Applications of Remote Sensing Technologies to Support Fire Suppression and Rehabilitation within the USDA Forest Service

T.J. Bobbe
Remote Sensing Applications Center, USDA Forest Service, Salt Lake City, Utah, USA

Abstract

Remote sensing technologies have the capability to provide accurate and timely information to fire suppression teams, land management agencies, and the public. The USDA Forest Service is currently using a combination of satellite and airborne remote sensing systems to map and monitor active wildland fires, and to map burn severity for post-fire rehabilitation. This paper will describe the applications of remote sensing systems to provide rapid response fire mapping and geospatial data to support fire suppression and rehabilitation efforts. Remote sensing systems are used to provide national scale - strategic planning level, and fine scale - tactical incident level fire maps and products. The national scale - strategic planning level fire maps are developed using the NASA Moderate Resolution Imaging Spectroradiometer (MODIS). The MODIS system provides a unique capability to image large geographic areas on a daily basis. Data from the MODIS sensor is used to prepare active fire maps and geospatial data three times a day for the entire United States. The actively burning areas are detected and mapped by the MODIS sensor at a 1 km spatial resolution. These maps and data are made available to fire managers, and the public through the internet at: http://activefiremaps.fs.fed.us. These maps have proved to be useful in monitoring actively burning fires, assisting in planning and allocating fire suppression resources, and informing the public on current fire activity across the nation. Finer resolution fire maps and geospatial data are provided to Incident Command fire suppression teams to assist in tactical level planning. A combination of airborne Forward Looking Infrared (FLIR), thermal imagers, and high resolution thermal infrared line scanner systems are used to acquire detailed imagery and data for quick response fire mapping products. These products are used to brief Incident Command staff and support local decisions on where fire suppression assets should be used. After a wildland fire is contained, local land managers are faced with the task of rehabilitating areas that are susceptible to soil erosion and landslides. Satellite and airborne remote sensing systems are used to quickly map burn severity and prioritize areas for revegetation and erosion control treatments.

Introduction

Remote sensing technologies have the capability to provide accurate and timely information to fire suppression teams, land management agencies, and the public. The USDA Forest Service is currently using a combination of satellite and airborne remote sensing systems to map and monitor active wildland fires, and to map burn severity for post-fire rehabilitation. Remote sensing systems are used to provide national scale - strategic planning level, and fine scale - tactical incident level fire maps and products. This paper will describe current remote sensing applications to support national scale active fire mapping, tactical scale fire mapping, and post-fire burn severity mapping.

I. National Scale Active Fire Mapping

Wildland fires burn over four million acres of land annually in the United States. Wildland fire managers at regional coordination centers and the National Interagency Fire Center

(NIFC) allocate resources for the control and suppression of large wildfire incidents. Wildfire detection and monitoring using remote sensing technologies is important to support strategic planning for resource allocation.

In an effort to provide the location of active fires, the Forest Service Remote Sensing Application Center (RSAC) has collaborated with NASA Goddard Space Flight Center (GSFC) and the University of Maryland Department of Geography to develop the Moderate Resolution Imaging Spectroradiometer (MODIS) Rapid Response system to produce daily active fire maps and associated image and fire information products for the entire United States (Descloitres et al. 2002). Additional support is provided by the NIFC and Forest Service Fire Sciences Laboratory.

The MODIS is a sensor on board two recently launched NASA Earth Observation System (EOS) satellites - TERRA and AQUA (NASA 2002). TERRA was launched in December 1999 and AQUA was launched in May 2002. TERRA follows a descending polar orbit crossing the equator at approximately 10:30 AM local time. AQUA follows an ascending polar orbit crossing the equator at 1:30 PM local time.

MODIS detects a broad spectral range of electromagnetic energy in 36 bands ranging from the visible to thermal infrared wavelengths and takes measurements at three nested spatial resolutions (250 meters, 500 meters and 1,000 meters). Each MODIS sensor has a wide 2,330 kilometer field of view that enables it to collect image data over nearly the entire globe twice daily - one day time and one night time observation approximately 12 hours apart. Fire detections are gleaned using MODIS thermal bands that are collected at 1,000 meter resolution on both day time and night time observations. Together, the MODIS sensors on board TERRA and AQUA provide a total of 4 daily thermal observations over the globe that are used for fire detection and monitoring.

