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Remote Sensing Imagery Support for Burned Area Emergency Response Teams on 2003 Southern California Wildfires

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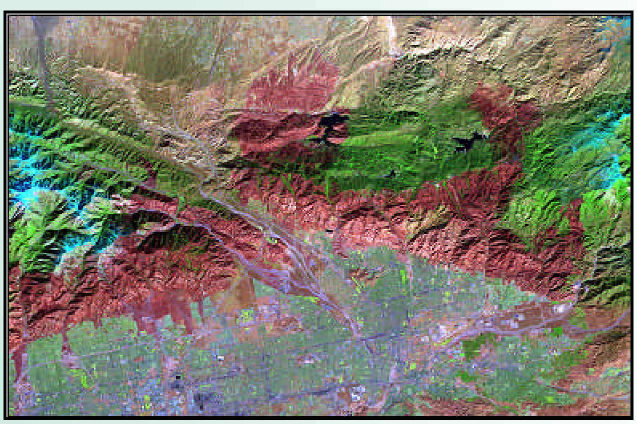
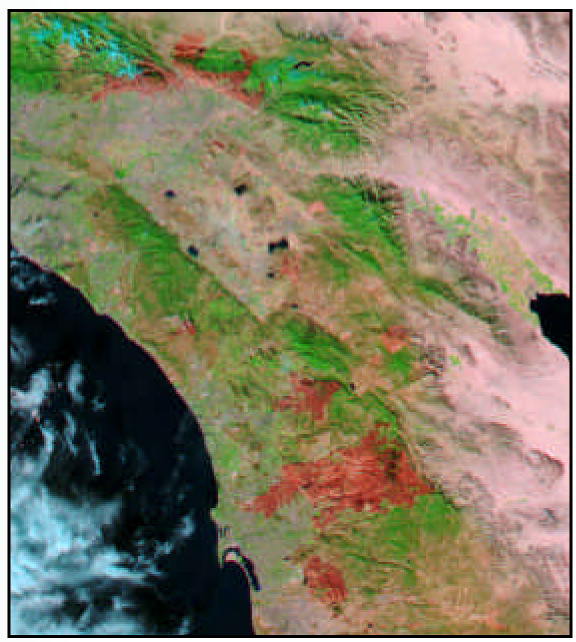


ASTER imagery of the Grand Prix and Old fires, acquired on November 18, 2003. The city of San Bernardino is south of the fires.



MODIS imagery of the Old, Grand Prix, Padua, Paradise, Cedar, and Otay fires in Southern California, acquired on November 5, 2003.

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Abstract

During the three weeks of fire suppression and immediate post-fire rehabilitation assessment in Southern California, the USDA Forest Service Remote Sensing Applications Center (RSAC) evaluated imagery from many different sensors. RSAC provides Burned Area Emergency Response (BAER) teams with imagery and derived data products to assist with mapping the burn severity. For fires that burned in Southern California, RSAC evaluated the application of several remote sensing platforms in emergency BAER assessment. This paper outlines each sensor used, the benefits and disadvantages of each, and the conclusions derived from RSAC's involvement in this process.

