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CONTINENTAL LAND COVER CLASSIFICATION USING METEOROLOGICAL SATELLITE DATA

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Summary: The use of the National Oceanic and Atmospheric Administration's advanced very high resolution radiometer satellite data for classifying land cover and monitoring of vegetation dynamics over an extremely large area is demonstrated for the continent of Africa. Data from 17 imaging periods of 21 consecutive days each were composited by a technique sensitive to the *in situ* green-leaf biomass to provide cloud-free imagery for the whole continent. Virtually cloud-free images were obtainable even for equatorial areas. Seasonal variation in the density and extent of green leaf vegetation corresponded to the patterns of rainfall associated with the inter-tropical convergence zone. Regional variations, such as the 1982 drought in east Africa, were also observed. Integration of the weekly satellite data with respect to time produced a remotely sensed assessment of biological activity based upon density and duration of green-leaf biomass. Two of the 21-day composited data sets were used to produce a general land-cover classification. The resultant land cover distributions correspond well to those of existing maps.

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Accurate, timely information on the distribution of vegetation on the Earth's surface is of considerable significance for many scientific and applied investigations. It is a prerequisite for understanding how changes in land cover affect phenomena as diverse as CO_2 concentrations in the atmosphere, the hydrologic cycle, and the energy balance at the surface-atmosphere interface. Such information about vegetative cover is also directly relevant in determining the rates of change of the Earth's biotic resources and how land use is adjusting to increasing demands on these resources.

Traditionally, the principal source of information was vegetation mapping by ground survey. But for very large areas such ground survey exceeds the capabilities of any single mapping agency, let alone a single individual. For such areas it is inevitable that the observations of many different people and groups have to be synthesized, with all the problems of reconciling disparate observations. The magnitude of the task can be seen in the map of and ancillary text on the vegetation of Africa south of the Sahara(*1*). Other vegetation maps of Africa or large parts of it include those of UNESCO(*2*), Eyre(*3*), and the World Atlas of Agriculture(*4*).

The use of such traditional methods for the timely production of internally consistent maps and spatial statistics is not feasible for areas on a continental or global scale. The impracticality of such methods is illustrated by the widely varying estimates of surface areas of world terrestrial ecosystems(*5*). An alternative is to look to remote sensing data especially those from satellites with their synoptic overview, as a basis for mapping. In numerous studies such remotely sensed data have been used to accurately map vegetation, crops, and other land cover types(*6*). The majority of these studies have used Landsat data and none of them attempted classification on a continental scale.

The lack of continental-scale vegetation classifications from Landsat data stems from their 80-m spatial resolution and 18-day repeat cycle. The 80-m spatial resolution of the Landsat multispectral scanner system (MSS) and associated 185- X 185-km scene results in a very substantial quantity of data (about 1000 Landsat scenes) to cover an area as large as Africa. Thus logistical and financial problems are formidable if the analysis is to be performed in a digital mode: the cost (1983) is $700,000 for the data alone for single-image coverage.

It is highly desirable however, to collect several images each year to minimize cloud cover and adequately monitor changes in vegetation over time(*7*). Multiple imaging within a given year allows classification to be based on differing phenological changes in different vegetation types(*6*). For areas like Africa such an approach becomes essential if cover types are to be spectrally discriminated because of the asynchronous responses of vegetation to seasonal rainfall north and south of the equator.

The 18-day Landsat repeat cycle, however, is inadequate for acquiring several cloud-free images in a year in many parts of Africa, especially in equatorial rain forests but also in much drier areas. In Sahelian areas, for example, cloud cover averages about 50 percent throughout the 60- to 80-day wet season, when changes in vegetation are most pronounced(*8*). In addition, substantial parts of the Earth's surface are not covered by Landsat receiving stations, so MSS data are infrequently available, though with the launching of the two Tracking and Data Relay Satellite Systems this problem may lessen in the future. In summary, Landsat data are a potentially useful source for mapping very large areas but as a practical tool they suffer from high cost, large amounts of data, and inadequate temporal resolution.

As an alternative to Landsat we propose the use of advanced very high resolution radiometer (AVHRR) data from the National Oceanic and Atmospheric Administrations (NOAA) meteorological satellites. Such data have already been shown to have significant potential for assessing and mapping vegetation over relatively modest areas(*9,10*). They have a much coarser resolution (1 and 4 km) and hence a much lower data volume and their temporal resolution is much higher, with 4-km imagery being almost globally available on a daily basis. We intend to address the questions of whether such data can be satisfactorily managed to provide multitemporal data sets with low cloud frequency and whether these data can provide useful information about vegetation of a complete continent, the one chosen being Africa. Evaluation of the latter question will clearly be a very lengthy process, since we are dealing with a very large area. However, by comparison with existing vegetation and land-cover maps and with reference to our own field experience, a preliminary evaluation is possible.

It should be stressed that we are attempting to map vegetation formations according to cover criteria rather than using any alternative criteria that have been proposed, such as environmental characteristics, phylogeny, or individual form features(*11*). Our techniques are based upon satellite data collected daily for one year from the continent of Africa, and we use the satellite-recorded multitemporal characteristics of land cover for large-scale classification purposes.

