Title:	Using Landsat to Examine Deforestation in Brazil
	Part I: Identify forested and deforested areas
	Part II: Calculate carbon emissions from deforestation
Product Type:	Curriculum
Developer:	Helen Cox (Professor, Geography, California State University, Northridge): helen.m.cox@csun.edu Laura Yetter (Research Asst., Institute for Sustainability, California State University, Northridge)
Target audience:	Undergraduate/Graduate
Format:	Tutorial (pdf document)
Software requirements*:	ArcMap 9 or higher (ArcGIS Desktop) (Parts I, II), ArcGIS Spatial Analyst (Part I)
Data:	Data provided: 1990 Landsat image subset and 2011 Landsat image subset
Estimated time to complete:	All parts: 4 hrs
	Part I: 2 hr.
	Part II: 2 hr.
Alternative Implementations:	• Part I provides a standalone exercise comparing forest areas in 1990 and 2011. In addition students compute the rate of deforestation for the image area. • Parts I and II together relate the deforestation rate in this area to carbon emissions and have students extrapolate results to the country of Brazil comparing emissions to those in the U.S.
Learning objectives:	Part I: • Understand the role that forests play in sequestering carbon dioxide from the atmosphere • Understand and use Landsat images • Understand and calculate the Normalized Difference Vegetation Index • Identify forested and un-forested areas • Calculate deforestation over two decades
	Part II: • Calculate carbon dioxide release as a result of deforestation in Brazil • Compare to U.S. annual emissions of carbon dioxide

*Tutorials may work with earlier versions of software but have not been tested on them

Using Landsat to Examine Deforestation in Brazil
Part I: Identify forested and deforested areas

Objectives:

- Understand the role that forests play in sequestering carbon dioxide from the atmosphere
- Understand and use Landsat images
- Understand and calculate the Normalized Difference Vegetation Index
- Identify forested and un-forested areas
- Calculate deforestation over two decades

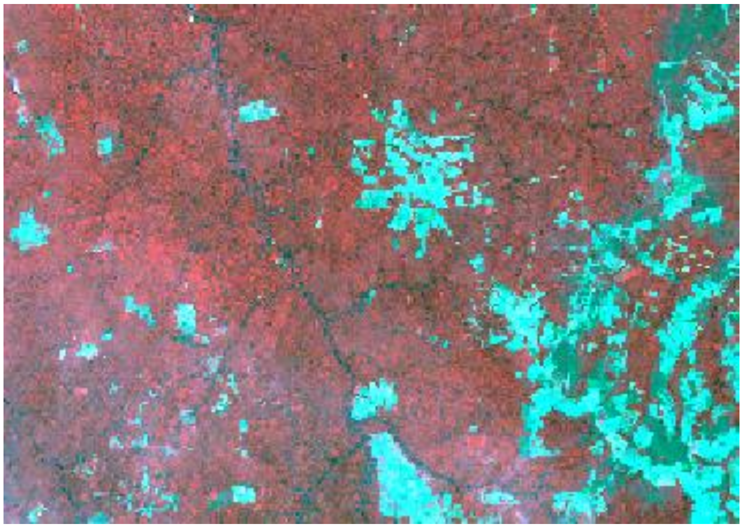
Forests play an important role in removing carbon from the atmosphere and help slow climate change. Forests sequester carbon dioxide from the atmosphere and store the carbon in biomass as leaves, bark, and branches. When deforestation occurs the stored carbon is released as carbon dioxide into the atmosphere as the tree decomposes (Gibbs et al. 2007). Mato Grosso is a Brazilian state in South America in a transition zone between the tropical rainforest of the Amazon and tropical savanna of the Cerrado that has experienced severe deforestation. Much of Mato Grosso has been cleared for soy farming and cattle grazing (http://www.bbc.co.uk/news/world-latin-america-13449792).

In this exercise we will look at an area within the Cerrado and determine how much of the study area has been lost to deforestation and how much carbon dioxide has been released over the past twenty years using remote sensing imagery from the Landsat 5 satellite. We will classify imagery taken from the satellite into forested and deforested areas and carry out change detection within a study area in the Mato Grosso to determine how much of the Cerrado has been deforested from 1990 to 2011. We will then use estimates of forest carbon stock to determine how much carbon dioxide was released as a result of deforestation.

1. View the Landsat images in ArcGIS

Add the 1990 and 2011 study area images (brazil1990_subset.img and brazil2011_subset.img) to ArcMap. These images were obtained using the Landsat 5 TM instrument. This instrument records reflected (and emitted) radiation at 7 different wavelengths (http://landsat.gsfc.nasa.gov/about/tm.html). If you are familiar with the electromagnetic spectrum you will see that band 1 corresponds to blue light, band 2 to green light, band 3 to red light, band 4, 5 and 7 to near infrared, and band 6 to thermal infrared. Set the display properties for the layers in ArcGIS so that band 1 is displayed as blue, band 2 as green and band 3 as red. This will produce a "true color" image.

