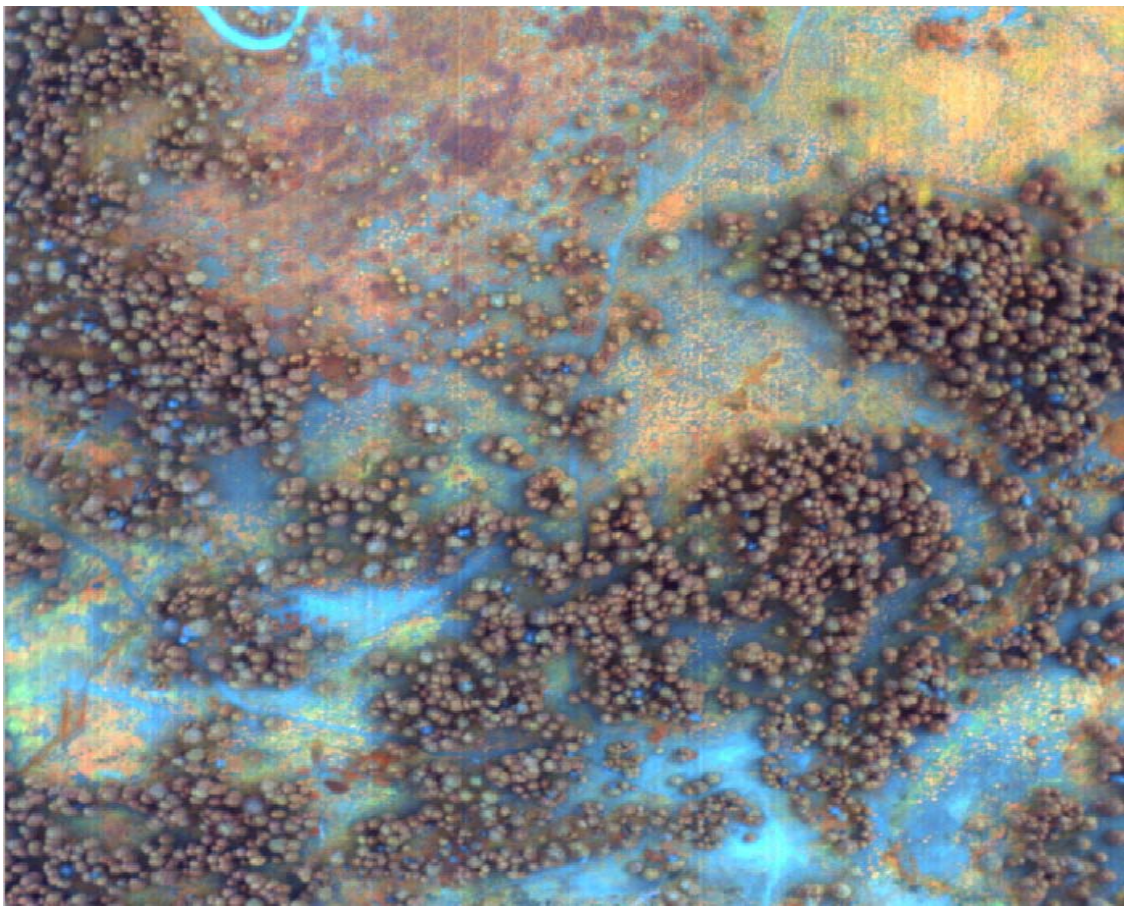
Cascade Siskiyou National Monument
Hyperspectral Imagery / LIDAR Project

Final Report

23 October 2002



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On the Cover:
On the cover is an IRGB data cube (752nm; 550nm; 454nm) that falls in the central portion of the border area between data tiles 9 and 16. The vegetative diversity apparent in this cube provides a graphic illustration of the spectral and spatial resolution of the hyperspectral imagery. The viewer will note that soil and rock areas are a blue (cyan) tone, there are noticeable grass areas shown in light pink and yellow, with several areas of a light green tone indicating perhaps vegetation in areas of wetter soils. Shrubs are noticeable in darker pink and purplish areas. Tree canopy is apparent by individual crowns and a magenta color. Interspersed with the tree canopy are grayish crowns indicative of either diseased trees or a different species from the predominant trees.
(cube file name: Siskiyou_Flight2_Run015Seq009[20020628_182155].bip)

Introduction and Objectives

During June 2002 Advanced Power Technologies, Inc. (APTI) was contracted to conduct a pilot project in the Cascade Siskiyou National Monument for the Oregon Bureau of Land Management (BLM). The primary objective of this project was to collect high spectral and spatial resolution airborne hyperspectral data as well as light detection and ranging (LIDAR) data. This data is intended to assist the BLM in their management needs and analysis for:

1) Inventorying surface cover and establishing a baseline for monitoring ecosystem health;
2) Determining the extent of noxious weed invasion;
3) Improving planning of fire-hazard reduction and plant community restoration projects.

The Washington D.C. BLM office coordinated the initial development and contracting of the project, while the Oregon State Office and Medford Field Office are responsible for project management and ground support.

The data collected and analyzed in this investigation will be used as a demonstration of the value added by high spatial and spectral resolution hyperspectral data in the visible and near infrared bands (nominally 370 nm - 945 nm wavelengths) and LIDAR data for addressing various BLM problems.

This is a unique area exhibiting ecological complexity and rich biodiversity that has experienced impacts associated with human activity and resource use, where hyperspectral imaging and LIDAR technology should have demonstrable value. Both wildfires and noxious non-native weeds have a dramatic and often negative impact on wildland plant and animal communities. Any technology that can help locate and discriminate unique ecological land cover components, ecosystem condition, major noxious non-native ground plant species (e.g. Starthistle, Medusahead) and the impacts of human activities will prove extremely valuable for coordinated management of the Monument. In addition it is beneficial to gather hyperspectral data that will serve as a baseline from which restoration treatment effects can be determined from change detection and quantification monitoring data gathered following treatment.

Nine field sites were chosen by BLM personnel for the demonstration effort. These sites were located in varied physical settings and contained representative vegetation species associated with pasture, wet meadow and forest ecosystems.

To address these issues APTI teamed with EnerQuest Systems LLC to survey the southern half of the Monument. APTI was the lead contractor for the investigation. APTI collected and processed the hyperspectral data, analyzed the hyperspectral and LIDAR data sets and produced the deliverable products described in this report. EnerQuest supplied the survey aircraft and the LIDAR data collection and processing for the investigation. Airborne data were collected over three days: June 27, 28, and 29, 2002 for a total of 71 final flight lines and approximately 1,450 hyperspectral data cubes.

Total area imaged was approximately 74,240 acres (183,373 hectares). The plan was to collect 83 mi^2. Approximately 116 mi^2 were collected during the 3-day period.

Overall the demonstration project achieved the goal of collecting high quality, high resolution (1 m^2) hyperspectral and LIDAR data for the Monument site. Orthorectified hyperspectral imagery and LIDAR-derived topography have been provided for the entire mission. A normalized difference vegetation index (NDVI) layer provides a first order visualization and quantitative indicator of the amount, density and condition of the vegetation in the study regions. Selected species classifications are provided for a subset of the data where ground data have been gathered in collaboration with BLM personnel.

Classification results indicate that many of the species of interest are identifiable and "mappable". Classification results for the noxious weed Medusahead indicate that this species of interest can be identified and discriminated. Classification results for Scirpus and Cattails indicate that wetland features can be identified and discriminated. Woody species such as Buckbrush were also successfully detected. In terms of tree species, Juniper and White Fir were successfully discriminated.

However not all species of interest are individually identifiable. Reasons for the inability to delineate all the species include small size (subpixel - less than 1 m^2 ground coverage), mixed species spatial distribution, same species spectral variability (due to e.g., species vigor, leaf and flowering condition) similar species spectral variability, and inadequate ground data to constrain the supervised classifications. In addition, cumulative spatial errors resulting from GPS data, image distortion and orthorectification can make location and selection of features of interest and their spectra difficult. This is particularly apparent with the selection of small vegetation clusters and individual trees and shrubs. It should be noted that a minimum mapping unit was not specified for any of these classifications. As such, when pixel-level errors of omission or commission occur, it must be remembered that these errors are on the order of nominally **one square meter**. Mapping at this scale and level of detail can be difficult in normal ground-based fieldwork, let alone from an altitude of 7,000 feet AGL. Additional ground data and a comprehensive evaluation of image classification methods is needed to complete the evaluation of hyperspectral species discrimination capabilities.

Finally, several sample FARSITE fire model runs were undertaken using data layers derived from the hyperspectral and LIDAR data. These runs incorporated simplistic weather and fuel characteristics parameters. The results are presented in the Fire Model Results section below and demonstrate the potential of high spatial resolution data in fire behavior prediction, fire hazard reduction and establishment of rehabilitation programs.

A complete discussion of the successes and shortcomings for this study is provided in the discussion section of the document. It should be noted that it is necessary for experienced field personnel to validate any ground species classification through site visits. This validation requires testing for both species identification and spatial extent.

This document serves as the final report for the project, and as such contains an overview of the project, the hyperspectral and LIDAR sensors used in this investigation, the data collection effort, data processing steps, a description and list of the deliverables and results, and a brief discussion of the overall merits of hyperspectral and LIDAR technology for BLM applications.

In addition to this paper document the appropriate BLM offices have already been provided with all of the collected hyperspectral data (in standard ENVI and ArcInfo community-accepted format) as well as digital ArcGIS project layers for viewing and analysis. The digital geographic information system (GIS) data are a primary deliverable for this investigation. Due to the project scope and short nature of the contract, the present study represents a small fraction of potential BLM applications of hyperspectral and LIDAR technology. The full wealth of information has not been extracted from the hyperspectral and LIDAR data sets at this stage. Nevertheless, the hyperspectral imagery associated classification and fire model inputs coupled with existing spatial data available at each Field Office, provide powerful tools for both BLM field operations and planning activities.

Site Description

Figure 1 depicts the general location of the project. A description of the physical setting of the project as taken from the Draft Resource Management Plan/Environmental Impact Statement (Bureau of Land Management, 2002, Medford District Office, Medford, Oregon) follows:

The Cascade-Siskiyou National Monument (CSNM) consists of 52,947 acres of federal land located in southern Jackson County, Oregon (figure 1). *The CSNM is located in the Klamath and Rogue River basins and four watersheds that have a combined total of approximately 780 miles of streams. The topography of the CSNM is variable with the area around Agate Flat being nearly level to slopes in excess of seventy percent along the headwalls of creeks in the Klamath River-Iron Gate watershed. Elevation ranges from 2,400 feet along Emigrant Creek to 6,134 feet at the top of Chinquapin Mountain. Average annual precipitation for this area ranges from 24 to 46 inches with most coming in the form of rain below 3,500 feet and snow above that level.*

The CSNM is noted for its biological and ecological diversity because of its location at the confluence of the Siskiyou range of the Klamath Mountains, Cascade Mountains and the Great Basin Geological Provinces. Each geological province providing its own special assemblage of organisms and ecological processes known as ecoregions which are based on geology, climate, soils, flora and fauna, elevation, and land use. There are three ecoregions identified in the CSNM having particular biological significance in terms of species richness, endemism, and unique evolutionary/ecological phenomenon (Bureau of Land Management, 2002, Medford District Office, Medford, Oregon, p.15).

Figure 1. Cascade Siskiyou National Monument study site

Instrumentation

Airborne sensors used for data acquisition consisted of an APTI AURORA™ hyperspectral imaging camera and an EnerQuest RAMS™ LIDAR system. Ground data were collected with a handheld spectrometer, GPS receiver and digital cameras.

APTI AURORA™ Hyperspectral Imaging System

The AURORA™ imaging system is a hyperspectral imaging sensor for the visible and near-infrared spectral range. The sensor is integrated with a PC-based system for data acquisition and near real-time processing. The system's unique capabilities include wide field-of-view coverage, high throughput and sensitivity with interchangeable optics for selectable field of view from any predefined geometry. The data acquisition component is optimized for continuous operation and is integrated with the Adaptive Spectral Processing and Identification System (ASPIS™). ASPIS™ is an automated near real-time processing system for unsupervised spectral demixing, terrain categorization, species identification and data compression. The sensor system is compact, lightweight and has low power consumption (see Figure 2).

The camera of the AURORA™ system has a thermo-electrically temperature stabilized and back illuminated CCD with 0.3-1.0 µm response and 12 x 12 µm pixel size. The low noise (<50e^- at 8 Mpix/sec/readout), high dynamic range (14 bits/pixel) sensor has a high frame rate (up to 229 fps max at 31 spectral bands, 184 fps max at 62 spectral bands) and very high quantum efficiency (>70%) in the 400-800 nm range.

The front optics of the AURORA™ system can be easily adapted to satisfy different geometry and resolution requirements by using interchangeable off-the-self lenses or custom remote controlled zoom lenses with aperture and zoom presets that allow absolute radiometric calibration. The sensor uses a holographic grating spectrograph, which extends the wavelength range coverage from 300-1100 nm. A maximum of 488 spectral bands with 1.15 nm resolution (12 µm slit, 1.2 nm/pixel) are possible with signal-to-noise ratio > 150:1 from 400-900 nm at 5% reflectance. In addition, the sensor is capable of on- and off-chip binning for adjustable bandwidth, band selection and a wide range of illumination coverage without saturation (5-95% ground reflectance). The swath width of the sensor is 640 pixels and the spatial resolution of the sensor is determined by the front optics, with up to 37 degrees wide field of view coverage.

The processing component of the system is hosted on a Windows 2000 workstation, with 1024 MB RAM and a RAID disk array (108GB). The computer system includes the data acquisition system and the hyperspectral data compression and processing system, which is part of ASPIS™. In addition to the continuous acquisition of hyperspectral data, motion of the airborne platform as measured by an onboard inertial navigation system is continuously logged during flight.

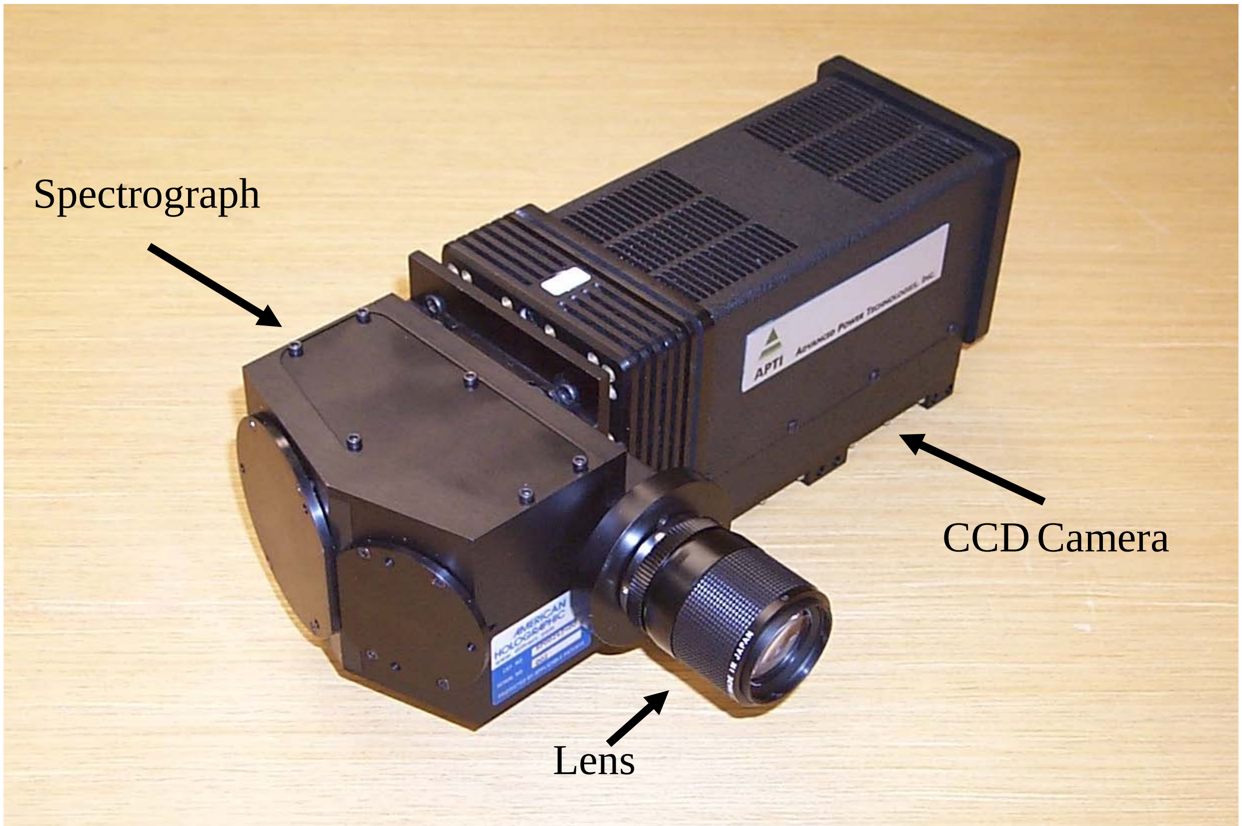

Figure 2. APTI AURORA™ hyperspectral sensor

For the Oregon 2002 mission 60 bands of visible and near-infrared spectral data were collected in the 376 nm to 945 nm wavelength range at a nominal resolution of 10 nm. To achieve the desired 1-meter ground resolution, the AURORA™ hyperspectral sensor was flown at a nominal altitude of 11,200 ft MSL and a speed of 118 knots. The hyperspectral camera was operated at a frame rate of 70 Hz with a 25mm focal length fore optic lens.

EnerQuest RAMS™ (LIDAR)

LIDAR (Light Detection and Ranging) is an active sensory system that uses laser light to accurately measure distances that are subsequently processed to yield ground elevation. When mounted in an airborne platform, LIDAR systems can rapidly measure distances between the airborne sensor and points on the ground (or a building, tree, etc.) to collect and generate densely spaced and highly accurate elevation data.

EnerQuest's Remote Airborne Mapping System (RAMS™) is comprised of a laser altimeter, relative position GPS, Inertial Measurement Unit (IMU), and large format (4096 x 4096) digital camera. This combination of advanced level sensor systems has the capability to simultaneously collect terrain data and digital imagery at a swath width of over 7,000 feet at rates exceeding 150-mph ground speed. The digital camera subsystem consists of a large format camera, which can collect clear imagery with better than 6 inch image resolution and match the swath width of the scanning laser. On-board electronics collect, format and store in-flight laser, camera, GPS, and IMU data on hard drives for subsequent automated processing. The system is flown in a Cessna 402B, twin-engine fixed wing aircraft with a Trackair flight management system to facilitate maximum collection rate and minimize costs. The RAMS™ LIDAR sensor system is shown in Figure 3.

Figure 3. EnerQuest RAMS™ LIDAR sensor

The scanning laser altimeter, which measures terrain directly, is integrated with an Inertial Measurement Unit (IMU) and Global Positioning System (GPS). These systems are combined to calculate the exact position and orientation of the sensors as they relate to the earth's surface at the time of data acquisition. The need for ground control panels, film development and stereo plotting are unnecessary for DEM generation and image rectification. Additionally, the laser has variable swath width, pulse rate, and scan rate to adapt to varying terrain and vegetation conditions. RAMS™ yields an absolute horizontal accuracy of less than 6 inches RMSE with a vertical accuracy of less than 2 inches RMSE for the LIDAR and image geopositioning systems. Relative positioning accuracy typically is better than 6 inches vertical and 1.5 foot horizontal. An overview of the RAMS™ laser specifications is provided in Table 1.

Laser Altitude	10,000 feet AGL Max
Laser Swath Width	7,250 feet Max
Laser Scan FOV	45 Degrees Max
Scan Rate	0-35 Hz (FOV dependent)
Laser Pulse Rate	100Hz-25kHz Max
Laser Returns	5 at 15kHz and 3 at 24kHz
Cross Track Spacing	0-25 feet
Along Track Spacing	3 feet minimum (Airspeed dependent)
Nominal X/Y Ground Sample Distance	5 feet
X, Y, Z Positional Accuracy	less than 1 foot RMSE absolute

Table 1. RAMS™ laser specifications

Ground Equipment

Ocean Optics Handheld Spectrometer

Reflectance measurements of various site representative ground cover species were collected with an Ocean Optics USB 2000 fiber optic handheld spectrometer (Serial Number USB2E1777) as part of the ground data collection effort on 27-28 June 2002. The Ocean Optics spectrometer is comprised of a fore optic lens linked to a spectrograph via an approximately 10 ft fiber optic cable. The instrument was set for a nominal field of view of 1°. The spectrometer measures light in the wavelength range of 350-1004 nm with a spectral resolution of 0.3 nm. The spectrometer has 2048 total bands and 12 bits of dynamic range, yielding an output range of 0 to 4096 digital counts. The spectrometer grating used for the field measurements has poor efficiency for ultraviolet (UV) wavelengths shorter than 400 nm and infrared (IR) wavelengths longer than 800 nm, so the raw spectrometer data were band pass filtered to retain wavelength information in the 400-800nm spectral band.

GPS Receiver

GPS data of representative ground cover and classes were collected on 27-28 June 2002 with a Trimble ProXRS GPS receiver. Differential corrections to locations were received real-time from the Omnistar wide area differential GPS service. This service calculates error budgets for GPS satellites and broadcasts differential corrections from several geostationary commercial satellites to the GPS receiver. Additional data were collected by BLM personnel using a Trimble GeoExplorer, with a manufacturer-stated horizontal accuracy of 3 to 5 meters.

Data Collection

The data collection consisted of both airborne hyperspectral and LIDAR data and ground survey data. The airborne data were collected using an APTI AURORA™ hyperspectral imaging system and EnerQuest RAMS™ LIDAR system. Airborne data were collected over three days: June 27, 28, and 29, 2002 for a total of 71 final flight lines and approximately 1,450 hyperspectral data cubes. Total area imaged was approximately 74,240 acres (183,373 hectares). The plan was to collect 83 mi^2. Approximately 116 mi^2 were collected during the 3-day period. Ground data digital imagery and spectral data were collected at select locations during the June mission. BLM personnel at the field site led the ground data collection effort.

Operational Considerations

After determining the suitable hyperspectral image resolution and LIDAR post spacing, flight lines were laid out to efficiently cover the areas of interest. As both the hyperspectral and LIDAR sensors are light-based instruments, atmospheric and weather conditions play an important role in determining data quality. Flights were conducted on a daily basis during the nominal hours of 0900 to 1300 local time. This time range was selected as the optimum window to maximize the background lighting whilst simultaneously minimizing the early morning effect of long shadows and the afternoon effect of atmospheric turbulence. For the Oregon 2002 mission the nominal aircraft altitude for the airborne data collections was 7000 ft above ground level (AGL), with a nominal ground speed of 118 knots. The hyperspectral camera was equipped with a 25 mm lens and operated at a frame rate of 70 Hz, with the aperture set at f-stop 2.8. The resultant ground resolution was nominally 1.0 m^2. Nominal post spacing of the raw LIDAR data is 1.5 meters across track and 2.5 meters along track.

Flight Lines

Flight lines were laid out to efficiently cover the areas of interest with minimal loss of coverage. At 1 m resolution and 640 cross track bands, the cross track ground swath of the hyperspectral sensor is 640 m. To minimize the chance of lost data and to account for aircraft platform motion (roll primarily) flight lines were developed to allow 30 percent side overlap for adjacent flight lines. The net result is a nominal ground swath width of 450 m for each pass of the aircraft over the survey areas. A data cube index is created providing cube (Image) locations and attributed with a substantial amount of information such as flight line, run and cube numbers, frame rate, altitude, for example. Figure 4 is the data cube index indicating hyperspectral image and LIDAR data coverage relative to the study area.

