Remote Sensing

Ratios Enhancements

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

In this module, we will explore methods used to enhance and derive additional information from image bands. We will start with a discussion of band ratios and end with an introduction to a variety of additional enhancement methods.

Module Topics

1. Band ratios
2. Principal component analysis
3. Tasseled cap transformation
4. Intensity, hue, and saturation
5. Convolution and moving windows
6. Raster pixel value extraction at point locations
7. Raster summarization by zones

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These are the topics covered in this module.

Ratios

Why use Band Ratios?

- Highlight features of interest
- Reduce the impact of illuminating conditions and topographic aspect
- Discriminate subtle spectral variations in a scene that are masked by the brightness variations in the image from individual spectral bands or in standard color composites
- Portray slopes of spectral reflectance curves between bands, which can be very different between surface materials.

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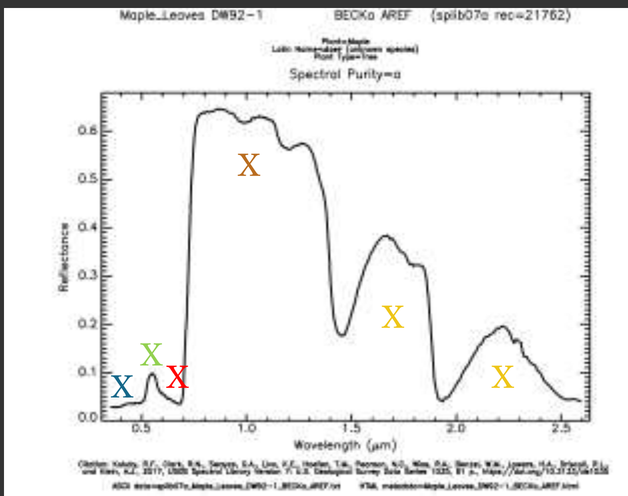
Creating ratios from image bands (e.g., Band X/Band Y) can provide useful information if the feature or phenomenon of interest has varying spectral reflectance in the different bands and if this difference is unique in comparison to other features in the image. Also, since topography can result in decreases in reflectance due to shadowing, ratios offer a means to reduce this impact. If two bands are both darker due to reduced illumination, then generating a ratio offers one means to reduce this impact and minimize the confounding variable of topography.

Ratios can also highlight subtle variations in a scene that are not obvious in the individual spectral bands or multiband composites.

Spectral Reflectance of Vegetation



Example: Maple Leaf
Data from USGS Spectral Library Version 7

- Blue = absorption by pigments
- Green = less absorption by pigment
- Red = absorption by pigments
- Near Infrared = reflect and
- scattered by interior cell walls
- Shortwave Infrared = absorption by water in plant tissue

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Let's review the spectral reflectance of green, healthy, photosynthetically active vegetation using a spectral reflectance curve of a maple leaf provided by the USGS Spectral Library.

Here, I have color coded different spectral ranges with different color "Xs."

This leaf tends to absorb as opposed to reflect a lot of visible radiation. However, it absorbs more blue and red in comparison to green. This is why leaves appear green to us. This absorption results from the pigments in the leaf, such as chlorophyll, that interact with sunlight in the process of photosynthesis to make energy and sugars for the plant. During the winter, when the tree is not photosynthetically active, the leaf will no longer appear green to us.

Green, healthy, and photosynthetically active leaves tend to scatter or reflect a larger proportion of incident near infrared radiation in comparison to visible light due to how this radiation interacts with cell walls. So, if we could sense near infrared radiation, a leaf would appear to be near infrared as opposed to green. However, this has no physical meaning since we can't see near infrared radiation.

In the shortwave infrared range, there are some absorption features associated with water in the plant tissue.

This graph highlights the wavelength specific nature of spectral reflectance.

Simple Ratio (SR)

- Vegetation
- Vegetation health

$$SR = \frac{NIR}{Red}$$

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Dividing NIR surface reflectance by red reflectance generates the simple ratio (SR). As described above, high values of this ratio indicate the occurrence of green healthy vegetation.

Normalized Difference Vegetation Index (NDVI)

$$\text{NDVI} = \frac{(NIR - Red)}{(NIR + Red)}$$

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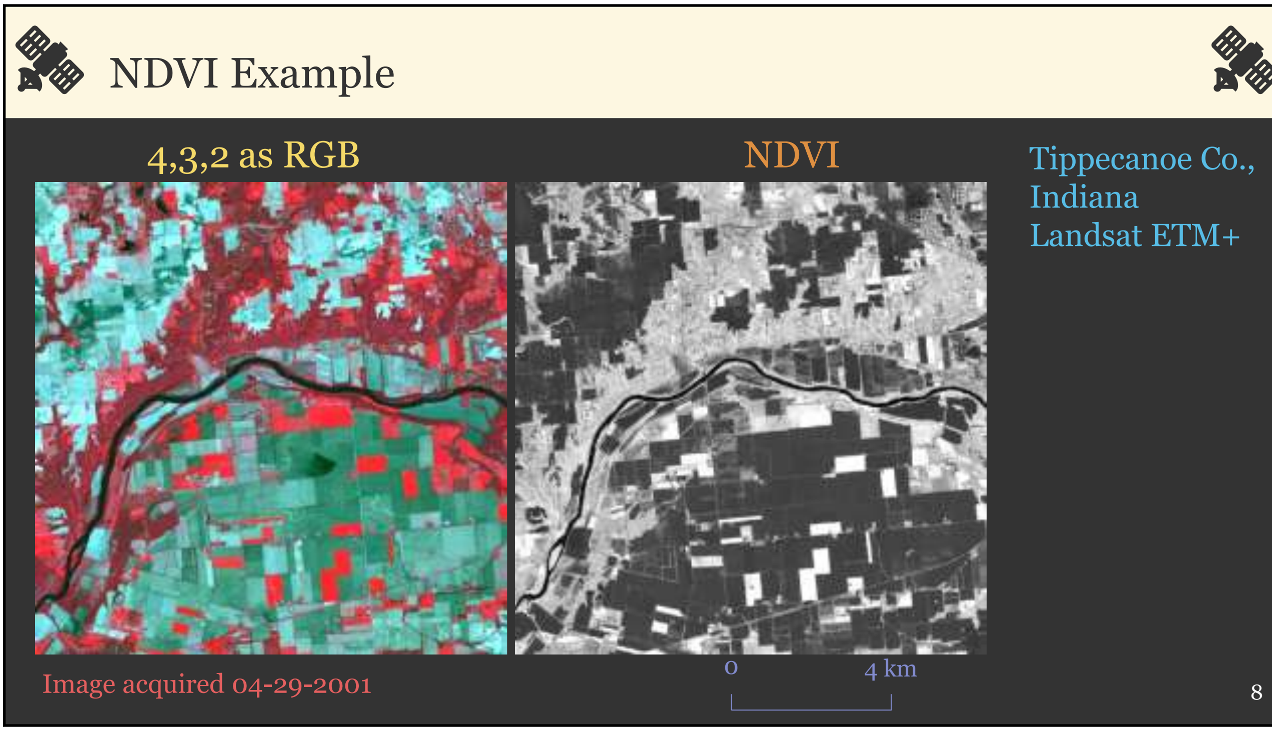
It is more common to generate ratios using normalized differencing methods. This involves differencing or subtracting the two bands then dividing by their sum.

The normalized difference vegetation index (NDVI) is the normalized difference version of the simple ratio, and it is generally more commonly used. Values of NDVI can range from -1 to 1 where values near 1 indicate the presence of green, healthy vegetation. Low values indicate non-vegetated surfaces or unhealthy vegetation.

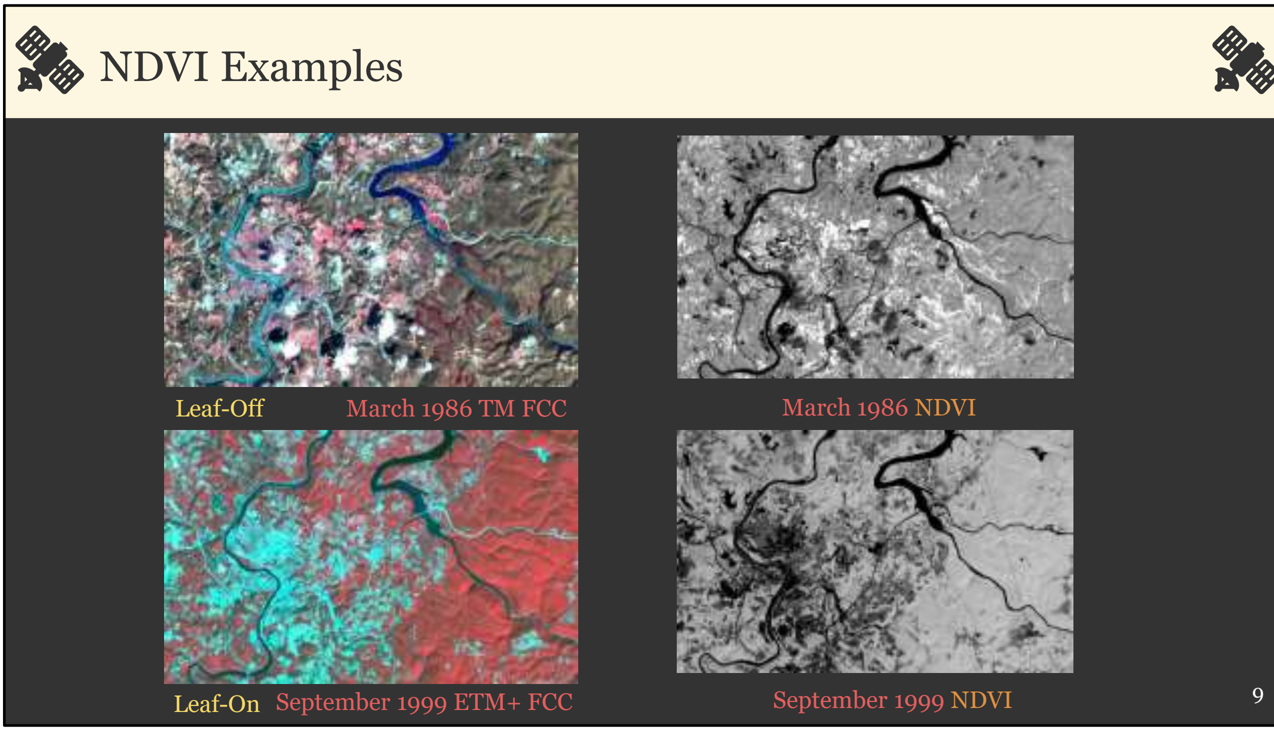
It should be noted that ratios can be calculated from DN values. However, it is generally preferable to calculate them from surface reflectance to provide a more consistent, calibrated, and quantitative result. However, this is not always possible; for example, not all sensors offer the required metadata and calibration characteristics to convert to surface reflectance.

