) Click the "< Show Toolbar" to add a toolbar with handy tools in the window:

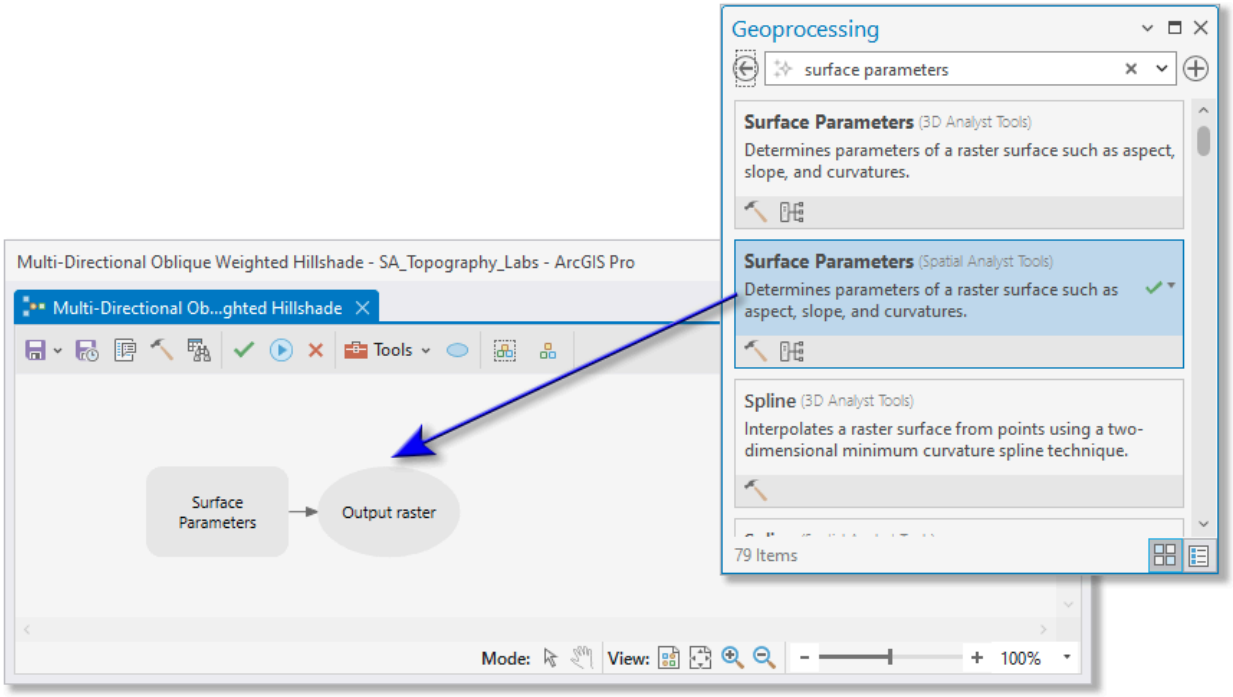


10) The MDOW Hillshade is calculated from 4 normal hillshades calculated from 4 different directions, where each normal hillshade is weighted according to how much the aspect of the landscape deviates from that direction. So let's start by adding the **Surface Parameters** process and set it to calculate aspect from your DEM.

   a) Click the Tools dropdown list 

to open your **Geoprocessing** pane.

   b) Search for **Surface Parameters**, then drag the Spatial Analyst version down into your model.



c) Double-click the **Surface Parameters** process in your model window to open it, and set the parameters as follows:

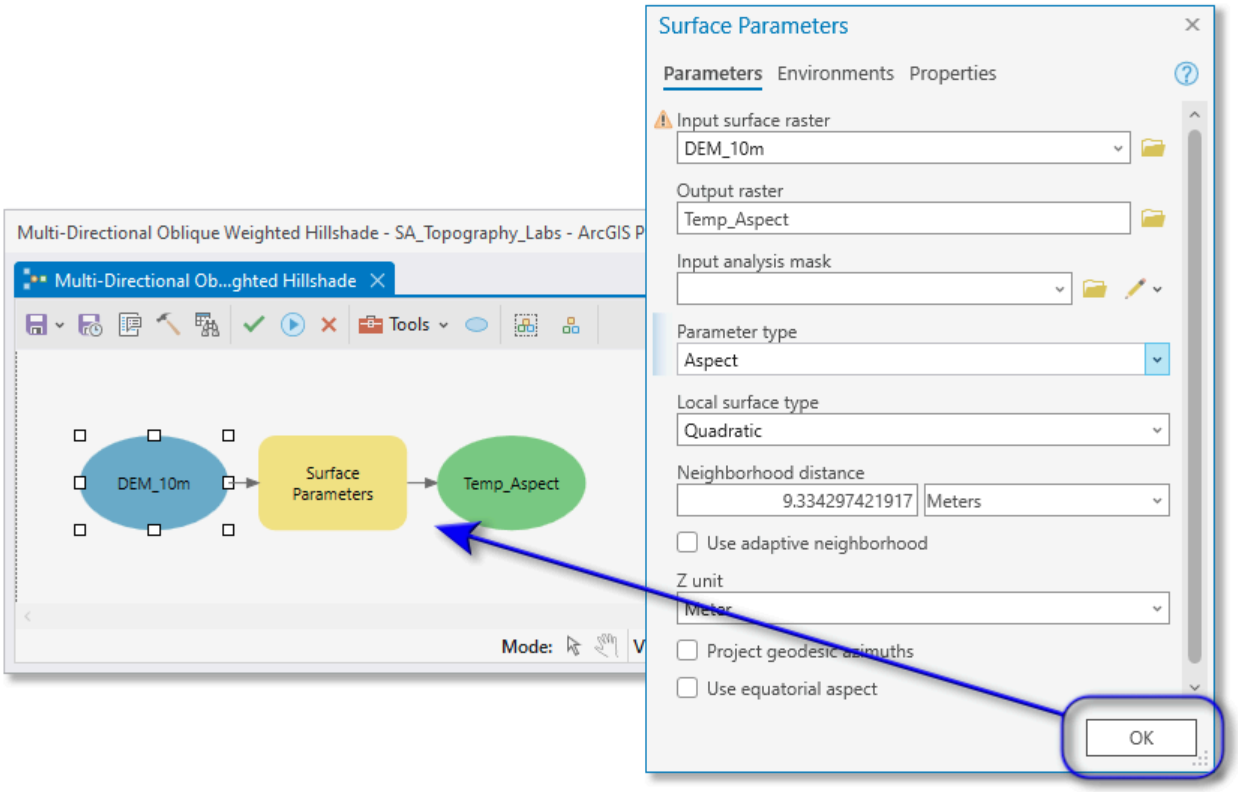
   i) *Input surface raster* = **DEM_10m**

   ii) *Output raster* = **Temp_Aspect**

   iii) Leave *Input analysis mask* blank.

   iv) Set *Parameter Type* **= Aspect**

   v) Leave all remaining parameters as their default values



11) The model will start to become complicated now. We will follow the same general strategy for each of our 4 directions, so we can build out a string of tools to do the strategy once, then copy-and-paste it 3 times and make minor edits to each copy.

    Our 4 directions will be built around a general MDOW direction of 315°. The 4 directions will be 247.5°, 292.5° 337.5° and 22.5°. The general strategy is as follows:

    a) Use the **Minus** tool to generate a separate raster for each direction showing how much aspect deviates from that direction.

    b) Use the **Times** tool to convert that "Deviation" raster to radians

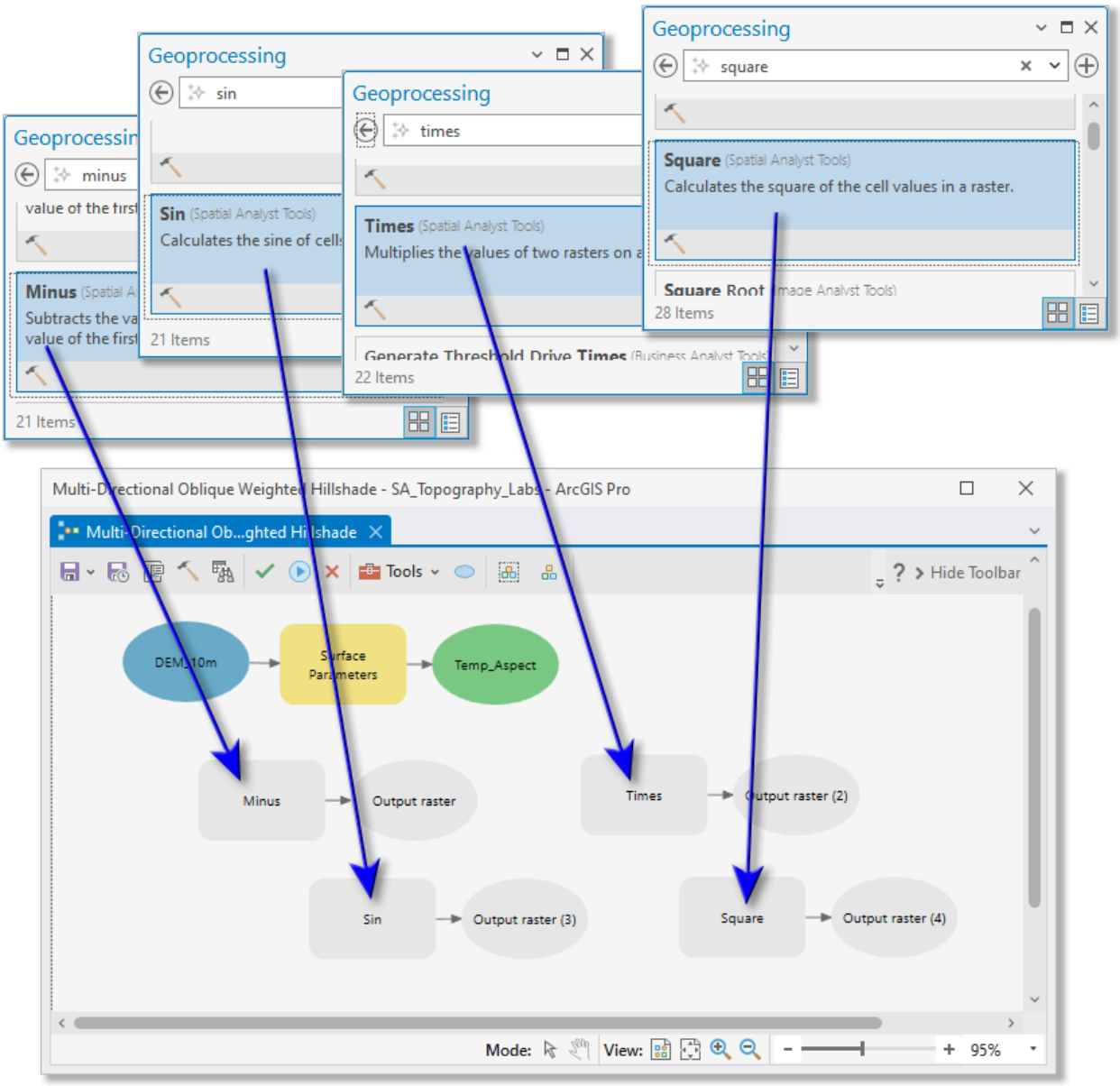
    c) Use the **Sin** and **Square** tools to calculate the Sine^2 of that "Deviation in Radians" raster, which we will use as a weighting factor

    d) Use the **Hillshade** tool to calculate a hillshade in that direction

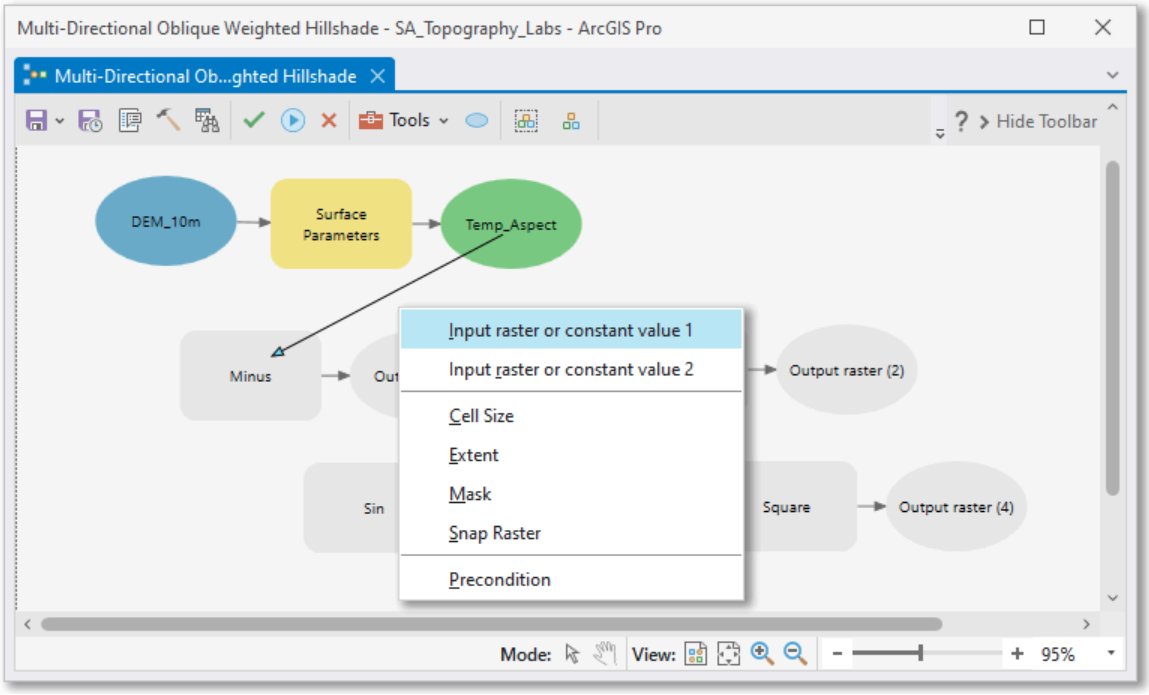
    e) Use the **Times** tool to multiply the hillshade by the Sine^2 weighting raster

    f) Use the **Raster Calculator** tool to add the 4 weighted hillshades together, and then divide the sum raster by 2.

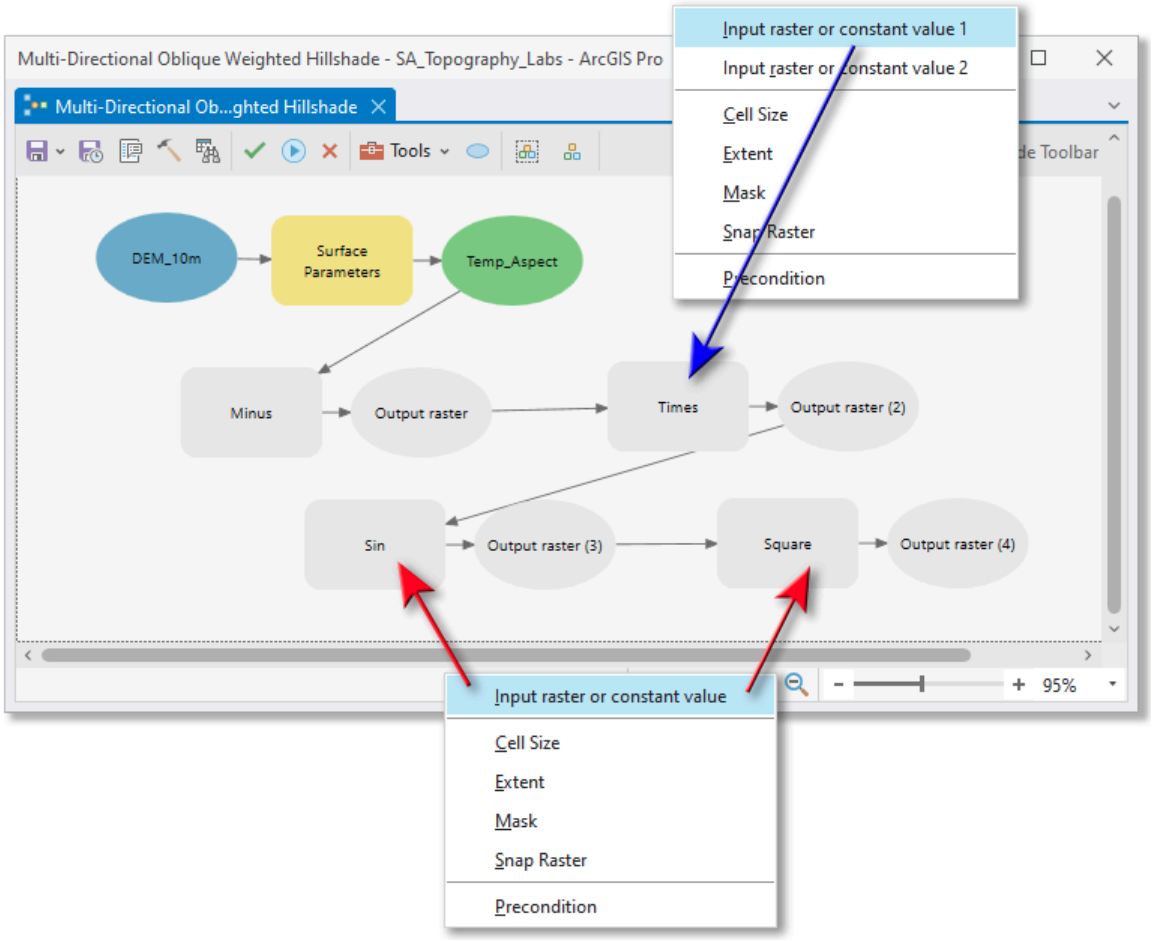
12) First add the "Minus", "Times", "Sin" and "Square" tools to your model:



13) Draw a line to connect the **Temp_Aspect** green oval to the **Minus** process (just position the mouse over the green **Temp_Aspect** oval, then click-and-drag to the **Minus** process) and set it to be **Input raster or constant value 1**.



14) Draw additional lines connecting the output raster for **Minus** to the **Times** process (again setting it as **Input raster or constant value 1**), and then a line connecting the output raster for **Times** to the **Sin** process, and then the output from **Sin** to the **Square** process (in both cases setting it to **Input raster or constant value**).

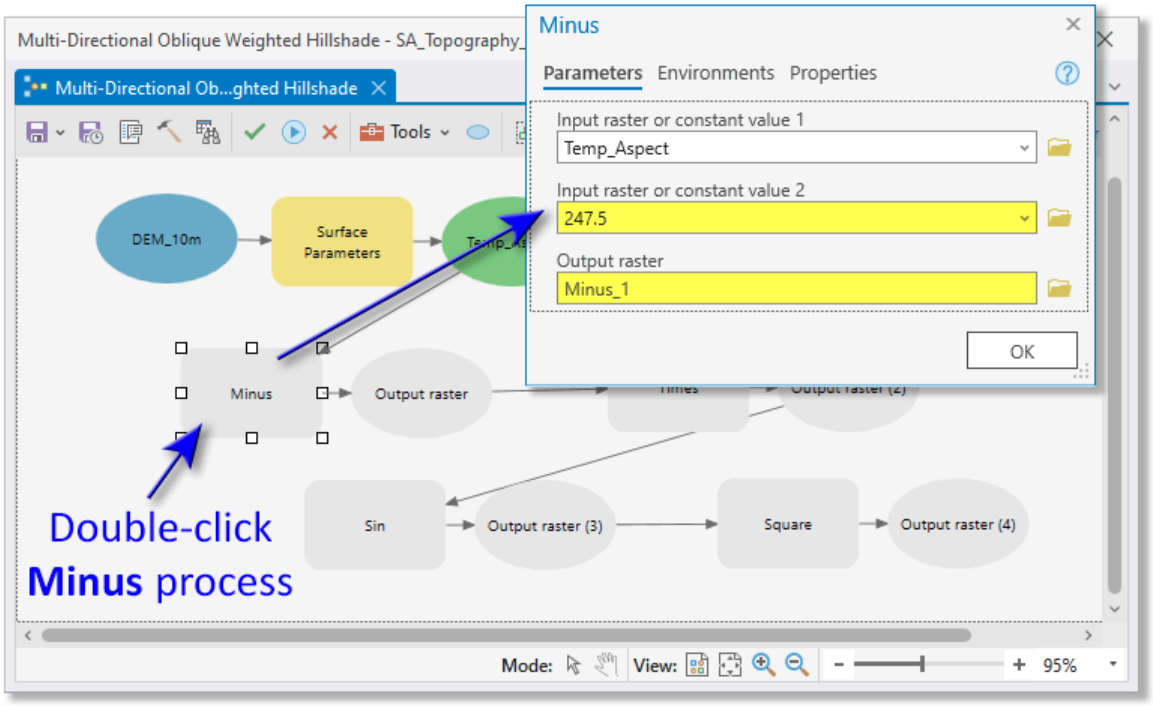


15) Double-click the **Minus** process and set the following:

a) Set the **Input raster or constant value 2** to be 247.5.

b) Set the **Output Raster** name to **Minus_1**

Note: This action will produce a raster showing how much Aspect deviates from 247.5°



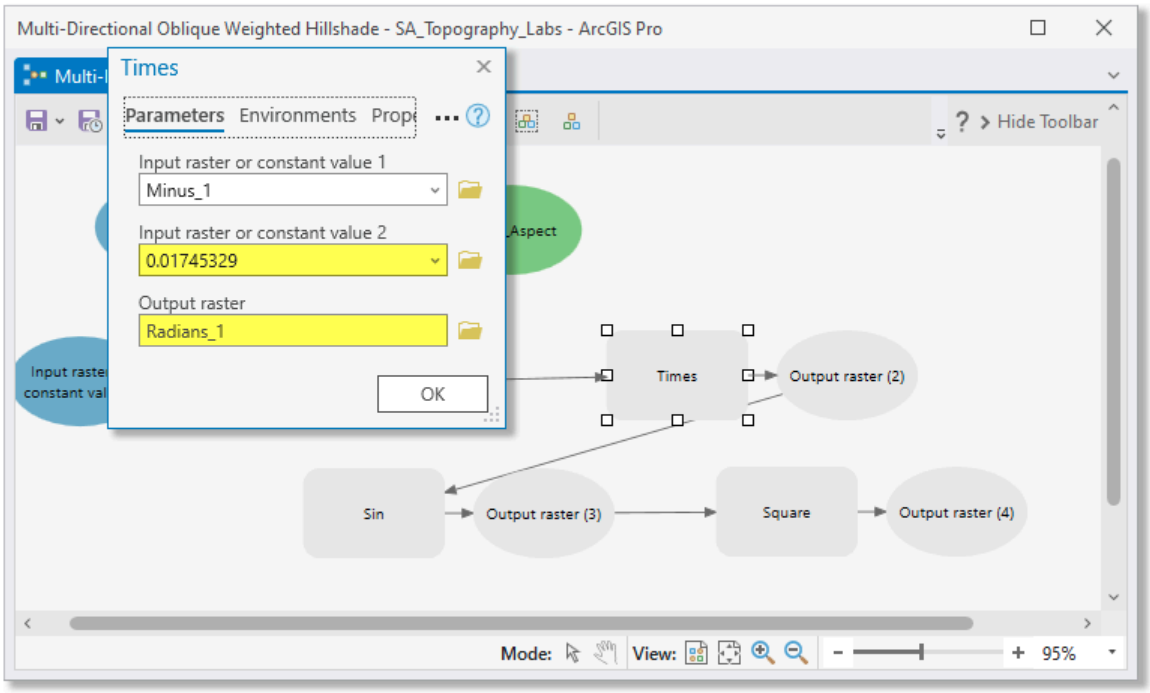
16) Double-click the **Times** process and do the following:

a) set the **Input raster or constant value 2** to be **0.01745329**.

b) Set the **Output Raster** to be **Radians_1**.