The Rapid Response system rapidly acquires and processes MODIS imagery on a daily basis. The system utilizes western United States MODIS data acquired in real time by RSAC MODIS Direct Broadcast receiving station in Salt Lake City, Utah and near real time MODIS data for the eastern United States and Alaska from the GFSC MODIS data stream. Both day and night time data are collected.

Since July 2001, the RSAC has used the MODIS Rapid Response system to produce daily regional and national scale active fire detection maps. MODIS imagery is continually acquired and processed 24 hours a day at GSFC and RSAC to derive current active fire detections. Raw fire detection data are compiled into fire GIS data layers. MODIS derived fire GIS data and imagery is further processed by RSAC to produce daily active fire maps and associated image and fire information products for the entire United States. The MODIS active fire maps are available for download in several formats from the MODIS active fire mapping program (http://activefiremaps.fs.fed.us) and NIFC (http://www.nifc.gov/firemaps.html) web sites. Poster sized MODIS active fire maps are compiled three times each day by RSAC for the 11 interagency designated geographic areas designated by the NIFC within the United States. Each map depicts currently active fires within the last 24 hours as well as the cumulative extent of previous fire detections on a cartographic base consisting of a shaded relief layer, roads, hydrology, boundaries and current large fire names. To supplement these maps, MODIS imagery of selected large wildfires is also produced on a daily basis. These images offer an up-to-date synoptic view of the active fire front, smoke plumes and burned areas. These MODIS derived products provide an understanding of the current wildfire situation in a geospatial context to wildland fire managers, the interagency fire community and the general public.

National scale active fire maps are intended to provide accurate and current information to assist wildfire managers in strategic planning. The information is used to make decisions on where and when to allocate critical fire suppression resources, such as high resolution airborne thermal infrared fire mapping systems at the NIFC. The national scale active fire maps allow managers to prioritize fire mapping needs and prepare flight plans for airborne thermal infrared systems. Fires that are not actively suppressed, such as fires burning in remote wilderness areas may not require higher spatial resolution maps. For these fires, MODIS maps are adequate to monitor fire location and activity.

II. Tactical Scale Fire Mapping

Fire managers require higher spatial resolution fire map products to support incident level decision making. Decisions such as where to place fire crews or airborne retardant drops require more detailed information than available from the national scale active fire maps. Tactical scale fire mapping is accomplished by using airborne thermal infrared systems. These airborne systems are grouped into three categories based on sensor and aircraft capabilities. The categories include Type 1 thermal infrared line scanners, Type 2 thermal infrared imagers, and Type 3 Forward Looking Infrared (FLIR). A combination of government operated and commercial owned systems are used for tactical fire mapping.

Type 1

Thermal infrared line scanners are best used for large area fire detection and first-time large fire mapping. These systems are mounted on fast fixed wing aircraft operated by the Forest Service or commercial firms. Some Type 1 products are delivered in near real-time with the use of satellite and radio communication. Type 1 systems have the highest production rates and utilize multiple thermal bands with sensitive detectors. The National Infrared Operations Group based at NIFC operates three Type 1 systems. These systems normally are flown during the night to provide fire map products to the Incident Command staff for the daily 6:00 AM fire management briefing. Key capabilities of the Type 1 systems include:

- Wide field of view (6 miles at 10,000 feet AGL)
- Two thermal infrared bands (3-5 and 8-12 micron) maximum sensitivity for fire without false detection, and high resolution of night time ground features
- High production rate - can cover over 700,000 acres per hour
- Provides digital geo-corrected imagery- utilizes digital elevation data, Inertial Measurement Unit (IMU) and Global Positioning System (GPS)
- Can be operated day or night

