THE CONTERMINOUS UNITED STATES AND ALASKA WEEKLY AND BIWEEKLY AVHRR COMPOSITES

07/08/2011

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INTRODUCTION

In 1987, the U.S. Geological Survey's Earth Resources Observation and Science (EROS) Center in Sioux Falls, South Dakota, began receiving Advanced Very High Resolution Radiometer (AVHRR) data from NOAA polar-orbiting satellites. The central United States location of EROS enables direct reception of all AVHRR overpasses of the lower 48 States, as well as much of Canada and Mexico. In 1989, EROS started acquiring afternoon AVHRR 1-km resolution daily observations to produce weekly and biweekly maximum normalized difference vegetation index (NDVI) composites of the conterminous United States and Alaska (Eidenshink 1992; Eidenshink 2006) as part of a vegetation monitoring program. The objective of the program is to compile a comprehensive time series of calibrated, georegistered, maximum NDVI composites. These data sets can be used in environmental monitoring, global climate change studies, and have been used in multiple ongoing operational applications.

The vegetation diversity of the United States provides opportunities for using both AVHRR data and the NDVI for monitoring vegetation condition in many ecosystems, including forests, agricultural crops, and grasslands. The NDVI data set provides a comprehensive growing season profile of these ecosystems, is extremely useful for assessing seasonal variations in vegetation conditions, and provides a foundation for studying long-term changes resulting from human or natural factors.

DATA SET CHARACTERISTICS

The conterminous United States data set is composed of twenty-six 14-day and fifty-two 7-day NDVI composites annually since 1989. The Alaska data set generally includes fourteen 14-day and twenty-eight weekly composites for the period April through October each year since 1990. Each composite includes 14 bands of information (described in Table 1).

Table 1. Band description of composite images

Band	Description
1	Top of atmosphere Channel 1 reflectance (Calibrated, no atmospheric correction)
2	Top of atmosphere Channel 2 reflectance (Calibrated, no atmospheric correction)
3	Radiance
4	Temperature
5	Temperature
6	NDVI
7	Satellite zenith
8	Solar zenith
9	Relative azimuth
10	Atmospherically corrected Channel 1 surface reflectance
11	Atmospherically corrected Channel 2 surface reflectance
12	QA/QC
13	Date index
14	Cloud mask

The image dimensions of the conterminous United States data set are 2,889 lines (rows) and 4,587 samples (columns) per band. The Alaska data set is 1,992 lines (rows) by 2,512 samples (columns) per band.

DATA PROCESSING

The following information describes the data processing flow that was used to create the composite data sets. All image processing was conducted using Land Analysis System (Ailts and others, 1990) software.

Scene Selection

Cloud-free AVHRR observations of the land surface are necessary for monitoring the vegetation conditions. A single AVHRR overpass is seldom completely cloud free. Holben (1986) showed that compositing AVHRR data acquired over several days produces spatially continuous cloud-free images over large areas with sufficient temporal resolution to study green vegetation dynamics. The duration of consecutive daily observations is called the compositing period. On a daily basis during a composite period, each observation over the conterminous United States was evaluated for cloud cover. Typically, two satellite overpasses per day occur over the conterminous United States, one over the eastern portion of North America and a second pass over the western part of the continent. There are several overpasses of Alaska each day due to its location in the northern latitudes. Every image that provided a clear observation of a large ground surface area at reasonable nadir viewing angles is included in the composite. On an average, 30 daily observations per biweekly period are included in the composite.

Satellite and Solar Viewing Geometry

The computation of the solar and satellite geometry is a process that derives the satellite zenith, solar zenith, and relative azimuth angle for each image pixel. The satellite viewing geometry information retained in the composite allows studies on the effects of off-nadir viewing and the investigation of potential data correction techniques. The viewing geometry is used during the calibration and atmospheric correction processing. A separate image band (Table 1) is created for each of these three angle computations.

The satellite zenith angle is computed in degrees, in which nadir is represented as 90 degrees. Therefore, values less than 90 degrees represent view angles in the back scattered direction and values greater than 90 represent the forward scatter direction. Note that the effective field of view of the satellite is approximately 55 degrees each side of nadir, but computed satellite zenith angles can exceed 55 degrees because of the curvature of the Earth.

