Remote Sensing

Georeferencing and Preprocessing

Image from NASA:
https://commons.wikimedia.org/wiki/File:Earth_Western_Hemisphere_transparent_background.png#filelinks

In this module, we will explore a variety of image pre-processing tasks with a focus on georeferencing and resampling.

Module Topics

1. Georeferencing
2. Control point selection
3. Georeferencing algorithms
4. Georeferencing assessment and RMSE
5. Resampling methods
6. Pixel aggregation
7. Reprojection, stacking, extraction, mosaicking, pyramids, pansharpening
8. Conversion between DNs, radiance, top of atmosphere reflectance, and surface reflectance

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These are the topics covered in this module.

Georeferencing

Georeferencing

- Process of aligning an unreferenced dataset with one that has spatial reference information.

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Georeferencing is the process of aligning an unreferenced dataset with one that has spatial reference information. As an example, you may want to use a paper map in your GIS. In order to use it effectively with other data layers, it will need to be referenced to the correct location in the map space. So, you will need to create a digital data file then apply a process to align it to other data layers in the map space. This is the process of georeferencing.

When aerial or satellite imagery are collected, they also need to be referenced to the correct location in the map space. So, this is a common preparatory task when working with spatial data.

Many GIS and remote sensing software packages provide georeferencing tools, including ArcGIS Pro, Erdas Imagine, and QGIS.

Control Points

- Used to register dataset to known location

Control points are an important component of the georeferencing process. Control points are used as reference and represent the same location in the data being referenced and reference data.

Control points can be created by digitizing examples on the screen. Whenever aerial imagery is collected, it is common for ground control points to be placed on the ground prior to the data collection. These ground targets are surveyed using GPS equipment. An analyst can then use the ground targets in the image and their associated coordinates to georeference the data. This method generally produces quality results. However, this is only possible if control points can be placed in the image prior to the data collection or if the analyst can identify control points in the image that can be surveyed after the collection, such as the location of a sidewalk crossing.

So, many times we are forced to create control points on the computer screen and georeference our data relative to a dataset that has already been referenced, such as aerial imagery.

Control Points

- Spread evenly around study area
- Enough points to use the algorithm of choice
- Use highest accuracy dataset possible
- Use locations identifiable on both datasets (known & unknown)

- From Point = location on the data being referenced
- To Point = same location on the reference data

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Collecting quality control points is key for successful georeferencing. Here are some suggestions for collecting quality control points. First, the control points should be spread evenly around the study area or image. If the control points are only collected within the center of the image, the algorithm used will have a difficult time accurately referencing the margins of the image. So, make sure to include some points in the image margins.

You should have enough points to use the desired georeferencing algorithm. The number of points needed depends on the algorithm, which we will discuss later.

Any positional errors in the input data will impact the georeferencing result. So, it is important to use quality reference data. Generally, we rely on high resolution imagery. Locations must be identifiable in both datasets: the data being referenced and the reference imagery.

Generally, I try to obtain as many quality reference points as possible. However, adding more points that may be suboptimal can cause issues. So, make sure the points that you use can be accurately located in both images. Adding points that are of low quality can decrease the quality of the result.

When defining a control point, you will need to identify it in both datasets. The from point is the location on the data being referenced while the to point is the location relative to the reference data. The algorithm will attempt to move the from point location to the to point location.

Transforming the Data

❖ In order to georeference data, it may need to be:

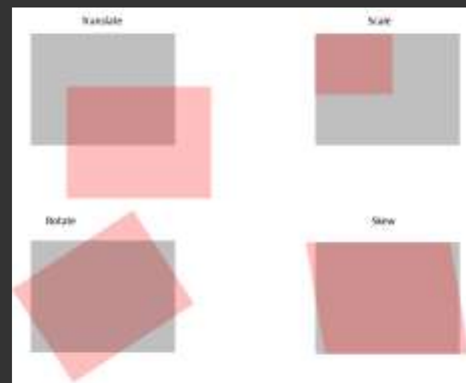
Rotated

Skewed

Scaled

and/or

Translated



These transformations are made using math.

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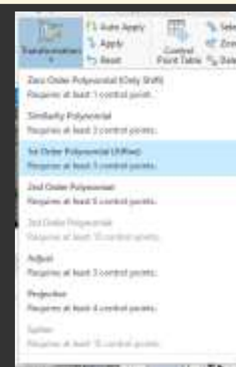
When performing georeferencing, different transformations can be applied. Translation implies moving the image without changing its shape or size. Changing the scale means to change the size of the image but not the shape. Rotation will reorient the scene relative to a point of rotation. Skew is used to change or distort the shape of the data. The transformations that can be applied depend on the algorithm used.

Transformation Methods



- Zero-Order Polynomial = just shift or translate the data (need 1 control point)
- First-Order Polynomial = shift, scale, and rotate (need 3 control points)
- Higher Order = more complex distortions can be applied
  - Rarely use higher order than third order
  - Need more control points
  - If raster dataset must be bent or curved, use a second- or third-order transformation

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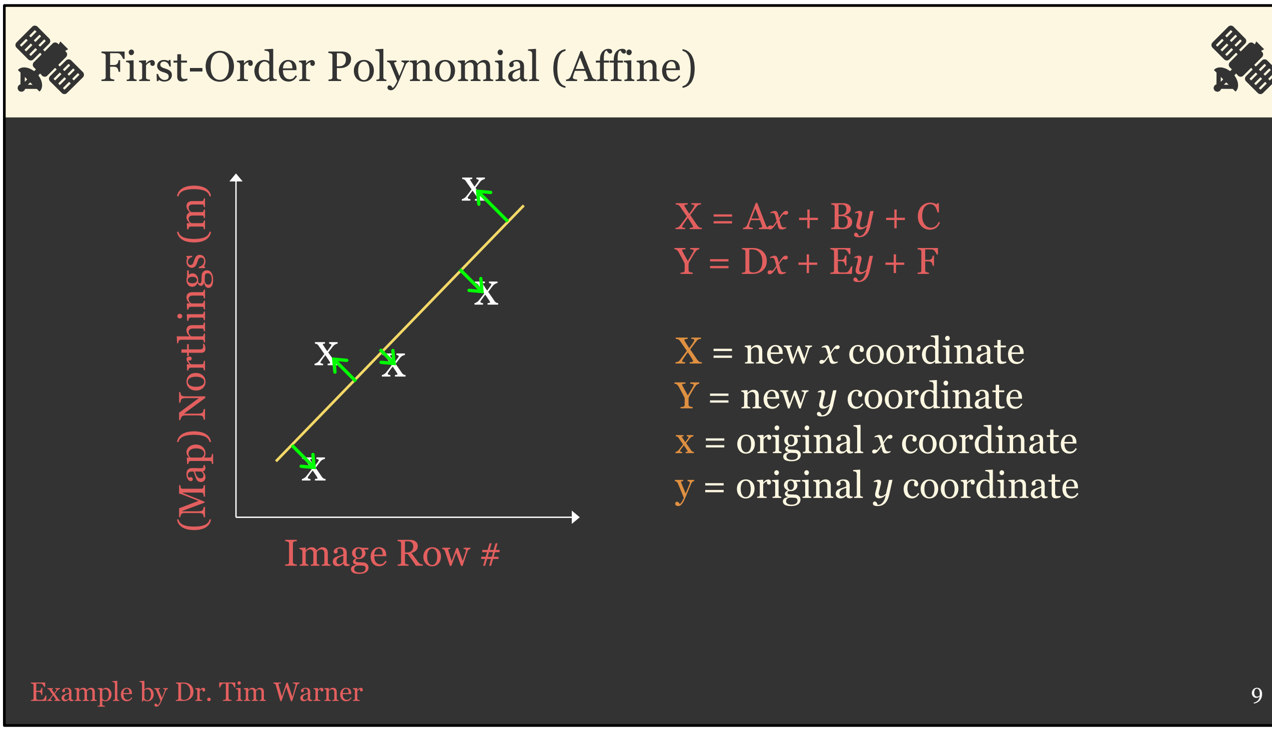
Polynomial equations can be used for georeferencing. Zero-order polynomials can only shift or translate the image and require only a single control point. First-order polynomials can translate, scale, and rotate the data. However, they cannot change the shape or skew the image. Three control points are required. Higher order polynomials can apply all four distortions and require more than three control points. We rarely use higher than third-order polynomials for georeferencing.

