NISGTC

The National Information, Security & Geospatial Technologies Consortium

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Written by: Nate Jennings

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Lesson 1: Overview of Remote Sensing

INTRODUCTION

In this lesson you will learn about the various types of remotely sensed data and remote sensor systems used in remote sensing. The information will help you understand the uses of remote sensing such as monitoring cropland, forests for fires, wetlands, and floods. You will learn about the history of remote sensing as well as where the industry is today and where it is going in the future. This lesson provides information on the elements and strategies of visual interpretation and digital image processing. An overview of ArcGIS is included in this lesson to help you gain a better understanding of this software used for remote sensing.

LESSON OBJECTIVES

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

1. Define remote sensing.
2. List different types of remotely sensed data and sensor systems.
3. Describe different types of remote sensing systems and their applications.
4. Describe the history and future trend applications of remote sensing.

LEARNING SEQUENCE

Required Reading	Read the following: • Online Lesson Material
Resources	Review the following: • None
Assignments	Complete the following assignments: • Application Paper • Quiz

INSTRUCTION

Remote Sensing

Remote sensing is basically observing the Earth and its phenomena using sensors, such as aerial and satellite systems that are not in contact with the Earth. An image analyst will use specialized software to study and analyze remotely sensed data. As part of these efforts image analysts will often create products such as maps, reports, and web services that are derived

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from these systems. Some examples include:

- Land cover classification map
- 3D elevation surface model that can be used in a viewshed analysis
- Image-based web map service that can be used in web and mobile mapping applications

Consider how remote sensing relates to other pieces of GIS and mapping. Figure 1 illustrates how remote sensing relates to the other pieces of GIS and mapping. Remote sensing includes digital image processing, image acquisition, and photogrammetry, which is the science and processing of making highly refined corrections to aerial photos. Remote sensing connects with GIS when an analyst needs to make maps, conduct spatial analyses, and perform geoprocessing.

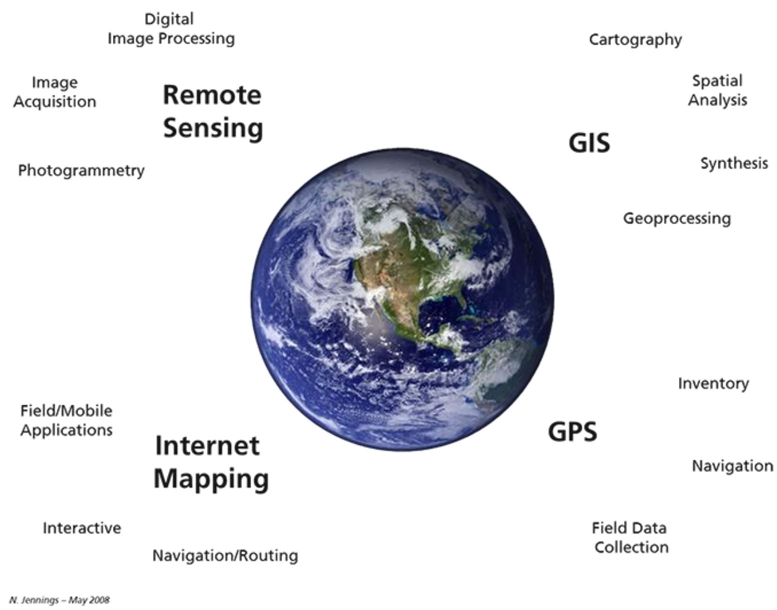


Figure 1 Remote Sensing and GIS

Remotely sensed data is often used as a background or as inputs to the geoprocessing functions within the GIS software. Remote sensing connects with GPS because the imagery can be used as a background in the GPS unit and provides a visual context when a person is using a GPS unit for data collection or navigation. Remote sensing connects with Internet mapping because again, the imagery can be used as a background and served up as a web map service. This can be used on web or mobile applications and provide visual context for these applications when they are used for navigation, routing, or for displaying other spatial data such as points of interest, traffic flow, areas of impact, etc. So as you can see remote sensing is an integral part of all aspects of GIS and location based information.

The lessons within this course will focus on remote sensing and include an introduction to a number of different kinds of imagery and various techniques to process the imagery to create and derive new spatial information.

Common Uses of Remote Sensing

There are many different kinds of remotely sensed imagery. Remote sensing can be used for a wide variety of studies and fields of interest.

Some of the most common uses of remote sensing include:

- Land cover/land-use mapping
- Change detection which means looking at and analyzing change in the landscape over time
- Forest monitoring such as timber management, forest fires and bug infestations disease
- Urban sprawl and changes in the urban environment
- Natural resource management of many kinds
- Cultural resource analysis such as mapping historical archaeological sites where people lived and how they used the land from past cultures
- Fire monitoring such as forest fires or urban fires
- Feature material identification such as being able to categorize and identify specific objects in an image such as rooftops, buildings, trees, roads, and other types of objects
- Disaster management such as pre-and post-flood events, earthquakes, tsunamis, and other natural disasters as well as human impacts such as community and people displacement
- Climate change and looking at the effect of changes in the climate over the landscape
- Agricultural monitoring such as how different crops grow over growing season or how crops change over time
- Mining operations for both the actual mining operation as well as remediation of a mining site
- Flood monitoring of pre-and post-flood events such as are seen in hurricanes, localized flooding, levee breaks, and tsunamis
- Changes in snow and ice such as ice breakup, iceberg monitoring, and navigation of ships through Arctic or Antarctic waters
- Wetland management of being able to map wetlands as well as map changes in the wetlands

Other uses of remote sensing will be described and discussed throughout this course. You are encouraged to do your own investigation on the Internet and keep up with current events where remotely sensed imagery and data are used.

Applied Uses of Remote Sensing

The following are examples of some of the uses of remotely sensed imagery and how this data can be incorporated into other applications.

Cropland Monitoring

Figure 2 is an example of cropland monitoring. This is a public website maintained by the USDA called CropScapes which is a web-based application that shows different types of crops that are grown throughout the United States. This data is updated annually and is derived from the MODIS and Landsat satellites. The general public and scientists can use this site to review, download data, and look at crop changes over time for different parts of the country and to do analysis on this information as needed. Review Figure 2: CropScape – National Agriculture Statistics Service of the USDA use MODIS and Landsat satellites to map and estimate crop type and monitor change in agriculture lands.

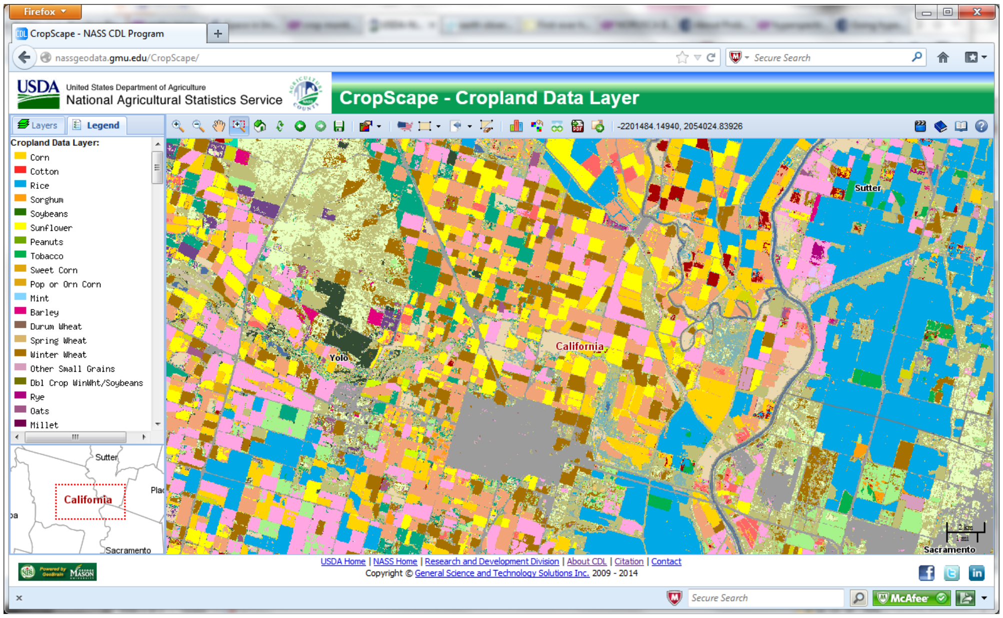


Figure 2 CropScape

Monitoring: Forest and Fire

Remotely sensed imagery can be used for forest and fire monitoring. As can be seen in Figure 3 there are two large active fires burning. You can see the active fires burning as well as the area that has burned and the smoke plumes that are coming off the fires. In addition you will notice that there are clouds in the image. This image was taken from a Landsat 7 satellite in June 2002 in an area of Arizona. Since the Landsat satellite orbits in space the satellite not only picks up the fires and the smoke, but also picks up the clouds that are in scene. Figure 3 is from the US Forest Service of the Rodeo and Chedeski Fires in Arizona from Landsat 7, June 21, 2002.

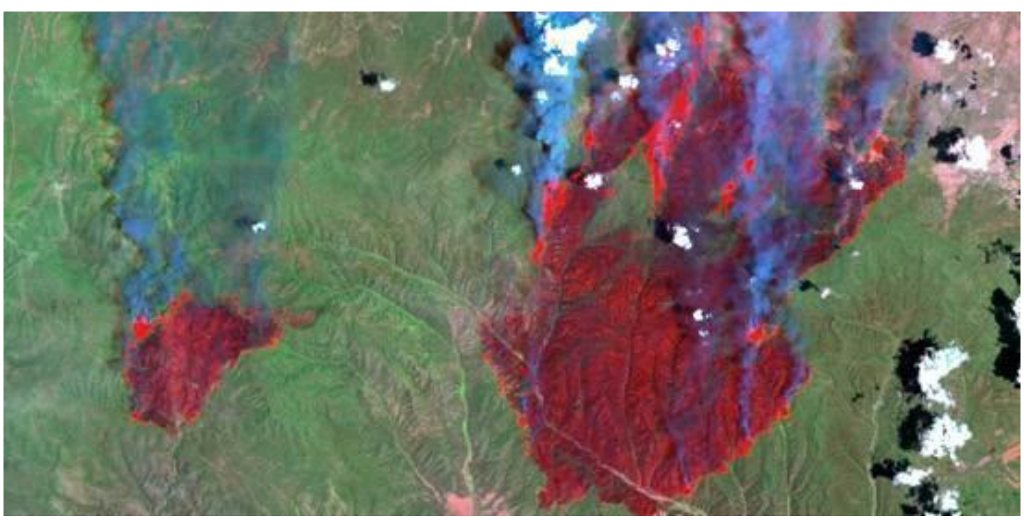


Figure 3 Monitoring Forest and Fire

Monitoring: Surface Mining

Here is an example of how remote sensing can be used to monitor mining operations. The image on the left shows a person holding a remote controlled airplane that is considered an unmanned aerial vehicle or UAV and is used to fly around a mining site to monitor the mining operations. The image on the right happens to be a surface mine in West Virginia. In this case the USGS is flying the UAV mission to collect imagery and information for the mining operation.

Figure 4 UAV Imaging

Wetland Mapping

Figure 5 is an example of different kinds of wetlands that have been identified using satellite radar imagery. The map is a section of a large wetland in Alaska that has been categorized into different wetland types. This screenshot represents a small web-based mapping application created by Jet Propulsion Laboratory that shows the wetland mapped in Alaska.

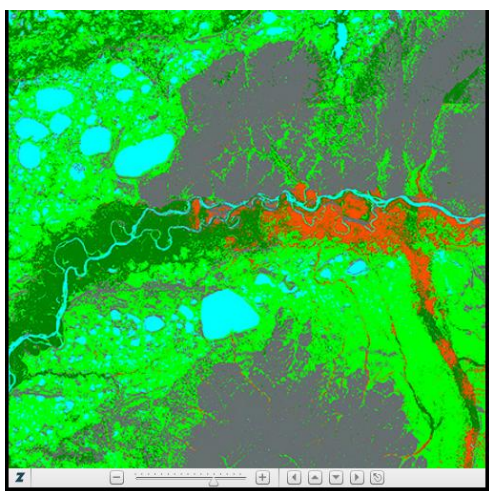


Figure 5 Wetlands Map

Monitoring: Floods

The images in Figure 6 are examples of how remotely sensed imagery can be used for flood monitoring. The top image shows the Mississippi River in a pre-flood event and then the image on the bottom shows the Mississippi River after a major flood that occurred in 1993. You can see how extensive the flood was in both Mississippi and Missouri rivers. This imagery and the maps derived from them were used to process insurance claims of affected property owners.

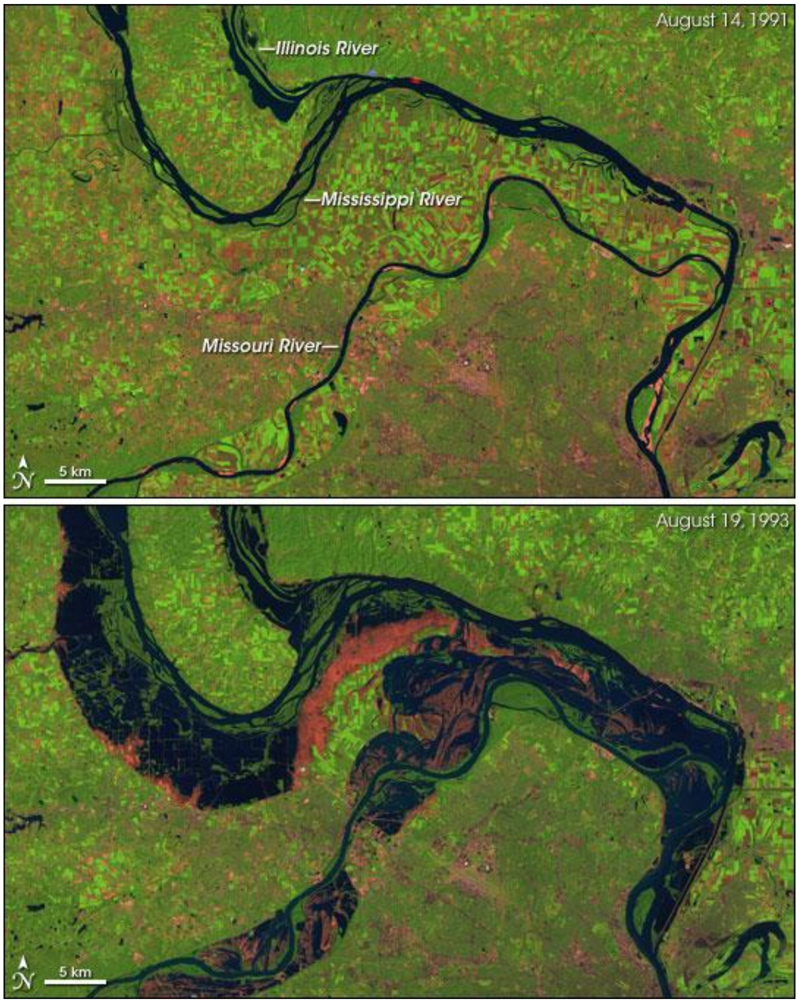


Figure 6 Flood Monitoring

Monitoring: Ice Conditions

Figure 7 illustrates how remotely sensed imagery can be used to monitor ice conditions. This image was taken by MODIS satellite in 2002 and in the center of the image there are two large icebergs near Antarctica. Remote sensing has also been used to monitor the Arctic and Antarctic sea ice freezing and thawing and the changing conditions of ice and snow as a result of climate change.

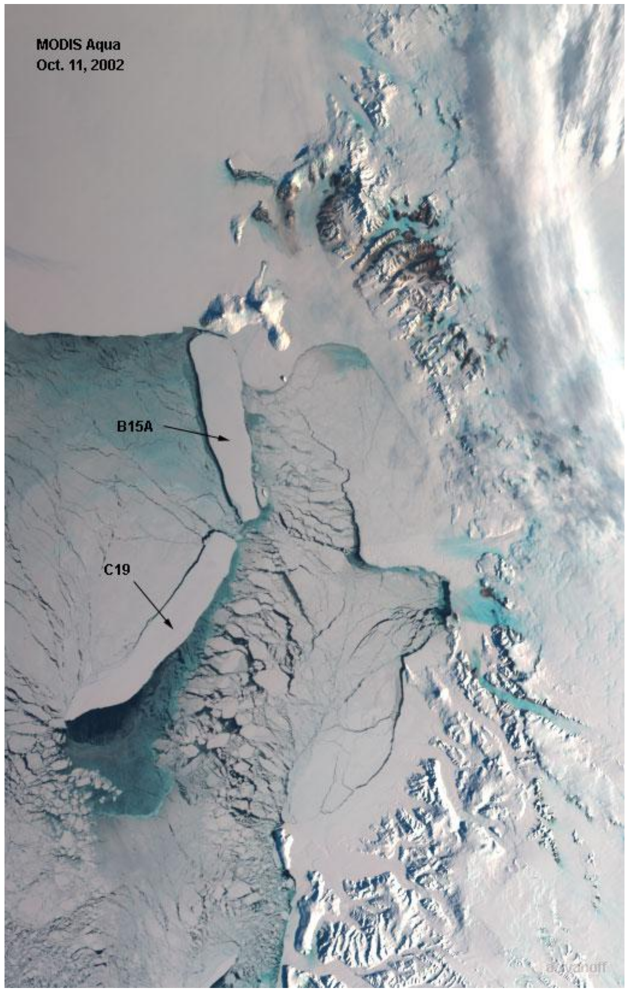


Figure 7 Ice monitoring showing two large ice bergs near Antarctica from the MODIS satellite, October 11, 2002

Feature Based Mapping

Feature-based mapping or object-based image classification is a digital image processing technique that can be used to identify specific kinds of objects in high-resolution imagery. The image shown on the left represents a high-resolution satellite called Worldview-2. On the right, the picture shows the mapped land cover and land use types that were categorized using feature-based mapping methods. Visible are trees, shrubs, soil, buildings, roads, and other paved surfaces that have been identified in this image.

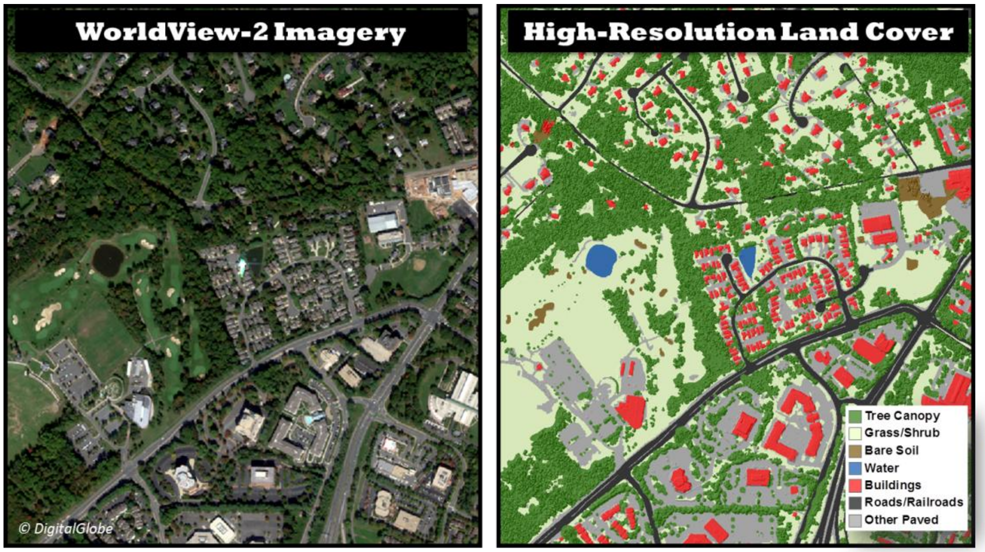


Figure 8 Feature Based Mapping

Past, Present, Future of Remote Sensing

Remote sensing has been around almost as long as photography itself. Chemical photography on a permanent medium has been around since the 1820's. Figure 9 shows some of the major milestones of remote sensing over the last 150 years.

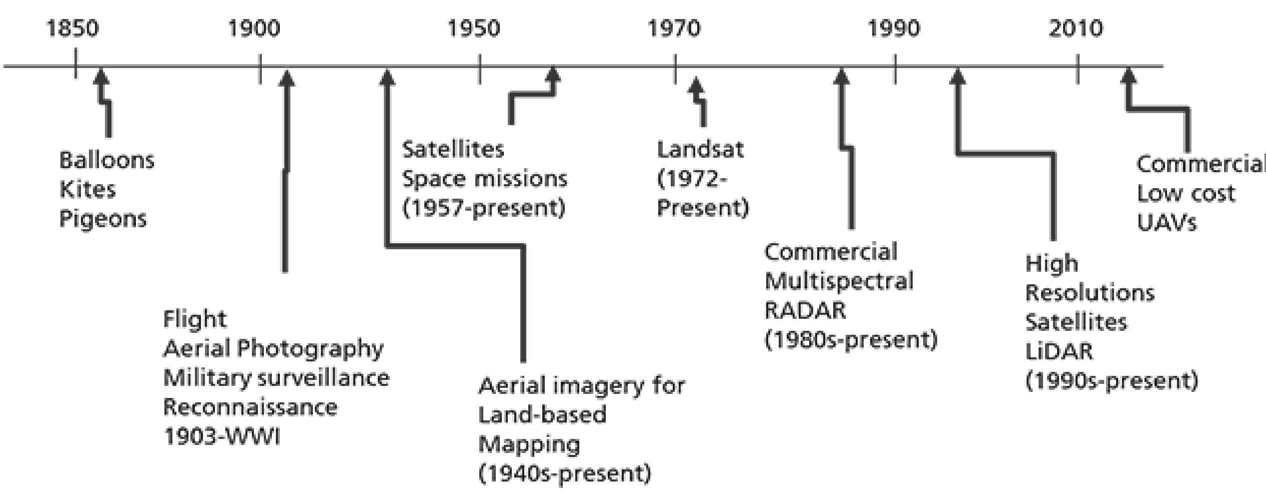


Figure 9 Milestones in Remote Sensing

1850's: The first cameras used for remote sensing started in the late 1850's with cameras attached to kites, balloons, and "pigeons".

1903: With the advent of modern flight, remote sensing was used in World War I on reconnaissance flights to "see" where the various military posts were located. Since then aerial photography or aerial imaging is a standard practice for military purposes.

1940's – Present: After the 1930s and 40s, aerial photography has been used to map and monitor natural resources such as agricultural lands, urban development, and changes in the natural environment.

1950's -1960's: During the development of the "Space Race" in the 1950s and 60s satellites were placed in orbit to test capabilities of communication and space flight.

1972: In 1972, the first satellite called the Earth Resource Technology Satellite (ERTS), and later renamed to Landsat-1, was put into orbit to monitor the Earth. Since then a number of government sponsored and private companies have placed Earth monitoring satellites into orbit. In February of 2013, the Landsat program marked its 40^{th} anniversary with the launch of Landsat 8.

1980's –Present: In the mid-1980s the US and other countries placed a variety of remote sensing satellites into space that include both multi-spectral and RADAR sensors.

1990's – Present: In the 1990s to the present day, aerial and space-based remote sensors have improved both the spectral and spatial resolutions. Some sensors such as Hyperspectral sensors can have over 200 unique spectral bands. Many airborne imaging systems can image with a ground resolution size of less than 3 inches, while commercial space-based imaging systems can capture image data in multiple wavelengths with a ground resolution of less than 1m. Also during this time, the development of LiDAR systems, sensors that capture high resolution elevation measurements using laser technology were also developed.

2010 – Present: In more recent and likely future times, the number and variety of satellite systems will continue to improve in both spectral and spatial resolution capabilities. In addition, the use of unmanned aerial vehicles (UAVs) and open source software have started to become popular and cost-effective for individuals and communities to capture, process, and use imagery from these systems as well as open new markets to offer new products and services that have in the past been cost prohibitive to develop and implement. Also, it is suspected that standards and regulations will be created and adopted by governments and agencies so that UAVs can be properly used for specific applications and balance the utility of such systems with privacy and "spying" issues.

Timeline

Figure 10 is a timeline of the approximate history of the various technologies just mentioned. All of the various remote sensing systems have been in continuous operation since their inceptions are listed. The Balloon, kite, and "bird" options have had some sporadic history with some breaks here and there. Once motorized flight became common, the "low tech" options faded.

During the 40s to 60s, balloons were used in part to develop weather predicting technology as well as test photographic systems that were the precursors to "space" photography and the modern Earth imaging systems.

In recent times digital photography has become more common place with high quality resolutions. The ability to mount and use low cost infrared digital imaging systems such as the kite and balloon mounted options have experienced a resurgence in interest and provide some opportunities for the "Do-It-Yourself" hobbyist to capture, process, and use "high tech" imaging systems. This was once limited to those with formal education and training in digital imaging systems and digital image processing techniques.

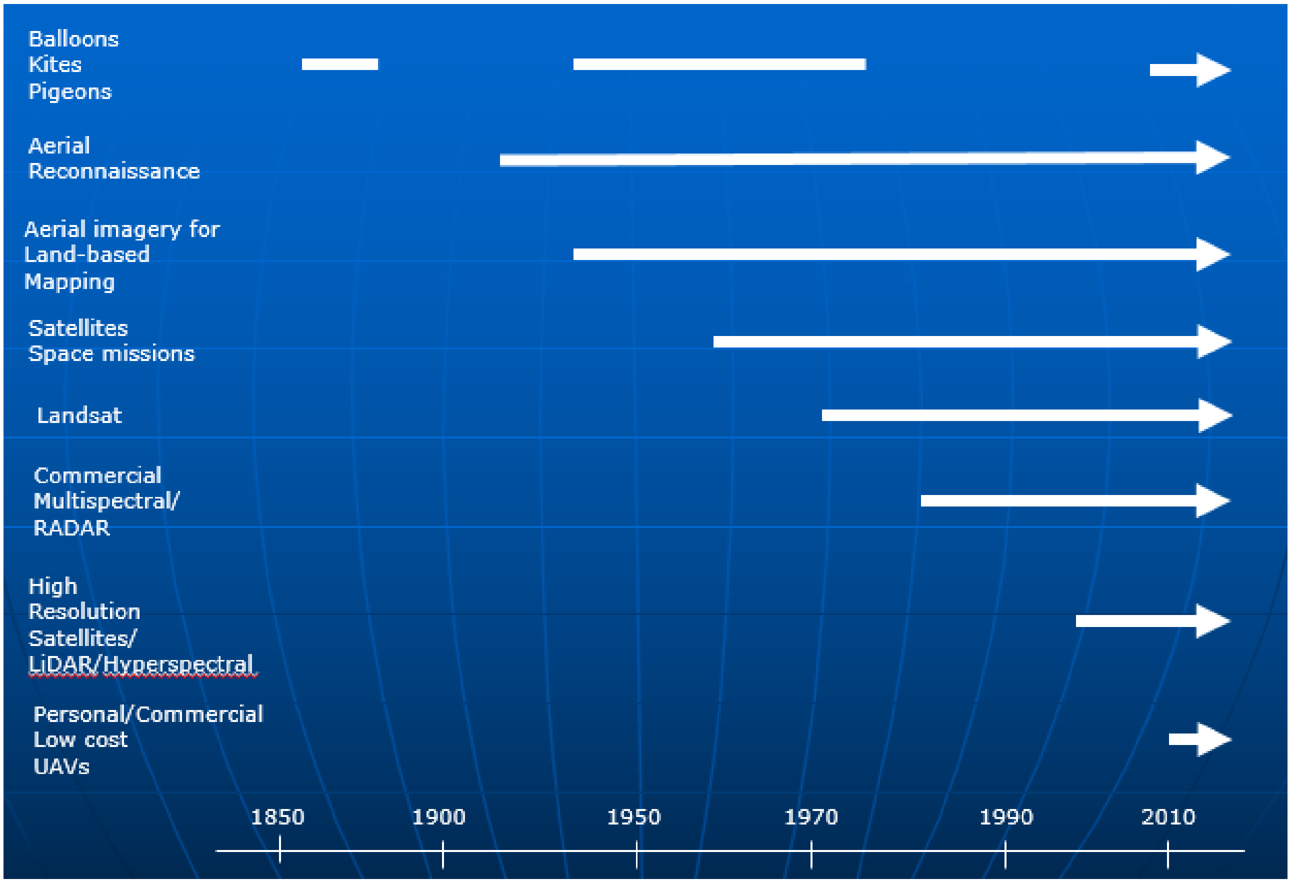


Figure 10 Timeline

Remote Sensing Technologies

Here are some examples of the remote sensing technologies just highlighted within the timeline.

Image Name	**Description**
Nadar Aerial Image	1858 – Gaspard-Félix Tournachon (aka Nadar) French photographer who was the first person to take aerial photographs. This is an image of a photo taken by George Lawrence in 1906 of San Francisco about 6 weeks after an earthquake. The camera was mounted to a kite. Market Street begins at the "tower" in the foreground and disappears in the distance. Golden Gate is in

	the upper right of the photo.
Kite Mounted Camera	1906 – George Lawrence, San Francisco, kite mounted camera ~6 weeks after the 1906 San Francisco Earthquake. The tower of the Ferry building (foreground) marks the beginning of Market Street. Golden Gate is towards the upper right where the sun is setting.
Pigeon Mounted Camera	1908: Julius Neubronner, A pigeon mounted camera. This image is a representation of the "pigeon mounted" camera on the right. The left image shows one of the photos taken from this kind of camera.
White Linear Features	1916 in France, German trenches in WWI. The vertical lines are the communication trenches. An aerial image taken from an airplane in France during World War 1. The white linear features are those of the "trenches" that were dug where troops fought from. The lines that run from the upper right to lower left represent the communication trenches where troops would send messages between military staff from one "line" to another.

Images from Modern Satellite Systems

The examples of images provided were taken from modern satellite systems. Figure 11 is a Landsat scene of a portion of the Central Valley in California. Sacramento, CA is in the lower right quadrant of the image. The Landsat pixel size is 30m. Figure 12 is a subset of the commercial Quickbird. The Quickbird pixel size is 2ft. Notice the level of detail in the Quickbird image.

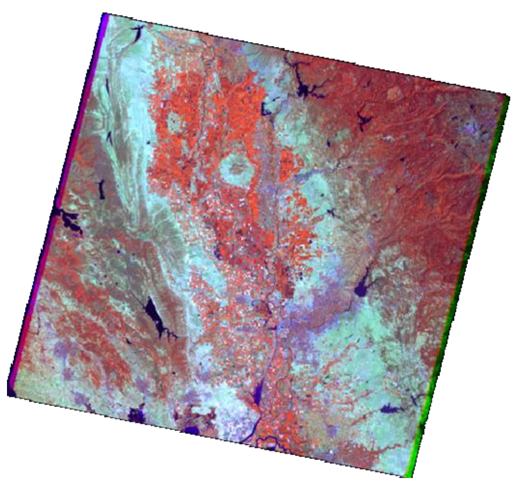


Figure 11 Landsat of Sacramento, CA

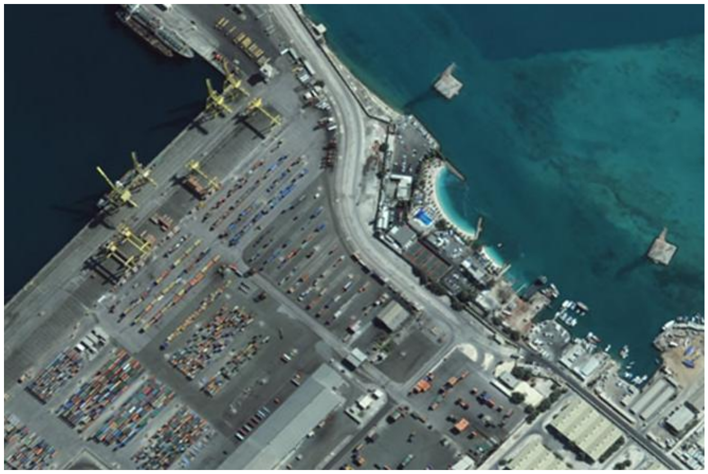


Figure 12 Subset of Commercial Quickbird

High Resolution Digital Aerial Photography

Figures 13 and 14 illustrate examples of high resolution digital aerial photography and an example of airborne LiDar data. Figure 14 represents high resolution elevation data. This subset of downtown Sacramento shows the ancient course of the American River. The current American River runs across the top of the image. The "ancient" river system is now covered with large trees and a residential area and would not be recognizable in a typical aerial photo.