Type 2

Type 2 systems are nadir viewing systems, which are typically mounted on fixed-wing aircraft. They usually utilize only one thermal infrared band. Nadir viewing means that the sensor is always pointing directly down perpendicular from the aircraft. This simplifies the geo-rectification calculations and typically increases the productivity of the IR system. Many of these systems have provisions to quickly disseminate the collected data. Type 2 systems are less sophisticated as compared to Type 1 systems, but are used to support many smaller fire incident mapping needs. Type 2 capabilities include:

- Useful for larger fires where type 3 systems will not be able to cover the entire fire in one flight
- Can be used for more than one fire within a region during a given day or night

Type 3

Type 3 sensors are typically FLIR systems. These systems are readily available from numerous commercial vendors, the military, and other federal agencies. These small format imaging systems are used to provide detailed tactical information at the fire front. They have a single thermal infrared band and might not have any data output other than what is shown on the sensor display. FLIR systems are lightweight, can be mounted on fixed-wing aircraft or helicopters, and are normally restricted to day time operations. Type 3 units are well suited for small fires, mop-up operations, and non-fire applications such as law enforcement or wildlife surveys (Warren 1984). There is also the potential for medium to large fire mapping for the more sophisticated Type 3 systems. Type 3 systems are broken down into three categories:

- Type 3a: Turret mounted units with geo-correction
    - Operated by both government and private contractors
    - GPS positioning used
    - Includes IMU or laser range finding for geo-correction
- Type 3b: Turret mounted units without geo-correction
    - Operated by both government and private contractors
    - GPS positioning used
    - No Inertial Measurement Unit (IMU) or laser ranging
- Type 3c: Handheld or mounted units
    - Cost < $15,000
    - Can be mounted on any platform
    - Simple operation

The smallest FLIRs are handheld units that are about the size and weight of a typical camcorder. Most Type 3 systems are mounted in ball turrets that can be pointed in multiple directions. They do require a trained operator and someone to interpret the information from the display or output to a map. This can be done in-flight or on the ground. A major drawback to these sensors is that they cover only about 1/4 to 1/3 of the area in one flight swath that is covered by Type 1 line scanners (Warren 1991).

Typically FLIR systems are combined with a GPS to collect geographic locations of the fire. There can be problems with doing so, since the FLIR is usually looking to the side and at an angle down to the fire and not directly over it, the fire location recorded by the GPS unit can be incorrect. Depending upon the sensors view angle and the distance between the aircraft and the fire, this error can be several thousand feet. Type 3a systems are those that incorporate stabilized mounts, laser ranging or some type of geo-correction to eliminate this error.

III. Post-Fire Burn Severity Mapping

To mitigate the effects of wildland fire on soil and duff layers, the Forest Service and other federal land management agencies prepare Burned Area Emergency Response (BAER) plans to stabilize soils and return vegetation cover to the burned areas as soon as possible. One of the first steps in the BAER process is the creation of a map that highlights the areas most in need of immediate erosion control and other protection measures. Traditionally this map was created by airborne sketch mapping in combination with field surveys. Recently, however, techniques have been developed using airborne and satellite remote sensing imagery as base maps to improve the accuracy of the initial burn severity product. These base maps have included mosaicked digital camera images and satellite imagery such as IKONOS, SPOT, and Landsat TM.

For airborne or satellite data to be useful for BAER survey teams it must meet several requirements. First, it must be collected immediately after the fire. Second, the imagery must be made available to BAER teams quickly, ideally within one to two days of containment of the fire. Third, it must have the spatial resolution necessary for BAER implementation decision making. While it is clear that no single source of imagery can meet all these requirements at every fire, each data source is likely to play an important role in BAER mapping work (Table 1).

Table 1. Comparison of Remotely Sensed Imagery for BAER Mapping.