The solar zenith angle is computed in degrees. The nadir (sun directly overhead) angle is designated as 0 degrees. Pixels with solar zenith angles greater than 80 degrees are excluded from inclusion in the composite data sets.

The relative azimuth angle is computed as the absolute difference between the solar azimuth and the satellite azimuth angles. The computed values are in the 0 - 180 range. The relative azimuth angle is computed instead of separate azimuth angles because only the absolute difference between the azimuth angles is required for atmospheric correction algorithms. Also, saving only the computed relative azimuth angle requires only one band in a daily observation and composite image instead of two, which reduces the image storage requirements.

Radiometric Calibration

Radiometric calibration is fundamental to understanding the quantitative measurements of a sensor. To date, data from NOAA-11, 14, 16, 17, and 18 AVHRR sensors have been used to produce the conterminous United States data set. The source of the calibration coefficients for each sensor varies (Table 2), but the basic method used to develop and apply the coefficients is very similar. The calibration coefficients and methodology for the thermal channels 3a, 3b, 4, and 5 are well documented by NOAA (Kidwell 1998, 2000). It is widely recognized that the calibration of channels 1 and 2, the visible and near-infrared bands, must include an accounting for sensor degradation (Rao et al. 1993; Kaufman and Holben 1993; Brest and Rossow 1992).

Table 2. A summary of the calibration sources and the valid timeframes used to produce the conterminous United States data set.

Satellite	Start Date	End Date	Source
NOAA 11	09/26/1988	03/26/1989	prelaunch
NOAA 11	03/27/1989	01/01/2020	Teillet and Holben (1994)
NOAA 14	12/30/1994	06/30/1995	prelaunch
NOAA-14	06/31/1995	01/01/2020	Vermote and Kaufman (1995)
NOAA 16	09/01/2000	06/24/2003	prelaunch
NOAA-16	06/25/2003	01/01/2020	NOAA
NOAA-17	06/24/2002	12/31/2002	prelaunch
NOAA-17	01/01/2003	01/01/2020	NOAA
NOAA-18	05/20/2005	09/12/2005	prelaunch
NOAA-18	09/13/2005	01/01/2020	NOAA
NOAA-19	02/06/2009	09/12/2009	prelaunch
NOAA-19	09/13/2009	01/01/2020	NOAA

Teillet and Holben (1994) provide a comprehensive evaluation of the calibration coefficients for NOAA-11 AVHRR channels 1 and 2, and their report provides the basis for the derivation of time variant calibration coefficients for NOAA 7, 9, and 11. They derived the coefficients from the results obtained from the desert validation approach of Kaufman and Holben (1993). Teillet and Holben (1994) developed the time-dependent coefficients based on two methods: a polynomial fit and a piecewise linear (PWL) fit of the observations over desert areas. They recommended a PWL fit to describe the trend of the gain or offset (y) with time (x). This function consists of a series of straight-line segments, joined to each other at points where values can be reliably estimated or at times designed to coincide with the start of the northern hemisphere growing season. The PWL is suitable for operational use because, unlike polynomial fits, the PWL will not change retroactively when new data are added to the end of the time series. This approach assumes that the degradation trend is linear between measurements of sensor performance of AVHRR channels 1 and 2. The equations for time-dependent radiometric calibration to radiance and reflectance for the visible and near-infrared channels of NOAA 7, 9, and 11 are described by Teillet and Holben (1994).

NOAA-14 was launched into an afternoon ascending orbit in December 1995. Shortly after launch, Vermote and Kaufman (1995) described the postlaunch calibration of AVHRR channels 1 and 2. Their coefficients were derived from ocean and cloud observations. Their work provided the first postlaunch calibration coefficients for NOAA-14, which was used by the USGS in the operational processing of AVHRR NOAA-14 data.

NOAA-16 became the primary afternoon operational system in January 2001. Initially prelaunch coefficients were used for calibration. In June 2003, NOAA began providing monthly updates of the calibration coefficients. The updates were based on analysis of NOAA-16 data using the desert calibration approach. The operational calibration algorithm that was implemented in 2003 was enhanced by reducing target contamination and accounting for the effects of bidirectional reflectance distribution function (Wu et al. 2010). The postlaunch calibration coefficients for NOAA-16 can be found online at http://www.osdpd.noaa.gov/ml/ppp/notices.html. In September 2003, NOAA-16 scan motor anomalies appeared that eventually rendered the data useless for greenness mapping.

