Using eMODIS Vegetation Indices for Operational Drought Monitoring

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Work performed under USGS contract 03CRCN0001.

(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

Droughts are normal recurring climatic phenomena that affect people and the landscapes they occupy at many scales (locally, regionally, and nationally) for periods of time varying from weeks to decades. The spatial and temporal variability and multiple impacts of droughts present challenges for mapping and monitoring on all scales.

Operational drought monitoring, by its very nature, requires repetitive measurements at the same location day after day, month after month, and year after year. Monitoring tools require reliable sources of time-series data at effective spatial and temporal scales to provide accurate and timely information. Satellite remote sensing is an obvious data source, supplying synoptic coverage of the land surface with objective, automated data collections for use in spatially specific models. Satellite information is especially appropriate over remote areas or areas with sparse field instrumentation.

Spectral vegetation indices (VI) are among the most commonly used satellite data products for the evaluation, monitoring, and measurement of vegetation cover, condition, biophysical processes, and change. They have been used for over two decades in a broad variety of applications, including monitoring the effects of drought over regional, national, and even multinational areas.

Historically, the most commonly used remote sensing instrument for large-area drought monitoring has been the daily orbiting National Oceanic and Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR), partially because there is now a sufficiently long time series to allow for the identification of anomalies to compare to “normal” conditions. The historical record for AVHRR data extends back over two decades globally at 4- to 8-kilometer (km) resolution (Tucker and others, 2005). Regional data series are also available, including a 19-year time-series dataset over the conterminous United States (CONUS) available from 1989 forward (Eidenshink, 2006).

A modern satellite-borne sensor, National Aeronautics and Space Administration’s (NASA) Moderate Resolution Imaging Spectroradiometer (MODIS), provides advancements in land remote sensing science and, similar to the AVHRR, distributes global data free of charge, providing an economical data source for use in operational monitoring programs (Justice and Townshend 2002).

NASA launched the Terra and Aqua platforms in 1999 and 2002, respectively, as part of its Earth Observing System (EOS). Both carry MODIS instruments distinguished by morning (Terra) and afternoon (Aqua) overpasses, providing complementary sources of daily global optical data that can be used in operational drought monitoring. MODIS is a 36-band sensor from which 10 by 10 degree products cast in the Sinusoidal projection are derived at 250-m, 500-m, and 1-km spatial resolution. In addition to being available globally at no cost to the public, the products generated from MODIS are superior to AVHRR because they provide higher spatial and spectral resolutions (Figure 1), more precise geolocation, and improved atmospheric corrections.

