Hyperion Validation in Yellowstone National Park Using AVIRIS, HyMap, and Field Spectra
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Research relating to validation of the EO-1 Hyperion instrument was carried out at Yellowstone National Park (YNP). The study site was located in the northeast corner of YNP that included Soda Butte Creek, Cache Creek, and the Lamar River. Mapping both depth and stream flow morphology appeared feasible using hyperspectral data. Low-altitude AVIRIS mapping of the Lamar River and Soda Butte Creek confluence took place on October 20, 1998. AVIRIS (Airborne Visible/Infrared Imaging Spectrometer) data acquired in 1996 was also used. HyMap™ hyperspectral scanner spectra acquired in October 2000 and ground spectra were also used as references to measure Hyperion performance.

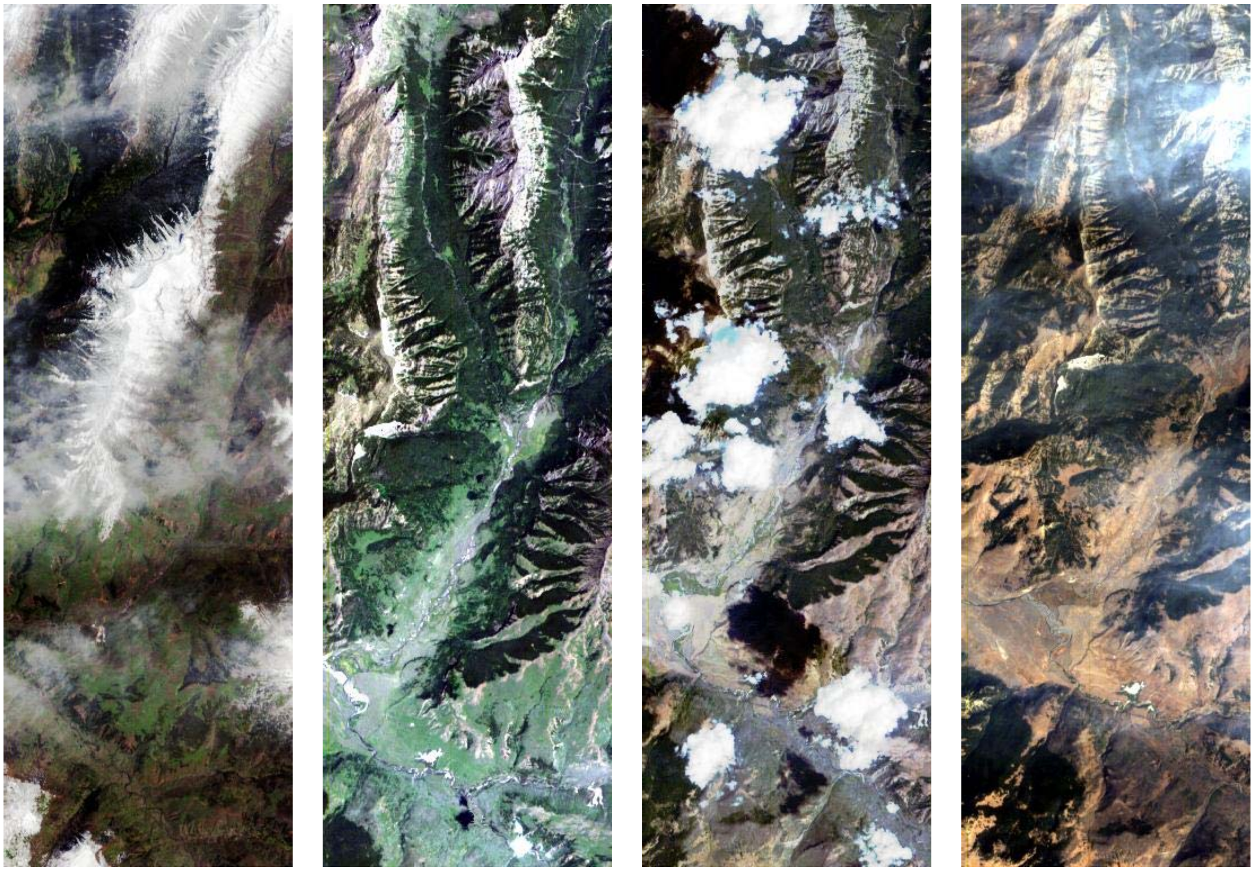
The Hyperion validation effort leveraged previous studies funded as part of the Earth Observations Commercial Applications Program (EOCAP) based at NASA's Stennis Space Center. These previous studies were tasked with exploring the operational use of hyperspectral data for riparian and in-stream ecology studies. These included large woody debris mapping (log jams in and near streams); stream flow morphology units (riffles, glides, pools, eddy drop zones, etc.); stream depth, sediment loads, algae content, and substrate; and riparian vegetation community mapping (sedge, willows, aspen, cottonwood, etc.). Although Hyperion validation could not address these small-scale issues directly, the accumulated airborne and field data would be leveraged to examine larger scale problems more suited to Hyperion's scaling.

