Assessment of Spatial and Temporal Trends of Fire Severity in the United States

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Abstract
Wildfire in the United States burns an average of 2.5 million ha annually in recent years and the disturbances represent challenges in managing diverse and sustainable ecological systems in the nation. Billions of dollars are spent on incident management, reduction of hazardous fuels, and restoration of fire-dependent ecosystems. National fire monitoring capabilities are needed to assess effects and effectiveness of the land management practices. One key component of the fire monitoring needs by the US federal government is mapping and reporting of fire severity by vegetation types. In response to the needs, a national fire severity monitoring project is being conducted in the United States to systematically assess trends in severity for all fires above a certain size threshold (202 ha in the east and 405 ha elsewhere in the country) from 1982 to present and beyond, using archived and new Landsat imagery (30 m spatial resolution). The technical foundation of the trend assessment is differenced normalized burn ratio, calibrated with composite burn index. In this presentation, We will outline operational aspects of the fire monitoring framework, and discuss major intended applications, including national annual assessment, national trend analysis, and vegetation succession modeling for the purpose of updating baseline vegetation data.

Introduction

Wildfires are a natural part of ecosystems and play an important role in maintaining and regenerating fire-dependent ecosystems. Since 1960, annual areas burned by wildfires in United States have seen a steady increase and the annual increase has accelerated in recent years by more than 75% (Figure 1, the National Interagency Fire Center[2] statistics). A number of factors are thought to have led to the increase: fuel build-up from fire protection programs; aging forests; changes in fire policy related to prescribed burning; expanded public access to and use of the forests; and higher temperatures and lower rainfall associated with climate change. Therefore, not only does the increase trend have profound impact on overall costs of managing fire-dependent ecosystems and communities that live in wildland-urban interfaces, it also represents a science challenge for restoring impaired ecosystems and assessing feedback mechanisms in face of the climate change trends. The U.S. national fire management policies such as the National Fire Plan and Healthy Forest Restoration Act[3] mandate reduction of hazardous fuels and restoration of ecosystems. However, to implement the policies to achieve desirable outcomes requires assessing and monitoring temporal and spatial dynamics of wildland fires at a resolution that meets both policy as well as field applications.

In light of the above needs, the federal government called for development of a remote sensing effort for monitoring severity of fire by vegetation types, and using the resulting data and maps as the basis for reporting effectiveness of various landscape treatments and effects of fires. Further, by relating mapped levels of fire severity to variables known to influence fire behavior such as prior management strategies (e.g., logging and fuel) and topography, global change researchers can gain a better understanding of the linkage between climate and fire. Beginning in October 2006, a joint U.S. Forest Service and U.S. Geological Survey (USGS) project was funded to develop a national

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[2] http://www.nifc.gov/
[3] http://www.fireplan.gov/

capability and provide fire severity data and reports at 30 m resolution for all forest, shrub, and herbaceous ecosystems that meet certain minimum sizes.

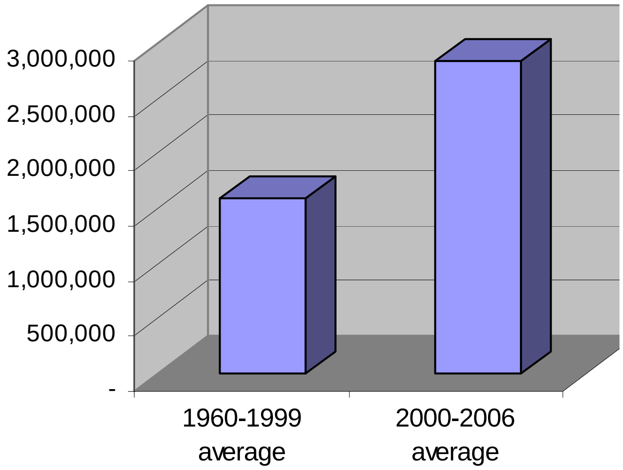

Figure 1—Number of ha burned annually, averaged for two time periods: 1960-1999, 2000-2006. Data source: National Interagency Fire Center.

