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# APPLICATIONS USING EO-1 HYPERION AT-SENSOR AND SURFACE REFLECTANCE: COMPARISONS AND CASE STUDIES

Yen-Ben Cheng<sup>1,2,†</sup>, Elizabeth M. Middleton<sup>1</sup>, Qingyuan Zhang<sup>1,3</sup>,  
Stephen Ungar<sup>1,3</sup>, Petya K. E. Campbell<sup>1,4</sup>

<sup>1</sup>National Aeronautics and Space Administration, Goddard Space Flight Center,  
Greenbelt, MD 20771, USA

<sup>2</sup>Earth Resources Technology, Inc., Annapolis Junction, MD 20701, USA

<sup>3</sup>Goddard Earth Science Technology Center, University of Maryland Baltimore County,  
Baltimore, MD 21250, USA

<sup>4</sup>Joint Center for Earth Systems Technology, University of Maryland Baltimore County,  
Baltimore, MD 21250, USA

<sup>†</sup> Corresponding author, e-mail: Yen-Ben.Cheng@nasa.gov

## ABSTRACT

The NASA EO-1 Hyperion observations were utilized to derive at-sensor Top-of-atmosphere (TOA) and ATREM-corrected surface reflectance over three study sites of different land use types. Direct comparisons between TOA and ATREM reflectance showed the most disagreement in the visible spectral region and regions that were affected by water absorption features. Nevertheless, as little as 3% overall differences were found for an arid desert scene. Furthermore, example applications using Hyperion at-sensor TOA reflectance were investigated. Selected band ratio vegetation indices calculated from both TOA and surface reflectance were correlated ( $r=0.6$  to  $0.94$ ) but differed in magnitude. For instance, NDVI calculated from at-sensor TOA reflectance consistently showed lower values. A potential quick-look product using these indices to model relative vegetation stress was demonstrated in this study.

**Index Terms**— Satellite applications, agriculture, ecology, vegetation

## 1. INTRODUCTION

The NASA Earth Observing One (EO-1) Mission has developed and validated cutting-edge technologies designed to enable future spectroscopic systems monitoring the Earth, for example the Decadal Survey Tier 2 mission under development, the Hyperspectral Infrared Imager (HypIRI). One of the sensors carried by the EO-1 satellite, Hyperion, provides high spatial ( $\sim 30$  m) and spectral ( $\sim 10$  nm FWHM from 350 nm to 2500 nm, 242 bands) resolution observations in the visible to shortwave infrared (VSWIR) spectral region. These continuous spectral observations provide a great opportunity to improve detecting and

identifying various land surface targets by using enhanced characterization techniques [1]. For instance, lots of efforts have been put toward retrieving vegetation leaf biochemical and canopy biophysical properties using spectrometer imagery [2-4]. One of the commonly used retrievals is the band ratio index, which is usually a combination of a signal band and a reference band. Examples include the pigment and structure sensitive Normalized Difference Vegetation Index (NDVI), the xanthophyll-based Photochemical Reflectance Index [5] and the canopy water content driven Normalized Difference Infrared Index [6, 7]. Because of the capability of retrieving information in physiology, structure and phenology, the VSWIR spectrometer imagery have also been utilized to delineate different land cover and plant functional types [2, 8].

Before utilizing spectrometer data in the applications described above, pre-processing and corrections are usually performed on the radiance data in order to convert radiance readings to reflectivity relative to incident solar radiation. Various models have been developed and utilized with Hyperion observations including the Atmosphere CORrection Now (ACORN, ImSpec LLC, Analytical Imaging and Geophysics LLC, Boulder, CO)[9] and the ATmosphere REMoval algorithm (ATREM)[10] to convert the radiance readings into apparent surface reflectance. On the other hand, the at-sensor Top-of-atmosphere (TOA) reflectance has also been investigated for its usage for different purposes [1]. We anticipate that there will be a critical need to provide quick-look reflectance data to users of future imaging spectroscopy, which can most easily be accomplished with TOA reflectance. However, the relative accuracy of TOA vs. surface reflectance products must be carefully evaluated. This paper investigates and explores the use of both at-sensor TOA reflectance and surface reflectance by comparing results of example applications.

