The 1990 Conterminous U. S. AVHRR Data Set

Jeffery C. Eidenshink
TGS Technology, Inc., EROS Data Center, Sioux Falls, SD 57198

ABSTRACT: The U.S. Geological Survey, using NOAA-11 Advanced Very High Resolution Radiometer (AVHRR) 1-km data, has produced a time series of 19 biweekly maximum normalized difference vegetation index (NDVI) composites of the conterminous United States for the 1990 growing season. Each biweekly composite included data from approximately 20 calibrated and georegistered daily overpasses. The output is a data set which includes all five calibrated AVHRR channels, NDVI values, three satellite/solar viewing angles, and date of observation pointer for each biweekly composite. The data set is intended for assessing seasonal variations in vegetation condition and provides a foundation for studying long-term changes in vegetation resulting from human interactions or global climate alterations.

INTRODUCTION

IN 1987, THE U.S. GEOLOGICAL SURVEY (USGS) established a reception station at the EROS Data Center (EDC) in Sioux Falls, South Dakota, for National Oceanic and Atmospheric Administration (NOAA) polar orbiting satellite data. The EDC station receives Advanced Very High Resolution Radiometer (AVHRR) data for the conterminous United States, southern Canada, and northern Mexico. Since 1988, EDC has conducted experimental programs using NOAA-9 and NOAA-11 data to produce weekly and biweekly maximum normalized difference vegetation index (NDVI) composites (Holben, 1986) of large regions of the United States. These experimental programs were designed to evaluate the use of 1-km resolution NDVI composites for monitoring vegetation condition in the United States. The work was based on similar studies of Africa where AVHRR data had been used to monitor drought conditions (Henricksen and Durkin, 1986) and grassland productivity (Justice and Hiernaux, 1986). The United States NDVI composites have been used for monitoring grassland and forest conditions and for assessing wildland fire danger (Eidenshink *et al.*, 1989; Eidenshink *et al.*, 1990).

In March 1990, the EDC began an operational program to produce NDVI composites for the conterminous United States. A comprehensive data set of calibrated, georegistered, maximum NDVI composites for the March through December time period was developed for monitoring seasonal variations of forest, agricultural, and grassland vegetation condition. Moreover, it was anticipated that the data set would provide a foundation for efforts to study long-term changes in vegetation resulting from human interactions or global climate alterations.

DATA SET CHARACTERISTICS

A primary factor in the development of the NDVI composites is the determination of the compositing period. Consideration must be given to the dynamics of vegetation growth of the study area and to the probability of cloud-free observations. Other investigators have used weekly, ten-day, and biweekly composite periods. Given the vegetation and climatic characteristics of the conterminous United States, a biweekly composite period was believed adequate for representing phenological conditions.

The EDC data set is comprised of 19 biweekly (2 March 1990 through 20 December 1990) maximum NDVI composites derived from the 1-km NOAA-11 daily orbital passes. Each biweekly composite includes ten images: calibrated AVHRR channels 1 to 5, the NDVI, satellite zenith viewing angle, solar zenith angle, the relative solar/satellite azimuth angle, and a pointer to the acquisition date of each pixel. The data in a composite are extracted from the accumulated daily orbital passes for a biweekly period using the maximum NDVI compositing process (Holben, 1986). Each image contains 2889 lines and 4587 samples (13.2 megabytes); consequently, each composite has a data volume of 132.5 megabytes.

PROCEDURES

All processing was conducted using the Land Analysis System (LAS) software (Ailts *et al.*, 1990) and consisted of the following steps:

- Scene selection
- Computation of the solar illumination and satellite viewing geometry
- Radiometric calibration
- Geometric registration
- Computation of the normalized difference vegetation index
- Compositing
- Output products

SCENE SELECTION

During the daytime, there are two or three NOAA-11 orbital passes over the conterminous United States. All passes without major cloud cover were selected. Typically, 20 daily passes were included in each biweekly composite.

