Geo/SAT 2

TROPICAL WET REALMS OF CENTRAL AFRICA, PART II

Paul R. Baumann
Professor of Geography (Emeritus)
State University of New York
College at Oneonta
Oneonta, New York 13820
USA

INTRODUCTION:

Part II of this instructional module deals with two different ways to classify vegetation patterns in Central Africa using the four MODIS data sets. The classification process groups similar pixels into land cover categories and allows land cover maps to be created. Also, this process permits acreage figures to be determined for each land cover class. If one has not done Part I, it is recommended that it be completed before working on this part. Part I contains information about the various climatic and vegetation condition throughout Central Africa and the MODIS data sets. This information will not be repeated in this part.
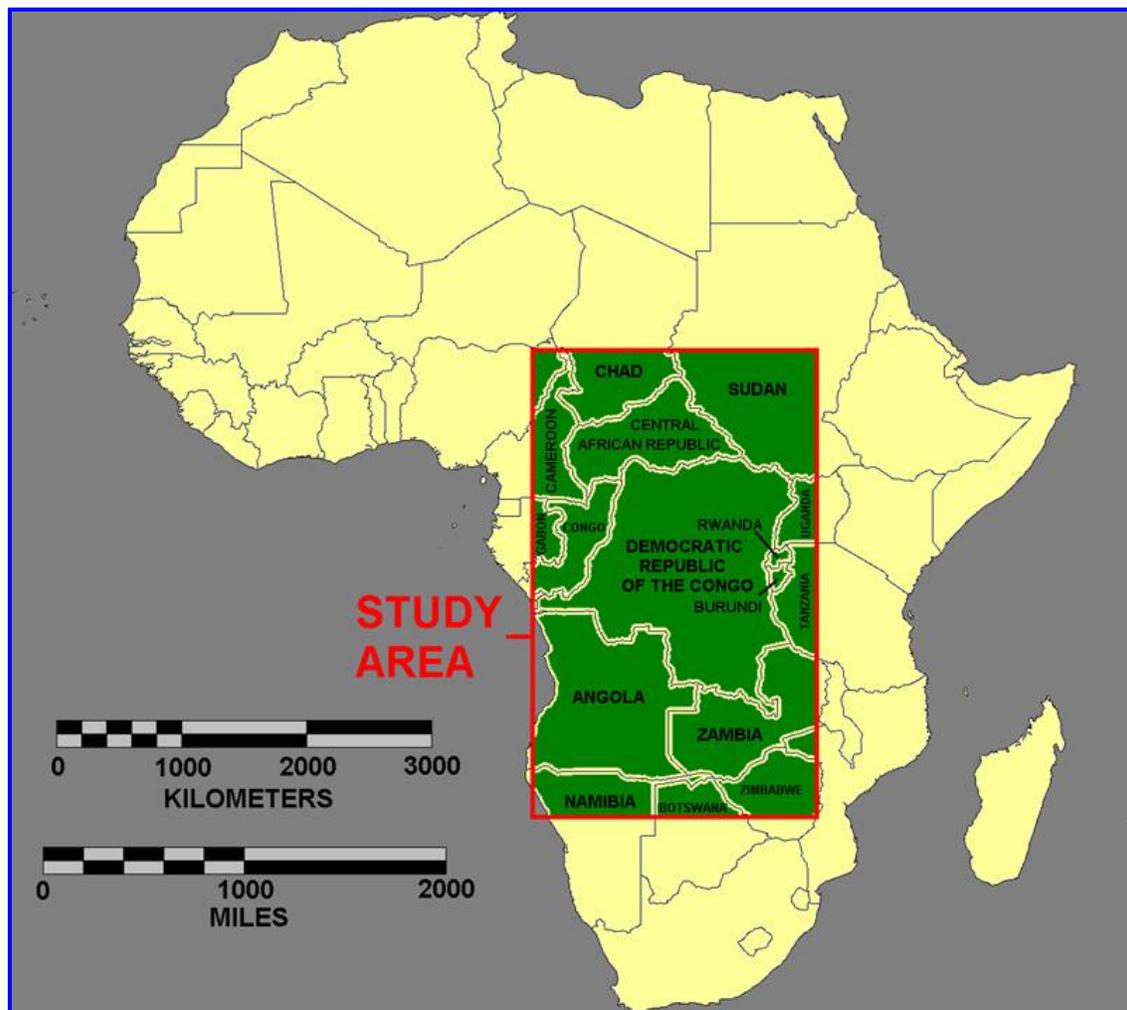

FIGURE 1: Study Area – Central Africa

Figure 1 identifies the area covered by the MODIS data sets. This area extends from the semiarid Sahel in Chad and Sudan, immediately south of the Sahara, to a similar semiarid region just north of the Kalahari and Namib deserts. It also reaches from the plateau edges along the west coast to the highlands that rim the Great Rift Valley. Within this area is one of the Earth's largest tropical wet environments. This module centers on classifying these environments.

VEGETATION INDICES

Since the 1960s, scientists have experimented with various vegetation biophysical variables, mainly based on remotely sensed data. This research has centered on the development of vegetation indices. More than 20 vegetation indices are in use. The most commonly used index is the Normalized Difference Vegetation Index (NDVI). Initially applied to Landsat MSS data, it is frequently used with Landsat TM and ETM+, AVHRR (Advanced Very High Resolution Radiometer), and SPOT HRV data as well as data from several other remote sensing scanners.

Normalized Difference Vegetation Index (NDVI)

The difference between visible and near-infrared reflectance by plants is used to identify green vegetation using the NDVI model. Sunlight consists of many spectral wavelengths. When the light from the sun strikes a surface, certain wavelengths are absorbed and others are reflected. The pigment in live green plant leaves, chlorophyll, strongly absorbs visible light (from 0.4 to 0.7 µm) for use in photosynthesis. These same leaves scatter light in the near-infrared spectral region (0.7 to 1.1 µm). Light in this region is not sufficient to be useful to synthesize organic molecules. In fact, if too much near-infrared light would be absorbed, it would over-heat the plant and damage the plant's tissues.

In visible light, green vegetated areas are very dark, almost black, while desert regions (like the Sahara) are light. With near-infrared light, green vegetation is brighter than it is in the visible light while deserts remain about the same. Figure 2 illustrates this condition. The right image is the red visible band from the MODIS summer data set. The very dark area is receiving large amounts of rain, resulting in lush green vegetation conditions. The area immediately above it is the semiarid Sahel that has sparse vegetation coverage. By contrast the left image, the near-infrared band, is much lighter and it is difficult to separate the semiarid and tropical wet areas. Through comparing visible and near infrared light, one can measure the relative amount of vegetation.