In January 2004, USGS began to use NOAA-17 AVHRR data for greenness mapping. NOAA-17 was launched and established a morning orbit in June 2002 and prelaunch calibration coefficients were used for the first six months of operation. NOAA provided monthly updated post launch calibration coefficients thereafter (http://www.osdpd.noaa.gov/ml/ppp/notices.html). Scan motor instabilities began in January 2010 which initially resulted in data dropouts followed by increased degradation ultimately rendering the NOAA-17 AVHRR data completely unusable.

NOAA-18 was launched and established an afternoon orbit in May 2005. For the first four months calibration was performed using prelaunch coefficients followed by monthly updates from NOAA. In January 2010, EROS AVHRR Greenness composite processing shifted from a NOAA-17 source to NOAA-18.

The NOAA-19 satellite was launched and began operation in February 2009 and like its predecessors, prelaunch coefficients were used for the first seven months followed by monthly NOAA calibration updates.

Atmospheric Correction

The most substantial improvement to the conterminous United States and Alaska AVHRR data sets has been the application of an atmospheric correction for ozone, water vapor absorption, and Rayleigh scattering. In 2001, the entire existing time series was reprocessed to include the atmospheric correction, which has been applied routinely since 2001.

Water vapor absorption affects measurements in the near-infrared band (channel 2) by reducing the reflectance by 10-30 percent, depending on the viewing geometry (Tanre et al. 1992). Rayleigh scattering and ozone absorption affect measurements in the red band (channel 1) by increasing the reflectance by 1-2 percent, depending on the viewing geometry. The combination of these effects results in significant error in the computation of NDVI and other vegetation indices.

The second simulation of the satellite signal in the solar spectrum (6S) radiative transfer model is used to quantify the difference between the radiance measured at the satellite and Earth-leaving radiance (Vermote et al. 1997). The length of the path and direction that the signal travels are very important. The viewing geometry factors that affect the path length and direction are the orientation of the sun and the sensor relative to the target. The viewing geometry is provided as part of the conterminous United States and Alaska data sets. Bandpass calculations of 0.005-micrometer spacing or better are recommended for the simulation (Teillet 1992). The 6S radiative transfer model includes the use of parameterized look up tables (LUTs) and interpolation. LUTs are generated from the radiative transfer code using four key parameters: solar zenith, satellite zenith, relative azimuth, and terrain elevation.

The corrections for ozone absorption and Rayleigh scattering are straightforward (Teillet 1991). Appropriate Rayleigh scattering correction must include an adjustment for atmospheric pressure that can be derived from the elevation of the target. Recommended reference values for Rayleigh optical depths for standard pressure and temperature conditions are available (Teillet 1990; El Saleous et al. 1994). The local elevation adjustment can be derived using digital terrain data. The correction for ozone absorption is based on concentration values from actual measurements derived from the Total Ozone Mapping Spectrometer (TOMS) or other appropriate sensors (El Saleous et al. 1994).

DeFelice et al. (2003) describe the correction for water vapor. Atmospheric water vapor concentrations are available from at least two sources. The NASA Goddard Space Flight Center distributes the TIROS Operational Vertical Sounder (TOVS) level 3 geophysical parameters derived using the physical retrieval algorithm designated as the so-called Path A and Path B schemes (Suskind et al. 1997). The archive data products consist of 1-degree-by-1-degree global fields of the three-dimensional, temperature-moisture structure of the atmosphere. The second source is the NOAA National Centers for Environmental Prediction (NCEP). Since 2005, NCEP has been the source of water vapor data used for EROS AVHRR Greenness mapping due to errors related to the TOVS instrument problems.

Scaling the Reflectance and Temperature Data

Reflectance values for channels 1 and 2 were converted to byte data, where the range 0 - 254 represents 0 to 63.5 percent reflectance. The value 255 corresponds to reflectance greater than 63.5 percent. Any feature with greater than 63 percent reflectance is considered to be bright and non-vegetative.