SOLAR ILLUMINATION AND SATELLITE VIEWING GEOMETRY

The NOAA polar orbiting satellites have a field of view greater than 55 degrees either side of nadir. Observations taken at such large view angles are affected by water vapor, aerosols, and other atmospheric constituents (Teillet, 1991). In addition, there is solar illumination variability along the orbital path (north/south direction). Solar illumination and satellite viewing geometry information is necessary for correction of illumination variability, and for studying and applying atmospheric correction techniques.

The satellite zenith, solar zenith, and relative solar/satellite azimuth angle, which is the absolute difference between the satellite and solar azimuth angles, are computed for each pixel, and a separate image of each angular relationship is generated. The Earth location information used for the viewing geometry computations is provided by NOAA (Kidwell, 1988).

The satellite zenith value at nadir (perpendicular to the surface) is 90 degrees. Values less than 90 represent view angles in the easterly direction and values greater than 90 represent westerly view angles. Note that, while the effective field of view of the satellite is approximately 55 degrees either side of nadir, computed satellite zenith angles can exceed 55 degrees because of the curvature of the Earth. The relative azimuth angle values are in the range 0 to 180 degrees. The solar zenith angle is always less than 90 degrees.

RADIOMETRIC CALIBRATION

Radiometric calibration of the AVHRR visible and near-infrared channels (channels 1 and 2) is an important consideration be-

PHOTOGRAMMETRIC ENGINEERING & REMOTE SENSING,
Vol. 58, No. 6, June 1992, pp. 809–813.