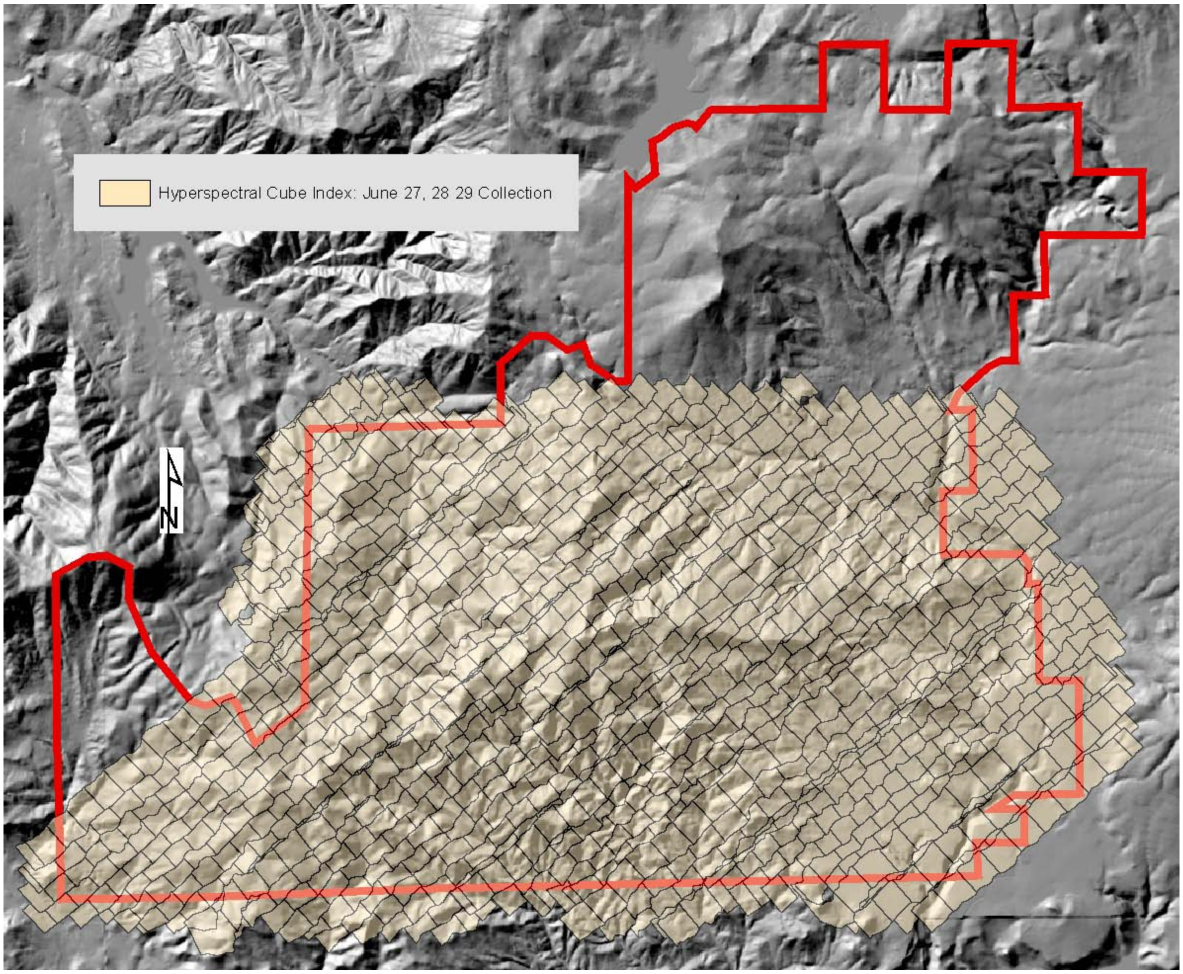

Figure 4. Hyperspectral data cube index

Hardware Installation

The AURORA™ hyperspectral camera system was installed onboard the EnerQuest Cessna 402B survey aircraft (see Figure 5) during the week of 23 May 2002 in Albuquerque, New Mexico. The EnerQuest Cessna aircraft routinely flies with the LIDAR sensor. For the BLM mapping mission the APTI AURORA™ hyperspectral imaging sensor was integrated with an onboard sensor mounting plate and an Applanix 510 inertial navigation system. The Applanix is a high precision navigation system that combines a Global Positioning System (GPS) receiver with a laser gyro 3-axis inertial navigation system.

Figure 5. EnerQuest Cessna 402B aircraft used for the BLM mapping mission

Figure 6 shows a view from under the plane of the arrangement of the LIDAR and hyperspectral sensors. The LIDAR sensor occupies the lower half of the picture and the hyperspectral camera lens can be seen in the upper right portion of the picture. EnerQuest's digital camera can be seen in the upper left corner of the image.

In Figure 7 the hyperspectral camera system is in the center of the picture and the hyperspectral data acquisition computer can be seen in the left side of the picture. An engineering test flight was conducted on 23 and 25 May 2002 to ensure proper functioning of the hyperspectral sensor suite and to gather data for navigation calibration. This sensor configuration remained intact on the EnerQuest plane from May through completion of the Oregon 2002 mission. During the Oregon data collection period the aircraft and differential GPS base station were operated out of Klamath Falls Regional Airport in Klamath Falls, Oregon.

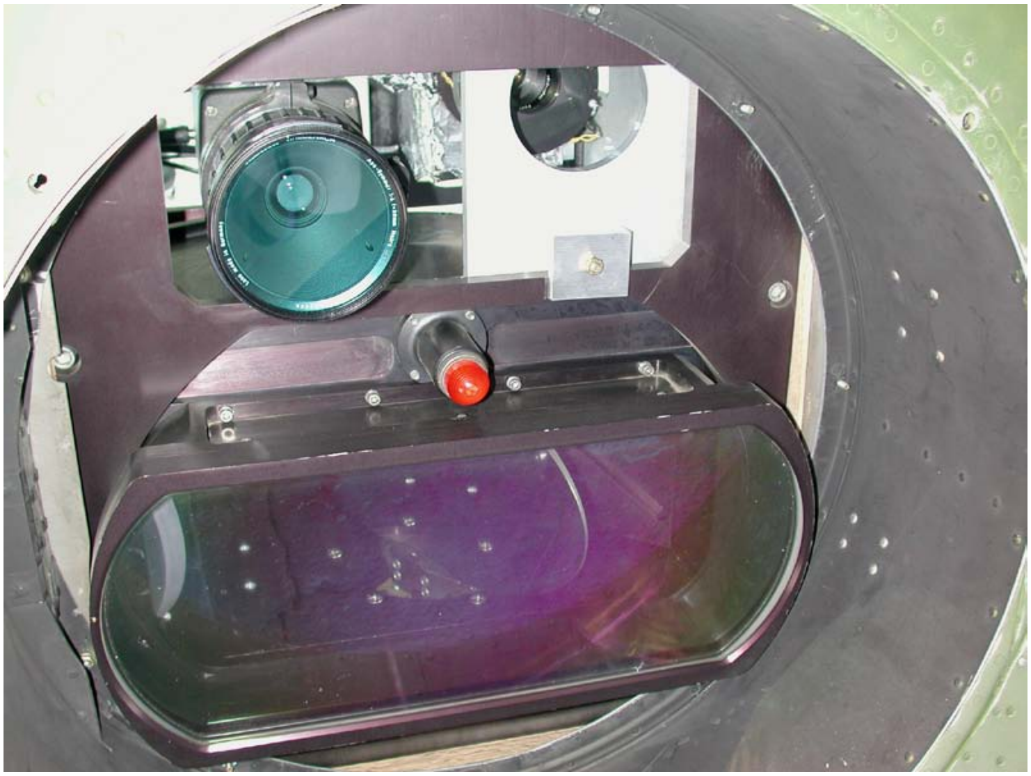

Figure 6. Exterior view of the hyperspectral and LIDAR sensors

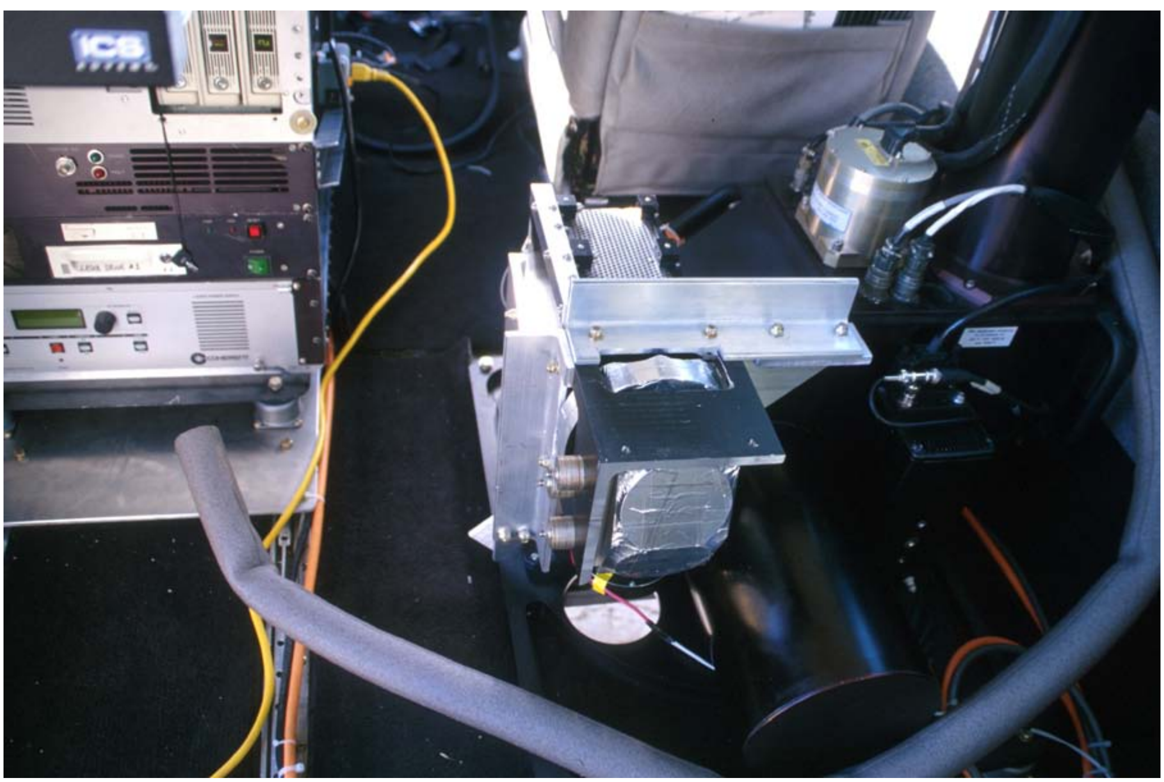

Figure 7. Interior view of the mounting of the LIDAR and hyperspectral sensors

Ground Data

An important part of any airborne hyperspectral data collection is ground data collection to assist the identification and classification of target species. BLM personnel were instrumental in selecting appropriate sites for ground truth data collection in support of the BLM June 2002 mapping mission. In addition, BLM personnel assisted APTI personnel with ground species identification and the collection of hand-held digital photographs, GPS location and spectral reflectance data.

Ground truth data were collected on June 27th and 28th. Ground reflectance spectra of subject species were collected using an Ocean Optics spectroradiometer. Multiple samples were taken of various vegetation species, as well as bare soil, dark frame, and calibration panel (Spectralon) samples. Hand-held digital photographs of representative vegetation were also taken to assist the identification process.

Figure 8 is a graphic comparing reflectance spectra from Buckbrush, Deerbrush, and Timothy Grass collected from Agate Flat #1, Boxer Ranch Gate, Slappy's Cabin and Oregon Gulch locations, respectively. Representative digital ground photos are presented in Figures 9-12. Buckbrush and Deerbrush are characteristic shrubs in the project area, while Timothy Grass is a preferred food for grazing animals.

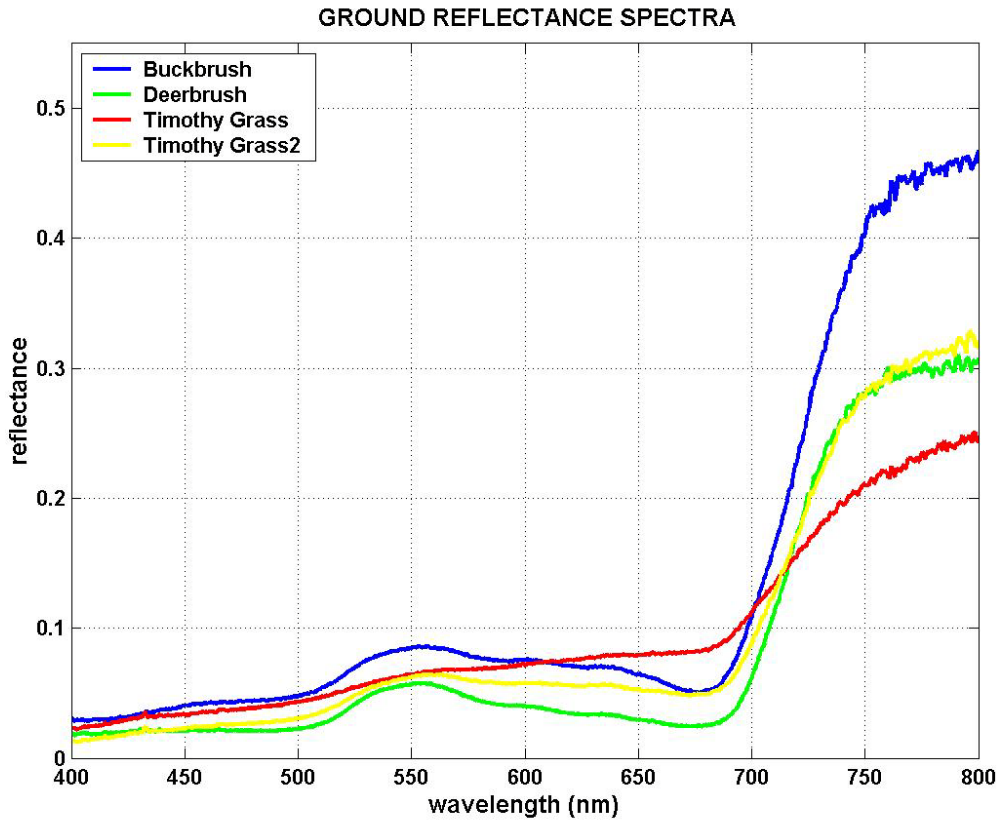

Figure 8. Ground Reflectance Data from Agate Flat #1 location

Figure 9. Buckbrush: Agate Flat #1 location

Figure 10. Deerbrush: Boxer Ranch Gate location

Figure 11. Timothy Grass: Slappy's Cabin location

LIDAR Data Collection

During the three-day time period of 27 June 2002 through 29 June 2002, LIDAR data were collected on a daily basis along predefined flight lines. The LIDAR data were acquired on a continuous basis during each flight. The raw LIDAR data were converted into digital elevation model (DEM) layers that served as the base data tiles for the BLM ArcGIS digital database. The data tiles in Figure 12 illustrate the nominal area of coverage.

Hyperspectral Data Collection

During the three-day time period of 27 June 2002 through 29 June 2002, hyperspectral data were collected on a daily basis along predefined flight lines. A complete listing of the hyperspectral data collected during the BLM mission is provided in Appendix A. Flights were conducted each day during the nominal hours of 0930 to 1230 local time. This time range was selected as the optimum window to maximize the background lighting whilst simultaneously minimizing the early morning effect of long shadows and the afternoon effect of atmospheric turbulence. Table 2 contains an overview of the daily surveys.

Date	BLM Mission Flight Number	Location
6-27-02	1	CSNM
6-28-02	2	CSNM
6-29-02	3	CSNM

Table 2. Overview of daily surveys

For the entire mission APTI AURORA™ sensor APTI #1 was used to acquire hyperspectral data. The camera was instrumented with a 25mm lens and operated at a frame rate of 70 Hz and an f-stop of 2.8. The hyperspectral sensor was flown at a nominal altitude of 11,200 ft MSL over ground elevations of nominally 4,200 ft, leading to an effective above ground level (AGL) of 7,000 ft. The aircraft was flown at a nominal speed of 118 knots. Due to the light nature of the Cessna 402B aircraft and moderate winds during portions of the data collection, some of the flight lines were wavy in nature. Nevertheless adequate overlap was planned for adjacent flight lines so data loss over the tasked survey sites was near zero. Roughly 74,240 acres (183,373 hectares) of hyperspectral data were collected for the BLM pilot project.

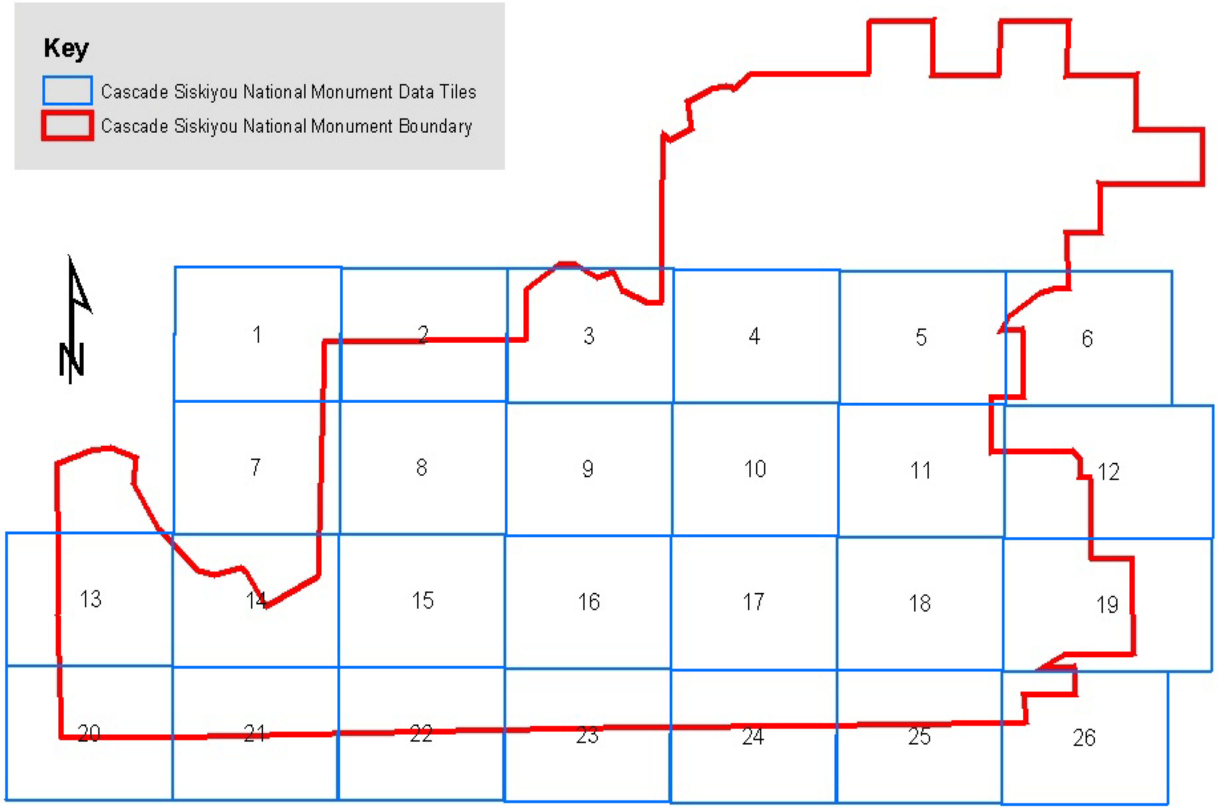

Figure 12. Hyperspectral and LIDAR mosaic data tiles

Data Processing

Prior to any hyperspectral classification, the raw hyperspectral data must be calibrated (field-flattened) and rectified. The raw LIDAR data must be filtered and converted to digital elevation models. This section provides details of the various steps involved in the processing of the hyperspectral and LIDAR data, and as such provides the background information necessary to understand the data that is presented in the results section that follows.

Hyperspectral Camera Calibration

The AURORA™ hyperspectral sensor is radiometrically calibrated at APTI's calibration facility. The calibration source is a NIST traceable Labsphere integrating sphere with four individually controlled light sources. The intensity of the source is stepped through the full illumination range that utilizes the full dynamic range of the hyperspectral imager (approximately 0-2000 Lumens). A least squares based quadratic multipoint calibration is performed for each combination of lens, f-number and sensor frame rate. For the BLM mission the primary operational configuration was a 25 mm lens, f-number 2.8, and a camera frame rate of 70 Hz. The quadratic fit to the multipoint illumination response corrects for the small deviations of sensor linearity, particularly at very low brightness levels and wavelengths near the edge of the wavelength response of the CCD and the lens transmittance. The radiometric calibrations are typically accurate to approximately 5% over the entire mission, while the relative band-to-band calibrations of the flat-fielded data are accurate to about 1%. The sensor radiometric calibration procedure is repeated when the sensor returns to the laboratory, to verify that no significant change has taken place.

The sensor wavelength calibration is achieved using a collection of spectral lamps in the laboratory. The lamp images are recorded prior to spectral binning, which represents a typical oversampling by a factor of 4 or 8, depending on the binning desired by the user. The typical binning is 8, resulting in 10 nm wide spectral bands, which optimizes the spectral resolution and data volume relative to the information contained in the data. The AURORA™ sensor deployed for this mission had a maximum of 488 spectral channels when no spectral binning is employed. Even though the split Offner spectrograph of the AURORA™ sensor has an extremely linear dispersion over the wavelength range of interest, a quadratic fit was used to determine the exact band centers for each configuration. The accuracy of the wavelength is 0.8 nm or approximately 1/10 of the width of the spectral bands. In addition the spectral smile is less than 1/20 of the width of the spectral bands.

During mission data collection, a series of "dark" frames is collected in between every data run (flight line). Dark frames are collected by completely blocking the lens aperture with a shutter. These data are used to update the black offset of every pixel in the calibration files prior to each run. The AURORA™ camera has stable pixel gains, but the dark offset can vary by as much as 1% of the dynamic range due to temperature and pressure fluctuations during flight. While this is a low level compared to most cameras, it must be corrected to maintain the radiometric accuracy over extended time intervals. Even though the AURORA™ has no moving parts, minor mechanical relaxation of the sensor occurs, particularly during the first few flight hours. This necessitates a slight gain correction, typically at the 1% level, early in the mission. The correction is accomplished using actual data over dark and bright uniform terrain, such as dark water and salt flats. The AURORA™ gains were adjusted after completing the mission and were used to calibrate the delivered hyperspectral data.

Data Georeferencing

For the BLM mission, the AURORA™ hyperspectral imaging sensor was interfaced with an Applanix inertial measurement unit to provide positioning and sensor platform motion measurements during the survey flights. The Applanix is a high precision navigation system that combines a Global Positioning System (GPS) receiver with a 3-axis laser gyro inertial measurement unit. In order to accurately georegister images collected with the AURORA™ system, it is necessary to determine the fixed offset angles of the sensor optic axis relative to the aircraft INS nadir direction. For this correction, the three angles relative to the aircraft's attitude (pitch, roll and heading) are required to be determined. The offset angles are computed by a numerical least squares algorithm to minimize the total square error in the prediction of the location of a number of absolutely known or coincident ground control points.

The navigation calibration procedure with coincident ground control points requires multiple overlapping flightlines. Navigation calibration flights were conducted in Albuquerque, New Mexico on 23 May 2002. These flights were conducted over the EnerQuest's known calibration site, where the aircraft is often deployed. A minimum of three north-south and three east-west flightlines were used for determining the navigational offsets. The flightlines were offset by 320 meters to provide a 50% overlap between adjacent flightlines. Figure 13 shows a mosaic of the three north-south and three east-west flight lines used in the navigational offset calibration. Seven coincident ground control points were observable in four of the overlapping hyperspectral cubes, and the eighth coincident ground control point was observable in three of the overlapping hyperspectral cubes.

A supplemental navigation calibration was performed over the Elko, Nevada airport on 28 May 2002 to ensure that the sensor had not shifted, which would have required new parameters. Data collected over Elko was consistent with that collected in Albuquerque. The calculated navigational accuracy of the calibration for the Nevada 2002 mission is 2 meters *rms*. Because the sensor remained mounted in the aircraft between the Nevada 2002 and the Oregon 2002 missions, a new navigation calibration was not required.