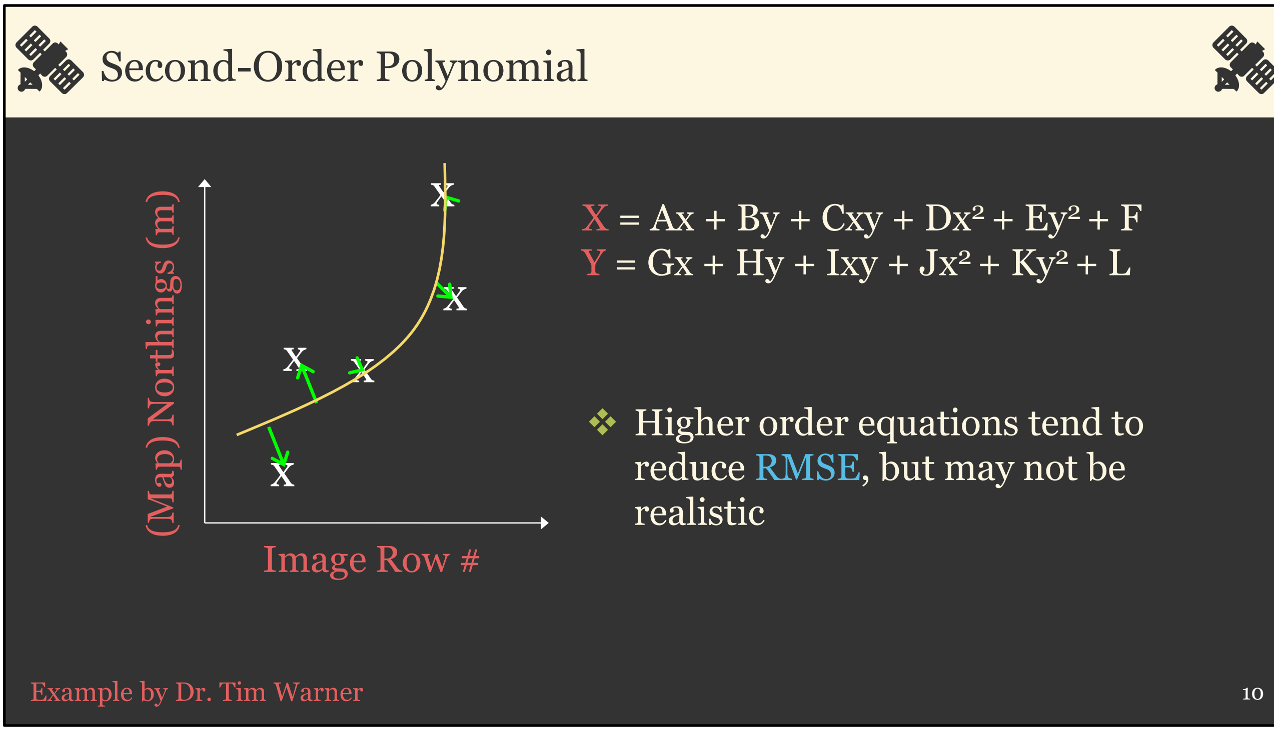


This slide provides an example of a first-order polynomial, also called an affine transformation. Here, the new X and Y coordinates are predicted using the original x, and y coordinates. Note that both coordinates are used to predict each of the new coordinates. The goal here is to determine appropriate coefficients to transform the data. Note that x and y are not raised to a power, as this is only first-order, so no square or cubed terms can be used.

The A term and D terms relate to changing the scale in the x and y directions, respectively. The B and E terms relate to rotation, and the C and F terms relate to translation. Again, this method does not allow for a skew to be applied. The terms are determined using the control points.

The underlying concept is actually much simpler than the complex terms used might suggest. We simply have an empirical relationship that tells us, based on the ground control points, how to convert from the row and column locations of pixels in the image to the map projection, which will be the new locations.

The length of the arrows in the diagram represent the error term or residual. We will discuss methods for assessing georeferencing error later in this module.

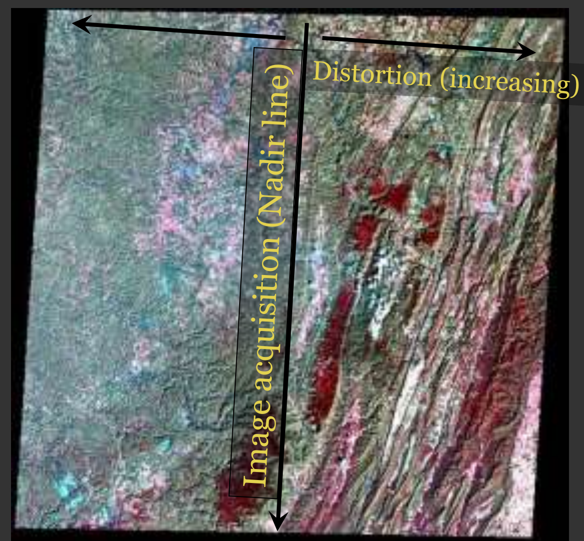


This slide shows that, as you increase the order of the equation (which determines how complex the line fitting can be – i.e. the higher the order, the more bends in the line), you automatically have the potential for less reported error (which is proportional to the green arrow length). However, it is not necessarily true that this is a more accurate representation. Note in particular that for extrapolations outside the rows/columns selected for the ground control points, very strange things can happen (as shown in this example – a high row number might map to an almost infinitely large northing!)

Note that the equations now included square or second order terms and that a total of 12 coefficients must be learned.

Polynomial Resampling Issues

- Need ground control points well-distributed across image
- Use lowest order polynomial possible
  - Small area: 1st order
  - Entire image: 3rd order



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Some issues to consider in selecting control points. For small areas, a first order polynomial is preferable. Higher orders can be used when referencing larger images or spatial extents. Generally, control points should be spread across the image extent. More distortion will be expected away from the nadir line of the scene.

Transformation Methods

- ❖Adjust = combines polynomial and triangular irregular network (need 3 control point)
- ❖Similarity = first order transformation which tries to preserve the shape of the original raster (need 3 control points)
- ❖Projective = commonly used for image data (need 4 control points)
- ❖Spline = uses rubber sheeting (need 10 control points)

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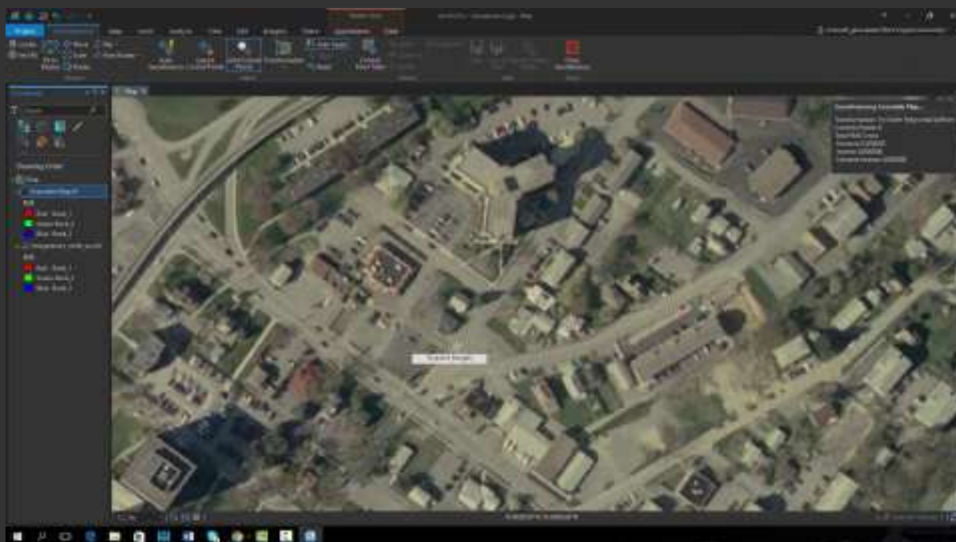
Other methods are available that do not rely on or solely rely on polynomial equations. This slide provides some examples. Again, different methods require different numbers of control points. The optimal method will depend on the data being referenced, the control points used, and the required transformations.

Video: Georeferencing in ArcGIS Pro



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How do you assess the quality of your result?

Root Mean Square Error (RMSE)

$$RMSE_x = \sqrt{\Sigma(x_{predicted} - x_{actual})^2/n}$$
$$RMSE_y = \sqrt{\Sigma(y_{predicted} - y_{actual})^2/n}$$
$$RMSE = \sqrt{(RMSE_x^2 + RMSE_y^2)}$$

- Measure of how well the now-referenced data match with the source
- Obtained by comparing the known location of the control point with the computed or predicted coordinates of the control point.

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Georeferencing is generally assessed using the root mean square error, or RMSE, statistic. This measure provides an assessment of how well the now referenced data matches the source or reference image. It is generally calculated by comparing the known location of the control point with the computed coordinates of the control point.

The predicted x and y coordinates are subtracted from the correct location to obtain a residual or error. The residuals are then squared, summed, then divided by the number of samples. Lastly, the square root is taken. This will provide a RMSE for the x and y directions. These measures can then be combined to obtain a total RMSE. RMSE will be reported in the map units or as number of pixels. Lower RMSE is better.

Here are some other notes regarding interpreting RMSE. RMSE can be misleading if the quality of the control points is suspect or poor. Also, algorithms commonly overfit to the control points. So, if control points are used to calculate RMSE, the accuracy can be inflated. It is best to withhold data points and calculate RMSE relative to these new locations.

How do you assess the quality of your result?

Correct X	Correct Y	Predicted X	Predicted Y	X Residual	Y Residual	X Residual Squared	Y Residual Squared
513,126.80	4,101,294.60	513,127.30	4,101,293.40	0.5000	-1.2000	0.2500	1.4400
513,123.20	4,101,303.40	513,118.10	4,101,302.10	-5.1000	-1.3000	26.0100	1.6900
513,203.80	4,101,209.10	513,203.10	4,101,207.20	-0.7000	-1.9000	0.4900	3.6100
513,182.60	4,101,377.80	513,181.60	4,101,379.90	-1.0000	2.1000	1.0000	4.4100
513,217.60	4,101,403.60	513,216.10	4,101,405.20	-1.5000	1.6000	2.2500	2.5600
						RMSE_X	2.45
						RMSE_Y	1.66
						RMSE	2.96

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This slide provides an example of an RMSE calculation. The correct and predicted x and y coordinates are differenced to obtain a residual. The residuals are then squared, summed, then divided by the number of samples. The last step is to take the square root. Once RMSEs are obtained in the x and y directions, they can be combined to obtain a total RMSE.

In this example, the total RMSE is 2.96 meters. This suggest that each pixel is, on average, 2.96 meters from its correct location.

What is considered an acceptable RMSE? This depends on many factors. For example, coarser spatial resolution data will tend to have a larger RMSE than fine resolution data as the larger pixel or cell size will result in some spatial ambiguity. For imagery, our goal is generally to obtain an RMSE that is smaller than the dimensions of a pixel or cell.

Some mapping tasks may require better georeferencing results than others. There will always be some georeferencing or positional error in your data.