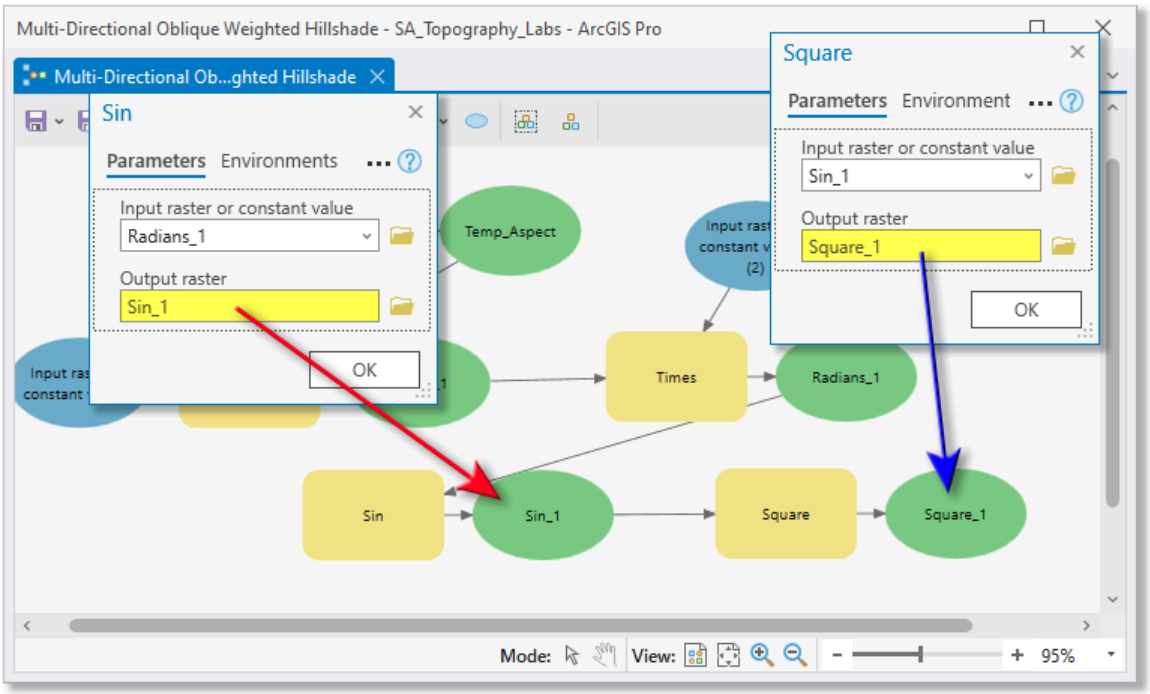
Note: This action will convert the deviation values from degrees to radians.

$$1\ \text{Radian} = \frac{\pi}{180} = 0.01745329$$

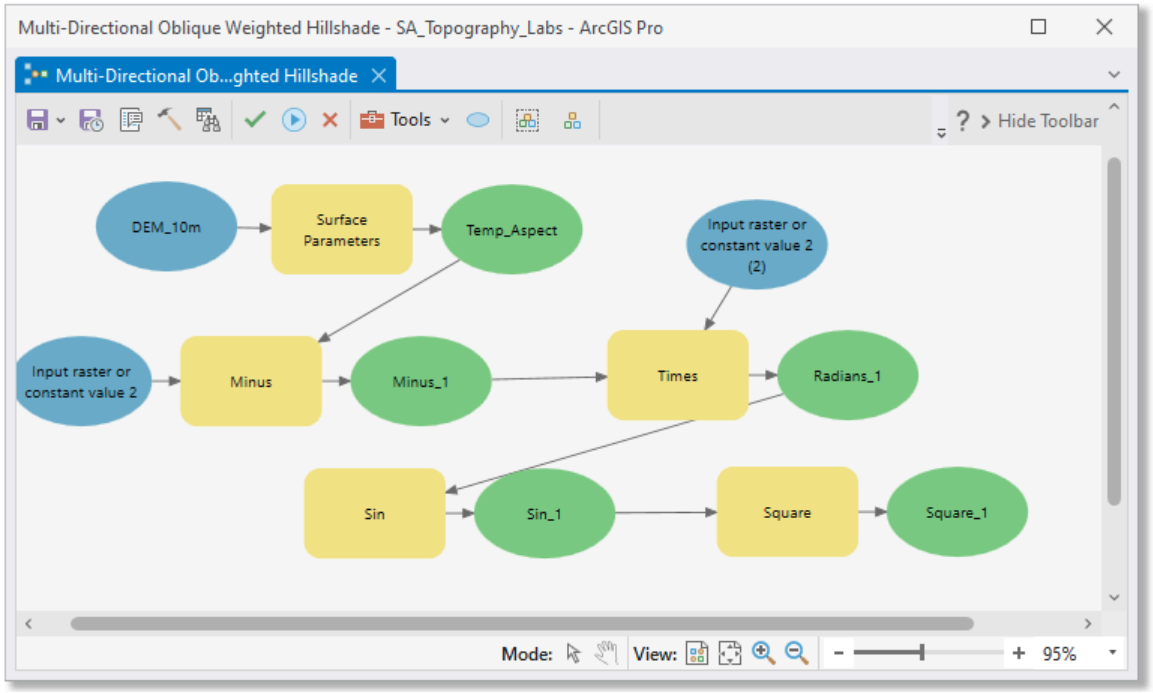


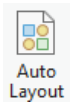
17) Double-click the **Sin** process and set the output raster name to be **Sin_1.**

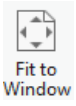
18) Double-click the **Square** process and set the output raster name to be **Square_1**.



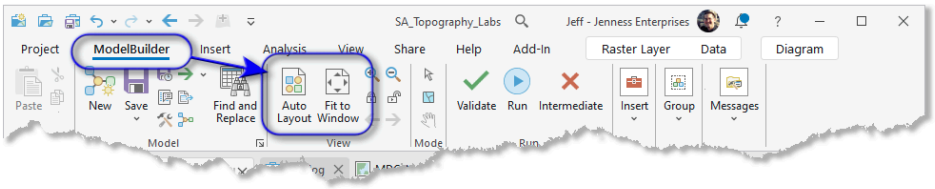
19) Now the string of tools that calculates the first weighting factor is complete.

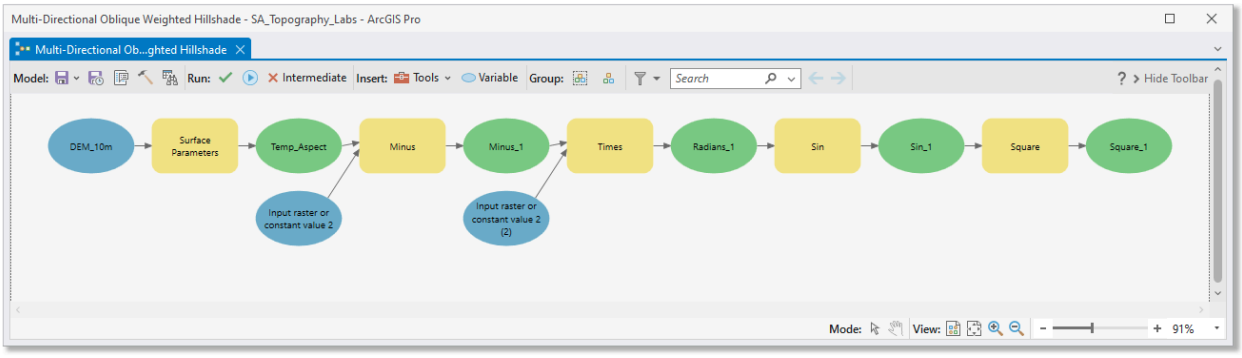


20) In your ArcGIS Pro ribbon, click the **ModelBuilder** tab and then the **Auto Layout** 

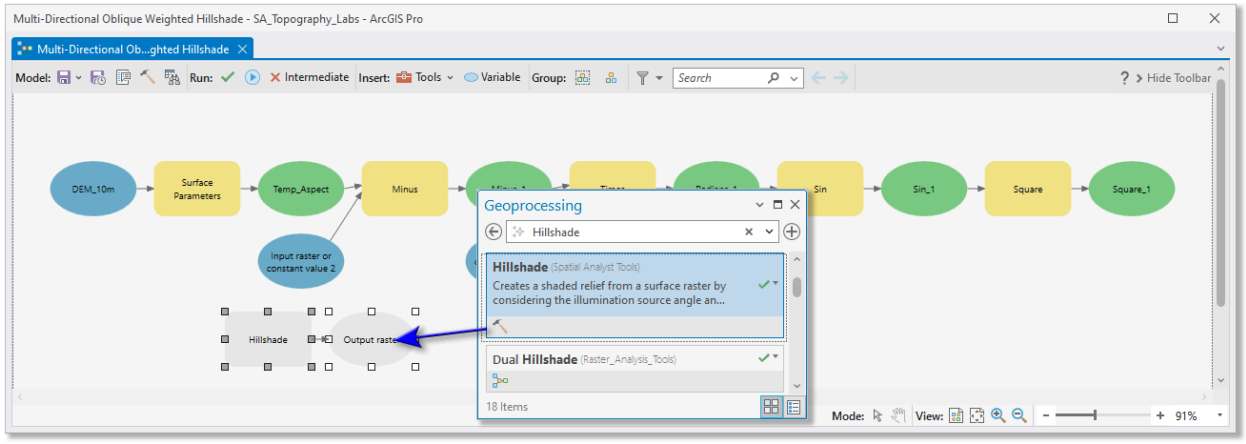
command and **Fit to Window** 

command to organize your layout better.

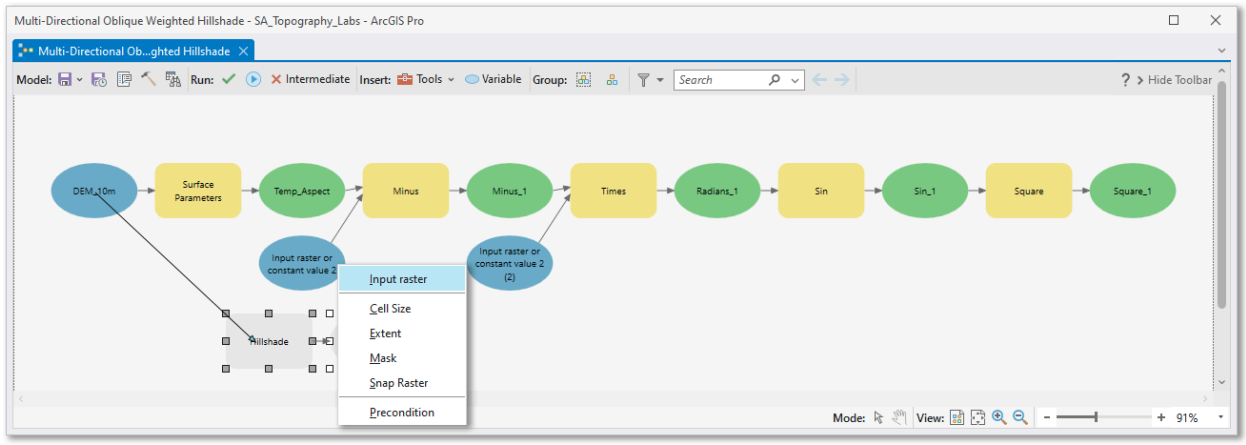




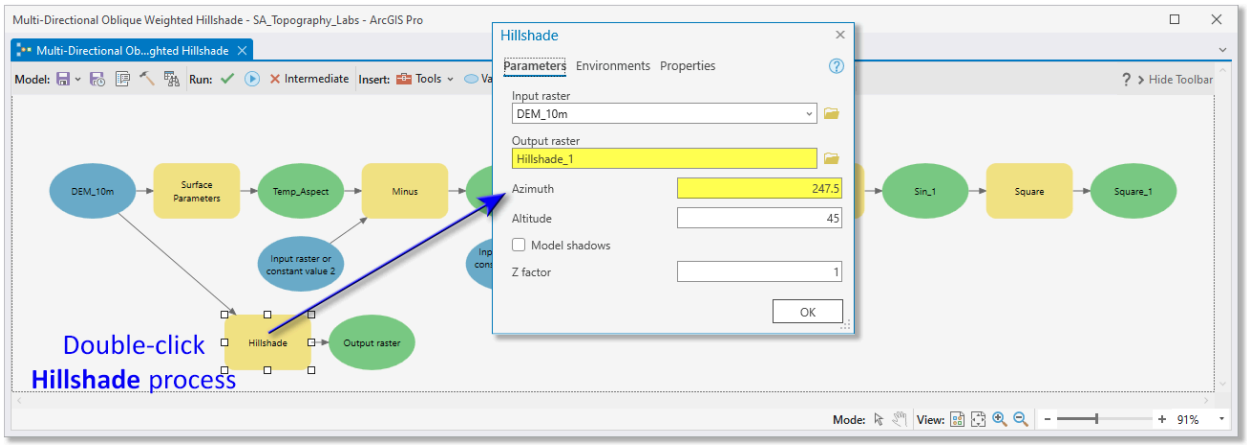
21) Find the **Hillshade** tool in your **Geoprocessing** pane and drag it into your Model window.



22) Draw a line connecting your **DEM_10m** blue oval to your **Hillshade** process, and set it to be the **Input Raster**:

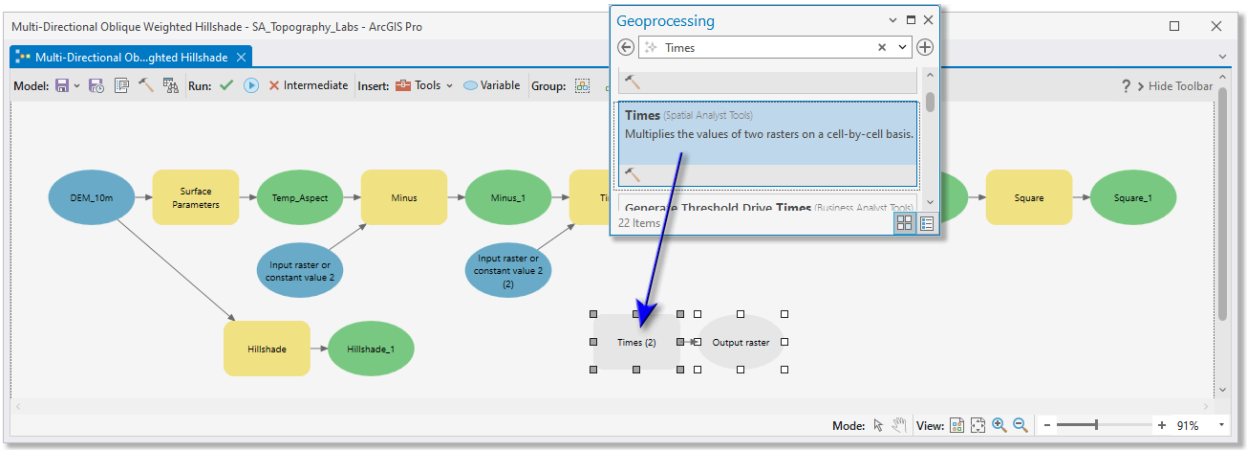


23) Double-click your **Hillshade** process and set the azimuth to be 247.5, and the **Output Raster** to be **Hillshade_1**.



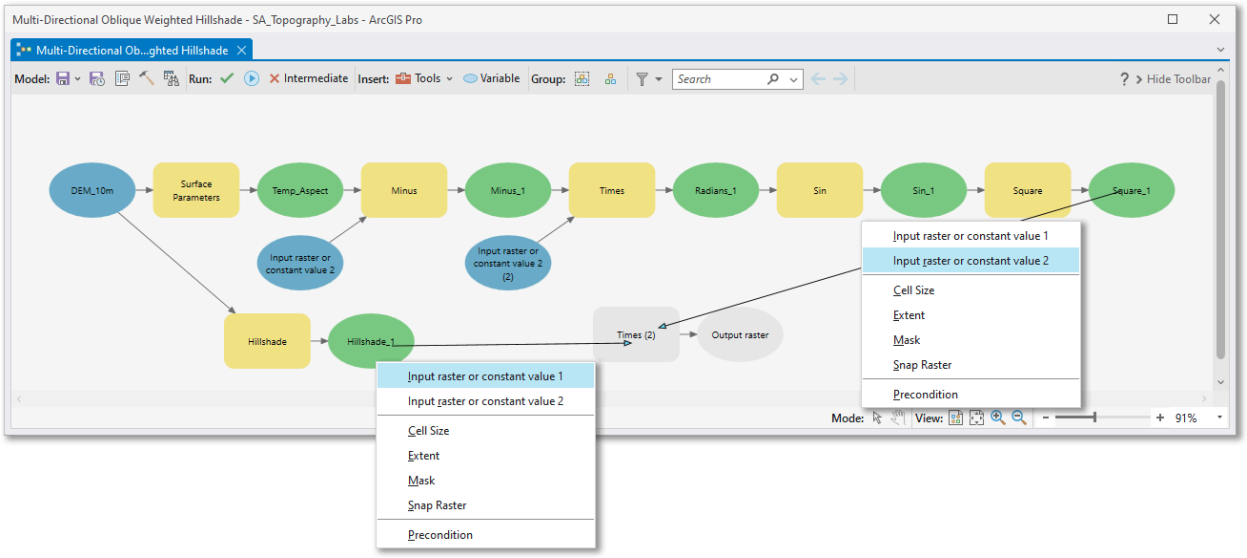
24) Now multiply the Hillshade raster by the Weighting factor for this hillshade.

    a) Find the **Times** tool in your **Geoprocessing** pane and drag it into your Model window.

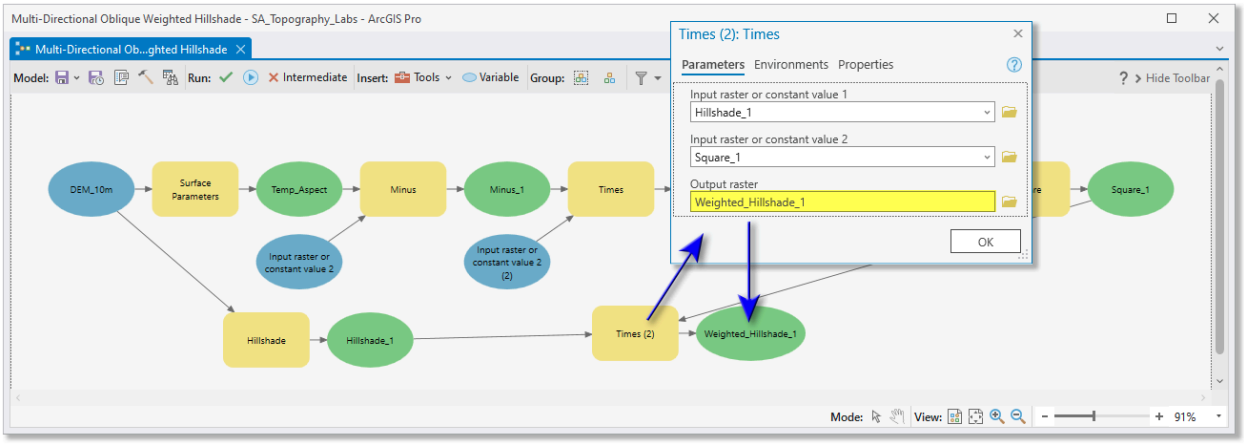


b) Draw a line connecting your **Hillshade** output (the green oval produced by your **hillshade** process) to your new **Times** process and set it to be **Input raster or constant value 1.**

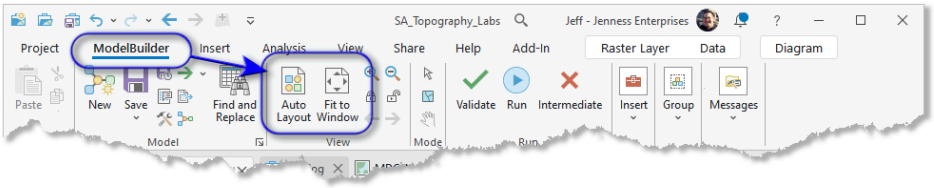
c) Draw a line connecting your **Square** output (the green oval produced by your **Square** process) to your new **Times** process and set it to be **Input raster or constant value 2.**

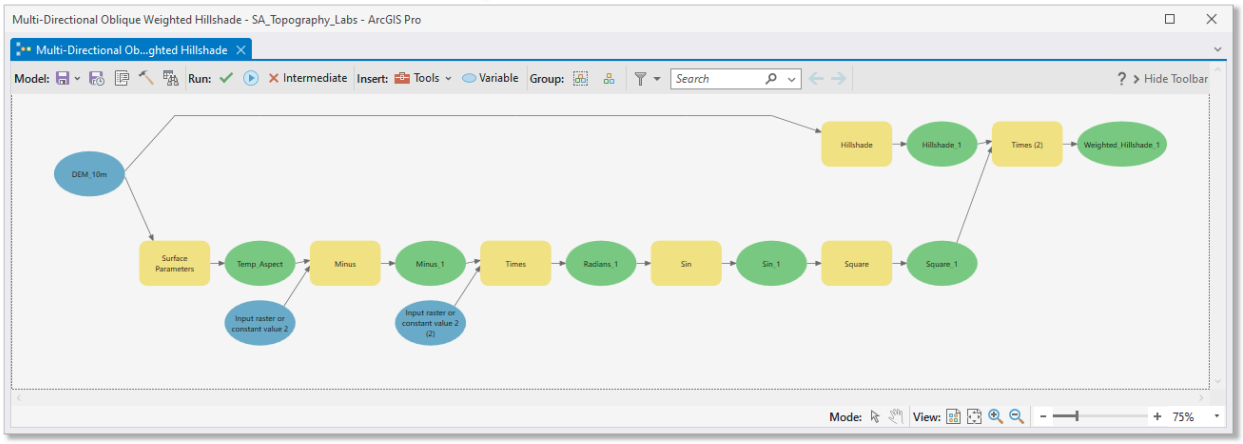


d) Double-click your **Times** process and name the output raster **Weighted_Hillshade_1**.



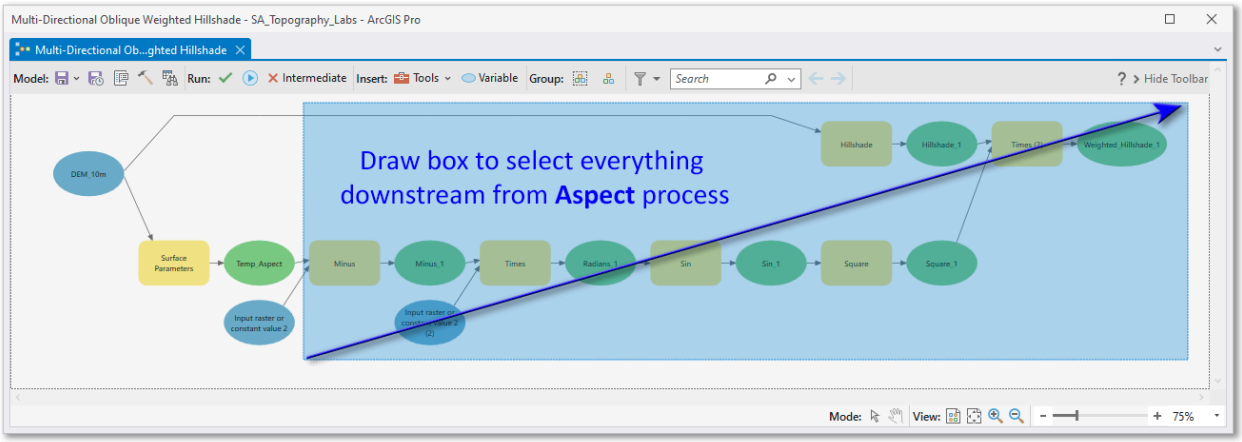
e) Reorganize your layout again using the **Auto Layout** and **Fit to Window** commands.

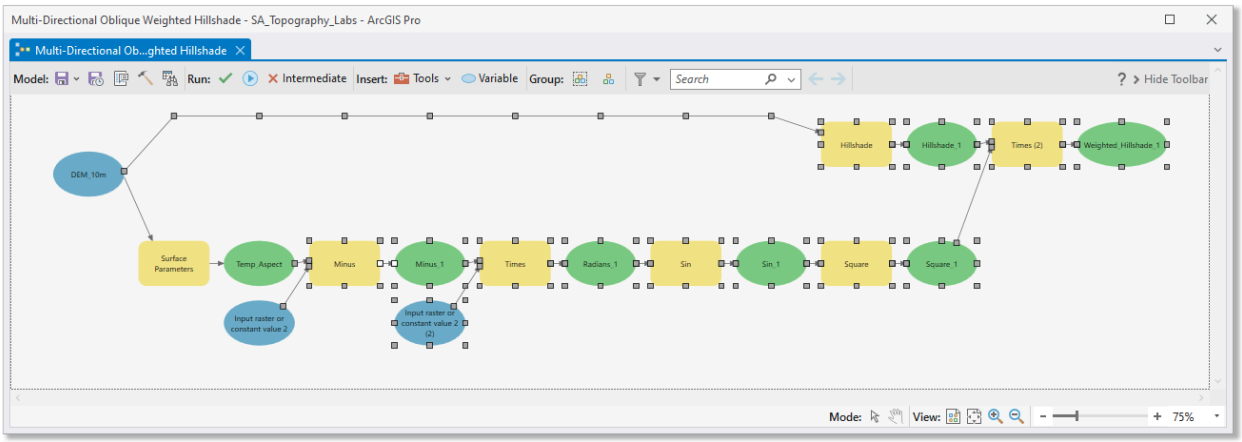




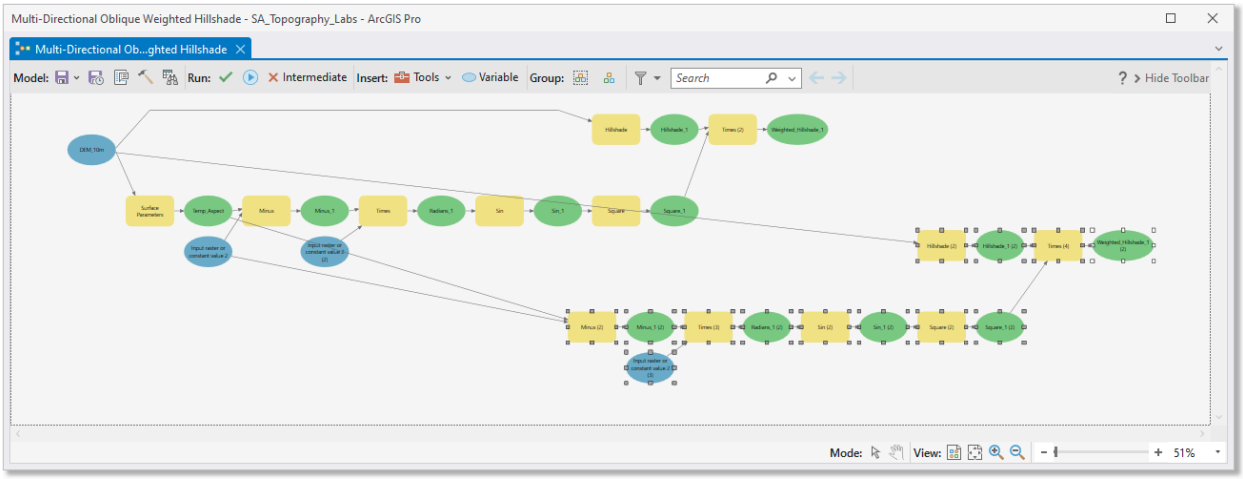
25) We now have all the necessary tools set up for one of our four weighted hillshades. Next, copy everything downstream from **Aspect**, and paste it three times into the model.

a) Select all the functions downstream from your **Aspect** process by drawing a box around them:

