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# Lesson 3: Sensor Platforms and Image Processing Basics

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## INTRODUCTION

This lesson examines sensor platforms, image processing, basics, band ratios, and transformations. You will learn about the relationship between wavelengths, sensors, and color display as well as the process of acquiring remotely sensed imagery. Information in the lesson will explain image processing in ArcGIS with examples to show the various steps required and to be considered. Band ratios and transformation aspects are exhibited with explanations to help you understand the concepts used in this process.

## LESSON OBJECTIVES

By the end of this lesson, you will be able to:

1. Describe the primary components of a digital image
2. Describe characteristics of passive and active remote sensing systems.
3. Explain common processing functions found within geospatial software: image composites, subsets, mosaics, and band ratios including NDVI and Tasseled Cap Transformation.
4. Create an image composite, image mosaic, and image subsets using ArcGIS.
5. Analyze results of work sensing workflow for image composites.

## LEARNING SEQUENCE

Required Reading	Read the following: <ul style="list-style-type: none"><li>• Online Lesson Material</li></ul>
Resources	Review the following: <ul style="list-style-type: none"><li>• None</li></ul>
Assignments	Complete the following: <ul style="list-style-type: none"><li>• Quiz</li><li>• Lab: Image Composite, Mosaic, Subset</li><li>• Exam</li></ul>



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## INSTRUCTION

### Remote Sensing Systems: Sensor Platforms

The different commonly used remote sensing systems can be divided into two categories, airborne and spaceborne. As can be seen in these lists, airborne systems include a wide range of sensors such as:

- **Panchromatic** is black and white imagery.
- **True Color Imagery** is imagery which we humans are most familiar with.
- **Color Infrared** typically includes the true color bands plus one color infrared band
- **Digital Orthophotos** are typically true color imagery, but has had substantial extra processing to remove various geometric anomalies such as building tilt, the geographic position of features based on changes in elevation. Digital orthophotos have also been processed to have a high quality spatial reference applied to it, which most end-users desire and expect.
- **Multispectral** imagery is an extension of the color infrared imagery in that this imagery will typically have multiple color infrared wavelengths being collected on the sensor and/or there are some extra color wavelengths such as "Red Edge" which is a wavelength range that exists between the "red" and "infrared" part of the electromagnetic spectrum. In recent times, scientists have shown that this "red edge" band has some special spectral benefit to vegetation analysis applications.
- **RADAR** is a sensor is one that collects image data based on radio waves. RADAR sensors typically have some special ability to provide information on vegetation structure, ice, and water properties.
- **LiDAR** is a sensor that collects image data based on emitting a laser beam. LiDAR sensors collect high resolution elevation data that can be useful to generate digital elevation models and to create 3D representations of objects such as buildings and tree structures
- **Hyperspectral** sensors typically collect spectral information in "hundreds" of bands vs. only a few (that is, 3 or 4) that are commonly found in true color or color infrared imagery

For spaceborne or satellite systems, the most widely used systems are multispectral, RADAR, and Hyperspectral. A satellite LiDAR mission called ICESAT that collected measurements on ice and vegetation heights was decommissioned in 2010 after a LiDAR sensor failure. A new satellite LiDAR mission, ICESAT-2, is planned for 2016.

### Optical Airborne

Here are some examples of the different satellite sensors and their respective imagery. Figure 1 shows a typical true color aerial photo. On the right side is an example of a color infrared aerial photo. The image in Figure 2 is considered an orthophoto but it is not a "true" orthophoto. Figure 3 is an example of a "True" orthophoto. Notice that the buildings in the image do not have any tilt in them.



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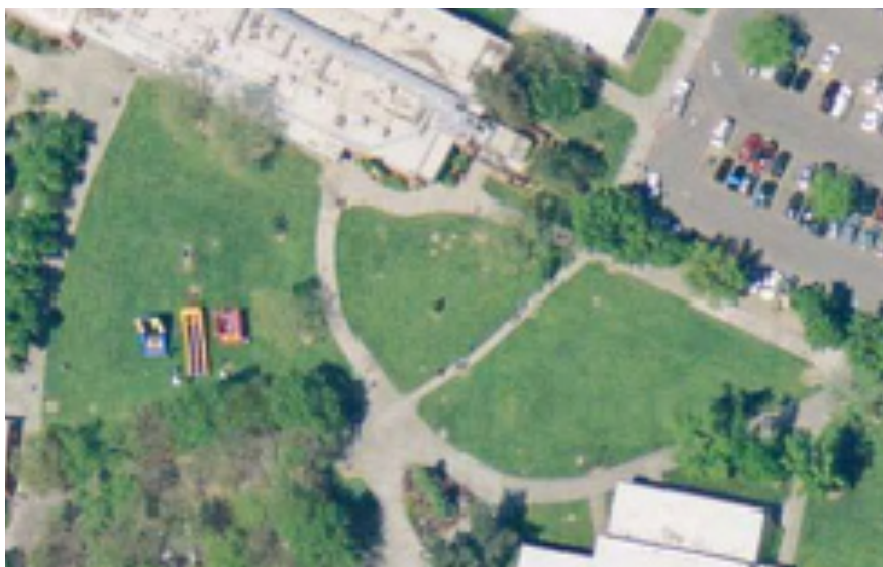


Figure 1 True Color Aerial



Figure 2 Orthophoto

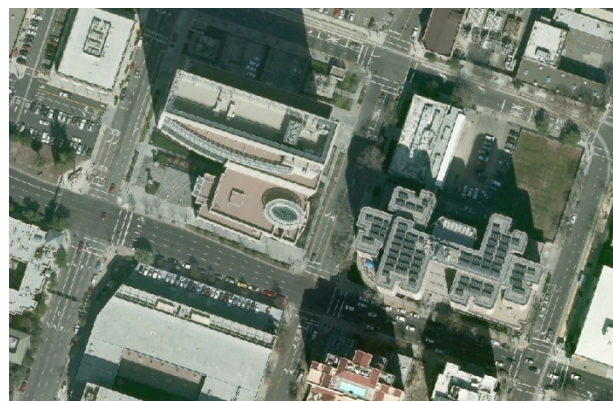


Figure 3 "True" Orthophoto



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## Optical Satellite Systems

Here are two examples of optical satellite imagery. The term “optical” is used since many satellites use optics to resolve features on the ground.

Example 1 is pictured in Figure 4 which is an image of Central Valley, California taken by Landsat. Sacramento is located in the southeast portion of the image. This is considered to be a typical Landsat Thematic Mapper image of the Central Valley in California.

Example 2 (Figure 5) is an image taken by the QuickBird satellite, which has a 2 ft. resolution which is the highest resolution commercially available satellite. Notice that in this image of the Port of Abu Dhabi in the United Arab Emirates you can view the individual cargo containers, buildings, and cargo cranes.

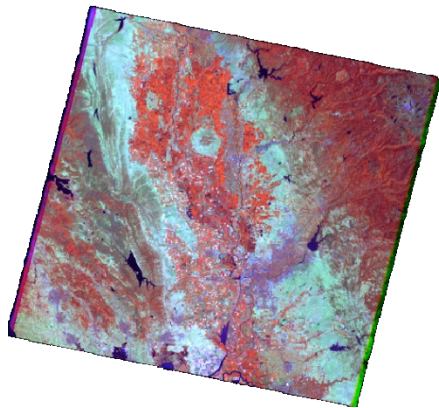


Figure 4 Landsat: Central Valley, CA

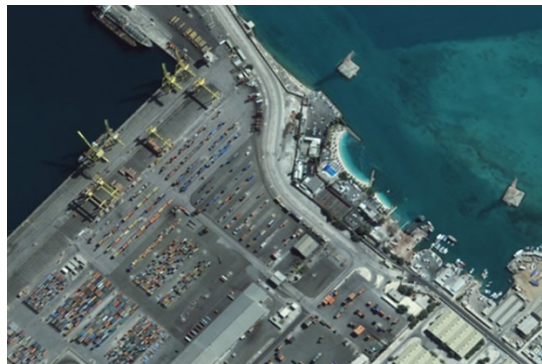
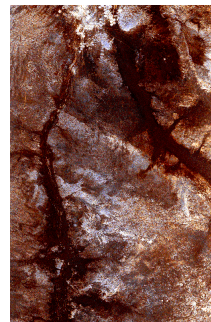
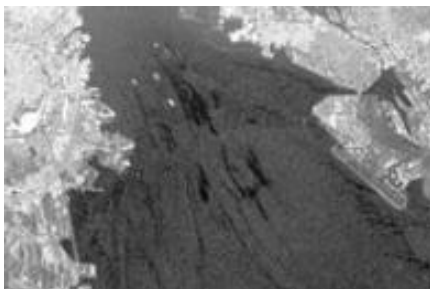


Figure 5 Port of Abu Dhabi in the United Arab Emirates (Image taken by QuickBird satellite)

## RADAR

RADAR has the ability to “see” below the ground in very dry, arid, and sandy conditions. In related studies, it has been found that subsurface areas that are between zero and 5m may be capable of being imaged by RADAR satellites. Here are a couple of examples of RADAR (Radio Detection and Ranging) imagery. Figure 6 is an image from the Canadian RADARSAT satellite of the oil spill that occurred in the San Francisco Bay in 2007. Figure 7 is an image from the Space Shuttle that was taken during the last of 4 Shuttle Imaging Radar missions to map topography and other features of the Earth. This image shows an historic wadi in Libya near the Kufra Oasis that is actually buried by sand.



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Figure 6 Canadian RADARSAT satellite

Figure 7 Shuttle Imaging Radar

### How does LiDAR operate?

To learn how LiDAR (Light Detection and Ranging) operates illustrations have been provided below. Figure 8 is an example of how an airplane carrying a LiDAR sensor shoots a laser beam at a high pulse rate. The light beam then hits an object on the ground and the light wave is then returned to the sensor. LiDAR is used to record highly accurate elevation data and is capable of collecting the structure of objects such as trees and buildings. Figure 9 is an image of a high resolution digital elevation data set that was derived from LiDAR. The image covers a residential area of Sacramento, CA and shows the elevation surface. Note the area marked as the "Ancient American River". This area is now covered by houses, but once was the river path of the American River. The current river channel is shown as a dark blue color at the top of the image.

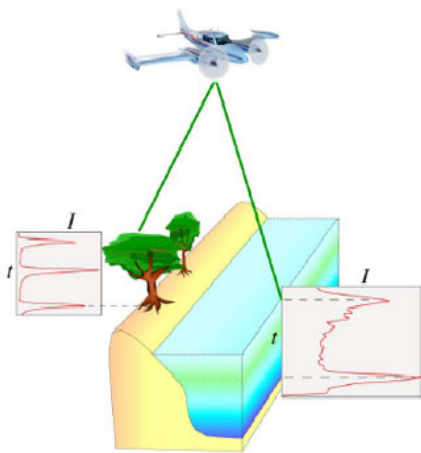


Figure 8 Airplane Carrying a LiDAR Sensor

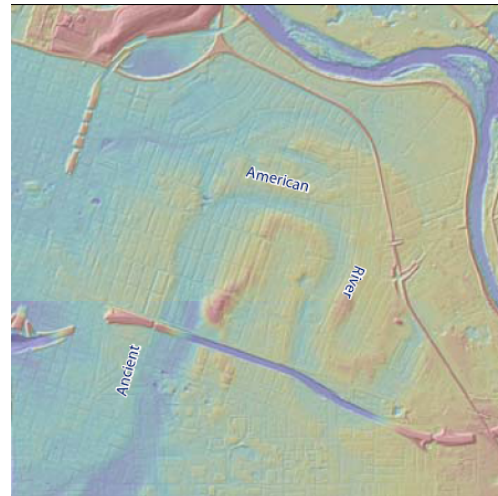


Figure 9 High Resolution Digital Model



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### How can LiDAR data be used?