Figure 13 High Resolution Digital Aerial Photography

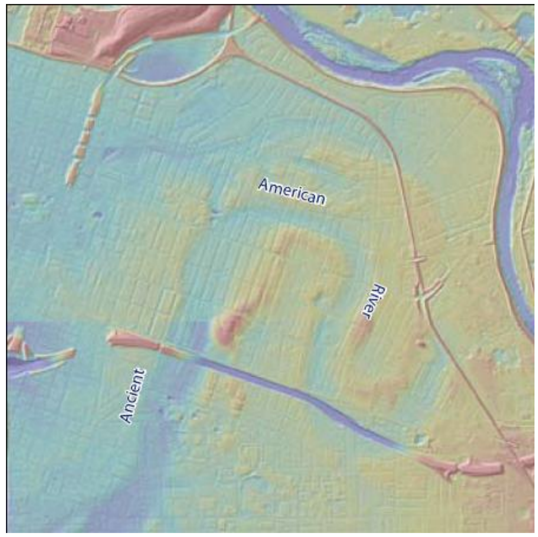


Figure 14 Aerial LiDAR

Future Remote Sensing Technology

Figure 15 includes some examples of current unmanned aerial vehicles include “copters”, kites, fixed wing remote controlled air planes, and balloons. Many of these are low cost, (less than a couple of thousand dollars), and can have various digital camera systems mounted to them and typically include true color can color infrared imaging systems. Many are also programmed for flight and the imagery processed with open source software.

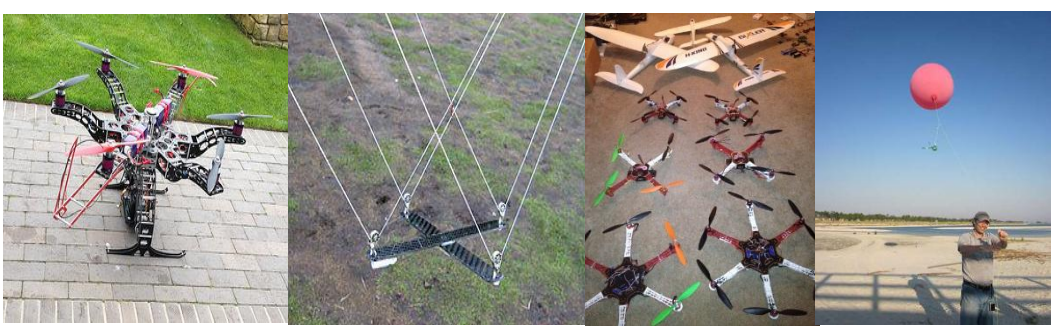


Figure 15 Examples of “low cost” UAVs for Personal and Community Use

Overview of Visual Interpretation

Part of remote sensing is to capture and process imagery. Other lessons that comprise this course will focus on the image processing aspects. One primary element of remote sensing is interpreting the imagery or the results of digital image processing routines. This is a key skill that image analysts develop and requires an understanding of the information collected by the sensor as well as the concepts and methods used to process the image data.

In addition to understanding the information collected by the sensor and analyzing the imagery, it is also helpful for the image analyst to have knowledge of the geographic area. The analyst may not always work or live in the area that the imagery was taken, so obtaining a background on the geography or learning about the kinds of features one would expect is often helpful. Analysts may also need to look at a variety of information sources that may include images and derivative data sets from past projects in the same area, review sensor characteristics and image processing methods that could be used to process the image.

It is also common that the image quality may not always be adequate to visually interpret objects. Some issues that affect visual interpretation are haze, smoke, cloud cover, shadows from clouds, buildings, or other landscape features such as tree canopy or mountains.

Visual interpretation also often takes a lot of patience and imagination and be able to tie concepts of how the sensor collects spectral information to the pixels in the image that represent the geographic features.

Performing Image Interpretation

Some common elements for performing image interpretation are as follows. These several of these elements are often used in any visual interpretation exercise and for any given type of imagery.

- **Shape** – this refers to the form, configuration or outline of an object. For example, a rectangular shape may represent a building

- **Size** – how large or small an object is relative to the image scale. Provided that the image has enough resolution to "identify" objects of interest, the object may appear as a small feature without much detail. In the case of high resolution imagery where there is a lot of detail in the image, the object of interest may appear large when the analyst zooms to the extent of the object

- **Pattern** – this refers to the spatial arrangement of the object. For example, an orchard or vineyard may appear in a regular arrangement of vegetation rows that represent the vines or the individual trees. A wetland may have an irregular pattern of open water and boggy vegetation areas

- **Tone** – tone refers to the relative brightness of an object for a given a color or black and white display. The analyst would expect building to appear bright in a true color image if the buildings are in an urban setting. Dark tones would be expected for the same urban areas when the image analyst is looking at an image that contains spectral information from color infrared imaging sensor.

- **Texture** – this refers to the spatial pattern of tone or color. Texture can play an important role in interpreting geographic objects in imagery. Some features will appear with a regular spacing of similarly colored or bright pixels; whereas others will tend to have a random pattern of pixels. For example, rows of corn in an image may have a regularly spaced set of bright pixels representing the corn and dark pixels representing the soil in between the corn rows. A wetland may have a random appearance of both dark and bright pixels.

- **Shadows** – shadows can assist the analyst to interpret features in the image. For example, shadows cast by palm trees may help to visually interpret palm trees.

- **Site** – the "site" of an object refers to its expected placement of this object based on the topography or geography that it is expected to be in. For example, certain kinds of trees grow at certain elevations or one would expect no trees above a certain elevation because some trees cannot grow above this elevation.

- **Association** – association refers to the placement of an object relative to other features. For example, wetlands might be expected to be found near rivers, streams, or creeks.

- **Resolution** – the image resolution limits the kinds of features an image analyst can interpret. For example, if an image has a 30m pixel resolution, it is likely not possible to identify individual buildings or houses. Whereas, in a high resolution image with 6in pixels, the details of houses and buildings can be identified (such as windows, gables, and vents).

Interpretation Strategies

Some of the general interpretation strategies that image analysts tend to use in any visual interpretation exercise are explained here.

Direct Observation

Direct Observation refers to actually "looking at" the imagery and interpreting the object and being able to identify it. For example, the feature I look at on an urban image is a high rise office building.

Inference of an Object

This concept involves an image analyst who can infer what the object is in the image by looking at surrounding geography and other nearby objects. For example, a specific kind of forest plant community can be inferred by its presence on a specific facing slope (such as South facing) of a hill.

Knowledge of the Area

It is often helpful to have knowledge of the geography and surrounding area when working on a remote sensing project. If the analyst does not live or work in the local area, then he or she may need to visit the area, talk to others who live or work there, and obtain and study other reference documents and information on the geography.

Reference Material

This includes various kinds of digital or paper information that can include maps, image classifications of land cover, stream and river networks, wetland maps, urban infrastructure, and acquiring digital geographic reference information such as streets, lake boundaries, forest stand information, trails, etc.

Digital Image Processing

Another major part of remote sensing is the use of digital image processing techniques to create and derive new information which can be other images, tables, or maps. Digital image processing is at the heart of remote sensing, since specialized software is required to obtain, analyze, and interpret information. Many different digital image processing software packages are available that can be used to process remotely sensed imagery. In this course, ArcGIS will be used. Other commercial software that is available are ERDAS Imagine, ENVI, and PCI Geomatics. Some popular open source software packages are Opticks and MultiSpec.

The digital image processing techniques involve running “computer algorithms” that operate over all or parts of the image and depend on what parameters are required and how the software vendor has chosen to implement these algorithms.

An Algorithm is essentially one or more math functions that are used to analyze the pixel values within in an image. The input data for these math functions can be individual pixels, specific image bands, subsets of pixels, or the entire image. Lesson 3 will focus on image components and the relationship between sensor wavelengths, the image, and some of the physical properties that can be derived from the image. Other lessons will focused on other involved processes such as land cover classification.

Digital Imaging Processing Routines

Some of the common digital image processing routines can be categorized in the following manner.

Data Composition

Data Composition refers to creating a multi-band image composite from individual sensor bands, creating image mosaics from multiple images, or subsets of images which might be a portion of an image that represents a project area for a mapping or image classification project. Data composition tasks are often considered a pre-processing step since an image (or images) needs to be compiled and made available so that other image processing steps can take place.

Image Rectification

Image Rectification this involves the process of locating an image without any spatial reference to geographic data that does contain a spatial reference. Image rectification is also considered a pre-processing step, since most remotely sensed imagery of the Earth needs to be referenced to an actual geographic location so that it can be used with other georeferenced data.

Filters

Many image processing packages provide s series of image filters that can be used to smooth or identify linear objects such as roads or crop boundaries.

Image Classification

A major task using remotely sensed imagery is being able to categorize land cover or land use. A number of image classification techniques exist for semi-automatically or automatically being able to categorize land cover or land use. These processes often involve a number of sequential steps and analyses to complete.

Derive New Data

In many cases, new data sets are often derived from the raw remotely sensed imagery. Some of these data may exist as temporary data for multi-step processes or they can be used by themselves or as inputs to modeling processes. Examples of these data sets are slope, aspect, texture, band ratios, and vegetation indices.

Image Fusion

Image Fusion is the process of merging imagery from different sensor types or different resolutions. Examples include high resolution color composites and merging RADAR data with multi-spectral data.

Data Conversion

A common activity that is used with remotely sensed imagery is changing the image format from type to another. This can include different file types (such as converting from an ERDAS Imagine file format to a TIF format). It can also include converting from an uncompressed format to a compressed format (or vice versa). Performing image compression often requires the use of additional commercial software extensions to image processing or GIS packages. Examples include the MrSID format from LizarTech and the ECW format created by Earth Resource Mapping and is now part of Integraph.

Special Algorithms

These include one or more related computer routines that are specific to unique types of remotely sensed data such as RADAR, Hyperspectral, or LiDAR. Often these routines are "add-on" packages to existing image processing or GIS software.

Digital Image Processing

Here are some examples of how the digital image processing routines can be implemented.

Tools with Parameters

Most often, the analyst will chose a routine that will pop-up a dialog box. The analyst will then need to fill in parameters such as inputs, output, and other specific parameters that are required or are optional for the routine to function properly. When the analyst clicks OK, the image will be processed with these parameters. The new image file can then be analyzed and visually interpreted or have other subsequent processes run on it.

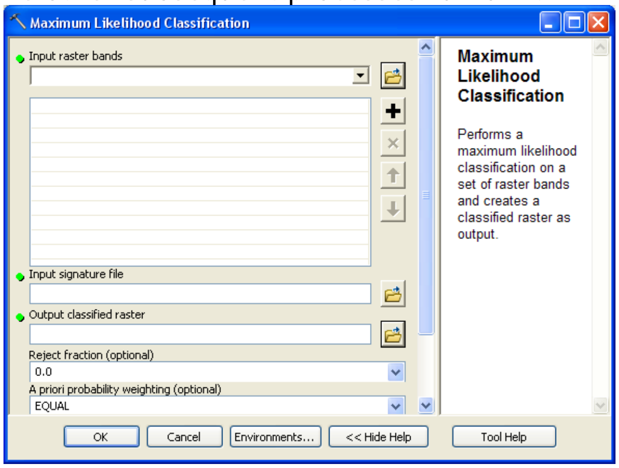


Figure 16 Analysis

Spatial Models

Another method to process image data is to use spatial models. In the case of ArcGIS this is accomplished through ModelBuilder. In other software packages this is achieved through a similar means of graphical objects being placed and connected in a "canvas" area to build the spatial model. The analyst can test and then run the model through a "Run" operation or tool.

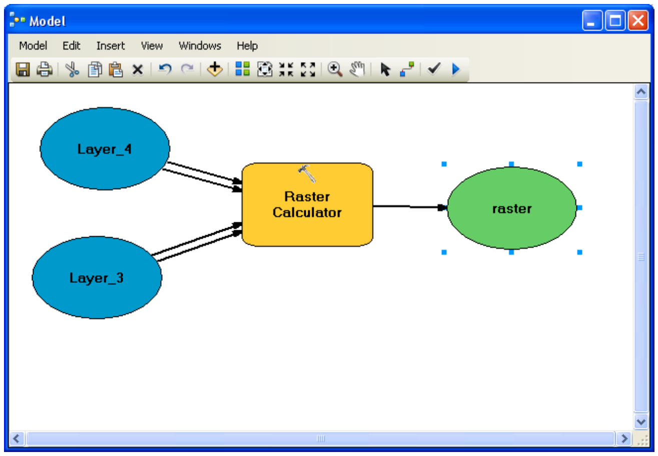


Figure 17 Spatial Models

Scripts

A third method of processing imagery is through writing computer code. In some cases, the tools are not available through the "out-of-the-box" software or add-on extensions. In these situations and provided that the analyst has the required programming skills, the analyst can write computer algorithms and image processing routines to process the image. If the analyst does not have the programming background to accomplish this, they can often partner with another person or organization that can perform the unique programming tasks. In some cases, the software vendor will have its own unique software tools to write and process the computer code. In many of the current commercial software packages, Python, C++, or similar common programming language is used to write specific image processing scripts.

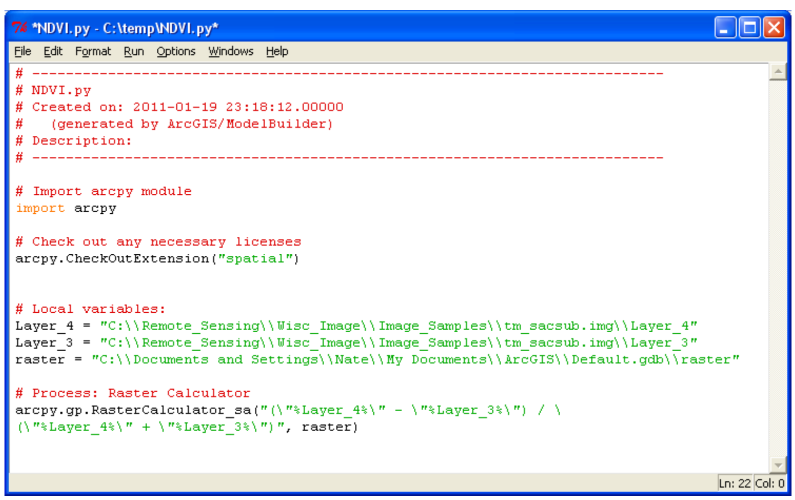


Figure 18 Image Processing Scripts

Overview of ArcGIS

ArcGIS will briefly be introduced as the software that will be used in this Remote Sensing course. The current version of ArcGIS 10.1 will be used. Older versions of ArcGIS can be used, but not all of the functionality for performing the image processing tasks in this course may be available.

As a student you should already be familiar with the basics of ArcGIS that were acquired in other foundational geospatial technology courses. Students are encouraged to review these courses and materials to gain a functional background with using ArcGIS and its components.

Major Components of ArcGIS

ArcGIS software has three major components.

ArcMap

ArcMap provides the ability to perform map design, data processing, and data analysis work and is where analysts will spend most of their time interacting and interpreting data.

ArcToolbox

The ArcToolbox provides the "geoprocessing" ability to perform image and vector based geographic analysis. Analysts run specific tools from the toolbox to carry out the image processing. ArcToolbox can process a multitude of raster, vector, and tabular data.

ArcCatalog

ArcCatalog is the explorer for spatial data. ArcCatalog is set up similar to the Windows Explorer, but is tailored for creating and managing spatial data sets. In many cases analysts will create new data sets, copy and paste data from one file location to another, and view properties of data sets through ArcCatalog.

ArcMap and ArcToolbox

Data can be loaded into the viewing window so the analyst can see the specific spatial data. Located on the right side of the viewing window is the table of contents that the analyst can use to turn on or off data as well as change colors, labels, and image band combinations. See the tab at the lower left named Table of Contents.

In addition, some tools may appear on top of the viewing window where the analyst can interact with the tool to change parameters or options for the image or data set.

Figure 19 shows the ArcToolbox. The list of tools is shown on the left side of the viewing window. The ArcToolbox can be "docked" in any location within ArcMap and can also appear as a vertical tab that can often be found on the right side of ArcMap. Toolboxes can open ToolSets and ultimately Tools that the analyst will add the parameters to perform image processing.

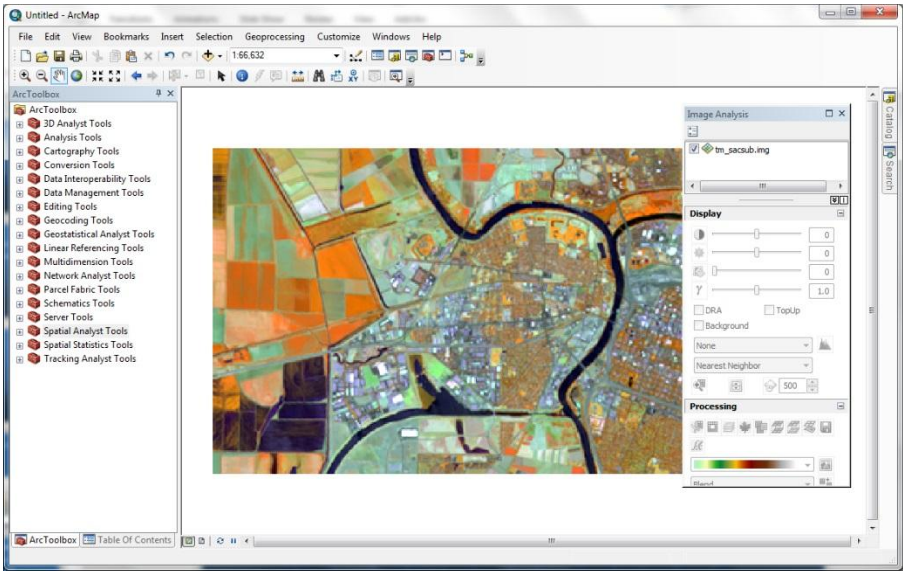


Figure 19 Screenshot of ArcToolbox

ArcCatalog

Figure 20 is an ArcCatalog, notice how it is organized by a number of folders that contain different kinds of spatial data sets. ArcCatalog requires "Data Connections" to be made so that the contents within the folders can be accessed. As can be seen in this image, the analyst can click on a folder and see the contents within it. The right side of ArcCatalog provides some basic details of the data types and formats. Analyst can also "right-click" the mouse and review other properties of the data sets.

In addition, the analyst can click on the ***Preview Tab*** to see an overview of the spatial data as well as preview the tabular data behind the geographic data. The analyst can also click on the ***Details Tab*** that will show the "metadata" about the data set. The metadata can provide useful information such as a short abstract summary of the data, who created the data, how it was compiled, the spatial reference of the data, when it was updated, and restrictions of use.

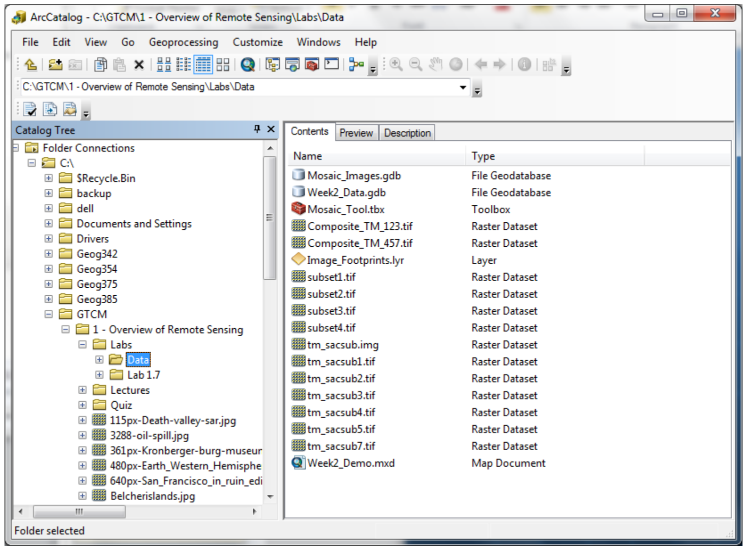


Figure 20 Screenshot of ArcCatalog

ArcGIS Overview

In this course a number of components of ArcGIS will be used to perform various kinds of image processing functions. The Image Analyst Window will be used to perform some of the preprocessing functions such as image subsets, mosaics, image composition from individual sensor bands, etc. The way to access the Image Analysis Window is through the Window menu option on ArcGIS, then click Image Analysis. The window shown on the right side of the viewing window will appear. The toolbars can be activated by right-clicking in the toolbar area towards the top of ArcGIS. In order for the 3D and Spatial Analyst toolbars and toolboxes to function, the extension must be turned on and can be done by clicking on Customize—Extensions. Remember, the extensions must be purchased and installed in order for ArcGIS to allow this functionality. The extensions must also be activated separately in both ArcMap and ArcCatalog. Other lessons in this course will provide more details on using some of the tools within each of these toolbars or toolboxes.

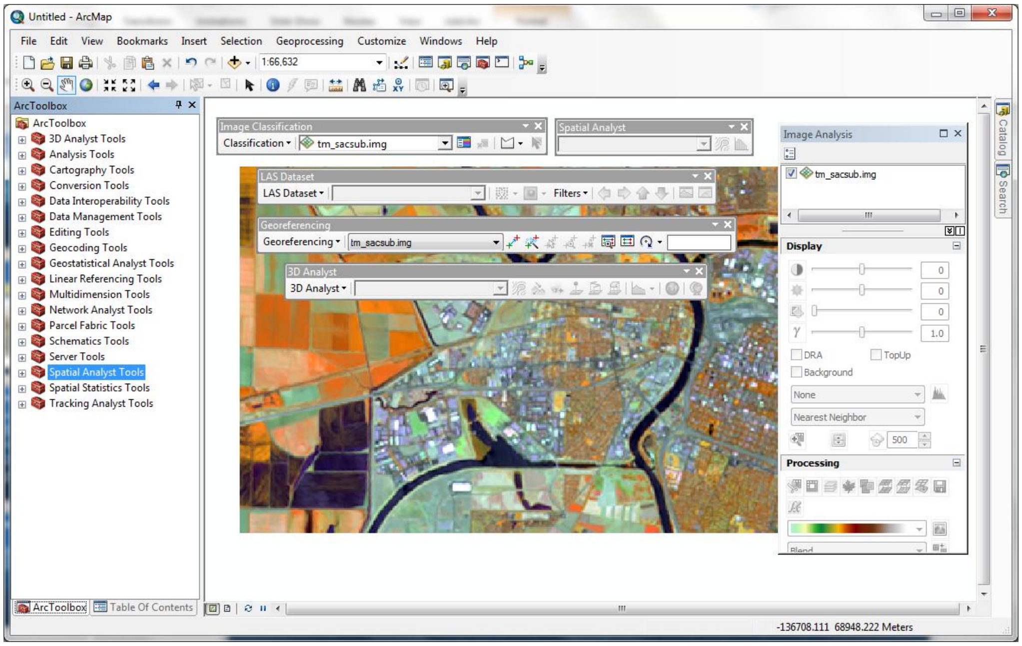


Figure 21 ArcGIS: Screenshot of Arc Toolbox - Using Spatial Analyst Tools

ArcGIS Extensions

In addition, a couple of ArcGIS Extensions will be used:

***Spatial Analyst**– the spatial analyst extension will be used to perform some of the image processing functions such as image classification, map algebra, and some raster modeling processes such as creating digital elevation models and slope and aspect layers

***3D Analyst** – the 3D Analyst extension will be used to perform operations on elevation data such as LiDAR.

NOTE: The asterisk indicates that these extensions will require an additional purchase to the ArcGIS software.

Toolbars and ArcToolboxes

A number of Toolbars and ArcToolboxes will also be used. Some of them are shown here.

- **Image Classification Toolbar** provides the ability to generate semi-automated and automated land cover or land use data sets.
- **3D Analyst Toolbar and tools** provides some tools for processing LiDAR and other terrain data.
- **LAS Dataset** is a toolbar and toolset that allows for some additional LiDAR data processing
- **Georeferencing Toolbar** provides the ability to perform image rectification
- **Spatial Analyst** is a toolbar and toolbox that allows for a variety of image processing and raster modeling tasks.

SUMMARY

In this lesson you learned about the various types of remotely sensed data and remote sensor systems used in remote sensing. The information helped you understand the uses of remote sensing such as monitoring cropland, forests for fires, wetlands, and floods. You learned about the history of remote sensing as well as where the industry is today and where it is going in the future. This lesson provided information on the elements and strategies of visual interpretation and digital image processing. An overview of ArcGIS was included in this lesson to help you gain a better understanding this software used for remote sensing.

ASSIGNMENTS

1. Application Paper
2. Quiz

Authoring Organization: Del Mar College
Written by: Nate Jennings

Authoring Organization: Del Mar College
Written by: Nate Jennings

Development was funded by the Department of Labor (DOL) Trade Adjustment Assistance Community College and Career Training (TAACCCT) Grant No. TC-22525-11-60-A-48; The National Information Security, Geospatial Technologies Consortium (NISGTC) is an entity of Collin College of Texas, Bellevue College of Washington, Bunker Hill Community College of Massachusetts, Del Mar College of Texas, Moraine Valley Community College of Illinois, Rio Salado College of Arizona, and Salt Lake Community College of Utah.

This workforce solution was funded by a grant awarded by the U.S. Department of Labor's Employment and Training Administration. The solution was created by the grantee and does not necessarily reflect the official position of the U.S. Department of Labor. The Department of Labor makes no guarantees, warranties or assurances of any kind, express or implied, with respect to such information, including any information on linked sites, and including, but not limited to accuracy of the information or its completeness, timeliness, usefulness, adequacy, continued availability or ownership.

Lesson 2: Physical Foundations

INTRODUCTION

In this lesson you will learn about physical principles of remote sensing and how sensors collect and record data. Electromagnetic spectrum and wavelengths are explained to help you understand how sensors detect reflected data. Transmission, absorption, and reflection are concepts of energy that are defined and exhibited in the content. You will also learn about passive sensors, optical and satellite sensors and active sensors such as RADAR and LIDAR.

LESSON OBJECTIVES

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

1. Describe the basic physical concepts on which remote sensing are based such as the electromagnetic spectrum, reflection and absorption.

2. Explain the physical differences between active and passive remote sensing systems.

LEARNING SEQUENCE

Required Reading	Read the following: • Online Lesson Material
Resources	Review the following: • None
Assignments	Complete the following: • Quiz

INSTRUCTION

Physical Principles of Remote Sensing

Before jumping into specific sensors and digital image processing, this lesson focuses on the physical principles of remote sensing and how sensors collect and record data. Most of the remote sensors that will be used in this course will detect reflected energy from the Earth that originates from the Sun. Some sensors such as RADAR and LiDAR provide their own energy source.

Figure 1 illustrates how some of the energy from the sun is scattered or absorbed by the atmosphere. The energy that reaches the Earth’s surface will have interactions with the objects it hits. In some cases the energy is absorbed by the vegetation, ground, or water. In other cases energy is transmitted through the object and passes onto another object. In still other instances this energy is reflected back through the atmosphere of which some of the energy is absorbed. The rest will pass through the atmosphere and be recorded on the remote sensor's electronics.

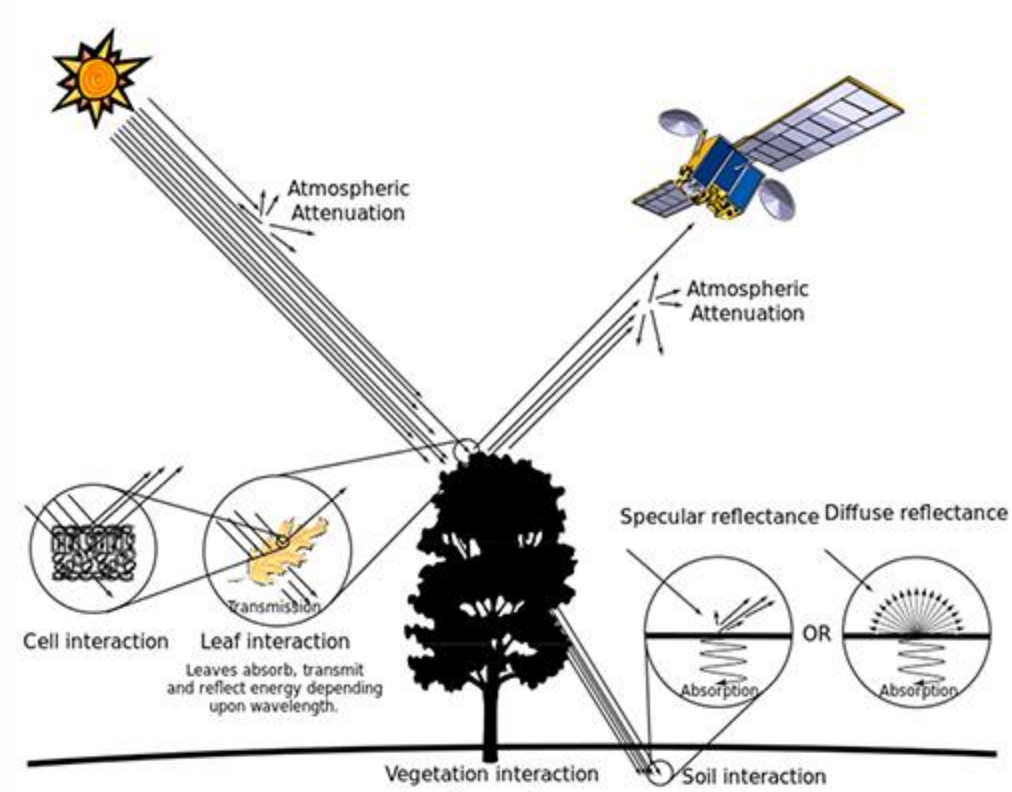


Figure 1 Sun Energy

Energy, Photons, and Wavelength

When talking about energy from the Sun, photons are quantities of energy that move at the speed of light. A relationship exists between the frequency and wavelength of a photon and the speed of light.

The equation shown indicates that the speed of light is a combination of the specific wavelength of light and its frequency.

Speed of Light = *Frequency of photon X wavelength of photon*

The next equation shows that by arranging the first equation, wavelength can be measured by taking the speed of light and dividing it by its frequency. Since the speed of light is a constant value of 300,000 km/hr (or 186,000 mi/hr) different kinds of light energy can be measured by its wavelength.

Wavelength = Speed of Light

Electromagnetic Waves

The energy that hits the Earth is considered electromagnetic radiation because the energy consists of two components of both electrical and magnetic waves. These different wave patterns form when an electron accelerates at a certain frequency. For a given wavelength of light, the frequency is the number of wave crests that pass the same point in one second. Because there is a continuum of electromagnetic radiation, different kinds of electromagnetic waves have different frequencies.

Electromagnetic waves that have higher energy states will have shorter wavelengths and higher frequencies. Electromagnetic waves that have lower states of energy will have longer wavelengths and shorter frequencies. For example, X-rays such as those that humans are exposed to when they are at the dentist or doctor's office have shorter wavelengths. Radio waves, on the other hand, have longer wavelengths and provide the means for us humans to listen to the radio.

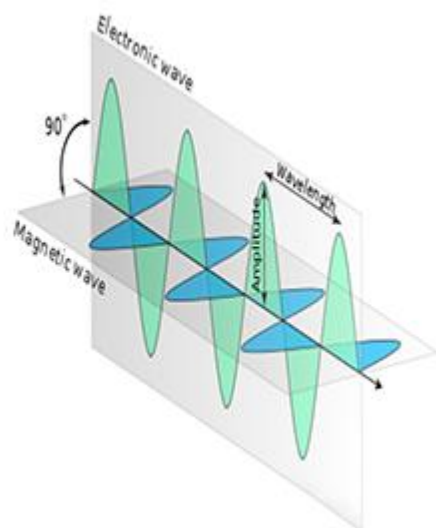


Figure 2 Electromagnetic Waves

Electromagnetic Spectrum

Figure 3 is a graph of the electromagnetic spectrum, the continuum of electromagnetic radiation. The portions of the electromagnetic spectrum highlighted are those that are detected by many of the remote sensors that will be discussed in this course.

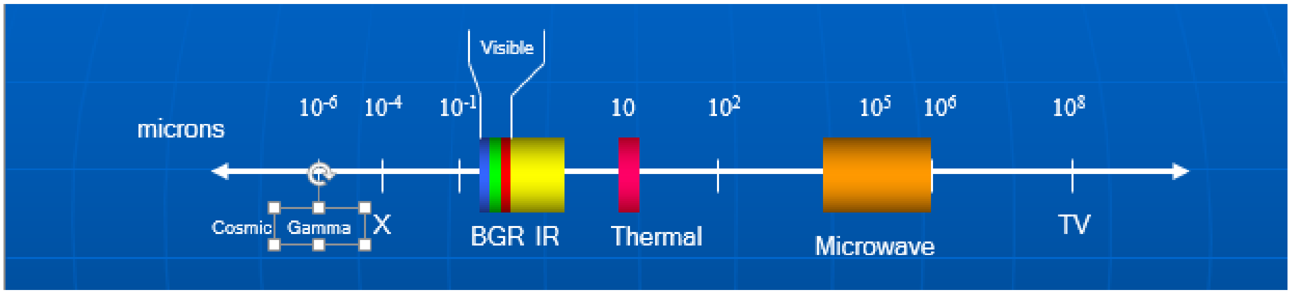


Figure 3 Electromagnetic Spectrum

The true color portion of the spectrum is detected and makes it convenient for humans to relate to the information being detected by the sensor.

