

## exercise 1

# introduction to avhrr images and creating global ndvi images

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

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  $55^\circ$  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 km<sup>2</sup>. However, the resolution becomes coarser as the sensor scans off to the side. When it is at  $55^\circ$  the resolution is approximately 17 km<sup>2</sup> (pixel area is about 17km<sup>2</sup>) 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  $30^\circ$  of nadir. The 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  $1 \text{ km}^2$  but can also provide a lower image resolution of approximately  $16 \text{ km}^2$ . In addition, several other resolutions can be created during the processing phase. Image resolutions used in the exercises for this module are either  $8 \text{ km} \times 8 \text{ km}$  or  $1^\circ \times 1^\circ$ .

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 $\mu\text{m}$	0.58–0.68 $\mu\text{m}$	0.58–0.68 $\mu\text{m}$	0.58–0.68 $\mu\text{m}$
2	0.725–1.10 $\mu\text{m}$	0.725–1.10 $\mu\text{m}$	0.725–1.10 $\mu\text{m}$	0.725–1.10 $\mu\text{m}$
3	3.55–3.93 $\mu\text{m}$	3.55–3.93 $\mu\text{m}$	3.55–3.93 $\mu\text{m}$	3.55–3.93 $\mu\text{m}$
4	10.5–11.5 $\mu\text{m}$	10.5–11.5 $\mu\text{m}$	10.5–11.3 $\mu\text{m}$	10.5–11.3 $\mu\text{m}$
5	Channel 4 repeated	Channel 4 repeated	11.5–12.5 $\mu\text{m}$	11.4–12.4 $\mu\text{m}$

### BEFORE YOU BEGIN THIS EXERCISE

make sure you have completed the following steps—instructions for them are in the *Tutorial*.

- Start *SEE Image*
- Configure *SEE Image*
- Load the *SEE\_macros*

## A

### *changing the clipboard size*

- 1 — Select 'Options/Preferences'. If the size is 1000 or more, click OK. If the size is less than 1000 do the next three steps.
- 2 — Change the 'Undo & Clipboard Buffer Size' to 1000. Click OK.
- 3 — Quit SEE Image.
- 4 — Restart SEE Image.

## B

### *opening uncorrected images from the five avhrr channels*

- 1 — Select 'File/Open' and go to Desktop | HD | SEE Image | Data | Veg | vgx1 | CHAN1ORB.TIF and click on Open.
- 2 — If the image is not in grayscale, select 'Options/Grayscale' to color the image.
- 3 — 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.
- 4 — Repeat the above steps for CHAN2ORB.TIF, CHAN3ORB.TIF, CHAN4ORB.TIF, and CHAN5ORB.TIF.

## exploring uncorrected avhrr images

Because some of the images we will be using to begin this exercise are large, it may be necessary to change the clipboard size.

*Do A and B 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.

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: ‘Go to File/Get Info’ 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

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  $64 \text{ km}^2$  (7.39 km high x 8.7 km wide) although most of the images have been subsampled by a factor of four to approximately  $1024 \text{ km}^2$  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.

## C

**opening and examining corrected avhrr images**

1 — Select 'File/Open' and go to Desktop | HD | SEE Image | Data | Veg | vgex1 | Ch1Stack | CH1270SM.TIF and click on Open.

2 — If the image is not grayscale, select 'Options/Grayscale' to color the image.

3 — Repeat the above steps for the following images located in Desktop | HD | SEE Image | Data | Veg | vgex1: Ch1Stack | CH1270SM.TIF; Ch2Stack | CH2270SM.TIF; Ch3Stack | CH3270SM.TIF; Ch4Stack | CH4270SM.TIF; Ch5Stack | CH570SM.TIF. Position the images so that you can see as much as possible for each image.

*Do C 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.

5. Why are there gaps between the different orbits?

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

**creating ndvi images**

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.

# D

## generating an ndvi image from avhrr channels

1 — Select 'Process/Image Math'.

2 — Select CH2270SM.TIF from the top drop-down menu and CH1270SM.TIF from the second drop-down menu. Select the - sign in the operator drop-down box. Enter "1" in the X box and "0" in the + box. Enter "Numerator" in the box next to the = and check the Real Result box. Click OK. The two images will be subtracted and the resultant image, Numerator, will be displayed.

3 — Select 'Process/Image Math'.

4 — Select CH2270SM.TIF from the top drop-down menu and CH1270SM.TIF from the second drop-down menu. Select the + sign in the operator drop-down box. Enter "1" in the X box and "0" in the + box. Enter "Denominator" in the box next to the = and check the Real Result box. Click OK. The two images will be added and the resultant image, Denominator, will be displayed.

5 — Select 'Process/Image Math'.

6 — Select Numerator from the top drop-down menu and Denominator from the second drop-down menu. Select the ÷ sign in the operator drop-down box. Enter "1" in the X box and "0" in the + box. Enter "NDVI" in the box next to the = and check the Real Result box. Click OK. 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.

*Do D now.*

7. 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.

