Fire Mapping with Hyperspectral and LiDAR Imagery

SpecTIR has been serving the hyperspectral and LiDAR markets for some years, it has been implemented and pursued with few areas of client/product overlap. Part of this has been due to engineering and system issues but also due to market divergence. There is however at least one large market segment, which would in fact, require the combination of these two systems. Specifically, fire management, control, and risk assessment. As shall be shown, there is an increasingly appreciated need in the field of fire modeling and management for improved imagery products of greater spatial and spectral resolution as well as physical and biophysical height and elevation data.

Previously, the hyperspectral imaging systems used by the industry have not been suited for this task due to their limitation to near-infrared wavelengths (~1000nm). Spectir's ability to provide full spectral coverage to 2450 nm, coupled with a fast multi-return LiDAR provides us an opportunity to provide services and products which, until now, have been unavailable.

Overview:

Data provided by the National Interagency Fire Center in Boise, Idaho, indicate that wildland fires damaged or destroyed more than 8,000 residences, commercial buildings, and outbuildings during the 2003 fire season. More than 60,000 fires burned about 3.9 million acres—about 80 percent of the 10–year annual average—and culminated with the disastrous fires of southern California in October. Tragically, 39 firefighters and residents lost their lives. Suppression costs again exceeded $1 billion. Although the number of fires remains reasonably constant from year to year, the burned acreage has been double the 10–year average in 3 of the past 4 years. In addition, the current 10–year average is higher than in previous 10–year periods.

Although there is debate concerning the causes, it is clear that there is a trend toward increasingly larger annual burned area. The increasing volume of fuel in many short fire-return interval ecosystems, when combined with summer droughts, is a critical factor in the spread of wildland fires and their resistance to control.

The cost of fighting wildfires on federal land is paid by federal wildland agencies such as the Forest Service, the Bureau of Land Management, the National Park Service, the Bureau of Indian Affairs, and Fish and Wildlife Service. Congress in 1998 mandated that these agencies work together to fight fires and are coordinated through the National Interagency Fire Center. State and local agencies pay part of the cost when non-federal land is involved. For large fires that threaten lives and private property, the President can authorize FEMA to pay 75 percent of the eligible costs of suppressing the fire.

The cost of recovery following wildfire includes forest rehabilitation and flood mitigation on public property, which are paid by the federal and state wildland agencies. Technical assistance and some grant money, is also available through the Natural Resources Conservation Service for fire mitigation projects on private land.

Private insurance pays for the majority of the recovery costs for private property and homeowners. In the wake of extraordinary fire events, like those in Colorado in 2002, the President may declare a major disaster, which triggers FEMA assistance for individuals and families to help with emergency housing and some other disaster-related emergency needs. FEMA works in partnership with the Small Business Administration (SBA), which provides low-interest disaster loans to eligible homeowners, renters, and businesses.

The National Fire Plan (NFP) provides impetus and funding to accelerate treatments for the reduction of fuels both in wildland areas and in the wildland-urban interface. In trying to meet NFP goals and integrate them into larger goals for land management and community protection, managers are increasingly challenged to justify treatments and to address questions concerning effects of increased levels of fuels treatment and altered fire regimes on threatened or endangered species, invasive plant species, wildlife habitat, air quality, and similar topics.

The Joint Fire Science Program (JFSP) is a partnership of six federal wildland management and research agencies with a need to address problems associated with managing accumulating wildland fuels, fire regimes, and fire-impacted ecosystems on lands administered by the partner agencies. The partner agencies include the USDA Forest Service and five bureaus in the Department of the Interior: Bureau of Indian Affairs, Bureau of Land Management, National Park Service, U.S. Fish and Wildlife Service, and the U.S. Geological Survey.

Example costs from the 2002 Colorado fire season:

These individual cases are provided to highlight the financial impetus for addressing fire management, control, and recovery from not just a governmental standpoint, but from the private insurance market as well.