	MODIS	Landsat 5	Landsat 7	SPOT 1 & 2	SPOT 4	SPOT 5	QuickBird	IKONOS	Airborne Digital
Temporal Resolution	1 to 2 days	16 days [1]	16 days [1]	agile[2]	agile[2]	agile[2]	agile[2]	agile[2]	variable
Multispectral Spatial Resolution	250m to 1km	30 m	30 m	20 m	20 m	10 m	2.8 m	4 m	1 - 4m
Panchromatic Spatial Resolution			15m	10m [3]	10m [3]	2.5&5m [3]	.6m [3]	1m [3]	1 - 4m
Image Footprint (km^2)	5,290,000	34,225	34,225	3,600	3,600	3,600	272	variable	varies .1 - .3
# Spectral of Bands	36 [4]	7 [4]	7 [4]	3 [5]	4 [4]	4 [5]	4 [5]	4 [5]	visible & CIR
Delivery Time	24 to 48 hours	24 to 48 hours	24 to 48 hours	6 to 12 hours	6 to 12 hours	6 to 12 hours	24 to 48 hours	24 to 48 hours	24 to 48 hours
Coverage Archive	Full[6] Recent	Full Extensive	Full Extensive	Full Extensive	Full Extensive	Some Recent	Some Recent	Some Recent	Some Recent
Cost per Scene	Free	$580	$720	$9,200	$9,200	$12,000	variable[7]	variable[7]	variable[8]

(1) Either L7 or L5 will pass over the same area every 8 days

(2) Off-nadir tasking requests for programming take 48 to 72 hours to process

(3) The panchromatic image must be purchased separately

(4) Includes Near-IR and Mid-IR

(5) Includes Near-IR

(6) Full coverage of North America

(7) Varies by size, but typically starts at $10,000

(8) Varies by fire size, additional processing required to mosaick individual images

Airborne digital camera imagery has proven to be an effective source of post-fire burn severity mapping. A pilot project conducted by the RSAC in 1996 demonstrated the usefulness of this technology (Lachowski et al. 1997). While users have found airborne digital camera imagery to be an excellent source of information about burned areas across the landscape, the imagery must be mosaicked and post-processed before it can be used. In addition, the availability of these data can be an issue, especially in areas where there is no acquisition contract in place or during the height of the fire season when it can be difficult to procure an aircraft to do the data collection.

Currently most BAER teams rely on satellite imagery since it provides larger, more cost effective geographic coverage and is readily used in an image processing and GIS environment. Since 2001, the RSAC has provided operational support to BAER teams in providing satellite imagery and derived burn severity map products. A total of 95 BAER incidents, 152 satellite scenes, and 3.2 million acres of burned area have been mapped from April 2001 - July 2003.

The basic product provided to field level BAER team members is the satellite image and a Burn Area Reflectance Classification (BARC) map. The map is typically created using change detection on a band ratio such as Benson and Key's Burn Ratio (Key and Benson 2001) and the Normalized Difference Vegetation Index (NDVI). The BARC output is delivered to the field in two forms. One has four classes: High, Moderate, Low, and Unburned. The other has 255 discrete values and allows field users to make their own classification decisions such as altering the threshold values between burn severity categories. The BARC map and satellite imagery provides a synoptic view of the burned area and allows for more consistent mapping decisions. In addition, the images and maps are often used to provide information to the public.

RSAC delivers standard products to all Forest Service BAER teams including burned area reflectance classification (BARC) data, post-fire satellite imagery, a digital elevation model (DEM), and slope/aspect data files. These products are delivered to the BAER team as they arrive at the incident. The BARC data and satellite imagery are used to:

- Focus the reconnaissance efforts of the BAER team on areas of greatest concern,
- Develop the BAER burn severity map,
- Create 3-dimensional models of the burned area and visualization products
- Prepare graphics for public meetings to show areas with increased erosion potential.

In addition to rapid delivery of satellite imagery and BARC data, RSAC provides other support to Forest Service BAER teams. Other support activities include:

- Monitoring fire activity and image acquisitions
- On-site technical support
- Web-based training modules

Conclusion

Remote sensing systems are currently being used by wildland fire and resource managers to assist in making decisions across multiple scales and large geographic areas. Maps and geospatial data products derived using remote sensing increase the efficiency of allocating resources to monitor, and suppress actively burning fires, and to mitigate post-fire impacts.

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