Resampling

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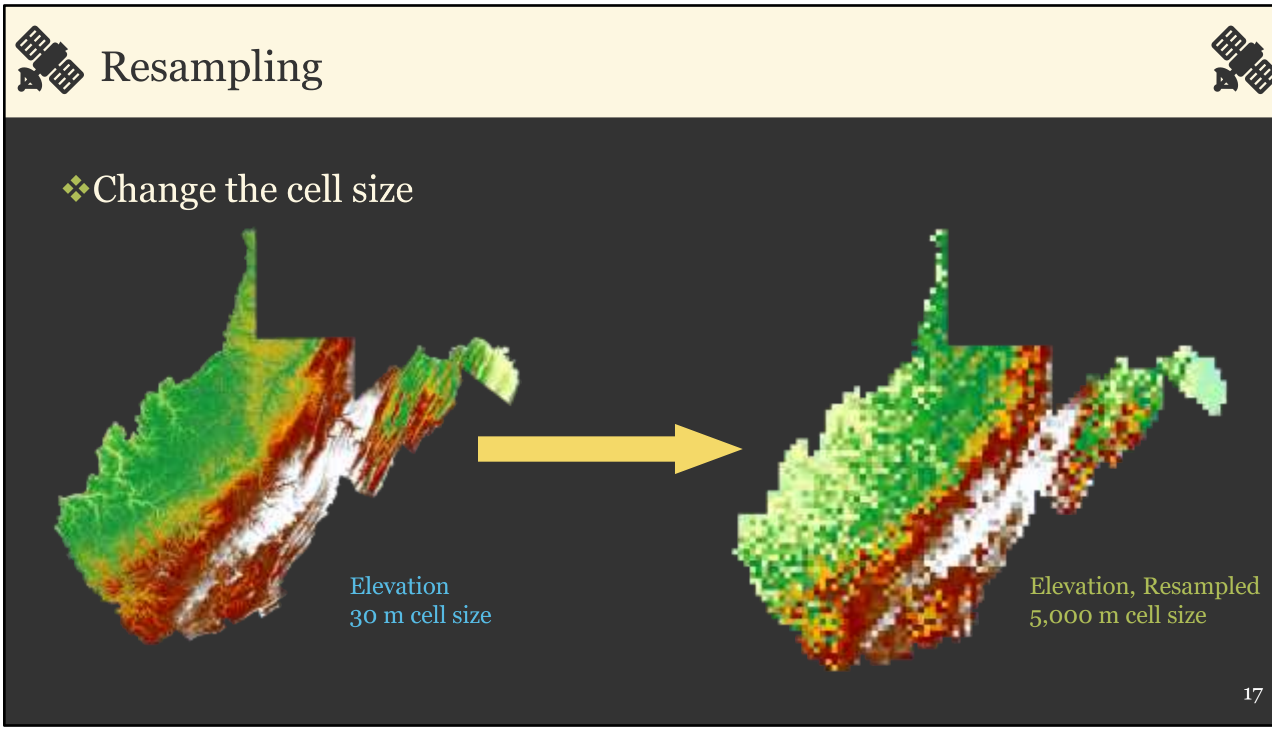

You may also need to resample the raster data (i.e., change the cell size).

For continuous raster data, such as elevation data, bilinear interpolation, cubic convolution, or pixel aggregation are commonly used.

Resampling Methods

- Majority Resampling
- Resamples using the most common cell value
- Good for categorical data

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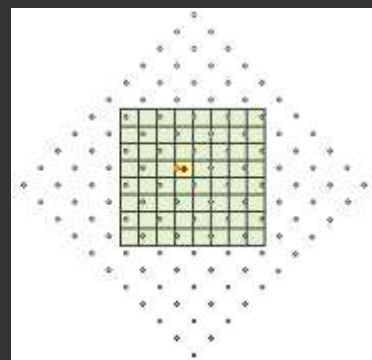
Majority resampling will assign the most common cell value of the original cells that fall within the new cell to the new cell.

This method is not generally used for continuous data or images. It is more commonly used for categorical data.

For example, if a land cover categorical raster grid was resampled using this method, each new cell would be assigned the majority land cover class from the smaller, original cells that fall inside of it.

Resampling Methods

- Nearest Neighbor
- New value will be the value of the original cell closest to the center of the new (larger) cell
- Good for categorical data



http://desktop.arcgis.com/en/arcmap/latest/extensions/spatial-analyst/performing-analysis/cell-size-and-resampling-in-analysis.htm

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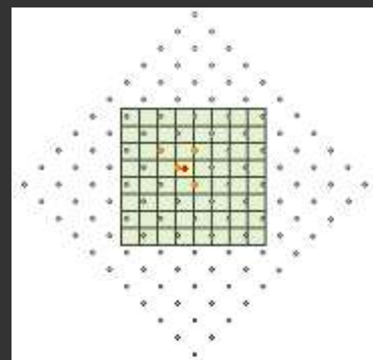
Nearest neighbor resampling assigns the closest cell value from the original raster grid to the new cell.

No averaging is performed, so this method can be used to resample both categorical and continuous data.

Resampling Methods

- Bilinear Interpolation
- Uses the inverse distance-weighted average of the four nearest pixel values to estimate a new pixel value
- The four cell centers from the input raster that are closest to the cell center for the output processing cell will be weighted based on inverse distance and then averaged
- Good for continuous data
- Creates a smoothed image



http://desktop.arcgis.com/en/arcmap/latest/extensions/spatial-analyst/performing-analysis/cell-size-and-resampling-in-analysis.htm

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Bilinear interpolation uses the inverse distance-weighted average of the four nearest pixel values in the original grid to estimate the new cell value.

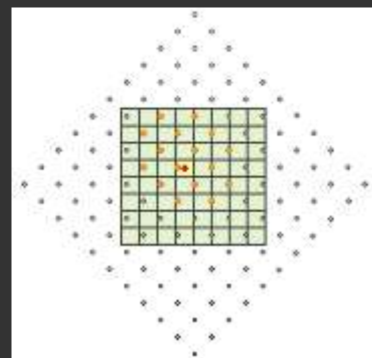
The four cell centers from the input raster that are closest to the cell center for the output processing cell will be weighted based on inverse distance and then averaged. So, nearer cells will have a larger weight in the calculation than cells that are further away.

Since averaging is performed, this method is not appropriate for categorical data. However, it can be used for continuous data.

This method tends to smooth the image or raster data.

Resampling Methods

- Cubic Convolution
- Similar to bilinear interpolation, except the 16 nearest input cell centers and their values are used
- Tends to sharpen images
- Good for continuous data



http://desktop.arcgis.com/en/arcmap/latest/extensions/spatial-analyst/performing-analysis/cell-size-and-resampling-in-analysis.htm

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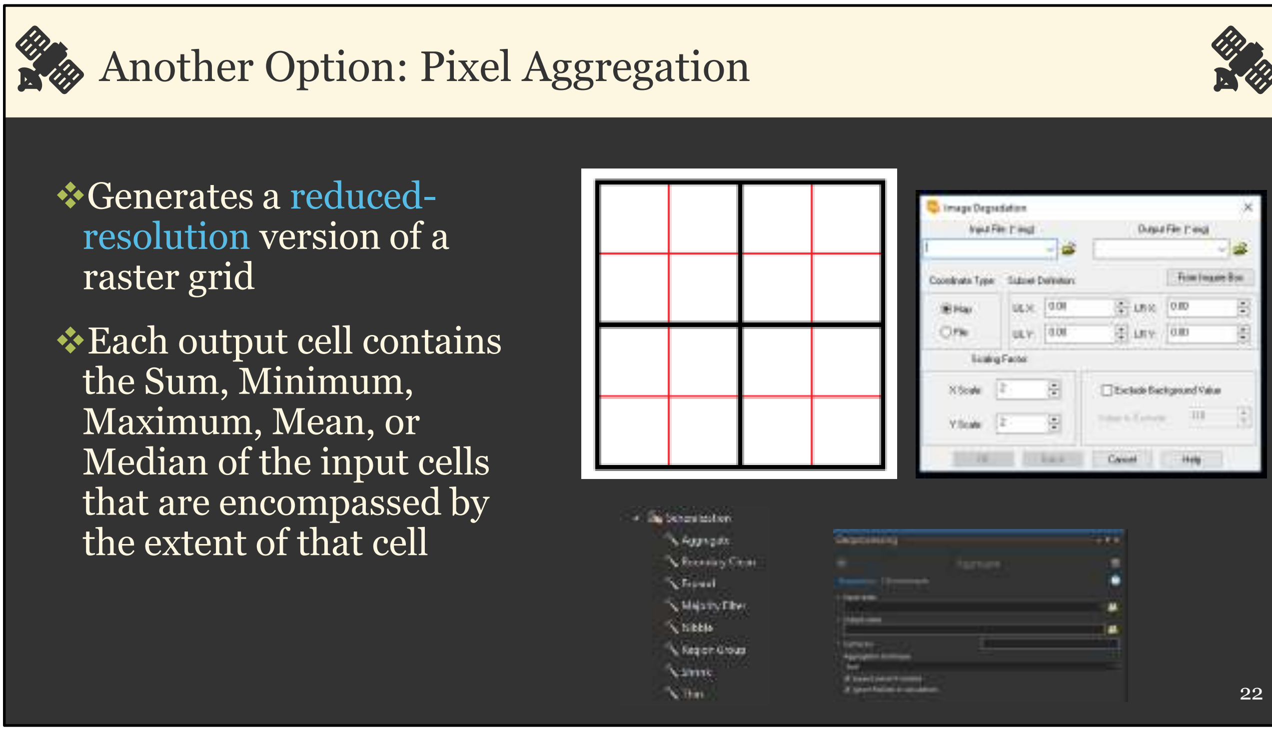
Cubic convolution is similar to bilinear interpolation except that the nearest 16 cells are used as opposed to the nearest 4. Since it makes use of averaging, it is also not appropriate for categorical data but can be used for continuous data.