Most vegetation indices use this difference between visible and near-infrared to quantify the density of plant growth. In the case of NDVI the difference is the near-infrared radiation (NIR) minus visible radiation divided by near-infrared radiation plus visible radiation. The red visible band is used for visible vegetation. Written mathematically, the formula is:

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

This formula, for a given pixel, creates a number that ranges from minus one (-1) to plus one (+1). A zero means no vegetation and a value close to +1 (0.8 - 0.9) indicates the highest possible density of green leaves. These values are rescaled from 0-255 to correspond to the value ranges for other bands.
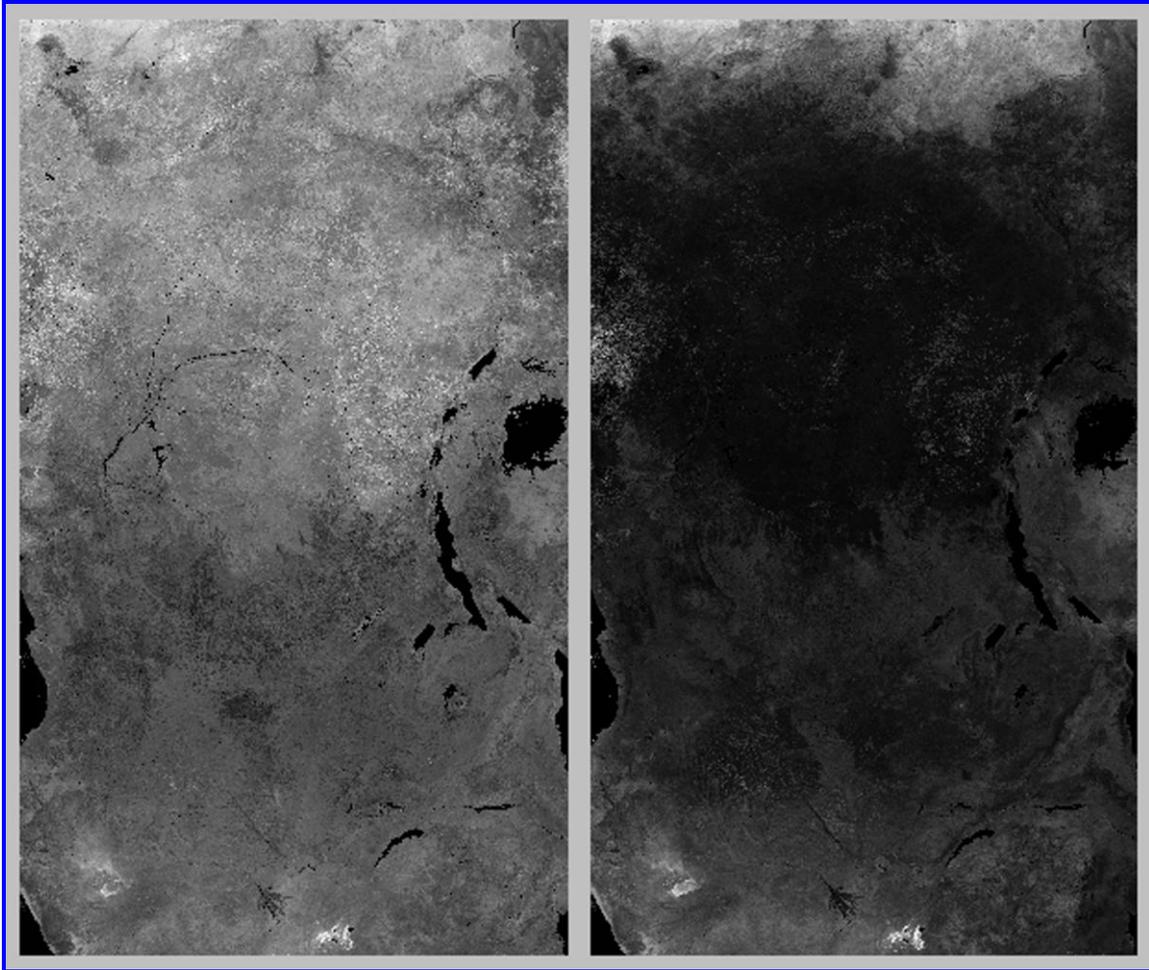
FIGURE 2: Near-Infrared Band (left) and Red Visible Band (right).

NDVI Classification

Using the EarthScenes image processing package a NDVI band was created for each of the four MODIS data sets. The package's **Arithmetic Operation** function, under the **Enhance** dropdown, provides several standard mathematical procedures. Procedure number 9 relates to the NDVI formula. The "P" in the formula stands for the picture or image band to be inputted. The near-infrared band, Band 2, is used for "P1" and "P3" and the red visible band, Band 1, for "P2" and "P4." The constant "C" value will be "1" for each of the bands except for "P2" where it will be "-1."

Figure 3 is the NDVI band for the summer MODIS data set, the same data set used to produce the two images in Figure 2. The very bright areas relate to vegetation with high densities of live green leaves. The brightness also relates to the values in the upper range of the rescaled data. The main bright area corresponds to the tropical rainforest and the wet season for the tropical savanna in the Northern Hemisphere. The black area in the upper portion of the image is the semiarid Sahel. Pixel values for this area will be at the lower end of the rescaled data. Water bodies are also shown as being black. Water reflects radiation in both the red visible and the near infrared portions of the spectrum.
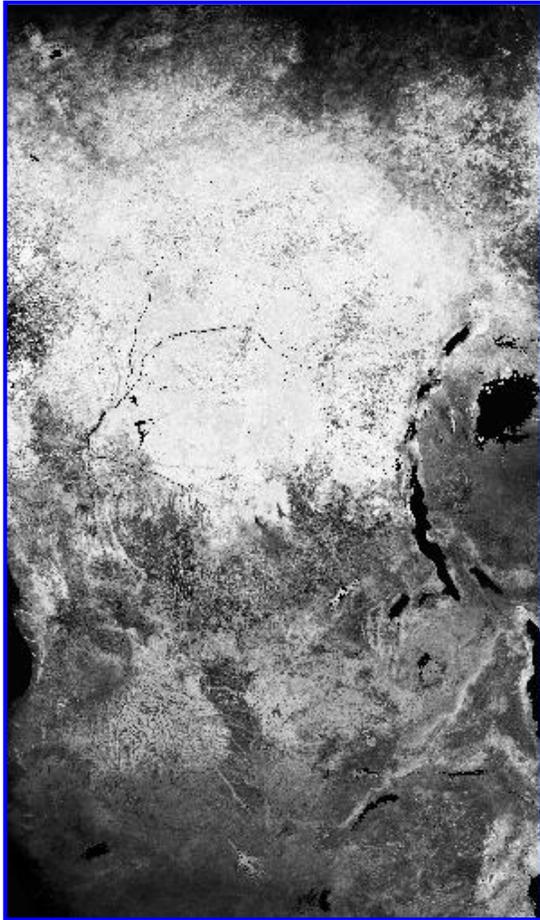
FIGURE 3: NDVI Band

In generating the NDVI values for an image, EarthScenes rescales the pixel values to range from 1 to 250. Thus, each of the four NDVI images has the same data range. Based on this rescaling procedure it is possible to use the same classification levels for each image. Table 1 identifies the levels as well as the land cover classes and colors associated with the levels. The first level deals with water. It is known that water will be at the lower end of the scale. Water bodies help as reference features to determine the location of other areas on an image. Except for water and very low green leaf density (VLGLD) the levels are divided into intervals of 50. The VLGLD class is slightly less than 50 to accommodate for the water class. Since ground truth information about green vegetation conditions is not available, having standard classification levels reduces bias when comparing the images.

