# AVHRR Map Products for Crop Condition Assessment: A Geographic Information Systems Approach

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## Abstract

*U.S. Department of Agriculture (USDA) policymakers and crop analysts use satellite imagery integrated in a geographic information system (GIS) to help assess crop conditions for flood and drought. The unique capabilities of GIS help the National Agricultural Statistics Service (NASS) in creating map products for this work. NASS is working cooperatively with the Agricultural Research Service's Remote Sensing Research Laboratory (RSRL) in investigating vegetative indices calculated from the Advanced Very High Resolution Radiometer (AVHRR) sensor on the National Oceanic and Atmospheric Administration (NOAA) satellite NOAA-11. EROS Data Center (EDC), U.S. Geological Survey, calculates a biweekly Normalized Difference Vegetative Index (NDVI) from AVHRR data. In 1993, the current year's stressed vegetation was compared with the 1992 crop year using AVHRR data. NASS uses GIS capability to combine diverse layers of information to overlay EDC's data with State and county boundaries, frost isoline data, and monthly precipitation data.*


## Introduction

The primary mission of the National Agricultural Statistics Service (NASS) is to monitor crop conditions in the United States and make appropriate monthly forecasts of crop acreage, yield, and production from survey information. NASS's Remote Sensing Section (RSS) studies and develops new capabilities of satellite data to provide supplementary information to help policymakers in following crop conditions.

RSS works directly with the Remote Sensing Research Laboratory (RSRL) of the U.S. Department of Agriculture's (USDA) Agricultural Research Service (ARS) to investigate the use of various parameters derived from satellite and ground based climate data to assess crop condition and yield. This research uses biweekly Advanced Very High Resolution Radiometer (AVHRR) composite data that the EROS Data Center obtains from NOAA's satellite NOAA-11. We maintain contacts with international groups and other government agencies that conduct related or parallel research in remote sensing and geographic information systems (GIS) for agriculture.

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With RSRL's help, the Remote Sensing Staff installed and used the Land Analysis System (LAS) software for AVHRR image processing and analysis (Ailts *et al.*, 1990). Although the National Aeronautics and Space Administration (NASA) developed LAS, the U.S. Geological Survey now supports it. We use LAS primarily to create AVHRR difference images that compare the current year's values to those of the corresponding period in the previous year. Several crop assessment products were developed during the 1993 crop year. Doraiswamy *et al.* (1994) describes products in more detail developed from this cooperative work.

The ARC/INFO software package (a product of ESRI, Inc., Redlands, California) extends LAS's capabilities to produce other data products. Most of our GIS map products are color maps at 1:15,000,000 scale of the conterminous United States. We provide larger scale maps of regional areas where greater detail is of value.

USDA policymakers used the AVHRR difference image map products to evaluate the 1993 crop conditions in the Midwest flood and Southeast drought areas as compared to the same areas during the 1992 crop season. Availability of frequent and timely biweekly difference images in map form provided useful information to the policymakers who evaluated crop conditions for areas affected by flood and drought.

Statistics Canada uses similar map products to monitor crop and pasture conditions in Canada, but has data available for a ten-year period (Korporal and Hillary, 1993). They compare both the current year AVHRR data to the previous year and to the ten-year average of available data. Another aspect of their research is an evaluation of using AVHRR data in yield models for crop yield estimation.

Crop yield can be another useful layer of information in a GIS. When combined with reports from individual counties and weather data, improved county crop yield estimates should be possible. Presently, spring wheat models are under evaluation with RSRL to use AVHRR images independently and with climate-based models.

## Satellite Overview

The NOAA-11 polar orbiting weather satellite acquires AVHRR images daily over the conterminous United States. There are usually two satellite images available from the two passes each day. However, a single AVHRR overpass is rarely cloud

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free so that one day's coverage is unlikely to provide a cloud-free image of the entire conterminous U.S.

Holben (1986) showed that compositing AVHRR imagery from several days' acquisitions produced spatially continuous cloud-free images over large areas with adequate temporal resolution to monitor vegetation condition. The compositing period is the duration of consecutive daily observations. Images that provide a cloud-free observation of a large ground surface area are included in the composite. On average, there are 18 daily observations per biweekly period in the composite (Eidenshink, 1992).