In the example on the left, NDVI has been calculated for a Landsat 5 TM image over a portion of West Virginia using Raster Calculator. Dark areas indicate lack of vegetation or unhealthy vegetation. The image on the left was also generated using Landsat 5 TM data. Darker green areas indicate higher NDVI values while lighter areas indicate lower values. Areas of timber harvest and deforestation are well differentiated.



NDVI does an excellent job of telling us where the vegetation is. Note that natural vegetation is slightly less bright than the field crops, which are being irrigated and fertilized. The image was acquired April 29, 2001.

This image provides information related to which agricultural fields are active and which are not.



NDVI signatures can also vary through time based on plant phenology and senescence. The top set of images represent leaf-off conditions from March. In this image, deciduous forests yield lower NDVI values than conifer forests. In contrast, the summer image set at the bottom of the slide shows little differentiation of forest types.

Summarizing these seasonal patterns can allow us to map and differentiate coniferous, mixed, and deciduous forests.

NDVI from MODIS

Product Name	Terra Product ID	Aqua Product ID
Vegetation Indices 16-Day L3 Global 250m	MOD13Q1	MYD13Q1
Vegetation Indices 16-Day L3 Global 500m	MOD13A1	MYD13A1
Vegetation Indices 16-Day L3 Global 1km	MOD13A2	MYD13A2
Vegetation Indices 16-Day L3 Global 0.05Deg CMG	MOD13C1	MYD13C1
Vegetation Indices Monthly L3 Global 1km	MOD13A3	MYD13A3
Vegetation Indices Monthly L3 Global 0.05Deg CMG	MOD13C2	MYD13C2

https://modis-land.gsfc.nasa.gov/vi.html

Image from Google Earth Engine

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The MODIS sensors onboard the Terra and Aqua satellites provide several different NDVI and vegetation index products at a coarse spatial resolution. Although these datasets are spatially coarse, they tend to have a high temporal gain. MODIS allows for nearly daily global data collection. By combining multiple scenes to generate cloud-free composites, NDVI estimates can be generated at 16-day to monthly intervals. MODIS is also very well calibrated, so these data tend to be very consistent over time and have proven to be valuable for change detection and global land cover and climate change studies.

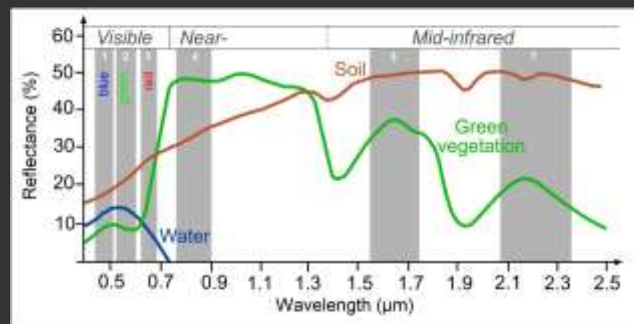
Normalized Difference Water Index (NDWI)

Gao, 1996

$$NDWI = \frac{(NIR - SWIR)}{(NIR + SWIR)}$$

McFeeters, 1996

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



https://seos-project.eu/remotesensing/remotesensing-c01-p06.html

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We will now move on to discuss indices used to differentiate and explore surface materials other than vegetation.

Different versions of the normalized difference water index (NDWI) are available. After Gao (1996) a water index can be generated from NIR and SWIR bands. McFeeters (1996) suggests a method that relies on the green and NIR bands. Here, we will discuss the latter.

Water has a higher green reflectance in comparison to NIR, as the spectral reflectance curve on this slide demonstrates. As with NDVI, the NDWI scales from -1 to 1. High values indicate the presence of water.

Normalized Difference Water Index

Sentinel-2 Image

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

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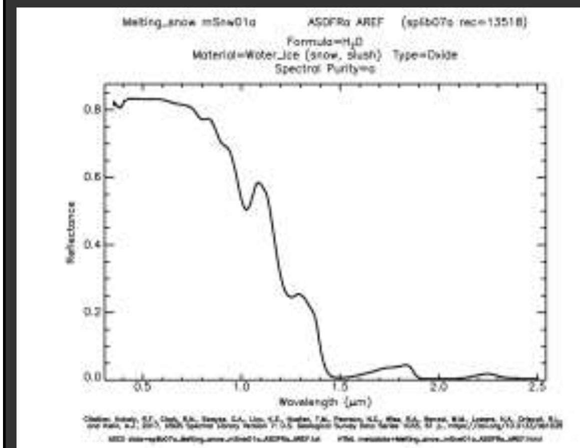
This is an example of the NDWI calculated from a Sentinel-2 image representing the area around Vancouver, British Columbia, Canada. Again, bright areas indicate the presence of water; the ocean, rivers, and lakes are well differentiated from other surfaces.

Normalized Difference Snow Index (NDSI)



Data from USGS Spectral Library Version 7

$$\text{NDSI} = \frac{(Green - SWIR)}{(Green + SWIR)}$$

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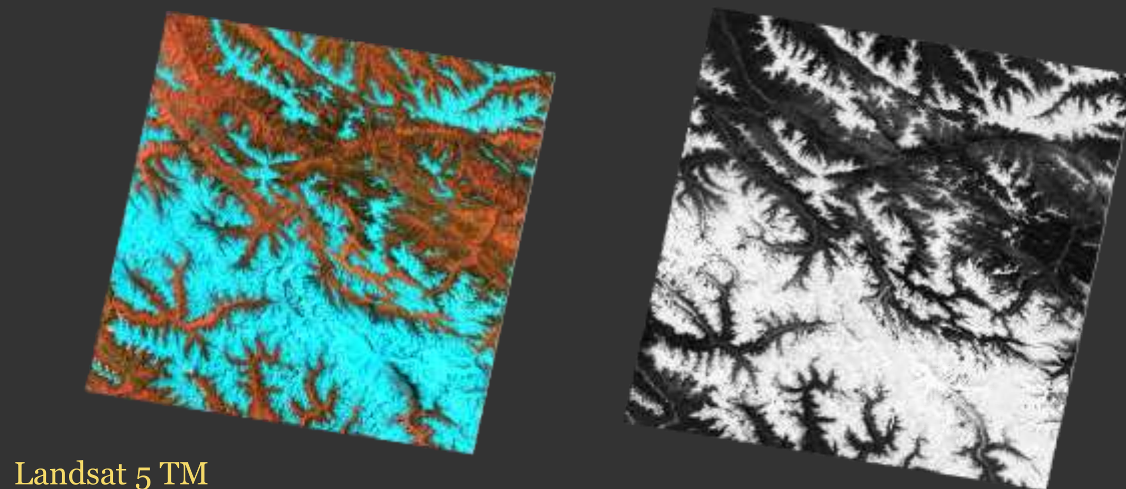
The normalized difference snow index (NDSI) uses the green and SWIR bands. Snow has a higher reflectance in the green band than the SWIR band.

Normalized Difference Snow Index (NDSI)



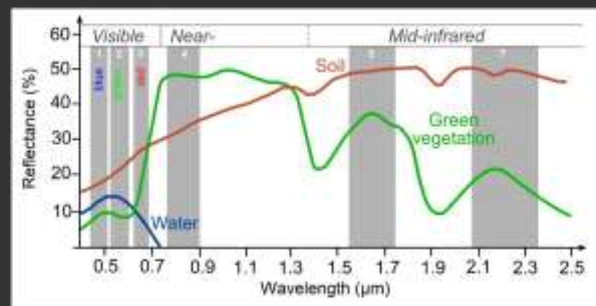
This image provides an example of the NDSI calculated from a Landsat 5 TM image covering a section of the Himalayan Mountains. Snow and glacial ice yield high values for this index whereas vegetation yields low values.

