

Studying Earth's Environment

From Space

**Module 2:
Computer Lab
Exercises**

**EXPLORING
GLOBAL LAND
VEGETATION USING
NASA SATELLITE
DATA**

Release: December 2002

**NASA Goddard Space Flight Center,
Earth Sciences Directorate**

If you have comments, problems or suggestions,
please email helpdesk@see.gsfc.nasa.gov



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List Of Exercises

Exercise 1—Introduction to AVHRR Images and Creating Global NDVI Images

Examine Advanced Very High Resolution Radiometer (AVHRR) data used to study global vegetation coverage and dynamics. Calculate the Normalized Difference Vegetation Index (NDVI) from the AVHRR data, investigate how the data is processed, and study how these images allow us to detect vegetation.

Exercise 2—Seasonal Greening of the Hemispheres

Examine how NDVI values change throughout the year, reflecting vegetation changes throughout the seasons. Using composite NDVI images for 1993, create a montage, animate a stack of NDVI images, and generate temporal profiles to view the dynamics of the seasonal changes.

Exercise 3—Vegetation Classification and Global Vegetation Patterns

Learn about vegetation classification and its importance in studying net primary productivity and in monitoring changes in Earth's surface vegetation. Look at a global classified land cover image. Investigate how the image was generated and use temporal profiles from NDVI images to classify land cover by matching the profiles to a profile legend.

Exercise 4—Land Cover Change in the Brazilian Amazon

Determine the role humans play in the change in land cover by examining NDVI images of the Amazon Basin in Brazil, in the state of Rondonia, where large tracts of land have been converted from forest to grazing land. Look at NDVI imagery for two dates that are several years apart, overlay road data, and perform a simple change detection procedure to highlight those areas that have been affected.

Exercise 5—Vegetation Dynamics in the Sahelian Zone

Determine the role that climatic change has on land cover conversion by examining the Sahel region of Africa -- a transition region between the Sahara desert and the wooded grasslands and tropical rainforests in central Africa. Use climatic precipitation data and animate several NDVI images to see how vegetation changes from year to year. Quantify results by calculating mean, standard deviation, and coefficient of variation of the images. Use image processing techniques to highlight a drought that took place in 1984.

Exercise 6—Comparing Estimates of Global Terrestrial Primary Production

Estimate Net Primary Productivity (NPP) and how it is important in understanding global biospheric functioning. Estimate global NPP using satellite imagery. Use two simple estimation methods and compare those results with a more mechanistic approach.

Introduction To Module 2: Global Land Vegetation Computer Lab Exercises

Overview

The set of exercises that follow were designed to explore characteristics of land cover and vegetation dynamics using satellite data. These exercises introduce students to basic image processing skills to display and analyze AVHRR and NDVI images demonstrating basic scientific applications. Each exercise has scientific discussions explaining what the student is observing. Students will use *NASA Image2000* to display and analyze the data sets.

The exercises are inquiry based and designed for advanced high school or college level classes. Our electronic textbook on global land vegetation contains supporting scientific information that may be used to answer and explain the distribution and dynamics of vegetation that the students will be observing. Additional background information can be found on the SEE website at <http://see.gsfc.nasa.gov/edu/SEES/>, in the Computer Lab Resources Data section, Satellite Data Information.

Before You Begin

These exercises assume that the *NASA Image2000* software and the Exercise Data are correctly installed on your system. Refer to the *NASA Image2000 Users Guide: Basic Operations* for assistance in installing the software.

NASA-Image2000

NASA Image2000 is an image processing software package available on multiple platforms, designed to bring high-end scientific image processing capabilities to the standard desktop computer. Developed to meet the needs of educators, *NASA Image2000* supports the display, analysis and processing of satellite imagery.

In the past, users have been forced to choose between software designed for expensive high-end computer systems, and software that lacked many of the tools necessary for performing analysis of satellite images. *NASA Image2000* is designed to provide those tools in a system that is suitable for simple applications, such as would be used in a classroom, but is powerful enough to support research.

The functionality built into *NASA Image2000* was designed to provide the capability for the display and analysis of geo-coded satellite imagery. The breadth of functionality, however, goes well beyond this scope, and most types of images can be used. Users can perform standard image processing tasks, similar to those available in general graphics packages. In addition, the system provides other less common functions, which are specifically intended for use with scientific images. These exercises provide an introduction both to image processing in general, and to the specific use of *NASA Image2000*.

Why Study Changes in Global Land Vegetation?

The study of global vegetation is of interest to numerous scientific (and other) disciplines, including but not limited to biology, ecology, forestry, agronomy, hydrology, meteorology, and some social sciences. Diverse questions require and utilize vegetation analysis. For example, an agricultural specialist might use satellite images to monitor wheat crops while a sociologist could use the same images to study land use practices. Foresters could look at forest extent to estimate timber amount while ecologists might need to use similar spacial areas in studies of nutrient cycling.

Vegetation dynamics refer to changes in vegetation over time, with temporal scales ranging from diurnal to seasonal, annual, decadal, and beyond. Changes can be relatively slow or fast, catastrophic or more subtle, depending on the cause. A variety of forces induces vegetation change, including seasonal variation (seasonal vegetation change is known as phenology), interannual meteorological differences, longer-term climate change, human activity (deforestation, burning of fossil fuel, acid rain, pollution), geologic events such as volcanic eruptions and over geologic time the moving of lithospheric plates.

Global vegetation and its dynamics play significant roles in energy and water budgets, atmospheric composition, land surface stabilization and roughness, land surface albedos (brightness or reflectance), animal habitats, and the production of food, materials and pharmaceuticals. Understanding changes in vegetation patterns and compositions through time, both in the short-and long-term, is crucial for assessments and predictions of global ecological conditions and sustainability of life-enhancing resources. The consequences of vegetation variability, whether caused by anthropogenic and/or naturally occurring forces, need to be considered as human population grows and presumably peaks in the 21st century. Remote sensing technologies employing satellites provide the ability to repeatedly image and monitor vegetation dynamics over large areas, including the entire globe. This makes the task of studying vegetation change on a global basis an attainable one.¹

The Data Set

The NOAA (National Oceanic and Atmospheric Administration) series satellites are meteorological platforms, designed to assist in weather prediction and monitoring. Sensors onboard meteorological satellites generally have very low spatial resolution compared to sensors that spe-

EXAMPLE

...Title of procedure...

1. Insert ...
 2. Select ...
 3. Go to:
 <i2kinstalled>| data | SEES |
 vegex1 | CHAN1ORB.TIF
 - 4—Click on ...
-

¹ Horning, Ned and Russell, Carol, *Studying Earth's Environment from Space* electronic textbook, Ch. 1

cifically study land features, however, their temporal resolution is high and areal coverage large, obtaining global information very frequently.

These satellites carried the AVHRR (Advanced Very High Resolution Radiometer), a wide-angle-view sensor with 5 spectral channels. The spatial resolution at nadir is 1.1 km, and NOAA archives AVHRR data in two forms: LAC (Local Area Coverage) data retain full resolution (1.1 km) and GAC (Global Area Coverage) data are resampled to 4 km spatial resolution.

Annual sequences of NDVI (Normalized Difference Vegetation Index) over the globe have been calculated using AVHRR spectral channels 1 and 2. The NDVI is useful for monitoring vegetation dynamics in time and space.²

The NDVI Images used in these exercises come from the global data set stored at the NASA Goddard Space Flight Center Distributed Active Archive Center (DAAC). The image files used in each computer lab exercise can be found at:

`<i2kinstalled>/data/SEES/Veg/vgex1-vgex6`

Getting Started

To use *NASA Image2000* software with Module 2: Global Land Vegetation, review the read.me file on the NASA Image2000 CD under “Using NASA Image2000 Software with outside applications, *Studying Earth's Environment from Space (SEES)*”. Instructions are listed on how to find SEES classroom resources (the electronic textbooks) and SEES computer lab resources (computer exercises, data satellite and sensor information, and instructor's guides).

Loading the Data

All the images and software required for using these lessons are included in the *NASA Image2000 CD* (v.1.1 or higher). Simply install the software as indicated in the Read Me file on the DC or in the *NASA-Image2000 Basic Users Guide (Section 2)*, located in the doc folder.

Important Notes On Presentation

Because there are multiple data source possibilities, navigational paths for moving through the hierarchical directory structure of your computer and *NASA Image2000* materials are referenced from the

² Horning, Ned and Russell, Carol, *Studying Earth's Environment from Space* electronic textbook, Ch. 5

location of your *NASA Image2000* installation. The path is depicted as follows:

```
<i2kinstalled>| data | SEES | < module name > |  
  <exercise name > | <file name >
```

In addition, notes, specific tasks and exercises are presented in the left column (see example at left).

For Further Research:

How to use the SEES electronic text to support inquiry based exercises

In several of the computer lab exercises, questions will be asked of the user that can not be directly answered through the image analysis software and activities. These questions can be directed to the SEES electronic textbook. This electronic textbook is organized like a printed textbook. It also contains digital files for the graphics that you may either view directly on screen or obtain high-resolution versions for sending to a printer to make color view graphs for overhead projectors. A glossary for each module is also provided. The electronic textbook for each module can also be used to support lecture materials, independent student investigations, or other applications that may require more detailed scientific background.

Accessing the SEES electronic textbook

The SEES electronic textbook is available in two locations:

- 1) On the web at <http://see.gsfc.nasa.gov/edu/SEES>. From the home page, find the link "Class Resources" under the module you are interested in. This will pull up the textbook homepage for that module. Links to each chapter are listed here, leading you to the detailed etext, digital files, and graphics you are searching for.
- 2) On the CD "Studying Earth's Environment from Space, educational materials for students and teachers grades 11-16," available from the NASA CORE (Central Operation of Resources for Education), at <http://core.nasa.gov> or toll free 866-776-CORE. Once the CD is loaded on your computer, you can access the home page for the etext by going to sees_v1/htmlpages/index.html for ozone and global land vegetation modules and sees_v2/htmlpages/index.html for polar sea ice and oceanography modules.

If you have comments, problems, or suggestions, please e-mail helpdesk@see.gsfc.nasa.gov.

Exercise 1: Introduction To AVHRR Images And Creating Global NDVI Images

Overview

In order to study global Vegetation coverage and dynamics it is necessary to have access to an appropriate data set. Imagery from satellites can often provide these data. One sensor in particular is especially well suited for global Vegetation studies, the Advanced Very High Resolution Radiometer (AVHRR) which is flown on NOAA's TIROS-N series satellites. The AVHRR sensor has five bands which range from the visible wavelengths to the thermal infrared. Using data from the first two channels, it is possible to create an image which is sensitive to the chlorophyll in plants and can therefore be used to map Vegetation. The resulting image is called a Normalized Difference Vegetation Index image (NDVI).

The remaining exercises in this module use NDVI images that come from the global data set that is stored at the NASA Goddard Space Flight Center Distributed Active Archive Center (DAAC). In this exercise we will see how these data are processed and how the NDVI images are created. To start with, we will go through the different processing steps necessary to create NDVI and composite images. We will then calculate an NDVI image and see how these images allow us to detect Vegetation. In the remaining part of the exercise we will compare images acquired using the five bands of the AVHRR sensor.

Background On The AVHRR Sensor



[SEES_v1/html_pages/vg_comp.html](https://sees.v1/html_pages/vg_comp.html) (Computer Lab Resources for GLV) "*Satellite and Sensor*". Global Vegetation Satellite and Sensor Information: The AVHRR instrument and associated platforms, Sections 1.1 and 1.2.

The NOAA TIROS-N series satellites which carry the AVHRR sensor operate in a circular, near-polar, Sun-synchronous orbit approximately 850 km above Earth. With this orbit the satellite circles Earth 14.1 times every day which is enough to provide global coverage twice a day. With each pass the AVHRR sensor can acquire a swath of data approximately 2,700 km wide. This is possible because the AVHRR sensor has a field of view that allows it to view up to 55° on either side of nadir (directly below it). When the sensor is at nadir, the resolution is 1.1 km x 1.1 km or 1.2 km². However, the resolution becomes coarser as the sensor scans off to the side. When it is at 55° the resolution is approximately 17 km² (pixel area is about 17km²) and the pixel shape is far from square. Because of this extreme distortion it is a common practice to use only the portion of an image that is within 30° of nadir. The

Before Beginning

- Make sure you have read through the Introduction to Module 2: Global Land Vegetation Computer Lab Exercises document.
 - Start *NASA Image2000*, or if it is already running close any open images
-

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number of lines in an image is dependent on how long the sensor is turned on. Each scan acquires one line and the instrument can scan at a rate of 6 lines per second.

The AVHRR sensor provides imagery with a high resolution of approximately 1 km² but can also provide a lower image resolution of approximately 16 km². In addition, several other resolutions can be created during the processing phase. Image resolutions used in the exercises for this module are either 8 km x 8 km or 1° x 1°.

Most of the AVHRR instruments acquire data in five channels although a new instrument launched in 1998 uses six channels. For the five-channel instruments, the first two channels detect reflected wavelengths in green and near infrared wavelengths. The third channel detects energy in midinfrared wavelengths and the fourth and fifth channels detect emitted thermal-infrared energy. Table 1 provides the actual wavelength ranges for each channel. The unit of the values for the first three channels is reflectance which is the fraction of incoming sunlight that is reflected. The two thermal channel units are Kelvin temperature.