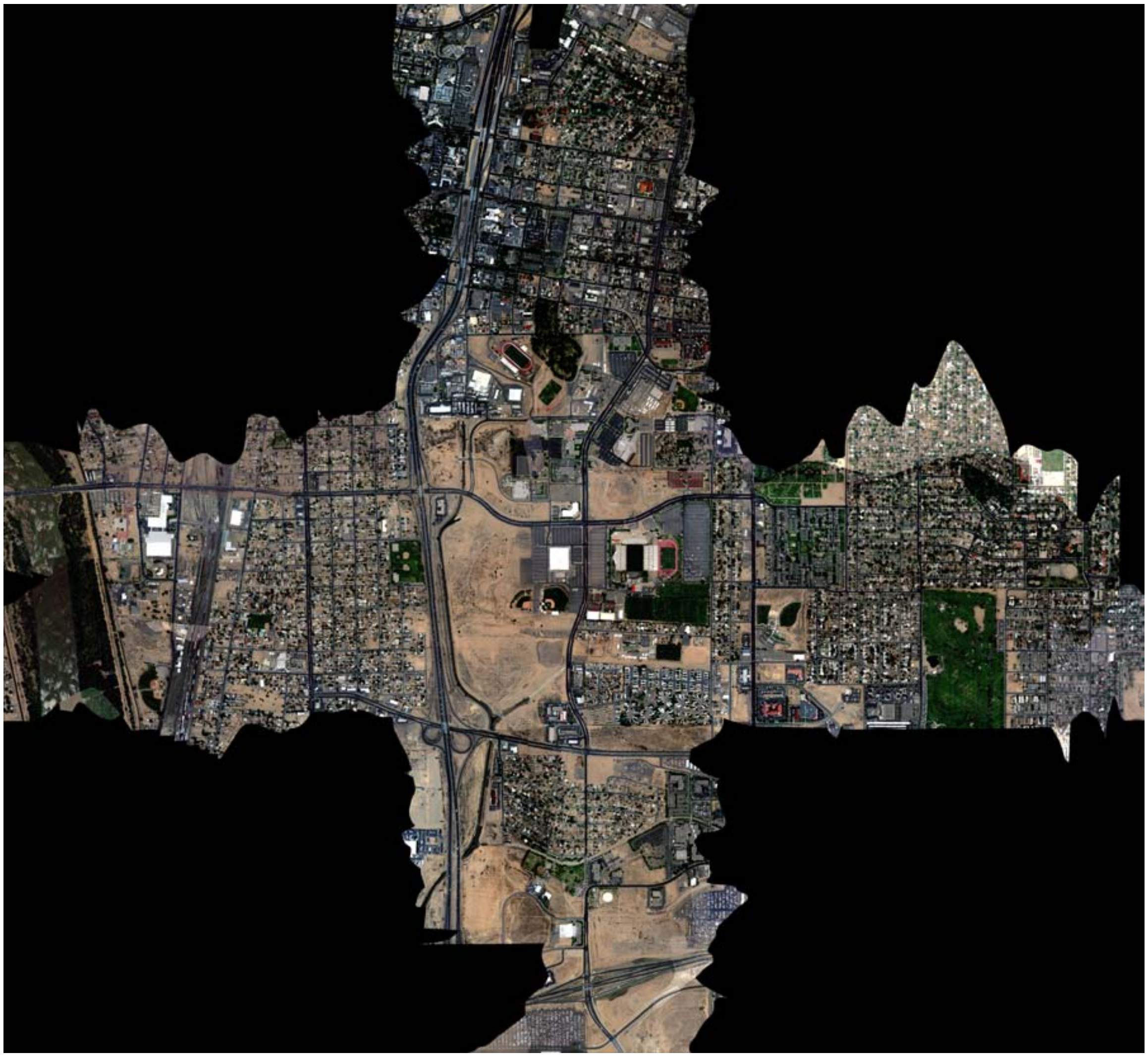

Figure 13. Navigation calibration mosaic over Albuquerque, New Mexico

Image Rectification

Image data observed in its raw form are subject to various distortions due to sensor platform motion (e.g., aircraft roll) and sensor orientation relative to the earth. Raw hyperspectral data are not immediately referenced to real-world locations. The process of geometrically correcting spatial data is often loosely referred to as *georeferencing* or *georegistration*. The georeferencing process, in one way or another, maps data in local or user-defined coordinate systems into real-world systems like latitude/longitude, UTM, or the State Plane Coordinate System. A number of terms including *rectification*, *georectification*, and *orthorectification* are often used interchangeably (and sometimes incorrectly) to refer to specific methods of georeferencing data. From a traditional photogrammetric standpoint, the term *rectification* describes the process of removing the effects of tilt from an image. This process does not account for variations in topography and therefore, in areas of sufficient relief, the resulting image will contain displacement and scale distortions. *Orthorectification* or *differential rectification* accounts for variations in topography, thereby removing most distortions due to relief displacement.

APTI’s georeferencing software uses an ortho*rectification* process to map raw image data to real-world locations. Based on the results of the calibration procedure, the precise position and orientation of the plane and its sensors are calculated. Along with a digital elevation model derived from the airborne scanning LIDAR or other sources if the LIDAR is not available (e.g. USGS or BLM), the position and orientation data are applied to reconstruct the geometry digitally, mapping raw hyperspectral data to ground locations.

LIDAR Processing

Post mission processing and filtering of the raw LIDAR data are necessary to derive digital elevation models (DEMs) of the bare earth surface. The primary purpose for the processing is to identify and remove vegetation and cultural features inherent in the raw data and sample the irregularly spaced data on a regular grid. For many applications the raw data prove useful for helping to quantify canopy height and other “above bare earth” features. Different levels of statistical filtering are required for each processing level, and an overview is provided below.

Surface fitting techniques using statistical filters are applied to the raw LIDAR data to identify the ground surface under vegetation or buildings. For a given search area, an initial surface [$z = f(x,y)$] is fit to the raw data. Data points lying above a predefined distance from the calculated surface are eliminated, and the surface is re-fit. This process is repeated until either the error residual (deviation of actual point elevation from calculated surface) falls below a pre-defined threshold, or there are insufficient points left to define a valid surface. The second condition is generally interpreted as meaning that the bare earth surface cannot be located (e.g., 100% vegetation coverage, or possibly insufficient ground point spacing).

The key inputs to the filter are the initial search size and the residual error threshold. The search size defines the size (dimension) of the area to be fitted. Generally the search area should be bigger than the area of the largest object to be removed. In practice this parameter is on the order of 20-300 feet. The residual defines the maximum average error, below which a valid surface is assumed. In practice, this parameter is on the order of 0.5 to 20 feet. Favorable results can be obtained by multi-pass filtering. For example, in an urban setting, a first pass with a large search size and high residual will remove large buildings, and a second pass, with a smaller search size and smaller residual will remove smaller artifacts (trees, automobiles, etc.).

Note that for this mission, both bare earth and vegetation height DEMs have been delivered. APTI continues to make improvements in the extraction of canopy and vegetation height from raw LIDAR data and combining it with hyperspectral data to enhance vegetation identification and classification results.

Hyperspectral Data Processing

Field-Flattening Procedure

The hyperspectral data in this report were analyzed and processed after a procedure called field-flattening is applied to it. Often this procedure is called sensor calibration, but field-flattening should not be confused with the process of calibrating the data to at-sensor radiance. When the sensor is exposed to a spatially uniform source of light, its response is not generally uniform. Each of the individual pixels in the hyperspectral sensor react differently, even when they are all exposed to the same levels of light. In addition, the sensor produces a non-zero response even when no light enters the sensor (when exposed to darkness). The field-flattening process corrects for these two characteristics of the sensor. The signal produced in response to no light is subtracted from the data, and data is corrected for non-uniform sensor response to a uniform source of light. After field-flattening, sensor data appears to respond linearly and uniformly to light. The data are zero in response to the absence of light, and spatially uniform objects in the image appear uniform in the data.

After calibrating and field flattening the raw hyperspectral data, various levels of processing are still required to derive products from the data. For the BLM mission more than 1450 cubes of hyperspectral data were collected. Each raw hyperspectral data cube contains 60 bands of spectral intensity values for 40,960 pixels (640 cross track elements x 640 in track elements). The resulting field-flattened cube dimension is 640 x 640 x 60 spectral bands (376 nm to 945 nm, with nominally 10 nm spacing). Each cube is 48 MB in size so the entire BLM mission collected nearly 70 GB of hyperspectral data.

The large data volume points out the dramatic need for further processing and dimensionality reduction. The power of hyperspectral data resides in both the high spatial and spectral resolution inherent in the data. This resolution often proves valuable for feature discrimination. Much of the hyperspectral data contains correlated information, so dimensionality reduction is achievable. One goal of hyperspectral processing is to cluster and isolate similar spectral signatures. This can be accomplished in many ways. The sections below describe processing steps that were applied to the hyperspectral data to produce useful products for the BLM mission.

Note that once the hyperspectral data have been calibrated and field-flattened, useful color high-resolution (1 m^2) images can immediately be produced. RGB composites can be produced from any combination of the 60 bands of spectral data. Typical RGB composites are generated for a visible RGB composite (650 nm : 540 nm : 440 nm) and a false-color infrared (IR) composite (730 nm : 540 nm : 440 nm).

Unsupervised Classification

Hyperspectral data provide a wealth of information for terrain discrimination and classification. A range of processing sophistication and automation can be applied to address the terrain categorization problem. A first-look analysis is often conducted using automated endmember analysis. APTI's Automated Spectral Processing and Identification System (ASPIS^{TM}) was used to process the field-flattened BLM hyperspectral data. ASPIS^{TM} determines a basis of spectra called endmembers that comprise the basic constituents of the scene. The endmembers approximate spectra of the "pure" substances that make up the scene. Every scene pixel can be represented as a linear combination of endmembers to better than the sensitivity threshold angle.

The sensitivity threshold angle controls the degree of feature discrimination. Spectra that match (via *n*-band spectral vector dot product) within the threshold angle are considered identical. Smaller values of the threshold (typically 1 to 2 degrees) will separate the scene into many different features, helping the user distinguish objects with similar spectra. Larger threshold values (typically 2 to 5 degrees) are used when the user is only interested in larger spectral distinctions.

Endmembers form a linearly independent basis, but are not orthogonal. The number of endmembers is directly correlated with the user-defined sensitivity threshold (degrees). The smaller the sensitivity threshold, the greater the number of generated endmembers. A terrain scene will typically decompose into 5 to 10 endmembers, whereas a city scene will typically decompose into 10 to 15 endmembers.

Supervised Classification

Numerous methods are available for conducting supervised classification of hyperspectral data, with varying degrees of ground data required to assist the identification and classification process and varying degrees of automation for each method. The usual goal of the classification step is to identify and discriminate targets or species of interest in selected scenes to produce classification/speciation maps. Two primary methods were employed in the analysis of the BLM hyperspectral data.

Spectral Angle

The spectral angle method compares image spectra with a reference spectrum or spectra to produce a measure of similarity between the image spectra and the reference spectrum for all selected image bands. Individual spectra are treated as geometric vectors in a space of dimension equal to the number of spectral bands (60 for the BLM hyperspectral data set). Angles between vectors can then be defined in the usual way and used as a measure of similarity for comparison with reference spectra. Note that a 0 degree angle corresponds to identical spectra. The greater the spectral angle between two spectra, the more different those two spectra are.

Reference spectra are collected from either ground spectral samples or selected from identifiable areas in an image. Atmospheric effects can complicate the use of ground sample spectra and it is often preferable to use spectra derived from the image or data set to be analyzed as reference spectra. Aside from the selection of an appropriate reference spectrum, the key input with spectral angle classification is the specification of a threshold match angle. Data spectra that match the reference spectrum within the threshold limit are classified the same while spectra that do not match the reference spectrum within the threshold limit are classified as different than the reference spectrum.

A number of factors influence the selection of a proper threshold, including the feature(s) of interest, feature complexity within the image and frequency of occurrence. Setting a low threshold limit can lead to a small number of matches while a high threshold limit often leads to false alarms. Adequate ground truth data are necessary to optimize the selection of the threshold value. Spectral angle matching is often a good first discriminant metric to try and is easily automated.

ASPIS™ Bloodhound Detection

The basic idea of Bloodhounds is to find by example. Using examples of target spectra taken from one scene, a Bloodhound will look for similar spectral signatures in other scenes. Several methods for Bloodhound detection are incorporated in APTI's ASPIS™ hyperspectral data processing and exploitation software. The spectral angle method described above is one of the Bloodhound methods available for classification and detection purposes. Another method is Constrained Energy Minimization (CEM). The CEM method uses the statistical variation in the scene to weight certain combinations of spectral bands more than others.

A third detection method is decimated wavelet. In the decimated wavelet method individual spectra are decomposed into a basis of wavelet functions that are scaled and translated versions of a single waveform. A decision is made to keep some of the wavelet functions and throw others away (decimation). The resulting reconstructed spectra are then compared using spectral angle.

All three detection methods described above can be applied using an individual reference spectral signature comprising a signature or a band by band mean of a set of reference spectra. Generally using the mean spectrum provides more robust classification results.

Spectral angle mapping within the Bloodhound method was used to derive example classifications. Representative image spectra were extracted from the areas where ground data were collected. These spectra were then used as bloodhounds to find spectra within the sample image as well as adjacent images, that fall within the spectral angle interval specified by the analyst. Descriptions of the spectra used as well as the results obtained are presented below.

Results and Analysis

Overview

The results section of this document contains a description of the results obtained during the initial analysis of the hyperspectral and LIDAR data collected during the June 2002 BLM mission. Also included is a description of the deliverables produced for the study, including the digital database that is an integral component of the analysis. Note that the results presented herein represent a preliminary analysis of only a small subset of the entire hyperspectral, LIDAR, and ground truth data.

Hyperspectral RGB Color Composite Imagery

RGB imagery on its own represents a high resolution (1 m^2) color composite that serves as a baseline view (akin to a large-area high-resolution airborne photograph) of ecosystem conditions for the surveyed areas in the time period of 27 - 29 June 2002. Spectral band intensities corresponding to 656 nm, 540 nm, and 444 nm were used for the R, G, and B components in the RGB color composite images throughout. Figure 14 shows an RGB color composite image of hyperspectral data collected for the Monument area.

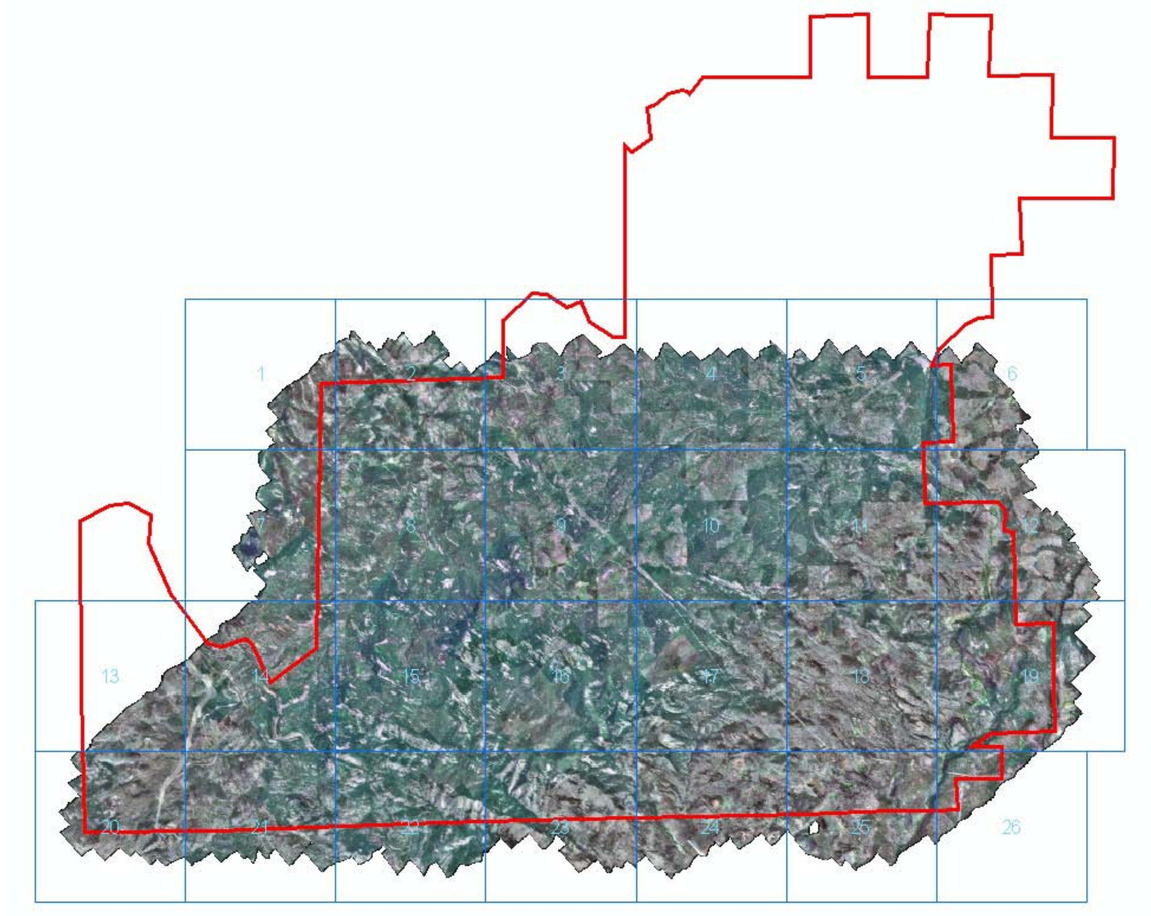

Figure 14. RGB color mosaic of the CSNM project area

Hyperspectral False-Color Infrared (IR) Composite Imagery

Infrared (IR) color composite imagery, with an IR spectral intensity band replacing the red band of a standard RGB color composite image, serves to highlight vegetation. This is due to the fact that chlorophyll-containing constituents have high spectral reflectance in the near-IR wavelength bands. Bright red pixels in a pseudo-color IR image typically indicate healthy tree constituents and/or dense vegetation. Less bright red pixels often indicate sparser vegetation, such as shrubs and grasses with some soil content, or less healthy vegetation. Non-vegetative constituents are typically indicated with a higher fraction of blue and green colors in a false-color IR image. Spectral band intensities corresponding to 733 nm, 540 nm, and 444 nm were used for the IR, G, and B components in the IRGB false color composite images throughout.

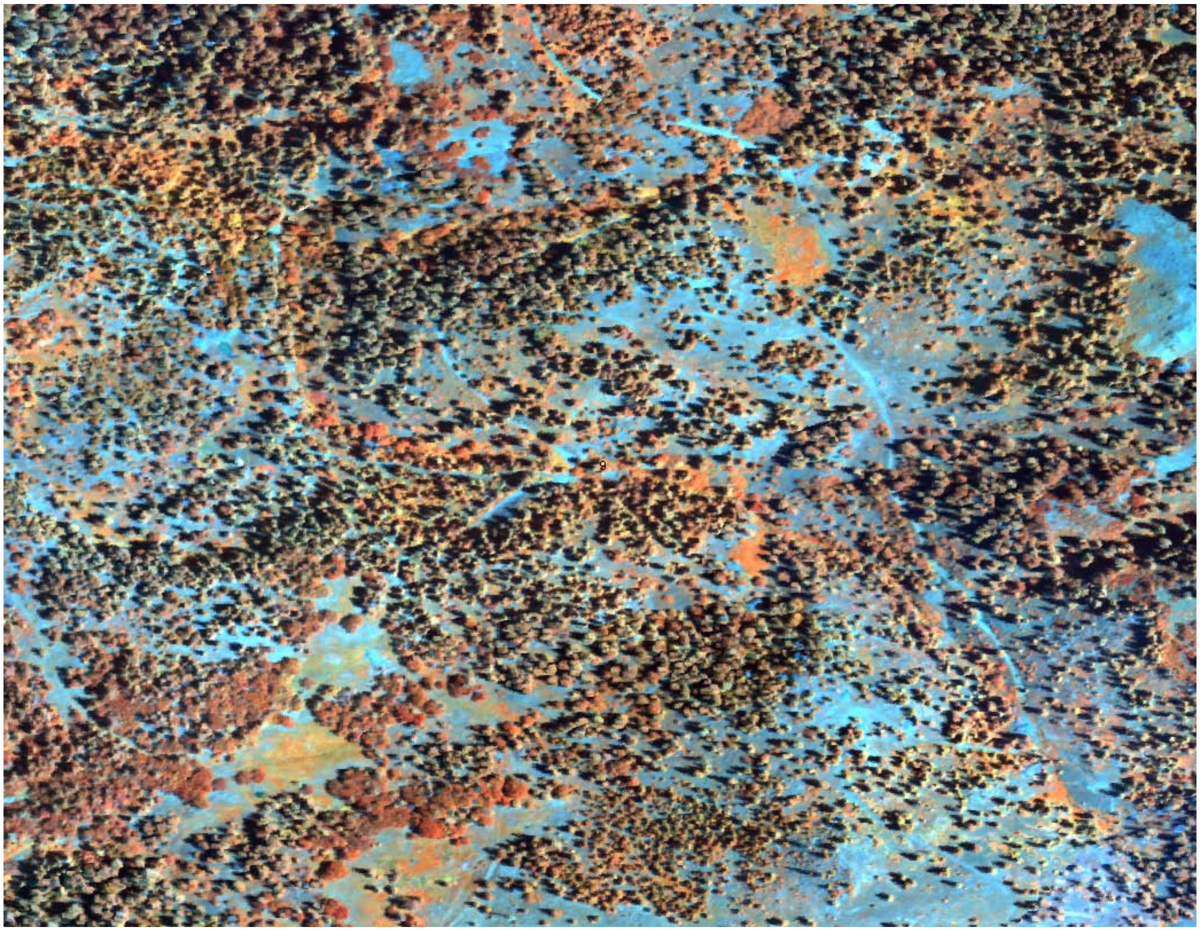

Figure 15. IRGB false-color mosaic of the CSNM project area

Figure 15 is a sample IRGB composite image of hyperspectral data collected in the central portion of the Monument study area, from the Data Tile Mosaic 9. The image covers an area of approximately 2 km^2 (494 acres). Note the heavily vegetated areas appearing bright red. There is also a tonal distinction between trees and shrubs. Finally, soil and rock areas appear in deep blue, while disturbed soils are a lighter blue.

Mosaics of RGB Color Composite and False-Color IR Composite Imagery

Individual hyperspectral data cube RGB color and false-color IR composite images were georeferenced and mosaicked together for the entire BLM mission to produce large-area coverage imagery and ArcView project data layers. Figure 16 illustrates a mosaic of RGB color composite imagery that is Tile 9 in its entirety. Numbers surrounding the mosaic indicate adjacent Data Tile numbers. Each Tile mosaic covers an area of approximately 16 km^2 (3950 acres).

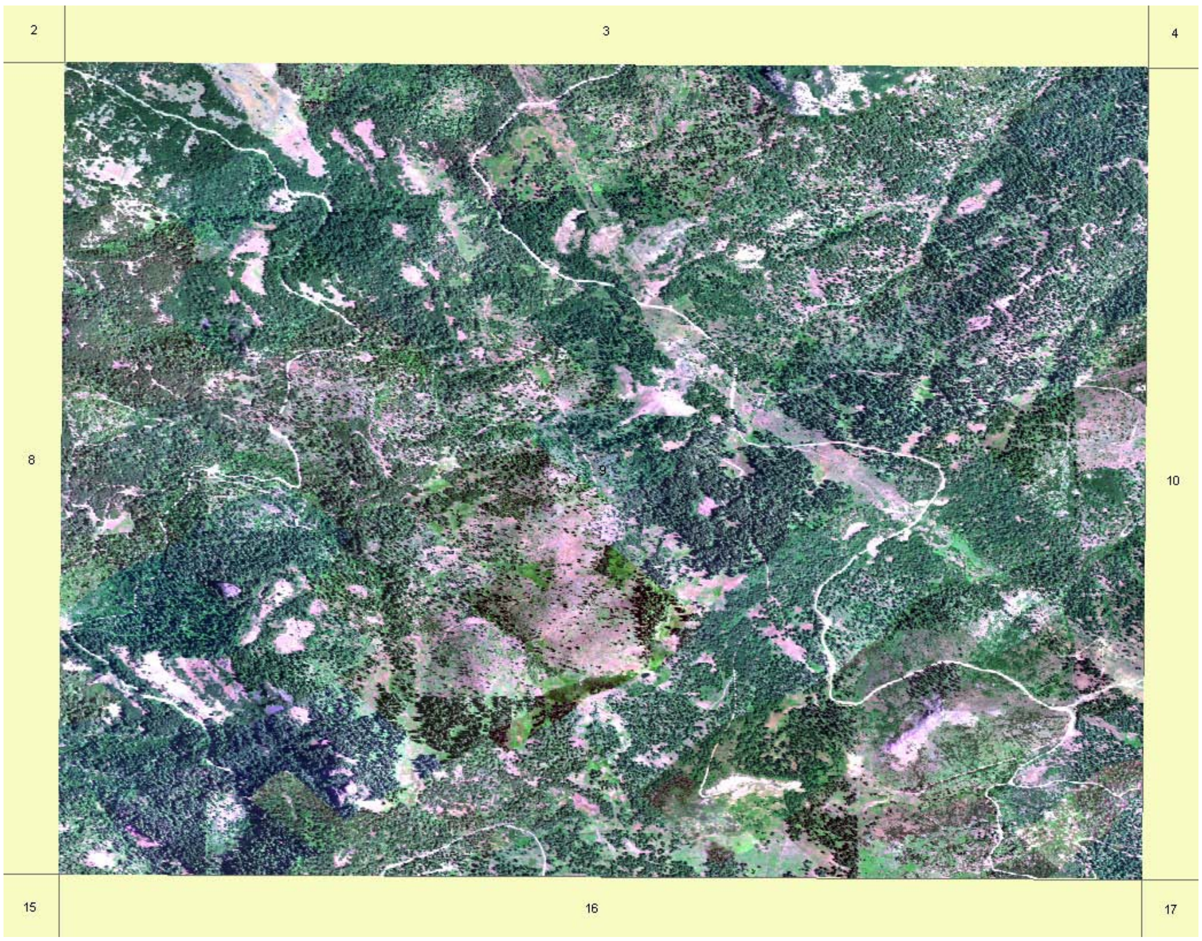

Figure 16. Data tile RGB color composite, central Monument area (Tile 9)

LIDAR-Derived Digital Elevation Models

Raw LIDAR data were processed to bare earth digital elevation models (DEMs) for the surveyed areas. In addition, a vegetation height layer was derived from differencing the unedited ("raw") and edited ("bare earth") DEMs. Figure 17 illustrates a sample hillshaded DEM derived from the unedited ("raw") LIDAR data collected of the Monument project area.

