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Using Satellite Imagery Analysis Together with Computer Simulation May Improve Burn Severity Mapping

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Fire Science Brief

RESEARCH SUPPORTING SOUND DECISIONS

Sampling fuels in the Cooney Ridge fire area, Montana, a high-intensity burn site. Credit: Eva Karau.

Using Satellite Imagery Analysis Together with Computer Simulation May Improve Burn Severity Mapping

Summary

This project compared and contrasted the utility and limitations of satellite-imagery and computer simulation modeling approaches to mapping fire effects and burn severity. The goal was to provide resource managers with tools to more effectively meet burned area rehabilitation objectives and manage fire on landscapes. Using satellite imagery analysis together with simulation modeling may improve burn severity mapping. The results of this study are being integrated into a comprehensive spatially explicit software analysis package for wildfire and prescribed fire management decision support.

Key Findings

- Fire severity simulation modeling efforts depend on accurate and comprehensive data input layers.
- Both satellite imagery and fire simulation modeling have limitations in attempting to predict burn severity, but used together they could be quite effective.
- Wildfire managers need consistent and standardized measures of estimating burn severity involving the physical variables that dictate severity, such as plant mortality.

Wanted: A real-time way to predict fire severity

Wildfires are increasing across the western United States, and their effects can be both beneficial and detrimental. The decision of whether or not to fight wildfires becomes more difficult and sensitive as development spreads into fire-prone natural areas. Fire managers need tools that allow them to rapidly assess possible fire effects so they can logically decide based on ecological reasons whether or not to fight a fire or, after the fire, where comprehensive rehabilitation should be done. They also need tools to help assess burn severity (meaning, in general, the magnitude of fire-caused damage to vegetation) across the landscape so they can efficiently allocate limited suppression, rehabilitation, and remediation resources.

Mixed fire severity in the Mineral Primm fire area, Montana. Credit: Eva Karau.

"We need to quantify burn severity of wildfires to manage the landscape into the future, to determine whether or not we should rehabilitate a site, and to determine if we've lost significant ecological resources," says Robert Keane, supervisory research ecologist with the Forest Service, Rocky Mountain Research Station, in Missoula, Montana. "If you can predict burn severity," Keane notes, "then you can predict what the wildfire will do to the non-economic, ecological resources."

Some wildfires can serve as a fuel treatment to bring the landscape back into the historical range of fire frequency. "Right now," Keane says, "there is no way to estimate that value; there is no way to say, 'Okay, it looks like this fire is actually improving the ecological condition.' If you let the wildfire go, you may actually save thousands, if not millions, of dollars in fuel treatment costs, and also help improve ecosystem health. An important way to evaluate this issue is by first predicting severity."

Fire managers need a real-time way to predict fire severity, because quality satellite imagery isn't always readily available, especially during a wildfire. "A lot of times that imagery isn't available for several months after the fire, or nobody is available to analyze it," explains Keane. Also, clouds and smoke may obscure wildfire effects.

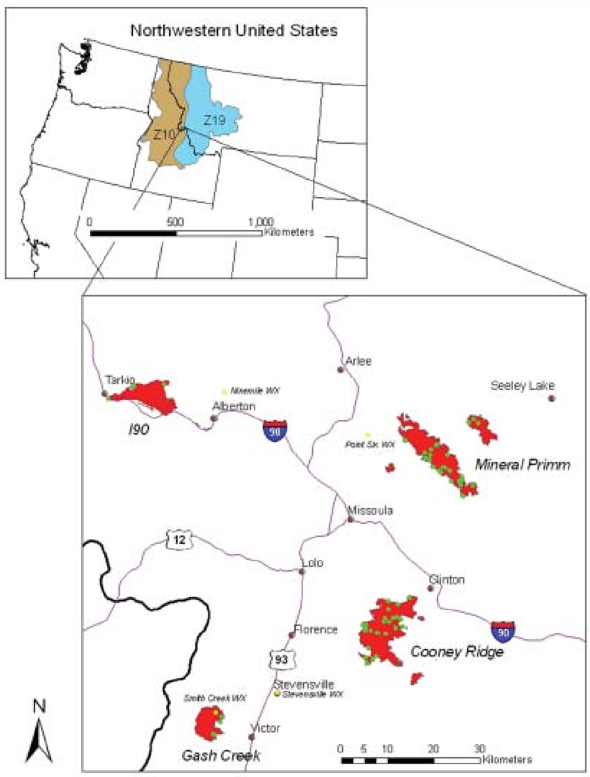
Burn severity mapping allows land managers to assess the severity of wildfire across the landscape and effectively and efficiently apply rehabilitation and restoration treatments, such as reforestation, erosion control, invasive plant management, and habitat restoration. Land managers and scientists use burn severity maps to link burn patterns to other disturbance factors, evaluate potential for vegetation recovery, assess wildlife habitat disturbance, determine the effects of fire on species of special concern, and gauge whether the fire had beneficial ecological effects by resetting the landscape back to a more historically similar state.

