HYMAP[*]: AN AUSTRALIAN HYPERSPECTRAL SENSOR SOLVING GLOBAL PROBLEMS – RESULTS FROM USA HYMAP DATA ACQUISITIONS

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Abstract

HyMap , an advanced hyperspectral sensor developed by Integrated Spectronics, Sydney Australia, represents the current state-of-the-art in airborne hyperspectral remote sensing. The sensor covers the 0.45 – 2.5 µm region in 126, approximately 15-nm-wide spectral bands with 3-10m spatial resolution and signal-to-noise ratios of 500-1000 or better. Analytical Imaging and Geophysics (AIG), Boulder, Colorado, USA, in cooperation with HyVista Corporation, Sydney, Australia (the company that operates HyMap), organized a hyperspectral "Group Shoot" across the USA during 1999 as the first step to providing affordable, high quality hyperspectral data on a commercial basis. Over 225 flightlines of HyMap data were collected for government, academic, and commercial customers. The standard product delivered by AIG/HyVista was fully-calibrated radiance data along with precision-geocoded, apparent reflectance spectral image data. This marks the first time that commercial hyperspectral data have been delivered in a standard map-referenced, reflectance corrected, ready-to-use form. Preliminary work with these datasets has demonstrated unprecedented spectral mapping capabilities for a variety of disciplines, including geology, vegetation studies, environmental assessment, near-shore marine mapping, and military applications. Data were also acquired in support of data simulation efforts for both future USA hyperspectral satellites and the proposed Australian ARIES hyperspectral satellite. This paper provides a description of the instrument, the group shoot concept, examples of the 1999 data, a description of the production processing flow, an overview of scientific analysis results, and detailed description of data analyses for selected sites/applications.

Introduction

Imaging Spectrometers, or "Hyperspectral" sensors provide a unique combination of both spatially contiguous spectra and spectrally contiguous images of the Earth's surface unavailable from other sources. Research-grade hyperspectral data have been available since the early 1980's (Goetz et al., 1985). Hyperspectral data have been used for detailed mapping of surface materials over the last 15+ years for geology (Goetz et al., 1985; Lang et al. 1987; Pieters and Mustard, 1988; Kruse, 1988; Kruse et al., 1993;

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[*] HyMap is a trademark of Integrated Spectronics

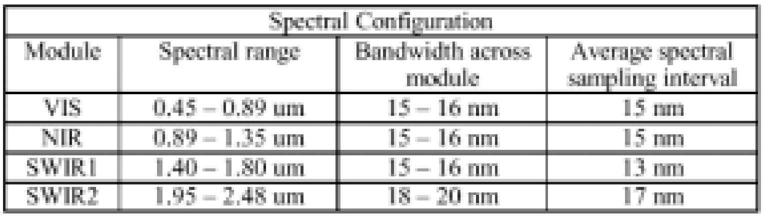
Crowley, 1993; Boardman and Kruse, 1994; Clark et al., 1996; Boardman and Huntington, 1996; Crowley and Zimbelman, 1996), atmospheric constituent gases (Gao and Goetz, 1990; Carrère and Conel, 1993; Borel and Schlapfer, 1996; de Jong and Chrien, 1996), vegetation (Peterson et al., 1988; Gamon et al., 1993; Elvidge et al., 1993; Chen et al., 1996; Green; 1996; Sabol et al., 1996), snow and ice (Nolin and Dozier, 1993; Green and Dozier, 1996), and dissolved and suspended constituents and water quality in lakes and other water bodies and the near-shore environment (Hamilton et al., 1993; Carder et al., 1993; Richardson and Ambrosia, 1996; ; Kruse et al., 1997).

The main impediment to more widespread use of these data until now has been data availability. The NASA Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) program has provided considerable data for the research community, but very little commercial data has been available. AIG conducted a hyperspectral "Group Shoot" during 1995 using the AVIRIS instrument as a first attempt to broaden the use of hyperspectral data for commercial purposes (Kruse et al., 1996). There are also some first generation commercial systems available (casi, DAIS, TRWSIII, Probe-1, etc). These, however, are either available only to a select group of investigators, operate over a limited wavelength range, or haven't as yet demonstrated true commercial viability. Analytical Imaging and Geophysics in cooperation with HyVista Corporation organized a second hyperspectral "Group Shoot" in the USA during 1999 as the next step to providing affordable, high quality hyperspectral data on a commercial basis (Kruse et al., 1999). The mission, flown using the HyMAP sensor (Cocks et al., 1998), a commercial system with 126 spectral bands at approximately 15 nm spectral resolution and spatial resolutions of 3-10 m demonstrates the viability of commercial hyperspectral data. This paper provides a description of the instrument, the group shoot concept, data examples, and processing results. High quality apparent reflectance data for over 225 flightlines have been delivered to Group Shoot participants and selected hyperspectral scenes acquired during the group shoot are available for purchase and delivery at http:/www.aigllc.com. AIG/HyVista also acquired additional HyMap data in the USA during May 2000, and a second USA mission is planned for August-September 2000.