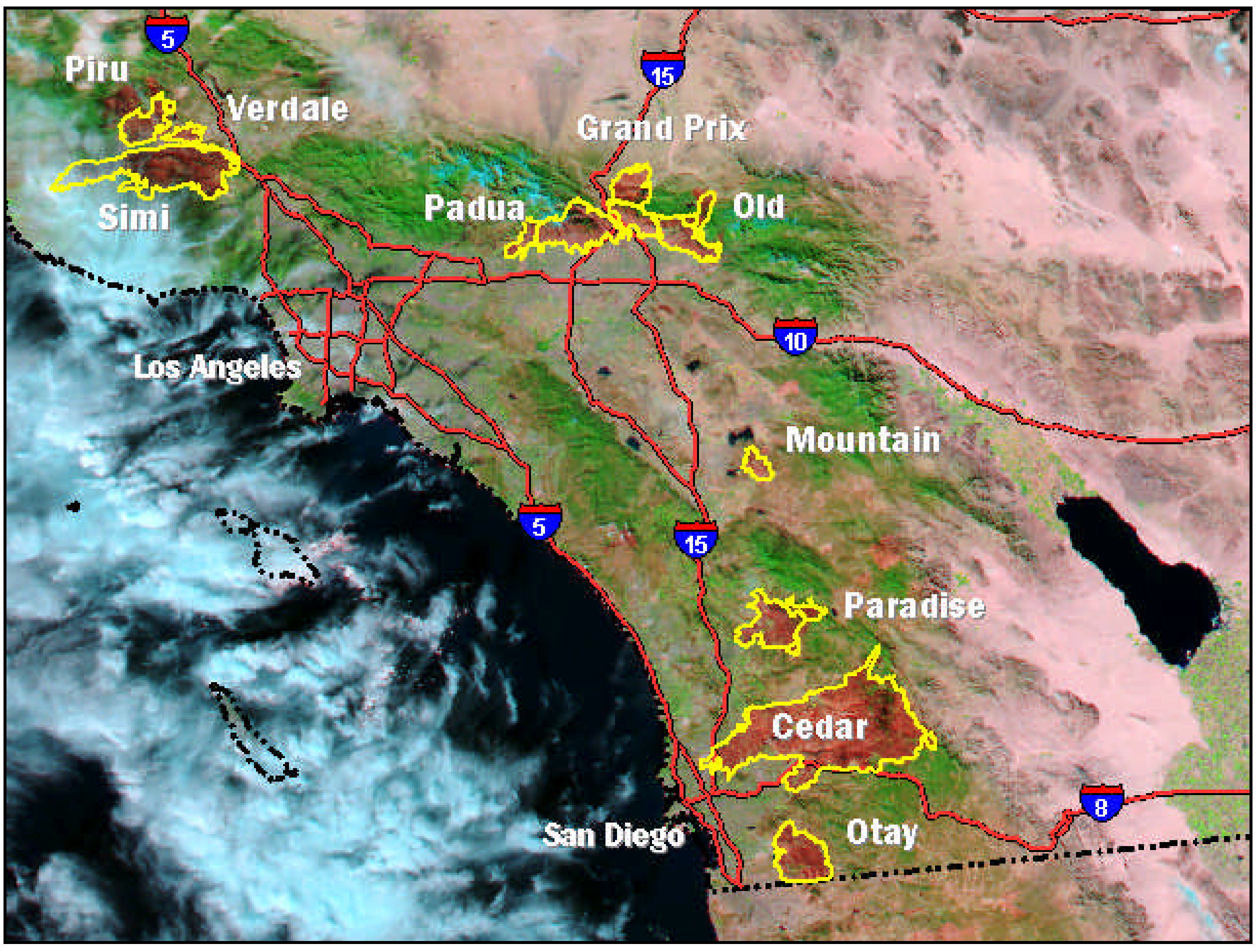

Figure 1 - False-color infrared MODIS scene showing fire locations, acquired November 5, 2003.

1. Background

After many years of continued drought, the most disastrous fires in California history burned approximately 750,000 acres of land during October and November, 2003. The fires burned over 4,000 homes, left at least 20 people dead, and required the work of over 11,000 firefighters to contain them. Intense media coverage brought the frightening scene experienced by residents of Southern California into the homes of the rest of the nation.

After fires are contained, other potential hazards still exist that could present extreme danger to residents in or near the burned areas. Intense fires often burn much of the existing ground cover in an area, leaving the soil exposed to the elements, such as rain, snow, and wind. Debris flows and erosion are common problems during storms in recently burned areas. To combat this potentially dangerous situation, Burned Area Emergency Response (BAER) teams are dispatched to the scene of fires to evaluate which areas are most at risk from debris flows and extreme erosion.

To assist BAER teams in evaluating the burned areas in a quick, efficient, and safe manner, the USDA Forest Service Remote Sensing Applications Center (RSAC) provides image support to these teams. Remotely-sensed imagery helps scientists to make educated, consistent, and accurate assumptions about conditions on the ground (Hardwick et al., 1997). At RSAC, working with input from fire effects specialists in the field, analysts have streamlined the process for immediate evaluation of burned areas using airborne and spaceborne multispectral imagery (Orlemann et al., 2002; Parsons, 2002).

This process includes acquiring imagery of wildfires at or near the time of containment and running spectral analyses on the data to produce a model of the conditions on the ground. This model of ground conditions is called the Burned Area Reflectance Classification (BARC). This process has been well researched and documented (Key and Benson, 2001).

During the three weeks of fire suppression and immediate post-fire rehabilitation assessment in Southern California, RSAC evaluated imagery obtained from many different sensors. These sensors were aboard airborne and spaceborne platforms, some private and some government-owned. Some were well researched, and others experimental. Included were SPOT Image Corporation’s SPOT 4 and SPOT 5 sensors, and the following sensors operated by NASA: Landsat 5 and 7, MODIS, MASTER, AIRDAS, and ALI. Each sensor listed here will be discussed in more detail in the following sections of this report. Other sensors collected imagery of the fires in Southern California, but they were not used for immediate BAER assessment due to lack of availability during the BAER emergency assessment timeframe.

2. Sensor Summary

The following information summarizes the various types of remotely-sensed data used to support the 2003 Southern California BAER teams. Technical specifications, cost, web links, advantages, and disadvantages of each data type are provided.

Each sensor description includes the spatial resolution, temporal resolution, swath width, and spectral resolution. These characteristics are defined as:

Spatial Resolution – amount of area covered by each picture element (pixel) of the data

Temporal Resolution – length of time (in days) between observations of the same area

Swath Width – ground area covered by a single overpass of the sensor

Spectral Resolution – the part of the electromagnetic spectrum that is sensed

2.1. SPOT 4 and SPOT 5

Sensor Information

	SPOT 4	SPOT 5
Spatial Resolution	20 m	10 m, 2.5 m panchromatic band
Temporal Resolution	Variable*	Variable*
Scene Size	56 km x 56 km	56 km x 56 km

Band	Spectral Resolution (µm)	Spectral Location
1	0.50 – 0.59	Green
2	0.61 – 0.68	Red
3	0.79 – 0.89	Near IR
4	1.58 – 1.73	Mid IR

* The SPOT sensor can be pointed at a specific target, which shortens the temporal resolution. SPOT can usually acquire an image within three days of tasking.

Costs

Use of SPOT 4 costs $1,900 per scene, plus additional fees for rush programming and delivery. RSAC typically pays about $9,175 for a SPOT 4 scene for BAER support. A SPOT 5 scene costs $3,300, plus additional fees for rush programming and delivery. RSAC typically pays about $10,575 for a SPOT 5 scene for BAER support.