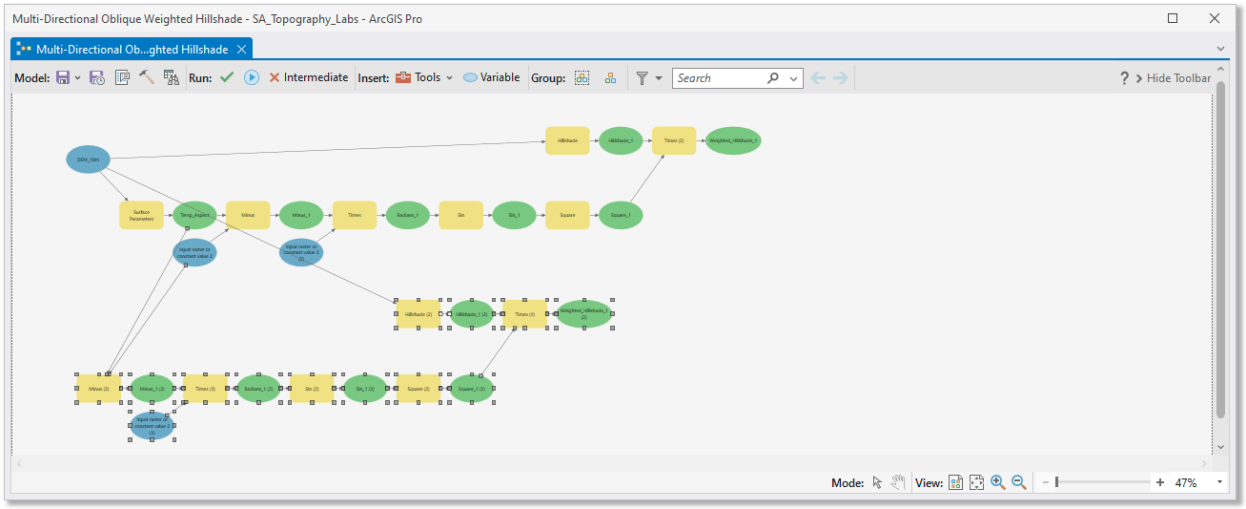




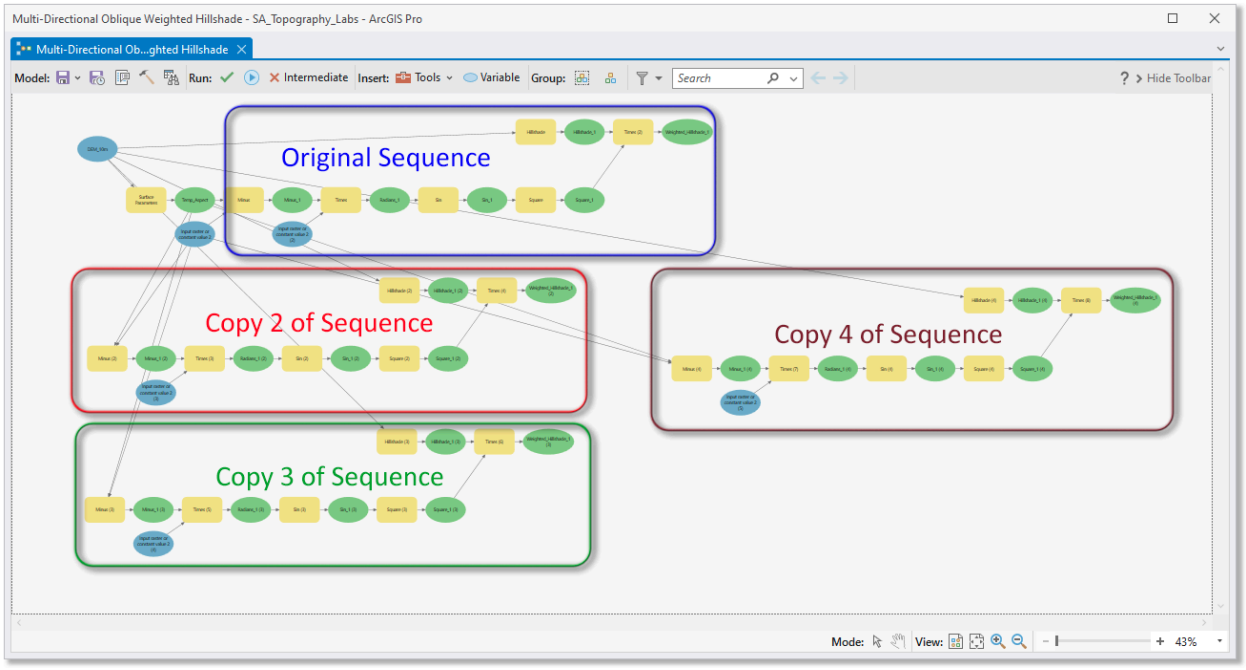
b) Click [Control]-C to copy all these functions, then click [Control]-V to paste them. They may appear overlapping your current set of tools, or possibly not. It's hard to predict where they'll go.



c) Drag the pasted set of tools down below your original set:



d) Click [Control]-V again to paste another copy, and drag that out of the way like you did before, then do it one more time so you have 3 copies of all these tools:



26) Currently all copies of the sequence are set for the compass direction 247.5°, and they all name the intermediate datasets the same. Edit the sequences so they reflect the correct directions, and change the intermediate dataset names so they don't get overwritten during the analysis.

a) In **Copy 2** of the sequence:

i) Double-click the **Minus** process to open it, and set the **Input raster or constant value 2** to be 292.5, and the **Output raster** to be **Minus_2**

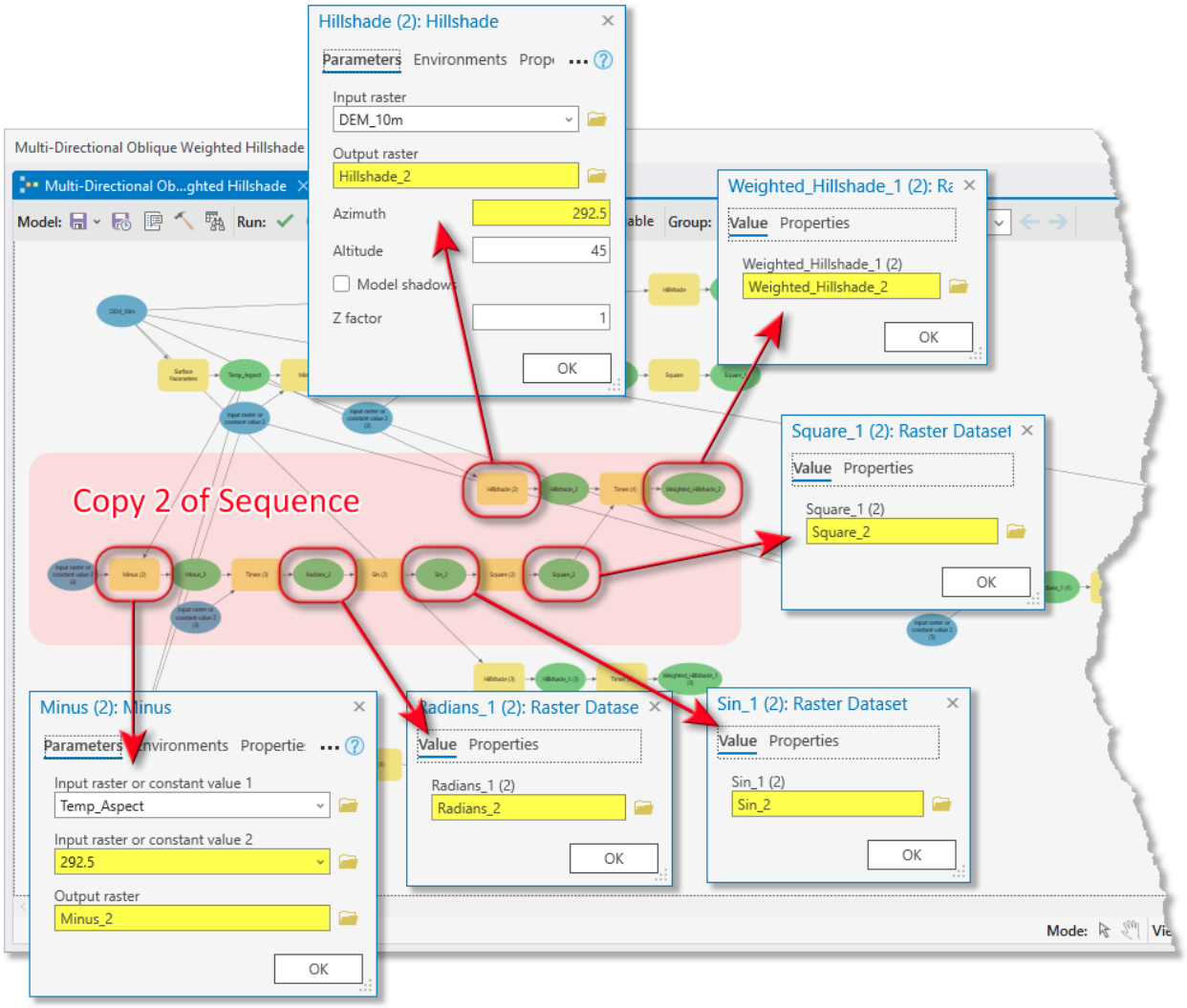
ii) Double-click the **Hillshade** process to open it, and set the **Azimuth** value to be 292.5, and the **Output Raster** to be **Hillshade_2**

iii) Double-click the green oval produced by the first **Times** process (immediately downstream from the **Minus** process), and set the name of that dataset to **Radians_2**

iv) Double-click the green oval produced by the **Sin** process, and set the name of that dataset to **Sin_2**

v) Double-click the green oval produced by the **Square** process and set the name of that dataset to **Square_2**

vi) Double-click the green oval produced by the second **Times** process (immediately downstream from the **Hillshade** and **Square** processes) and set the name of that dataset to **Weighted_Hillshade_2**



b) In **Copy 3** of the sequence:

i) Double-click the **Minus** process to open it, and set the **Input raster or constant value 2** to be 337.5, and the **Output raster** to be **Minus_3**

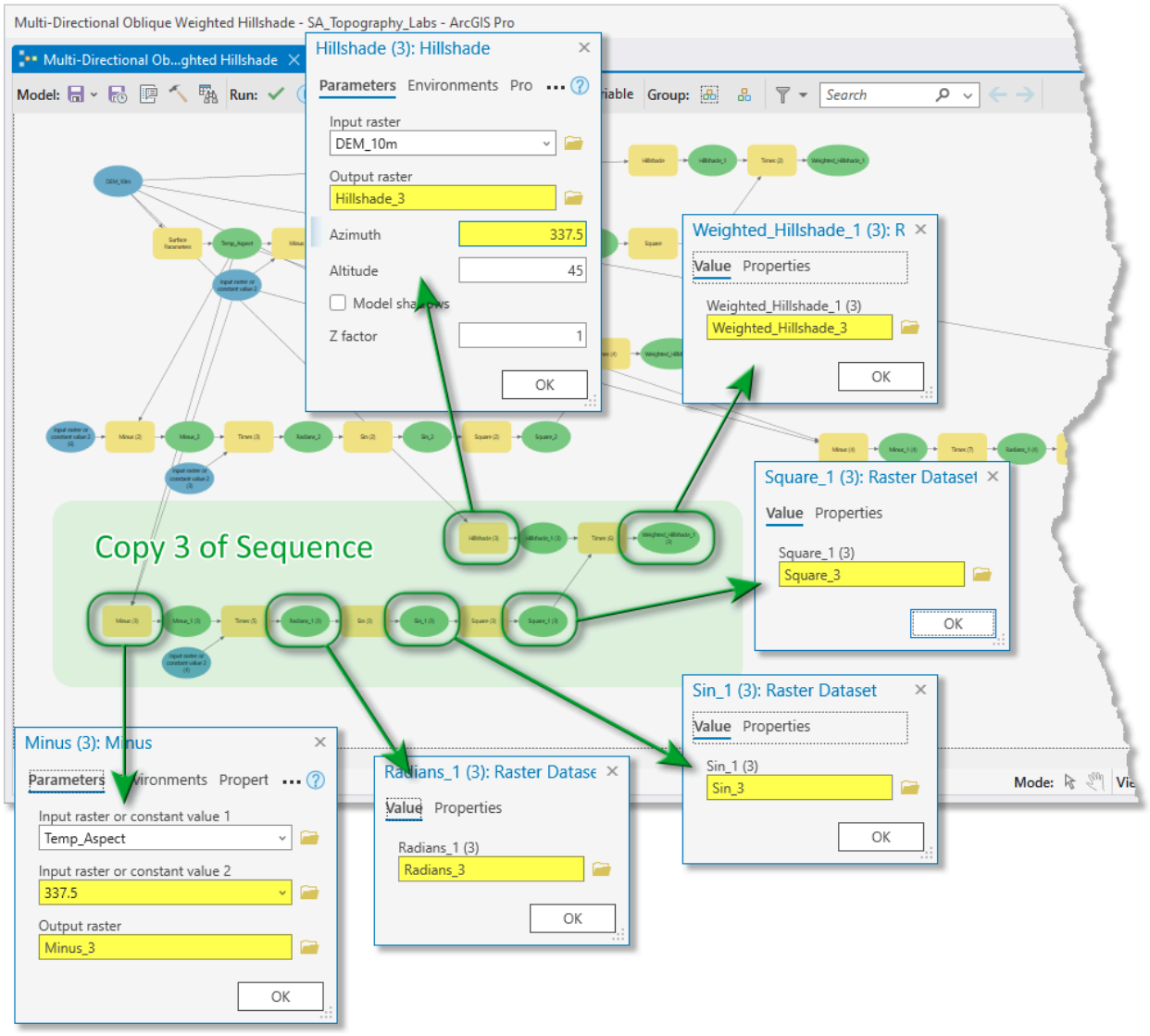
ii) Double-click the **Hillshade** process to open it, and set the **Azimuth** value to be 337.5, and the **Output Raster** to be **Hillshade_3**

iii) Double-click the green oval produced by the first **Times** process (immediately downstream from the **Minus** process), and set the name of that dataset to **Radians_3**

iv) Double-click the green oval produced by the **Sin** process, and set the name of that dataset to **Sin_3**

v) Double-click the green oval produced by the **Square** process and set the name of that dataset to **Square_3**

vi) Double-click the green oval produced by the second **Times** process (immediately downstream from the **Hillshade** and **Square** processes) and set the name of that dataset to **Weighted_Hillshade_3**



c) In **Copy 4** of the sequence:

i) Double-click the **Minus** process to open it, and set the **Input raster or constant value 2** to be 22.5, and the **Output raster** to be **Minus_4**

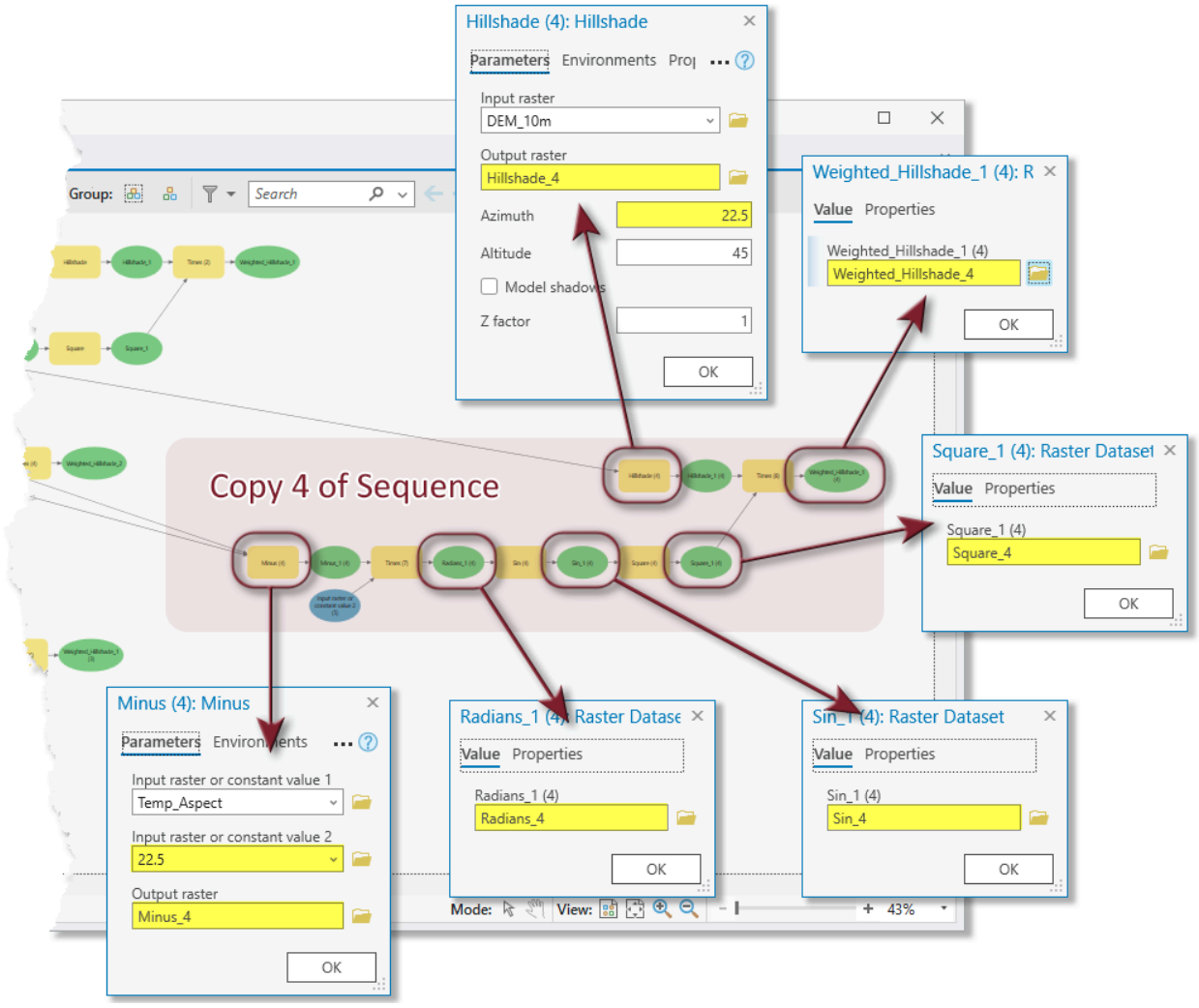
ii) Double-click the **Hillshade** process to open it, and set the **Azimuth** value to be 22.5, and the **Output Raster** to be **Hillshade_4**

iii) Double-click the green oval produced by the first **Times** process (immediately downstream from the **Minus** process), and set the name of that dataset to **Radians_4**

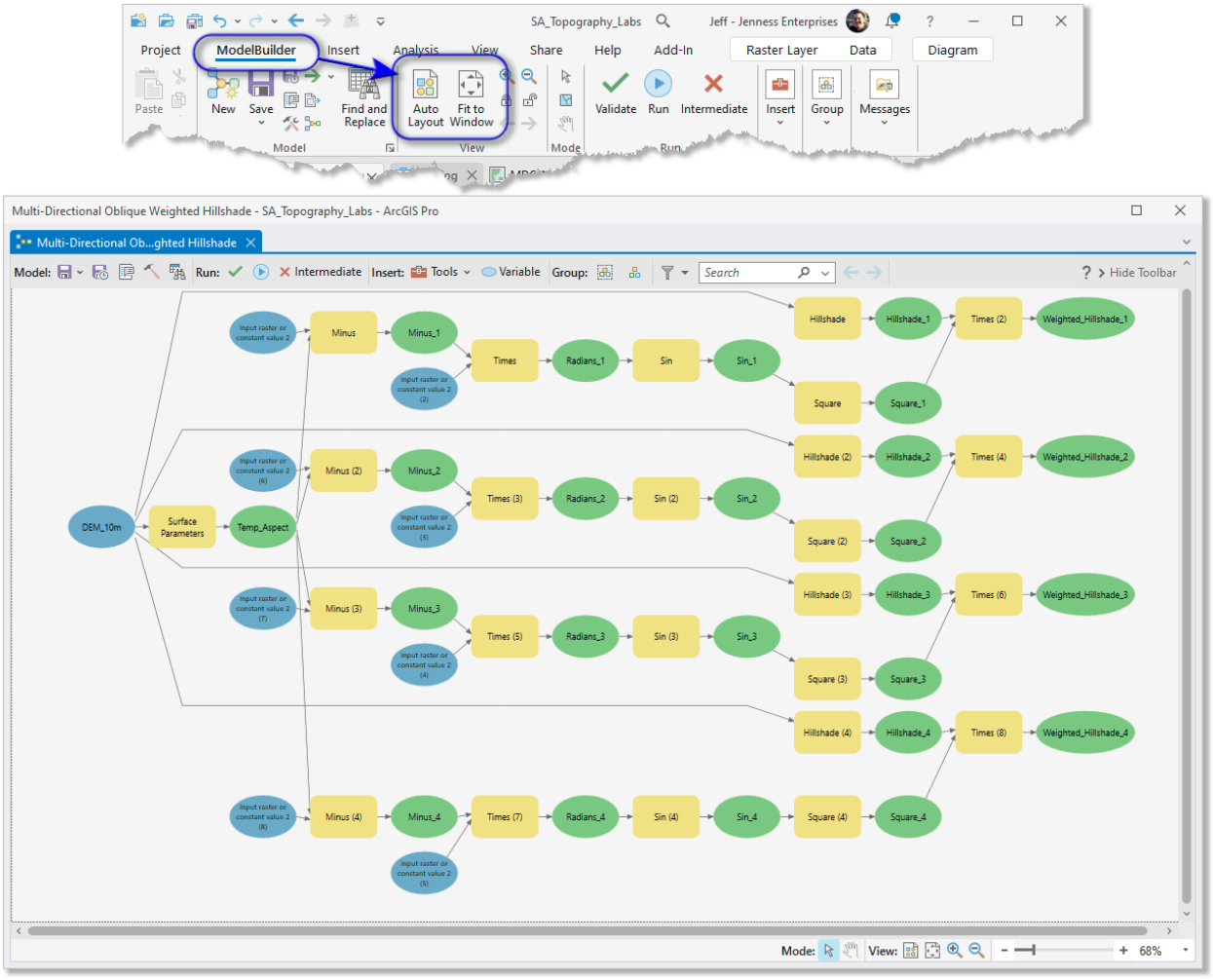
iv) Double-click the green oval produced by the **Sin** process, and set the name of that dataset to **Sin_4**

v) Double-click the green oval produced by the **Square** process and set the name of that dataset to **Square_4**

vi) Double-click the green oval produced by the second **Times** process (immediately downstream from the **Hillshade** and **Square** processes) and set the name of that dataset to **Weighted_Hillshade_4**

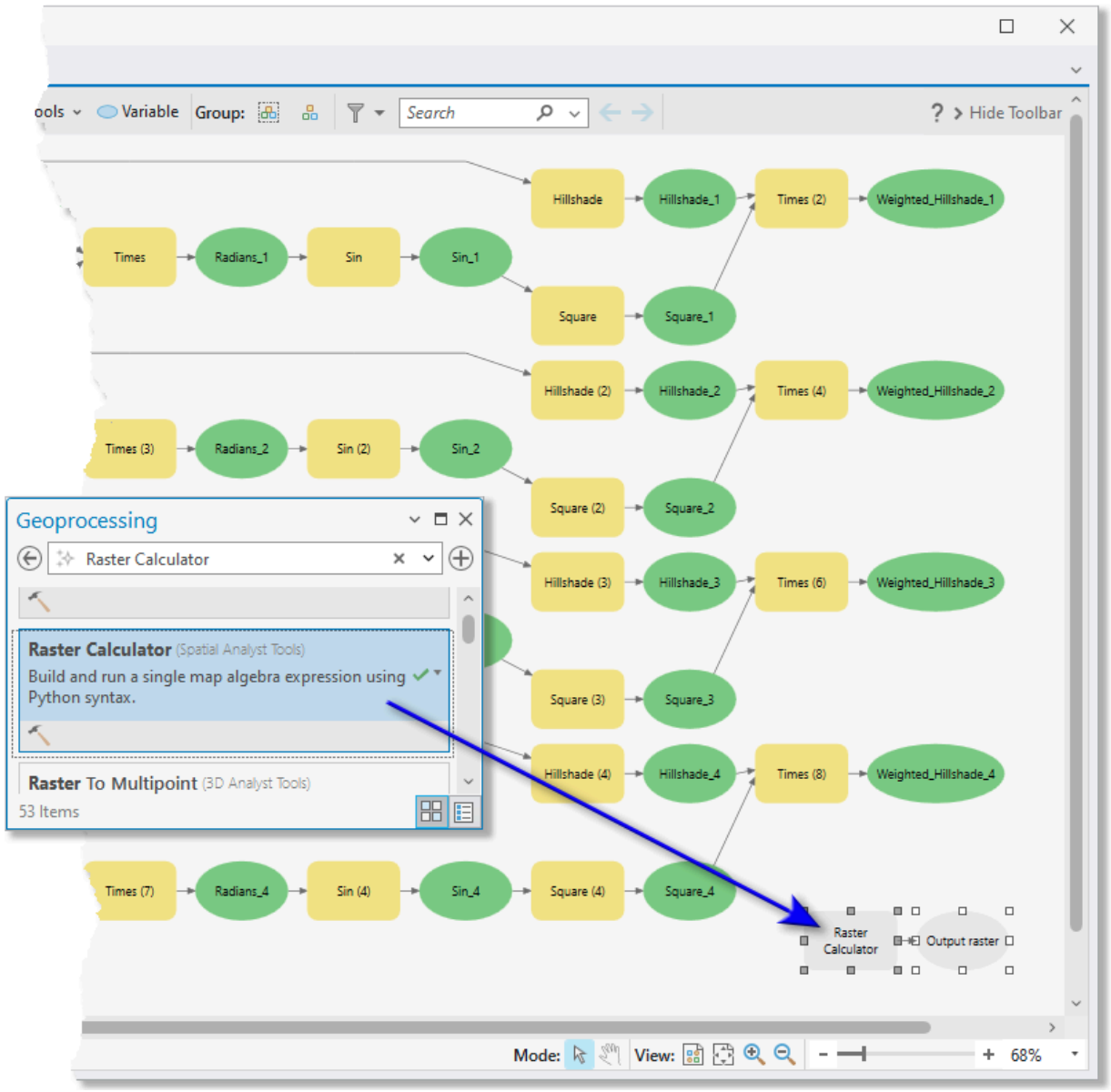


27) We now have all the tools set up to produce 4 weighted hillshades. Reorganize your layout again using the **Auto Layout** and **Fit to Window** commands.