**8a.** 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 Value (Channel 1)	CH2270SM.TIF Value (Channel 2)	NDVI Value

**8b.** 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).*

**9a.** Locate a region that you know is covered with bare soil or has no vegetation. What is the region you selected?

**9b.** What is the approximate range of NDVI values for this region with no vegetation?

**9c.** How does this compare to cloud values? Why do you think this is so?

**10a.** 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.

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

**10b.** What do the values tell you about the reflectance of light by water in AVHRR Channels 1 and 2?

**10c.** Is the resulting NDVI value the same as for water and clouds? Why or why not?

**11a.** 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.

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

**11b.** Explain why the value for Channel 2 is higher than for Channel 1.

*Close all images before proceeding.*

### compositing ndvi and avhrr images

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.

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.

**E****generating a temporal profile to evaluate an image pixel**

1 — Select 'File/Open' and click in the Open All checkbox. Go to Desktop | HD | SEE Image | Data | Veg | vgex1 | NDVIStack | NDV270SM.TIF and click Open. Make sure only the 10 NDVI images from day 270 through day 279 are open. If other images are also open, close them before going to step 3.

2 — Select 'Stacks/Windows to Stack'.

3 — Select the line selection tool (dashed line) from the Tools window and then click on the pixel located at X=51, Y=122.

4 — Select 'Special/Plot Temporal Profile' and click OK for both the Maximum and Minimum value for the Y axis.

*Do E now.*

**12a.** Based on the temporal (Z-axis) profile plot, which date has the highest NDVI value for the pixel at X=51, Y=122?

**12b.** Why are some of the NDVI values for this pixel equal to -1?

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

**13a.** 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 value for each pixel in a new image window. SEE Image has macros that will allow us to do both steps easily.

*Do F 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.

**14a.** What is the value for the pixel?

**F****generating a date index image**

1 — Activate the NDV270SM.TIF–NDV270SM.TIF stack.

2 — Select 'Special/CompositeDates' and enter "DateIndex" in the box under Enter Date-Image Title then click OK. The image will appear white.

3 — Move the cursor over the image and look at the values in the Info window.

4 — Select the DateIndex image and then select 'File/Save As'. Click the TIFF radio button. Go to Desktop | HD | SEE Image | Images | Veg and enter "DateIndex.TIF" in the Save As box. Click OK.

5 — Select 'Options/Color Tables/System' to view the date value distribution in color.

**14b.** Is this value reasonable based on your answer for 11a? 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.

## G

### *generating an ndvi composite image*

- 1 — Activate the “NDV270SM - NDV270SM” stack.
- 2 — Select ‘Special/CompositeStack’ and enter “NDVIComposite” in the box under Enter Compositing Image Title then click OK. When the file selection window appears, go to Desktop | HD | SEE Image | Images | Veg | DateIndex.TIF.
- 3 — Select ‘Options/Color Tables/DAAC NDVI’ to color the image.
- 4 — With the composite image selected, select ‘File/Save As’. Click the TIFF radio button. Go to Desktop | HD | SEE Image | Images | Veg and enter “NDVIComposite.TIF” in the Save As box then click OK.

*Do G now.*

**15a.** 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.

**15b.** Select the composite image (NDVICom.TIF) then move the cursor to X=51, Y=122 and note the NDVI value here.

**15c.** Is there a difference between the two pixel values? Explain.

## H

### *generating an avhrr channel composite image*

- 1 — Repeat the steps in G using a stack from one of the AVHRR channels rather than the NDVI stack. AVHRR channel stack images are in Desktop | HD | SEE Image | Data | Veg | vgex\ (Ch1Stack, Ch2Stack, Ch3Stack, Ch4Stack, or Ch5Stack). Each directory has 10 images. Only the 10 daily images should be included in the stack before processing. Name the output images CH1Com, CH2Com, CH3Com, CH4Com, and CH5Com and save them in Desktop | HD | SEE Image | Images | Veg. It will be necessary to create composite images for channels 4 and 5 (CH4Com and CH5Com) in order to complete step J.
- 2 — Repeat the compositing process for another channel if time permits.

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

*Do H now.*

*Close all images and stacks before proceeding.*

## I

*applying a mask to an image*

1 — Select 'File/Open'. Go to Desktop | HD | SEE Image | Images | Veg | vgex1 | NDVIComposite.TIF. Click on Open.

2 — Select 'File/Open' and go to Desktop | HD | SEE Image | Data | Veg | vgex1 | Masksm.TIF to open the image that will be used to mask out water.

3 — Select the Mask image. Select 'Edit/Select All' followed by 'Edit/Copy Selection'.

4 — Select the NDVIComposite.TIF image. Select 'Edit/Paste'. The overlay image will completely cover the base image at this point.

5 — Select 'Windows/Show Paste Control'.

6 — In the Paste Control window, click and hold the Transfer Mode pop-up menu ('Copy' is the default setting) and select 'Replace'. The NDVI composite image will now have the water pixels masked.

7 — Select 'Windows/Hide Paste Control' to close the Paste Control window.

## J

*opening avhrr composite images*

1 — Select 'File/Open' and go to Desktop | HD | SEE Image | Images | Veg | CH4Com to open the NDVI composite image.

2 — 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.

3 — 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.

**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.

*Do I now.*

*Close all images and stacks before proceeding.*

**investigating avhrr channels 4 and 5**

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.

*Do J now.*

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

**16a.** Do you see much difference between the two images? Why or why not?

**16b.** Where do you tend to find the colder pixels? Explain.

**16c.** Is the central part of Africa warmer or cooler than the north and south? Why might you expect this based on previous observations in this exercise?