This method tends to sharpen images more than bilinear interpolation.

Bilinear interpolation and cubic convolution are both commonly used to resample image data.

Bilinear interpolation tends to smooth raster data because each output cell is calculated as a weighted average of the four nearest input cells. This averaging reduces abrupt local variation and pulls extreme values toward surrounding values. Cubic convolution uses a larger neighborhood of cells and fits a curved surface through the nearby values, allowing it to better preserve local gradients and detail. As a result, bilinear interpolation often produces a smoother output, while cubic convolution often produces a sharper-looking output, although it may introduce slight overshoot or values outside the original data range.



Another option to change the cell size is to use pixel aggregation. This is also sometimes referred to as image degradation.

When using this method, a statistic from the cells that fall within the new larger cell is calculated and returned to the new cell.

Examples include sum, minimum, maximum, mean, or median.

The raster data can only be reduced in resolution in such a manner that a whole number of input cells will fall perfectly within a new cell. For example, a 2-by-2 meter raster grid could be converted to a 4-by-4 meter grid but not a 3-by-3 meter output.

This method can be used for both categorical and continuous data depending on the statistic returned.

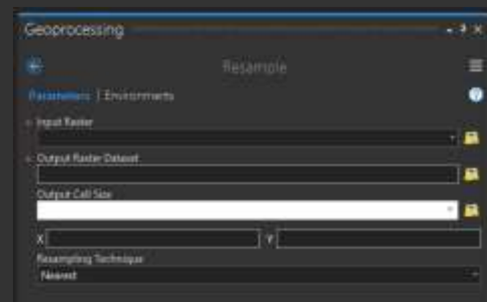
Resampling in Erdas Imagine

- Resample
- Degrade

In Erdas Imagine, resampling can be performed with the Resample Tool while pixel aggregation requires the use of the Image Degradation Tool.

Resampling in ArcGIS Pro

- A good resource:
- http://desktop.arcgis.com/en/arcmap/latest/extensions/spatial-analyst/performing-analysis/cell-size-and-resampling-in-analysis.htm



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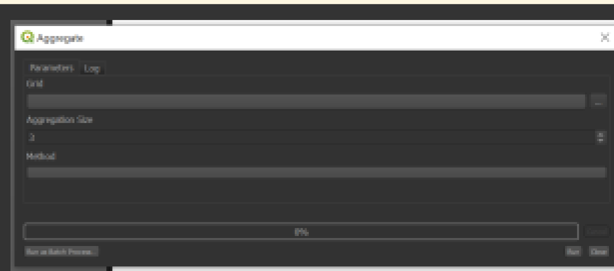
If you would like to read more about resampling, check out this ESRI link.

Note that resampling is made available in a variety of GIS and remote sensing software packages, including ArcGIS Pro, Erdas Imagine, and QGIS.

Resampling in QGIS



- Resampling and pixel aggregation tools are available in QGIS, GDAL, GRASS, and SAGA

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Since resampling is a very common task, most software packages, including open-source software, have tools for resampling and pixel aggregation.

Other Pre-Processing Tasks

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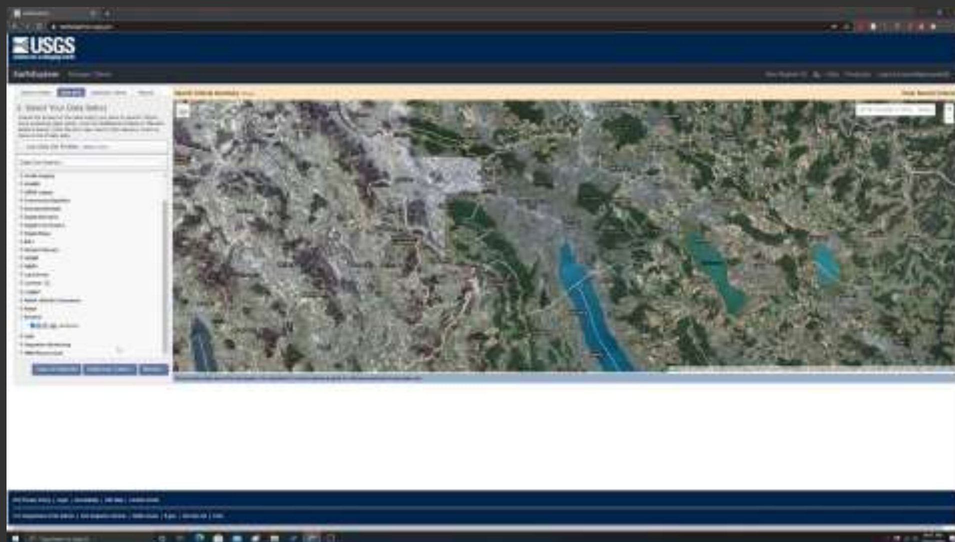
Video: USGS EarthExplorer Data Download



Reprojecting

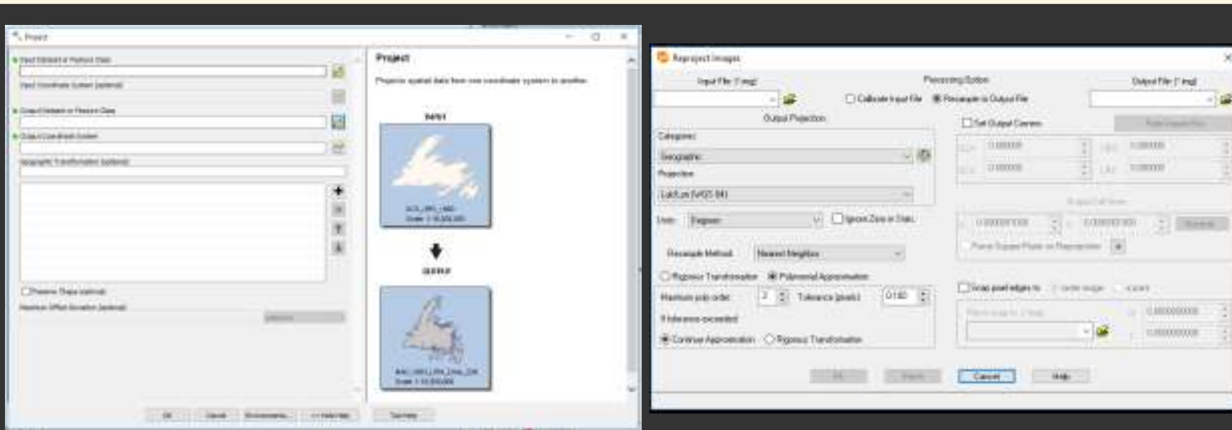


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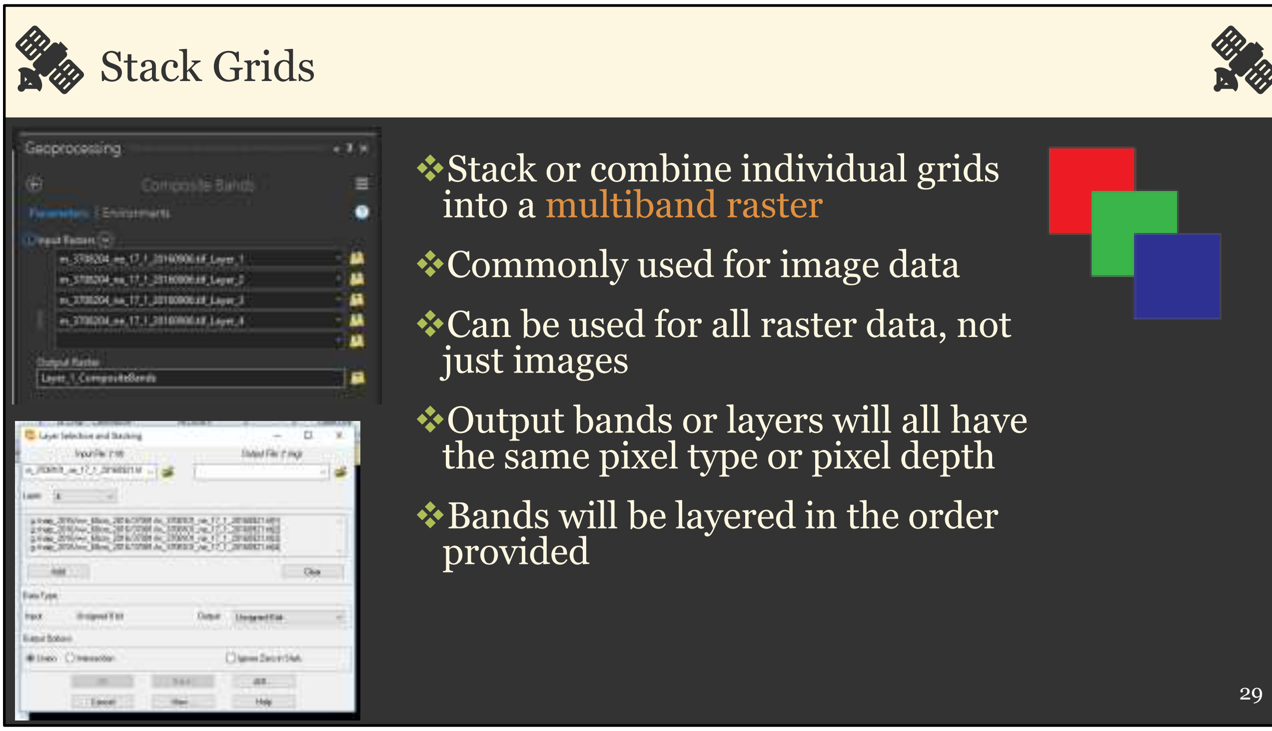
Image reprojection relates to changing the spatial reference system. For example, data with only a geographic coordinate system defined can be transformed to a different geographic coordinate system and/or projected to a projected coordinate system. Alternatively, data can be transformed from one projected coordinate system to another.