Normalized Burn Ratio (NBR)

$$\text{NBR} = \frac{(NIR - SWIR2)}{(NIR + SWIR2)}$$

Note: Bands must be in reflectance not radiance or DN values

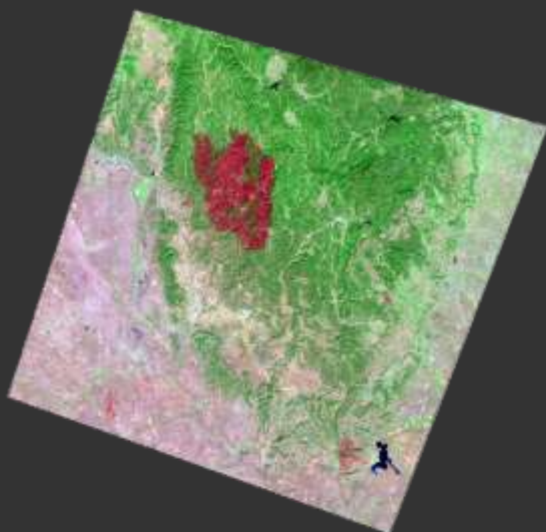
Bands 4 = 0.76µm – 0.90µm
Band 7 = 2.08µm – 2.35µm

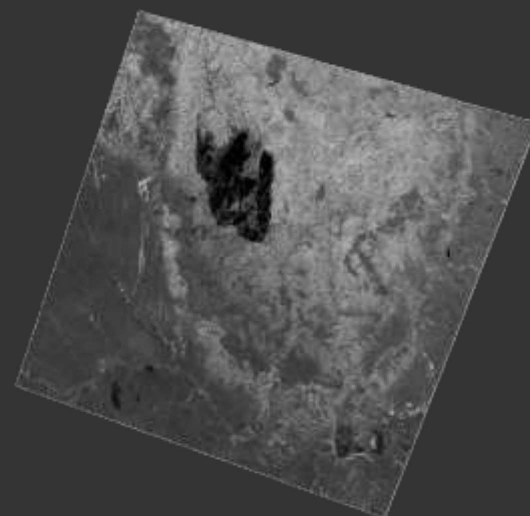


http://www.seos-project.eu/modules/classification/classification-c01-p05.html

The normalized burn ratio (NBR) is used to map forest fires and predict forest fire severity. Burned areas have a spectral signature similar to bare soil. Or, they will have a high SWIR reflectance and a lower NIR reflectance. In contrast, vegetation will show a higher NIR reflectance and a lower SWIR reflectance. So, this index allows for a differentiation of burned areas from unburned vegetation.

Normalized Burn Ratio (NBR)





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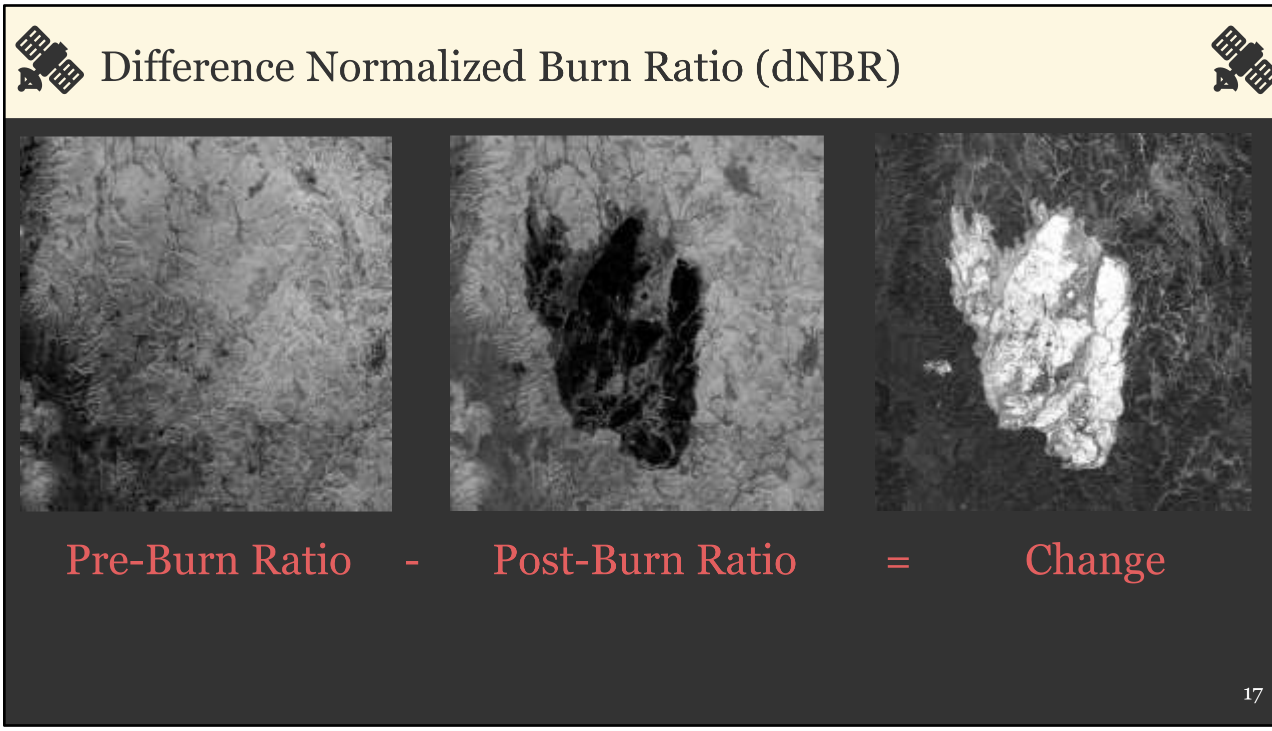
This example scene shows a large fire scar in the Black Hills of South Dakota. This false color composite is defined as follows: Red = SWIR2, Green = NIR, Blue = Green. So, red areas indicate more SWIR reflectance and less NIR reflectance and could indicate a fire scar.

The second image shows the NBR. Dark pixels indicate burned areas.



In order to detect fires, it is common to compare change in the NBR overtime using pre-fire and post-fire data. For the same fire shown in the prior slide, the two ratios provided summarize conditions before and after a fire. These two indices are then subtracted to obtain the difference normalized burn ratio (dNBR) where higher values indicate higher burn severity.

Burn severity should be calculated from surface reflectance data as opposed to DN values, especially if differencing will be applied. This is so that a more consistent and quantifiable product is produced.

FIREMON

- Several U.S. agencies including the USDA, US Forest Service, USGS, and the National Biological Information Infrastructure (NBII) have partnered to create the Fire Research and Management Exchange System (FRAMES).
- FRAMES (http://frames.nbii.gov) has grown and has developed and implemented an agency independent Fire Effects Monitoring and Inventory System (FIREMON) that uses standardized field and remote sensing techniques to characterize fire events.

https://www.frames.gov/partner-sites/firemon/firemon-home/

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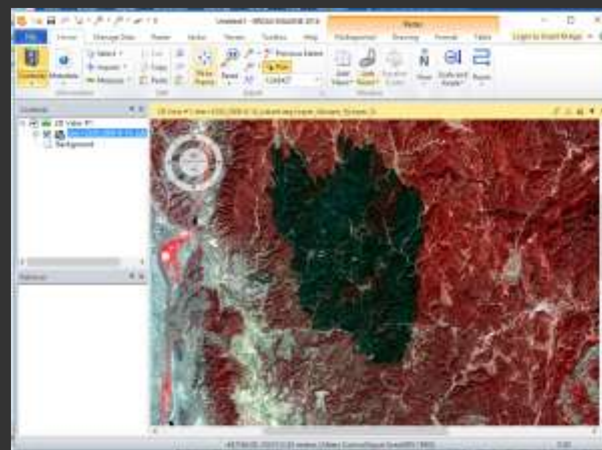
The dNBR has been operationalized for fire detection, monitoring, and burn severity mapping. One example is the FIREMON project.

FIREMON: Remote Sensing Component

Uses Landsat TM and/or ETM+ data

Steps

1. Atmospherically correct the before and after images to "at-satellite" or reflectance values.
2. Perform a Normalized Burn Ratio (NBR) on both the before and after fire images.
3. Use the image differencing technique to find the burned area or dNBR.
4. Scale the dNBR image by 10^3 and reference the Severity Level thresholds described by FIREMON to determine burned and unburned areas.



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This slide summarizes the remote sensing-based steps in the FIREMON process.

Soil-Adjusted Vegetation Index (SAVI)

$$\text{SAVI} = \frac{(NIR - Red)}{(NIR + Red)} \text{ X } (1 + \text{L})$$

- ❖Adjusts NDVI using soil brightness factor
- ❖L = amount of green vegetation cover

Huete, A. R., 1988, "A soil-adjusted vegetation index (SAVI)," *Remote Sensing of Environment*, Vol 25, 295–309.

A variety of band ratios can be calculated, depending on what image bands or spectral ranges are available. We will not cover all ratios. However, I did want to provide at least an introduction to some other common ratios that can be calculated from common multispectral sensors, such as the Landsat sensors or Sentinel-2 MSI.

Differences in soil reflectance can cause a confounding signature in the NDVI if you want to differentiate the vegetation signature specifically. As a result, several adjustments or modifications of the NDVI have been proposed. One example is the soil-adjusted vegetation index (SAVI), which includes a variable (L) to correct for differences in green vegetation cover at each cell.

Modified Soil-Adjusted Vegetation Index (MSAVI)

$$\text{MSAVI} = (1/2)*(2(\text{NIR}+1)-\text{sqrt}((2*\text{NIR}+1)^2-8(\text{NIR}-\text{Red})))$$

- Adjusts SAVI for the effect of bare soil

Qi, J. et al., 1994, "A modified soil vegetation adjusted index", *Remote Sensing of Environment*, Vol. 48, No. 2, 119–126.

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The modified soil-adjusted vegetation index (MSAVI) further adjusts NDVI and SAVI to reduce the impact of bare soil reflectance.

