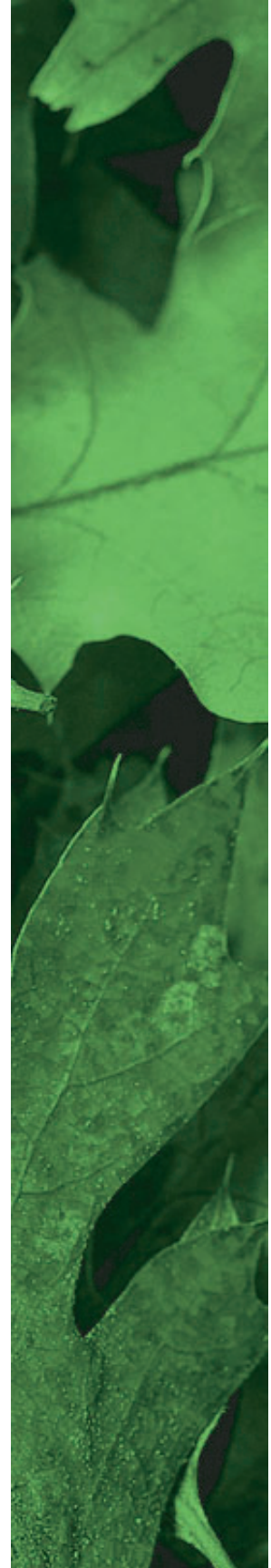Studying Earth's Environment
From Space
Module 2: Global Land Vegetation

Instructor's Guide
for
Computer Resources

GLOBAL LAND VEGETATION
MODULE
Release:
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introduction

The *National Science Education Standards* developed under the auspices of the National Research Council specifies "Science as Inquiry" as major content standard for all grade levels. The activities that students engage in during grades 9–12 and in undergraduate science courses should develop the students' understanding of and ability to do scientific inquiry. An understanding of the nature of scientific inquiry involves awareness of why scientists conduct investigations, the role technology and mathematics plays in scientific design and analysis, the criteria used to judge data and models, and the impact that communication has on the development of scientific ideas. Among the abilities identified as necessary to do scientific inquiry are

- identification of concepts and questions that guide scientific investigations;
- use of technology and mathematics to improve inquiries and communication skills
- formulation and revision of scientific explanations and models based on logic and evidence.

One of the recommendations of the National Science Foundation Report, *Shaping the Future: New Expectations for Undergraduate Education in Science, Mathematics, Engineering, and Technology,* is that faculty "build into every course inquiry, processes of science...a knowledge of what [science, mathematics, engineering, and technology] practitioners do, and the excitement of cutting-edge research."

Both the National Council of Teachers of Mathematics in their publication, *Curriculum and Evaluation Standards for School Mathematics,* and the American Mathematical Association of Two Year Colleges in *Crossroads in Mathematics: Standards for Introductory College Mathematics Before Calculus* espouse the use of real-world examples and technology to teach and reinforce mathematical concepts.

To address the standards in both science and mathematics, the materials in this module were designed to use image processing technology to enhance a student's understanding of scientific inquiry using a well-publicized subject, the characteristics and dynamics of global land vegetation. The exercises employ "hands-on" data processing in the form of image generation and analysis to give students the opportunity to work with data as research scientists do. The lectures provide the most current scientific thought with supporting data. Additional materials such as an introduction to basic image processing concepts, background on the ozone satellite and sensor, and format information for the data sets have been made available to address ancillary questions that may arise.

references

Crossroads in Mathematics: Standards for Introductory College Mathematics Before Calculus. American Mathematical Association of Two Year Colleges, 1995. http://www.richland.cc.il.us/imacc/standards/

Curriculum and Evaluation Standards for School Mathematics. National Council of Teachers of Mathematics. 1989. http://www.wnc.org/reform/journals/ENC2280/280dtoc1.htm

National Science Education Standards. National Research Council, National Academy Press, 1996. http://www.nap.edu/readingroom/books/nses/html/

Shaping the Future: New Expectations for Undergraduate Education in Science Mathematics, Engineering, and Technology. National Science Foundation, Directorate for Education and Human Resources, 1996 (NSF 96-139). http://www.ehr.nsf.gov/EHR/DUE/documents/review/96139/start.htm

exercises

Each exercise for the Global Land Vegetation Module was designed to illustrate concepts connected with issues in current global change research involving vegetation. They are presented as guided inquiry activities. Working through an activity, students are asked to perform selected image processing steps using specified data sets. Questions associated with each operation direct attention to the concept being elicited or probe for a student's understanding of the tools being employed.

This instructor's guide provides the following for each exercise.

Learning objectives that specify the concepts and operations students are expected to investigate
Science process skills, those broadly transferable abilities used in scientific disciplines that students must employ to complete the exercise. A description can be found at http://www.science.cc.uwf.edu/narst/research/skill.htm
National Science Education Content Standards for grades 9–12 embodied in the exercise
Image processing skills or operations in SEE Image that students use to interpret the data sets
Mathematical tools that are required in the data processing or analysis
Resource materials where information to complete or enhance each exercise can be located
Answers to exercises with selected images.

exercise 1
introduction to avhrr images and creating global ndvi images

To study global vegetation coverage and dynamics one needs 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) flown on NOAA's TIROS–N series satellites. The AVHRR sensor has five bands that range from the visible wavelengths to the thermal infrared. Using data from the first two channels, it is possible to create an image that 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 (NDVI) image.

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

learning objectives

When students complete Exercise 1 they should be able to

Understand the difference between AVHRR channels and the information each provides.

Understand data problems associated with uncorrected AVHRR images and satellite orbit position.

Differentiate cloud, water, and land pixels on AVHRR and NDVI images..

Generate an NDVI image from AVHRR channels 1 and 2..

Composite an AVHRR or NDVI image and understand the compositing process.

science process skills
observing
inferring
communicating
measuring
interpreting data

national science education content standards
A: Ability to do science inquiry
   Understanding about science inquiry
D. Energy in the Earth system
E: Understanding about science and technology
G: Nature of scientific knowledge

image processing skills
importing an AVHRR or NDVI image
generating an image stack
generating a temporal (z-axis) profile
generating a date index image
compositing an AVHRR or NDVI image
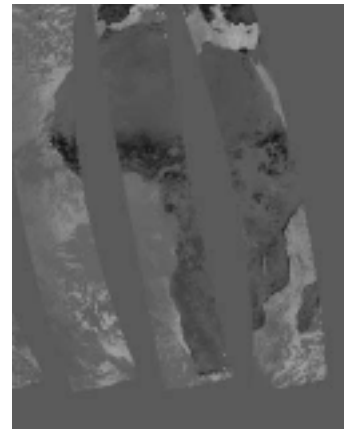applying an image mask

mathematical tools
interpreting a graph

resource materials
Global Land Vegetation Document on the AVHRR Satellite and Sensor
Global Land Vegetation eTextbook, Chapter 4 (vegetation indices)

answers to exercise 1

1. These images show Madagascar (center is X = 80, Y = 460) and the east coast of Africa including the Nile river basin (center is X = 130, Y = 2245).