Figure 17. Hillshaded LIDAR-derived "raw" digital elevation model (DEM) of a portion of Tile 9, central Monument area

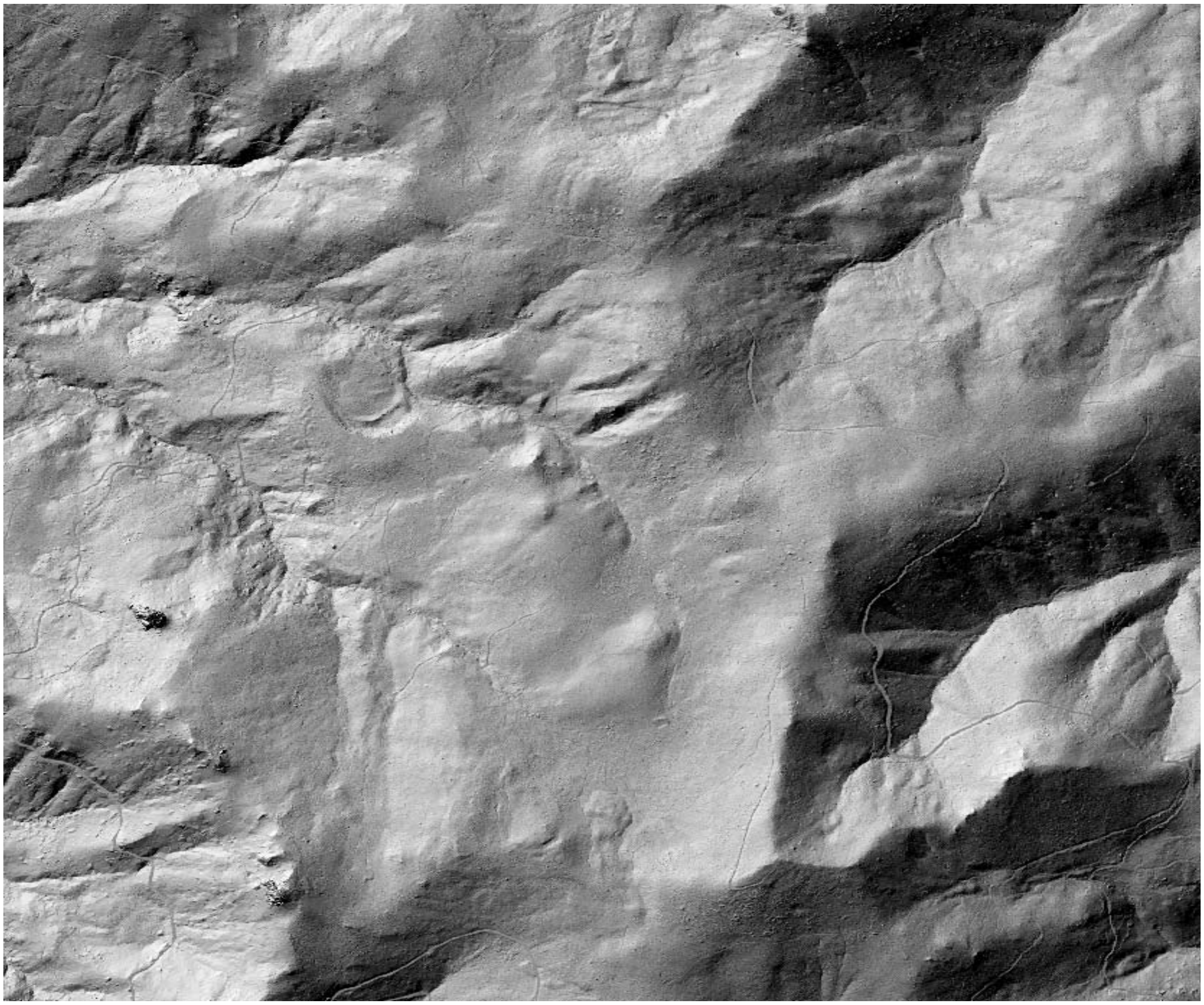

Figure 18. Hillshaded LIDAR-derived "bare earth" digital elevation model (DEM) of a portion of Tile 9, central Monument area

Figure 18 is a bare earth example DEM and Figure 19 is the vegetation height layer. All of these DEM examples are from data Tile 9, in the central portion of the Monument project area. DEMs and the vegetation height layer for the field site were created in the standard set of data tiles also used by the RGB and IR imagery. The LIDAR-derived DEMs are delivered in the Arcinfo GRID format. Each grid (one per *data tile*) is an array of elevation values at 1-meter horizontal spacing. Elevations are relative to the National Geodetic Vertical Datum of 1988 and expressed as meters.

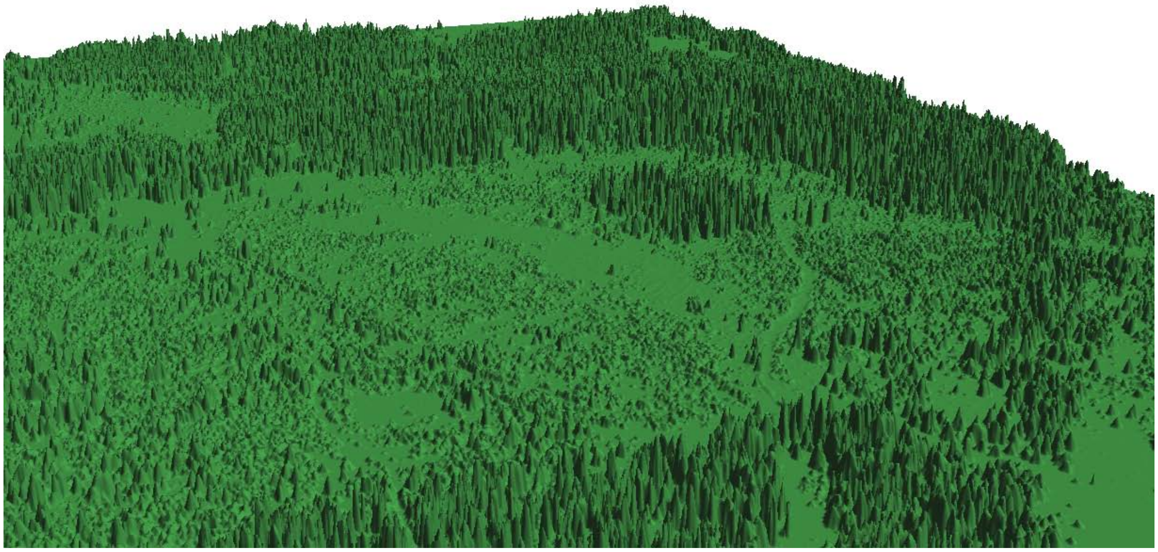

Figure 19. LIDAR-derived vegetation height data layer of a portion of Tile 9, central Monument area

The LIDAR data has a multitude of potential uses ranging from topographic mapping and modeling through vegetation biovolume quantification. Topographic mapping includes generation of surface models, contours and watershed analysis. Biovolume calculation is a broad term that includes vegetation height and density measurement as well as derivation of vegetation biomass. Finally, the LIDAR-derived vegetation height data can be incorporated into the hyperspectral data classification process as a measure of texture and for stratification of vegetation classes. APTI has ongoing internal research and development programs addressing the use of LIDAR data for biovolume calculation and classification enhancement.

Normalized Difference Vegetation Index (NDVI) Imagery

A first order visualization and quantitative indicator of the amount, density and condition of the vegetation in the study area is provided by Normalized Difference Vegetation Index (NDVI) imagery. This data layer provides landscape scale overview of vegetation occurrence and condition for the entire study area. It provides a baseline indicator of vegetation and nonvegetation, extent and condition, allowing for monitoring of change over time. NDVI is defined as

$$(p_{NIR} - p_{red}) \ / \ (p_{NIR} + p_{red}),$$

where p is the surface reflectance. The bands chosen for the NIR band and the red band vary depending upon the resolution of the data, with typical bands being 750 - 850 nm for the NIR band and 650 nm for the red band. The difference in surface reflectances divided by the sum of the surface reflectances helps compensate for different amounts of incoming light. NDVI ranges between 0 and 1, with typical values varying from 0.1 for bare soils to 0.9 for dense vegetation.

Figure 20 is a sample IRGB image from Tile 9 and Figure 21 the same image expressed as an NDVI image. Increasing values from above nominally 0.2 (deep red/magenta in Figure 20; yellowish green in Figure 21) typically indicate healthy, dense vegetation. Values between nominally 0.0 and 0.2 (pink to light red in Figure 20; yellowish green in Figure 21) typically indicate sparser vegetative ground cover. Values less than 0 (blue in Figure 20; yellow in Figure 21) typically indicate non-vegetative ground cover (e.g., soil, rocks). Georeferenced and mosaicked NDVI imagery constitutes a data layer delivered as part of the overall CSNM data set.

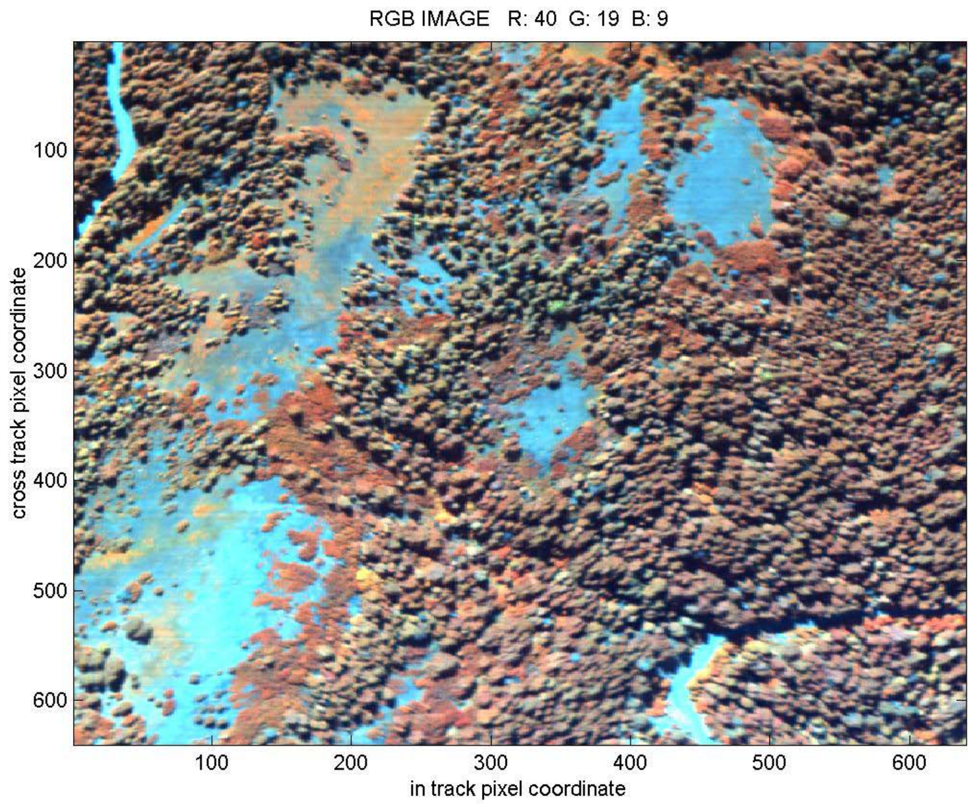

Figure 20. IRGB image of a portion of Tile 9

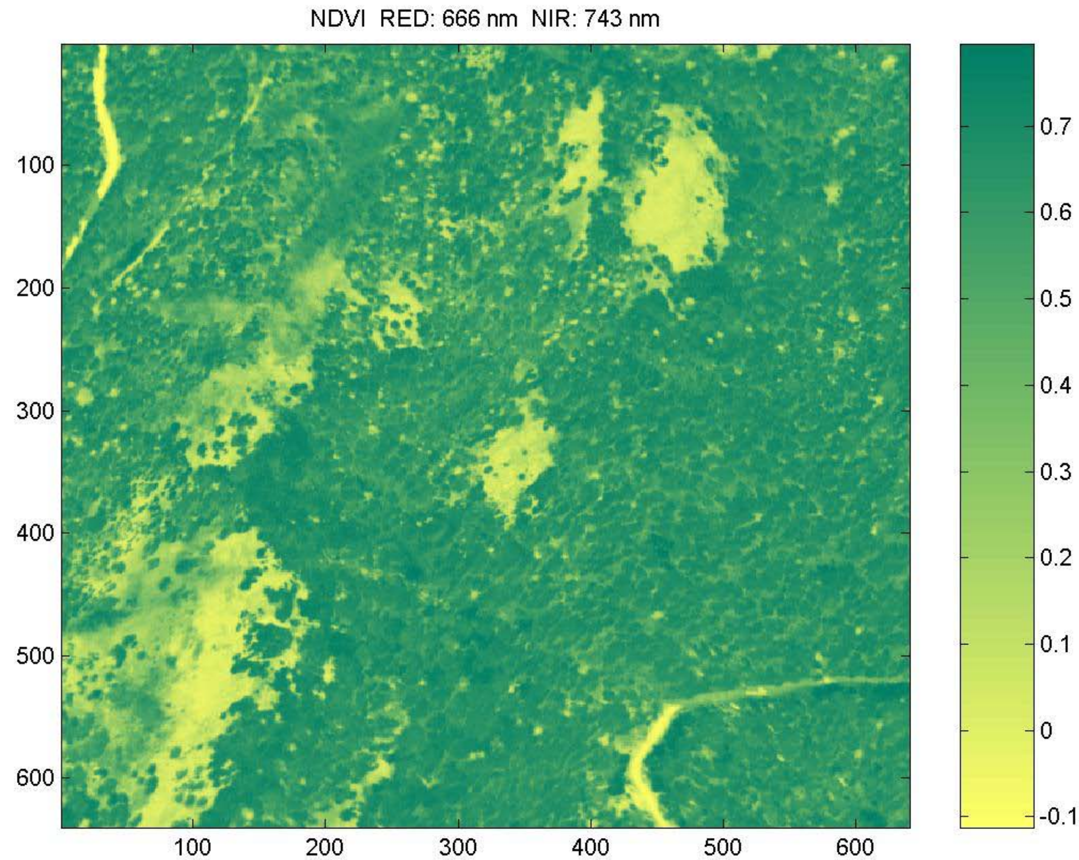

Figure 21. NDVI image of a portion of Data Tile 9

Classification Overview

The primary objective of this project was to collect and process airborne hyperspectral imagery and LIDAR data. A secondary objective is to demonstrate the utility of the hyperspectral data by deriving image classifications for a small number of sites and features. Ground data collected during the June 27 and 28 field visits were used to perform a supervised classification. Hyperspectral data cubes encompassing the field sites were classified using the Spectral Angle Mapper Bloodhound method. These data cubes are organized into clusters of two or more adjacent cubes. Figure 22 shows the general location of the clusters in the project area. The clusters in blue represent data cubes of areas with a diversity of features and where APTI collected ground data. Table 3 presents a summary of the results of the classification evaluation.

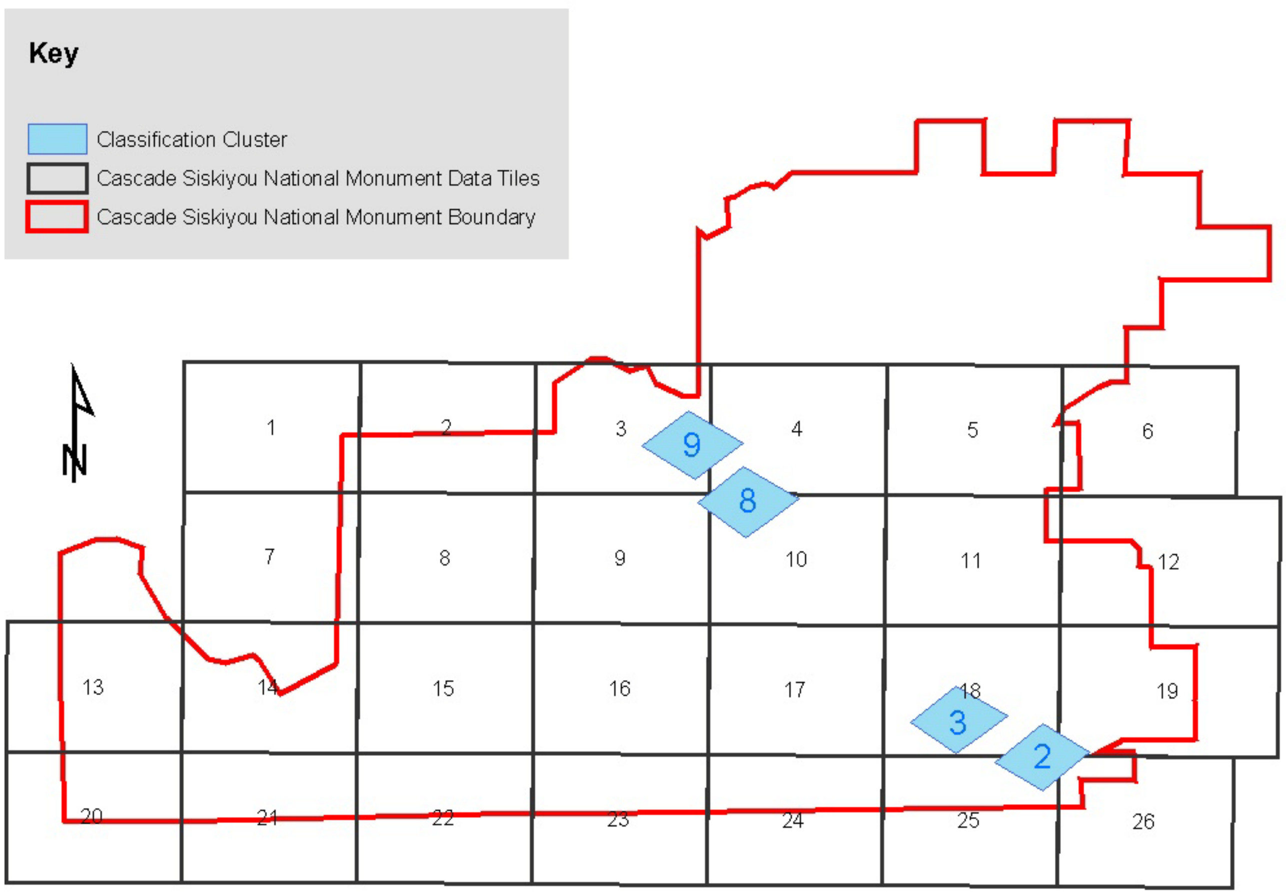

Figure 22. Hyperspectral data cube cluster locations

Cluster	Species Type	Number of Species Detected	Spatial Extent (Hyperspectral Data Cubes)
2	Juniper, Needlegrass, Medusahead	3	2 cubes
3	Buckbrush, Medusahead	2	3 cubes
8	Cattail, Incense Cedar, Scirpus, White Fir	4	3 cubes
9	Oregon Ash, Scirpus	2	3 cubes

Table 3. Inventory of Hyperspectral Data Classifications

The supervised classification procedure involves selecting regions of interest (ROIs) of known or representative features, evaluating the "purity" of the ROIs, determining the appropriate spectral angle threshold and evaluating the results using a priori information (i.e. ground data).

Regions of Interest (ROIs)

Regions of Interest (ROIs) are comprised of pixels and their associated spectra user selected from the hyperspectral data cube. These spectra are raw, "at-sensor" response spectra, not corrected to radiance. However they can be used as surrogates for at-sensor radiance and are used to identify all pixels within the data cube, or data set, that fall within a user-specified spectral angle match tolerance. This tolerance can be simply thought of as a confidence interval set by the user. Factors that affect how representative the chosen ROI spectra include feature patch size, adjacency effects, canopy coverage, purity and topography. Primary features of interest in this study are vegetation species. Minimum patch size is a function of sensor resolution. A reasonable rule of thumb is that a patch should be three to five times larger than minimum resolution. For this project that translates to 9 – 25 square meters based on a 1 square meter pixel. Adjacency effects refer to the influence of included or nearby features of different composition that can modify the spectra exhibited by the desired feature in the ROI. Related to adjacency is the concept of purity, which in this project refers to the vegetation complex in the ROI. Inclusions of other vegetation species in an ROI patch will modify the spectra exhibited. Related to purity is canopy coverage. ROIs with sparse canopy coverage will exhibit a strong soil influence in the spectra. Finally, topography can affect illumination angle, producing glint, shadowing and illumination non-uniformity. This description provides a brief overview of factors to consider in selecting spectra for supervised classification.

Intra-Species Spectral Variability

In creating ROIs, multiple spectra are selected to enhance the spectral characterization of the feature of interest by compensating for intra-species spectral variability. In practice, the mean of the selected spectra that comprise the ROI is used for spectral angle classification method. In the context of ROI creation, variability can be thought of as an indicator of the similarity of spectra. ROI variability can be evaluated using the Signature Set Editor™ (SSE) module of ASPIS™. The SSE module has a function called the Match Grid, which compares the angular deviation of each spectrum selected in the ROI creation process. Minimizing this angular deviation produces an ROI with a smaller variation or match angle, of spectra that describe the feature of interest. The match angle is a valuable indicator of the spectral angle threshold selected by the user in the classification process. A rule of thumb for vegetation detection is a five-degree or less angular deviation in the ROI. A deviation or variability greater than approximately five degrees indicates a high degree of variability in an ROI and a low probability of detecting the feature of interest. Too much variability in ROI spectra means that confusion between the feature of interest and other features with similar spectral characteristics may occur, resulting in false detections. This is the effect of intra-species variability being greater than inter-species variation.

Inter-Species Spectral Variability

The Match Grid also provides a means to evaluate the spectral separability of species by illustrating variation between spectra and ROIs of different species. The match angle between features indicates whether those features can be spectrally discriminated one from the other. Following from the rule of thumb above, an inter-species match angle greater than approximately five degrees indicates a reasonable degree of uniqueness and separability. Figures 23 through 25 provide examples of the spectral separability between woody and grass species in the CSNM project area. These graphics show spectra organized in quadrants, with lighter colors indicating lower match angles and darker colors indicating higher match angles. The lower numbers are typically within the ROI ("intra") and the higher numbers are between the ROIs ("inter").

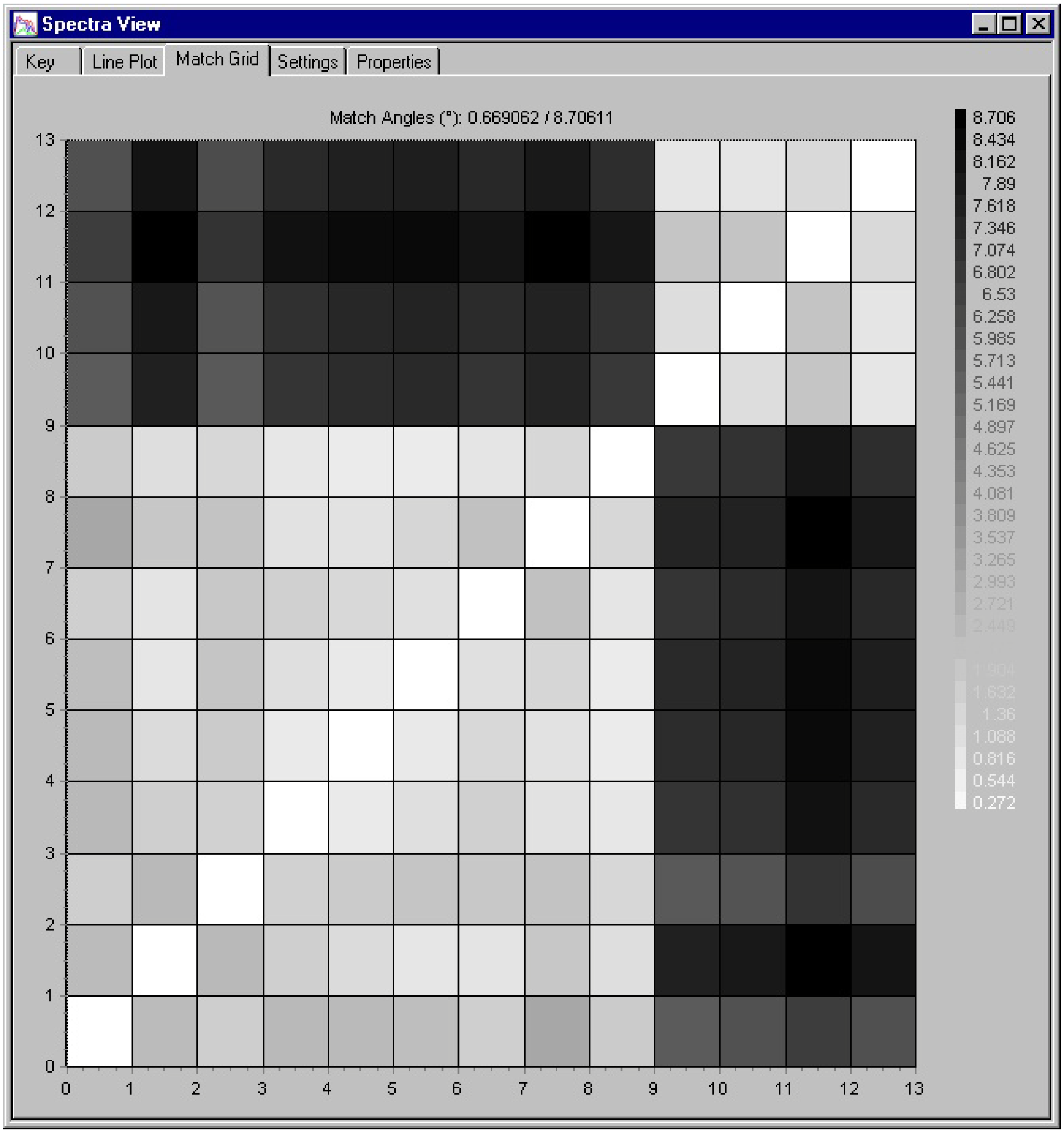

Figure 23. "Scirpus" (columns 1-9) versus Douglas Fir (columns 10-13) match grid

Figure 23 compares "Scirpus" (Bulrush; an emergent and wetland species) spectra (9 spectra in the SW quadrant; intra-species maximum match angle of approximately 2.99 degrees), to Douglas Fir spectra (4 spectra in the NE quadrant; intra-species maximum match angle of approximately 2.02 degrees). The dark quadrants (NW, SE) are the interspecies comparison areas, while the light areas are the intra-species individual ROIs. The colors and values indicate the difference between intra- (light) and inter- (dark) comparison of the ROIs. The maximum match angle between the two species is 8.70611 degrees indicating a moderate level of separability.