0099-1112/92/5806–809$03.00/0

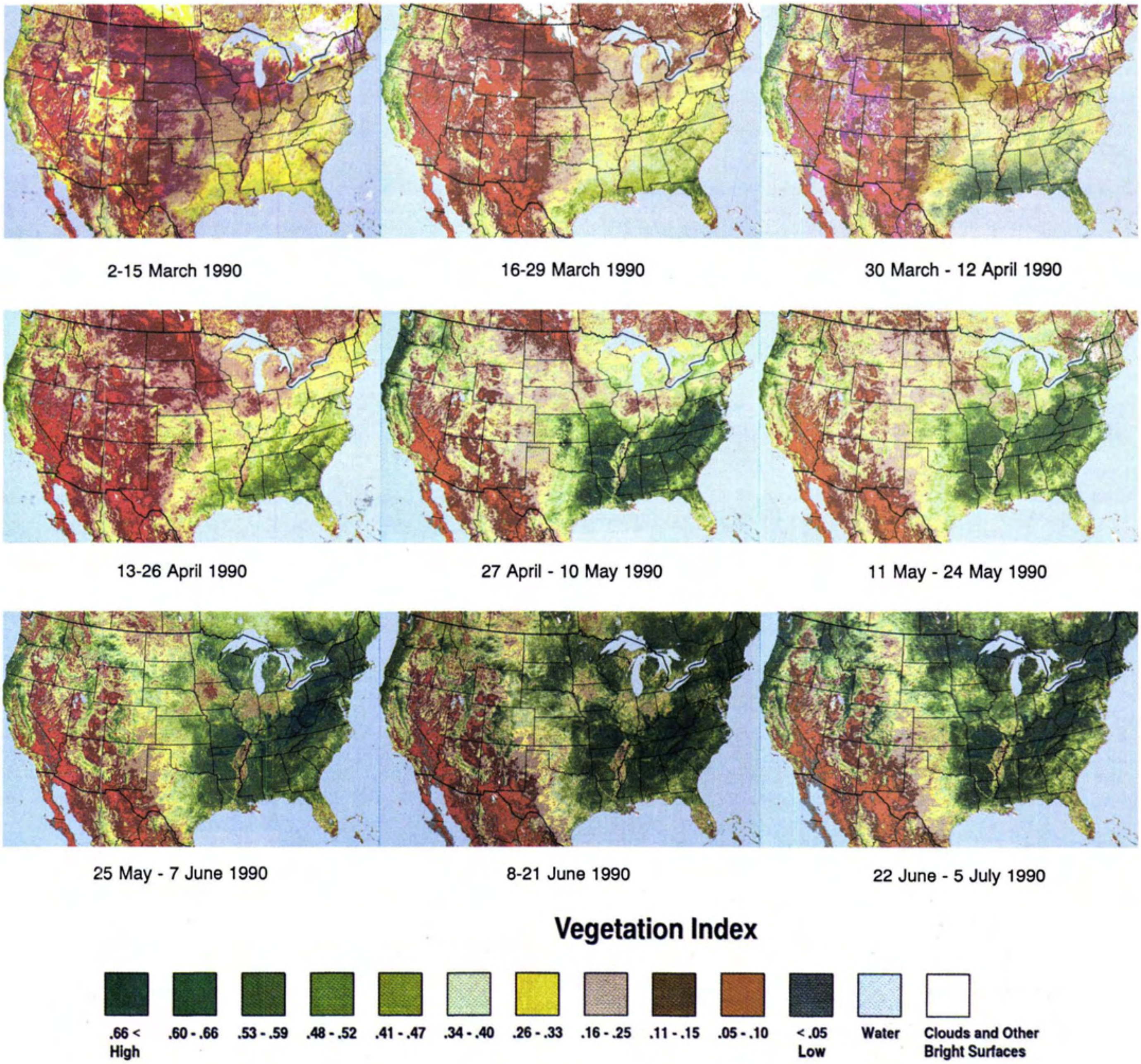

PLATE 1a. Color-coded biweekly NDVI images of the conterminous U.S. for the period 2 March - 5 July 1990.

cause there is poor preflight calibration, no onboard calibration, and difficulty with inflight calibration. Preflight calibration coefficients can change while the instrument is in storage or after launch due to the space environment. Degradation of AVHRR sensors after launch has been well documented (Rao, 1987; Price, 1987; Holben *et al.*, 1990). Several studies have used stable sites such as homogeneous desert targets to monitor the degradation of the sensors after the satellite has been launched. The EDC accounted for sensor degradation by using modified preflight gain coefficients developed from a study by Holben *et al.* (1990) that was based on measurements of desert targets. The adjusted gain coefficient for channel 1 is 0.09325 and 0.08475 for channel 2.

Besides radiometric calibration, the solar illumination variability which occurs in the north/south direction within an orbit was corrected using the cosine of the solar zenith angle. The radiometric calibration and solar illumination correction of channels 1 and 2 was completed using the following formula:

$$R = (d^*d/z) * (a + b^*c) = (d^*d^*a)/z + (d^*d^*b^*c)/z \qquad [1]$$

where

R is reflectance,
d is the mean earth-sun distance in astronomical units,
z is the cosine of the solar zenith angle,
a is the intercept,
b is the gain coefficient, and
c is the digital count.