The project, called Monitoring Trends in Burn Severity (MTBS), was designed to serve three primary user groups with one set of data and information:

1) National policies and policy makers such as the National Fire Plan, which require information about long-term trends in burn severity and recent burn severity by vegetation types, fuel models, condition classes, results and accomplishments.

2) Field management units that benefit from GIS-ready maps and data for pre- and post-fire management decisions and monitoring.

3) Scientific communities will be able to use a national consistent database of fire disturbances together with other existing databases such as Fire Regime and Condition Class and LANDFIRE. The databases provide powerful potential for studies related to fire management effectiveness, climate change, and ecosystem disturbance monitoring.

In the following sections, we describe methodological designs of the project, current status and findings, and examples of applications.

Methodological designs

In developing an operational methodology for implementing MTBS project, a number of technical aspects were considered and are discussed below. These include: definition of burn severity, basic remote sensing model to estimate and model spatial burn severity, satellite sensor choices, temporal depth of the national assessment, minimum size of fires to map, threshold values to break burn severity into discrete classes, and national reporting and data dissemination approaches.

Prior to the current national effort, the USGS has cooperated with the U.S. National Park Service (NPS) for developmental research for mapping burn severity and providing data for land management monitoring purposes. We continued the use of the same definition for burn severity, which was based on a federal interagency term for fire (or burn) severity, defined as: "degree to which a site has been altered or disrupted by fire; loosely, a product of fire intensity and residence time." Extensive collections of field plots called composite burn index (CBI) were stored in an interagency Fire Effects Monitoring and Inventory System (FIREMON, Lutes *et al*., 2006) and were available to support such a definition.

The remote sensing model used for mapping burn severity was based largely on experiences drawn from the joint USGS-NPS project, using a time-differenced (i.e. pre-and post-fire) ratio of near infrared and shortwave infrared spectral bands called differenced normalized burn ratio (DNBR, Key and Benson, 1999; Key and Benson, 2002). In recent years, various studies have been conducted that compared DNBR with other spectral indices including differenced normalized vegetation index, differenced effective vegetation index, and differenced relative DNBR. Our research findings, conducted under the USGS-NPS research over 15 fires of different vegetated ecosystems in the U.S., showed that DNBR performed no worse, and mostly better, than all the other indices in estimating CBI severity levels of different vegetation types and time since fire (Zhu, *et al.* 2006). Given that DNBR was considered a computationally simple model and that it was a relatively mature approach given extensive CBI-based studies, we chose to continue with this remote sensing model.

The DNBR approach has been mostly used on Landsat TM or ETM+ data, which was considered appropriate for this project given the availability of archived and continuous availability of 30-meter coverage that economically supplied pre- and post-fire reference dates to cover potentially all fires in the nation. The fact that the USGS Landsat archive for TM and ETM+ could go back to 1982 was an important consideration. Because of severe droughts and greater than normal numbers of catastrophic fires in recent years (since 2000), it was essential for the trend analysis to account for potential climate variability and base the assessment on a longer period of time than just the last several years. By going back to 1982 while going forward with annualized mapping, we theorized that the timeline would be long enough and adequate for a national analysis of trends in burn severity for the National Fire Plan.

The number of wildland fires that occur in the United States varies each year between tens and hundreds of thousands of incidents and the fires occur in almost all states. For the MTBS project, it was determined that the minimum size of fires that would be mapped each year should be 202 ha (500 acres) or greater in eastern U.S. (east of central plains in the US), and 405 ha (1,000 acres) or greater elsewhere in the country, including boreal Alaska and tropical Hawaii. Based on recent estimates, the minimum sizes should account for more than 95% of annual burned areas.

