Evaluation of the Consistency of Long-Term NDVI Time Series Derived From AVHRR, SPOT-Vegetation, SeaWiFS, MODIS, and LandSAT ETM+ Sensors

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***Abstract*—This paper evaluates the consistency of the Normalized Difference Vegetation Index (NDVI) records derived from Advanced Very High Resolution Radiometer (AVHRR), SPOT-Vegetation, SeaWiFS, Moderate Resolution Imaging Spectroradiometer, and LandSAT ETM+. We used independently derived NDVI from atmospherically corrected ETM+ data at 13 Earth Observation System Land Validation core sites, eight locations of drought, and globally aggregated one-degree data from the four coarse resolution sensors to assess the NDVI records agreement. The objectives of this paper are to: 1) compare the absolute and relative differences of the vegetation signal across these sensors from a user perspective, and, to a lesser degree, 2) evaluate the possibility of merging the AVHRR historical data record with that of the more modern sensors in order to provide historical perspective on current vegetation activities. The statistical and correlation analyses demonstrate that due to the similarity in their overall variance, it is not necessary to choose between the longer time series of AVHRR and the higher quality of the more modern sensors. The long-term AVHRR-NDVI record provides a critical historical perspective on vegetation activities necessary for global change research and, thus, should be the basis of an intercalibrated, sensor-independent NDVI data record. This paper suggests that continuity is achievable given the similarity between these datasets.**

***Index Terms*—Advanced Very High Resolution Radiometer (AVHRR), Moderate Resolution Imaging Spectroradiometer (MODIS), SPOT, vegetation.**

I. Introduction

VARIOUS remote-sensing-based studies have revealed compelling spectral relationships between the red and near-infrared (NIR) part of the spectrum to green vegetation [1]. Due to vegetation pigment absorption (chlorophyll, proto-chlorophyll), the reflected red energy decreases, while the reflected NIR energy increases as a result of the strong scattering processes of healthy leaves within the canopy. Directly using the amount of reflected red and/or NIR radiation to study the biophysical characteristics of vegetation is very inadequate, for reasons rooted in the intricate radiative energy interaction at the canopy level, background, and atmospheric impacts on the signal and the nonuniqueness of the signatures. When, however, two or more bands are combined into vegetation index (VI), the vegetation signal is boosted and the information become more useful [2]. Vegetation indices can then be used as surrogate measures of vegetation activity [3], [4]. The most widely used form of VI, the Normalized Difference Vegetation Index (NDVI), was introduced by Deering in 1978 [5] and Tucker in 1979 [3] and is the ratio of the difference of the NIR and red band divided by their sum. The NDVIs properties help mitigate a large part of the variations that result from the overall remote-sensing system (radiometric, spectral, calibration, noise, viewing geometry, and changing atmospheric conditions). Some land-surface types are not robustly represented by NDVI, such as snow, ice, and nonvegetated surfaces, where atmospheric variations and sensor characteristics dominate [6].

NDVI is often used as a monitoring tool for the vegetation health and dynamics, enabling easy temporal and spatial comparisons [7]. In order to make effective use of NDVI data, issues related to the remote-sensing system need to be addressed. The most serious are clouds, which render any observation useless by obstructing the target, and, to a lesser degree, the effects of the Bidirectional Reflectance Distribution Function (BRDF). To overcome these issues, maximum value compositing was developed as an operational approach to producing cloud free consistent NDVI maps. Multiple daily images are processed to create a representative, cloud-free image with the least atmospheric attenuation and viewing geometry effects [8]. The maximum value compositing (MVC) technique is the most widely used method and is based on maximizing the NDVI signal over a preset period of time. While MVC helps screen for clouds, it was found to also favor extreme viewing geometry (large solar zenith angles and large view angles in the forward scatter direction) [9] and, to a lesser extent, cloud shadow. Several studies attempted to address these issues with modest and mixed results [10]–[12].

On a global basis, several factors can influence differences in NDVI across sensors. Impacts from BRDF are well documented [10], [13]. Additionally, the Spectral Response Functions (SRFs) for the different sensors can lead to systematic differences in NDVI [14]. Each sensor has its own instantaneous field of view, swath width, and orbiting geometry. Ad-

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justing for this list of known differences is somewhat tractable but, in many cases, beyond the capability or resources available to many users [15]. In this study, we evaluate the publicly available NDVI products from four operational NDVI products from four sensors. Our analysis is conducted without any adjustment for BRDF or sensor-specific characteristics (such as SRF). The justification for this approach is to conduct a user-based analysis to indicate by how much and where these operational products differ.