Transformed Soil-Adjusted Vegetation Index (TSAVI)

$$\text{TSAVI} = \frac{(s(NIR - s*Red - a))}{(a*NIR + Red - a*s + X*(1+s^2))}$$

- Adjusts for soil brightness influences
- s = the soil line slope
- a = the soil line intercept
- X = an adjustment factor that is set to minimize soil noise

Baret, F. and G. Guyot, 1991, "Potentials and limits of vegetation indices for LAI and APAR assessment," *Remote Sensing of Environment*, Vol. 35, 161–173.

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The transformed SAVI further adjusts for soil noise or differences.

Perpendicular Vegetation Index (PVI)

$$PVI = \frac{(NIR - a * Red - b)}{(sqrt(1 + a^2))}$$

- Similar to NDVI but sensitive to atmospheric variation
- a = slope of the soil line
- b = gradient of the soil line

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The perpendicular vegetation index (PVI) provides another option for minimizing the impact of soil reflectance on vegetation indices.

Visible Atmospherically Resistant Index (VARI)

$$\text{VARI} = \frac{(Green - Red)}{(Green + Red - Blue)}$$

- ❖Highlight vegetation using only visible bands
- ❖Mitigate illumination effects

Gitelson, A., et al. "Vegetation and Soil Lines in Visible Spectral Space: A Concept and Technique for Remote Estimation of Vegetation Fraction." *International Journal of Remote Sensing 23*(2002): 2537–2562.

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The visible atmospherically resistant index (VARI) provides a vegetation index option when only visible bands are available. This index relies on the higher green reflectance of photosynthetically active and healthy vegetation in comparison to red and blue. If a NIR band is available, NDVI is preferable to VARI.

Normalized Difference Moisture Index (NDMI)

$$\text{NDMI} = \frac{(NIR - SWIR1)}{(NIR + SWIR1)}$$

- Sensitive to moisture in vegetation
- Monitor droughts and fuel levels for fires

Wilson, E.H. and Sader, S.A., 2002, "Detection of forest harvest type using multiple dates of Landsat TM imagery." *Remote Sensing of Environment*, 80 , pp. 385-396.

Skakun, R.S., Wulder, M.A. and Franklin, .S.E. (2003). "Sensitivity of the thematic mapper enhanced wetness difference index to detect mountain pine beetle red-attack damage." *Remote Sensing of Environment*, Vol. 86, Pp. 433-443.

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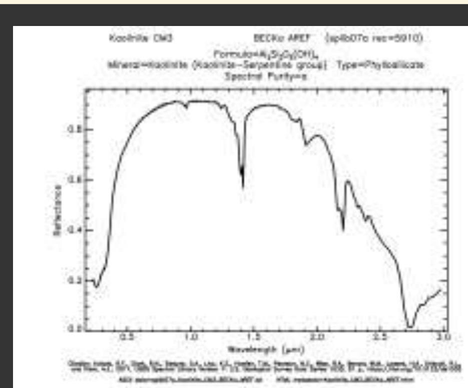
A general moisture index is derived from the Landsat SWIR1 and NIR bands. The normalized difference moisture index (NDMI) makes use of the spectral reflectance of water in the SWIR1 band range, is sensitive to moisture in vegetation, and is used to monitor for droughts.

Clay Mineral Ratio

$$\text{Clay Mineral Ratio} = \frac{SWIR1}{SWIR2}$$

- Makes use of 2.0-2.3 micrometer clay absorption features

Amro F. Alasta, "Using Remote Sensing data to identify iron deposits in central western Libya." *International Conference on Emerging Trends in Computer and Image Processing*(ICETCIP'2011) Bangkok Dec., 2011.



Data from USGS Spectral Library Version 7

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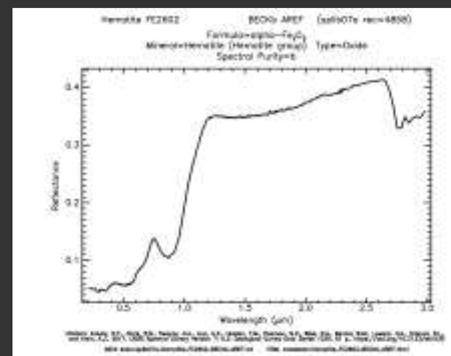
As discussed in a prior module, clay minerals have a characteristic absorption feature at ~2.2 µm. This allows for the detection of clay minerals by dividing the Landsat SWIR1 band by the SWIR2 band.

Ferrous Minerals Ratio

$$\text{Ferrous Mineral Ratio} = \frac{SWIR}{NIR}$$

Segal, D. "Theoretical Basis for Differentiation of Ferric-Iron Bearing Minerals, Using Landsat MSS Data." *Proceedings of Symposium for Remote Sensing of Environment*, 2nd Thematic Conference on Remote Sensing for Exploratory Geology, Fort Worth, TX (1982): pp. 949-951.



Data from USGS Spectral Library Version 7

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The ferrous mineral ratio makes use of the SWIR and NIR ranges.

Normalized Difference Built-Up Index (NDBI)

$$\text{NDBI} = \frac{SWIR - NIR}{SWIR + NIR}$$

- Emphasizes man-made built-up areas

Zha, Y., J. Gao, and S. Ni. "Use of Normalized Difference Built-Up Index in Automatically Mapping Urban Areas from TM Imagery." *International Journal of Remote Sensing* 24, no. 3 (2003): 583-594.

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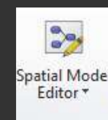
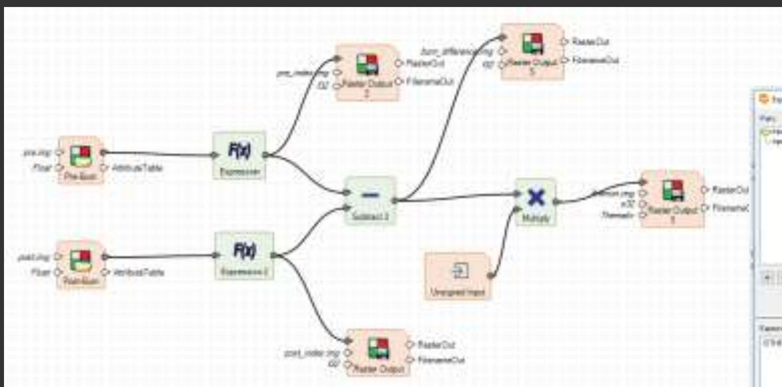
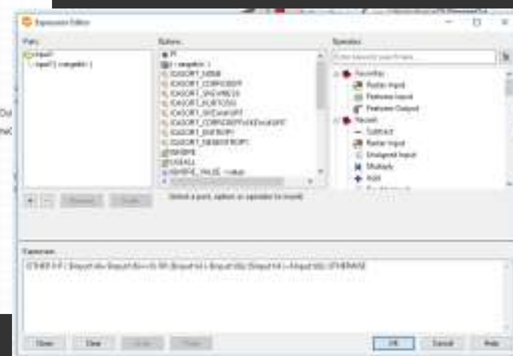
The normalized difference built-up index (NDBI) is used to emphasize man-made or built-up areas dominated by impervious surfaces, such as asphalt and concrete. These surfaces tend to show a higher SWIR reflectance in comparison to NIR.

Ratios in Erdas Imagine

- Use Spatial Model Editor







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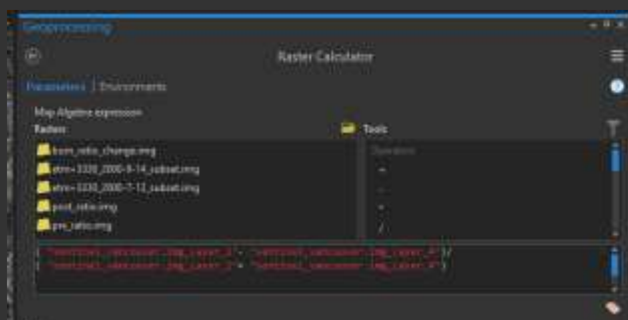
Ratios can be calculated in Erdas Imagine using the Spatial Model Editor and available functions. In the provided example, we have generated a model to calculate the difference normalized burn ratio (dNBR) from pre- and post-fire images that have been converted to spectral reflectance.

The Expression functions calculate the pre-NBR and post-NBR separately. The Subtract function is used to subtract them and obtain the dNBR. Lastly, the dNBR is multiplied by 1,000 to return an integer output.

Ratios in ArcGIS Pro

- Raster Calculator
- Built-In Indices



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Ratios can be calculated in ArcGIS Pro using the Raster Calculator Tool. There are also built-in Raster Functions for calculating several common ratios.

Enhancements

Principal Component Analysis (PCA)

- Orthogonal transformation
- Converts *n* correlated variables into *n* uncorrelated variables
- Idea is that variance is information
- Generally, variability in data are described in a smaller number of principal components, thus reducing the number of needed variables

https://www.statistixl.com/features/principal-components/

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We will now provide an introduction to some other common image enhancement methods.

One common issue with image data is that the different spectral bands tend to be correlated with each other. This results in redundant information based on the assumption that variability is information. So, it might be desirable to generate new, uncorrelated bands from the original bands that are not correlated and, thus, capture the information content available in the original data in a smaller number of variables. This is the purpose of principal component analysis, or PCA.

