USE OF EO-1 HYPERION DATA FOR INTER-SENSOR CALIBRATION OF VEGETATION INDICES

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1. INTRODUCTION

Numerous satellite sensor systems useful in terrestrial Earth observation and monitoring have recently been launched and their derived products are increasingly being used in regional and global vegetation studies. The increasing availability of multiple sensors offer much opportunity for vegetation studies aimed at understanding the terrestrial carbon cycle, climate change, and land cover conversions. Potential applications include improved multi-resolution characterization of the surface (scaling); improved optical-geometric characterization of vegetation canopies; improved assessments of surface phenology and ecosystem seasonal dynamics; and improved maintenance of long-term, inter-annual, time series data records. The Landsat series of sensors represent one group of sensors that have produced a long-term, archived data set of the Earth's surface, at fine resolution and since 1972, capable of being processed into useful information for global change studies (Hall et al., 1991).

Spectral vegetation indices are one example of satellite-based products for mapping temporal and spatial variations in surface biophysical parameters. Vegetation index products from Advanced Very High Resolution Radiometer (AVHRR), SeaWiFS, SPOT-VEGETATION, Moderate Resolution Imaging Spectroradiometer (MODIS), Global Imager (GLI), Landsat, and other sensors are now or soon will be widely available for monitoring both seasonal and long-term ecosystem dynamics. Their combined use can greatly improve ecosystem spatial and temporal variability studies in two ways, (1) through inter-sensor synergies and (2) through multi-sensor data and product continuity records. Seasonal and inter-annual vegetation dynamics have been readily observed with moderate resolution satellite products, such as the 20-year NOAA-AVHRR normalized difference vegetation index (NDVI) time series record (Los, 1993: Roderick et al., 1996).

With the launch of new sensor systems, there is interest in maintaining data continuity and compatibility across the sensor-specific data sets. However, there will also exist compatibility problems among the various satellite data products due to differences in their sensor characteristics as well as algorithms used (Gao, 2000; Gitelson and Kaufman, 1998). Some of the multi-sensor differences, key to their synergy, may become limitations to data and product continuity. This includes the issue vegetation index (VI) continuity and compatibility among the various sensors, which must first be addressed. In shifting from an older sensor to a newer one, one can take advantage of 'state of the art' technology advancements (e.g., better sensor materials) and improved scientific knowledge (e.g., better spectral band configurations), however, there is the dilemma of maintaining data continuity across a time series data record while allowing for new and improved algorithms and data processing.

The "key" factors affecting continuity and compatibility of VI data sets computed from different sensors involve;

- sensor calibration and degradation
- differences in spatial resolutions and their associated point spread functions (PSF)
- co-registration and geolocation
- differences in spectral bandpass filters
- atmospheric correction methods (O_3, H_2O, aerosols)
- cloud masking methods and their efficiency
- compositing techniques and period

Narrow and broad-band vegetation indices were investigated by Elvidge et al. (1995). Miura et al. (2002) utilized Hyperion imagery along a Brazil transect and showed VI translation between sensors to be land cover, soil, and biomass dependent. Yoshioka et al. (2003) developed an algorithm for translating VI data among sensors utilizing a linear approximation of vegetation isolines and numerical simulations using leaf and canopy radiative transfer models. They applied the algorithm to a Hyperion image and were able to significantly reduce the differences in NDVI data for a wide range of LAI conditions.

In this study we used EO-1 Hyperion imagery obtained over a set of biome types to generate broadband reflectance and VI values for various Earth observing satellite sensors. Multi-sensor comparisons and analyses of vegetation index products are made for the "Constellation" series of sensors that include Landsat-7 ETM+, EO-1, Terra-MODIS/ASTER, and the Multispectral Medium-Resolution Scanner (MMRS), as well as for additional fine and moderate resolution sensor systems. We focus on the spectral issues (filter response function, bandwidth, center wavelength) influencing the derived reflectance and vegetation index values and also address the various issues involved in multi-sensor synergy use, including translation, data continuity, and scaling. The objectives for this study were (1) to investigate the "spectral" continuity and compatibility of reflectances and VIs among the different sensors using Hyperion scenes over a range of land cover types, and (2) to investigate target dependencies (land cover, soil, etc.) on the translation coefficients among sensors.