The HyMap Sensor

HyMap is a state-of-the-art aircraft-mounted commercial hyperspectral sensor developed by Integrated Spectronics, Sydney, Australia, and operated by HyVista Corporation (Figure 1). HyMap provides unprecedented spatial, spectral and radiometric excellence (Cocks et al., 1998). The system is a whiskbroom scanner utilizing diffraction gratings and four 32-element detector arrays (1 Si, 3 liquid-nitrogen-cooled InSb) to provide 126 spectral channels covering the 0.45 – 2.5 µm range over a 512-pixel swath. Table 1 summarizes the spectral characteristics for the four spectrometers. The Y-direction of the imagery is provided by the aircraft motion. During the 1999 USA deployment, data were collected with spatial resolutions ranging from 3 to 10 meters. As summarized below, the HyMap series of sensors has attained a high level of performance in spectral and radiometric calibration accuracy, signal to noise ratio, geometric characteristics, and operational stability.

Figure 1. The HyMap sensor (left) and aircraft used for the USA acquisitions (a Cesna 402) and part of the HyVista/AIG team (right).



Spectral Configuration			
Module	Spectral range	Bandwidth across module	Average spectral sampling interval
VIS	0.45 – 0.89 um	15 – 16 nm	15 nm
NIR	0.89 – 1.35 um	15 – 16 nm	15 nm
SWIR1	1.40 – 1.80 um	15 – 16 nm	13 nm
SWIR2	1.95 – 2.48 um	18 – 20 nm	17 nm

Table 1: HyMap Sensor Characteristics (From Cocks et al., 1998).

Spectral Calibration (Summarized from Cocks et al., 1998)

The HyMap sensor is spectrally calibrated in the laboratory by programming it to view a 150 mm diameter beam from a collimator directed into the sensor. A monochromator and QI light source are used to illuminate (via an optical fiber coupling) the field stop of the collimator, the monochromator is scanned in wavelength, and the sensor records the signal levels at each wavelength. Wavelength positions of emission lines from a Ne lamp or the absorption band positions present in a plastic with known absorption features are measured and verified with a Nicolet FTIR. Spectral calibration procedures are used to determine the band center wavelengths and bandwidths. Overall spectral calibration accuracy is estimated as better than 0.5 nm.

Radiometric Calibration (Summarized from Cocks et al., 1998)

The HyMap sensor is radiometrically calibrated by having the sensor directly view a 250 mm square pad of Spectralon (SRT-99-100 from Labsphere) which is illuminated by a 1000 W QI lamp (Optronics Laboratories FEL-C). The lamp is about 650 mm from the pad and illuminates it at normal incidence. The sensor views the pad at an angle of 45 degrees. The calibration data for the Spectralon pad and FEL lamp are supplied by the manufactures and are traceable to NIST standards. At this time, the largest source of radiometric calibration error (particularly in the SWIR region) is the uncertainty in the lamp calibration information supplied by the manufacturer.

Signal-to-Noise Ratio (SNR) (Summarized from Cocks et al., 1998)

HyMap sensors have consistently delivered outstanding SNR performance. In-lab signal to noise ratios achieved by the sensor while imaging a 50% reflectance target at a solar zenith angle of 30 degrees approach 1000:1. Comparative analysis of dark images (with the sensor's shutter closed) recorded on the ground using laboratory power and during flight have not detected any significant levels of aircraft vibrational or electronic noise. Typically, the dark current noise varies by only about 0.1 DN between laboratory and airborne measurements, thus ground-based measurements of SNR are a very good indicator of the sensor's in-flight performance.

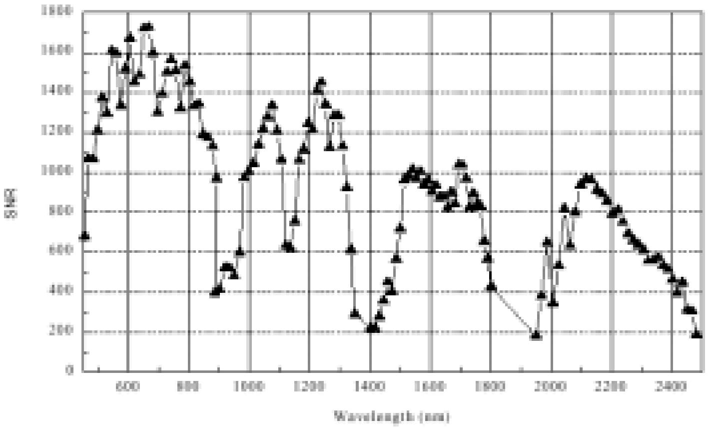


Figure 2: In-lab signal-to-noise ratios achieved by the HyMap sensor (from Cocks et al., 1998)

Geometric Corrections (Summarized from Cocks et al., 1998; and Boardman, 1999)

A Zeiss-Jena SM2000 stabilized platform is used to provide 1st level image geometry information. The system is hydraulically actuated and provides +/- 5 degrees of pitch and roll correction. The yaw can be offset by +/- 20 degrees with +/- 8 degrees of stabilization. The yaw offset or drift is currently set manually by the operator. The platform provides a residual error in nadir pointing of less than 1 degree and reduces aircraft motion effects by a factor ranging from 10:1 to 30:1.