Additional Information on SPOT

www.spot.com

Benefits of Using SPOT

The SPOT sensor is a good resource for images of burned areas. The combination of 10-meter and 20-meter pixel sizes and the necessary spectral bands means SPOT will continue to be a valuable sensor for burned area analysis.

Disadvantages of Using SPOT

The biggest drawback to using SPOT imagery is the high cost of the delivered data. An individual scene is not expensive, but the extra fees added to ensure priority satellite programming and prompt delivery more than triple the cost of the data itself. To ensure prompt image delivery, RSAC also orders SPOT imagery without any terrain correction. This adds a few hours of processing time to make the imagery usable for immediate post-fire assessment but saves days of processing time at SPOT Image Corporation.

Southern California Support Summary

On November 7, RSAC received a SPOT 5 (10 meter) scene that was acquired over the Paradise and Cedar fires on November 5. This was the first high-resolution imagery obtained over either fire. A normalized burn ratio (NBR) was computed on the burned areas in the imagery, followed by a GIS overlay with the National Land Cover Database (NLCD) vegetation layer. On November 18, RSAC received two more SPOT 4 scenes that, combined with the previous SPOT 5 scene, provided a clear look at all the fires in the San Diego region.

Field teams were very pleased with the high correlation between the BARC data and field observations. Prior to obtaining this SPOT scene, the best imagery field teams had received was 250-meter MODIS. The SPOT product was a marked improvement for field users.

RSAC experienced some delivery problems with SPOT imagery during the Southern California fires. The SPOT federal civilian distributor preemptively tasked the data collection; unfortunately the acquired imagery did not allow for complete coverage of the fires. Additionally, the SPOT distributor did not identify the acquisition as an emergency purchase; therefore, the data went to an archive causing a 48-hour delay in delivery. RSAC met with the distributor in early December, 2003 to resolve these issues.

Fires Covered by SPOT Imagery

SPOT imagery was obtained for the Cedar, Paradise, Otay, and Mountain fires.

2.2. Landsat

Sensor Information

	Landsat 5	Landsat 7
Spatial Resolution	30 m	30 m, 15 m panchromatic band
Temporal Resolution	16 days	16 days
Scene Size	185 km x 185 km	185 km x 185 km

Band	Spectral Resolution (µm)	Spectral Location
1	0.45 – 0.52	Blue
2	0.52 – 0.60	Green
3	0.63 – 0.69	Red
4	0.76 – 0.90	Near IR
5	1.55 – 1.75	Mid IR
6	10.4 – 12.5	Thermal IR
7	2.08 – 2.35	Mid IR
8*	0.52 – 0.90	Green – Near IR

* Band 8 is only on Landsat 7 and is a panchromatic band.

Costs
Because the Forest Service is a partner in the Multi-Resolution Land Characteristics (MRLC) consortium, a Landsat 5 scene purchased through the MRLC program costs $580 and a Landsat 7 scene is $720.

Additional Information
landsat7.usgs.gov

Benefits of Using Landsat
Due to a cooperative effort between the USGS EROS Data Center (EDC) and RSAC, Landsat imagery can be delivered to RSAC within 24 hours of acquisition. These data are rapidly delivered to RSAC as terrain-corrected images and are ready for analysis. Landsat scenes are inexpensive and no rapid delivery fees are attached to the final cost.

When available, Landsat imagery is the desired form of imagery for use in BARC modeling due to its low cost, adequate resolution for BAER work, speed of delivery, large footprint, and spectral characteristics.

Disadvantages of Using Landsat
The temporal resolution of 16 days makes Landsat imagery acquisition sometimes problematic. The fires in Southern California highlighted the disadvantages of the long revisit time of Landsat. Due to the orbit tracks, RSAC had only one opportunity to acquire a

Landsat image after most of the fires were contained. That one opportunity was mostly lost due to clouds.

Southern California Support Summary

The first acquisition attempt for Landsat 5 over these fires was November 3, 2003. However, clouds covered 95% of the burned areas at that time and only the very northern portion of the Grand Prix and Old fires were visible through the clouds. Upon request from the field, RSAC purchased the scene and delivered it to field users.

The USGS Eros Data Center (EDC), the main distributor of Landsat data, sent a 15 meter, panchromatic-sharpened Landsat 7 scene for these fires free of charge. However, due to problems with the scan line corrector (SLC) on the sensor instrument, only the middle 20 km of the imagery was useful. Unfortunately, there were no fires burning in the usable middle 20 km. This imagery was delivered to field users and used for visual interpretation. Landsat 7 will not be used operationally in future BAER imagery efforts until the SLC malfunction can be corrected.

Fires Covered by Landsat Imagery

The Old and Grand Prix fires were covered by Landsat imagery. Cloud- and smoke-free imagery of the Simi, Verdale, Piru, and Padua fires was acquired on November 10, after immediate BAER assessment was complete. Clear imagery of the Cedar, Paradise, Otay, and Mountain fires was acquired on November 19.