Table 1: Wavelength Sensitivity for Each Channel of the AVHRR Sensors

Channel #	TIROS-N	NOAA-6, 8, 10	NOAA-7, 9, 11, 12, 14	NOAA 13
1	0.55-0.90 mm	0.58-0.68 mm	0.58-0.68 mm	0.58-0.68 mm
2	0.725-1.10 mm	0.725-1.10 mm	0.725-1.10 mm	0.725-1.10 mm
3	3.55-3.93 mm	3.55-3.93 mm	3.55-3.93 mm	3.55-3.93 mm
4	10.5-11.5 mm	10.5-11.5 mm	10.5-11.3 mm	10.5-11.3 mm
5	Channel 4 rep.	Channel 4 rep.	11.5-12.5 mm	11.5-12.5 mm

 **Exercise 1.A**

Opening uncorrected images from the five AVHRR channels

1. Pull down the **File** menu and select **Open**. Locate the following file and click on **Open**:
<i2kinstalled> | data | SEES | Veg | vgex1 | CHAN1ORB.TIF
2. Click on the pan (hand) tool in the Tools window and then move the hand to the CHANORB1.TIF image. Click and hold the mouse button then drag the hand toward the top or bottom of the image window to move the image. Explore the image using the hand tool.
3. Repeat the above steps for CHAN2ORB.TIF, CHAN3ORB.TIF, CHAN4ORB.TIF, and CHAN5ORB.TIF.

Exploring Uncorrected AVHRR Images

 **Do Exercise 1.A now.**

These images were acquired by the AVHRR instrument onboard NOAA-11 during one orbit on the afternoon of day 270 (September 27) in 1991. For this satellite, the afternoon orbit goes from south to north (ascending). The scanner acquires data at a rate of 6 lines/second. The image resolution at nadir is 1.1 km x 1.1 km.

Look at the images. CHAN2ORB.TIF gives the best contrast in land and sea features.

Answer These Questions:

1. Can you tell what area of Earth these images cover? Explain.
2. Why are the images upside down?
3. Why do the images look distorted near the left and right edge?
- 4a. Is there a way to determine how long the sensor took to acquire these images? (Hint: Make sure the arrow tool is selected and the image is active. Then pull down the **View** menu and select **Image Info**, and click on the **Source** tab to get the dimensions of one of the images. Height is equivalent to number of scan lines). Explain.
- 4b. Determine the time it took to acquire the images.

Close all images before proceeding.

Investigating Geometrically And Atmospherically Corrected AVHRR Images

Overview

The first step in processing AVHRR images is to reduce the geometric distortions due to the sensor scanning off-nadir and due to the movement of Earth and satellite. This process is called navigation. During navigation the geographic location of each pixel is calculated so that its position on Earth is known. The resolution of the image is also determined during the navigation process. The remaining images in this exercise were processed to have a resolution of approximately 64 km² (7.39 km high x 8.7 km wide) although most of the images have been subsampled by a factor of four to approximately 1024 km² to save disk space.

In addition to correcting for geometric distortions, corrections are also made to reduce the effects of particulates in the atmosphere. This can be particularly important when a global event occurs such as the eruption of Mount Pinatubo in June of 1991. During this eruption, enough volcanic ash was spewed into the atmosphere to affect global temperature and rainfall for several months. Using sophisticated algorithms, many of the effects caused by particulates in the atmosphere can be reduced. The images you will use now have been atmospherically corrected.



Exercise 1.B

Opening and examining corrected AVHRR images

1. Pull down the **File** menu and select **Open**.
2. Locate the following file and click **Open**. and go to
`<i2kinstalled> | data | SEES | Veg | vgex1 | Ch1Stack | CH1270SM.TIF`
3. Repeat the above steps for the following images located in
`<i2kinstalled> | data | SEES | Veg | vgex1:`
 - Ch1Stack | CH1270SM.TIF;
 - Ch2Stack | CH2270SM.TIF;
 - Ch3Stack | CH3270SM.TIF;
 - Ch4Stack | CH4270SM.TIF;
 - Ch5Stack | CH5270SM.TIF.

Position the images so that you can see as much as possible for each image.



Do Exercise 1.B now.

Each of these images covers the entire African continent and Madagascar. The images were acquired on day 270 (September 27) in 1991. You can see the orbit from the first part of this exercise displayed on the right side of the image. Notice that this image strip no longer looks distorted. In addition to geometric corrections, these images are radiometrically corrected. Radiometric corrections are applied so that the pixel values accurately represent the geophysical parameter they are measuring.

Answer These Questions:

1. Why are there gaps between the different orbits?

Close the CH3270SM.TIF, CH4270SM.TIF, and CH5270SM.TIF images before proceeding.

Creating NDVI Images



Exercise 1.C

Generating an NDVI image from AVHRR channels

1. Pull down the **Image** menu and select **Math>Calculator**.
2. Select CH2270SM.TIF from the top drop-down menu and CH1270SM.TIF from the second drop-down menu. Select the **Subtract** from the operator drop-down box. Enter “Numerator” in the box next to the = and check the **Real Result** box. Click **Execute**.

The two images will be subtracted and the resultant image, Numerator, will be displayed.

3. Pull down the **Image** menu and select **Math>Calculator**.
4. Select CH2270SM.TIF from the top drop-down menu and CH1270SM.TIF from the second drop-down menu. Select **Add** from the operator drop-down box. Enter “Denominator” in the box next to the = and check the **Real Result** box. Click **Execute**. The two images will be added and the resultant image, Denominator, will be displayed.
5. Pull down the **Image** menu and select **Math>Calculator**.
6. Select Numerator from the top drop-down menu and Denominator from the second drop-down menu. Select **Divide** from the operator drop-down box. Enter “NDVI” in the box next to the = and check the **Real Result** box. Check the **Filter NAN&Inf** box. Click **Execute**. The two images will be divided and the resultant image, NDVI, will be displayed.
7. Close Numerator and Denominator and position the remaining three images (NDVI, CH1270SM.TIF, CH2270SM.TIF) so that they can all be seen.

Overview

The characteristics of AVHRR Channels 1 and 2 are such that they can be used to measure the photosynthetic activity on Earth’s surface. This is because the sensitivity of Channel 1 measures reflected red light that is largely absorbed by green plants. The sensitivity of Channel 2 is in the infrared wavelength region which is strongly reflected by plants. By ratioing these two channels we can highlight Vegetated areas where the red channel (1) reflectance is fairly low and the infrared channel (2) is higher. The resulting image is called a Normalized Difference Vegetation Index (NDVI) image. The formula to calculate NDVI is:

$$\text{NDVI} = (\text{NIR} - \text{RED}) / (\text{NIR} + \text{RED})$$

where RED is the reflectance for Channel 1 and NIR is the reflectance for Channel 2. The addition and subtraction is done to normalize the values to restrict them to a range of -1 to +1.



Do Exercise 1.C now.



SEES_v1/html_pages/vg_textbook: Chapter 4, Section 5 “Plant and Vegetation Community Properties,” Spectral Vegetation Indices, Figure 4.01-4.04. This section will be referred to throughout the rest of Exercise 1.

Answer These Questions

1. You can read the NDVI or channel values on an image by activating that image (clicking on it) and moving the cursor over various pixels. The NDVI or channel value for the pixel under the cursor will be displayed after Value: in the Info Window. Move the cursor over the three images to get an idea of how the values are distributed and represented (in grayscale) on the images.
- 2a. Look for cloud features on the CH1270SM.TIF and CH2270SM.TIF images. Locate a cloud pixel and record the value for that pixel on each of the AVHRR images. Find the same pixel on the NDVI image and record its value.

Cloud Pixel	CH1270SM.TIF (Channel 1)	CH2270SM.TIF (Channel 2)	NDVI Value

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- 2b. What do the values tell you about the reflectance of clouds in AVHRR Channels 1 and 2?

NOTE:

When the NDVI value for a pixel is close to zero it indicates that the RED and NIR values are very close in value (since $NIR-RED = 0$ when the values are the same).

- 3a. Locate a region that you know is covered with bare soil or has no Vegetation . What is the region you selected?
- 3b. What is the approximate range of NDVI values for this region with no Vegetation ?
- 3c. How does this compare to cloud values? Why is this is so?
- 4a. Look for water features on the CH1270SM.TIF and CH2270SM.TIF images. Locate a water pixel that is not overlaid by clouds and record the value for that pixel on each of the AVHRR images in the table below. Find the same pixel on the NDVI image and record its value.
- 4b. What do the values tell you about the reflectance of light by water in AVHRR Channels 1 and 2?

Water Pixel	CH1270SM.TIF (Channel 1)	CH2270SM.TIF (Channel 2)	NDVI Value

- 4c. Is the resulting NDVI value the same as for water and clouds? Why or why not?
- 5a. Locate a Vegetation pixel on the NDVI image (one with a high NDVI value). In the table below record the NDVI value and the corresponding values for the same pixel on the Channel 1 and Channel 2 images.
- 5b. Explain why the value for Channel 2 is higher than Channel 1.

Vegetation Pixel	CH1270SM.TIF (Channel 1)	CH2270SM.TIF (Channel 2)	NDVI Value

Close all images before proceeding.

Compositing NDVI And AVHRR Images

Overview

In order to eliminate the gaps in between the orbits in the single-day images which we looked at in previous sections it is necessary to select the best pixels from several days of images. This can be done using a process called compositing. During the compositing process images from several days (often 10 days or an entire month) are evaluated and the pixel from the “best” day is selected for the output image. The “best” pixel is defined as the pixel that has the highest NDVI value from the set being composited. Using the highest NDVI value, clouds are minimized or eliminated and blank (no data) areas are replaced with data. When a date for a particular pixel is selected from the series of NDVI images, that same date is used to create the composite for each of the five AVHRR channels.



Exercise 1.D

Generating a temporal profile to evaluate an image pixel

1. Pull down the **File** menu and select **Open**. Locate and select (but do not open) the following directory:

```
<i2kinstalled> | data | SEES | Veg | vgev1
| NDVIStack
```

2. Click on the **DensityCal** tab, and enter the following values:

The checkbox “**Use in next open image**” should be checked.

Y Intercept = -1.025

Slope = 0.008

Units = NDVI

3. Click on the **Open** button.

The Open Directory dialog is displayed.

4. Select the **Stack** radio button and then click **OK**.

The images are opened in a stack.

5. Pull down the **View** menu and select **Image Info** to open the Image Info window to see the image coordinates. Select the rectangle selection tool (dashed square) from the Tools window and then click on the pixel located at X=51, Y=122.

6. Pull down the **Stack** menu and select **Z-Profile**.

To see which date has the maximum NDVI value for a particular pixel we will generate a temporal profile for a pixel. The macro which does this determines the value for a given pixel on each image in a stack and plots the values as a function of the image stack number.



Do Exercise 1.D now.

Answer These Questions:

- 1a. Based on the temporal (Z-axis) profile plot, which date has the highest NDVI value for the pixel at X=51, Y=122?
- 1b. Why are some of the NDVI values for this pixel equal to -1?

Move back and forth through the stack of images using the “slider” tool, watching where on an orbital path the selected pixel appears on each date (image). You can monitor the image date from the title bar.

- 2a. What are possible reasons why this day-272 image has the highest NDVI value for the selected pixel?

Keep the image stack (NDV270SM–NDV270SM) open but close the profile plot window.

The compositing process involves two steps. The first step involves creation of a date index image which is an array of numbers that displays the date (or slice number) with the highest NDVI value for each pixel from the images in the stack to be composited. This date index is then used for the second step; building the composite image. To build the composite image we locate (using the date index) and place the best

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**Exercise 1.E**

Generating a date index image

1. Activate the NDV270SM.TIF–NDV270SM.TIF stack.
2. Pull down the **Special** menu and select **Miscellaneous> Make Index Image**
4. Move the cursor over the image and look at the values in the Info window.
5. Pull down the **File** menu and select **Save As**. Name the image “DateIndex.TIF” and save it at the following location:
`<2kinstalled> | data | SEES | Veg | vegex1`
6. Pull down the **View** menu and select **Look Up Table (LUT)** to view the date value distribution in color. Click on the **Load** button and select Rainbow.lut.

**Exercise 1.F**

Generating an NDVI composite image

1. Make sure the DateIndex.TIF, created in exercise 1.E is open, and activate the “NDV270SM - NDV270SM” stack.
2. Pull down the **Special** menu and select **Miscellaneous>Composite Image**. Make sure the checkbox next to the black thumbnail is checked, and Click on the **OK** button.

The Composite image is created.
3. Pull down the **View** menu and select **Look Up Table (LUT)** to open the LUT window. Click **Load**, and select the ‘DAAC NDVI.lut’ file, then click **OK** to color the image.
4. With the composite image selected, Pull down the **File** menu and select **Save As**. Name the file “NDVIComposite.TIF”, and save it at the following location:
`<2kinstalled> | data | SEES | Veg | vegex1`

**Do Exercise 1.E now.**

The number for a particular pixel on the DateIndex image represents the stack number of the image with the highest NDVI value for that pixel.

Locate the pixel X=51, Y=122 on the DateIndex image.

Answer These Questions:

- 3a. What is the value for the pixel?
- 3b. Is this value reasonable based on your answer for 5a in the last section? Explain.