## Vegetation Index Characteristics

AVHRR data are usually analyzed by employing one or more vegetative indices. The Normalized Difference Vegetative Index (NDVI) is a frequently used index. This index is the difference of the visible light band (Band 1) from the near-infrared band (Band 2) divided by their sum (Tucker *et al.*, 1986). NDVI values have a relationship to the phenological growth stages of crops (Perry and Lautenschlager, 1984).

EDC calculates NDVI values and other variables from the AVHRR sensor data of the NOAA-11 satellite when creating both weekly and biweekly composite images. Composite images are created by selecting the maximum NDVI value for each pixel in images from the given period.

We have used only the biweekly AVHRR composite data for 1989 through 1993. Because the Lambert Azimuthal Equal Area projection displays the North American continent with minimal distortion, our image products continue use of this projection created by EDC.

## Research Activities

The following discussion presents our AVHRR satellite imagery research and shows our use of satellite data and GIS for crop condition assessment. Evaluations of these map products will continue in 1994.

### Difference Image

We produce a difference image by subtracting an earlier year's NDVI values for a specified period from those of the current year. The difference image measures the comparative crop vegetation vigor between the periods. However, because these periods do not necessarily have the same crop growth stages across the U.S., a careful examination of supplementary crop and weather information is necessary when evaluating the difference images. Early or late planting information along with weather conditions can aid in determining the meaning of changes in the NDVI values.

Twelve biweekly periods beginning with 14 May and ending on 28 October 1993 were compared with the corresponding 12 biweekly periods from 15 May to 29 October 1992. Timely difference image maps in various forms were RSS's primary AVHRR data products during 1993. These images helped policymakers to locate and evaluate the areal extent of excessive water and flooding on crops in Iowa, Minnesota, and other Midwest States. They were also helpful to the Agricultural Statistics Board and other USDA policymakers for examining drought conditions in the southeast states.

Categories for the difference images consist of five intervals (Table 1). Table 1 lists the color coded ranges of AVHRR NDVI differences with an interpretation of their relative significance. The categories for the NDVI difference images were selected from an examination of 1992 minus 1991 crop season difference ranges for the midwest and so are suggested guidelines. Additionally, RSS overlaid State and county boundaries, and displayed lines to represent average first frost dates.

### The Land Characteristics Database

USGS's EDC and the Center for Advanced Land Management Information Technologies of the University of Nebraska at Lincoln jointly developed land-cover information using satellite data. Their work showed how multi-temporal AVHRR data, supplemented by ancillary data and analyzed in a structured manner, can effectively characterize land-cover (Loveland *et al.*, 1993). They developed a Land Characteristics Database by analyzing multiple layers, including eight U.S. AVHRR biweekly composite images for 1990. Ancillary data layers were the following: elevation, climate, ecoregions, major land resource areas, along with land-use and land-cover data (Loveland *et al.*, 1991).

EDC provided a Beta version of the Land Characteristics Database compiled at a one-kilometre resolution for the conterminous United States. This Land Characteristics Database contains 167 categories obtained from an analysis of the AVHRR data with the associated ancillary data. From a description of the categories, we selected a preliminary subset of 61 categories to represent cropland. The remaining areas that contain little cropland or agricultural activity have a neutral color in the final map product. Areas containing water or areas in Canada or Mexico are colored blue.

Overlay of the Land Characteristics Database takes place after the creation of the difference image. Although some areas labeled as noncropland do contain cropland areas, Loveland has stated that "Adequate methods to verify [the accuracy of] 1-km resolution land-cover classifications conducted over continental-sized areas do not exist" (Loveland *et al.*, 1991, p. 1462).

The Land Characteristics Database appears to represent the cropland and noncropland dichotomy quite well at the continental U.S. level. However, because some areas with major crops are not correctly labeled as cropland, our research plans are to evaluate AVHRR data with other supplementary information (such as county crop acreage, area sampling frame (see below), and other available satellite data) to meet the specific needs of RSS for selected crops and States.

## Computer Resources

### Image Processing System

The Land Analysis System (LAS) was installed on a VAXstation 3100 Model 38. The VAXstation has graphics windows capabilities and three gigabytes of hard disk storage for program files and data storage.