2.3. Moderate Resolution Imaging Spectroradiometer (MODIS)

Sensor Information

Spatial Resolution	250 m, 500 m, 1000 m multispectral
Temporal Resolution	Multiple daily acquisitions
Scene Size	2300 km

Band	Spectral Resolution (µm)	Spectral Location
1	0.62 – 0.67	Red
2	0.841 – 0.876	Near IR
3	0.459 – 0.479	Blue
4	0.545 – 0.565	Green
5	1.23 – 1.25	Mid IR
6	1.628 – 1.352	Mid IR
7	2.105 – 2.155	Mid IR
8 – 50	0.405 – 0.965; 3.66 – 14.385	Blue – Thermal IR

Costs

RSAC has a MODIS receiving station at the RSAC facility in Salt Lake City, Utah, so there is no cost for MODIS imagery.

Additional Information

modis.gsfc.nasa.gov

Benefits of Using MODIS

Two NASA satellites, Aqua and Terra, each hold a MODIS sensor; both satellites pass over the continental US multiple times each day, greatly increasing the odds of acquiring cloud-free imagery in comparison to the Landsat sensor. Also, the first seven bands of MODIS were designed to simulate the Landsat sensor, allowing users to view MODIS imagery much the same way as Landsat imagery. For example, Landsat band combination 7, 4, and 3 shows burn scars as bright red and healthy vegetation as bright green. To achieve the same effect with MODIS, the 7, 2, and 1 band combination is used. In these bands, there is little spectral difference between the Landsat and the MODIS bands.

Disadvantages of Using MODIS

The sole disadvantage to using MODIS imagery in reflectance classifications is the coarse spatial resolution. The finest pixel size is 250 meters, which often is too coarse for fire analysis.

Southern California Support Summary

MODIS provided the earliest look at the fire situation in Southern California. Every afternoon, “quick look” images of scenes acquired in the previous hours were available for viewing. These “quick looks” also provided daily weather and smoke reports during image acquisition coordination from other sensors. For example, NASA’s ASTER sensor was set to acquire imagery of the Cedar and Otay fires near San Diego on November 4. However, the MODIS “quick look” acquired that same day over the same area showed thick cloud cover, so RSAC informed NASA not to rush the processing of the ASTER image.

RSAC also used MODIS data to produce BARC data. For some fires, the normalized difference burn ratio was used in analysis on pre- and post-fire MODIS images. This product came back with mixed results. However, in some cases, such as the Grand Prix, Old, and Padua fires, this was the only look the field users got from satellite imagery during the BAER time frame. Field users were able to use the MODIS-derived BARC as a rough guide, but still had to expend considerable field time to produce the burn severity map used in the BAER assessment.

Fires Covered by MODIS Imagery

MODIS imagery was captured for all Southern California fires.

2.4. MODIS/ASTER Airborne Simulator (MASTER)

Sensor Information

Spatial Resolution	5 – 50 m depending on type of aircraft used to fly the sensor
Temporal Resolution	Airborne sensor*
Scene Size	Variable**

Band	Spectral Resolution (µm)	Spectral Location
1-25	0.4 – 2.5	Blue – Mid IR
26-40	3.0 – 5.0	Thermal IR
41-50	7.0 – 13.0	Thermal IR

* Because the MASTER sensor is flown on an airplane (DC-8, ER-2, or King Air Beachcraft B200), the temporal resolution varies depending on how often the sensor is flown.

** Scene size will vary depending on the flight altitude during data collection.

Costs

Because the MASTER sensor is experimental and the data were provided at no cost to the Forest Service, the true cost of the data is unknown at this time. RSAC was informed that the Department of Homeland Security and Federal Emergency Management Agency (FEMA) paid for all MASTER image acquisitions.

Additional Information

masterweb.jpl.nasa.gov

Benefits of Using MASTER Imagery

MASTER provides a good multispectral view of fires. Because pixel size can vary from 5 to 50 meters depending on flight altitude, users can often receive imagery with sufficient resolution for their needs. The inclusion of NIR and SWIR bands on this sensor allowed RSAC to run the BARC models and produce accurate results.

Another benefit of using this imagery and all airborne sensors is the ability to task the sensor to fly on certain days and over specified areas. This allows analysts to acquire imagery during the downtime between satellite acquisition attempts.

Disadvantages of Using MASTER Imagery

One major disadvantage of this sensor is that it is still experimental. Because of that, there is no standard protocol for tasking the sensor and rapid delivery cannot always be relied on.

Southern California Support Summary

NASA acquired imagery using the MASTER sensor on Saturday, November 1, 2003. This imagery covered the Simi, Piru, and Verdale fires. RSAC received these images Sunday morning, November 2, 2003. For this specific acquisition, the pixel size of the imagery was 31.5 meters.

The imagery was delivered to analysts at RSAC in a format unusable in standard Forest Service image processing software and incorrectly georegistered. To make the data useful, many steps were taken to properly align the imagery and export it to a useable format.

To produce the BARC maps, analysts resampled the pre-fire Landsat 7 image and the NLCD vegetation layer to match the spatial resolution of the MASTER imagery. Once all the data was in the same spatial context, the BARC maps were produced.

BAER teams in the field for both the Simi and Piru fires reported high correlation between the BARC maps and what was observed in the field. With relatively little ground-truthing, the final soil burn severity map was produced with the BARC data as the mapping foundation.