Principal Component Analysis (PCA)

- Eigenvectors
- Values needed to create principal components from a linear combination of the input variables

\# EIGENVALUES AND EIGENVECTORS

\# Number of Input Layers: 6 — Number of Principal Component Layers: 6

# PC Layer	1	2	3	4	5	6
# Eigenvalues	1441846.83621	271631.53245	45726.39454	2928.82266	1993.02311	708.18719
# Eigenvectors						
# Input Layer						
1	0.07643	0.31423	0.41331	0.33788	0.30618	0.07478
2	0.13114	0.31426	0.44427	0.38922	0.24305	-0.72937
3	0.15877	0.43231	0.43667	-0.38515	-0.08298	0.09658
4	0.79381	-0.54500	0.24239	-0.09599	0.05435	0.03264
5	0.48906	0.35524	-0.53907	0.50564	-0.29589	0.02840
6	0.28712	0.43763	-0.30578	-0.61413	0.58389	-0.03853

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The process of principal component analysis involves the transformation of the raw image bands into a new space in which the resulting bands, or principal components, are not correlated. Calculating PCA involves some matrix algebra and the use of a covariance matrix. A mathematical proof of this concept is beyond the scope of this course. The key concept here is that PCA allows for the determination of Eigenvectors, which are effectively coefficients that can be applied to each band to obtain a new band or principal component that explains a certain proportion of the variance in the raw input data.

For example, in the provided table 6 input bands are being used to obtain 6 uncorrelated, new principal component bands. To obtain the first principal component specifically, the following equation is applied:

$PC1 = (B1 * 0.07643) + (B2 * 0.13114) + (B3 * 0.15877) + (B4 * 0.79381) + (B5 * 0.48906) + (B6 * 0.28712)$.

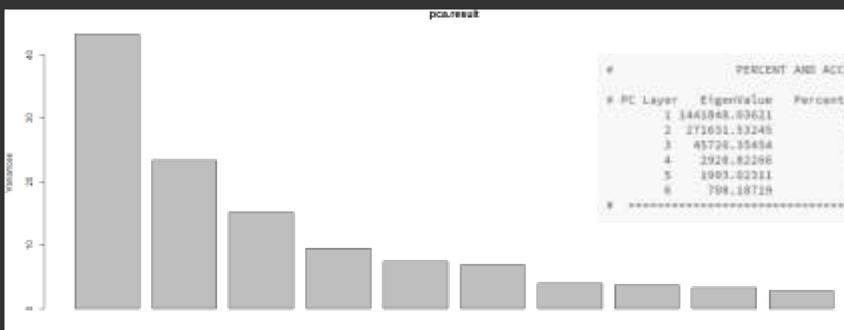
Other principal component bands will be calculated using the associated coefficients.

The Eigenvalue for each principal component relates to the amount of variance explained: larger eigenvalues indicate a larger proportion of variance explained.

In summary, the process of PCA allows for the determination of Eigenvectors which are used to calculate principal components from a linear combination of the input variables.

Principal Component Analysis (PCA)

- Generally, the first principal component explains the most variability in the data
- Explained variability decreases with increased PC
- Can visualize with a Scree Plot



PERCENT AND ACCUMULATIVE EIGENVALUES

PC Layer	EigenValue	Percent of EigenValues	Accumulative of EigenValues
1	1441848.03621	81.6987	81.6987
2	271651.33245	15.3913	97.0900
3	45726.35454	2.5910	99.6810
4	2920.82266	0.1660	99.8469
5	1983.02311	0.1128	99.9598
6	798.18719	0.0401	100.0000

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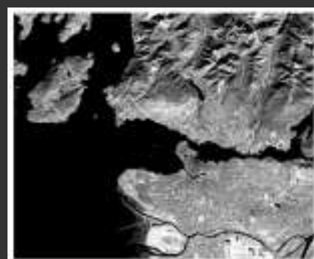
Again, one of the key uses of PCA is to reduce the dimensionality of your input data by capturing the information content, or variability, in a smaller number of features.

The Scree Plot provides a means to visualize the explained variance. Again, larger Eigenvalues indicate more explained variance. In the provided example, PC1 captures 81.7% of the variance, PC2 captures 15.4%, and PC3 captures 2.3%. Cumulatively, PC1 through PC3 capture 99.7% of the variance. So, six bands could be reduced to three with only a slight loss in information content.

Calculating Principal Components

Original Image



PC 1

PC 2

PC 3

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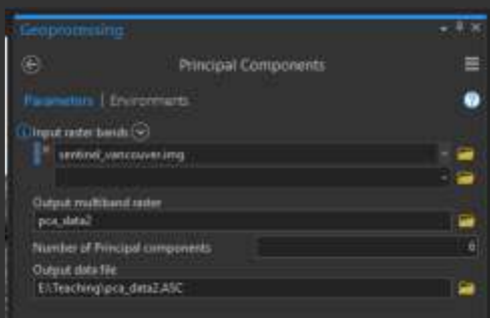
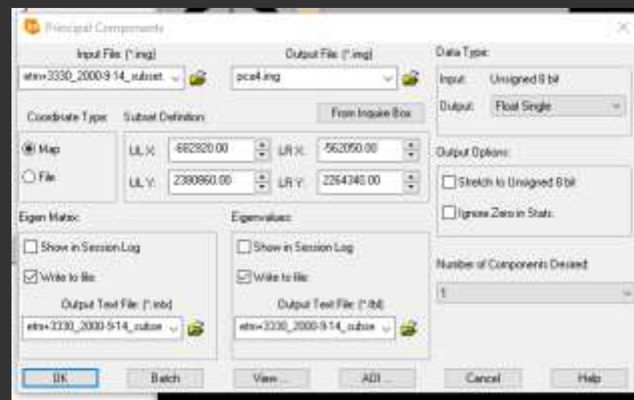
This image shows the first three principal components calculated from a Senstinel-2 image of Vancouver, British Columbia, Canada.

Calculating Principal Components





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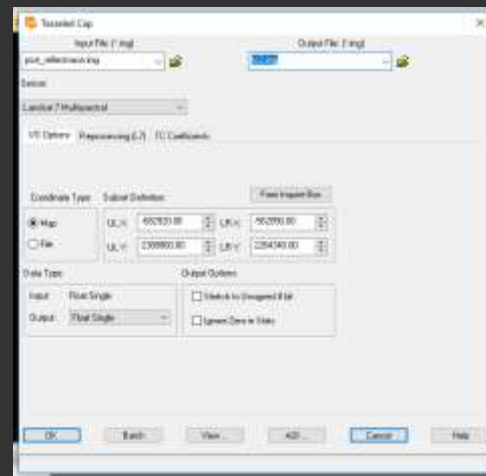
Principal components can be calculated in both ArcGIS Pro and Erdas Imagine.

When calculating PC bands, the bands should all have the same scale (e.g., 8-bit or 16-bit). If data are combined using different scales or radiometric ranges, they will need to be converted to a common scale prior to undertaking PCA.

Tasseled Cap Transformation

- Similar to PCA, but with pre-defined eigenmatrix
- Brightness = relates to soil reflectance
- Greenness = amount of green vegetation that is present
- Wetness = moisture content/conditions



Kauth, R.J. and Thomas, G.S. 1976, The Tasselled Cap—A Graphic Description of the Spectral-Temporal Development of Agricultural Crops as Seen by LANDSAT. LARS Symposia, paper 159.

Crist, E.P., 1985. A TM tasseled cap equivalent transformation for reflectance factor data. *Remote Sensing of Environment*, *17*(3), pp.301-306.

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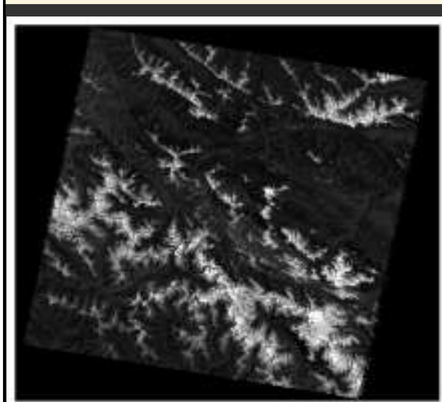
A concept related to PCA is the tasseled cap transformation. The goal of this transformation is to convert the Landsat bands to new bands that highlight some key information. Specifically, a pre-defined Eigenmatrix of Eigenvectors is used to generate measures of brightness, greenness, and wetness from the input bands. Brightness relates to soil reflectance, with bare, bright soils yielding a strong signature. Greenness relates to the occurrence of green, healthy vegetation while wetness relates to water and moisture content.

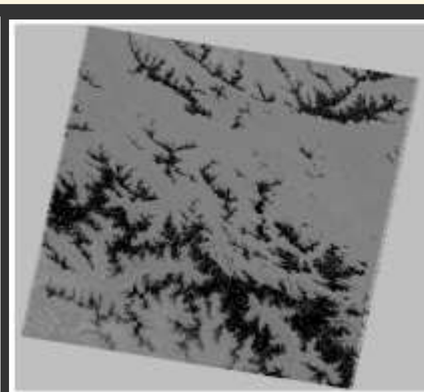
Since all Landsat sensors are unique, different Eigenvalues are used to generate the tasseled cap transformation. Also, this conversion generally requires spectral reflectance data as opposed to DN values.

If you are wondering why this transformation is called tasseled cap, this relates to the shape of the data distribution in this transformed space, which happens to look like a tasseled cap.

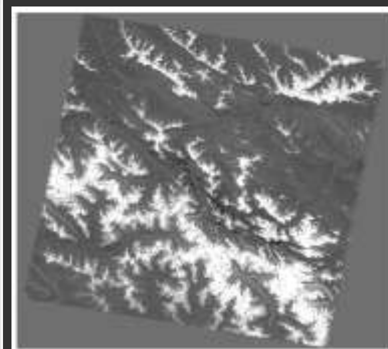
Tasseled Cap Transformation



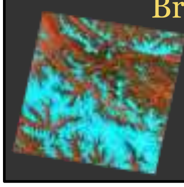
Brightness



Greenness



Wetness



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This image shows brightness, greenness, and wetness as calculated from a Landsat 5 Thematic Mapper scene over the Himalayan Mountains.