In addition, a larger range of Infrared radiation is also detected. Although the human eye is not capable of "sensing" this part of the electromagnetic spectrum, it is very import to remote sensing, since much of the valuable information content can be sensed and recorded on remote sensor devices.

The microwave portion of the electromagnetic spectrum is indicated which ranges from approximately 1 centimeter to 1 meter. RADAR sensors operate in this portion of the spectrum.

When analyzing and processing remotely sensed imagery, it is important to know which wavelengths the remote sensor is able to detect and record.

The wavelengths for the respective portions of the electromagnetic spectrum shown in the graph are noted on the slide. The unit of measure for these wavelengths is either nanometers or microns (also known as micrometers).

- Blue is 0.4 to 0.5 microns (or 400 to 500 nanometers)
- Green is 0.5 to 0.6 microns (or 500 to 600 nanometers)
- Red is 0.6 to 0.7 microns (or 600 to 700 nanometers)
- Near Infrared is 0.7 to 0.9 microns (or 700 to 900 nanometers)

Depending on the sensor, other portions of the infrared part of the electromagnetic spectrum will be detected at approximately 1.6-1.8 microns and at approximately 2.1 to 2.4 microns. These sections of the electromagnetic spectrum are sometimes referred to the short wave infrared.

On some remote sensors, such as Landsat, the wavelengths between 8 and 14 microns are detected and recorded. This section of the electromagnetic spectrum represents the thermal wavelengths. This section is sometimes called the "heat" band(s), since these wavelengths represent objects that emit thermal radiation such as cooling towers at power plants. Some handheld thermal sensors can pick up body heat.

Transmission, Absorption and Reflectivity

The previous segment introduced electromagnetic radiation, the electromagnetic spectrum, and wavelengths. This section will extend this discussion by showing how these sensors are capable of detecting these wavelengths.

- Specific remote sensors are tuned to specific portions of the electromagnetic spectrum. This allows data to be collected and the imagery created from these sensors will provide useful information to remote sensing analysts who need to study earth phenomena across different geographical extents.
- Since satellite-based remote sensors orbit the earth above the Earth's atmosphere, not all wavelengths can be detected by the system.
- Electromagnetic radiation can be transmitted, absorbed, or reflected. The brown section of the figure provided indicates that energy passing through the atmosphere cannot easily be detected by a space or airborne remote sensors. In these cases the atmosphere may absorb or scatter energy and thus not being detected by the sensor.
- The portions of the spectrum that have a small atmospheric opacity influence indicate that most of these wavelengths will make it to the Earth's surface and back to the remote sensor and not be too affected by the Earth's atmosphere.

Transmission, Absorption, and Reflection

Atmosphere allows for electromagnetic radiation to be transmitted, absorbed, or reflected. Please review the definitions and the example image provided.

Transmission

Transmission indicates that energy from the sun will pass through the atmosphere and in some cases will pass through the object being sensed (such as leaves).

Absorption

Absorption refers to energy that is absorbed by the object and may be transformed into another form of energy (such as heat or chemical energy. For example the Sun's energy is absorbed by plant material and converted into chemical energy when photosynthesis occurs).

Reflection

Reflected energy occurs when the energy from the sun (or sensor) hits an object and is returned to the sensor. Energy can be reflected from atmospheric gases or dust particles, but the energy that is reflected from the Earth's surface and actually hits the remote sensor is recorded. This recorded reflected energy ultimately is stored in pixels (picture elements) that make up the digital image. The human eye detects electromagnetic radiation in the blue, green, and red part of the spectrum. Many remote sensors do this too, but they are also capable of recording reflected energy that our eyes cannot see such as the infrared part of the electromagnetic spectrum. Being able to detect the infrared part of the electromagnetic spectrum is important to many remote sensing applications.

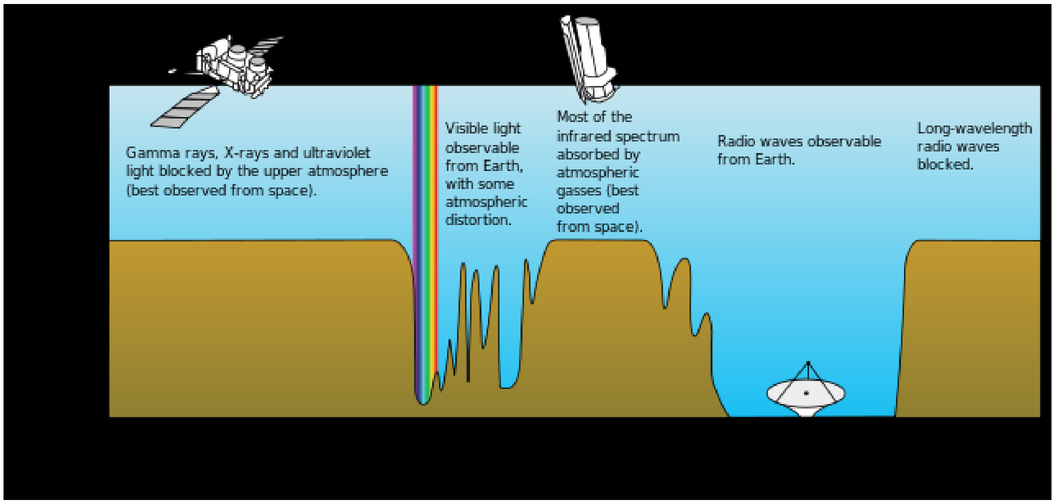


Figure 4 Illustration: Reflection as described in the above paragraph

Material Reflectivity and Wavelengths

Figure 5 is an example of an electromagnetic spectrum that includes the range from the true color (Blue, Green, and Red) to the infrared portion near 2.4 microns.

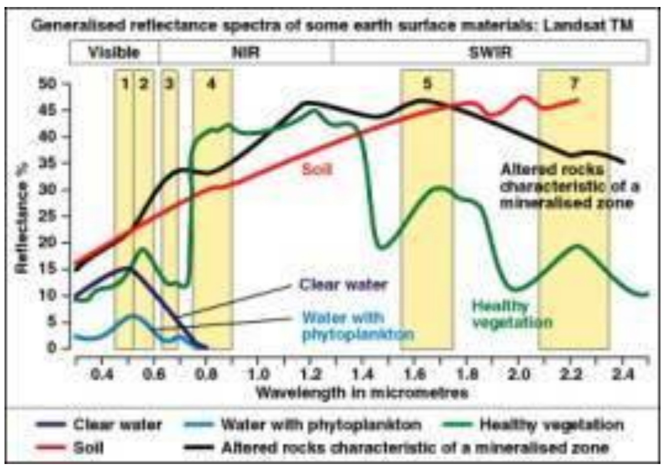


Figure 5 Electromagnetic Spectrum with True Color

- The yellow vertical bars represent the wavelength sensitivity of the Landsat Thematic Mapper satellite. The numbers represent the individual band numbers on the sensor. You will note that bands 1, 2, and 3 refer to the Blue, Green, and Red part of the electromagnetic spectrum. Bands 4, 5, and 7 represent different portions of the infrared part of the spectrum. Band 6 is not shown, but refers to the thermal portion of the spectrum which is beyond the extent of this graph.
- The vertical axis represents the percent reflectance. The different colored curves represent different general land cover types.
- Note the blue curves represent water and for the most part, water is not very reflective. There is a peak between the blue and green wavelengths and this

contributes to the color we often see in true color aerial photos or satellite imagery. Note that in the infrared part of the electromagnetic spectrum that there is almost no reflectance. This is because the infrared energy is absorbed by water.

- Now look at the green curve. This curve represents healthy green vegetation. Note that in the true color part of the spectrum that healthy green vegetation is only a little more reflective than water. There is a peak in the green wavelength and we expect this in true color imagery, since healthy green vegetation is "green."
- In the different portions of the infrared wavelengths there is a dramatic change in the percent reflectance of energy. Note that in the near infrared part of the spectrum that healthy green vegetation has a very high curve which indicates that healthy green vegetation is highly reflective in near infrared wavelengths. In the green wavelengths, healthy green vegetation is approximately 20% reflective. In the near infrared wavelengths, the same healthy green vegetation is approximately 40-45% reflective.
- In addition, healthy green vegetation has a couple of other portions of the electromagnetic spectrum where it has higher reflectivity than the green wavelength. Note that with the Landsat satellite these portions of the electromagnetic spectrum can detect this reflected energy.
- The red curve on the graph represents the reflectivity of soil. In the true color part of the spectrum soil is a little more reflective than healthy green vegetation and has a positive reflectance trend from the blue, to green, to red wavelengths. As we look at the infrared portions of the electromagnetic spectrum, soil continues this upward trend. Soil surpasses the percent reflectance in the shortwave portions of the spectrum.
- The black curve on the graph shows the reflectance curve of rocks. Rocks have a similar reflectance pattern as soil for the blue wavelength and then have a higher percent reflectance for the green and red wavelengths. This trend extends into the near and shortwave infrared portions of the electromagnetic spectrum.

Overall, it is clear that the infrared wavelengths provide a much richer source of reflected energy for different kinds of land cover types than the true color portions of the spectrum. This will become apparent when developing processes and sample areas for land cover classification activities and feature identification tasks.

Regarding vegetation, healthy green vegetation has lower reflectance in the true color portions of the spectrum, but much higher reflectance in the infrared portion of the spectrum. Water has relatively low reflectance and tends to absorb almost all of the infrared wavelengths. For vegetation analysis, infrared wavelengths are important and will assist the image analyst to identify and discriminate different vegetation cover types that have similar reflectance values and curves in the true color part of the electromagnetic spectrum.

Spectral Response of Subalpine Fir

Figure 6 is of the spectral response across the true color and near infrared portions of the electromagnetic spectrum for subalpine fir. The green line indicates the spectral response for a non-infested fir. The red curve indicates the spectral curve for fir trees that have been infested with a beetle.

It is important to note that for the true color portion of the electromagnetic spectrum that there is little difference between the spectral response for non-infested and infested trees. However, in the near infrared portion of the spectrum notice that the differences are much greater and so with a sensor that can record reflectance in the near infrared portion of the spectrum, there is a good chance that trees that are infested with the beetle can be detected and mapped across the forest. Knowing this, forest managers can make decisions on the types of treatments to apply to the forest to manage or eradicate the beetle infestation.

This ability for remote sensors to discriminate vegetation differences in the infrared portions of the electromagnetic spectrum is very important for many natural resource management applications.

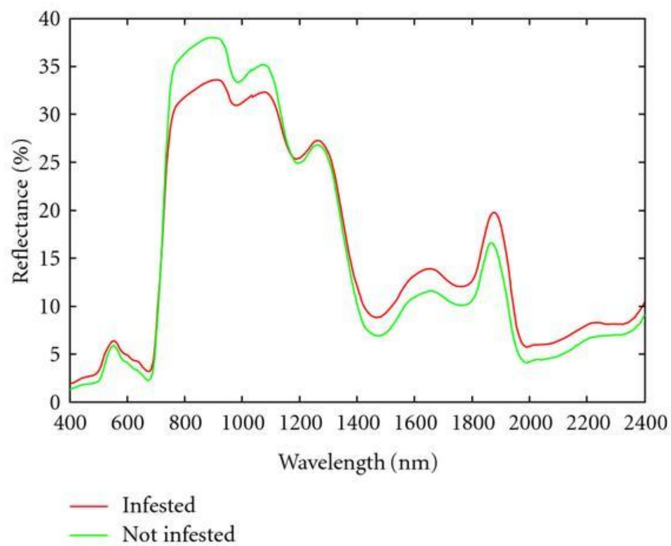


Figure 6 Spectral Response of Subalpine Fir

Passive and Active Sensors

The section on Physical Foundations showed that the primary source of energy for remote sensing comes from the sun. In greater detail, passive and active sensors are defined.

Passive Sensors

A sensor that images this reflected energy is considered to be passive. Passive sensors include all of the optical aerial and satellite sensors. Optical sensors refers to those that contain lenses that help resolve the features at are being sensed.

Active Sensors

Another kind of sensor that is used for remote sensing is considered active. Active sensors are those that have an energy source on board the instrument. RADAR and LiDAR are active sensors.

- RADAR emits radio wave from the sensor to sense objects on the ground
- LiDAR emits a fast moving laser beam from the sensor to capture information about elevation and heights of objects

RADAR and LiDAR will be discussed in more detail in the lesson, *Sensor Platforms, Image Processing Basics, Band Ratios, and Transformations*.

Figure 7 illustrates the differences between Passive Sensor (e.g. Landsat) vs. Active Sensor (e.g. RADARSAT): The illustration on the left shows the Sun's energy reflecting off of objects and getting recorded on the remote sensor. Some of the sun's energy is reflected or absorbed by the Earth's atmosphere. The illustration on the right shows an active RADAR sensor that emits radio waves that hit objects on the ground. The energy is reflected back to the sensor and recorded. RADAR waves are capable of passing through the Earth's atmosphere and so can collect information when it is cloudy or when it is dark.

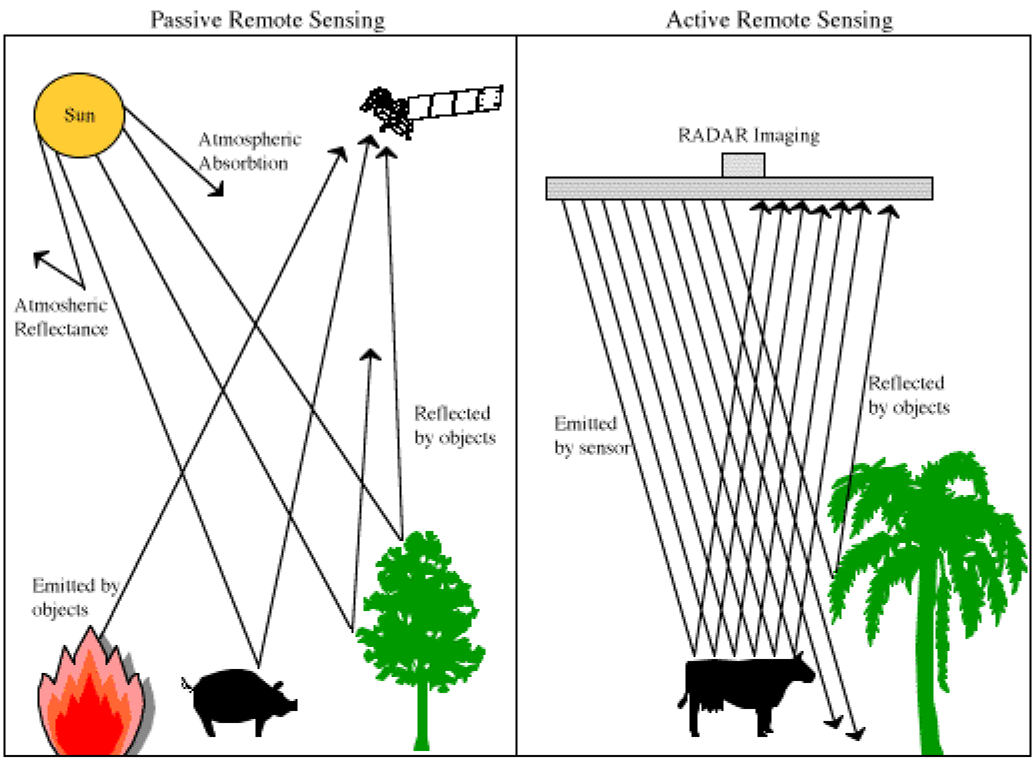


Figure 7 Passive Sensor (e.g. Landsat) vs. Active Sensor (e.g. RADARSAT)

SUMMARY

In this lesson you learned about physical foundations. Electromagnetic spectrum and wavelengths were explained to help you understand how sensors detect reflected data. Transmission, absorption, and reflection are concepts of energy that were defined and exhibited in the content. You also learned about passive sensors, optical and satellite sensors, and active sensors such as RADAR and LIDAR.

ASSIGNMENTS

1. Quiz

Authoring Organization: Del Mar College
Written by: Nate Jennings

Development was funded by the Department of Labor (DOL) Trade Adjustment Assistance Community College and Career Training (TAACCCT) Grant No. TC-22525-11-60-A-48; The National Information Security, Geospatial Technologies Consortium (NISGTC) is an entity of Collin College of Texas, Bellevue College of Washington, Bunker Hill Community College of Massachusetts, Del Mar College of Texas, Moraine Valley Community College of Illinois, Rio Salado College of Arizona, and Salt Lake Community College of Utah.

Lesson 3: Sensor Platforms and Image Processing Basics

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: • Online Lesson Material
Resources	Review the following: • None
Assignments	Complete the following: • Quiz • Lab: Image Composite, Mosaic, Subset • Exam

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.

Figure 1 True Color Aerial

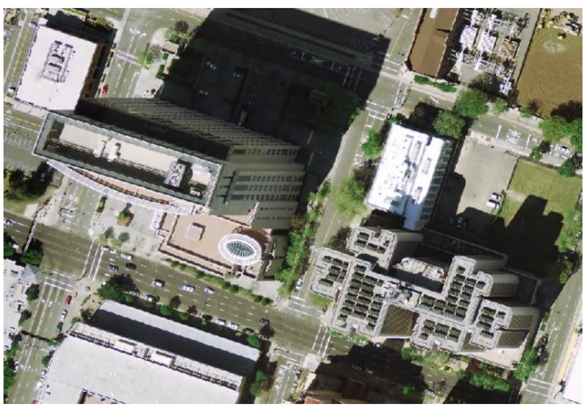


Figure 2 Orthophoto

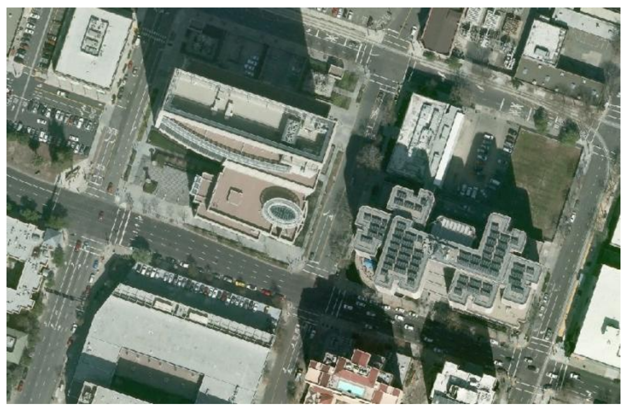


Figure 3 “True” Orthophoto

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.

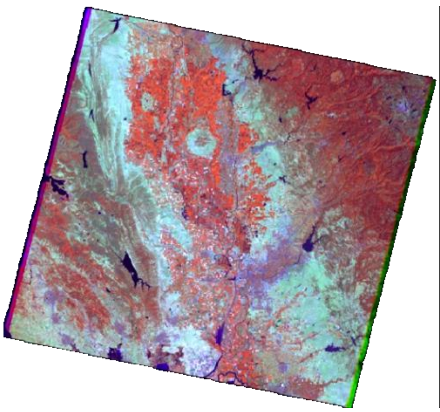


Figure 4 Landsat: Central Valley, CA

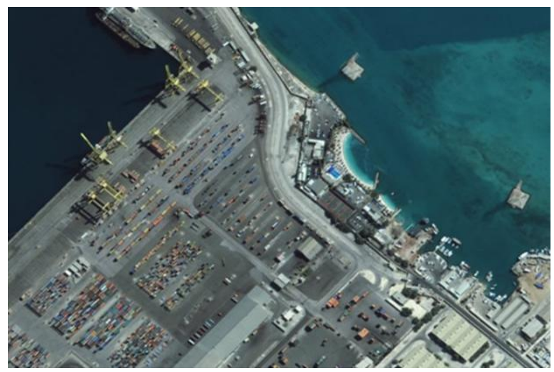


Figure 5 Port of Abu Dhabi in the United Arab Emirates (Image taken by QuickBird satellite)

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.

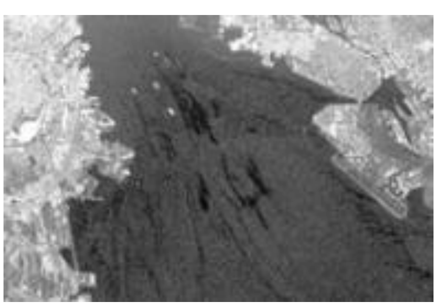


Figure 6 Canadian RADARSAT satellite

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.

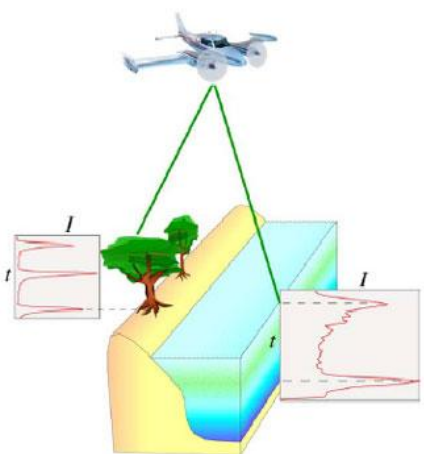


Figure 8 Airplane Carrying a LiDAR Sensor

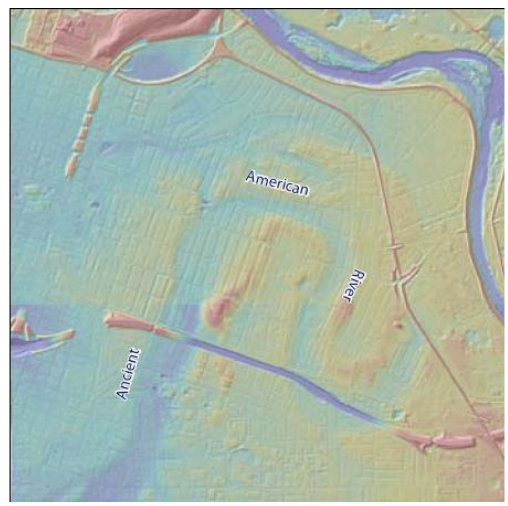


Figure 9 High Resolution Digital Model

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.

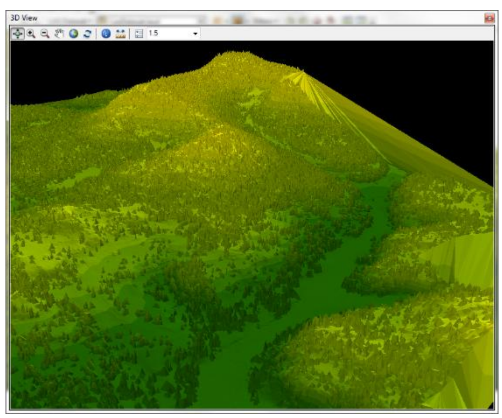


Figure 11 3D Perspective View of Elevation Data

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.

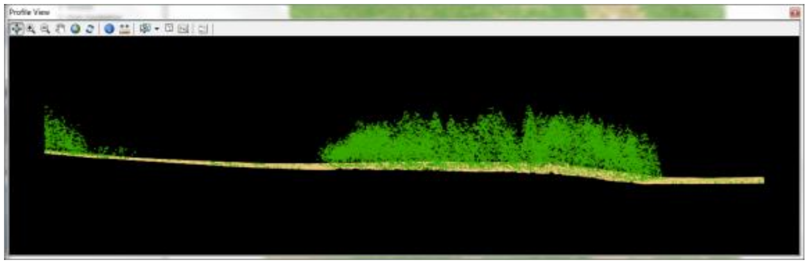


Figure 12 Profile View of a 3D Perspective View of Elevation Data

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.

Figure 13 Hyperion satellite image

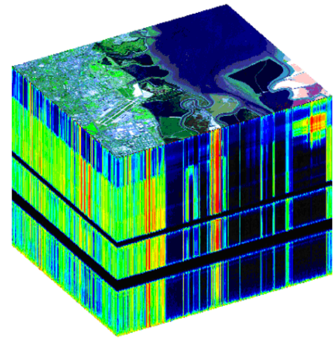


Figure 14 AVIRIS Hyperspectral Cube

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.

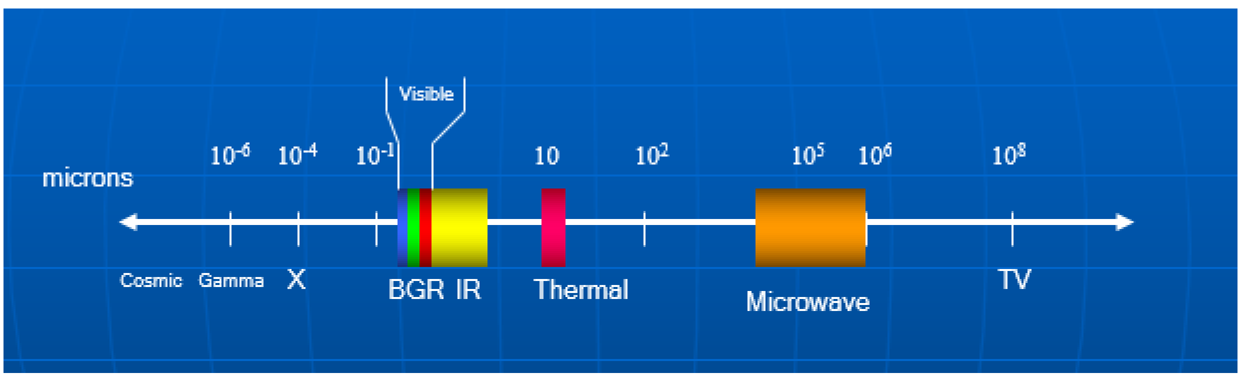


Figure 15 Electromagnetic Spectrum

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.

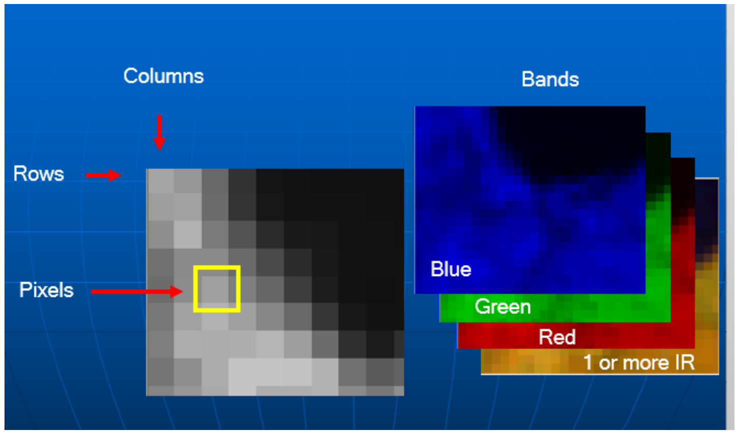


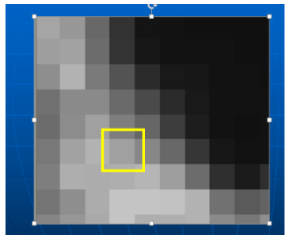
Figure 16 Composition of a Remotely Sensed Image

- 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^{th} 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^{th} and 2 to the 16^{th} have much larger brightness value ranges than 8 bit data.



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, discreet 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.

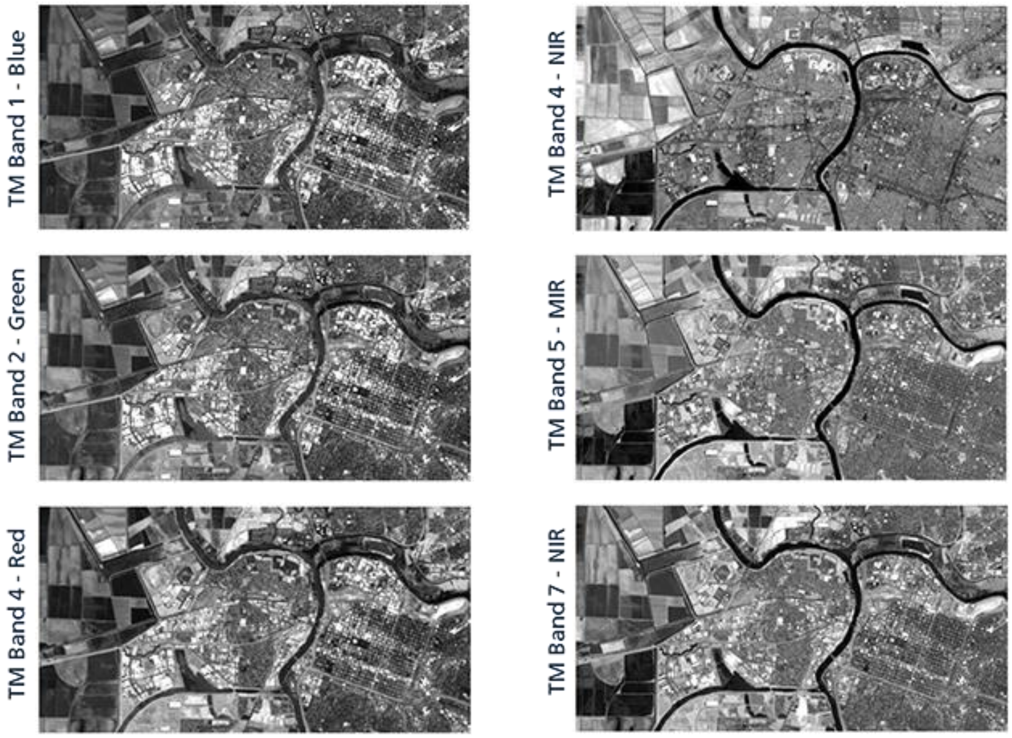


Figure 18 Six Landsat TM bands collected by the Landsat satellite

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.

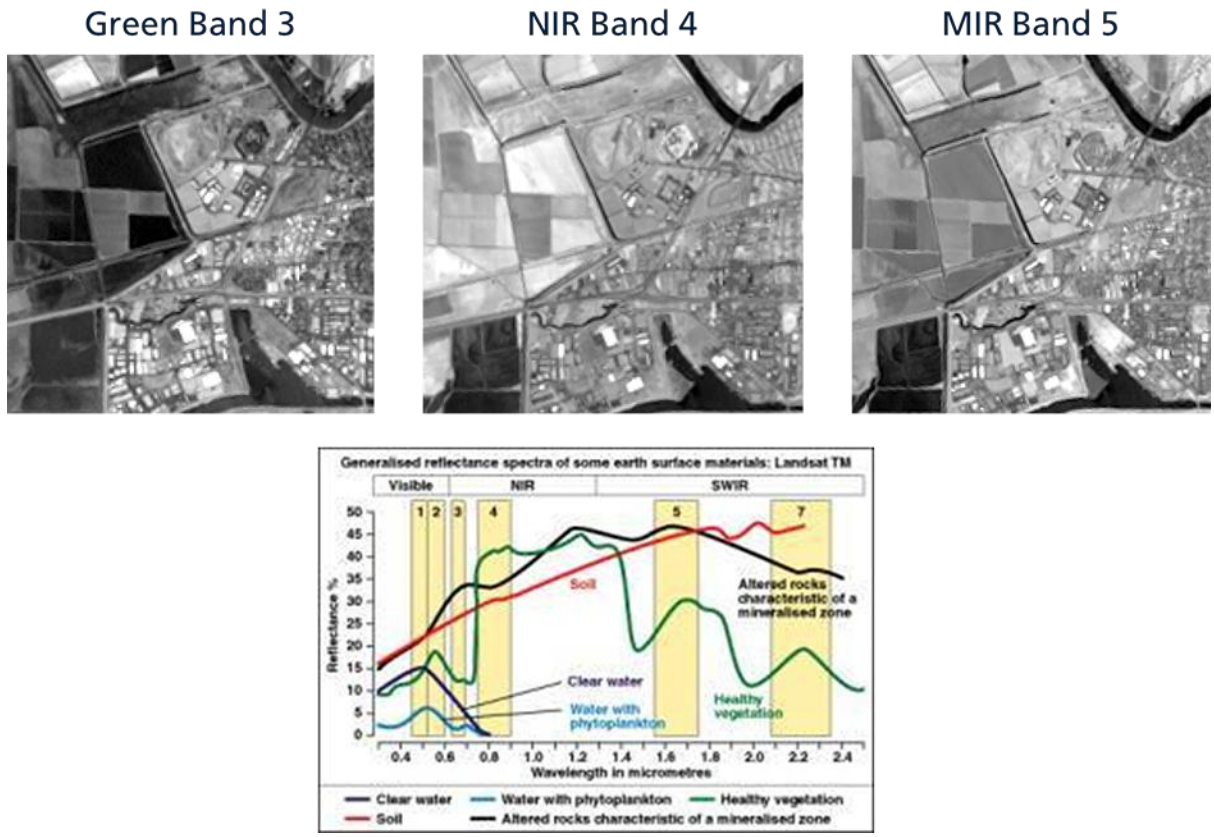


Figure 19 Illustration: Sensor Bands, Wavelengths, and Reflectance

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.