Satellite imagery and simulation models: Comparing their ability to predict burn severity

Keane and Eva Karau, an ecologist with the Forest Service, Rocky Mountain Research Station in Missoula, recently completed a project with the goal of comparing and contrasting model-based spatial fire effects and satellite-derived burn severity maps using reference data gathered in the field for validation.

The researchers evaluated the two methods of mapping burn severity for four wildfires in western Montana between 2003 and 2005 using 64 plots for field reference. The satellite imagery technique involved an analysis of pre- and post-burn conditions called Differenced Normalized Burn Ratio (ΔNBR). The fire effects simulation used the FIREHARM spatial computer model, which contains the fire effects model First-Order Fire Effects Model (FOFEM). Keane and Karau then assessed the potential to use these two techniques together to accurately and rapidly assess spatial fire severity.

Keane's research group has developed several simulation models that allow the user to predict burn severity for a range of weather and fire conditions. FIREHARM is "a spatial model that simulates common measures of fire behavior, fire danger, and fire effects" to rate fire hazard, and then describes burn severity quantitatively over multiple temporal and spatial scales using simulated weather and fuel moisture data. The models can be rerun frequently as conditions change to update fire management decisions, providing a viable platform for planning and real-time fire severity evaluations.



Map of study areas showing LANDFIRE zones (brown and blue), wildfires (red), weather stations (yellow points), and plot locations (green points). Credit: Eva Karau.

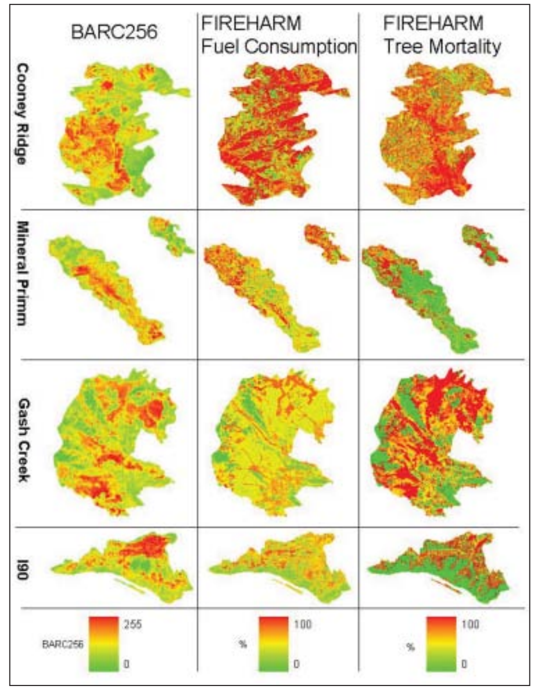
Most of the data needed to run FIREHARM, including digital maps of topography, vegetation, and fuels, as well as local weather and fuel moisture information, is available for the continental United States through the National LANDFIRE Mapping Project (www.landfire.gov), which was completed in fiscal year 2009. Simulation is limited by the quality of the spatial data required by the FIREHARM model.

Use the two techniques together?