Reflectance values for channels 1 and 2 were converted to

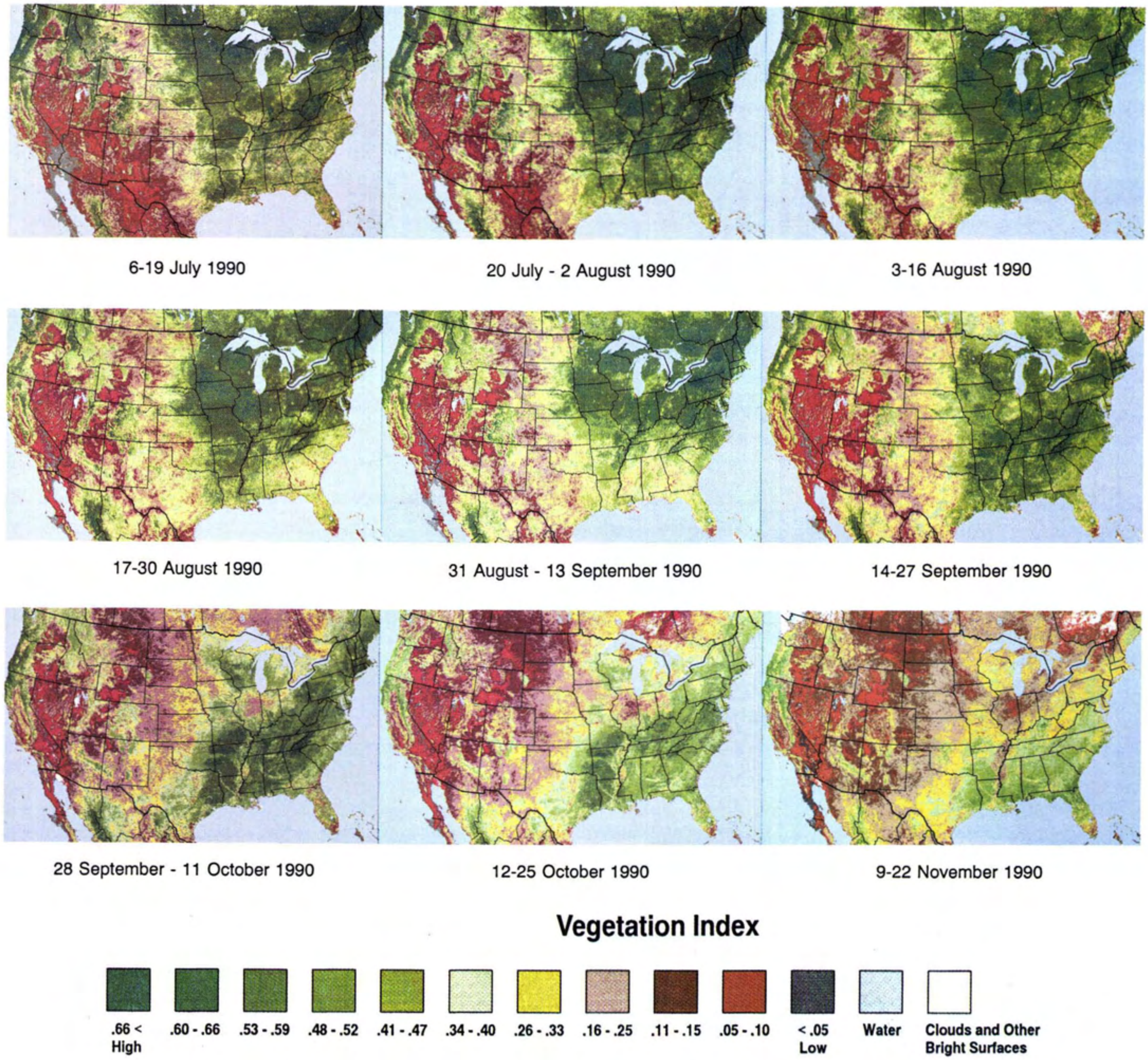

PLATE 1b. Color-coded biweekly NDVI images of the conterminous U.S. for the period 6 July - 22 November 1990.

byte data where the range 0 to 254 represents 0 to 63.5 percent reflectance (0.25 percent per bin) and the value 255 is a grouping of reflectance values greater than 63.5 percent. Any feature with greater than 63 percent reflectance is assumed to be a cloud, snow, or a bright non-vegetated surface.

The calibration coefficients for AVHRR thermal channels 3,4, and 5 are derived onboard the satellite using a view of a stable blackbody and deep space as a reference (Kidwell, 1988). The calibration process converts raw data values to energy (milliwatts/m2-steradians-cm-1) using the following formula:

$$E = a + bc \qquad [2]$$

where

E is energy,
a is the intercept,
b is the gain coefficient, and
c is the digital count.

Energy is converted to brightness temperature using the inverse of Planck's radiation function. The brightness temperatures are represented in Kelvin units. Two different scaling factors were used to convert the brightness temperatures to byte data. For data processed through 21 June 1990, 190 is subtracted from the brightness temperature value and the difference is multiplied by 2 to maintain one-half percent accuracy (i.e., a brightness temperature of 280 becomes 180). For data processed after 21 June 1990, 202.5 is subtracted from the brightness temperature value and the difference is multiplied by 2 to maintain one-half percent accuracy (i.e., a brightness temperature of 280 becomes 155). The first scaling factor groups high brightness temperatures at the value 255, whereas the latter scaling factor groups fewer values at 255 and provides more sensitivity at high brightness temperatures. The scaling was changed to make the data more sensitive at high-brightness temperatures to support an urban heat island study being conducted by NOAA.