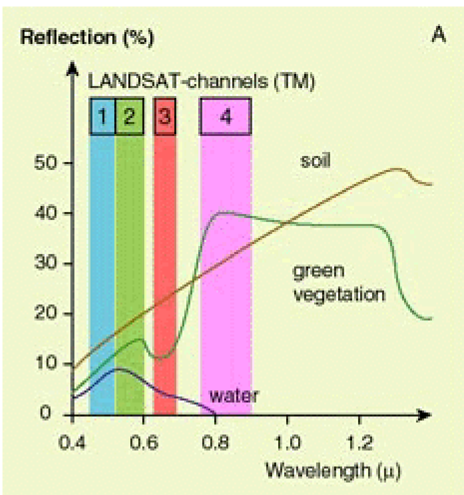
Vegetation shows up best at near infrared (NIR) wavelengths so scientists often use false color NIR images to detect vegetation. You can see a false color infrared image by setting the display properties so that band 4 is displayed as red, band 3 as green and band 2 as blue:



Note how the vegetation shows up brightly in band 4 (red).

2. Calculate the normalized difference vegetation index (NDVI) for both images.

The NDVI is a measure of the amount of green vegetation in an area, and can be used to distinguish forested from deforested areas. It is based on the relative reflectance of near infrared and red light. Researchers have studied the spectral reflectance of vegetation and know that green chlorophyll absorbs red light (0.63-0.69 µm, band 3) thus reducing the amount of reflected red light; the spongy mesophyll cells in leaves are excellent reflectors of near-IR energy (0.76- 0.90 µm, band 4). Thus green vegetation has low reflectance of red light and high reflectance of near-IR light. Vegetation that is yellow, because it is dying or because it is naturally yellow, will reflect less near infrared. Therefore the NDVI can only detect greenness and not vegetation of different colors.



Taken from: http://galathea3.emu.dk/satelliteeye/casestudies/copenhagen/chp-ex2_en.html. In the above image the vegetation signature has a low reflectance (absorption) in band 3 (red) and high reflectance in band 4 (near infrared).

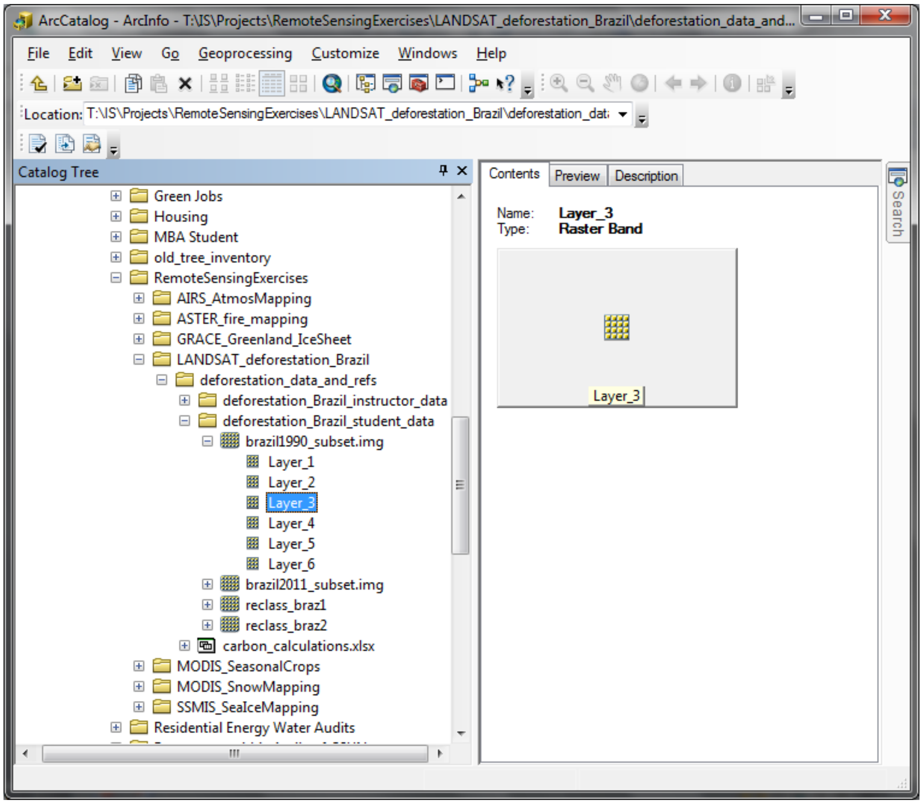
The NDVI is the ratio of the difference between the reflectance in the red and near infrared bands divided by the total reflectance in these two bands. It is computed by using the equation:

NDVI = (band 4 (NIR) – band 3 (Red))/ (band 4 (NIR) + band 3 (Red)).

