9 Remotely sensed burn severity mapping

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Introduction

With nearly a century-long national policy of fire suppression, many of our nation's forests have an unnaturally heavy accumulation of brushy ground fuels and dense young trees. These "ladder fuels" provide the connection between *low-intensity* ground fires and *high-intensity* crown fires.

In 2000, almost 7 million acres burned across the USA. The extraordinary number, size, and, in some cases, severity of these fires was due to drought conditions, weather patterns, and a large number of lightning strikes. Compared with the previous ten-year average, more than twice the number of acres were consumed. Such fire activity is inconsistent with the National Park Service (NPS) mission "to preserve and to protect," and the NPS Fire Management Program focus of "restoring and maintaining natural processes associated with fire." The NPS fire management program includes hazardous fuels reduction, prescribed fire, wildland fire for resource benefits, and wildland fire suppression (Gale 2000).

All of the fire preconditions referred to above were present at the Grand Canyon in 2000. A prescribed fire "blacklining" operation in the Outlet Prescribed Fire Unit encountered unexpected high winds on May 9, which caused the fire to "spot" outside the unit. The resulting fire consumed more than 13,000 acres, burning through several forest types and fuel model classes, at varying intensities. Having burned off the North Rim and into inaccessible canyonlands, the Outlet Fire was in suppression mode until fully controlled on August 30, and was declared completely out on November 14.

Objective

Robert Stanton, director of NPS, specified that the agency's fire programs are to "scientifically manage wildland fire using best available technology as an essential ecological process to restore, preserve, or maintain ecosystems…" (Stanton 1998). In a joint report to the president in response to the wildfires of 2000, one of the key recommendations made by the secretaries of Interior and Agriculture was that damaged landscapes be restored and communities rebuilt (Babbitt and Glickman 2000). Immediately following wildfire control, that process is implemented and recorded in a burned area emergency rehabilitation report. Stabilization and restoration are facilitated by a spatial understanding of fire severity. Recognizing this, the 1998 Joint Fire Science Plan encouraged research that develops "airborne and satellite-based remote sensing applications, for quantifying ... fire effects such as ... fire distribution and severity" (Botti and Saveland 2001).

It is the objective of Grand Canyon National Park's Fire Management Program and its Science Center GIS Lab to support these national recommendations. Towards that end, we have implemented a fire severity mapping procedure that accurately and cost-effectively measures fire severity, and that can be done with computer

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software and hardware common to most national park Geographic Information System (GIS) departments.

Methods

Traditional methods of recording burn severity involve traversing the interior of the fire by foot or observing it from an airborne platform, and then mapping (by hand) resource damage into predetermined classes. The burn severity coding matrix, with severity fields ranging from unburned to heavily burned, and records of substrate and vegetation, was modified to four simple classes (unburned, low severity, moderate severity, or high severity), incorporating substrate and vegetation concerns, as detectable from an aerial view (Botti et al. 1992).

Where fire size and time permit, this method provides satisfactory results. As fire sizes increase, and time becomes a constraining factor, traditional methods become costly and labor-intensive to the point where accurate mapping of severity classifications is precluded.

For the Outlet Fire, a visual estimation from a helicopter provided the first measure of fire severity. Within an hour, the park's fire ecologist visually estimated and mapped fire severity into four classifications. The classes were drawn in the field onto a 15-minute U.S. Geological Survey (USGS) topographic quadrangle map (Figure 9.1). In view of the time and cost constraints, this was an effective but difficult mapping exercise, at a charged rate of approximately $2,500 per hour for helicopter use alone.