2. These images appear upside down because the orbit is ascending (from south to north) so the first line (top) of the image is the southernmost portion of the area covered by the satellite and the last line (bottom) is the northernmost portion of the area scanned.

3. Draw an imaginary line running from top to bottom down the center of each image. This line represents the points where the sensor was looking at nadir (directly below it) so there is no significant distortion. As the scanner looks off to the side more surface area is covered by a single pixel. This gives the effect that each image is wrapped around a cylinder and distorts each image more as you move away from the center line.

4. a. image lines / scan rate = time to acquire image

   b. The image has 2400 lines and the scanner acquires data at a rate of 6 lines per second, so 2400 lines divided by 6 lines per second = 400 seconds, or 6 minutes 40 seconds.

   c. 100 and 650 Dobson Units (DU) although most values fall between 200 and 500 DU

5. Remember from an earlier discussion that the portions of the image that were acquired when the AVHRR scanner was looking more than 30 degrees off to either side of the nadir are eliminated. The black sections represent these regions.

6. Clouds appear white on channels 1 and 2 and dark on channels 4 and 5.

7.
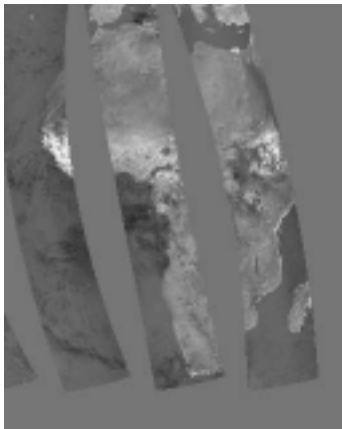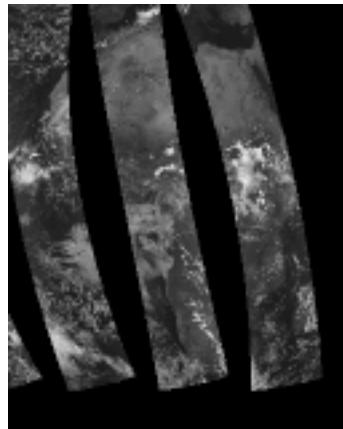
Numerator   *Denominator*   *NDVI*

8. a. Below is a sample pixel. It may not match a student selection.

| Cloud pixel	CH1270SM.TIF value (channel 1)	CH2270SM.TIF value (channel 2)	NDVI value
X = 177, Y = 116	0.86	0.83	–0.02

    b. Reflectances are nearly the same for channels 1 and 2 and are very high because there is little absorbance.

9. a. Sahara Desert is a good choice.

    b. 0.00–0.02 for bare soil

    c. Clouds and bare soil have similar responses (little absorbance, high reflectance) on both channels so the NDVI values are effectively zero.

10. a. The pixel illustrated below may not match student selection.

| Water pixel	CH1270SM.TIF value (channel 1)	CH2270SM.TIF value (channel 2)	NDVI value
X = 24, Y = 70	0.05	0.03	–0.30

    b. Water reflectance is very low in both channels 1 and 2 because water absorbs strongly in both channels.

    c. Clouds are strong reflectors in both channels while water is a strong absorber in channels 1 and 2. The NDVI values will be close to zero for clouds and zero to negative for water pixels.

11. a. Sample pixel below may not match student selection.

Vegetation pixel	NDVI value	CH1270SM.TIF value (channel 1)	CH2270SM.TIF value (channel 2)
X = 198, Y = 99	0.44	0.11	0.25

    b. The value for channel 2 is higher than for channel 1 because green vegetation absorbs red light (giving low channel 1 reflectance value) and reflects near-infrared light (giving a high channel 2 value).

12.
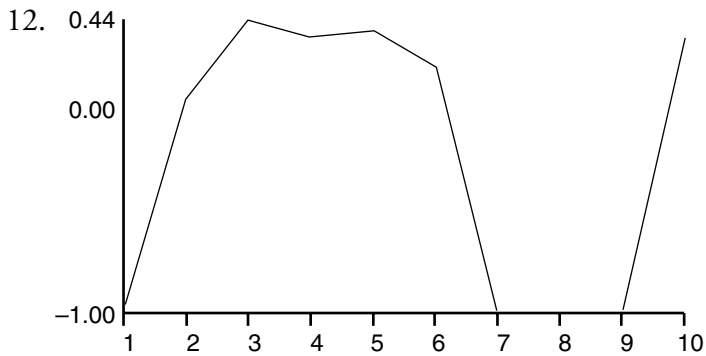
    a. The third image, Day 272, has the highest NDVI value for this pixel.

    b. On some of the images there are no data for this pixel because of the satellite sensor position.

13. This pixel has a valid data value and fewer clouds. Looking at the third slice (Day 272) you can see that this pixel falls close to the middle of the orbit, which means the sensor was looking nearly vertical. This means there are fewer distortions than when the sensor is looking at the pixel off to the side.

14. a. 3

    b. The answer is reasonable because the date index represents a compilation indicating the image with the best value for each pixel and from the temporal profile we know that image 3 has the maximum value for 51, 122.

15.
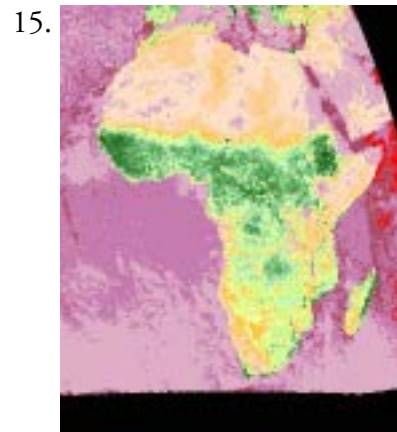
    b. NDVI = 0.44

    c. Values are the same as should be expected since the composite is made from values determined by the date index.

16.
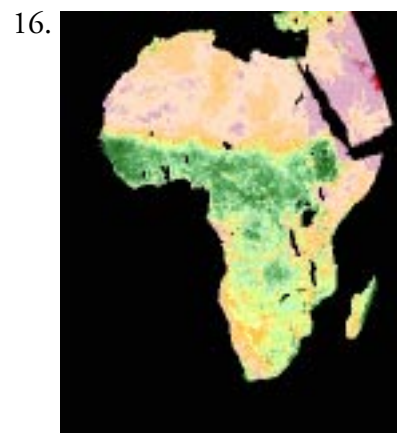
    a. Temperature values are similar since channels 4 and 5 record emitted thermal energy and are used primarily to measure cloud, sea, and land surface temperature.

    b. The water tends to be colder than land in Africa during the afternoon since the land emits thermal radiation more than water.

    c. The central part of Africa is generally cooler because it has more forest cover and emits less thermal radiation. This vegetation cover is evident from the NDVI image.

exercise 2
seasonal greening of the hemispheres

Most students have experienced vegetation changes throughout the seasons with the degree of change depending on their geographic location. Unless the students have lived in varied locations they may not have a sense of differences in the timing of changes in the two hemispheres or within the same hemisphere. These vegetation changes 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.