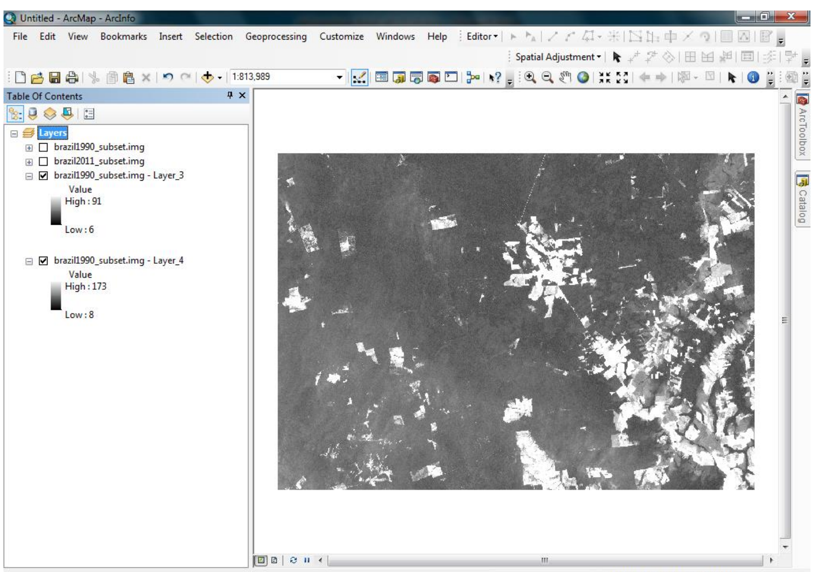
NDVI ranges from +1 to -1. Positive values indicate healthy green vegetation, values near 0 indicate bare land, and negative values represent clouds, water, or snow (because they reflect red better than NIR).

Note that the images provided are in Imagine (.img) format. If you encounter any problems with manipulating these in ArcGIS you should convert them to the native GIS format, .grid. (Right click on the image, choose Data, Export and then set the format to GRID.)

Currently the 1990 and 2011 images have all of their bands displayed. However, the individual raster bands are needed to calculate the NDVI. To get the bands by themselves go to ArcCatalog. Locate the 1990 raster image and expand the plus sign next to the image. Add Layer 3 (band 3, red) and Layer 4 (band 4, NIR) to your map.

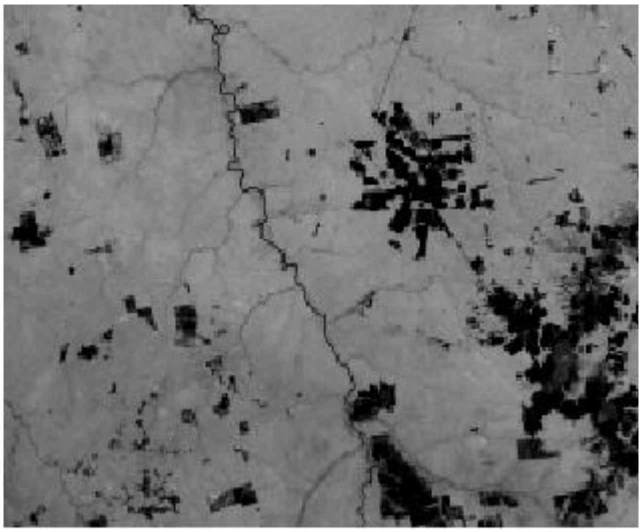


The bands will display as gray scale images.

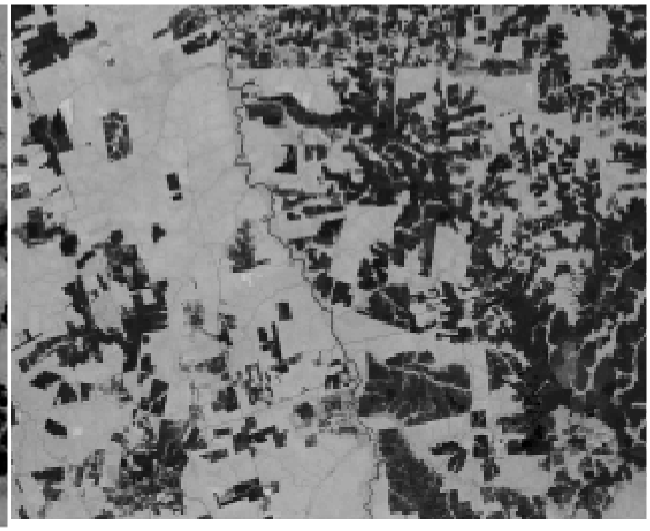


To generate NDVI images with ArcMap use the Raster Calculator. The Raster Calculator is in the Spatial Analyst toolbar not in the toolbox. Select Tools> Customize>Spatial Analyst. The Raster Calculator is located in the pull down menu on the Spatial Analyst box in the toolbar. Create the NDVI equation from above, add "Float" before the numerator equation and before the denominator equation to allow for decimal points in the results (Float (band 4 - band 3)/ Float (band 4 + band 3)). Execute the calculation and add the results to your map.