Here are some additional examples of how LiDAR data can be used. Figure 10 shows a digital surface model for a portion of the Philmont Boy Scout Ranch in New Mexico. The elevation data has been draped over a hillshade layer. The small bumps in the data are actually the tops of individual shrubs. The hillshade is a derivative layer that can be created from the elevation data. A hillshade is a data layer that models shadows as if the sun were shining from a particular angle on the horizon. The hillshade layer can be used to create the appearance of a 3D effect when viewing LiDAR or other digital elevation data.

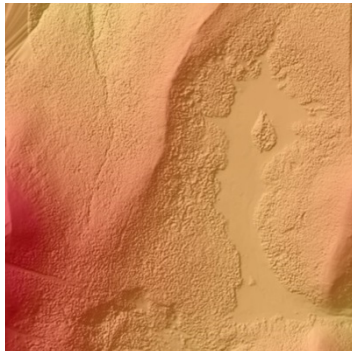


Figure 10 Digital Surface Model

Figure 11 is an example of a 3D perspective view of elevation data. The elevation data is essentially being viewed from a different vantage point than just straight down. Again, the individual shrubs can be modeled. This view has been exaggerated to enhance the appearance of elevated terrain.

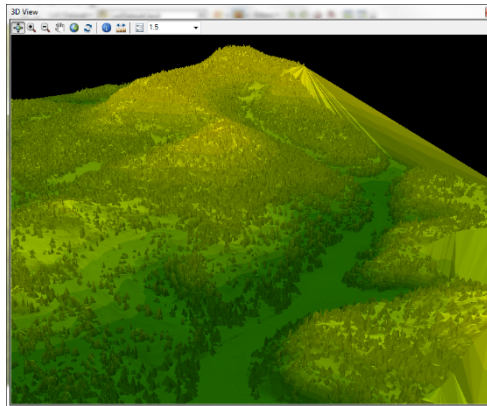


Figure 11 3D Perspective View of Elevation Data



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Figure 12 shows a profile view of a small section of the above image, the 3D perspective view of elevation data. Within the current version of ArcGIS (10.1 or greater), raw LiDAR data can be viewed with a profile tool. This tool allows for the viewing and editing of LiDAR data while working in ArcMap. This is a recent enhancement that has made raw LiDAR data more useful than with using older versions of ArcGIS.

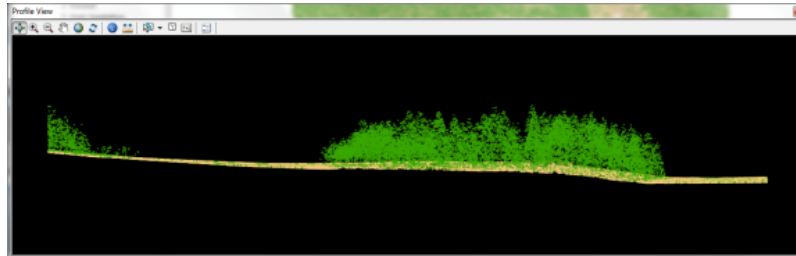


Figure 12 Profile View of a 3D Perspective View of Elevation Data

## Hyperspectral

There are currently three popular hyperspectral sensors that are used today.

- **AVIRIS:** the Airborne Visual/Infrared Imaging Spectrometer
- **Hyperion:** a hyperspectral satellite
- **Proba-1:** a satellite that contains the CHRIS hyperspectral instrument

All of these capture imagery in dozens or hundreds of wavelengths (or bands) versus only a few that you have seen in aerial or satellite multi-spectral systems. In addition to these three hyperspectral sensors there are a number of private commercial companies that have started to develop, deploy, collect, and process hyperspectral data for clients. Some of these are related to mining, and monitoring the illegal cultivation of plants used in controlled substances.

Figure 13 is a Hyperion satellite image that captured an active fire in Tucson, AZ. Figure 14 is an AVIRIS "hyperspectral cube" which is a graphic rendition that shows the dimensionality of hyperspectral data. The black "bands" across the bottom of the imagery indicate parts of the electromagnetic spectrum where energy from the sun is absorbed by water vapor or atmospheric gases. The red "bands" indicate that the dimensionality of the data as being highly reflective whereas the blue "bands" indicate low reflectivity.



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Figure 13 Hyperion satellite image

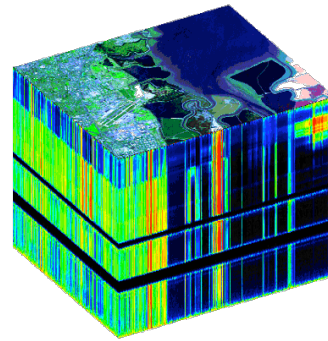


Figure 14 AVIRIS Hyperspectral Cube

### Relationship between Wavelengths, Sensors, and the Color Display

Now that you have an idea of how remote sensors collect image data and you have an overview of some of the major remote sensing systems, this lesson provides an overview of how this data can be displayed on a computer monitor. It is important to understand the relationship between the wavelengths being captured by the system and how an analyst can use the computer to display some of this information when conducting visual analysis or for interpretation of image processing results.

### Electromagnetic Spectrum

This is an electromagnetic spectrum that was seen in the previous lesson. Shown are the various wavelengths that are captured by different remote sensors.

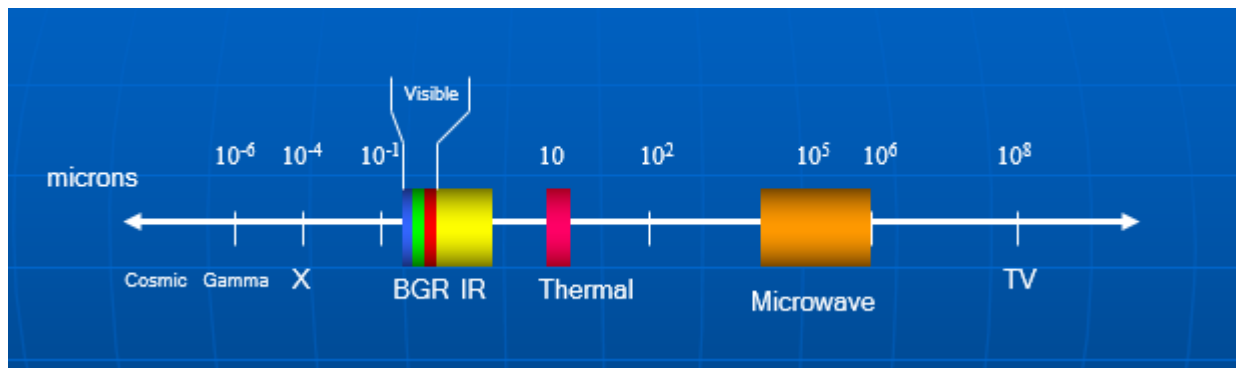


Figure 15 Electromagnetic Spectrum

### Generic Remotely Sensed Image

A generic remotely sensed image is an "image" made up of rows and columns of pixels or picture elements (Figure 16). For each given wavelength a separate image "band" exists. In some software packages and other literature a band is sometimes referred to as a channel, layer, raster, or grid). Nonetheless, remotely sensed imagery normally contains at least three bands corresponding to the Blue, Green, and Red wavelengths captured by the sensor. Other additional bands (mostly portions of the color infrared part of the spectrum are also captured on the sensor.



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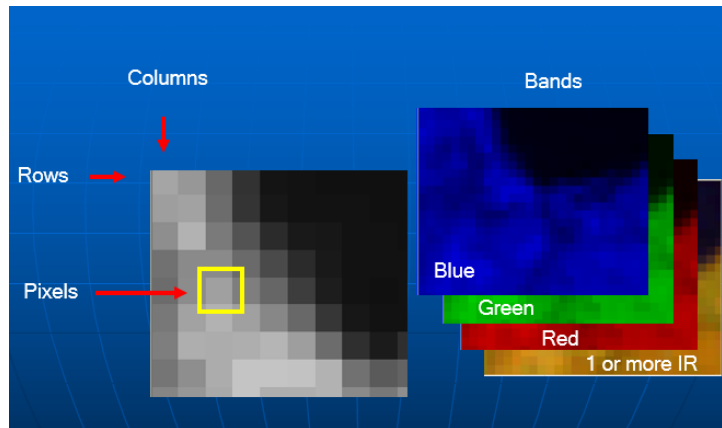


Figure 16 Composition of a Remotely Sensed Image

- The image can contain multiple bands each representing a specific wavelength that is captured by the sensor and each band is made up of rows and columns of pixels. It is common to see thousands or tens of thousands of rows and columns for a given image set. The bands can range from three, four, many, or in the case of hyperspectral imagery, dozens or hundreds of bands.
- For each row and column, the individual pixels contain the “information” collected by the sensor. This information is often the relative brightness value of the response for a given area on the ground. For example, an area of the earth that reflects high in the infrared wavelength will have a “large” brightness value. This large brightness value will tend to show up as a pale gray or white area in the image. Those areas that reflect less for a given wavelength will tend to appear as darker pixels on the image; hence the brightness values will be smaller.
- The range of brightness values depends on how many bytes can be stored in a pixel. A byte is the basic quantity of computer disk space that is needed to store values.
- For many remotely sensed image data sets the unique brightness range value that can be collected is 256. Two hundred and fifty six values required 2 to the 8<sup>th</sup> bytes or sometimes referred to as 8-bit data. Highly reflective material will tend to have very bright pixels in the image (closer to the value 256) and material that is not very reflective for a given wavelength will tend to have brightness values closer to zero and will appear darker on the image. Two other common brightness ranges are also included. Notice that 2 to the 12<sup>th</sup> and 2 to the 16<sup>th</sup> have much larger brightness value ranges than 8 bit data.

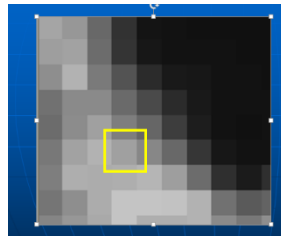


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Bytes	Brightness Range
$2^8$	= 256
$2^{12}$	= 4096
$2^{16}$	= 65536

Figure 17 Unique Brightness Range

- Brightness values are the numbers that are used in digital image processing routines. Later on in the course, we will use the image data sets (that include the pixels for some or all of the image bands) and create new images. The image processing routines will use the pixels values to “analyze” and then create the new data sets.
- Pixel values can represent other values that are not related to the reflectance of a remote sensor. Some of these can include elevation, discrete values such as unique land cover types, soil types, wetland categories, and derived values from image processing routines such as slope, aspect, and texture.

