A 19-year time series of 1-km AVHRR satellite data of the conterminous United States and Alaska

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(Extended abstract/invited presentation requested for the National Integrated Drought Information System Knowledge Assessment Workshop: Contributions of Satellite Remote Sensing to Drought Monitoring, February 6-8, 2008)

Introduction

Since 1989, the U.S. Geological Survey (USGS) Earth Resources Observation and Science Center (EROS) has produced 1-km advanced very high resolution radiometer (AVHRR) satellite data sets for the conterminous United States and Alaska (Figure 1)(Eidenshink 2006). The data sets are comprised of a time series of weekly and bi-weekly vegetation condition or greenness composites based on the maximum normalized difference vegetation index (NDVI) (Eidenshink 2006). The data sets measure the annual and interannual patterns of vegetation growth and condition over landscapes and ecosystems in the United States and Alaska. The greenness data are used to monitor the effects of drought; quantify agricultural production; monitor the health of forests, shrublands, and grasslands; forecast fire danger; map land cover change; characterize the effects of climate change; and provide the basis for many other applications.

Over the 19-year period, the USGS has processed AVHRR data acquired by four different National Oceanic and Atmospheric Administration (NOAA) daily polar orbiting environmental satellites (NOAA-11, -14, -16, and -17). The AVHRR data are acquired over the conterminous United States from the direct reception system at EROS. The data coverage of Alaska is obtained from NOAA. The USGS also has developed the AVHRR data acquisition and processing system (ADAPS) to perform radiometric calibration, atmospheric correction, geometric registration, compositing, and cloud screening of AVHRR data.

Processing Methods

Radiometric Correction

Radiometric calibration is fundamental to understanding the quantitative measurements of a sensor. Data from NOAA-11, -14, -16, and -17 AVHRR sensors have been used to produce the conterminous United States and Alaska data sets. The source of the calibration coefficients for each sensor varies, but the basic method used to develop and apply the coefficients is very similar (Table 1).

Table 1. A summary of the calibration sources and the valid timeframes used to produce the conterminous United States and Alaska data sets.

Satellite	Start Date	End Date	Source
NOAA-11	09/26/1988	03/26/1989	prelaunch

NOAA-11	03/27/1989	present	Teillet and Holben (1994)
NOAA-14	12/30/1994	06/30/1995	prelaunch
NOAA-14	06/31/1995	present	Vermote and Kaufman (1995)
NOAA-16	09/01/2000	06/24/2003	prelaunch
NOAA-16	06/25/2003	present	NOAA
NOAA-17	01/01/2004	present	NOAA

The calibration coefficients and methodology for channel 3a and the thermal channels 3b, 4, and 5 are well documented by NOAA (Kidwell 2000). Table 2 provides the spectral ranges of the AVHRR sensor. 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. 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. Vermote and Kaufman (1995) described the postlaunch calibration of NOAA-14 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 were used by the USGS in the operational processing of AVHRR NOAA-14 data.

Table 2. AVHRR Spectral Ranges

Band Number	**NOAA Satellites: 11, 14**	**NOAA Satellites: 16, 17**
1	0.58 - 0.68	0.58 - 0.68
2	0.725 - 1.10	0.725 - 1.10
3a		1.58 - 1.64
3b	3.55 - 3.93	3.55 - 3.93
4	10.30 - 11.30	10.30 - 11.30
5	11.50 - 12.50	11.50 - 12.50
	(in micrometers)	(in micrometers)

NOAA-16 became the 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 (Kaufman and Holben, 1992). The postlaunch calibration coefficients for NOAA-16 can be found at http://noaasis.noaa.gov/NOAASIS/ml/calibration.html.

In January 2004, the USGS began to use NOAA-17 data for greenness mapping. Postlaunch calibration coefficients provided by NOAA are being used for the calibration of NOAA-17 data (http://noaasis.noaa.gov/NOAASIS/ml/calibration.html).

Atmospheric Correction

The most substantial recent 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 (DeFelice et al 2003).

The conterminous United States and Alaska data sets have no correction for stratospheric aerosol, such as the correction applied to the GIMMS data set (Vermote *et al.* 1997). The only major event that produced stratospheric aerosol during the 16-year period of the data set is the eruption of Mount Pinatubo in 1991. The stratospheric aerosol from Mount Pinatubo had the most significant effect in the equatorial region of the world. The impact in the northern hemisphere was relatively smaller.

Compositing

The compositing process requires that each daily AVHRR overpass be precisely registered to a common map projection to ensure that each daily 1-km pixel is referenced to the correct ground location. An observation used in a composite must have a root mean square error less than 1 pixel (1000 m). The map projection used for the conterminous United States data set is Lambert Azimuthal Equal Area. The map projection used for the Alaska data set is Albers Equal Area.