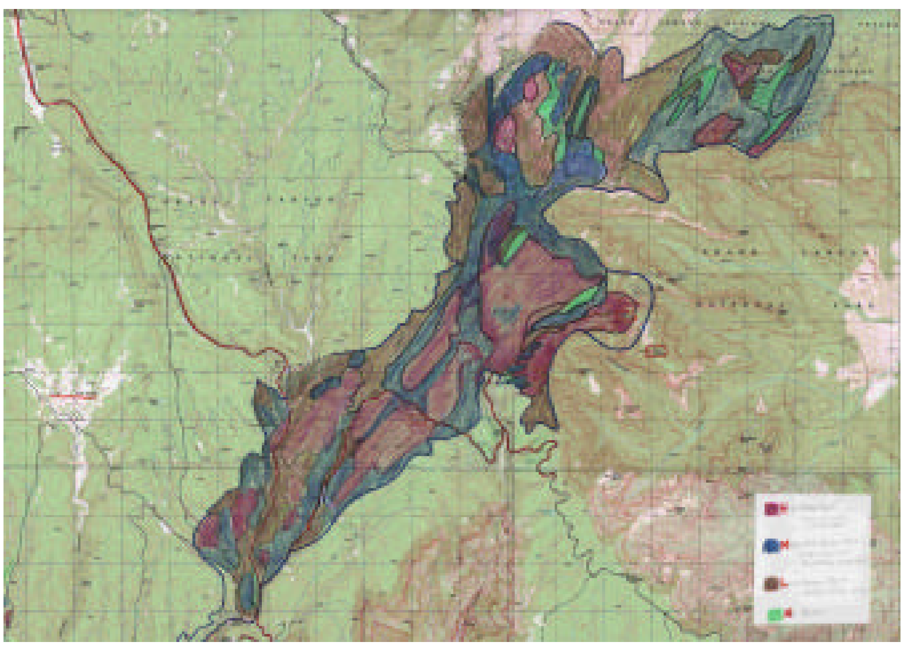

Figure 9.1. Hand-drawn fire severity map of Outlet Fire, 2000.

Airborne- and satellite-based remote sensing platforms are uniquely suited for large landscape assessments. Satellite-based platforms have recently become increasingly cost-effective, through recent efforts by the National Aeronautic and Space Administration (NASA), USGS, and NPS to make satellite imagery more available.

Prices for current radiometrically and geometrically corrected imagery range from about $600 for Landsat 7 imagery (Level 1G), to $1,500 (at Level 2A) for SPOT 4 imagery. Terrain-corrected Landsat 7 imagery costs $900 (at pricing specifically for federal agencies).

For purposes of comparison, Landsat 7, SPOT 4, and Ikonos satellite scenes were requested for dates as close as possible to the beginning and end of the Outlet Fire. Image pre-processing appropriate to capabilities expected of NPS GIS departments was requested, i.e., scenes that had been radiometrically corrected, geometrically corrected, and ortho-rectified (terrain-corrected). The Landsat 7 scenes we received were fully pre-processed, while the SPOT 4 scenes were radiometrically and geometrically corrected but not ortho-rectified. For comparison purposes, we ortho-rectified the SPOT 4 scenes in ERDAS Imagine (Figure 9.2). Unfortunately, we were unable to obtain Ikonos scenes in time for this comparison.

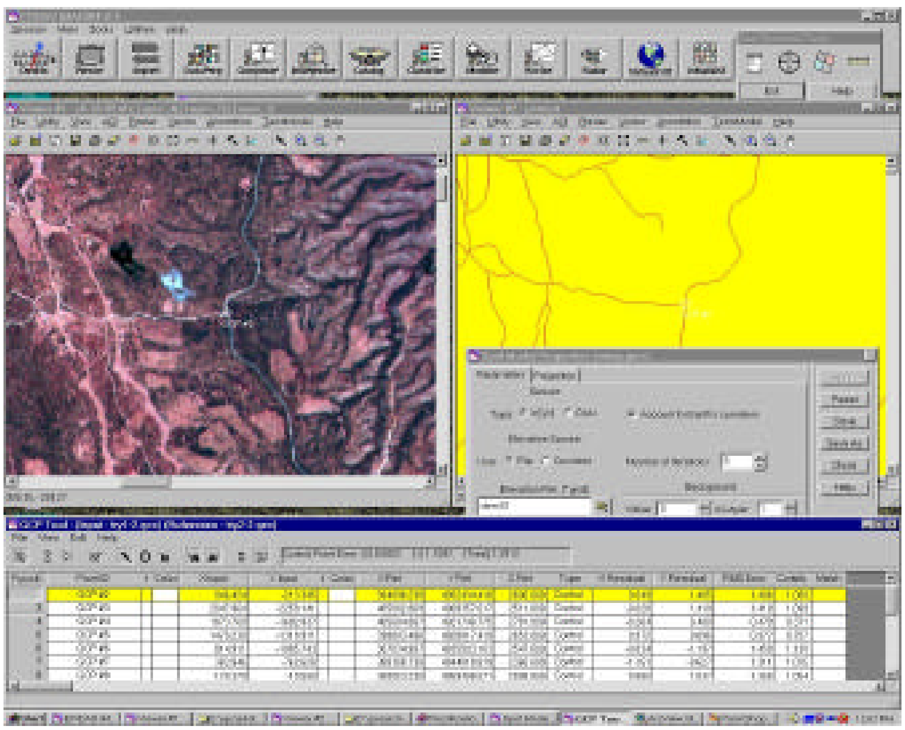

Figure 9.2. Ortho-rectification of SPOT 4 imagery, using ERDAS software.