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.

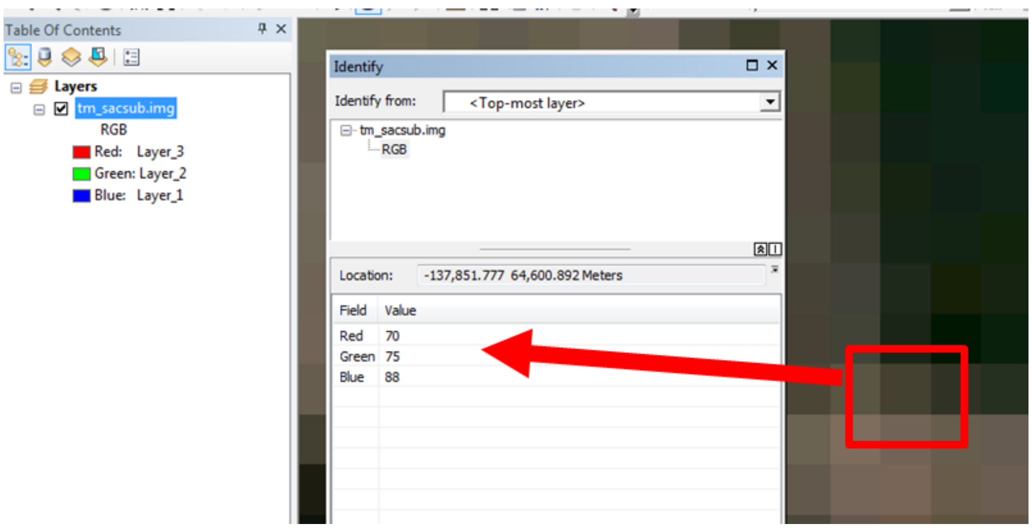


Figure 20 Specific Pixel Range

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.

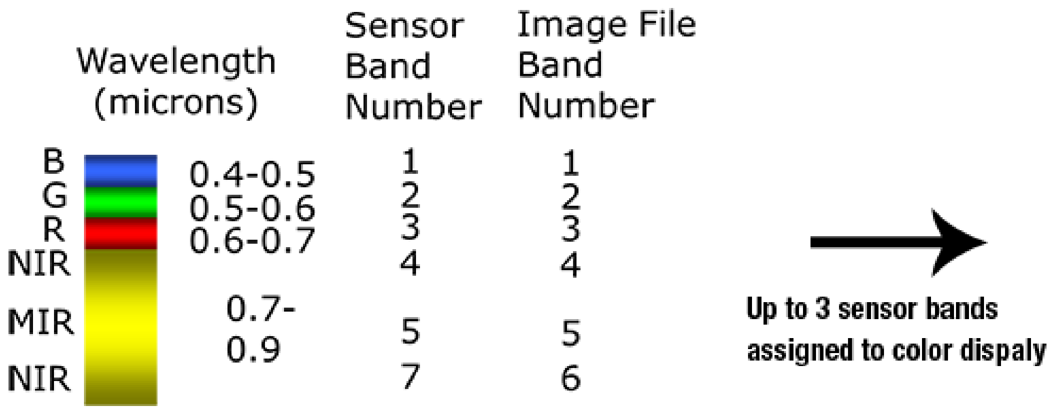


Figure 21 Wavelengths Chart

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 show on the image on the right of Figure 22.

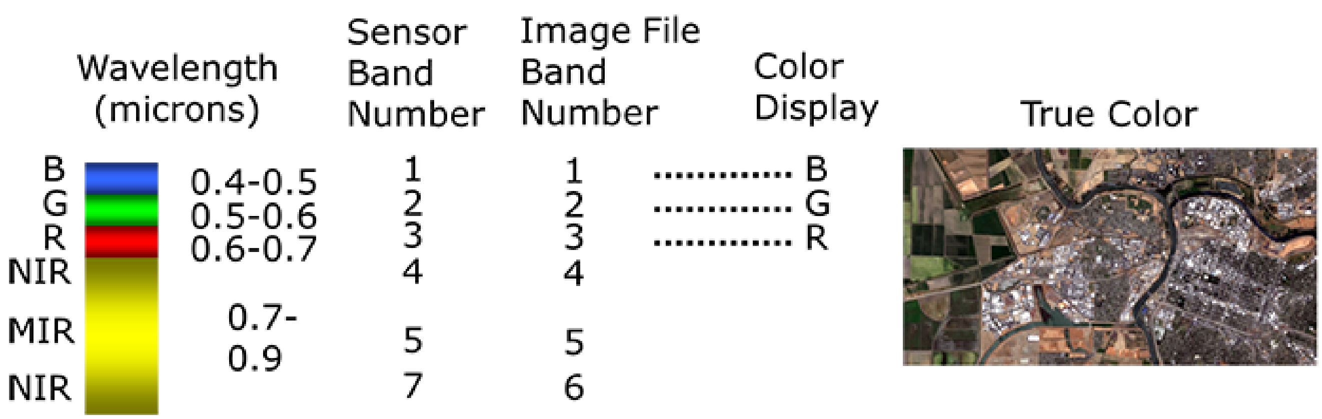


Figure 22 (Left) True Color Sensor Bands (Right) True Color

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.

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.

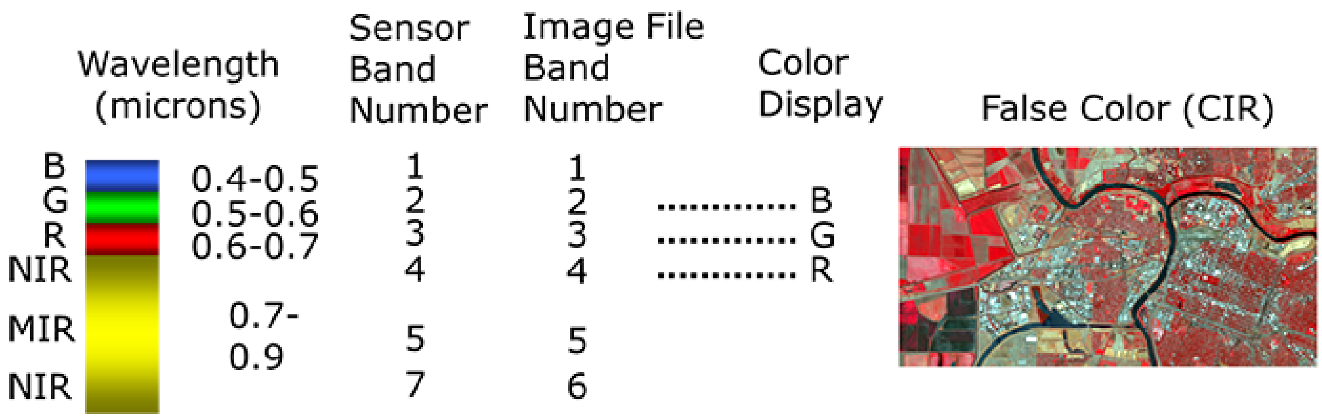


Figure 23 (Left) True Color Sensor Bands Chart (Right) False Color Infrared

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.

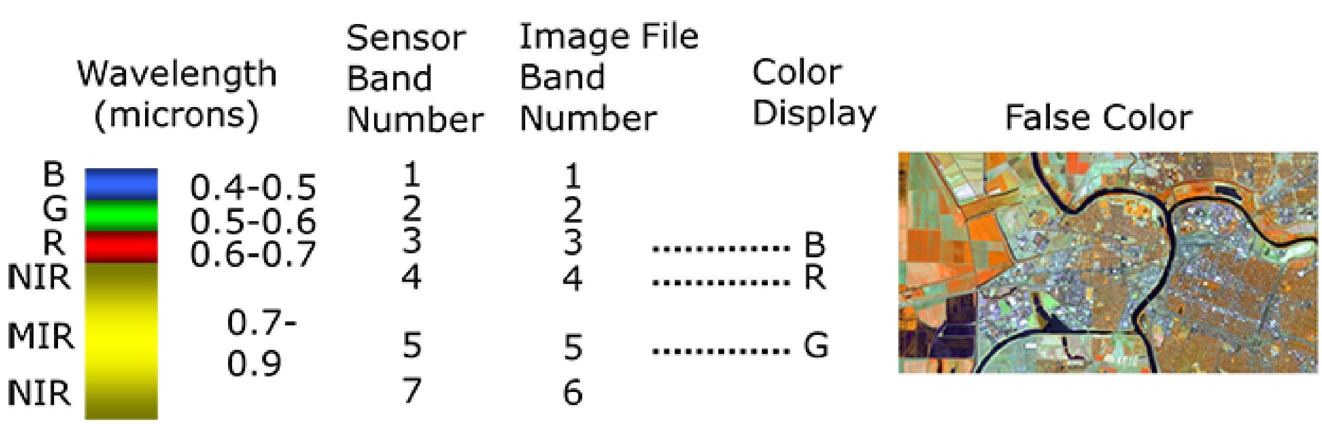


Figure 24 (Left) True Color Sensor Bands Chart (Right) False Color Red Sensor

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.

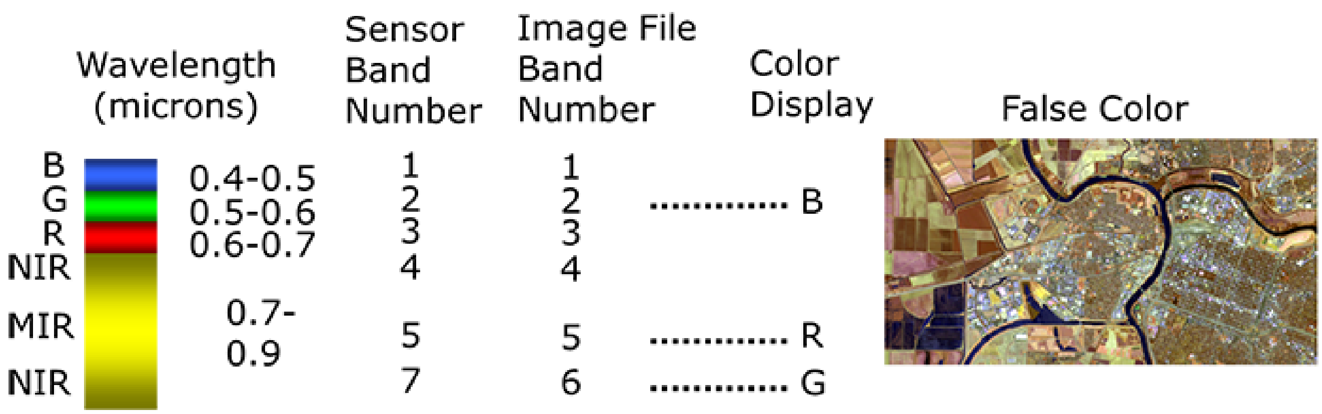


Figure 25 (Left) True Color Sensor Bands Chart (Right) False Color Green Sensor

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.

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

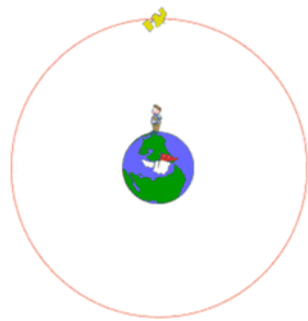


Figure 27 Geosynchronous Orbit

- **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

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.

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.

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 Stated 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

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.

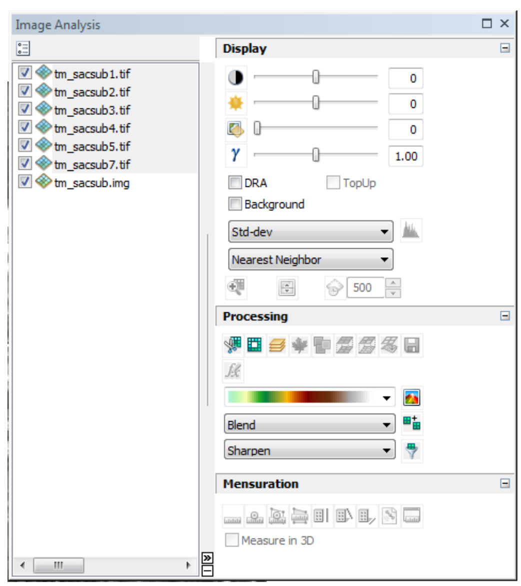


Figure 28 ArcGIS: Screenshot of Image Analysis Window

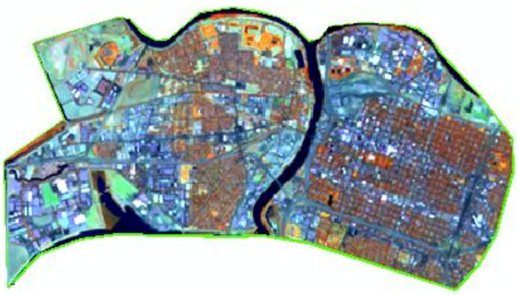


Figure 29 Pre-processing Step 1

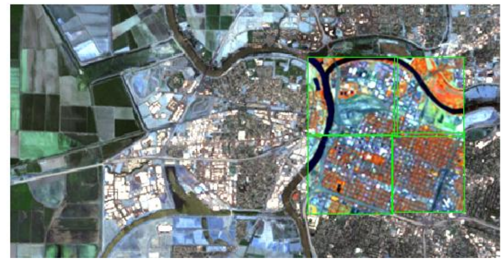


Figure 30 Pre-Processing Step 2

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.

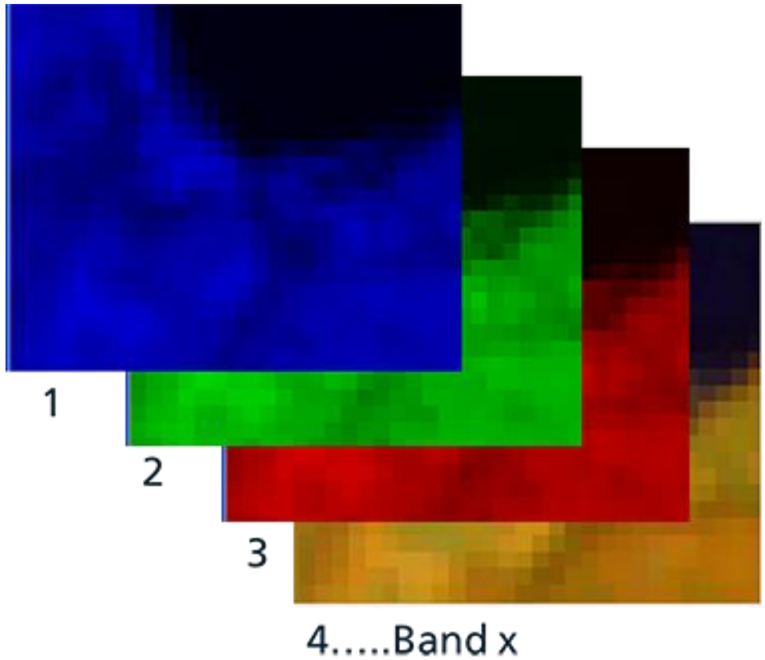


Figure 31 Individual Bands

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:

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

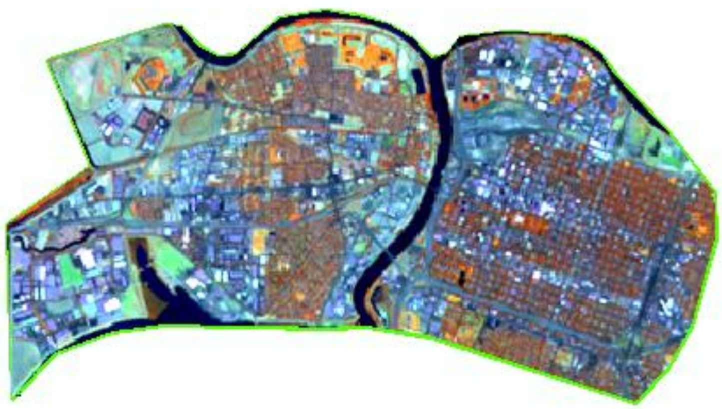


Figure 34 Image Subset

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.

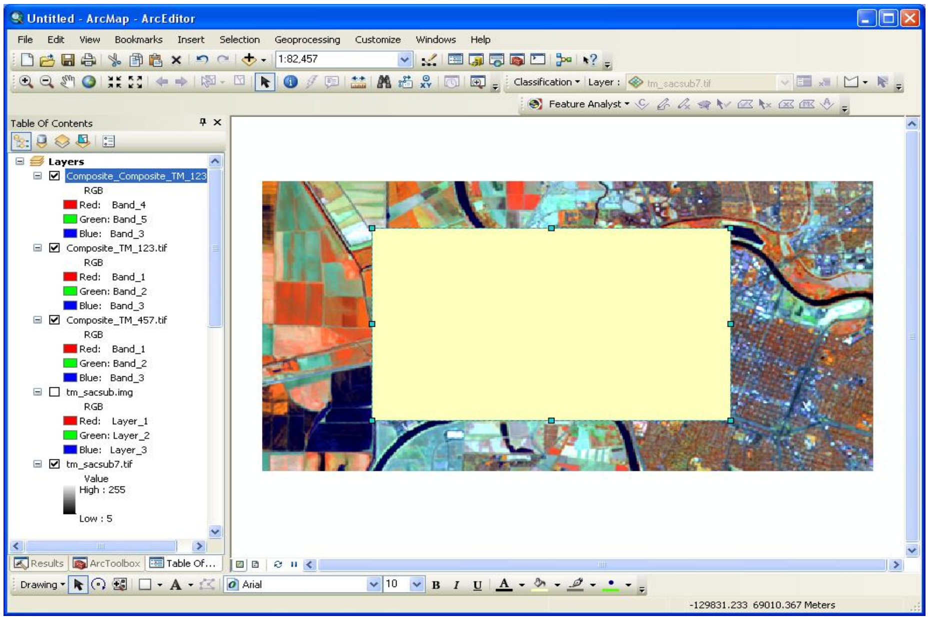


Figure 35 Image Analysis Window Example 1

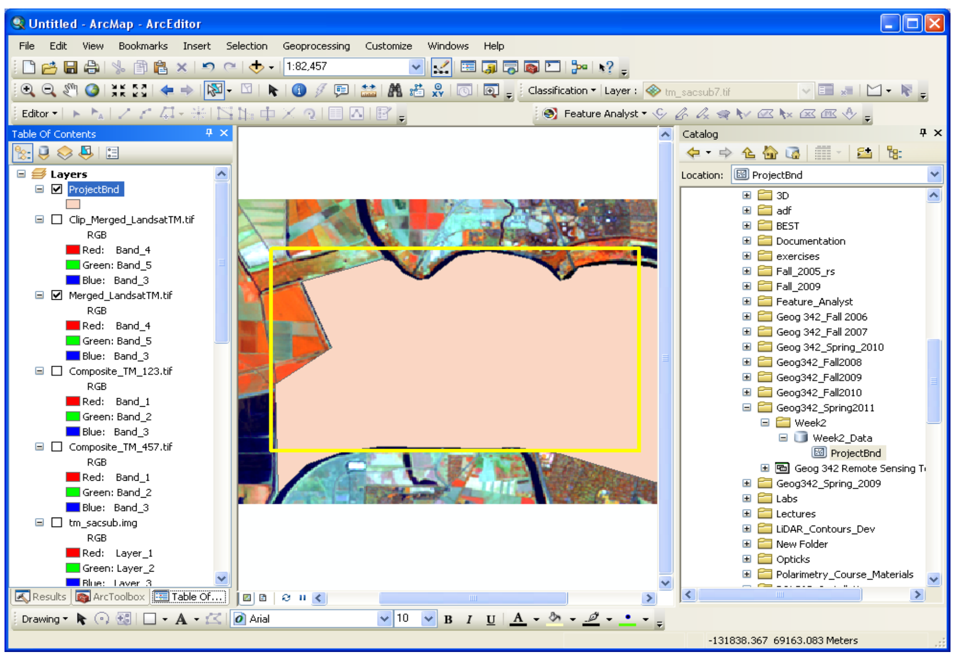


Figure 36 Image Analysis Window Example 2

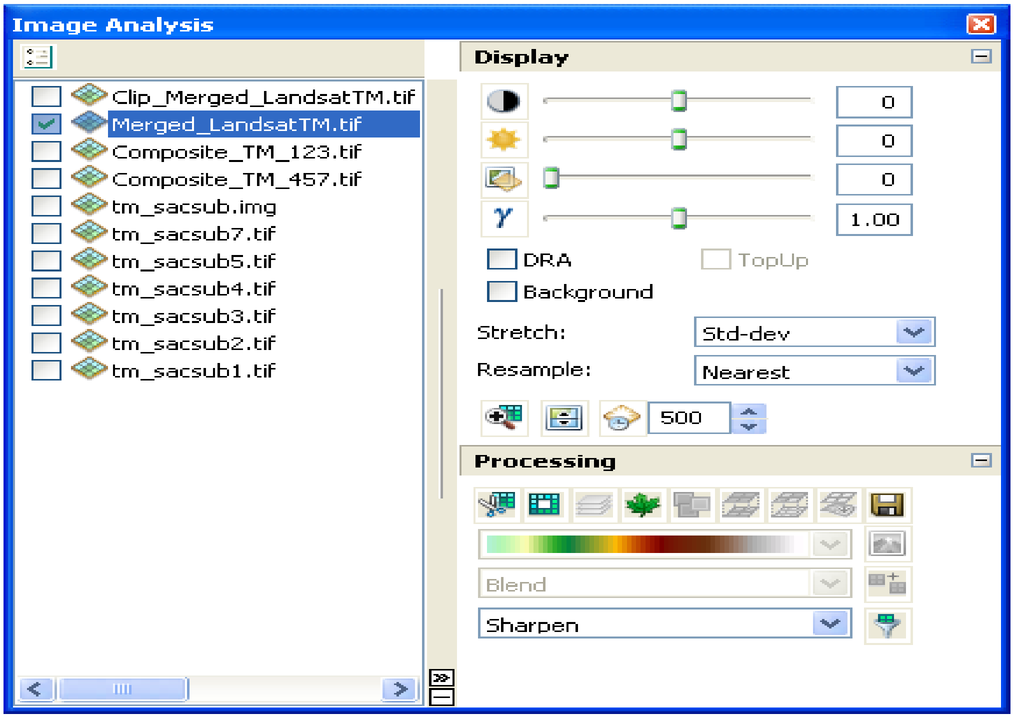


Figure 37 Image Analysis Window Example 3

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.

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

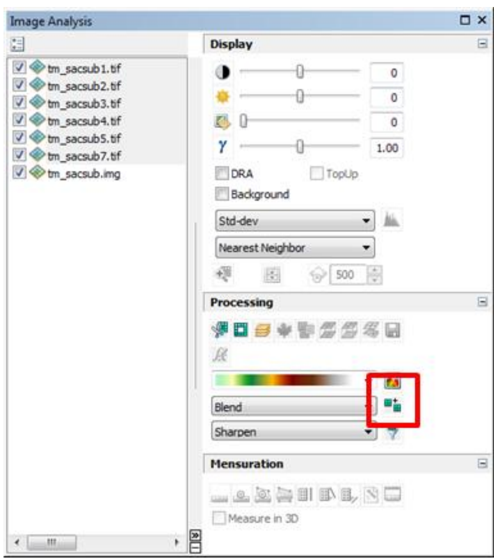


Figure 40 ArcGIS: Screenshot of Image Analysis Window

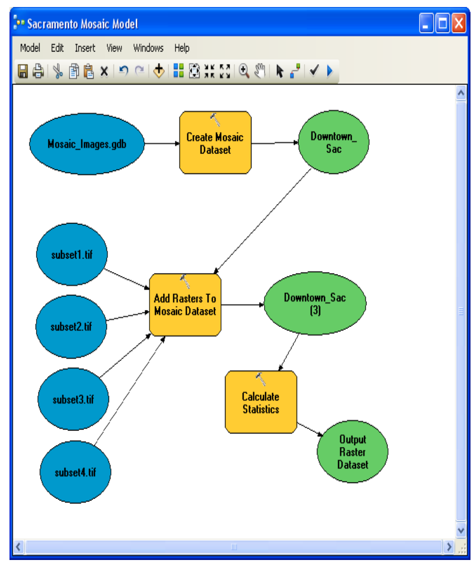


Figure 41 Image Mosaic

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.

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.

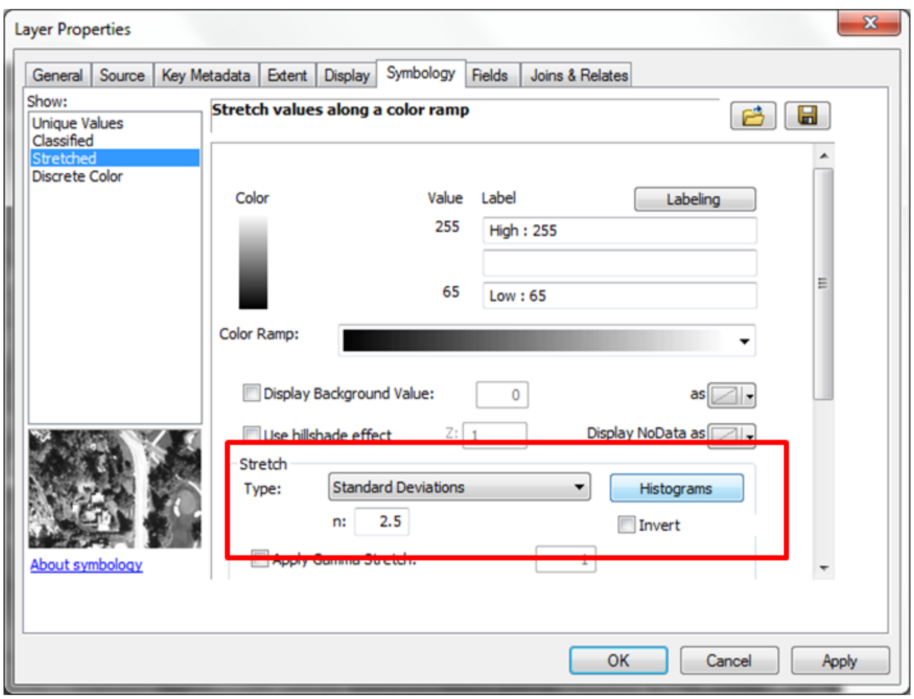


Figure 42 Screenshot of Symbology Tab

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.

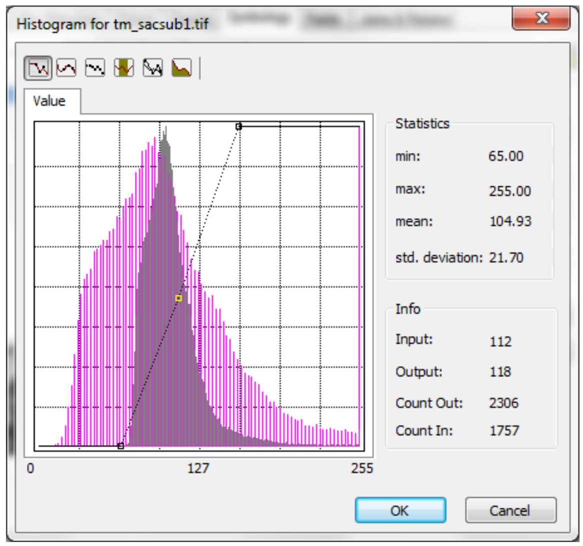


Figure 43 Histogram: Stretched Distribution

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.

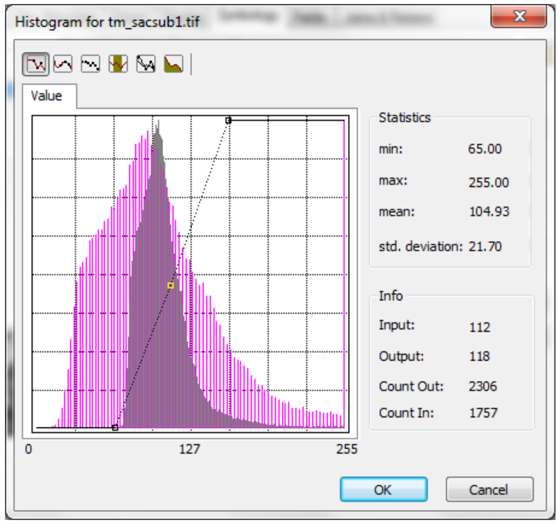


Figure 44 Histogram: Stretched Distribution

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

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.

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.

NIDV 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.

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.

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.

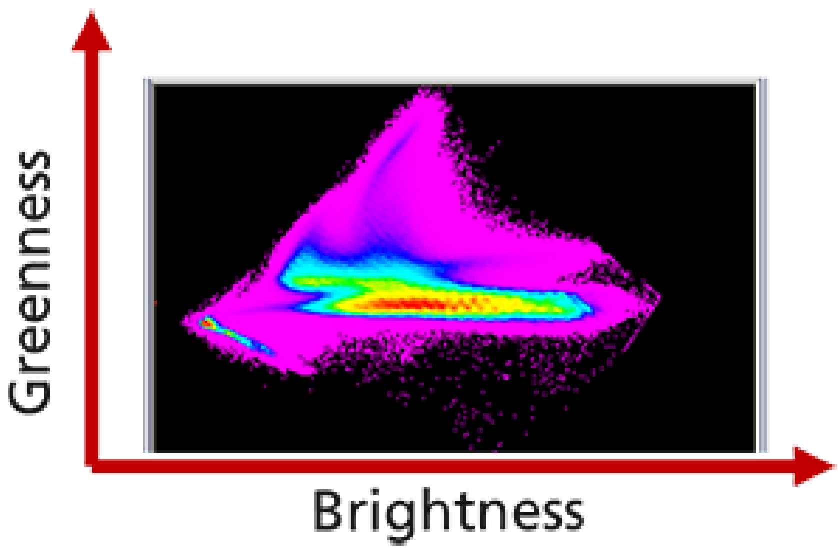


Figure 48 Tasseled Cap

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.

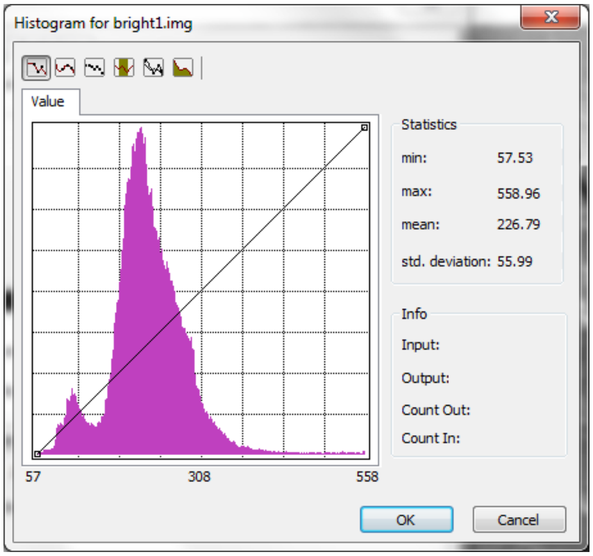


Figure 49 Brightness Band

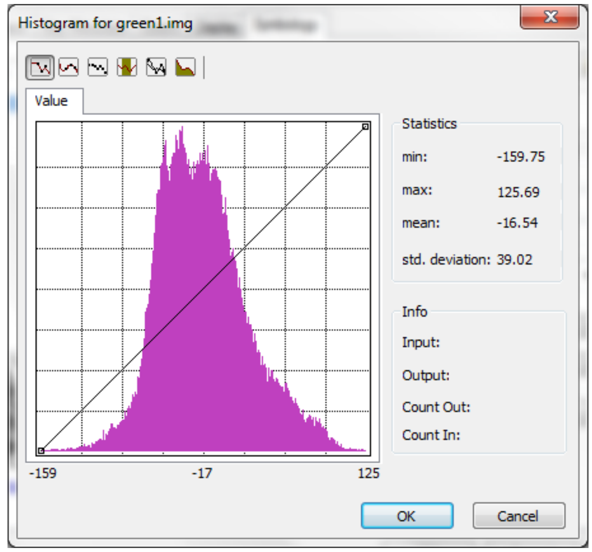


Figure 50 Greenness Band

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.

Figure 52 Greeness 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.

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

Authoring Organization: Del Mar College
Written by: Nate Jennings

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Lesson 4: Photogrammetry

INTRODUCTION

In this lesson you will learn about photogrammetry and the photogrammetric process. This lesson will cover fundamental concepts of photogrammetry which includes topics that are primarily related to aerial imagery. In addition, you will gain an understanding of the photogrammetric process which involves complex math functions, routines and expensive specialized photogrammetric software. This lesson will also describe concepts used to perform correction on aerial imagery.