Analysts use LAS to extract AVHRR data from 8-millimetre digital tapes obtained from the EROS Data Center, subtract the corresponding two years' images, and overlay the EROS Land Characteristics Database. These biweekly maximum NDVI composites have been georegistered by the EROS Data Center, and projection parameters are provided. The process of compositing daily observations for each biweekly period required registration of each daily overpass to a common map projection (Lambert Azimuthal Equal Area) to ensure that each 1.0-kilometre pixel represented the same ground location. A base map was developed as a reference to handle the image to image registration of the data (Eidenshink, 1992). NASS uses the image's header record to provide georeferencing of the individual AVHRR pixel values for subtracting images. AVHRR images in LAS format have a header of 512 bytes and consist of 2889 lines or rows by 4608 samples or columns (13 megabytes) with a Band Sequential (BSQ) format.

#### Geographic Information System Applications

ARC/INFO is being used under UNIX on a Sun SPARCstation network. Map composition capabilities allow the creation of biweekly difference image maps that compare an index of the current year's vegetation with the previous year for a corresponding period. These difference images aid in our crop condition assessment reporting program.

The File Transfer Protocol (FTP) is used to send the one-band binary difference image in BSQ format from the VAXstation to the Sun SPARCstation. After transferring the image, the analyst defines the image file as a band-interleaved-by-line (BIL) image format. Because ARC/INFO supports the BIL format, creation of an ASCII header file is the next step. This header file describes the image data (number of rows and columns, number of bands, appropriate georeferencing information, and so forth).

The analyst converts the difference image to a raster-based grid format with a cell size of 1.0 kilometre. Creating a grid file consists of accessing only the ASCII generated header file by skipping the header information of the BIL difference image file.

An ASCII legend/key file is created that contains the desired colors for the difference image (Table 1), with the associated text describing the color representation. The analyst uses a look-up table to shade the legend and annotate the map. An ASCII remap look-up table defines the NDVI difference ranges (as mentioned previously) to color the difference image based on pixel values.

The pixel values used in coding the degree of difference between years were determined by creating difference images for 1992 minus 1991 using periods during the growing season. The pixel values were divided equally into five intervals using histograms for the combined periods.

The EROS Data Center uses digital values of zero to 201 to represent the NDVI values of minus one to plus one. After creating the difference image, we add 100 to create an image with positive values. The pixel values used for color assignment are the following: ranges 1-37 as Blue - Water, Mexico and Canada; 38-63 as Magenta - Much Lower; 64-89 as Maroon - Lower; 90-115 as Gray - Same; 116-140 as Yellow - Higher; and 141-167 as Green - Much Higher. These ranges are the same for a given year.

The analyst creates a map composition of the difference image at a 1:15,000,000 scale in a Lambert Azimuthal Equal Area projection. A remap table makes possible shading each pixel according to its NDVI value. Both legend and textual information are then added with the State and county boundaries onto the image. After generating the final map composition as a postscript file, the analyst prints the file using a CALCOMP 6613 postscript color printer with ten megabytes of internal memory.

Examples of the difference image products are shown in Plates 1 and 2. Plate 1 shows the image data for Period 20 (25 June - 8 July 1993 minus 26 June - 9 July 1992). This first image compares the time of maximum flooding in Iowa and Missouri along with the drought conditions in Georgia, South Carolina, and Florida during 1993 with the more normal 1992 growing year. Plate 2 portrays Period 24 (23 July - 5 August 1993 minus 24 July - 6 August 1992). This period shows a time in 1993 with reduced flooding in Iowa and

TABLE 1. THE COLOR CODED RANGES OF AVHRR NDVI DIFFERENCES WITH AN INTERPRETATION OF THEIR RELATIVE SIGNIFICANCE

| Color | Label | Current Vegetation Vigor |
|---|---|---|
| Green | Much Higher | Much higher than the previous year |
| Yellow | Higher | Higher than the previous year |
| Gray | Same | Similar to that of the previous year |
| Maroon | Lower | Lower than the previous year |
| Magenta | Much Lower | Much lower than the previous year |
| Tan | Noncrop | Masked out (noncrop areas) |
| Blue | Water | Masked out (Water, Mexico, Canada) |

Missouri and improved conditions in South Carolina and Florida when compared with 1992. Substantial weather, crop information, and ground observations are necessary to interpret the difference image according to conditions for the two years. Research is continuing to improve the capabilities of the difference images to provide the areal and temporal extent of drought, flooding, and improved crop conditions for the conterminous U.S..