28) The four green ovals on the far right are your four weighted hillshades. The final steps are to add these 4 weighted hillshades together, and divide the sum by 2. We can do all of that in the Raster Calculator.

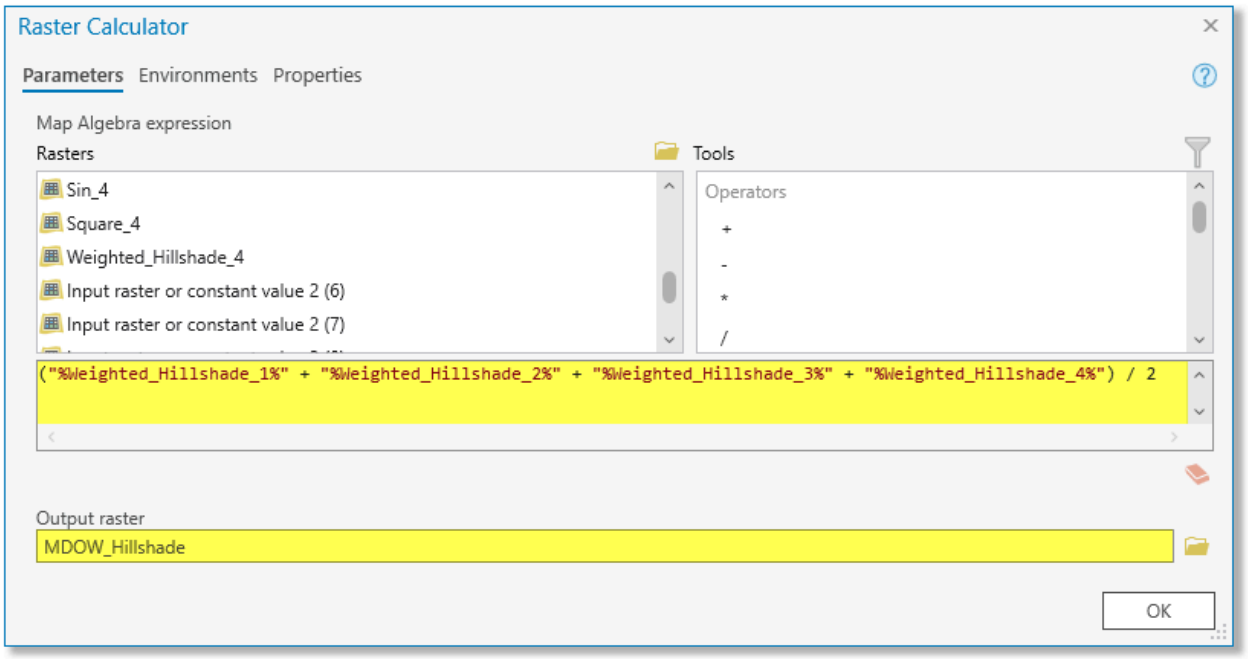
a) Find the **Raster Calculator** tool in your **Geoprocessing** pane and drag it into your Model window.



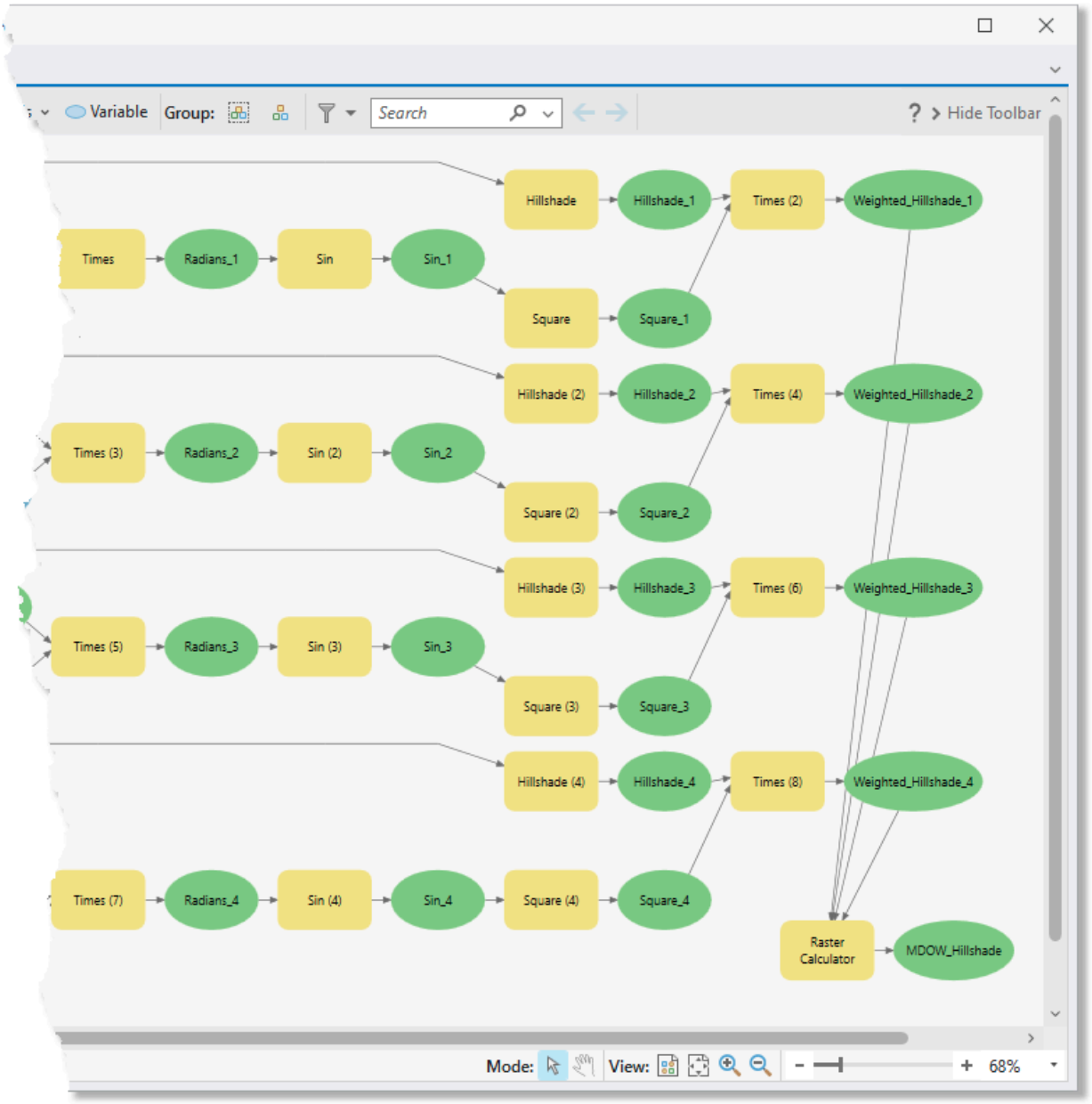
b) Double-click on your new **Raster Calculator** process and set the calculation string as follows (and be careful to put parentheses around the 4 summed weighted rasters):

("%Weighted_Hillshade_1%" + "%Weighted_Hillshade_2%" + "%Weighted_Hillshade_3%" + "%Weighted_Hillshade_4%") / 2

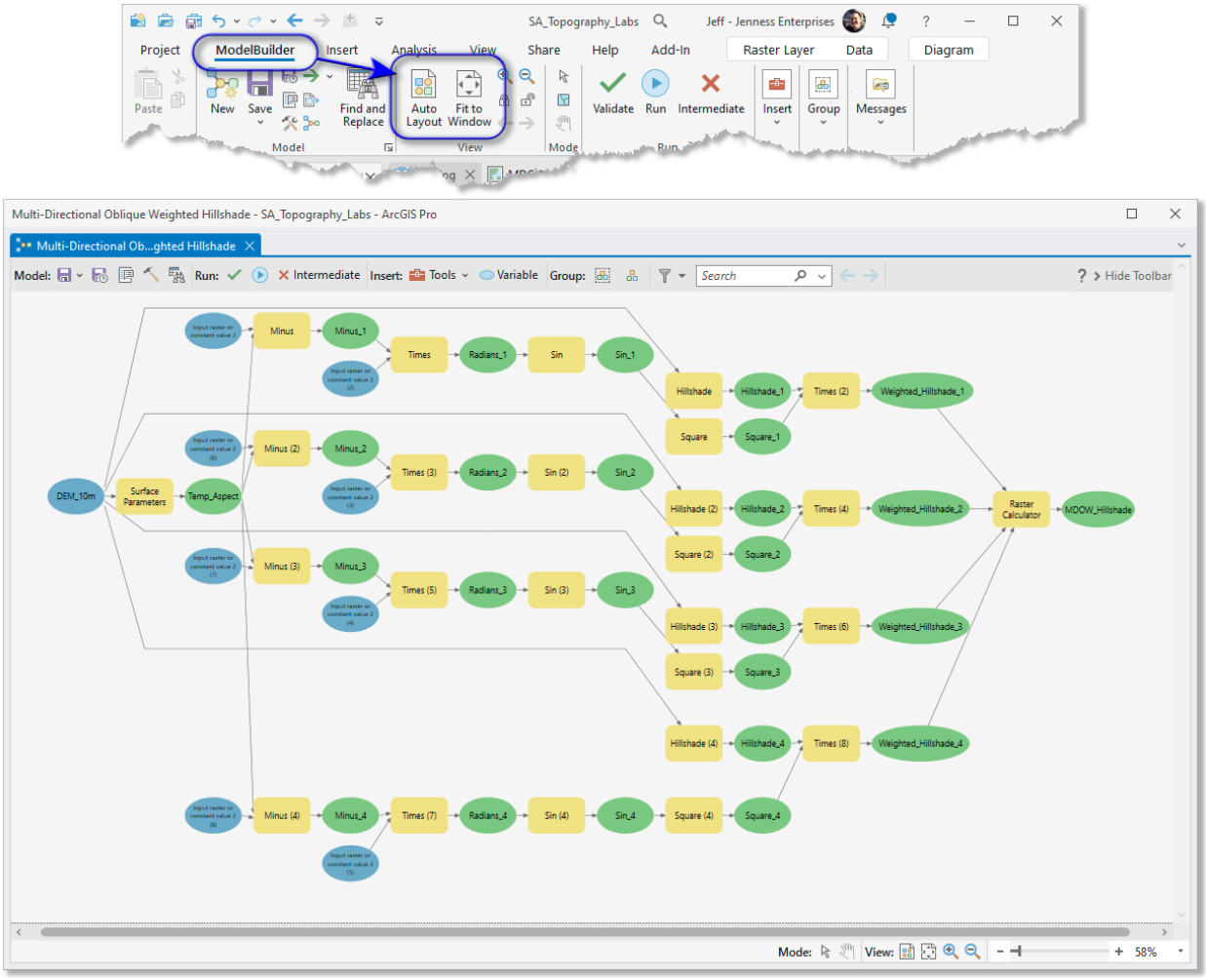
c) Set the Output Raster to **MDOW_Hillshade**



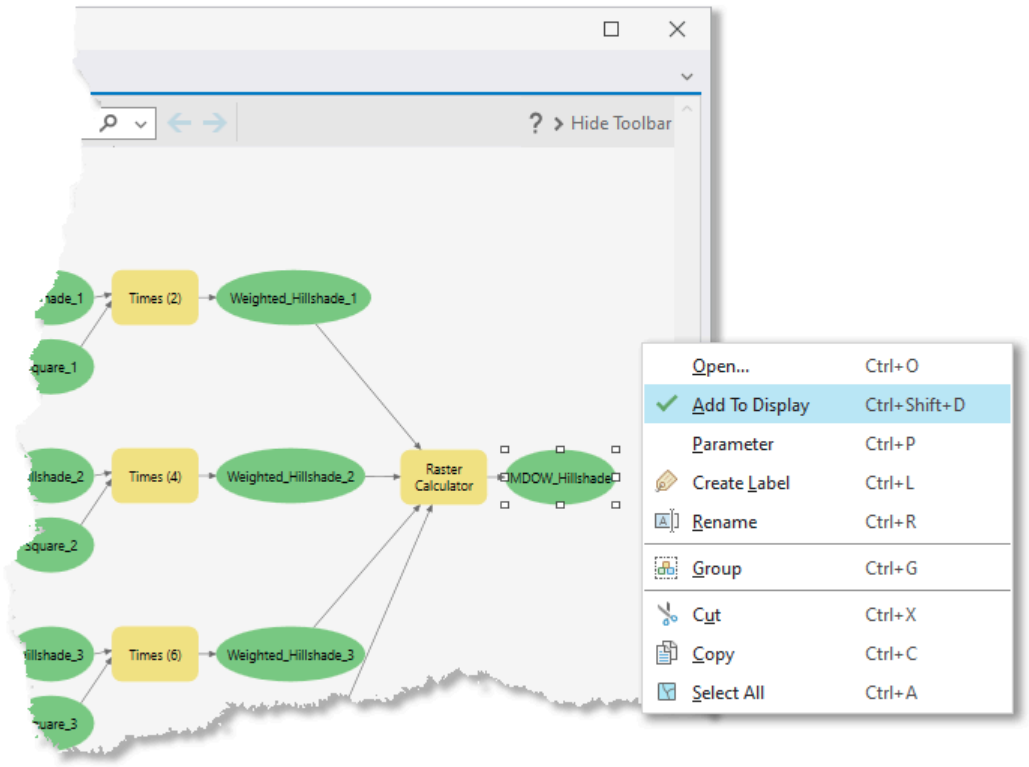
d) Observe that referencing your 4 weighted rasters in the **Raster Calculator** process caused them to link automatically to that process in the Model window:



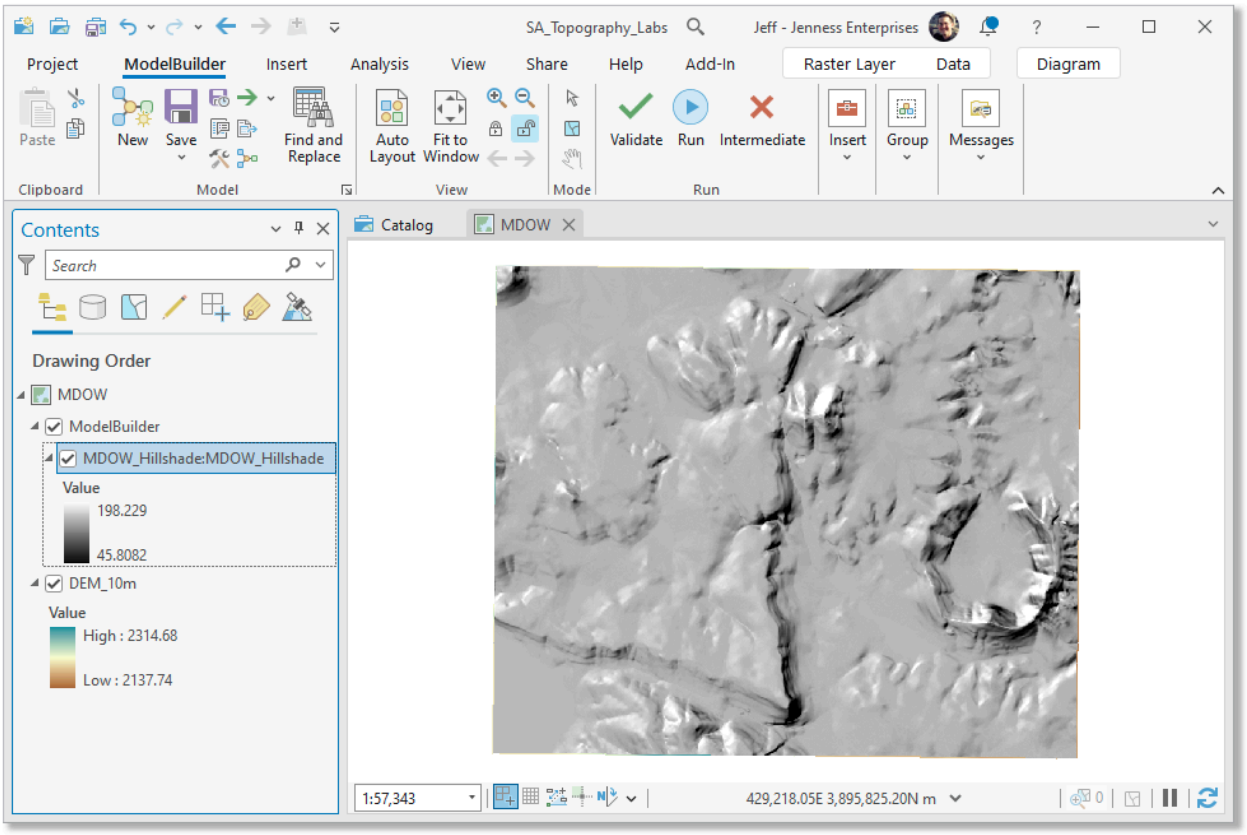
29) Reorganize your model one last time using the **Auto Layout** and **Fit to Window** commands:

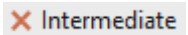


30) Right-click on your final **MDOW_Hillshade** green oval and confirm that it is set to add the new raster to your layout:

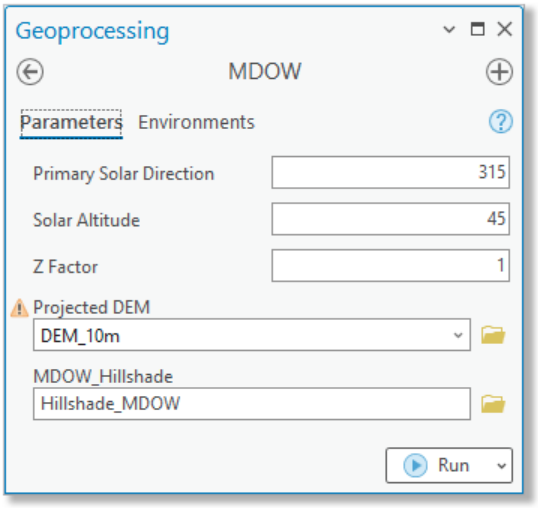


31) Your model is complete and now ready to run. Click the **Save** command to save your edits, then the **Validate** command to check for any hidden errors, and finally the **Run** command to run your model. With any luck, your now MDOW hillshade will be added to your current map. If it does not appear, then you'll just have to add it manually.

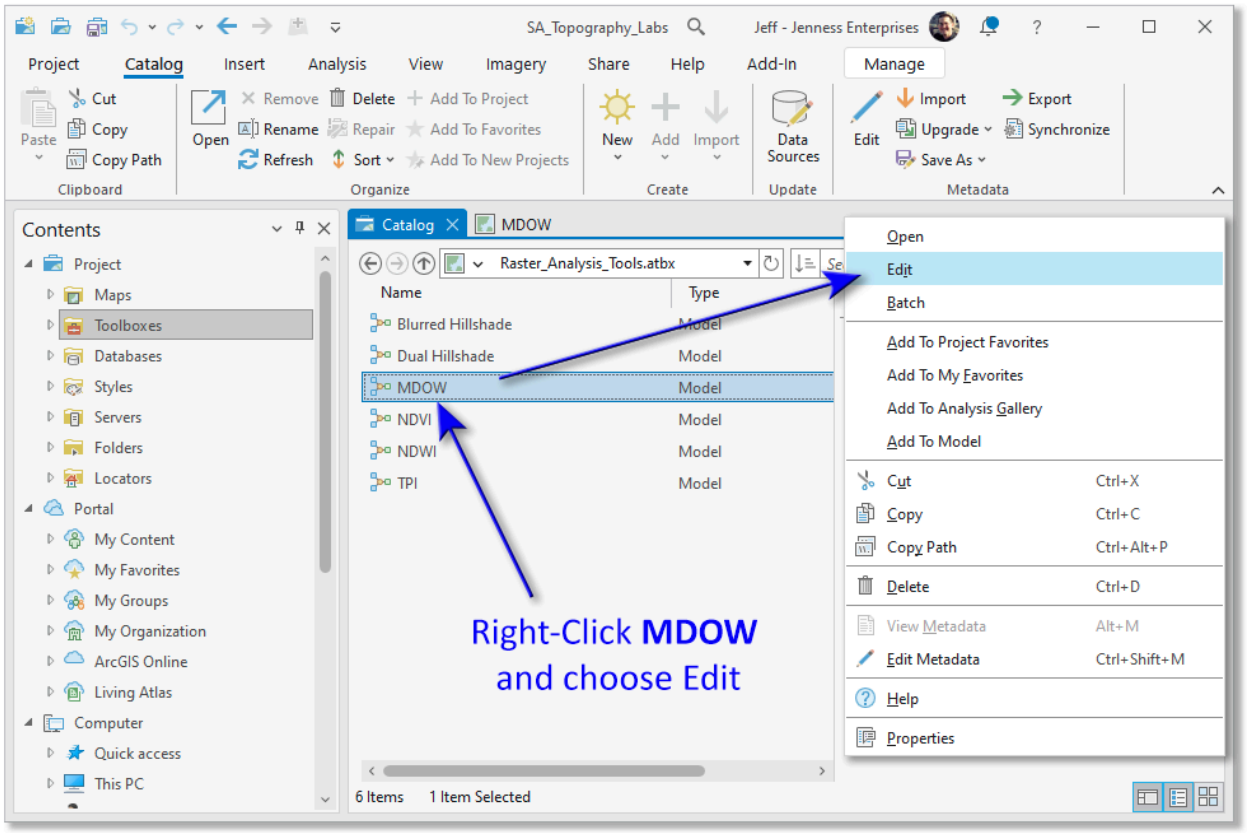


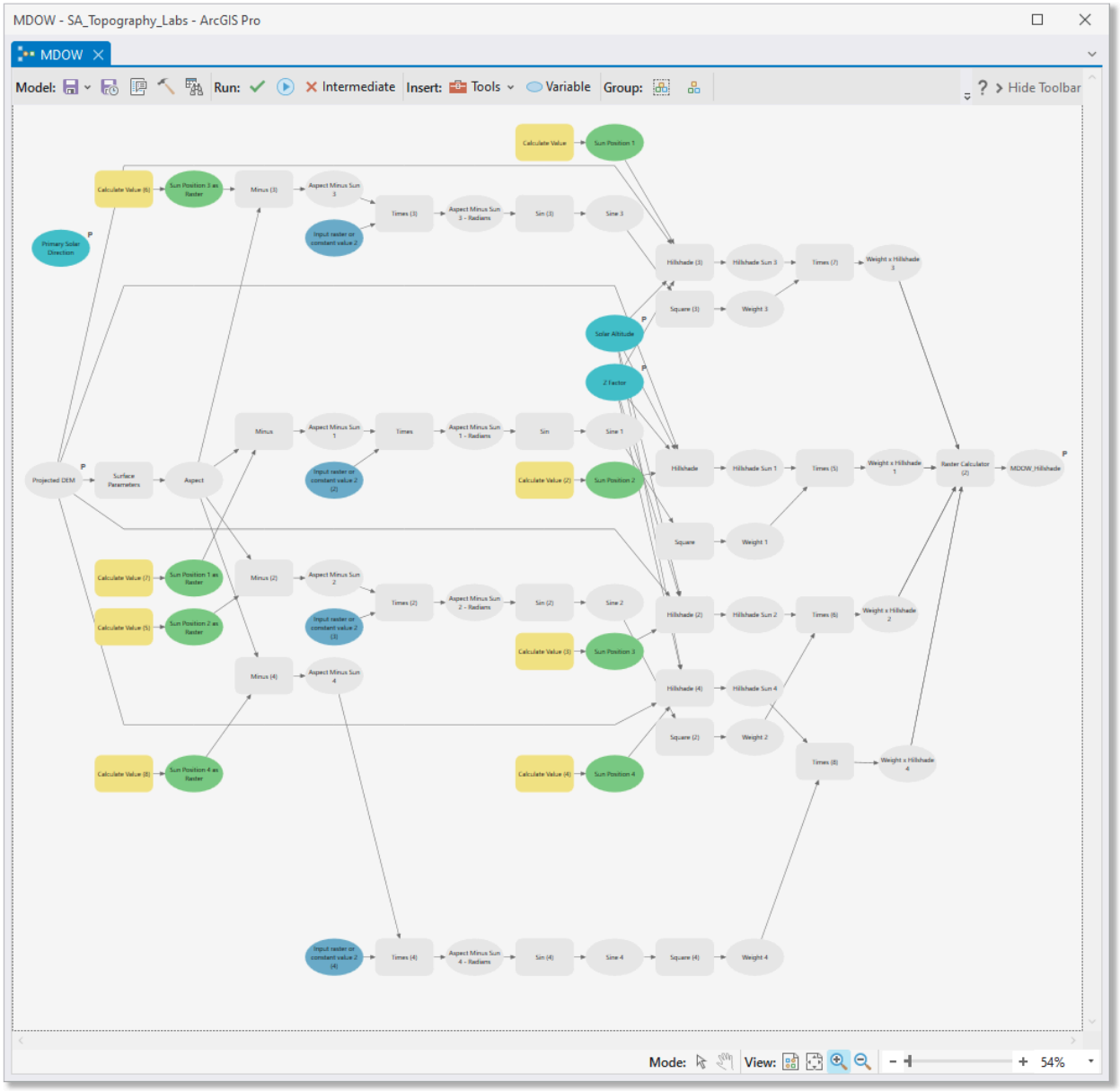
32) Upon completion, click the **Delete Intermediate** command  to get rid of the 25 intermediate raster datasets that were generated by the model.