2. STUDY SITES AND METHODS

There are many techniques that can be used to analyze multi-sensor differences in VI's, including the use of 'real' satellite sensor observations. The advantages of this approach are that the real data from which we wish to establish translation are used and this also encompasses all sources of uncertainty, including filter degradation and calibration drift. The disadvantages are the time intervals between different sensor 'looks' over the same target and the confusion created with possible variations resulting from sun angle and atmosphere differences. One must also be precise in co-registration of the two sensor data sets with additional uncertainties resulting from geolocation error. A more controlled approach is to utilize finer resolution sensor data and simulate the responses of coarser resolution sensor data sets. Hyperion hyperspectral data are thus ideal to simulate MODIS, SeaWiFS, AVHRR, and GLI pixels, the advantages being that only a single atmosphere and sun angle are involved and there are no spatial registration errors. The disadvantage is that the data is synthetic and the spectral response functions and modulation transfer function (MTF) need to be approximated.

We utilized Hyperion data over a 400–2500 nm wavelength range with nominal spectral resolution of 10 nm at 30 m ground resolution. The radiometrically calibrated level 1A images were first corrected for vertical destriping noise by using the average values of assumed homogeneous areas for subsequent pixel adjustment. The data were then spectrally convolved to the bandpasses of the sensors of interest and then processed to atmospherically-corrected reflectances and VI's. The variations in spectral bandpass properties encountered in this study are shown in Fig. 1. Some atmospheric simulations were also conducted with the "6S" radiative transfer code.

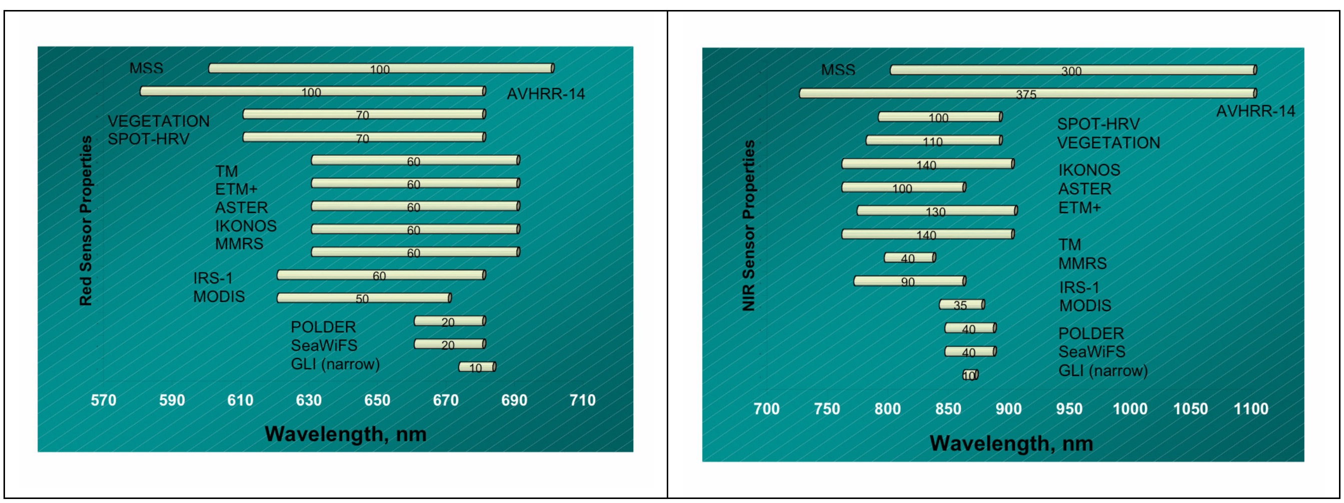

Figure 1. Variations in red (left) and near-infrared (right) spectral bandpasses among various Earth observing sensors used in vegetation studies.

