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An empirical investigation of cross-sensor relationships of NDVI and red/near-infrared reflectance using EO-1 Hyperion data

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Abstract

Long term observations of global vegetation from multiple satellites require much effort to ensure continuity and compatibility due to differences in sensor characteristics and product generation algorithms. In this study, we focused on the bandpass filter differences and empirically investigated cross-sensor relationships of the normalized difference vegetation index (NDVI) and reflectance. The specific objectives were: 1) to understand the systematic trends in cross-sensor relationships of the NDVI and reflectance as a function of spectral bandpasses, 2) to examine/identify the relative importance of the spectral features (i.e., the green peak, red edge, and leaf liquid water absorption regions) in and the mechanism(s) of causing the observed systematic trends, and 3) to evaluate the performance of several empirical cross-calibration methods in modeling the observed systematic trends. A Level 1A Hyperion hyperspectral image acquired over a tropical forest—savanna transitional region in Brazil was processed to simulate atmospherically corrected reflectances and NDVI for various bandpasses, including Terra Moderate Resolution Imaging Spectroradiometer (MODIS), NOAA-14 Advanced Very High Resolution Radiometer (AVHRR), and Landsat-7 Enhanced Thematic Mapper Plus (ETM+). Data were extracted from various land cover types typically found in tropical forest and savanna biomes and used for analyses. Both NDVI and reflectance relationships among the sensors were neither linear nor unique and were found to exhibit complex patterns and bandpass dependencies. The reflectance relationships showed strong land cover dependencies. The NDVI relationships, in contrast, did not show land cover dependencies, but resulted in nonlinear forms. From sensitivity analyses, the green peak (~550 nm) and red-NIR transitional (680 – 780 nm) features were identified as the key factors in producing the observed land cover dependencies and nonlinearity in cross-sensor relationships. In particular, differences in the extents to which the red and/or NIR bandpasses included these features significantly influenced the forms and degrees of nonlinearity in the relationships. Translation of MODIS NDVI to "AVHRR-like" NDVI using a weighted average of MODIS green and red bands performed very poorly, resulting in no reduction of overall discrepancy between MODIS and AVHRR NDVI. Cross-calibration of NDVI and reflectance using NDVI-based quadratic functions performed well, reducing their differences to ±.025 units for the NDVI and ±.01 units for the reflectances; however, many of the translation results suffered from bias errors. The present results suggest that distinct translation equations and coefficients need to be developed for every sensor pairs and that land cover-dependency need to be explicitly accounted for to reduce bias errors.

Keywords: Continuity; NDVI; Vegetation index; Reflectance; MODIS; AVHRR; ETM+; Hyperion; Cross-calibration

1. Introduction

There is a need among the science communities to advance our scientific understanding and analysis of the terrestrial carbon and biogeochemical cycles toward ultimate predictions of the Earth system behavior. This requires accurate and precise descriptions of how terrestrial vegetation functions, how it interacts with other components of the Earth system, and how it has been changing on a continuum of spatial and temporal scales.

Spectral vegetation indices (VIs) are one of the more important satellite products in monitoring temporal and spatial variations of vegetation photosynthetic activities and biophysical properties. The most widely used has been the normalized difference vegetation index (NDVI), which is the red and near-

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infrared (NIR) reflectance difference divided by their sum (Tucker, 1979). The long term, moderate resolution dataset starting in 1980s with NOAA Advanced Very High Resolution Radiometer (AVHRR) and now transitioning to Moderate Resolution Imaging Spectroradiometer (MODIS) onboard the Terra and Aqua satellite platforms, is of great importance for monitoring ecosystem variability and response to seasonal and inter-annual environmental changes (e.g., Dong et al., 2003; Huete et al., 2002; Myneni et al., 1997; Zhang et al., 2003). Regardless of the recent failure of the Scan Line Corrector in the latest sensor, the Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) sensor series also continue to provide the high spatial resolution data base of Earth imagery begun in 1982 with the same spectral bands, enabling more detailed, consistent change detection.