Compositing is a technique used to merge multiple daily observations, acquired over a specific period, into a single image. We produce weekly and biweekly composites using the maximum value compositing (MVC) method (Holben 1986). The MVC approach requires a series of georegistered daily observations for a selected time period or compositing period. The NDVI is examined pixel by pixel for each observation during the compositing period to determine the maximum value. On the average, 10 daily passes per week can be georegistered and used in a conterminous United States composite. Selection of the maximum NDVI is assumed to represent the maximum vegetation “greenness,” a measure of photosynthetic activity and serves to reduce the number of cloud-contaminated pixels. The only other criterion used in the compositing is the exclusion of pixels with a solar zenith angle greater than 80 degrees. Solar zenith angles greater than 80 degrees occur in northern latitudes in winter, especially for periods of major orbital drift.

Cloud Screening

Although the maximum NDVI compositing process tends to reduce cloud contamination in a composite, cloud contamination is often present in the weekly and biweekly composites. In 2003, we began using an adaptation of the cloud clearing of AVHRR data-Phase 1(CLAVR-1) algorithm developed by NOAA (Stowe *et al.* 1999). CLAVR-1 uses a series of tests of reflectance, temperature, land cover, and geographic location to identify clouds. 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 also 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.

Data Quality Uncertainties

There are three primary factors that affect the data quality of the conterminous U.S. and Alaska composite data sets. The first is residual cloud contamination. The operational cloud screening technique has been evaluated over a variety of land cover types and seasonal vegetation characteristics. The evaluation has shown the potential exists for residual cloud contamination over very green land surface characteristics in the summer time. This is due to the insensitivity of temperature and spectral measures of brightness to detect scattered low altitude clouds. Cloud contamination can also exist in winter time over cold snow free or snow covered land surfaces due to the insensitivity of the temperature and brightness threshold to detect clouds from snow or extremely cold bare ground. Smoothing filters or aggressive threshold values can reduce the cloud contamination. But some "good" data will likely be screened as clouds.

There is no correction for aerosol contamination in the composite data sets. This is due primarily to the lack of consistent aerosol measurements over the entire time series. The largest effect from aerosols occurs during major volcanic eruptions and even major wildfire outbreaks. There has been one major volcanic eruptions have occurred during the time frame; Mount Pinatubo (1991).

The third factor is satellite orbital drift. Orbital drift for AVHRR data has occurred to some degree for most missions. Generally, the longer the operational time period the greater the drift. At launch the typical time of day for the afternoon observation is 1:30 pm local solar time (LST). The drift is characterized as a shift in the time of the observation to late afternoon. The worst case scenario for AVHRR happened with NOAA-14 where the time of observation drifted past 5:00 pm LST in 2000. Because of the drift, we have decided not to use year 2000 data in the derivation of the long term means.

Data Format

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 calibrated channels 1 to 5, satellite viewing geometry data (three bands), atmospherically corrected channels 1 and 2 reflectance, a quality-control band indicating 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. The individual bands are produced as standard binary files with no header. The images can be utilized in any image processing system that can import binary files. A standard header file can be created from information included in documentation. Information on data availability and other general information can be found at http://eros.usgs.gov/greenness/index.html

The products from the conterminous United States and Alaska data sets are scaled to byte (8-bit) data. Reflectance values for channels 1, 2, and 3A are converted to byte data, where the range 0–254 represents 0–63.5 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 channel 3B, 4, and 5 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).

A separate image band is created for the satellite zenith, solar zenith, and relative azimuth angle for each image pixel. The solar zenith is computed in degrees, where 90 degrees represents the horizon or terminator, the dividing line between the illuminated and the unilluminated part of the Earth's surface. The satellite zenith angle is computed in degrees, where 90 degrees represents nadir. Therefore, values less than 90 degrees represent view angles in the back scattered (easterly) direction, and values greater than 90 represent the forward scatter (westerly) 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 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.

Anomaly Products

To make the time series NDVI more useful to land managers, products have been developed to characterize the NDVI in terms of growing season status. These products are: visual greenness (VG) , relative greenness (RG), and departure from average (DA) (Figure 2). Visual greenness maps portray current NDVI compared to a standard value that represents a very green reference such as an alfalfa field. VG is calculated using the formula:

$VG_t = NDVI_t / 0.66 * 100$

where:

$NDVI_t$ is the NDVI value for the current composite period
0.66 is a typical maximum NDVI observed over dense green vegetation

On VG maps, dry areas typically have low visual greenness values because their NDVI values are usually low and lush areas typically have high visual greenness values because their NDVI is generally high. Visual greenness values range from 0 to 100.