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

learning objectives
When students complete Exercise 2 they should be able to

Describe seasonal changes in vegetation in each hemisphere.

Recognize and describe the differences in temporal greening patterns in the northern and southern hemispheres from an animation or montage of images.

Generate and interpret a temporal profile of NDVI values for any location on Earth and relate the profile to seasonal greening patterns.

Generate and interpret orthographic (polar) or Hammer projections of NDVI images.

science process skills
observing
inferring
communicating
measuring
interpreting data

national science education content standards
A: Ability to do science inquiry
    Understanding about science inquiry
C: Behavior of organisms
D: Energy in the Earth system
E: Understanding about science and technology
G: Nature of scientific knowledge

image processing skills
importing an AVHRR NDVI image
generating an image stack
creating a montage from a stack
animating an image stack
generating a temporal (z-axis) profile
generating Hammer and orthographic projection images
locating or determining latitude and longitude on an image using a macro

mathematical tools
interpreting a graph

resource materials
Global Land Vegetation eTextbook, Chapters 2 (seasonal changes in radiation) and 4 (vegetation indices)

answers to exercise 2

1.

   a.   Maximum NDVI value ∼0.8   Minimum NDVI value ∼ –0.2

   b.   NDVI is calculated as follows:

      NDVI = (NIR – RED) divided by (NIR + RED)

      where NIR represents the near infrared signal for a given pixel and RED represents the red reflectance for that pixel. In the NDVI you see a direct comparison between the near infrared and red reflectances in the numerator. This difference is normalized by the sum of the reflectances in the denominator, the purpose of this normalization is to adjust for varying light levels.

      One of the advantages of NDVI is that its range of possible values is limited to a value between 1 and 1. If both the near infrared and red reflectances are equal, NDVI has a value of zero. Bare soils generally have low, positive values of NDVI. As the amount of green vegetation increases in a pixel, NDVI increases in value to nearly 1. Negative NDVI values can occur; usually this is caused by snow or water occurring in the pixel.

   c.   Students should notice seasonal changes with lower NDVI values (violet colors) more prevalent in the winter hemisphere. There is a distinctive seasonal change evident in the northern hemisphere but the seasonal change is less obvious in the southern hemisphere.

2.   During the beginning and end of the year the extreme portions of the northern and southern hemisphere seem to disappear from the images because NDVI values are based on infrared and red light reflectances. During the polar night there is no incident radiation and therefore no reflected light for the satellite to measure. The "no-data" values are displayed in blue like the oceans and so parts of the land masses seem to vanish.

3.   a.   Generally, the color shifts from green through shades on the LUT window to violet and back to green.

b. In the northern hemisphere July appears to have maximum greening while December and January appear to have the least. Some data are missing in the northern hemisphere during these months due to polar night.

4. a. There is a similar pattern of more to less to more greening, however, there are significant areas, particularly in South America, that are always green. The change is not as obvious as in the northern hemisphere.

    b. Largest areas of green appear during January through May in the southern hemisphere when the northern hemisphere is just beginning to green. The greenness also appears to move from more southern latitudes in January to April to more equatorial latitudes in May through September.

5. a. – d. The NDVI values and pattern of change in values for this section will depend on the pixels selected by the student. NDVI values in the northern hemisphere should start small (~00.1), increase to the maximum (~0.6) in summer months, and then decrease through fall and into winter. Southern hemisphere values will generally have less variation and should show an increase, decrease, increase pattern in NDVI values.

6.
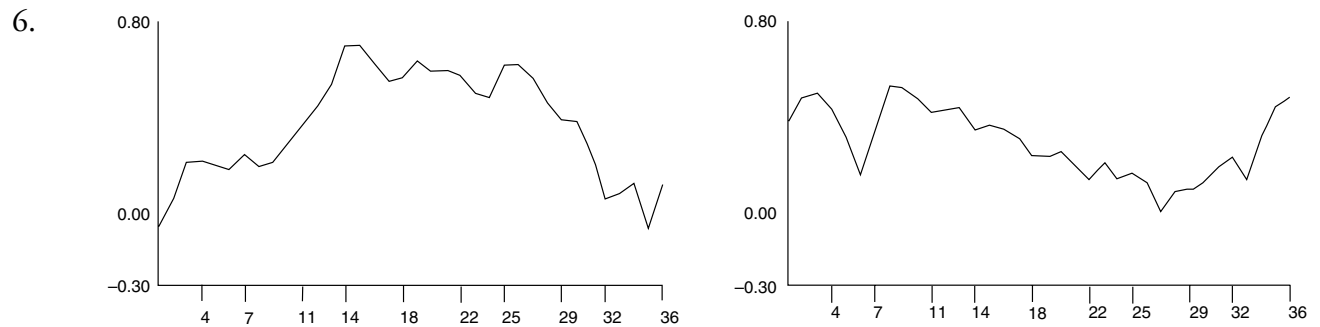
a. The values in this table will vary depending on the pixels selected. Values below are for the pixels suggested in the exercise (86, 54 = northern; 208, 105 = southern).

	northern hemisphere	southern hemisphere
Maximum NDVI Value	0.7	0.53
Month & Day of Max. Value	May 11 & 21	March 11
Minimum NDVI Value	−0.07	0.01
Month & Day of Min. Value	January 1	September 21

b. In the northern hemisphere the temporal profile should show that NDVI values were highest in summer and lowest in winter.. Forthe southern hemisphere the curve has the opposite shape. Comparing the two graphs we can see that the trend of NDVI values is opposite in the northern and southern hemisphere.

exercise 3
vegetation classification and global vegetation patterns

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

Students start this exercise by looking at a global land cover classified image and exploring the extent of various cover types. Next, they investigate how the classified image was generated by selecting several predefined pixels for 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 they select other pixels from the stack of monthly composites and try to determine what type of vegetation is represented by each pixel.

learning objectives

When students complete Exercise 3 they should be able to

Interpret a global vegetation classification image to assess class distribution and compute areas covered by each vegetation class.

Generate and interpret temporal profiles of NDVI values to classify a pixel by land cover from global NDVI images

Understand some of the complexities of generating and applying global land cover classification techniques on a global scale.