### Landsat Image Bands

Figure 18 is an example that illustrates each of the 6 Landsat TM bands collected by the Landsat satellite. Notice that none of these are “color” since each band represents only one specific wavelength. As such, the data are viewed as a series of “gray level” pixel values. Dark pixels are those that do not reflect highly for the given wavelength, whereas the brighter pixels are those that have high reflectivity for the given wavelength.

You can see for each image band that the same area does not look the same. This is because the different materials reflect differently in the various wavelengths. Remember the Physical Foundations lesson showed the spectral curve for several major land cover types and that for any wavelength, some material reflected higher than others.



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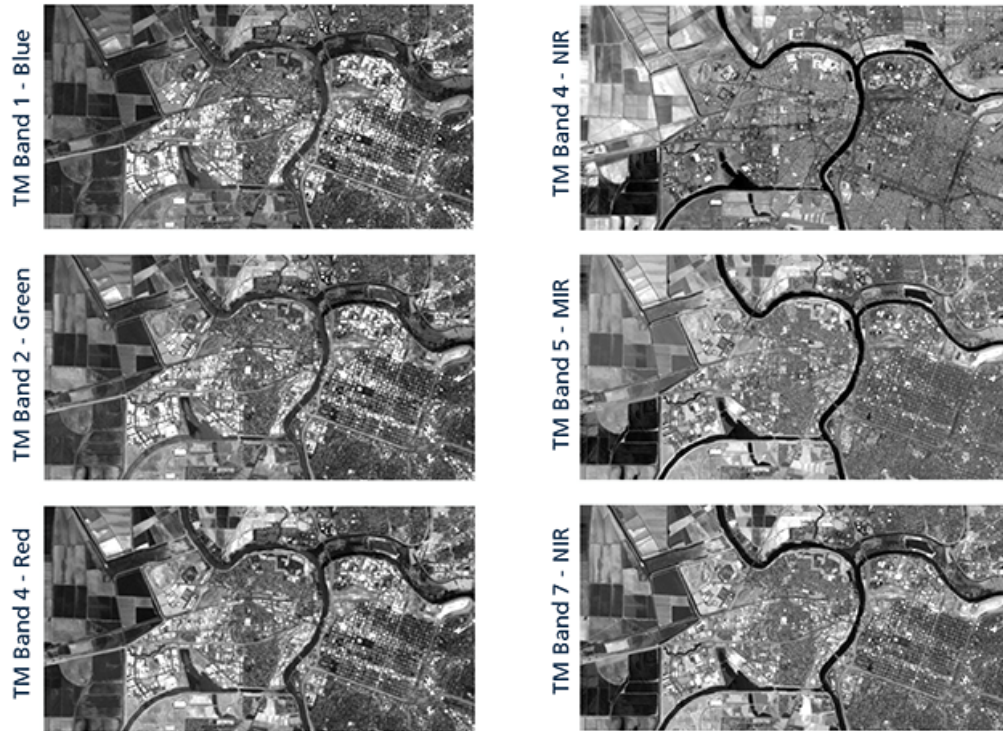


Figure 18 Six Landsat TM bands collected by the Landsat satellite

### Sensor Bands, Wavelengths and Reflectance

The image below illustrates a small section of the previous image that contains areas of agriculture, built up, and water. The spectral curve illustration is provided to remind you that different materials reflect differently in different wavelengths. Notice for the agricultural area on the left side of the image that some of the fields appear dark in the Green Band, but very bright in the color near infrared band and not so bright in the mid-infrared band, Band 5. What this indicates is that for this specific area, the field tends to not reflect highly in the green wavelength, but has a little higher reflectance in the mid infrared band (Band 5) and very high in the near infrared band (Band 4). Remember, healthy green vegetation is not highly reflective in the “green” wavelength, but much higher in the near and mid infrared wavelengths. Refer to the spectral curve graph at the bottom provided within Figure 19.



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Green Band 3



NIR Band 4



MIR Band 5

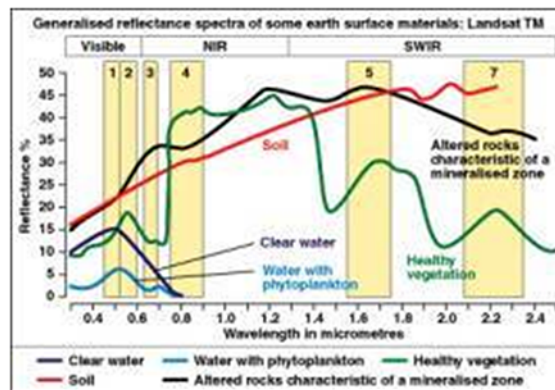


Figure 19 Illustration: Sensor Bands, Wavelengths, and Reflectance

### Viewing Image Bands on a Color Display

So, keeping this in mind, that different materials reflect differently in different wavelengths, the next part of being able to “do something” with remotely sensed imagery is to be able to see some of this information in color on a computer screen.

The way to do this is to assign one of the color display planes (which is Blue, Green, or Red) to one of the sensor bands. The display of the image in color results from the fact that different sensor bands reflect differently and because each band is assigned to either the Blue, Green, or Red plane of the color display. The combination of blue, green, and red computer display for a given pixel, renders each pixel in “color”. That is, for one of the image bands assigned to the Blue, Green, or Red color display, the individual pixel values for each of these image bands will have its respective brightness values shown on one of the color planes. The combination of these pixel values that are displayed on the Blue, Green, or Red color monitor will show up as some “color”.

The provided image, Figure 20, shows a specific pixel in the image. The sensor bands Blue, Green, and Red are assigned to the color display as Blue sensor band being assigned to the Blue color display, the Green sensor band being assigned the Green color display, and the Red sensor band being assigned the Red color display.



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When the analyst clicks on the pixel with the Identify tool in ArcMap, the following values appear:

- The Red color display shows the Red sensor band brightness value of 70.
- The Green color display shows the Green sensor band brightness value of 75.
- The Blue color display shows the Blue sensor band brightness value of 85.

This color combination yields the greenish-brown or olive colored pixel. Since all of the brightness values are no really high, then this pixel tends to appear darker than those pixels with a higher pixel value. The red arrow indicates the individual image bands assigned to one of the color planes (B, G, or R) on a computer monitor.

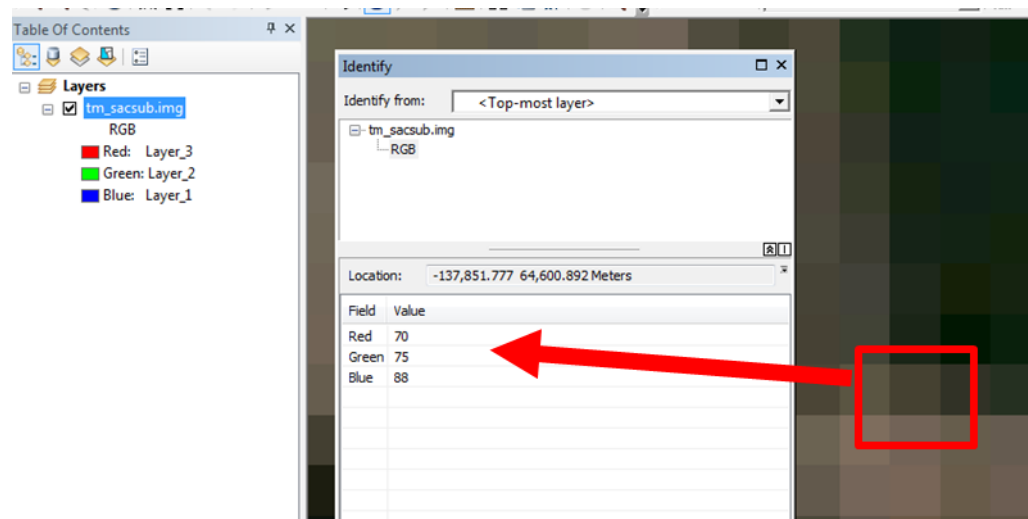


Figure 20 Specific Pixel Range

The chart provided in Figure 21 shows the wavelengths that are assigned to the respective sensor bands (in this case or the Landsat satellite). For Landsat, since there are six commonly used wavelengths and thus, a six-band image is used by an image analyst. Since not all bands can be viewed at one time, up to three of these bands can be assigned to different color planes on the computer monitor. Depending on which three bands are assigned to the different color planes, the remotely sensed image can viewed with different colors and tones. The red arrow indicates the individual image bands assigned to one of the color planes (B, G, or R) on a computer monitor.



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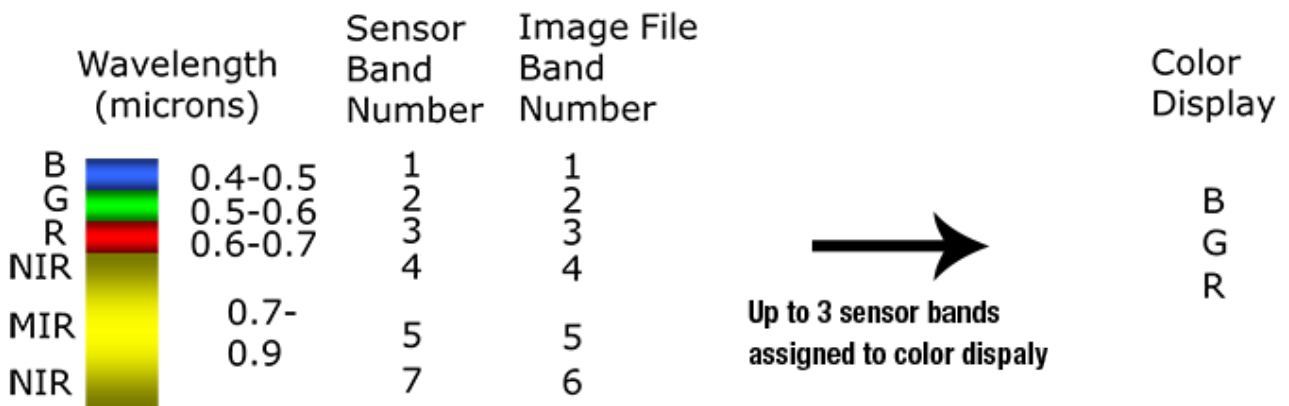


Figure 21 Wavelengths Chart

### Image Band v. Color Display Example 1

The chart provided in Figure 22 illustrates true color sensor bands (which are typically bands 1, 2, and 3 in the image) are assigned the Blue, Green, and Red color display planes, respectively. The analyst is then capable of viewing the remotely sensed image in "true color" as shown on the image on the right of Figure 22.