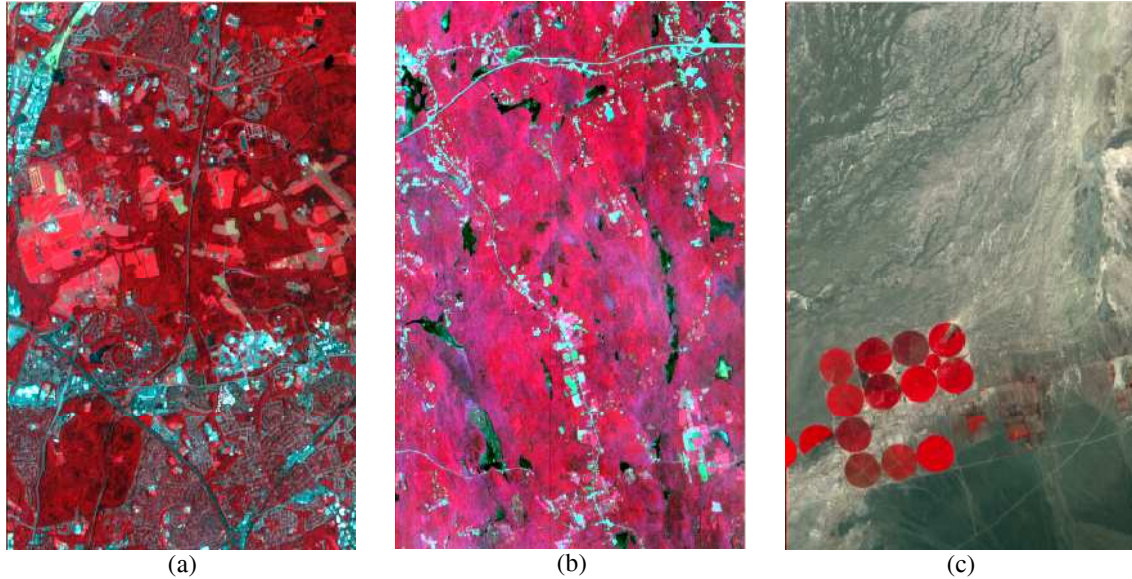


Figure 1. Color infrared (CIR) composition of EO-1 Hyperion imagery on (a)Greenbelt/Beltsville, MD on DOY 231, 2008; (b)Harvard Forest, MA on DOY 159, 2008; (c)Railroad Valley, NV on DOY 176, 2008.

## 2. METHODS

The study utilized three sets of Hyperion imagery acquired over various land cover types across the growing season: Greenbelt/Beltsville, MD (urban/agriculture; DOY 108, 172, 190, 231, and 277 of 2008; Fig. 1a); Harvard Forest, MA (mixed forest, DOY 128, 159 of 2008; Fig. 1b), and Railroad Valley, NV (desert/agriculture; DOY 176 of 2008; Fig. 1c).

To calculate at-sensor TOA reflectance, we followed the algorithm presented in Griffin et al. [1] but utilized an improved solar spectral irradiance model developed by Thuillier et al. [11] instead. The algorithm calculates the at-sensor TOA reflectance by dividing the channel radiance by the incident solar flux corrected for sun angle and earth-sun distance [1]. Surface reflectance was retrieved using the ATREM [10] algorithm. The algorithm is a MODTRAN (Moderate Resolution Transmittance Code)-based model developed to remove any noise and effects caused by scattering and absorption from the atmosphere. In this study, we utilized a version of ATREM that has recently been customized for the EO-1 Hyperion characteristics.

Two example applications were presented in this study to compare the use of at-sensor TOA reflectance and ATREM-derived surface reflectance. The first application was vegetation indices retrievals. Three band ratio indices were calculated from both at-sensor TOA and surface reflectance: the Normalized Difference Vegetation Index (NDVI, using bands centered at 650 and 854 nm), the Photochemical Reflectance Index (PRI, using bands at 531 and 570 nm)[5], and the Normalized Difference Infrared Index (NDII, using bands centered at 854 and 1638 nm)[6, 7]. For the Greenbelt/Beltsville scene, a field campaign was conducted on a USDA research cornfield (39.03°N,

76.85°W) on DOY 231 and DOY 277, 2008. Canopy-level reflectance observations were collected one meter above the vegetation canopy with a nadir view using an USB4000 Miniature Fiber Optic Spectrometer (Ocean Optics Inc., Dunedin, Florida, USA), having a spectral resolution of ~1.2 nm (sampled at 0.2 nm). Vegetation indices were calculated from these *in situ* measurements and were compared to retrievals from EO-1 Hyperion observations.