Hyperion validation research objectives were threefold:
1. Ecological Validation – Can Hyperion data be used to create meaningful and unique products with ecological value in YNP?
2. Algorithm Development – Can researchers use Hyperion data to explore and develop the suite of new algorithms that will be required for space-based area-array imaging spectrometry?
3. Hyperion characterization – Can researchers use the Hyperion data in YNP, in conjunction with supporting field and AVIRIS data, to characterize Hyperion's on-orbit performance?

The answer to all three questions was "Yes."

Several research topics were explored:
1. Demonstrate the ecological products derived from Hyperion data
2. Explore multi-temporal leverage using spectral trajectories to exploit repeat Hyperion coverages and vegetation phenology
3. Investigate improved methods for characterization and removal of **C**alibration and **R**eduction **A**ccuracy **P**roblems, i.e., "CRAP" =vertical stripes
4. Use AVIRIS, HyMap, and ground spectra as references to measure Hyperion performance
5. Investigate problems inherent in making multi-swath large-area coverages
6. Use research results to examine the spatial/spectral/radiometric design trade-offs for future space systems.

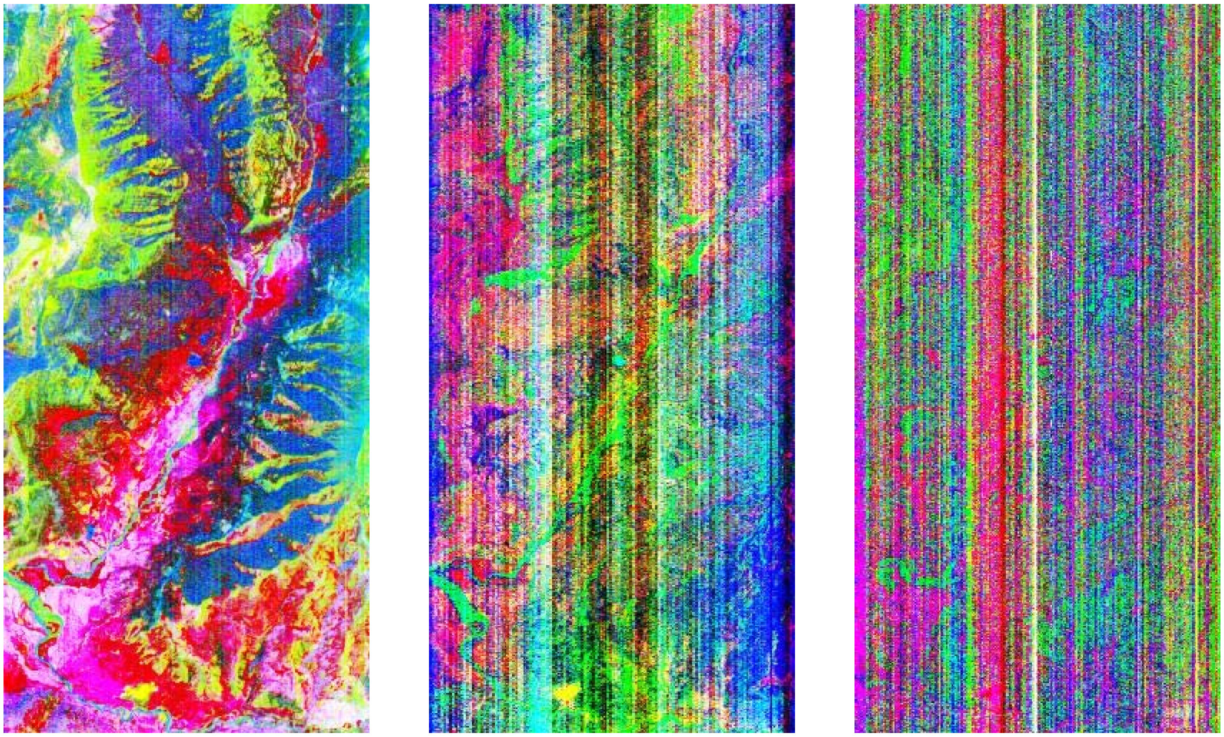
The study used several hyperspectral data sets: AVIRIS archival high-altitude data sets acquired in August 1996 and July 1997; AVIRIS experimental low-altitude data sets from October 1998 and July 1999; HyMap low-altitude data from October 2000; and a series of Hyperion data acquisitions in 2001 that were limited in usefulness by varying degrees of cloud cover (Figure 1). In addition, the study used field data consisting of surveyed ground sites with detailed vegetation plot mapping; ASD (Analytical Spectral Devices) and GER (Geophysical and Environment Research Corp.) field spectrometry of vegetation and stream units; and accumulated U.S. Geological Survey/Biological Resources Division mapping results.