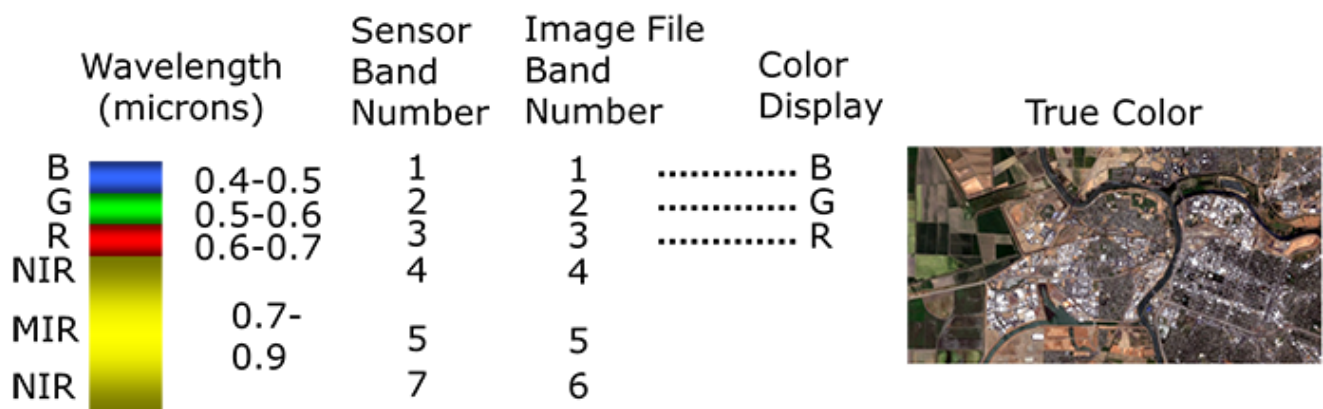


Figure 22 (Left) True Color Sensor Bands (Right) True Color

### Image Bands v. Color Display: Example 2

If the analyst changes the band combination assignment from sensor bands 1, 2, and 3 of Blue, Green, and Red, respectively to the following combination of:

- Band 2 (Green sensor band) is assigned to Blue
- Band 3 (Red sensor band) is assigned to Green
- Band 4 (Near infrared band) is assigned to the Red Color Display plane, then the following image appears on the computer monitor.



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This "Band Combination" is referred to as a "False Color Infrared" as shown in the image located on the right in Figure 23. For vegetation mapping and analysis applications that use a single color infrared band, this band combination is typically used for color display.

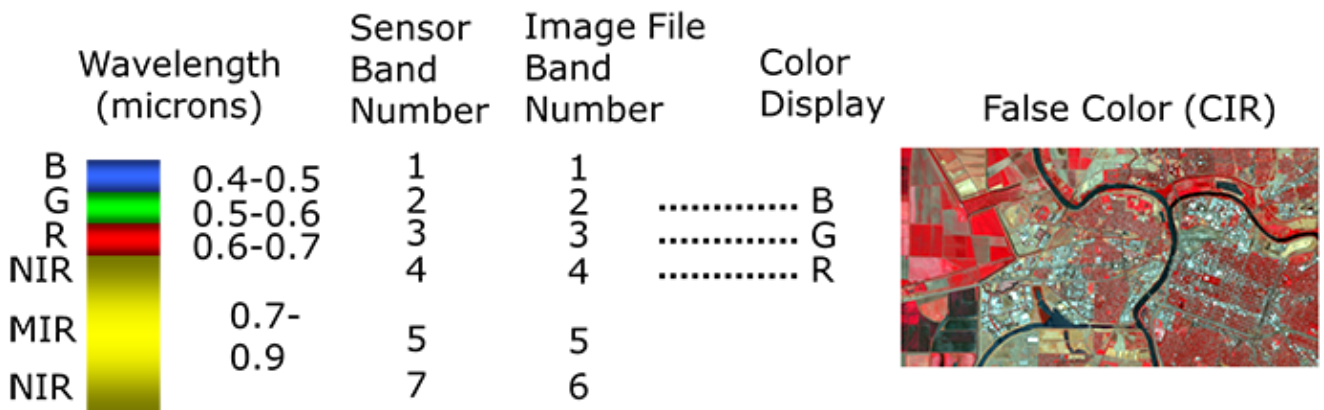
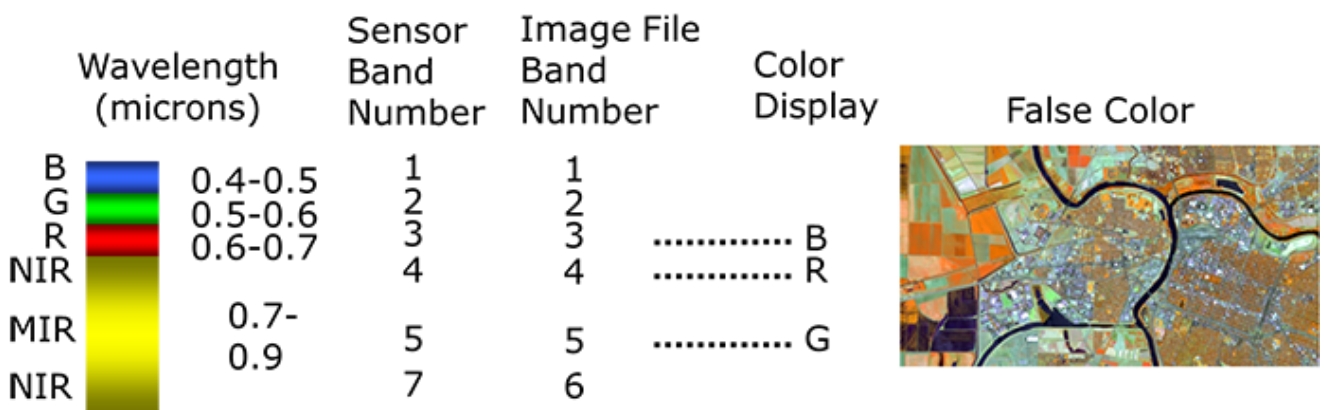


Figure 23 (Left) True Color Sensor Bands Chart (Right) False Color Infrared

### Image Band v. Color Display: Example 3

Figure 24 illustrates a different false color image display that has the Red sensor band (Band 3) assigned to the Blue color display, the Near infrared sensor band (Band 4) displayed as Red, and the Mid infrared sensor band (Band 5) assigned to Green.

Notice that vegetation typically appears as tones of orange, urban areas appear bluish gray, and non-vegetation, bare areas appear a light green. This is another band combination that is typically used with Landsat data by analysts conducting vegetation analysis or land cover mapping. The benefit of this band combination is that two of the infrared wavelengths are being assigned a color display and is a way to maximize the "information content" collected by the sensor so that humans can "see" the reflectivity of the infrared wavelengths through the use of the color monitor.



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Figure 24 (Left) True Color Sensor Bands Chart (Right) False Color Red Sensor

#### Image Band v. Color Display: Example 4

Figure 25 is an example of another “false color” band combination where the Green sensor band (Band 2) is assigned to the Blue color display, the Mid infrared band (Band 5) is assigned to the Red color display and the Near infrared band (Band 6) is assigned to the Green color display.

So any three sensor bands can be used to assign to the Blue, Green, and Red color displays and it does not always have to be the three true color bands. The band combination that is used depends on what kinds of visual interpretation is needed and if the analyst wants or needs to see the infrared data on screen.

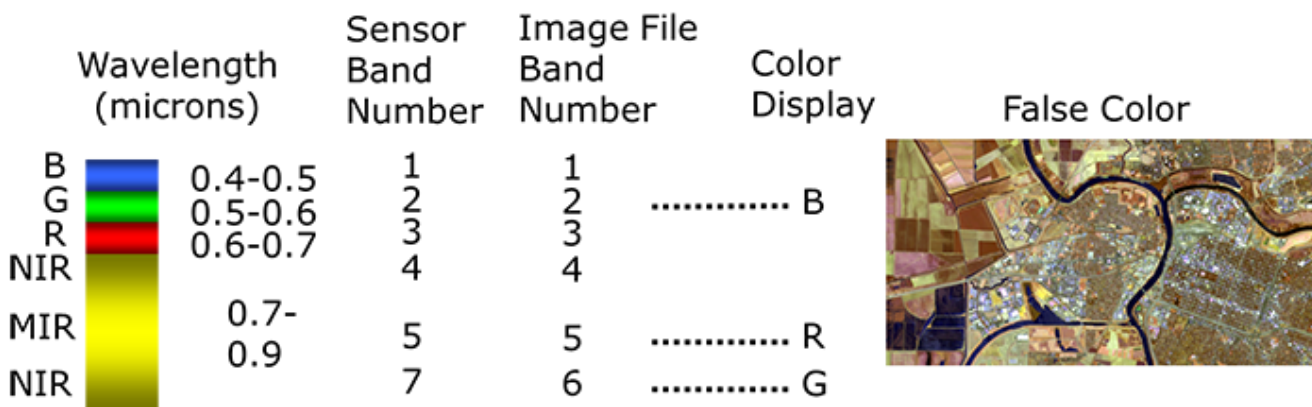


Figure 25 (Left) True Color Sensor Bands Chart (Right) False Color Green Sensor

#### Acquiring Remotely Sensed Imagery

This part of the lesson focuses on the acquisition of remotely sensed imagery. In many cases to obtain current imagery an organization must have it collected. This can be in the form of planning an aerial flight mission or tasking a satellite to perform this acquisition. In either case, the requesting organization works with a contractor or contacts the satellite distribution company directly to determine the specific requirements to obtain the imagery.

For historical imagery a purchase may be required depending on the source of the imagery, licensing, and distribution requirements. For imagery that is collected through US government sources such as the federal government, state government, regional, and local governments, these may be obtained for “free” either directly from the agency that manages the data or through publicly accessible spatial data web sites. For imagery that are not purchased directly through a US firm or US subsidiary, foreign governments or agencies may need to be contacted and may have additional restrictions and requirements for obtaining and using the imagery.

#### Satellite and Aerial Characteristics

There are satellite and aerial characteristics of remotely sensed imagery which may affect how the imagery is tasked, ordered, and collected.



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## Satellite

For satellite imagery some of the items to consider when ordering imagery are:

- **The resolution** is important to consider if there is more than one resolution for pixel size, this should be determined.
- **The area of coverage** provides a project boundary. This is often in a GIS format.
- **The uses of the imagery** considers how an organization or project team uses the imagery. Will it be used for only a background? Will the imagery be used to conduct a land cover mapping exercise that will use image processing techniques? Will other derived image sets be created such as band ratios?
- **The repeat period** is also important which indicates how often a satellite will return to the same orbit to image the same geographic area. The repeat period can be a small number of days to more than two weeks depending on how fast the satellite is traveling, the altitude of the orbit, and if the sensor can be pointed to the same geographic location on subsequent orbits of the satellite.

Here are two examples of how satellites can image the Earth.

Figure 26 is an image which shows a polar orbit, representing a satellite that travels in a polar orbit which means the satellite orbits around the Earth and crosses both the North and South Poles. This is the most common orbital path that almost all satellites take that image the earth.