Remote sensing techniques

With digital imagery, advantages in analysis are first seen in the opportunity to perform mathematical operations on the image, some simple, and some involving complex sequences of formulas.

One of the simpler operations performed is *change detection*, where the pixel values of one scene are subtracted from the corresponding pixel value of a later one. Seasonal variations in vegetation are sufficiently different that they may be easily detected by change detection. In the case of the Outlet Fire, which started in early May, the vegetation of the area had already leafed out. From SPOT 4, we received satisfactory image scenes dated June 10, 1999, and September 25, 2000. From

NASA–USGS, we received Landsat 7 image scenes dated May 5, 2000, and June 6, 2000. The Landsat 7 scenes were nearly ideal for purposes of change detection, with image capture taking place just days before the Outlet Fire started and then after nearly 95% of the fire had burned.

Another remote sensing method, using a more complex mathematical operation, is referred to as *image classification.* One image classification technique is referred to as *iso-clustering*, where clusters of similar pixels are placed into separate classes. What the human eye can discern comparing one image to another, iso-clustering does mathematically, with multiple image sets. For our purposes, we chose iso-clustering classification for an independent comparison.

Landsat 7 and SPOT 4 are functionally similar, but differ in the spectral and spatial resolution of their images. Landsat 7 (the seventh generation of Landsat spacecraft) and SPOT 4 (the fourth generation of SPOT spacecraft) employ a different number of spectral bands receiving similar but different spectral ranges, at differing resolutions (Table 9.1).

Landsat 7			***SPOT 4***		
Band number	*Spectral range (microns)*	*Resolution (meters)*	*Band number*	*Spectral range (microns)*	*Resolution (meters)*
1	0.45-0.515	30	1	0.50-0.59	20
2	0.525-0.605	30	2	0.61-0.68	20
3	0.63-0.690	30	3	0.79-0.89	20
4	0.75-0.90	30	4	1.58-1.75	20
5	1.55-1.75	30	Pan	0.61-0.68	10
6	10.40-12.5	60			
7	2.09-2.35	30			
Pan	0.52-0.90	15			

Table 9.1. Comparison of spectral and spatial resolution: Landsat 7 and SPOT 4.

Landsat 7 and SPOT 4 images underwent the same image processing. All spectral bands, and all combinations of spectral bands, were inspected visually for image quality and analyzed for sensitivity to fire effect.

For Landsat 7, bands 2, 4, 5, and 7 selected spectral ranges that were particularly effective in capturing signatures of vegetation moisture stress analysis, vegetation turgidity, amount of vegetation biomass, and the green reflectance of healthy vegetation, respectively. With SPOT 4, bands 1, 2, 3, and 4 approximated Landsat 7 bands 2, 3, 4, and 5, respectively, with approximately the same spectral ranges (a slight 0.02- to 0.04-micron shift to right) and signature selectivity. For purposes of comparison, before and after Landsat 7 and SPOT 4 image pairs underwent exactly the same level of image analysis routine. Each pair:

- Was inspected, band-by-band, for perceived differences in the pre- and post-fire images;
- Underwent change detection;

- Underwent an unsupervised classification, initially with all bands, then with three bands, selected for classification sensitivity; and
- Underwent NDVI (normalized difference vegetation indexing), a remote sensing technique commonly used where vegetation is the primary reflectance object. NDVI is calculated from the reflected solar radiation in the near-infrared (NIR) and red wavelength (RED) bands via the algorithm: NDVI = (NIR – RED) / (NIR + RED). For SPOT 4, the NIR is band 3 and the RED is band 2. For Landsat 7, the NIR is band 4 and the RED is band 3.

Landsat image pairs underwent a recently introduced remote sensing technique, NBR (normalized [differencing] burn ratio), which is similar to NDVI (Key and Benson 1999). The NBR technique relies on the use of Landsat 7 band 4 and band 7, spectral ranges not available in SPOT 4.

Results

Visual comparisons were made of each band, each band combination, each band combination classification, and the successive normalizations. Random point reflectance value correlations were made between, and within, the above comparisons. All bands of both satellite platforms were capable of detecting change between the start and end of the fire. A small amount of change was detectable outside the Outlet Fire perimeter, but was limited to areas off of the North Rim. This was presumably due to the differences in the before and after sun angles, inducing different ground shadowing in a more sparse pinyon–juniper forest type, descending into a desert scrub community. Band combinations with the greatest differences (widest reflectance value amplitude) between images were viewed to be most sensitive in detecting change.