In addition, a state-of-the-art GPS/INS "C-MIGITS II" system developed by Boeing was installed on HyMap starting with the 1999 flight season. This device provides real-time delivery of position and attitude using combined Digital Quartz Inertial Measurement Units and a MicroTracker Global Positioning System receiver. The C-MIGITS II device was bolted directly to HyMap, measuring its position and three axes of rotation at rate of 10 Hz. The position information from the GPS system and the 3-axis attitude data from the INS accelerometers are combined in a tightly coupled Kalman filter approach to give real-time information on x, y and z position values as well as roll, pitch and true heading. The stated accuracy is 4.5 meters and 1.0 milliradian when operated with differential GPS.

For the USA 1999 HyMap data, by using the high accuracy position and attitude information provided by the C-MIGITS II system, it was possible to create and employ a full photogrammetric camera model for HyMap geocorrection. Images were geocoded by ray tracing each pixel to the ground surface and implementing a nearest-neighbor resampling scheme. After geocorrection, the data are planimetrically correct, and are projected absolutely in the UTM map grid system, giving precise coordinates for each pixel.

The 1999 USA Group Shoot

Concept

The Group Shoot concept was designed to allow organizations to share the high costs normally associated with dedicated deployment of a hyperspectral sensor. The idea behind the group shoot was that organizations interested in acquiring hyperspectral data pool their resources to fly specific sites of interest. AIG acted as the coordinator for the group shoot by determining interest in bringing HyMap to the USA, by enrolling participants, coordinating flights, developing custom software, and performing centralized data processing and delivery. The initial plan called for deployment of HyMap to the USA for 4-6 weeks during 1999. Based on high interest from 30+ organizations, nearly 300 flightlines were selected for acquisition across the country.

Execution

HyMap data acquisition by HyVista took place from 3 September – 11 October 1999. Over 225 flightlines were collected corresponding to better than 85% of the proposed data acquisitions (by area). Some data were not acquired because of weather and other operational considerations. Data delivery for some clients was accomplished within one day with on-the-ground quality control review. General data delivery was accomplished within approximately 4 weeks of completion of data acquisition. To the best of our knowledge, this represents the first commercial delivery of apparent reflectance corrected and geometrically corrected hyperspectral data as a standard data product.

Figure 3: Data acquired for the 1999 HyMap USA Groupshoot. Sites mapped are marked with asterisks.

Participants

Commercial clients included Chevron, SAIC, Marconi, Autometric and others. Government participation included CRREL, SITAC, USGS, LLNL, EPA, PNL, and JPL/Warfighter. Academic sponsors included Purdue University, University of California Santa Cruz, the Elkhorn Slough Foundation, University of Colorado (CSES), University of Texas Austin, the University of Southern Mississippi, the South Dakota School of Mines, and Moss Marine Labs.

Data Examples and Applications

Data were collected for a variety of interests and disciplines. These included urban studies (Figure 4a), littoral and near-shore marine studies (Figure 4b), environment (Figure 5), minerals and geology (Figure 6), and vegetation studies (Figure 7). Other sponsor interests (not shown) included military and intelligence applications, cross calibration, and satellite system modeling. Images shown are not geometrically corrected.

Figure 4: A) Urban Studies Application: True color image of a portion of San Francisco, California. B) Near Shore Marine Application: True color image of a portion of the Bolivar Peninsula, Texas.

Figure 5: Environmental Application: True color image of a portion of the Great Miami River, Ohio