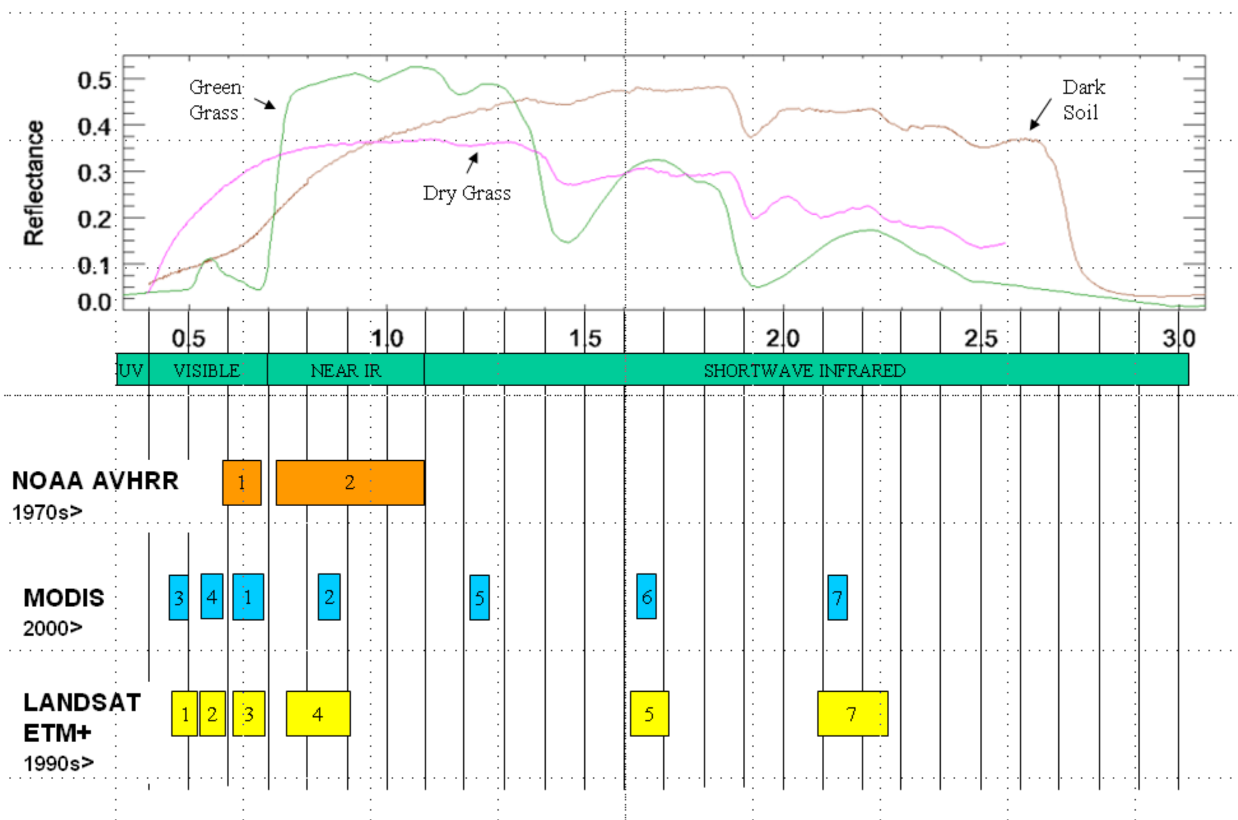

Figure 1. The optical (land) channel band widths for NOAA AVHRR, MODIS, and Landsat ETM+ instruments.

The earth science community uses MODIS land products for numerous research applications, which include mapping deforestation, identifying desertification, fire fuel estimation, burn scar identification, ecosystem evolution, invasive species potential, grazing impacts, and crop yield estimation (Fensholt, 2004; Thenkabail and others, 2004; Anderson and others, 2005; Chenzhen and others, 2005; Chuvieko and others, 2005; Kawamura and others, 2005; van Leeuwen and others, 2006; Wardlow and others, 2007). MODIS brings potential enhancement to any application where daily regional assessments are necessary to identify significant changes to the land surface that may indicate phenomena related to climate change. Table 1 lists some monitoring applications currently operating with MODIS data.

Table 1. Operational monitoring applications that incorporate MODIS data.

Program	Application/Link	Geographic Region
Famine Early Warning System (FEWS), (USGS/AID)	Early warning and vulnerability information *http://earlywarning.usgs.gov/adds/*	Various Countries (International)
Production Estimates and Crop Assessment Division (PECAD), (USDA-FAS)	Production estimates and crop assessment *http://www.fas.usda.gov/cropexplorer*	Various Countries (International and U.S.)
Upper Midwest Aerospace Consortium	NDVI, Visible and NIR *http://dngp.umac.org/newdngp372/index/php*	Northern Great Plains, U.S.
The International Research Institute for Climate and Society (IRI)	Monitoring tools for epidemic malaria and desert locust conditions *http://iridl.ldeo.columbia.edu/index.html*	Various Countries (N. Africa, Arabian Peninsula, India)

Important considerations of data characteristics related to operational monitoring in the selection of satellite data sources include data cost, data continuity, period of record, file format, geographic coverage, latency, and delivery schedule.

MODIS is attractive from a data continuity perspective as a follow-on to AVHRR, and its record of acquisition from 2000 to present is becoming long enough to provide homogeneous time-series information. Its 2,000-km swath is easily applied to daily global coverage needs, and MODIS data specifications ensure improved accuracy over previous satellite sensors.