SPOT. SPOT 4 sensors were the most specific (detecting the narrowest spectral ranges), and change detection routines across individual bands were effective, but particularly so with the combination of bands 4, 2, and 1. Unsupervised classifications were also effective, with the 4-2-1 composite being the most so. Band 3 was ineffective in detecting the changes induced by fire across the vegetative surface offered by the Grand Canyon's North Rim forests. Performing a NDVI operation on reflectance values (B3-B4 / B3+B4) yielded the widest amplitude (Figure 9.3).

Landsat. Change detection routines across each of Landsat 7's seven band combinations were similarly effective in demonstrating change, but were most successful in bands 7, 5, and 4. Unsupervised classifications were effective, with greater sensitivity found in the combination of bands 7, 5, and 4. An NDVI operation was performed on Landsat 7 bands 4 and 3, and bands 5 and 3 (to compare both NIR bands). Visual findings supported the literature on vegetative indexing optimization with band 4 and band 3 normalization. An NBR operation was performed on Landsat 7's bands 7 and 4, yielding one of the wider ranges of reflectance value amplitude differences. The greatest sensitivity to differences in reflectance values was found in a change detection operation on the NBR performed on before and after Landsat 7 images (Figure 9.4). SPOT and Landsat image differencing from selected bands, selected band combinations, and indexed band combinations all yielded more change-sensitive estimations of fire severity than did visual estimation from a helicopter.

Discussion

Grand Canyon National Park's entry into remote sensing was initially seen as a way of supporting fire effects monitoring of prescribed fire management. This was to involve a consistent annual selection of image capture dates. Those national parks which keep annual records of the date of vegetation "green-up" will have an advantage in being able to predict a "window of opportunity." (Coincidentally, the Outlet Fire occurred within our time frame being considered for yearly monitoring.) Shifting to "short-term monitoring," satellite imagery (Landsat 7 and SPOT 4) was acquired from two of three vendors, with image acquisition from Ikonos delayed until green-up in 2001.

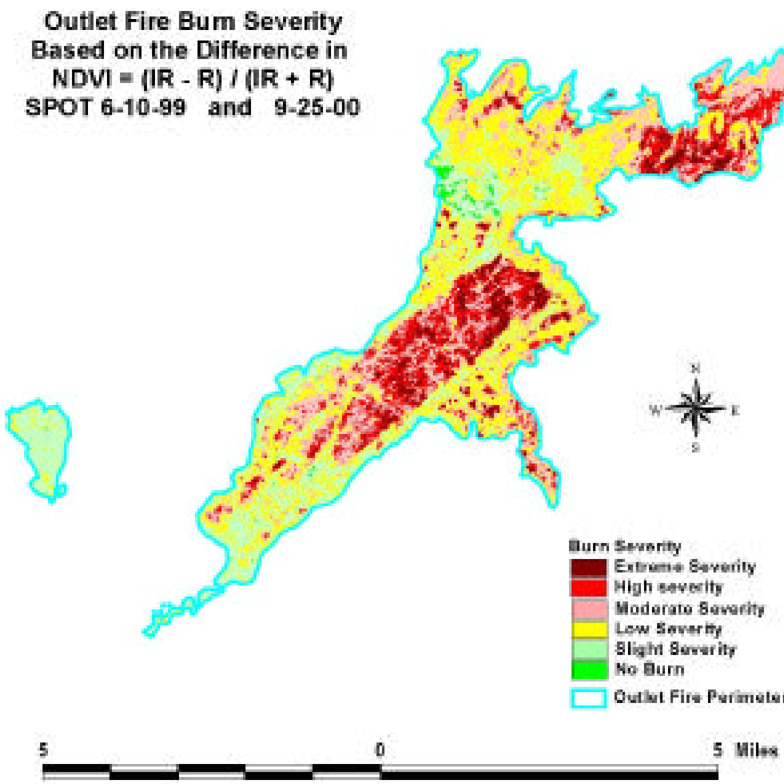

Figure 9.3. NDVI of SPOT 4, Outlet Fire, 2000.

SPOT. Differencing SPOT scene pairs required more noise filtering (changes detected independent of the change due to fire). SPOT scene pair differencing produced a lower change value amplitude, perhaps due to the increased selectivity (narrower spectral band widths) of its sensors.