I generally recommend that all data layers be projected to the same coordinate system for combined use in an analysis. Note that there are not always exact mathematical transformations available to change between coordinate systems, so some positional error or uncertainty can be introduced. However, this is not always avoidable.

There are tools available for reprojecting geospatial data in most geospatial software packages, including ArcGIS Pro, Erdas Imagine, and QGIS.



You may have many raster grids that you would like to combine to a single file by stacking the separate grids or bands as a single multiband file.

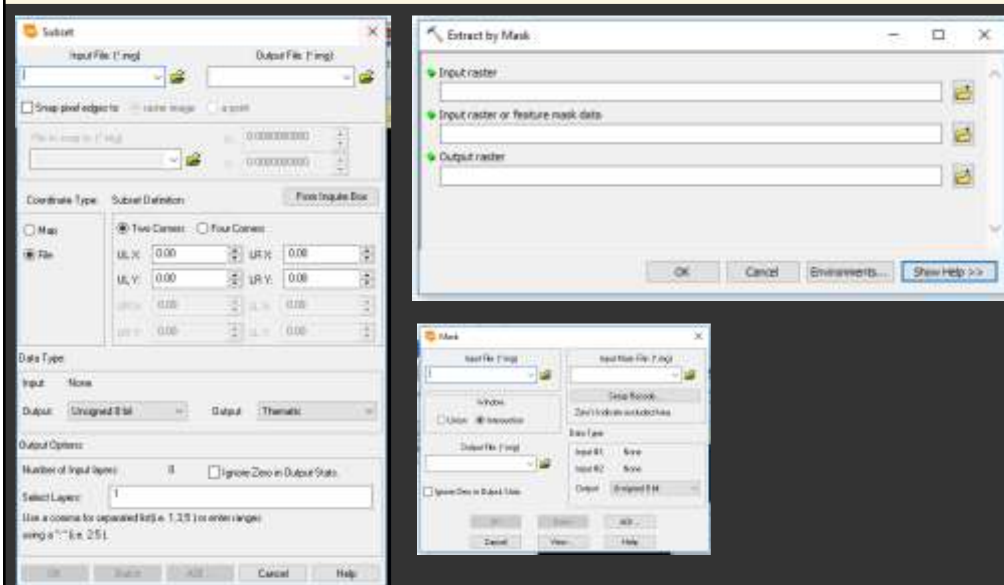
As an example, when Landsat data are downloaded, they are often provided as individual bands. However, you may want to use these data as a multiband image for analysis or symbology. So, you would need to combine the bands into a single raster with multiple bands.

This can be accomplished using the Composite Bands Tool in ArcGIS Pro or the Stack Tool in Erdas Imagine.

It is possible to stack more than just image bands. For example, you could stack a set of topographic variables into a multiband file. I have found this to be useful when preparing data for modeling.

All bands or layers in a stack must have the same pixel type. For example, if you stack three 8-bit grids and one 16-bit grid, all the data will be converted to 16-bit. If one of your input grids is float, then all your grids will be converted to float.

Subset Image



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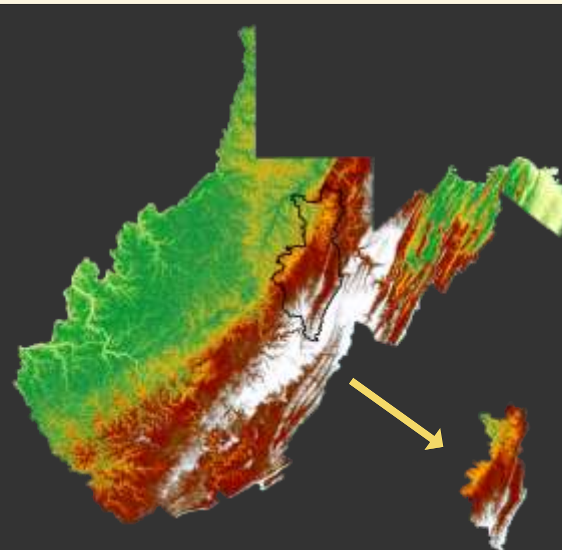
Subsetting an image means to extract out a spatial extent from a larger datasets. ArcGIS Pro provides several tools to accomplish this including Extract by Mask and Clip Raster. In Erdas Imagine, the Subset and Mask tools are used in a similar manner.

Extraction Methods

- Extract by Circle = extract cells that fall into a circle that is defined by a center coordinate and radius
- Extract by Mask = extract cells that fall within a raster or polygon mask
- Extract by Point = extract cells at point locations
- Extract by Polygon = extract cells that fall within the extent of a polygon as defined by its vertices
- Extract by Rectangle = extract cells that fall within a rectangular extent



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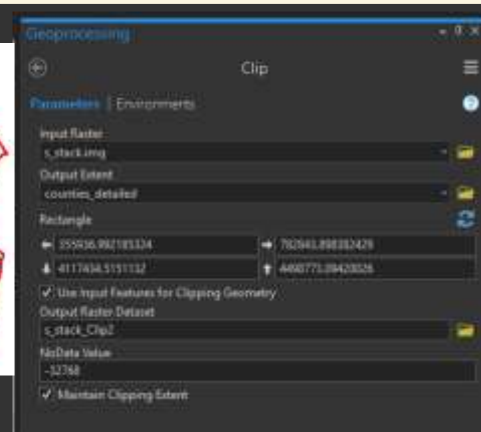
There are many extraction methods available.

If you have a predefined extent as a vector polygon or raster mask, I would suggest the Extract by Mask Tool.

Image Clip Tool in ArcGIS Pro



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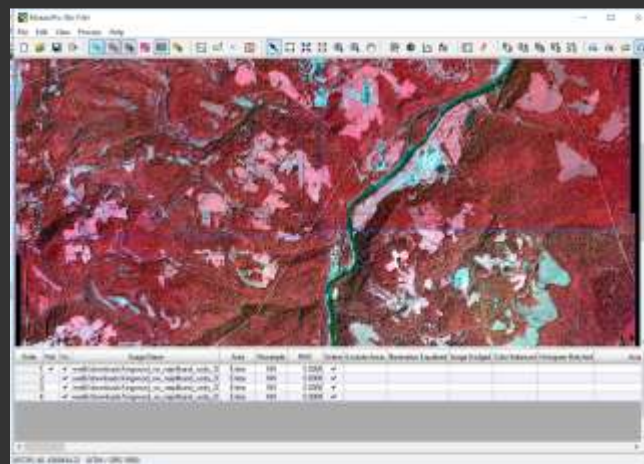
The Clip Raster Tool in ArcGIS Pro is also useful for subsetting or masking multiband raster data. Note that this is different from the Clip Tool used for extracting vector spatial data.

Merging Scenes

Must take into account:

1. Tonal balance between images
2. Color correction
3. Seam lines
4. Resampling methods



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Other than extracting a spatial subset from a dataset, you may want to merge multiple files together. When merging image data specifically, you may need to apply some additional processing steps in order to make the data more homogenous so that the boundaries of individual scenes are less noticeable.

Merging Scenes

Tool Options:

1. Mosaic Pro
2. Mosaic Pro from 2D View
3. Mosaic Express

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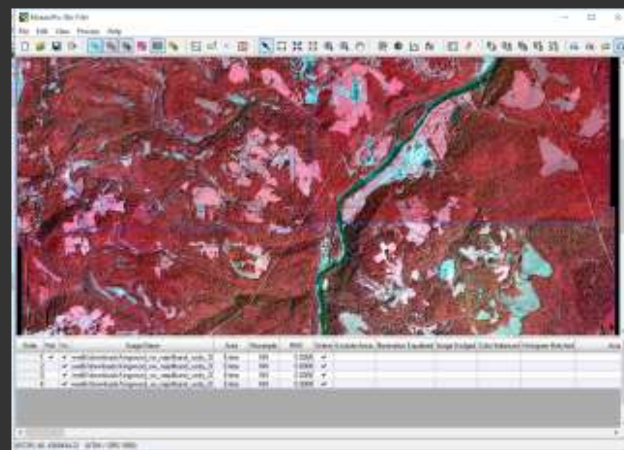
In Erdas Imagine, several tools are available to mosaic raster data. Here, I will discuss the MosaicPro Tool, which provides a lot of control over how data are merged and pre-processed.

Seam Lines

- Controls how images are combined
- Options:
  - Most-nadir = overlapping area of the images where the distance to the center point of each image is equal
  - Geometry-based = based on the geometry of the overlapping regions instead of pixel values. For an overlapping region involving only two images, the geometry-based seam line divides the overlap into two equal parts
  - Overlay-based = choose this option to base the seam line generation directly on the active area of each input image. The image on top will use its entire active area as the seam polygon



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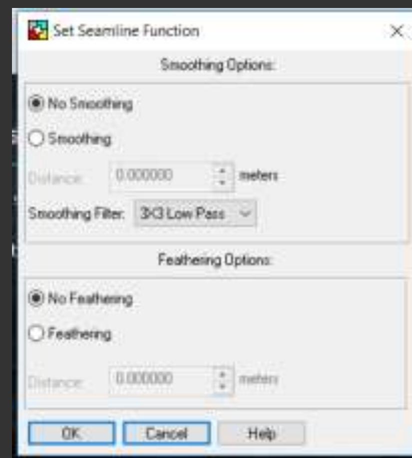
The Mosaic Pro Tool allows the analyst to define how images are combined by defining seam lines. Most-nadir tries to minimize the distance from the center point of each image. Geometry is based on overlapping image footprints. In overlapping areas, the seam line will be placed in the center of the overlapping areas, essentially splitting it into two equal parts. Overlay-based seam lines decide on seams based on the order of the input files. The image on top will take on its entire extent with subsequent layers filling gaps.