However, operational users have identified barriers that must be overcome to assimilate MODIS products in their work. Standard MODIS products have been designed to accommodate the needs of science investigators, but several elements of the product specifications limit their relevance and use in decision support systems. First, the standard MODIS VI products are composited on a 16-day interval, reducing the temporal sensitivity often needed in vegetation monitoring applications. Second, the standard product tiles are cast on a Sinusoidal mapping grid and are available as HDF-EOS format, both of which present barriers to the ready assimilation of data into modeling and monitoring frameworks. Third, and perhaps most importantly, the standard products are not generated, delivered, and made available quickly enough to support monitoring requirements in near-real time. While the positive characteristics of MODIS represent a valuable extension of the global AVHRR record, many operational users continue to find difficulty overcoming the aforementioned barriers to effectively detect, monitor, and model change on an abbreviated time scale.

Operational use of MODIS: The eMODIS System

The USGS-EOS MODIS (eMODIS) system was designed, developed, and partially implemented in 2007 in response to the needs of a variety of operational applications. eMODIS products provide a consistently processed time series of MODIS vegetation index and surface reflectance data in 7-day intervals tuned to the CONUS AVHRR calendar (Eidenshink, 2006). eMODIS shares the precision and historical continuity of standard MODIS products but offers enhanced temporal frequency, faster production output, GeoTiff format, and a map projection compatible to the historical AVHRR time series. Table 2 summarizes the product specifications that set this system apart from other MODIS processing and delivery mechanisms.

Table 2. eMODIS system specifications

Monitoring target	Vegetation, land surface phenology, drought
Source instrument, mission, processing chain	MODIS instrument Aqua and Terra missions (Terra launched in 1999, overpass time 1030) (Aqua launched in 2002, overpass time 1330)
Product description	• NDVI (Band 2 – Band 1 / Band 2 + Band 1) • Atmospherically corrected surface reflectance (Bands 1-7) • Quality (reflectance and NDVI) • Day of Acquisition • Metadata
Spatial resolutions	250-m, 500-m, and 1,000-m
Geographic map projection	Lambert Azimuthal Equal Area
File format	Geotiff (zipped)
Geographic extent	Conterminous United States (48 states) (daily expedited data products starting in 2008, Alaska historical prototyping in 2008)
Product frequency	Daily
Product delay (or Latency)	Expedited: < 24 hours from last observation Historical: < 30 days from last observation
Period of record	Expedited Prototype: Sep 2007 forward Expedited: Jan 2008 forward Historical: 2005-2007, 2008 forward planned
Gaps (or time-series heterogeneity)	Only as applicable from spacecraft anomalies
Product access (anonymous FTP)	ftp://elpdl02.cr.usgs.gov/eMODIS
Compatibility with commonly used software	Yes
Relevant citations	Maiersperger and others, 2007

Historical and expedited eMODIS data streams are generated with Collection 5 production algorithms (http://modis-250m.nascom.nasa.gov/cgi-bin/QA_WWW/newPage.cgi?fileName=MODLAND_C005_changes) acquired from the

MODIS Adaptive Processing System and software recycled from the former EROS direct broadcast system. Historical products are based on level-1B data acquired from the MODIS Level-1 and Atmospheres Archive and Distribution System (LAADS), while expedited products are generated using the same basic approach but using expedited Level-1B data from the Near Real Time (NRT) system at NOAA.

The resulting double-production stream generates 7-day weekly intervals (Tuesday to Monday) historically, and daily 7-day rolling intervals in near-real time (expedited). NDVI and Surface Reflectance composites (see Figure 2) are produced over the conterminous United States (CONUS) to provide continuity with the EROS CONUS 1-km AVHRR weekly composite data products.