Figure 26 Polar Orbit

Figure 27 represents a “geosynchronous” orbit which means that the satellite remains in a stationary position relative to the rotation of the earth. The satellite rotates at the same velocity as the Earth so the satellite can image the same part of the earth all of the time. Many weather satellites and communications satellites are placed in geosynchronous orbits



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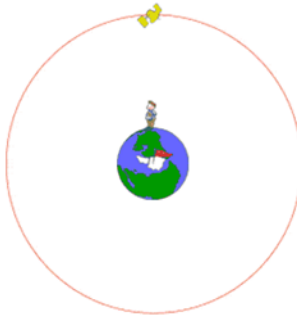


Figure 27 Geosynchronous Orbit

- **The number of look angles:** If the satellite has the capability of using multiple look angles, then this can cut down the time to acquire imagery by tasking the satellite to “look” off of center to capture the same geographic area on subsequent orbits or passes of the satellite.
- **The number of spectral bands:** How many bands does the sensor have? If there are only a few, such as true color and a single infrared band, then there may be some limitations for performing certain kinds of analyses. In the case of hyperspectral, there may be sets of bands that are of interests or can be “programmed” for use when the satellite is collecting image data.
- **Spectral sensitivity:** This also refers to the number of spectral bands and also refers to the different “ranges” of wavelengths that are captured. Most sensors use very similar wavelength ranges, but some do differ from one another. In addition there may be special wavelength ranges, such as the “red edge” that may only be found on some sensors. These will often be highlighted on satellite websites or through communication with sales or technical staff.

Some optional processing and available products may be necessary or of interest to an organization or project group. These can be discussed and the need determined, depending on the scope, project, need, and budget of the project.

## *Aerial*

For aerial imaging some different characteristics need to be considered when acquiring this type of imagery.

- **Flying height** is the altitude at which the plane flies. Typically, lower altitudes yield higher image resolutions, but will require more flight lines to cover a geographic area.
- **Ground resolution** refers to the pixel size that will be recorded on an aerial image. The organization requesting the imagery will need to determine this and also balance this with the flying height, other parameters, and the overall budget for the aerial image collection.
- **Quantity of tilt** refers to how much building tilt will be allowed for an image collection. Areas that do not have tall buildings, do not have this problem. Urban and metropolitan areas that do have tall buildings, the amount of tilt can be a problem, especially if the



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organization is concerned with identifying features in streets or alongside walks. Tilt in an image can also be a problem when information about bridges or elevated roads need to be viewed. Tilted features in an aerial image will appear skewed or off to one side as result of the flying height and how far from the center these features appear in an image.

- **Sun angle and shadows** can have a dramatic effect in an image. If the sun angle is too low when the image was taken, longer or darker shadows can appear in the image which can obstruct other features that are found within the shadow area.
- **Time of day** is also related to the sun angle and shadows. Typical aerial collections are acquired between 10am and 2pm since these times of the day will have high sun angles. Aerial imagery taken in winter months can experience both low sun angles and long shadows and will depend in part which latitude the geographic area is located.
- **The type of collection** is also important and can significantly increase the cost of the aerial imaging project. Sometimes a high resolution elevation surface is needed or required in addition to aerial imagery. It is often more cost effective in the long run to collect both kinds of data during one project, but collecting both elevation and aerial imagery at the same time can be more expensive compared to the cost of either data set collected by itself. A project budget needs to be developed that supports the data that is required at a specific time. Typically, once a high resolution elevation surface is collected, it may not need to be recollected during subsequent image collections. Additional LiDAR or elevation data will need to be recollected when significant changes occur in the topography (such as a result of earth quakes, floods, and mining) or when the vertical structure changes such as urban centers contain more high-rise buildings.
- **End and side lap** are another important characteristic for aerial image collection. These quantities are important in the cases of performing edge matching, color balancing, digital elevation surface creation, and orthophoto rectification processes. The quantities can be small if ortho correction is not significantly important for making accurate measurements on lengths and areas. If a high quality image base is required, then significant end and side lap will be required. The amount of end and side lap can significantly increase the cost and needs to be balanced by available budget and overall spatial and tonal quality of the delivered image product.

### Satellite Image Acquisition

Satellite or aerial imagery must be ordered or have an aerial mission completed to acquire the imagery. Depending on the kind of satellite or aerial imaging requirements, different methods of acquisition exist for each kind of image data set.

For satellite image acquisition, some of the satellites must be tasked to acquire images, since they may not be capable of continuously collecting imagery. In the case of the Landsat satellite imagery is collected in a continuous fashion and follows certain orbital paths. Images can be ordered by selecting images from specific locations along the path. In the cases where satellites must be tasked, often times an acquisition project will include the geographic location outlined by a project boundary.



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In addition, the requester will want to provide the maximum level of acceptable cloud cover because satellites orbit above the clouds. In addition, the time frame for collection will be needed. The project may require the imagery to be collected in a short period of time to limit significant vegetation changes throughout the project area. The collection time frame and maximum cloud cover will be balanced so that imagery can be collected in a reasonable amount of time so the rest of the image analysis project can take place within the project timeline.

Other options that can be included in the image acquisition order is the georeference to assign to the delivered image as well as any additional post processing such as ortho correction, terrain correction, haze removal, and merged or fused image products.

### Aerial Image Acquisition

For aerial image acquisition some of the parameters are different since this imagery is collected on air planes that fly below cloud cover. Like satellite imagery, a project boundary is often required. A spatial reference is often provided to the image acquisition team. In addition, the image acquisition mission will collect true color imagery, color infrared imagery, multispectral imagery, and/or LiDAR depending on the specific requirements of the project and budget.

- Most city or local government image acquisitions collect true color imagery and may or may not include LiDAR. The LiDAR collection depends on any existing LiDAR collection and the quality of the LiDAR. If LiDAR does not exist or does not meet the requirements for the project, then additional LiDAR may be collected.
- Aerial image acquisitions should meet or exceed National Map and Digital Data Product Accuracy Standards. Specific standards are detailed within [National Geospatial Program Standards and Specifications](#).
- A clear understanding of “ortho corrected” vs. “true ortho correction” means between the requesting agency and the aerial imaging company needs to be determined and agreed upon. Often times, “ortho correction” refers to the “base” features found in the imagery will be correction for its positional accuracy. Urban or metropolitan areas that include tall buildings and structures may contain building tilt in “ortho corrected” imagery. If the requesting agencies require the ability to see features between the tall buildings, then a “true ortho correction” process must be requested. This can cost more to acquire and process the imagery, but it can be worth the cost and make the imagery for valuable to the agency or agencies using the data. Often times only the area with tall buildings, structures, bridges, and overpasses require the “true ortho correction” process. The rest of the imagery can use the standard “ortho correction” process.
- The organization will also want to specify a pixel size for the imagery. The pixel size, will in part, determine the flying characteristics of the aerial collection and will affect the total cost of the project. Also, the mission should be planned with a “leaf on” or “leaf off” condition. Aerial collections require several month lead time to plan and schedule. For a “leaf off” condition for the Northern Hemisphere, missions will need to be funded and planned before the mid-winter (or pre-spring) months occur. Once the temperature warms and trees begin to expand their buds, the “leaf off” condition will rapidly change to a “leaf on” condition. In a similar fashion, summer collections will want to be planned and scheduled in the wintertime. Many aerial image collections occur through public agencies, so additional planning for funding based on fiscal budget cycles will also need to be considered.



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## Imagery: Public or Private Organizations

Imagery are typically purchased and acquired by public or private organizations. In the case of public agencies, some of these will need to determine if a single agency can fund the entire image collection project or if there needs to be partnerships formed to jointly share the cost of the collection.

In the case of the private organization image acquisitions occur because of the companies client needs or the organizations specific business needs. For example, an environmental consulting company may purchase imagery based on the client's project needs. A mining or timber harvest company may purchase imagery for their own business needs of mining operations or forest management practices.

In both cases, some image licensing may occur based on how the imagery is collected and data sharing and distribution policies. Some geographic areas may be restricted from image collected based on international agreements and laws. Image acquisition on behalf of foreign governments and private entities may have their own data sharing and distribution policies. In these cases discussions and agreements will need to occur to determine who and how imagery is used, shared, and distributed.

## Public Domain Imagery

Public domain imagery is that imagery that the general public can access "free of charge" or for nominal processing and handling fees. In the United States, since many public agencies operate on the tax contributions of the general public, much of the image data collected by these groups eventually make it to the public domain through agency websites and spatial data clearing houses.

A couple of clearinghouses to consider are the US Geological Survey (USGS) [national map viewer](#) where the general public can search, request, and download both image and vector data for free throughout the United States. The [CalAtlas](#) site is an example of a state-wide spatial data clearinghouse that provides access to the general public for California specific geospatial data. Keep in mind that that a number of months may be required to post recent public domain imagery and other spatial data sets.

Numerous regional, county, and local government spatial data clearinghouses exist. Many of these can be discovered through Internet searches. In a similar fashion, international sites can be discovered. Many international agencies outside of the United States charge fees for "publically collected" data.

## Additional Resources

Here are few websites that may include some additional image data collections that can be obtained for free, especially those related to topography and elevation data.

- [The National Map](#)
- [Earth Explorer](#)
- [National Elevation Data](#)
- [Shuttle Radar Topography Mission \(SRTM\)](#)
- [The CGIAR Consortium for Spatial Information](#)



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## Using Software to Process Remotely Sensed Imagery

This part of the lesson will cover some basic functionality of some common image “pre-processing” functions. This section also introduces some of the functions of ArcGIS, the software that will be used in this course.

Most of this section will be experienced through the lab assignment. This part of the lecture is to provide a broad overview of image composition, image subset, image mosaics, and image stretching.

## Pre-Processing Images

Some of the common functions that are used by image analysts before getting started with other image processing routines are to piece together an image from individual sensor bands, create an image subset based on a project boundary, or to merge a number of adjacent images into a single image. These routines can be thought of as “pre-processing” steps that an image analyst might have to use before performing other image analysis.

The most current version of ArcGIS can conveniently implement these routines through the use of the Image Analysis Window. This Image Analysis Window can be found by going to ArcMap and click on Windows—>Image Analysis.