Change the symbology of the NDVI layer to Stretched with a Black to White color ramp if it is not already displayed this way. Repeat the process for the 2011 layer. Your NDVI images should look like:



1990



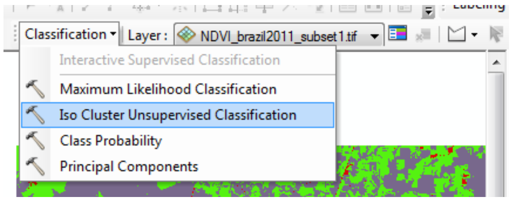
2011

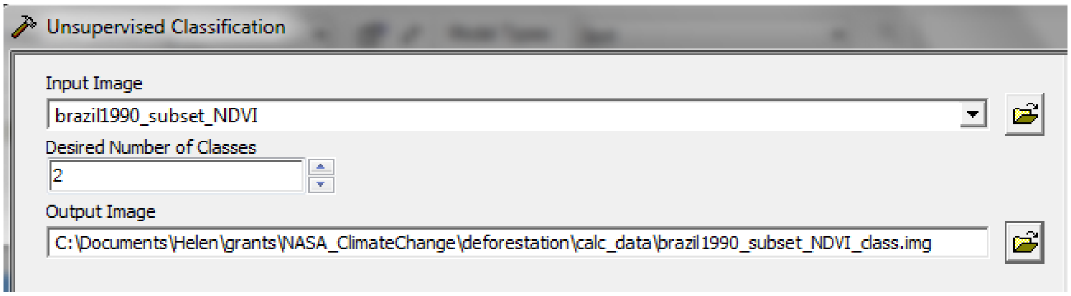
Lighter (brighter) shades indicate a higher NDVI value and therefore more green vegetation. The dark areas are un-forested.

3. Classify into forest and non-forest areas using the automated feature.

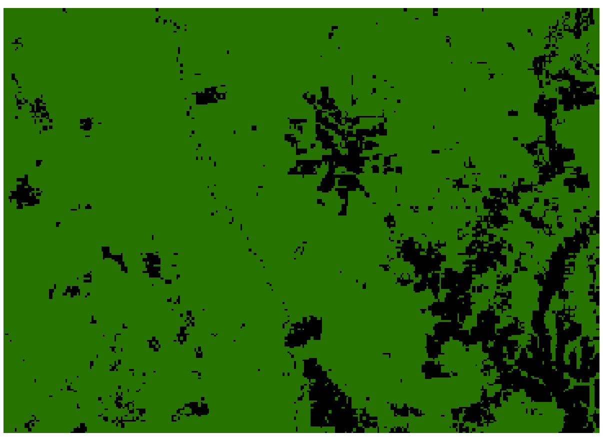
We can classify the areas into forest and non-forest based on the NDVI value. You can do this manually or use an automated classification feature. The automated feature is useful for obtaining a quick view of the area that is forested and the area that is not, but we will be using the manual method in order to calculate areas as described in the next section.

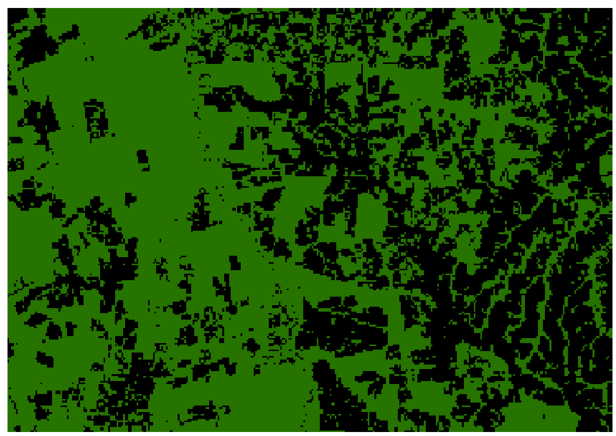
First we'll demonstrate using the automated feature. Use the Image Classification toolbar (under Customize -> Toolbars-> Image Classification). Click the classification button and choose Iso Cluster Unsupervised Classification. (Unsupervised classification is one that is done automatically by the computer and doesn't require the user to 'train' the computer to recognize different land cover types.) On the toolbar, set the Layer to the 1990 NDVI layer, and the desired number of classes to 2. Your menu might look different in different versions of ArcGIS. In ArcGIS 9.3, use Spatial Analyst Toolbox> Multivariate> Iso Cluster. This will generate a signature file for the classification. Then use the Maximum Likelihood tool to generate the classified output file.





Give the output image an appropriate name like that shown above. Repeat for the 2011 image. Examine the results. You can choose your own color scheme for display.


1990

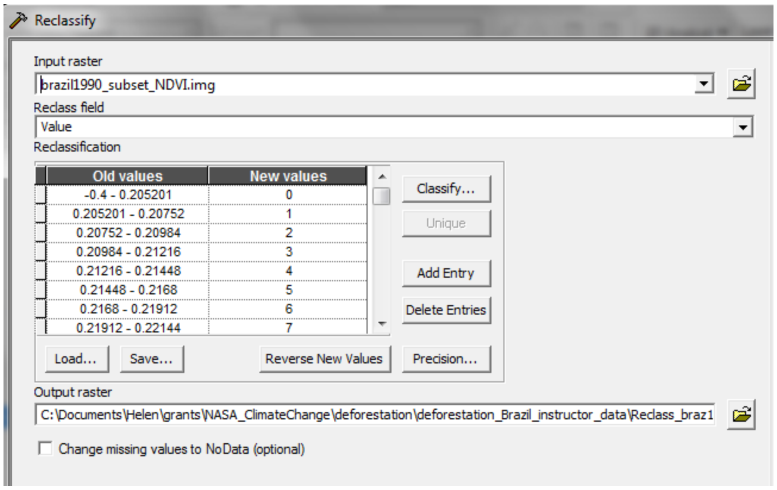

2011

Values of 1 represent deforested areas (black in these images) and values of 2 represent forest (green in these images) areas. You can clearly see the difference over two decades.