RG was introduced by Eidenshink et al. (1990) and Burgan and Hartford (1993). Relative greenness (RG) maps indicate current vegetation greenness compared to a historically observed NDVI range. RG is calculated using the formula:

$RG = (NDVI_t – Min) / Range * 100$

where

$NDVI_t$ is the NDVI value for the current composite period
Min is the historical minimum NDVI value for a location
Max is the historical maximum NDVI value for a location
Range = Max - Min

On RG maps, any pixel appears fully green when the NDVI for that pixel reaches its maximum value, and fully cured when the NDVI reaches its minimum value. Because each pixel is normalized to its own historical range, all areas (dry to wet) can appear fully green at some time during the growing season. Thus, both dry (Nevada) and lush (Western Washington) areas can reach relative greenness values of 0 and 100 percent even though Nevada has much sparser vegetation than Western Washington.

Departure from average (DA) is used to compare current-year vegetation greenness with average vegetation greenness for the same time of year, based on the long term conditions. The DA is calculated using the formula:

$DA_t = NDVI_t / NDVI_{mt} * 100$

where:

$NDVI_t$ =NDVI for the current time period
$NDVI_{mt}$ =mean NDVI for the current time period
DA_t=departure from average NDVI for the current period

EROS provides weekly updates of DA maps. Each week, the current vegetation condition is compared to the historical average for the same period. Positive departure from average values indicates that the vegetation is healthy and developing normally for the specific vegetation type. Low values during the growing season indicate that the vegetation is under stress, possibly from drought, or is behind in development.

Data Access

Historical and current composites of the conterminous United States and Alaska are provided free for download from two principle sources. Historical and current 7 and14-day composites are available for download from USGS EarthExplorer (http://edcsns17.cr.usgs.gov/EarthExplorer/). The individual composites are all 14 bands, compressed.

Current composites and the anomaly maps can be viewed and downloaded at the USGS Integrated Vegetation Mapping (IVM) website (http://ivm.cr.usgs.gov/viewer). The NDVI and other derivatives can be downloaded as individual images.

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References

Burgan, R.E.; Hartford, R.A. Monitoring vegetation greenness with satellite data. Ogden, UT: United States Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, General Technical Report INT-297. 1993: 13p.

DeFelice, T. P., P. Piriano, D. Lloyd, J. Meyer, and T.T. Baltzer, 2003. Water vapour correction of the daily 1 km AVHRR global land dataset: Part 1—Validation and use of the water vapour input field, *International Journal of Remote Sensing*, 24(11):2365–2375.

Eidenshink, Jeff, 2006. A 16-year time series of 1 km AVHRR satellite data of the conterminous United States and Alaska, *Photogrammetric Engineering and Remote Sensing*, 72(9):1027-1035.

Eidenshink, J. C., Burgan, R. E.,&Haas, R. (1990).Monitoring fire fuels condition by using time series composites of Advanced Very High Resolution Radiometer (AVHRR) data. International Symposium on Advanced Technology in Natural Resource Management, Washington, D.C. (pp. 68−82).

Holben, B. N., 1986. Characteristics of maximum-value composite images from temporal AVHRR data, *International Journal of Remote Sensing*, 7:1417–1434.

Kaufman, Y. J. and Holben, B. N., 1992, Calibration of the AVHRR visible and near-IR bands by atmospheric scattering, ocean glint, and desert reflection. *International Journal of Remote Sensing*, 14(1), 21-52.

Kidwell, K. B., 2000. *NOAA KLM User's Guide*, National Oceanic and Atmospheric Administration, Washington, D.C.

Stowe, L. L., P.A. Davis, and P.E. McClain, 1999. Scientific basis and initial evaluation of the CLAVR-1 global clear/cloud classification algorithm for the advanced very resolution radiometer, *Journal of Atmospheric and Ocean Technology*, 16:656–681.

Teillet, P. M., and B.N. Holben, 1994. Towards operational radiometric calibration of NOAA AVHRR imagery in the visible and near-infrared channels, *Canadian Journal of Remote Sensing*, 20(1):1–10.

Vermote, E., and Y.J. Kaufman, 1995. Absolute calibration of AVHRR visible and near-infrared channels using ocean and cloud views, *International Journal of Remote Sensing*, 16(13):2317–2340.