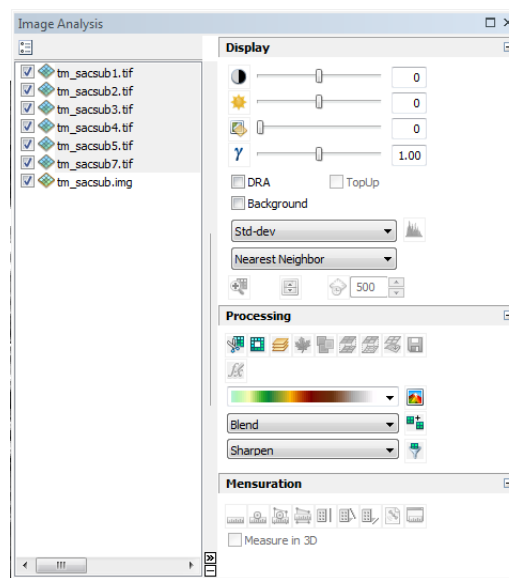


Figure 28 ArcGIS: Screenshot of Image Analysis Window



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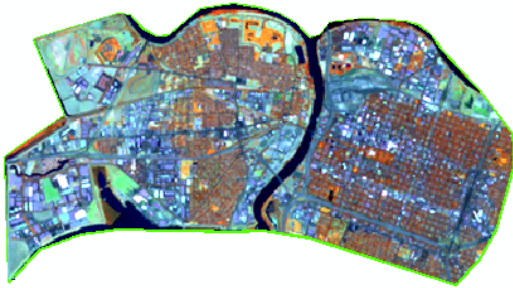


Figure 29 Pre-processing Step 1

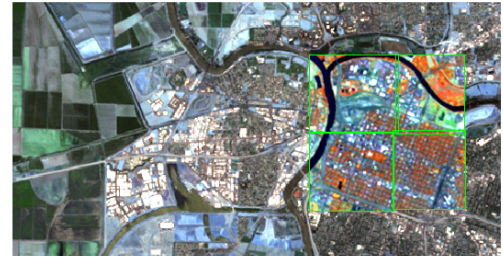


Figure 30 Pre-Processing Step 2

### Image Composite

Image composition is the ability to combine individual image bands together to generate a single image. This routine is often used in the raw image is provided as separate image band files or if the analyst obtains individual bands from spatial data clearinghouses.

The essential task is to combine each image band in the wavelength order that it was collected in. For example, typically multispectral imagery is ordered by shortest wavelength to longest wavelength. In most cases, image band 1 will be the blue wavelength sensor band, image band 2 will be the green wavelength, image band 3 will be the red wavelength, and image band 4 will be a near infrared wavelength. If other sensor bands exist, then they will follow the specific band order as indicated by the satellite vendor or the air photo collection platform or sensor.



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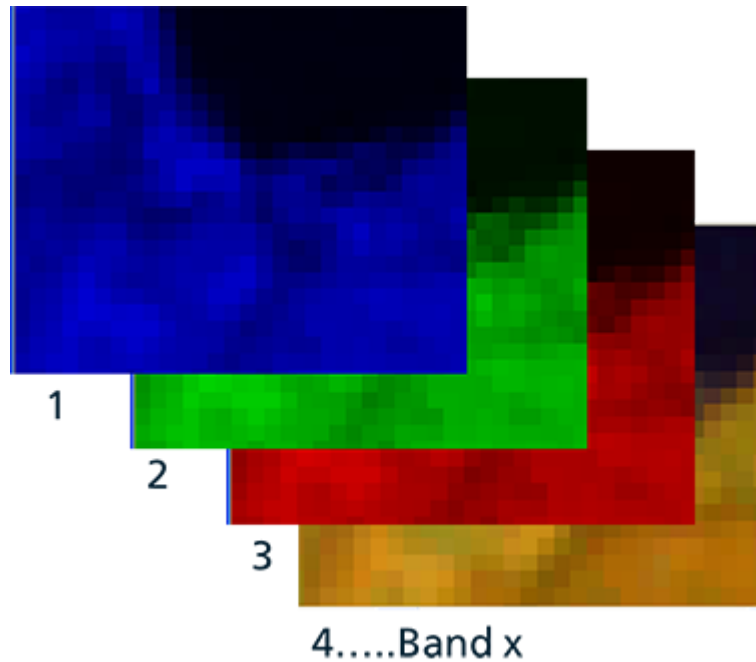


Figure 31 Individual Bands

The result of the image composition routine is a single multispectral image. Review Figure 32 for an example.



Figure 32 Multi-band

### Image Subset

Image subset is a method of “clipping” out an area from a single image. For example a specific geographic project area of interest may exist within the image. Using a project boundary or the viewing area of the image window, a smaller image can be “cut out” of the image. This can be useful to trim down the image size and can also help speed up the image processing tasks since only a portion of an image is being analyzed versus the full geographic extent of the image. Typical methods to subset an image are a rectangle, a polygon, or an image mask.

Review the following examples:



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Figure 33 is an image mask. This image is an image that contains only one pixel value and thus can be used as a data set to extract geographic areas from other image data sets. The image illustrates the full extent of the image and a project boundary that is shown as a green outline.



Figure 33 Image Mask

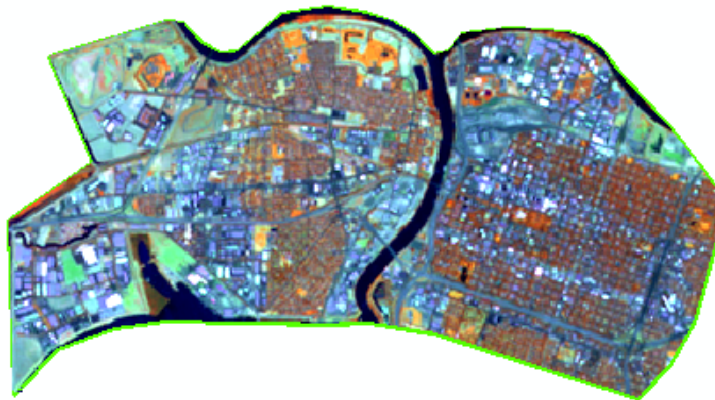


Figure 34 Image Subset

### Image Subset: Examples

Here is an example of a rectangular area as well as a polygon. The Image Subset tool in the Image Analysis Window is outlined by the red box in the bottom illustration.



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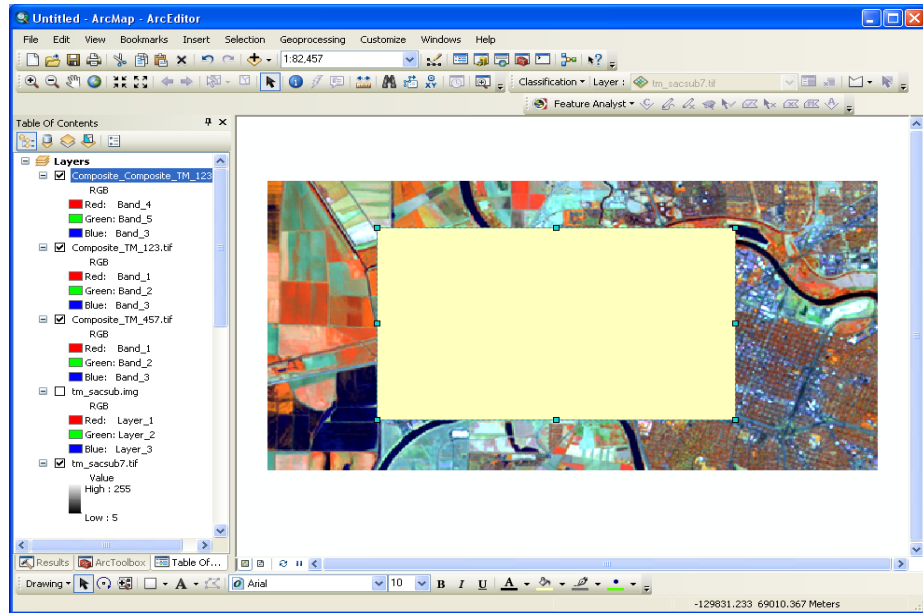


Figure 35 Image Analysis Window Example 1

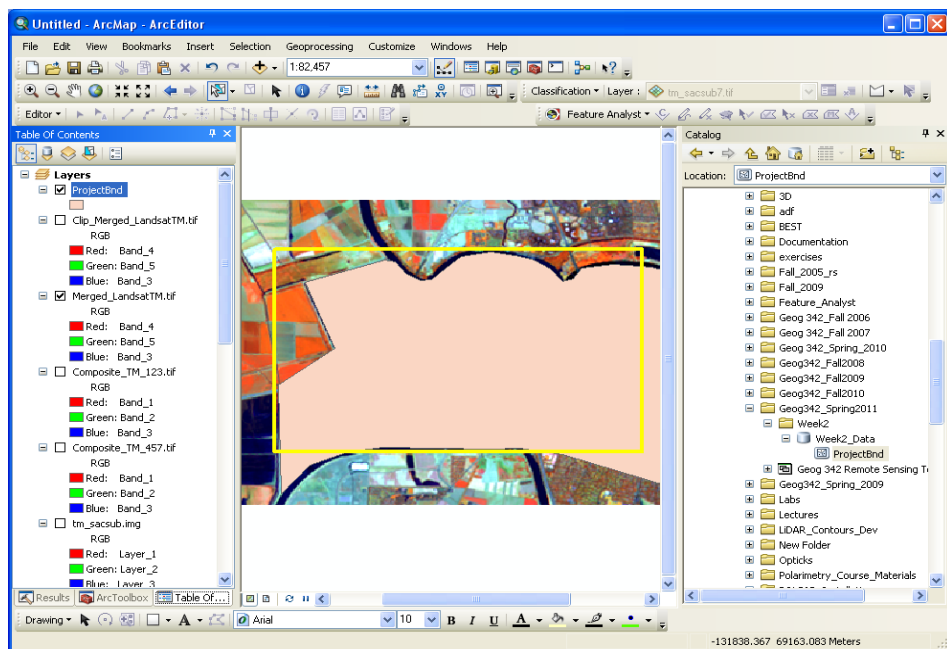


Figure 36 Image Analysis Window Example 2



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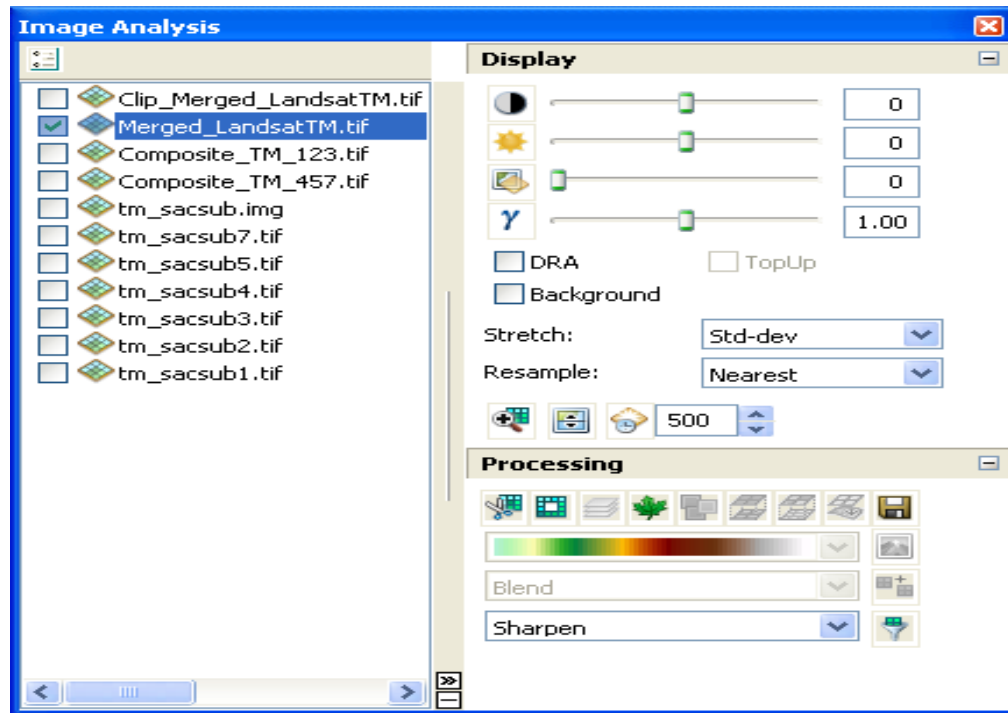


Figure 37 Image Analysis Window Example 3

### Image Mosaic

Another routine that might be useful when processing imagery is to merge adjacent images together. This routine is called Image Mosaic and can be found on the Image Analysis outline by the red box on the bottom illustration.