Due to the success of this imagery, another acquisition attempt over other fires in Southern California was requested. NASA responded that the MASTER sensor had been removed from the airplane but the MODIS Airborne Simulator (MAS) sensor was available later in the week. The MAS sensor was the precursor to MASTER and is very similar in spectral and spatial characteristics. However, on the day of the MAS acquisition attempt, Southern California was blanketed in thick cloud cover and no images were acquired. That was the last opportunity for image acquisition using either the MASTER or MAS sensors.

Fires Covered by MASTER Imagery

The Simi, Piru, and Verdale fires were covered by MASTER imagery.

2.5. Airborne Infrared Disaster Assessment System (AIRDAS)

Sensor Information

Spatial Resolution	12 m
Temporal Resolution	Airborne sensor*
Scene Size	Variable**

Band	Spectral Resolution (µm)	Spectral Location
1	0.64 – 0.71	Red
2	1.57 – 1.70	Mid IR
3	3.75 – 4.05	Thermal IR
4	5.50 – 13.0	Thermal IR

* Because the AIRDAS sensor is flown on an airplane, the temporal resolution varies depending on how often the sensor is flown.

** Scene size will vary depending on the flight altitude during data collection.

Costs

The AIRDAS data was acquired through NASA Ames and delivered free of charge to the Forest Service for the Southern California fires.

Additional Information

geo.arc.nasa.gov/sge/UAVFiRE/uavpayload.html

Benefits of Using AIRDAS Imagery

As with all airborne sensors, imagery can be acquired over specific, chosen locations. There are no satellite orbit tracks that constrain acquisition attempts. This sensor provides good multispectral looks at fires and is very useful during active fire suppression efforts. The pixel size of 12 meters is also useful for analysts doing visual interpretation.

Disadvantages of Using AIRDAS Imagery

Although the imagery was terrain-corrected, there was visible warping along the edges. RSAC received the images in four different pieces, one for each flight line. RSAC analysts encountered problems color-matching each piece while creating a mosaic of all four pieces.

The production of a BARC from this imagery for BAER teams was not possible because AIRDAS lacks the appropriate spectral bands (AIRDAS has no near-infrared band) and there were radiometric differences between flight lines.

Southern California Support Summary

The AIRDAS sensor has been used numerous times in fire suppression efforts. Previously, the sensor was utilized for the 2002 Biscuit and McNally fires. AIRDAS proved to be useful for the delivery of near real-time images to Incident Command centers to show where the active fire fronts were burning. However, those images were only for interpretation and were not georegistered, so they could not be used in a GIS.

For the Southern California wildfires, cooperators from NASA and Sky Research acquired imagery of the Cedar fire near San Diego using the AIRDAS sensor on November 6, 2003. At the time of acquisition, this was to be the highest resolution image of the Cedar fire. The imagery was acquired on four different flight lines running west to east.

Because of data format issues previously mentioned, this imagery was not used in any classifications; however it was the first nearly complete image of the Cedar fire. Despite a few gaps in the flight lines of the AIRDAS product, this imagery covered nearly all the Cedar fire. Prior to the AIRDAS imagery, field users had received only MODIS and partial SPOT coverage of the Cedar Fire. As multispectral imagery with 12-meter pixel size, users found this imagery valuable as an immediate post-fire snapshot, but it was not used to map burn severity.

Fires Covered by AIRDAS Imagery

AIRDAS imagery was obtained for the Cedar fire.

2.6. Advanced Land Imager (ALI)

Sensor Information

Spatial Resolution	30 m, 10 m panchromatic band
Temporal Resolution	16 days
Scene Size	37 km x 185 km

Band	Spectral Resolution (µm)	Spectral Location
1	0.43 – 0.453	Blue
2	0.45 – 0.515	Blue
3	0.525 – 0.605	Green
4	0.63 – 0.69	Red
5	0.775 – 0.805	Near IR
6	0.845 – 0.89	Near IR
7	1.2 – 1.3	Mid IR
8	1.55 – 1.75	Mid IR
9	2.08 – 2.35	Mid IR
Pan	0.48 – 0.69	Blue - Red

Costs
The ALI data was acquired through NASA Goddard and were delivered free of charge to the Forest Service for the Southern California fires.

Additional Information
eo1.gsfc.nasa.gov/Technology/ALIhome1.htm

Benefits of Using ALI Imagery
The ALI is an experimental sensor and provides Landsat-type panchromatic and multispectral bands. These bands have been designed to mimic six Landsat bands with three additional bands covering 0.433-0.453, 0.845-0.890, and 1.20-1.30 µm. In theory, this sensor could be a replacement for Landsat 7.

The spectral similarities to Landsat allow analysts to use ALI in BARC models with the results showing high correlation to ground observations. The ALI follows the same orbit track as Landsat 7 and could be a good alternative to Landsat 5 when clouds or smoke interfere during acquisition.

Disadvantages of Using ALI Imagery
Because this sensor is still experimental, NASA does not acquire the full 185 kilometer by 185 kilometer footprint. The two ALI images RSAC received were different sizes, but both were much more narrow than a typical Landsat footprint. For example, the image acquired of

the Old/Grand Prix fires was only 37 kilometers wide and 185 kilometers in length. Unfortunately, most the fires in Southern California were large east to west. Since the ALI follows a satellite orbit track that runs north to south, the ALI images RSAC received only covered small portions of select fires. The only fire acquired with full ALI coverage was the Verdale Fire, a small fire of 8,650 acres that burned east of Los Angeles. The rest of the fires that were imaged had partial or complete cloud cover.