The other application was to develop a unique map product by combining the three vegetation index maps previously produced (NDVI, PRI, NDII) as inputs to a standard unsupervised classification routine, for each TOA and surface image. These classification maps provided several levels of relative vegetation stress (either nine levels or aggregated to three levels).

## 3. RESULTS

Examples of at-sensor TOA reflectance (Fig. 2a) and ATREM-derived surface reflectance (Fig. 2b) are shown for the Railroad Valley scene. Direct comparisons between spectra of at-sensor TOA and ATREM surface reflectance were performed on all three sets of imagery. The largest disagreements between TOA and ATREM reflectance occurred in the visible region (~400 to 700 nm), most likely due to atmospheric scattering effects caused by aerosols. Significant differences were also found in the spectral region between 1500 and 2000 nm for vegetated areas (e.g., forest and crops), most likely due to higher surface water content. The amplitude of the differences varied for different scenes. For the arid Railroad Valley scene, the overall differences were consistently under 3% across the spectrum. On the other hand, differences as large as 10% were found for the visible region in the Harvard Forest

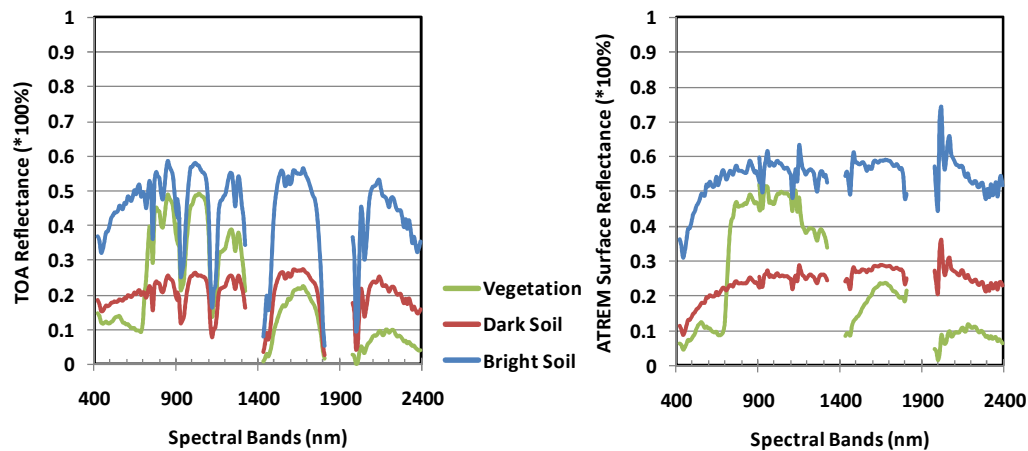


Figure 2. Comparisons between Hyperion at-sensor TOA reflectance (left panel) and ATREM-corrected surface reflectance (right panel) for the arid Railroad Valley, NV scene on DOY 176, 2008.

scene, possibly due to the variable atmospheric conditions associated with land cover types. In general, the disagreement between TOA and surface reflectance was higher in vegetated areas than in non-vegetated areas.

Vegetation indices retrieval was selected as an example application to compare TOA and surface reflectance. NDVI and NDII showed good correlation between at-sensor and surface reflectance indices ( $r \sim 0.94$ ) but also varied scene by scene. However, both TOA NDVI and NDII indices showed lower values than comparable values retrieved from ATREM surface reflectance. This resulted because the TOA reflectance had relatively lower values in the near-infrared (NIR) spectral region and higher values in the visible spectral region. In contrast, the most significant disagreement between indices retrieved from TOA and surface reflectance was found for the PRI ( $r \sim 0.6$ ), because its two narrow visible region green bands are more sensitive to atmospheric effects than indices that utilize NIR bands.

For the Greenbelt/Beltsville area, we also compared Hyperion-derived vegetation indices with *in situ* observations acquired using an USB4000 Miniature Fiber Optic Spectrometer. Results are summarized in Table 1. Values of NDVI derived from ATREM surface reflectance were consistently higher than those determined *in situ* (Table 1). On the contrary, values of NDVI derived from at-sensor TOA reflectance were lower than *in situ* NDVI (Table 1). For the PRI, *in situ* values from both days were negative, indicating physiological stress, with lower (more negative) values indicating more stressful conditions were expressed on the October date during senescence (Table 1). The PRI derived from ATREM reflectance was consistently lower than *in situ* PRI (Table 1). However, the PRI derived from at-sensor TOA reflectance was considerably higher and showed positive values on both days—which would be erroneously interpreted as a non-stress condition.