Methods

The AVHRR of the NOAA satellites were chosen to provide the data(*12*) (Table 1). Earlier data from this sensor onboard the television and infrared observing satellite (TIROS) were unsatisfactory because of the overlap between the visible and near-infrared bands, which made it impossible to calculate a normalized-difference vegetation index. We chose data from NOAA-7 since that satellite images in the afternoon, whereas NOAA-6 images in the early morning and has significant portions of its broad swath in darkness. A disadvantage of NOAA-7 data compared with NOAA-6 data is that the atmosphere tends to be cloudier, especially in equatorial areas, in the early afternoon than in the early morning. Global-area coverage (GAC) data with a 4-km resolution were initially chosen rather than the finer resolution local-area coverage (LAC) data with a 1-km, resolution, since only the former are available daily for the whole continent and consequently can provide a geographically comprehensive cloud-free data set of the continent when composited over several weeks.

Table 1
Characteristics of the NOAA-6, NOAA-7, and NOAA-8 advanced very high resolution radiometers(*13*). Orbit: sun synchronous, 102° inclination, 101.6-minute orbital period, 0730/1930 (NOAA-6 and NOAA-8) and 1430/0230 (NOAA-7) overpass times.

Quantizing levels:	1024 (10 bits)
Field of view:	1.1 km at Nadir
Swath width:	2700 km (2048 pixels)
Spectral channels:	0.55 – 0.68 μm
	0.73 – 1.1 μm
	3.5 – 3.9 μm
	10.5 – 11.5 μm
	11.5 – 12.5* μm

*Not on NOAA-6

The 4-km GAC data are partly resampled 1-km LAC data; the first four 1-km picture elements are averaged and this average is then used to represent a 3 X 5 picture element block(*13*). The GAC data are tape-recorded onboard the satellite and subsequently transmitted to receiving stations either in Virginia or Alaska.

Three NOAA-7 orbits cover Africa each day. The data are processed by NOAA and the channel 1 (C_1) and channel 2 (C_2) GAC values remapped daily into a 1024 X 1024 array for the northern and southern hemispheres. The C_1 and C_2 values are used to generate the normalized-difference vegetation index: $(C_2 - C_1)/(C_2 + C_1)$(*14*). This vegetation index has been shown to be strongly correlated with green-leaf biomass and green-leaf-area index(*15*). It is important to note that such relationships in general hold for a given vegetation formation. Thus direct comparison between the normalized-difference vegetation indices for different formations do not necessarily indicate differences in green-leaf activity. But for a given location, the normalized-difference vegetation index from successive images will show changes in the status of the vegetation community in terms of green-leaf biomass or leaf-area index.

Every week the maximum value of the normalized-difference vegetation index was selected by NOAA for each picture element in the two 1024 X 1024 arrays, along with the associated pixel values for C_1 and C_2(*16*). Selecting these maximum values minimizes the effects of clouds and atmospheric aerosols, both of which decrease the index and increase the C_1 and C_2 values(*17*). An additional advantage of the compositing process is that data tend to be selected from near-nadir positions rather than off-nadir positions because the latter tend to have a greater atmospheric backscattered component(*17*).

The weekly composited data have a grid-cell size of 15 X 15 km at the equator and 24 X 24 km at 60° north or south latitude. The satellite data used to prepare this grid cell could represent an area as small as 1.1 X 4.4 km at nadir or about 8 X 8 km at a ± 56° scanning angle. Thus we see that the AVHRR GAC data used for each grid cell are undersampled by a factor of 4 to ~100 relative to the actual area and geographic location of each composite grid cell.