Seam Lines

- **Smoothing** = smooth image using a function within a distance of the seam line
- **Feathering** = blend pixels from all images in overlapping area



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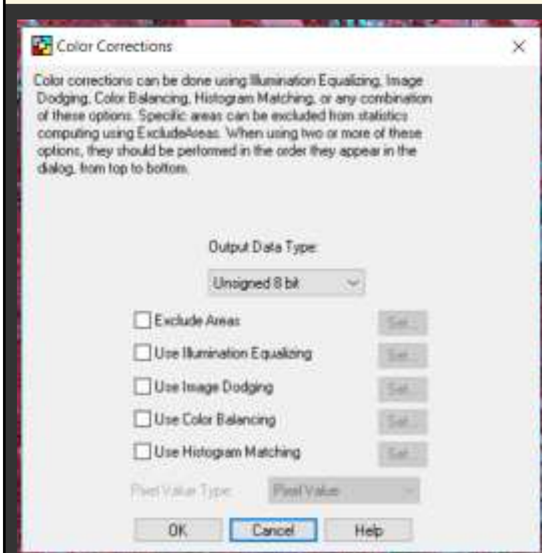
You can also determine how pixel values are blended near seamlines. For example, smoothing and feathering can be used to blend the images so that seam lines are less noticeable.

It is also possible to manually define seam lines and use landscape features to hide the boundaries. For example, seam lines could be placed along roads, at ridge tops, or in the center of river channels.

Color Correction



- Illumination Equalization = adjust variations of illumination or color of an image
- Dodging = calculates statistics for image and then apply a statistical correction to the intensity value of each pixel
- Color Balancing = attempts to remove the variations within the scene and is done before applying the between-scene matching algorithms
- Histogram Matching = match the overall color and shading among images before the mosaic process. Converts the histogram of one band of an image to resemble another histogram

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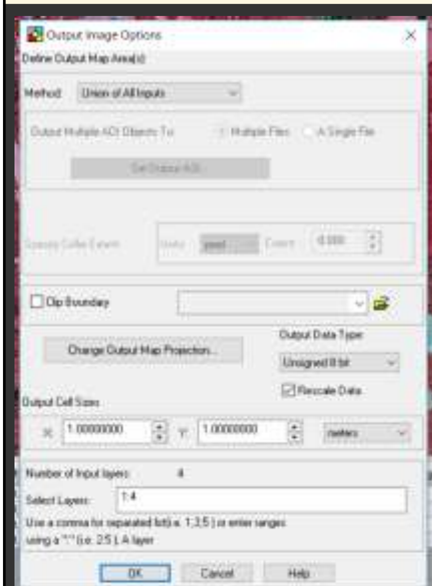
You are also able to control the distribution of colors or brightness between images to make them look more homogenous and make edges less obvious. Methods for color correction include illumination equalization, dodging, color balancing, and histogram matching. These different methods can be used individually or in different combinations and have settings that impact the resulting DN value manipulations. Read through the provided descriptions of these methods.

Output Options



- Can write output to one file
- Can write output to many files based on polygon extents
- Can mask/clip to a boundary
- Can define cell size, resampling method, projection, and data type
- Can rescale data
- Can specify what bands to export
- Formats: ECW, IMG, JPEG2000, MrSID, PNG, TIFF, etc.

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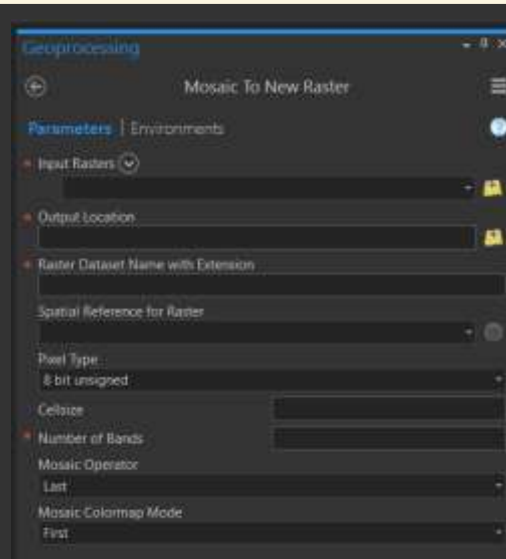
Some additional mosaicking options include where to write the output file and what to name it. It is also possible to write out to multiple files using defined areal extents. This might be necessary, as some extents may be too large to write out to a single file. The output extent can also be masked relative to a polygon boundary.

You can also define the cell size of the output, the resampling method, the output projection, and the pixel data type (8-bit, 16-bit, 32-bit float, etc.). Note that changing the data projection as part of the mosaic process can significantly increase the computational time. You can also specify if data should be rescaled, for example from 16-bit to 8-bit, and which bands to export.

Lastly, you can choose an output file format. Common uncompressed output file formats include Erdas Imagine (.img) and GeoTiff (.tif). JPEG2000 is a good option to output compressed data with a much smaller file size. MrSID is another good compression option; however, it is proprietary.

Mosaic to New Raster

- Combine single band or multiband raster grids into a single raster
- Can be used for all types or raster grids, including images
- Must specify file extension, pixel type, cell size, and number of bands



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The Mosaic to New Raster Tool allow for raster mosaicking in ArcGIS Pro. However, it does not offer many options for dealing with seam lines and color balancing.

This tool will require you to define a pixel type (8-bit, 16-bit, float, etc.), a file extension (I commonly use Image (.img) or TIFF (.tif)), an output cell size, and the number of bands.

Mosaic to New Raster

Assigning values at overlapping locations:

FIRST = The output cell value of the overlapping areas will be the value from the first raster dataset mosaicked into that location

LAST = The output cell value of the overlapping areas will be the value from the last raster dataset mosaicked into that location. This is the default

BLEND = The output cell value of the overlapping areas will be a horizontally weighted calculation of the values of the cells in the overlapping area

MEAN = The output cell value of the overlapping areas will be the average value of the overlapping cells

MINIMUM = The output cell value of the overlapping areas will be the minimum value of the overlapping cells

MAXIMUM = The output cell value of the overlapping areas will be the maximum value of the overlapping cells

SUM = The output cell value of the overlapping areas will be the total sum of the overlapping cells

NAIP Orthophotography

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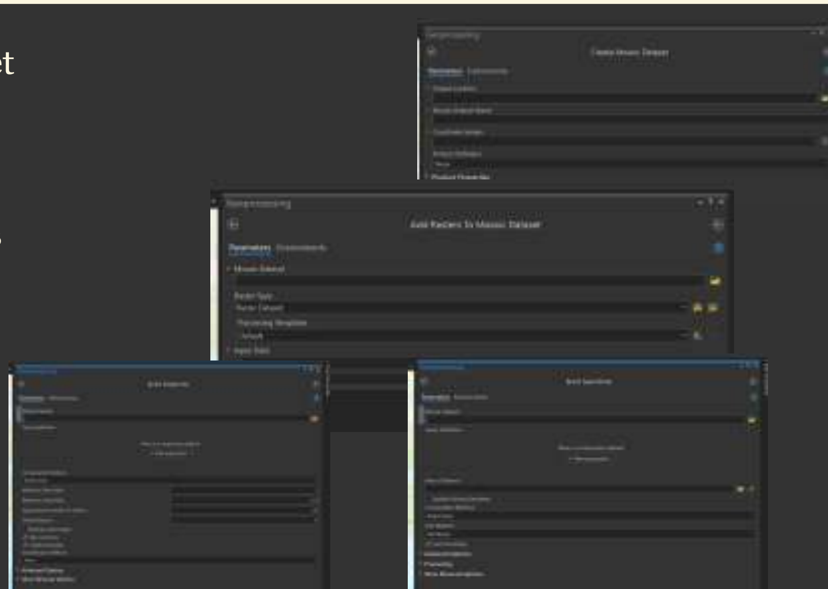
When you have overlapping values, a method must be applied to obtain the cell value in the overlapping areas. When there is no overlap, the decision is easy, as there is only one cell value available at that location.

For continuous data, many methods are available, including first, last, mean, maximum, and minimum. Since categorical data cannot be averaged, first or last are commonly used.

Take some time to review the methods described on the slide.

Mosaic Datasets

- ❖Create mosaic dataset
- ❖Define schema
- ❖Add raster data
- ❖Calculate boundaries
- ❖Calculate footprints
- ❖Calculate seam lines
- ❖Build overviews
- ❖Color balance



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In the ArcGIS/ESRI environment, Mosaic Datasets allow for the generation of virtual raster grids that reference other data files. So, these are not true raster files but offer a means to reference multiple actual files to view and work with these data.

ArcGIS Pro includes a variety of tools for building and manipulating Mosaic Datasets. For example, you can alter the scheme, which changes the characteristics of the mosaic and the types of data that can be included, add and delete raster data, calculate the boundary of the mosaic and the footprints of individual images within it, define how data will be combined based on seam lines, define what data will be displayed or used at different scales, define color balancing rules, and build overviews, similar to raster pyramids.

Note that many geoprocessing tools can accept mosaic datasets as input. However, these datasets cannot be used outside of the ArcGIS environment.

Pyramids

- Reduce spatial resolution versions of the data to aid in faster display

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Raster datasets can be large files, especially if they cover a large spatial extent and/or have a small cell size. This can result in slow display.

Building pyramid layers provides a means to improve the display speed and performance of raster layers.