Table 1: Raw Data Levels

LAND COVER CLASS	LEVEL	COLOR
Water	1-4	Blue
Very low green leaf density (VLGLD)	5-50	Tan
Low green leaf density (LGLD)	51-100	Brown
Moderate green leaf density (MGLD)	101-150	Bright Green
High green leaf density (HGLD)	151-200	Green
Very high green leaf density (VHGLD)	201-250	Dark Green

With the levels determined the next step is to classify the NDVI band. First create a histogram of the NDVI band. Second, click the **Classify** dropdown under EarthScenes and select the **Density Slice** classifier. Click on **"Window and Layer Processing"** and select the NDVI band as input. Next, identify the layer in which the classified NDVI band will be placed. The histogram for the NDVI band will appear with instructions on how to slice the bands into different levels. Use the level numbers indicated in Table 1. A classified image will appear in psychedelic colors. To obtain the colors listed in Table 1, it will be necessary to create a new color table using the **Look-up-tables** dropdown. The values for the classified image range from 1 to 6; thus, a classified color table should be created and used.
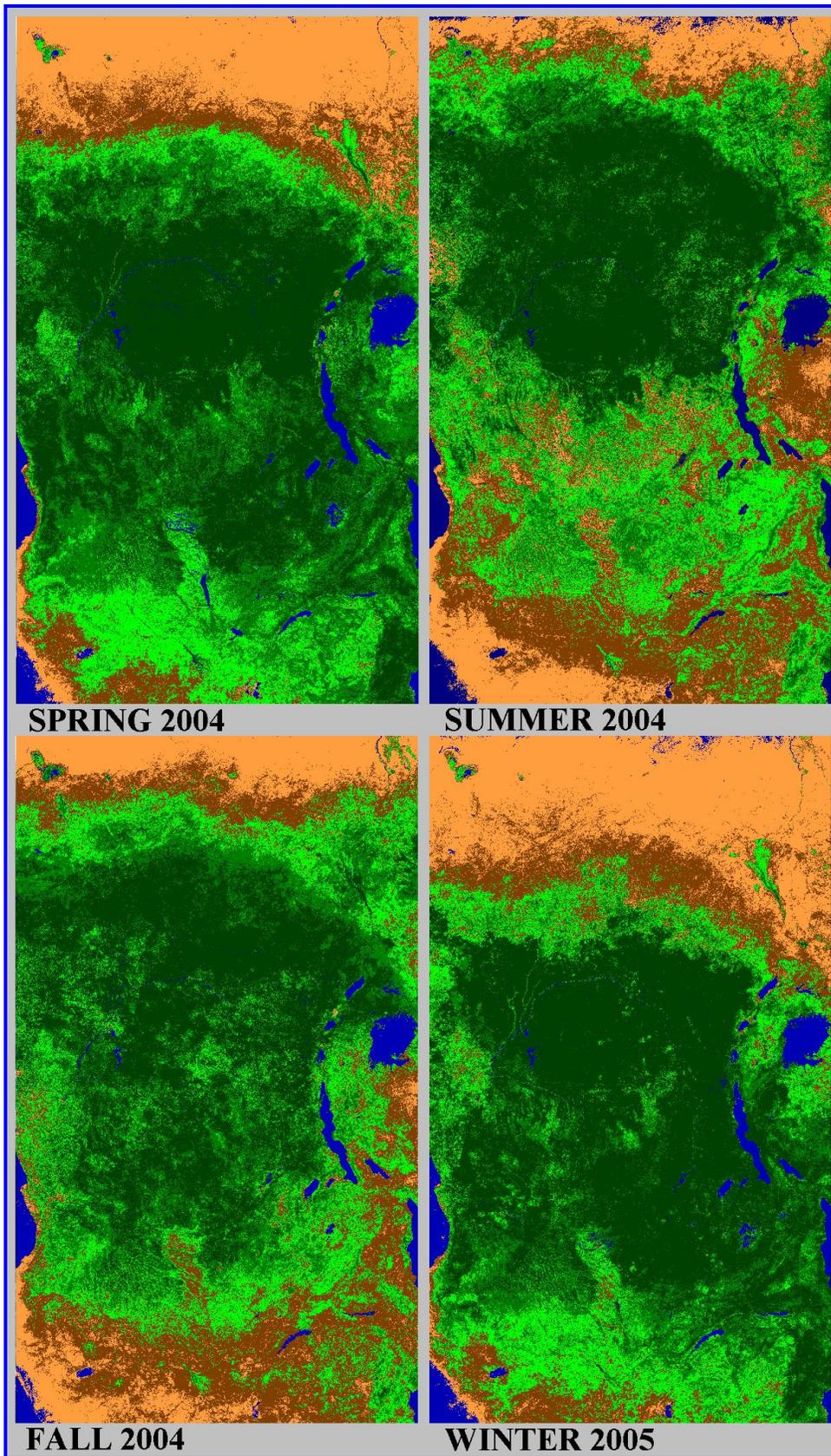
SPRING 2004   SUMMER 2004

FALL 2004   WINTER 2005

FIGURE 4: The Four NDVI Classified Images.

Figure 4 shows the classified images for the four data sets. The seasonal north-south shift of dense green vegetation can be observed as well as the expansion and contraction of the semiarid and arid areas. The summer and winter images show false water conditions at their northern edges in the Sahara. This water pattern might be due to clouds. The one area in the northwest corner of all four images is Lake Chad where water and wetlands do exist. Another cloud condition appears on the western edge of the images where some scattered tan color can be seen. This situation relates to the heavy clouds associated with the monsoonal rains along the plateau escarpments.