LESSON OBJECTIVES

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

1. Define photogrammetry.

2. Explain fundamentals of photogrammetry concepts.

3. Use photogrammetric concepts such as scaling resolution to interpret aerial photography.

4. Explain the concepts of calibration, rectification, and orthorectification.

5. Perform an image rectification.

LEARNING SEQUENCE

Required Reading	Read the following: • Online Lesson Material
Resources	Review the following: • None
Assignments	Complete the following: • Quiz • Lab: Image Rectification

INSTRUCTION

Elements of Photogrammetry

Photogrammetry is the study of making highly accurate spatial measurements from aerial photos or images. Often the photogrammetrist is interested in making sure distances, areas, and heights of objects are accurate. The photogrammeterist is also capable of creating digital elevation models of surfaces, of landscapes or an urban environment. A photogrammeterist is one who creates digital orthophotos or image products from aerial photography or satellite imagery.

Prior to the use of computers and fast work stations photogrammetry was performed manually using devices called stereoplotters. Binocular scopes were used to make measurements and perform complex mathematical calculations. These were then translated on hard copy maps and products. In today's world photogrammetery is performed using fully digital means from the collection of the imagery to the photo corrections to the final products, typically orthorectified images.

Photogrammetry is a complicated and very technical field that involves experience and knowledge in complex calculus, trigonometry, and the understanding of how aerial images are taken on aircraft. In addition one must know how an image relates to the physical geography beneath it.

For those interested in the math and the technical details of photogrammetry, students are encouraged to review and study the material found at the end of this presentation. This photogrammetry unit will focus on some of the concepts and general processes photogrammeterists use to perform corrections and generate products for aerial imagery rather than discussing the mathematics behind the photogrammetric processes.

Common Issues with Aerial Imagery

To perform high quality photogrammetry, specialized photogrammetric software and a keen knowledge of math is needed along with the ability to understand the physical relationships of the image being collected on the sensor as it relates to the geography below the aircraft.

Photogrammetry is often conducted by highly trained staff that has additional education, training, and certifications. The American Society for Photogrammetry and Remote Sensing is the premiere organization for certifying photogrammeterists and remote sensing scientists. Students are encouraged to check The Imaging & Geospatial Information Society for more information regarding photogrammetry, remote sensing, and certification. Some of the common issues related to most aerial image collections include the following: differences in scale, feature distortion, sensor anomalies, and sensor position.

- **Differences in Scale:** Not all geographic areas are perfectly flat and so have varying scales throughout the image. This can be a problem when trying to measure accurate distances and areas.
- **Feature Distortion:** Due to changes in scale as well as vertical features not being imaged directly below the aircraft, these features can become distorted by leaning away from the center of the image. The leaning features or tilted buildings can obscure other important features in the image such as roads, sidewalks, natural areas, and other features.
- **Sensor Anomalies:** Anomalies in the lens on the camera and in the air craft can also introduce issues in the images.
- **Sensor Position:** The sensor position can also affect how features are imaged. Aircraft cannot fly perfectly level, straight or at a constant altitude. As a result features can appear tilted, elongated, shortened, or overlaying other features. The size and shapes of features can also be distorted. Photogrammetric methods and processes attempt to minimize and eliminate such issues in the images after they are collected.

Accurately Measuring Distance and Area

Once images have been processed using photogrammetric methods, accurate distances and areas can be made, even in areas with a varying terrain.

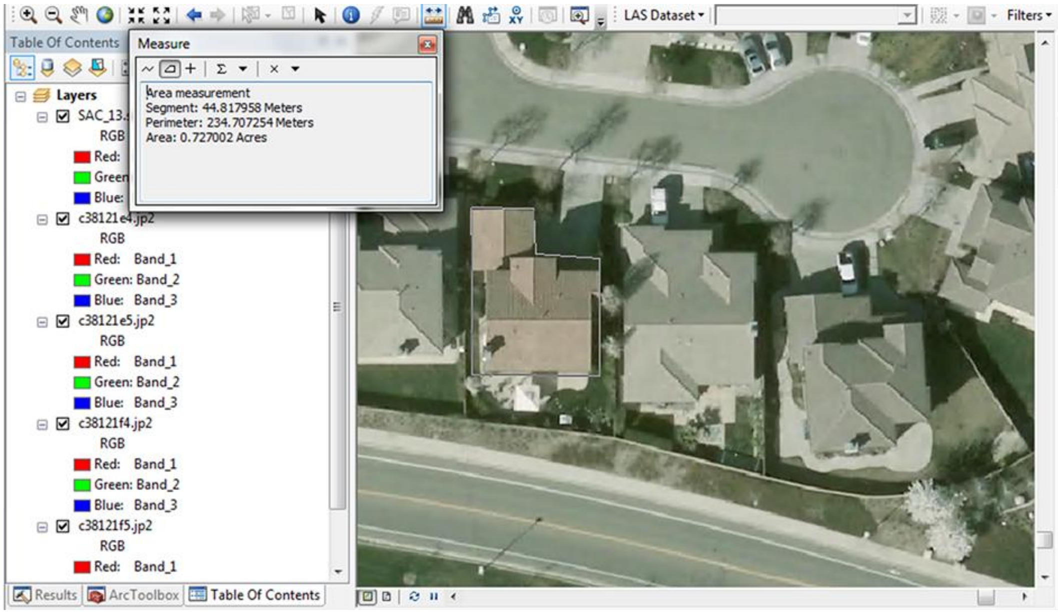


Figure 1 Screenshot: Accurately Measuring Distance and Area

LiDAR

LiDAR is often acquired in addition to aerial image collections since a high resolution digital elevation model is produced that can provide the elevation value for every pixel in the image. LiDAR may also provide additional elevation values so that vertical structures such as trees, buildings, bridges, levees, power lines, and towers can be accurately mapped. LiDAR often provides a more cost effective means of obtaining and mapping very small changes in the surface elevation; vertical structure versus traditional survey; and manual analytical photogrammetric methods. It is important to understand that photogrammetry may not produce as accurate of a product as do survey projects but the intent of photogrammetry for aerial imagery is to produce high quality air photo bases and products that satisfy "mapping grade" types of applications. These applications are usually accurate to a few inches to more than a meter or more and depend on the project and intended use of the products.

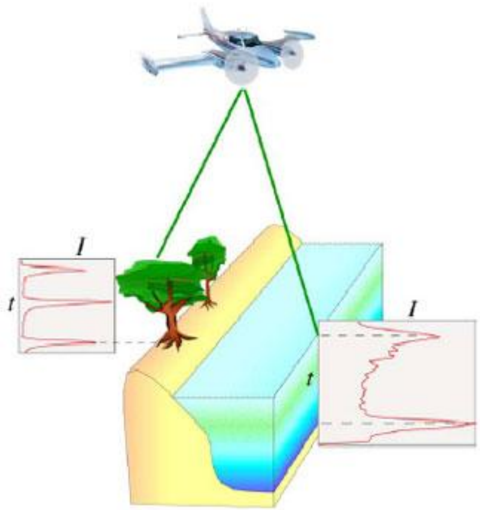


Figure 2 LiDAR Detection Process

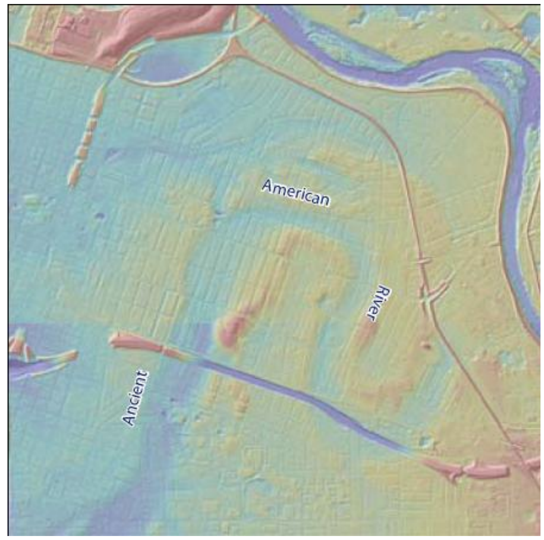
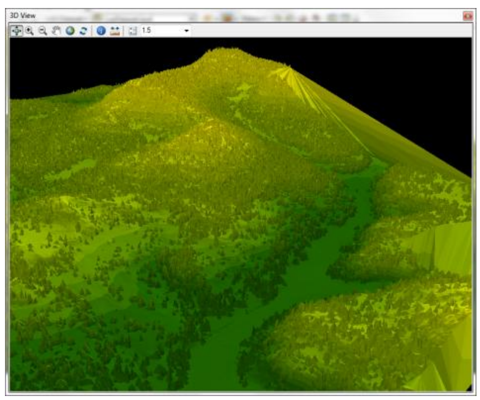


Figure 3 High Resolution Digital Model

Accurately Measure Heights and Adjust for Different Scales

LiDAR can assist by being able to accurately map heights and make the proper adjustments for differences in scale that are often found throughout a project area.



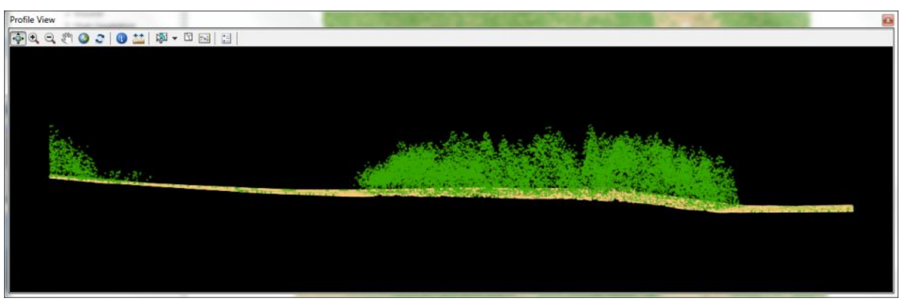


Figure 4 Screenshots: Examples of Differences in Scale

Create Contours

Another product that is often produced from photogrammetric methods is the generation of high quality contours for a project area. The level of detail depends on the flying and image collection characteristics decided on in the project development phase.

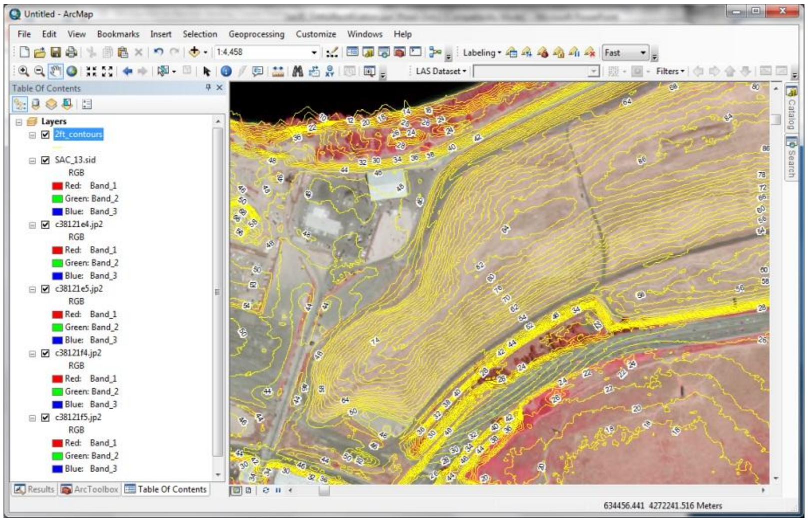


Figure 5 Screenshot: Using ArcMap to Create Contours

Creating an Ortho Image

One of the most commonly created products from photogrammetry is the orhtophoto or otho image. These images are often corrected and processed so that a high quality image base can be developed for many mapping purposes. Ortho images have a geographic reference and measurements made on features that are at the base elevation which are highly accurate. Vertical structures may or may not have a correction applied to them depending on how the project was developed for aerial collection and the project budget available.

Both of the images provided have been "orthorectified", meaning that the features at the base elevation (i.e. those at ground level) have been corrected to a high accurate standard. Notice that the image on the left of the buildings is tilted whereas the image on the right includes a correction which has been applied to remove the tilt on the buildings so that the streets and sidewalks can be seen. Even though both images are considered orthorectified, the image on the right is considered to be a "true ortho image" because the building tilt has been removed.

One can see that for municipal use, the image on the right is more useful than the one on the left because all of the features appear in the image. In the image on the left some of the features are obstructed as a result of the building tilt.

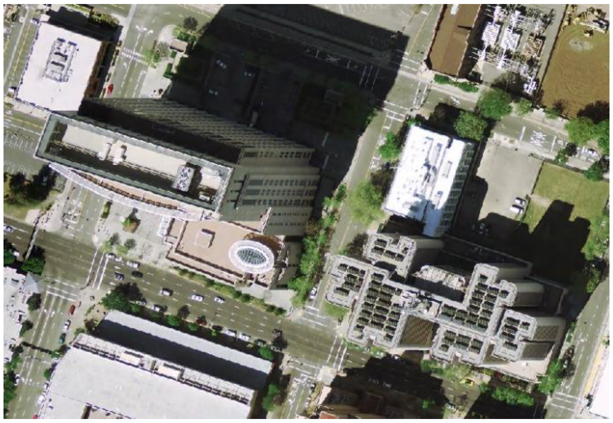


Figure 6 Orthophoto

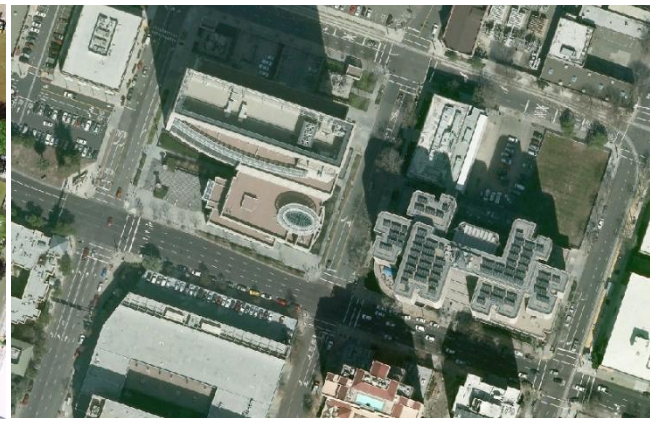


Figure 7 “True” Orthophoto

Recommended References: For more technical and detailed explanations including examples, you are encouraged to refer to the following references:

Wolf and Dewitt, 2000. *Elements of Photogrammetry with Applications in GIS*, 3rd ed., McGraw Hill, ISBN: 0072924543 and ISBN-13: 978-0072924541

Lillesand, Kiefer, and Chipman, 2007. *Remote Sensing and Image Interpretation*, 6th ed., Wiley & Sons, ISBN: 0470052457 and ISBN-13: 978-0470052457

The Photogrammetric Process

A number of issues appear in aerial imagery that can be corrected through the photogrammetric process. These were described in the previous lesson and are summarized here again.

- **Differences in scale** can be due to differences in elevation throughout the image and can affect the accurate measurements of distances and areas such as lengths of roads or areas of land on the image.

- **Feature Distortion** is when vertical features, those features not lying directly on the ground, will appear distorted if they are not imaged directly below the camera. The distortions can come in the form of the features leaning off to one side and tall buildings appearing to be tilted.

- **Sensor Anomalies** are anomalies in the lens orientation and curvature which can introduce distortions on the image.

- **Sensor position** is the physical position and orientation of the camera on the aircraft during the time of image exposure it can impose distortions on the image. Even though great care is taken to build and mount a camera on an aircraft and even if the aircraft has inertial damping systems and a GPS to keep the plane oriented, there can still be distortions resulting from the camera’s position and the attitude of the plane.

Differences in Scale

The illustration provided demonstrates the aspects of a plane with an aerial camera flying at a specific height. A vertical object (shown in red) is shown at two different elevations. The yellow object off to each side shows what the object would look like on the image. Notice that the yellow object is leaning outward from the base of the object. In addition, since the red object on the right is closer to the camera, there will be even more pronounced lean than the object on the left. (NOTE, the image does not accurately represent this lean, but it is important to remember that the vertical features will appear distorted on the images.)

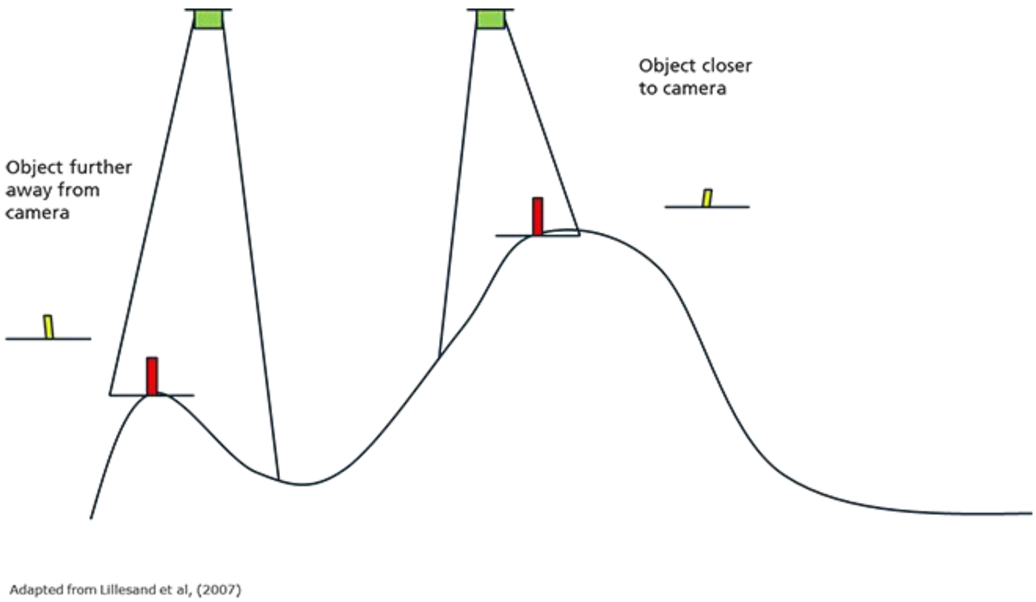


Figure 8 Differences in Scale

Building Tilt

The images below show the effect of building tilt. Both images show the same features although the image on the right shows the two buildings with pronounced tilt. The sides of both buildings are seen in the image and the buildings appear to lean up to the right. This results from the building images being captured directly below the aircraft.

The image on the left shows only the roof tops of the buildings and they are not tilted. This results from the building images being directly below the aircraft at the time of exposure.

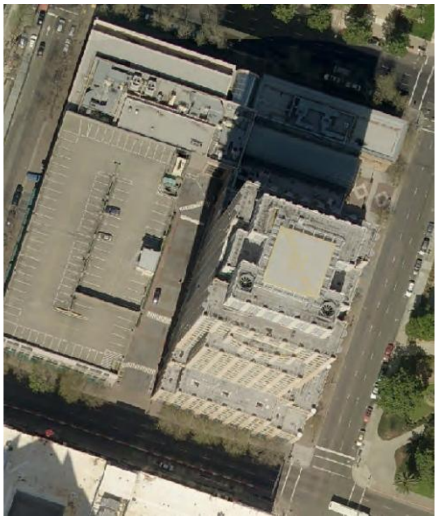


Figure 9 Building Tilted

Figure 10 Building not Tilted

Heights of Objects and Elevation

The heights of objects and elevations can be measured and derived from the use of parallax. Parallax is the relative position of an object from two different perspectives. In the case of aerial photography parallax can be measured and quantified from measuring the same feature in two overlapping images or "stereopairs." A mathematical relationship exists between the same object on two overlapping photos and it can be used to derive the heights of objects as well as the elevation for every pixel in the image.

Requirements

Several pieces of information are needed to perform the mathematical computations needed to correct issues found in aerial imagery.

Fiducial Marks

Aerial images must contain fiducial marks (which are often shown as crosshairs in each corner and on the sides of a photograph). For fully digital imagery, digital image calibration techniques are used.

Images within a given flight line and for subsequent flight lines need to have significant overlap on the ends and sides. It is common to have greater than 60% end lap and 40% side lap in aerial imaging missions.

Camera Calibration Report

A Camera Calibration Report is required for aerial imaging projects. This report provides detailed measurements and specifications that are required to perform some of the photogrammetric processes. Some of the important information on the camera calibration report includes:

- The focal length of the lens stated in millimeters.
- The principle point which is the point on the image that represents a line from the back of the camera and intersects the focal plane. This line is perpendicular to the focal plane. The focal plane is the planar surface where the image is

exposed or recorded. The principle point of a camera is expressed as an x and a y value and is provided in millimeters. The approximate principle point can be derived by intersecting opposing fiducial marks on the image.

- The image resolution is also required. For scanned film this will be the scanning resolution stated in millimeters or dots per inch. For digital images this will be the pixel size.

Digital Elevation Model
A digital elevation model may be available that can be used in aerial image collection projects. If a digital elevation model does not exist and there is enough overlap in the imagery then a digital elevation model can be derived. This will be dependent on how the aerial image collection is specified and defined.

Surveyed Ground Control
Surveyed ground control points of static known locations are also required. This will help relate the imagery collected on the camera to the ground and can also help with the derivation of the digital elevation model. Surveyed ground control points can provide a quantitative accuracy assessment on the image collection, derived image, and elevation products.

Special Photogrammetric Software
As mentioned earlier, specialized photogrammetric software will be required to perform all of the photogrammetric adjustments, computations, and to derive the digital image products such as ortho images and digital elevation models.

Common Photogrammetric Steps
The general photogrammetric process follows these steps.

Step 1: Georeference
Assign a georeference so that the analyst knows which spatial coordinate system will be assigned to the imagery.

Step 2: Interior Orientation
Perform the interior orientation. This step sets up the orientation of the camera and photographic plane at the time of image collection.

Step 3: Exterior Orientation
Perform the exterior orientation. This step is performed multiple times for each image in the image collection area and determines the orientation of the image when it was collected on the camera. This establishes a relationship between the images coordinates and the real-world coordinates on the ground. This step is often very involved and can take a significant amount of time. The corrections can be applied to a single image, a strip of images in a flight line, or as a block of images across a project area.

Step 4: DEM Extraction
Step four involves the creation of a digital elevation model (DEM). If one is already provided or available then this step may not be required. In addition, digital contour data sets can be created from the digital elevation model.

Step 5: Ortho Image Production

Ortho image production is one of the primary final steps in the photogrammetric process. Photogrammetry is use quite a bit to generate ortho images. Ortho images are those that have all of the mentioned anomalies removed so that accurate measurements and locations can be made. Ortho image products results in a high quality image based that can be used in other GIS and analytical processes.

In addition to the ortho image production, images in a flight strip or block are often mosaicked into a single image data set where the individual images have been color balanced so that the resulting image has a similar tone and color across the entire collection area.

Georeference

When assigning a georeference to an image for ortho image production, the real-world coordinate system must have values in the horizontal (latitude, Y/longitude, X) and vertical planes (elevation, Z). Images must be **georeferenced** to a real world coordinate system and must **have X, Y, Z values (lat (Y),long (X), elevation (Z)**.

Exterior Orientation

The illustration provided shows a simplified version of the exterior orientation process. Essentially, a mathematical relationship exists between the orientation of the photo on the aircraft at time of collection and the physical ground. Basically, there are a number of parameters that are determined mathematically through the exterior orientation process. These parameters are required for each image in an air photo collection (which can often involve thousands of photos). The exterior orientation parameters and computations are used to perform a variety of corrections on the image to generate the ortho image or the collection of ortho images in an aerial project. Exterior orientation involves re-creating the position and angular orientation of photos at time of exposure of the image.

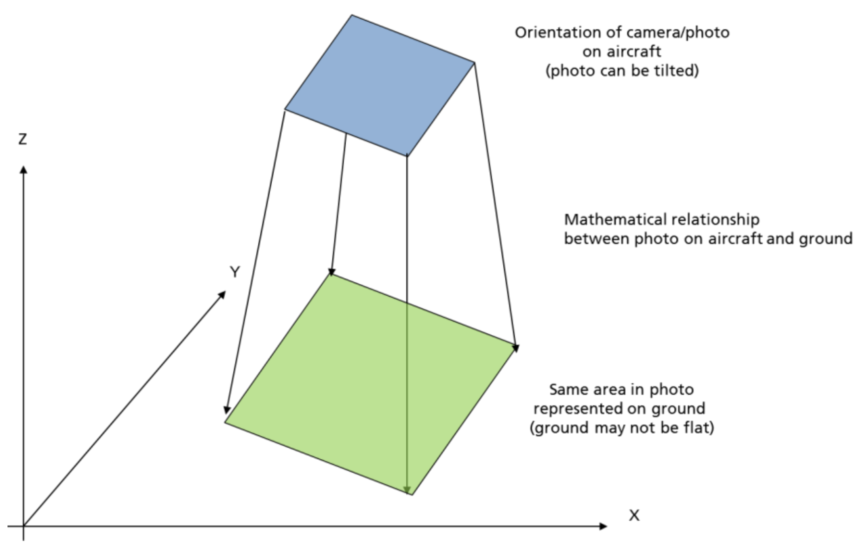


Figure 11 Exterior Orientation Process

Recommended References: For a more technical and detailed explanation including examples, you are encouraged to refer to the following text.

Wolf, P., Dewitt, B. (2000). *Elements of Photogrammetry with Applications in GIS*, 3rd ed., McGraw Hill, ISBN: 0072924543 and ISBN-13: 978-0072924541

Ground Control and Tie Points

As it relates to the relationship between the image and the ground, it is common to have a large number of ground controls and/or tie points. The ground control points are often collected through survey methods and may already exist or need to be collected as part of an aerial image collection. Tie points are often commonly identified objects or pixels in the overlap area of neighboring images. Tie points can number in the dozens, hundreds, or thousands depending on the aerial extent of the image collection and the number of images collected. Current photogrammetric methods have automated ways of collecting and evaluating the quality of tie points.

Ground control and tie points are also used to generate the digital elevation model. The quality of an ortho image is only as good as the quality of data provided to the input parameters.

Quality data would entail:

- Identifiable ground control points.
- High scanning rate or high image resolution
- Well distributed high density of ground control and tie points.

Correcting Strips and Blocks of Images

The photogrammetric process can be used for single images, strips of images along flight lights, and blocks of images. These can be comprised of multiple flight lights over a given aerial image project area.

Ortho Image Production

The typical method used to generate an ortho image involves determining the elevation value for each pixel in the oriented and corrected image. Next write each pixel to an output image. The resulting ortho image will no longer include distortions.

In an ortho image product all of the distortions have been removed such as the differences in scale, the image tilt, and relief displacement (or the displacement of objects on the image resulting from them not being imaged directly below the camera).

It is important for the image analyst (or photogrammeterist) to pay close attention to the parameters used and assigned in the photogrammetric process. This is because small inaccuracies in the orientation parameters and digital elevation values can have dramatic effects on the quality of output to generate the ortho image products.

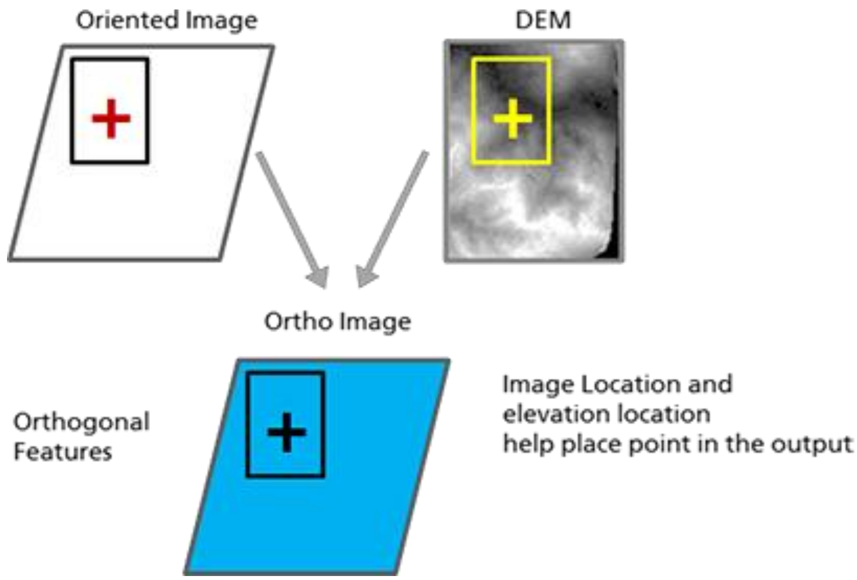


Figure 12 Illustration: Ortho Image Production

Example: Ortho Images

The images below are the same images that were seen earlier in the presentation. Both of these images are ortho images, however, only the image on the right is considered a "true ortho image" because the building tilt distortion has been removed. In some cases, an ortho image aerial collection project may want to include areas that will be "true ortho corrected."

Areas such as metropolitan areas with tall buildings, road infrastructure with bridges, and multi-level overpasses and interchanges may be areas where the "true ortho" image correction are performed. Other areas that do not have tall buildings or metropolitan areas where surface infrastructure (such as road striping, manholes, sidewalks, trees, and other features) need to be seen, do not have to have the "true ortho" correction process applied. "True ortho" areas will require additional images to be collected and can add to the overall aerial image project cost.

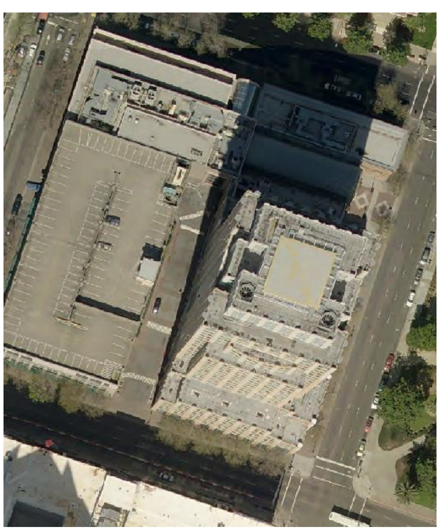


Figure 13 “True” Ortho Image: Building tilt has been removed

Figure 14 Building not Tilted

SUMMARY

In this lesson you learned about photogrammetry and the photogrammetric process. The first part of the lesson covered fundamental concepts of photogrammetry which included topics that are primarily related to aerial imagery. In addition, you gained an understanding of the photogrammetric process which involves complex math functions, routines and expensive specialized photogrammetric software. This lesson described concepts used to perform correction on aerial imagery.

ASSIGNMENTS

1. Quiz
2. Lab: Image Rectification

Authoring Organization: Del Mar College
Written by: Nate Jennings

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Lesson 5: Remote Sensing and Image Classification

INTRODUCTION

In this lesson you will learn about image classification. The first section of the lesson focuses on what image classification and explains attributes, special features, and traditional image classification. You will gain an understanding of how spectral signatures are used, and evaluated. Supervised and unsupervised classification are also explained and demonstrated as well as the conversion process of spectral classes to information classes.

LESSON OBJECTIVES

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

1. Define image classification.

2. Explain supervised, object-based image classification techniques.

3. Perform image classification techniques such as supervised and unsupervised classification on remotely sensed data.

LEARNING SEQUENCE

Required Reading	Read the following: • Online Lesson Material
Resources	Review the following: • None
Assignments	Complete the following: • Quiz • Lab: Unsupervised Classification • Lab: Supervised Classification

INSTRUCTION

Image Classification Overview

Image classification is one of the primary areas that some image analysts spend the majority of their time. This lesson will introduce some of the common image processing methods that are used in the industry. As one might imagine there are a number of ways that remotely sensed imagery can be used to develop land cover or land use maps. Image classification is a collection of methods that an image analyst can use to categorize (or "classify") pixel values into land cover of land use types. Shown in the image below are many of the commonly used image classification methods. The unsupervised, supervised, and object-based image classifiers will be discussed in this lesson since these are the most often used methods. The other two, spectral un-mixing and the fuzzy classifier will not be discussed.

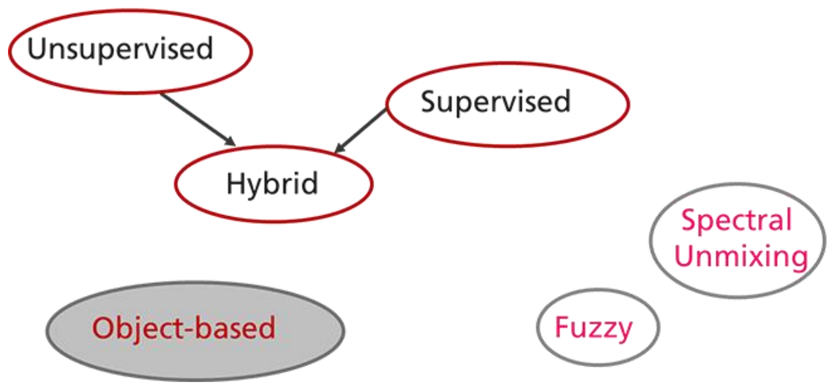


Figure 1 Image Classification Methods

Common Attributes

Some of the common attributes with all types of image classifiers are:

- The ability to auto categorize pixels into land cover or land use types.
- Although image classifiers can work on any kind imagery, they often work best when the image data set contains information from multispectral data that include both the true color and infrared band.
- The classifiers evaluate the spectral patterns across an image. Similar spectral patters are often identified by how similar or different one or more pixels are to other pixels. Spectral pattern can be evaluated by the use of spectral signatures or areas identified on the image as containing the same spectral characteristics.
- Most image classification processes involve more than a single step and often include a "training phase, evaluation phase, and classification phase" each of which can involve multiple steps to complete. In addition, the classification is often iterative meaning that some of the steps need to repeat multiple times or the overall classification process needs to occur more than one time to obtain a reasonable and accurate result.

