Evaluation and Validation of EO-1 Hyperion for Geologic Mapping

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Abstract— NASA's EO-1 Hyperion sensor, launched in November 2000, provides the first opportunity to evaluate short-wave-infrared (SWIR) spaceborne hyperspectral capabilities. Hyperion covers the 0.4 to 2.5 µm range with 242 spectral bands at approximately 10nm spectral resolution and 30m spatial resolution. Selected validation results for geology over USA sites with abundant ground truth and airborne hyperspectral data are described here.

I. Introduction

Spectroscopy in the solar spectral range, 0.4 to 2.5 µm, provides diagnostic information about many important Earth-surface materials. In particular, the 2.0 to 2.5 µm (SWIR) spectral range covers vibrational features of hydroxyl-bearing minerals, sulfates, and carbonates common to many geologic units and hydrothermal alteration assemblages[1]. "Hyperspectral" sensors or Imaging Spectrometers provide a unique combination of both spatially contiguous spectra and spectrally contiguous images that allow mapping these features[2]. Research-grade airborne hyperspectral data have been available for over 20 years and have proven the ability of these systems to uniquely identify and map many minerals, even in sub-pixel abundances[3, 4].

The launch of NASA's EO-1 Hyperion sensor in November 2000 marks the first operational test of a SWIR spaceborne hyperspectral sensor. Hyperion covers the 0.4 to 2.5 micrometer spectral range with 242 spectral bands at approximately 10nm spectral resolution and 30m spatial resolution over a 7.5km swath from a 705km orbit[5]. Validation sites in a variety of geologic terrains were selected based on pre-existing abundant supporting information in the form of extensive field mapping and spectral measurements, and previous or scheduled airborne hyperspectral data. Results for selected sites in the USA and around the world have been previously reported[6,7]. Selected USA results are summarized here.

II. Airborne Hyperspectral Baseline

Airborne hyperspectral data serve as the baseline for comparative determination of Hyperion spectral, spatial and radiometric properties. Current airborne sensors provide high-spatial resolution (2-20m), high-spectral resolution (10-20nm), and high SNR (>500:1) data. The Airborne Visible/Infrared Imaging Spectrometer (AVIRIS), flown by NASA/Jet Propulsion Laboratory (JPL) is a 224-channel imaging spectrometer with approximately 10 nm spectral resolution covering the 0.4 – 2.5 µm spectral range[8]. AVIRIS is flown as a research instrument on the NASA ER-2 aircraft at an altitude of approximately 20 km, resulting in approximately 20-m pixels and a 10.5-km swath width. Since 1998, it has also been flown on a Twin Otter aircraft at low altitude, yielding 2 – 4m spatial resolution.

III. Methods

Analytical Imaging and Geophysics LLC (AIG) has been a proponent of standardized methods for analysis of hyperspectral data[11]. Methods currently in use include 1) data pre-processing (destriping of Hyperion data), 2) correction of data to apparent reflectance using the ACORN[12] [MODTRAN4-based] atmospheric correction software, 3) removal of residual errors using EFFORT, linear transformation of the reflectance data to minimize noise and determine data dimensionality, 4) location of the most spectrally pure pixels, 5) extraction and automated identification of endmember spectra, and 6) spatial mapping and abundance estimates for specific image endmembers[13]. A key point of this methodology is the reduction of data in both the spectral and spatial dimensions to locate, characterize, and identify a few key endmember spectra that can be used to explain the rest of the hyperspectral dataset. Once these endmembers are selected, then their location and abundances can be mapped from the original data. These methods derive the maximum information from the hyperspectral data themselves, minimizing the reliance on *a priori* or outside information. Many of these methods are incorporated in the commercial software package "ENVI™".

IV. Results

A. Cuprite, Nevada, AVIRIS and Hyperion

Cuprite, NV, was selected for initial comparative Hyperion analysis because the Cuprite Mining District has been studied for over 20 years using remote sensing[14]. AVIRIS data acquired on July 21 1995 with 20m pixels were analyzed using the above procedures in the 2.0 – 2.5 µm range to extract key alteration minerals. Minerals identified using AVIRIS include kaolinite dickite, several varieties of alunite, buddingtonite, muscovite, and calcite (Figure 1). The AVIRIS image-map shown in Figure 2 presents a simplified coding of the mineralogy – only showing the most spectrally abundant mineral in each pixel. Hyperion data were acquired for Cuprite, NV, on 1 March 2001. Level 1 data provided by NASA were destriped then corrected to reflectance using ACORN. All bands for the 2.0-2.5 µm range were analyzed using AIG's standardized procedures. Figure 2 shows a color-coded image map of the mineral mapping results.