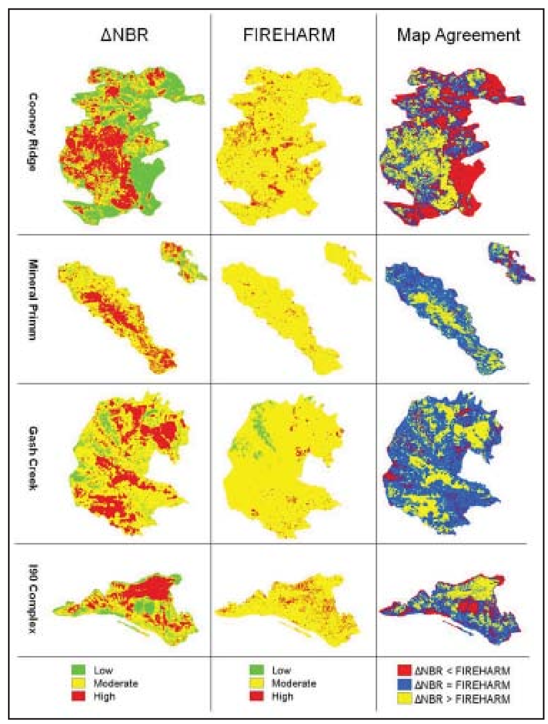
> *"We found that both techniques have their problems... Both have similar accuracy rates, which are quite low. But together, they could actually give us an alternative way to predict severity."*

"We found that both techniques have their problems," Keane says. "Both have similar accuracy rates, which are quite low. But together, they could actually give us an alternative way to predict severity."

Burn severity maps produced by the two approaches were quite variable. Map agreement for the two techniques ranged from 33 to 65 percent for the four sampled wildfires. Both approaches had the same overall map accuracy as compared to a sampled composite burn index (58 percent).



Maps of burn severity and fire effects for the four fire areas (arranged in rows from first to last: Cooney Ridge, Mineral Primm, Gash Creek, and I90 Complex. Column 1: BARC256 (ΔNBR scaled from 0–255 (unclassed)). Column 2: FIREHARM simulated Fuel Consumption (%). Column 3: FIREHARM simulated Tree Mortality (%). Credit: Eva Karau.



Satellite-derived and model-simulated maps of burn severity for the four fire areas (arranged in rows from first to last: Cooney Ridge, Mineral Primm, Gash Creek and I90 Complex). Column 1: ΔNBR (classed as Low, Moderate, and High Burn Severity). Column 2: FIREHARM Burn Severity (classed as Low, Moderate, and High Burn Severity) Column 3: difference map showing discrepancy and agreement between ΔNBR and FIREHARM burn severity maps (red means ΔNBR severity was lower than FIREHARM severity, blue means the maps are in agreement, and yellow means ΔNBR severity was higher than FIREHARM severity). Credit: Eva Karau.

Keane and Karau found that when the satellite imagery performed poorly (in predicting fuel consumption), the model performed relatively well, and when the model performed poorly (in predicting tree mortality), the imagery performed relatively well.

Despite the limitations, Keane and Karau concluded that both techniques have value for fire managers, depending on the time, place, resources, and data available. "Real-time assessments of fire effects can be successfully accomplished using a modeling approach, whereas long-term severity assessments for rehabilitation efforts could use the imagery data," they wrote.

"We envision that fire managers could use this technology in real-time wildfire operational assessments and immediate post-wildfire rehabilitation planning," explains Keane. "Burn severity maps of burned and unburned areas can be created by FIREHARM very quickly (overnight) using LANDFIRE data. These maps can be used to evaluate the benefits of allowing the fire to burn or the drawbacks of trying to put it out."

Comparison to historic landscape conditions

Keane's team is currently developing software to use simulated burn severity maps to compare historical burn severity to severities within a recently burned area. "As satellite or air-borne images become available, image-derived burn severity maps can be integrated with simulated fire effects maps to design wildfire remediation plans and implement rehabilitation efforts," as they note in the final project report.

Keane explains where this technology is currently: Information about burn severity now "goes into a complex ecosystem model [computer software called FLEAT—Fire and Landscape Ecology Assessment Tool], and the model simulates what the landscape will look like at one, ten, and a hundred years in the future. It then compares those predictions to what the landscape looked like historically and evaluates whether the fire is moving the landscape away from what it looked like in the past. If it is, then perhaps suppression of the fire is indicated. But if the wildfire is moving the landscape toward historical conditions, then perhaps the fire should be allowed to burn under acceptable weather conditions."