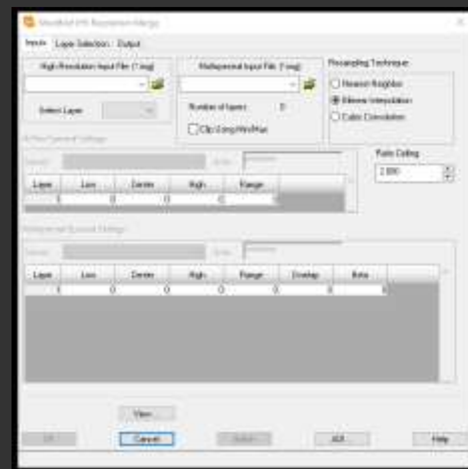
Pyramids are reduced spatial resolution versions of the data. When you are zoomed out, the reduced resolution data are drawn. The high spatial resolution, or original, data are not drawn until you zoom in.

This can greatly improve display speed as you zoom in and out or pan around.

If you plan to work with raster data, especially if you will need to zoom and pan around the data, such as when digitizing, I highly recommend building pyramids. This process can be slow, but it may save you time in the long run.

Pansharpening

- Using higher spatial resolution panchromatic data to sharpen coarser image data
- Different methods are available



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Pansharpening involves using a higher spatial resolution image to sharpen coarser data. Generally, a panchromatic band is used to sharpen an RGB, CIR, or multispectral image. For example, a panchromatic band is collected along with the Landsat 8 multispectral data. This panchromatic band can then be used to sharpen, or improve the spatial resolution, of the other bands.

Uses

1. Sharpen multispectral Landsat 7 ETM+ data using panchromatic band
2. Sharpen multispectral Landsat 8 OLI data using panchromatic band
3. Sharpen multispectral commercial satellite data using panchromatic band

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Some examples of pansharpening include the use of the panchromatic band to sharpen Landsat 7 ETM+ or Landsat 8/9 OLI/OLI-2 data. Also, many commercial, multispectral sensors include a panchromatic band that can be used to sharpen the multispectral data.

Pansharpening Methods

- Brovey = uses a method that multiplies each resampled, multispectral pixel by the ratio of the corresponding panchromatic pixel intensity to the sum of all the multispectral intensities. It assumes that the spectral range spanned by the panchromatic image is the same as that covered by the multispectral channels
- ESRI = uses a weighted average and the additional near-infrared band (optional) to create its pan-sharpened output bands. The result of the weighted average is used to create an adjustment value (ADJ) that is then used in calculating the output values
- IHS = converts the multispectral image from RGB to intensity, hue, and saturation. The low-resolution intensity is replaced with the high-resolution panchromatic image. If the multispectral image contains an infrared band, it is taken into account by subtracting it using a weighting factor. The result is then transformed from IHS to RGB

http://desktop.arcgis.com/en/arcmap/10.3/manage-data/raster-and-images/fundamentals-of-panchromatic-sharpening.htm

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Different methods or algorithms are available to perform pansharpening. This slide highlights some methods available in ArcGIS Pro. A full discussion of these methods is outside the scope of this course. Note also that new pansharpening techniques are being pursued, as this is an active areas of research. For example, recent research has explored the use of deep learning to pansharpen multispectral data.

Convert to Surface Reflectance

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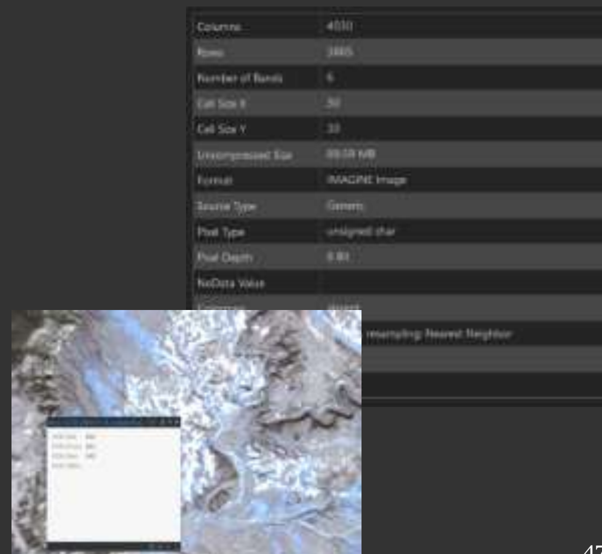
Digital Numbers (DN)

- Imagery = raster data
- Each band measures reflectance within a range of wavelengths
- A multispectral image is a stack of image bands
- Reflectance is represented as DN values
- Higher DN = more reflectance in the measured wavelength range
- DN values do not have physical units
- DN values are not percent reflectance values



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In this last section, we discuss methods for converting DN brightness values to radiance and spectral reflectance. We will focus specifically on methods applicable to Landsat data.

Note that these steps have become less necessary as data are more commonly being provided already processed to surface reflectance. For example, Analysis Ready Data (ARD) are currently being provided for Landsat data and can be downloaded from EarthExplorer or LP DAAC. Regardless, we argue that there is still value in understanding how this conversion is applied.

What is actually stored on the pixel?

1. Brightness value as digital number (DN)
   - 8-bit
   - 16-bit
   - 32-bit
   - Float
2. A physical measurement
   - Radiance
     - The amount of radiation reflected from an area
     - Must apply gain and offset to pixel DN value
     - Example units: W/(steradian m^2 μm)
   - Reflectance
     - Proportion of the radiation striking a surface to the radiation reflected off of it
     - Top of Atmosphere = not corrected for atmospheric effects
     - Surface reflectance = atmospheric corrections are applied

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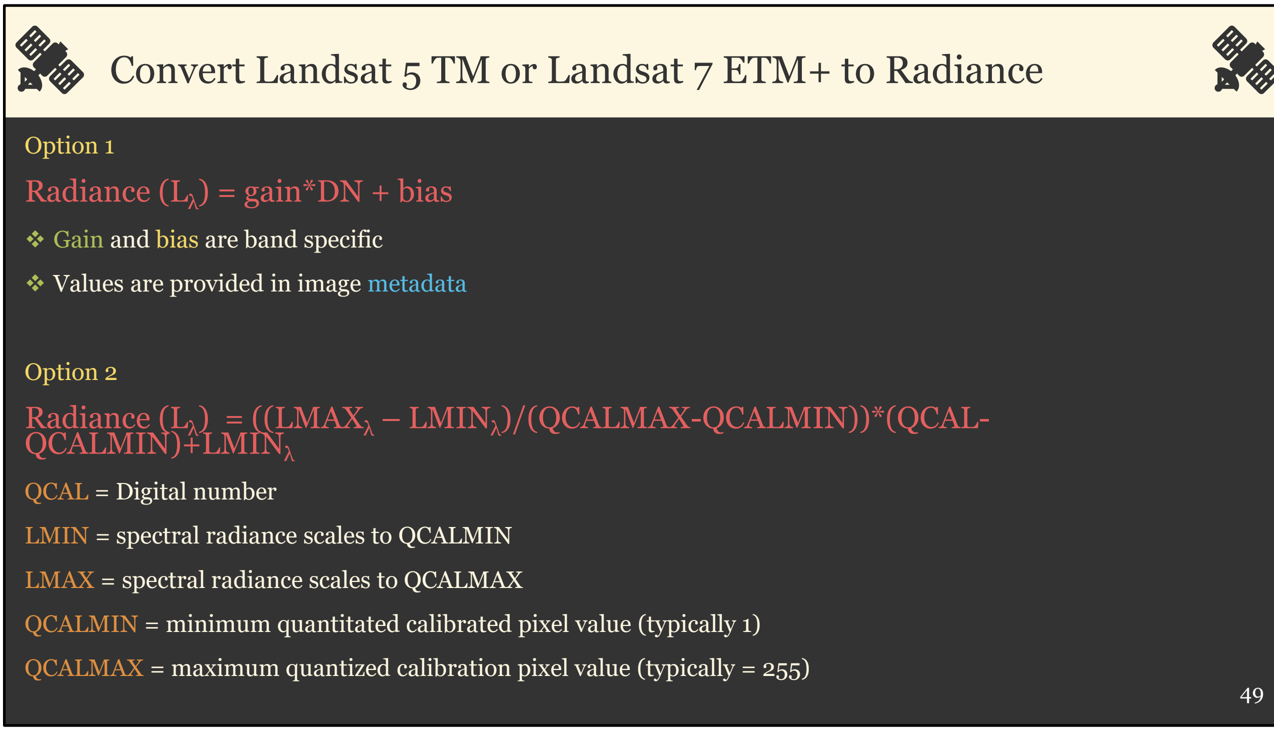
To begin, it is possible to estimate radiance and reflectance from DN values if the instrument or sensor is calibrated and adequate metadata are provided.

Radiance represents the amount of radiation reflected from an area or pixel. The units of radiance are W/(steradian m2 μm); it is energy (Joules) per unit time (seconds) (remember, Watts = Joules per second) per area (meters squared). Steradian corrects for the curved spherical surface of the Earth. This is like radians, but in 3D. Lastly, this is per wavelength. So, in summary, radiance is energy per unit time per unit area per wavelength (and corrected for the fact that the surface of the Earth is curved).

Reflectance represents the percent of the radiation at a specific wavelength that is reflected. Top of the atmosphere (ToA) reflectance incorporates the signal from both the land surface and the atmosphere. Surface reflectance has been atmospherically corrected to factor out the impact of the atmosphere to more accurately approximate the surface reflectance of the Earth's surface at the pixel location.

In short, it is possible to estimate radiance and reflectance from DN values if a sensor is well calibrated. For example, spectral reflectance products are available for Landsat, Sentinel-2, and MODIS data.



For Landsat 5 TM and Landsat 7 ETM+ data, radiance can be estimated using the provided gain and bias for each band or the provided LMIN, LMAX, QCALMIN, and QCALMAX values provided in the image metadata. The equations for both methods are provided here.