Energy is converted to brightness temperature using the inverse of Planck's radiation function. The brightness temperatures are represented in Kelvin units. A scaling factor was used to convert the brightness temperatures to byte data. A scaling factor of 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).

Geometric Registration

The compositing process requires that each daily overpass be precisely registered to a common map projection to ensure that each daily 1-km is referenced to the correct ground location. Past experiments with image registration have shown that image-to-image registration provides 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 geometric accuracy (root-mean-square error of less than 1.0 pixel) compared to traditional image-to-map procedures (Kelly and Hood, 1991).

The geometric registration of an observation is a two-step process. First, a systematic correction is applied to the calibrated channel 2 (near-infrared) data. The near-infrared channel is used because water bodies that are commonly used as control points have the most contrast to land in the near-infrared channel. The systematic correction is based on a satellite platform model that yields an error of approximately three pixels. The second step is to develop the precision correction using several hundred ground control points (GCPs) selected from the systematically corrected image and a corresponding precision registered base image. Each GCP is centered in a chip that is an image segment 32 lines by 32 samples. The locations of the GCP chips from the systematic image are correlated with the chips from the base image using gray-scale correlation. A polynomial transformation is derived based on a least-square fit of a set of GCPs and corresponding image (pixel) locations. The control points must be well distributed throughout the image. If substantial cloud cover exists throughout the image, the registration process will fail because no point within the chip will correlate with the base image. If a significant number of control correlations fail, the image is not used in the composite. The polynomial transformation derived from the correlation of channel 2 is then used to georeference all of the remaining bands associated with an observation. The map projection used for the conterminous United States data set is Lambert Azimuthal Equal Area. Table 3 provides details on projection parameters of the conterminous United States. Table 4 provides details on the projection parameters of Alaska.

Table 3. Lambert Azimuthal Equal Area (LAZEA) projection of the conterminous United States

Parameters:	
Radius of sphere	6,370,997.0 meters
Longitude of central meridian	100 00 00 West
Latitude of origin	45 00 00 North
False easting	0
False northing	0
Units of measure	meters
Pixel size	1,000 meters
For the conterminous United States (2000)	
Center of pixel (1,1)	(-2050000, 752000)
Number of lines	2,889
Number of samples	4,587
LAZEA minimum bounding rectangle:	
In projection meters:	
Lower left	(-2050500, -2136500)
Upper left	(-2050500, 752500)
Upper right	(2536500, 752500)
Lower right	(2536500, -2136500)
In decimal degrees of longitude and latitude:	
Lower left	(-119.9722899 23.5837576)
Upper left	(-128.5300591 48.4030555)
Upper right	(-65.3946489 46.7048989)
Lower right	(-75.4163527 22.4793919)
In degrees, minutes, and seconds of longitude and latitude:	

Lower left	(-119 58 20 23 35 02)
Upper left	(-128 31 48 48 24 11)
Upper right	(-65 23 41 46 42 18)
Lower right	(-75 24 59 22 28 46)

Table 4. Albers Equal-Area Conic projection of Alaska

Parameters:
- First standard parallel 55 00 00 N
- Second standard parallel 65 00 00 N
- Longitude of central meridian -154 00 00 W
- Latitude of origin 50 00 00 N
- False easting 0
- False northing 0
- Units of measure Meters
- Pixel size 1,000 meters

Center of pixel (1,1) (-977000, 2422000)
Number of lines 1,992
Number of samples 2,512

Albers meters for minimum bounding rectangle:
- Lower Left (-977000, 431000)
- Upper Left (-977000, 2422000)
- Upper Right (1534000, 2422000)
- Lower Right (1534000, 431000)

Geographic decimal degrees:
- Lower Left (-168.5970, 52.9222)
- Upper Left (-179.8476 70.0416)
- Upper Right (-116.0057 67.6962)
- Lower Right (-131.5953 51.5372)

Geographic degrees, minutes, and seconds:
- Lower Left (-168 35' 49" 52 55' 20")
- Upper Left (-179 50' 51" 70 02' 30")
- Upper Right (-116 00' 21" 67 41' 46")
- Lower Right (-131 35' 43" 67 32' 14")

Normalized Difference Vegetation Index (NDVI)

The NDVI is the difference of near-infrared (channel 2) and visible (channel 1) reflectance values normalized over the sum of channels 1 and 2 (NIR-VIS)/(NIR+VIS). The NDVI equation produces values in the range of -1.0 to 1.0, where increasing positive values indicate increasing green vegetation and negative values indicate nonvegetated surface features such as water, barren, ice, snow, or clouds. The NDVI can be derived at several points in the processing flow. To retain the most precision, the NDVI is derived after calibration of channels 1 and 2, prior to scaling to byte range. Computation of the NDVI must precede geometric registration and resampling to maintain precision in this calculation.