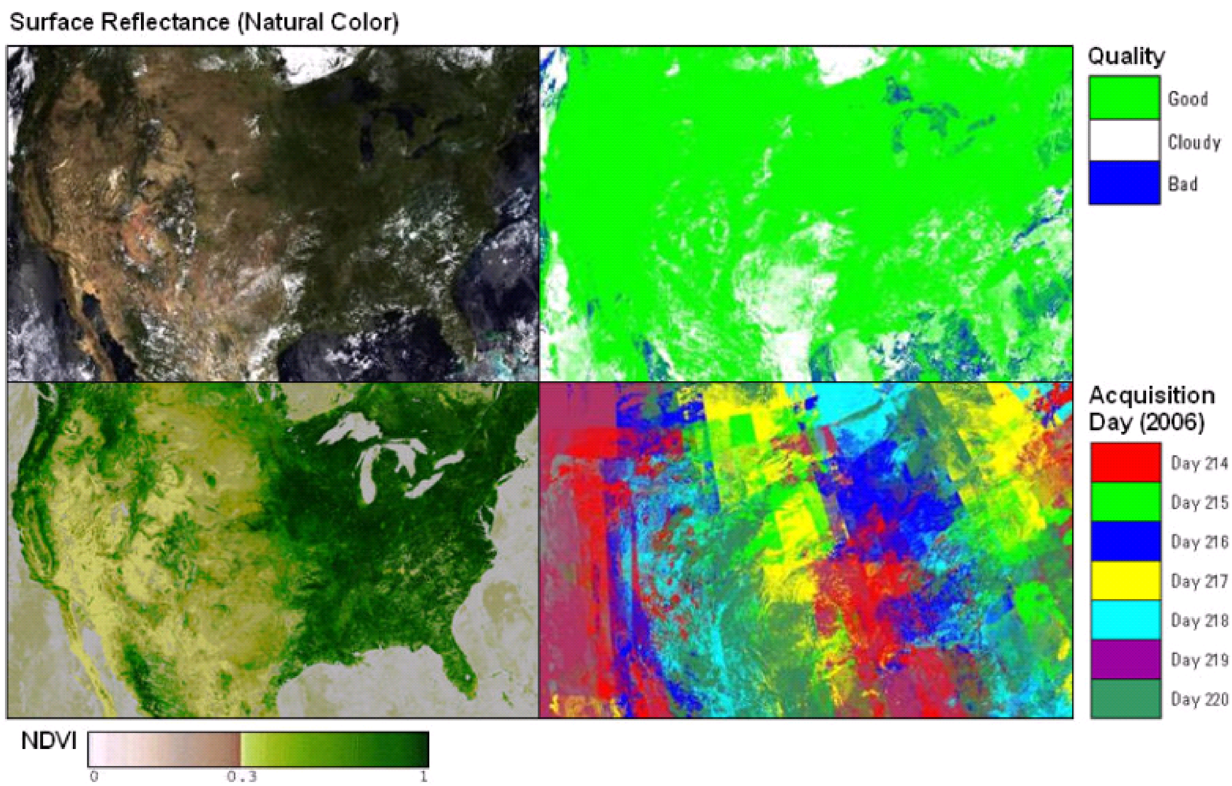

Figure 2. eMODIS Product Examples

The 7-day intervals over which eMODIS composites are calculated are conducive to certain monitoring applications, but at the cost of incorporating some cloudy data. All clouds and otherwise undesirable pixels are marked clearly as such in the quality product included with the eMODIS composites but cannot be completely removed. Some development effort has been put toward exploration of a combined Terra and Aqua eMODIS compositing process to minimize the number of cloudy pixels in a 7-day interval, but the primary current focus has been to create as much single-instrument data as possible. Postprocessing filtering of the 7-day eMODIS data using a weighted-least-squares regression algorithm (Swets and others, 1999) is planned in 2008. This technique is used to fill data values identified as clouds or undesirable pixels in the quality product and minimize noise mainly related to atmospheric contamination (Reed and others, 2003).