Convert Landsat 5 TM or Landsat 7 ETM+ to Reflectance

ToA Reflectance (ρ_λ)= $\pi * L_\lambda * d^2 / ESUN_\lambda * \cos \theta s$

L_λ = radiance

d = Earth-Sun distance in astronomical units

ESUN = mean solar exoatmospheric irradiance

θs = solar zenith angle

*Converting to surface reflectance will require modeling the atmosphere

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Once radiance is obtained, top of atmosphere surface reflectance can be estimated using the Earth-Sun distance, which varies throughout the year due to Earth's elliptical orbit around the Sun, the mean solar exoatmospheric irradiance, which relates to the amount of energy being emitted by the Sun in the wavelength range corresponding to the band of interest, and solar zenith angle, which relates to the illuminating geometry.

Note that this will yield an estimate of the top of atmosphere reflectance per band. Since no atmospheric correction is applied, this is not surface reflectance.

Converting Landsat 8 data to Radiance

$$L_\lambda = M_L Q_{cal} + A_L$$

L_λ = TOA spectral radiance (Watts/(m^2 * srad * µm))

M_L = Band-specific multiplicative rescaling factor from the metadata (RADIANCE_MULT_BAND_x, where x is the band number)

A_L = Band-specific additive rescaling factor from the metadata (RADIANCE_ADD_BAND_x, where x is the band number)

Q_{cal} = Quantized and calibrated standard product pixel values (DN)

https://www.usgs.gov/core-science-systems/nli/landsat/using-usgs-landsat-level-1-data-product

Converting Landsat 8 data to radiance is generally simpler. This simply requires the use of the equation above and the band-specific multiplicative rescaling factors, band-specific additive rescaling factors, and the quantized and calibrated DN values. The necessary values are provided in the metadata and are band specific.

Converting Landsat 8 data to Reflectance

$$\rho_\lambda` = M_p Q_{cal} + A_p$$

$\rho_\lambda`$ = TOA planetary reflectance, without correction for solar angle

M_p = Band-specific multiplicative rescaling factor from the metadata (REFLECTANCE_MULT_BAND_x, where x is the band number)

A_p = Band-specific additive rescaling factor from the metadata (REFLECTANCE_ADD_BAND_x, where x is the band number)

Q_{cal} = Quantized and calibrated standard product pixel values (DN)

https://www.usgs.gov/core-science-systems/nli/landsat/using-usgs-landsat-level-1-data-product

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To convert Landsat 8 data to reflectance, it is not necessary to convert to radiance first. Instead, top of atmosphere reflectance can be estimated by using reflectance-based multiplicative and additive rescaling factors in place of the values provided for radiance. However, this does not correct for solar angle or illumination geometry.

Converting Landsat 8 data to Reflectance

$$\rho_\lambda = \frac{\rho_\lambda`}{\cos\theta_{SZ}} = \frac{\rho_\lambda`}{\sin\theta_{SE}}$$

ρ_λ = TOA planetary reflectance

θ_{SE} = Local sun elevation angle. The scene center sun elevation angle in degrees is provided in the metadata (SUN_ELEVATION)

θ_{SZ} = Local solar zenith angle ($\theta_{SZ} = 90° - \theta_{SE}$)

*Converting to surface reflectance will require modeling the atmosphere

https://www.usgs.gov/core-science-systems/nli/landsat/using-usgs-landsat-level-1-data-product

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To correct for illumination geometry, you will need to use the provided equation and the location- and time-specific sun elevation angle and solar zenith angle.

Convert to Top of Atmosphere Brightness Temperature

$$T = \frac{K_2}{\mathrm{Ln}(K_1/L_\lambda) + 1)}$$

T = Top of atmosphere brightness temperature (K) where:

L_λ =TOA spectral radiance (Watts/(m² * srad * µm))

K_1 =Band-specific thermal conversion constant from the metadata (K1_CONSTANT_BAND_x, where x is the thermal band number)

K_2 = Band-specific thermal conversion constant from the metadata (K2_CONSTANT_BAND_x, where x is the thermal band number)

https://landsat.usgs.gov/using-usgs-landsat-8-product

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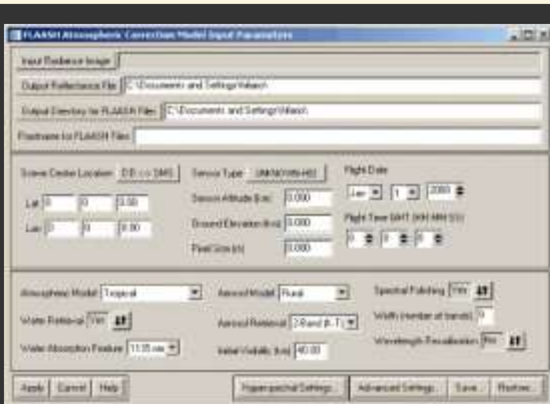
This equation shows how to estimate atmosphere brightness temperature in Kelvin from the Landsat 8 TIRS thermal channels and constants provided in the metadata. There are some known issues with the thermal bands provided by TIRS.

FLASH module in ENVI



❖Tool to convert to reflectance

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There are different options available for converting top of atmosphere reflectance to surface reflectance by modelling out the impact of the atmosphere. One option is the FLASH module in ENVI.

Note that NASA has developed its own methods that are applied to ARD data. If surface reflectance is required, we recommend using the ARD data as opposed to calculating surface reflectance yourself.

Landsat Reflectance Data

- Landsat data can be downloaded as reflectance data from EarthExplorer
- Landsat Analysis Ready Data (ARD)
  - ToA reflectance
  - ToA brightness temperature
  - Surface reflectance (atmospherically corrected)
  - Provisional surface temperature
  - Pixel quality assessment
- Tier 1
  - DN values
  - Suitable for time-series analysis
  - Terrain corrected
  - Well characterized radiometry and inter-calibrated across the different Landsat sensors
  - Georegistration <= 12 m RMSE
  - Radiometrically calibrated and geolocated consistently across the full collection for all the sensors
- Tier 2
  - Do not meet Tier 1 criteria

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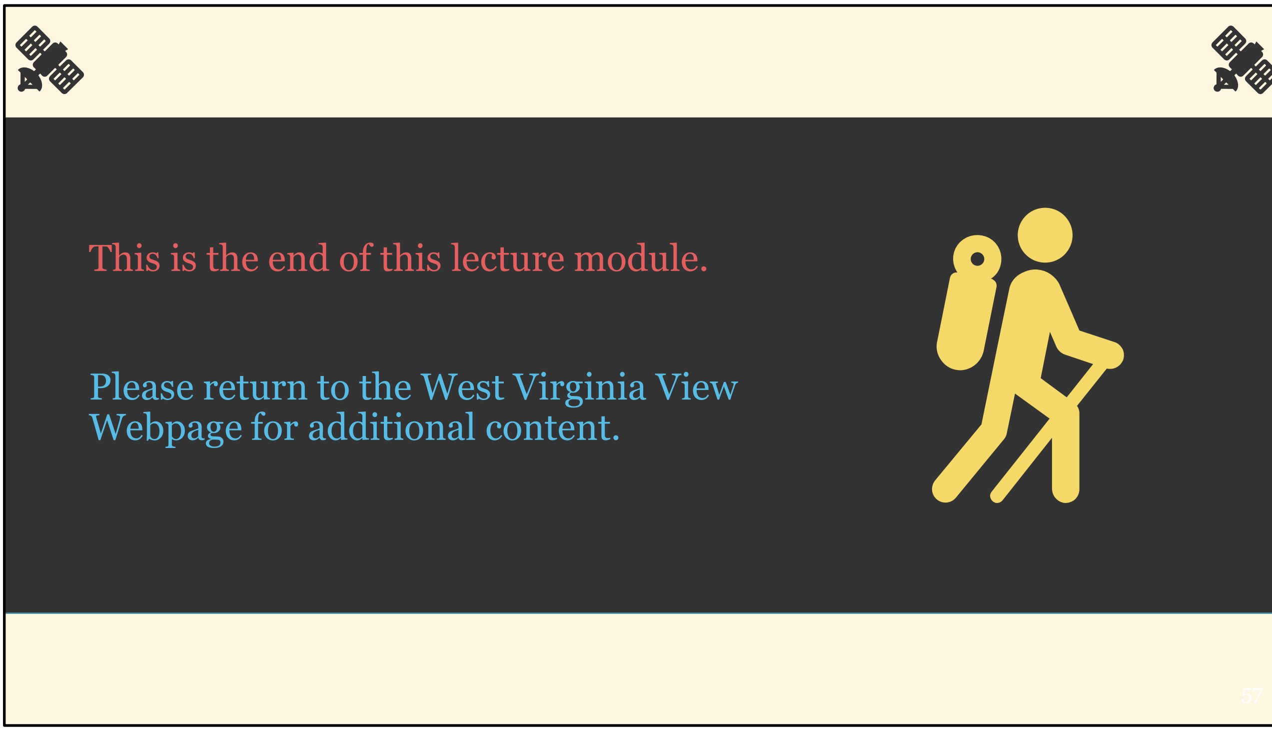
This last slide describes some of the characteristics of different Landsat data products. Again, ARD products have already had conversions applied to obtain top of atmosphere reflectance or surface reflectance by incorporating atmospheric correction. Additional quality and cloud contamination information is provided as additional bands that can be used for cloud masking and quality assessment.

Tier 1 data are delivered as calibrated DN values. These are generally suitable for time series analysis, have been terrain corrected to alleviate geometric distortions, allow for comparison between different Landsat sensors, are georeferenced with an RMSE of less than 12 meters, and are radiometrically calibrated and geolocated consistently across the full collection archive for all sensors.

Tier 2 data have not met all the standards of Tier 1 data. Generally, Tier 2 data should only be used for quantitative analysis if completely necessary and/or Tier 1 or ARD data are not available.



Thanks! Hope you found this useful.