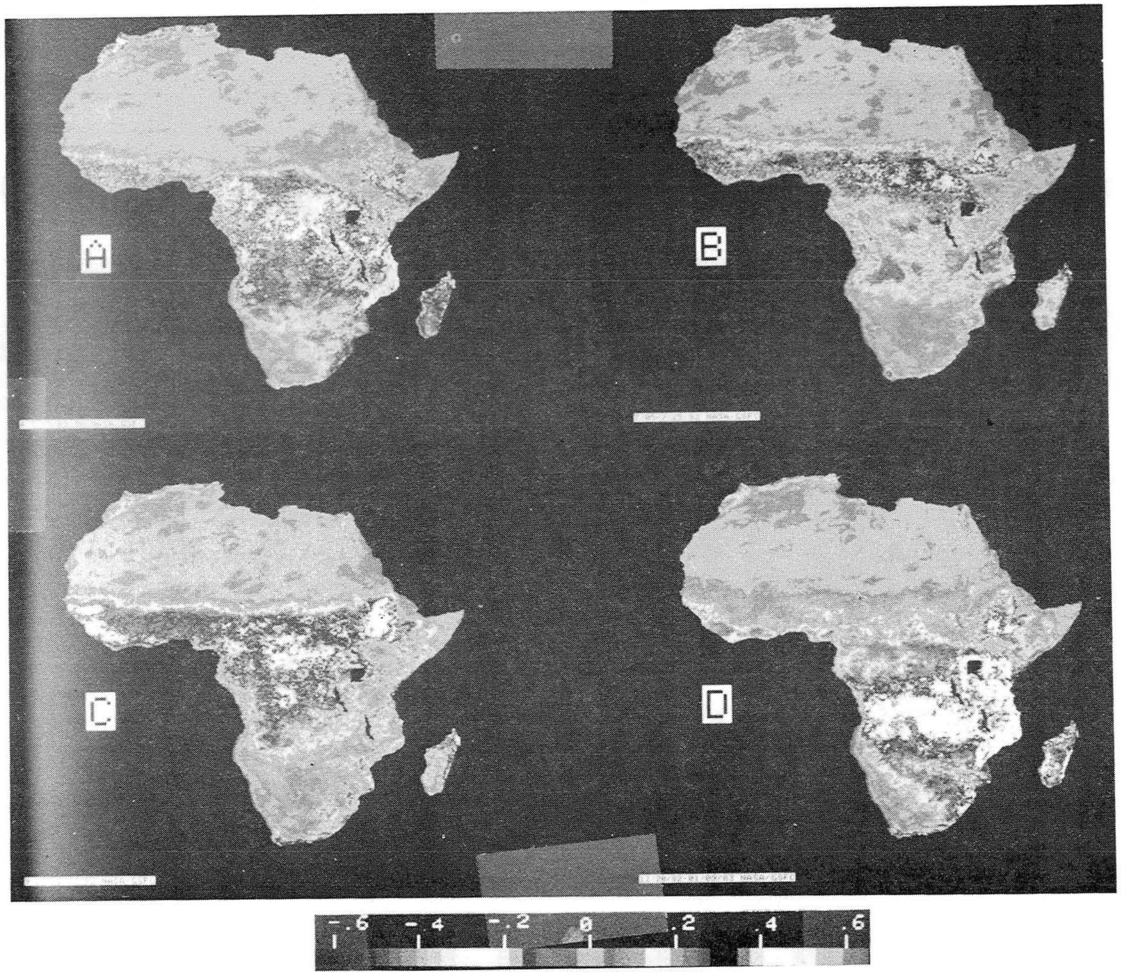
Weekly composite AVHRR data were obtained from NOAA from mid-April 1982 to April 1983. These data were remapped from a polar stereographic projection to a Mercator projection so that Africa was contained within a single image. Inspection showed that for most weeks the compositing process produced images with over 5 percent cloud cover, especially in equatorial regions. Consequently, further compositing was used to combine data obtained over 3 weeks to reduce cloud cover to less than 5 percent. It proved possible by this process to create 17 separate composite images with cloud cover less than 5 percent for the period April 1982 to April 1983. Compositing was performed on the Hewlett-Packard-1000 and Ramtek image-processing system at the Sensor Evaluation Branch, Goddard Space Flight Center, National Aeronautics and Space Administration. The importance of combining data over periods of time to minimize clouds and atmospheric effects while maintaining the ability to record the temporal dynamics of vegetation must be stressed, and this method is fundamental to the work we describe herein.

Multitemporal Dynamics of Green Leaf Biomass

The ability to successfully composite daily satellite data on a continental scale provided the means to overcome the problem of extensive cloud cover in equatorial and other areas. Once cloud-free data were available at frequent intervals, the large-scale multitemporal dynamics of green-leaf biomass could be recorded. Figure 1 illustrates the seasonal changes in green leaf biomass for Africa at four selected 21-day intervals from April 1982 to February 1983. In April-May 1982 the rainy season was ending in Southern Africa, while an area north of a line extending from Guinea Bissua in the west to Jos, Nigeria, and from there east at 5°N latitude was devoid of appreciable green-leaf biomass except for the Lake Chad Basin, the Sudd of southern Sudan, the Ethiopian Highlands, the Nile River and its delta, and the northern African coast of Morocco, Algeria, and Tunisia.

In the July 5-25, 1982 composite image, Africa south of the equator appeared much drier than it had 3 months earlier; Tanzania, Kenya, and Somalia appeared very dry except for coastal areas. The northern edge of the green-vegetation line extended from ~ 11°N latitude across Africa to the Ethiopian Highlands. Southern Africa south of 18°S latitude was very dry. The Ethiopian Highlands had more green-leaf biomass than they did 3 months earlier, but the northern parts of Morocco, Algeria, and Tunisia appeared drier than they did 3 months earlier.

The September 27, 1982 to October 17, 1982, composite image showed the boundary of green-leaf activity to have moved to ~ 13°N latitude. It also showed a significant increase in green-leaf biomass south of 11°N latitude extending south to Angola and Zaire. Africa south of Angola and Zaire as well as eastern Africa appeared very dry(*18*) but Somalia and Ethiopia showed higher amounts of green-leaf biomass than they had 3 months earlier.



Normalized Difference Vegetation Index

Figure 1. The normalized difference vegetation index from Africa for four selected 21-day periods. (A) April 12 – May 2, 1982; (B) July 5-25, 1982; (C) September 27 – October 17, 1982; and (D) December 20, 1982 – January 9, 1983. These data are the maximum normalized-difference values from 3 weeks of the NOAA global vegetation-index product and have a spatial resolution of 15 km at the equator. The tan and brown colors represent no green vegetation, the orange and gold colors represent higher amounts of green vegetation, and the reds and purples represent the highest amounts. Values for green vegetation range from 0.05 to 0.65.

The December 20, 1982, to January 9, 1983, image showed dry conditions from the Sahara southward except in coastal areas of equatorial Africa, the Niger Delta, Lake Chad, the Sudd, the Ethiopian Highlands, and generally to 5°N latitude in central Africa. The tropical rain-forested area was in its drier season, the rainy season had come to the southern Africa savanna, and the "short" rains had come to eastern Africa, ending a drought there.