Cache Creek June 6, 2001 | **Soda Butte Creek, July 2, 2001** | **Soda Butte Creek, September 4, 2001** | **Soda Butte Creek, October 6, 2001**

Figure 1. Hyperion image subsets.

Researchers encountered several problems relating to Hyperion data. First, area-array non-uniformity led to serious vertical striping in MNFs (minimum noise fractions) and processed results (Figure 2). Also, Hyperion's signal-to-noise ratio (SNR) of under 100:1 limited the instrument's suitable applications and results. Misregistration between visible and near infrared (VNIR) and shortwave infrared (SWIR) bands was also a serious concern in areas of high spatial frequency. Further, Hyperion's narrow swath width (7.5 km) posed major problems for operational uses. Cloud cover presented a problem, even in Wyoming (which tends to have clear skies). Focal plane "funnies" led to echo and smear. Finally, VNIR spectral smile required that resampling be done (or that a new suite of software be invented to deal with the condition).



MNF 1, 2, 3 **MNF 4, 5, 6** **MNF 7, 8, 9**

Figure 2. Hyperion SWIR MNF images.

Investigators applied pre-processing methods to Hyperion data. One, the orthorectification capability of Hyperion, would allow time-series modeling and inter-instrument and integration of field spectra and other ground truth data. This process has become operational with typical RMS (root mean square) errors of ~10 meters depending on ground truth accuracy. It was found that orthorectification accurate to 1/3 of a pixel permitted direct integration with a GIS (geographic information system) and ground truth. In Figure 3, Hyperion data is compared with Landsat Enhanced Thematic Mapper Plus (ETM+) three-dimensional data. The orthorectified Hyperion swath is superimposed on the ETM+ 3D view. The increased capabilities of Hyperion allow more detailed vegetation community mapping and greater subpixel accuracy. Figure 4 shows a Hyperion image and its corresponding coarse vegetative class map.

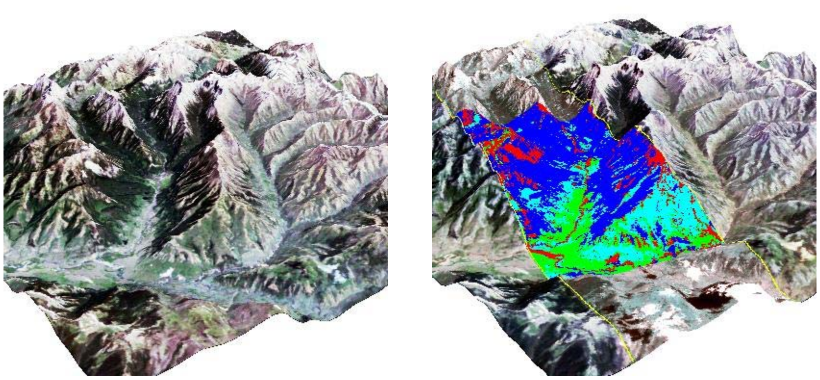


Figure 3. Landsat 7 ETM+ 3D scene and same scene with Hyperion swath superimposed.