- Image classification, although can be automated or semi-automated, there is still some human involvement to help train image classifiers, evaluate results, and to make judgments on how well an image classification exercise performed.

- An accuracy assessment is required to quantify how well the image classifications worked and how valid the output data set is. Image classification accuracy assessment is the subject of lesson six where it will be discussed in detail.

Special Features of Image Classification

Some special characteristics of image classification that will not be covered in this lesson are spatial pattern recognition and temporal analysis. However, they will be briefly outlined to provide you with a basic understanding of what they entail.

Spatial Pattern Recognition

Spatial pattern recognition is often used by some of the more involved image classification processes such as the object-based image classification methods. Specialized software is usually required to take advantage of spatial patterns as part of an image classification.

Temporal Analysis

Temporal analysis is often a "next step" in image classification where the results of two or more image classifications can be used to monitor change over time in the landscape that can be a factor of natural causes, human induced change, or natural disasters. Depending on the kind of change to identify and quantify, other special image processing software may be required.

No "Right Way"

As with many image processing activities, there is no single "right way" of performing image classification. Often times the image classification methods are based on the scope of a project, the kinds of land cover types needing identification, and project budget and resources. The processes are usually subjective since there is judgment that is required of the image analyst. Even though some statistical methods can be used to independently identify land cover types and quantify accuracy, the analyst is still heavily involved in creating and interpreting data and products that result from image classification protocols.

Traditional Image Classification

Figure 2 outlines the steps that are often used to perform a "traditional" image classification. Traditional refers to image processing methods that analyze only spectral content from the image and do not consider specific "spatial patterns", shapes, or the context of specific objects. These traditional methods typically are applicable to medium and coarse image resolutions (that is, greater than 20m pixel sizes).

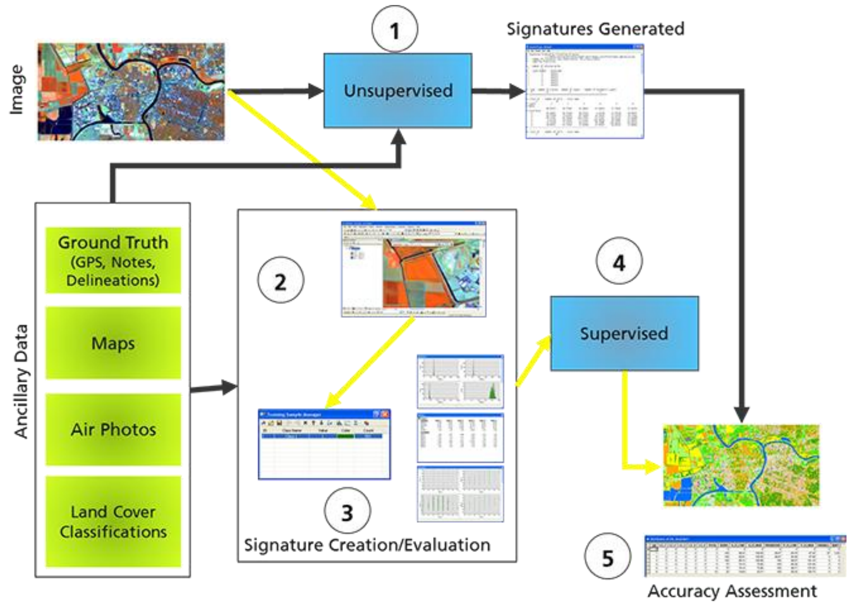


Figure 2 Traditional Image Classification Process

- The black arrows show the workflow for an "unsupervised" image classification. The yellow arrows show the steps for a "supervised" image classification.
- For the unsupervised approach, an image is automatically classified into broad groups of pixels that have similar "spectral" characteristics. The image analyst needs to spend time identifying the specific land cover types in the image. Often times, additional methods and time is required to identify areas that have more than one cover type present in the group.
- The supervised approach begins with the analyst identifying representative samples of the specific land cover types that are expected to be identified in the image classification. The samples often require field visits and/or photo interpretation or consulting other resources to identify the land cover types. Once these specific samples are identified then they can be used as the input to a supervised image classification algorithm that generates the output land cover map.

Traditional Image Classification Process: Hybrid Approach

Here is an example of the "hybrid" approach mentioned both methods are combined into a single process to generate an image classification output data set. The general steps are numbered.

Step 1

This step uses an unsupervised classification routine to segment the original remotely sensed image into unique groups of similar kinds of pixel values.

Step 2

Once the segments are identified "training" sites can be identified in each "spectral segment". These are field verified using on ground surveys, air photo interpretation, and other image classification or maps to determine the specific land cover categories to be mapped in the output.

Step 3

Spectral signatures are created from the training sites then evaluated to make sure the spectral variability of each land cover category is represented.

Step 4

The spectral signatures are used to perform a supervised image classification that then generates the final image classification output.

Step 5

The image classification output data set is assessed for accuracy for each of the land cover categories. If some land cover classes have been poorly identified then some or all of the above steps may be performed multiple times to improve the land cover classification accuracy.

The accuracy assessment and methods are often written up in a formal document and contain the explanations of the methods and the interpretations of the results as well as a provision for recommendations of use and further action.

Object-Based Image Classification

Here is the basic process for object-based image classification. This is an over simplified workflow where each step usually requires a number of steps.

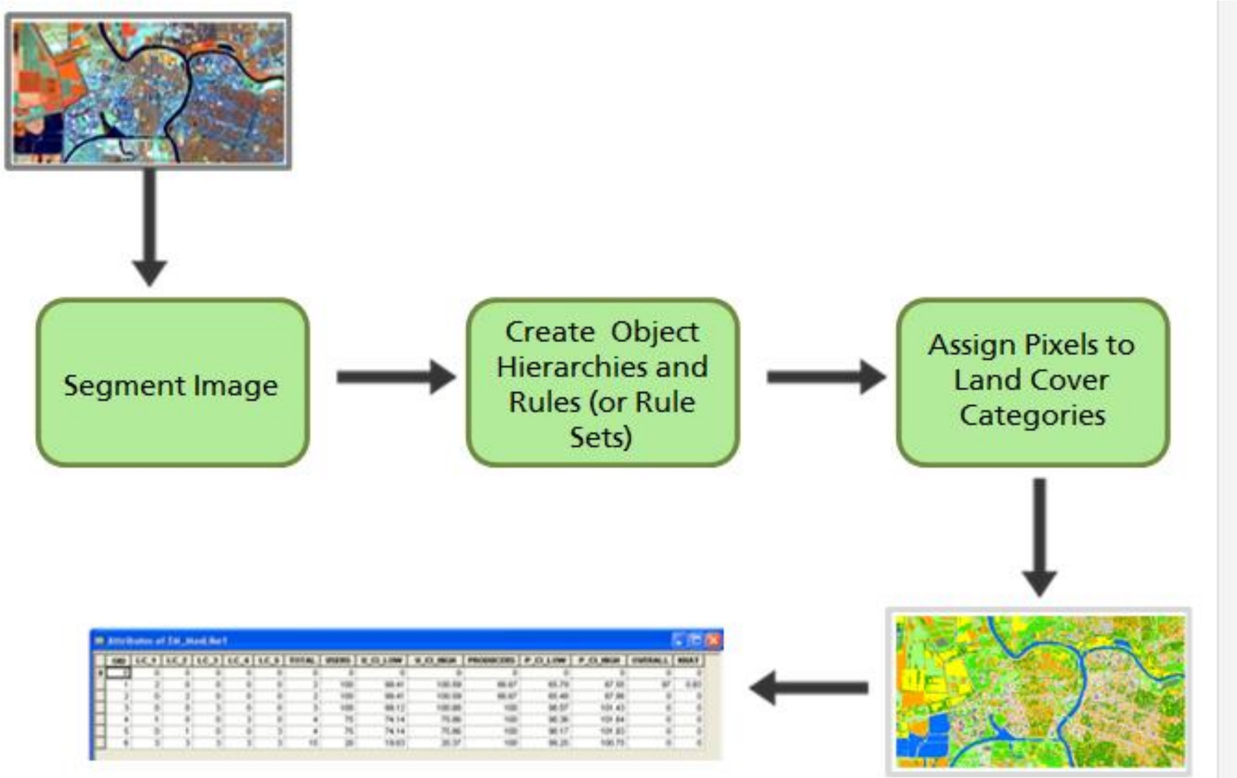


Figure 3 Object-Based Image Classification Process

Segment Image: The first step is to segment the image into spectrally similar components. This is similar to an unsupervised classification, but there are often other parameters to guide the segmentation output. The scale and image resolution can impact the segmentation process as well as the level of detail in the output result.

Object Hierarchies and Rules: Once the image is segmented, a number of rules are created that are placed in a decision hierarchy. Some of the rules refer to the spectral content of the image while others refer to the size, shape, pattern, connectivity, scale, and texture of an area on the image. This will be the primary basis for the object-based image classification process. Other layers such as NDVI, elevation, slope, texture, among others may be developed that become part of the decision hierarchy.

Assign Pixels: The pixels are then classified into different land cover types or material types based on the decision rules.

Analyst Review: The analyst reviews the output and make additional adjustments are required to obtain a quality output. As with the other classification methods, an accuracy assessment is performed and interpreted in addition to a written document.

Recommended Reference: The following reference is recommended for additional information regarding object-based image classification methods.

de Jong, S.M. and F.D. van der Meer, Eds., *Remote Sensing Image Analysis Including the Spatial Domain*, Kluwer Academic Publishers, Dordrecht, The Netherlands, 2004.

Classification Scheme

All image classification projects begin with a classification scheme that identifies and defines the specific land cover types that are required for the project. Typically, the classification scheme is agreed upon by a project group that includes the client. The specific land cover types need to be exhaustive as to cover all of the expected land cover types within the project area. The project team must also agree to the specific definitions of each land cover type. These are usually discussed and then written definitions in addition to pictures and sample sites are described.

Many land cover classification schemes are based on work conducted by Anderson, Hardy, Roach and Witmer (1976). Object-based image classification schemes may include many other factors such as those described above, since they do not rely solely on spectral content from the image.

Hierarchical Classification Scheme

Most of the time the land cover classification scheme is hierarchical which begins with general land cover types and then identifies more specific land cover types. The land cover classification scheme is often shown as a decision tree that shows the relationships between the general and more specific land cover categories.

This image is an example of a hierarchical classification scheme and is based on the Anderson classification scheme which can be found in Developing the Classification System section outlined within *A Land Use and Land Cover Classification System for Use with Remote Sensor Data* (Anderson, et al 1976).

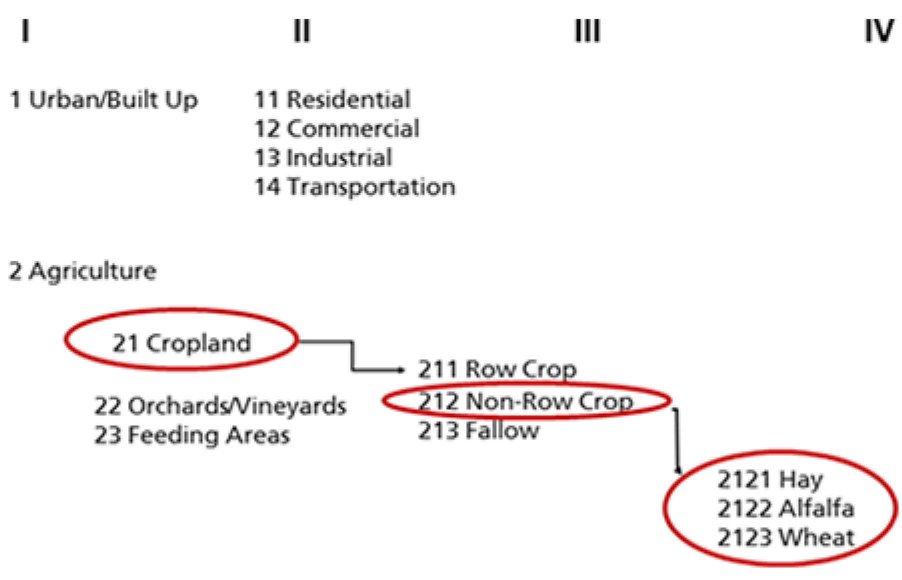


Figure 4 Hierarchical Classification Scheme

At the top are four levels of detail with the most general land cover types on the left and moving to more specific levels of detail on the right.

In the example two major land cover types are shown, Urban/Built-up and Agriculture. Notice that the urban/built up category only has a second level of detail. The agricultural land cover type is broken down further into four levels of detail. The Cropland category and its respective hierarchy are shown in the red circles.

Tracing the Cropland category, this can further be broken down into Row Crops, Non-Row Crops, or Fallow fields. The Non-Row Crop can be further divided into specific crop types of Hay, Alfalfa, and Wheat.

The classification scheme itself is exhaustive for these cover types that would be expected in a typical land cover classification that contains an Agriculture land cover type and specific crop types. The classification scheme defines a level of detail provided the imagery and classification methods can identify the specific cover types. If the specific cover types cannot be identified, the next general level of detail can be used.

This kind of classification schemes allows for the flexibility of providing different levels of detail in the output image classification provided the information, image resolution, spectral content, and image processing methods are capable of identifying the most specific types. If they are not, then a more generalized depiction of the land cover type is provided in the image classification output.

Minimum Mapping Unit

The minimum mapping unit is important to identify as part of an image classification project because this can limit the level of detail found in the output image classification. In many image classification projects, individual pixel sizes do not represent the level of detail in the output image classification. More often, contiguous groups of pixels that form an area better represent the level of detail in an image classification product.

The minimum mapping unit represents the smallest mappable area that will be identified in the output image classification. The minimum mapping unit is defined based on a number of factors such as image resolution, scale of the project area, the number of bands in the image, the specific kinds of land cover types or features to identify as well as the time of year and any obstructions that may affect the ability to identify such features. Examples include clouds, shadows, shadows cast by buildings, building or vertical structure overlay, and others.

The minimum mapping units is agreed upon by the project team and client and is often expressed as an area (for example, 10 hectares). Once an image classification is complete, a "smoothing" algorithm is often used to aggregate the classified pixels into contiguous areas that meet the minimum mapping unit size.

Size depends on:

- Classification Scheme
- Purpose
- Types of features to ID
- Scale of image
- Pixel size of image

- Time of Year
- Identifiable obstructions

ArcGIS 10

The lab exercises for this lesson will use some of the Spatial Analyst and Image Classification tools provided in ArcGIS as listed below. More details will be provided in the lab exercises.

Image Classification Toolbar

The Image Classification Tool bar will be used to perform the two common traditional unsupervised and supervised classification methods. In addition, the Image Classification Toolbar will be used to create and review spectral signatures that are used in the supervised classification tool.

Image Classification Toolbar includes the following:

- IsoCluster Unsupervised Classification
- Maximum Likelihood Supervised Classification
- Probability
- Principal Components

Spatial Analyst Toolbox – Multivariate Toolset

The Multivariate Toolset within the Spatial Analyst Toolbox will be used to evaluate spectral signature files. The classification tools can also be found in the Multivariate Toolset.

Multivariate Toolset includes the following:

- All of the Image Classification Toolbar +
- Dendrogram – spectral signature analysis
- IsoCluster – autogenerate spectral signatures
- Edit Signatures

Spatial Analyst Toolbox – Reclass Toolset

The reclassify tool can be found in the Reclass Toolset within the Spatial Analyst Toolbox and is used to create the final set of land cover classes in an image classification output. Provided below are a few references that you can refer to on your own to read about and study for additional information regarding the overview of image classification and object-based image classification methods.

Lillesand, Kiefer, and Chipman. *Remote Sensing and Image Interpretation*, 6th ed., Wiley & Sons, 2007. ISBN: 0470052457 and ISBN-13: 978-0470052457

de Jong, S.M. and F.D. van der Meer, Eds., *Remote Sensing Image Analysis Including the Spatial Domain*, Kluwer Academic Publishers, Dordrecht, The Netherlands, 2004.

Navulur, K., *Multispectral Image Analysis Using the Object-Oriented Paradigm*, CRC Press, Boca Raton, FL, 2007.

Spectral Signatures

A spectral signature is a group or cluster of pixels that have similar spectral characteristics. What this means is for any given area of pixels that are considered to be similar, the pixel values for a given band are often similar and when statistical measures are computed for this area the following is often found:

1. The mean or average value for the group of pixels is similar to individual pixel values
2. The standard deviation and variance for the area of pixels is often small, meaning that the different pixel value are similar to the mean value of the area

The spectral signature is the identified group of pixels and the statistics that can be computed for the group of pixels. That is the group of pixels and its statistical measures that make up the specific definition for the spectral signature.

Spectral signatures can be auto-generated through the use of the unsupervised classification method or can be manually defined by the analyst where specific areas are delineated on the image and individual statistics can be computed.

Spectral Signature – Manual Delineation

This image is an example of a spectral signature that has been delineated by an analyst. The area within the yellow polygon contains 599 pixels and at the bottom are the specific statistics computed for each band within this area of 599 pixels. The area delineated in addition to the specific statistics computed for this area represents a "spectral signature" for the Rice land cover type.

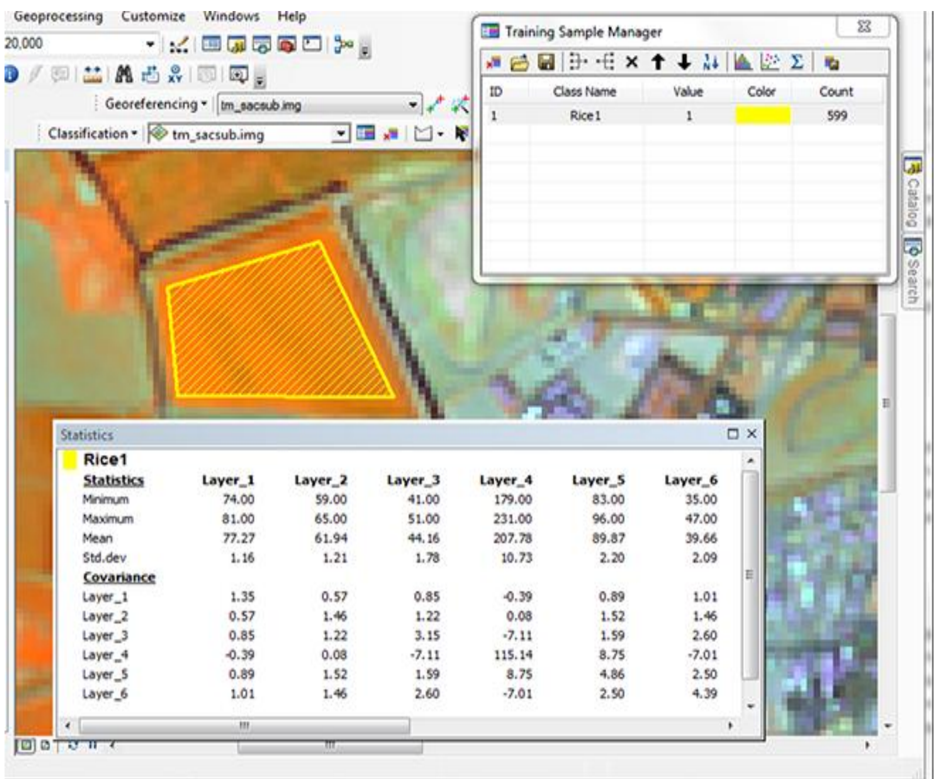


Figure 5 Spectral Signature Example

Spectral Signature: Auto-generated

The image below is an example of an unsupervised classification routine creating an image output with only one spectral category shown. When the unsupervised classification method is performed a number of unique spectral areas are created. These are often broad groupings of pixels where each unique group contains a number of pixels and corresponding statistics. A spectral signature file can be generated from the unsupervised process that can be used in subsequent image classification procedures.

The yellow in the image is the geographic extent of Spectral Class 2. Note that this class contains a number of pixels that are scattered throughout the image. The bottom image of Figure 5 is the portion of the spectral signature file created from the unsupervised process. The image band numbers and spectral signature means are shown across the top. A "co variance" table is also shown. Covariance is a statistical measure of how the pixels values within the spectral signature area vary between the different image bands. The variance for a given band is the value along the diagonal of the covariance table. The variance is outline in red. Remember, the variance for a given band describes how different individual pixels within the spectral signature area are to the mean of the pixel values in the spectral signature area.

unsuper.gsg - Notepad

File Edit Format View Help

```
#  Class ID     Number of Cells    Class Name
       2              222
# Layers          1          2          3          4          5          6
# Means
               90.76126   71.91441   69.28829  117.06757   79.53604   53.87838
# Covariance
      1        40.09207   34.06092   50.05556  -37.00190   10.16928   31.90748
      2        34.06092   35.56278   50.02026  -20.68650   16.84699   30.31534
      3        50.05556   50.02026   80.58620  -42.91549   27.49183   49.77278
      4       -37.00190  -20.68650  -42.91549  225.99089   70.10841   -2.05057
      5        10.16928   16.84699   27.49183   70.10841   99.89689   68.02024
      6        31.90748   30.31534   49.77278   -2.05057   68.02024   78.54170
# -----------------------------------------------------------------------
```

Figure 6 Unsupervised Classification Routine

How are Spectral Signatures used?

In an image classification project all of the types of land cover that need to be identified in the image need to be sampled. Since not all specific land cover types look the same on an image, these land cover types must have spectral samples that cover the variability of the land cover type.

When identifying spectral signatures, whether automatically or manually, additional reference information is needed, field work or air photo interpretation may be required, in addition to having some specific knowledge of the geographic area. Image analysts can spend considerable time creating, evaluating, and modifying spectral signatures. Since obtaining high quality spectral signatures is an important part of image classification routines, analysts need to spend quality time developing these spectral signature sets.

In some sources spectral signatures may also be referred to as "training sites" or those spectral signatures that are used to "train" spectral classifiers.

Creating Spectral Signatures

Spectral signatures are often created as part of the supervised classification process and begin with drawing polygon areas on an image similar to the example shown in the previous figures. Identifying spectral signatures on an image often require using additional information such as conducing field visits for "ground truthing", maps, air photo interpretation, and other land cover maps.

One of the goals of creating spectral signatures is to sample the variability of the land cover classes across the image because the same land cover types can different spectral characteristics in different parts of the image.

Samples: Three Types of Land Cover Types

The illustration shows (Figure 7) multiple samples of three different land cover types (noted with A, B, or C). Each of the individual spectral signatures has a mean, standard deviation, variance that describes the spectral characteristics of the land cover type. Each signature that represents the same land cover type may have slightly different spectral characteristics which will represent the variability of the land cover type.

The analyst will need to pay close attention to how spectral signatures are collected because this will be the information that is used in supervised classification methods. If spectral signatures are delineated or identified incorrectly, then the output image classification will likely have errors or issues.

High quality spectral signatures are those that represent only a single cover type based on the classification scheme, contain homogeneous pixel values, and have small standard deviations and variances for each image band. For some land cover types this is not always achievable, but the analyst should strive to sample single land cover types when creating spectral signatures.

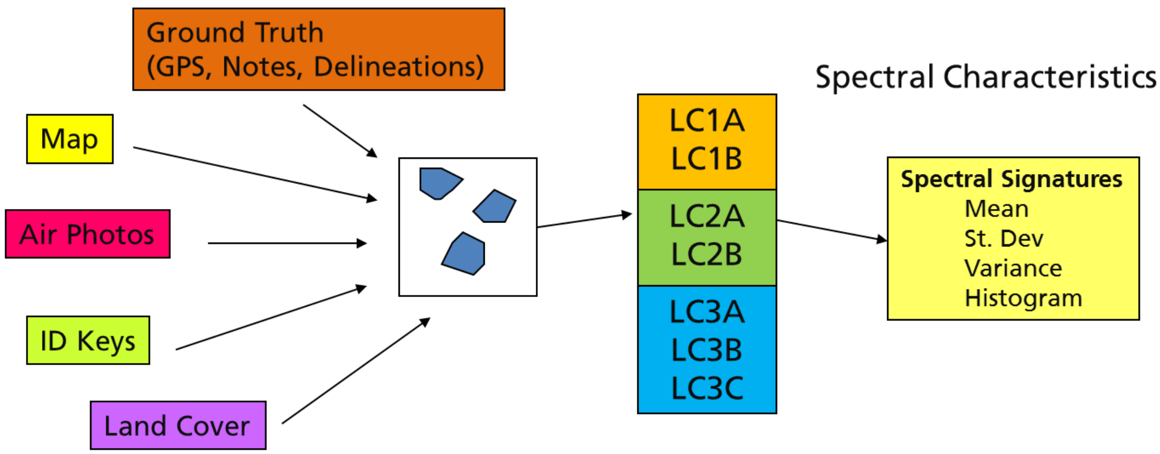


Figure 7 Multiple Samples of Different Land Cover Types. Each different land cover type is noted with A, B, or C.

Creating Spectral Signatures in ArcGIS

Creating spectral signatures in ArcGIS is performed using the Training Sample Manager on the Image Classification Toolbar which can be seen in the image provided (Figure 8). When the user creates a spectral signature on the image, the individual spectral characteristics can be reviewed by using one or more of the spectral evaluation tools. Three tools are available: histograms, signature statistics, and scatter plots. Keep in mind that the histogram and the signature statistics are the most often used tools when reviewing specific spectral signature quality.

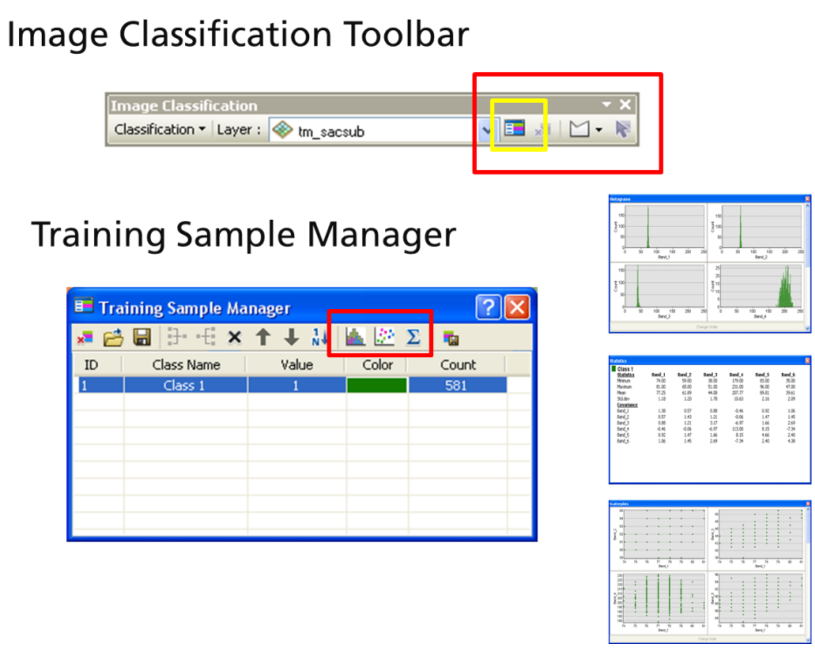


Figure 8 Creating Spectral Signatures using ArcGIS: Screenshots are included of the Image Classification Toolbar the Training Sample Manager and the three tools available (histograms, signature statistics, and scatter plots).

- **Histograms**
  The histogram is a graph of the specific pixel values and the pixel count for each unique brightness value. A histogram can be created for each image band. A spectral signature that is delineated for a single land cover type will appear as a single curve on the histogram. If a spectral signature has multiple curves, this is an indication there may be more than one land cover type delineated in the spectral signature area.

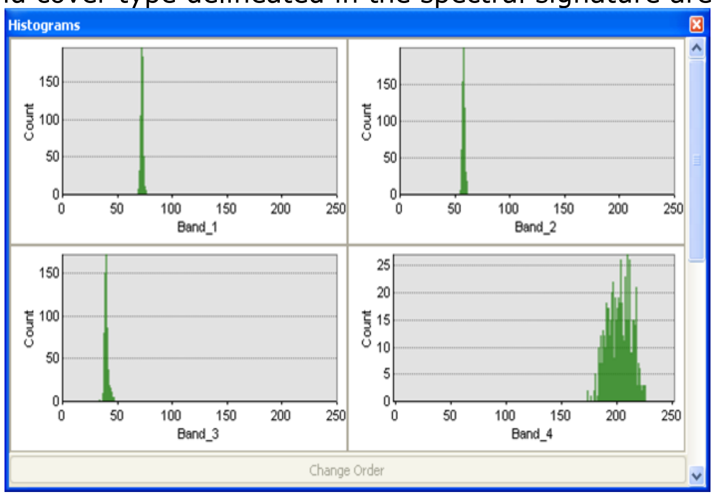
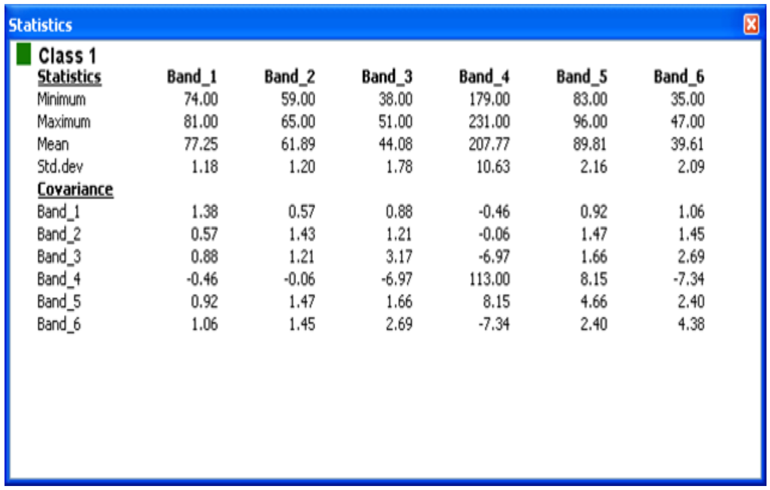


Figure 9 Histograms

- **Signature Statistics**
  The spectral signature statistics tool is commonly used to review the means, standard deviations, and variances for a given signature. The analyst can easily see specific values and determine if a spectral signature seems to represent a single cover type.

  If the standard deviations and variances are large across multiple bands, then the spectral signature may include multiple land cover types. A high quality spectral signature will often have small standard deviations and variances.



Statistics

Class 1

Statistics	Band_1	Band_2	Band_3	Band_4	Band_5	Band_6
Minimum	74.00	59.00	38.00	179.00	83.00	35.00
Maximum	81.00	65.00	51.00	231.00	96.00	47.00
Mean	77.25	61.89	44.08	207.77	89.81	39.61
Std.dev	1.18	1.20	1.78	10.63	2.16	2.09
Covariance						
Band_1	1.38	0.57	0.88	-0.46	0.92	1.06
Band_2	0.57	1.43	1.21	-0.06	1.47	1.45
Band_3	0.88	1.21	3.17	-6.97	1.66	2.69
Band_4	-0.46	-0.06	-6.97	113.00	8.15	-7.34
Band_5	0.92	1.47	1.66	8.15	4.66	2.40
Band_6	1.06	1.45	2.69	-7.34	2.40	4.38

Figure 10 Signature Statistics

- **Scatter Plot**
  Scatter plots are graphical representations that compare individual pixels within the spectral signature between two bands. For example, the pixel values found in band 1 are plotted against the pixel values found in band 2. The same can be done for band 2 to band 3, band 3 to band 4 and so on.