Tasseled Cap Transformation

Feature	TM 1	TM 2	TM 3	TM 4	TM 5	TM 7
Brightness	0.2043	0.4158	0.5524	0.5741	0.3124	0.2303
Greenness	-0.1603	-0.2819	-0.4934	0.7940	-0.0002	-0.1446
Wetness	0.0315	0.2021	0.3102	0.1594	-0.6806	-0.6109
Fourth	-0.2117	-0.0284	-0.1302	-0.1007	0.6529	-0.7078
Fifth	-0.8669	-0.1835	0.3856	0.0408	-0.1132	0.2272
Sixth	0.3677	-0.8200	0.4354	0.0518	-0.0066	-0.0104

For Landsat 5 Thematic Mapper (TM)

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This table provides the Eigenvalues for calculating the brightness, greenness, and wetness bands from input Landsat 5 TM bands as spectral reflectance. For example, to calculated brightness, each input band would be multiplied by the associated coefficient in the first row of the table then added together. Note that the thermal band is not included.

The fourth through sixth components are not generally included, as they do not provide much additional information. However, coefficients are provided.

The following slides provide the coefficients for Landsat 7 ETM+ and Landsat 8 OLI.

Eigenvalues have also been determined for other sensors, such as MODIS and Sentinel-2 MSI.

Tasseled Cap Transformation

Feature	ETM+ 1	ETM+ 2	ETM+ 3	ETM+ 4	ETM+ 5	ETM+ 7
Brightness	0.3561	0.3972	0.3904	0.6966	0.2286	0.1596
Greenness	-0.3344	-0.3544	-0.4556	-0.6966	-0.0242	-0.2630
Wetness	0.2626	0.2141	0.0926	0.0656	-0.7629	-0.5388
Fourth	0.0805	-0.0498	0.1950	-0.1327	0.5725	-0.7775
Fifth	-0.7252	-0.0202	0.6683	0.0631	-0.1494	-0.0274
Sixth	0.4000	-0.8172	0.3832	0.0602	-0.1095	0.0985

For Landsat 7 Enhanced Thematic Mapper (ETM+)

Tasseled Cap Transformation

Feature	OLI 2	OLI 3	OLI 4	OLI 5	OLI 6	OLI 7
Brightness	0.3029	0.2786	0.4733	0.5599	0.508	0.1872
Greenness	-0.2941	-0.243	-0.5424	0.7276	0.0713	-0.1608
Wetness	0.1511	0.1973	0.3283	0.3407	-0.7117	-0.4559
Fourth	-0.8239	0.0849	0.4396	-0.058	0.2013	-0.2773
Fifth	-0.3294	0.0557	0.1056	0.1855	-0.4349	0.8085
Sixth	0.1079	-0.9023	0.4119	0.0575	-0.0259	0.0252

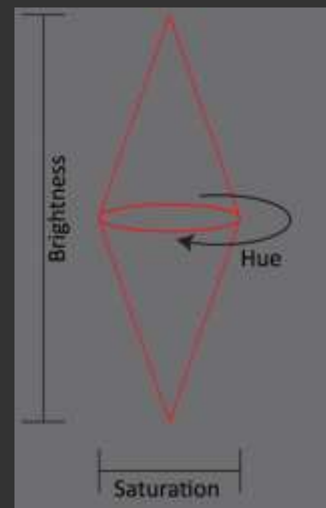
For Landsat 8 Operational Land Imager (OLI)

Intensity-Hue-Saturation (IHS)

- Convert from RGB space to IHS Space
- Intensity ~ Brightness/lightness (0-1)
- Hue ~ Color (0-360)
- Saturation ~ Dullness/color mixed with gray (0-1)

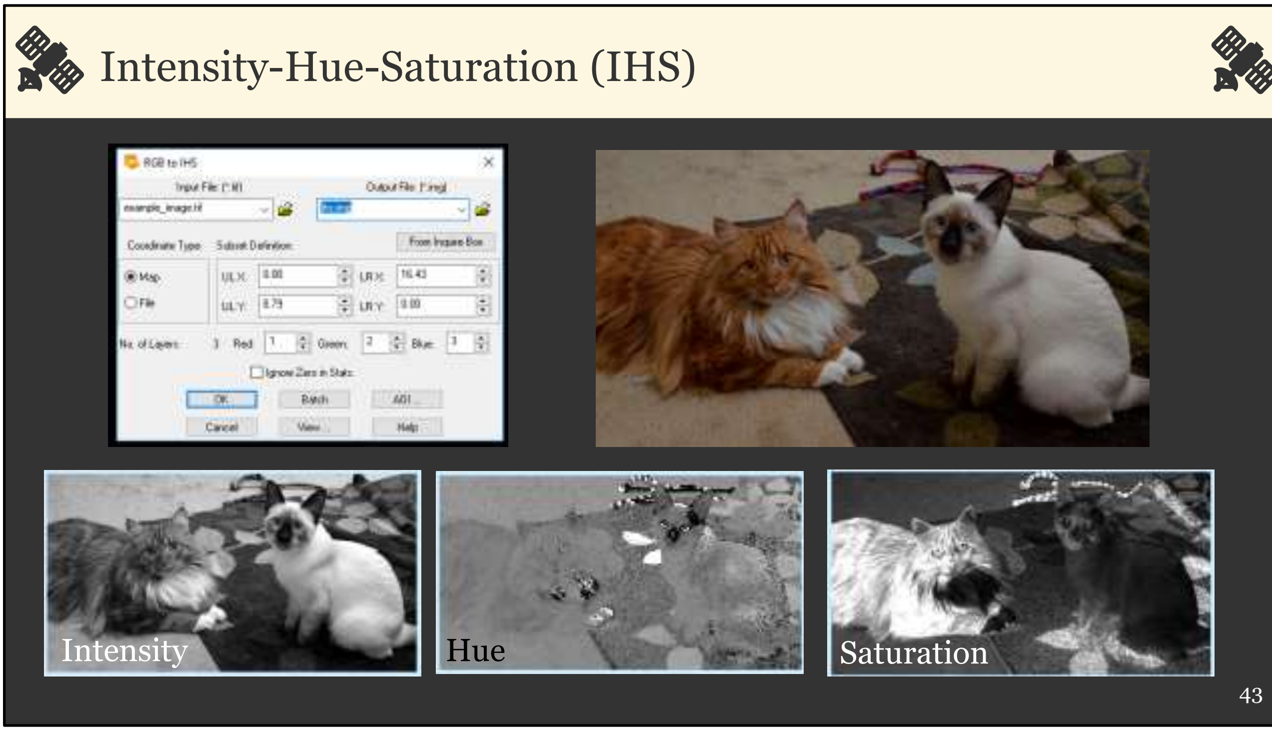

Example from Adobe Illustrator


Example from ArcGIS Pro



RGB bands can be converted into a different color space to represent intensity, hue, and saturation. Intensity relates to brightness/darkness or black/white and is generally scaled from 0 to 1 where 0 represents black and 1 represents white. Hue relates to the base color and is scaled from 0 to 360 to represent the full color wheel. Saturation represents mixing the base color or hue with gray and is scaled from 0 to 1. Sometimes intensity and/or saturation are represented as a percentage from 0% to 100% as opposed to a proportion from 0 to 1.

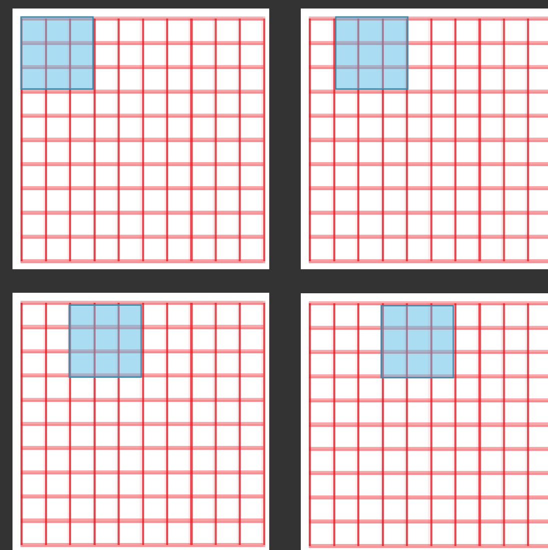
This transformation only uses the RGB data. Additional bands are not factored into this transformation. As a side note, IHS space is also sometimes used for pansharpening.



This slide shows an example of intensity, hue, and saturation outputs generated from an image of my cats: Freddy and Peri. Again, intensity relates to light vs. dark, hue relates to base color, and saturation relates to mixing the base hue with gray.

What is a neighborhood?

- Neighborhood analysis, moving window analysis, focal operation, kernel analysis
- Make calculation or compare cell values around a center cell



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Many raster analysis tasks rely on comparing a raster grid cell value to the values in neighboring cells. These types of processes go by many names including neighborhood analysis, moving window analysis, focal operations, and kernel analysis.

Further, these types of processes are not limited to geospatial analysis. Similar techniques are used to blur or sharpen photographs in digital photo editing software packages.

These methods function by moving a window over the raster surface. A calculation is performed based on the cell values within the moving window. The result is then written to a new raster at the location associated with the cell at the center of the window.

The window then moves on to the next cell, using a different center cell and window. The calculation is performed again, and the process continues until all cells have been used as the center cell.

This slide conceptualizes a 3-by-3 cell window moving over a raster grid. For example, the mean of the cells within the window could be calculated then returned to a new cell at the location of the center cell in the grid. The window will then move on to the next cell and perform the calculation again.