The movements of the intertropical convergence zone were clearly evident in the development of green-leaf biomass following periods of precipitation. Thus we were using the green-leaf biomass as an integrator of climate. In addition to observing the drought conditions in Tanzania and Kenya before they ended with the "short" rains of November and December 1982(*18*), we observed marked seasonal changes in the normalized-difference vegetation index over the tropical rain forest (Fig. 1 and 2). These changes could have arisen in part because of a bidirectional effect variations in the angle subtended by the direction of solar illumination, target location, and look direction of the sensor. However, they may also be a function of seasonal changes in biological activity. In addition, the boundaries of zones of equal normalized-difference vegetation index across Africa between 5°N and 12°N latitude were remarkable linear.

To quantify the yearly vegetation response for Africa we have integrated the multitemporal normalized difference vegetation index with respect to time for the period from April 1982 to April 1983 (Fig. 3). This technique is of considerable significance in indicating the cumulative biological activity or approximate total dry matter accumulation within a given vegetation type for the period of observation. This is so because the normalized-difference index is highly correlated to the projected green-leaf area or green-leaf biomass, which indicates the area of photosynthetic absorbing surface, and the latter in turn is related to the rate of photosynthesis. Frequently collected spectral data when integrated with respect to time, have been shown to be highly correlated to the total dry matter accumulation for the period of observation for wheat(*7*), corn(*19*) and pastoral ecosystems(*9*). Although this technique has not been tested across different

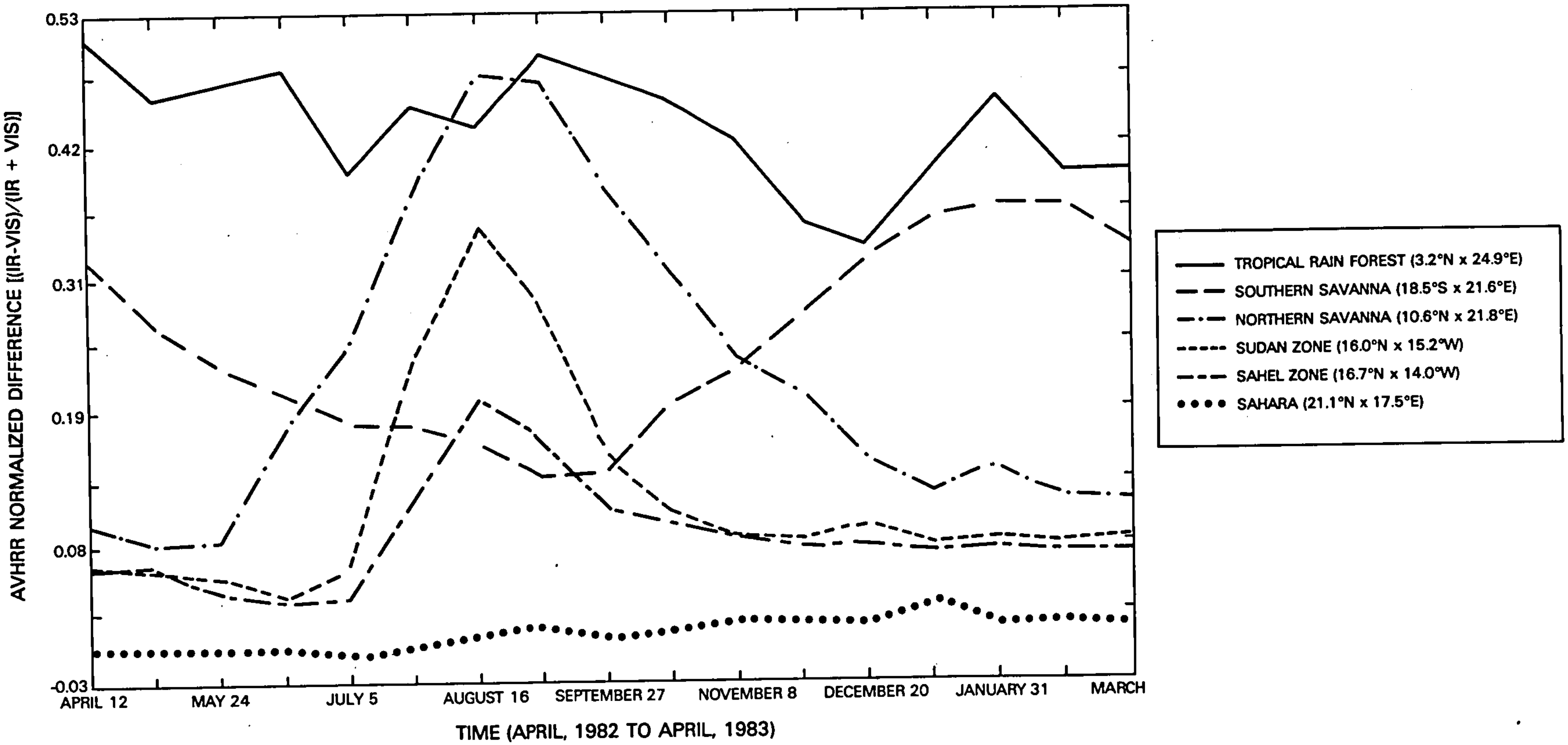
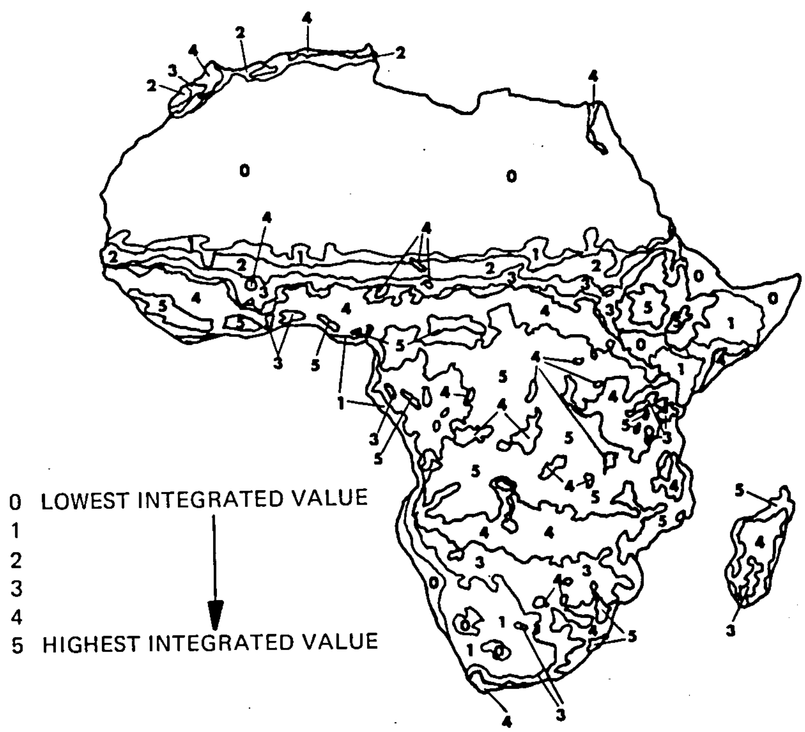