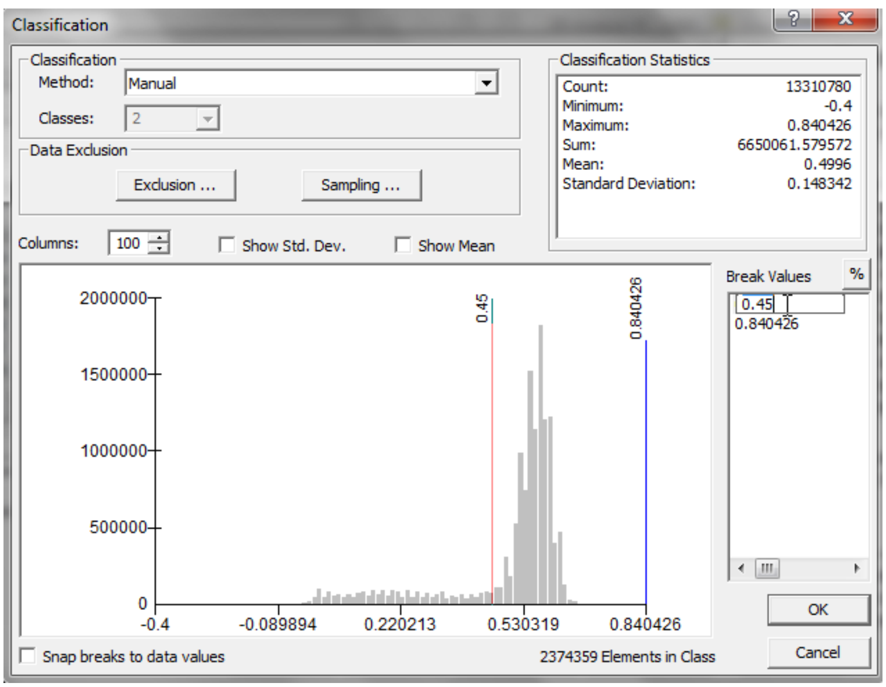
The way that the classification is done will influence the exact areas that are marked as forest and non-forest. The automated algorithm does its best to distinguish the different land covers based on their reflectance or NDVI value but the NDVI threshold chosen by the computer for assigning the two categories may not be exactly the same in the 1990 and 2011 case. Because we want to calculate the area of forest that changed we will set this threshold manually so that it is exactly the same for both dates.

4. Classify into forest and non-forest areas manually.

Go to the Toolbox and under Spatial Analyst select Reclass then Reclassify. Choose your Input raster (1990 NDVI raster) and the classify box should pop up with your current symbology settings (see below).

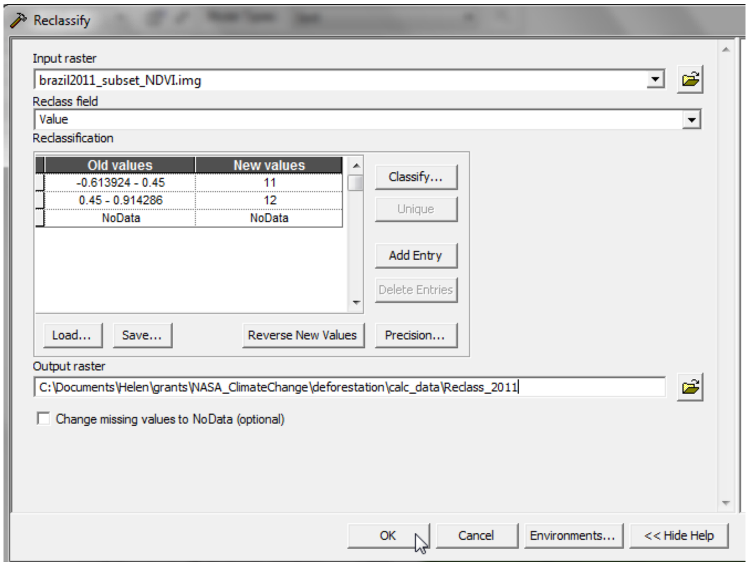


Use the Classify button to set these to Manual Classification with two classes. In order to be able to change the number of classes to 2 you may have to first change to a different method of classifying, like 'Equal Interval', and then change the number of classes to 2. When you have done this, change back to 'Manual'. Set the first class to end at 0.45 (or 145). Press OK.



Enter an appropriate name for the new classified raster and press OK.