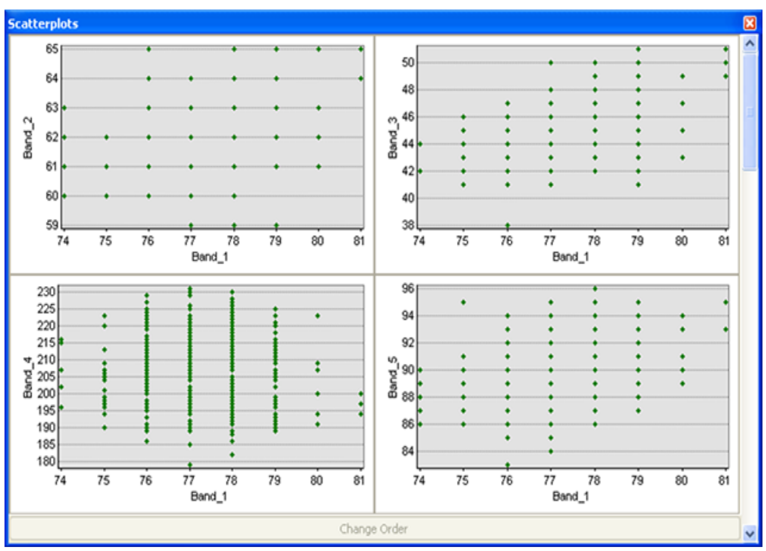


Figure 11 Scatter Plots

Training Sample Manager

To delineate a spectral signature using the Training Sample Manager, the analyst chooses the polygon tool and draws a polygon for a single land cover type. Care is taken not to delineate an area that represents more than one cover type. For example, in the Figure 12, the polygon is drawn within the field boundary of the image. Note the area delineated does not follow the edge of the field or include areas that are definitely not within the field itself.

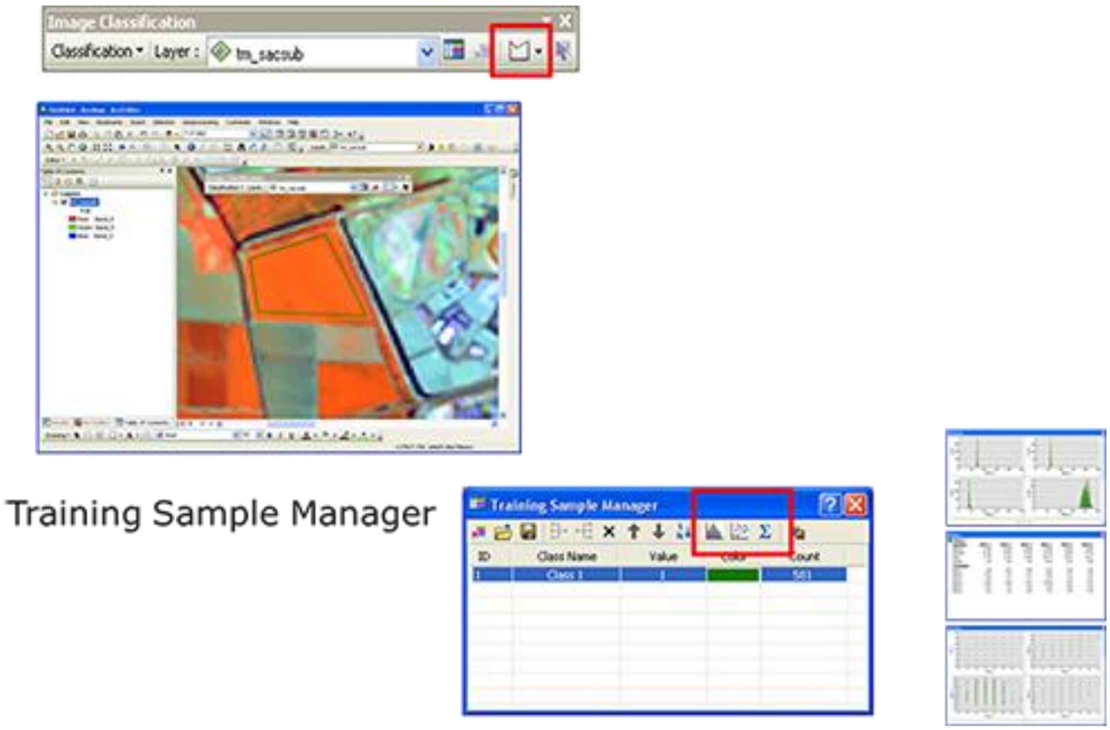


Figure 12 Screenshot of the Training Sample Manager being used to delineate a spectral signature as discussed under the Training Sample Manager heading above.

Evaluating Spectral Signatures

Once the signature is delineated the different spectral evaluation tools can be used to review the quality of the signature. The same process can be used to create new signatures for all of the different land cover types. When a full set of spectral signatures is created, a signature file can be saved.

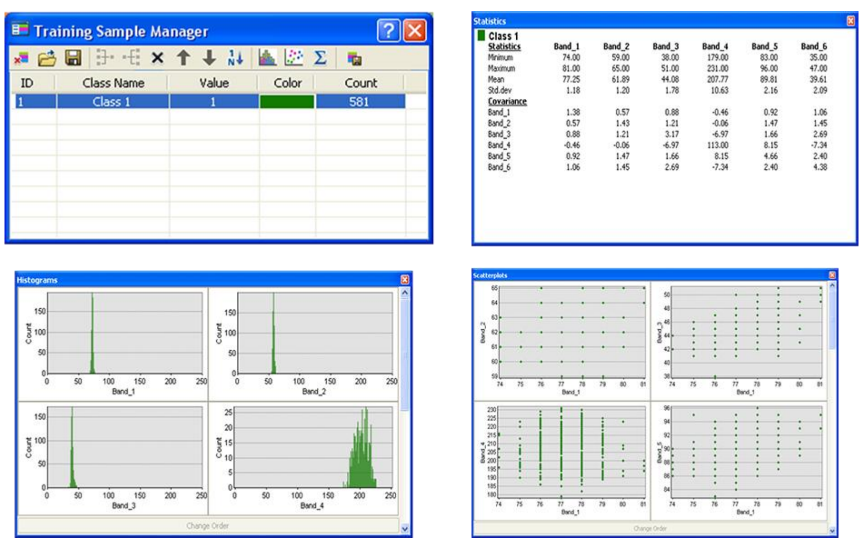


Figure 13 Spectral Signatures

Dendogram

Once a number of spectral signatures are created in the Training Sample Manager, the entire group of signatures can be evaluated by using the Dendrogram Tool in the Multivariate Toolset under the Spatial Analyst Toolbox. The input to this tool is the spectral signature file created when the spectral signatures are delineated.

The dendrogram tool runs and generates a text file that shows a series of connected lines. The left side of the file represents specific signature numbers. For each pair of signatures a horizontal line is shown and then a vertical line connects the two signatures together. The length of the horizontal lines determines how similar or different a pair of spectral signatures is from one another. Short horizontal lines indicate that a pair (or group) of signatures are similar. Longer horizontal lines indicate dissimilarity or an indication that two or more spectral signatures may represent different land cover types.

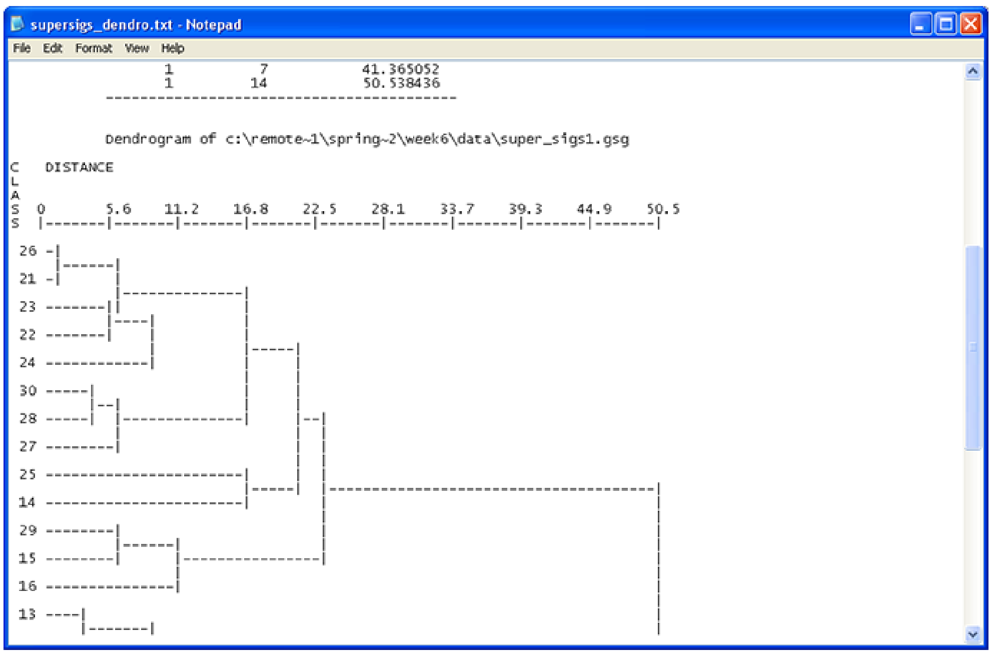


Figure 14 Dendogram

Dendrogram Routine

The dendrogram routine is often run to check entire spectral signature sets where the analyst can then make decisions to make adjustments on individual spectral signatures and add or delete spectral signatures.

It is good practice to evaluate both individual and a full set of spectral signatures before implementing an image classification routine. The analyst should insure that the spectral signatures are high quality and the full set represent the land cover classes that are expected to be categorized in the image classification.

Unsupervised Classification

The unsupervised classification method automatically categorizes image pixels into a specific number of "spectral classes" or categories that have similar spectral characteristics. These groups of pixels have the same kinds of pixel values and the standard deviations and variances are small. This, however, is all relative, since the number of classes assigned by the user may include multiple cover types that actually have similar spectral characteristics. This can be a problem for the analyst and can produce erroneous information in an output image classification.

A number of common unsupervised classification options exist in image processing software: ISODATA, IsoCluster, and K-Means are three such processes.

- **ISODATA** stands for Iterative Self Organizing Data Analysis). As the name indicates, this algorithm iterates multiple times to eventually create a categorized image and can optionally generate a spectral signature file that contains spectral characteristics for each spectral class identified in the image output.

- The **IsoCluster** is a slight modification of the ISODATA algorithm and is the version that is offered in ArcGIS.

- **K-Means** is another option for unsupervised classification where the analyst identifies a specific pixel for specific land cover types. This "seed" pixels serves to initiate the K-Means unsupervised algorithm.

Unsupervised Classifications in ArcGIS

Two unsupervised classification processes exist in ArcGIS. The IsoCluster Unsupervised Classification produces both an image and an optional spectral signature file. The IsoCluster Tool only generates the spectral signature file. The input parameters for each tool are nearly identical. For either model the IsoCluster operation requires a set of parameters. Each one is described within the Spectral Classes.

IsoCluster Unsupervised Classification Tool

Provided below is a description of the IsoCluster Unsupervised Classification tool. It is important to note that the IsoCluster Unsupervised Classification tool requires an image output.

IsoCluster Unsupervised Classification Tool (ArcGIS)

- **Input image data set** is the input multispectral image data set.
- **Number of output spectral classes** is the number of expected unique groups of pixels (i.e. spectral classes). The spectral classes represent pixels with similar spectral characteristics and may or may not refer to specific land cover types). A value of 2 or greater is required.
- **Minimum number of pixels in a class** refers to the minimum number of individual pixels used to create a spectral class. The default is 20 and is often used.
- **Sample interval** refers to how often input pixels will be evaluated for inclusion into a spectral class. The default is 10 and is usually used.
- **Output image** is the output image containing groups of pixels with a unique spectral class (often an integer data type).

- **Output Spectral Signature File (optional)** is a file that can be used for further spectral analysis or for use with a supervised classification method

IsoCluster Tool

The IsoCluster Tool provides an option to have the analyst assign a specific number of iterations to run the IsoCluster process and does not produce an output image, but only an output spectral signature file. Provided below is a description of the IsoCluster Tool.

IsoCluster Tool

- **Input image data** set is the input multispectral image data set.
- **Number of output spectral classes** is the number of expected unique groups of pixels (i.e. spectral classes). The spectral classes represent pixels with similar spectral characteristics and may or may not refer to specific land cover types). A value of 2 or greater is required.
- **Number of Iterations** refers to the maximum number of iterations the IsoCluster Tool will run before stopping the process.
- **Minimum number of pixels** in class refers to the minimum number of individual pixels used to create a spectral class. The default is 20 and is often used.
- **Sample interval** refers to how often input pixels will be evaluated for inclusion into a spectral class. The default is 10 and is usually used.
- **Output Spectral Signature File** is a file that can be used for further spectral analysis or for use with a supervised classification method

Unsupervised Classification Process: 6 Step Process

The unsupervised classification process basically requires six steps to complete.

Step 1

The user sets up the algorithm with the required parameters. Often the number of spectral classes and a number of iterations are required, but can be different depending on the software used.

Step 2

Behind the algorithm, the first process that is implemented is to create a set of means for each specific spectral cluster (or spectral class) which contains a group of pixels. The initial set of classes is arbitrary.

Step 3

The image pixels are evaluated against the "spectral class" means. For a given pixel, if it is similar to one of the class means, then it is assigned to that specific spectral class. If the pixel does not meet any of the spectral classes, then it is not considered during this iteration.

Step 4

After the assignment of some of the pixels, the spectral class statistics are recomputed. If the statistics significantly change, then a new spectral class is created. If the spectral classes have similar statistics, then they can merge.

Step 5

Individual pixels are again checked again to see if they are similar to one of the spectral classes and then assigned one of the specific spectral classes. Essentially, steps 3 and 4 are iterated and repeated until the number of iterations is reached or the spectral class statistics do not change between subsequent iterations.

Step 6

The final step is to assign all of the pixels to one of the spectral classes and generate an output image and optionally a spectral signature file.

Unsupervised Example

Figure 15 shows an example of the classified image output and the associated spectral signature file. The output image is often initially displayed as a gray scale image. The analyst can assign colors to each output spectral class.

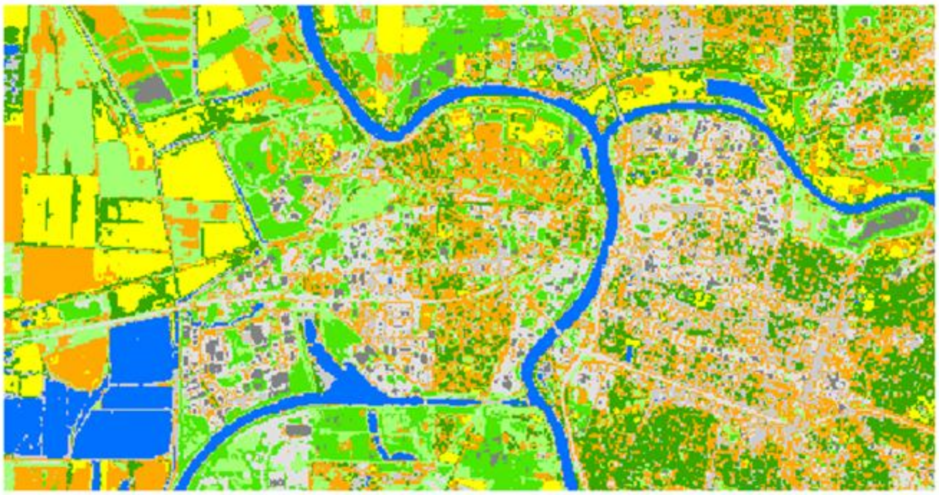
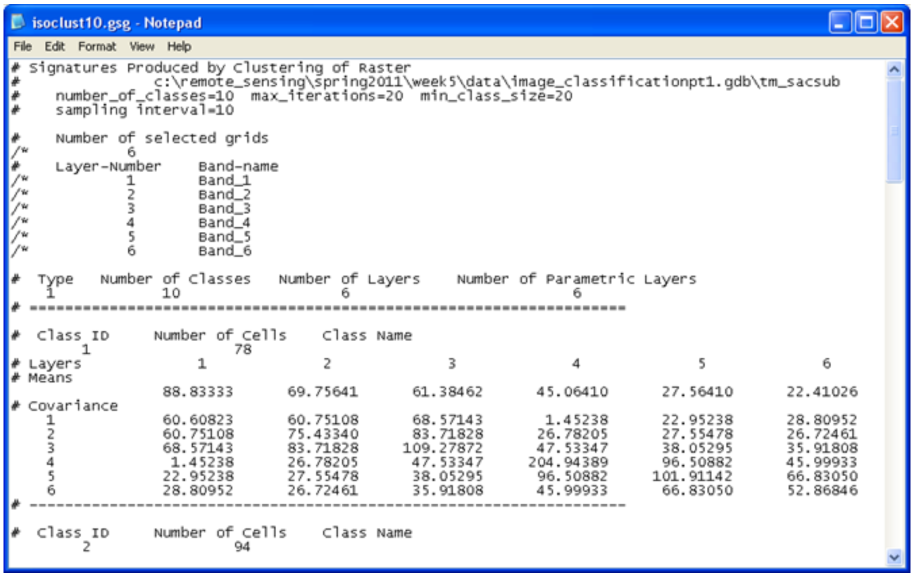


Figure 15 Output Classified Image


isoclust10.gsg - Notepad

```
# Signatures Produced by Clustering of Raster
#                  c:\remote_sensing\spring2011\week5\data\image_classificationpt1.gdb\tm_sacsub
#    number_of_classes=10  max_iterations=20  min_class_size=20
#    sampling interval=10

#    Number of selected grids
/*            6
#    Layer-Number     Band-name
/*            1       Band_1
/*            2       Band_2
/*            3       Band_3
/*            4       Band_4
/*            5       Band_5
/*            6       Band_6

#  Type    Number of Classes    Number of Layers    Number of Parametric Layers
    1             10                   6                      6
# ===================================================================

#  Class ID      Number of Cells     Class Name
       1                78
# Layers            1              2              3              4              5              6
# Means
                 88.83333       69.75641       61.38462       45.06410       27.56410       22.41026
# Covariance
    1            60.60823       60.75108       68.57143        1.45238       22.95238       28.80952
    2            60.75108       75.43340       83.71828       26.78205       27.55478       26.72461
    3            68.57143       83.71828      109.27872       47.53347       38.05295       35.91808
    4             1.45238       26.78205       47.53347      204.94389       96.50882       45.99933
    5            22.95238       27.55478       38.05295       96.50882      101.91142       66.83050
    6            28.80952       26.72461       35.91808       45.99933       66.83050       52.86846
# -------------------------------------------------------------------

#  Class ID      Number of Cells     Class Name
       2                94
```

Figure 16 Optional Signature File

Typically, once an unsupervised classification is performed significant work is still required by the analyst. The output of the unsupervised classification is "spectral" classes and not "information" classes.

Remember a "spectral class" is a set of pixels that have similar spectral characteristics (irrespective of the actual land cover type). This is why a spectral signature file can be created from an unsupervised classification routine.

An "information class" is one that actually represents one of the land cover categories in a classification scheme. An information class can be represented by one or more spectral classes and often requires a subsequent processing step to "recode" spectral classes into information classes. This process will discussed more depth further in this lesson.

Spectral classes derived from an unsupervised classification can and often do contain pixels from one or more specific land cover types. The analyst will not know which land cover type (or types) each spectral class represents. Additional field work, air photo interpretation, and/or additional image classification processes are required to properly identify unique land cover types in the resulting classification output data set.

Supervised Classification

This segment of the lesson discusses another traditional image classification process, the supervised classification. The object-based image classification method will not be discussed in this lesson since there are not methods within ArcGIS that where this can be used. The general process has already been identified and students are encouraged to review the references provided in the Overview of Remote Sensing lesson.

Supervised Steps

As the name implies the image classification requires supervision by the analyst. This comes in the form of creating spectral signatures for the different expected land cover classes in the geographic area. The analyst will know or be able to determine the specific land cover type for each spectral signature. The supervised classification process can be illustrated in three steps.

Step 1 - Training

The analyst creates "training" sites for the different land cover classes expected in the output. The analyst will create spectral signatures that cover the variability for each land cover type. The collection of spectral signatures represents the "knowledge" that is needed by the supervised classification to "train" the classifier to identify the specific land cover types in the output image.

Step 2 - Classification

Once the spectral signature file is created, it will be used as the primary input to perform the image classification.

Step 3 - Output

The last step (or really, the result of the classification step) is to create the actual output image. In addition to the output image, there may be associated tables of quantities of land cover types, an accuracy assessment, and a report.

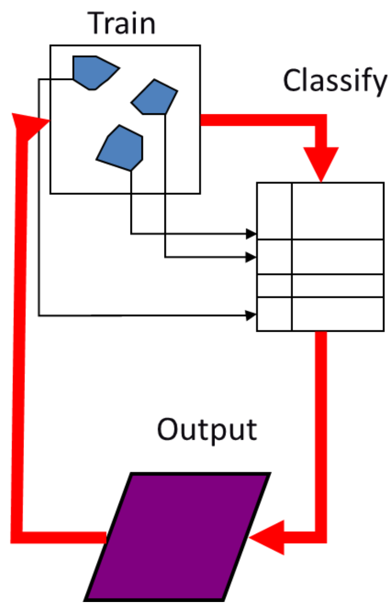


Figure 17 Supervised Classification Process

Creating Spectral Signatures

The key to the success of the supervised classification is the quality of the spectral signature file and the individual spectral signatures that make up the file. Each land cover type should have a number of spectral samples that represent the spectral variability of the class. Being able to properly identify these will often require field visits, air photo interpretation, and reviewing other land cover maps.

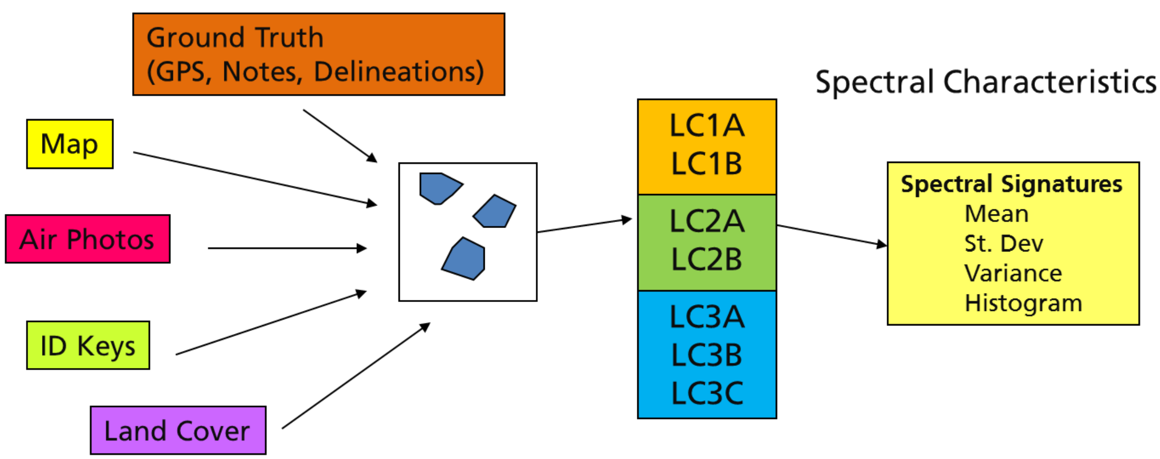


Figure 18 Example of Spectral Characteristics

Evaluating Spectral Signatures

Once the spectral signatures are created, they need to be individually and collectively evaluated to make sure each signature represents one and only one land cover type and the entire set of the spectral signatures represents well-grouped signatures that represent all of the land cover types expected in the resulting land cover classification data set. Spectral evaluation tools are often available in digital image processing software that is capable of performing image classifications.

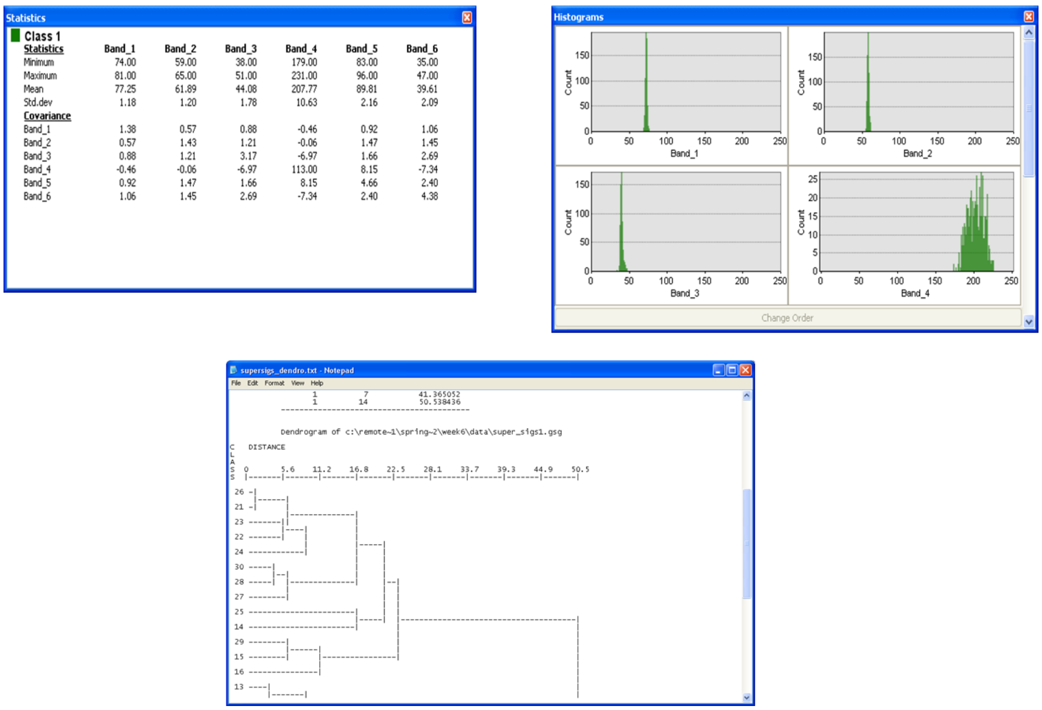
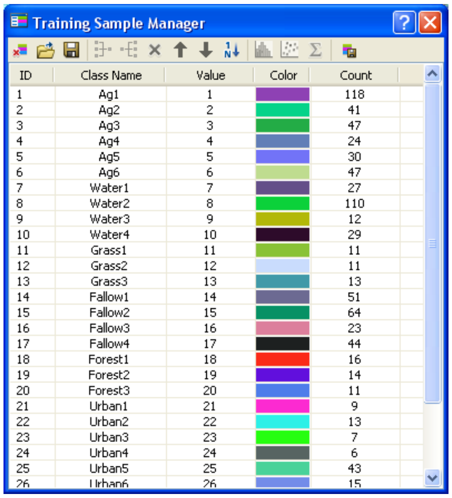


Figure 19 Digital Image Processing: Evaluating Spectral Signatures

Supervised Classification Example

Once a high quality spectral signature file is created and has been evaluated and tuned to contain the best set of spectral signatures of each land cover type, it is used in the supervised classification algorithm (often the Maximum likelihood algorithm) which then generates the output classified image.

The result of the supervised classification does contain the individual spectral classes where each category in the output supervised classification represents one of the spectral signatures from the spectral signature file. Since the signature file contains multiple signatures for each land cover type, the resulting image classification needs to be further refined into "information classes." This will be the subject of the next segment of the lesson titled, Spectral Classes to Information Classes, and will represent the final stage of the image classification process.



ID	Class Name	Value	Color	Count
1	Ag1	1		118
2	Ag2	2		41
3	Ag3	3		47
4	Ag4	4		24
5	Ag5	5		30
6	Ag6	6		47
7	Water1	7		27
8	Water2	8		110
9	Water3	9		12
10	Water4	10		29
11	Grass1	11		11
12	Grass2	12		11
13	Grass3	13		13
14	Fallow1	14		51
15	Fallow2	15		64
16	Fallow3	16		23
17	Fallow4	17		44
18	Forest1	18		16
19	Forest2	19		14
20	Forest3	20		11
21	Urban1	21		9
22	Urban2	22		13
23	Urban3	23		7
24	Urban4	24		6
25	Urban5	25		43
26	Urban6	26		15

Figure 20 Required Signature File

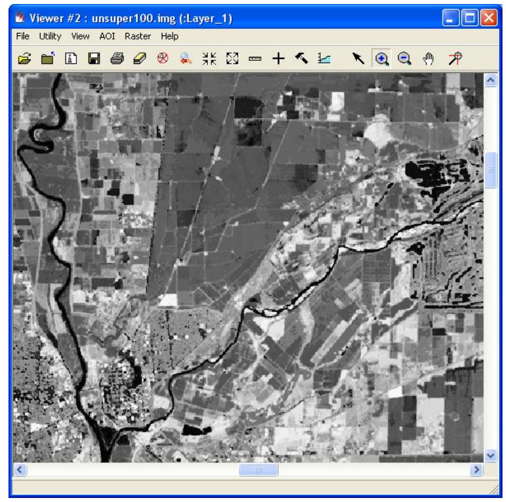


Figure 21 Output Classified Image

Recommended References: The following text is recommended for further study of spectral signatures.

Lillesand, Kiefer, and Chipman, 2007. *Remote Sensing and Image Interpretation*, 6th ed., Wiley & Sons, ISBN: 0470052457 and ISBN-13: 978-0470052457

Spectral Classes to Information Classes

This segment of the lesson covers the conversion of spectral classes to information classes. In many of the traditional image classifier routines the output image data set represents spectral classes, that is, each output class represents a unique set of pixels that have similar spectral characteristics. Since many spectral classes represent a single land cover type (or information class), a reclassification process is required to convert the spectral classes to the specific information classes that represent the land cover types in the final classification data set.

Conversion Process

A simple classification scheme (Figure 22) is shown on the left and a representation of the spectral signature file that was created to generate the image classification.

An output image classification is show at the bottom of Figure 22 and the corresponding spectral class categories shown above it. Note that each unique spectral class is represented by a number which also corresponds to the signature number in the table on the left side of Figure 22. The groups of spectral classes have been outlined in colored boxes that represent the different land cover types.

The arrows in the spectral class list are pointing to the individual information classes or the specific land cover types that the spectral will be reclassed. Once the spectral classes have been reclassed or recoded to the information class, which is from the spectral class numbers 11 through 55 to the information classes 1 through 5, the final land cover classification is complete.

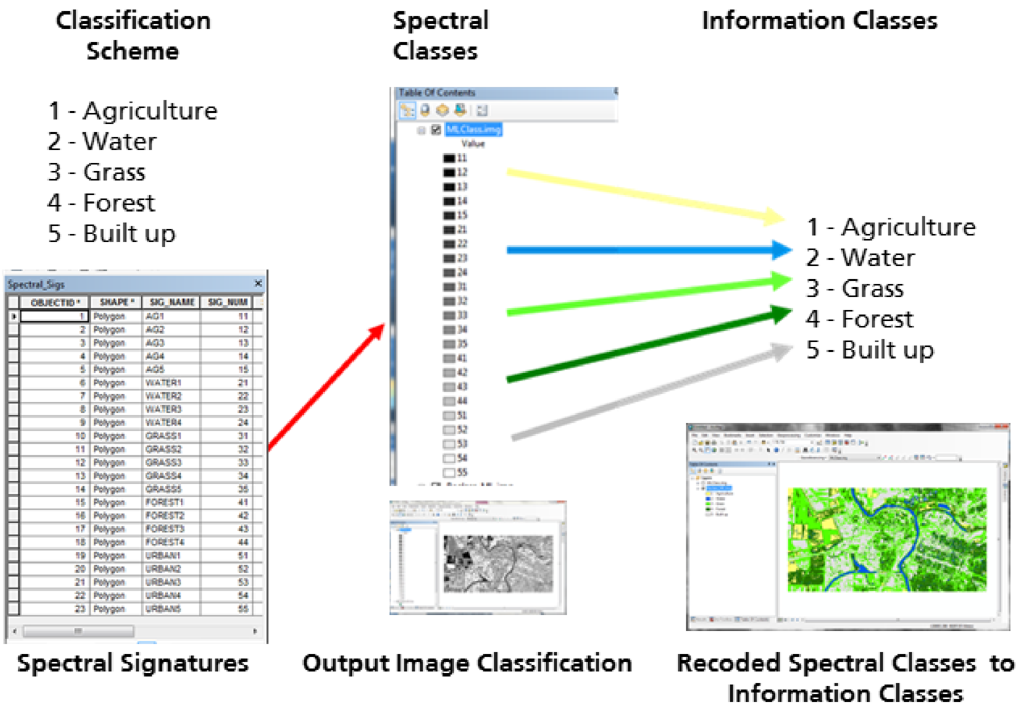


Figure 22 Conversion Process: Simple Classification Scheme

Spectral Class

This image is a more detailed representation of the original output from an image classification that shows the spectral classes. Note that this output image is normally depicted with gray scale values and then are assigned meaningful colors after the spectral classes have been recoded to information classes. You will note that the spectral classes range from 11 to 55, where each number represents a specific spectral class. See the previous Figure 22 and look at the spectral signature table to see the respective spectral signature names are that relate to the spectral class numbers.