Hyperion imagery over a range of international core land validation sites of varying land cover types and surface conditions were utilized in this study, including a Hyperion data over Maricopa Agriculture Center in Arizona, the

Mandalgovi steppe site in Mongolia, and the Harvard forest long-term ecologic research (LTER) site (Fig. 2). At each of the Hyperion sites, data were extracted from a 20 x 20 pixel area for further analyses.

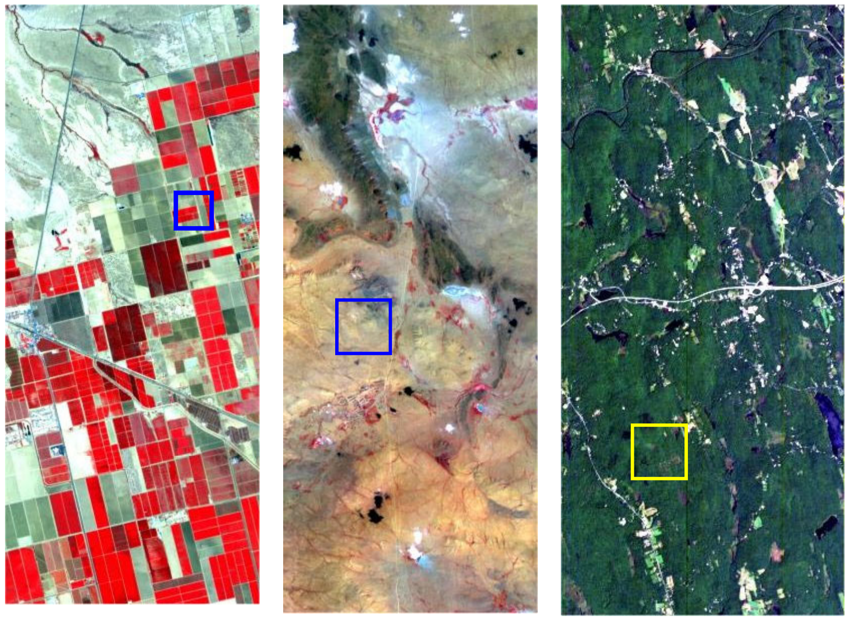

Figure 2. EO-1 Hyperion imagery over the study sites used in the evaluation of vegetation indices. Maricopa September 29, 2001 (left); Mandalgovi August 31, 2001 (middle); and Harvard forest September 5, 2001 (right).

3. RESULTS

The Hyperion bandpass-convolved results over the Harvard forest study area are shown in Fig. 3 for the MODIS, Landsat-7 ETM+, and NOAA-AVHRR 14 sensors under atmospherically corrected (surface) and uncorrected (top-of-atmosphere, TOA) conditions. There were much higher inter-sensor variations encountered with the TOA results, indicating the strong interactions of atmosphere and sensor bandpass on the resulting red, NIR, and NDVI data. The AVHRR varies the most from the other sensors with higher red reflectances and lower NIR and NDVI values. The surface NDVI values from the AVHRR are lower than the other 2 sensors due to the higher red reflectance response. The Maricopa Agriculture study site had a bi-modal range of surface conditions with bare soil and highly-vegetated crops present in the same scene (Fig. 4). The red reflectance results among the 3 sensors varied only slightly in both TOA and surface cases while the NIR results only varied in the uncorrected, TOA data with AVHRR yielding the lowest reflectances and MODIS the highest. This may be an atmosphere water vapor effect with the AVHRR bandpass the most vulnerable to water vapor while the MODIS NIR bandpass was designed to be free of water vapor contamination. The TOA- NDVI values followed the same pattern with AVHRR having the lowest values and MODIS the highest. By contrast, the surface-based NDVI values differed less significantly.