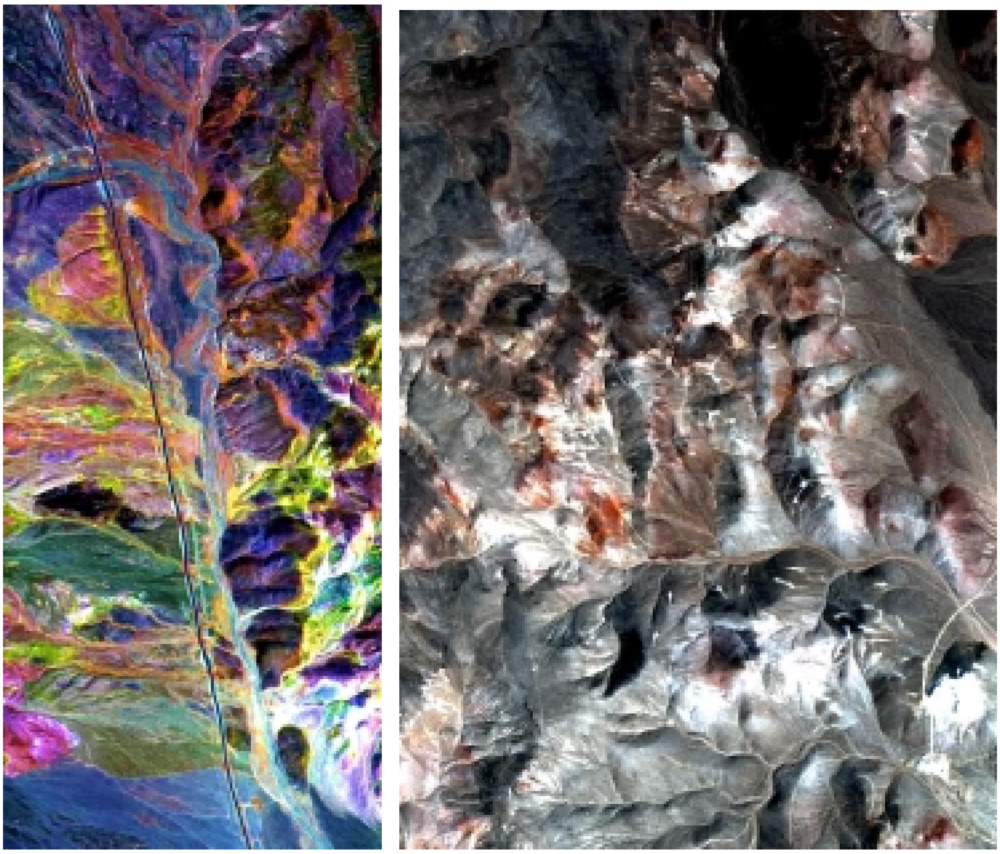


Figure 6: Geology and Mineral Mapping Applications: Left, Saturation-enhanced true color image near Cuprite, Nevada (5m spatial resolution). Right, True color image of part of Cuprite, Nevada (3m spatial resolution).

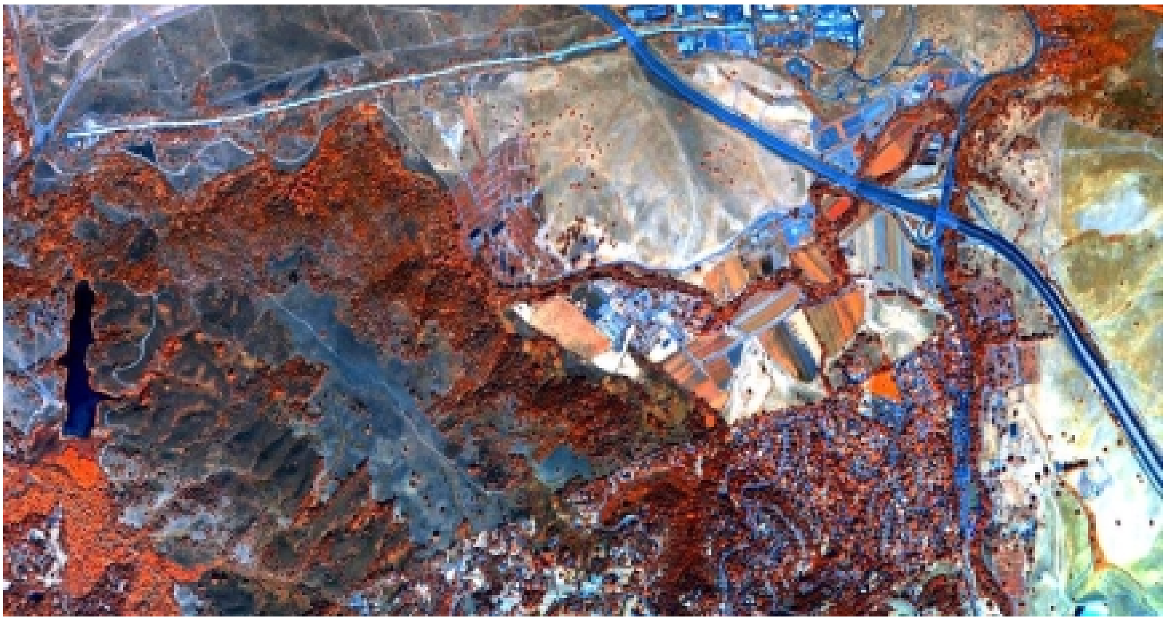


Figure 7: Vegetation Mapping Application: Portion of a false color infrared (CIR) image of HyMap flightline over the Jasper Ridge Biological Preserve, California.

Data Processing

Data were collected on Mammoth 8mm tape at a rate of greater than 20Gb per day. Preprocessing consisted of making duplicates of aircraft tapes, reading the data from tape, performing the radiance calibration, correction to apparent reflectance, performing the "EFFORT" correction, calculating the geometric correction and producing a geometrically-corrected quicklook image, and writing the standard product Radiance and Reflectance CDs (over 1000 delivered/archived). Additional processing consisting of endmember extraction, mapping, and quantification was performed on the two group sites (Cuprite, Nevada and Jasper Ridge, California) and on selected sponsor data.

1999 Group Shoot Spectral and Radiometric Calibration

Spectral and radiometric calibration was accomplished by HyVista Corporation utilizing standardized procedures (Cocks et al., 1998) Both pre- and post-mission calibration were performed for the 1999 USA HyMap group shoot. In addition, acquisition of dark current measurements for each flight was performed using an on-board reference lamp and a shutter synchronized to scan line readouts. Gains/offsets were calculated utilizing the radiometric calibration information to allow conversion of the raw DN counts to radiance values in $\mu W/cm^{-2}/nm/sr$. In addition, measurements for a laboratory cross-comparison with the AVIRIS instrument were made at JPL. An in-flight cross calibration was also planned, but was not accomplished because of weather and scheduling problems.