Figure 2. The normalized-difference vegetation index from April 1982 to April 1983 at six African locations. One data value is plotted per location for each 21-day period. The first day of each 21-day period is indicated on the X-axis (i.e., April 12 is actually April 12, 1982, to May 2, 1982, etc.). Each plotted value represented averages of nine picture elements.



Integrated Normalized Difference Vegetation Index

Figure 3. The integrated normalized-difference vegetation index from Africa for 17 21-day composites from April 1982 to April 1983. This figure represents the integrated green leaf biomass or density for period. Four of the 17 21-day periods appear as Figure 1.

ecological zones, the data we report on are well suited for this purpose. Fig. 3 indicated that a general zonation resulted which largely agreed with vegetation and climate types(*20*), with the exception of the tropical forested area. The reasons for this are currently under study.

Land Cover Classification

The integrated image discussed above is also of considerable interest because its patterns are highly correlated with many major land-cover types found in Africa. For example, the highest values correspond well to the rain forest and the lowest to desert and semidesert areas. This relationship suggested that a continent-wide land cover classification should prove feasible, and the following procedure was adopted. From the 17 cloud-free geographically referenced data sets, two (April 12-May 5 and August 16-September 5) were chosen for this investigation. These were chosen since their wide temporal separation provided an opportunity to use phenological changes to classify the vegetation cover. For two reasons, the variable chosen to define the feature space was the normalized-difference vegetation index. First, this index is well correlated with the projected green-leaf-area index and green-leaf biomass for a given vegetation type; hence the images from the two dates give us a direct indication of the temporal dynamics of the green leaf vegetation. Second, use of this index means that differences in radiance received at the sensor as a result of differences in solar elevation should be largely eliminated.

The classification procedure used was interactive, relying on the analyst to select areas in the feature space belonging to each class. Picture elements of the whole 640 X 512 scene were represented in the feature space on the monitor of the image-processing system. By use of a trackball, the boundaries of areas belonging to each class were selected. Locating these areas could have been made simply on the basis of *a priori* knowledge of green-vegetation dynamics. The principles used are illustrated in Fig. 2 and 4. Fig. 2 was constructed for locations centrally within the indicated vegetation types, and it shows quite clearly that at any one date confusion between classes is likely,

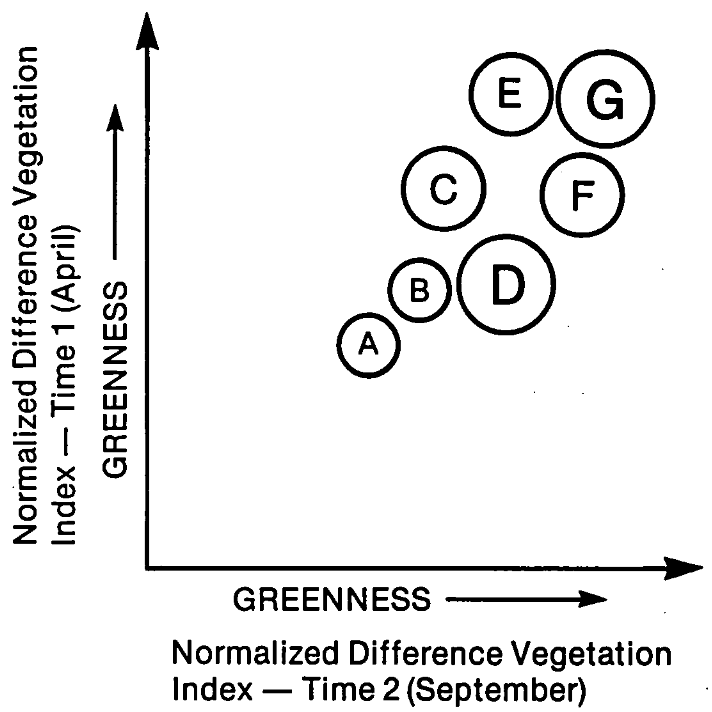


Figure 4. The two-dimensional representative of the various clusters formed by the normalized-difference vegetation index for April 12 – May 2, 1982, and August 16 – September 5, 1982. (A) water, (B) desert and semidesert, (C) southern hemisphere savanna, (D) northern hemisphere savanna, (E) southern hemisphere seasonal forest and grassland, (F) northern hemisphere seasonal forest and grassland, and (G) closed canopy forest. See also Fig. 1 and 2.