In the following graphs we analyze in more detail the inter-sensor spectral bandpass effects on the computed vegetation indices. The top portion of Fig. 5 shows that all bands are highly inter-correlated, as would be expected since they are measuring within the same portion of the spectrum. One can also note, however, that the inter-sensor relationships have significant slope and/ or intercept differences. The AVHRR and ASTER NIR reflectances, for example, deviate significantly from the 1:1 line (Fig. 5). In the lower portion of Fig. 5, we plotted the surface reflectance difference ($\rho_{sensorX}$ - ρ_{MODIS}) to highlight these deviations. Using the MODIS reflectances as the reference (any sensor could be used for the reference case), we see that the differences associated with a different bandpass in the red and NIR region are dependent on the initial MODIS reflectance condition and that a second sensor's response could result in higher or lower values. In the case of the red bandpass, maximum deviations from the MODIS value occur at low and high reflectance conditions with deviations increasing as the MODIS surface reflectance departs from 0.15 in either direction (Fig. 5). In the case of the NIR reflectances, minimum variations occur at low MODIS reflectances (<0.33) with deviations becoming stronger as MODIS NIR reflectance increases in value. Another observation worth noting is that for any given MODIS reflectance values, there are varying reflectance values for a second sensor, e.g., a MODIS reflectance value of 0.40 in the NIR yields numerous ASTER reflectances.

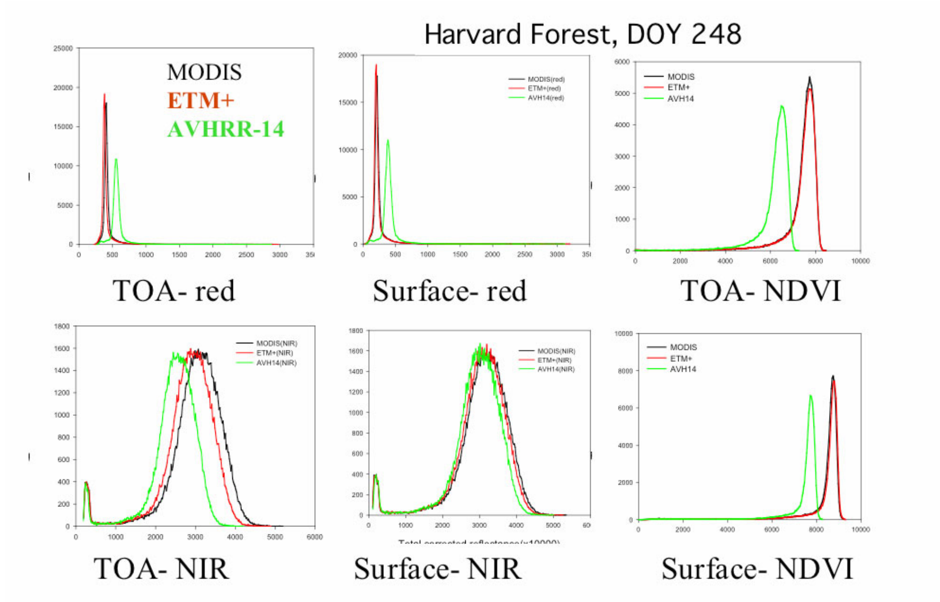

Figure 3. Histograms of red, NIR, and NDVI data over the Harvard forest study site for the 3 sensors, MODIS, Landsat-7 ETM+, and NOAA-AVHRR-14, and for TOA and atmospherically-corrected (surface) conditions.