science process skills

observing
inferring
communicating
measuring
classifying
interpreting data

national science education content standards

A: Ability to do science inquiry
Understanding about science inquiry
C: Behavior of organisms
E: Understanding about science and technology
G: Nature of scientific knowledge

image processing skills

importing single and multiple AVHRR NDVI images
applying color tables
projecting an image
density slicing
measuring areas with density slicing
generating an image stack
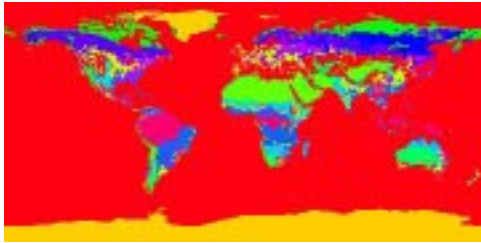generating a temporal (z-axis) profile

mathematical tools

generating and interpreting a plot
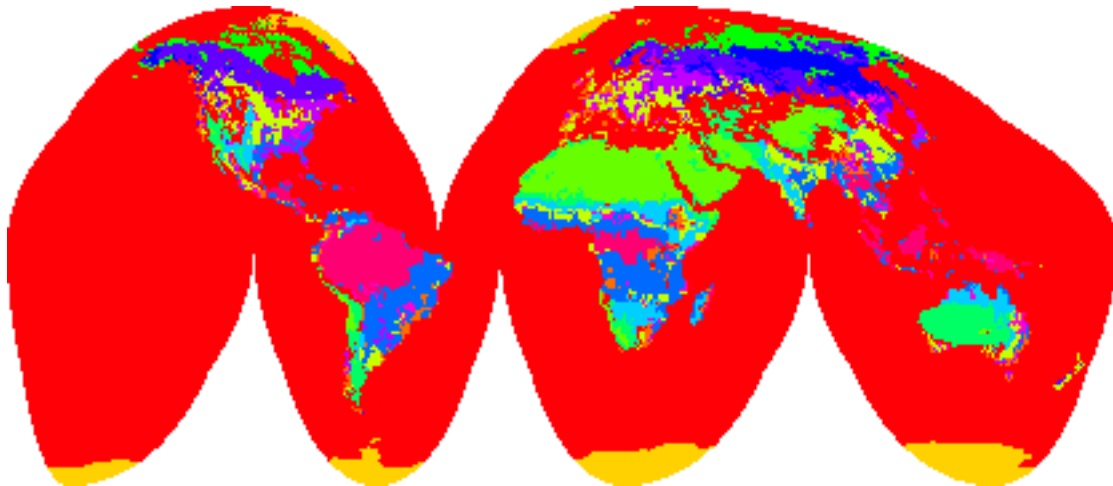
resource materials

Global Land Vegetation eTextbook, Chapter 6 (discussion of vegetation and land cover classification schemes)

answers to exercise 3

1. Because the image is rectangular but Earth's surface is spherical, each pixel does not represent the same area. Pixels at high latitudes represent less surface area than pixels at the equator.

2.

3. Some of the classes appear to fall within certain latitude ranges. Examples include: 1 (broadleaf evergreen) equatorial; 4 (coniferous forest and woodland) high latitude in northern hemisphere; 5 (high latitude deciduous forest and woodland) high latitude in northern hemisphere; 10 (tundra) high latitude in northern hemisphere; and 11 (desert or bare ground) latitude mainly in northern hemisphere.

    Other classes have representation scattered over various latitudes. Examples are: 2 (broadleaf deciduous forest and woodland); 7 (c4 grassland); 9 (shrubs and bare ground); and 12 (cultivation).

4. No class seems to predominate.

5.

class (mean)	land cover type	area (km²)
0.0	water	482,400,544
1	broadleaf evergreen forest	17,744,406
2	broadleaf deciduous forest & woodland	4,414,462
3	mixed coniferous & boradleaf deciduous forest & woodland	8,853,655
4	coniferous forest & woodland	17,398,174
5	high latitude desiduous forest & woodland	7,604,746
6	wooded c4 grassland	22,888,430
7	c4 grassland	11,623,514
9	shrubs & bare ground	14,751,970
10	tundra	9,224,618
11	desert, bare ground	22,616,390
12	cultivation	17,830,964
13	ice	21,379,846
14	c3 wooded grassland	6,195,086
15	c3 grassland	15,357,876

The land cover classes with the largest areas are wooded c4 grassland and desert and bare ground.

6.
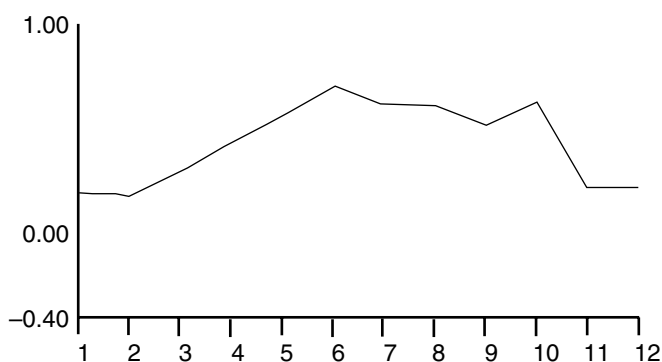
7–8.
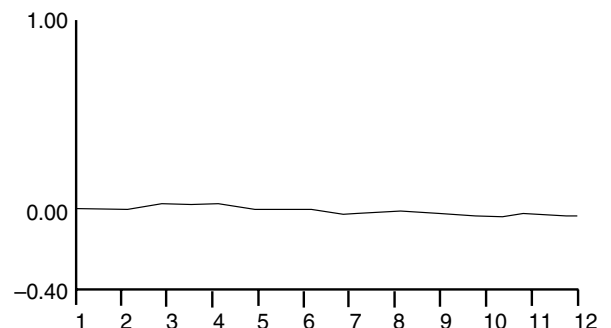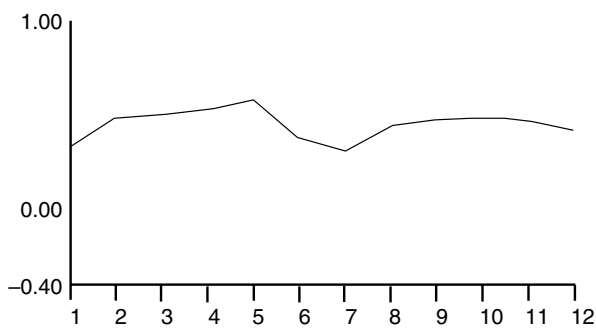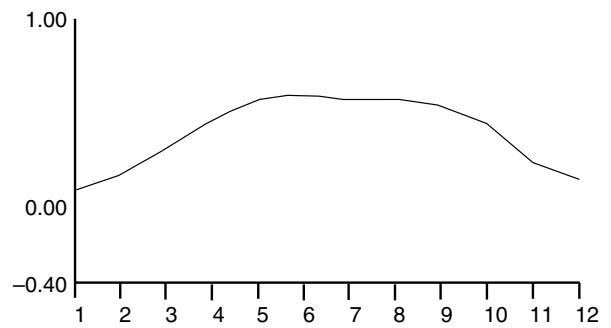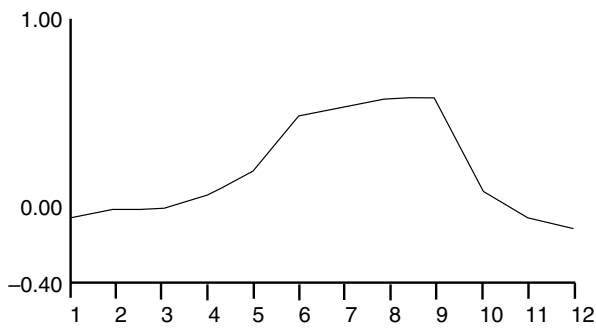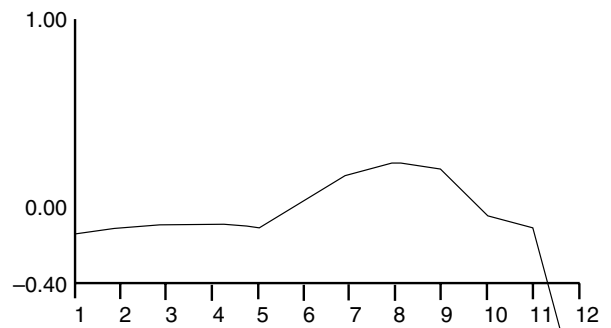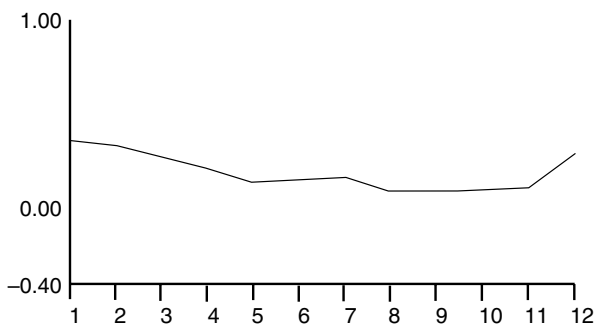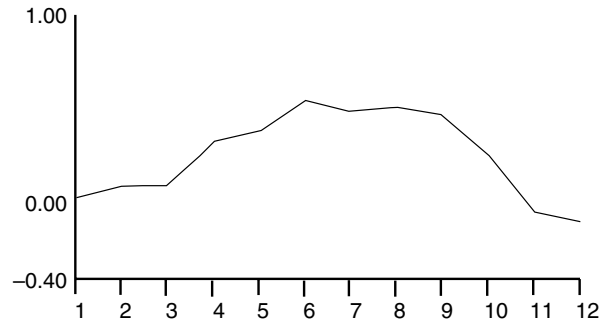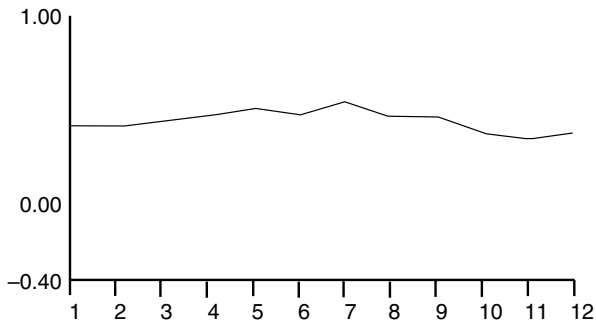
Profiles for these pixels match the legend profiles relatively closely.