Atmospheric Correction

The HyMap Group Shoot data were corrected to apparent reflectance using “ATREM” software available from the Center for the Study of Earth from Space (CSES) at the University of Colorado, Boulder (CSES, 1999). ATREM is an atmospheric model-based calibration routine, and requires input of data parameters such as the acquisition date and time, the latitude and longitude of the scene, and the average elevation, along with atmospheric model parameters. No ground measurements are used in the ATREM correction. The specific parameters required by ATREM are explained in more detail in the ATREM users guide available from the University of Colorado (CSES, 1999).

EFFORT Correction

Even thought the ATREM correction is adequate for most analysis purposes, the spectra usually still contain residual atmospheric and instrument effects, which inhibit direct comparison to spectral libraries. These residual effects are typically exhibited as a superimposed “sawtooth” effect. AIG has recently implemented a correction for these residual effects that greatly improves the quality of AVIRIS spectra (Huntington and Boardman, 1996; Boardman, 1998a). This correction, the “EFFORT” correction takes advantage of the fact that a typical hyperspectral scene contains a number of featureless spectra. Because these spectra still contain the residual noise effects, they can be used to characterize the nature of the noise. Featureless spectra are identified by calculating a Legendre polynomial fit to each spectrum in the image, and then determining which spectra are well-modeled by their corresponding polynomial. The effects of albedo are also incorporated through normalization, as because the noise appears primarily to be a gain problem, we expect the fit to get worse with increasing albedo. Once the well-modeled spectra are determined, then the gains and offsets required to explain the difference between the modeled spectrum and the actual spectrum are determined in a fashion similar to empirical line calibration (Kruse et al., 1990). A linear regression is used to calculate the gain and offset for each band that will make the ATREM featureless spectra look like the modeled spectra. These gains and offsets are then applied to every spectrum in the HyMap data set. The resulting spectra contain all of the fine absorption feature detail of the ATREM data, but without the sawtooth noise, and thus are much easier to compare to library spectra (Figure 8).

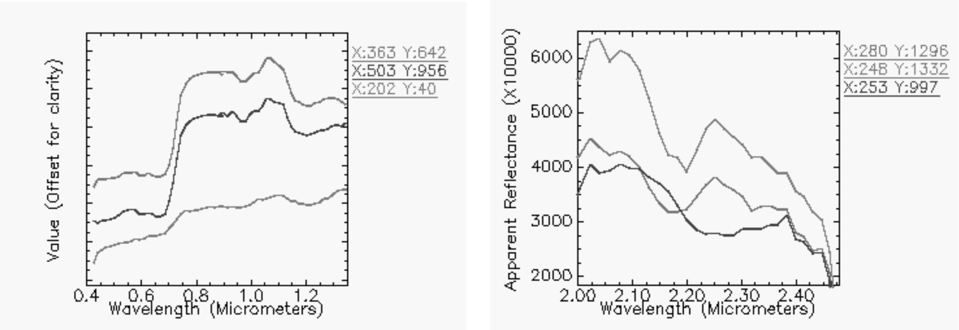


Figure 8: Sample apparent reflectance spectra. Left, Vegetation spectra; right mineral spectra for Kaolinite (top), Alunite (center), and hydrothermal silica (bottom). Note that these are for single pixels - not spectral averages.

Geometric Correction

Routine delivery of geometrically corrected hyperspectral data is now possible beginning with the USA HyMap data acquisition (Boardman, 1999). The HyMap geostabilized platform and high quality differential GPS augmented with a Boeing C-MIGITS GPS/INS and post-processing are used to establish precise geolocation (Figure 9). A geometrically corrected true color image (quick look), geometric correction factors, and software to convert the data to map coordinates were provided to the participants with each HyMap dataset. This allows users to analyze their data and then to convert analysis results to map-based products.