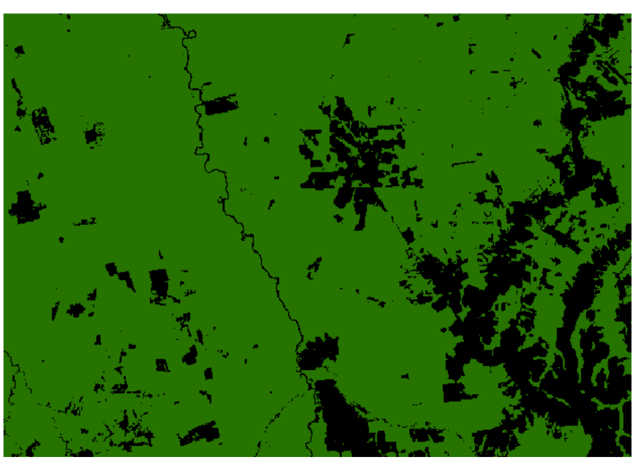
Now repeat for the 2011 raster but this time after setting the classes to two and the lower limit to 0.45 (or 145) choose new values of 11 and 12 for the new values. (You will see the reason for this choice shortly.)



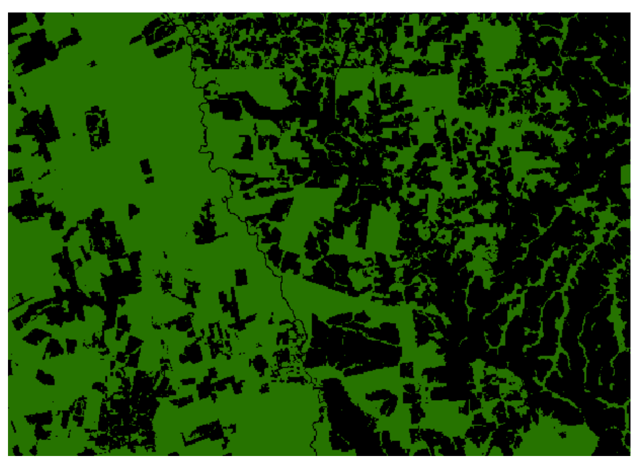
You should now have two new rasters whose pixel values are either all 1 or 2; or 11 or 12.

Note: There have been some instances where the Reclass function has not worked correctly and has changed the cell size and location of the image. If this happens for you, the best workaround is to export your data (NDVI image) into ArcGIS's native GRID format. (Right click on the image, choose Data, Export.) Then try to Reclass.

Color the low values black and the high ones green (as before). Your image should now look like that shown below (LHS). Repeat for the 2011 image. Now we have classified the images for the two dates based on NDVI in exactly the same way so the areas in each class can be directly compared.



1990

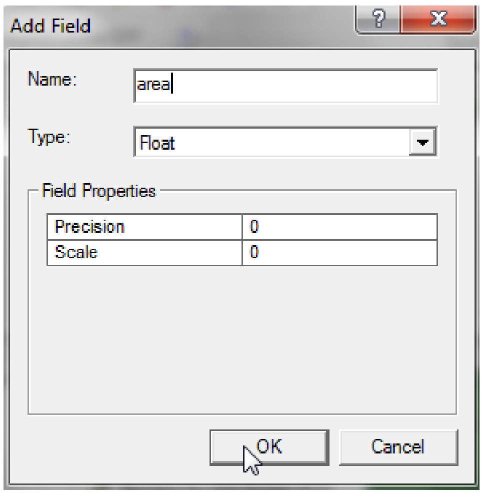


2011

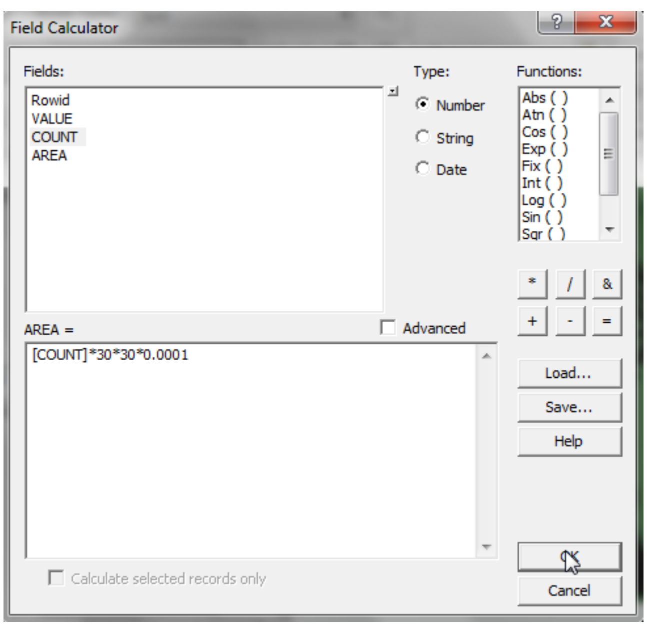
Compare the new classified images to the ones you obtained through the automated method. They should look very similar but may have slight differences in the exact numbers of black and green pixels.

5. Calculate areas of forest and non-forest

Open the attribute table for the 1990 reclassified image. You will see the **pixel counts** (i.e. the number of raster cells) for each type of area (non-forest and forest). Landsat imagery has a 30 meter x 30 meter cell size so you must multiply the count by 30x30 to find out the area in square meters of each class type, then multiply by 0.0001 to convert square meters to hectares. You can do this manually or add a field to store this information: Click on the Options box, choose Add Field, change the data type to Float, give the field a name (area), and press OK.