Hayman Fire
Fire: This fire started June 8 in Park County, four miles northwest of Lake George in Pike National Forest. It later spread into Jefferson, Douglas and Teller counties.
Damage: The fire burned 137,760 acres, and destroyed 133 homes, one business, and 466 other structures. Three people were injured.
Cost: $119.8 million
Firefight: $39.1 million (state/local share was $5.7 million, of which FEMA reimbursed $4.3 million)
Forest rehabilitation: 37.5 million
Insurance: 38.7 million
SBA loans: 3.8 million
FEMA/state disaster grants: 459,898
Local volunteer committees: 260,000

Coal Seam Fire
Fire: The Coal Seam fire started June 8, four miles west of Glenwood Springs, from an underground coal fire.
Damage: The fire burned 12,209 acres, and destroyed 29 homes and 14 outbuildings.
Cost: $16.8 million
Firefight: $7.3 million(State/local share was $2 million, of which FEMA reimbursed $1.5 million)
Forest rehabilitation: $1.7 million
Insurance: 6.4 million
SBA loans: 1.3 million
FEMA/state disaster grants: 101,821

Miracle Complex
Fire: This complex included two fires: the Dierich Creek Fire and the Long Canyon Fire. Both fires started in Mesa County June 8, one from a campfire and one from lightning.
Damage: The Dierich Creek Fire burned 2,533 acres, and the Long Canyon Fire burned 1,418 acres, for a combined total of 3,951. Three people were injured.
Cost: $1,985,700
Firefight: $1.7 million (State/local share was $208,666, of which FEMA reimbursed $156,450)
Forest rehabilitation: $162,800
Insurance: N/A
SBA loans: $122,900
FEMA/state disaster grants: N/A
Local volunteer committees: N/A

Missionary Ridge
Fire: This fire started June 9 in a ditch beside Missionary Ridge Road, about 15 miles northeast of Durango.
Damage: The fire burned 70,485 acres, and destroyed 56 homes and 27 outbuildings. One firefighter was killed, and 48 other people were injured.
Cost: $74.6 million
Firefight: $40.4 million (State/local share was $2.6 million, of which FEMA reimbursed $1.9 million)
Forest rehabilitation: $9.47 million
Insurance: 17.7 million
SBA loans: 6.8 million
FEMA/state disaster grants: 109,931
Local volunteer committees: 105,431

Potential Clients:

As previously discussed, several Department of the Interior Bureaus cite fire fuel mapping specifically as one of their remote sensing derived products to which a share of their annual spending is applied. While the actual dollar amount expended is unavailable at this time we can get a feel for what remote sensing costs these agencies (The National Park Service, The Bureau of Land Management, and the USGS) have been budgeting.

	Remote Sensing Expenditures (in $ Millions)				
	1999 (act.)	2000 (act.)	2001 (act.)	2002 (est.)	2003 (est.)
BLM	1.3	1.35	1.4	1.5	1.5
USGS	50.2	50.7	48.8	51.2	49.9
NPS	1.2	1.35	2.45	2.65	2.85

(http://www.nps.gov/gis/gisday/gallery2002/remote_sensing.htm)

There is also National Fire Plan (NFP) Research Funding. Available funding for NFP research has remained relatively constant since 2001. However, the sources of this funding have varied from year to year at approximately $25 million per year. In fiscal year 2003, Forest Service R&D received a $21 million appropriation for the Forest Service NFP research program. In addition, $5 million in emergency funds, originally allocated for NFP research in fiscal year 2002, was released for spending in early 2003 and became available to support NFP research projects. $20 million (plus $5 million emergency funds) was distributed to research stations to support the 78 Forest Service NFP research teams.

In 2003, under the category of Fire Fighting, $8.5 million was spent on 26 research teams. From the project titles listed in the appendix, 15% of these projects directly reference fuel mapping and/or remote sensing for improved fire modeling.

Under the category of hazardous fuel management, ~$10.5 million (29 research teams = $360,000/project/yr) was spent on research regarding management of hazardous fuels and ~$3.5 million dollars were allocated to rehabilitation/restoration projects (12 research teams @ avg. $291,666/project/yr). These are two additional funding topics that also would most certainly benefit from access to not only reliable fuel mapping capability, but also vegetation health and status mapping if it could be provided.

Many of the projects in the 2003 fiscal year report highlighted fire modeling advances with the incorporation of GIS and Remote Sensing inputs. This includes such programs as LANDFIRE protocols and FARSITE modeling program. Again emphasizing the need for species/vegetation mapping, vegetation health, moisture condition mapping, topography, canopy closure and measurement inputs.