Southern California Support Summary

Images were acquired over parts of the Simi, Piru, and Verdale fires near Simi Valley, CA, and over parts of the Old and Grand Prix fires near San Bernardino, CA. This imagery was acquired on November 5, 2003 and delivered to RSAC the next day in ENVI file format.

The ALI has many of the same bands as Landsat, and all the required bands to perform a normalized burn ratio. However, due to cloud cover and the successful production of BARC maps using the MASTER sensor, RSAC did not deliver additional derived products using ALI imagery. The normalized burn ratio (NBR) was computed on imagery of the Verdale Fire, but the results were not significantly different than those produced using the MASTER imagery. To avoid confusing field users, RSAC did not release the NBR results using ALI imagery.

Fires Covered by ALI Imagery

ALI images were obtained for the Verdale fire and parts of the Simi, Piru, Old, and Grand Prix fires.

2.7. Other sensors

Despite the number of sensors used in evaluating burned areas for emergency assessment, there were still many sensors not utilized.

RSAC attempted to use the ASTER and MAS sensors but was thwarted by cloud cover. ASTER is a pointable spaceborne sensor with temporal resolution of 7-10 days. The initial data collection was cloudy and the next attempt was long after immediate BAER efforts were complete. MAS is an airborne sensor that was only available on one day for image acquisition. During that acquisition, clouds covered the burned areas.

EarthData acquired high-resolution airborne imagery of most the fires, but the extremely long post-processing time required to get this imagery into a useful format did not allow analysts to use it for BAER purposes. As of February 2004, these images still had not been delivered to RSAC.

The IKONOS and Quickbird sensors both produce excellent, very high-resolution images (less than 5 meters). However, both have very small footprints and do not have all the spectral bands necessary to run the BARC models. In addition, the level of detail provided by the very high-resolution sensors is well beyond the needs of a BAER team, which normally deal with 40 acre minimum mapping units. IKONOS and Quickbird imagery require some pre-processing before the data are delivered to RSAC, which in turn slows the delivery time of imagery and BARC data to BAER teams.

3. Southern California Wildfire Timelines

The following information was extracted from archived National Interagency Fire Center (NIFC) incident management situation reports (www.cidi.org/wildfire/).

3.1. Grand Prix Fire

Date	Acreage	Percent Contained	Notes
10/22/03	825	0	
10/23/03	1,958	15	
10/24/03	3,500	35	
10/25/03	12,600	19	
10/26/03	27,182	23	Posted MODIS scene; partial smoke cover.
10/27/03	51,284	25	Determined that Landsat pass 40/36 was on Nov. 3. Contacted BAER Team leader, Greg Kuyumjian, about RSAC's involvement.
10/28/03	57,232	35	
10/29/03	59,229	35	Email sent to notify EDC about Landsat pass on Nov. 3.
10/30/03	91,207	40	Increase in acreage due to inaccurate reporting.
10/31/03	91,207	75	Processed and released MODIS imagery. Produced single scene normalized burn ratios as a first look at fire situation. Scene partially cloudy. Tasked SPOT for data acquisition.
11/1/03	59,358	95	
11/2/03	59,448	95	
11/3/03	59,448	95	Landsat pass was 95% cloudy; field team decided to purchase anyway; tasked ASTER to acquire (earliest date was Nov. 18).
11/4/03	59,448	98	Received Landsat 5 image; delivered to BAER team member Henry Shovic.
11/5/03	59,448	98	Received mostly cloudy scene acquired by ALI; posted it to FTP site.
11/6/03	59,448	98	Posted cloud-free MODIS scene from Nov. 5 and BARC data to FTP site. Posted Landsat 7 scene from Oct. 26.
11/7/03	59,448	98	
11/8/03	59,448	98	
11/9/03	59,448	100	

3.2. Piru Fire

Date	Acreage	Percent Contained	Notes
10/24/03	1,000	0	
10/25/03	1,250	30	
10/26/03	1,253	90	Posted MODIS scene; partial smoke cover.
10/27/03	25,000	5	
10/28/03	29,324	10	
10/29/03	55,812	20	
10/30/03	68,022	30	Processed and released MODIS imagery and BARC data.
10/31/03	63,716	30	
11/1/03	63,991	40	MASTER imagey acquired.
11/2/03	63,991	80	Obtained MASTER imagery; released BARC data to field
11/3/03	63,991	80	

11/4/03	63,991	85	Obtained clear MODIS imagery of fire.
11/5/03	63,991	90	Released MODIS and BARC data to field.
11/6/03	63,991	90	
11/7/03	63,991	90	
11/8/03	63,991	90	

3.3. Simi Fire

Date	Acreage	Percent Contained	Notes
10/26/03	47,150	0	Posted MODIS scene; partial smoke cover.
10/27/03	80,000	5	
10/28/03	92,000	5	
10/29/03	97,880	25	
10/30/03	105,665	40	Processed and released MODIS imagery and BARC data.
10/31/03	107,240	60	
11/1/03	108,304	85	MASTER imagery acquired.
11/2/03	108,204	100	Obtained MASTER imagery; released BARC data to field.