but that when values for April and September are compared, unique characterization can be achieved. Thus tropical rain forest will have high values of the vegetation index and desert will have low values for both dates, whereas savanna and other seasonal vegetation will have higher values for one date and lower for the other. Diagrammatically we would expect the principal cover types to be arranged in the feature space as shown by Fig. 4. On the basis of this pattern, boundaries to the classes were located and the classified scene was then produced. Some obvious errors were apparent, so minor changes were made to the feature space boundaries and a final image was produced with two further iterations (Fig. 5). It is clear from Fig. 5 that the same class lay in different locations within the feature space according to whether the area was north or south of the equator. Thus, after the initial classification, the corresponding pairs of classes for moist savannas, dry savannas, and wooded grasslands were combined.

Several qualifications need to be made concerning the cover map shown in Fig. 5. We should stress that we did not primarily attempt definitive or even quasi-definitive land-cover classifications of Africa, but instead attempted to evaluate the feasibility of using NOAA-7 AVHRR data for this purpose. No formal performance evaluation has been carried out. Such an evaluation would clearly be extremely time consuming, mainly because of the disagreements in the literature concerning the distribution of various cover types(5) and substantial field checking would be required. Qualitative comparison with existing vegetation maps such as that shown in Fig. 6 suggests generally close agreement, although certain errors can be noted. The classification of desert (yellow) north of the equator includes both deserts and other semiarid zones with precipitation up to 300 mm/year (Fig. 5). As such this includes a portion of the Sahelian zone (200-500 mm/year). The extent of closed-canopy forest in eastern Africa is probably overestimated. In coastal Gabon in western Africa, the amount of rain forest may have been somewhat underestimated because the remarkably high frequency of clouds and haze in the early afternoon in this area probably lowered the normalized difference vegetation index derived from the satellite sensor below what it should