9. Since pixel selection for this question is left at the discretion of the student there are no correct answers. Check to see how well a student's classification based on profile matched the classification for the pixel from the VEG_CLSS.VGC image.

10. The area covered by each pixel is large and as a result some areas have mixed land cover. This might add error to the classification.

exercise 4
land cover change in the brazilian amazon

In this exercise students look at the higher resolution 8km Normalized Vegetation Index (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.

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

learning objectives
When students complete Exercise 4 they should be able to

Interpret land cover from NDVI images.

Monitor change in land cover over time by comparison of NDVI values.

Understand possible anthropomorphic reasons for land cover change

science process skills
observing
inferring
communicating
measuring
interpreting data

national science education content standards
A: Ability to do science inquiry
     Understanding about science inquiry
C: Interdependence of organisms
E: Understanding about science and technology
F: Environmental quality
     Natural and human induced hazards
     Science and technology in local, national, and global challenges
G: Nature of scientific knowledge

image processing skills
opening an image
applying an overlay
using image math to ratio two images
applying a LUT

mathematical tools
generating and interpreting a ratio image

resource materials
Global Land Vegetation eTextbook, Chapters 7 (aspects of land cover change including how to measure it) and 8 (the role of humans in land cover change)
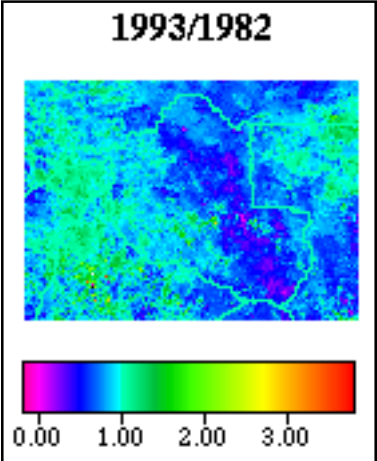
answers to exercise 4

1. From September 1982 to September 1993 there has been a decrease in NDVI values evident in a region running from northcentral to southeast in Rondonia. The decreased values are visible as a shift from green to yellow in pixel color.

1982 1993
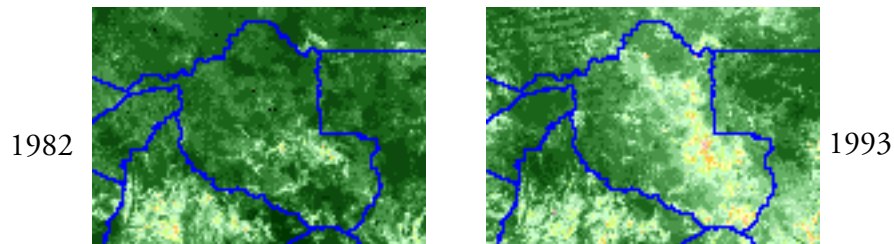
Students may speculate on causes for the changes including climatic differences and development by man.

2. It is possible to perform mathematical operations on the two images to provide a third image because each pixel has a numerical value associated with it that can be processed mathematically. Since both images cover the same region and are the same size, there is a pixel-for-pixel match between the two images.

3.

a, Colors representing ratio values less than 1 are medium blue to purple.

b. More pixels with values below 1.

c. Pixels with ratio values less than 1 have decreased NDVI values from 1982 to 1993. There is less photosynthetic activity where ratio values are below 1.

d. The land cover for this region changed from vegetation to bare soil from 1982 to 1993 probably caused by intervention by man.

4.

1982   1993
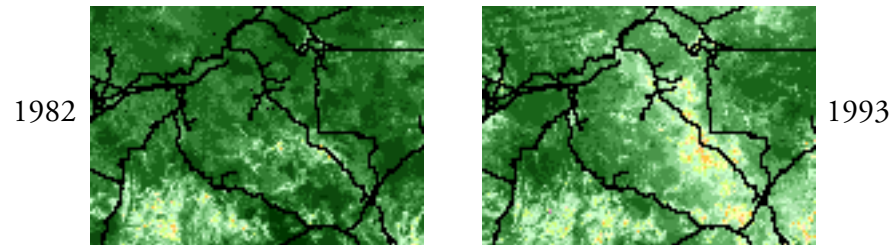
a. Areas that decrease in NDVI value (based on the 1993 image) border road positions.

b. It is likely that road development and clearing of land for settlements and agriculture are responsible for the change in NDVI values in this region of Brazil. Discussion of changing land use patterns is found at the end of the exercise.

exercise 5
vegetation dynamics in the sahelian zone

Exercise 4 illustrated an example of land cover conversion that is the result of human actions. In some areas, 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.