As stressed in Part I the images showing the full study area have been scaled down and do not convey the complexity of the landscape. Figure 5 is an enlargement of a small portion of the study area during the summer period and displays a greater amount of detail. The Congo River with its braided pattern can be easily seen; whereas, the river in the summer image shown in Figure 4 cannot be detected. The two large water bodies are Lake Tumba (top) and Lake Mai-Ndombe (bottom). Although quite large these two lakes can be barely seen in Figure 4. The areas designated as being LGLD and VLGLD on Figure 5 cannot be seen on Figure 4. EarthScenes allows one to pan and roam over an entire image at full resolution. The areas of LGLD and VLGLD are deforested areas.
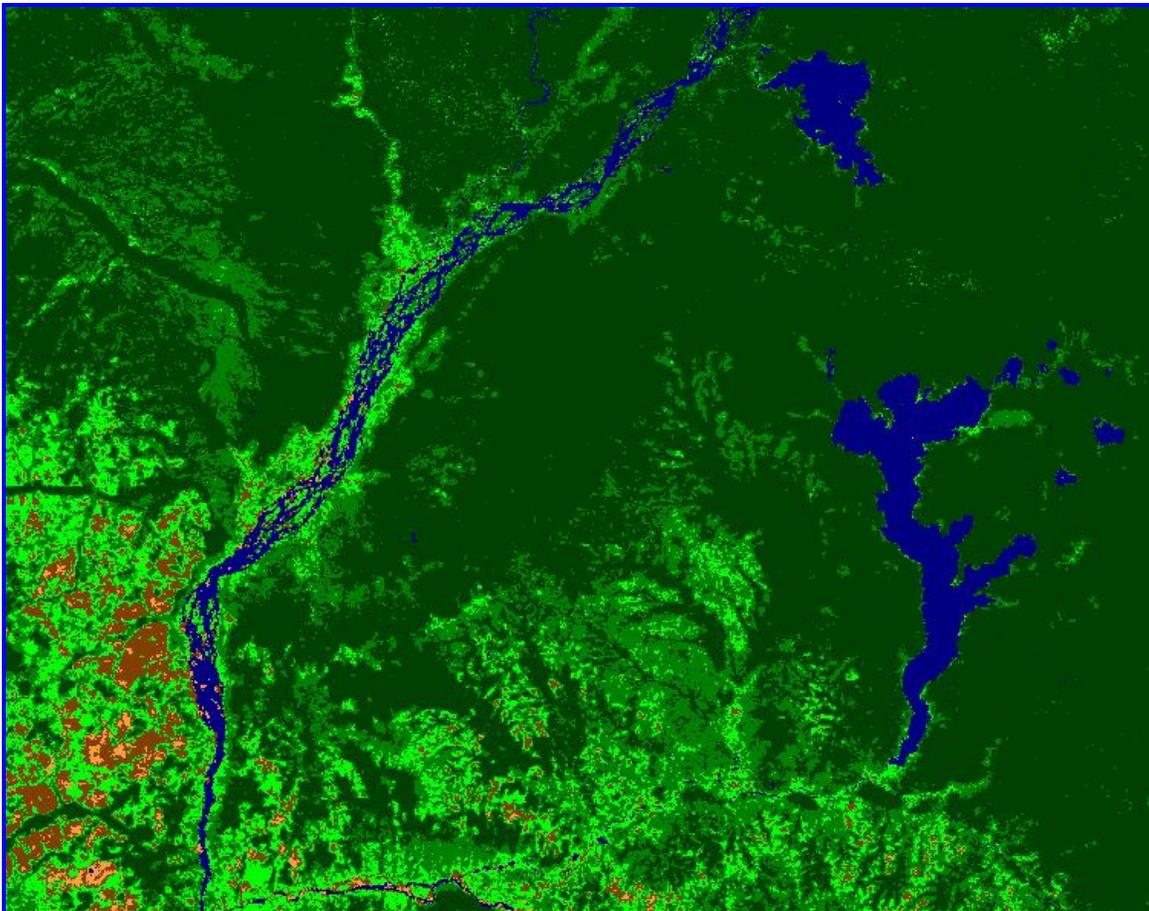
FIGURE 5: Enlargement of the Summer NDVI Classified Image.

The next step is to merge the four classified images into one image representing annual vegetation coverage. EarthScenes does not provide one mathematical procedure for summing the four images. However, two images can be added together. Using procedure number 4 under **Enhance\ Arithmetic Operation** two images can be summed. In this case the images are classified images that have values ranging from 1 to 6. When added the new image will have values from 2 to 12. In using procedure number 4 the constant "C" values will be 1.

With four seasonal images one could have six different combinations of two images. However, for this module only two combinations were developed. The first combination was the summer and winter classified images and the second combination was the spring and fall classified images. Once two images were combined to form a new image, the new image was classified using the **Density Slice** classifier. A histogram of the new image had to be created before classification could occur. The level values used to slice the data into six classes are shown in Table 2.

Table 2: Classified Data Levels

LAND COVER CLASS	LEVEL	COLOR
Water	1-2	Blue
Very low green leaf density (VLGLD)	3-4	Tan
Low green leaf density (LGLD)	5-6	Brown
Moderate green leaf density (MGLD)	7-8	Bright Green
High green leaf density (HGLD)	9-10	Green
Very high green leaf density (VHGLD)	11-12	Dark Green

The images created through this process are shown in Figure 6. The summer-winter classified image shows the VHGLD class concentrated along the Equator. The Equatorial Low Pressure with its high amounts of rainfall is centered over the Equator during both the summer and the winter periods. The VHGLD class in the spring-fall classified image is spread over a much larger geographic area than what is shown in the Summer-Winter image. Also, it is not as heavily concentrated. Large patches of HGLD and MGLD can be seen throughout the VHGLD areas. The spread out pattern and the lack of a solid concentration relates to the Equatorial Low Pressure being at its two extreme locations during its annual migration cycle.

Once these two classified images were developed, they were combined to form the final image, which is a summation of all four images. The same steps used to produce the two previous images were used to develop this final image. Figure 6 shows this image. The VHGLD area is highly concentrated as it was the summer-winter combination and is more spread out like it was in the spring-fall combination. Table 3 gives the number of square miles and square kilometers in each class for the final image. EarthScenes provides a pixel count for each land cover class after an image is classified. These counts can be converted into square miles and square kilometers. Recall that a pixel is 500m by 500m in size. The square miles figures were used to produce a bar graph (Figure 7).
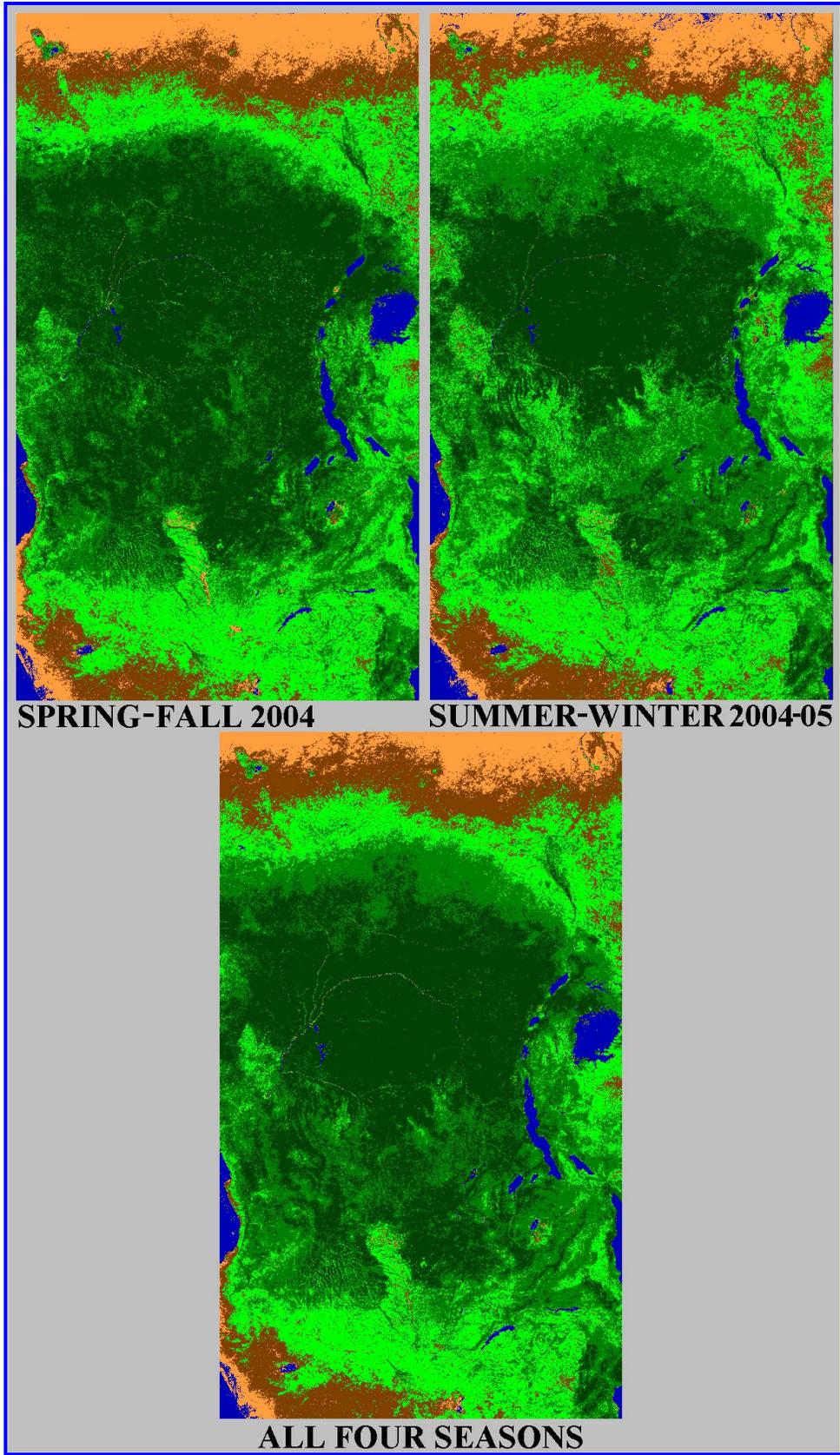
SPRING‑FALL 2004