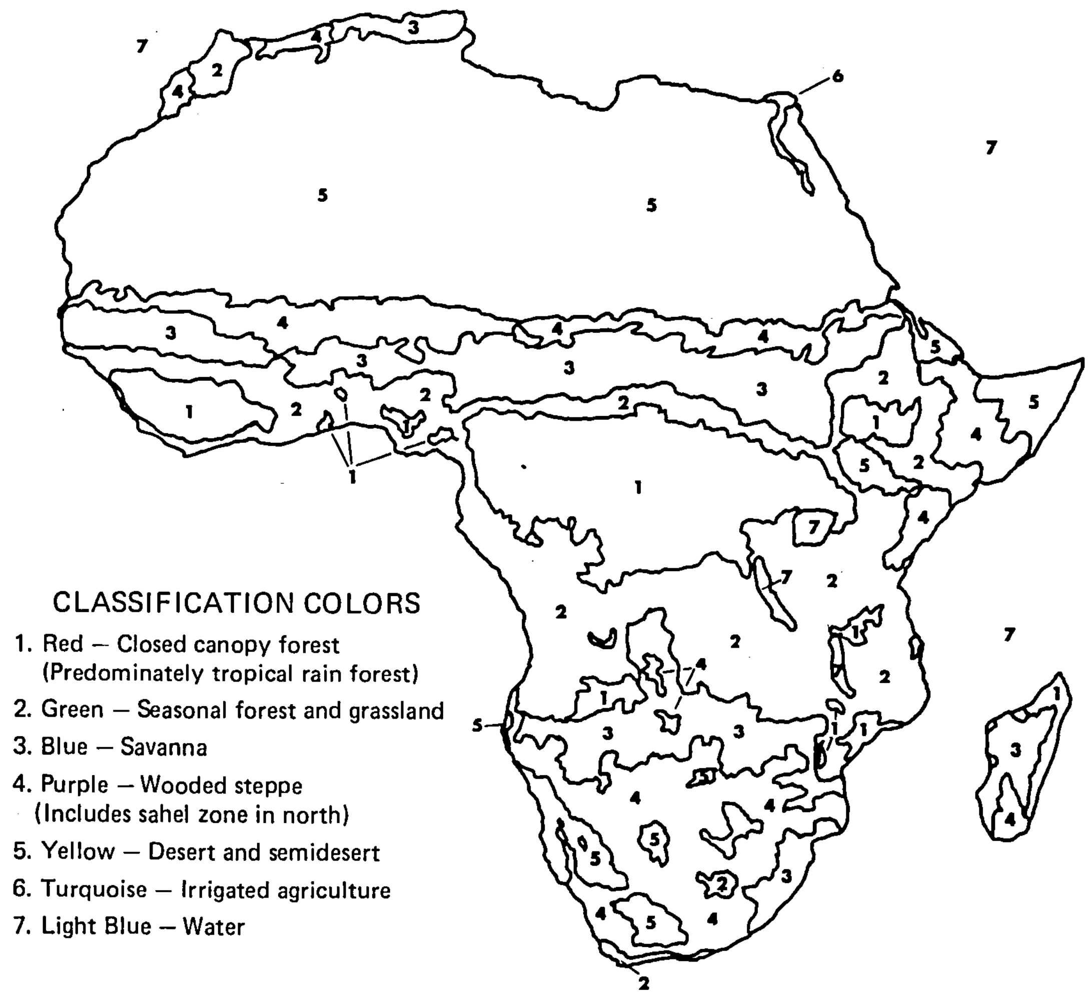


Figure 5. Preliminary land-cover classification of Africa produced from two 21-day composited images, one April 12-May 2, 1982, and one August 16-September 5, 1982.

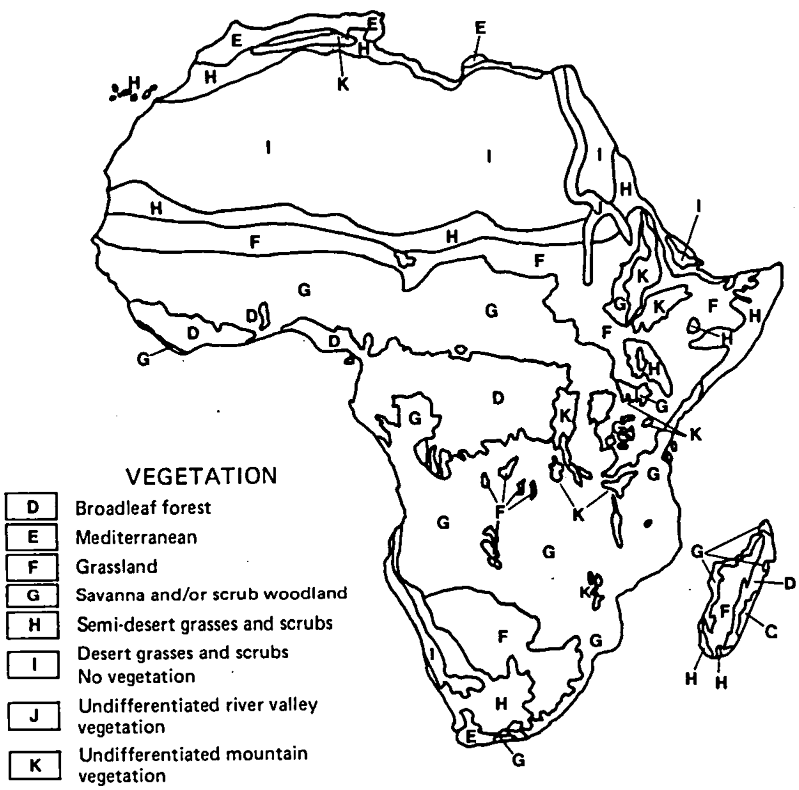


Figure 6. A generalized vegetation map of Africa(*20*).

have been. Immediately south of the southern limits of the rain forest in Zaire, a small wooded steppe is incorrectly shown; an explanation for this anomaly is not apparent at present. The classification of vegetation on the Mediterranean coast is described in the same terms as that in the rest of the map. More detailed mapping at a later date should be accompanied by labelling on the basis of the known differences in the assemblage of vegetation formations in this area. These several qualifications should not detract from the very large measure of correct classification displayed by our satellite-derived map.

Conclusions

The use of the NOAA-7 AVHRR sensor with its high temporal frequency meant that over a 3-week period there was a very high chance of virtually every location within the whole of continental Africa being cloud-free for at least one date with GAC data. The mapping of the images to a common geographically referenced data base provided the basis for rapid compositing to produce cloud-free images of the entire continent, in which haze effects and look-angle effects were greatly reduced. Using the 0.55- to 0.68 μm band in the visible and the 0.73- to 1.1 μm band in the near infrared, a spectral normalized difference vegetation index was calculated to allow the green-leaf dynamics of the main cover types to be readily assessed for the whole of Africa. This index was used to construct a continent-wide cover classification based on the distinctive multitemporal response of the main vegetation cover types. The resultant cover map is the first one of a complete continent to be produced by remote-sensing methods and corresponds closely to the distribution of cover types in conventionally produced maps. The potential of these methods lies in the prospect of internally consistent mapping and eventually monitoring of the main cover types of extremely large areas. Given the modest computing power of the procedure used, efficient cost-effective global mapping and monitoring of vegetation cover by remote sensing is clearly possible for the first time on a continuing basis.

References and Notes

1. R. W. J. Keay, *Vegetation Map of Africa* (Clarendon Press, Oxford, 1959).

2. United Nations Education, Scientific and Cultural Organization (UNESCO), *Vegetation Map of the Mediterranean Region* (Paris, 1968).