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

learning objectives
When students complete Exercise 5 they should be able to
Understand different criteria for defining a land region.
Interpret the relationship between rainfall amounts and vegetation as measured by NDVI values.
Interpret interannual and intraannual vegetation patterns from NDVI images.

Use standard deviation and coefficient of variation images to evaluate seasonal and regional patterns in vegetation change.

science process skills
inferring
communicating
measuring
interpreting data

national science education content standards
A: Ability to do science inquiry
Understanding about science inquiry
E: Understanding about science and technology
F: Environmental quality
Natural and human induced hazards
G: Nature of scientific knowledge

image processing skills
opening an NDVI image
applying a LUT
applying an overlay
animating an image stack
using image math to calculate a
• stack average
• standard deviation image for a stack
• coefficient of variation image for a stack
using image math to compare two images

mathematical tools
generating and interpreting:
• standard deviations
• coefficients of variation
• a ratio image

resource materials
—none listed—

answers to exercise 5

1. a. Highest rainfall value **4000**   Color **pale yellow**
        Lowest rainfall value   **100**   Color **white**

    b. White lines with values of approximately 100 mm rainfall per year roughly define the Sahara
        Desert region based on the location.

2. White is 100 mm so 150 mm must fall between white and dark blue isobytes. Either of these can be
    assumed to be the upper geographic boundary and the lower rainfall boundary. Bright red defines
   the lower geographic and higher rainfall boundary.

3.
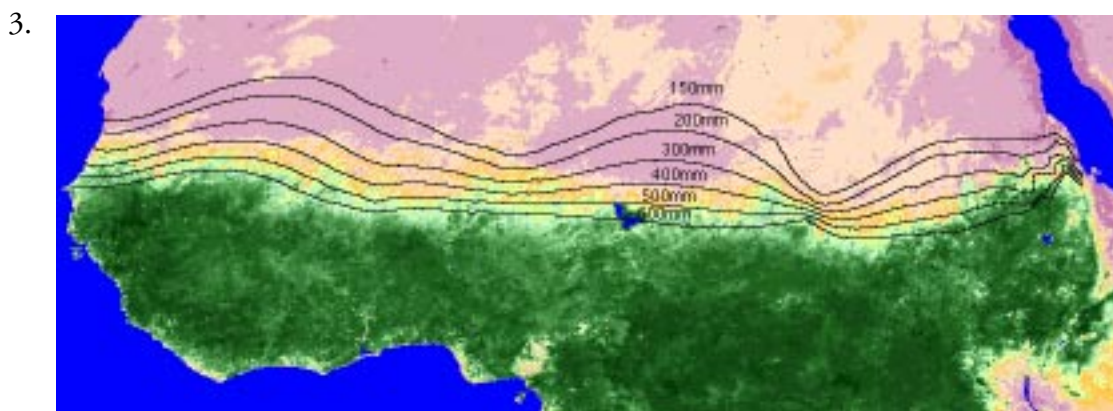
    approximate range of NDVI values in the Sahel   **–0.06 to 0.42**

4. a. Months showing the largest area of high NDVI values: **August and September**

    b. Months showing the largest area of low NDVI values: **January and December**

    c. Region showing the least change in NDVI values: **Sahara Desert** because rainfall is so low that
        vegetation is not supported.

5. If rainfall amounts were roughly the same for September from year to year you would expect little
    change in vegetation patterns from year to year.

6. To check for variations you could generate a stack of September images for a period of years and look
    at differences and similarities in the vegetation (NDVI values) on the stacked images.

7. a. There is variation in the Sahel based on NDVI values and degree of displayed greenness.

    b. Most extensive September vegetation in the Sahel occurred in 1988 or 1992.

   c.   Least extensive September vegetation in the Sahel occurred in 1984.

   d.   Drought or plant disease might lead to minimum vegetation development in the Sahel.

8.   Amendments to answers in 7 if appropriate.

9.   In SEE Image, overlays destroy underlying data so it is important to start with unmodified images.

10.

SahelSD
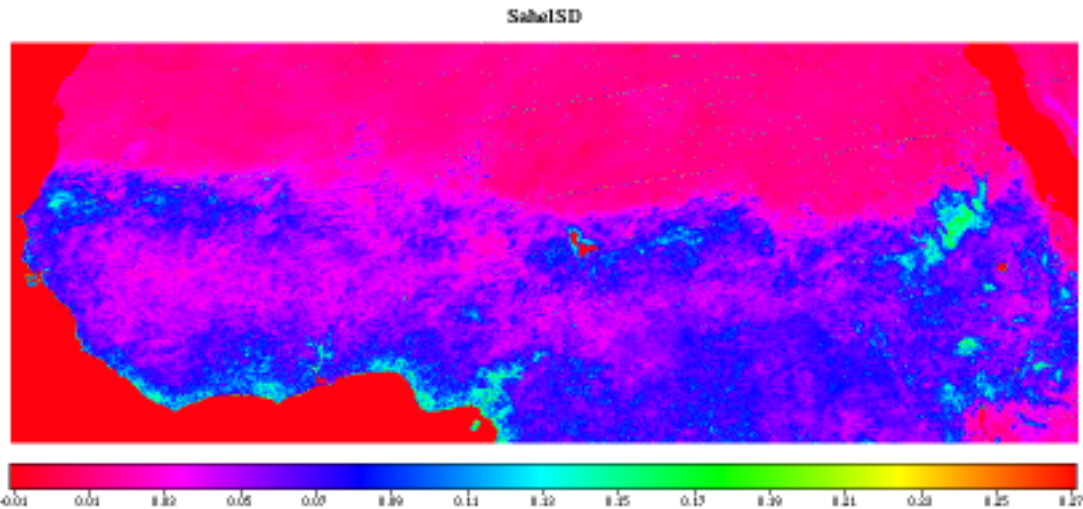
   a.   Largest standard deviation values   *orange and red*

   b.   Range of standard deviation values   *0.0 – 0.27*

   c.   Large standard deviations in NDVI values indicate a region with large changes from year to year.

   d.   The Sahel is clearly distinguished from the Sahara because of the blue regions with larger standard deviations. It is not as easily distinguished from the equatorial rainforests to the south.

11.