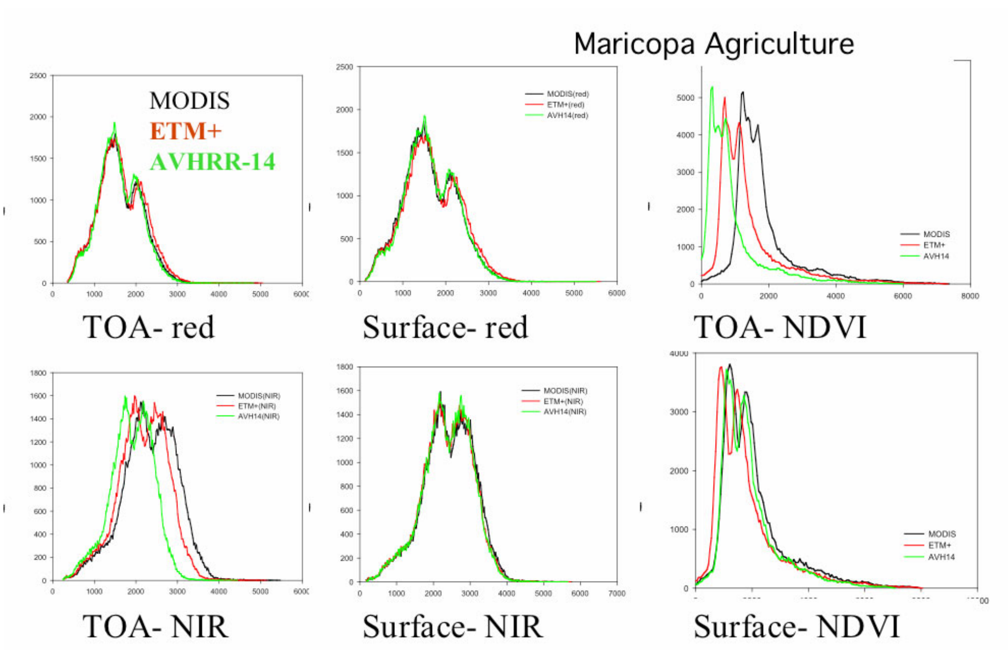

Figure 4. Histograms of red, NIR, and NDVI data over the Maricopa Agriculture Center study site for the 3 sensors, MODIS, Landsat-7 ETM+, and NOAA-AVHRR-14, and for TOA and atmospherically-corrected (surface) conditions.