Whiles a burn severity map of continuous DNBR values may be suitable for field applications in most cases, national reporting of severity trends by vegetation and other stratification types required mapping of the continuous DNBR into discrete classes. Consistent classification of burn severity over time was considered a technical challenge (and remains so), largely because of difficulties in normalizing effects of pre-fire vegetation and fuel conditions, post-fire imagery qualities and imagery dates since fire, topographic and other biophysical variations, and varying responses of different vegetated ecosystems to post-fire satellite data, all on a fire-by-fire basis. Drawing from experiences of the USGS-NPS research conducted in the last several years (Zhu *et al.* 2006), we adopted a basic approach of selecting severity class threshold values on a Landsat scene-by-scene basis, guided by analysis of available CBI field data.

Finally, mapped fires would be distributed spatially via a map server, and national statistical reports would be submitted on an annual basis that documented distributions of burn severity by stratifications such as major vegetation types, ecological regions, and land ownerships.

Project Status and Results

The first annual report produced by the MTBS project is that of 2004, which has been submitted to the federal government documenting fire statistics of year 2004 with tables and graphics (Table 1, Figure 2). In addition, the project is making incremental delivery of region "fire atlases" (map stacks of fires between 1982 and 2003).

Table 1. Summary areas (ha) and percentage of mapped burn severity classes in 2004 in the United States.

Burn severity classes	Conterminous US		Alaska/Hawaii		Total	
	Ha	%	Ha	%	Ha	%
Unburned-low	151,452	32	456,288	17	607,740	19
Low	201,313	42	626,598	23	827,911	26
Moderate	83,409	17	796,180	30	879,589	28
High	20,384	4	288,315	11	308,699	10
Increased greenness	9,413	2	32,939	1	42,352	1
Non-processed mask	14,581	3	467,714	18	482,294	15
Total	480,552	100	2,668,034	100	3,148,586	100

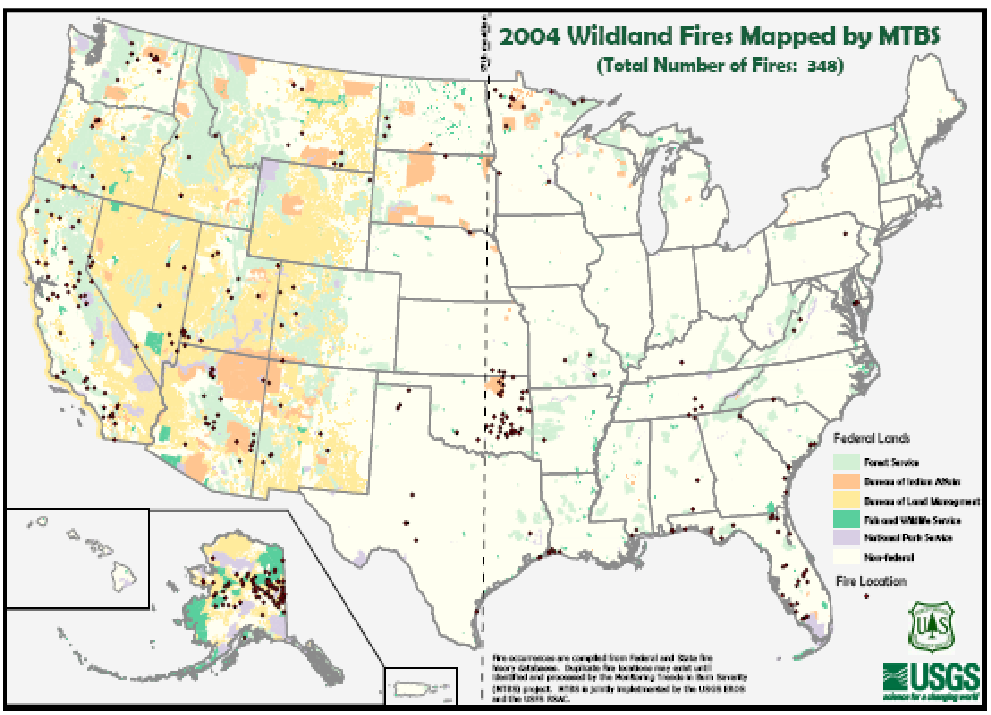

Figure 2—2004 wildland fires mapped for the Monitoring Trends in Burn Severity project