Drought Monitoring with eMODIS Inputs

Consistent time-series NDVI data have provided the basis for establishing normal or expected vegetation condition baselines, the identification of anomalies, and detection of trends or change. Many characteristics of the eMODIS 7-day NDVI data have been designed to be consistent with the characteristics of the conterminous U.S. AVHRR historical 1-km time series (Eidenshink, 2006) to facilitate eMODIS use in monitoring applications that already rely on 1-km AVHRR (e.g., RangeView: http://rangeview.arizona.edu). Time-series data are frequently converted into metrics that target or highlight the detection of anomalies. These higher-order metrics are vital tools for rapidly monitoring conditions, and the time series of MODIS might be extended if it is possible to link AVHRR and MODIS data histories. These metrics include (but are not limited to) Relative Greenness, the Percent of Average Seasonal Greenness (PASG), and the Vegetation Drought Response Index (Burgan and Hartford, 1993; Brown and others, in press). Several other higher-order metrics exist in the literature; however, this review is focusing on those that have been operational over CONUS from AVHRR and are planned to be produced operationally from eMODIS.

Relative Greenness

Relative greenness is an NDVI-based indicator of the vegetation vigor as compared to the observed historical range. On relative greenness 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. This metric is incorporated into wildland fire management decisions. In the past, both relative greenness and 1,000-hour fuel moisture data have been evaluated for indicating broadscale fire potential (Burgan and others, 1998). Research is ongoing to determine the strength of this relationship. Values range from 0 to 100 percent of the greenness range measured for each pixel. Recent AVHRR relative greenness images are provided through an interactive Web mapping interface (http://gisdata.usgs.net/website/ivm/viewer.php).

Percent of Average Seasonal Greenness

The PASG is a measure that shows the relationship (expressed as a percent) of the vegetation conditions for portions of the growing season related to historical average conditions for comparable time periods. While Relative Greenness is based on the NDVI from a single composite period (usually 7 days), the PASG also includes an integration of the NDVI above a baseline (referred to as Seasonal Greenness), which provides normalization across multiple sensors and orbital conditions. The PASG values range from 0 to 250 percent of the Seasonal Greenness range as measured for each pixel. The data are truncated at 250 percent for PASG to be delivered as byte data. The PASG is one of the key satellite variables involved in Vegetation Drought Response Index (VegDRI) models. More information on the PASG calculations is found in Brown and others (in press). Recent PASG (as well as the below mentioned VegDRI) products are provided by way of an interactive Web mapping interface (http://gisdata.usgs.gov/website/Drought_Monitoring/viewer.php).

Vegetation Drought Response Index (VegDRI)

The VegDRI is a modeled indicator of drought stress on vegetation based on historical observations of time-series NDVI metrics, climate-based drought indices, and biophysical land surface characteristics. Brown and others (in press) describe the VegDRI variables and methodology at length. In short, the VegDRI methodology consists of three main steps: 1) data processing, summarization, and organization in a database, 2) training of empirically derived VegDRI models for three seasonal phases (spring, summer, and fall) using classification and regression tree methodology, and 3) application of the appropriate model to geospatial data.

Operational VegDRI image products are summarized into seven categories reflecting varying ranges of drought-induced vegetation condition. The maps are currently provided in near-real time (usually 24–36 hours after satellite overpass) from two different Web interfaces (http://gisdata.usgs.gov/website/Drought_Monitoring/viewer.php and http://www.drought.unl.edu/vegdri/VegDRI_Main.htm).

Data Continuity and Uncertainly Issues Affecting Operational Monitoring

Many factors may affect the uncertainty of satellite-derived vegetation index metrics regardless of the satellite source. Factors include the atmospheric state and methods for correction (for example, aerosol optical thickness and water vapor), calibration accuracy, satellite spectral channel response functions, compositing schemes, and co-registration (van Leeuwen and others, 2006). It is useful to approach multi-sensor discrepancies by using analysis techniques such as data smoothing or normalization.