GEOMETRIC REGISTRATION

The compositing process requires each daily overpass to be precisely registered to a common map projection to ensure that from day to day each 1-km pixel is referenced to the correct ground location. Past experiments with image registration have shown that image-to-image registration provided the precision needed for temporal data sets and the use of digital image correlation techniques produced consistent image-to-image registration results. An evaluation of AVHRR image-to-image registration using automated correlation techniques showed an improvement in throughput and geometric accuracy (root-mean-square error (RMSE) less than 1.0 pixel) compared to traditional image-to-map procedures (Kelly and Hood, 1991).

In an image-to-image registration process, the input images are registered to a reference image. A reference image of the conterminous U.S. was prepared by registering approximately 20 near-nadir cloud-free segments of NOAA-11 channel 2 (near infrared) daily observations to the USGS 1:2,000,000-scale Digital Line Graph (DLG) hydrography data set. The daily observations were from the 1989 growing season. The DLG data were rasterized to 1-km cells and transformed to the Lambert Azimuthal Equal Area (LAEA) map projection. This map projection was chosen because it is appropriate for the North American continent and because the equal area characteristic enables easy measurement of area throughout the data. Water bodies were used as control points between the DLG and AVHRR data. Each segment was verified for accuracy (RMSE less than 1.0 pixel). The segments were digitally mosaicked to produce a single reference image for use in registering the 1990 growing season data. The accuracy of the reference image was verified to have an RMSE less than 1.0 pixel.

For each daily observation during the 1990 growing season, a satellite platform model was used to create a systematic correction grid that transformed the data using a subset of control points common to both the reference and systematic image. The systematic correction was applied to the calibrated channel 2 (near infrared) data. The sensitivity of the platform model and resulting systematic correction will have an RMSE near 7 pixels. This registration accuracy is unacceptable for compositing. However, the systematic correction references the data to the reference image well enough to dramatically increase the correlation efficiency. Correlation was conducted using a set of approximately 250 control points which were selected from the reference image. Coefficients for a first-order polynomial adjustment were computed on the basis of the points successfully correlated and applied to the systematic correction grid to produce a precision correction grid. The precision correction grid was applied to the calibrated data (channels 1 to 5) and the viewing geometry bands using nearest neighbor resampling.

NORMALIZED DIFFERENCE VEGETATION INDEX (NDVI)

The NDVI is the difference of near-infrared (AVHRR channel 2) and visible (AVHRR channel 1) reflectance values normalized over the sum of channels 1 and 2 ($(2-1)/2+1$). In this data set, the NDVI is calculated from the calibrated, geometrically registered data which has been scaled to byte range. The NDVI equation produces computed values in the range of -1.0 to $+1.0$, where increasing positive values indicate increasing green vegetation and negative values indicate non-vegetated surface features such as water, barren land, ice, snow, or clouds. These computed NDVI values are converted to a byte data range of 0 to 200, where a computed NDVI value of -1.0 equals 0, a computed NDVI value of 0 equals 100, and a computed NDVI value of $+1.0$ equals 200.

COMPOSITING

The maximum NDVI compositing process determines which portion of each daily pass is included in the composite (Holben, 1986). The NDVI values are examined pixel by pixel for each of the approximately 20 daily passes comprising a biweekly period to determine which pixel has the maximum value. The highest NDVI value is assumed to represent the maximum vegetation "greenness," a measure of photosynthetic activity. Selection of the maximum NDVI also serves to reduce the number of cloud-contaminated pixels, and theoretically reduces the effects of atmospheric conditions associated with large off-nadir viewing angles.

Because NDVI values for water are much lower than NDVI values of clouds, a cloudy observation over water would usually be chosen instead of a clear observation. To retain clear observations over water, the NDVI byte values 0 to 99 (unscaled NDVI values -1.0 to -0.01) were inverted so that clear observations of water would have a higher NDVI value than a cloud and would be selected in the compositing process.

PRODUCTS

The output of the compositing process is a ten-band data set with one band containing the maximum NDVI value for each pixel selected from a daily overpass. Eight of the remaining nine bands are the coincident channels 1 to 5 and satellite viewing geometry data (three bands) for each pixel selected from the same daily pass as the maximum NDVI value. The tenth band contains values pointing to the scene identification numbers of the selected daily passes.