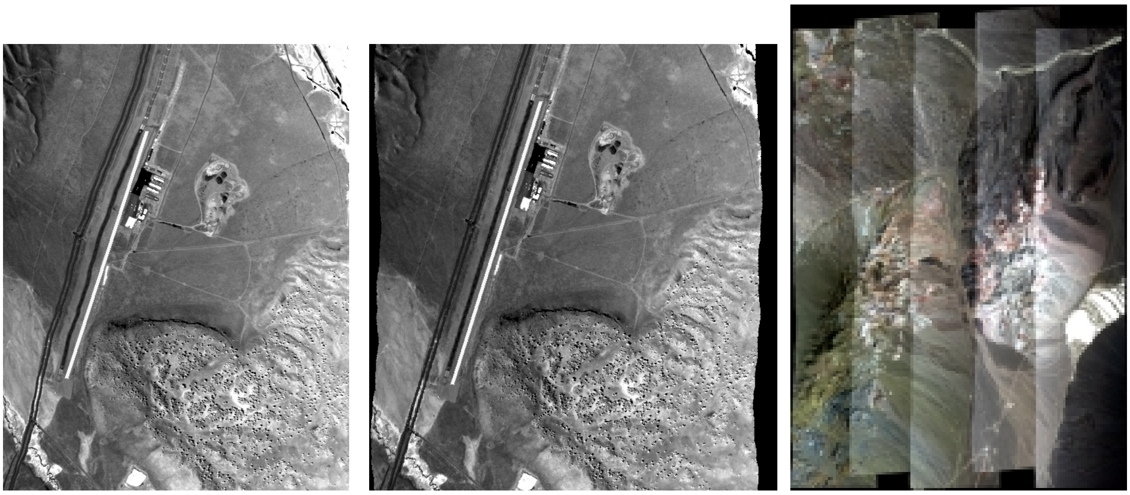


Figure 9: A). Left, Raw HyMap image in the vicinity of the Mammoth Mountain airport. Note the curved runway (black line next to the drawn white reference line). B). Center, Geocorrected HyMap image. Compare the straight runway to the reference line. C). Right, Sample mosaic from multiple geometrically corrected flightlines (5m data) of Cuprite, Nevada (no histogram matching applied).

Detailed Material Mapping and Quantification

AIG optionally offered additional processing of the data to extract spectral endmembers and map their locations and abundances. These analyses followed standardized AIG methodologies consisting of reduction to apparent reflectance using ATREM (CSES, 1999), spectral data reduction using the Minimum Noise Fraction (MNF) transformation (Green et al., 1988, Boardman et al., 1995), spatial data reduction using the Pixel Purity Index™ (PPI) (Boardman et al., 1995), an n-Dimensional Visualizer™ to determine image endmembers (Boardman et al, 1995), identification of endmembers using their reflectance spectra (Kruse et al., 1993; Kruse and Lefkoff, 1993) in the Spectral Analyst™, and mineral mapping using Mixture-Tuned Matched Filtering (Boardman, 1997, 1998b). Typical results are shown in Figures 10-13.

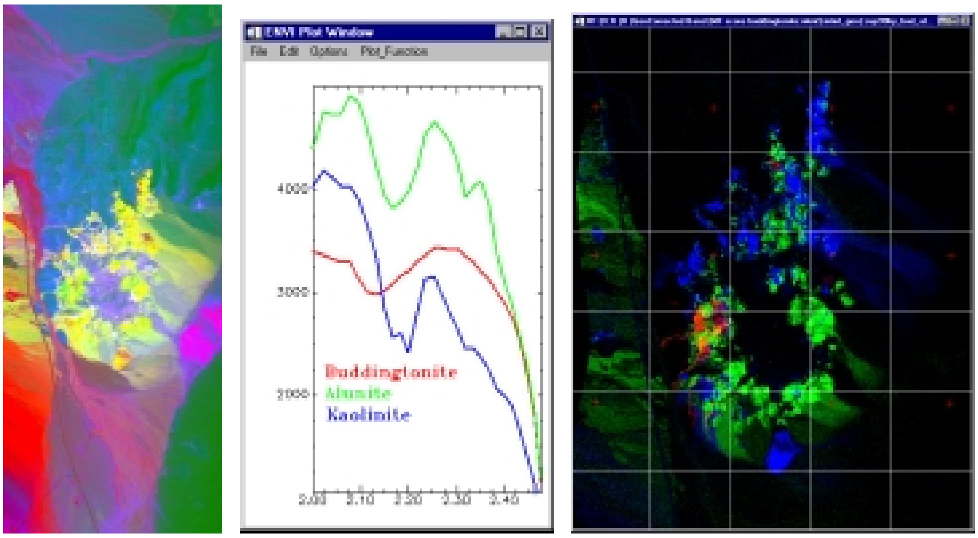


Figure 10: Mineral Mapping Application: Left, MNF bands 1, 2, 3 (RGB); Center, single-pixel apparent reflectance spectra of spectral endmembers; Right, Mineral map (Buddingtonite, Alunite, Kaolinite coded as RGB).