SahelCV
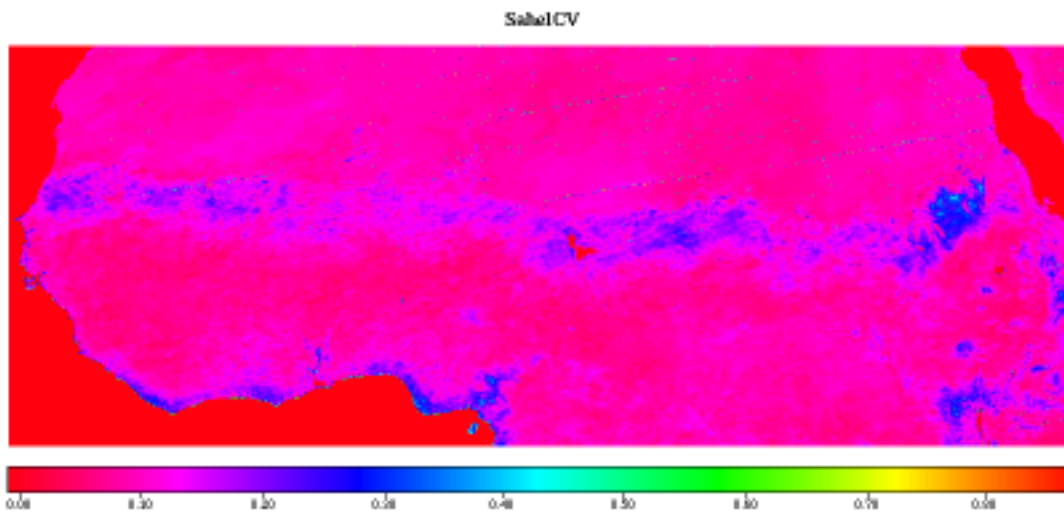
   a.   The Sahel and western coastal regions have the highest coefficient of variation values.

   b.   The Sahel is clearly distinguishable from the Sahara Desert and the equatorial rainforests as a band with higher CV values.

   c. High coefficient of variation values indicate that the Sahel is a region of more year-to-year change than the desert or equatorial rainforests.

   d. Variations in rainfall might account for the larger variation in NDVI values in the Sahel.

12.

Sept84-SeptMean
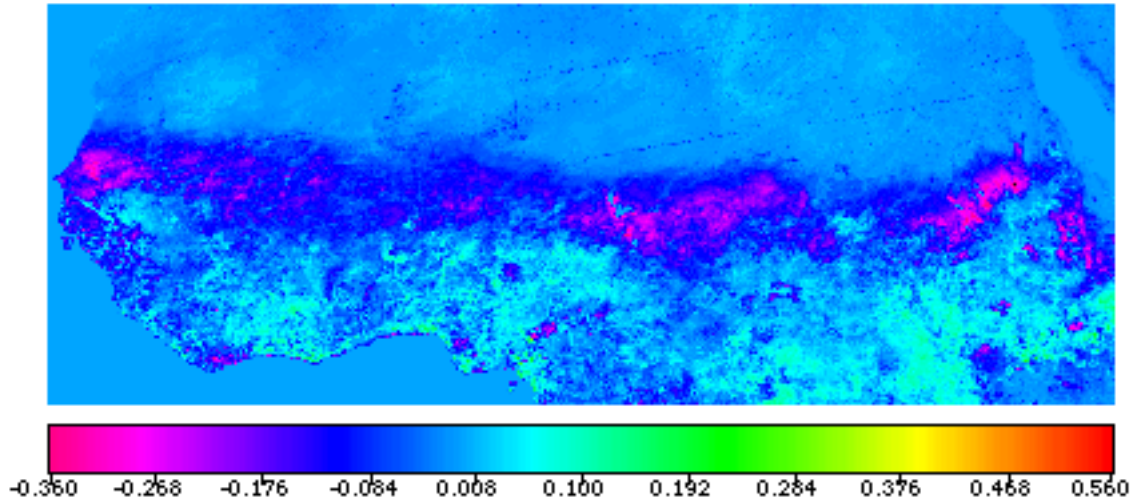
   a. Negative values represent areas where the mean September NDVI values are higher than September 1984 NDVI values for corresponding pixels. Positive values occur where the NDVI value for September 1984 was higher than the mean.

   b. Sahel range of values   *−0.36 to 0.14*

   c. Since there are many pixels with negative NDVI difference values in the Sahel you can conclude that the vegetation in the Sahel was sparser in 1984 than is typical for September in this region.

   d. The most probable cause for this difference is drought during 1984. See discussion that follows this question.

exercise 6
comparative estimates of global terrestrial primary productivity

Net primary productivity is importance in understanding global biospheric functioning. A great deal of research has gone into estimating Net Primary Production (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 students estimate global NPP using two simple methods and then compare those results with the output of a more mechanistic approach.

The electromagnetic radiation in the region between 400–700 nanometers (nm) is known as Photosynthetically Active Radiation (PAR). 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 amount of cloud cover 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 students use TOMS PAR.

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 AVHRR can be used to estimate PAR absorption (APAR) by relating the NDVI to the proportion, or fraction of absorbed PAR as Fpar. We will assume for this exercise 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).

learning objectives
When students complete Exercise 6 they should be able to
>   Interpret images of NPP values.
>   Understand how different NPP calculations vary in different models and how the values are determined.

science process skills
>   observing
>   inferring
>   communicating
>   measuring
>   interpreting data

national science education content standards
>   A: Ability to do science inquiry
>   Understanding about science inquiry
>   C: Matter, energy, and organization in living systems
>   E: Understanding about science and technology
>   G: Nature of scientific knowledge

image processing skills
>   opening an NDVI image
>   applying a LUT
>   using image arithmetic to calculate a modified image
>   using image math to compare two images
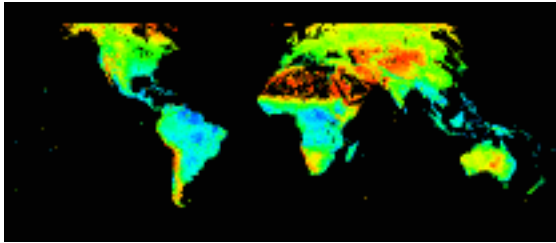
mathematical tools
>   generating & interpreting a difference image

resource materials
Global Land Vegetation eTextbook, Chapter 5 (discussion of NPP and its importance in understanding global biospheric functioning)
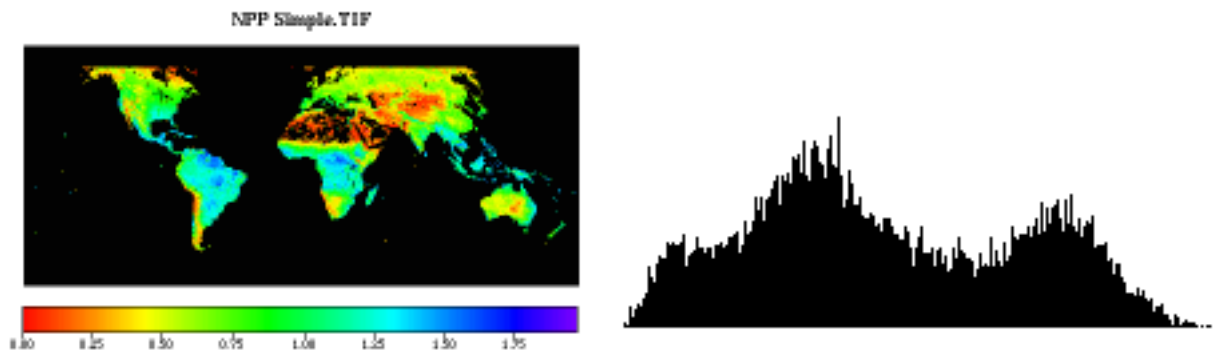
answers to exercise 6

1.

APAR units are $J/m^2/yr \times 10^9$ or $GJ/m^2/yr$ (gigajoules per meter squared per year).