For each composite period, EDC prepares a set of standard products, including color maps and statistical summaries. Color maps (Plates 1a and 1b) depict the NDVI values in 13 classes, including a class for clouds, snow and other bright surface features, and a water class. Clouds, snow, and other bright surfaces are identified by using a threshold of the sum of channels 1 and 2. The water class is a mask developed from USGS 1:2,000,000-scale DLG hydrography and refined using a density slice of channel 2 data. The cloud screening and water mask are only applied to the maps and statistics generation. The digital composite data do not have a water or cloud mask applied. Maps are produced at both 1:5,000,000 scale and 1:15,000,000 scale. Standard statistics include a summary of the mean NDVI for each county in the United States. The statistics are distributed as a table which can easily be imported to spreadsheets.

SUMMARY

The 1990 AVHRR data set is a comprehensive collection of calibrated, georegistered, biweekly maximum NDVI composites for March through December. A consistent set of documented standards have been used to process the data. The data are designed to be flexible enough for use in both basic research and operational vegetation monitoring programs.

Each of the calibrated, georegistered daily observations and the biweekly composites are archived and distributed on 9-track magnetic tape media. In addition, the 1990 biweekly composite data set was reproduced on a set of five CD-ROMs. Each CD-ROM includes up to four biweekly composite data sets of the conterminous United States and selected supporting data sets. The supporting data sets are linework and polygon images of climatic division boundaries from NOAA, major land resource area (MLRA) boundaries from the USDA Soil Conservation Service, and county boundaries from the USGS 1:2,000,000-scale DLG data. All supporting images are in raster format and registered to the

1990 AVHRR data set. The CD-ROMs do not include any of the individual daily pass data.

The CD-ROMs and 9-track magnetic tapes are distributed at cost of reproduction by the USGS/EDC. Information on data set distribution is available from Customer Services, EDC, Sioux Falls, South Dakota, 57198; telephone: (605) 594-6507.

EDC plans the continuing development of biweekly NDVI data sets, thereby providing a foundation for studies of long-term changes resulting from human interactions or global climate alterations.

ACKNOWLEDGMENTS

The work described in this report was performed under U.S. Geological Survey contract 14-08-0001-22521. Any use of trade, product, industry, or firm names in this publication is for descriptive purposes only and does not imply endorsement by the U. S. Government.

REFERENCES

Ailts, B., D. Akkerman, B. Quirk, and D. Steinwand, 1990. LAS 5.0—An image processing system for research and production environments: *Proceedings, American Society for Photogrammetry and Remote Sensing/American Congress of Surveying and Mapping Annual Convention*, Denver, Colorado, 18-24 March, Vol. 4, pp. 1-12.

Eidenshink, J. C., R. H. Haas, D. M. Zokaites, and D. O. Ohlen, 1989. Integration of remote sensing and GIS technology to monitor fire danger in the northern Great Plains: *Proceedings, National Conference, Challenge for the 1990's, Geographic Information Systems*, Ottawa, Canada, 27 February to 3 March, pp. 944-956.

Eidenshink, J. C., R. E. Burgan, and R. H. Haas, 1990. Monitoring fire fuels condition using time series of Advanced Very High Resolution Radiometer data: *Proceedings, International Symposium on Advanced Technology in Natural Resource Management, Second*, Washington, D.C., 12-1 November, pp. 68-82.

Henricksen, B. L., and J. W. Durkin, 1986. Growing period and drought early warning in Africa using satellite data: *The International Journal of Remote Sensing*, November, Vol. 7, No. 11, p. 1583.

Holben, B. N., 1986. Characteristics of maximum-value composite images from temporal AVHRR data: *The International Journal of Remote Sensing*, November, Vol. 7, No. 11, p. 1417.

Holben, B. N., Y. S. Kaufman, and J. D. Kendall, 1990. NOAA-11 AVHRR Visible and Near-IR Inflight Calibration: *The International Journal of Remote Sensing*, Vol. 11, No. 8, pp. 1511-1519.