In the attribute table, right click on the column name ("Area") and choose Field Calculator. Answer "Yes: to the warning, and enter the calculation as shown below (pixel count * 30 * 30 * 0.0001) for the area in hectares.



The area should now be displayed in the attribute table.

Repeat the steps for the 2011 layer.

Answer the questions below:

1. How many hectares of forest were there in 1990?

2. How many hectares of forest were there in 2011?

3. How many hectares of non-forest were there in 1990?

4. How many hectares of non-forest were there in 2011?

5. How many hectares of forest were lost within our study area from 1990 to 2011?

6. What is the percentage of deforestation from 1990 to 2011 (i.e. what % of forest area was lost)?

7. What is the percentage of increase in the amount of non-forested land from 1990 to 2011?

This tells us the overall change in landcover area for the two types but we don't know how much land was re-forested. We will calculate this below.

6. Using Map Algebra to analyze land use change

We will now subtract the 1990 classified image from the 2011 one (See steps below).

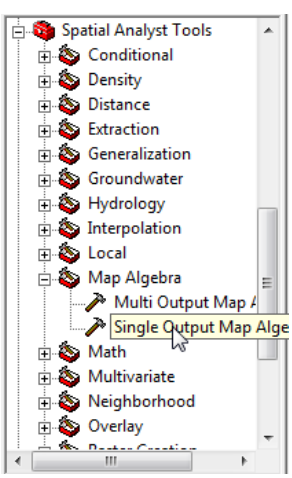
8. What will be the possible values of the pixels when we do this?

9. What land cover change does each of these pixel values correspond to?

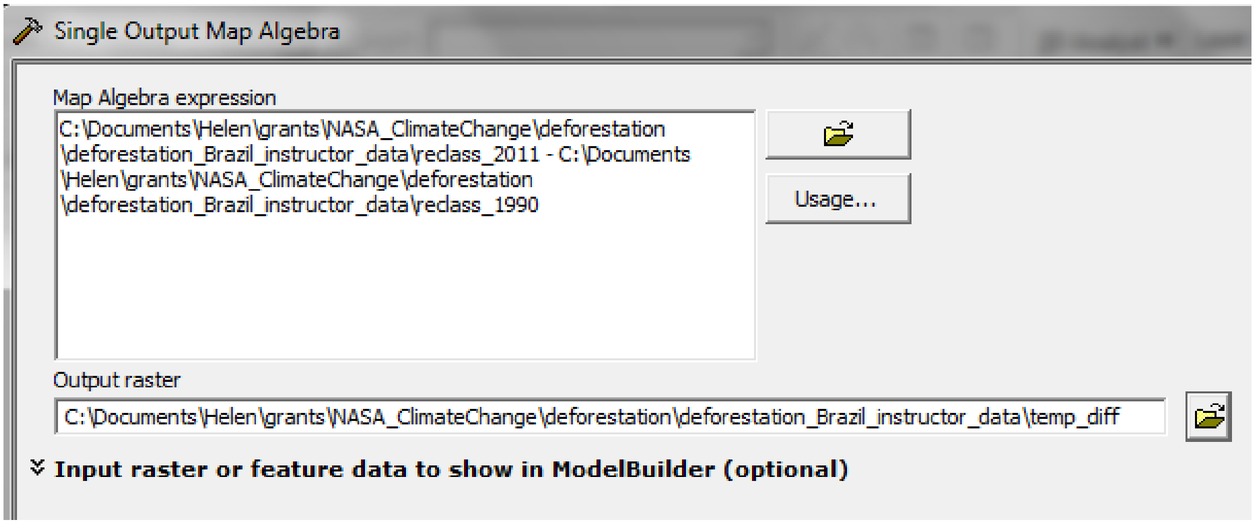
Let's carry out the subtraction using Raster Calculator.

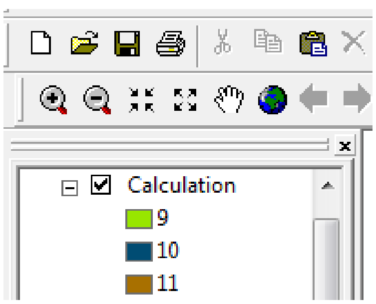
In ArcMap 9.3-

(Spatial Analysis -> Map Algebra -> Single Output Map Algebra).



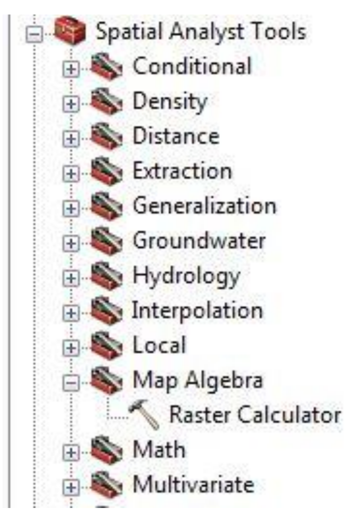
Enter an expression for subtracting the reclassified 1990 image from the 2011 one and save the result in a new raster (name it "2011-1990_difference" or something similar). In ArcMap 9.3, a new raster will automatically be created and displayed under "Calculation".