Using this date index image we can now create composite images for NDVI and each of the AVHRR channels. For each pixel the compositing program looks at the date index image and then selects the pixel from that day and puts it into the output image. The same date index image is used to create a composite of NDVI and AVHRR channel images.

**Do Exercise 1.F now.****Answer These Questions:**

- 4a. Select the stack of NDVI images and use the “,” or “.” key to bring the third slice (NDV272SM) to the top of the stack. Move the cursor to pixel location X=51, Y=122 and note the NDVI value here.
- 4b. Select the composite image (NDVICom.TIF) then move the cursor to X=51, Y=122 and note the NDVI value here.
- 4c. Is there a difference between the two pixel values? Explain.

Close the NDV270SM–NDV270SM stack and the NDVIComposite.TIF image.

 **Exercise 1.G**

Generating an AVHRR channel composite image

1. Repeat the steps in Exercise 1.F using a stack from one of the AVHRR channels rather than the NDVI stack. AVHRR channel stack images are in *<i2kinstalled>* | data | SEES | Veg vgx1 | (Ch1Stack, Ch2Stack, Ch3Stack, Ch4Stack, or Ch5Stack).

Click on the DensityCal tab and enter the following values:

Ch1Stack or Ch2Stack: Y
Intercept = -0.1, Slope = 0.0043,
Units = %


Ch3Stack, Ch4Stack, or
Ch5Stack: Y Intercept = 150,
Slope = 0.7137, Units = Kelvin

Name the output images CH1Com, CH2Com, CH3Com, CH4Com, and CH5Com and save them in

<i2kinstalled> | data | SEES | Veg

It will be necessary to create composite images for channels 4 and 5 (CH4Com and CH5Com) in order to complete Exercise 1.I

2. Repeat the compositing process for another channel if time permits.
-

 **Do Exercise 1.G now.**

Close all images and stacks before proceeding.

Masking An Image

Since we are interested only in terrestrial Vegetation it would be easier to view these images if only land masses were visible. We can accomplish this by masking out large water bodies.



Exercise 1.H

Applying a mask to an image

1. Pull down the **File** menu and select **Open**. Locate the following file:
`<i2kinstalled> | data | SEES | Veg | vgex1 | NDVIComposite.TIF.`
 2. Click on the **DensityCal** tab, and enter the following values:
The checkbox "**Use in next open image**" should be checked.
Y Intercept = -1.025
Slope = 0.008
Units = NDVI
 3. Click on the **Open** button.
The Open Directory dialog is displayed.
 4. Pull down the **View** menu and select **Image Layers**.
 5. Click on the **Add** button on the Layers window. Locate the following file:
`<i2kinstalled> | data | SEES | Veg | vgex1 | Masksm.TIF`
 6. Enter "255" in the Transparency text field.
 7. Click **Open**.
The mask is added to the image in a separate layer, and the water pixels will be masked.
-



Do Exercise 1.H now.

Close all images and stacks before proceeding.

Investigating AVHRR channels 4 and 5

Overview

You had a chance to investigate the AVHRR Channels 1 and 2 when you generated an NDVI image. In this section we will look at two more AVHRR channels to see how they are different and what information each one provides. The images you will use are processed so that the pixel values represent actual geophysical values. Recall that the values for Channels 1, 2, and 3 are reflectance, which is measured as a percentage of incident light. Channels 4 and 5 values are temperature in Kelvin. Channel 3 is often used to map fires and for cloud and snow detection, but it is not generally used for Vegetation mapping. We will not look at this channel here. Channels 4 and 5 are used for measuring sea surface and land surface temperatures and mapping nighttime clouds.



Exercise.1.I

Comparing AVHRR composite images

1. Pull down the **File** menu and select **Open**. Locate the following file and click on **Open** to open the NDVI composite image:

<i2kinstalled> | data | SEES | Veg |
vgex1 | CH4Com.TIF

2. Click on the **DensityCal** tab, and enter the following values:

The checkbox "**Use in next open image**" should be checked.

Y Intercept = 0.7137

Slope = 0.0.7137

Units = Kelvin

3. Click on the **Open** button.

The Open Directory dialog is displayed.

4. Repeat this to open CH5Com.TIF.

Click and hold the top bar of the channel 5 image (CH5COM) window and drag it to the upper right corner of the screen.

5. Click and hold on the top bar of the channel 4 image (CH4COM) window and drag it so it is positioned to the left of the channel 5 image.



Do Exercise 1.I now.

Move the cursor around the two images and read the temperature in Kelvin of the pixels in the Info window.

Answer These Questions:

- 1a. Do you see much difference between the two images? Why or why not?
- 1b. Where do you tend to find the colder pixels? Explain.
- 1c. Is the central part of Africa warmer or cooler than the north and

Exercise 2: Seasonal Greening Of The Hemispheres

Overview

Vegetation changes throughout the seasons. These changes are offset between the northern and southern hemispheres so when vegetation is greening up in the northern hemisphere it is undergoing senescence in the southern hemisphere.

Before Beginning

- Make sure you have read through the Introduction to Module 2: Global Land Vegetation Computer Lab Exercises document.
 - Start *NASA Image2000*, or if it is already running close any open images
-

In this exercise we will compare how NDVI values change throughout the year. We will start by loading up all the 10-day composite NDVI images for 1993 and then color them using the standard NDVI color table. We will then create a mosaic to view all of the images at one time. The next step will be to create a stack and then project the stack to minimize distortions. To view the dynamics of the seasonal changes we will animate the stack. We will use a temporal profile to illustrate how vegetation cover in one place changes over time. We will also see how we can change perspectives on an image through projections.

Earth's seasons exist primarily because of the changing angle of incidence of the Sun's rays and the length of time the Sun shines on a particular part of Earth. We can visualize these changes by monitoring vegetation throughout the year.

The normalized difference vegetation index (NDVI) provides us with an indication of how much green vegetation exists at a particular place on the ground. Using these values we can generate an image that can be very useful to study how vegetation changes over time. The vegetation changes that we will study in this exercise are those that are caused by a changing of the seasons.

The formula for NDVI is

$$\text{NDVI} = (\text{NIR} - \text{RED}) / (\text{NIR} + \text{RED})$$

where NIR stands for a value from a near-infrared image channel and RED is a red image channel value. This formula is based on the fact that healthy green vegetation reflects a greater proportion of near-infrared light than red light. The NDVI values can range from -1 to $+1$ with most values ranging from 0 to 0.6. With this information we can see that healthy green vegetation would give us a high NDVI value because more near-infrared light would be reflected than red light. For bare soil on the other hand, both near-infrared and red light are strongly reflected so the NDVI would be near zero. Water and ice reflect a little more red than near-infrared light so those values tend to be slightly negative. The creation of an NDVI image is illustrated in Exercise 1.



Exercise 2.A

Preparing data for observation—
importing and stacking images

- 1 Pull down the **File** menu and select **Import>Import DAAC AVHRR**. Locate and select the following directory, then click **OK**:

```
<i2kinstalled> | data | Veg | vgex2 |
NDVI1993
```

The Import DAAC AVHRR dialog is displayed.

- 2 Make sure the **Import DAAC AVHRR NDVI Image** radio button and the **Calibrate images when imported** check box are selected, and click **OK**.

All 36 images will open automatically.

- 3 Pull down the **Stacks** menu and select **Windows to Stack>Include All Layers**.



Exercise 2.B

Color the stack using a LUT:

- 1 Pull down the **View** menu and select **Lookup Table (LUT)**

The LUT window is displayed.

- 2 Click on the **Load** button.

The Open File window is displayed.

- 3 Select the LUT you wish to apply, called “DAAC_NDVI.LUT”

- 4 Click on the **Open** button.

The new color LUT will be applied to all images in the stack.



Exercise 2.C

Making a montage of the 36 images

- 1 Pull down the Stacks menu and select **Montage**.

continued on next page...



Do Exercises 2.A, 2.B, and 2.C now.

These composites are processed so that there are three composites per month. For each month, the first 10 days are composited to make the first 10-day composite image and the second set of 10 days make up the second image. The days remaining in the month (11 in the case of January) are composited for the third image of the month. With this information we know that the first three images (1–3) are from January, the second set of three images (4–6) are from February, and so on.

Investigating Seasonal Greening From A Montage

You will notice that the colors range from violet to green on the image and LUT. To see the NDVI values associated with specific colors, move the cursor over the color of interest in the LUT window and read the associated NDVI Value in the Info window.

Answer These Questions:



SEES_v1/html_pages/vg_textbook: Ch. 4, Section 5:

“Plant and Vegetation Community Properties : Spectral Vegetation Indices”

- 1a. Moving the cursor up and down the LUT, determine the minimum and maximum NDVI values for this image.

Maximum NDVI value _____

Minimum NDVI value _____

- 1b. How do these values correspond to what you know is the possible NDVI range?

- 1c. Do you see a distinctive pattern of change as you scan through the images in the montage? Explain.

Close the Montage image window. You do not need to save it unless told to by your instructor.

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Exercise 2.C, con't...

- Under the "**Basic Layout**" tab enter "6" for columns, "6" for rows. Under the "**Advanced Layout** tab" enter "1" for increment. Leave the rest at the default settings.

The Montage image is displayed.

- Pull down the **View** menu and select **Look Up Table (LUT)** to open the LUT window. Click on the **Load** button and select "DAAC_NDVI.lut", then click **OK**.

The montage image is colored.

**Exercise 2.D**

Animating an image stack

- Click on the stack of images to activate it.
- Pull down the **Stack** menu and select **Animate...**

The Animate Stack window is displayed.

- For "quick" animation, accept the default radio button selection of Frames/Second (1-30), and edit the text field to define the speed of the animation (in frames per second).
- Click on the **Start** button to start the animation.

It may be easier to explore seasonal changes by moving through a stack of images rather than using a montage. We can use our eyes to scan a series of sequential images looking for changes or we can use a technique based on the flip-books or film loops you may have played with or seen as a child. We can animate a stack so that each image is flashed in sequence giving the impression of motion. *NASA Image2000* will allow us to animate a stack of images or move through the same stack sequentially.



Do Exercise 2.D now.

Investigating Seasonal Greening From An Animation

Animate the stack of 36 images from 1993. As you view consecutive images starting in January the changes in vegetation can be seen.

Answer These Questions:

SEES_v1/html_pages/vg_textbook: Ch. 2, Section 1, Figure 2.05 "Earth's Radiation Balance and the Global Greenhouse": Energy from the Sun to the Earth's Surface.

- One odd phenomenon is that during the beginning and end of the year the extreme portions of the northern and southern hemisphere disappear. What is a possible explanation for this?

The extreme polar regions disappear because the long polar night at these latitudes prevents the satellite from collecting data.

Flip through each of the images in the stack using the animation or moving through the images one by one concentrating on the northern hemisphere.

- What happens to the color as you proceed through the images (or seasons)?
- What month(s) represents maximum greening for the northern hemisphere? Which month(s) shows minimum greening?

Now concentrate on the southern hemisphere.

- Watching the animation—do you see a similar pattern of change? Explain.
- Do the periods of maximum and minimum greening occur at the same time as in the northern hemisphere? Explain.

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Let's look at some specific regions to see how the NDVI values change through the seasons. To do this we will use the option of moving through the images sequentially as described in D5.

- 5a. Make sure that you have returned to the first image in the stack. Select a northern hemisphere location that is seen in all images and seems to change over time, and place the cursor on that point. The equator is located at Y=90 for these images. Record the approximate geographic location of the point below (i.e., U.S. state or region, European country). From the Info window record the X-Y coordinates for the position and the NDVI value below. Keep the cursor in the same position and use the period (.) key to move to the fourth image (first composite image for February) and record the NDVI value in the table on page 5. Repeat this procedure for the same point on the first composite image of each month.

Approximate northern hemisphere geographic location:

Northern hemisphere location coordinates: X= ____ Y= ____

- 5b. Select a southern hemisphere location that is in all images and seems to change over time and place the cursor on point. Record the approximate geographic location of the point below (i.e., that African or South American country or region). From the Info Window record the X-Y coordinates for the position and the NDVI value below. Keep the cursor in the same position and move to the fourth image (first composite image for February) and record the NDVI value in the table below. Repeat this procedure for the same point on the first composite image of each month.

Approximate southern hemisphere geographic location:

Southern hemisphere location coordinates: X= ____ Y= ____

Image	NDVI Value	
	Northern	Southern
ND930101		
ND930201		
ND930301		
ND930401		
ND930501		
ND930601		
ND930701		
ND930801		
ND930901		
ND931001		
ND931101		
ND931201		

5c. What is the pattern of change in values from January to December for each hemisphere?

5d. Is the numerical change pattern the same or different for the points you selected in the two hemispheres? Explain.

Looking at the images, you see that the United States begins greening up in April and by the summer months vegetation is at peak greenness. When the northern hemisphere is experiencing peak greenness the southern hemisphere is less green than it was in January.

Comparing Temporal Profiles In The Northern And Southern Hemisphere

Earlier in this exercise you manually collected temporal (time) data for the northern and southern hemispheres to look at patterns in NDVI

values as a measure of seasonal greening. We can generate a plot of the temporal data for a location manually or use the capabilities of the image software.

Since we are dealing with a stack of images that change with time we can think of the stack as having a Z-axis, or a time axis. If we sample the same geographic point on each image in the stack we can obtain a

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temporal, or Z-axis, profile for that location. A macro in the software will allow us to do this and plot the results quickly.