Note: The sample **MDOW** model available for download at the link above (see **For Fun** at the beginning of this lab exercise) is very similar to the exercise you just completed, except that I set several of the operating parameters to be model parameters. Doing this allows you to run the model by double-clicking on it in the toolbox and setting such parameters as the DEM, primary solar direction, and output dataset manually.



Setting these parameters to be model parameters makes the tool much more flexible and easier to run with different sun locations or on different data. Please take a look at that sample if you'd like to see how to set the model up to run this way. Just open the downloaded toolbox **Raster_Analysis_Tools**, right-click on the model named **MDOW** and click "Edit" to open the model window.




MDOW - SA_Topography_Labs - ArcGIS Pro
MDOW
Model:
Run:
Intermediate
Insert:
Tools
Variable
Group:
Hide Toolbar
Mode:
View:
54%

Exercise 13 [Optional]: Creating a Blurred Hillshade

Objectives

- Learn to generate a blurred, which is one of the Swiss Method strategies for making hillshades more attractive. Not everybody agrees that blurred hillshades are more attractive, though, so give this some careful thought before you apply it.

Data used

- Raster layer file **DEM_10m.lyr**, in folder **..\Class_GIS_Data\Raster_Functions\...** This layer file references a raster dataset named **DEM_10m** in the file geodatabase **Lab_Data.gdb**, and is an approximately 10m resolution Digital Elevation Model (DEM) showing elevation (in meters) within the general extent of the Semester D Management Unit in the Centennial Forest.

- Optionally, any additional data or online basemap layers you prefer, such as topo maps or imagery. These won't be used in the analysis but they are often useful to help orient yourself or see the analysis within a larger landscape context.

For Homework

There is no homework due from this lab exercise.

For Fun

I have created a sample model named **Blurred Hillshade** that will calculate a blurred hillshade from a DEM, similar to what you'll do in this lab exercise. I've also added models that do a few other things we describe in these labs, that you are welcome to download and play with. The toolbox is saved in a geodatabase you can download from here:

https://drive.google.com/file/d/1MDMLqwZolsCLVpKiy9i75aQceRI-gIPw/view?usp=sharing

Exercise

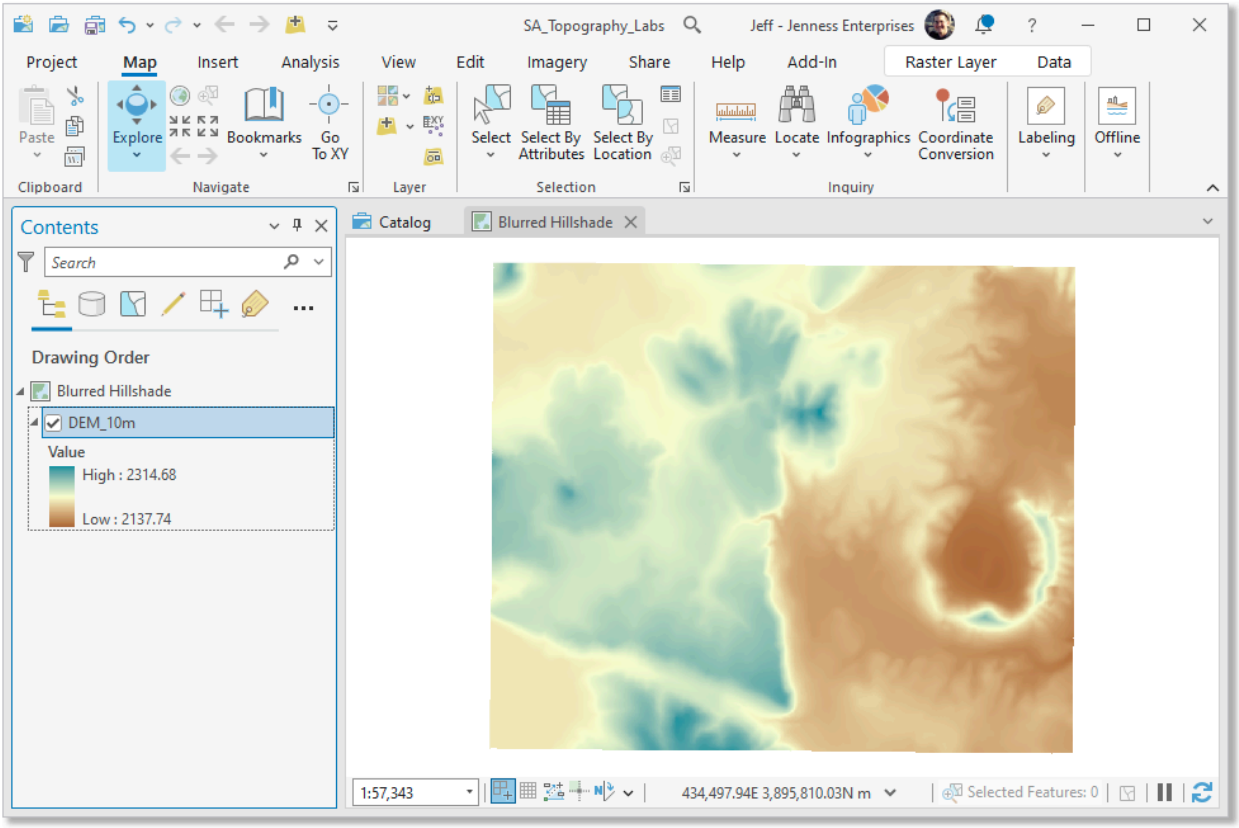
Based on the DEM (digital elevation model), you will generate a new hillshade raster that resembles a normal hillshade except that it is blurred so the sharp edges are rounded off and de-emphasized. This can make a hillshade more subtle and less distracting in a map.

You will also see how to construct the steps in ModelBuilder, so you can easily apply the steps to different DEMs in the future.

Take a look back at Lab Exercise 3 if you want to review the discussion on hillshades from geographic (Latitude/Longitude) DEMs, and for resolving differences between elevation units and X/Y coordinate system units.

Prepare your Map and Data:

1) Open a blank map in ArcGIS Pro. If you still have ArcGIS Pro open from the previous exercise, you may simply insert a new map.
2) Make sure you have the **Spatial Analyst** extension turned on. See Exercise 1 if you have questions on this.
3) If it is not already present, then load the **Layer** file **DEM_10m.lyr** from the folder **..\Class_GIS_Data\Raster_Functions\...** as you did in Exercise 1.
4) If you loaded the Layer file, you should see the following.



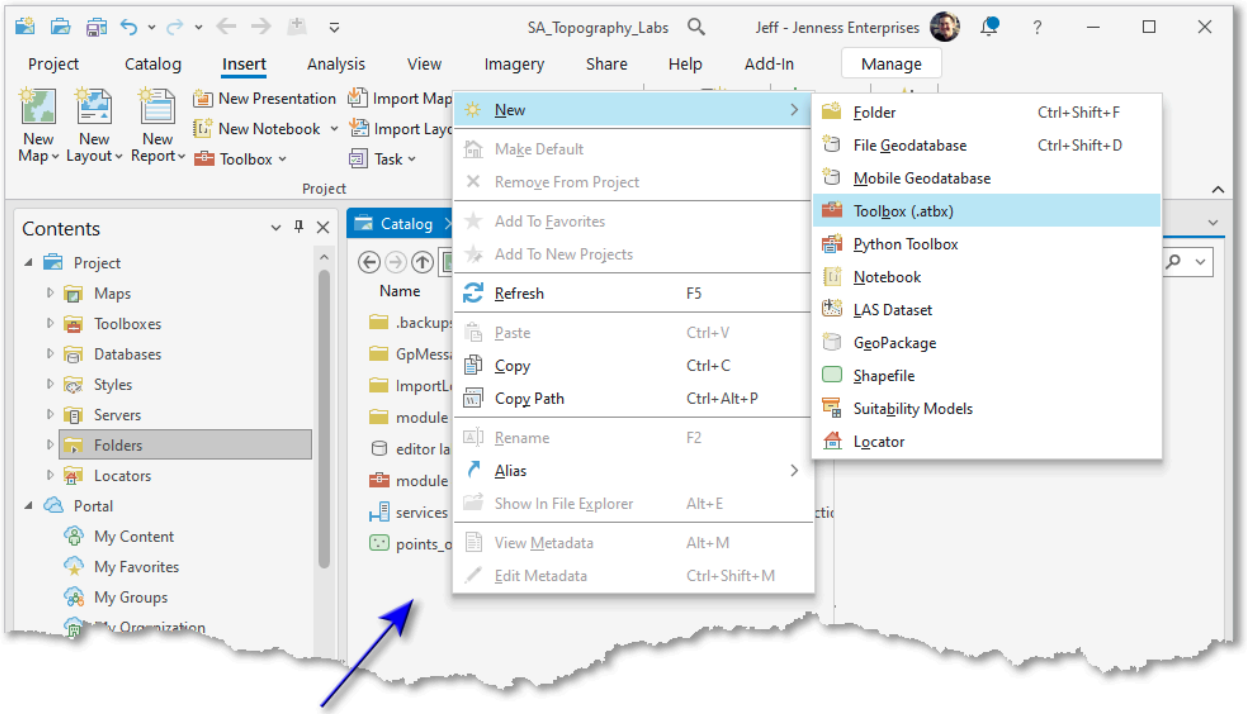
5) Optionally, load any online basemap layers or other background data you like.

Prepare your toolbox:

This exercise will construct a model which will let you easily run this process again in the future. To do this we will need to have a toolbox available to hold the model. ArcGIS Pro models have to be stored in toolboxes.

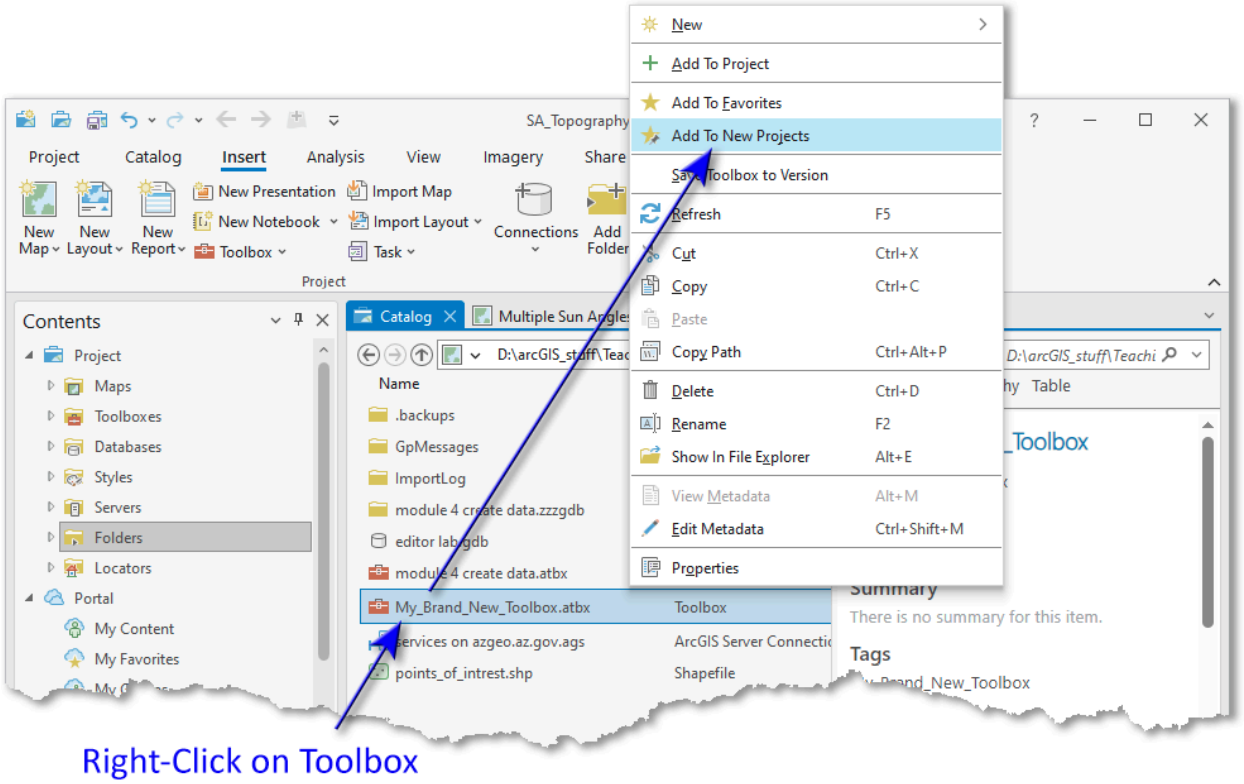
Your ArcGIS Pro project comes with its own toolbox, which we will use in this lab exercise.

If you wish, though, please feel free to create a new toolbox. It's easy to do. Just use your Catalog view to navigate to either a folder or geodatabase where you want to create it, then click "New" and then "Toolbox":



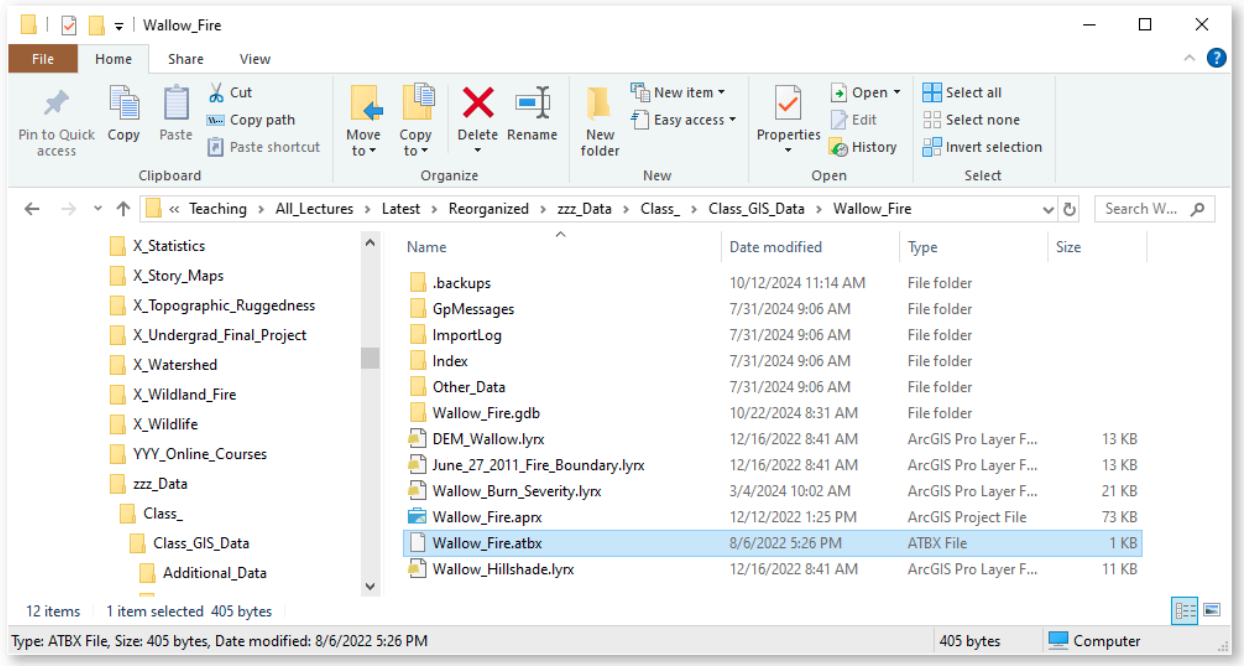
Right-Click in Folder or Geodatabase, then click “New”, then “Toolbox”

And remember that, regardless of whether you create a new toolbox or use the current ArcGIS Pro Project toolbox, you can always access that toolbox from new ArcGIS Pro projects. If you have a toolbox you want to always be available in any new ArcGIS Pro project you create, just right-click on it in Catalog view, and choose “Add to New Projects”:



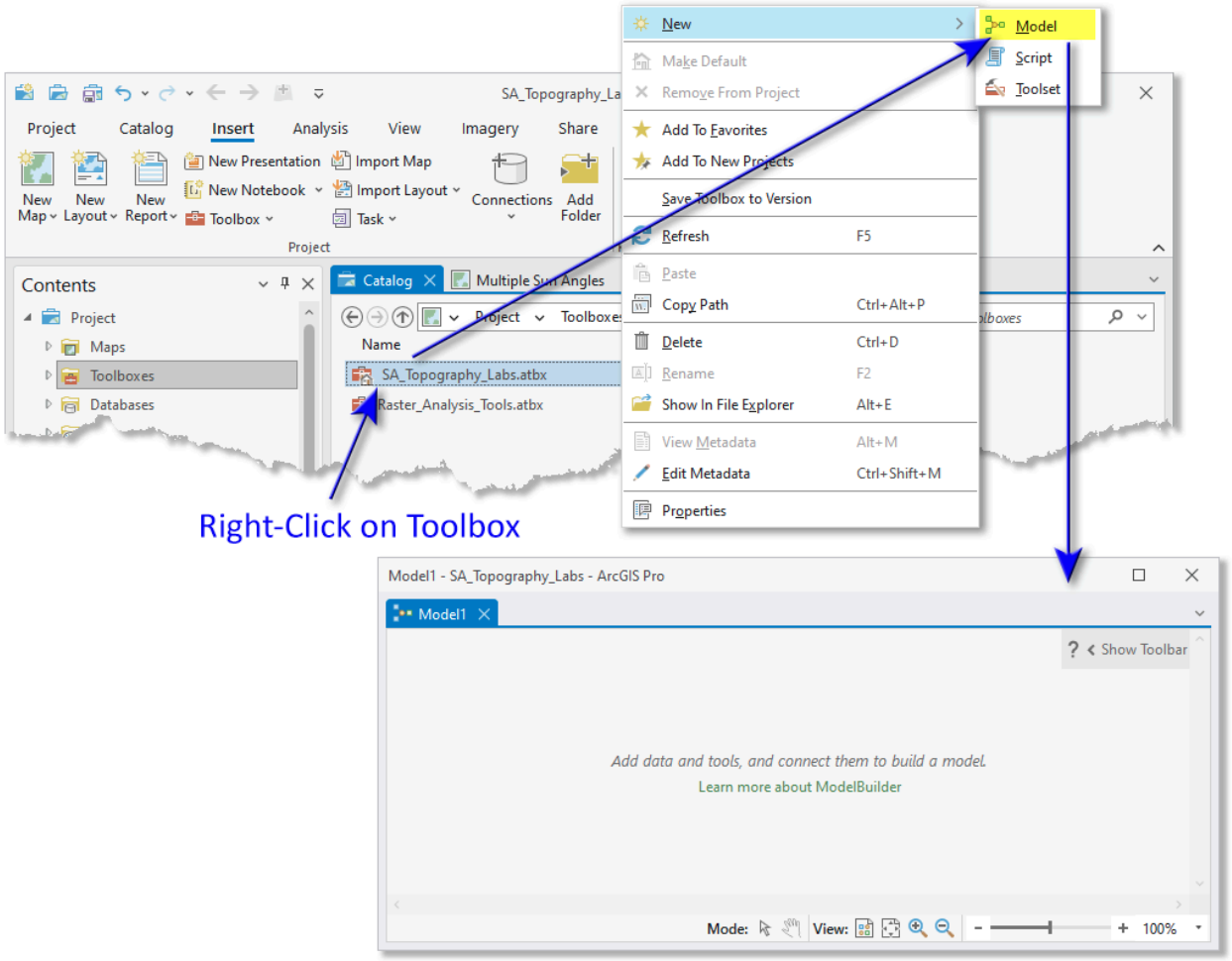
Right-Click on Toolbox

And you can easily share ArcGIS Pro toolboxes with colleagues simply by sending them the ATBX file:



Create the Model:

6) Right-click on your preferred toolbox, click “New”, then “Model”

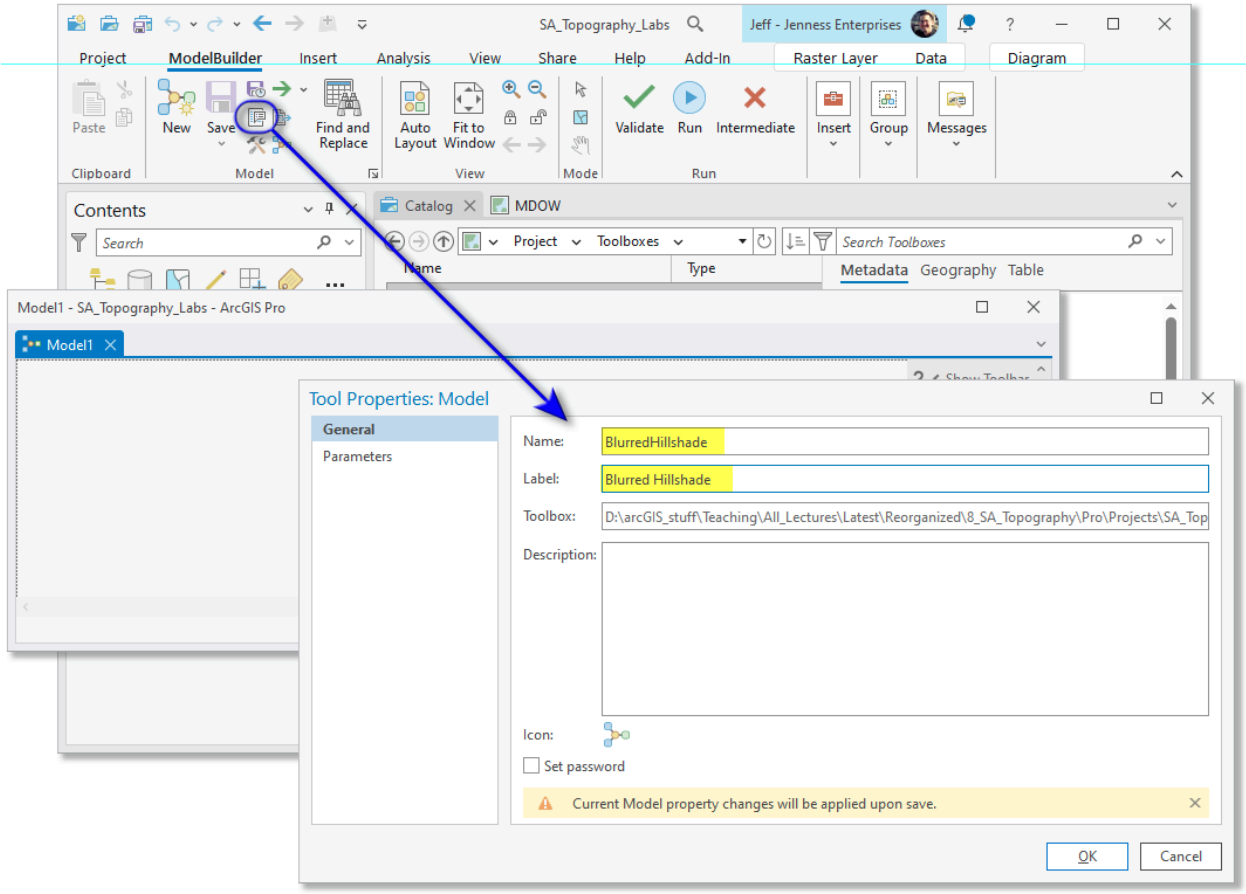


7) Change the Name and Label of your model.

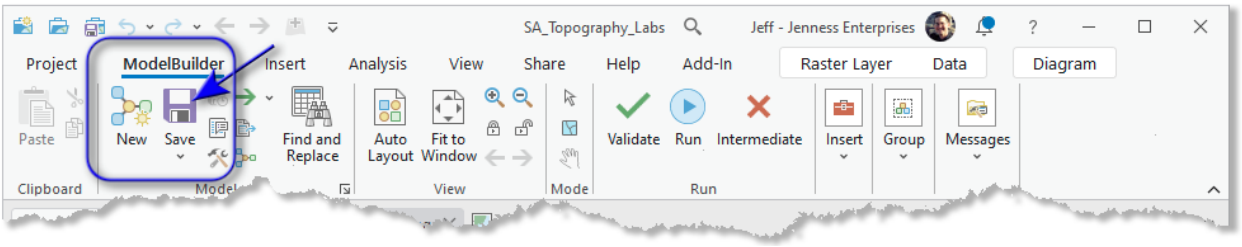
   a) In the ArcGIS Pro Ribbon, click the "ModelBuilder" tab, then the Properties icon  to open the Tool Properties window.

   b) Set the **Name** to "BlurredHillshade". Note that the name cannot have any non-alphanumeric characters in it, so no spaces, periods or underscores.