In the context of NASA's Committee on Earth Observation Satellites (EOS), validation is defined as "the process of assessing by independent means the quality of the data products derived from the system outputs" [16]. In this paper, we first utilize NDVI from ETM+ data as the independent data by which we assess the quality of NDVI output from Advanced Very High Resolution Radiometer (AVHRR), SPOT-VGT, SeaWiFS, and MODIS. The definition allows for intercomparisons between sensors to assess the general agreement of the output from these sensors, as long as that output is independently constructed. For our sensor intercomparison, we examine eight areas where droughts were detected between 2000 and 2004, 13 EOS validation sites, as well the global distribution in difference between the four sensors. The goal of this paper is provide the user of operationally available NDVI products an understanding of how to properly interpret and utilize these data and suggest applications where further adjustments to the operational products would be required for analysis involving data from multiple sensors.

II. Data and Methods

Data from four sensors were used in this study: global products from AVHRR on the NOAA satellites, SPOT Vegetation (VGT), land data from SeaWiFS and MODIS NDVI products. In addition, high resolution NDVI data from Landsat 7's Enhanced Thematic Mapper plus (ETM+) were used as an independent measure (Table I).

A. Data

All four NDVI time series are based on the maximum value compositing technique [8]. This method minimizes differences in the spectral properties, radiometric resolution, residual atmosphere effects, and, most importantly, minimizes clouds. By selecting the pixel with the maximum NDVI signal and minimum atmospheric effects, the same day is usually selected for each sensor reducing any temporal discrepancies in the time series. In the case of MODIS sensor, a constrained-view MVC (CV-MVC) is used to minimize the off-nadir tendencies of the MVC.

We used maximum-value AVHRR NDVI composites [8] from the NASA Global Inventory Monitoring and Modeling Systems (GIMMS) group at the Laboratory for Terrestrial Physics [18] from July 1981–May 2004. A postprocessing satellite drift correction has been applied to this dataset to further remove artifacts due to orbital drift and changes in the sun-target-sensor geometry [19]. As a result of AVHRR's wide spectral bands, it is more sensitive to water vapor in the atmosphere. An increase in water vapor results in a lower NDVI signal, which can be interpreted as an actual change if

TABLE I

NDVI Datasets Used in This Study: Sensors and the Data Source, Spatial and Temporal Resolutions, Equatorial Crossing Time, and Field of View for Each Sensor

Sensor	AVHRR	SPOT Vegetation	MODIS	SeaWiFS	LandSAT ETM+
Data Source	GIMMS NDVIg Operational Dataset	FAS-GIMMS, VITO	MODIS-Land and Vermote/ Saleous	SeaWiFS/ GSFC/GIM MS	Corrected scenes from EOS web
Spatial Resolution	8000 m and 1 degree	1000 m and 1 degree	500 m, 5000 m, 1degree	4633 m, 1 degree	30 m
Temporal Resolution	15 day and monthly	10 day and monthly	16-day and monthly	monthly	1 to 9 scenes, 1999-2001
Equatorial Crossing	~9 AM - ~6 PM	10.30 AM	10.30 AM	12.05 PM	10:00 AM
Field of View (FOV)	±55.4°	±101°	±55°	±58.3°	±15.4°

no correction is applied [20]. The maximum value composite should lessen these artifacts. The GIMMS operational dataset incorporates data from sensors aboard NOAA-7 through 14 with the data from the AVHRR on NOAA-16 and 17 using SPOT data as a bridge for a by-pixel intercalibration. Details of these corrections can be found in [18] and [19]. After calibration, the AVHRR NDVI data dynamic range was adjusted to values of -0.05 to 0.95 to match more closely that of the SPOT- and MODIS-based NDVI.

IV. Discussion and Conclusion

For the past decade, newer and more sophisticated sensors are becoming operational providing biophysical measurements that are aimed at addressing various global change related questions. NASA's MODIS sensors on-board Terra and Aqua satellites are providing a series of advanced remote-sensing-based land products [22], [37]. However, to achieve any meaningful monitoring of the land surface vegetation, stable, intercalibrated long term vegetation records (a decade or longer) are a key requirement [38]. Efforts for using data from MODIS and other sensors with the historic AVHRR vegetation NDVI records are proving to be challenging. There is a need for additional research into improving the long-term AVHRR data record and addressing the cross-sensor NDVI continuity [39].

Using the standard products instead of modeled simulations, we were able to intercompare various datasets with the historic AVHRR NDVI record. This analysis revealed that, although relatively large differences existed between the four NDVI datasets, the NDVI anomalies exhibited similar variances. Composited NDVI images are fairly robust, which can be seen when comparing time series with NDVI from Landsat ETM+ images that have been corrected for atmospheric effects.

This research suggests that progress can be made toward a unified NDVI dataset given that absolute variances across sensors are relatively similar, especially when seasonality is removed. Benefits of this work include enabling the use of the longer AVHRR time series to calculate the normal trends and any anomalies in combination with other sensors, the successful merging of various data sets from SPOT-VEG, MODIS, and SeaWiFS, and others quantitatively with the historic 25-year AVHRR NDVI data record, and the potential associated with using multiple NDVI data sources, especially in the event of one dataset's absence.