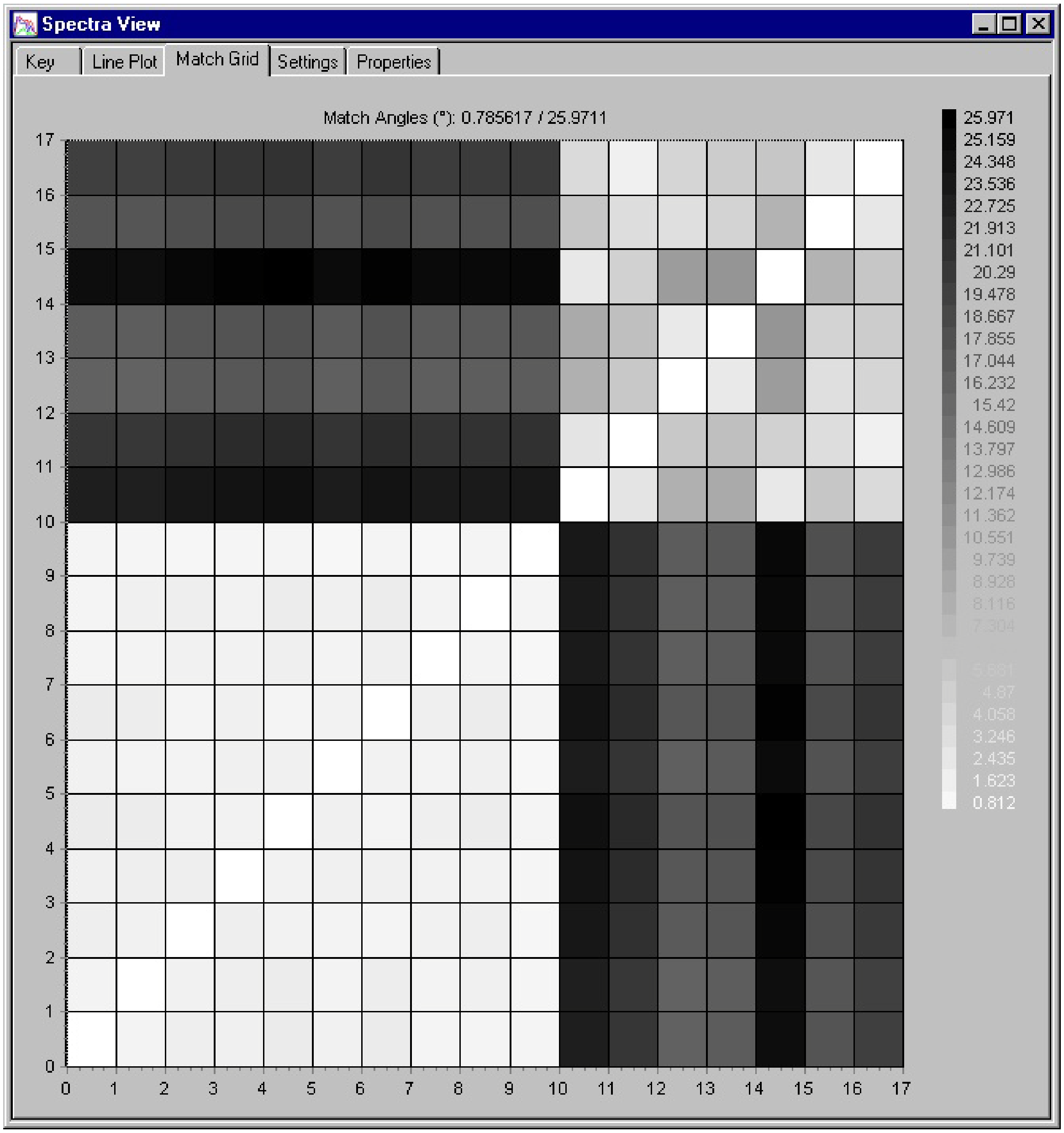

Figure 24. Medusahead/Tritelia mix (columns 1-10) versus Juniper (columns 11-17)

Figure 24 compares a Medusahead/Tritelia mixture (10 spectra in the SW quadrant; intra-species maximum match angle of approximately 2.06 degrees) with Juniper (7 spectra in the NE quadrant; intra-species maximum match angle of approximately 10.82 degrees), with the maximum inter-species match angle of approximately 25 degrees indicating a high degree of separability.

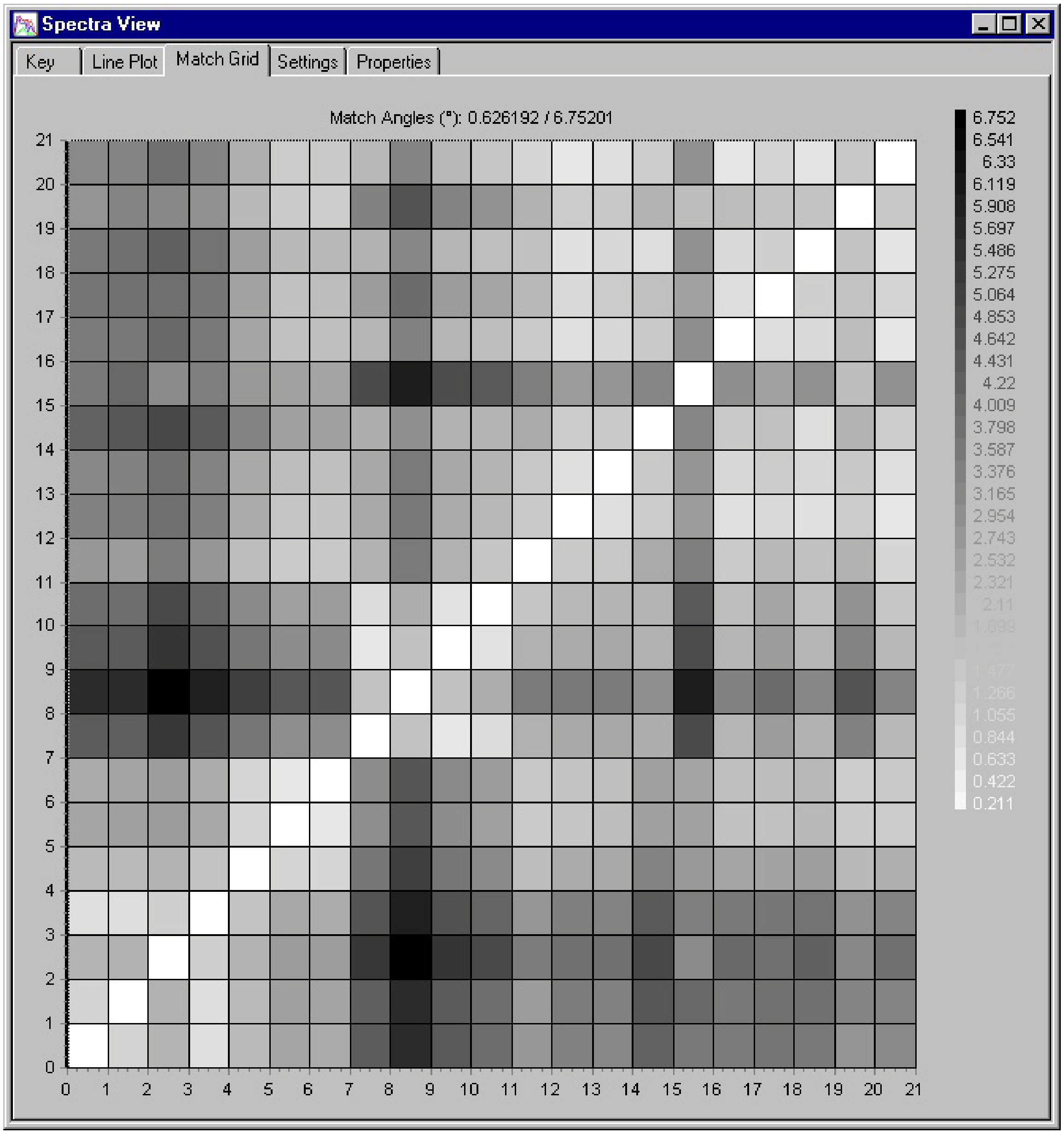

Figure 25. Douglas Fir (columns 1-4) versus White Fir (columns 5-21)

Figure 25 compares Douglas Fir (4 spectra in the SW quadrant; intra-species maximum match angle of approximately 2.02 degrees) to White Fir spectra (17 spectra in the NE quadrant; intra-species maximum match angle of approximately 2.06 degrees) and, as is to be expected, there is very little spectral distinction between the two species. The maximum inter-species match angle is 6.75201 degrees.

Classification Results

Classification results using the Spectral Angle Mapping method are summarized and illustrated below. As the classification was a secondary objective, to be explored to the extent possible, a limited number of cubes and vegetation species were examined. Due to the limited scope of this effort, it is not possible to establish the accuracy and validity of the classifications. Thresholds and parameters chosen yielded very conservative detections that fell within the limits of the ground data polygons. A bonafide classification effort would include ancillary vegetation mapping data, consideration of topography and topographic effects and an extensive field effort for clarification of confusions (false detections), anomalies and overall classification accuracy. While an effort such as is described above is beyond the scope of this study, positive preliminary detections and results were achieved. The following set of figures display a partial set of examples of detections achieved for species that were collected during the field effort on 27 and 28 June 2002. The yellow circles highlight the general location of the feature species and polygons collected using GPS. All images displayed are IRGB GeoTiffs.

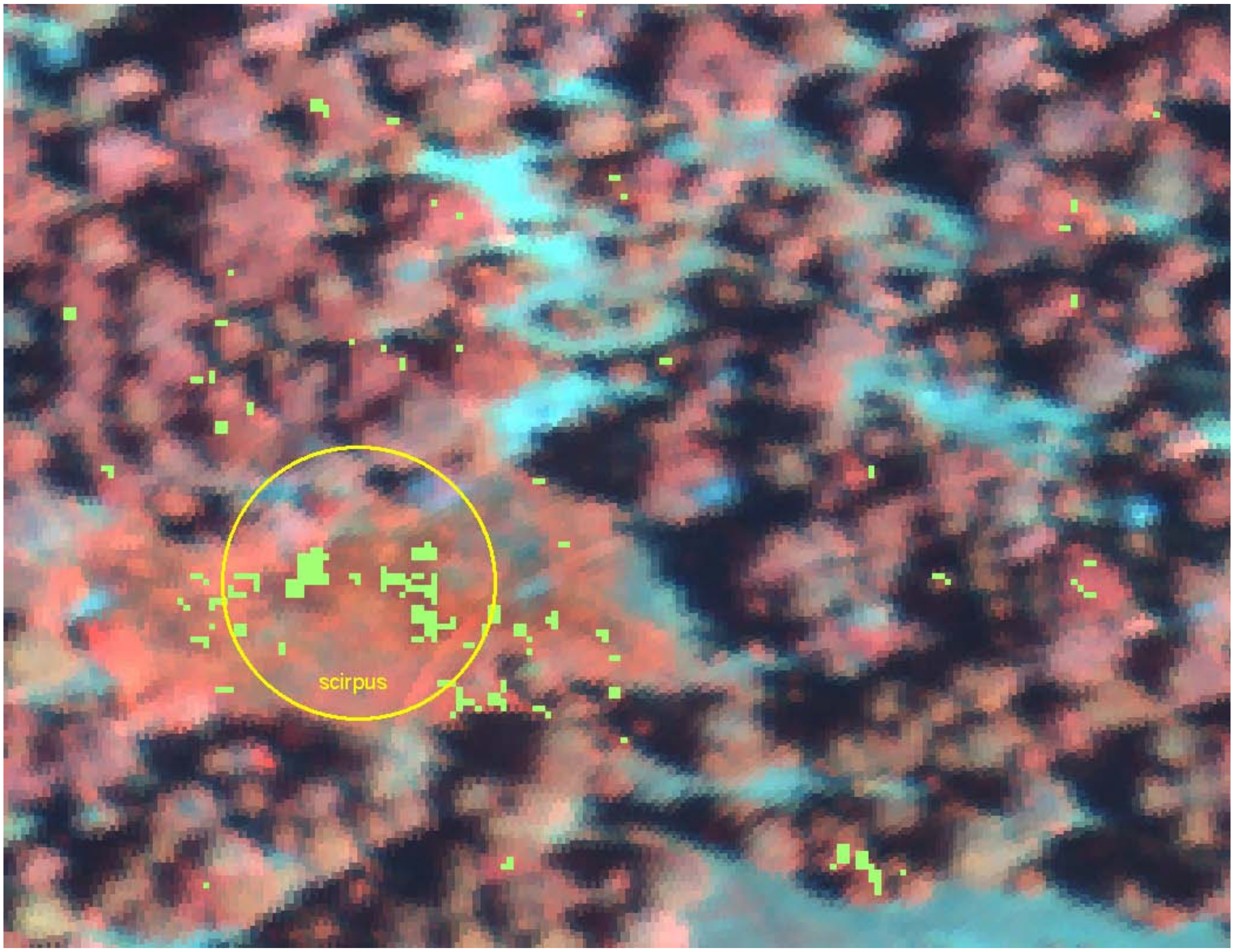

Figure 26. Cube Cluster 8 Scirpus example detection results (apti_062802_poly.shp ground data)

Figure 26 presents detection results for Scirpus, wet meadow vegetation from cube Cluster 8 draped on an IRGB GeoTiff. The ground data shape file that identified the features of interest is apti_062802_poly.shp.

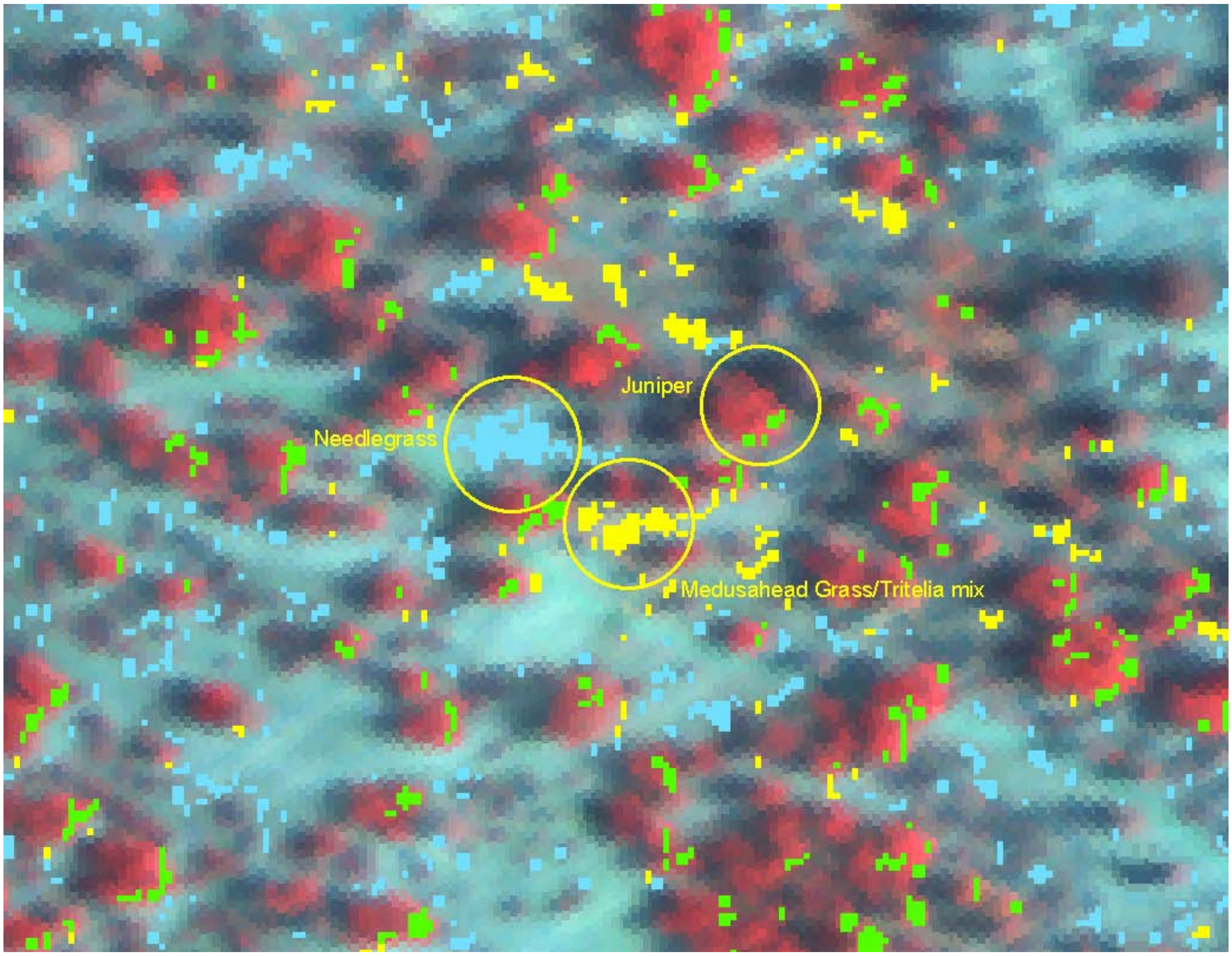

Figure 27. Cube Cluster 2 Needlegrass, Medushead/Tritelia mix and Juniper example detection results (blm_062702_poly.shp ground data)

Figure 27 illustrates several of features of interest, including Needlegrass, Medushead/Tritelia grass mixture and Juniper. The ground data shape file that identified the features of interest is blm_062702_poly.shp.

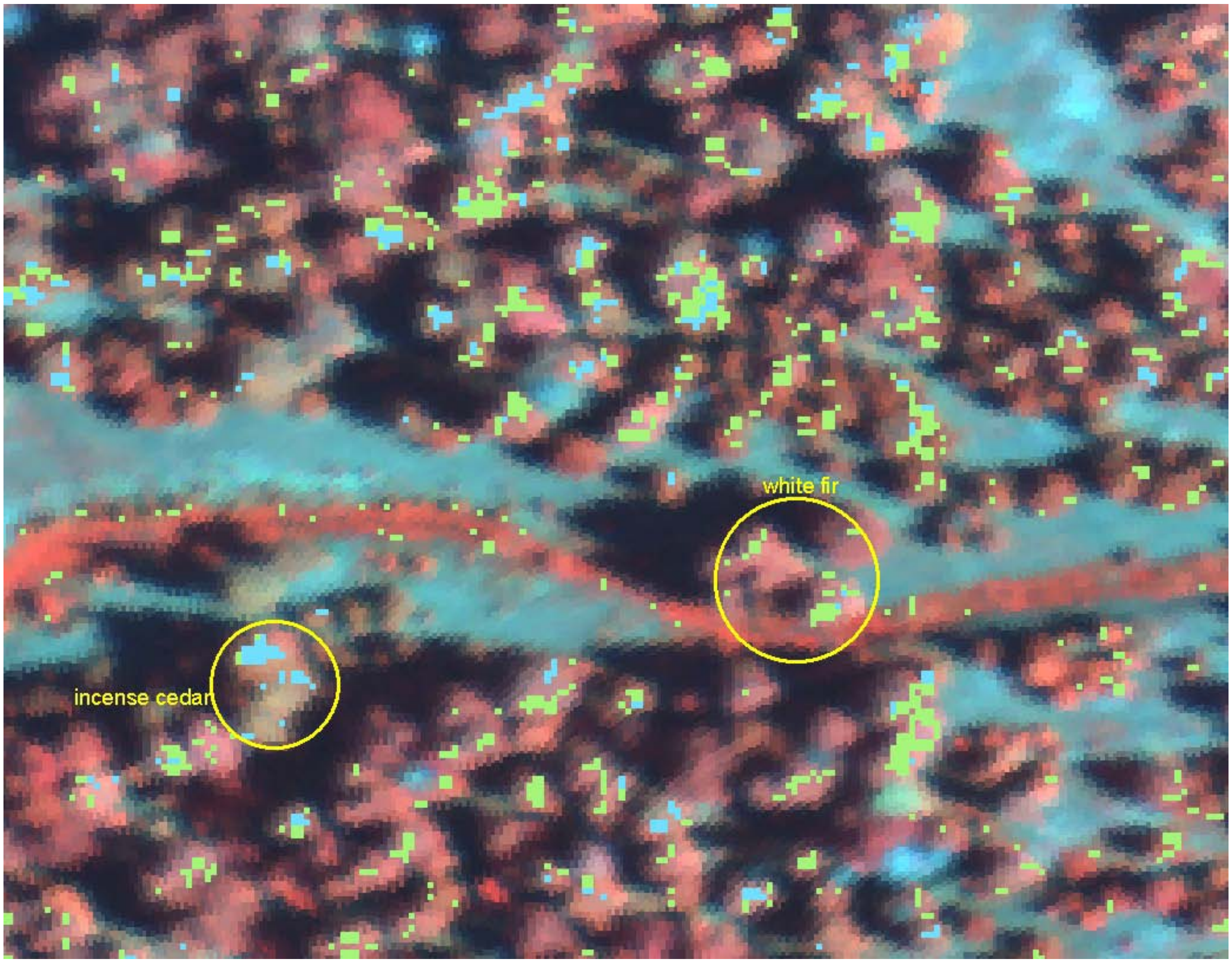

Figure 28. Cube Cluster 8 Incense Cedar and White Fir example detection results (apti_062802_poly.shp ground data)

Figure 28 illustrates incense cedar (light blue) and white fir (green) detection results from cube Cluster 8 draped on an IRGB GeoTiff. The ground data shape file that identified the features of interest is apti_062802_poly.shp.

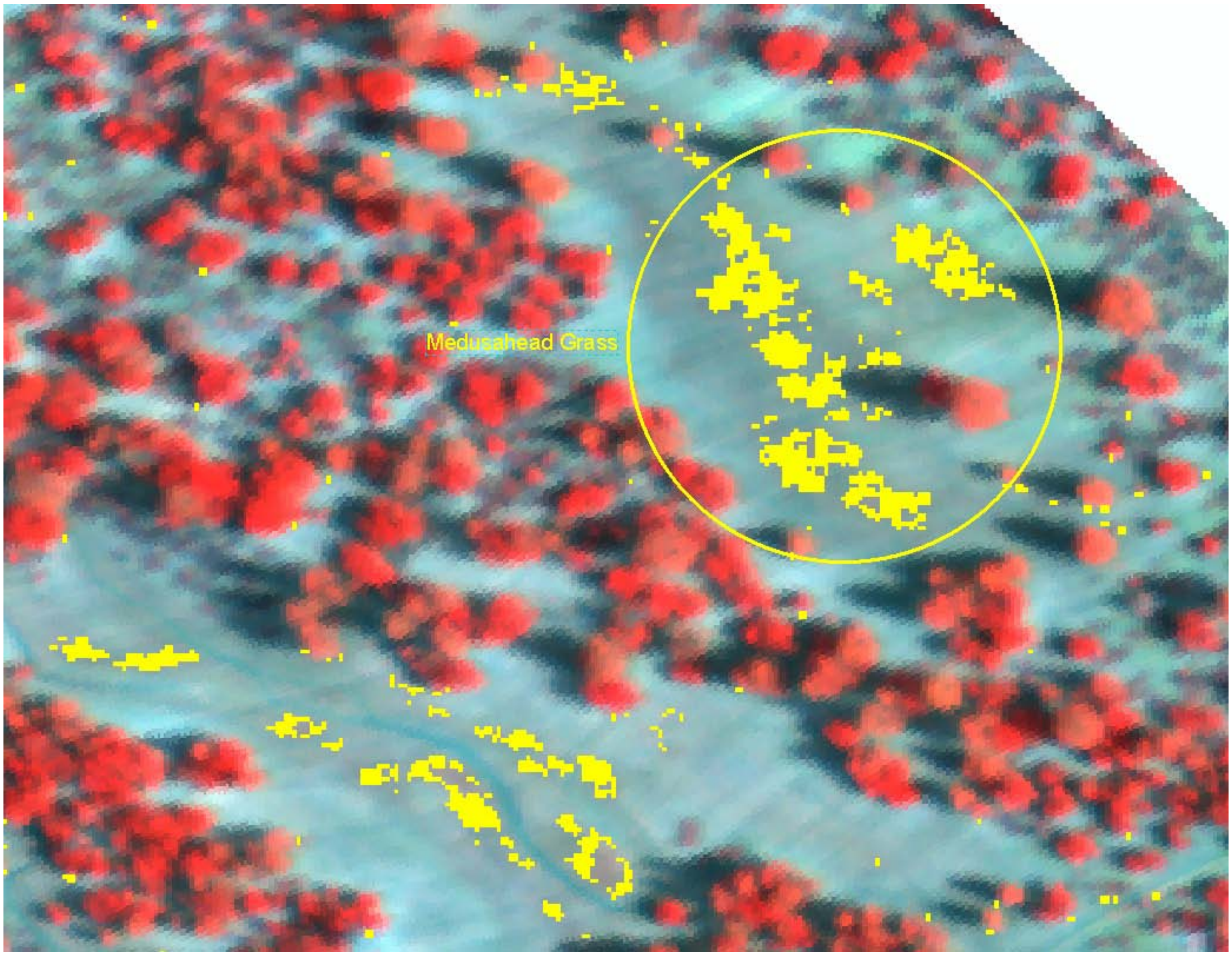

Figure 29. Cube Cluster 3 Medusahead Grass example detection results (blm_062702_poly.shp ground data)

Figure 29 illustrates detections for a Medusahead dominant patch (yellow) from cube Cluster 3. Ground data for this patch was collected on 27 June 2002 and can be found in the blm_062802_ploy.shp shapefile. This result shows very good agreement with the ground data collected.