Typically, the adjacent images are overlapping and are of the same or near the same date of collection. Ideally, an image mosaic will have a seamless and color balanced appearance. This will occur when the neighboring images have the same date and were collected close to the same time and have similar collection characteristics (such as the same flying height and camera angle parameters). If these conditions are not met, then an image mosaic may have a mix of different color tones and the features within the image may have the appearance of having different image collection angles. That is, a tall building may be viewed with multiple perspectives vs. one perspective or a straight down appearance.

ArcGIS contains the Image Mosaic tool so that analysts can easily create a larger image from multiple images. If many images need to be merged that do contain multiple perspectives and require a high level of spatial accuracy and color balancing, then other software that is suited for this need will need to be purchased or have the imagery processed by the image acquisition firm.

If an agency receives many high resolution image data sets that have the same spatial reference, are color balanced, and have a high level of spatial processing, then the Mosaic tools from within the Data Management Toolbox under the Raster toolset can be used to generate a large mosaic or to be able to load many image data sets into an enterprise database such as SQL Server or Oracle.



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Another option to perform an Image Mosaic is to use a model such as that shown below. A model may be useful when a large number of repetitive tasks need to be performed multiple times.



Figure 38 Image Mosaic 1



Figure 39 Image Mosaic 2

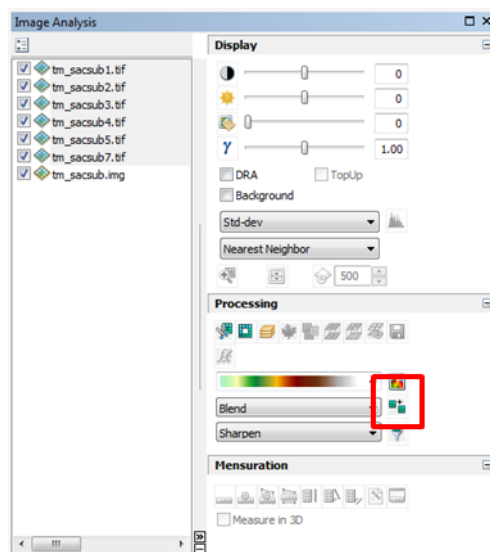


Figure 40 ArcGIS: Screenshot of Image Analysis Window

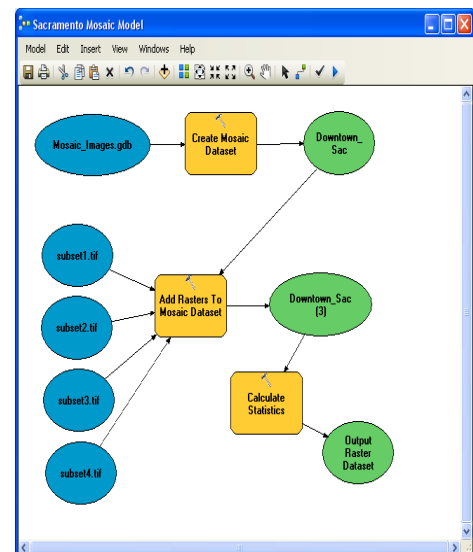


Figure 41 Image Mosaic

## Image Stretching

Image stretching is mentioned here, since this is a way to modify the visual appearance of an image and make it more visually interpretable by the analyst.

In many cases these days with image processing and GIS software, when an image is loaded into a viewing display, the image will open and look a certain way. For the most part the images will tend to look just fine. In some cases, the images may appear kind of hazy, or grey, or have a brownish tint to them. Part of this may be a result of the kind of image stretch performed on the image as it is being loaded into an image viewer. If an image does not look real appealing, then an image stretch can be performed on it.



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In the case of ArcGIS there are a number of options that can be used and the appearance of the image can be manipulated by the user in a customized fashion by modifying the histograms of an image.

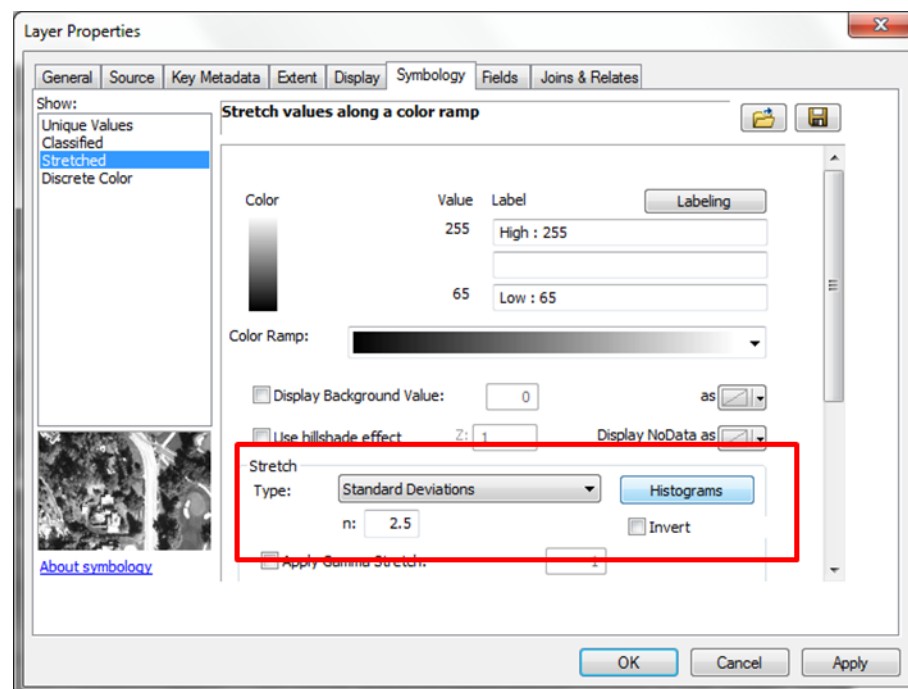
- When an image is stretched, the original pixel values get redistributed across a specific brightness range. The brightness range depends on how many unique values are available for a given image band. In many cases the unique range of brightness values is 256 or what is referred to as 8-bit data.
- As mentioned in an earlier lesson, the number of bytes that can be stored in an image band determines its brightness range.
- When an image is stretched, the appearance of the image can improve.

### Image Stretching Methods

Different kinds of image stretching methods are provided within the **Symbology Tab** of the Properties window of an image data set. The different kinds of image stretches are outlined with the red box. Note that the Histogram button is enabled. Histograms must be available before an image can be stretched.

Histograms represent the pixel count and distribution of unique pixel values or brightness values in a given image band. The histograms are created by computing the image statistics for each band. This is performed in ArcGIS when the image is loaded and the program does not detect pre-computed image statistics. In some cases a tool may exist to compute the statistics. This would need to be completed before performing the image stretch.

Once histograms are created, the **Histogram** button can be clicked to bring up the graphical display of the pixel count and distribution of pixels.



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Figure 42 Screenshot of Symbology Tab

This image provided below in Figure 43 illustrates the histogram created. This histogram shows the distribution of the original unstretched data shown in gray. The stretched distribution is shown in pink. Notice that there are gaps in the pink distribution. This is because some of the original brightness values were repartitioned to different brightness values. Also note that the brightness range for the original is smaller than the pink brightness value range. This means that the original image would have less contrast while the stretched version would have more contrast and appear to have more visually distinctive features.

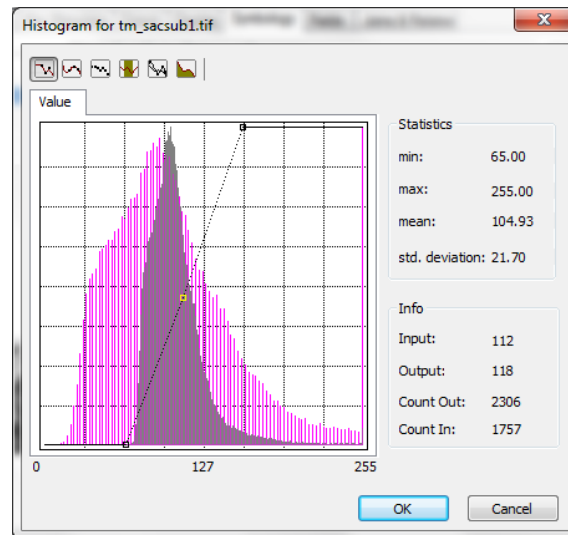


Figure 43 Histogram: Stretched Distribution

### Band Histograms

The analyst can also move the controls found in the histogram around and change the resulting stretch of an image. Most often one of the provided image stretching choices is used versus using a customized stretch. Typical options for image stretching that can be found in most image processing software packages are:

- Standard Deviation
- Linear or Min-Max
- Histogram Equalization

The most commonly used stretch is the Standard Deviation, since this stretch seems to provide an image display with a good contrast among all of the features within the image. Students are encouraged to consult software help to discover more details about these image stretching types. Essentially, each of these image stretching methods use statistics and mathematics to compute new distributions of brightness values that then get applied to the imagery when it is displayed in an image viewer. Figure 44 is a Band Histogram. The user can left-click and move mouse to also alter the histogram. The gray represents the original distribution and the pink represents the "stretched" distribution.



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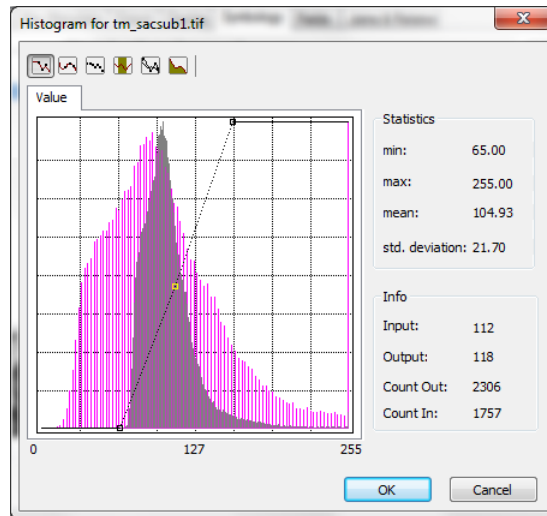


Figure 44 Histogram: Stretched Distribution

## Band Ratios and Transformations

Remote sensors collect image data across different geographies irrespective of the sun angle, the elevation, slope or how steep a hill is, or aspect, the direction the slope is facing, or how variable different kinds of materials occur across the image. In a geographic landscape the same kinds of vegetation can occur across different slopes, aspects, elevations, and will grow with different amounts of sunlight hits it. From an imaging point of view, this same material may look different on the image based on these different perspectives. This can make image analysis, and especially automated processes to identify vegetation, difficult. One way to help mitigate this problem is to use band ratios.