Convolution

- Uses moving windows
- Compare cell values in a window
- Can enhance differences (high pass)
- Can minimize differences or smooth (low pass)
- Can detect or enhance edges (edge detection)
- Can change the window size

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Convolution techniques make use of moving windows to perform spatial manipulations of the data and/or compare cell values to surrounding cells. Examples include high pass filters, low pass filters, and edge detection.

The user can change the size and/or shape of the window and the values used in the kernel.

High Pass

- Exaggerate/enhance differences

-1	-1	-1
-1	8	-1
-1	-1	-1

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A high pass filter is used to highlight differences. High values are returned when the center cell in the window has a very different value than its neighbors. The provided 3 x 3 kernel is an example of a high pass filter. In this case, the center cell value is multiplied by 8 while all neighboring cells are multiplied by -1. The resulting values are then added together to return a value at the center cell location in the new grid.

As an example, let's say that all cells in the window hold a value of 1. The result here will be -8 + 8 = 0. So, the same cell values will yield back a low value of zero. In contrast, neighboring cell values that are different from the center cell, will yield back a higher value, thus highlighting differences. For example, if all neighboring cells were 0 and the center cell was one, the results would be 0 + 8 = 8.

Edge Detection

❖Enhance or detect edges

-1	-1	-1
-1	8	-1
-1	-1	-1

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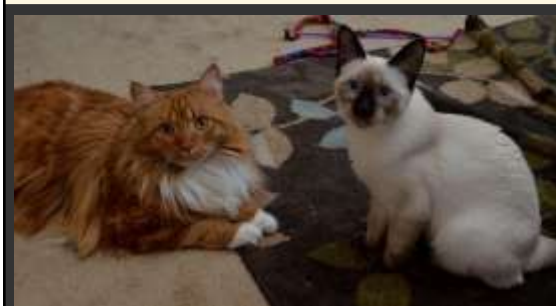
Edge detection is one use of high pass filters, as these filters highlight local differences in DN values, which can correspond to edges or transitions between features in the image.

Low Pass



- Smooth or minimize differences

1	1	1
1	8	1
1	1	1

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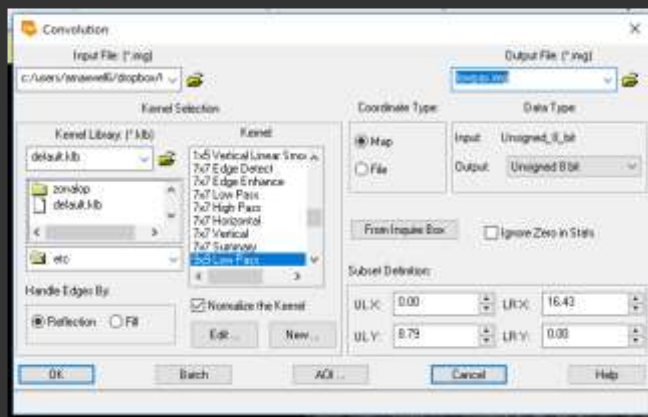
Low pass filters perform the opposite operation: they reduce the impact of local differences to average or smooth the output. These types of filters are often used to smooth, blur, or remove local image noise.

Convolution in Erdas Imagine



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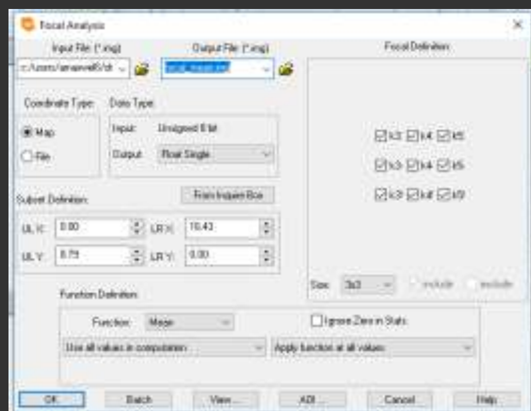
Erdas Imagine provides a variety of convolution operations. You can also define your own kernels with varying values and window sizes.

Convolution options are more limited in ArcGIS Pro, unless you make use of Raster Functions.

Focal Analysis

❖Calculate a statistic within a 3 x 3 moving window



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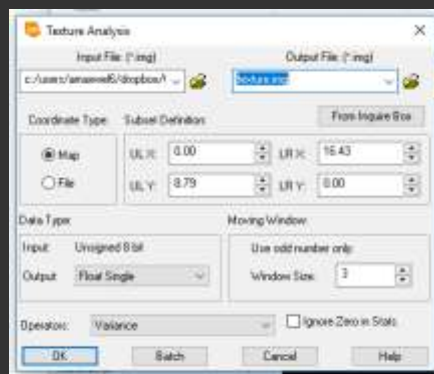
Focal statistics is a type of moving window analysis. As the name implies, this method is used to calculate a statistic within a moving window.

As the window progresses over the raster grid, the resulting statistic is written to a new cell at the center cell location. The process continues to perform the calculation using all the cells in the original grid as the center cell.

Texture

- Calculate textural measures within a window



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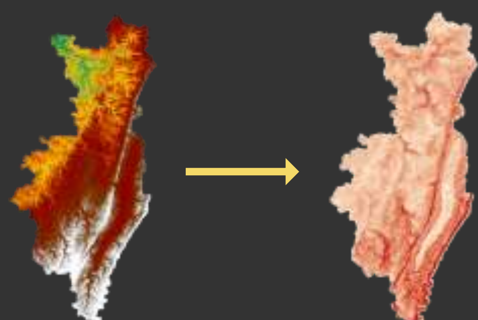
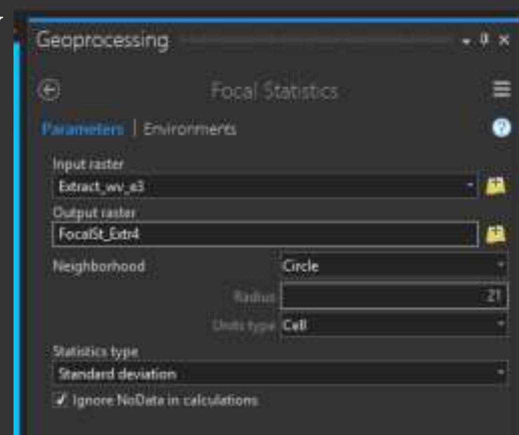
Measures of local texture or variability also commonly rely on moving windows.

Focal Statistics (ArcGIS Pro)

- ❖Calculates a statistic within the window
- ❖Stores result on center cell in new output
- ❖Completes operations for all cells





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Focal statistics can also be calculated in ArcGIS Pro with the Focal Statistics Tool. This will generate a raster output where each cell holds the local statistic calculated in the moving window centered on that cell location.

Focal Statistics

MEAN = Calculates the mean (average value) of the cells in the neighborhood.

MAJORITY = Calculates the majority (value that occurs most often) of the cells in the neighborhood.

MAXIMUM = Calculates the maximum (largest value) of the cells in the neighborhood.

MEDIAN = Calculates the median of the cells in the neighborhood.

MINIMUM = Calculates the minimum (smallest value) of the cells in the neighborhood.

MINORITY = Calculates the minority (value that occurs least often) of the cells in the neighborhood.

RANGE = Calculates the range (difference between largest and smallest value) of the cells in the neighborhood.

STD = Calculates the standard deviation of the cells in the neighborhood.

SUM = Calculates the sum (total of all values) of the cells in the neighborhood.

VARIETY = Calculates the variety (the number of unique values) of the cells in the neighborhood.

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A variety of statistics can be calculated using focal statistics.

For a continuous surface, such as a digital elevation model or a topographic slope grid, the mean, maximum, median, minimum, range, standard deviation, or sum may be calculated.

Many statistical values don’t make sense for categorical raster grids, such as land cover. However, the majority, minority, or variety could be calculated.

As an example, the variety measure would calculate the number of unique categories within the moving window.

Take some time to review the available statistics presented on this slide.

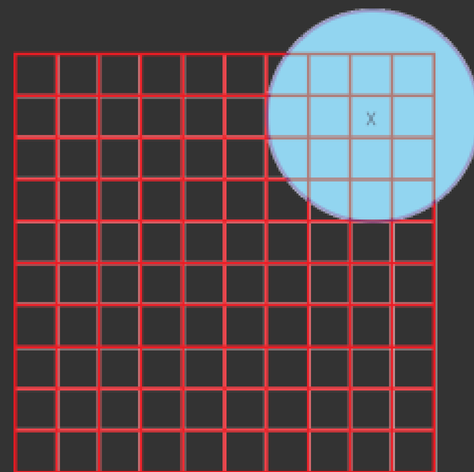
As a final note, larger windows sizes are generally used to represent more coarse or generalized patterns while smaller windows are used to represent more local patterns.

There is not necessarily a correct window size. Instead, this depends on the use case. If you are not sure what window size to use, I would recommend experimenting with multiple window sizes.

It is also possible to make a calculation using different window sizes then take an average.