(http://jfsp.nifc.gov/documents/2003business_summary.pdf)

Private Insurers:

As recently as June this year, numerous news articles are identifying the increasing utilization of such technologies as GIS modeling and Remote Sensing by Insurers to identify areas of high risk and set household coverages at competitive rates.

By John W. Schoen
Senior Producer
MSNBC
Updated: 4:36 p.m. ET June 15, 2004

Since the catastrophic firestorms of 2003, insurance companies covering homeowners in areas prone to wildfires have redoubled efforts to identify areas of highest risk and provide adequate coverage at competitive prices. To do so, they're increasingly relying on advanced technology, including the latest in satellite mapping and sophisticated computer modeling.
….
Last year's fires provided a wake-up call to homeowners in fire prone areas — and to insurers and state regulators. Total losses from those fires exceeded $2 billion. Major fires in California's San Diego and San Bernardino counties alone killed 24 people, destroyed 3,700 homes and burned 750,000 acres.

"While efforts to protect property are on the increase, the indications are this year could shape up to be a very costly one, since there has been little change in the conditions that were seen in 2003," said Loretta Worters, vice president of communications at the Insurance Information Institute, a trade group.
…
"There are a lot of private companies out there," said Stephen Niccolai, a loss mitigation coordinator at State Farm. "And they're a lot of GIS folks within the forest services, the BLM (Bureau of Land Management), U.S. forest services, individual state forest services, counties, and municipalities. And a lot of them are doing their own assessments."

How the technology works
One popular product, known as ***FireLine,*** *determines fire risk using several key factors, including the type and amount of combustible fuel near a building , the slope of the terrain, and available road access for firefighters. In a study of the 2003 California wildfires, 97.5 percent of the areas that burned was in the highest risk areas identified by the system, according to ISO, the insurance information and consulting firm that sells FireLine to insurers.*

http://msnbc.msn.com/id/5138792/

There is undoubtedly increasing utilization of these emerging technologies, and the potential in terms servicing this market is continuing to grow. As an issues paper prepared by the company ISO who provides financial and risk calculations for other insurance agencies, observed; the increasing suburbanization and development trends will only increase the financial impacts of wildland fire:

"While unprecedented amounts of fuel have accumulated, the population has shifted. More and more people are living in or near areas prone to wildfire. During the twentieth century, the population of the

United States has moved west. In recent decades, the population has also become more dispersed. Those trends have increased the number of people living in heavily vegetated areas where wildlands meet urban development — the wildland/urban interface. "These new wildland/urban immigrants give little thought to the wildfire hazard," according to the Federal Wildland Policy.

The result is more homes and other structures at risk. Together, the accumulation of fuel and development in hazardous areas pose particular challenges for insureds and insurers, as well as government agencies responsible for fire prevention, mitigation, and suppression.

*In broad perspective, the challenges and their respective solutions fit into two categories. The first category consists of socio-environmental challenges associated with the unprecedented accumulation of fuel and population growth in areas prone to wildfire. The solutions to those challenges involve mitigating potential **losses though increased understanding of fire behavior**, public education, fire-safe building codes, landscaping ordinances, and the like.*

*The second category consists of the risk decision challenges insurers face in underwriting properties exposed to the wildfire hazard — challenges much like the ones insurers face in underwriting properties exposed to hurricanes, earthquakes, and other natural hazards. The solutions to those challenges include: developing and implementing appropriate underwriting guidelines; **measuring and managing the aggregate amount of wildfire exposure** in an insurer's book of business; managing the **geographic distribution of exposures** to prevent excessive concentration in any single area or contiguous areas prone to wildfires; and educating agents and insureds about loss mitigation."*

(http://www.iso.com/studies_analyses/docs/study009.html)

<u>Market Opportunity:</u>

Hyperspectral:

Whereas "Fire Line", "Far Site", and other similar modeling products use satellite data and USGS 7.5' minute DEMS, there is a distinct opportunity to provide improved capabilities with higher resolution data such as could be provided by a combined LiDAR/spectral imaging system.