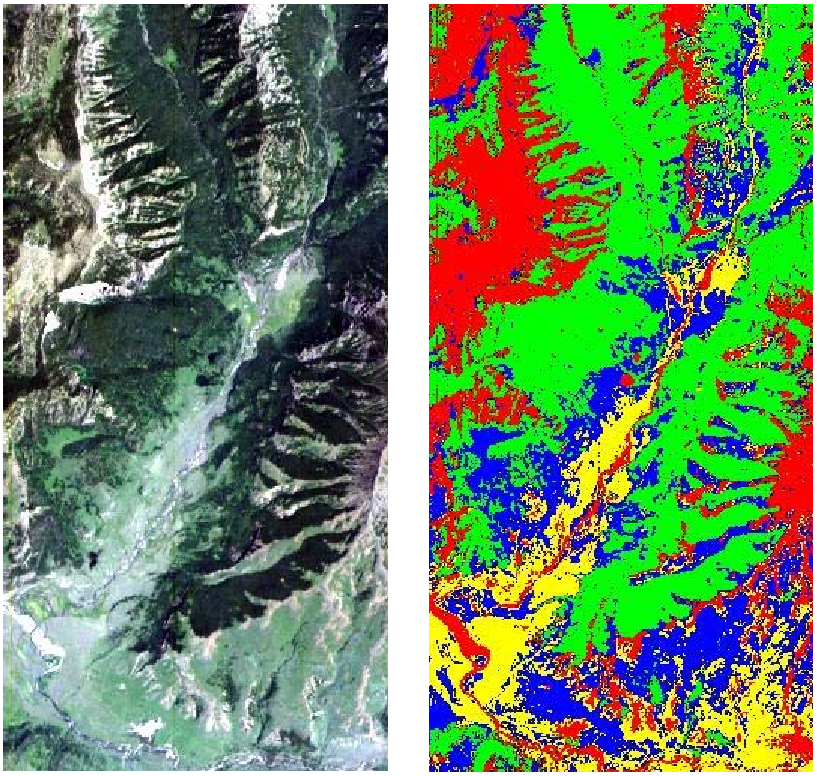


Figure 4. Hyperion coarse mapping of vegetation. Mineral soil (red), coniferous forest (green), upland grasslands (blue), and riparian vegetation (yellow) are mapped.

Another type of pre-processing looked at an area-array version of EFFORT (Empirical Flat Field Optimal Reflectance Transformation) “polishing” that leverages both spectral and spatial regularizations (Figure 5). With dual masks and EFFORT spectral fit models, the problem of spectral and spatial regularization can be solved band-by-band. The general concept and specific implementations have been proven using simulation data, but the level of Hyperion’s SNR has prevented real success in the application of Hyperion data sets. Problems with calibration and reduction accuracy (CRAP) have been common in hyperspectral imaging data and their processing, and will be a limitation of a spaceborne AVIRIS-class platform. In fact, this problem is often the “high hurdle” in Hyperion data. While simulation using “CRAP contaminated” AVIRIS data has been successful, its application to Hyperion has not been successful because of its similar scale of errors and noise. The method actually added more CRAP than it removed.

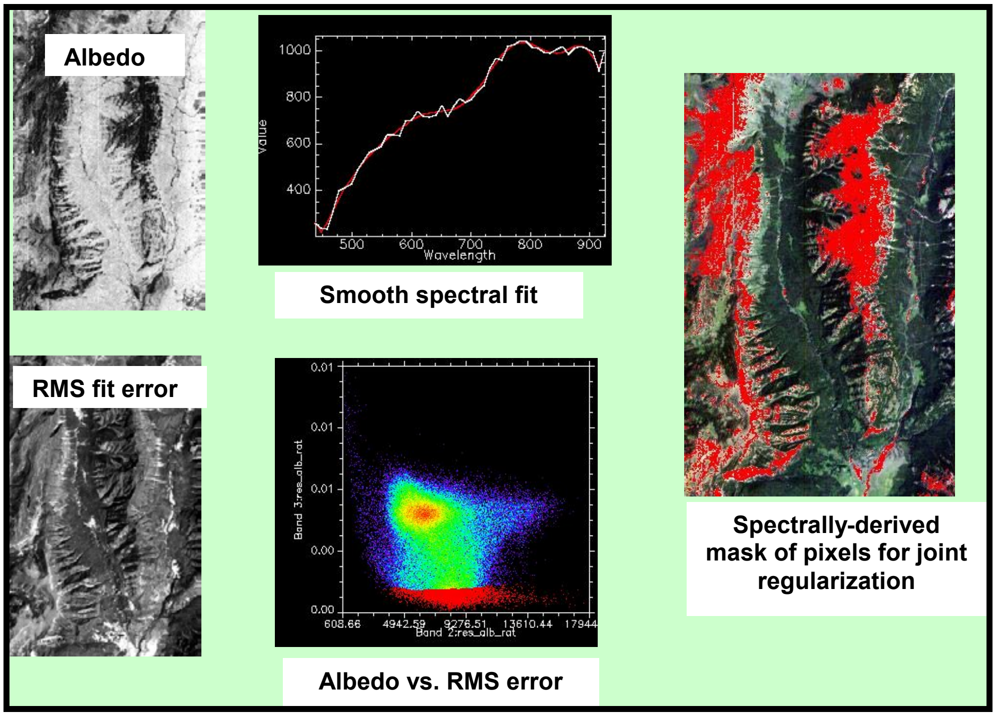


Figure 5. Development of spectral-based leverage.

Conclusions:
In this investigation, Hyperion worked as well as, or better than, expected and can be used for hyperspectral imaging investigations including conifer species and plant community mapping. The work at YNP clearly validated Hyperion performance and the value of space-based hyperspectral imaging to ecological studies.

Nevertheless, issues remain. Hyperion's SNR places it at about the "1991" level in the AVIRIS evolution, but other limitations must be considered. Hyperion's area-array non-uniformity and other artifacts are serious and affect its suitable applications. Although on-orbit data have some advantages, they also have certain limitations. This research team suggests the importance of retaining airborne imaging. In spaceborne hyperspectral imagery, the issues that must be tackled first have been identified as SNR, uniformity, stability, and then calibration. Hyperion's limited swath width, area-array data uniformity, SNR, and calibration must improve in the next generation.