Vermote, E., N. El Saleous, Y.J. Kuafman, and E. Dutton, 1997. Data preprocessing: Stratospheric aerosol perturbing effect on the remote sensing of vegetation: Correction method for the composite NDVI after the Pinatubo eruption, *Remote Sensing Reviews*, 15:7–21.

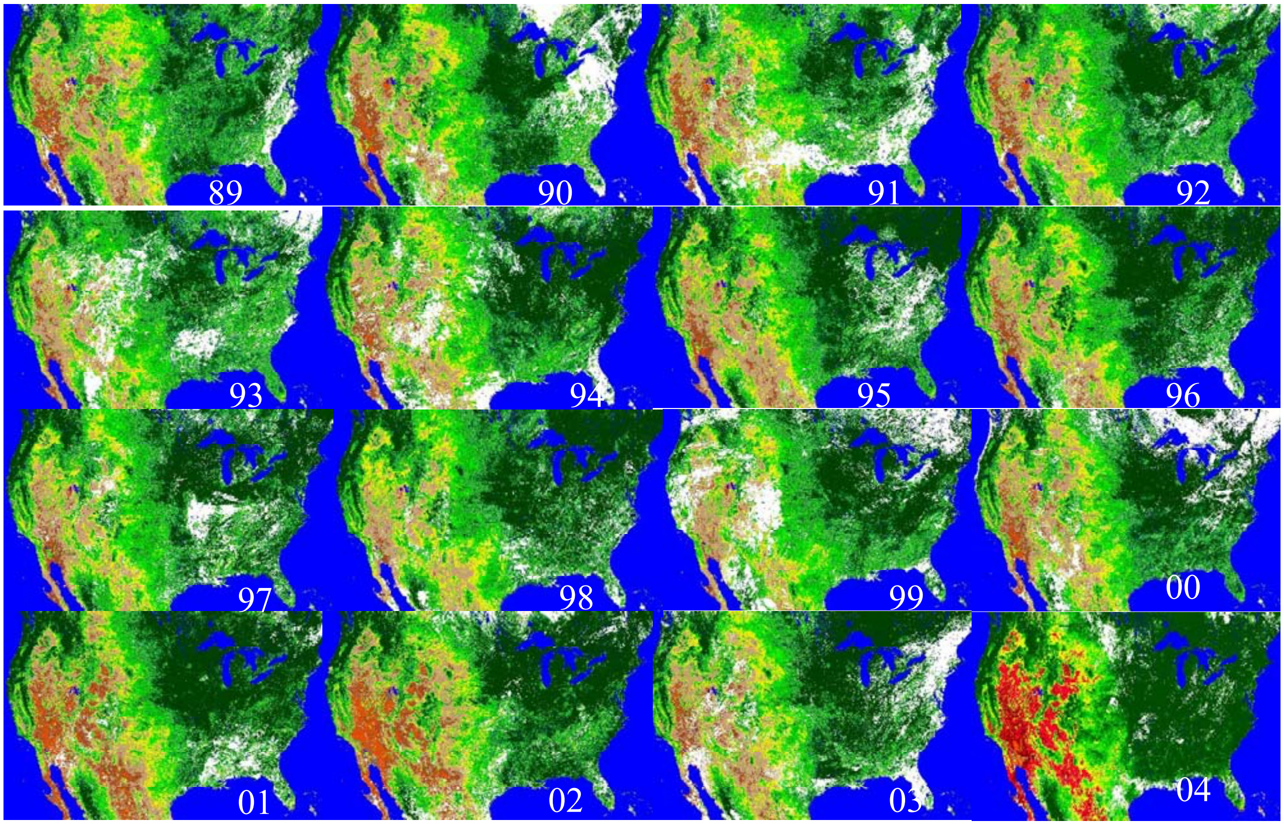

Figure 1. A 16-year time series of NDVI data of the conterminous United States for the period ~August 6, 1989-2004.