Justice, C. O., and P. H. Y. Hiernaux, 1986. Monitoring the grasslands of the Sahel using NOAA AVHRR data: Niger 1983: *The International Journal of Remote Sensing*, November, Vol. 7, No. 11, p. 1475.

Kelly, G. G., and J. J. Hood, 1991. AVHRR Conterminous United States Reference Data Set: *Technical Papers, 1991 ACSM-ASPRS Annual Convention*, Vol. 3, pp. 232-239.

Kidwell, K. B., 1986. *NOAA Polar Orbiter Data Users' Guide*, National Oceanic and Atmospheric Administration, World Weather Building, Room 100, Washington, D.C.

Price, John C., 1987. Calibration of satellite radiometers and the comparison of vegetation indices: *Remote Sensing of the Environment*, Vol. 21, No. 15, pp. 15-27.

Rao, Nagaraja C. R., 1987. *Pre-Launch Calibration of Channels 1 and 2 of Advanced Very High Resolution Radiometer*, NOAA Technical Report NESDIS 36, Satellite Research Laboratory, National Environmental Satellite, Data, and Information Service, Washington, D.C., 62 p.

Teillet, P. M., 1991. Radiometric and atmospheric correction procedures for AVHRR preprocessing in the solar reflective channels: *5th International Colloquium on Physical Measurements and Signatures in Remote Sensing*, Courchevel, France, pp. 101-104.

(Received 13 February 1991; revised and accepted 22 October 1991)

Forthcoming Articles

Paul V. Bolstad and *T. M. Lillesand*, Rule-Based Classification Models: Flexible Integration of Satellite Imagery and Thematic Spatial Data.
Pat S. Chavez, Jr., Comparison of Spatial Variability in Visible and Near-Infrared Spectral Images.
Liang-Chien Chen and *Liang-Hwei Lee*, Progressive Generation of Control Frameworks for Image Registration.
Russell G. Congalton and *Greg S. Biging*, A Pilot Study Evaluating Ground Reference Data Collection Efforts for Use in Forest Inventory.
G. M. Foody, N. A. Campbell, N. M. Trodd, and *T. F. Wood*, Derivation and Applications of Probabilistic Measures of Class Membership from the Maximum-Likelihood Classification.
Dennis L. Helder, Bruce K. Quirk, and *Joy J. Hood*, A Technique for the Reduction of Banding in Landsat Thematic Mapper Images.
David M. Kummer, Remote Sensing and Tropical Deforestation: A Cautionary Note from the Philippines.
Rongxing Li, Building Octree Representations of Three-Dimensional Objects in CAD/CAM by Digital Image Matching Technique.
Jay Lee, Peter F. Fisher, and *Peter K. Snyder*, Modeling the Effect of Data Errors in Digital Elevation Models on Feature Extraction.
John Grimson Lyon, Ross S. Lunetta, and *Donald C. Williams*, Airborne Multispectral Scanner Data for Evaluating Bottom Sediment Types and Water Depths of the St. Mary's River, Michigan.
John Grimson Lyon and *Richard G. Greene*, Use of Aerial Photographs to Measure Historical Areal Extent of Lake Erie Coastal Wetlands.
Scott O. Mason and *Kam W. Wong*, Image Alignment by Line Triples.
Jeng-Jong Pan and *Chein-I Chang*, Destriping of Landsat MSS Images by Filtering Techniques.
Benoit Rivard and *Raymond E. Arvidson*, Utility of Imaging Spectrometry for Lithologic Mapping in Greenland.
A. K. Skidmore and *R. J. Turner*, Map Accuracy Assessment Using Line Intersect Sampling.
James L. Smith, Jesse A. Logan, and *Timothy G. Gregoire*, Using Aerial Photography and Geographic Information Systems to Develop Databases for Pesticide Evaluations.
Stephen V. Stehman, Comparison of Systematic and Random Sampling for Estimating the Accuracy of Maps Generated from Remotely Sensed Data.
Torbjörn Westin, Inflight Calibration of SPOT CCD Detector Geometry.
Ulrich Wieczorek, Scale Reduction and Maximum Information Loss of Different Information Categories.