Exercise 2.E

Generating a temporal profile

1. Select the rectangle selection tool (dashed square) in the Tools window.
2. Click the mouse somewhere in the northeast United States. Point X=86, Y=54 is a good one to select.
3. Pull down the Stack menu and select Z-Profile.

You will generate a plot of NDVI values as a function of time.
4. Repeat the last two steps with a point in southern Africa that has high NDVI values in January. Point X=208, Y=105 is good.



Do Exercise 2.E now.

Answer These Questions:

- 6a. When do the maximum and minimum NDVI values occur for each hemisphere? Record the data in the table on the next page. Express the Month and Day as the date from the image name on the stack title. To assist you, be aware that the values on the x-axis of the profile represent the slices in the stack. For example, the number 1 represents the data for 930101 and 23 is 930811.

	Northern Hemisphere	Southern Hemisphere
Maximum NDVI Value		
Month/Day of Max. Value		
Minimum NDVI Value		
Month/Day of Min. Value		

- 6b. What do the temporal graphs tell about the seasonal greening patterns in the two hemispheres?

Changing Perspective—Projecting A Stack Of Images

To aid in analyzing a stack of images you may wish to center a particular geographic location or change your view from space. There are several special projection functions in *NASA Image2000* you can use to do that.

Map projections are used to represent a spherical object on a flat surface such as paper or a computer screen. For this exercise that spherical object is Earth. Unprojected images are very distorted, which is obvious when you look at the country outline. We can greatly reduce distortion by using different map projections.

There are three map projections that have been incorporated into *NASA Image2000*. The first is called the Orthographic projection, which shows Earth as if viewed from deep space. It is often used to view the polar regions that are often distorted when using other projections. In an Orthographic polar projection, the area of greatest distortion

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tion occurs in the region around the equator. In *NASA Image2000* you can generate a south polar or north polar projection.

The second projection is called Hammer and is used to display global data. Shapes of features are distorted in the Hammer projection, especially near the top and bottom edges, but the area of those features is not distorted. In other words, each pixel in the image represents the same area. For that reason it is often an excellent choice for global analysis. The Hammer projection function allows you to define the center longitude for the projection. This allows you to control what portion of the globe will be in the center of the image window.

Last is the Interrupted Goode Homolosine projection, which is also an equal area projection, but it differs from the Hammer projection in that the globe is not presented as a continuous feature. The Goode projection is interrupted so that all of the land masses are continuous with the exception of Antarctica. The interrupted nature of this projection helps preserve the shape of land masses.

You can animate or move sequentially through a projected stack of images in the same manner as with unprojected stacks using Steps D4 and D5



Exercise 2.F

Generating a Polar Projection

1. Be sure the stack of images is active.
 2. Pull down the **Stack** menu and select **Project Stack > Polar**.
 3. Click on the “North” radio button. The stack will be transformed into square images showing only the northern hemisphere
-



Do Exercise 2.F now.

Move sequentially through this north polar projection stack. Notice the areas of missing data on a number of the images at the top (ND930101) and bottom (ND931221) of the stack caused by the polar night as described above.

You may generate the south polar projection by repeating the above steps selecting option 2 for a southern projection and entering “South Polar” for the name of the projected image. It is important that the original unprojected stack is selected before launching any projection.



Exercise 2.G

Generating a Hammer Projection

1. Click inside the projected stack window to make the window active.”
 2. Pull down the **Stack** menu and select **Project Stack > Hammer**.
 3. Enter “-100” for a reference longitude. This longitude corresponds to the center of the United States, so the resulting image will be centered on the U.S. You will see that the Hammer projection transforms the globe into a football shape.
-



Do Exercise 2.G now.

Exercise 3: Vegetation Classification And Global Vegetation Patterns

Before Beginning

- Make sure you have read through the Introduction to Module 2: Global Land Vegetation Computer Lab Exercises document.
- Start *NASA Image2000*, or if it is

Overview

Vegetation classification is important in studying net primary productivity and in monitoring changes in Earth's surface vegetation. In this exercise we will see how phenology can be used to group vegetation into classes that have similar temporal profiles using global monthly composited NDVI data.

We start this exercise by looking at a global classified land cover image and exploring the extent of various cover types. Next, we will investigate how the classified image was generated by selecting several predefined pixels from a stack of 12 monthly NDVI composites for 1987, generating temporal profiles, and matching the temporal profiles for the pixels to a temporal profile legend. For the last step we will select other pixels from the stack of monthly composites and try to determine what type of land cover is represented by each pixel.

Exploring The Distribution Of Different Vegetation Types From A Classified Image

To monitor vegetation change on a global scale and develop accurate model concepts such as Earth's radiation budget and net primary productivity, it is important to be able to classify land cover types quickly and over large surface areas. The most efficient way to do this is with satellite data. However, first it is necessary to develop classification techniques that use specific parameters such as NDVI values or changes in NDVI values with time to identify land cover types. This is an area of active research. In fact, this exercise is based on a study conducted by R.S. DeFries and J.R.G. Townshend at the University of Maryland (NDVI-derived land cover classifications at a global scale. *International Journal of Remote Sensing*, 15:3567-358, 1994).

First we will explore a global image that classifies pixels into the world's major land cover types. This type of image can be used for input to climate models.



Exercise 3.A

Opening a classified vegetation map

1. Pull down the **File** menu and select **Open**. Locate the following file:


```
</I2KInstalled> | data | SEES | Veg |
vgex3 | VEG_CLSS.TIF
```
2. Click on the **Geo** tab, and enter the following values:

Image X = 0

Image Y = 0

Model X = -179.5

Model Y = 89.5

Units = "Degrees"

X Scale = 1

Y Scale = 1

Projection "Unprojected (lat/lon)"
3. Click on the **Open** button.

The file will open in a new image window.



Do Exercise 3.A now.



SEES_v1/html_pages/vg_textbook: Chapter 6, Section 1-3: "Vegetation Classification with Satellite Observations." Figures 6.01-6.06.

Answer These Questions:

1. The image you see covers the entire globe with each pixel representing 1.00 degree of latitude and 1.25 degrees of longitude. Does each pixel on the image represent an equal area? How can you tell?

If we want to be sure we are comparing equal areas we need to generate an equal area projection, that is, one in which each pixel represents the same surface area.



Exercise 3.B

Generating an equal area projection

With the vegetation map active, Pull down the **Image** menu and select **Geometric Transformations> Projections>Goode**.



Do Exercise 3.B now.

2. Move the cursor over the different classes (represented by different colors) in the Goode Class image. As you do this the classification number for a specific area (color) will be found as the Value entry in the Info window. A legend for these values is located below. Note how the different classes are distributed around the globe.

Legend for the Classified Map

1	c3 grassland
18	c3 wooded grassland
35	ice
52	cultivation
68	desert, bare ground
85	tundra
102	shrubs and bare ground
136	c4 grassland
153	wooded c4 grassland
170	high latitude deciduous forest and woodland
187	coniferous forest and woodland
203	mixed coniferous and broad-leaf deciduous forest and woodland
220	broadleaf deciduous forest and woodland
237	broadleaf evergreen forest
254	water



SEES_v1/html_pages/vg_textbook: Chapter 4, Section 1.2, Table 1: “Classification of Natural Vegetation by Canopy Structure- An Example from Eastern Africa (Pratt & Gwynne 1977)”

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3. Is any general pattern apparent in the distribution of vegetation classes? Explain.
4. Apart from water and ice, are there any classes that seem to predominate? Explain.

To determine the surface area represented by each of the land cover classifications we can use the density slice tool to select and highlight certain values and then use an analysis tool to measure the area. Density slicing allows the user to take a range of values (block of values) and assign a color to them. The default color is red but can be changed. The LUT tool can be used to manipulate the density slice when density slicing is enabled.

First we will define a range by moving the upper and lower boundaries of the density slice. The boundaries can be monitored in the Info window. We will change the color block default color from red to black since red is a color used for one of the classes. Then we will move the density slice block up and down the LUT window, which will change the upper and lower boundaries of the values that we are interested in highlighting in black.



Exercise 3.C

Making a density slice with the LUT tool

1. Pull down the View menu and select Look Up Table (LUT).
The LUT window is displayed.
2. Click on the **Slice** button to open the Density Slice Editor. Click on the **Color Chooser** button.
3. When the color selection window appears, click on the color squares to change the “new” color of the block to **black** and click **OK**.
4. In the Density Slice window type “0” in the **Start Index** text box and “16” in the **End Index** test box. Be sure to hit return after typing in each value.
5. Close the Density Slice Editor window.



Do Exercise 3.C now.


Place the cursor in the middle of the black color block on the LUT window and slowly move the block up the LUT window. You will notice that areas on the globe are highlighted in black. You can determine the classification number for a particular highlighted region by placing the cursor over one of the blackened areas on the image.

Now we will measure the area represented by each of the land cover types on this image.



Exercise 3.D

Measuring density slice regions

1. Pull down the **Image** menu and select **Analysis>Measurement Table**. Click on the **Options** button to view the Table options. “Check” the **Area** and **Mean** checkboxes. Click **OK**.
2. Click on the **Reset** button to reset the Measurement Table values.
3. Click on an image to bring it to the front, then pull down the **Image** menu and select **Properties>Set Scale**. Select ‘Kilometers’ from the Units pop-up menu. Enter “111.2” for Known Distance. Enter “1” for Measured Distance in Pixels. Enter “1” for Pixel Aspect Ratio. Click **OK**.
4. Activate the Goode Class image. Activate the LUT Tool. Move the black color block at the top of the LUT window to the bottom of the window by clicking on it and dragging it to the bottom. The large area covered by water will be black.
5. Click on the Measure icon button on the tool bar, or pull down the **Image** menu and select **Analysis>Measure**. The Results window will display area in square kilometers and mean which is the  the classification number.
6. Slowly move the color block up the LUT window until the black color on the Goode Class image disappears and reappears over a different set of pixels. Click on the Measure icon and the values for this new vegetation category will appear in the Table.
7. Repeat step 6 while moving from bottom to top of the LUT window. When you are finished you should have mean values from 0–15 (with 8 missing) and accompanying areas. You can measure any class (mean) you missed by moving the density slice color block on the LUT window so that mean value desired is within the Upper and Lower range in the Info window and repeating step 6.
8. Transfer the measurements to the table at right. If you have a printer selected for your computer, you can print the results by activating the Measurement Table. Then pull down the **File** menu and select **Print**.



Do Exercise 3.D now.

Answer These Questions:

Class (Mean)	Land CoverType	Area (km ²)
1	c3 grassland	
18	c3 wooded grassland	
35	ice	
52	cultivation	
68	desert, bare ground	
85	tundra	
102	shrubs and bare ground	
136	c4 grassland	
153	wooded c4 grassland	
170	high latitude deciduous forest and woodland	
187	coniferous forest and woodland	
203	mixed coniferous and broad-leaf deciduous forest and woodland	
220	broadleaf deciduous forest and woodland	
237	broadleaf evergreen forest	
254	water	

5. Which land cover types predominate on the basis of area (excluding water and ice) in this 1987 image?

Repeat Exercise 3.D, step 3, changing the Units from Kilometer to Pixels. Then close all open images.

Classifying Land Cover Using Temporal Profiles

Overview

How do you generate a classification system for land cover types from satellite data? One way is to look at the spectral signature of different types of land cover. Instruments such as the Advanced Very High Resolution Radiometer (AVHRR) are able to measure radiation of multiple wavelengths reflected from Earth's surface. Reflectance in the near-infrared and red wavelengths can be used to generate an index of vegetation called the Normalized Difference Vegetation Index (NDVI). The values for this index range from -1 to $+1$. Bare soils have NDVI values that are near zero while green vegetation shows values approaching $+1$. Negative values generally result from snow or water. NDVI values can be used to distinguish between vegetation and bare soils in an image but NDVI values from a single date are often insufficient to determine the type of vegetation.

To refine the classification of vegetation, we can use the change in NDVI values over the period of a year. For example, water will not show a change in NDVI values while a deciduous forest that loses its leaf cover will have NDVI values that vary seasonally. We can use this change-over-time information to identify different types of vegetation by plotting the NDVI values for a particular pixel for each of the twelve months of the year. This plot is called a temporal profile. Different types of vegetation have characteristic temporal profiles.

The different classes on the VEG_CLSS.TIF image have been categorized by temporal profiles. We can use these profiles to assist in identifying the land cover associated with a particular pixel.

We can generate land cover temporal profiles using a stack of NDVI images that cover the same area over a year and are arranged sequentially based on date. If we select a specific pixel on the top image and look along the Z-axis (at the same pixel through the stack) we can see variation in the NDVI value along the Z or time axis. SEE Image allows us to sample an area along the Z axis through a stack and plot the results.

Close all images.



Do Exercise 3.E now.



Exercise 3.E

Importing, stacking and coloring global monthly NDVI composites for 1987

1. Pull down the **File** menu and select **Import>Import DAAC AVHRR**. Locate and select the following directory, and click **OK**.

```
<I2KInstalled> | data | SEES | Veg |
  vgex3 | NDVI1987
```

The Import DAAC AVHRR dialog is displayed.

2. Make sure the **Import DAAC AVHRR** Image radio button and the **Calibrate images when imported** checkbox are selected. Click **OK**.