To scale the computed NDVI results to byte data range, the NDVI computed value, which ranges from -1.0 to 1.0, is scaled to the range of 0 to 200, where computed -1.0 equals 0, computed 0 equals 100, and computed 1.0 equals 200. As a result, NDVI values less than 100 now represent clouds, snow, water, and other nonvegetative surfaces and values equal to or greater than 100 represent vegetative surfaces.

Date of Acquisition

The date of acquisition images are provided to allow a user to identify the specific daily observation (satellite scene number) used for each pixel. The date images for each composite identify each daily image as a unique value. The unique value is linked to an inventory of the daily observations.

Compositing

The greenness data set is a time series of weekly and bi-weekly maximum NDVI composites of the conterminous United States and Alaska. The maximum NDVI compositing process determines which pixels of each daily pass are included in the composite (Holben, 1986). Selection of the maximum NDVI is assumed to represent the maximum vegetation "greenness", a measure of photosynthetic activity, and also serves to reduce the number of cloud-contaminated pixels. The NDVI values are examined pixel by pixel for each of the observations comprising a weekly period to determine which pixel has the maximum value. For the conterminous United States, this is about 10 to 15 daily passes per week.

The output of the compositing process is a 14-band data set with one band containing the maximum NDVI value for each pixel selected from the daily overpasses. The remaining 13 bands are the data values that are coincident with the observation value selected as the maximum NDVI value. They include channels 1 to 5, satellite viewing geometry data (three bands), corrected channels 1 and 2 reflectance, a quality-control band indicting the origin of the water vapor and ozone values, a band that contains a pointer to the scene identification number for each pixel selected from the same daily pass as the maximum NDVI value, and the cloud mask.

Cloud Screening

In spite of the maximum NDVI compositing process, clouds are present in the composites. Several factors contribute to the cloud contamination. Often persistent seasonal weather and cloud patterns, such as the monsoon season in the southwest or early spring conditions in the northern portion of the conterminous United States, limit the number of cloud-free observations. The clouds are more prevalent in weekly rather than biweekly composites simply because of the number of observations available. Snow and clouds in Alaska are particular problems. As was mentioned in the section on geometric registration, it is not possible to accurately geometrically register an image if too many clouds are present.

Clouds have low NDVI values because the channel 1 and channel 2 values are nearly equal. However, sub-pixel clouds produce an NDVI that is a blend of clouds and clear surface. Cloud presence can confound the measurement of vegetation condition. The worse case example is sub-pixel clouds over a very green surface condition where the resulting NDVI is reduced and appears to be affected by drought.

All of the conterminous United States and Alaska composites have been cloud screened using an adaptation of the cloud clearing of AVHRR data (CLAVR) algorithm developed by NOAA (Stowe et al. 1999). CLAVR uses a series of tests of reflectance, temperature, land cover, and geographic location to identify clouds. Overcast clouds are relatively easy to detect, but sub pixel clouds are much more difficult. The occurrence of sub-pixel warm clouds over warm surfaces that often occurs during the summer or cold clouds over cold surfaces in the winter, is difficult to detect. Therefore, sub-pixel cloud contamination can be present in the composites even after cloud screening. Band 14 of a composite includes the cloud mask derived from CLAVR. The cloud mask has values from 0 to 200. The individual values are keyed to which test was ultimately used to determine if the pixel is clear or cloudy. Values less than 100 are clear, values 100 or greater are clouds.

DATA ACCESS

The USGS EarthExplorer can be used to search and download the USGS AVHRR composites. The data sets are located under the category AVHRR at:
http://EarthExplorer/.

CONTACT INFORMATION

For more information please contact Customer Services, EROS, U.S.
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