3.4. Old Fire

Date	Acreage	Percent Contained	Notes
10/26/03	10,000	0	Posted MODIS scene; partial smoke cover.
10/27/03	24,000	5	Determined that Landsat pass 40/36 was on Nov. 3; Contacted BAER Team leader, Greg Kuyumjian, about RSAC's involvement.
10/28/03	26,000	10	
10/29/03	36,780	10	Email sent to notify EDC about Landsat pass on Nov. 3.
10/30/03	47,960	10	
10/31/03	95,395	15	Processed and released MODIS imagery. Produced single scene normalized burn ratios as a first look at fire situation. Scene partially cloudy. Tasked SPOT for data acquisition (all attempts were cloudy).
11/1/03	91,281	45	
11/2/03	91,281	65	
11/3/03	91,281	78	Landsat pass was 95% cloudy; field team decided to purchase anyway. Tasked ASTER to acquire (earliest date was Nov. 18).
11/4/03	91,281	93	Received Landsat 5 image; delivered to BAER team member Henry Shovic.
11/5/03	91,281	96	Received mostly cloudy scene acquired by ALI; posted it to FTP site. Posted cloud-free MODIS scene from Nov. 5 and BARC data to FTP site.
11/6/03	91,281	100	Posted Landsat 7 scene from Oct. 26.

3.5. Cedar Fire

Date	Acreage	% Contained	Notes
10/26/03	6,000	0	Posted MODIS scene; partial smoke cover.
10/27/03	6,000	0	
10/28/03	180,000	0	
10/29/03	233,192	15	
10/30/03	251,000	15	
10/31/03	272,318	42	Tasked SPOT for acquisition.
11/1/03	275,833	65	
11/2/03	281,666	90	
11/3/03	281,298	95	
11/4/03	280,293	99	
11/5/03	280,278	100	Released cloud- and smoke-free MODIS scene to field. Cloud-free SPOT 5 scene acquired; RSAC released imagery and data to field Nov. 7.

3.6. Paradise

Date	Acreage	Percent Contained	Notes
10/26/03	1,600	0	Posted MODIS scene; partial smoke cover.
10/27/03	15,000	0	
10/28/03	30,000	15	
10/29/03	40,000	20	
10/30/03	49,800	20	
10/31/03	56,000	30	Tasked SPOT for acquisition.
11/1/03	56,700	50	
11/2/03	56,700	65	
11/3/03	56,700	75	
11/4/03	56,700	77	
11/5/03	56,700	85	SPOT 5 cloud-free image acquired. Posted MODIS scene and derived BARC data.
11/6/03	56,700	95	
11/7/03	56,700	100	Delivered SPOT imagery and derived BARC data to field. Obtained AIRDAS imagery and released mosaic to the field.

3.7. Mountain Fire

Date	Acreage	Percent Contained	Notes
10/27/03	2,000	0	Posted MODIS scene from Oct. 26; partial smoke cover.
10/28/03	9,742	55	
10/29/03	9,890	85	
10/30/03	10,331	100	

3.8. Padua Fire

Date	Acreage	Percent Contained	Notes
10/28/03	8,000	15	Posted MODIS scene from Oct. 26; partial smoke cover.
10/29/03	9,446	50	
10/30/03	10,466	90	
10/31/03	10,466	95	Provided partial MODIS from Oct. 28 and BARC coverage of fire. Tasked SPOT for acquisition.
11/1/03	10,466	95	
11/2/03	10,466	95	

3.9. Otay Fire

Date	Acreage	Percent Contained	Notes
10/27/03	10,000	0	Posted MODIS scene from Oct. 26; partial smoke cover.
10/28/03	45,291	90	
10/29/03	45,971	100	

Images obtained after BAER assessment:

Fire Name	Sensor	Acquisition Date
Cedar	SPOT 4 Landsat 5	11/18/03 11/19/03
Paradise	SPOT 4 Landsat 5	11/18/03 11/19/03
Otay	SPOT 4 Landsat 5	11/18/03 11/19/03
Old	Landsat 5 ASTER	11/19/03 11/18/03
Grand Prix	Landsat 5 ASTER	11/19/03 11/18/03
Padua	Landsat 5 Landsat 5 ASTER	11/10/03 11/19/03 11/18/03
Simi	Landsat 5	11/10/03
Piru	Landsat 5	11/10/03
Verdale	Landsat 5	11/10/03
Mountain	SPOT 4 Landsat 5	11/18/03 11/19/03

4. Conclusions

Many imaging platforms exist to provide imagery of post-fire conditions. RSAC had the opportunity to test many sensors during the three weeks of fire suppression and immediate post-fire rehabilitation assessment in Southern California. The results varied based on weather conditions, sensor characteristics, and the operational status of the sensor.

With proven sensors (Landsat, SPOT), analysts can expect a standardized file type with known geographic and radiometric corrections. With some of the experimental images, a variety of techniques were needed, such as terrain-correction procedures, to convert the imagery into a usable image. However, most of the acquired imagery was delivered to RSAC quickly, allowing the rapid production and delivery of BARC data. Some of the imagery offered was not delivered in time for BAER applications; however, those data sets may prove useful for long-term monitoring purposes.

Many BAER team members are unaware of the remote sensing tools available to them during assessment. BAER teams may also have different needs: one BAER team's main concern may be the development of the burn severity map quickly and efficiently; another BAER team's main concern may be how to best rehabilitate specific small watersheds where high-resolution imagery is needed to assist in that assessment. Figure 2 shows the many different sensor options available to BAER team members based on their specific need. Table 1 provides an abbreviated list of attributes for many remote sensing platforms available to the BAER community during emergency burned area assessment.