Our final step was to develop a unique map product by combining the three vegetation index maps previously produced (NDVI, PRI, NDII) as inputs to a standard

unsupervised classification routine, for each TOA and surface image. These classification maps provided several levels of relative vegetation stress (either nine levels or aggregated to three levels). The nine levels showed the best description of relative stress across the scenes, but a simpler version was obtained when grouped into just three levels. The maps derived from TOA vs. surface reflectance were compared for both the nine and three categories of stress, by calculating the average difference over all levels. In the Greenbelt/Beltsville scenes, the overall differences for maps produced from TOA vs. surface data were larger for the nine category map in springtime (31%) vs. summer (15%), indicating that surface conditions were more uniform in the middle of the growing season than during the green-up phase. Aggregating to three stress levels increased the agreement between TOA and surface maps; for example, only a 4.2% difference was found in the summertime (Fig. 3). However, for the Harvard Forest, similar differences were found in the early growing season (DOY 128) and in the vegetative stage (DOY 159). The differences were approximately 20% for the nine level stress map and 10% for the three stress level map, whether produced using at-sensor TOA reflectance or surface reflectance.

#### 4. SUMMARY

The applications and uncertainty assessment of EO-1 Hyperion at-sensor and surface reflectance were studied in this paper. Vegetation indices derived from ATREM surface reflectance showed satisfactory performance and agreement with *in situ* observations. Compared to atmospherically corrected surface reflectance, at-sensor TOA reflectance required less computing time but showed less satisfactory performance overall. Nevertheless, the TOA results were comparable with the results derived from surface reflectance when several indices were combined into a three level classification map to describe vegetation stress. One should notice that the differences and uncertainties could be site



Table 1. Comparisons between *in situ*, Hyperion TOA, and ATREM vegetation indices values in an experimental USDA corn field on DOY 231 and 277, 2008. Values are shown as mean±S.D.

		<i>In situ</i>	Hyperion TOA	Hyperion ATREM
DOY 231, 2008	PRI	-0.027±0.007	0.049±0.010	-0.036±0.018
	NDVI	0.740±0.024	0.720±0.012	0.800±0.011
	NDII	N/A	0.310±0.023	0.430±0.022
DOY 277, 2008	PRI	-0.063±0.009	0.031±0.011	-0.080±0.023
	NDVI	0.690±0.042	0.630±0.018	0.720±0.016
	NDII	N/A	0.150±0.011	0.230±0.012

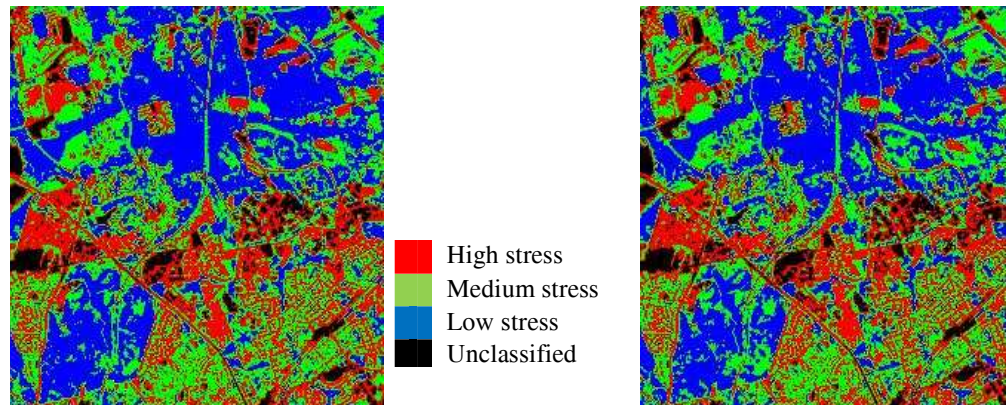


Figure 3. Vegetation stress map (3 levels) produced with at-sensor TOA reflectance (left panel) and ATREM surface reflectance (right panel) over the Greenbelt/Beltsville area on DOY 190, 2008.

and time dependent since some variables were not taken into account when calculating at-sensor reflectance (e.g. viewing geometry and atmospheric conditions). Hence, further investigations are needed for the use of at-sensor reflectance for potential on-board processing products and fast response applications such as to monitor fire and other disasters in near real-time.

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