

exercise 6

comparing estimates of global terrestrial primary productivity

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.

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*

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 Vegetation 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).

A

opening an apar image

1 — Select 'File/Open'. Go to Desktop | HD | SEE Image | Data | Veg | vgex6 | APAR.TIF. Click Open.

Do A now.

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.

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 these assumptions. In the steps that follow we will, in effect, convert the units of the original image ($\text{J}/\text{m}^2/\text{yr} \times 10^9$) into kilograms of carbon per meter squared per year ($\text{kgC}/\text{m}^2/\text{yr}$) on the new image.

Do 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 $\text{kgC}/\text{m}^2/\text{yr}$).

B

generating an npp image through image arithmetic

1 — Activate APAR.TIF. Select 'Process/Arithmetic/Multiply' then enter "0.5" in the Constant To Multiply By: box. Make sure there is an X in the Real Result check box. Click OK. A new window named APAR.TIF*0.500 will appear.

2 — Select 'File/Save As' and enter "NPP Simple.TIF" in the Save As box. Go to Desktop | HD | SEE Image | Images | Veg and click Save.

C**generating a histogram for an npp image**

1 — Click on the NPP Simple image to activate it and then select ‘Analyze/Show Histogram’.

Do 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’.

Important Notes: Only one histogram window is available, so if you generate a histogram for a second image or region, the second histogram will replace the first. If you wish to retain the first as an image file, be sure to save it before generating another histogram. This is important if you wish to compare histograms.

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 free-hand) from the Tools window to outline an area. Then select ‘Analyze/Show Histogram’ to display the histogram for that area.

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?

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 another approach

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 deciduous forest & woodland	0.50
mixed coniferous & broadleaf deciduous forest & woodland	0.65*
coniferous forest & woodland	0.78
high latitude deciduous forest & woodland	0.50
wooded c4 grassland	0.55*
c4 grassland	0.63
shrubs & 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.

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.

D**generating another npp image using image math**

1 — Select 'File/Open'. Go to Desktop | HD | SEE Image | Data | Veg | vgex6 | APAR_CON.TIF. Click Open.

2 — Select 'Process/Image Math'.

3 — Select APAR.TIF from the top drop-down menu and APAR_CON.TIF from the second drop-down menu. Select the X sign in the operator drop-down box. Enter "1" in the X box and "0" in the + box. Enter "NPP Assigned.TIF" in the box next to the = and check the Real Result box. Click OK. The two images will be multiplied together and the resultant image, NPP Assigned.TIF, will be displayed.

4 — Select 'Options/Color Tables/Rainbow'.

5 — Activate NPP Assigned.TIF, select 'File/Save As' and enter "NPP Assigned.TIF" in the Save As box. Go to Desktop | HD | SEE Image | Images | Veg. Click Save.

6 — Close APAR_CON.TIF.

7 — Select NPP Assigned.TIF. Select 'Analyze/Show Histogram'.

Do D now.

5a. From the histogram, what is the approximate range of NPP values on this image?

5b. How does the range compare to the range for the NPP Simple.TIF image?

5c. Do the same regions have high NPP values on this image as in the simple image?

5d. Do any regions show significant differences in NPP values between the two images? Explain.

5e. What range of values is found in the United States?

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.

E***opening and converting an npp image derived from another approach***

1 — Go to Desktop | HD | SEE Image | Data | Veg | vgex6 | GLOPEM.TIF. Click Open.

2 — Select 'Process/Image Math'.

3 — 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 "1" in the X box and "0" in the + box. Enter "NPP Modeled.TIF" in the box next to the = and check the Real Result box. Click OK.

4 — Close GLOPEM.TIF and keep NPP Modeled.TIF open.

5 — Select NPP Modeled.TIF. Select 'Analyze/Show Histogram'.

Do 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.

6a. From the histogram, what is the approximate range of NPP values on the NPP Modeled.TIF image?

6b. 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

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.

7. What general observations can you make about the distribution of NPP values starting with NPP Simple.TIF and progressing to NPP Modeled.TIF.

8a. 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.

8b. Repeat the procedure for three more pixels at widely varying geographic locations (i.e., equatorial, midlatitude, multicontinent).

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

8c. Looking at the table of values for each image, is there a trend in values for the images based on the model used? Explain.

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.

F**calculating difference images using image math**

1 — Select 'Process/Image Math'.

2 — If the file NPPSimple.TIF was closed and then opened again it will be necessary to do the following. Select 'Process/Image Math.' Select NPPSimple.TIF from both the top and bottom drop-down menu. Select 'Copy' from the Operator drop-down menu. Enter "1" in the X box and "0" in the + box. Enter "NPPSimple" in the box next to the = and check the Real Result box. Click OK. Delete the original NPPSimple.TIF image.

Select NPPModeled.TIF from the top drop-down menu and NPPSimple.TIF from the second drop-down menu. Select the minus (–) sign from the operator drop-down menu. Enter "1" in the X box and "0" in the + box. Enter "Modeled–Simple" in the box next to the = and check the Real Result box. Click OK.

3 — If the file NPPAssigned.TIF was closed and then opened again it will be necessary to do the following. Select 'Process/Image Math.' Select NPPAssigned.TIF from both the top and bottom drop-down menu. Select 'Copy' from the Operator drop-down menu. Enter "1" in the X box and "0" in the + box. Enter "NPPAssigned" in the box next to the = and check the Real Result box. Click OK. Delete the original NPPAssigned.TIF image.

Repeat step 2 but insert NPPAssigned.TIF from the second drop-down box and insert the name "Modeled–Assigned" in the box next to the = sign.

4 — Repeat step 2 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.

5 — Select 'Options/Color Tables/32 Colors' to color the new images.

Do F now.

9. 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.

10a. Are most of the values negative or positive?

10b. What do negative results tell you about the NPP values calculated using the vegetation classes compared to the simple model?

10c. 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.

11a. Are most of the values negative or positive?

11b. What do negative results tell you about the NPP values calculated using the GLOPEM model compared to the simple model?

11c. 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.

12a. Are most of the values negative or positive?

12b. Which regions show the greatest differences in NPP values?

13. Consider all three difference images (Modeled–Simple, Modeled–Assigned, and Assigned–Simple). Do the same regions show deviations on all images? Explain.

14. 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 veg-

etation 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.