SUMMER‑WINTER 2004‑05

ALL FOUR SEASONS

FIGURE 6: NDVI Four Seasons Combined

Table 3: NDVI Four Seasons

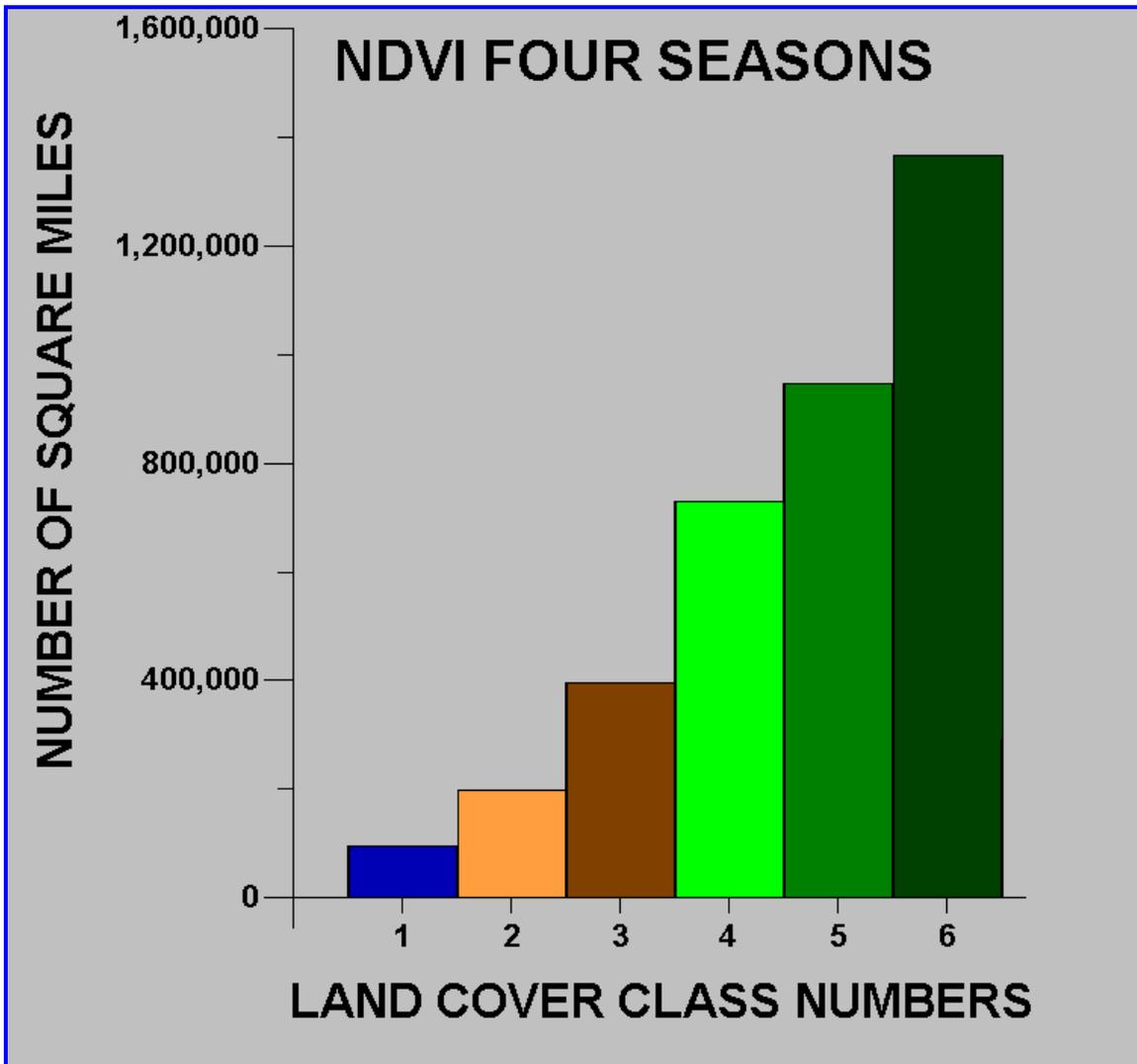| CLASS	LAND COVER CLASS	SQ. MI.	SQ. KM
1	Water	95,815	247,986
2	Very low green leaf density (VLGLD)	198,370	513,412
3	Low green leaf density (LGLD)	395,186	1,022,803
4	Moderate green leaf density (MGLD)	730,360	1,890,286
5	High green leaf density (HGLD)	945,882	2,448,092
6	Very high green leaf density (VHGLD)	1,366,474	3,536,650

FIGURE 7: NDVI Four Seasons-Square Miles by Class

The study area is 3,732,087.48 square miles in size, making it larger than the United States including Alaska. The VHGLD class makes up 36.61 percent of this total area. This condition is reflected in Table 3 and Figure 7. This percentage level appears to be high based on limited empirical knowledge of the area.

Enhanced Vegetation Index (EVI)

When the Terra spacecraft with the MODIS scanner was launched in 1999, a NASA Science Team was formed to study MODIS imagery as well as imagery from the other scanners on the satellite. This team prepared a new vegetation index, called the Enhanced Vegetation Index (EVI). It improved upon the quality of the NDVI ratio. The EVI takes full advantage of MODIS' new, state-of-the-art measurement capabilities. While the EVI is calculated similarly to NDVI, it corrects for some distortions in the reflected light caused by the particles in the air as well as the ground cover below the vegetation. The EVI data product also does not become saturated as easily as the NDVI when viewing rainforests and other areas of the Earth with large amounts of chlorophyll.

EVI is an 'optimized' index designed to enhance the vegetation signal with improved sensitivity in high biomass regions and improved vegetation monitoring through a de-coupling of the canopy background signal and a reduction in atmospheric influences. EVI is computed following this equation:

$$EVI = G \times \frac{(NIR - RED)}{(NIR + C1 \times RED - C2 \times BLUE + L)}$$

where NIR/RED/BLUE are atmospherically-corrected or partially atmospherically corrected surface reflectances; L is the canopy background adjustment that addresses non-linear, differential NIR and red radiant transfer through a canopy; and C1, C2 are the coefficients of the aerosol resistance term, which uses the blue band to correct for aerosol influences in the red band. The coefficients adopted in the MODIS-EVI algorithm are: L=1, C1 = 6, C2 = 7.5, and G (gain factor) = 2.5.