Band ratios can help normalize these effects and can help improve automated image classification processes. In addition, band ratios can be implemented to derive various biophysical properties from the imagery such as the quantity of biomass, water content, and plant stress to name a few.

## Common Band Ratios

As the name indicates a band ratio essentially takes the values from one band and divides it by the values of another band. Since all of the pixels in a given image are coincident, the math to perform a band ratio is relatively simple.

A couple of common band ratios are shown. Typically, the Blue, Green, and Red bands essentially have the same "informational content" in them, so ratios of Blue to Green or Green to Red or Blue to Red are not common. What is more common is taking a ratio of the Infrared wavelength to the red wavelength. Remember that oftentimes, remotely sensed imagery is used for vegetation and natural resource applications and the infrared wavelengths tend to reflect much higher than the true color bands. These kinds of ratios can be important to assist with vegetation analysis.

## Red Band



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In the case of the Red band being divided by the infrared band, vegetation is going to reflect much lower in the red wavelength and much higher in the infrared wavelength. Performing this ratio, materials that low in red, but high in infrared, the resulting image will show these areas as dark. The values in the ratio will have a small numerator and large denominator. Performing the math, the result will be a small number.

In terms of the image, these areas will appear dark. For example, healthy green vegetation reflects low in red, but high in infrared. Doing the Red to infrared ratio, the resulting pixel values will be small and hence appear dark on the image. In Figure 45 the image shows agricultural areas towards the left side of the image as being dark. These areas have healthy green vegetation that are fertilized and watered, but because they reflect higher in the infrared wavelengths than in the red wavelengths, they appear dark on the image.



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Figure 45 Normalized Difference Vegetarian Index (NDVI)

### *Normalized Difference Vegetation Index*

Another popular ratio is called the Normalized Difference Vegetation Index or NDVI. This ratio is a combination of taking the difference of the infrared and subtracting the red and dividing it by the sum of the infrared and red bands. This ratio is very good about identifying where the healthy green vegetation is and to also show areas that may be under different kinds of plant stress. The stress may come from drought conditions, beetle infestation, plant diseases, poor soil, fire and heat, and other influences.

Other specific kinds of ratios are related to soil moisture, agricultural stress, and forest health. Students are encouraged to investigate other resources online or in other text books that discuss image processing and image enhancements using band ratios.

### **NDVI Output**

The Image Analysis Window has an NDVI tool that can perform this band ratio automatically. The default setting for showing this result is by using a color display. In this case, the colors in green represent areas that have a high NDVI value. Those with shades of light orange and yellow to a light brown are areas that have little or no healthy green vegetation. Sometime this kind of display can be confusing because the analyst may not be aware of which colors represent small NDVI values and may think that the output image contains multiple bands, when in fact, the NDVI contains only a single band. The images provided illustrate a couple of different ways ArcGIS represents the NDVI output.

The colored illustration provided below just happens to use a color ramp appearance to show individual pixel values in color.



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Figure 46 Illustration of a color ramp using appearance to show individual pixel values in color.

The grey illustration is how NDVI is represented in a variety of software packages. The image is a gray-scale image indicating that it is a single band image. Looking at the NDVI algorithm one can determine that the larger the difference there is between a large infrared value and a small red value, the brighter the resulting NDVI values. A large difference in infrared and red values will result in a larger positive number in the numerator. In the case of healthy green vegetation, these areas will show up as brighter pixels. Notice the bright areas in the agricultural field in the left side of the bottom image. If the opposite occurs where there is a small infrared value (for example, water) and a larger red value in the numerator, then the resulting NDVI will be smaller (or even negative) and the image will appear dark. For example, in areas of where there is standing water, infrared wavelengths essentially are zero because water absorbs infrared wavelengths.

Also in the black and white image areas that contain vegetation appear to have brighter shades of gray or white. One can see that on the lower right of the bottom image that there are extensive light gray areas which in this case represent tall deciduous trees that are well maintained in an urban environment. The darker gray areas are typically commercial buildings, built up, or bare soil.



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Figure 47 Illustration of how an NDVI is represented in a variety of software packages. The image is a gray-scale image indicating that it is a single band image.

### Image Transformations

Another popular biophysical algorithm that is often used with Landsat or IKONOS imagery is the Tasseled Cap transformation. The tasseled cap transformation is one that evaluates all of the pixel data in a Landsat or IKONOS image and creates derivative image bands that refer to:

- Brightness or how bright materials are in an image
- Greenness or how green materials are in an image
- Wetness or how wet materials are in the image

The name tasseled cap comes from the shape that occurs when two different resulting tasseled cap components are plotted against each other. In the illustration below, the pixel distribution of the brightness band is plotted against the greenness band distribution. Note the pointedness of the graph and looks like a tassel on a cap.

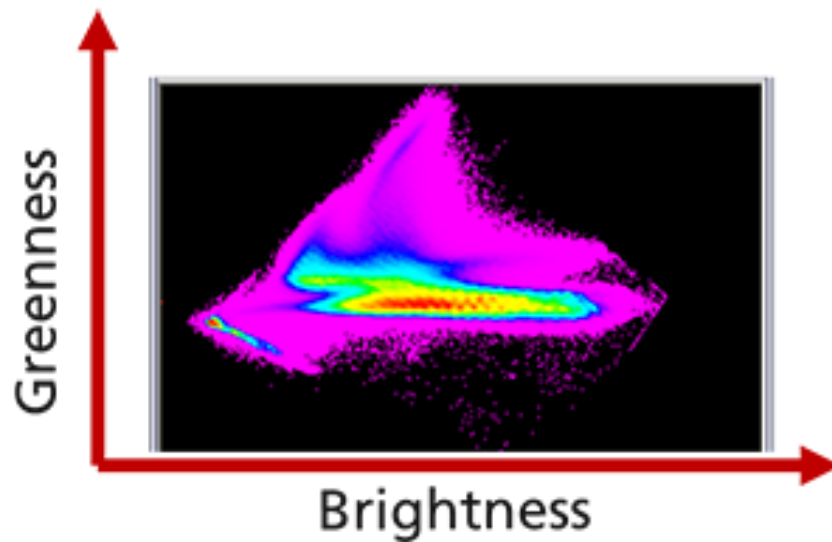


Figure 48 Tasseled Cap

### Brightness and Greenness

If you remember back to the previous lesson, each image band has a distribution of pixels. If the distribution of pixels were plotted, there would appear a range of brightness values and some of those pixels would occur more frequently throughout the image than others. The images provided illustrate the individual Brightness and Greenness bands plotted separately. Notice the large peaks on each graph. These are brightness values that have larger pixel counts than other brightness values. If the analyst was able to plot the combination of the brightness value and the greenness value for each pixel, the output would look similar to that in Figure 48.



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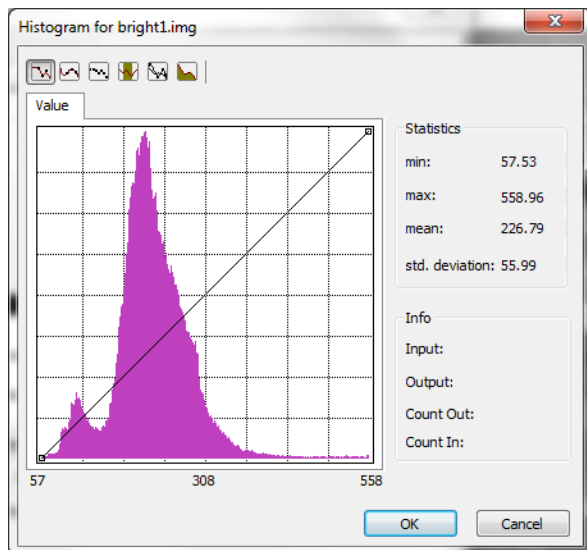


Figure 49 Brightness Band

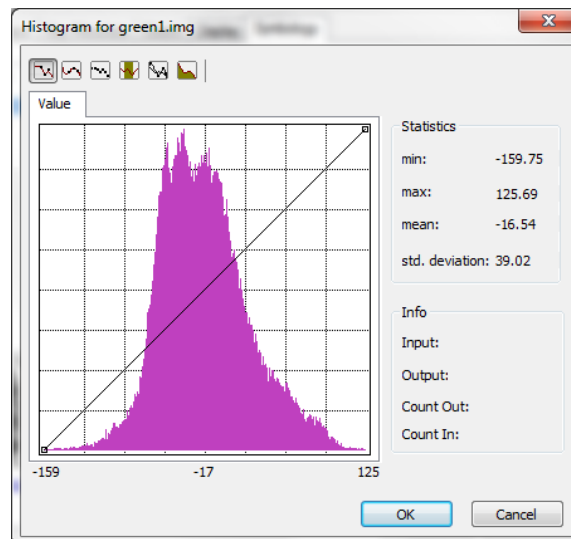


Figure 50 Greenness Band

### Landsat TM: Tasseled Cap

The following examples illustrate the individual Tasseled Cap components that are derived from the Tasseled Cap routine for a small portion of a Landsat TM scene.

Figure 51 is an image which shows a gray scale image where brighter values represent areas in the image that appear as bright objects. In this image, these would represent buildings, dry bare soil, and industrial areas. Darker areas will represent areas that tend to NOT be bright, so this will include much of the vegetated areas or have tree canopy above residential areas or pavement in this image.



Figure 51 Example of Brighter Values within Image

The image below (Figure 52) represents the greenness component. Brighter values in this image will represent areas that are healthy green vegetation. Darker values will tend to NOT be green vegetation or have mixed pixels that are not vegetation.



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Figure 52 Greenness Component

Figure 53 represents the wetness component. Bright areas will represent areas that have either open water or strong water content responses. The rivers and vegetation show up brighter throughout this image because the vegetation contains a lot of water content within its leaves. Dark areas will represent urban or build up areas that do not have any vegetation canopy covering it. Mid-gray level values will be those areas of bare soil that may be damp or have some small vegetation growing on it such as newly planted fields or low lying areas with sporadic vegetation scattered throughout it.



Figure 53 Wetness Component

## Tools

As was briefly mentioned earlier, a number of tools are available within ArcGIS to perform these tasks. These include the Image Analysis Window, the Raster Calculator, and using Model Builder. All of these except the Tasseled Cap routines can be found within ArcGIS. The tasseled cap routine mentioned in this lesson was created by the author and is provided as part of the content for this lesson. Check the Data folder for this lesson to review, modify, and run the Tasseled Cap Python script.



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## SUMMARY

This lesson examined sensor platforms, image processing, basics, band ratios, and transformations. You learned about the relationship between wavelengths, sensors, and color display as well as the process of acquiring remotely sensed imagery. Information in the lesson explained image processing in ArcGIS with examples to show the various steps required and considered. Band ratios and transformation aspects were exhibited with explanations to help you understand the concepts used in this process.

## ASSIGNMENTS

1. Quiz
2. Lab: Image, Composite, Mosaic, Subset
3. Exam



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