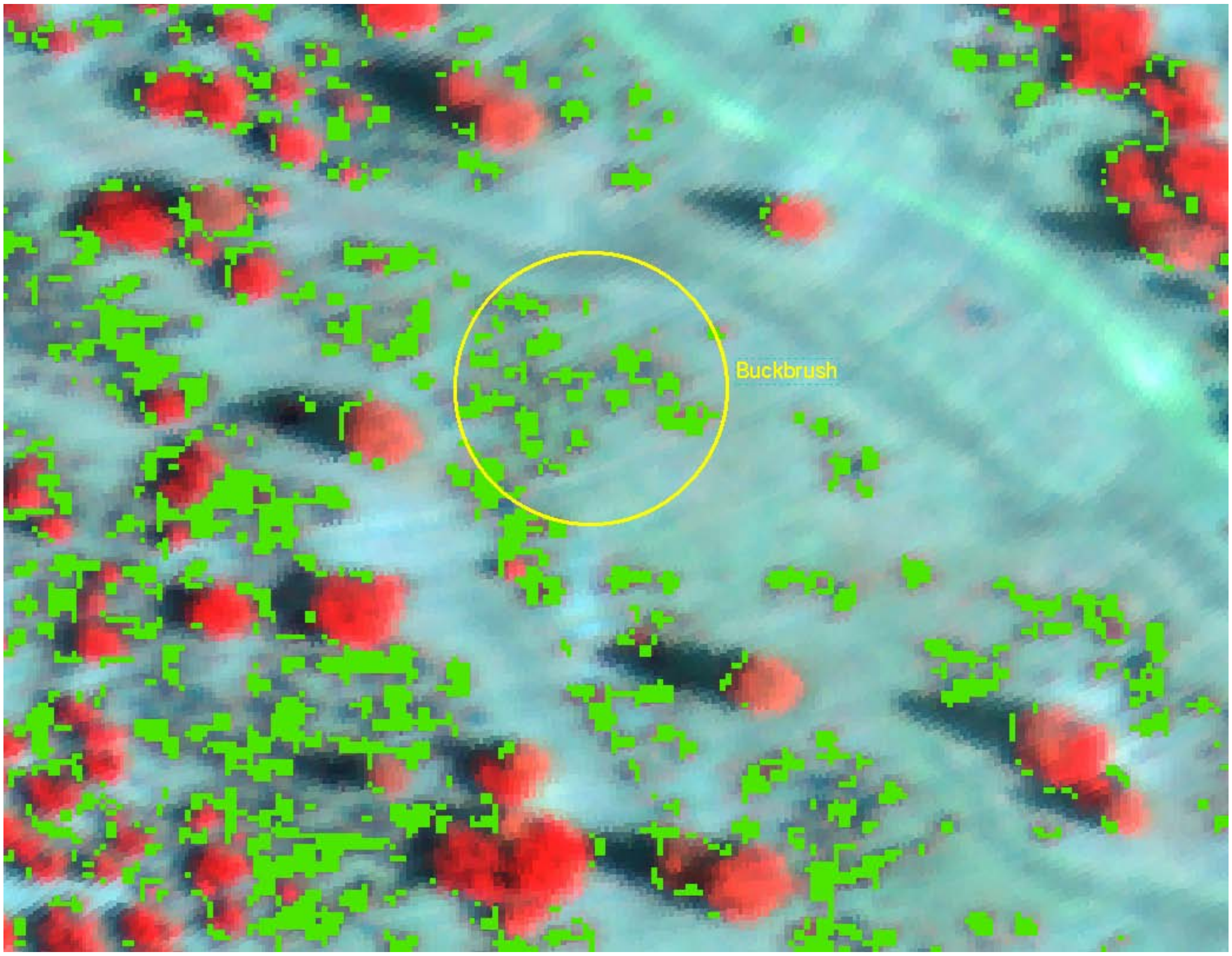

Figure 30. Cube Cluster 3 Buckbrush example detection results (blm_062702_poly.shp ground data)

Figure 30 illustrates example detections for Buckbrush in cube Cluster 3, based on ground data found in the blm_062702_ploy.shp shapefile. There are numerous shrub features detected in this scene, which highlights the point that validation, through use of ancillary data and additional fieldwork, is necessary.

Fire Model Results

In order to demonstrate the utility of the CSNM hyperspectral and LIDAR in fire hazard reduction and burned area restoration, a series of data layers were derived as inputs to the FARSITE fire model (Fire Area Simulator; version 3.0.91, author Mark A. Finney). Results of a series of simple fire simulations are presented below.

Hyperspectral and LIDAR data of the CSNM project area (see Figures 31 and 32) were processed to derive fuel model type, canopy cover, ground elevation, slope angle and aspect. These inputs, combined with simplistic weather conditions and fuel moisture contents, were fed directly into the FARSITE fire model for simulation of fire growth rates and behavior.

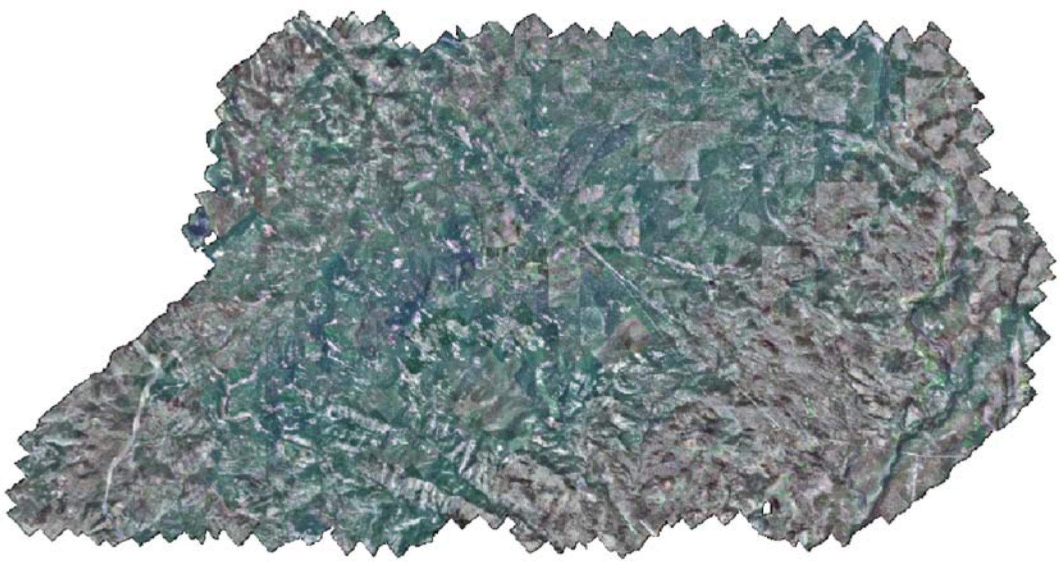

Figure 31. RGB color composite image of the CSNM project area

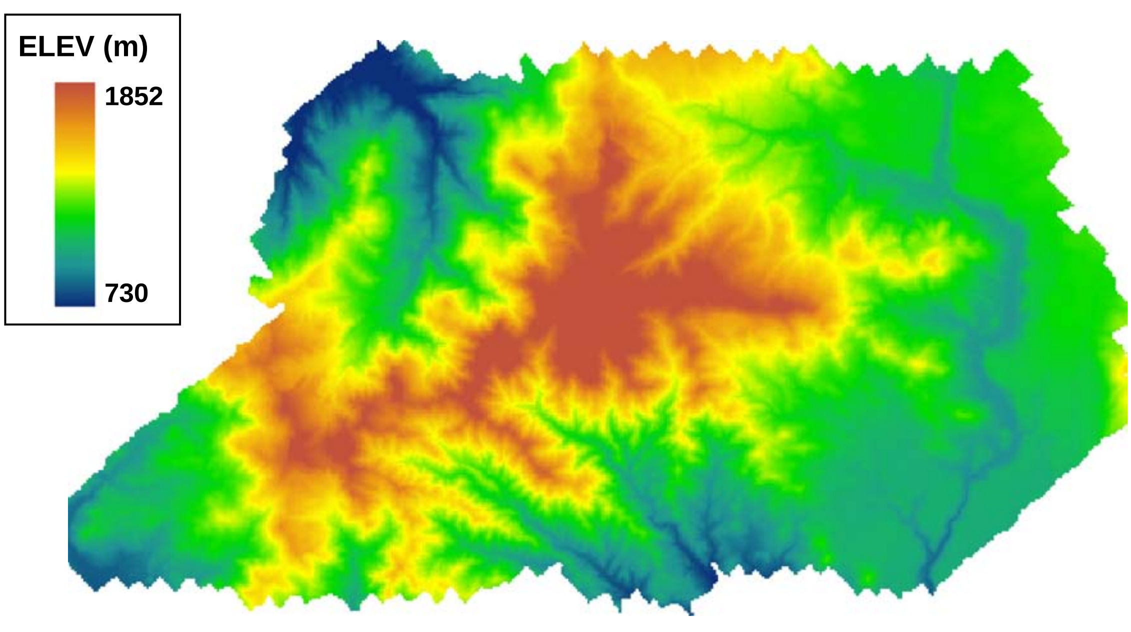

Figure 32. LIDAR DEM mosaic CSNM project area

Fuel model types were derived from a crude classification scheme combining hyperspectral and LIDAR data, with LIDAR data providing canopy height information to assist in the classification of trees in the project area. Classification of data as soil, grass or trees followed the simple set of rules written below:

> NDVI intensity < 0.2, pixel class = soil;
> NDVI intensity ≥ 0.2 and height < 2.0m, pixel class = grass;
> NDVI intensity ≥ 0.2 and height ≥ 2.0m, pixel class = tree;

The result of the classification described above is an assignment of each pixel into one of three classes, namely soil, grass or tree (see Figure 33).

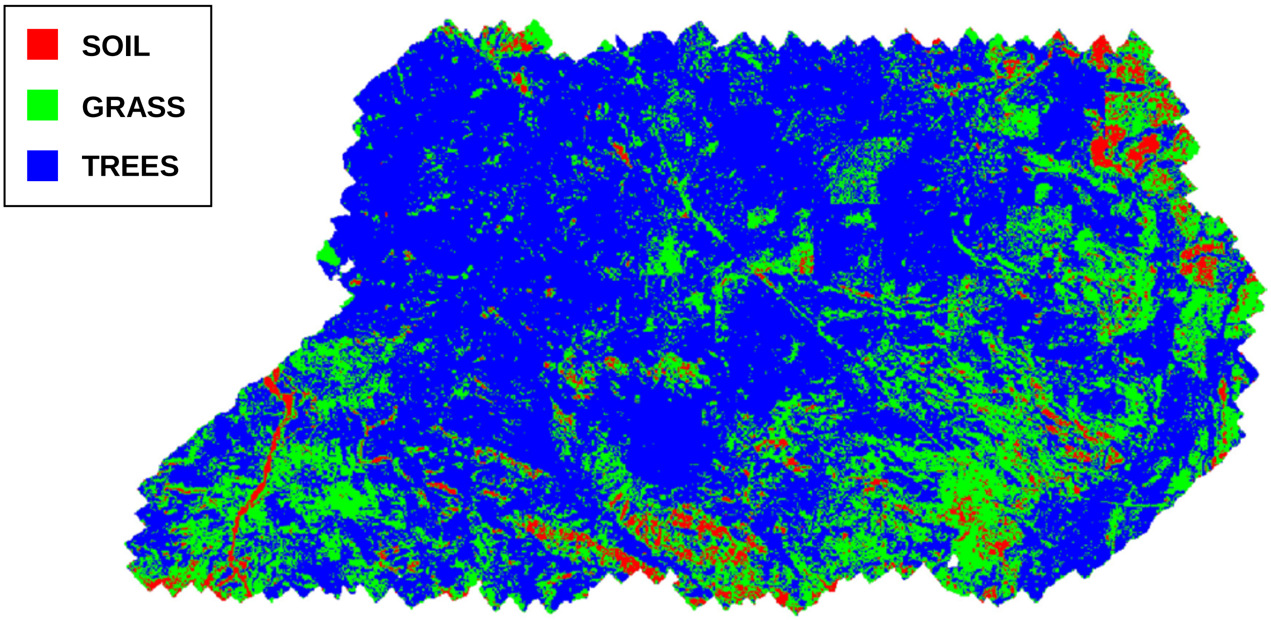

Figure 33. Classification map of soil, grass and trees for the CSNM project area shown at 1 m^2 ground resolution

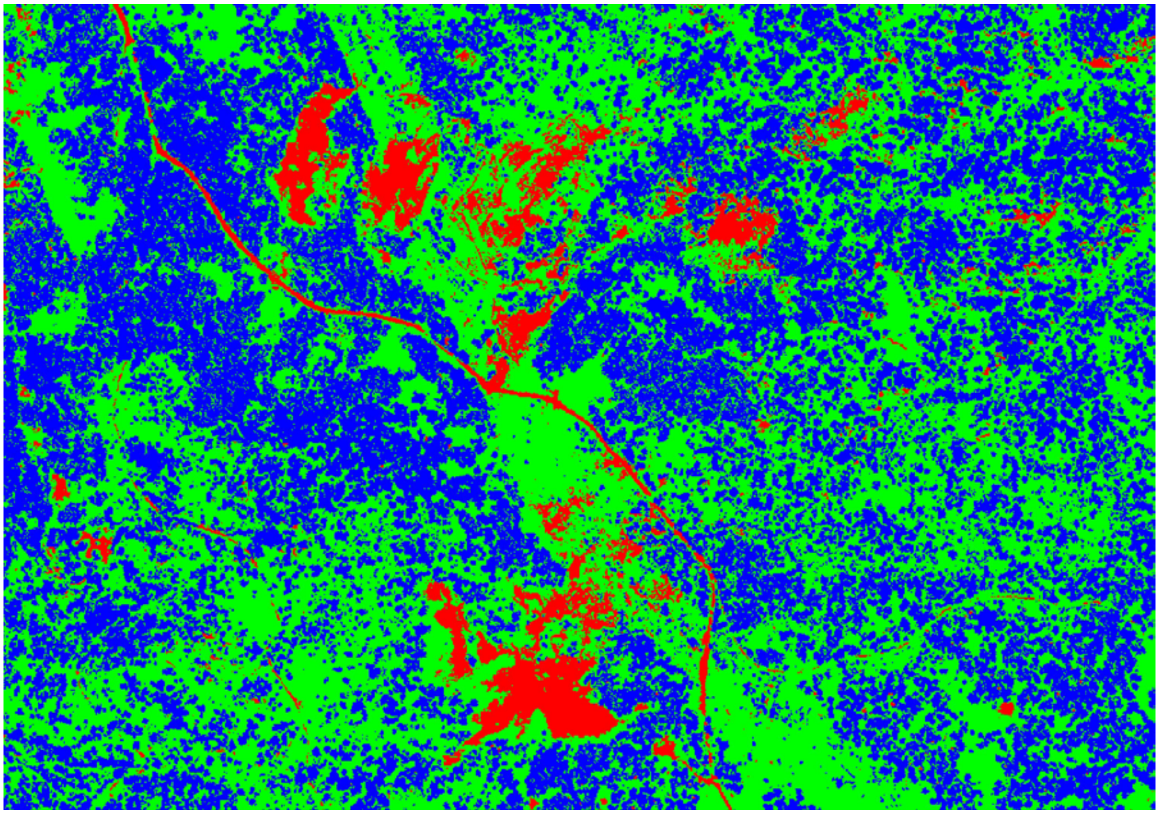

Figure 34. Zoom view of Classification map (see Figure 33 above)

Figure 34 is an enlarged view of the three-class map (soil, grass, trees) derived for input to the fire model. It illustrates the level of detail obtainable using the 1 square meter hyperspectral data.

The fuel model types used for this investigation are based on Anderson's fuel model classification system (reference: Anderson, H. E., 1982, Aids to Determining Fuel Models for Estimating Fire Behavior, USDA Forest Service General Technical Report INT-122, 22 pp). Fuel model 1 corresponds primarily to annual and perennial grasses. All trees were assigned fuel model type 8. A fuel model classification of 0 has been assigned to soil, rocks, buildings and water in the study region. The FARSITE model ignores a fuel model designation of 0. Figure 35 illustrates the estimated input fuel model types at an aggregated 1-acre resolution for the CSNM study area. Terrain-related inputs to the fire model have been estimated from the LIDAR-derived elevation throughout.

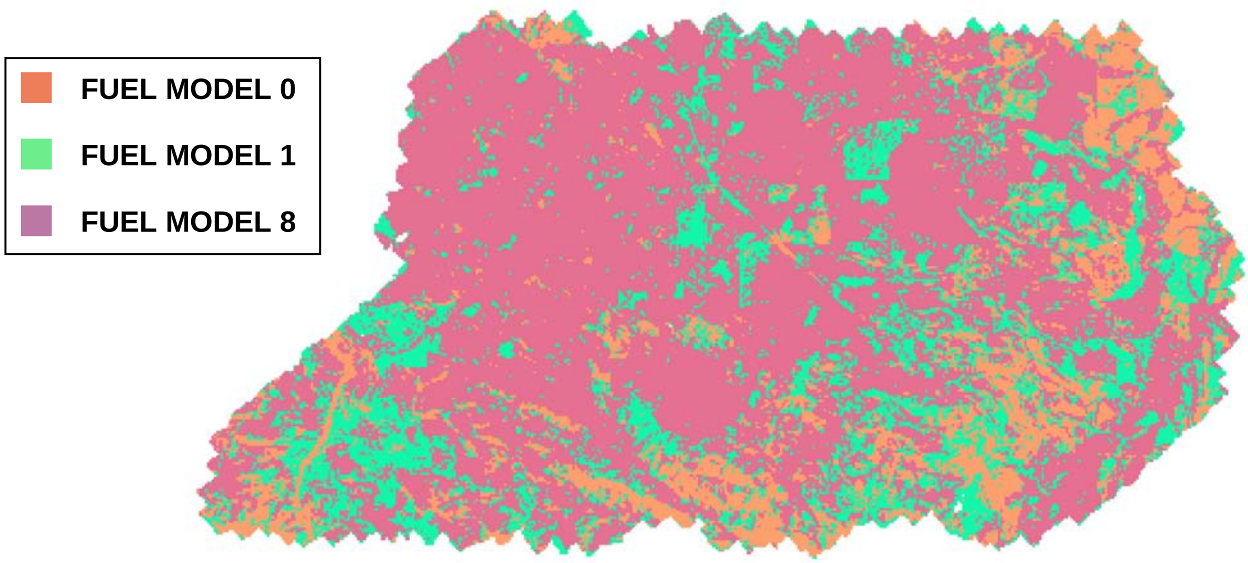

Figure 35. Fire fuel model classification for the ground cover in the Siskiyou project area shown at 1-acre ground resolution

Canopy cover layers were derived from differencing the raw LIDAR and estimated bare earth data. Figure 36 illustrates the canopy coverage in the CSNM project area. Figure 37 is average tree height derived from the vegetation height layer and summarized per acre for the CSNM project area. This layer serves as the tree crown height input layer for the model simulations. Other tree-related parameters have been assumed constant for the runs considered here (see Table 4 below).

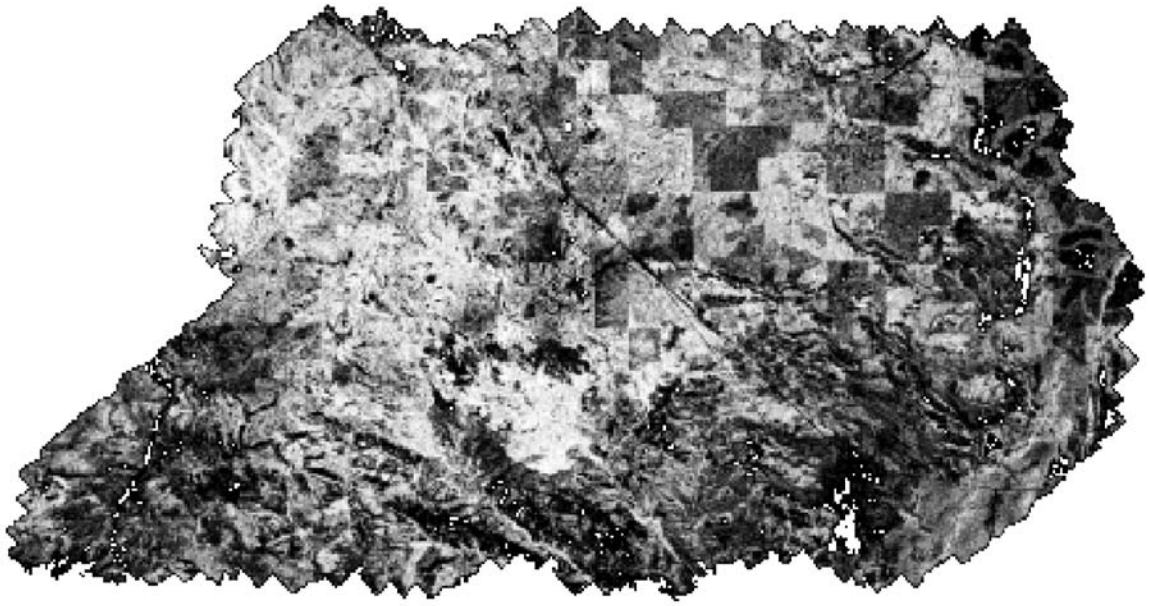

Figure 36. Canopy coverage in the Siskiyou project area shown at 1-acre ground resolution. Values range from 0% (black) to 100% (white)

Figure 37. Tree crown height in the Siskiyou project area shown at 1-acre ground resolution. Values range from 2m (black) to 30m (white)

crown base	4 m
bulk density	0.2 kg/m^3
foliage MC%	100%
diameter	30 cm

Table 4. Tree parameterization

Tree-related parameters input to the model simulations are listed in Table 4. Input weather conditions were constant for all runs. A wind velocity of 15 mi/hr from the SSW (200°) was assumed throughout. Temperatures ranged from a low of 50°F at 0500 local time to a high of 80°F at 1400 local time. Atmospheric humidity was assumed constant at 50% during the entire day and throughout all runs. Simplistic estimates of fuel moisture content and burn rates of the different fuel types were also assumed for this study. Fuel model type 0 has no associated moisture content or burn rate. Parameters used for fuel models 1 and 8 are contained in Table 5 below. No adjustments were applied to weight the fuel model parameters via the FARSITE adjustment file.

Fuel Model	1-hr Fuel Moisture	10-hr Fuel Moisture	100-hr Fuel Moisture	Live Herbaceous Fuel Moisture	Live Woody Fuel Moisture
1	5	10%	10%	100%	100%
8	10%	20%	20%	200%	200%

Table 5. Fuel Model Parameterization

Table 6 provides an overview of three runs that were conducted as part of this study. The two primary input values that have been altered to assess their impact on fire evolution are fire ignition source location and spatial variability in crown height. Spatial fire extent as a function of fire duration is overlaid on the input fuel model type for runs 1 – 3 in Figures 38-40, respectively.