One possible enhancement is creating a median image for the earlier years of data to compare with the current year. Comparisons of this sort would be of particular value in 1994 because the 1993 data has such extreme conditions of flooding for Iowa and Missouri. Our research plans are to develop the capability of making comparisons with multiple years of data.

## Other Research Areas

Other research areas under evaluation are the following:

- applying frost isolines to difference images,
- overlaying of meteorological data on AVHRR NDVI images,
- removing the crop mask from the difference image,
- working with satellite images as raster-based grids, and
- developing an overlay of area sampling frame data.

#### Frost Isoline Overlay

Application of frost isoline digital files created from NOAA Weather Service boundaries is another overlay or GIS layer to the NDVI images. After converting the boundaries, we overlay the frost isoline onto the difference image. Analysts can use these isolines to locate average dates of the first frost for possible crop damage.

#### Meteorological Data Overlay

Another product under evaluation is that of converting monthly precipitation weather data to create a contoured isohyet map overlay onto a biweekly AVHRR NDVI composite image. The methodology for making this product is explained in the following paragraphs.

NOAA collects monthly precipitation data from 450 reporting Climate Analysis Center meteorological weather stations and stores the data in ASCII files. Image data are imported and compiled into a point coverage. The analyst projects the coverage into the Lambert Azimuthal Equal Area projection.

Production of a triangulated irregular network (TIN) structure from the point coverage is possible using ARC/INFO. The analyst generates a surface model that represents the geographic extent of the weather station data. A TIN delineates a surface of irregularly spaced sample points with $(x,y,z)$ coordinates to correspond with each weather station's (latitude, longitude, precipitation) coordinates. Connection of these