These long term observations, however, require much effort to ensure continuity/compatibility due to drifts in calibration, filter degradation, and variations in band locations and/or bandwidths (e.g., Bryant et al., 2003; Che & Price, 1992; Goward et al., 1991; Kaufman & Holben, 1993). In particular, inter-sensor VI product continuity became a critical and complicated issue due to different sensor characteristics and product generation algorithms, as with AVHRR and MODIS, a requirement that needs to be addressed (Cihlar et al., 2002). There are the "horizontal" continuity issue (e.g., from AVHRR to MODIS) and the multi-scale, "vertical" continuity/compatibility issue involving simultaneous coarse to fine scale acquisitions (e.g., AVHRR and/or MODIS to ETM+ and/or Advanced Spaceborne Thermal Emission and Reflection Radiometer, ASTER). The underlying issue here is that VI values for the same targets recorded under identical conditions will not be directly comparable because input reflectance values differ from sensor to sensor (Teillet et al., 1997; Yoshioka et al., 2003).

One key sensor characteristic that varies widely among sensors is the spectral bandpass filters (BPFs) and, thus, many studies have focused on this "spectral issue." Teillet et al. (1997) showed that, for a forested region in southeastern British Columbia, the NDVI is affected by differences in bandwidth, notably of the red bands. On the other hand, the NDVI values were found to be strongly affected by the proximity of the red and NIR bands to the red edge region (690–750 nm) in a Brazilian tropical savanna region (Galvao et al., 1999). Trishchenko et al. (2002) used modeled spectral datasets to investigate the sensitivity of the NDVI and reflectance to BPFs for selected sensors, including AVHRR, MODIS, Satellite Probatoire d'Observation de la Terre (SPOT) VEGETATION, and Advanced Earth Observing Satellite II (ADEOS-II) Global Imager (GLI). Both the NDVI and reflectance were found to be sensitive to the BPFs, causing notable differences in their values not only among the sensors with large spectral characteristic differences (AVHRR, MODIS, VEGETATION, and GLI), but also among some of the AVHRR sensor series (Trishchenko et al., 2002). Recently, Gallo et al. (2004) compared the AVHRR and MODIS NDVI data over the conterminous USA and showed that the composite AVHRR NDVI data were associated with the corresponding MODIS data with over 90% of the variation explained by a simple linear relationship.

Several attempts have been made to reconcile NDVI data produced from different sensors. Trishchenko et al. (2002) developed a series of quadratic, "spectral correction" functions to translate the reflectance and NDVI of selected sensors to NOAA-9 AVHRR-equivalents, whereas Steven et al. (2003) used simple linear relationships to cross-calibrate the NDVI to a precision of 1–2% for agricultural crop monitoring. Gitelson and Kaufman (1998) attempted to generate AVHRR-equivalent NDVI data from MODIS reflectances by taking weighted averages of MODIS narrow green and red bands to simulate "AVHRR-like" MODIS NDVI. Although their analyses showed promising results, it was complicated by the fact that the optimum weights were dataset-, and thus, land cover-dependent. Another practical method for translating the NDVI from MODIS to AVHRR was proposed by Gao (2000), which re-introduced water vapor contaminations into the MODIS NIR band to simulate the broad AVHRR channel 2. Yet another approach was proposed by Yoshioka et al. (2003), which accounts for target greenness and brightness in the translations.

In the present study, we also focused on the spectral issue and investigated cross-sensor relationships of the NDVI as well as the red and NIR reflectances. The specific objectives of this study were: 1) to understand the systematic trends in cross-sensor relationships of the NDVI and reflectance as a function of spectral bandpasses, 2) to examine/identify the relative importance of the spectral features (i.e., the green peak, red edge, and leaf liquid water absorption regions) in and the mechanism(s) of causing the observed systematic trends, and 3) to evaluate the performance of several empirical cross-calibration methods in modeling the observed systematic trends. The key questions being raised here were whether or not cross-sensor relationships of the NDVI and reflectances could be generalized and, if so, could be modeled by empirical means for tropical biomes. Our approach was to spectrally aggregate hyperspectral imagery to simulate various sensor bandpasses. The image data used here were acquired over a tropical forest–savanna transitional zone in Brazil with a satellite-borne hyperspectral sensor, Hyperion, onboard the Earth Observing One (EO-1) platform (Ungar et al., 2003). The area exhibits a wide variety of land surface conditions with varying amounts of green and senescent vegetation components, which allowed for analysis of inter-sensor NDVI and reflectance relationships in their full dynamic ranges and their land cover dependencies.

2. Materials and methods

2.1. Site description

Our study area was located on a tropical forest–savanna transitional region along an eco-climatic gradient in Brazil where two distinct biomes met and co-existed (Table 1). The area consisted of a preserved national park, Araguaia National Park, surrounded by a complex mosaic of undisturbed forest/savanna and converted land areas. A wide range of land cover