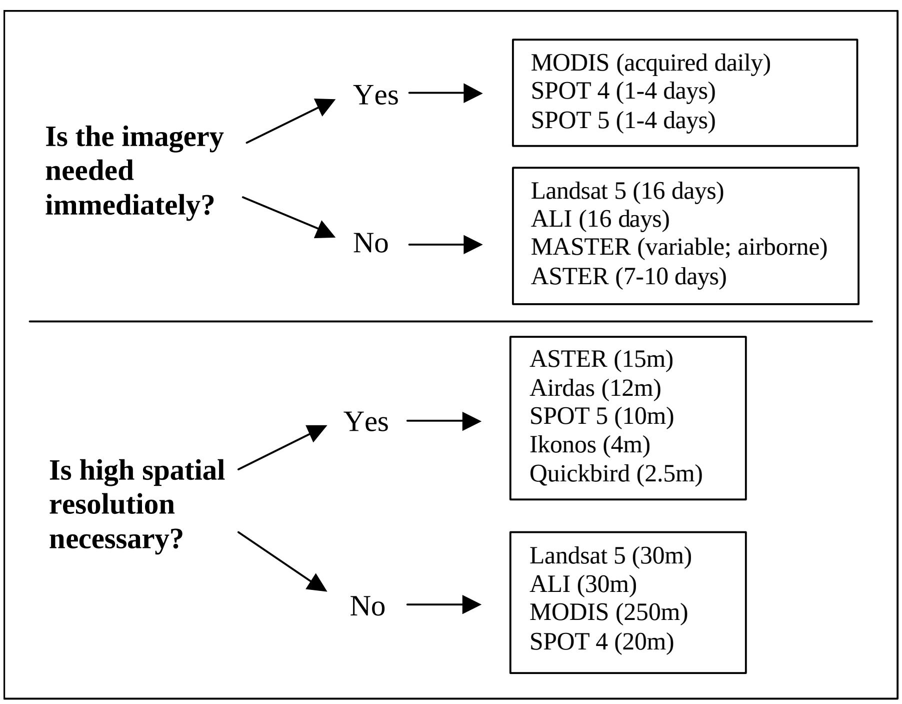

Figure 2—Different remote sensing platforms are ideal for different situations.

The Southern California wildfires highlighted the need to have many different sensor options to assist in mapping burned areas for BAER teams. While the Landsat platform is the desired sensor for use in BARC modeling, the failure of the scan line corrector on the Landsat 7 sensor, and the lengthy revisit time of both Landsat instruments highlight the need to also use other remote sensing systems.

The use of satellite imagery to support BAER applications is a valuable service. With the right tools, this service saves time, money, and significantly reduces the amount of aerial and ground reconnaissance, thus reducing the exposure of BAER personnel to hazardous post-fire conditions.

Table 1—Attributes to consider when deciding which sensor to use for BAER assessment

	Spatial Resolution	Temporal Resolution	Footprint	SWIR Band?*
MODIS	250m	Daily	2330 x 2330 km for 5-minute granule	Yes
MASTER	30m	Variable; airborne	Variable; dependent on altitude	Yes
Landsat 5	30m	16 days	185 x 185 km	Yes
ALI	30m	16 days (8 days after Landsat 5)	Variable; experimental	Yes
SPOT 4	20m	Variable; between 1-4 days	60 x 60 km	Yes
ASTER	15m	Variable; 7-10 days	60 x 60 km	Yes
AIRDAS	12m	Variable; airborne	Variable; dependent on altitude	No
SPOT 5	10m	Variable; between 1-4 days	60 x 60 km	Yes
Ikonos	4m	Variable; between 2-11 days	11 x 11 km	No
Quickbird	2.5m	Variable; between 2-11 days	16.5 x 16.5 km	No

** The SWIR band is required to run the Normalized Burn Ratio (NBR)*

5. References

Hardwick, P., H. Lachowski, P. Maus, R. Griffith, A. Parsons, and R. Warbington, 1997. *Burned Area Emergency Rehabilitation (BAER) Use of Remote Sensing*, (USDA Forest Service, RSAC-0001-TIP1, Remote Sensing Applications Center, Salt Lake City, Utah).

Key, C. and N.C. Benson, 2001. The Normalized Burn Ratio (NBR): A Landsat TM Radiometric Measure of Burn Severity [http://nrmsc.usgs.gov/research/ndbr.htm].

Orlemann, A., M. Saurer, A. Parsons, and B. Jarvis, 2002. Rapid Delivery of Satellite Imagery for Burned Area Emergency Response (BAER). *Proceedings of the Ninth Biennial Forest Service Remote Sensing Applications Conference*, 8 –12 April, San Diego, California (American Society for Photogrammetry and Remote Sensing, Bethesda, Maryland) Unpaginated CD-ROM.

Parsons, A., B. Jarvis, and A. Orlemann, 2002. Mapping Post-Wildfire Severity Using Remote Sensing and GIS, *Proceedings of the Twenty-second Annual ESRI International User Conference,* 8 –12 July, San Diego, California, Unpaginated CD-ROM. USFS Remote Sensing Applications Center, Salt Lake City, UT.