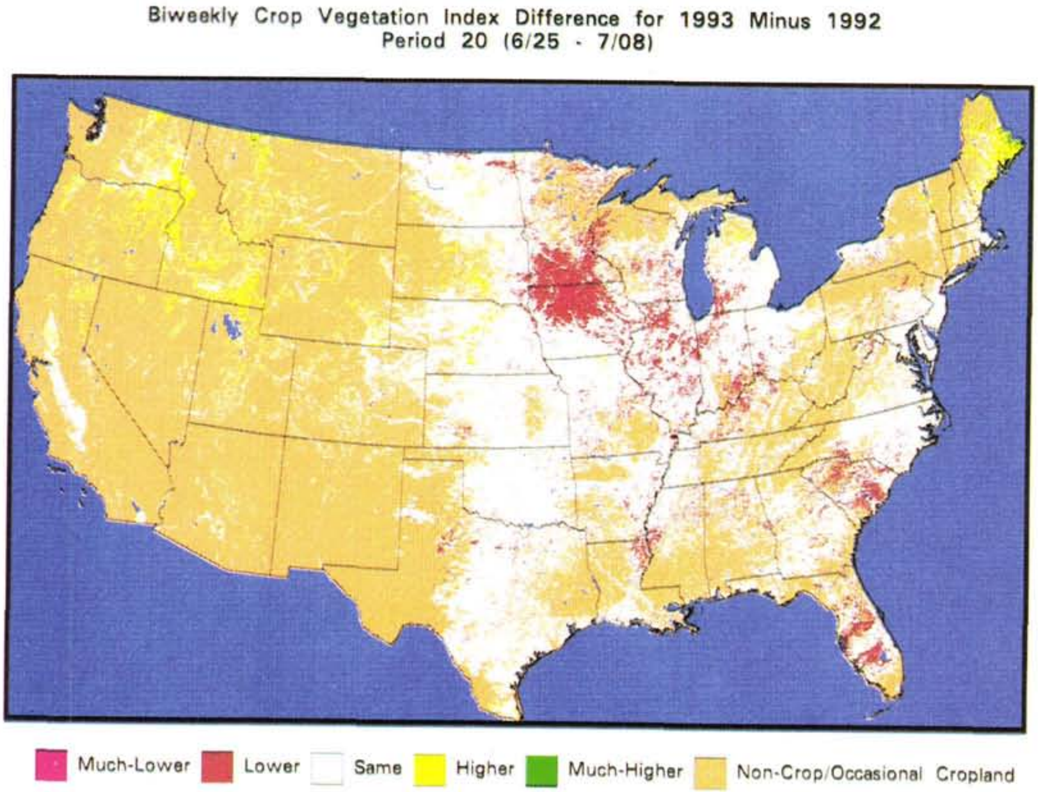


Plate 1. Period 20, 25 June - 8 July 1993 minus 26 June - 9 July 1992 compares the time of maximum flooding in Iowa and Missouri along with the drought conditions in Georgia, South Carolina, and Florida during 1993 with the more normal 1992 growing year.

points with edges creates a set of non-overlapping triangles that model the surface.

The third process entails creating a contour coverage to convert the TIN structure into a line coverage at specified contour intervals (e.g., one inch, two inches, and so forth). Adjusting the degree of spatial smoothing allows creation of smooth flowing contour lines from primitive jagged contours. Editing and cleaning the contours, overlaying the NDVI imagery with that of the completed contour coverage, and labeling associated text are the next steps.

Displaying the maximum NDVI values of the current composite biweekly period on a map composition is the final step. Pixel values range from minus one to one, with values less than zero indicating snow, cloud cover, water, or other non-vegetative surfaces (Eidenshink, 1992). Values greater than zero represent increasing levels of photosynthesis.

Commodity specialists can highlight localized areas under stress by precipitation extremes. They can examine areas of soybeans, corn, and cotton production for potential drought or excess water induced stress when producing crop yield estimates. Research is continuing to improve the accuracy and usefulness of this product.

#### The Difference Image with No Crop Mask

A difference image with no crop mask is under consideration, because the mask has inaccuracies that reduce the effectiveness of the masked image in States with less cropland. However, the mask will still remove major water bodies and both Mexico and Canada. A difference image with no crop mask will allow an examination of all changes throughout the U.S. without regard to agricultural conditions. This product should be most useful for pasture and range feed condition analysis.

#### Satellite Images as Raster-Based Grids

The use of raster-based (grid-cell) capabilities of ARC/INFO (GRID) with satellite data is underway. One example of this capability is the development of an algorithm to produce the AVHRR difference images. This procedure converts both years' biweekly images for the difference image into raster-based grids for each period. As a module of ARC/INFO, GRID provides an efficient method for processing image data using the capabilities that are common between both software modules.

Subtraction of the two grids creates a difference image. Then, the analyst decides whether or not to apply the crop mask and compiles the map composition of the difference image for printing.

#### Area Sampling Frame Overlay

NASS uses area sampling frames to conduct surveys to collect agricultural data (Cotter and Nealon, 1987). An area sampling frame must contain a way of listing all parcels of land within an area of interest. These land parcels, which are