All 12 images will open, overlaying each other automatically.

3. Pull down the **Stacks** menu and select **Windows to Stack>Include all Layers**. The images will compress into a stack.

4. Pull down the **View** menu and select **Look Up Table (LUT)** to open the LUT window. Click on the **Load** button and select "DAAC_NDVI.lut", then click **OK**.

All images in the stack are colored.

Creating Temporal Profiles For Different Land Cover Types

Now that we have a stack of images we can generate temporal profiles.



Exercise 3.F

Generating a temporal profile

1. Activate the stack ND8701–ND8701. Click the rectangle selection tool (the dashed square) in the Tools window.
2. Move the cursor over the second pixel listed in the table below and click on that pixel.
3. Pull down the **Stack** menu and select **Z-Profile**.



Do Exercise 3.F now.

The resulting temporal profile (Z-Axis Profile Plot) shows the months on the x axis (1=January, since we stacked the images in order from January to December). The NDVI values are displayed on the y axis.

Answer These Questions:

1. Sketch the profile, labeling the axes. If you have a printer you may print the profile by selecting 'File/Print Image'.

Compare the profile you created with the plots in the profile legend shown at the end of this exercise. As you make the comparison keep in mind the profile shape, the starting value for the plot, the lengths of level and inclined segments, and the maximum values on the curves.

2. Repeat the plot routine for each pixel in the table below, comparing each profile to the legend. You may notice that some curves have precipitous rises or declines at the beginning or end of the plots. This may be a result of no-data values on the first and last images. Consider the rest of the curve for comparison purposes. How well do your profiles match the profiles for the specific land cover type?

Pixel Location		Land Cover Type
X	Y	
115	95	Broadleaf evergreen forest
98	53	Broadleaf deciduous forest & woodland
98	40	Coniferous evergreen forest & woodland
209	110	Woodland grassland, southern hemisphere
104	30	Tundra
311	38	Northern latitude deciduous forest & woodland
88	51	Cultivated northern hemisphere
200	90	Cultivated southern hemisphere
180	65	Desert bare ground

Identifying Land Cover Types Using Temporal Profiles

Now that you have had some experience looking at temporal profiles for different land cover let's use that information to classify some additional areas on your images.

Answer These Questions:

3. Select six pixels from around the globe that appear to represent varying land cover types. Avoid water and high latitudes where there may be snow or ice cover. Using the instructions in procedure F for generating a profile, produce one for each pixel and identify the cover type from the temporal profile legend. Record each pixel location and your classification in the table below. Locate the same pixel in the VEG_CLSS.TIF image to see how that pixel was classified.

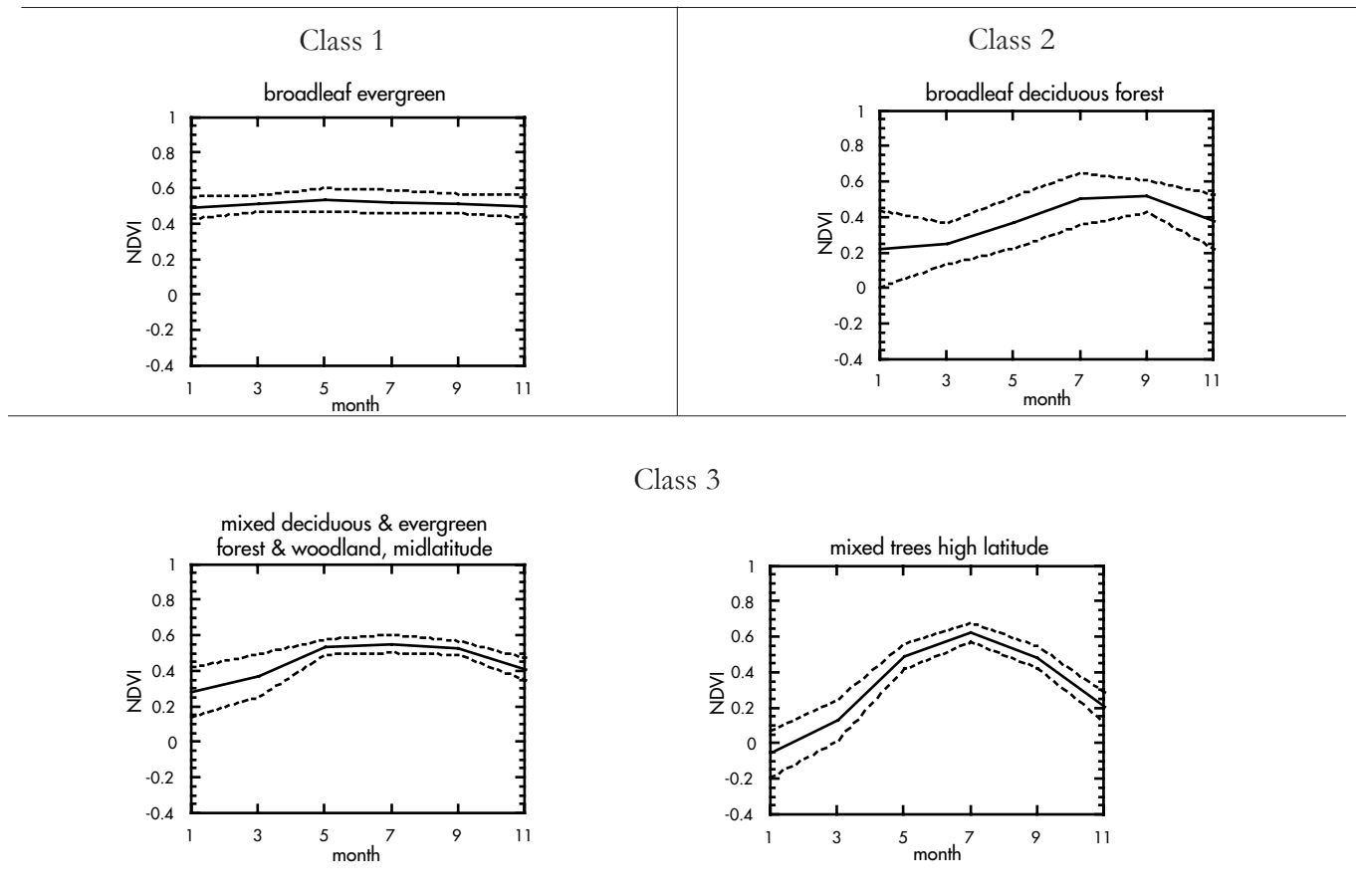
Pixel Location		Land Cover Type
X	Y	

4. How accurate were your classifications?
5. What might be the possible causes for wrongly classifying a particular pixel?

As you try to identify different cover type classes you will see that in some cases the profile of the pixel does not seem to fit any of those in the legend or it seems to be in between two or more profiles. This illustrates that it can be very difficult to make a decision as to how to classify a particular pixel. The task of image classification is to make the best choice possible given the restraints of the algorithm (formula for the classification). In some cases a pixel may be incorrectly classified. Even if a pixel is “correctly” classified based on the rules of the classification process, it may actually be composed of more than one class.

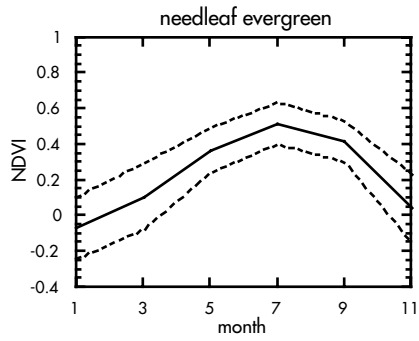
Exploring Global Land Vegetation Using Satellite Data—Computer Lab Exercises

The classified vegetation map used in this exercise was generated using an automated classification process. This process involved selecting representative pixels, known as training sets, for each vegetation class. This was done using vegetation maps. Statistics from these training sets were then used to assign a particular land cover type to each pixel using a computer algorithm. In essence, for each pixel the algorithm compares the reference profile from each training set (these are the profiles that we used as a reference in this exercise) with the profile of the twelve NDVI images. Once the best match is found that particular pixel is assigned a value that identifies it with a particular cover type. This is similar to what we did in this exercise.

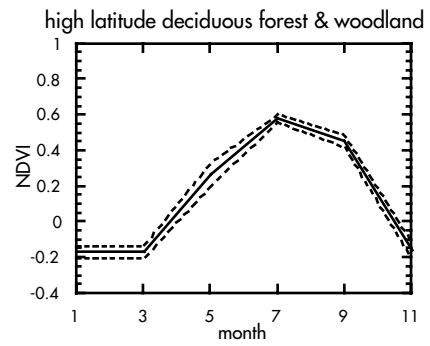


Exploring Global Land Vegetation Using Satellite Data—Computer Lab Exercises

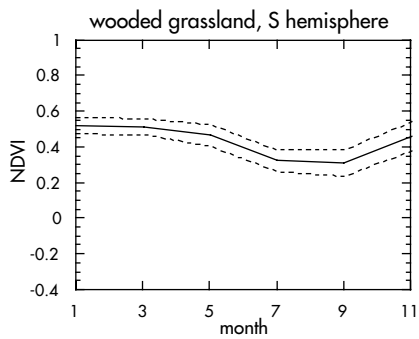
Class 4



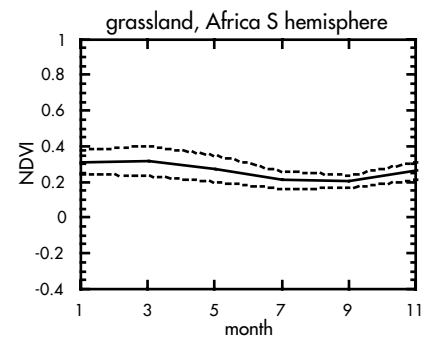
Class 5



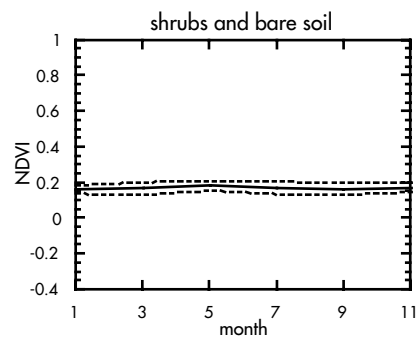
Class 6



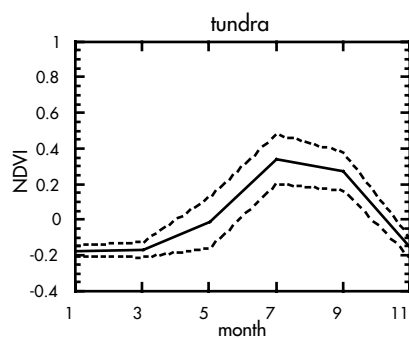
Class 7



Class 9

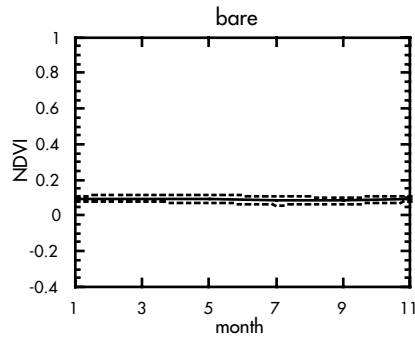


Class 10

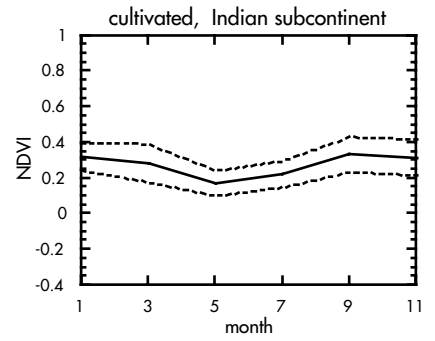
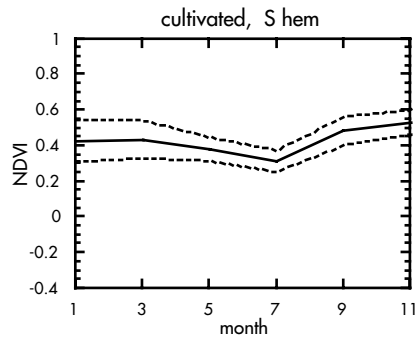
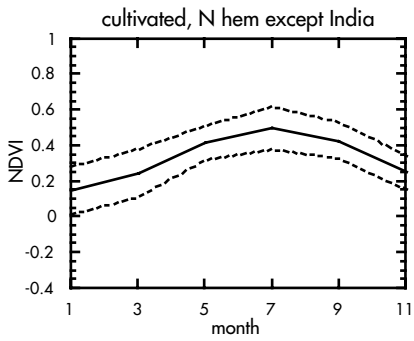


Exploring Global Land Vegetation Using Satellite Data—Computer Lab Exercises

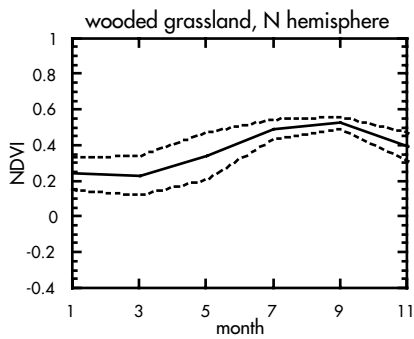
Class 11



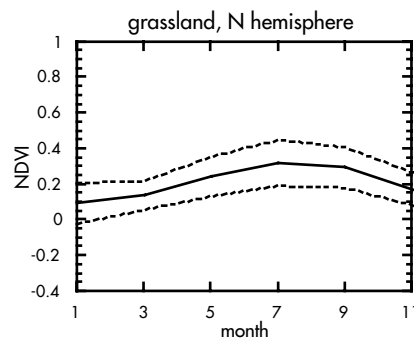
Class 12



Class 14



Class 15



Exercise 4: Land Cover Change In The Brazilian Amazon

Overview

Humans play a role in the change in land cover. To illustrate this in this exercise we will look at the higher resolution 8km NDVI images for an area in Brazil. In the Amazon Basin in Brazil large tracts of land have been converted from forest to grazing land as part of a government program.