Results show that, in 2004, wildland fires occurred in many ecological regions in the nation, including dry and mesic mountain forests in the west, humid forest, shrub and herbaceous lands in the east, and boreal forests in Alaska. MTBS mapped not only forest, but shrub, herbaceous and wetland types. In addition, it is interesting to note that, comparing the conterminous US with Alaska and Hawaii in terms of severity classes, the conterminous US had more low severity fires (74% between unburned-low and low burns) than that of Alaska and Hawaii (40% in the same two categories).

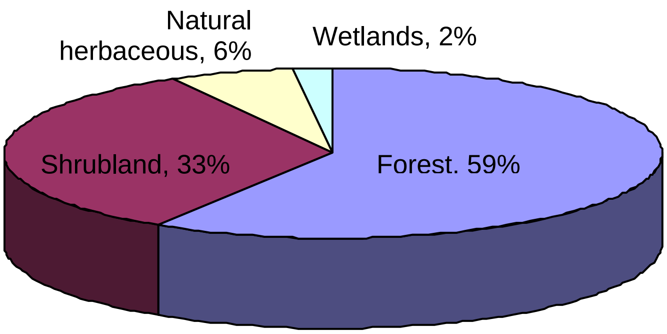

Figure 3—Breakdown of major land cover types mapped for 2004 wildland fires.

Applications

The MTBS project represents a national effort to spatially and temporally document the recent history of wildland fires. Users have access to data and national reports about any given region's fire records, severity maps, fire perimeter, and other related products. Analysis can be conducted for regional fire return frequency, severity trends, and, by linking with other vegetation or land management databases, fire effects and land management assessments. We have been involved in two specific examples of applications using MTBS data:

Example 1: updating LANDFIRE. The LANDFIRE project maps vegetation (both potential and existing), surface and canopy fuels, and fire regime condition classes. The project is required to develop a methodology to update the comprehensive spatial database for major ecosystem disturbances including wildland fire, forest logging, insect and diseases, wind storms, and invasive annual grasses. DNBR maps developed by this project will the need for fire data.

Example 2: understanding fuel treatment effectiveness. The U.S. federal government, under the National Fire Plan and other fire management policies, is conducting costly fuel treatments in order to reduce fire hazards. To understand effectiveness of fuel treatments in achieving desired outcome of reducing fire severity and size, we are conducting research to compare DNBR maps with fuel treatment GIS coverage maps for study sites across the nation.

Summary

As a national wildland fire monitoring project, the MTBS project is being conducted to report and assess trends in burn severity over time. The project has the following specifications:

- Temporal: 1982 to 2010 (and potentially onward)
- Spatial: nationwide, all fires that meet minimum size requirements
- Nominal spatial resolution: 30 m
- Minimum fire sizes: 202 ha or greater for eastern states, 205 ha or greater elsewhere for the nation

- Technical basis: CBI field plots as ground reference for magnitude of severity, DNBR as the remote sensing method for mapping burn severity.
- National reporting: annual reporting of 5 severity classes by major land cover/vegetation types.

The operational monitoring project is being conducted with understanding that there still remain technical challenges and uncertainties. Like many other definitions, the term burn (or fire) severity means different things to different people. For this project, we use the term as defined in the interagency FIREMON protocol, Lutes *et al*., 2006). The field CBI data have been used as the ground truth for measuring the level of burn severity, although in areas of the country the field protocol has not worked most consistently. The DNBR method is at the best an estimate of CBI and there is lack of a consistent approach for selecting threshold values for DNBR severity classes. Technical issues like these remain as research topics.

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