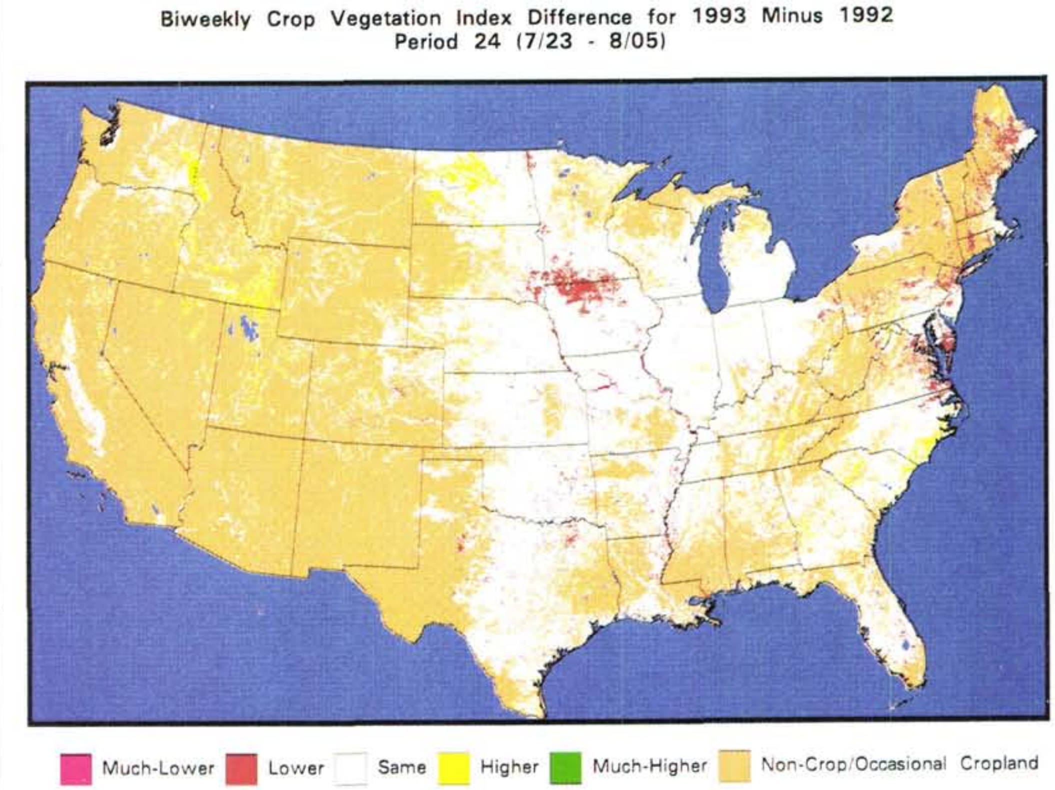


Plate 2. Period 24, 23 July - 5 August 1993 minus 24 July - 6 August 1992 shows a time in 1993 with reduced flooding in Iowa and Missouri and improved conditions in South Carolina and Florida when compared with 1992.

sampled areas, are defined according to ownership and easily identifiable boundaries. Because the distribution of the crops can vary widely across a State, NASS divides the land into homogeneous groupings called strata. These strata allow enhancing the precision of the survey estimates by using optimal allocation of the total sample within the strata.

In a cooperative agreement, NASS and the National Aeronautics and Space Administration (NASA) have developed a Computer Assisted Stratification and Sampling (CASS) system to create area frames using digital data as inputs (Cotter and Mazur, 1992). Landsat thematic mapper (TM) data are the primary source for delineating strata according to land use. USGS Digital Line Graph (DLG) data aid in determining appropriate boundaries for the strata. The current focus of the stratification is on developing county-by-county stratifications within a chosen State.

Creating a statewide coverage requires converting the CASS stratification of each county from a DLG file to an ARC/INFO coverage. Edgematching adjacent counties together comes next. Joining all the counties creates a statewide coverage that is ready to project onto the satellite data. When overlaying the biweekly AVHRR data, the analyst projects the strata as a Lambert Azimuthal Equal Area Projection on a 1.0-kilometre grid.

North Dakota and South Dakota are the two States that are undergoing accuracy verification. We plan to use the information from this area frame as another source of information to help in improving EDC's Land Characteristics Database for specific crops and regions.

## Conclusion

We will continue to investigate other uses of AVHRR satellite data with LAS and GIS technologies. Many new possibilities of exploiting GIS in remote sensing activities await NASS's continuing research. Remotely sensed and other spatially oriented information contribute in making crop yield forecasts, acreage estimates, and graphical data presentations. Combining satellite data in a GIS can enhance the AVHRR NDVI composite imagery by overlaying State and county boundaries, frost isoline data, and monthly precipitation data. Different yield and forecast models are under evaluation as to their effectiveness and utility.

Difference imaging has provided USDA policymakers and crop analysts useful tools to aid decision making in the evaluation of the catastrophic events that occurred in 1993. This series of images displayed a comprehensive profile of the growing season for assessing the seasonal variations in vegetation condition.

EDC's Land Characteristics Database demonstrates imagery classification on a continental scale. However, large scale analysis at the regional or State level may require more detailed breakdowns of the categories to provide information on the location of crops of interest. The cooperating groups plan to improve the Land Characteristics Database for a selected set of States and crops.

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