Run ID	Fire Source Location	Grid Resolution	Tree Crown Height	Duration
1	Siskiyou high tree density area	1 acre	Actual mean of grid element	10 days
2	Siskiyou high tree density area	1 acre	Constant height of 20m assumed	10 days
3	Siskiyou low tree density area	1 acre	Actual mean of grid element	5 days

Table 6. Siskiyou Fire Model Runs

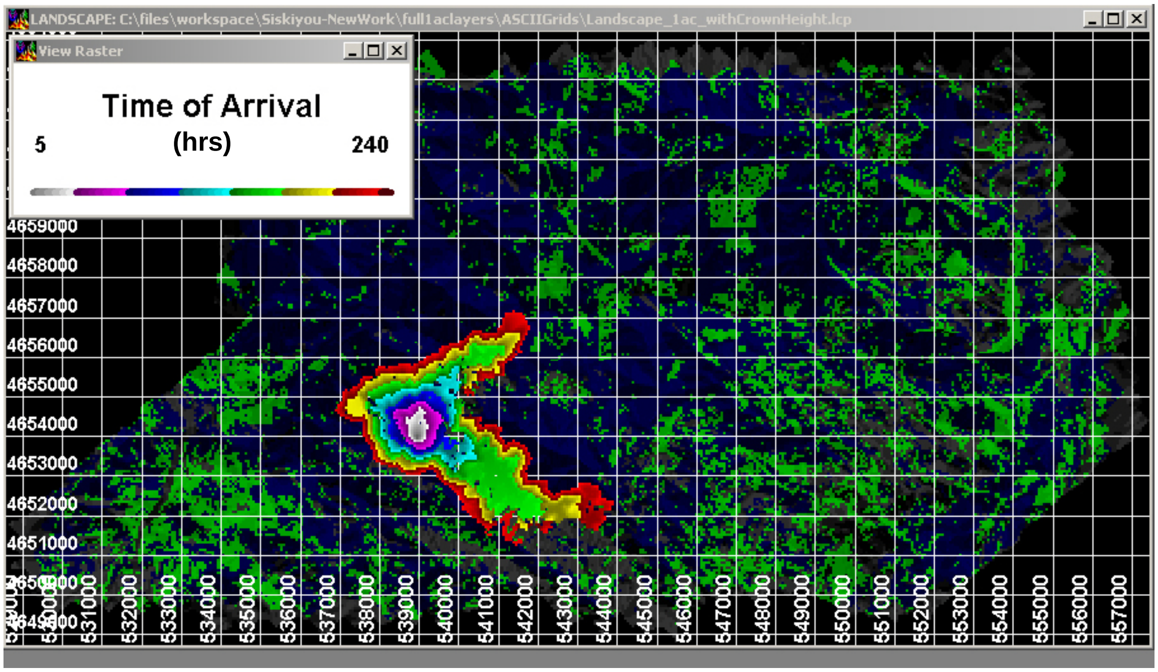

Figure 38. Fire evolution for model run 1

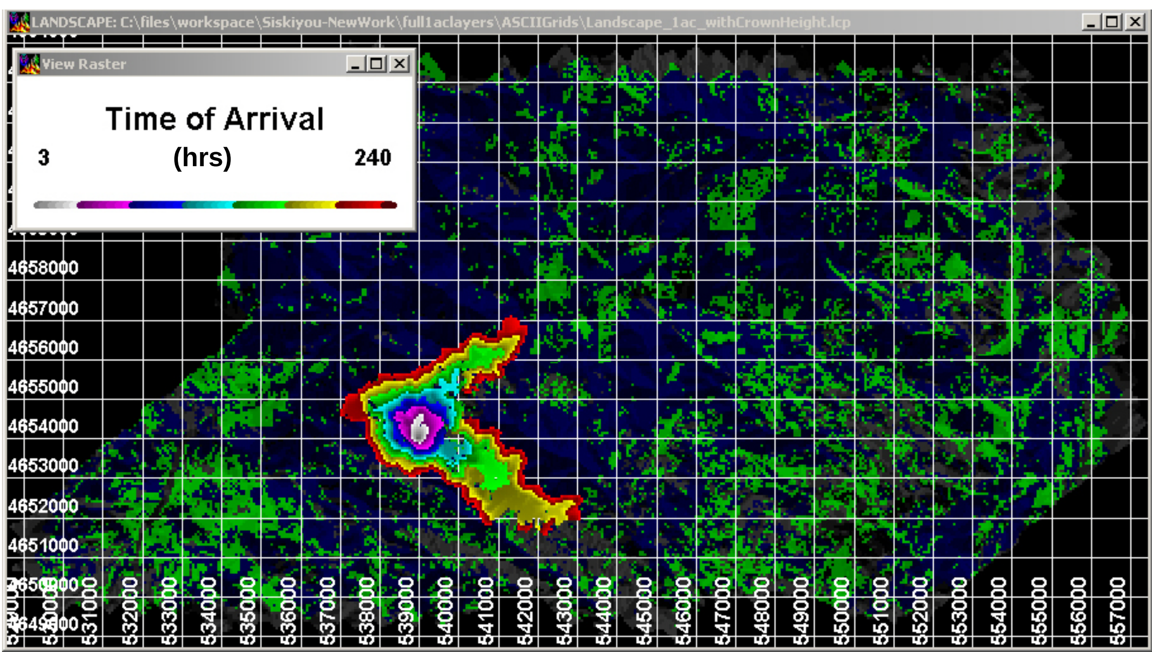

Figure 39. Fire evolution for model run 2

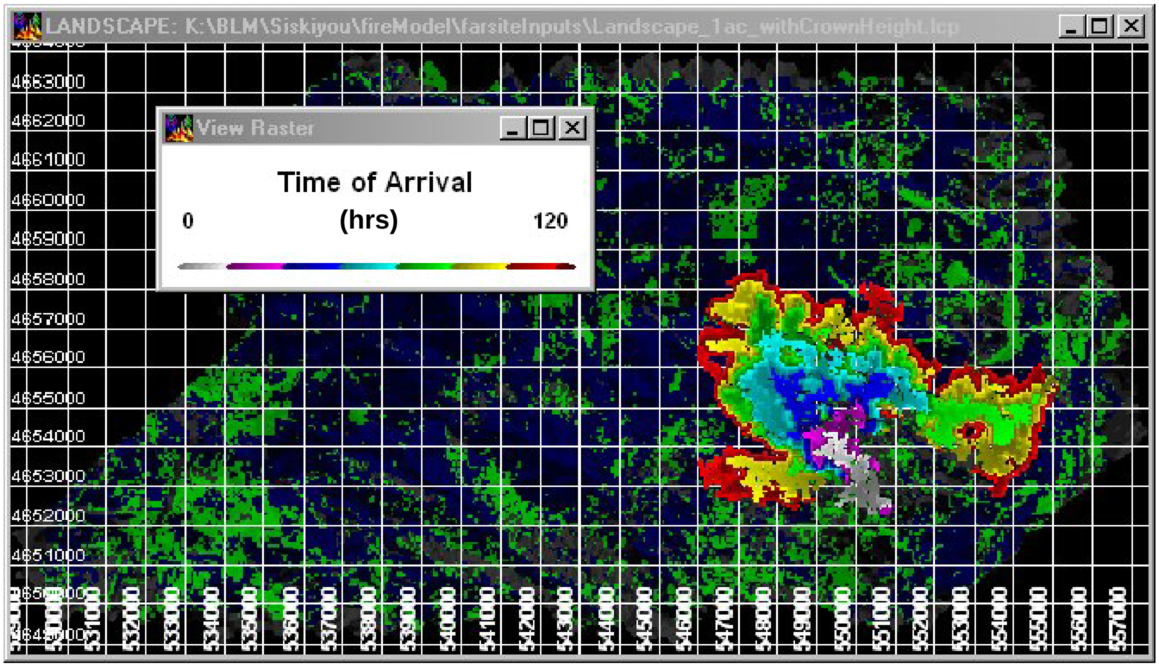

Figure 40. Fire evolution for model run 3

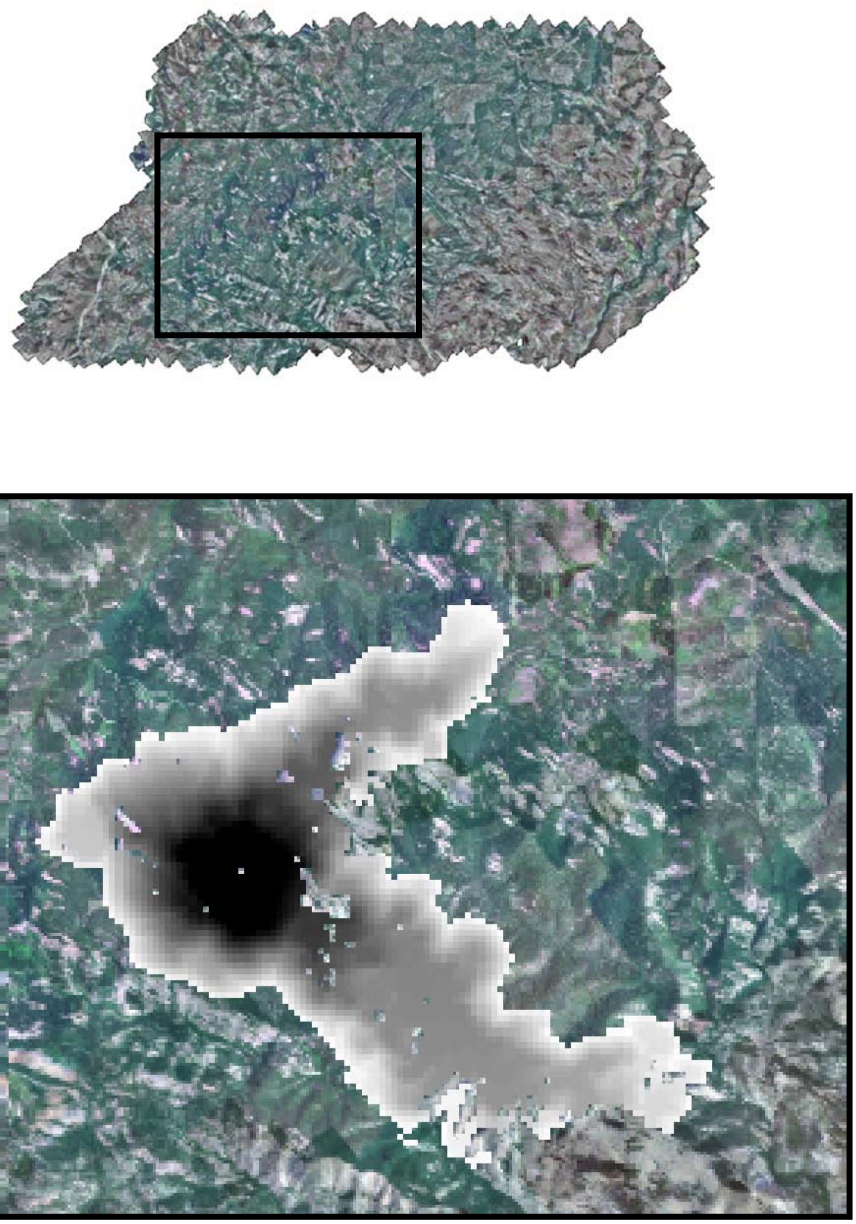

Figure 41. Fire evolution overlaid on RGB imagery for model run 2

Figure 41 shows spatial fire extent as a function of fire duration overlaid on RGB imagery for model run 2.

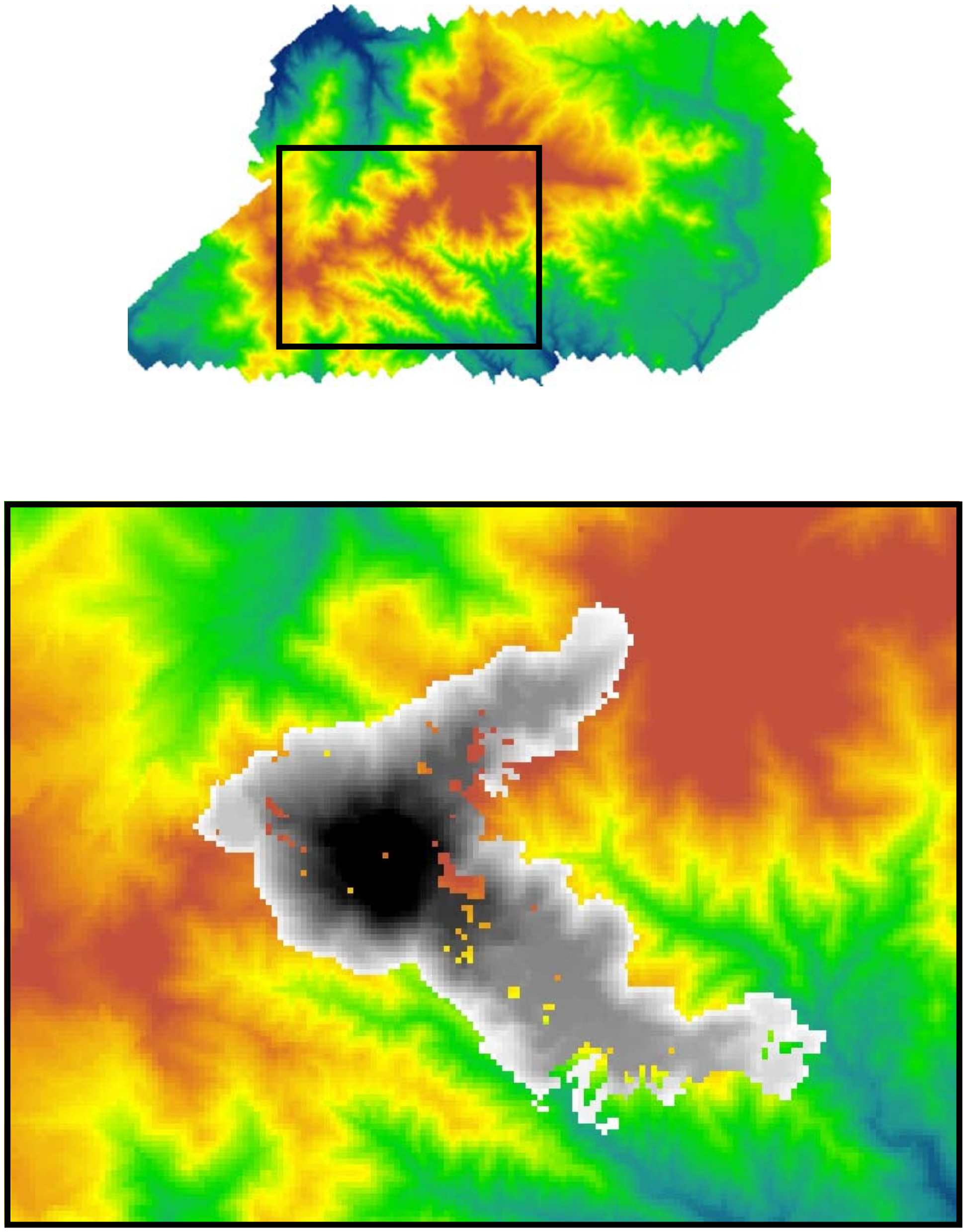

Figure 42. Fire evolution overlaid on LIDAR elevation for model run 2

Figure 42 illustrates the effects of topography on fire movement. The fire appears to move along the ridgeline to the SSE in contrast to directly following the influence of the wind originating from the SSW.

Digital Deliverable Overview

This subsection contains an overview of the digital deliverables produced during the analysis of the June 2002 BLM demonstration effort. A more detailed listing of the digital data distribution accompanying this report is contained in Appendix B. Digital deliverables include raw hyperspectral data and a suite of GIS products derived from the hyperspectral and LIDAR collection and classification effort. At the foundation of the GIS products are three base map layers: hyperspectral RGB composite imagery, infrared (IR) false-color composite imagery and LIDAR-derived digital elevation models (DEMs). These three products cover the entire flight area designated for the Cascade Siskiyou National Monument in southern Oregon.

All digital deliverables are compatible with current GIS and remote sensing software, including ESRI's ArcView 3x and ArcGIS 8x, ERDAS Imagine, and ENVI. The data are in the Universal Transverse Mercator (UTM) coordinate system, zone 10N, units in meters, horizontally referenced to the North American Datum of 1983, and vertically referenced to the National Geodetic Vertical Datum of 1988.

Data Index Shapefiles

Three layers were created to help the user navigate the data: 1) a hyperspectral data cube index; 2) a data tile index; and 3) a classification study area index. To maintain a manageable file size all base data layers (RGB imagery, IR imagery, NDVI mosaic, selected thematic layers, all vegetation height grids, "raw" and edited LIDAR grids) were divided into nominal 4000 x 4000 meter square *data tiles*. *Data tiles* (26 in all) are stored as polygon shapefiles and represent the nominal spatial extent of the individual RGB, IR and DEM digital data products. Each base map layer is stored by tile name, followed by data tile type. For example, the first data tile is named *csnm_01*, the DEM is named either *csnm_raw_01 or csnm_bare_01*, the RGB image is named *csnm_rgb_01.tif*, and the IR image is named *csnm_ir_01.tif*. The vegetation height layer is named *csnm_veg_01*.

For each classification area (cluster of cubes), a cluster polygon shapefile exists. This layer defines the general spatial extent of the classifications, indicated by cluster name.

The final index layer is a polygon shapefile denoting the boundaries of all *raw* hyperspectral data. Each hyperspectral data cube is nominally a 640m x 640m x 60 band 3-dimensional array of hyperspectral measurements. More than 1400 data cubes were collected during the entire BLM mission. Because the cubes are not referenced to a real-world coordinate system, this polygon index layer serves as a useful guide to the raw hyperspectral data. For each raw data cube, a polygon exists describing the cube's flight line, date of collection, raw data file name.

Classification Layers

As part of the demonstration effort vegetation species classifications were carried out in selected areas of the project. These areas are shown in Figure 22 and are denoted as cube "Clusters".

Classifications conducted in the selected study areas are delivered in ESRI's ArcGIS Shapefile format. There is one polygon shapefile per species per Cluster. Each classification shapefile has attributes denoting species name and area in m^2, acres, and hectares. Note some polygons from different species shapefiles overlap. This indicates an area that contains mixed ground cover (more than one vegetation species contributing spectral information) and/or classification confusion owing to similar species spectral signatures. Table 7 provides definitions of attributes added to the shapefiles that are specific to the classification detections. Table 8 lists file-naming information about the classification detection shapefiles.

Sp_Name	Classification species name
Cluster	Cube cluster number
Grd_Data	Ground data shapefile
Ref_Cube	Cube from which ROIs were derived

Table 7. Shapefile Classification Attribute Definitions

Shapefile Name	Species	Cluster Number
jun_cl2.shp	Juniper	2
mhd_cl2.shp	Medusahead	2
ndl_cl2.shp	Needlegrass	2
bbr_cl3.shp	Buckbrush	3
mhd_cl3.shp	Medusahead	3
ctl_cl8.shp	Cattail	8
inc_cl8.shp	Incense Cedar	8
scr_cl8.shp	Scirpus	8
wir_cl8.shp	White Fir	8
ash_cl9.shp	Oregon Ash	9
scr_cl9.shp	Scirpus	9

Table 8. Classification Shapefile Names

In addition to the hyperspectral classifications, a Normalized Difference Vegetation Index (NDVI) image descriptive dataset was created. The NDVI data, which cover the entire study area, are stored as an ArcInfo GRID with typical values ranging from –0.1 (bare rock and soil) to 0.8 (healthy, dense vegetation).

Discussion and Conclusion

Overall

During June 2002 Advanced Power Technologies, Inc. (APTI) was contracted to conduct a pilot project in the Cascade Siskiyou National Monument for the Oregon Bureau of Land Management (BLM). The primary objective of this project was to collect high spectral and spatial resolution airborne hyperspectral data as well as light detection and ranging (LIDAR) data. This data is intended to assist the BLM in their management needs and analysis for:

1) Inventorying surface cover and establishing a baseline for monitoring ecosystem health;
2) Determining the extent of noxious weed invasion;
3) Improving planning of fire-hazard reduction and plant community restoration projects.

Airborne data were collected over three days: June 27, 28, and 29, 2002 for a total of 71 final flight lines and approximately 1,450 hyperspectral data cubes. Total area imaged was approximately 74,240 acres (183,373 hectares). The plan was to collect 83 mi^2. Approximately 116 mi^2 were collected during the 3-day period. The data collected and analyzed in this investigation will be used as a demonstration of the value added by high spatial and spectral resolution hyperspectral data in the visible and near infrared bands (nominally 370 nm - 945 nm wavelengths) and LIDAR data for addressing various BLM problems.

Overall the demonstration project achieved the goal of collecting high quality, high-resolution (1 m^2) hyperspectral and LIDAR data for the Monument site. Orthorectified hyperspectral imagery and LIDAR-derived topography have been provided for the entire mission. A normalized difference vegetation index (NDVI) layer provides a first order visualization and quantitative indicator of the amount, density and condition of the vegetation in the study regions. Selected species classifications are provided for a subset of the data where ground data have been gathered in collaboration with BLM personnel.

Classification

Classification results indicate that many of the species of interest are identifiable and "mappable". Classification results for the noxious weed Medusahead indicate that this species of interest can be identified and discriminated. Classification results for Scirpus and Cattails indicate that wetland features can be identified and discriminated. Woody species such as Buckbrush were also successfully detected. In terms of tree species, Juniper and White Fir were successfully discriminated.

However not all species of interest are individually identifiable. Reasons for the inability to delineate all the species include small size (subpixel - less than 1 m^2 ground coverage), mixed species spatial distribution, same species spectral variability (due to e.g., species vigor, leaf and flowering condition) similar species spectral variability, and inadequate ground data to constrain the supervised classifications. In addition, cumulative spatial errors resulting from GPS data, image distortion and orthorectification can make some location and selection of features of interest and their spectra difficult. This is particularly apparent with the selection of small vegetation clusters and individual trees and shrubs. It should be noted that a minimum mapping unit was not specified for any of these classifications. As such, when pixel-level errors of omission or commission occur, it must be remembered that these errors are on the order of nominally **one square meter**. Mapping at this scale and level of detail can be difficult in normal ground-based fieldwork, let alone from an altitude of 7,000 feet AGL.

For supervised classifications, all of the aforementioned issues come into play when selecting an appropriate species reference spectrum (comprising the ROI). Classification results will be best when proper reference spectra are used. This points to the importance of gathering precise ground data for each species of interest. In addition to precise ground data it is equally important to gather data at multiple sites for the species of interest to both constrain the classification and to understand *a priori* the inter-species and intra-species spectral variability. Ideally, the ground data would contain ground reflectance measures for all species of interest at multiple measurement locations. Ground data spectral measurements also provide independent measures for assessing classification accuracy. Finally, the use of ancillary existing data including vegetation distribution, topography and roadways (for location of disturbed soil areas and as pathways for dispersion) can refine the spectral classification.

Intra-species variability for certain target species of interest can be of the same order as the inter-species variability for the full complement of species (see the Classification Results discussion above). Intra-species variation classifications for some species may not be possible. However, differentiating between certain species may be possible with additional ground-truthing and verification using the already-collected data.

Additional ground data and a comprehensive evaluation of image classification methods is needed to complete the evaluation of the CSNM hyperspectral species discrimination. However, as a spatial digital database, the information collected in this project lends itself very easily to quantification and spatial analysis using GIS methods.

Fire Hazards

In terms of improving planning of fire-hazard reduction and plant community restoration projects, the mosaics created for the entire study area (RGB, psuedo-IR, NDVI, canopy coverage, canopy height and topography) provide a landscape level tool for hazard reduction and restoration. This data provides a spatial database of occurrence, extent and condition of vegetation. Analysis of this data can provide indication of the amount of living versus dead vegetation and fuel volumes. In addition, the synoptic view illustrates the road and trail network in the study area. This is important from a perspective of access for fire and resource management, as well as the impacts of these roadways and trail on vegetation communities. When combined with available weather data and fire fuel characteristics data, the landscape level products provide a powerful fire behavior prediction tool.

Finally, several sample FARSITE fire model runs were undertaken using data layers derived from the hyperspectral and LIDAR data. These runs incorporated simplistic weather and fuel characteristics parameters. The runs are presented in the Fire Model Results section and demonstrate the potential of high spatial resolution data in fire behavior prediction. The addition of realistic weather parameters and fire fuel characteristics will provide a powerful fire behavior prediction tool.

Future Applications

The hyperspectral and LIDAR data collected during the June 2002 mission represent a high-resolution spatial database with numerous applications beyond the relatively narrow focus of this pilot project. An overarching goal of the present investigation was to determine if the combination of hyperspectral and LIDAR technologies is an effective landscape-level monitoring tool for various BLM interests. We believe this top-level goal has been met with the initial results provided to date. The hyperspectral data serve as a June 2002 baseline from which restoration treatment effects can be determined from data gathered following treatment.