Fire behavior is a product of fuels, terrain and weather, which vary in importance depending upon fire regime and season. Wildfire fuels, because of high spatial and temporal variability, represent one of the greatest sources of uncertainty in predicting fire danger. Currently, fire danger is most often assessed using broad band sensors such as the Advanced Very High Resolution Radiometer (AVHRR), the Moderate Resolution Imaging Spectroradiometer (MODIS), or Thematic Mapper (TM). Maps are generated through some combination of classification to map fuel types, meteorology and ancillary information such as slope, aspect, elevation, and fire history.

The finer spectral information provided by a hyperspectral instrument facilitates the mapping of biophysical and chemical information that is directly related to the quality of wildfire fuels, including above ground live biomass, canopy moisture etc. This capability is currently absent with the use of coarser space borne systems. Increasingly NASA AVIRIS hyperspectral data has been incorporated in fuel mapping and fire risk analysis and has been shown to provide greater utility for improving current methodologies.

For example, the ratio of green live foliage to dead materials is an important determinant of fire hazard. One method for estimating live and dead canopy components is Spectral Mixture Analysis of hyperspectral data. Fuel moisture is potentially the most important factor impacting fire hazard. In chaparral fires, much of the fire is carried by green, live foliage as a crown fire. As fuels dry seasonally, the amount of energy required to burn off the water decreases and fire hazard increases. Direct measures of canopy moisture can also be accomplished from hyperspectral data with bandwidths and spectral range matching AVIRIS.

Research funded by the National Fire Plan joint center found that the use of broad band, multispectral system (such as those cited above), are severely limited in vegetation moisture mapping, concluding that fuel moisture estimation is limited to grasslands, with a poorer relationship for shrubs and no relationship for forests. Conversely in assessing results from AVIRIS data, the research team concluded that:

"Hyperspectral sensors have the potential for producing a large number of products for fire hazard assessment. Hyperspectral sensors capture many of the elements essential to fuels mapping including accurate vegetation identification (potentially to species levels) and measures of green live biomass and live fuel moisture. When combined with analysis tools such as SMA [Spectral Mixing Analysis], hyperspectral data can be used to map areal portions of live and non-photosynthesizing canopy components."
(http://jfsp.nifc.gov/conferenceproc/Ma-08Robertsetal.pdf)

Remote sensing is also considered an increasingly important tool for monitoring post-fire recovery following an event. Fire scars can be readily mapped using a diversity of techniques and post-fire recovery assessed by revisiting the site

LiDAR:

While a commercially operated, cost effective hyperspectral system with similar spectral capabilities as that of AVIRIS (without its operational unreliability) would be useful in addressing many needs within this market, it is only part of the solution.

Crown fire is now a chief concern among many forest managers in the western US and Canada because they have increased in frequency, intensity and size in many. Compared to surface fires, crown fires are responsible for many more burned acres, more smoke per acre, greater and longer lasting ecological damage (i.e. higher severity), greater threats to firefighter and public safety and increased risk of property and structure loss.

Research over the last two decades has identified four canopy characteristics that significantly affect the incidence of crowning. The **crown base height** (height of the bottom of the live crown from the ground surface), **crown bulk density** (mass per unit volume of combustible crown biomass, including foliage, twigs and branches), **stand height** (average height of the dominant tree strata in a stand) and **canopy closure** (percent vertically projected canopy cover in the stand). A number of fire models and computer-based fire modeling systems require estimates of these canopy fuel characteristics to accurately simulate crown fires.

Much of these data layers can be derived from analysis of multiple return LiDAR data of sufficient posting density. And the possibility of enhanced data extraction from the combination of the spectral and elevation data of a single sensor system may address many of the remaining data requirements.

So not only would the LiDAR component provide all of the topographic data inputs, it would also enhance the ability to generate the biophysical measurements as well.

To illustrate this point, on the following pages I have included some canopy analysis performed on a LIDAR all return data.

Conclusions/Thoughts:

1. I believe that there is a substantial amount of research/study money available from this market segment that could be accessed to help defray the initial costs of working on a combined hyperspectral/LiDAR instrument package.
2. I believe there is a definite long-term commercial market for providing services and products to both Governmental and Private entities.
3. By emphasizing the development and implementation of biophysical mapping capabilities of multi-return LiDAR, we can increase the utility and frequency of data collections over simple floodplain, terrain-mapping applications.
4. Even if entry and participation in this market was revenue neutral, I believe the PR/marketing benefits would make such work worthwhile to the company as a whole.