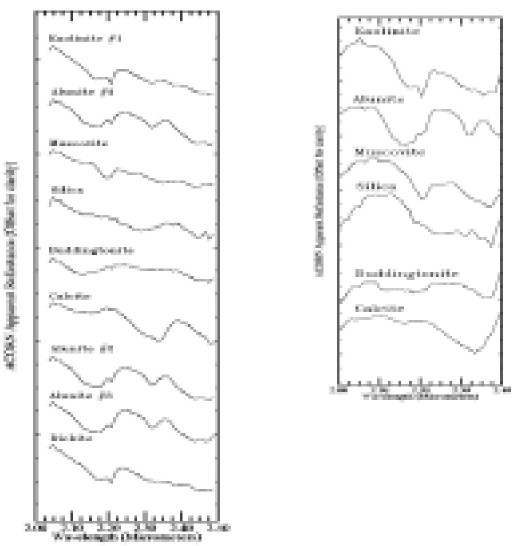

Figure 4. Endmember spectra extracted from Cuprite, NV, AVIRIS data (left) and Hyperion data (right)

Comparison of the two datasets shows that Hyperion identifies similar minerals and produces similar mineral mapping results as AVIRIS. Our analysis indicates however that the Cuprite Hyperion data do not allow extraction of the same level of detailed mineralogic information as AVIRIS (eg: fewer minerals, separation of within-species variability)[14]. It is possible to extract more detailed mineralogic information from the AVIRIS data as well as abundance information[13]. Additionally, while extraction of abundance information from Hyperion may be possible, it is more difficult and results are less accurate than for AVIRIS.

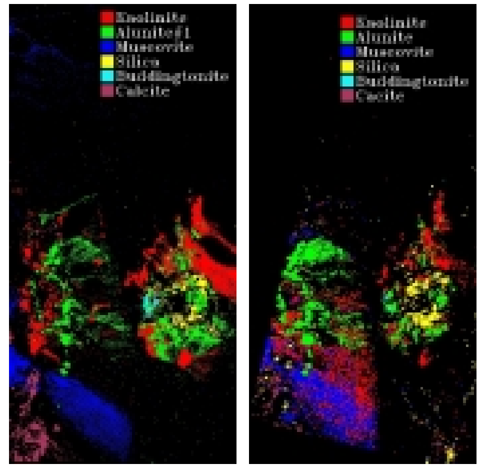

Figure 2. Cuprite mineral maps from AVIRIS data (left) and Hyperion (right). Bear in mind that AVIRIS mineral map has been simplified.

B. SNR Comparisons and Implications

Previous Hyperion investigations show that there is a strong relationship between the acquisition time of year and the signal-to-noise ratio (SNR) of the Hyperion data[7]. SNR for the same targets are higher in the summer and lowest in the winter. This has a direct effect on spectral mineral mapping, with lower SNR resulting in extraction of less detail (fewer minerals identified and less detail in specific spectra)[15]. Calculation of data SNR using a Mean/Standard Deviation method for a homogeneous target (Stonewall Playa) produces the results shown in Figure 3 for the Cuprite AVIRIS (June 1997) and Hyperion (March 2001). A second, summer-season Hyperion SNR is shown for a site in northern Death Valley, CA. All SNR are normalized to 50% reflectance.

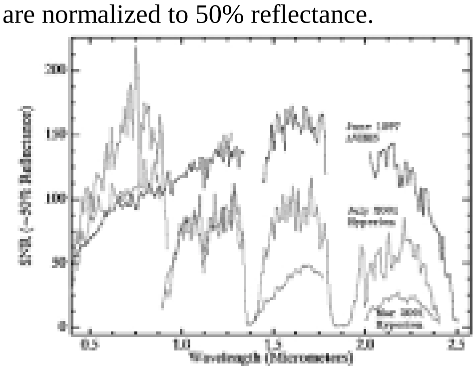

Figure 3: SNR Comparisons

Other factors affecting calculated SNR may include site latitude, target brightness, processing level, smoke, and clouds. While SNR shown here are representative of those that can be extracted directly from the data, higher SNR can probably be obtained through analysis of the data dark current signal.

V. Conclusions

Initial results at selected Hyperion validation sites establish that Hyperion is performing to specifications and that data from the SWIR spectrometer can be used to produce useful geologic (mineralogic) information. Comparison of airborne hyperspectral data (AVIRIS) to the Hyperion data shows that under optimum conditions ("summer" season, bright targets), Hyperion provides similar (however, somewhat degraded) information content, with the principal limitation being confusion of similar mineral signatures and limited mapping of fine spectral detail. These performance differences are based on lower signal-to-noise ratios (approximately 50:1 in the SWIR for Hyperion versus >500:1 for the airborne sensors). Minerals identified and mapped using Hyperion include kaolinite, alunite, buddingtonite, calcite, chlorite, dickite, dolomite, muscovite, montmorillonite, zeolites, and hydrothermal silica. We have also been able to demonstrate mapping the difference between calcite and dolomite and mapping solid solution differences in micas caused by substitution in octahedral molecular sites. Unfortunately, Hyperion data collected under less than optimum conditions (winter season, dark targets) have marginal SWIR SNR and allow mapping of only the most basic mineral occurrences and mineral differences. This results in a recommendation that future HSI satellite sensors have significantly higher SNR performance specifications for the SWIR (at least 100:1).

VI. Acknowledgments

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VII. References

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