We begin the exercise by looking at NDVI imagery for two dates that are several years apart to visualize the change in land cover in the state of Rondonia in Brazil. Next we will perform a simple change detection procedure to highlight those areas that have changed. To better understand the human role in this land cover conversion we will overlay road data on the image. We finish the exercise by looking at high resolution satellite images to see more detail.

Land cover simply describes the dominant substrate at a given area, typically vegetation amount and type. Alterations to land cover can be due to natural or anthropogenic influences. Often it is a combination of these two influences and it can be very difficult to understand what forces were responsible for modifying a particular area.

In this exercise we will focus on land cover change that was initiated by a policy put in place by the Brazilian government and then made worse by the fact that the soils would not sustain agricultural crops.

The primary data for this exercise are 8km NDVI images of South America. Supplementary data are from the multispectral scanner (MSS) and thematic mapper (TM) sensors onboard the Landsat satellites. These data provide a higher resolution image that allows us to see more details in the structure of the deforestation. The MSS and TM images are made up of combinations of three image channels that are combined to produce a color image. Each of the component image channels records the reflected light for different wavelengths. The color scheme used for this image is called false color because the colors do not represent the colors that would be seen by the human eye. The false color scheme used in the high resolution images in this exercise is commonly used for images used to study vegetation.



SEES_v1/html_pages/vg_textbook: Chapter 7: “Detecting and Monitoring Land Cover Change with Remote Sensing” and Chapter 8 “The Human Dimension of Land Use and Land Cover Change (Section 2.3: Deforestation).

Before Beginning

- Make sure you have read through the Introduction to Module 2: Global Land Vegetation Computer Lab Exercises document.
 - Start *NASA Image2000*, or if it is already running close any open images
-



Exercise 4.A

Opening two Rondonia images

1. Pull down the **File** menu and select **Open**. Locate and select the following directory, then click **Open**:

```
<i2kinstalled> | data | Veg | vgex4
| Rond0982.TIF
```

Follow the same steps to open Rond0993.TIF. These are images of the Rondonia region of Brazil taken in September 1982 (Rond0982.TIF) and September 1993 (Rond0993.TIF).

2. Select the zoom (magnifying glass) icon in the Tools window and click twice on each image to zoom in by 400%. Place the two images next to each other. You can return the images to their original size by selecting the **Unzoom** button in the Tools window.



Exercise 4.B

Ratioing the two rondonia images

1. Pull down the **Image** menu and select **Math>Calculator** to activate the Image Calculator.
2. Select Rond0993.TIF from the uppermost drop-down menu. Then select Rond0982.TIF from the second drop-down menu. Select **Divide** from the Operation drop-down menu. Type “1993/1982” in the **Results** box next to the equal sign (=). This will be the name of the output image. Select the **Real Result** check box since the resulting image pixel values will be outside the 1–254 range. Check the **Filter NAN&Inf** box then click **Execute** to perform the division
3. Pull down the **View** menu and select **Look Up Table (LUT)** to open the LUT window. Click on the Load button and select “32Colors.lut”, then click **OK**.



Do Exercise 4.A now.

Investigating Changes In Rondonia Images

Answer These Questions:

1. What changes are evident from the September 1982 to September 1993 images? What do you think may be responsible for these changes and why?

To see the degree of change in the same area for two images we can “ratio” the images. In this process we compare the values of the same pixel on each image through a ratio calculation. When this is done for all pixels the result is a new image composed of compared values. This can be interpreted to look at relative change and is referred to as a change detection method.

2. Why is it possible to perform mathematical operations on the two images to provide a third image?



Do Exercise 4.B now.

Move the cursor over various areas in the resulting image.

- 3a. What colors represent ratio values less than 1?
- 3b. Does the ratio image contain more pixels with values above or below 1?
- 3c. Consider the pixels with ratio values less than 1. What do these ratio values tell you about the difference in NDVI values in 1993 compared to 1982?
- 3d. What do you think has happened to the land cover for this region from 1982 to 1993?

Exploring Global Land Vegetation Using Satellite Data—Computer Lab Exercises

**Exercise 4.C**

Overlaying a road layer

1. Select Rond082. Click the Magnifying Glass Tool from the Tools window then click on the **Unzoom** button to reduce the image to its original size. Repeat the procedure for Rond993.
2. Pull down the **View** menu and select **Image Layers**.
3. Click on the **Add** button on the Layers window. Locate the following file:


```
<i2kinstalled> | data | Veg |
vgex4 | roads.tif.
```
4. Enter "255" in the Transparency text field, and click **Open**.

The overlay is applied to the image.
5. You can zoom in on either image using the procedure in step A.2.

**Exercise 4.D**

Looking at high resolution satellite images of Rondonia

1. Pull down the **File** menu and select **Open**. Locate and select the following file, and click on the **Open** button:


```
<i2kinstalled> | data | Veg |
vgex4 | MSS72.tif.
```
2. Repeat this step to open MSS92.tif.

**Do Exercise 4.C now.**

- 4a. How does the change in NDVI value correspond with road development?
- 4b. What is the likely process(es) occurring with road development that may be responsible for the change in NDVI values in this region of Brazil?

With the roads overlaid on the NDVI image one can see that there is a strong link between a road and surrounding deforestation.

**Do Exercise 4.D now.**

These images were acquired from the Landsat satellite and are much higher resolution than the NDVI images. The first image, MSS72, was acquired in 1972 shortly after the road was cut through the forest. The second image was acquired in 1992. In these images, forests are colored red and the deforested regions are white and blue-green. With these high resolution images one can see that there are a number of small parallel roads that intersect the main roads.

Close all images when you are finished. DO NOT save them unless told to do so by your instructor.

Discussion

Rondonia is a state in western Brazil that shares a border with Bolivia. The deforestation within Rondonia is one of the most extreme cases of deforestation in recent history. Much of the deforestation is linked to changes in policy by the Brazilian government. The government saw the Amazon as a natural resource that could provide a living for a large number of Brazilians that were overcrowding the coastal cities. In addition to these social reasons, Brazil had political reasons to have Brazilians living near its borders.

In order to facilitate this migration of citizens, a network of roads was created. In 1979 only 1,434 kilometers of roads existed in Rondonia and by 1988 that figure had jumped to 25,324. As people poured into Rondonia, a tremendous area of forest was cleared so they could make a living. Deforestation areas in Rondonia increased from about 6,281 square kilometers in 1980 to 23,998 square kilometers in 1988.

Unfortunately the objectives of this resettlement did not work out. Most of the people who settled in Rondonia moved from the south or southwest part of Brazil instead of the large cities. Also, much of the land use that was practiced in Rondonia did not support long-term family subsistence. Typically, a farmer would cut down and then burn the forest to prepare the land for planting crops. After about 4 years the tropical soil was degraded to a point where only grasses would grow at which point cattle were often raised. With continuing degradation of the soil even cattle ranching becomes problematic and more forest has to be cleared.

Exercise 5: Vegetation Dynamics In The Sahelian Zone

Overview

Before Beginning

- Make sure you have read through the Introduction to Module 2: Global Land Vegetation Computer Lab Exercises document.
- Start NASA Image2000, or if it is already running close any open images

Exercise 5.A

Opening a precipitation image of Africa and overlaying African country boundaries

1. Pull down the **File** menu and select **Open**. Locate and select the following file:
`<i2kInstalled> | data | SEES | Veg | vgex5 | AfRainMM.TIF`
2. Click on the **DensityCal** tab, and enter the following values:
 The checkbox **“Use in next open image”** should be checked.
Y Intercept = -15.81
Slope = 15.81
Units = mm
3. Click on the **Open** button.
4. Color the image by pulling down the **View** menu and selecting **Look Up Table (LUT)** to open the LUT window. Click on the Load button and select “Rainbow1.lut”, then click **OK**.
5. Pull down the **View** menu and select **Image Layers**.
6. Click on the **Add** button on the Layers window. Locate the following file:
`<i2kInstalled> | data | SEES | Veg | vgex5 | Overlays | AfCtry.TIF`
7. Enter “255” in the Transparency text field.
8. Click **Open**.
 The overlay is added to the image in a separate layer, and the countries are outlined in black.

In Exercise 4 we saw an example of land cover conversion that is the result of human actions. In some regions, major land cover change is caused by climatic changes. One area where this is evident is in the Sahel region of Africa. The Sahel is the transition region between the Sahara desert and the wooded grasslands and tropical rainforests in the central portion of Africa.

We will start this exercise by defining the Sahel using climatic precipitation data. Next we will animate several images to see how Vegetation cover changes from year to year. To quantify this, we will calculate mean, standard deviation, and coefficient of variation images. In the last part of the exercise we will use image processing techniques to highlight a drought that took place in 1984.

The images for this exercise are located in two folders. The first, SahelSeptNDVI, contains 13 NDVI September monthly composite images. The second folder, Sahel1993NDVI, contains 12 NDVI monthly composite images for 1993.

All of these Sahel images were created by cutting out a window with a width of 800 pixels and a height of 300 pixels from the Africa 8km monthly composite NDVI imagery available from the Goddard DAAC. The upper left image coordinate for this window is X=25, Y=200.



SEES_v1/html_pages/vg_textbook: Chapter 7: “Detecting and Monitoring Land Cover Change with Remote Sensing” and Chapter 8 “The Human Dimension of Land Use and Land Cover Change (Section 2.4: Agriculture)”

Investigating Precipitation Patterns In Africa

Do Exercise 5.A now.

Move the cursor over the different lines in the image and look at the values in the Info window. These values give the approximate annual rainfall in millimeters for the isohyet covered by the cursor. There is some rounding error because of the way NASA Image2000 scales large numbers to the range of 0–255 so you should round the number displayed in the Info window to the nearest 100. For example, at image coordinate X=466 Y=388 the value is 901.19. This value should be rounded to 900mm.

Answer These Questions:

- 1a. Determine the value and color associated with
 highest rainfall: value_____color_____

 lowest rainfall: value_____color_____
- 1b. What color lines approximately define the Sahara Desert region? Explain.

Locate the region between 150 mm and 600 mm of rainfall just south of the Sahara.

2. What colors define the upper and lower limits of the region?

This transition region between the Sahara and the tropical rainforests of Africa is called the Sahel. The Sahel is sometimes defined by using geographic coordinates. One set of coordinates defines the Sahel as the region between 10°N–25°N, and 18° W–45° W. The problem with using geographic coordinates is that they are a somewhat arbitrary way to define an area that is described by its unique ecological zones. We will explore this region and an alternate way to define it in the rest of the exercise.



Exercise 5.B

Opening an NDVI Africa image and overlaying the precipitation Isohyets for the Sahel

1. Close all images currently open. Do not save changes unless told to do so by your instructor.
2. Pull down the **File** menu and select **Open**. Locate and select the following file, then click **Open**:
`<i2kInstalled> | data | SEES | Veg |
 vgex5 | Sahe | SeptNDVI |
 SahND0993.TIF.`
3. Color the image by pulling down the **View** menu and selecting **Look Up Table (LUT)** to open the LUT window. Click on the Load button and select “DAAC_NDVI.lut”, then click **OK**.
4. Pull down the **View** menu and select **Image Layers**.
5. Click on the **Add** button on the Layers window. Locate the following file:
`<i2kInstalled> | data | SEES | Veg |
 vgex5 | Overlays | SahelRain.TIF.`
4. Enter “255” in the Transparency text field.
5. Click **Open**.
 The overlay is added to the image in a separate layer.

Investigating NDVI And Precipitation Values In The Sahel



Do Exercise 5.B now.

Move the cursor over the image and note the changing NDVI values in the Info window.

Answer These Questions:

3. What is the approximate range of NDVI values in the Sahel for this September image?

Because the Sahel is a transitional zone it is an area with a great deal of month-to-month and year-to-year variation. To explore the variations we can generate and animate a stack of images.

Investigating Monthly Changes In The NDVI Values In The Sahel



Exercise 5.C

Opening, stacking, and animating monthly images for 1993

1. Close all open images. Do not save changes unless told to do so by your instructor.
2. Pull down the **File** menu and select **Open**. Locate and select the following directory, then click **Open**:
`<i2kInstalled> | data | SEES | Veg | vgex5 | Sahel1993NDVI`
The Open Directory dialog is displayed.
3. Select the **Stacks** radio button.
4. Color the stack: Pull down the **View** menu and select **Look Up Table (LUT)** to open the LUT window. Click on the Load button and select “DAAC_NDVI.lut”, then click **OK**.
5. Pull down the **Stacks** menu and select **Animate...**
The Animate Stack dialog is displayed.
6. Click on the **Start** button.
This cycles through the stack quickly and continuously. To stop the animation, click on the **Stop** button.