Whereas the NDVI is chlorophyll sensitive, the EVI is more responsive to canopy structural variations, including leaf area index (LAI), canopy type, plant physiognomy, and canopy architecture. The two visible images complement each other in global vegetation studies and improve upon the detection of vegetation changes and extraction of canopy biophysical parameters.

One of the most successful applications of EVI was reported by Alfredo Huete and his colleagues in early 2006. Typically the Amazon forest is viewed as having a monotonous growing season, where vegetation growth has no particular pattern. Using the MODIS EVI product Huete and his colleagues were able to show, for the first time, that contrary to that notion the Amazon forest does exhibit distinct growth during the dry season with serious implications to our current understanding of the carbon cycle and sinks and subsequently the questions surrounding green house gases and global warming. Whether that is a result of climate change or the normal behavior remains to be seen.

EVI Classification

EarthScenes does not provide a single mathematical step to handle the EVI formula. Thus, it is necessary to calculate the formula in two steps. Also, two of the constants can be removed from the formula. The gain factor (G) of 2.5 is designed to take into account 12 bit data sets with values potentially ranging from 0 to 4095. In this case the data have been converted to 8 bits with a range of 0 to 255. Multiplying the 8 bit data by 2.5 pushes practically all of the pixel values to 255 and does not produce a meaningful image. L is a constant of 1. It is basically rounding up the denominator portion of the formula by 1, which does not significantly alter the final product. The modified formula is:

$$EVI = \frac{(NIR - RED)}{(NIR + 6 \times RED - 7.5 \times BLUE)}$$

The first step in calculating the formula is to use mathematical procedure number 4. P1 will be band 1 (visible red band) and P2 will be band 4 (visible blue band). The constants will be 6 and -7.5. The results of this calculation will be stored as a new layer.

The formula now becomes the same formula for NDVI.

$$EVI = \frac{(NIR - RED)}{(NIR + New\ Layer)}$$

The second step uses mathematical procedure number 9. P1 and P3 are band 2; P2 is band 1; and P4 is the new layer. The constant "C" value will be "1" for each of the bands except for "P2" where it will be "-1."

From this point the methodology used to produce and classify the NDVI images is the same. An EVI image was produced for all four seasons and these images were classified. Figure 8 shows the four classified images. One of the major differences between the seasonal EVI images and the seasonal NDVI images is the significant decrease in the amount of area classified as being VHGLD. Some areas that were classified as VHGLD in the NDVI images are now HGLD and MGLD. Also, the LGLD increased noticeably in the Sahel during the spring and fall seasons. The VHGLD increased along the west coast during the winter season, which might relate to a better penetration of the clouds by the EVI.

Figure 9 is the summer EVI enlargement that compares to the NDVI enlargement (Figure 5). In the NDVI enlargement the VHGLD class dominates but only small patches of this class exist in the EVI enlargement. The HGLD class now dominates and much of the area identified as HGLD in the NDVI enlargement has become MGLD. If the EVI provides a better method for detecting green leaf density, than the decrease in VHGLD in a large tropical wet region such as Central Africa could have serious ramifications in our understanding about global climatic conditions.
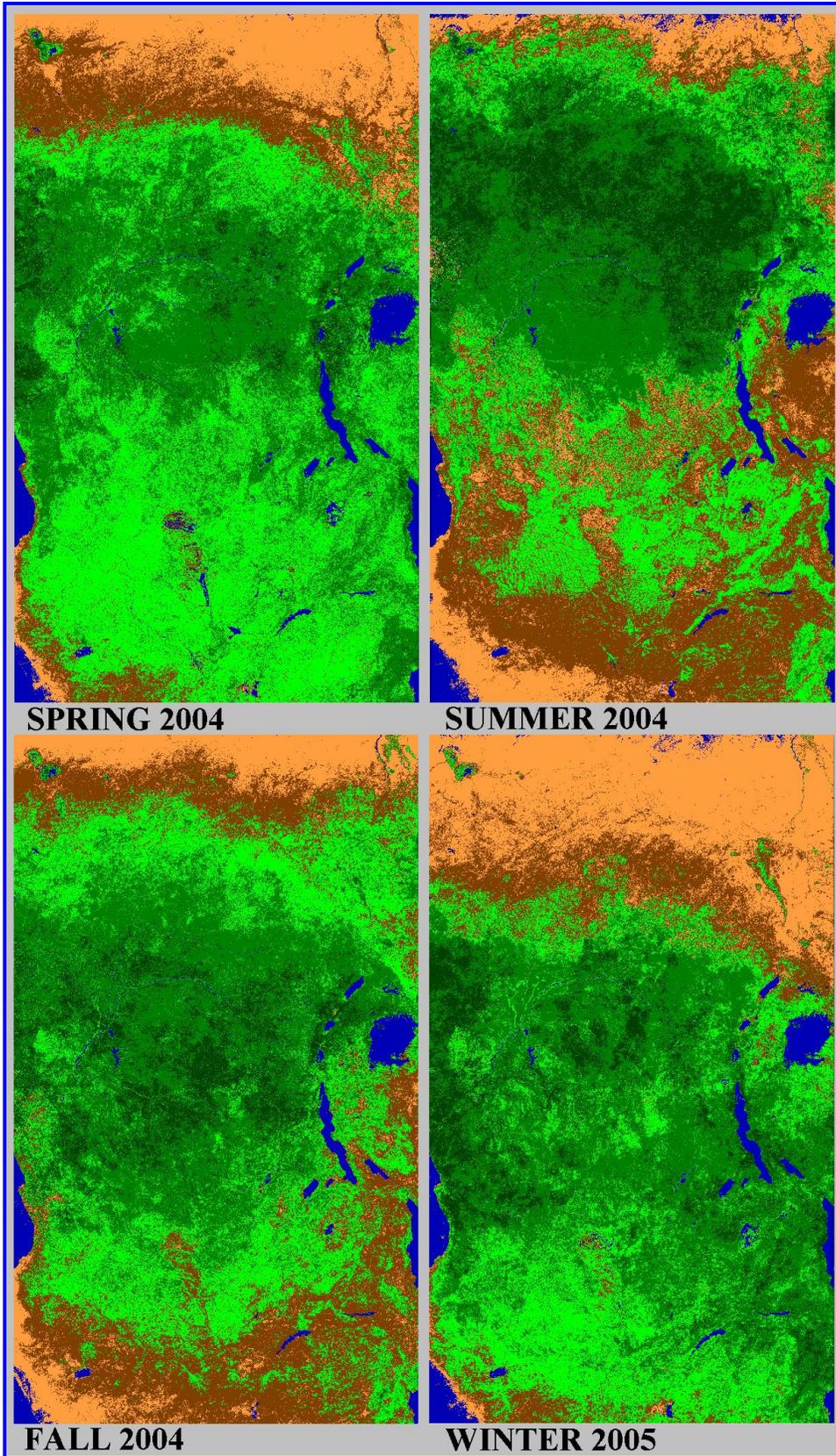
SPRING 2004