Edge Cells

- Edge cells will not have a full set of neighbors



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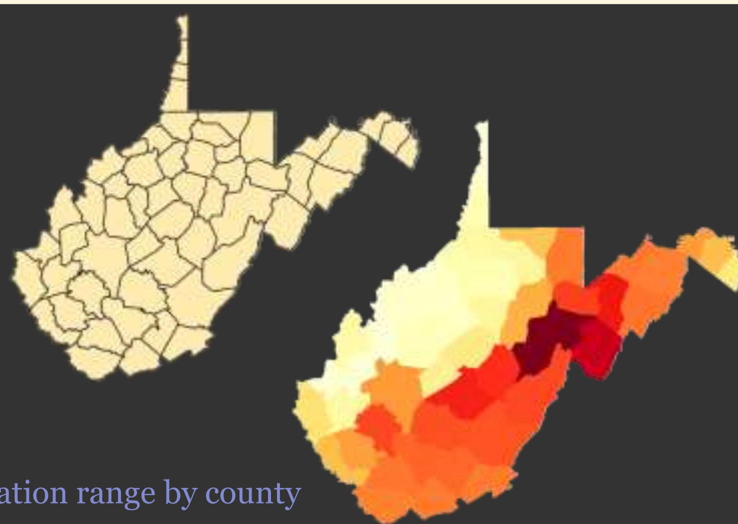
It may have occurred to you that cells near the edge of the raster will not have a full set of neighbors as demonstrated in this slide. In these situations, two options are available. First, the result could be calculated using only the available cells. Second, results could only be calculated for cells that have a full set of neighbors. If the second option is used, the size of the raster grid, or the number of rows and columns, will be reduced.

If you are concerned with this issue, I would recommend running an analysis using a larger extent than is required. That way, you will always have a full set of cells to cover the extent of interest.

These last set of slides explain how to summarize raster data relative to polygon or areal extents or at point locations.

Zonal Statistics

- Used to obtain statistics from a continuous raster within an area or zone as defined by another raster or a polygon vector layer
- Can obtain results as a raster surface for a single statistic



Elevation range by county

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A common spatial analysis task is to summarize raster data relative to vector data. For example, you may want to summarize continuous raster data relative to polygons.

This can be accomplished using the Zonal Statistics Tool.

This method will calculate a statistical measure, such as the mean, median, standard deviation, minimum, or maximum, from the cell values within a zone.

The zones can be defined using a categorical raster or vector polygons. If vector polygons are used, then they will be converted to raster zones prior to the summarization.

As a result, this method generally will not work correctly if overlapping polygons are used, since only one code can be assigned to each cell.

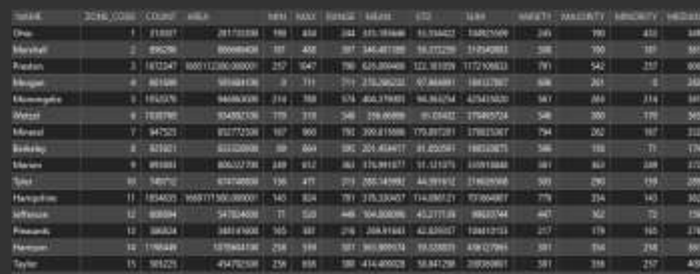
The result will be a statistical measure that will be the same for each cell within each zone.

The example above shows the range of elevation for each county in West Virginia. Since the zones were defined as counties, all cells in the same county were assigned the same value, in this case the elevation range.

Since a singe band raster is produced, only one statistical measure can be generated at a time.

Zonal Statistics as Table

- ❖Used to obtain statistics from a continuous raster within an area or zone as defined by another raster or a polygon vector layer
- ❖Can obtain multiple statistics as a table: mean, majority, maximum, median, minimum, minority, range, standard deviation, sum, and variety
- ❖Can use table join to join the results back to the zone data



Elevation statistics by county

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If you would like to calculate multiple statistics in a table format, this can be accomplished using Zonal Statistics as Table.

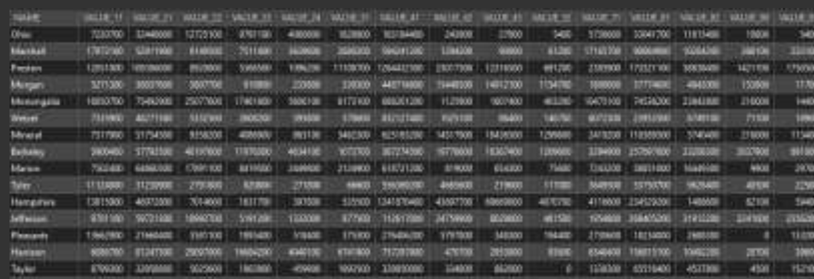
Instead of producing a raster output for a single statistical measure, a table output is generated that can provide multiple statistical measures.

Each row in the table will correspond to a zone, in this example a specific county.

If you would like to associate these results with the original zones, this can be accomplished using a table join. Here, this table could be joined back to the county vector file using the shared NAME field.

Tabulate Area

- Used to obtain areas for categories in a categorical raster within an area or zone as defined by another raster or polygon vector layer
- Areas will be in square map units
- Can use table join to join the results back to the zone data



Area of land cover by county

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The Zonal Statistics tools are designed to provide summary statistics relative to zones and are generally more applicable for summarizing continuous raster data, such as a digital elevation model.

If you would like to summarize categorical raster data, such as land cover, this can be accomplished using the Tabulate Area Tool.

The output will be a table that provides the land area of each category within each zone.

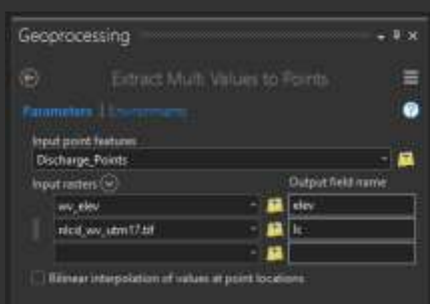
If you would like to obtain the percentage of the land area as opposed to the area, then you could perform table calculations in new fields.

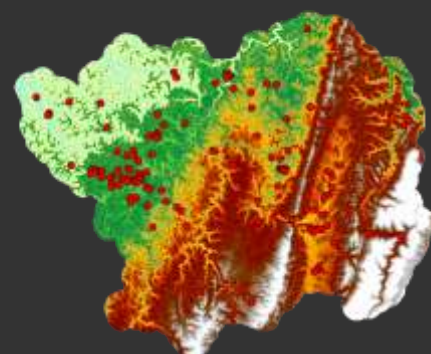
This table could also be joined to the original zone using a table join for further analysis.

Similar to the Zonal Statistics tools, vector polygon zones will be converted to raster zones to perform the summarization. So, incorrect results will be produced for overlapping polygons.

Extract Values to Points

- ❖Extract raster values at point locations and add the data to the attribute table
- ❖Can use Extract Multi Values to Points Tool or Extract Values to Points Tool





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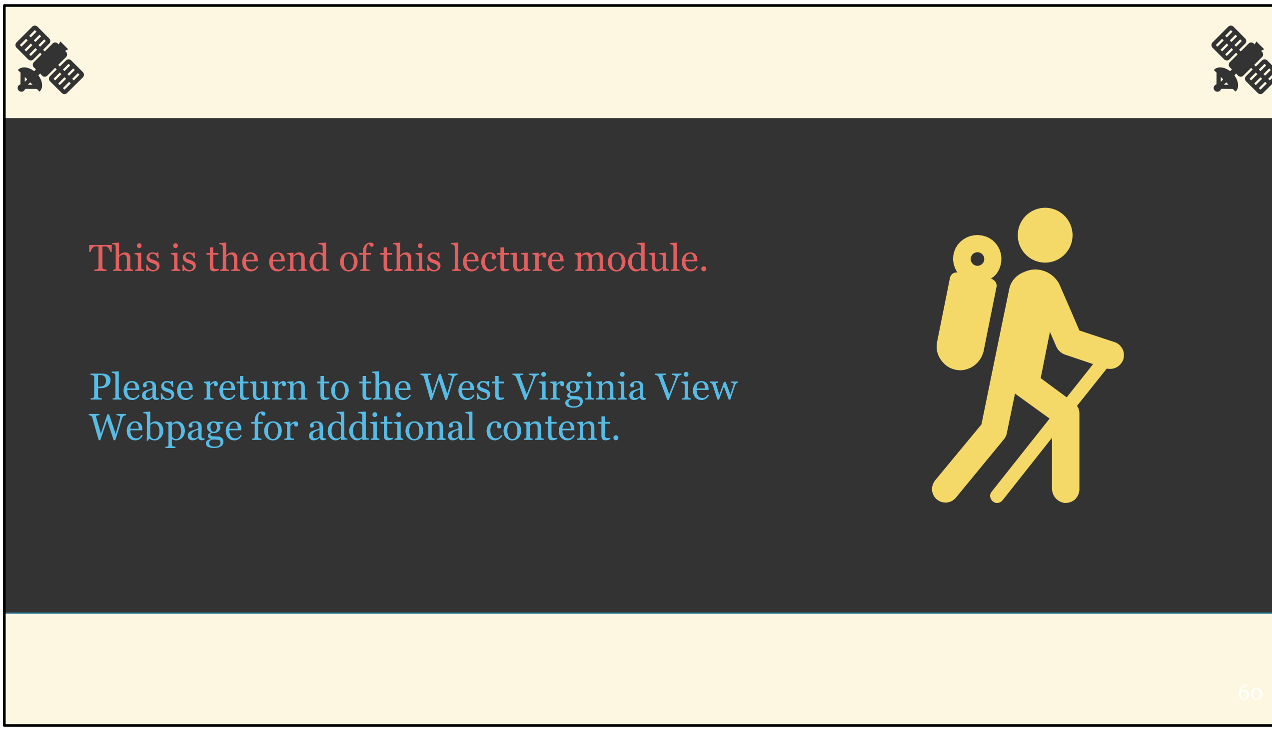
It is also possible to extract values at points. The result will be a new field in the attribute table for the point layer that holds the cell value from a raster grid occurring at that location.

This is an easy way to extract cell values at point locations in preparation for later analysis.



Thanks! Hope you found this useful.