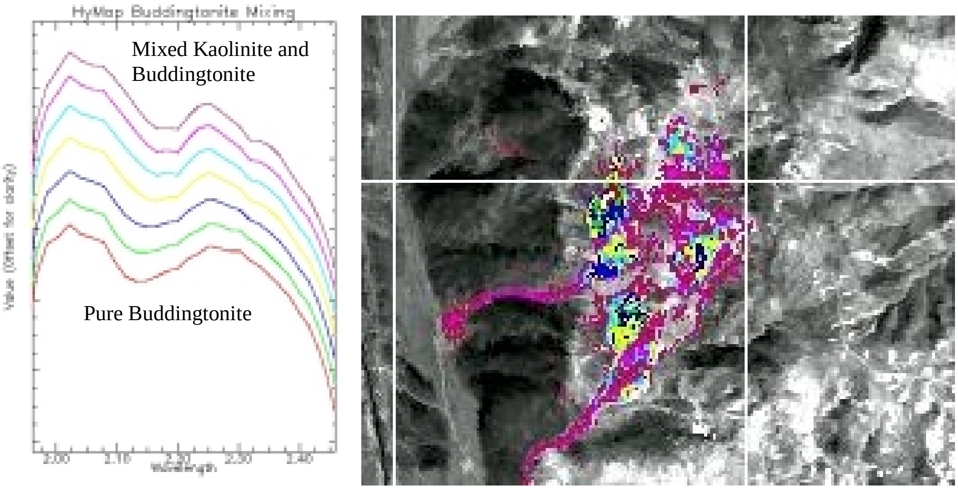
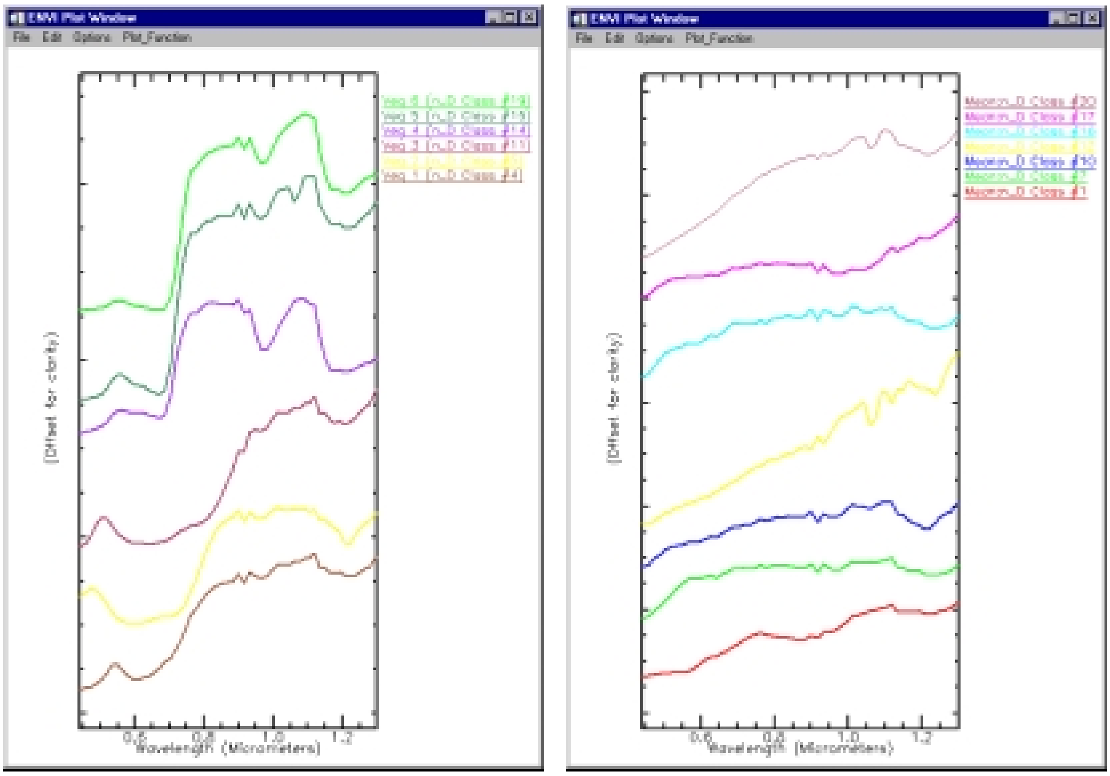


Figure 11: Mineral Mixing: Left, Apparent reflectance spectra of buddingtonite mixtures extracted from the Cuprite, Nevada HyMap data. Right, color-coded mapping results showing buddingtonite concentration overlain on a grayscale image.



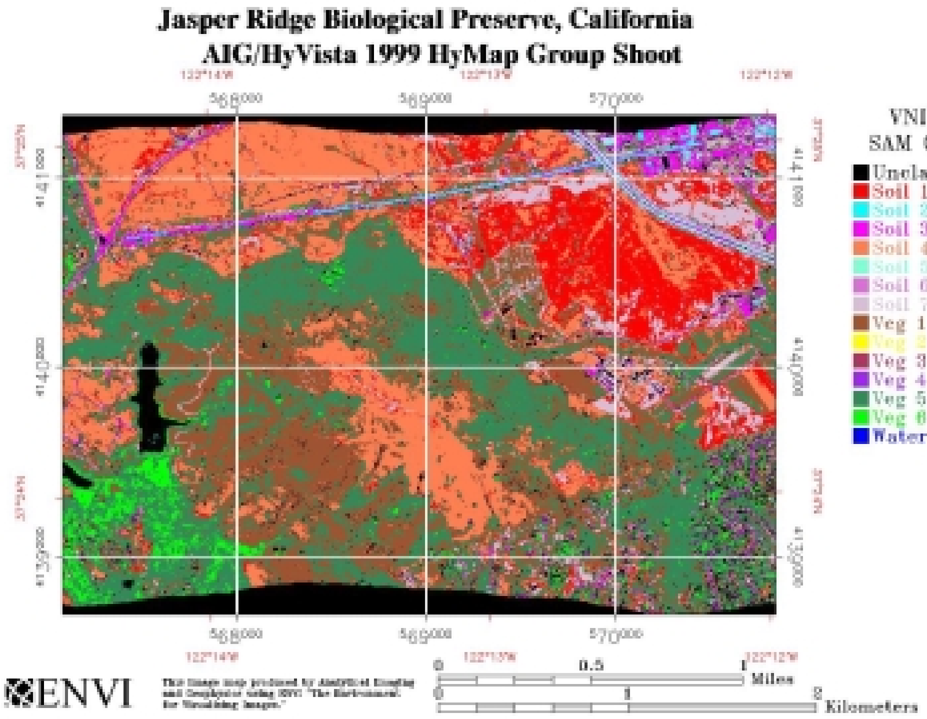


Figure 12: Vegetation and Soil Mapping Application: Analysis results for the Jasper Ridge Biological Reserve, California. Top, endmember spectra for vegetation and selected soils. Bottom, Spectral Angle Mapper (SAM) results geocorrected to a map base.