For both before and after imagery, normalization of the differences between SPOT 4 bands 4 and 3 was successful, and change detection performed on these before and after NDVI images provided the most sensitive (widest amplitude) SPOT 4 burn severity estimation. Normalization of the differences in burn ratio requires spectral band ranges not found with SPOT 4 sensors, and so the technique was not performed with SPOT 4 image pairs.

Landsat. Performing a change detection operation on the band combination of 4, 5, and 7 between imagery pairs yielded the widest amplitude of any other band combination, from either Landsat or SPOT imagery pairs. Performing an unsupervised classification of the above operation resulted in a similar amplitude and spatial representation. Recognition by the unsupervised classification of these similar values and shapes supports the hypothesis that the change being measured is the change caused by the Outlet Fire. Performing a change detection operation on image pairs that had their *vegetation index differences normalized* provided a more discriminating, sensitive classification of burn severity. Of all operations undertaken from either satellite platform, performing a change detection operation on image pairs that had their *burn ratios normalized* provided the most discriminating and sensitive classification of burn severity.

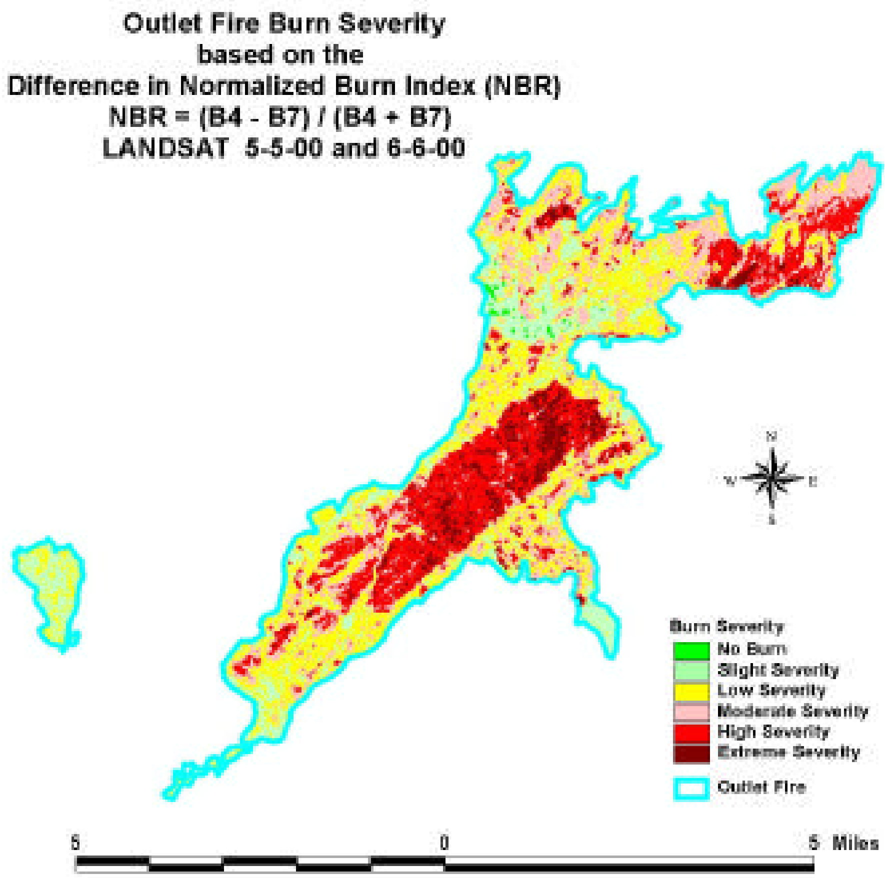

Figure 9.4. "Differenced" NBR of Landsat 7 before and after images.

Conclusion

Increasingly, rapid mapping of burn severity is becoming an integral part of the wildfire suppression process. Primary usage is in burned area emergency rehabilitation; specifically, to prioritize rehabilitation efforts that follow immediately after large fire control. Mapping from the ground (or from low-elevation airborne platforms) can be the most accurate assessment of fire severity for smaller fires. As fire area and burn severity increases, the time- and cost-effectiveness of ground assessment diminishes quickly. Techniques such as change detection, image classification, NDVI, and NBR provide increasing accurate and precise assessments of fire severity. Increased image availability, reasonable image pricing, and the average national park GIS department's capability to process, enhance, and analyze satellite imagery all provide impetus for recommending remote sensing technologies for the task of fire severity mapping. For national parks with a need for resource monitoring, the purchase of annual satellite imagery could go hand-in-hand with these fire management applications. Efforts in Grand Canyon National Park are underway to incorporate satellite imagery analysis in support of the fire effects monitoring portion of the prescribed fire management program.

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