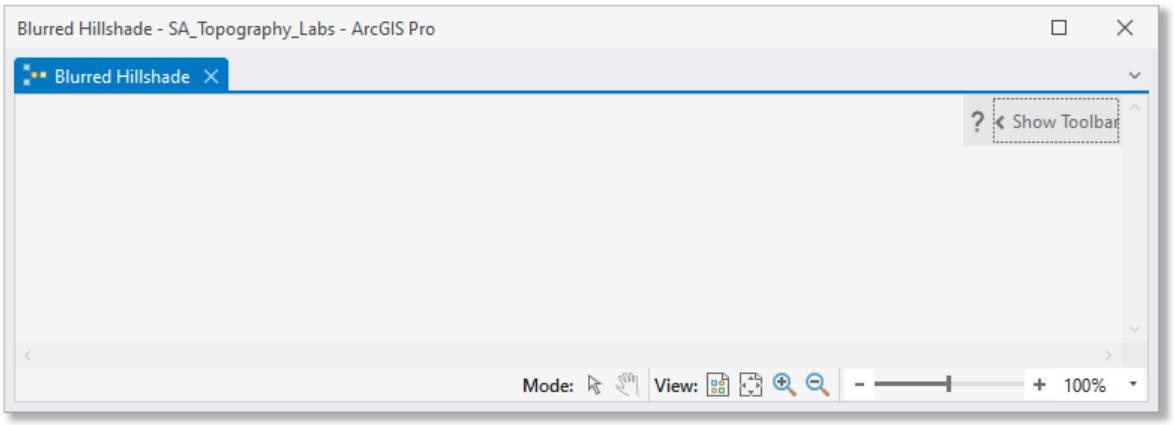
   c) Set the **Label** to "Blurred Hillshade". There are no restrictions on the text you use for your label.



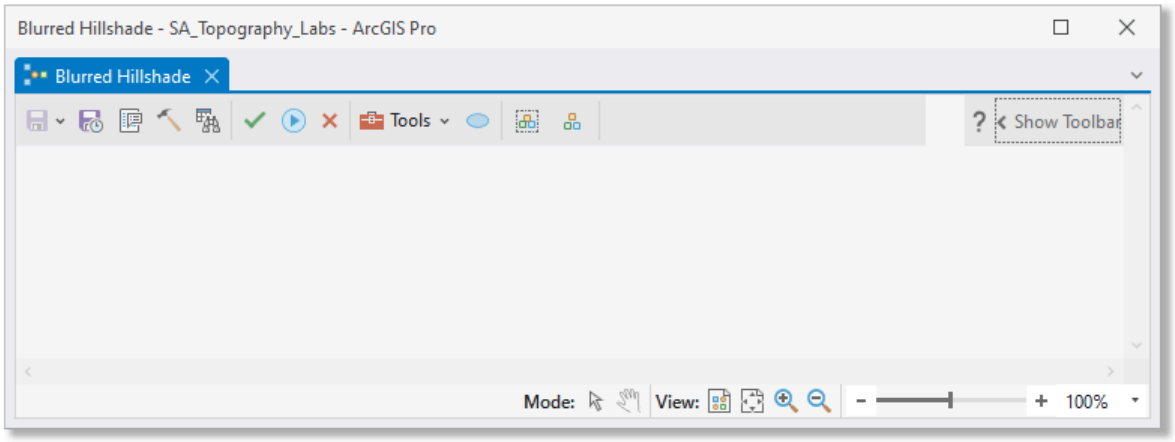
8) In the ArcGIS Pro Ribbon, click the **ModelBuilder** tab and then the **Save** icon to save your changes.

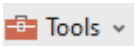


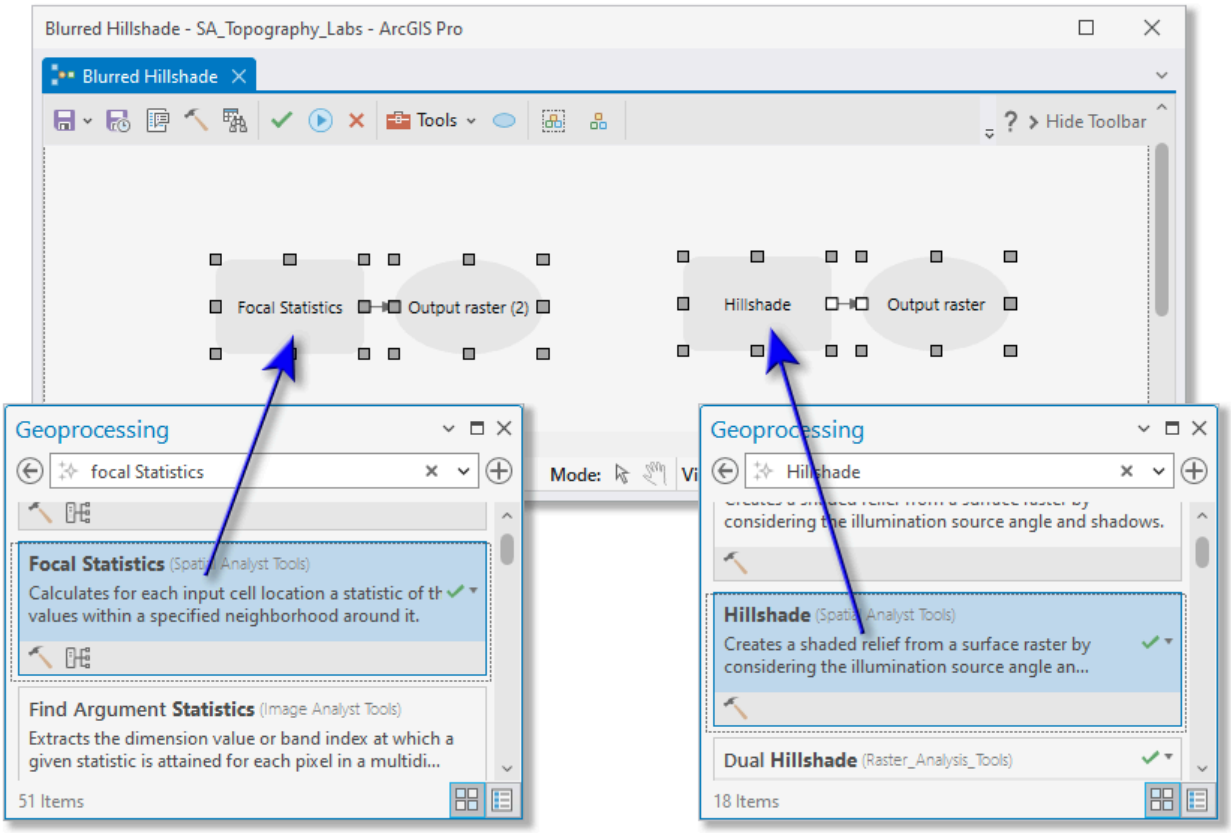
9) You should now have an empty model window that looks like the following:



10) Click the "< Show Toolbar" to add a toolbar with handy tools in the window:



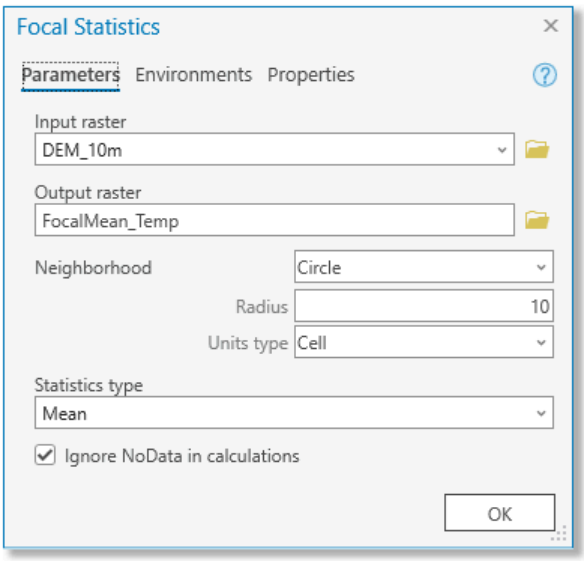
11) Click the **Tools** command  to open the **Geoprocessing** pane, then add a **Hillshade** process and a **Focal Statistics** process to your model.

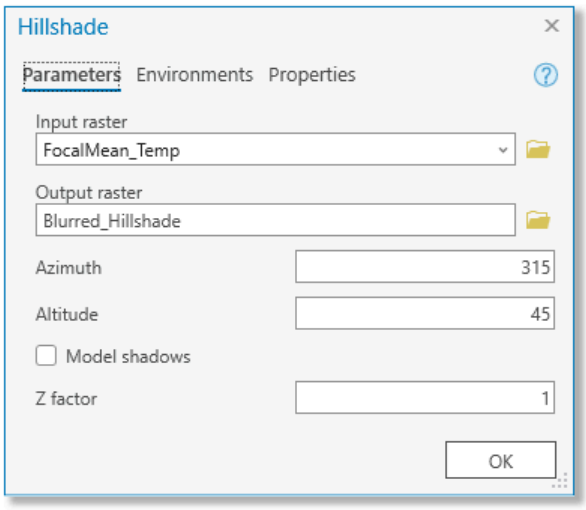


12) Set the parameters for your **Focal Statistics** process:
    a) Input Raster = **DEM_10m** raster from your map.
    b) Output raster = **FocalMean_Temp**
    c) Neighborhood = **Circle**
    d) Radius = **10**
        i) **Important Note:** This radius value determines how blurred your landscape will be. The appropriate value depends on the resolution of your raster, and how zoomed in to it your layout is. Set a larger value for more blurring, or a smaller value for less blurring. You will almost certainly try several values before you settle on one you like!
    e) Units type = **Cell**
    f) Statistics type = **Mean**
    g) Turn on **Ignore NoData in calculations**
13) For your **Hillshade** process:
    a) Input Raster = **DEM_10m** raster from your map.
    b) Output raster = **Blurred_Hillshade**
    c) Azimuth = **315**
    d) Altitude = **45**

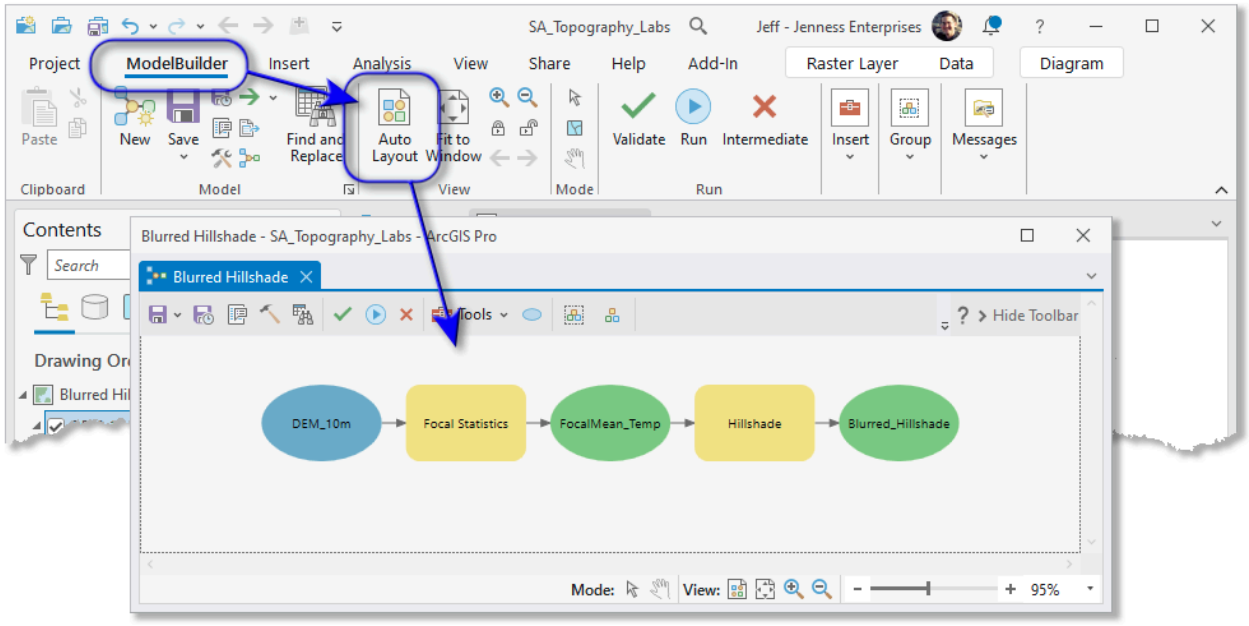
e) Leave “Model Shadows” **unchecked**

f) Set the Z-factor = **1**

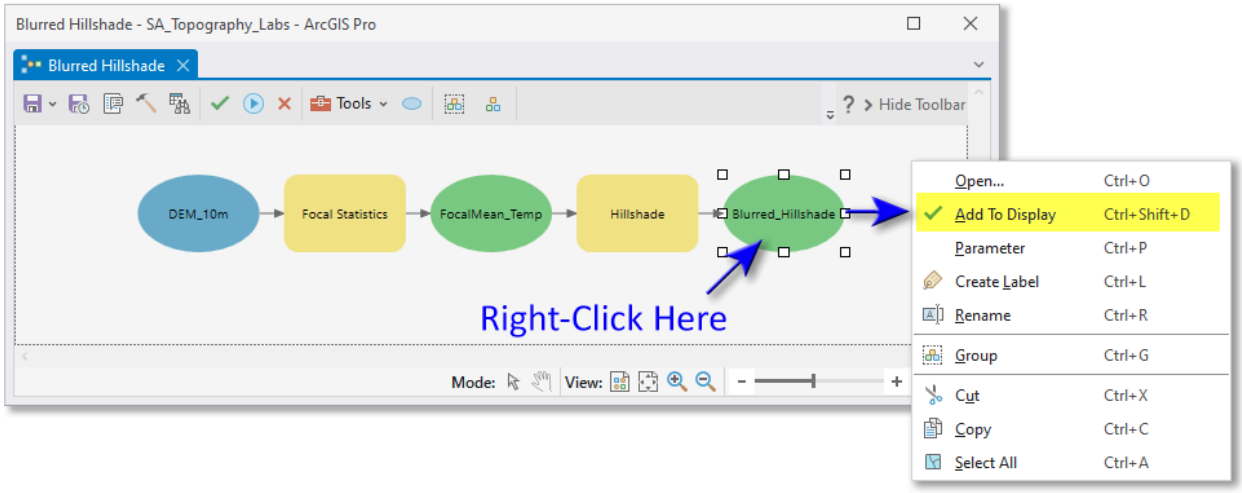




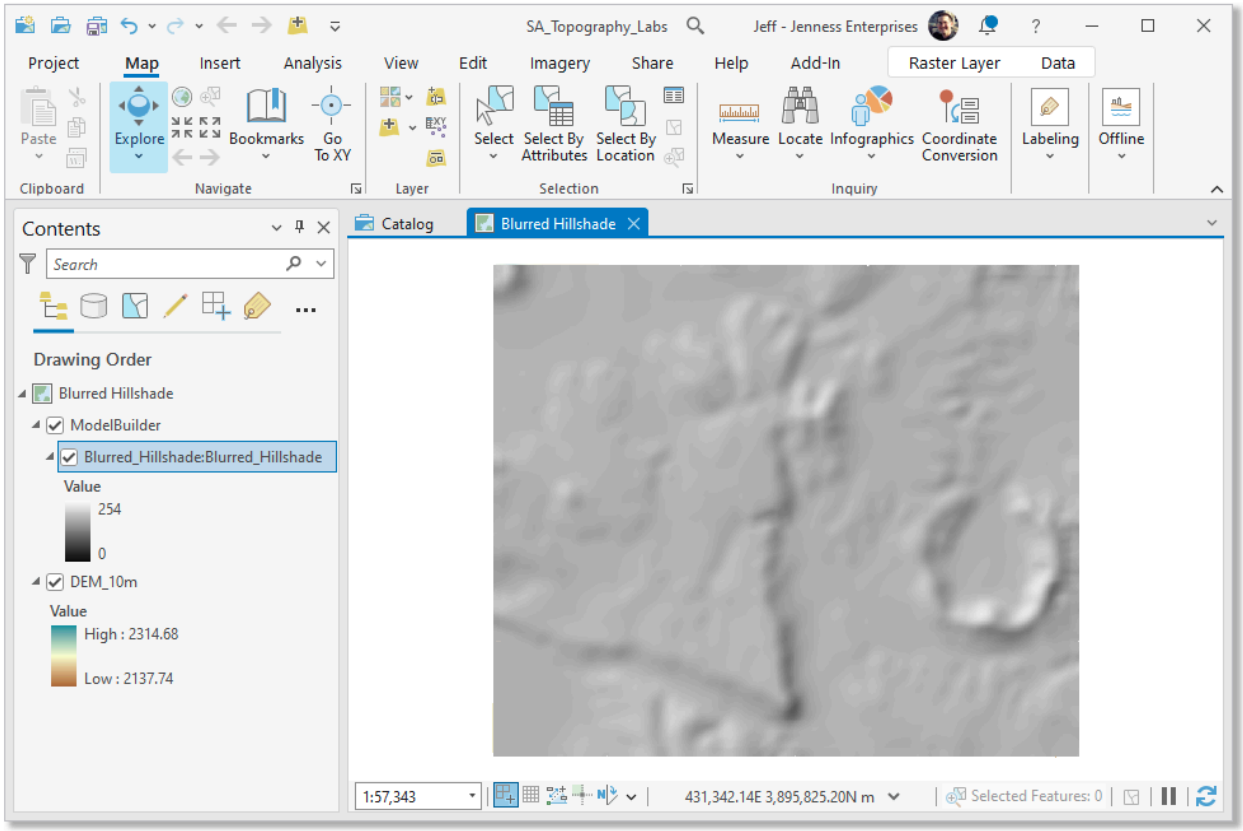
14) In your ArcGIS Pro Ribbon, click the **ModelBuilder** tab, then **Auto Layout** to organize the model processes:



15) Right-click on your **Blurred_Hillshade** green oval and confirm that your new raster is set to add to the map:

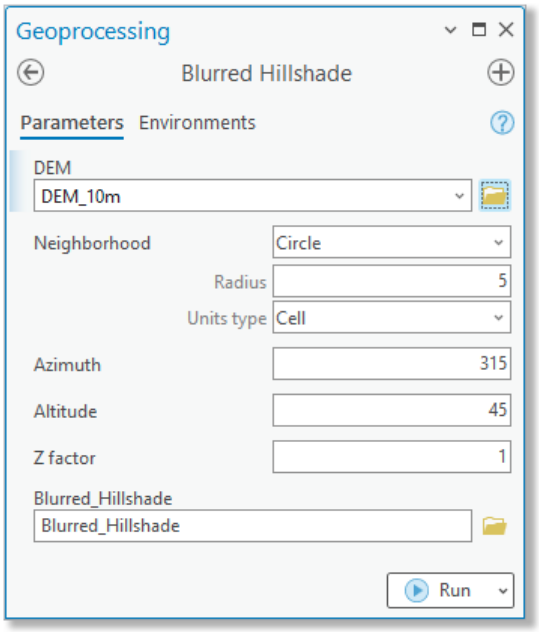


16) Your model should now be ready to run. Save your model by clicking the **Save** command , then click the **Validate** command to look for any obvious errors, and finally the **Run** command to create your blurred hillshade.

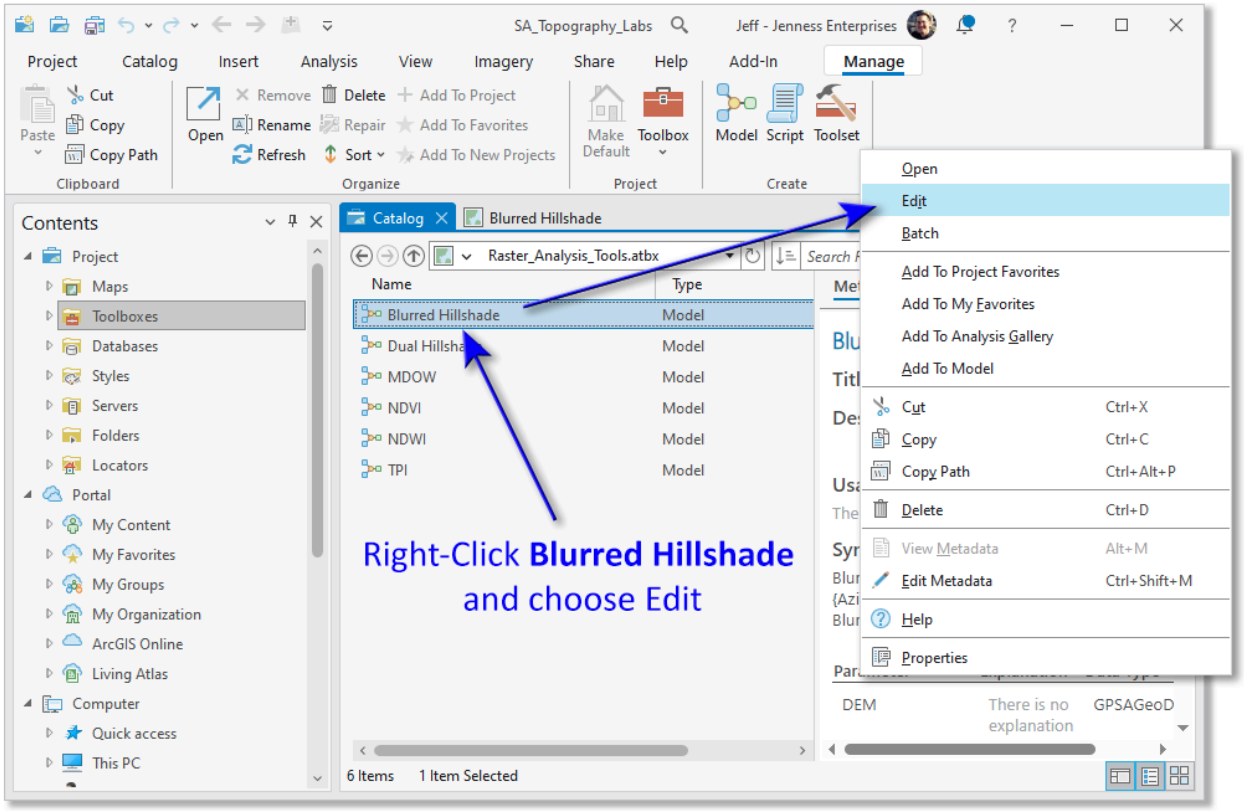


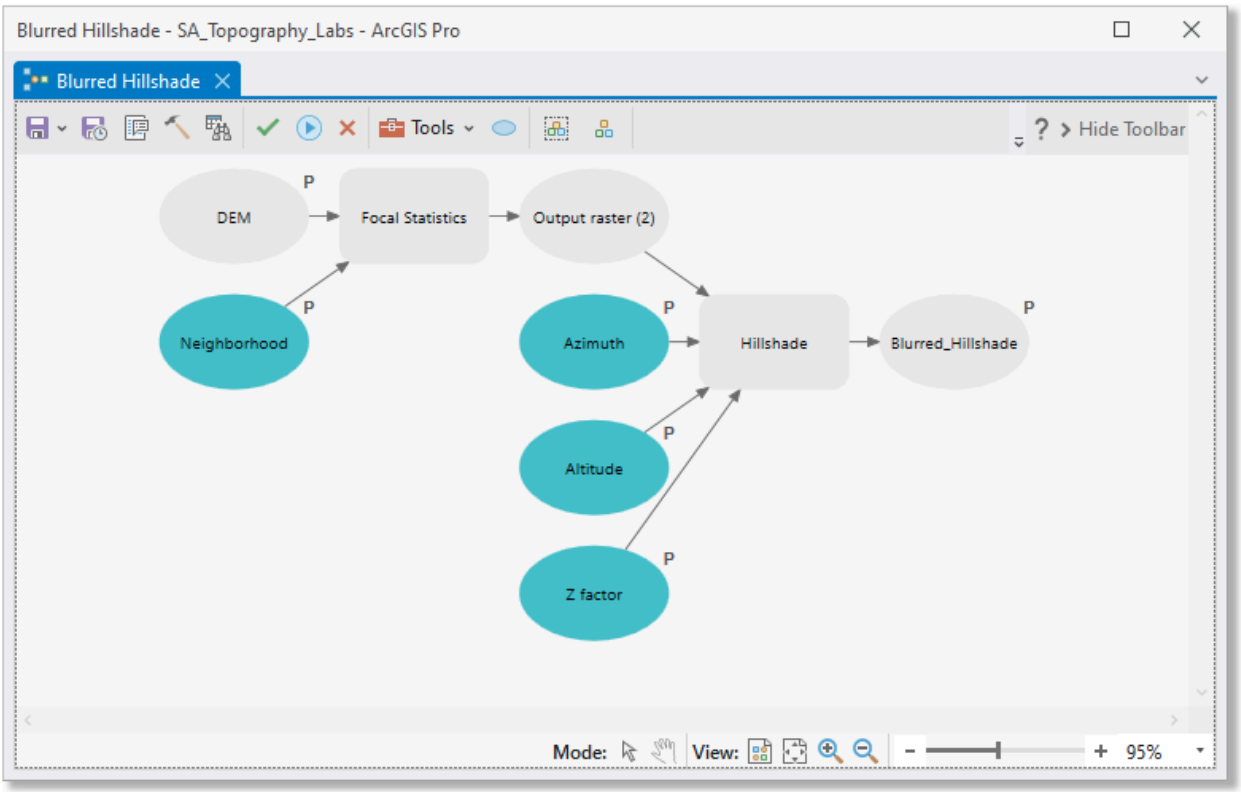
17) Finally, click the **Delete Intermediate** icon to delete the intermediate dataset created by this model (**FocalMean_Temp**).

Note: The sample **Blurred Hillshade** model available for download at the link above (see **For Fun** at the beginning of this lab exercise) is very similar to the exercise you just completed, except that I set several of the operating parameters to be model parameters. Doing this allows you to run the model by double-clicking on it in the toolbox and setting such parameters as the DEM, neighborhood size, sun positions, and output dataset manually.



Setting these parameters to be model parameters makes the tool much more flexible and easier to run with different sun locations, different neighborhood sizes, or on different data. Please take a look at that sample if you'd like to see how to set the model up to run this way. Just open the downloaded toolbox **Raster_Analysis_Tools**, right-click on the model named **Blurred Hillshade** and click "Edit" to open the model window.