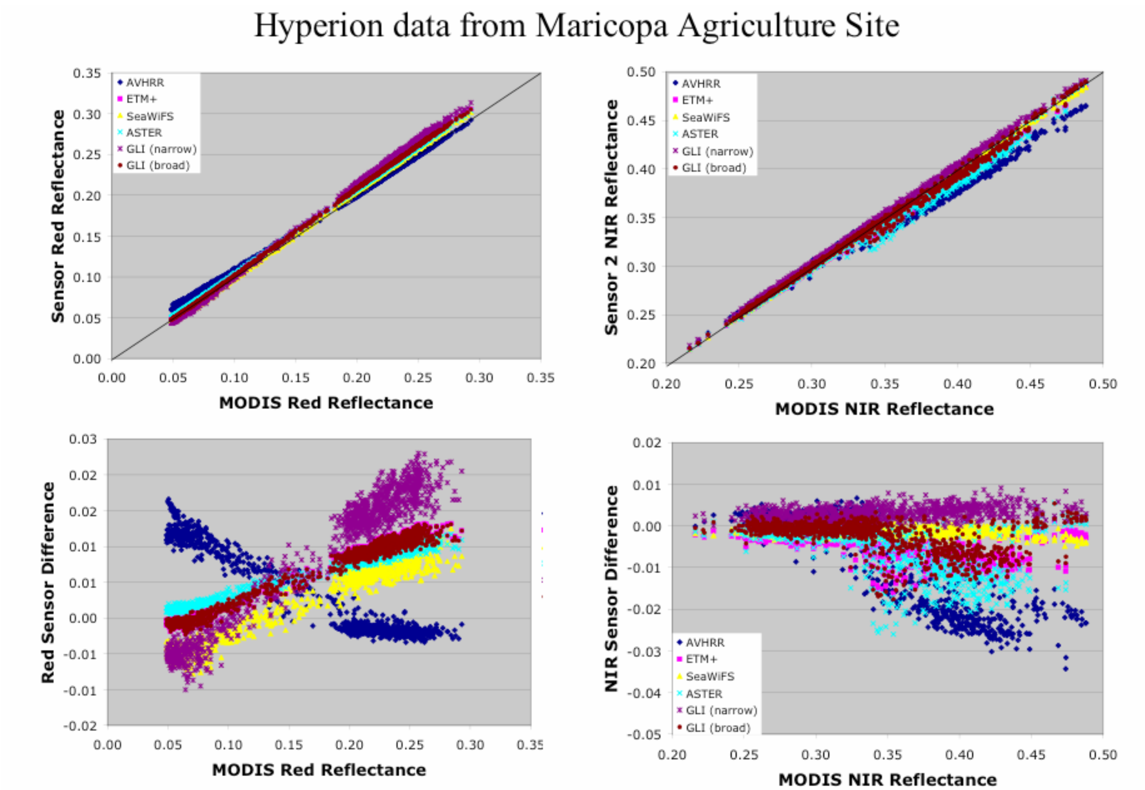

Figure 5. Hyperion-generated crossplots of inter-sensor band surface reflectances (top) and their differences using MODIS as a reference (bottom).

In Fig. 6, the corresponding VI values are plotted using the sensor differences to highlight the deviations. The NDVI comparisons behaved similar to the red bandpass comparisons in Fig. 5. Thus, the difference in NDVI between MODIS and AVHRR become greater at higher NDVI values, i.e., MODIS NDVI values are higher than AVHRR at higher biomass conditions (up to 0.07 NDVI units). In the right hand side of Fig. 6 we also compared a partially atmosphere corrected data set (only corrected for Rayleigh scattering and ozone absorption) and we found that atmosphere plays a bigger role in inter-sensor relationships than bandpass differences among sensors. However, in the case of the enhanced vegetation index (EVI) (Huete et al., 2002), atmosphere-induced variations are not so strong and bandpass variations among sensors become greater with higher MODIS EVI values (Fig. 6). There are not as many sensors available for comparisons given the need for a blue band for the EVI computation.

4. CONCLUSIONS AND DISCUSSION

We investigated continuity and compatibility of the broadband reflectances and VIs across various Earth observing sensors. EO-1 Hyperion data was used in different biome sites to synthetically generate multi-sensor reflectances and VI's, including the NDVI and EVI. Our analyses focused on the spectral issue (spectral characteristics of multiple sensors and their influences on the derived VI values). The sensors considered in this spectral syntheses were MODIS, AVHRR, SeaWiFS, VEGETATION, GLI, ASTER, and ETM+. The major findings were that:

- VI relationships among sensors were neither linear nor unique and were found to exhibit complex patterns and dependencies on spectral bandpasses.
- From the biophysical point of view, inter-sensor VI relationships varied with land cover types and surface characteristics. Thus, a prior knowledge of such ecosystem parameters as leaf area index (LAI), land cover type, and soil brightness are needed for exact translation.
- Atmospheric contaminations were found to increase the discrepancies and land cover dependencies of inter-sensor VI relationships, of which magnitudes depends both on level of atmospheric contaminations and on amount of vegetation density.