Do Exercise 5.C now.

View the stack of monthly Sahel images for 1993 through several cycles.

Answer These Questions:

- 4a. Which months show the largest area of high NDVI values?
- 4b. Which months show the largest area of low NDVI values?
- 4c. What region shows the least change in NDVI values? Why might this be expected?

Investigating Year-to-year Vegetation Variations For September In The Sahel

Answer These Questions:

1. Would you expect significant changes in Vegetation patterns to occur from year to year in September in the Sahel? Explain.
2. Based on what you have done so far, what might you do to check for year-to-year variations?

To look at year-to-year variations you will set up a stack of images for the month of September from 1981 to 1993.



Exercise 5.D

Opening and stacking a series of September NDVI images for the Sahel

1. Close any images that are open. Do not save changes unless told to do so by your instructor.
2. Pull down the **File** menu and select **Open**. Locate and select the following directory, then click **Open**:

```
<i2kInstalled> | data | SEES | Veg | vgex5 | SahelSeptNDVI.
```

The Open Directory dialog is displayed.
3. Select the **Stacks** radio button.
4. Color the stack: Pull down the **View** menu and select **Look Up Table (LUT)** to open the LUT window. Click on the **Load** button and select "DAAC_NDVI.lut", then click **OK**.



Do Exercise 5.D now.

Animate the stack and view it through several cycles (refer to procedure D5 for instructions). Locate Lake Chad at the center of the image (blue) and use it as a reference point as you flip through the stack. The most southern point of Lake Chad is near the southern edge of the Sahel.

Answer These Questions:

- 3a. Is there variation from year to year in the NDVI values in the Sahel region for September? Explain.
- 3b. What year shows the most extensive September Vegetation in the Sahel?
- 3c. What year shows the least extensive September Vegetation in the Sahel?
- 3d. What possible causes might lead to minimum Vegetation development in the Sahel?

Exploring Global Land Vegetation Using Satellite Data—Computer Lab Exercises



Exercise 5.E

Overlaying the precipitation image for the sahel on the stack

- 1 Pull down the **Stack** menu and select **Overlays>Overlay from File**. Locate and select the following file, then click **Open** to add the precipitation layer for the Sahel:

<i2kInstalled> | data | SEES |
Veg | vgex5 | SahelRain.TIF

2. Pull down the **Stack** menu and select **Overlays>Choose Overlays Transparent Pixel Value**. Enter "255" in the text box and click **OK**.

The overlay is displayed over each image in the stack, with only the lines and text showing.

**Do Exercise 5.E now.**

Animate the stack with the overlay (refer to procedure D5 for instructions).

Answer These Questions:

4. Review the questions in (7) above again using the overlay stack. Record any changes or additional observations here.

As you look at the September NDVI monthly composites for consecutive years, you will notice that the NDVI values on the edge of the Sahelian region vary significantly from year to year. This is largely because this area is very sensitive to changes in precipitation amounts and timing. In particular, notice how the image for 1984 is very different from the other images. We will discuss why this is the case in the last step of this exercise.

Close all images and do not save unless asked to do so by the instructor.

Investigating Quantitative Changes In September NDVI Values For The Sahel—A More Advanced Look

Overview

If we want to get a more quantitative measure of the changes in a region over multiple years we can compute a standard deviation on the image stack.

Answer These Questions:

1. Before we compute a standard deviation image it is important to begin with images that do not have overlays. Why?



Exercise 5.F

Opening and stacking a series of September NDVI images for the Sahel

Repeat Exercise 5.D.



Do Exercises 5.F and 5.G now.

Move the cursor over the “ahelSD image while monitoring the values in the Info window.



Exercise 5.G

Calculating a standard deviation of an image set

1. Activate the SahelSeptNDVI stack . Pull down the **Stack** menu and select **Statistics> StandardDeviation**. Select the “**Scale Image to Byte Range**” radio button.”
2. Color the image by pulling down the **View** menu and selecting **Look Up Table (LUT)** to open the LUT window. Click on the Load button and select “Spectrum”, then click **OK**.

Answer These Questions:

- 2a. What color represents the largest standard deviation values?
- 2b. What is the range of standard deviation values on the image?
- 2c. What do large standard deviations in NDVI values indicate about a region on an image?
- 2d. Is the Sahel clearly distinguished from the Sahara? From the equatorial rain forests? Explain.



Exercise 5.H

Calculating a coefficient of variation image

1. Activate the SahelSeptNDVI stack. Pull down the **Stack** menu and select **Statistics> Covariance**. Select the “**Scale Image to Byte Range**” radio button.”
2. Color the image by pulling down the **View** menu and selecting **Look Up Table (LUT)** to open the LUT window. Click on the Load button and select “Spectrum”, then click **OK**.



Do Exercise 5.H now.

Move the cursor over the SahelCV image while monitoring the values in the Info window.

As you have seen, if we calculate a standard deviation image the Sahel is easily differentiated from the Sahara Desert but it blends in with the wooded areas to the south. This is because the NDVI values are higher in the wooded areas and therefore a smaller relative change in NDVI in the wooded areas will appear similar to the relatively high change in the Sahel. To differentiate regions of high change we can calculate a coefficient of variation on the stack of images. The coefficient of variation is calculated by dividing the standard deviation by the mean. This gives us a method that is more sensitive to changes in low NDVI areas.

Answer These Questions:

- 3a. What region has the highest coefficient of variation values?
- 3b. Is the region clearly distinguishable from the Sahara Desert and the equatorial rain forests? Explain.
- 3c. What do high coefficient of variation values indicate about this region?
- 3d. What possible climatic conditions might account for the larger variation in NDVI values in the Sahel?

Looking at the coefficient of variation image you can see the Sahel region is one of high change in Vegetation cover throughout the year. Some people have suggested that it may be more appropriate to define the extent of the Sahel by using a coefficient of variation threshold since this provides information about Vegetation dynamics.

A more accurate way to look at this variation within the Sahel would be to calculate the coefficient of variation for the monthly data over a period of several years. This can be done as an additional exercise.

Investigating NDVI Value Variation In The Sahel For A Specific Year—1984



Exercise 5.I

Calculate a mean image from September Sahel images

1. Close SahelSD and SahelCV. Do not save them unless told to do so by your instructor.
2. Activate the SahelSeptNDVI stack . Pull down the **Stack** menu and select **Statistics> Mean**. Select the “**Maintain Current Calibration**” radio button.

The Mean image is displayed.

3. Color the image by pulling down the View menu and selecting Look Up Table (LUT) to open the LUT window. Click on the Load button and select “DAAC_NDVI.lut”, then click OK.
4. Close the SahelSeptNDVI stack .



Exercise 5.J

Generating a difference image from the September 1984 image and the September average image

1. Pull down the **File** menu and select **Open**. Locate and select the following directory, then click **Open**:
`<i2k\installed> | data | SEES | Veg | vgex5 | SahelSeptNDVI | SahND0984.`
2. Pull down the **Image** menu and select **Math>Calculator** to activate the Image Calculator.
3. Select SahND0984 from the uppermost pop-up menu. Select SahelSeptMean from the second pop-up menu (underneath the first one). Select **Subtract** from the Operation pop-up menu. Type “Sept84-SeptMean” in the results box next to the equal sign (=). This will be the name of the output image. Select the Real Result check box since the resulting image pixel values will be outside the 1–254 range. Click **OK**.
4. Color the image by pulling down the **View** menu and selecting **Look Up Table (LUT)** to open the LUT window. Click on the Load button and select “Spectrum”, then click **OK**.

Overview

To identify an individual year of significant change we can compare the image for a specific month in a year to the mean of that month generated from images over several years.



Do Exercises 5.I and 5.J now.

Move the cursor over various regions in the image and notice the values in the Info window.

Answer These Questions

1a. What do positive values represent? Negative values?

1b. What range of values do you find in the Sahel?

1c. What do the Sahelian NDVI difference values indicate about Vegetation in this region this year compared to average September Vegetation ?

1d. What is a possible cause for this difference?

When we subtract the monthly image for September 1984 from the average of all the September monthly composites from 1981 to 1993 we can see that there was a significant difference between the average image and the 1984 image. This difference was caused by a serious drought that was one of the worst in Africa’s history.

On the following page is a table of the precipitation record for a few meteorological stations in the Sahel for the period of May 1–May 30. From the table you can see that 1984 was a very dry year.

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Station	Latitude (N)	Longitude (E)	Rainfall (mm) May 1-Oct. 30, 1993	May 1-Oct. 30 30-year average (mm)
Khartoum	15° 36'	32° 32'	1	158
Kassala	15° 28'	36° 24'	98	321
Gedaref	14° 02'	35° 24'	325	579
El Obeid	13° 10'	30° 14'	97	386
El Fasher	13° 28'	25° 20'	69	283
Nyala	12° 04'	24° 53'	182	470
Kadugli	11° 00'	29° 43'	369	764
Abu Nama	12° 44'	34° 08'	371	576
Kosti	13° 10'	36° 40'	86	396
Sennar	13° 33'	33° 37'	193	470
Wad Medani	14° 25'	33° 31'	127	362

Exercise 6: Comparing Estimates Of Global Terrestrial Primary Productivity

Overview

Net Primary Productivity (NPP) is important in understanding global biospheric functioning. A great deal of research has gone into estimating NPP using satellite imagery, but the estimates of global NPP from different approaches vary depending on, among other things, the validity of assumptions related to the efficiency of light use for NPP. In this exercise we will estimate global NPP using two simple methods and then we will compare those results with the output of a more mechanistic approach.



SEES_v1/html_pages/vg_textbook: Chapter 5 “Overview of Remote Sensing Systems for Monitoring Vegetation”

Before Beginning

- Make sure you have read through the Introduction to Module 2: Global Land Vegetation Computer Lab Exercises document.
 - Start *NASA Image2000*, or if it is already running close any open images
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Investigating Net Primary Productivity Through APAR Images

Primary production is the term used to describe the rate at which organic materials are produced by plants. It is usually expressed as a unit weight per area (i.e., tons per acre, grams per m²). There are two general types of primary production: gross primary production (GPP), which is the total amount of material produced (energy lost through respiration is not taken into account); and net primary production (NPP) or the increase in biomass, which is the material produced beyond that immediately used by the plant. Since production depends on photosynthetic rates we can estimate GPP and NPP by looking at light absorption by Vegetation .

The electromagnetic radiation in the region between 400–700 nanometers (nm) is known as Photosynthetically Active Radiation (PAR). This is the energy plants use to power photosynthesis. The amount of PAR incident at Earth’s surface can be derived from an instrument best known for its use in mapping depletion of the ozone layer, the Total Ozone Mapping Spectrometer (TOMS). Ultraviolet observations from TOMS are used to depict cloud cover, and the cloud amount is used to reduce the potential amount of incident PAR at Earth’s surface. Other satellite data can also be used for this purpose, but in this exercise we use PAR values derived from TOMS data.

The amount of incident PAR absorbed by Vegetation is an important factor in determining photosynthetic rates. Surface reflectance in the visible and infrared wavelengths, as detected by the Advanced Very High Resolution Radiometer (AVHRR), can be used to estimate PAR absorption (called APAR) by relating the Normalized Difference Vege-

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**Exercise 6.A**

Opening an APAR image

1. Pull down the **File** menu and select **Open**. Locate and select the following directory, then click **Open**:
`<i2kInstalled> | data | SEES | Veg | vgx6 | APAR.TIF.`
2. Click on the **DensityCal** tab, and enter the following values:
 The checkbox "**Use in next open image**" should be checked.
Y Intercept = 3.95
Slope = 0.0155
Units = $\text{J/m}^2/\text{yr} \cdot 10^9$
3. Click on the **Open** button.

**Do Exercise 6.A now.**

tation Index (NDVI) to the proportion, or fraction, of PAR that is absorbed by terrestrial Vegetation. We refer to this fraction of absorbed PAR as fPAR. For this exercise we will assume that NDVI and fPAR are linearly related; that is, that they are directly proportional to one another. When fPAR and incident PAR are combined, we have a measure of the amount of canopy light absorption (APAR).

This is a global image of the APAR amount for the entire year 1987. Since this quantity is a measure of the energy available for photosynthesis we can use it to estimate plant primary production. To determine the units for image values select 'File/Get Info' and look under Unit of Measure. Close the Info window when you are finished.

Answer These Questions:

1. What are the units for APAR in this image?

The units for this APAR image are billions (10^9) of joules (gigajoules or GJ) per square meter per year. A joule is equivalent to 1 watt per second, so a gigajoule is equivalent to one billion watts per second. We can also express APAR units in megajoules (MJ). One GJ is equivalent to a thousand megajoules.

- 2a. Select a pixel close to where you live and record the APAR value here.
- 2b. What would an average daily value be? (Hint: the value provided is a yearly average.)
- 2c. Would you expect the same value every day? Explain why or why not.

During the summer in, say, Washington, DC, Earth's surface receives about 0.025 GJ or 25 MJ per square meter per day when the atmosphere is clear but the average is approximately 6 MJ per square meter per day.