2. a. This APAR value will vary depending on the pixel selected.

   b. Daily value = yearly average divided by 365.

   c. Daily values will vary because of changing Sun angle (and solar insolation) and meteorological conditions.

3.

   a. Approximate range of values 0.0–$1.68 \, kgC/m^2/yr$ (one pixel at 1.75 and 1.97).

   b. Geographic regions with high NPP values are equatorial. Since there is a greater amount of solar insolation in this zone, the APAR and, therefore, grams of carbon processed should be higher.

   c. Range of values in the United States 0.0–$1.44 \, kgC/m^2/yr$.

4. The basic assumption used to generate this image is that vegetation everywhere on Earth converts a single MJ of APAR into a single gram of biomass. It does not take into account productivity differences in vegetation type. It does not consider weather patterns and their effect on productivity.

5.

NPP Assigned.TIF
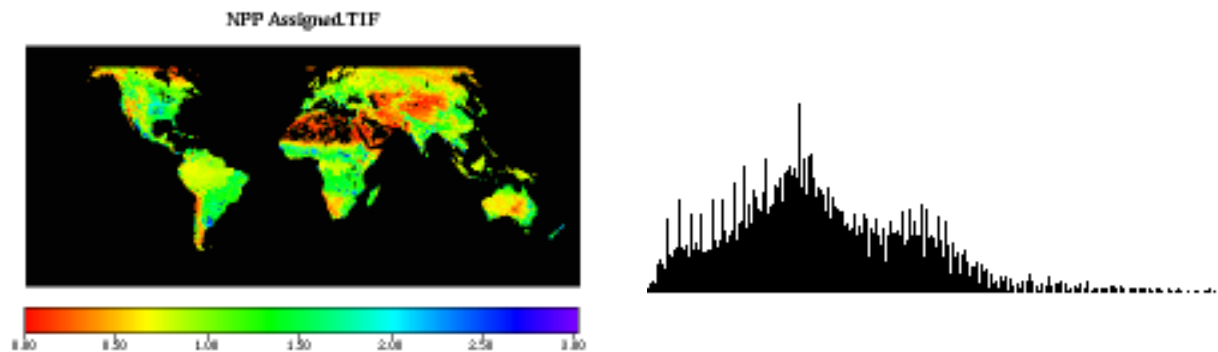
a. Approximate range of NPP values   0.0–2.85 kgC/m²/yr (1 pixel at 3.03).

b. Range on the assigned image is larger than the simple image.

c. Approximately the same regions have high NPP values on both images.

d. There are higher values in US southcentral regions; northern hemisphere high latitudes, western equatorial regions of South America and Africa.

e. Range of values in the United States   0.0–2.71 kgC/m²/yr.

6.
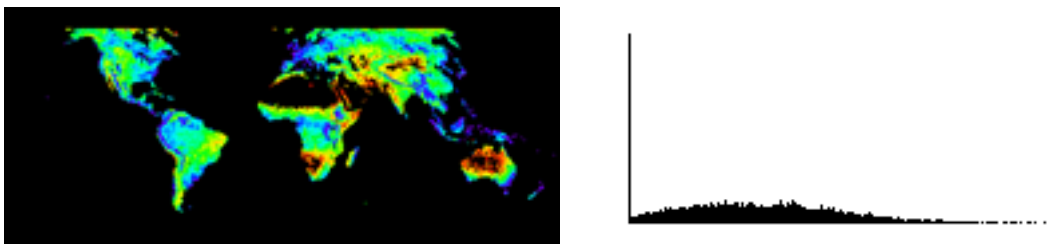
a. Approximate range of NPP values 0.0–1.19 kgC/m²/yr.

b. Generally the values are significantly lower on the Modeled image than comparable regions on the other two images based on a scan of values.

7. The NPP values in the "NPP Simple.TIF" and "NPP Assigned.TIF" images show more large area clustering and a more zonal distribution than the "NPP Modeled.TIF" image.

8. a–b. The values below are sample pixel selections and may not match student selections.

pixel location (x, y)	approximate geographic location	npp value (kg/m²/yr)		
		simple	assigned	modeled
98, 49	southcentral US	1.23	2.55	0.86
156, 108	eastern Brazil	1.28	1.41	0.44
278, 25	northern Asia	0.78	0.78	0.62
228, 96	western equatorial Africa	1.18	1.30	0.75

c. Looking at the table of values for each image, the simple and modeled values are lower than the assigned values. The modeled values are significantly lower than both of the other image values.
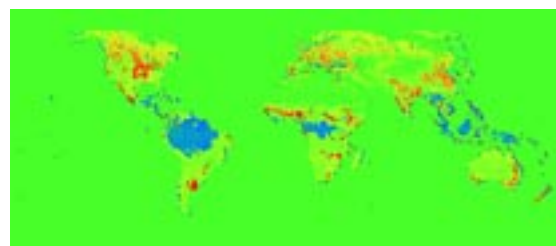
9.
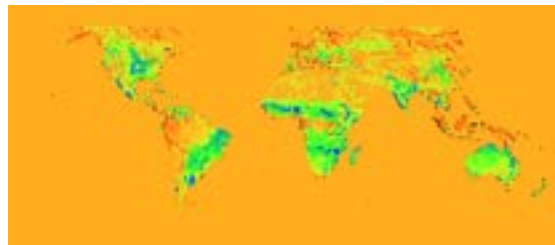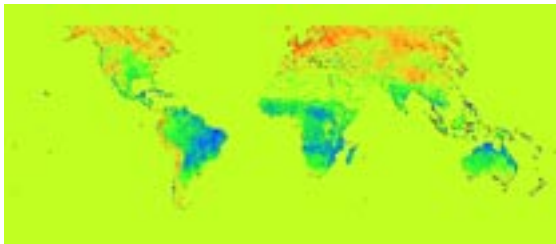
Color range representing positive values
    green-yellow to red
Color that represents extreme negative values
    purple

10. a. Most values are positive.

b. Negative results tell you that the NPP values calculated using the classes are smaller than those in the simple model.

c. Zone showing the greatest negative differences in NPP values is roughly 20 degrees above and below the equator.

11. a. There are more or less the same number of positive values as negative values.

    b. Negative results tell you that the NPP values calculated using the GLOPEM model are smaller than those in the simple model.

    c. Greatest negative differences (blue) are in the equatorial regions with positive largest differences (yellow and red) in northern Asia, Canada, and the Andes mountains of South America.

12. a. Most values are negative.

    b. Equatorial and Sahelian Africa, eastern South America, central US, India, north and east Australia.

13. All differences images show deviations in equatorial Africa, Sahel, India, central US, and eastern Australia.

14. What are the advantages and disadvantages of the three models for calculating NPP?

	advantages	disadvantages
Simple	Easy to compute.	Makes simplistic assumptions about biomass production and does not account for differing productivity of vegetation types; does not account for variables affecting productivity.
Moderate	Easy to compute; considers different productivity levels of vegetation classes.	Makes simplistic assumptions about productivity of all vegetation in a giome; does not account for variables affecting productivity.
GLOPEM	Accounts for more variables that affect NPP.	More difficult to compute.