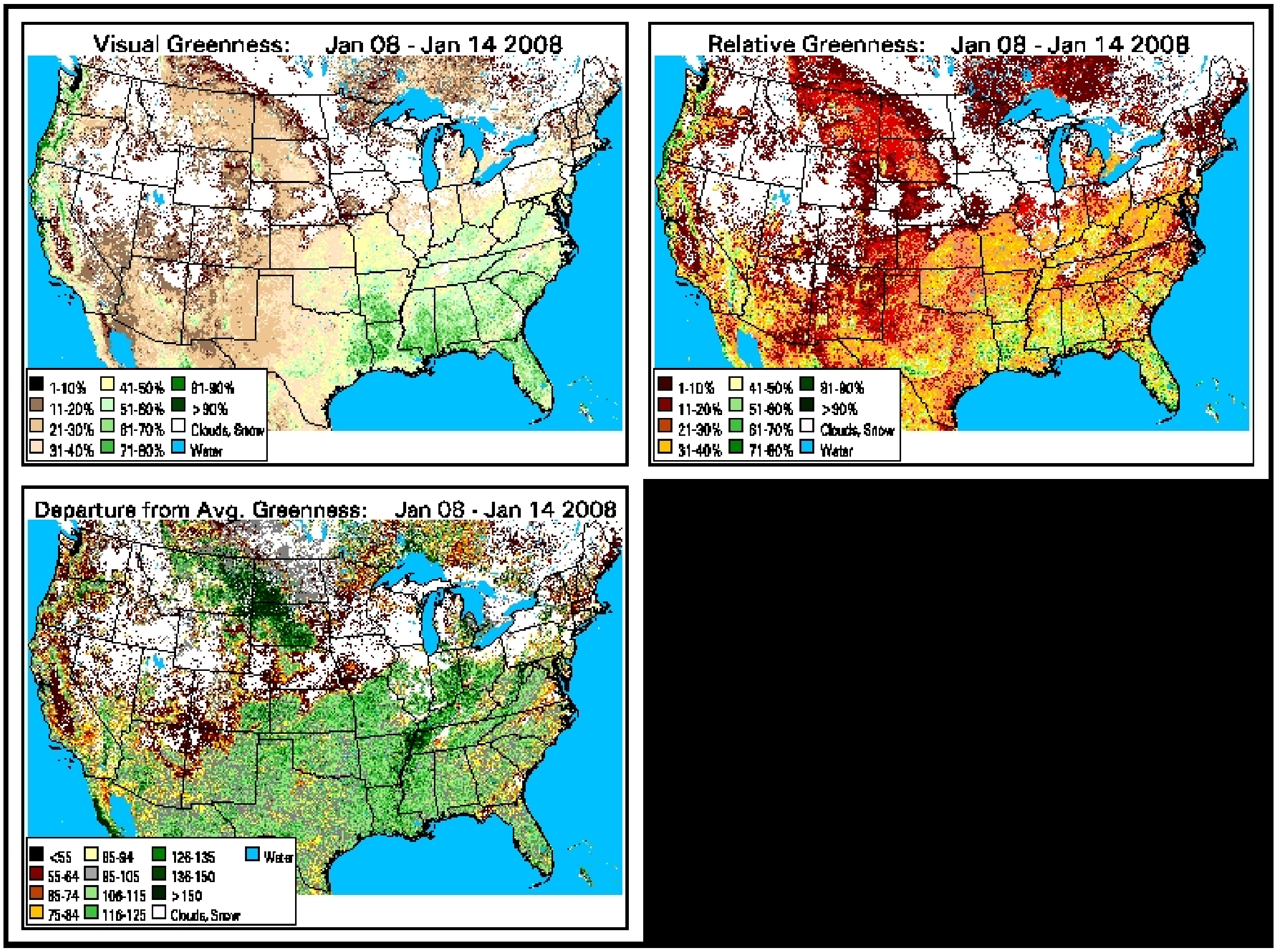

Figure 2. Visual greenness, relative greenness, and departure from average greenness for the period Jan. 8, 2008 to Jan. 4, 2008.

USGS CONUS AVHRR specifications

Monitoring target	Vegetation dynamics
Source instrument, mission, processing chain	AVHRR instrument NOAA-11, -14, -16, -17 missions
Product description	• NDVI (Band 2 – Band 1 / Band 2 + Band 1) • Calibrated data (Bands 1-5) • Atmospherically corrected (Bands 1-2) • Quality control • Cloud mask • Day of Acquisition • Satellite Viewing Geometry
Derivative Products	• Departure from Average (updated weekly) • Relative Greenness (updated weekly) • Visual Greenness (updated weekly)
Spatial resolutions	1-km
Geographic map projection	Lambert Azimuthal Equal Area
File format	flat binary raster, band sequential format
Geographic extent	Conterminous United States (48 states)
Product frequency	7-day, 14-day, and 14-day updated weekly
Product delay (or Latency)	~24 hours from last observation
Period of record	1989-2007, 2008 forward planned
Gaps (or time-series heterogeneity)	Data for 2000 not recommended due to orbital drift of NOAA-14
Product access (anonymous FTP)	http://edcsns17.cr.usgs.gov/EarthExplorer/ , http://ivm.cr.usgs.gov/viewer/
Compatibility with commonly used software	Yes (user must construct header file from documentation)
Relevant citations	Eidenshink, 2006