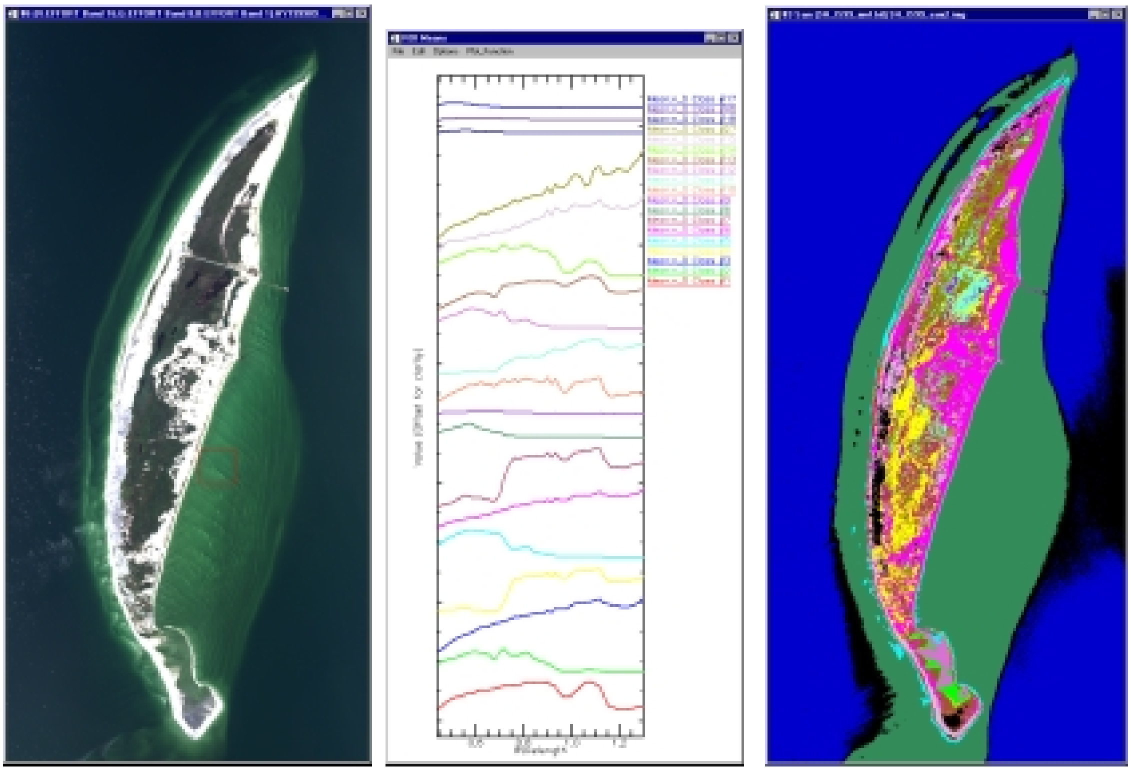


Figure 13: Near-Shore Marine Mapping Example: Spectral mapping results for Ship Island, MS. Left, True color composite; Center, Endmember Spectra; Right, Spectral Angle Mapper Results.

Conclusions

This effort has demonstrated that cooperative hyperspectral data acquisition, a "Group Shoot" can provide an efficient means for organizations to share some of the costs and apparent risks of using a new technology while getting data specific to their needs. The 1999 USA HyMap acquisition provided high-quality, site-specific hyperspectral coverage of selected sites of importance to group shoot sponsors. Data were provided to sponsors as apparent reflectance, with geocorrections to map based products. Over 225 fully calibrated HyMap flightlines were delivered to sponsors within only a few weeks of acquisition.

The HyMap data set new standards of hyperspectral data excellence in terms of spectral and radiometric calibration, image geometry, and SNR. This paper shows data examples and briefly summarizes analysis results for several different disciplines (mineral mapping, soils/vegetation mapping, and near-shore marine mapping) that support these conclusions. The HyMap data provide detailed, high-quality, hyperspectral measurements, that when combined with quantitative processing and analysis, yield spectacular results.

Data acquired during the 1999 AIG/HyVista HyMap USA Group Shoot are now available for commercial purchase. Based on the initial results of this Group Shoot, AIG/HyVista is organizing similar missions during 2000.

Acknowledgements

Many thanks to the sponsors who made the HyMap Group Shoot Possible. HyMap is a Trademark of Integrated Spectronics.

Data Availability and Distribution

Research-mode data acquired as part of the 1999 USA HyMap Group Shoot are available for purchase from Analytical Imaging and Geophysics. Site coordinates and quick-look images can be previewed on the World Wide Web at http://www.aigllc.com. For additional information contact AIG at the address below.

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