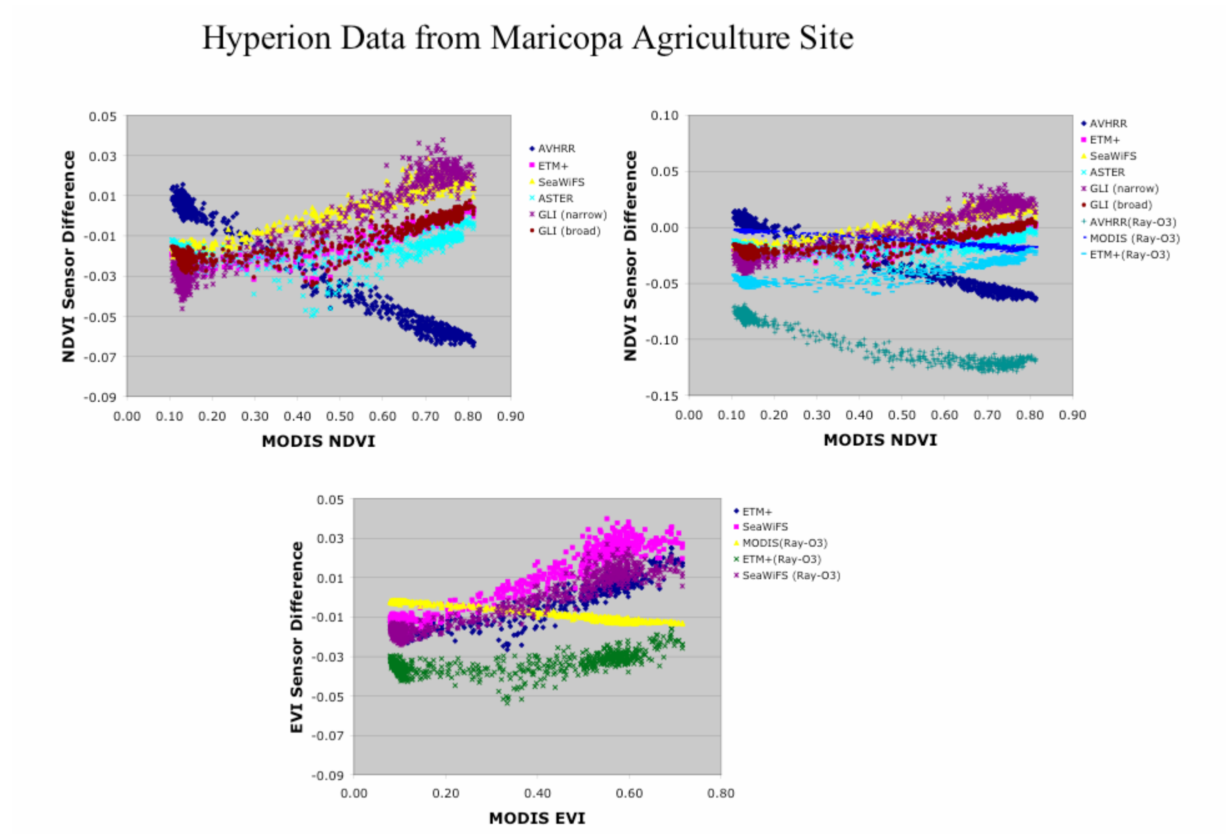

Figure 6. Hyperion generated crossplots of inter-sensor NDVI differences (top) and inter-sensor EVI differences (bottom) using MODIS as a reference.

Vegetation index relationships among sensors were found to exhibit complex patterns and dependencies based only on their spectral bandpasses. Thus, a reflectance or VI value from one sensor can yield multiple values in a second sensor. NDVI relationships among sensors varied with surface conditions, such as land cover type, biophysical parameter amounts, and possibly canopy background. The results shown here demonstrate that inter-sensor calibration and continuity of VI's are achievable but require biophysical and land cover characterization of surface conditions. We found that the atmosphere resistant VI's would provide improved multi-sensor translations, by reducing the effects of atmosphere on inter-sensor translation of VI's. Other factors that could affect the multi-sensor VI values to a greater extent include the cloud masking algorithm, BRDF-related effects, and the method of compositing, such as maximum value compositing (MVC), constrained view angle MVC (CV-MVC), minimum 'blue' compositing ('min. blue'), BRDF- based compositing, etc.

Multi-sensor comparisons with actual data from Landsat, EO-1, MODIS, AVHRR, and Terra are also needed to confirm some of the observations reported in this study. Such studies will become even more relevant in establishing a long term time series record involving the AVHRR time series record (1981-) with MODIS (2000-) and the next generation of the National Polar-orbiting Operational Environmental Satellite System (NPOESS).

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