3. S. R. Eyre, *Vegetation and Soils, a World Picture* (Arnold, London, 1963).

4. Committee for the World Atlas of Agriculture, *World Atlas of Agriculture* (Agosteri-Novare, Italy, 1969).

5. B. Bolin, E. T. Degens, S. Kempe, P. Keter, *The Global Carbon Cycle* (Scope Report 13), (John Wiley, New York, 1979); N. I. Bazilevich, Y. L. Rodin, N. V. Rozov, *Sov. Geogr. Rev. Transl. 12,* 293 (1971); H. J. M. Bowen, *Trace Elements in Biochemistry* (Academic, New York, 1966); E. S. Deevery, *Sci. Am. 203,* 195 (1960); F. B. Golley, in *Ecosystem Structure and Function,* J. A. Weins, Ed. (Oregon University Press, Corvallis, 1972); H. Lieth, *Geogr. Taschenbuch* (Franz Steiner Verlag, Wiesbaden, 1964); G. Schmidt, *Vegetations Geographie auf Okologisch-Soziologischer Grund Loge* (Teubren Verlog, Leipzig, 1969); H. L. Shantz, *Ecology 35,* 143 (1960); L. D. Stamp, *Our Developing World* (Faber and Gaber, London, 1960); R. H. Whittaker, *Communities and Ecosystems* (Macmillan, Toronto, 1970); R. W. Whittaker, G. E. Likens, in *Carbon and the Biosphere,* G. M. Woodwell, E. V. Pecan, Eds. (National Technical Information Services, Springfield, Va., 1973); R. H. Whittaker, G. E. Lidens, in *Primary Production of the Biosphere,* H. Lieth, R. H. Whittaker, Eds. (Springer-Verlag, Berlin, 1975).

6. M. C. Bauer, J. E. Cipra, P. E. Anuta, J. E. Etheridge, *Remote Sens. Environ. 8,* 77 (1979); M. D. Fleming, J. S. Berkebile, R. M. Hoffer, *LARS Note 72475* (Laboratory for Applications of Remote Sensing, LARS, West Lafayette, IN, 1975); C. O. Justice, *Proc. Am. Soc. Photo-*

gram., 303 (Albuquerque, N.M., 1978); T. Le Toan, P. Cassirame, J. Quach, and R. Marie, *Proc. 11th Intl. Symp. Remote Sens. Environ.*, 1483 (Ann Arbor, Mich., 1977).

7. C. J. Tucker, B. N. Holben, J. H. Elgin, J. E. McMurtrey, *Remote Sens. Environ. 11,* 171 (1981).

8. The average reported cloud cover was 45 percent in Landsat images obtained between July 15 and October 15 from 1972 to 1982 in northern Senegal and southern Mauritania.

9. C. J. Tucker, C. Vanpraet, E. Boerwinker, A. Gaston, *Remote Sens. Environ.* (in press, 1983).

10. R. C. Cicone, M. D. Metzler, in *Proc, 1982 Machine Processing of Remotely Sensed Data,* 291 (Laboratory for Applications of Remote Sens., West Lafayette, IN, 1982); T. I. Gray, D. G. McCrary, *AGRISTARS Report EW-N1-04042* (Houston, TX, 1981); J. P. Ormsby, *IEEE Trans. Geosci. Remote Sens. GE-20,* 262 (1982); S. R. Schneider, D. F. McGinnia, In *Proc. 1982 Machine Processing of Remotely Sensed Data* (Laboratory for Applications of Remote Sens., West Lafayette, IN, 1982); S. R. Schneider, D. F. McGinnis, J. A. Gatlin, *NOAA Tech. Report 84* (Washington, 1981); J. R. G. Townshend, C. J. Tucker, in *Matching Remote Sensing Technologies and their Applications,* 97 (Remote Sensing Soc., London, 1981); C. J. Tucker, J. A. Gatlin, S. R. Schneider, M. A. Kuchinos, in *Proc. of Conf. on Remote Sensing of Arid and Semi-Arid Lands,* 973 (1982).

11. D. J. de Laubengels, *Mapping the World's Vegetation* (Syracuse University Press, 1975).

12. The AVHRR instruments on previous satellites in the television and infrared observing satellite (TIROS) series had a different spectral configuration for AVHRR channel one which made calculation of a normalized difference green-leaf density vegetation index impossible. A normalized difference vegetation index calculation has been possible with the AVHRR instrument since the launch of NOAA-6 in June 1979, NOAA-7 in June 1981, and NOAA-8 in March 1983.

13. K. A. Kidwell, *NOAA Polar Orbiter Specifications* (Dept. of Commerce, Washington, 1979).

14. J. W. Rouse, R. H. Haas, J. A. Schnell, D. W. Deering, in *3rd Symp. on Significant Results Obtained with ERTS-1*, 309 (NASA SP-351, Washington, 1973).

15. C. J. Tucker, *Grass Forage Sci. 35*, 177 (1980); D. L. Kimes, B. L. Markham, C. J. Tucker, J. E. McMurtrey, *Remote Sens. Environ. 11*, 401 (1981).

16. J. D. Tarpley, S. R. Schneider, R. L. Morey, *J. Am. Meteorol. Soc.*, (in press).

17. B. N. Holben, R. S. Fraser, *Intern. J. Remote Sens.* (in press, 1983).

18. Landsat research by D. R. Thompson and O. A. Wehmanen, *Photogram. Engr. Remote Sens.* 45, 201 (1979) showed results for smaller areas of drought similar to those we report.

19. B. L. Markham, D. S. Kimes, C. J. Tucker, and J. E. McMurtrey, *Photogram. Eng. Remote Sens. 48*, 1599 (1982).

20. McGraw-Hill Co., *Man's Domain* (McGraw Hill, New York, 1975).

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16. Abstract

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