The remote sensing science community has recognized the value of long-term continuity in satellite data series for earth science research and applications (Murphy and others, 2003; Brown and others, 2006 Tucker and others, 2005. Knowledge of the compatibility of AVHRR-based NDVI and NDVI from other instruments, both current and future, is needed as the basis for continued long-term monitoring of the land surface. Prior research has shown promising results for harmonizing NDVI data produced from different sensors (Brown and others, 2006; Miura and others, 2006; Gallo and others, 2005); however, a practical methodology is still being developed to support effective cross-sensor monitoring capabilities in the United States.

Future data continuity efforts related to USGS drought monitoring in CONUS will focus on the application of transition algorithms translating AVHRR observations into MODIS and vice versa. Figure 3 shows 7-day NDVI from AVHRR, Aqua eMODIS, and Terra eMODIS (mean and standard deviations calculated over the U.S. Corn Belt). During 2005 and 2006, the linear relationships between smoothed time-series NDVI data streams are characterized by high R^2 (0.976, 0.994, 0.975, and 0.992 for 2005 Aqua, 2006 Aqua, 2005 Terra, and 2006 Terra, respectively). The winter months show a much lower relationship, likely due to the optical bandpass differences between AVHRR and MODIS, especially in the red channels. Further research into the AVHRR and eMODIS compatibility for monitoring use is ongoing.

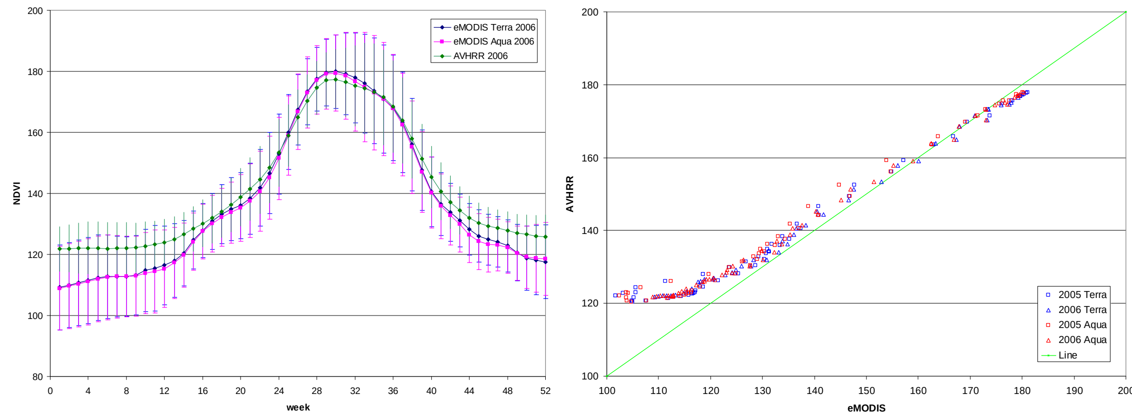

Figure 3. Time-series NDVI from AVHRR, Terra eMODIS, and Aqua eMODIS 2005 and 2006 data streams.

Future Plans

One salient feature of eMODIS is the capability to generate and distribute expedited products operationally. Many applications are inadequately served by the latency and delivery schedule of the standard MODIS products. Building on this service model, several other USGS projects have expressed requirements for related products, both for the CONUS area and for other geographic regions. For example, the USGS Carbon project is sponsoring the expansion of the eMODIS system to include customized VI products over Alaska in FY2008. These datasets will also be offered to the wider community; however, additional funding will be needed to create the anomaly products necessary for input into drought monitoring.

Other users have expressed interest in daily products and 14-day composites. Researchers have also proposed that the USGS serve expedited MODIS data to applications with a need for land surface temperature data that have shown promise as part of simple energy balance modeled data (Senay and others, 2007) for assessment of actual evapotranspiration in near-real time.

The Visible/Infrared Imager/Radiometer Suite (VIIRS) is the planned follow-on operational instrument to the AVHRR. VIIRS will collect land bands very similar to those of the MODIS sensor. The USGS/EOS eMODIS NDVI service is newly established but intends to build on early success to serve operational monitoring applications in the United States and provide a bridge to the future VIIRS sensor.

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