SA_Topography_Labs
Jeff - Jenness Enterprises
Project
Catalog
Insert
Analysis
View
Imagery
Share
Help
Add-In
Manage
Cut
Copy
Copy Path
Paste
Open
Remove
Rename
Refresh
Delete
Repair
Sort
Add To Project
Add To Favorites
Add To New Projects
Clipboard
Organize
Make Default
Toolbox
Project
Model
Script
Toolset
Create
Contents
Project
Maps
Toolboxes
Databases
Styles
Servers
Folders
Locators
Portal
My Content
My Favorites
My Groups
My Organization
ArcGIS Online
Living Atlas
Computer
Quick access
This PC
Catalog
Blurred Hillshade
Raster_Analysis_Tools.atbx
Name
Type
Blurred Hillshade
Model
Dual Hillsha
Model
MDOW
Model
NDVI
Model
NDWI
Model
TPI
Model
Right-Click Blurred Hillshade
and choose Edit
Open
Edit
Batch
Add To Project Favorites
Add To My Favorites
Add To Analysis Gallery
Add To Model
Cut
Ctrl+X
Copy
Ctrl+C
Copy Path
Ctrl+Alt+P
Delete
Ctrl+D
View Metadata
Alt+M
Edit Metadata
Ctrl+Shift+M
Help
Properties
DEM
There is no explanation
GPSAGeoD
6 Items
1 Item Selected


Blurred Hillshade - SA_Topography_Labs - ArcGIS Pro
Blurred Hillshade
Tools
Hide Toolbar
DEM
Focal Statistics
Output raster (2)
Neighborhood
Azimuth
Hillshade
Blurred_Hillshade
Altitude
Z factor
P
Mode:
View:
95%

Appendix: Issues with Directional Data

Just FYI: This is a newsletter article I wrote in 2012 for the Spatial Ecology and Telemetry Working Group of The Wildlife Society. Some of you might find the information interesting.

Issues with Directional Data

Many characteristics of wildlife habitat and behavior include a directional component. Animal movement may tend to angle toward or away some landscape feature, and the strength of the attraction or repulsion effect may change with proximity to that object. Aspect (i.e. the azimuth the landscape faces in the direction of steepest slope) is an intuitively valuable habitat variable because north-facing slopes are typically cooler and more mesic while south-facing slopes are generally warmer and more xeric (at least in the northern hemisphere!). Habitats can be dramatically different depending on which side of a hill you stand on.

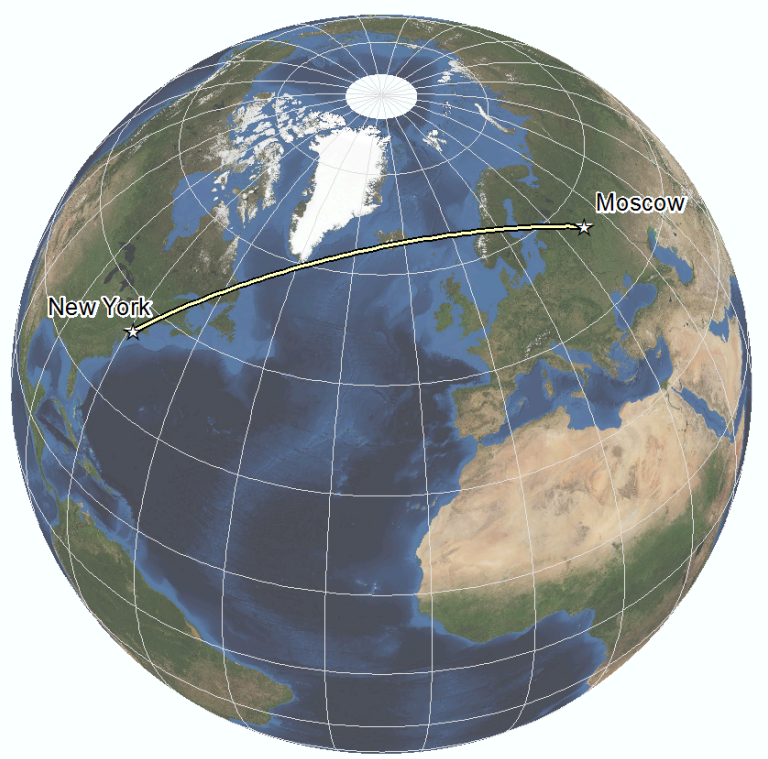
Direction can be difficult to analyze statistically because of its circular nature. The difference between 1 degree and 360 degrees is the same as the difference between 1 degree and 2 degrees, making it difficult to plug into a typical statistical model. This article will discuss some issues we often face with directional data plus some basic ideas to describe and analyze it. Many of the concepts can also be applied to other periodic data such as time, but this article will focus on direction.

An additional complication is that sometimes we consider direction as a single value (the "forward" direction) and sometimes we count both the forward and reverse directions. In wildlife analysis, direction is usually treated as a single value. We are interested in where an animal is going and why it chooses to go in the direction it does. Or we are interested in the general aspect of a habitat block, and what that means to our species of interest. In some cases, however, we need to consider both the direction and its opposite value. Analysis of geologic fracture lines on the landscape should be considered to go in both directions. Analysis of trails or paths should be treated similarly, except in the rare case of one-way trails.

Azimuths and Geodesic Curves

In most cases the direction or azimuth value is easy to define. The aspect at a point can be derived with a little math from a DEM (see "Special Considerations for Aspect" below) or with a compass. The azimuth of a movement segment is simply the azimuth from the starting to the ending points of that segment.

Complications arise if we are interested in azimuths over long distances. The straight-line segment over a long distance is best approximated by a geodesic curve representing the great circle distance (i.e. "As the crow flies") between two points. The problem here is that, with a few rare exceptions, azimuth values change constantly over the course of a geodesic curve. Consider the geodesic curve connecting New York City, USA to Moscow, Russia:



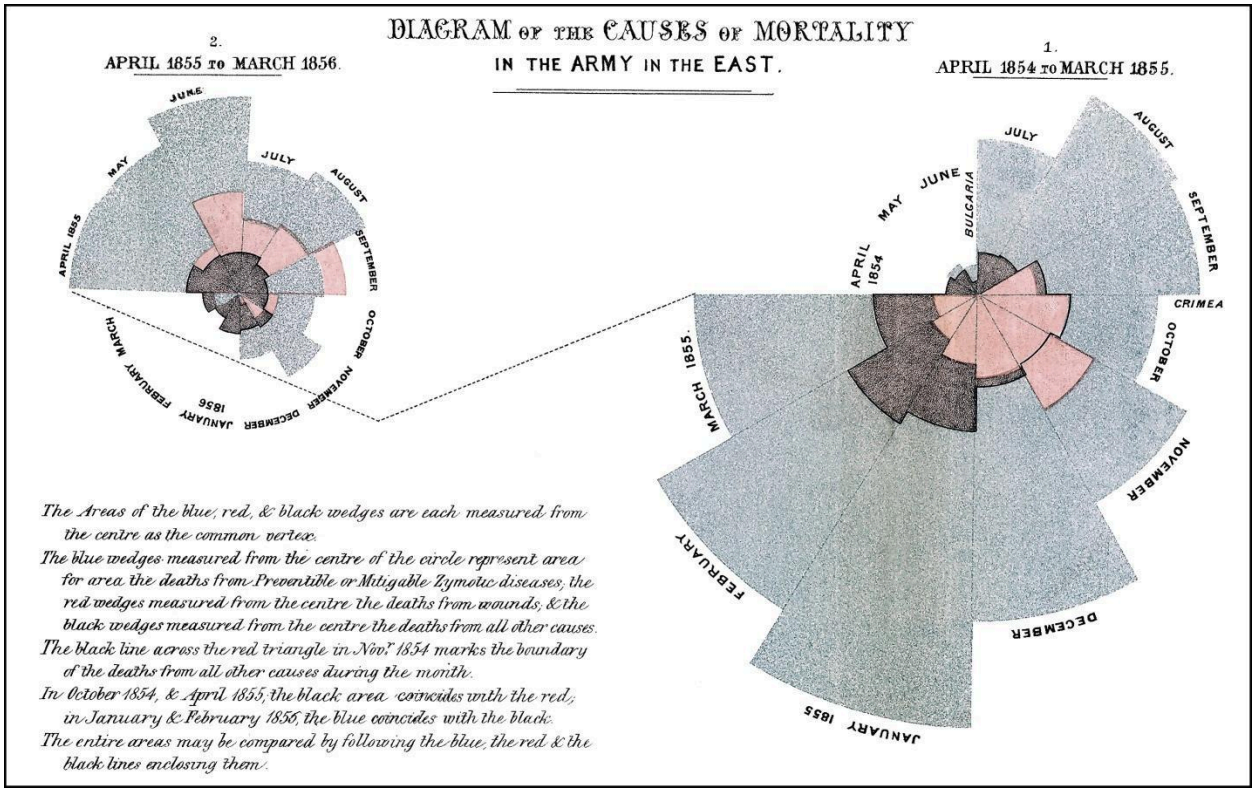
The line from New York starts at a bearing of 34°, continues in a straight line the entire way, but ends up on a bearing of 130° when it reaches Moscow.

For movement segments less than a few hundred miles, and sufficiently far away from the poles, the differences between the starting and ending azimuths tend to be negligible. For long distances and for analysis near the poles, however, we should be aware of this phenomenon and be careful about how we define our directional values.

Graphically Representing Directional Data

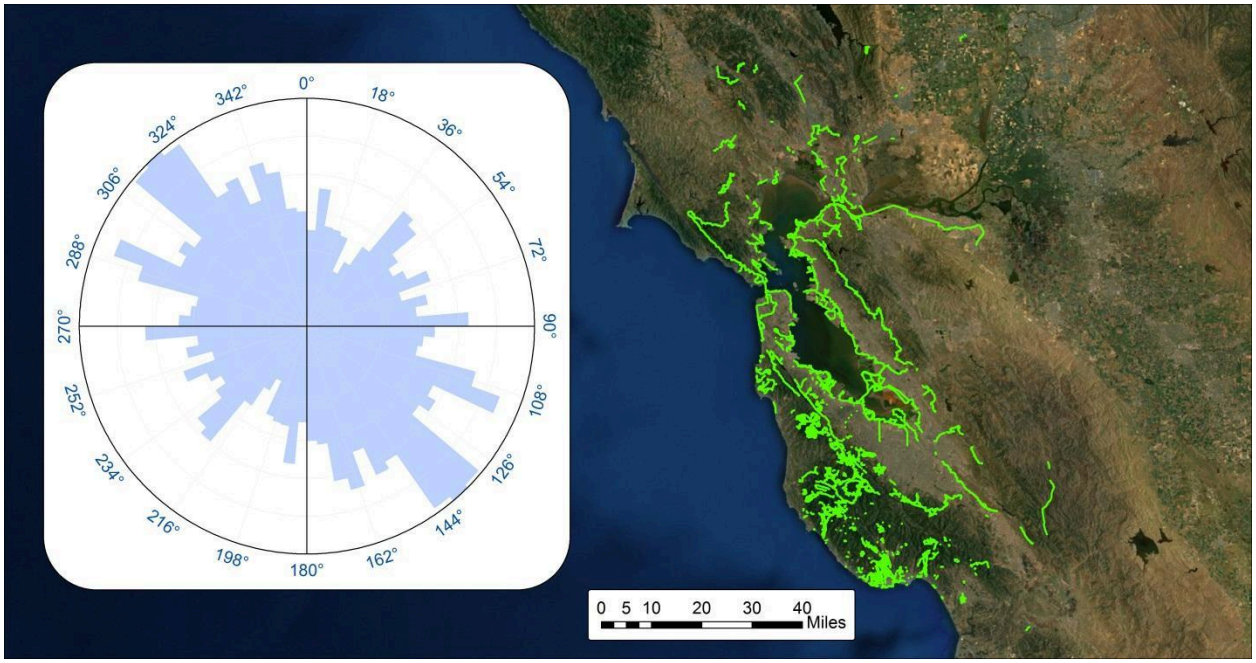
Because of the circular nature of directional data, we typically use circular plots to display the distribution. Most of these circular plots are variations on the standard histogram, except wrapped in a circle so that the maximum possible X-axis value wraps back to touch the minimum possible value.

One of the more famous and historically interesting of these is the Rose Plot or Rose Diagram, named as such because the histogram bins resemble flower petals. This type of diagram was originally popularized by nurse and statistician Florence Nightingale, who used it to show seasonal patterns in soldier mortality (see http://en.wikipedia.org/wiki/Florence_Nightingale for the source of the famous image below). Nightingale actually called these diagrams “coxcombs” because they resemble the comb of a rooster.

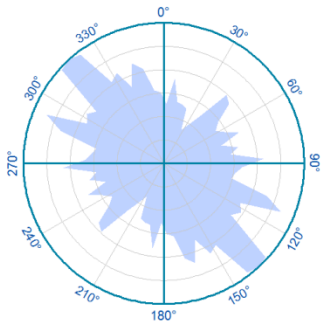


Nightingale's plots showed that mortality is very seasonal, and that far more soldiers died from disease than from wounds, and that most of them died in the winter.

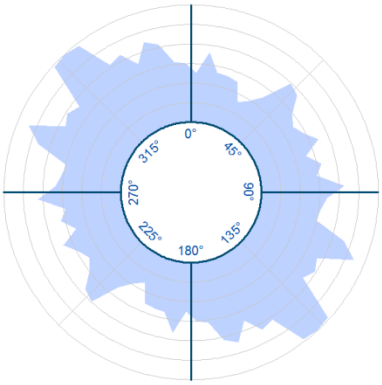
This method also works very well for displaying directional data. For example, given a set of trails in the San Francisco Bay area, we can use a rose plot to illustrate the general Northwest/Southeast orientation of those trails:



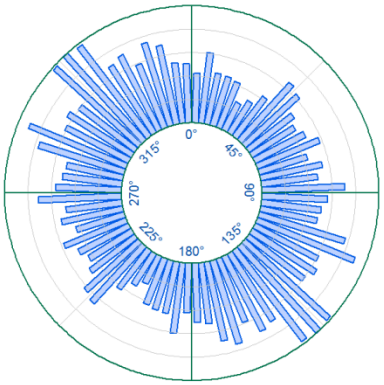
Common variations on the traditional rose plot include symbolizing the histogram bins as “Peaks and Valleys”, and putting the bins on the outside of the circle rather than the inside.



Peaks and Valleys

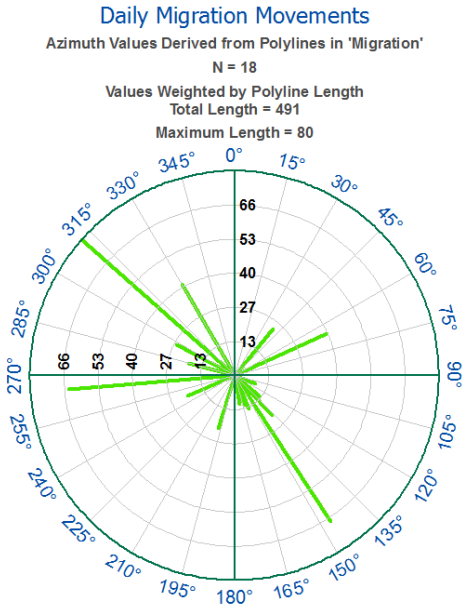


External Peaks and Valleys

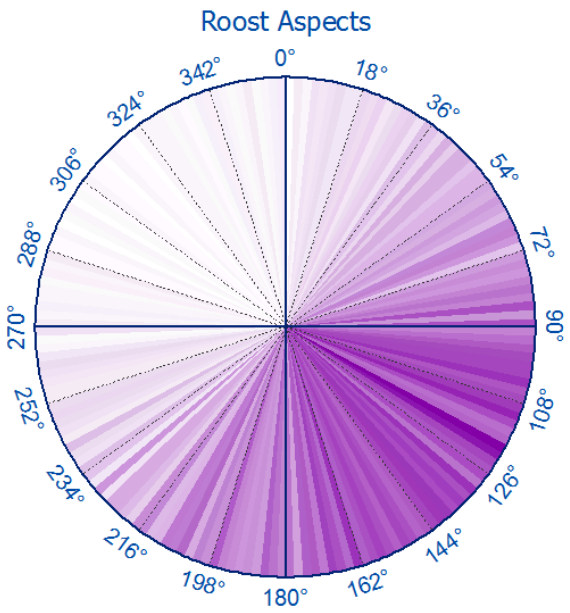


External Histogram Bins

When only a few direction values need to be displayed, you can simply show the bearings in a circular plot.



Another interesting method is a pie chart-type image where the “slices” are shaded according to the proportion of the data that faces that particular direction:



Although this last method is less effective at showing the shape of the distribution than other methods, it is still an interesting style of illustration because it is so visually intuitive. In the image above, it is easy to see that the observed roost locations predominately face toward the southeast.

For those who are interested, the author has provided a free ArcGIS extension to create all the plot types illustrated above (see http://www.jennessent.com/arcgis/polar_plots.htm). Additional software tools can be found with a Google search. Fisher (1995:15-30) also discusses alternative methods for graphing circular data.

Analyzing Directional Data

Circular Statistics

Before beginning this section, I want to emphasize two important points that people very often make mistakes with:

1) **Do not calculate the mean direction using the arithmetic mean!** This is especially frustrating because the arithmetic mean is sometimes correct and sometimes wildly incorrect. For example, the mean direction of 90° and 180° is 135°, which coincidentally is equal to the arithmetic mean $\left(\frac{90+180}{2}=135\right)$. But what is the mean direction of 359° and 1°? They are both pointing almost due north (± 1°), and clearly the true mean direction is exactly due north. However, the arithmetic mean gives us 180° $\left(\frac{359+1}{2}=180\right)$, which is due *south* and exactly the opposite of the correct answer. The correct way to calculate the mean direction is described below.

2) **If you apply a Sine or Cosine transformation, make sure to convert the values to radians first!** Most analytical software and programming languages have sine and cosine functions, but these functions usually assume the values are in *radians*, not *degrees*. There are exactly 2π (~6.28) radians in a circle. This means that the software will assume that a difference of 3.14 (i.e. π)

units is equivalent to going halfway around the circle. If your data are in degrees, then the software will interpret a change in 2° to be roughly equivalent to going a third of the way around the circle. Fortunately, it is easy to convert to radians using the following formula:

Degrees to Radians: $$Radians = \frac{Degrees \times \pi}{180} = \frac{Degrees \times (3.14159265358979)}{180}$$

It is possible that your software has a function that allows you to calculate sines and cosines from degrees (many calculators do), but even in this case you must remember to set the switch correctly.

Fortunately, there are well-established methods available for analyzing circular or periodic data such as movement direction or aspect. The circular nature of the data lead to very specific and interesting approaches to calculating measures of central tendency and dispersion. Some of the basic descriptive statistics are:

Mean Direction and Mean Resultant Length

Where: θ = Direction in Radians

$$C = \sum_{i=1}^{n} \cos\theta_i \qquad S = \sum_{i=1}^{n} \sin\theta_i \qquad R^2 = C^2 + S^2$$

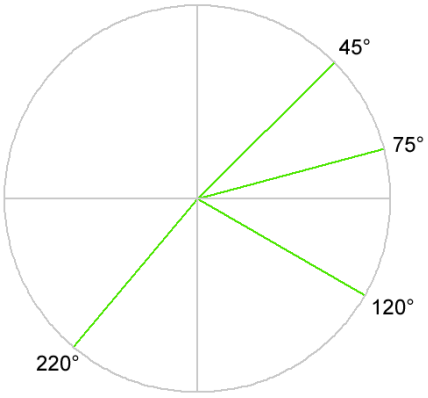
Mean Direction: $$\bar{\theta} = \begin{cases} \tan^{-1}(S/C) & S > 0,\ C > 0 \\ \tan^{-1}(S/C) + \pi & C < 0 \\ \tan^{-1}(S/C) + 2\pi & S < 0,\ C > 0 \\ \pi/2 & S > 0,\ C = 0 \\ -\pi/2 & S < 0,\ C = 0 \end{cases}$$

Resultant Length: $R = \sqrt{R^2}$

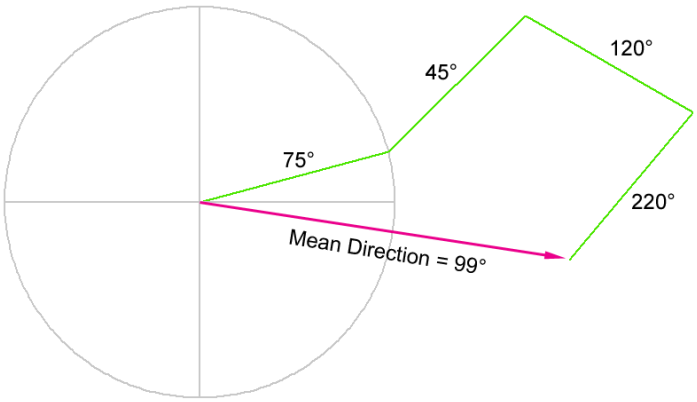
Mean Resultant Length: $\bar{R} = \frac{R}{n}$

The equations for mean direction look a little confusing, but the logic is actually very intuitive. It is simply a process of vector addition, where each direction value is a single vector. Vector addition essentially connects all the direction vectors into a path, and the mean direction is just the direction to the last point on the path.

For example, consider a scenario with 4 direction values at 45°, 75°, 120° and 220°:

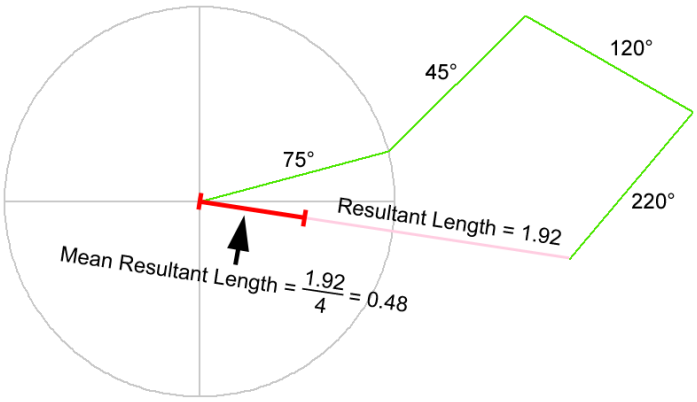


We connect the 4 bearings in a path (vector addition just adds up the ΔX and ΔY components of each vector, which is the same as treating each bearing as a segment in a path). It does not matter what order we connect the vectors in; they will always end up at the same point. The **Mean Direction** is the bearing from the start of the path to the end of the path.



On a side note, this is also the way to calculate the mean direction of an actual observed movement path. If you have a series of locations from a GPS collar on an elk, for example, and you wonder what average direction the animal moved over the day, then that average direction is simply the direction from the first GPS location of the day to the last.

The **Mean Resultant Length** $\bar{R}$ is the basis for several values of dispersion (analogous to variance or standard deviation), and is calculated as the straight-line distance from the starting point to the ending point of the path divided by the number of segments (if the segments are unit vectors, where each vector has a length of 1) or by the total length of the path if the segments have variable lengths.



Notice that the mean resultant length has a potential range of 0 to 1. If all the vectors pointed in exactly the same direction, the *resultant length* would then be equal to the total path length and the *mean resultant length* would be equal to 1. This is the scenario with the minimum possible variance or dispersion in the vectors. The more the path wanders around, the shorter both the *resultant length* and the *mean resultant length* will be. If the path ended back at the origin, then both values would be equal to 0.

Variance and Standard Deviation:

Mardia and Jupp (2000), Fisher (1995) and Batschelet (1981) describe circular statistics analogous to variance and standard deviations, based on the mean resultant length $\bar{R}$.

Circular Variance: $V = 1 - \bar{R}$ (Mardia & Jupp, Fisher)

Angular Variance: $s^2 = 2\left(1 - \bar{R}\right)$ (Batschelet)

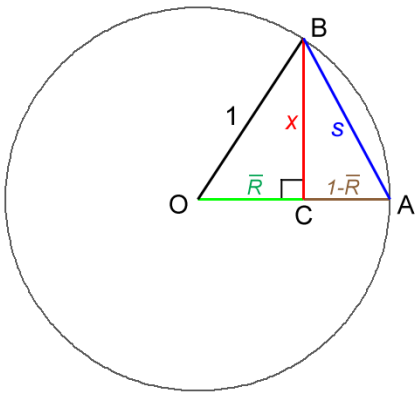
Circular Standard Deviation: $v = \sqrt{\left(-2\ln\bar{R}\right)}$ (In Radians) (Mardia & Jupp, Fisher)

Angular Deviation: $s = \sqrt{s^2} = \sqrt{2\left(1 - \bar{R}\right)}$ (In Radians) (Batschelet)

The *Circular Standard Deviation* and *Angular Deviation* are both in units of Radians, but these can easily be converted to Degrees.

Radians to Degrees: $Degrees = \frac{180}{\pi}(Radians)$

Batchelet points out that *circular standard deviation* and the *angular deviation* tend to be close to each other for most values of $\bar{R}$. However, as $\bar{R}$ tends toward 0, *circular standard deviation* tends toward ∞ while *angular deviation* tends toward a maximum value of $\sqrt{2}$. Batchelet, summarizing from Seyfarth and Barth (1972), presents a geometric derivation of angular deviation which also provides a visual sense of what the concept means.