SUMMER 2004

FALL 2004

WINTER 2005

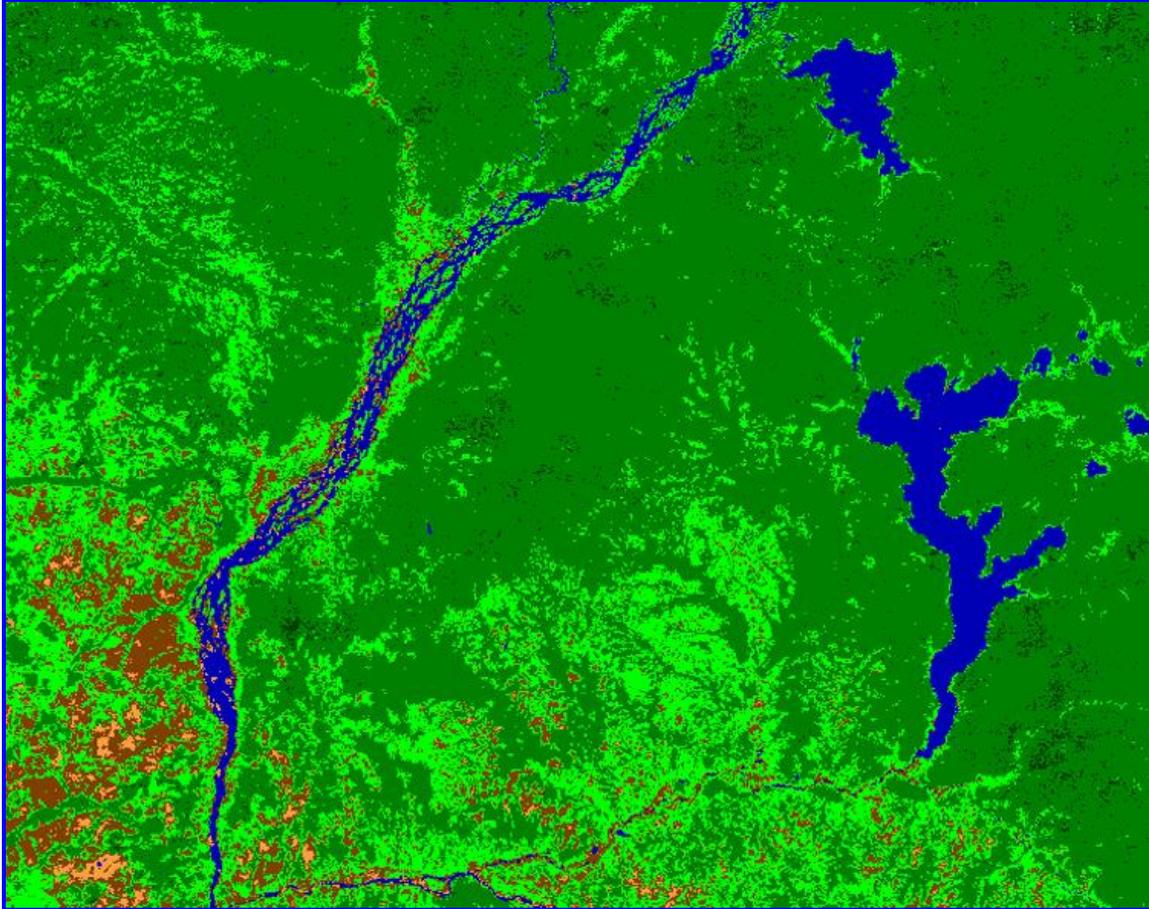**FIGURE 8: The Four EVI Classified Images.**

**FIGURE 9: Enlargement of the Summer EVI Classified Image.**

Some other changes between Figures 5 and 9 can be seen. The Congo River and its tributaries are better defined in the EVI enlargement than in the NDVI enlargement. However, the two large lakes and similar water bodies are basically the same. Also, the large patches of LGLD and VLGLD are the same. The EVI enlargement does show more small patches of these two classes.

As with the case of the NDVI images, the spring and fall and the summer and winter EVI images, respectively, were combined to form two new images and these images were merged to create the final image (Figure 10). Although the final EVI image shows a large decrease in the VHGLD class from the final NDVI image, it does appear to have more VHGLD areas than some of the seasonal EVI images. If correct, this condition might be due to certain geographic areas having VHGLD in several of the seasonal images. These areas should be investigated and maybe protected. The final EVI image has a much more developed VHGLD region along the west coast than the final NDVI image. This is the location of the tropical monsoon forest and an area that has a large amount of cloud cover as winds from the Atlantic Ocean bring in moisture and encounter plateau escarpments. EVI appears to do a better job of reducing the cloud condition than NDVI.
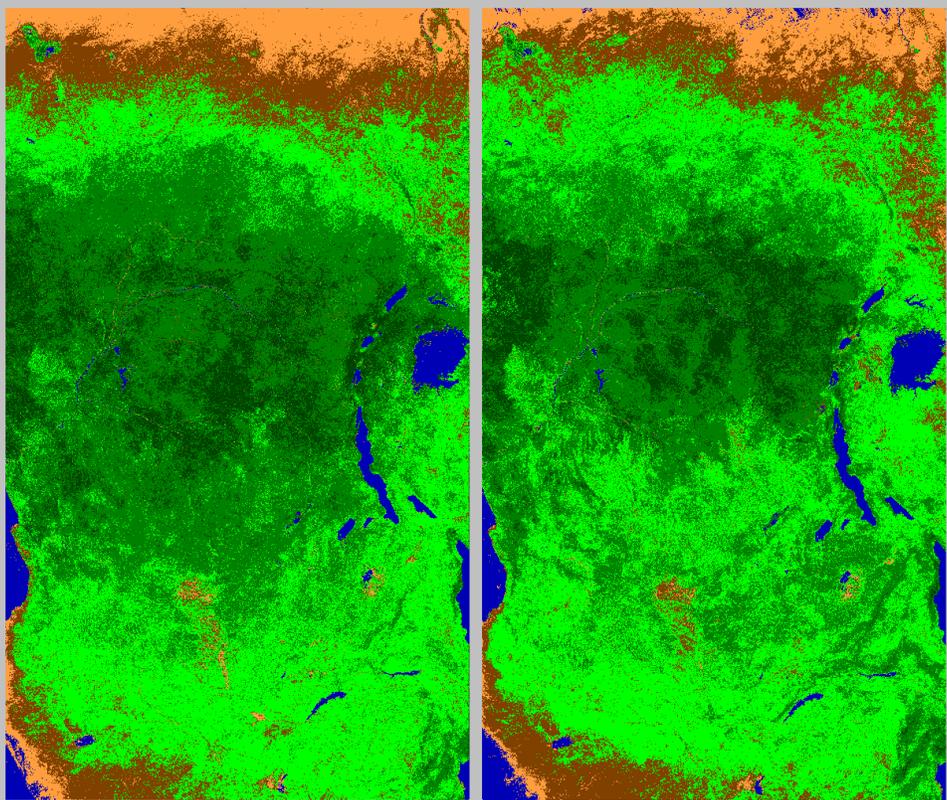
SPRING-FALL 2004   SUMMER-WINTER 2004-05
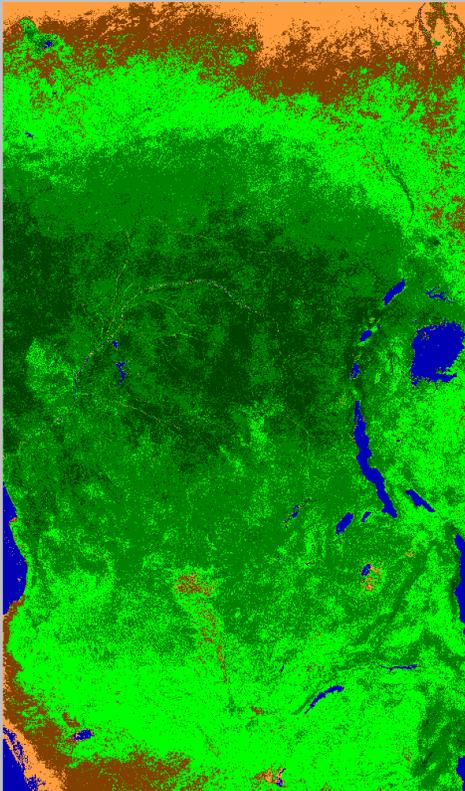
ALL FOUR SEASONS