Calculating NPP Using A Simple Approach

We can calculate NPP in a simple manner by assuming that all Vegetation everywhere on Earth converts a single MJ of APAR into a single gram of biomass. One GJ would be converted to a kilogram of biomass. To convert from total biomass to grams of carbon, we multiply by 0.5 since about half of the biomass is made up of carbon. Using image arithmetic we can generate an NPP image from the APAR image using

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**Exercise 6.B**

Generating an NPP image through image arithmetic

1. Activate APAR.TIF. Pull down the **Image** menu and select **Math>Arithmetic Operators> Multiply Constant**, then enter “0.5” in the **Constants** box. Click **OK**. The image is altered.
2. Pull down the **File** menu and select **Save As**, and enter “NPP Simple.TIF” in the Save As box. Find the following location, then click **Save**:

<2kinstalled> | data | Veg

**Exercise 6.C**

Generating a histogram for an NPP image

1. Click on the NPP Simple image to activate it and then pull down the **Image** menu and select **Analysis>Histogram**.
The Histogram dialog is displayed.
2. Enter “255” in the **Highest Value** text field. Accept the other defaults, and click **OK**.

The histogram is displayed.

**Do Exercise 6.B now.**

Move the cursor over various points on the image and note the number next to Value in the Info window. The first number is the calculated NPP for the given pixel. The second value is the system value and can be ignored.

To get a picture of the distribution of values on this image we can generate a histogram. If we generate one for an NPP image, it provides the number of pixels in an image for each value (in kgC/m²/yr).

**Do Exercise 6.C now.**

The “X” axis contains the NPP values and the “Y” axis contains the number of pixels for a particular NPP value. To read the histogram information, select the histogram window. Move the cursor into the histogram window and move it over the black regions of the histogram while viewing the results in the Info window. Level shows the NPP value and Count lists how many pixels there are for that Level. This histogram can be printed by selecting ‘File/Print Histogram’.

You may save the histogram as an image file but you will not be able to access the Count and Level values from that image file. Be sure to record any data you need from the histogram before saving it as an image. Look in the Tutorial for directions on saving or exporting histogram information to other applications.

You may generate a histogram on an area of an image by selecting one of the dotted selection tools (rectangle, polygon, or freehand) from the Tools window to outline an area. Then select ‘Analyze/Show Histogram’ to display the histogram for that area.

Answer These Questions:

- 3a. From the histogram, what is the approximate range of NPP values on this image?
- 3b. From the image, what geographic regions have high NPP values? Why is this reasonable?
- 3c. What range of values is found in the United States?

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4. What problem(s) might there be with the basic assumption used to generate this image (all Vegetation everywhere on Earth converts a single MJ of APAR into a single gram of biomass)? Explain.

We will see in the remainder of the exercise why our basic assumption is not a realistic one.

Investigating NPP Using Other Approaches

Overview

A second way to calculate NPP is to assign individual biomass yield values to each Vegetation type on Earth. This means that we have to rely on the classification of Vegetation into different types that have similar biomass yield values (which may not be easy). For the moment we will assume it is possible. The following table shows how different Vegetation types might convert APAR into biomass. It is based on measurements acquired at different sites around the world and then assigned to entire classes of Vegetation across the planet.

Vegetation Type	Conversion Factor (gC/MJ APAR)
Water	0.0
Broadleaf evergreen forest	0.31
Broadleaf evergreen forest & woodland	0.50
Mixed coniferous & broadleaf deciduous forest & woodland	0.65*
Coniferous forest and woodland	0.78
High latitude deciduous forest and woodland	0.50
Wooded c4 grassland	0.55*
C4 grassland	0.63
Shrubs and bare ground	0.63
Tundra	0.63
Desert, bare ground	0.63
Cultivation	1.03
Ice	0.0
C3 wooded grassland	0.55*
C3 grassland	0.63

* Cases where an adequate conversion factor was not defined. These values were calculated based on other similar classes.

These conversion values were derived from work done by Ruimy, A., Dedieu, G. and Saugier, B. 1994. Methodology for the estimation of terrestrial net primary production from remotely sensed data. *Journal of Geophysical Research* 99:5263–5283.

Exercise 6.D

Generating another NPP image using the Image calculator

1. Open the APAR.TIF file as described in step 6.A, then pull down the **File** menu and select **Open**. Locate and select the following directory:


```
<i2kinstalled> | data | SEES | Veg |
  vgex6 | APAR_CON.TIF.
```
2. Click on the **DensityCal** tab, and enter the following values, then click on the **Open** button:

The checkbox **“Use in next open image”** should be checked.

Y Intercept = 1.03

Slope = 0.00404

Units = grams C/MJ
3. Pull down the **Image** menu and select **Math>Calculator**.
4. Select APAR.TIF from the top drop-down menu and APAR_CON.TIF from the second drop-down menu. Select **Multiply** from the operator drop-down box. Enter “NPP Assigned.TIF” in the **Results** box next to the = and check the **Real Result** box. Click **Execute**. The two images will be multiplied together and the resultant image, NPP Assigned, will be displayed.
5. Color the image by pulling down the **View** menu and selecting **Look Up Table (LUT)** to open the LUT window. Click on the Load button and select “Rainbow.lut”, then click **OK**.
6. Activate NPP Assigned.TIF. Pull down the **File** menu and select **Save As**, and enter “NPP Assigned.TIF” in the Save As box. Locate the following directory and click Save:


```
<i2kinstalled> | Images | Veg .
```
7. Close APAR_CON.TIF.
8. Select NPP Assigned.TIF. Pull down the **Image** menu and select **Analyze>Histogram**.

The image APAR_CON.TIF was created by inserting the values from the table for each Vegetation class into the ISLSCP classified image (VEG_CLSS.TIF) that was introduced in Exercise 3. We can use this image to generate another image with assigned NPP values by multiplying the values for each pixel on the original APAR image by the conversion image.

Do Exercise 6.D now.

Answer These Questions:

- 1a. From the histogram, what is the approximate range of NPP values on this image?
- 1b. How does the range compare to the range for the NPP Simple.TIF image?
- 1c. Do the same regions have high NPP values on this image as in the simple image?
- 1d. Do any regions show significant differences in NPP values between the two images? Explain.
- 1e. What range of values is found in the United States?



Exercise 6.E

Opening and converting an NPP image derived from another approach

1. Pull down the **File** menu and select **Open**. Locate and select the following directory, then click **Open**:
`<i2k\installed> | data | SEES | Veg | vgex6 | GLOPEM.TIF.`
2. Click on the **DensityCal** tab, and enter the following values, then click on the **Open** button:
 The checkbox "**Use in next open image**" should be checked.
Y Intercept = 1.2
Slope = -0.00471
Units = KgC/m²/yr
3. Pull down the Edit menu and select Duplicate Image.
4. With this new image selected Pull down the File menu and select Save As, and enter "NPP Modeled.TIF" in the Save As box. Locate the following directory and click save:
`<i2k\installed> | images | SEES | veg | vegex6`
5. Pull down the **Image** menu and select **Math>Calculator**.
6. Select GLOPEM.TIF from the top drop-down menu and GLOPEM.TIF from the second drop-down menu. Select 'Copy' from the operator drop-down menu. Enter "NPP Modeled.TIF" in the **Results** box next to the = and check the **Real Result** box. Click **OK**.
7. Close GLOPEM.TIF and keep NPP Modeled.TIF open.
8. Select NPP Modeled.TIF. Pull down the **Image** menu and select **Analyze>Histogram**. Enter "255" in the Highest Value text field. Accept the other defaults, and click OK. The histogram is displayed.

Investigating NPP Using A Third Approach

A third approach to estimating global NPP from satellite data makes no assumptions about biomass yields from APAR. Instead it uses APAR to determine potential photosynthesis and then it calculates the amount of actual photosynthesis by reducing the potential amount to account for stresses associated with high or low temperature and moisture amounts. The amount of actual photosynthesis is called gross primary production (GPP). Not all GPP is used for plant growth, however, because some of it is lost to respiration. That is, carbon is expended in the construction and maintenance of biomass. When respiration is subtracted from GPP, we end up with the net amount of biomass production; that is, NPP.



Do Exercise 6.E now.

Copying the image using Image Math generates values in a format needed for accurate calculations using the GLOPEM image later in this exercise.

For more information about the model used to calculate this NPP image go to the WWW site: <http://www.inform.umd.edu/geog/glopem/>.

To see the units for this image select 'File/Get Info' and look at the Unit of Measure: line.

Answer These Questions:

- 2a. From the histogram, what is the approximate range of NPP values on the NPP Modeled.TIF image?
- 2b. Are the values generally higher, lower, or the same for comparable regions on the NPP Modeled.TIF image compared to the previous two NPP images? Explain.

Close the histogram window.

Comparing The Three Different Calculations Of NPP

Overview

Make sure the three images, NPP Simple.TIF, NPP Assigned.TIF, and NPP Modeled.TIF, are open. If they are not, use the 'File/Open' command to open them.

Position the three images so that they line up vertically.

Answer These Questions

1. What general observations can you make about the distribution of NPP values starting with NPP Simple.TIF and progressing to NPP Modeled.TIF.
- 2a. Select a pixel on NPP Simple.TIF. Record the X and Y values for the pixel, the approximate geographic location, and the NPP value in the table below. Find the same pixel on the other images and record the NPP values. Be sure that you have activated an image by clicking on the title bar before locating the pixel and recording the NPP value.
- 2b. Repeat the procedure for three more pixels at widely varying geographic locations (i.e., equatorial, midlatitude, multicontinent).
- 2c. Looking at the table of values for each image, is there a trend in values for the images based on the model used? Explain.

Pixel Location (X,Y)	Approximate Geographic Location	NPP Value (kg/m ² /yr)		
		Simple	Assigned	Modeled



Exercise 6.F

Calculating difference images using image math

1. If the file NPPSimple.TIF was closed and then opened again it will be necessary to follow the instructions in Exercise 6.A step 2 to calibrate this image.
2. Pull down the **Image** menu and select **Math>Calculator**.
3. Select NPPModeled.TIF from the top drop-down menu and NPPSimple.TIF from the second drop-down menu. Select **Subtract** from the operator drop-down menu. Enter “Modeled–Simple” in the **Results** box next to the = and check the **Real Result** box. Click **OK**.
4. If the file NPPAssigned, TIF was closed and then opened again it will be necessary to follow the instructions in Exercise 6.A step 2 to calibrate this image.
Repeat step 3 but insert NPPAssigned.TIF from the second drop-down box and insert the name “Modeled–Assigned” in the box next to the = sign.
5. Repeat step 3 but insert NPPAssigned.TIF from the top drop-down menu and NPP Simple.TIF from the second drop-down menu. Insert the name “Assigned–Simple” and click **OK**.
6. Color the image by pulling down the **View** menu and selecting **Look Up Table (LUT)** to open the LUT window. Click on the Load button and select “32Colors”, then click **OK**.

A More Quantitative Look At The Three NPP Models

To look at differences in the three NPP images more quantitatively we can generate “difference images” using image math. We will look at how the Simple and Assigned images compare to each other and to the image generated by GLOPEM.



Do Exercise 6.F now.

Answer These Questions

3. Move the cursor up and down the LUT window.

What color range represents positive values? _____

What color represents extreme negative values? _____

Activate the Assigned–Simple image and move the cursor over pixels in the image while monitoring the values in the Info window.

- 4a. Are most of the values negative or positive?
- 4b. What do negative results tell you about the NPP values calculated using the Vegetation classes compared to the simple model?
- 4c. Which zone shows the greatest negative difference in NPP values?

Activate the Modeled–Simple image and move the cursor over pixels in the image while monitoring the values in the Info window.

- 5a. Are most of the values negative or positive?
- 5b. What do negative results tell you about the NPP values calculated using the GLOPEM model compared to the simple model?

- 5c. Which regions show the greatest differences in NPP values?

Activate the Modeled–Assigned image. Move the cursor over it and monitor the NPP values in the Info window.

- 6a. Are most of the values negative or positive?
- 6b. Which regions show the greatest differences in NPP values?

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7. Consider all three difference images (Modeled–Simple, Modeled–Assigned, and Assigned–Simple). Do the same regions show deviations on all images? Explain.
8. What do you think are the advantages and disadvantages of the three models for calculating NPP?

Close all images when you are finished. Do not save images unless told to do so by your instructor.

Discussion

The results of this exercise show that these three approaches to estimating global NPP produce different results. In the case of the first two approaches the different results are entirely due to the assumption of constant biomass yield values for different Vegetation types. The third approach is probably more realistic because it is more mechanistic; that is, the third approach uses APAR as a mechanism to drive photosynthesis and then accounts for stress terms and for respiration.

There are many other models that estimate NPP on a global scale, but few use satellite observations to detect actual processes occurring at Earth's surface. Most models make assumptions about Vegetation conditions or assign rates for different processes based on the assumption that plot measurements are reliable at much broader scales or for entire biomes. All approaches based on satellite observations are driven primarily by light absorption, but other approaches place greater emphasis on water or nutrients. All these various approaches have advantages and pitfalls, but it is likely that only those models that use satellite observations will provide realistic maps of global biospheric processes like NPP because they observe actual conditions at Earth's surface frequently. Thus satellite observations have become crucial to our understanding of the functioning of the biosphere. By manipulating the values that drive these models—for example, by assuming that photosynthesis or respiration rates will change with changing climate—we can even predict the biosphere's responses to change and gain insight into future conditions on Earth.