Given a unit circle with Radius = 1, and with:

- Point *A* defined as on the circle horizontal from the Origin *O*
- Point *C* defined as $\bar{R}$ distance along segment *OA* (remember that $\bar{R}$ will always be between 0 and 1)
- Point *B* defined as on the circle vertical from Point *C*

Then ***s*** (angular deviation) is just the length of the line connecting points A and B. The angular deviation can therefore be calculated by applying the Pythagorean theorem to ΔBCO and ΔABC:

From the Pythagorean Theorem on ΔBCO:

$$x^2 + \bar{R}^2 = 1^2$$

$$\therefore x^2 = 1 - \bar{R}^2$$

From the Pythagorean Theorem on ΔABC:

$$s^2 = \left(1 - \bar{R}\right)^2 + x^2$$

Substituting for x:

$$\begin{aligned} s^2 &= \left(1 - \bar{R}\right)^2 + \left(1 - \bar{R}^2\right) \\ &= \left(1 - \bar{R}\right)\left(1 - \bar{R}\right) + 1 - \bar{R}^2 \\ &= 1 - 2\bar{R} + \bar{R}^2 + 1 - \bar{R}^2 \\ &= 2 - 2\bar{R} \\ &= 2\left(1 - \bar{R}\right) \end{aligned}$$

$$\therefore s = \sqrt{2\left(1 - \bar{R}\right)}$$

Based on this illustration, it is easy to see that $s = 0$ when $\bar{R} = 1$, and that $s = \sqrt{2}$ when $\bar{R} = 0$

Note: A mean resultant length $\left(\bar{R}\right)$ near 1 always implies a tightly focused set of directions, but a mean resultant length near 0 does **not** necessarily imply a high amount of variation or dispersion. All it implies is that the directions balance each other out. This can occur with a uniform distribution of directions, in which case there truly would be high dispersion. It can also occur, however, if you have a number of

bearings in one direction and an equal number in the opposite direction. For example, perhaps you have a bird with distinct and separate roost and forage locations. Every day the bird travels to the forage location and then returns to the roost location. In this scenario, the bird only goes in two distinct and opposite directions (to the forage location, and then back to the roost location). The bird's movement directions are highly focused and predictable, but the mean resultant length would be 0 and consequently the variance would be high. As with most situations, plotting the distribution of the data is a good way to understand what is really happening.

Just as with standard statistics, there are a number of circular distributions and sophisticated analytical techniques available. These go beyond the scope of this newsletter article, but please refer to Jammalamadaka and SenGupta (2001), Mardia and Jupp (2000), Zar (1999; see especially ch. 26 and 27), Fisher (1995) and Batschelet (1981) for some good texts on circular statistics, distributions (i.e. the Fisher, Von Mises and Wrapped Normal distributions), circular hypothesis testing and other analytical techniques. There is also a good circular statistical package for R, originally based on Jammalamadaka and SenGupta's text. As of June, 2012, the manual for this package can be viewed at http://cran.wustl.edu/web/packages/circular/circular.pdf.

Other Methods to Analyze Directional Data

If we want to include direction as one of several independent predictor variables in a traditional statistical analysis, then we must transform the value into something approaching a linear measure. There are a few straightforward ways to do this, although any transformation will probably violate some of the assumptions of most traditional statistical tests.

Classification of Aspect Values

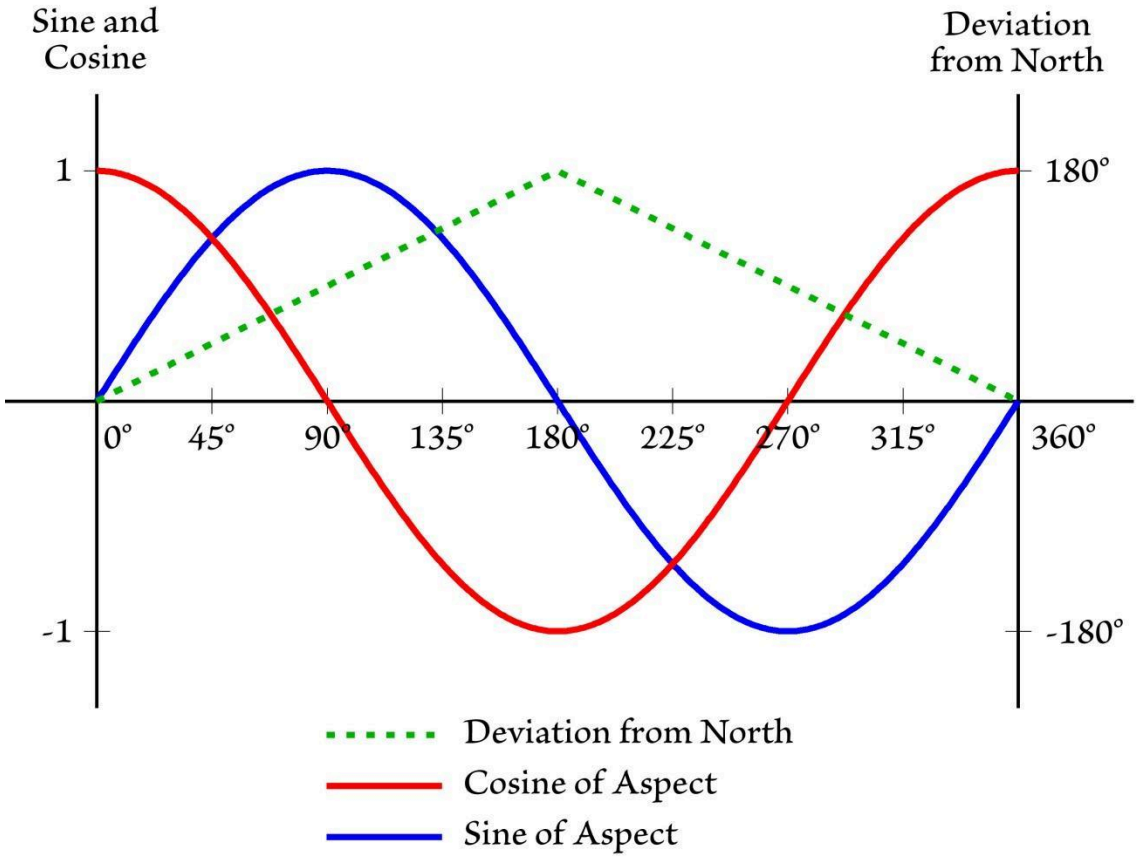
Probably the easiest transformation is to simply group your direction values into general and intuitive ranges (for example, "N" = 315 – 45, "E" = 45 – 135, "S" = 135 – 225, and "W" = 225 - 315), creating a categorical dataset which may be appropriate for some analyses.

Deviations from a Bearing

A simple and basic transformation is to convert your direction values into deviations from a direction of interest. For example, if you felt that the object of your study was likely to be affected by the north- vs. south-facing aspect phenomenon, then you might define your direction values in terms of "Deviation from North" where each value would reflect the distance, in degrees, from due North. Your full set of transformed values would range from 0 to 180 (see figure below). This option has the advantage of maintaining a constant interval between units, such that the difference in direction between 0 and 1 degree is the same as the difference between 90 and 91 degrees.

Sine and Cosine Transformations

Aspect values are often converted to sine and cosine values, essentially decomposing them into north-south and east-west components. *Remember to convert your direction values to radians before doing this transformation!* Sine values range from -1 (at due west) to 1 (at due east), while cosine values range from -1 (at due south) to 1 (at due north). Note that this method does not maintain a constant interval between units. The sine and cosine values change by a variable amount depending on the direction, such that a change in sine corresponding to a change of 1 degree = 0.00015 when going from 90 to 91 degrees, but increases by more than 2 orders of magnitude to 0.017 when going from 180 to 181 degrees. This issue may be important in your statistical analysis if your method assumes that your data are interval-level.



Trimble and Weitzman (1956) and Beers et al. (1966) suggest an interesting alternative combining two of the approaches above, rescaling aspect values based on an optimum bearing (135° for Trimble & Weitzman, and a general equation for any aspect of interest for Beers et al.) then taking the sine of the rescaled values, then adding 1, which they put to extensive use in site productivity research for timber stands. Beers et al.'s general equation is:

$$A' = \text{Transformed Aspect Code}$$
$$= \sin\left[A + (90 - A_{Max})\right] + 1$$
$$= \cos(A_{Max} - A) + 1$$

Where:

A_{Max} = The aspect which is to be assigned the highest numerical value on the transform scale

Special Considerations for Aspect

How Aspect is Calculated

Aspect is calculated from the directional East-West and North-South gradients at a particular point. There are various methods for estimating these directional gradients from a 3x3 set of elevation points, but in general aspect is defined as the direction of maximum slope. Given that *G* = east-to-west gradient and *H* = north-to-south gradient, then aspect is calculated as follows:

$$\text{Mathematical Direction (in degrees)} = \text{atan2}(H, -G)\left(\frac{180}{\pi}\right)$$

The "atan2" function is a method of calculating the arctangent $\left(\tan^{-1}\right)$ using two values (ΔX and ΔY), and it has a possible range representing a full circle (-π to +π radians, or -180° to +180°). The standard arctangent function can only produce values ranging from $-\frac{\pi}{2}$ to $+\frac{\pi}{2}$, or -90° to +90°. This atan2 function is the same one used to calculate mean direction above, and is calculated as follows:

$$\text{atan2}(y,x):\ \bar{\theta} = \begin{cases} \tan^{-1}\left(\frac{y}{x}\right) & y > 0,\ x > 0 \\ \tan^{-1}\left(\frac{y}{x}\right) + \pi & y \geq 0,\ x < 0 \\ \tan^{-1}\left(\frac{y}{x}\right) - \pi & y < 0,\ x < 0 \\ \pi/2 & y > 0,\ x = 0 \\ -\pi/2 & y < 0,\ x = 0 \\ \text{Undefined} & y = 0,\ x = 0 \quad \text{(i.e. no movement)} \end{cases}$$

Mathematical direction is different than compass direction. In the mathematical polar coordinate system, 0° is equivalent to due east and polar directions increase in a counter-clockwise direction. Compass direction starts at north and increases in a clockwise direction. Therefore we must convert the mathematical direction to a compass aspect according to the following rules:

if *Mathematical Direction* > 90° then *Aspect* = (450 – Direction)

Otherwise *Aspect* = (90 – Direction)

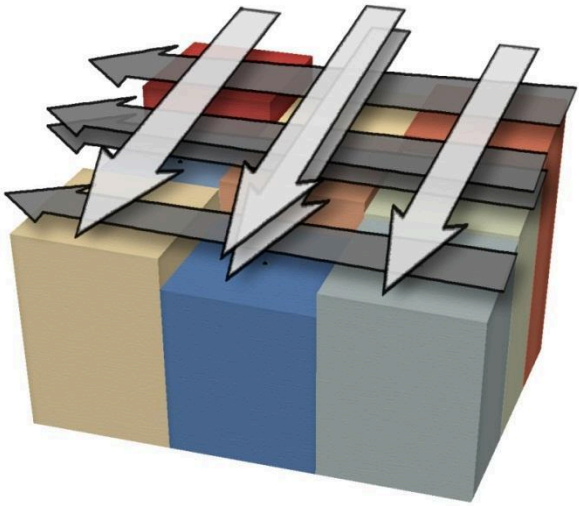
ArcGIS uses Horn's method (Horn 1981, Burrough and McDonnell 1998)to calculate the east-west (G) and north-south (H) gradients from a 3x3 array of elevation points. The figure below shows the 8 elevation values that are used to calculate aspect at the central cell XX (note that the formula does not use the elevation value at the central cell):

```
Z1 ---- Z2 ---- Z3
 |       |       |
 |       |       |
 |       |       |
Z4 ---- XX ---- Z6
 |       |       |
 |       |       |
 |       |       |
Z7 ---- Z8 ---- Z9
```

In Horn's Method, the north-south gradient is calculated from all three columns in the 3x3 array, with the central column weighted twice as high as the two outer columns. The east-west gradient is calculated in a similar manner.

$$\text{East-West Gradient} = G = \frac{\left[\left(Z_3 + 2Z_6 + Z_9\right) - \left(Z_1 + 2Z_4 + Z_7\right)\right]}{8\Delta x}$$

$$\text{North-South Gradient} = H = \frac{\left[\left(Z_1 + 2Z_2 + Z_3\right) - \left(Z_7 + 2Z_8 + Z_9\right)\right]}{8\Delta y}$$



Is this the best method to calculate aspect?

Interestingly, Jones (1998) compared several slope and aspect algorithms on a mathematical surface in which the true exact slope and aspect at any point could be calculated. He found that Horn's method did better than most methods, but was marginally worse than a method called the 4-cell method. He then tested all methods on a true landscape DEM and found that the rankings among methods were consistent, so Horn's method still came in 2nd place.

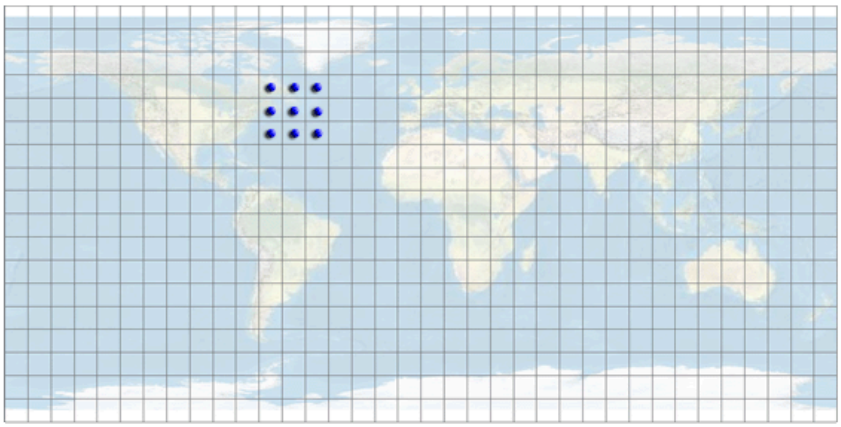
Another tidbit: Michael Hodgson (1995) published a paper using the same mathematical surface that Jones (1998) did, in which he demonstrates that the area represented by computed slope and aspect is actually larger than the raster DEM cell size. 8-cell algorithms (such as *Horn's* method) more accurately reflect values for an area approximately twice the cell size, while 4-cell algorithms (such as the *4-Cell* method) reflect an area approximately 1.6X the original cell area.

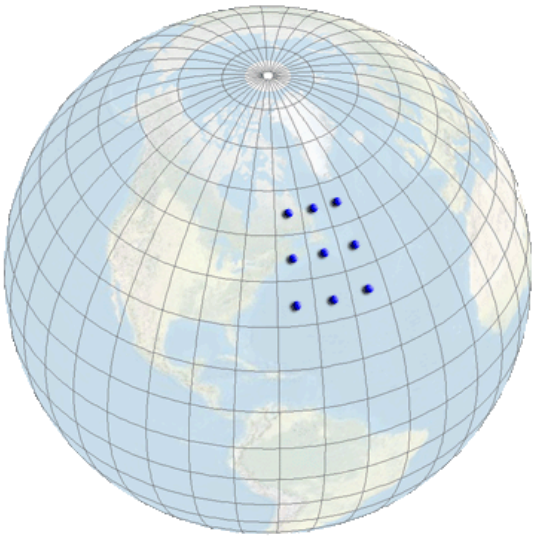
In sum, a method called the 4-cell method is simpler, slightly quicker to calculate, more precise and marginally more accurate than Horn's method.

For those who are interested, the author offers a free ArcGIS extension that will calculate slope and aspect using a variety of methods including both Horn's method and the 4-cell method (see http://www.jennessent.com/arcgis/surface_area.htm). This extension does not require Spatial Analyst.

Issues with Aspect

As a consequence of determining aspect from East-West and North-South components, aspect can be difficult to calculate from geographically-projected (latitude/longitude) data. The equations above all work for 3x3 arrays in which the elevation locations are all equally spaced along both the X- and Y-axes. However, this is not the case with latitude / longitude data. Raster cells that are square in unprojected space actually form trapezoids when viewed on the actual surface of the planet.





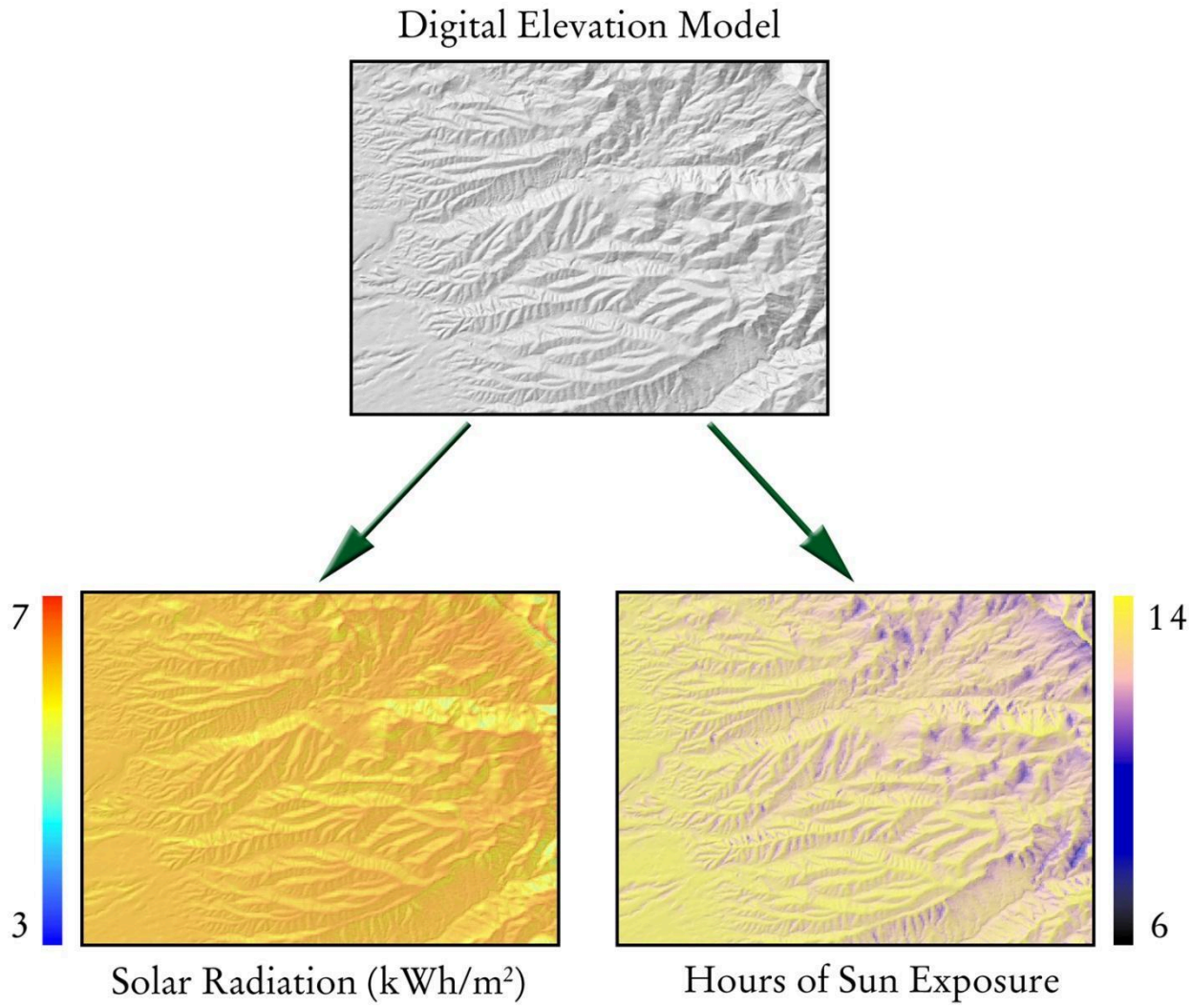
In this case, we cannot treat the cell size as a single constant value. The methods to correct for latitude/longitude data go beyond the scope of this article but are described in Jenness (2011; see especially p. 40 - 49 of the manual at http://www.jennessent.com/downloads/DEM%20Surface%20Tools%20for%20ArcGIS.pdf). For those who are interested, the author's free ArcGIS extension DEM Surface Tools will automatically correct for latitude/longitude data (see http://www.jennessent.com/arcgis/surface_area.htm).

Solar Insolation: An alternative to Aspect

Aspect has a well-established history in habitat analysis. It is both easy to measure and a good predictor of certain habitat characteristics. However, in some cases we are really interested in how much direct sunlight hits an area (insolation), which is a function of aspect, slope, nearby topography, landscape reflectivity and atmospheric effects, and as such may be a more important driver of habitat characteristics than aspect alone. In such cases, it may be worthwhile to estimate insolation directly rather than use aspect as a surrogate. There are a few approaches you can take:

ESRI's Solar Radiation Tool

As of version 9.2 of ArcGIS and Spatial Analyst, ESRI has included a tool in the Toolboxes to calculate solar radiation for specific points on the landscape, or over the entire landscape.



This function incorporates both direct and diffuse radiation and shadows from nearby topography. It includes several useful options, including:

1) Outputs either the amount of energy hitting the ground (in Watts per Hour), or the total number of hours in which the ground is exposed to the sun.
2) Can be calculated for specific dates, seasons or years.
3) Has optional parameters where you can specify the general atmospheric conditions in your area of interest.
4) Has optional parameters where you can specify how intensively it examines the local topography before determining the amount of radiation hitting an area.

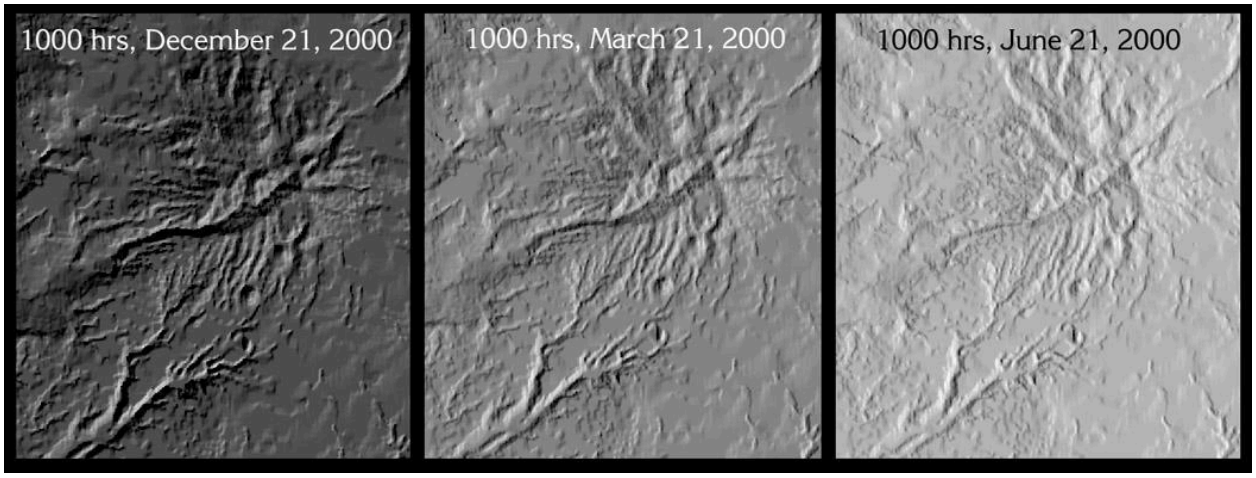
In general, this is a wonderful and exciting new tool. I have noticed two minor drawbacks to the tool:

1) It is slow on large grids, and on occasion I have needed to let it run for hours or days.
2) I do not believe that it incorporates reflectivity off the landscape. This would be hard to model, of course, and would depend on exactly how reflective your landscape is (snow reflects very differently from lava rocks, for example).

Despite these two minor drawbacks, I expect that this tool will become very valuable for habitat analysis.

Hillshade

For those who do not have access to the Solar Analyst, you can use the hillshade function available in many GIS packages get a reasonable estimate for the relative amount of sunlight that hits the landscape at a single point in time. Values will typically range from 0 (meaning no sunlight hits the landscape) to 255 (meaning the angle of the landscape is facing the sun directly). Hillshades are difficult to calculate if your DEM is in geographic coordinates, but the author offers a free ArcGIS tool to do this (see http://www.jennessent.com/arcgis/surface_area.htm) which does not require Spatial Analyst.



References

Batschelet, E. 1981. Circular statistics in biology. Academic Press, London; New York.

Beers, T. W., P. E. Dress, and L. C. Wensel. 1966. Notes and Observations: Aspect Transformation in Site Productivity Research. Journal of Forestry 64:691–692.

Burrough, P. A., and R. A. McDonnell. 1998. Principles of geographical information systems. Oxford University Press, Oxford.

Fisher, N. I. 1995. Statistical analysis of circular data. Cambridge University Press, Cambridge [England]; New York.

Hodgson, M. 1995. What cell size does the computed slope/aspect angle represent? Volume 61. Photogrammetric engineering and remote sensing, American Society for Photogrammetry and Remote Sensing, Bethesda, MD, ETATS-UNIS.

Horn, B. K. P. 1981. Hill shading and the reflectance map. Proceedings of the IEEE 69:14–47.

Jammalamadaka, S. R., and A. SenGupta. 2001. Topics in circular statistics. World Scientific, River Edge, N.J.

Jenness, J. 2011. DEM Surface Tools: An ArcGIS Extension for Analyzing Raster Elevation Datasets. Jenness Enterprises. <http://www.jennessent.com/arcgis/surface_area.htm>. Accessed 27 Jun 2012.

Jones, K. H. 1998. A comparison of algorithms used to compute hill slope as a property of the DEM. Computers & Geosciences 24:315–323.

Mardia, K. V., and P. E. Jupp. 2000. Directional statistics. Wiley, New York.

Mark, R. K. 1992. A multidirectional, oblique-weighted, shaded-relief image of the Island of Hawaii. US Dept. of the Interior, US Geological Survey,.

Seyfarth, E.-A., and F. G. Barth. 1972. Compound slit sense organs on the spider leg: Mechanoreceptors involved in kinesthetic orientation. Journal of Comparative Physiology A: Neuroethology, Sensory, Neural, and Behavioral Physiology 78:176–191.
Trimble, G. R., and S. Weitzman. 1956. Site Index Studies of Upland Oaks in the Northern Appalachians. Forest Science 2:162–173.
Zar, Jerrold H. 1999. Biostatistical Analysis. 4th edition. Pearson Education.