Note 1: I have placed a PowerPoint presentation containing the LiDAR canopy images and descriptions onto the server. It can be retrieved at HQ_Filer\Data\rs\ow_LiDARapp_forestry.ppt

Note 2: Some questions may arise about the stated interest of Spectir to expand their sensor to include thermal wavelengths. I have restricted myself to trying to address the capabilities we have in hand at this time. The inclusion of longer wavelengths may indeed be useful for soil and vegetation moisture mapping (specifically evapotranspiration), however there is still some questions regarding the cost/benefit ratio. Also, I believe we should be very careful about expectations of the utility of a combined LiDAR/hyperspectral/thermal sensor as a realtime, in-fire tool due to the obvious reason that fire and smoke would render the first two systems useless. Much of the money being put into satellite based fire monitoring systems is specifically in the thermal range, however there may indeed be a market for a standalone, on the scene, thermal mapping system for early fire monitoring. Apparently Itres has found such use for their thermal system.

Figure 1

Figure 1 shows a traditional LiDAR derived canopy closure map. This is a measure of closure that is integrated through the entire canopy. It is derived by the ratio of those LiDAR shots classified as <u>not bare earth</u> divided by the total number of LiDAR shots in the given grid area. For this example, a 4-meter grid was used. So for example if within that 4 by 4-meter area, 10 out of 20 points are classified as not bare earth then the canopy closure estimate would be 50%.

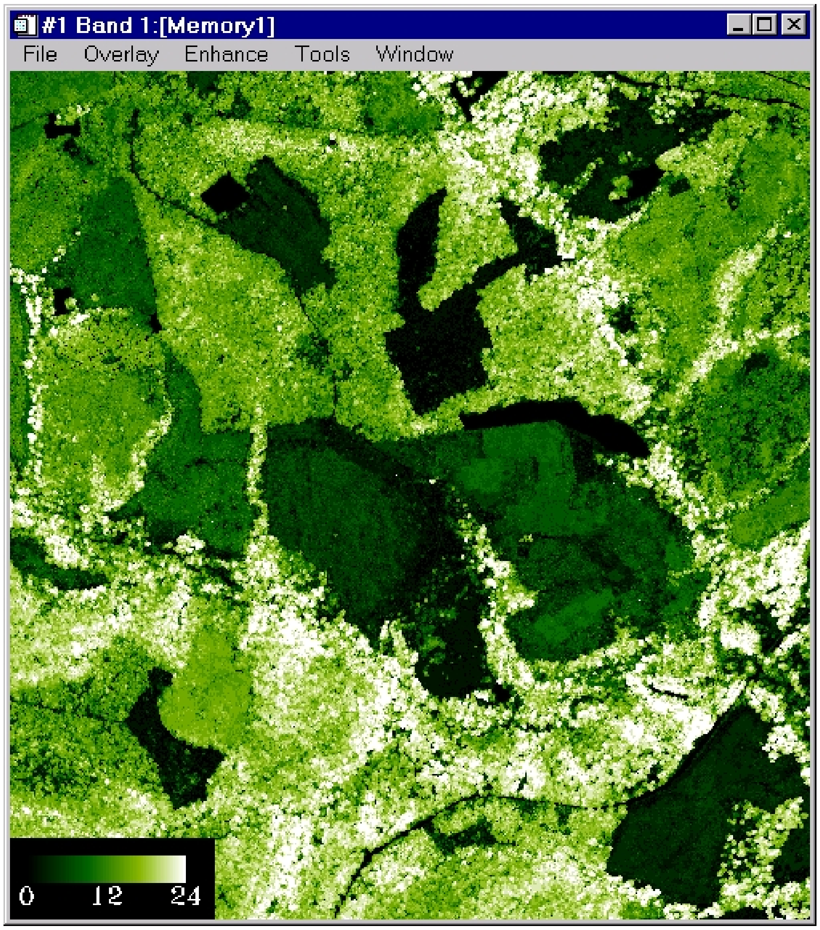

Figure 2

Figure 2 shows another LiDAR product that can be derived from the canopy closure information. Here the emphasis is on evaluating the data in elevational “cake slices” to find out at which elevation does the greatest canopy closure occur. In the above example, the color ramp highlights the values in meters above ground level. In other words, those areas in the canopy where the greatest canopy closure occurred between 21 to 24 meters and above are in shades of white. As the color gets progressively darker, the elevation at which the maximum canopy closure occurs is getting lower.