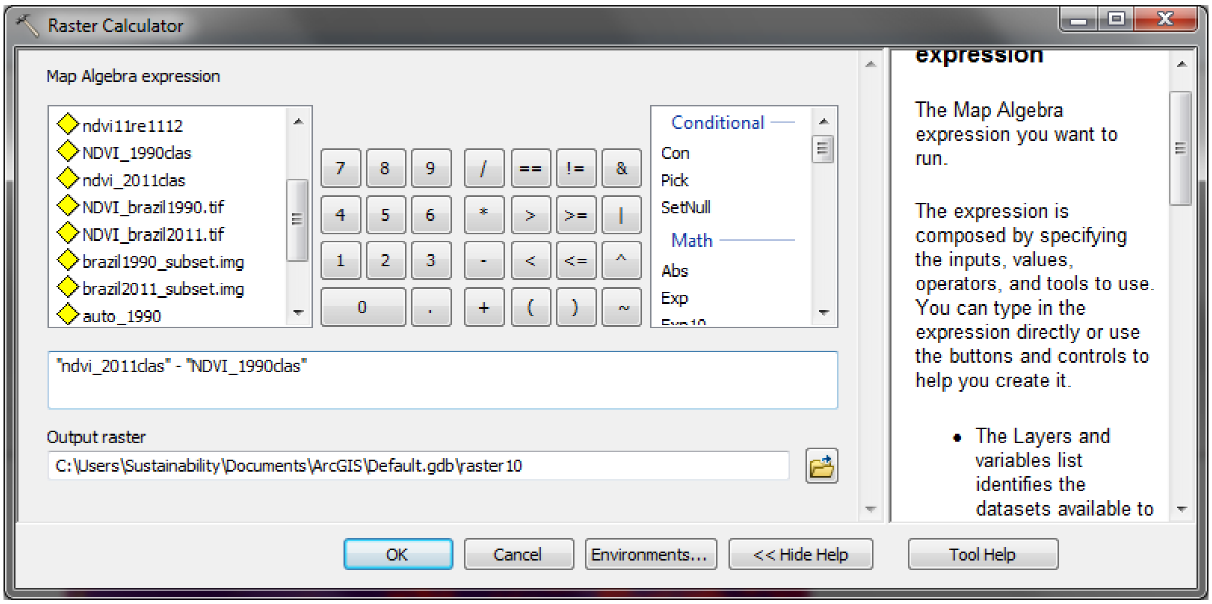


In ArcMap 10.0-

(Spatial Analysis -> Map Algebra -> Raster Calculator).



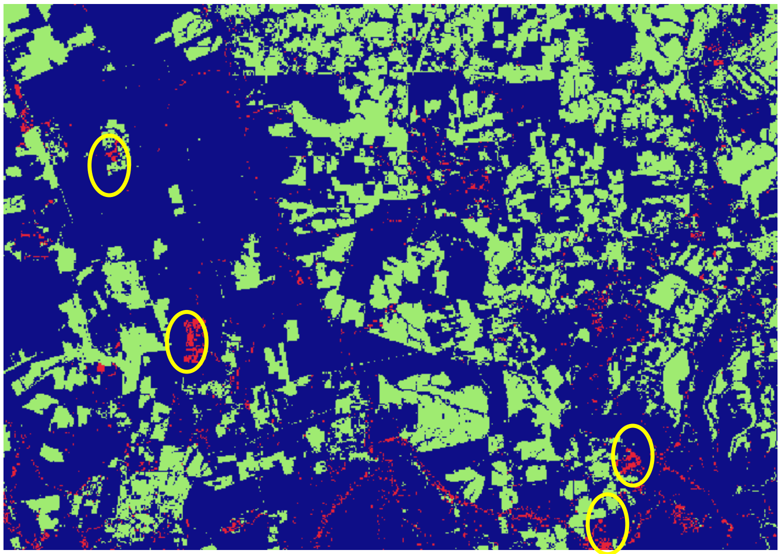
Enter an expression for subtracting the reclassified 1990 image from the 2011 one and save the result in a new raster (name it "2011-1990_difference" or something similar). Make sure there is no space between the parentheses and the minus sign ("-"). Otherwise the tool will fail to execute properly.



After completing the previous step in either ArcMap 9 or 10, use the Properties -> Symbology menu to color the results by Unique Values. Choose colors appropriate to the land cover changes taking place. The Symbology menu will show you the number of pixels falling into each category. Fill in the following table based on your results, and note what is happening by looking at the areas in your original images where change is taking place.

Change value	**Corresponding land cover change**	**# of pixels in this category**	**calculated area (hectares) in this category**	**Observations/Comments based on looking at original images for these areas of change**
9				
10				
11				

Make a printout of your change image and circle three or four areas where reforestation has taken place.



Part II will challenge you to investigate the carbon dioxide emissions associated with this scale of deforestation.

References

Gibbs, Brown, Niles and Foley, Environ. Res. Lett., 2 (2007) 045023 (13pp), [doi:10.1088/1748-9326/2/4/045023](doi:10.1088/1748-9326/2/4/045023)