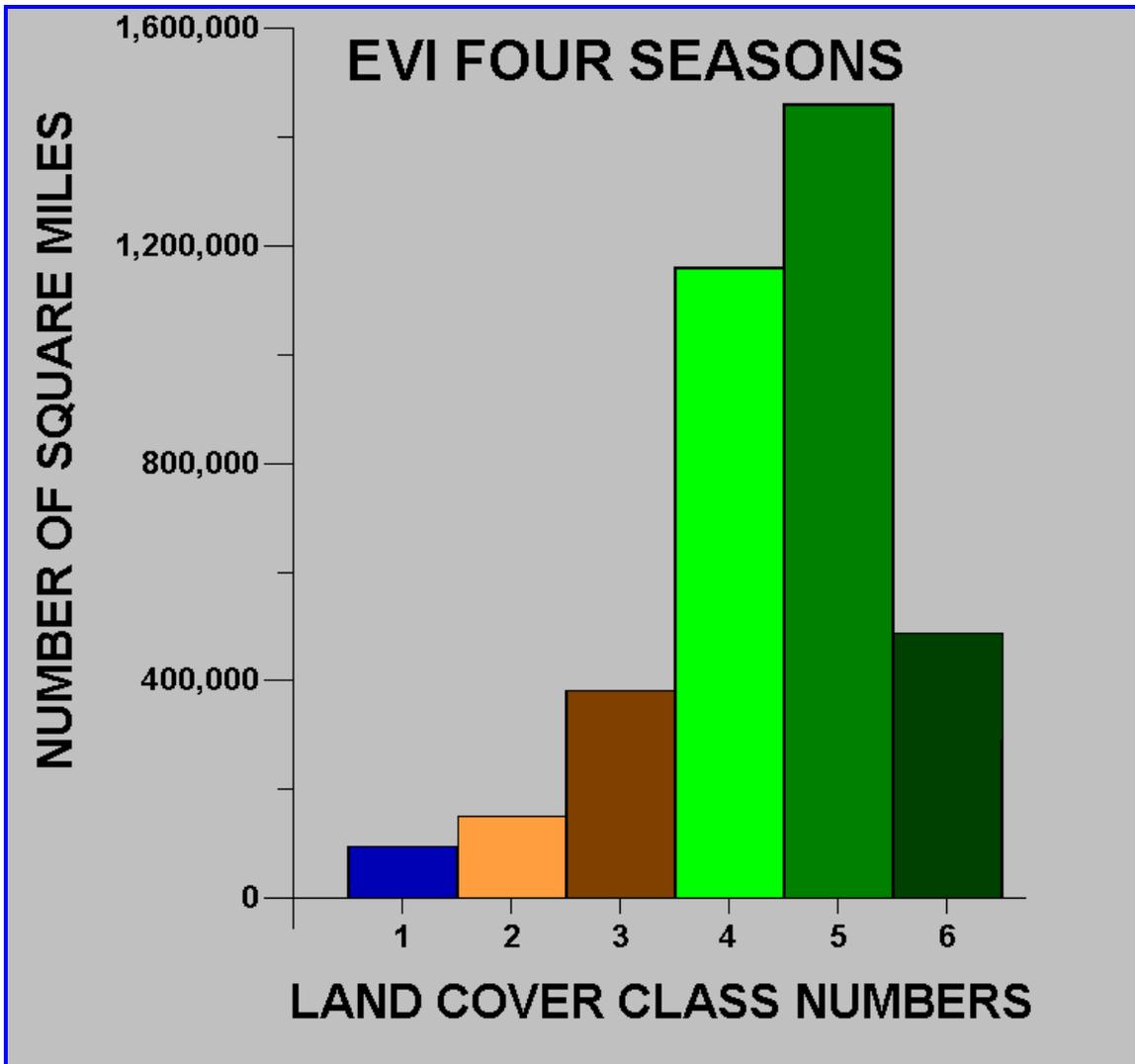**FIGURE 10: EVI Four Seasons Combined**

FIGURE 11: EVI Four Seasons-Square Miles by Class

Table 4: EVI Four Seasons

CLASS	LAND COVER CLASS	SQ. MI.	SQ. KM
1	**Water**	**95,796**	**247,936**
2	**Very low green leaf density (VLGLD)**	**151,526**	**392,172**
3	**Low green leaf density (LGLD)**	**381,880**	**988,365**
4	**Moderate green leaf density (MGLD)**	**1,157,453**	**2,995,669**
5	**High green leaf density (HGLD)**	**1,458,716**	**3,775,387**
6	**Very high green leaf density (VHGLD)**	**486,717**	**1,259,699**

Table 4 shows the amount of area covered by the six land cover classes. Figure 11 is a graphical presentation of the square mile values in Table 4. The table as well as the graph supports the observations made about the significant decrease in the amount of VHGLD

and the corresponding increases in HGLD and MGLD in the EVI classified images in comparison to the NDVI classified images. The final NDVI classified image has a large, rather solid dark green color centered on the Equator. One might view this area as not only a region of VHGLD but also as a tropical rainforest. The other colors form a nice transition from a tropical rainforest to a semiarid areas especially moving northward. The image corresponds nicely to the vegetation patterns frequently depicted on classical vegetation maps of Central Africa. The final EVI classified image is more complicated especially in the area around the Equator. The rainforest is not shown as a solid, compacted entity but as a number of patches located away from the main rivers and their settlements. It appears to be a more realistic picture of the vegetation conditions. It would be nice to compare it to an image from fifty years ago to see if similar vegetation conditions existed or if major changes have occurred.

Suggested Readings:

Huete, A. R., et al. 2002. Overview of the radiometric and biophysical performance of the MODIS vegetation indices. *Remote Sensing of Environment* 83(2002) 195-213.

Huete, A. R., et al. 2006. Amazon rainforest green-up with sunlight in dry season. *Geophysical Research Letters*, 33, L06405, doi:10.1029/2005GL025583.

Jensen, J. R. 2000. *Remote Sensing of the Environment: An Earth Resource Perspective,* Upper Saddle River, New Jersey: Prentice Hall.

Myneni, R. B., et al. 1995. The interpretation of spectral vegetation indexes. *IEEE Transactions on Geoscience and Remote Sensing*, 33, 481-486.

Sellers, P. J. 1985 Canopy reflectance, photosynthesis, and transpiration. *International Journal of Remote Sensing*, 6, 1335-1372.