This potentially gives us information about canopy structure, stand age, and understory condition, which are important components to habitat mapping as well as feeding into fuel mapping and fire modeling.

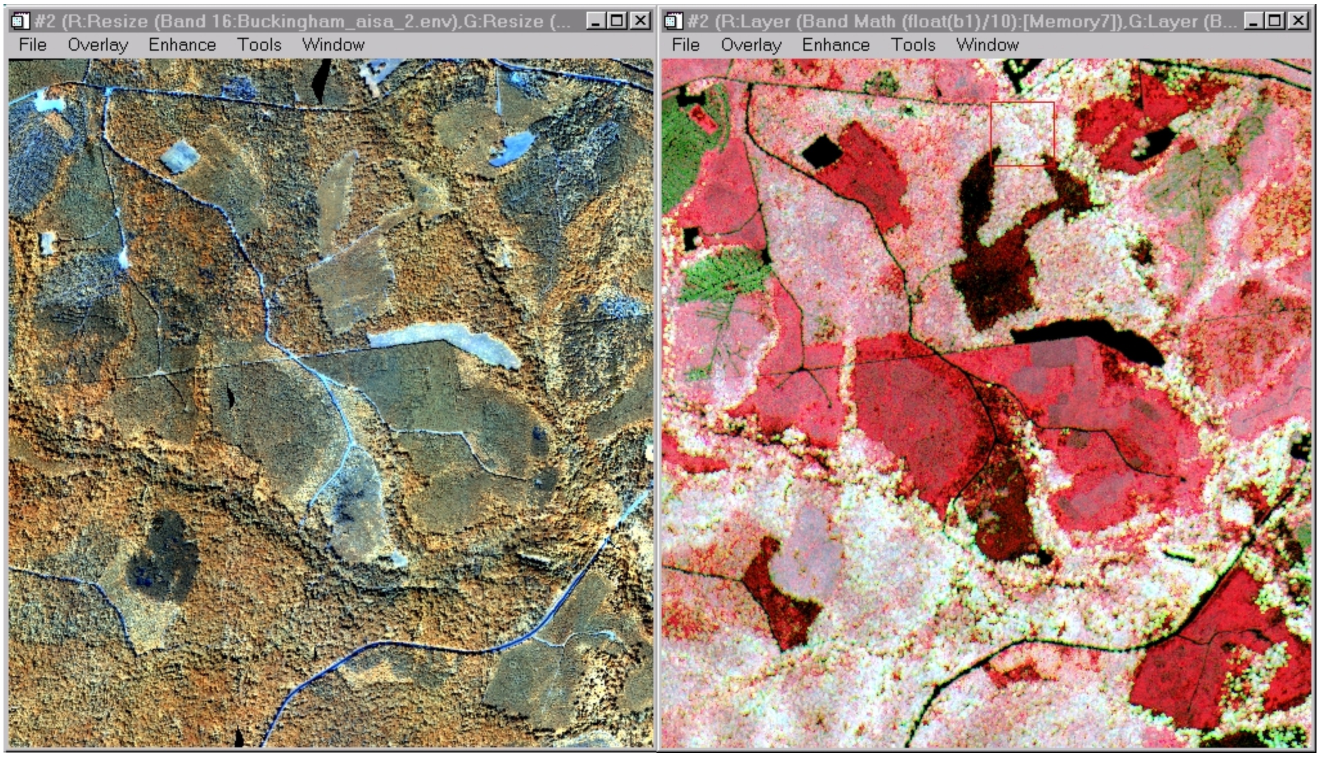

Figure 3

The various derivative LiDAR products can be combined for classification and other analysis purposes. In figure 3, a 3-band composite was generated using the canopy height, the integrated canopy closure, and the elevation of maximum canopy closure data. The abundance of information can be seen when comparing this image to the color image composite on the left (AISA data).

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