Due to the project scope and short time frame of the contract, the present study represents a small fraction of potential BLM applications of hyperspectral and LIDAR technology. There are a multitude of applications that could be investigated, including delineation of the existing roadway and trail network, delineation and quantification of burned areas and severity of burn, pest and disease infestation, tree heights, density and volume, to name a few. The full wealth of information has not been extracted from the hyperspectral and merged hyperspectral/LIDAR data sets at this stage. Nevertheless, the hyperspectral imagery and associated classification, coupled with existing spatial data available at each Field Office, provide a powerful tool for both BLM field operations and planning activities.

Complementary to this paper document is a digital database consisting of the collected hyperspectral data as well as digital ArcGIS data layers for viewing, analysis, and validation. These data have been provided to the appropriate BLM offices. The digital GIS data are a critical deliverable for this investigation.

A Ground Data Collection Report, dated 31 July 2002, was also delivered to the BLM Oregon office to document the ground truth spectra and digital photographs delivered with the hyperspectral data. This report should be used in conjunction with the previously-delivered Ground Data Collection Report to understand the data and methods used to gather, identify, and spectrally-classify the CSNM species described in this pilot program.

Appendix A: Hyperspectral Data Collection Log

Date	Flight Name	**Run**	**HSSeq**	**Start Time**	**End Time**	**Start Lat (°)**	**Start Long (°)**	**End Lat(°)**	**End Long (°)**	**Ground Swath (m)**
6/27/02	SISKIYOU_FLIGHT1	1	28	131255	131706	41.99869898	-122.5207775	42.11296519	-122.3454373	678.34
6/27/02	SISKIYOU_FLIGHT1	2	34	131958	132510	42.12106611	-122.4115494	42.00217983	-122.5955023	661.70
6/27/02	SISKIYOU_FLIGHT1	3	29	132809	133232	41.99955921	-122.5292497	42.11748008	-122.3483179	661.08
6/27/02	SISKIYOU_FLIGHT1	4	35	133546	134107	42.11933575	-122.4215166	42.00130155	-122.6047061	661.79
6/27/02	SISKIYOU_FLIGHT1	5	30	134354	134824	41.99976249	-122.537053	42.11683345	-122.3577103	654.24
6/27/02	SISKIYOU_FLIGHT1	6	35	135155	135710	42.11939317	-122.4290106	42.00031541	-122.6161725	663.06
6/27/02	SISKIYOU_FLIGHT1	7	29	135921	140348	41.99941909	-122.5457244	42.11751911	-122.3627792	660.09
6/27/02	SISKIYOU_FLIGHT1	8	34	140656	141207	42.11912931	-122.4379183	42.00173002	-122.6194995	661.05
6/27/02	SISKIYOU_FLIGHT1	9	31	141426	141904	41.997739	-122.5564329	42.11837009	-122.3697625	659.38
6/27/02	SISKIYOU_FLIGHT1	10	33	142212	142711	42.12096476	-122.4452424	42.00335139	-122.6266386	660.93
6/27/02	SISKIYOU_FLIGHT1	11	29	142944	143407	41.99981682	-122.5623608	42.11662556	-122.3803136	687.47
6/27/02	SISKIYOU_FLIGHT1	12	32	143704	144158	42.11981425	-122.4530301	42.00329095	-122.6328268	668.20
6/27/02	SISKIYOU_FLIGHT1	13	29	144420	144846	41.99967715	-122.5680026	42.11652667	-122.3895738	673.70
6/27/02	SISKIYOU_FLIGHT1	14	33	145152	145652	42.12088749	-122.4598262	42.00161775	-122.6450482	675.06
6/27/02	SISKIYOU_FLIGHT1	15	29	145911	150336	42.00237507	-122.5729031	42.11767959	-122.3968717	679.15
6/27/02	SISKIYOU_FLIGHT1	16	31	150609	151053	42.11975264	-122.4698916	42.00640064	-122.6461603	670.52
6/27/02	SISKIYOU_FLIGHT1	17	29	151259	151723	41.99940043	-122.5862325	42.11606846	-122.4062016	675.00
6/27/02	SISKIYOU_FLIGHT1	18	30	151959	152429	42.11970502	-122.4778736	42.01007937	-122.6477899	681.71
6/27/02	SISKIYOU_FLIGHT1	19	14	152621	152820	41.99947199	-122.5943383	42.05472497	-122.5097942	668.35
6/27/02	SISKIYOU_FLIGHT1	20	29	153549	154012	42.12127905	-122.4837304	42.01536014	-122.6478736	681.68
6/27/02	SISKIYOU_FLIGHT1	21	28	154154	154611	41.99775307	-122.5921162	42.1147127	-122.415803	676.05
6/27/02	SISKIYOU_FLIGHT1	22	29	154912	155337	42.1096595	-122.345438	42.00434517	-122.5106641	680.14
6/27/02	SISKIYOU_FLIGHT1	23	20	155532	155834	42.00067259	-122.4534352	42.07937617	-122.3328157	668.23
6/27/02	SISKIYOU_FLIGHT1	24	28	160117	160535	42.10771333	-122.3438842	42.00550785	-122.5017529	669.71
6/27/02	SISKIYOU_FLIGHT1	25	20	160810	161111	41.9988716	-122.4498322	42.07777751	-122.3273952	655.30
6/27/02	SISKIYOU_FLIGHT1	26	27	161358	161802	42.10436068	-122.3398936	42.00441297	-122.4932818	677.54
6/27/02	SISKIYOU_FLIGHT1	27	20	162051	162354	42.00122891	-122.4621283	42.08177109	-122.3374482	659.10
6/27/02	SISKIYOU_FLIGHT1	28	25	162722	163112	42.09865934	-122.3410958	42.00561456	-122.4839955	673.30
6/27/02	SISKIYOU_FLIGHT1	29	21	163423	163735	42.00039858	-122.4698339	42.08754001	-122.3378121	669.31
6/28/02	SISKIYOU_FLIGHT2	1	28	125213	125627	42.09636702	-122.3358819	42.00483279	-122.4809596	668.47
6/28/02	SISKIYOU_FLIGHT2	2	13	125905	130059	42.00173029	-122.395812	42.0553115	-122.3127553	667.79
6/28/02	SISKIYOU_FLIGHT2	3	22	130405	130726	42.07629356	-122.3258128	42.00530845	-122.4361252	660.09
6/28/02	SISKIYOU_FLIGHT2	4	9	131015	131134	42.00246319	-122.3872198	42.0356333	-122.3346095	663.53
6/28/02	SISKIYOU_FLIGHT2	5	21	131616	131929	42.07222168	-122.3248367	42.0048428	-122.4294868	671.85
6/28/02	SISKIYOU_FLIGHT2	6	11	132159	132338	42.00150168	-122.3797744	42.04449725	-122.3131406	665.91
6/28/02	SISKIYOU_FLIGHT2	7	20	132657	133001	42.06946325	-122.3206465	42.00602275	-122.418978	668.63

Date	Flight Name	Run	HSSeq	Start Time	End Time	Start Lat (°)	Start Long (°)	End Lat(°)	End Long (°)	Ground Swath (m)
6/28/02	SISKIYOU_FLIGHT2	9	18	133707	133946	42.0654729	-122.3178969	42.00539561	-122.4119048	662.35
6/28/02	SISKIYOU_FLIGHT2	10	13	134909	135108	41.99990937	-122.3908177	42.04957804	-122.3145408	657.49
6/28/02	SISKIYOU_FLIGHT2	12	14	140119	140322	42.00203212	-122.4041568	42.057406	-122.3184281	668.60
6/28/02	SISKIYOU_FLIGHT2	13	26	140643	141038	42.09323872	-122.3784403	42.00468805	-122.5154587	675.90
6/28/02	SISKIYOU_FLIGHT2	15	15	142042	142301	42.08892371	-122.4400353	42.03924428	-122.5156288	679.74
6/28/02	SISKIYOU_FLIGHT2	16	10	142545	142717	42.06695392	-122.5166727	42.10774633	-122.4554134	679.86
6/28/02	SISKIYOU_FLIGHT2	17	14	143055	143303	42.09541717	-122.4387227	42.05059869	-122.5068296	668.26
6/28/02	SISKIYOU_FLIGHT2	18	13	143607	143805	42.04099	-122.486226	42.09425507	-122.4061141	659.16
6/28/02	SISKIYOU_FLIGHT2	19	14	144225	144433	42.09304911	-122.4501194	42.04708451	-122.5211479	654.52
6/28/02	SISKIYOU_FLIGHT2	20	11	144759	144936	42.04442663	-122.4885927	42.08632019	-122.4235187	653.75
6/28/02	SISKIYOU_FLIGHT2	21	13	145443	145641	42.07491367	-122.4540532	42.03181141	-122.5197513	671.75
6/28/02	SISKIYOU_FLIGHT2	22	12	145911	150058	42.06406861	-122.57435	42.11622893	-122.4983577	692.11
6/28/02	SISKIYOU_FLIGHT2	23	9	150446	150610	42.12012598	-122.526845	42.0903573	-122.5724205	674.04
6/28/02	SISKIYOU_FLIGHT2	24	11	150838	151019	42.06929726	-122.5770002	42.11343402	-122.5078483	657.40
6/28/02	SISKIYOU_FLIGHT2	25	9	151411	151531	42.11972016	-122.5358339	42.09128244	-122.5786452	669.59
6/28/02	SISKIYOU_FLIGHT2	26	10	151842	152014	42.07376661	-122.576406	42.11301278	-122.5166767	669.00
6/28/02	SISKIYOU_FLIGHT2	27	8	152354	152501	42.1213144	-122.5409242	42.09838703	-122.576459	661.61
6/28/02	SISKIYOU_FLIGHT2	28	10	152749	152914	42.07777682	-122.5760464	42.11547487	-122.5205096	669.50
6/28/02	SISKIYOU_FLIGHT2	29	5	153300	153347	42.12101923	-122.5489781	42.10617573	-122.573515	667.52
6/28/02	SISKIYOU_FLIGHT2	30	8	153709	153819	42.08488447	-122.5767997	42.11389554	-122.53016	672.16
6/28/02	SISKIYOU_FLIGHT2	31	7	154934	155039	42.15061334	-121.7812385	42.16470317	-121.7235674	655.48
6/28/02	SISKIYOU_FLIGHT2	32	7	155355	155457	42.14297411	-121.7228126	42.17682057	-121.742169	682.12
6/28/02	SISKIYOU_FLIGHT2	33	21	155759	160114	42.30937285	-121.825951	42.43251087	-121.9187159	638.99
6/29/02	SISKIYOU_FLIGHT3	1	13	123554	123753	42.06233018	-122.5781138	42.11373493	-122.499209	688.71
6/29/02	SISKIYOU_FLIGHT3	2	10	124132	124306	42.120379	-122.5257487	42.09069172	-122.5735247	647.59
6/29/02	SISKIYOU_FLIGHT3	3	13	124618	124814	42.06816762	-122.5784619	42.11632678	-122.5034795	659.29
6/29/02	SISKIYOU_FLIGHT3	4	8	125201	125316	42.11768564	-122.5370926	42.09495588	-122.5737371	647.62
6/29/02	SISKIYOU_FLIGHT3	5	12	125609	125758	42.07297731	-122.5851391	42.11341187	-122.515997	652.45
6/29/02	SISKIYOU_FLIGHT3	6	8	130104	130216	42.12028119	-122.5421814	42.09886803	-122.5748279	648.40
6/29/02	SISKIYOU_FLIGHT3	7	10	130625	130755	42.07923179	-122.5769455	42.11376138	-122.5240662	663.28
6/29/02	SISKIYOU_FLIGHT3	8	6	131059	131153	42.1199805	-122.5503495	42.10555458	-122.5740987	653.69
6/29/02	SISKIYOU_FLIGHT3	9	9	131621	131740	42.08432793	-122.5765282	42.11436548	-122.5305769	662.16

Table 9. Partial listing of hyperspectral cube database attributes

Appendix B: Digital Deliverables

This appendix lists the deliverable data products and their distribution. Products were distributed in two stages. Stage 1 deliverables included a Ground Data Collection Report, 1 DVD of all mosaics (RGB, IR, NDVI) and a data tile index shapefile, 1 DVD of all raw LIDAR DEMs and 16 DVDs of raw hyperspectral data with a hyperspectral cube index shapefile. Additional copies of all but the raw hyperspectral data DVDs were created for distribution to BLM field personnel.

Stage 2 deliverables include this report, 1 DVD of all edited ("bare earth") LIDAR DEMs and vegetation height ArcGIS grids and classification ArcGIS shapefiles for selected cubes arranged by "Cluster".

With the exception of Cube Cluster classification products, all base data layers (RGB imagery, IR imagery, NDVI mosaic, selected thematic layers, all vegetation height grids, "raw" and edited LIDAR grids) are indexed by *data tiles*. Each data tile (26 in all) covers an area of approximately 1600 hectares (3954 acres). Classification data are indexed by cube *Cluster*, with extent varying between 2 and 3 hyperspectral data cubes (each cube is approximately 100 acres). The following tables summarize the number of digital data files created and delivered to the BLM.

Cluster Number	**Supervised Classification Shapefiles**
2	1
3	1
8	4
9	2

Table 10. Number of files created for each classification study area.

The following 3 sections list the contents of the DVD data directories.

Cascade Siskiyou Data Deliverables Readme Files and File Lists

```
HYPERSPECTRAL DVD CONTENTS

Hyperspectral data for the Cascade Siskiyou National Monument Hyperspectral
Imaging and LIDAR Project were collected between 6-27-02 and 6-29-02.  A total
of 1325 hyperspectral data cubes were collected over the CSNM project area,
totaling approximately 60GB.  The data is organized on DVD disks as follows.

FLIGHT DATES
------------
6-27-02  Flight 1
6-28-02  Flight 2
6-29-02  Flight 3

DVD CONTENTS
------------
DISK01:      Flight 1 Runs 01 - 03
DISK02:      Flight 1 Runs 04 - 05
DISK03:      Flight 1 Runs 06 - 07
DISK04:      Flight 1 Runs 08 - 09
DISK05:      Flight 1 Runs 10 - 12
DISK06:      Flight 1 Runs 13 - 15
DISK07:      Flight 1 Runs 16 - 18
DISK08:      Flight 1 Runs 19 - 21
DISK09:      Flight 1 Runs 22 - 24
DISK10:      Flight 1 Runs 25 - 28
DISK11:      Flight 1 Run 29 and Flight 2 Runs 01 - 04
DISK12:      Flight 2 Runs 05 - 10
DISK13:      Flight 2 Runs 11 - 15
DISK14:      Flight 2 Runs 16 - 22
DISK15:      Flight 2 Runs 23 - 30 and Flight 3 Runs 01 - 02
DISK16:      Flight 3 Runs 03 - 09


SHAPEFILE DATA INDEX
--------------------

In addition to the hyperspectral data described below,each DVD also contains a
complete index to the hyperspectral data in shapefile format
(csnm_cube_index.shp).  This shapefile contains one polygon for each
hyperspectral data file and is referenced to UTM Zone 10, NAD83, Meters. Refer
to the metadata file (csnm_cube_index.txt) for more information.  Note each DVD
has a duplicate and complete copy of the shapefile index.


FILE DESCRIPTIONS
-----------------

Hyperspectral data files are arranged according to flight, run and sequence
number.  The files for each flightline are named with a descriptive title, a
single run number for each line, multiple sequences, and approximate dates and
times.  The data sequences are contiguous.

- Sample Files -
Siskiyou_Flight1_Run001.LN1
Siskiyou_Flight1_Run001Seq001[20020627_171255].Bip
Siskiyou_Flight1_Run001Seq001[20020627_171255].Hdr
Siskiyou_Flight1_Run001Seq001[20020627_171255].snc
siskiyou_flight1_run001seq001[20020627_171255].txt
Siskiyou_Flight1_Run001Seq002[20020627_171304].Bip
Siskiyou_Flight1_Run001Seq002[20020627_171304].Hdr
Siskiyou_Flight1_Run001Seq002[20020627_171304].snc
siskiyou_flight1_run001seq002[20020627_171304].txt
etc...
```

- File Type Descriptions -
.ln1   post-processed INS navigation data, one file per run
.bip   hyperspectral data file, one file per sequence
.hdr   ENVI header file, one file per sequence
.snc   navigation synchronization file, one file per sequence
.txt   FGDC metadata file in ASCII format, one file per sequence

The number in the brackets of the filename ([20020627_173631]) corresponds to the UTC time the file was collected (YYYYMMDD_hhmmss). The hyperspectral data files are the *.bip file and the *.hdr file. All *.bip files are ENVI compatible, binary format, and band interleaved by pixel. The header files contain the pertinent information about each associated data file, including sensor settings, spectral band cropping, aircraft altitude, aircraft speed, data type, number of cross-track and along-track pixels, number of spectral bands, pixel resolution, and wavelength channels. The FGDC compliant metadata files (*.txt) also provide additional information about the data.

Hyperspectral and LIDAR data for the Cascade Siskiyou National Monument Hyperspectral Imaging and LIDAR Project were collected between 6-27-02 and 6-29-02. This DVD contains raw LIDAR digital elevation models in ArcInfo GRID format. All grids are cut to nominal 4x4km data tiles. Refer to the data tile index shapefile (csnm_datatile_index.shp) for information on the tiling scheme. FGDC compliant metadata exists as xml and txt files and can be found in the same directory as their respective data files. The data is organized on DVD as follows.

LIDAR DVD CONTENTS
----

raw_lidar	26 raw LIDAR DEMs in ArcInfo GRID format
shapefiles	2 indices to all LIDAR tiles and hyperspectral data cubes in shapefile format

FILE DESCRIPTIONS

LIDAR data are delivered in ArcInfo GRID format. Several other file types are also included and are discussed below.

- Sample Files -
csnm_raw_01 (grid directory)
csnm_raw_01.aux
csnm_raw_01.rrd
cnsm_raw_01.txt
etc...

- File Type Descriptions -
.lyr ArcMap layer file pointing to all mosaics in group, stores legend/labelling information
.aux Auxillary image file containing extra image information (created/used by ArcMap)
.rrd Reduced resolution dataset containing image pyramids (speeds display in ArcMap)
.xml Metadata file compatible with ArcCatalog (located inside grid directory)
.txt FGDC metadata file in ASCII format

COORDINATE SYSTEM

All data on this DVD is referenced to UTM Zone 10, NAD83, Meters. Elevations are in meters and referenced to NAVD88.
MOSAIC DVD CONTENTS

Hyperspectral data for the Cascade Siskiyou National Monument Hyperspectral Imaging and LIDAR Project were collected between 6-27-02 and 6-29-02. This DVD contains orthorectified RGB, IR, and NDVI mosaics derived from the hyperspectral data. All mosaics are cut to nominal 4x4km data tiles. Refer to the data tile index shapefile (csnm_datatile_index.shp) for information on the tiling scheme. FGDC compliant metadata exists as xml and txt files and can be found in the same directory as their respective data files. The data is organized on DVD as follows.

Mosaic DVD CONTENTS

ir	26	Near-IR image composite mosaics in GeoTiff format
ndvi	26	Normalized Difference Vegetation Index (NDVI) image mosaics in ArcInfo GRID format
rgb	26	RGB image composite mosaics in GeoTiff format
shapefiles	1	index to all 26 mosaic tiles in shapefile format

FILE DESCRIPTIONS

Mosaics are delivered in GeoTiff and GRID format. Several other file types are also included and are discussed below.

- Sample Files -

All RGB Mosaics.lyr
csnm_rgb_01.aux
csnm_rgb_01.rrd
csnm_rgb_01.tif
csnm_rgb_01.tif.xml
csnm_rgb_01.txt
csnm_rgb_02.aux
csnm_rgb_02.rrd
csnm_rgb_02.tif
csnm_rgb_02.tif.xml
csnm_rgb_02.txt
etc...

- File Type Descriptions -

.lyr ArcMap layer file pointing to all mosaics in group, stores legend/labelling information
.aux Auxillary image file containing extra image information (created/used by ArcMap)
.rrd Reduced resolution dataset containing image pyramids (speeds display in ArcMap)
.tif GeoTiff image file
.xml Metadata file compatible with ArcCatalog
.txt FGDC metadata file in ASCII format

COORDINATE SYSTEM

All data on this DVD is referenced to UTM Zone 10, NAD83, Meters.

Hyperspectral data for the Cascade Siskiyou National Monument Hyperspectral Imaging and Lidar Project were collected between 6-27-02 and 6-29-02. This DVD contains the final project report, classifications derived from the hyperspectral and lidar data, filtered bare earth lidar data, vegetation height data, and sample fire model inputs. Lidar data and unsupervised classifications are cut to nominal 4x4km data tiles. Refer to the data tile index shapefile (csnm_datatile_index.shp) for information on the tiling scheme. FGDC compliant metadata exists as xml and txt files and can be found in the same directory as their respective data files. The data is organized on DVD as follows.

DVD CONTENTS

```
farsite_fire_inputs        Sample fire model inputs formatted for FARSITE
lidar_bare_earth           26 filtered lidar grids
lidar_vegetation_height    26 vegetation height grids
supervised_classifications Sample species detection shapefiles
tiling_scheme              Data tile index shapefile
unsupervised_classifications     26 classification grids (1: soil, 2: grass, 3: trees)
```

FILE DESCRIPTIONS

All lidar and unsupervised classification data are in ArcInfo GRID format. Supervised classifications are in shapefile format. The sample fire model inputs correspond to FARSITE's landscape layers and are included in ArcInfo GRID ans ASCII Raster formats.

- File Type Descriptions -

.lyr ArcMap layer file pointing to all mosaics in group, stores legend/labelling information
.aux Auxillary image file containing extra image information (created/used by ArcMap)
.rrd Reduced resolution dataset containing image pyramids (speeds display in ArcMap)
.tif GeoTiff image file
.xml Metadata file compatible with ArcCatalog
.txt FGDC metadata file in ASCII format

COORDINATE SYSTEM

All data on this DVD is referenced to UTM Zone 10, NAD83, Meters.

Appendix C: Hyperspectral Data File Formats

All *.bip hyperspectral data files are ENVI compatible (data type = 2), binary format, and band interleaved by pixel.

The header files contain the pertinent information about each associated data file, including sensor settings, spectral band cropping, aircraft altitude, aircraft speed, data type, number of cross-track and along-track pixels, number of spectral bands, pixel resolution, and wavelength channels. A sample header file is provided below.

Sample header file: Siskiyou_Flight1_Run004Seq006[20020627_173631].Hdr

```
ENVI
description={ Created by the APTI ASPIS DLL
date=20020627
time=173631
sensor name=APTI PV PS276-R3A (5-10-02)
sensor manufacturer=PixelVision
sensor model=PV652ADVSNT04FTCNTN
sensor serial number=PS276
sensor revision=3A
sign type=1
calibration file=Siskiyou_Flight1_Run004PostDark_cal.bip
spectral binning=8
cross track binning=1
spectral offset=0
cross track offset=0
spectral size=64
cross track size=640
field of view=17.584778
cross track ifov=0.027694
in track ifov=0.027694
sensor focal length=24.826704
sensor f stop=2.800000
sensor focus=100000.000000
sensor frame rate=70.000000
electronic shutter percent=100.000000
sensor gain=0
sensor spectral ccd size=496
sensor cross track ccd size=640
sensor cross track pixel size=0.012000
sensor in track pixel size=0.012000
spectrograph slit width=0.012000
spectrograph magnification=1.000000
cross track channel count=2
spectral channel count=2
cross track channel divide=320
spectral channel divide=30  // Before processing was 31
sensor data min=-100.000000,-100.000000,-100.000000,-100.000000
sensor data max=16350.000000,16350.000000,16350.000000,16350.000000
crop cross track left=0
crop cross track right=0
crop spectral low=0  // Before processing was 1
crop spectral high=0  // Before processing was 1
```

```
noise threshold=80.000000
dark current noise=8.000000
shot noise multiplier=0.050000
red band=27  // Before processing was 28
green band=17  // Before processing was 18
blue band=7  // Before processing was 8
spectral padding=0  // Before processing was 2
cross track padding=0
navigation time offset=0.000000
navigation heading offset=-0.271993
navigation pitch offset=-0.317897
navigation roll offset=-1.149058
nominal altitude=11244.422852
nominal ground elevation=4200.000000
nominal speed=118.574524
}
interleave=bip
data type=2
byte order=0
header offset=0
file type=ENVI Standard
samples=640
lines=640
bands=60
pixel size={1.034051,0.842857}
wavelength={0.376387,0.386028,0.395670,0.405311,0.414953,0.424594,0.434235,0.443877,
0.453518,0.463160,0.472801,0.482442,0.492084,0.501725,0.511367,0.521008,
0.530649,0.540291,0.549932,0.559574,0.569215,0.578857,0.588498,0.598140,
0.607781,0.617422,0.627064,0.636705,0.646347,0.655988,0.665629,0.675271,
0.684912,0.694554,0.704195,0.713837,0.723478,0.733119,0.742761,0.752402,
0.762044,0.771685,0.781327,0.790968,0.800609,0.810251,0.819892,0.829534,
0.839175,0.848816,0.858458,0.868099,0.877741,0.887382,0.897023,0.906665,
0.916306,0.925948,0.935589,0.945231}
```