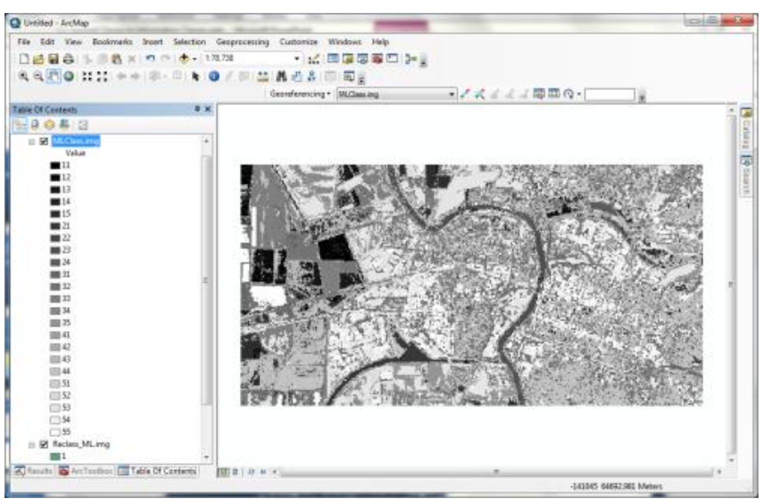


Figure 23 Output Classified Image

Information Classes

The image provided shows the final classification data set where the spectral classes have been recoded to the information classes. Colors have also been applied to make the resulting image more meaningful. Note also that the land cover names are showing in the table of contents of the ArcMap window.

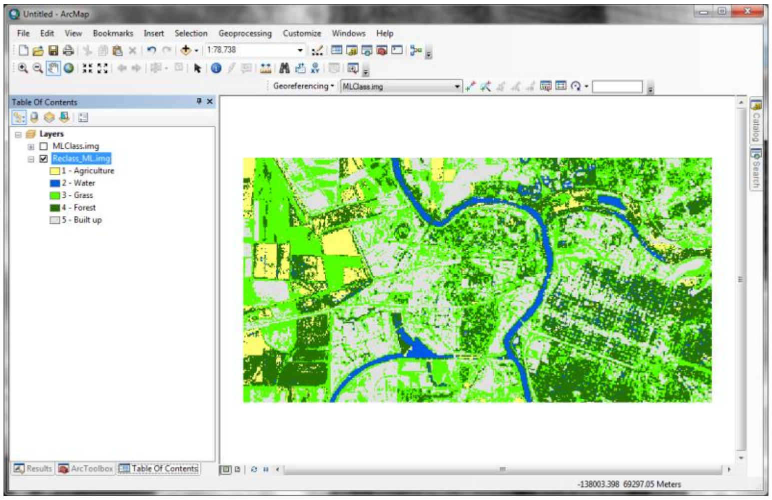


Figure 24 Recode Spectral Classes to Information Classes

Recode Spectral Classes to Information Classes

The recoding process is performed by using a tool to convert the spectral classes to information classes. In the case of ArcGIS, the Reclassify tool is used. The spectral classes 11 through 55 found in the output image from the supervised classification process are re-assigned to the values 1 through 5 to match the number corresponding to the specific land cover types (that is information classes) found in the classification scheme. Once the recoding process is complete, the image final image classification is complete. Appropriate colors can be assigned and the specific land cover names can be added to a table associated with the image file or can be renamed as part of a legend on a land cover map. Review Figures 25-27.

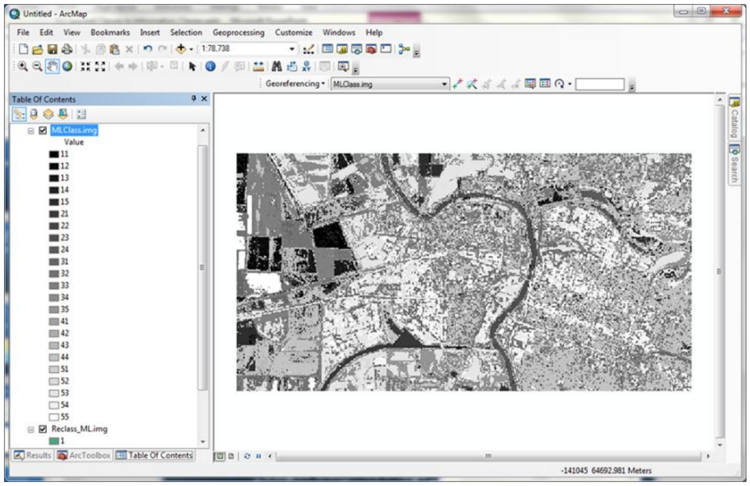


Figure 25 Output from Image Classification

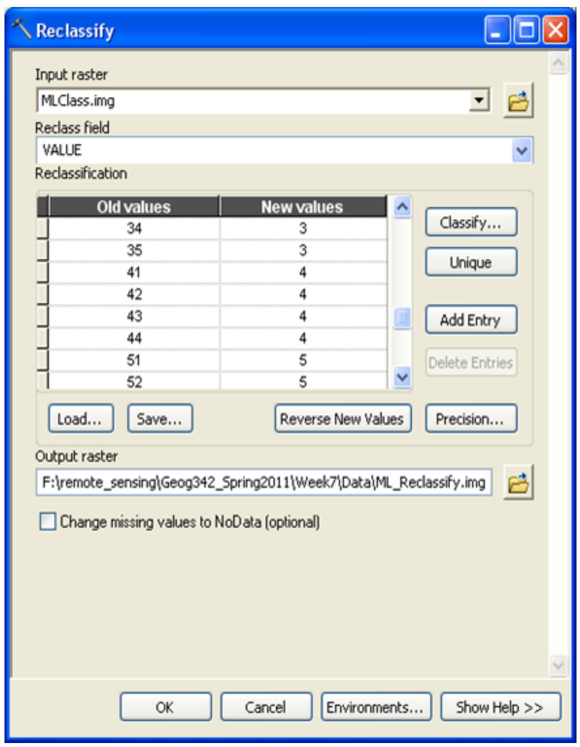


Figure 26 Screenshot of Reclassify box

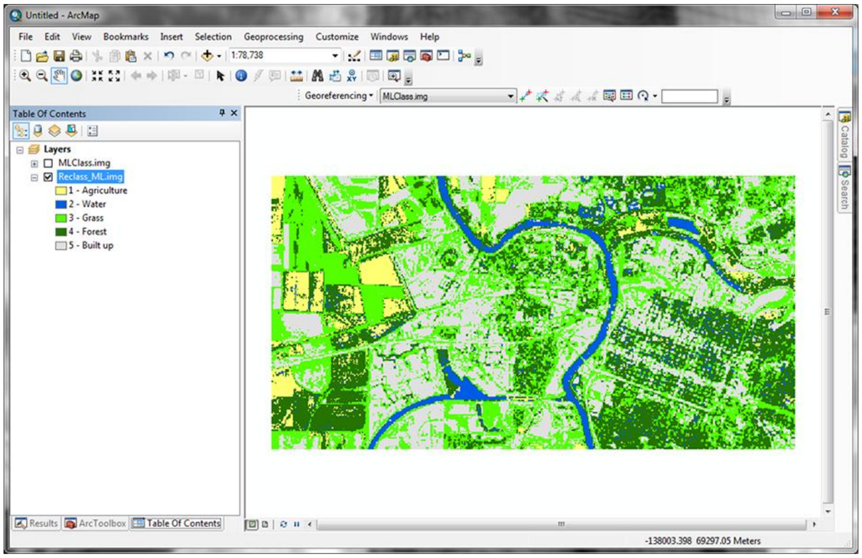


Figure 27 Recoded Spectral Classes to Information Classes

SUMMARY

In this lesson you learned about image classification. The first section of the lesson focused on what image classification and explains attributes, special features, and traditional image classification. You gained an understanding of how spectral signatures are used, and evaluated. Supervised and Unsupervised classification were also explained and demonstrated as well as the conversion process of spectral classes to information classes.

ASSIGNMENTS

1. Quiz
2. Lab: Unsupervised Classification
3. Lab: Supervised Classification

NISGTC

The National Information, Security & Geospatial Technologies Consortium

Authoring Organization: Del Mar College
Written by: Nate Jennings

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Lesson 6: Accuracy Assessment

INTRODUCTION

This lesson will provide a general overview of some of the basic concepts of accuracy assessment and how it can be used specifically for qualifying a land cover data set derived from remotely sensed imagery using image classification methods. The last lesson focused on different land cover classification methods. The classification process involved a number of steps and processes to actually generate the result, the classified land cover map; however, up to this point we do not know how good the result is.

LESSON OBJECTIVES

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

1. Explain the importance of accuracy assessments and why they are used for image classification project(s).

2. Describe the computed measures of a typical accuracy assessment.

3. Perform an accuracy assessment on the products of remote sensing workflows.

4. Incorporate accuracy assessment results into interpretation and analysis of workflow outputs.

LEARNING SEQUENCE

Required Reading	Read the following: • Online Lesson Material
Resources	View the following: • None
Assignments	Complete the following: • Quiz • Lab: Accuracy Assessment

INSTRUCTION

Accuracy Assessment: Classification Process

During the classification process, the analyst fills in the blanks with inputs and outputs and a few other parameters and clicks the OK button to generate a result. The analyst may have color coded the results or converted spectral classes into information classes, but we still don't know how good the answer is.

Authoring Organization: Del Mar College
Written by: Nate Jennings

For a real-world product, the data must be qualified with statistical information as to how good the result is and how well the methods used to produce the end product worked. Besides the quantitative assessment of the product, a written document often accompanies the results that provide the explanation and interpretation of the results.

Some software packages provide statistical analysis tools which can be used, but having some background such as education and/or training in statistics is often helpful, since the quantitative analysis, interpretation, and written documentation and explanation of the results are left to the analyst who performed the image analysis work.

Assessment Measures

The final classification an analyst obtains from a set of digital image processing methods is not finished until there is a quantitative assessment conducted.

The assessment provides two basic measures:

1. It provides a quantitative measure of how “good” the final classification is
2. It provides some inference as to how well the methods such as the training sets, the spectral signature analysis, and image processes methods were to generate the product.

If the image classification accuracy assessment turned out well, then one can conclude that the methods used to generate the result were appropriately conducted and executed.

Sampling Options

When talking about statistics one often refers to sampling methods and design to obtain samples that can be used to generate the statistics. Two common sampling methods that are used with image classification projects are random sampling and stratified random sampling.

Often times the stratified random sampling approach is used to collect training and accuracy assessment samples, since there are categories of land cover types that are being evaluated and so samples are often chosen within the geographic extents of these land cover types.

In any case, the samples taken must be independent. Samples should not be exactly adjacent to one another, since pixels in the adjacent area could be in more than one sample. The samples should also represent the spectral breadth of each land cover type, so samples should be taken throughout the extent of each category. Samples used for training the image classifier cannot be used for performing the accuracy assessment.

Ideally, an analyst would take enough samples for each land cover type that would result in “statistically valid” results. In many practical situations, this may not be possible. Regardless, taking independent samples to perform any quantitative analysis is better than no quantitative analysis.

Sampling Methods

The images provided illustrate two sampling methods: random sampling and stratified random sampling. The samples are taken at random locations throughout the image, irrespective of the land cover type.

Each of the colors represents specific land cover types. Within each category, random samples are chosen throughout the extent of the respective category. Normally, spectral samples are taken early in the land cover classification process before an actual image classification algorithms is executed. Once the land cover type for each spectral sample is known (often through the use of ground truth or photo interpretation), the samples are divided into training samples and accuracy assessment samples.

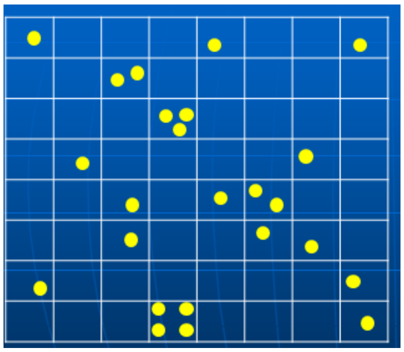


Figure 1 Random Sample

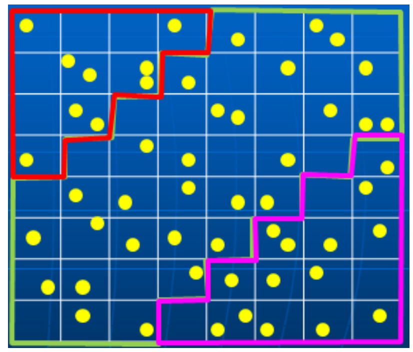


Figure 2 Stratified Random Sample

Image Classification Assessment Accuracy

This section focuses on the methods used to perform an accuracy assessment for an image classification. Typically, the stratified random sampling method is used to generate samples for the accuracy assessment. Depending on the software package an accuracy assessment can be performed using either individual pixels or groups of pixels. In most current image classification work, a group of pixels (or polygons) is the base unit for conducting the accuracy assessment. As mentioned earlier, the polygons used as training sites for the image classifier should not be used for assessing the accuracy of the image.

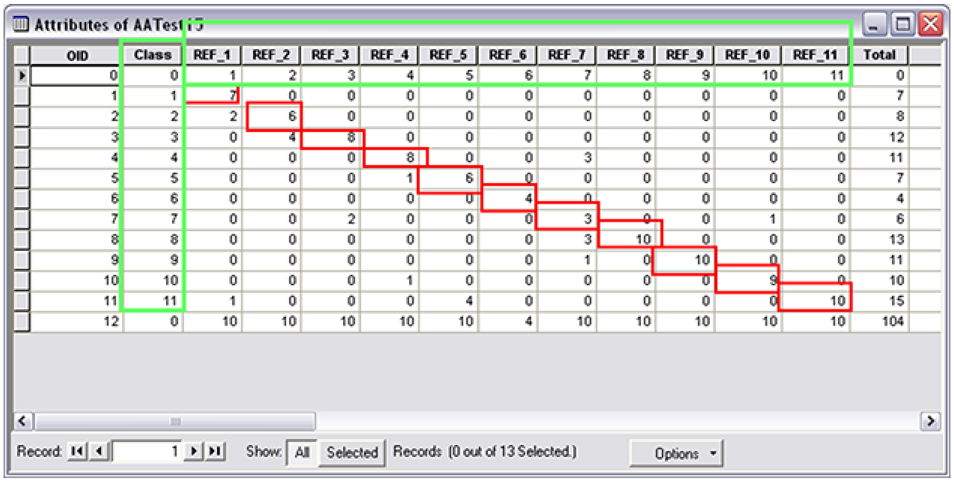
An analyst must have some kind of program to perform the accuracy assessment. Since the accuracy assessment computes statistical values, a statistics software package is needed such as Statistical Analysis System (SAS) or Statistical Package for the Social Sciences (SPSS) if the image processing software does not have an accuracy assessment routine or module. In the lab accompanying this unit, a custom-built accuracy assessment program has been created by the author that students can use for this course as well as their own image classification work. This program functions within the ArcGIS software. See the lab for more details.

A general rule of thumb for parsing out training versus accuracy assessment sites is to use approximately two thirds of the sites for training the classifier and about one third are set aside for performing the accuracy assessment. Since all of the spectral samples are delineated at the same time and the land cover type identified through ground truth or air photo interpretation, the sites can be divided into training and accuracy assessment sites for each land cover type before executing the image classifier.

Error Matrix

This is an example of an Error Matrix, a table that is created and filled in with values when an accuracy assessment program is executed. The matrix is essential a square table that has the same number of rows and columns which represent the different land cover types in the classified image.

When the accuracy assessment routine is run, the error matrix is filled in with values. The values along the diagonal, which are shown as the "red" boxes, represent the total number of accuracy assessment polygons that were categorized or classified correctly. The values that are off of the diagonal are accuracy assessment polygons that are misclassified.



OID	Class	REF_1	REF_2	REF_3	REF_4	REF_5	REF_6	REF_7	REF_8	REF_9	REF_10	REF_11	Total
0	0	1	2	3	4	5	6	7	8	9	10	11	0
1	1	7	0	0	0	0	0	0	0	0	0	0	7
2	2	2	6	0	0	0	0	0	0	0	0	0	8
3	3	0	4	8	0	0	0	0	0	0	0	0	12
4	4	0	0	0	8	0	0	3	0	0	0	0	11
5	5	0	0	0	1	6	0	0	0	0	0	0	7
6	6	0	0	0	0	0	4	0	0	0	0	0	4
7	7	0	0	2	0	0	0	3	0	0	1	0	6
8	8	0	0	0	0	0	0	3	10	0	0	0	13
9	9	0	0	0	0	0	0	1	0	10	0	0	11
10	10	0	0	0	1	0	0	0	0	0	9	0	10
11	11	1	0	0	0	4	0	0	0	0	0	10	15
12	0	10	10	10	10	10	4	10	10	10	10	10	104

Figure 3 Error Matrix Table

Measures Computed

Several measures are computed as part of the accuracy assessment.

1. The error matrix provides user's and producer's categorical accuracies for each land cover type
    a. A user's accuracy describes how well each land cover type is categorized in the data set
    b. A producer's accuracy describes how well the methods were implemented to achieve the land cover data set.
2. The overall accuracy
3. The Khat or Kappa statistic compares the overall accuracy with the possibility of randomly assigning land cover types to the image pixels.
4. In some accuracy programs a set of confidence intervals are provided for both the user's and producer's accuracy. The accuracy assessment program used in this lab computes confidence intervals.

Error Matrix – Commission Error (Included)

Each land cover category can be reviewed and evaluated in an error matrix. By looking at each row the analyst can look at all of the non-diagonal values to see what kind of confusion exists between the different land cover types. If the off-diagonal values are high or there are a large number of off-diagonal values within the error matrix, this can infer there is more confusion between the category that was assessed and other land cover types found in the image classification. These errors are grouped into two categories, commission error and omission error.

Commission errors are those non-diagonal values that occur along each row. In the example shown here 1 site of category 1 and 4 sites of category 5 were classified (or included) as category 11.

Attributes of AATest15

OID	Class	REF_1	REF_2	REF_3	REF_4	REF_5	REF_6	REF_7	REF_8	REF_9	REF_10	REF_11	Total
0	0	1	2	3	4	5	6	7	8	9	10	11	0
1	1	7	0	0	0	0	0	0	0	0	0	0	7
2	2	2	6	0	0	0	0	0	0	0	0	0	8
3	3	0	4	8	0	0	0	0	0	0	0	0	12
4	4	0	0	0	8	0	0	3	0	0	0	0	11
5	5	0	0	0	1	6	0	0	0	0	0	0	7
6	6	0	0	0	0	0	4	0	0	0	0	0	4
7	7	0	0	2	0	0	0	3	0	0	1	0	6
8	8	0	0	0	0	0	0	3	10	0	0	0	13
9	9	0	0	0	0	0	0	1	0	10	0	0	11
10	10	0	0	0	1	0	0	0	0	0	9	0	10
11	11	1	0	0	0	4	0	0	0	0	0	10	15
12	0	10	10	10	10	10	4	10	10	10	10	10	104

Record: 1 Show: All Selected Records (0 out of 13 Selected) Options

Figure 4 Error Matrix – Commission Error (Included)

Error Matrix – Omission Error (Excluded)

In a similar manner the omission error can be evaluated by looking at the non-diagonal values in each column. In this case, seven sites that should have been categorized as class 7 were categorized as another class. In this example, three of these sites were categorized as class 4, three were categorized as class 8, and one site was classified as class 9. As can be seen, class 7, class 4, and class 8 may have significant confused between the three classes and should each be re-evaluated before completing a final accuracy assessment to see if one or more of these mapped land cover types can be improved.

Attributes of AATest15

OID	Class	REF_1	REF_2	REF_3	REF_4	REF_5	REF_6	REF_7	REF_8	REF_9	REF_10	REF_11	Total
0	0	1	2	3	4	5	6	7	8	9	10	11	0
1	1	7	0	0	0	0	0	0	0	0	0	0	7
2	2	2	6	0	0	0	0	0	0	0	0	0	8
3	3	0	4	8	0	0	0	0	0	0	0	0	12
4	4	0	0	0	8	0	0	3	0	0	0	0	11
5	5	0	0	0	1	6	0	0	0	0	0	0	7
6	6	0	0	0	0	0	4	0	0	0	0	0	4
7	7	0	0	2	0	0	0	3	0	0	1	0	6
8	8	0	0	0	0	0	0	3	10	0	0	0	13
9	9	0	0	0	0	0	0	1	0	10	0	0	11
10	10	0	0	0	1	0	0	0	0	0	9	0	10
11	11	1	0	0	0	4	0	0	0	0	0	10	15
12	0	10	10	10	10	10	4	10	10	10	10	10	104

Record: 1 Show: All Selected Records (0 out of 13 Selected) Options

Figure 5 Error Matrix – Omission Error (Excluded)

Error Matrix – User's Accuracy

The user's accuracy can be computed by taking the number of polygons that were correctly classified and divided by the row total. These are shown in the yellow boxes (Figure 6). In addition, Figure 7 shows another part of the error matrix table that contains the actual user's accuracy for this land cover class. Also, the respective confidence intervals are computed as well.

Attributes of AATest15

OID	Class	REF_1	REF_2	REF_3	REF_4	REF_5	REF_6	REF_7	REF_8	REF_9	REF_10	REF_11	Total
0	0	1	2	3	4	5	6	7	8	9	10	11	0
1	1	7	0	0	0	0	0	0	0	0	0	0	7
2	2	2	6	0	0	0	0	0	0	0	0	0	8
3	3	0	4	8	0	0	0	0	0	0	0	0	12
4	4	0	0	0	8	0	0	3	0	0	0	0	11
5	5	0	0	0	1	6	0	0	0	0	0	0	7
6	6	0	0	0	0	0	4	0	0	0	0	0	4
7	7	0	0	2	0	0	0	3	0	0	1	0	6
8	8	0	0	0	0	0	0	3	10	0	0	0	13
9	9	0	0	0	0	0	0	1	0	10	0	0	11
10	10	0	0	0	1	0	0	0	0	0	9	0	10
11	11	1	0	0	0	4	0	0	0	0	0	10	15
12	0	10	10	10	10	10	4	10	10	10	10	10	104

Record: 1 Show: All Selected Records (0 out of 13 Selected.) Options

Figure 6 Error Matrix – User's Accuracy Table 1

Attributes of AATest15

Total	Users	ULow95CI	UHigh95CI	Producers	PLow95CI
0	0	0	0	0	0
7	100	98.1312	101.869	70	68.614
8	75	73.5676	76.4324	60	58.645
12	66.6667	65.3306	68.0027	80	78.413
11	72.7273	71.3243	74.1303	80	78.440
7	85.7143	84.1169	87.3116	60	58.645
4	100	98.1312	101.869	100	97.533
6	50	48.9301	51.0699	30	29.099
13	76.9231	75.4641	78.382	100	98.029
11	90.9091	89.2187	92.5995	100	98.029
10	90	88.3264	91.6736	90	88.234
15	66.6667	65.3828	67.9506	100	98.029
104	0	0	0	0	0

Record: 1 Show: All Selected Records (0 out of 13 Selected.) Op

Figure 7 Error Matrix – User's Accuracy Table 2

Error Matrix – Producer's Accuracy

Likewise, the producer's accuracy can be computed by taking the number of correctly classified polygons and dividing by the column total as shown in the yellow boxes (Figure 8). Figure 9 shows the respective producer's accuracy and the accompanying confidence intervals.

Attributes of AATest15

OID	Class	REF_1	REF_2	REF_3	REF_4	REF_5	REF_6	REF_7	REF_8	REF_9	REF_10	REF_11	Total
0	0	1	2	3	4	5	6	7	8	9	10	11	0
1	1	7	0	0	0	0	0	0	0	0	0	0	7
2	2	2	6	0	0	0	0	0	0	0	0	0	8
3	3	0	4	8	0	0	0	0	0	0	0	0	12
4	4	0	0	0	8	0	0	3	0	0	0	0	11
5	5	0	0	0	1	6	0	0	0	0	0	0	7
6	6	0	0	0	0	0	4	0	0	0	0	0	4
7	7	0	0	2	0	0	0	[illegible]	[illegible]	0	1	0	6
8	8	0	0	0	0	0	0	3	10	0	0	0	13
9	9	0	0	0	0	0	0	1	0	10	0	0	11
10	10	0	0	0	1	0	0	0	0	0	9	0	10
11	11	1	0	0	0	4	0	[illegible]	[illegible]	0	0	10	15
12	0	10	10	10	10	10	4	[illegible]	10	10	10	10	104

Record: 1 Show: All Selected Records (0 out of 13 Selected.) Options

Figure 8 Error Matrix – Producer's Accuracy Table 1

Attributes of AATest15

Total	Users	ULow95CI	UHigh95CI	Producers	PLow95CI	PHigh95CI	Overall	KHAT
0	0	0	0	0	0	0	0	0
7	100	98.1312	101.869	70	68.6141	71.3859	77.8846	0.755918
8	75	73.5676	76.4324	60	58.6452	61.3548	0	0
12	66.6667	65.3306	68.0027	80	78.4131	81.5869	0	0
11	72.7273	71.3243	74.1303	80	78.4402	81.5598	0	0
7	85.7143	84.1169	87.3116	60	58.6452	61.3548	0	0
4	100	98.1312	101.869	[illegible]	97.5337	102.466	0	0
6	50	48.9301	51.0699	30	29.0994	30.9006	0	0
13	76.9231	75.4641	78.382	100	98.0291	101.971	0	0
11	90.9091	89.2187	92.5995	[illegible]	[illegible]	[illegible]	0	0
10	90	88.3264	91.6736	90	88.2348	91.7652	0	0
15	66.6667	65.3828	67.9506	100	98.0291	101.971	0	0
104	0	0	0	0	0	0	0	0

Record: 1 Show: All Selected Records (0 out of 13 Selected.) Options

Figure 9 Error Matrix – User's Accuracy Table 2

Error Matrix – Overall Accuracy

The overall accuracy can be computed by taking summing the individual values along the diagonal and dividing by the total number of accuracy assessment sites. The values along the diagonal are accuracy assessment polygons that have been correctly classified (Figure 10). The overall accuracy assessment is shown in the table illustrated in Figure 11.

Attributes of AATest15

OID	Class	REF_1	REF_2	REF_3	REF_4	REF_5	REF_6	REF_7	REF_8	REF_9	REF_10	REF_11	Total
0	0	1	2	3	4	5	6	7	8	9	10	11	0
1	1	7	0	0	0	0	0	0	0	0	0	0	7
2	2	2	6	0	0	0	0	0	0	0	0	0	8
3	3	0	4	8	0	0	0	0	0	0	0	0	12
4	4	0	0	0	8	0	0	3	0	0	0	0	11
5	5	0	0	0	1	6	0	0	0	0	0	0	7
6	6	0	0	0	0	0	4	0	0	0	0	0	4
7	7	0	0	2	0	0	0	3	0	0	1	0	6
8	8	0	0	0	0	0	0	3	10	0	0	0	13
9	9	0	0	0	0	0	0	1	0	10	0	0	11
10	10	0	0	0	1	0	0	0	0	0	9	0	10
11	11	1	0	0	0	4	0	0	0	0	0	[illegible]	[illegible]
12	0	10	10	10	10	10	4	10	10	10	10	[illegible]	104

Record: 1 Show: All Selected Records (0 out of 13 Selected.) Options

Figure 10 Error Matrix – Overall Accuracy Table 1

Attributes of AATest15

Total	Users	ULow95CI	UHigh95CI	Producers	PLow95CI	PHigh95CI	Overall	KHAT
0	0	0	0	0	0	0	0	0
7	100	98.1312	101.869	70	68.6141	71.3859	77.8846	0.755918
8	75	73.5676	76.4324	60	58.6452	61.3548	0	0
12	66.6667	65.3306	68.0027	80	78.4131	81.5869	0	0
11	72.7273	71.3243	74.1303	80	78.4402	81.5598	0	0
7	85.7143	84.1169	87.3116	60	58.6452	61.3548	0	0
4	100	98.1312	101.869	100	97.5337	102.466	0	0
6	50	48.9301	51.0699	30	29.0994	30.9006	0	0
13	76.9231	75.4641	78.382	100	98.0291	101.971	0	0
11	90.9091	89.2187	92.5995	100	98.0291	101.971	0	0
10	90	88.3264	91.6736	90	88.2348	91.7652	0	0
15	66.6667	65.3828	67.9506	100	98.0291	101.971	0	0
104	0	0	0	0	0	0	0	0

Record: 1 Show: All Selected Records (0 out of 13 Selected.) Options

Figure 11 Error Matrix – Overall Accuracy Table 2

Kappa "Khat" Statistics

The Kappa or "Khat" statistic is also commonly computed and shown in addition to the overall accuracy value. This value provides a measure that compares the actual accuracy assessment to that of randomly assigning pixels to land cover categories or chance agreement. Provide below is the basic computation that is involved. The actual computation can be found in the *Remote Sensing and Image Interpretation* book by Lillesand, Kiefer, and Chipman, (2007). The same computation logic is used in the accuracy assessment program provided in the lesson 6 lab.

As an example, if a Khat value of 0.70 was computed, this means that the image classification is 70% better than an image classification resulting from chance (or random assignment of pixels to land cover categories).

Khat = <u>Observed Accuracy – Chance Agreement</u>
1 – Chance Agreement

$$\text{Khat} = \frac{\text{Observed Accuracy} - \text{Chance Agreement}}{1 - \text{Chance Agreement}}$$

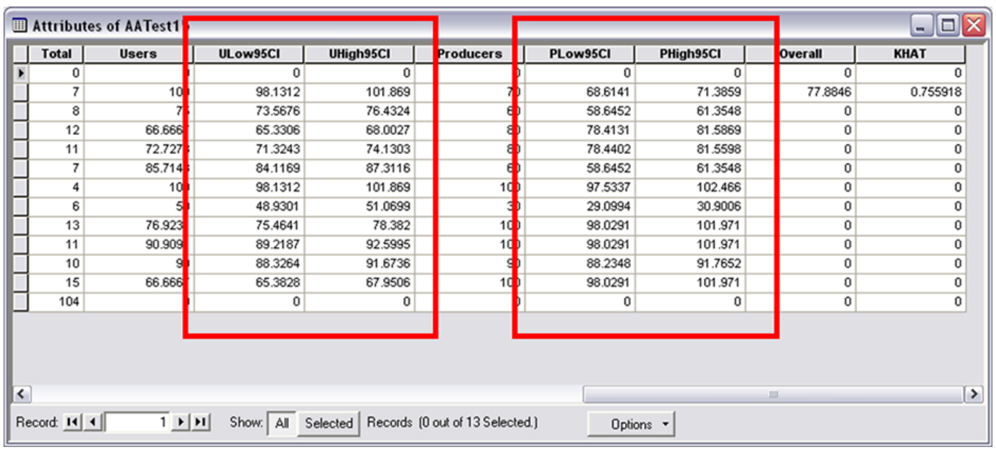
Khat = 0.70 indicates an observed classification is 70% better than one resulting from chance.

Key Elements of Khat Statistics

- Khat tends to be stated as a lower and more conservative value than the overall accuracy
- A low Khat value indicates that an observed classification accuracy is no better than a random assignment of pixels
- The Khat computation incorporates diagonal and non-diagonal components
- Both the overall and the Khat statistics are stated as part of an accuracy assessment.

Confidence Intervals

The confidence intervals for each category are also useful since they can provide a low and high range for the user's and producer's accuracy to fall within and can provide a measure of how variable the categorical accuracy can be throughout the resulting image classification.



Total	Users	ULow95CI	UHigh95CI	Producers	PLow95CI	PHigh95CI	Overall	KHAT
0	0	0	0	0	0	0	0	0
7	100	98.1312	101.869	70	68.6141	71.3859	77.8846	0.755918
8	75	73.5676	76.4324	60	58.6452	61.3548	0	0
12	66.6667	65.3306	68.0027	80	78.4131	81.5869	0	0
11	72.7273	71.3243	74.1303	80	78.4402	81.5598	0	0
7	85.7143	84.1169	87.3116	60	58.6452	61.3548	0	0
4	100	98.1312	101.869	100	97.5337	102.466	0	0
6	50	48.9301	51.0699	30	29.0994	30.9006	0	0
13	76.923	75.4641	78.382	100	98.0291	101.971	0	0
11	90.909	89.2187	92.5995	100	98.0291	101.971	0	0
10	90	88.3264	91.6736	90	88.2348	91.7652	0	0
15	66.6667	65.3828	67.9506	100	98.0291	101.971	0	0
104	0	0	0	0	0	0	0	0

Figure 12 Confidence Intervals Table

Accuracy

To conclude, an image analyst is more concerned with the quality of each class being classified correctly, that is, the producer's accuracy. The user is often concerned about how well each class has been identified, that is the user's accuracy. Also, the categorical accuracies are often more important that the overall accuracy because the end-user really does want to be able to have confidence in the mapped land cover types, since the specific categories may be used in subsequent processes and analyses.

SUMMARY

In this lesson you learned about accuracy assessment and image classification assessment accuracy. The classification process and assessment measures were explained and sampling examples were provided for your understanding. This lesson also provided examples and an explanation of an error matrix used to determine the accuracy of images.

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ASSIGNMENTS

1. Quiz
2. Lab: Accuracy Assessment