To describe landscape history, Keane's team simulates fire and vegetation development for 5,000 years. He explains, "Five thousand years is necessary to describe the entire range of possible historical conditions. If the lightening would have hit some other place or the wind would have blown differently, the fire pattern would have been totally different. So, if you just use historical data, you're going to underestimate the range of historical conditions. So what we do with the simulation modeling is simulate thousands of years so that we can make sure that historical fire regime is completely represented on the landscape. It gives us a better estimate of the historic range of variability. Not only what did happen but what could have happened."

Decisions about whether or not to fight fires are typically made based on the danger to people and structures. "But if you've got a wilderness fire or a remote fire burning and you run this computer program and find out that you're actually returning the landscape to its historical range of variation, then you might be more apt to allow it to burn than to put it out."

Keane's model results can be fed into the Rapid Assessment of Values At Risk (RAVAR) program to quantify the value added or lost through a fire. RAVAR, developed by another research group at the Missoula Forestry Sciences Laboratory, identifies the resources, such as private structures, public infrastructure, hazardous waste sites, and regionally identified natural resource management priorities, threatened by ongoing large wildfires. RAVAR data and analysis feeds into Wildland Fire Decision Support System (WFDSS), a computer program that helps fire managers make decisions regarding wildfire fighting.

Keane cautions that all of the models and software his team develops are for research purposes. They create a prototype program, and if fire managers agree that it's useful, specialized computer programmers make the research program user-friendly. Keane notes that all his team's models and programs mentioned here will go into the Wildland Fire Assessment Tool (WFAT), which is already in use by managers. WFAT uses locally specific fire weather to generate fire danger maps.

Sources of error and uncertainty

Both satellite imagery and computer simulation methods of predicting burn severity currently include significant sources of error and/or major drawbacks. Both methods require considerable specialized training to run and significant computer resources. Simulation modeling can be run overnight, whereas satellite imagery may be unavailable for weeks or months after a fire.

Modeled map results are limited by the quality of the Geographic Information System (GIS) input data, the complex behavior of a spreading wildfire, and inaccurate data on weather and fuel conditions stemming from field-sampled data. "LANDFIRE data layers, while valuable and essential for fire management," says Keane, "contain a high degree of error, especially in the mapping of wildland fuels."

Sampling fuels in the Mineral Primm fire area.
Credit: Eva Karau.

Also, “there is no standardized way to predict severity,” Keane notes. “So you’re automatically including subjectivity in any estimate of severity that you get on-site. This means that any ground-truth data that you’re collecting is somewhat biased to the collection method rather than truly representing fire severity. In other words, the sampling of fire severity has a high degree of uncertainty.” This field-sampling error also contributes to the error of simulation modeling because the simulations are based in part on field data.

Satellite-derived maps of burn severity are not based on physical measures of fire effects. “You’re trying to correlate the reflectance off the landscape to some measure of severity, and there are a lot of factors that influence this correlation,” Keane says. FIREHARM’s output of fire effects measurements, in physical units, may be more meaningful.

New measures of severity are needed

Keane and others would like to see the concept of “fire severity” revisited. “I think it’s time for a revolution in fire severity,” he says. “The main problem is that too many people like to collapse the ecological effects of wildfire down to a three-category ordinal severity measure when the factors that control severity are much more complex. By using just three classes, you’re actually getting rid of all the important information on fire effects. It’s about time we start talking about fire severity in terms of quantitative measures using variables that are continuous and actually describe something—like plant mortality or fuel consumption.”

“So I think that one of our big findings,” he continues, “is that we need better, more consistent standardized measures of severity. And severity itself shouldn’t be the measure; we should be measuring the actual variables that are a component of severity. I think that’s where the main research should be and that’s where fire science should go.”

New project will integrate and build on these techniques

A project of Keane’s newly funded by the Joint Fire Science Program (JFSP) and Fire and Aviation Management of the Forest Service will, among other things, correlate fire severity from satellites and from simulations in a GIS analysis package. The new tool will provide “a suite of severity measures,” including satellite and simulated measures.

“What we need to do now is put them both together into one application, so that management could use them as an integrated system,” says Keane. “All our findings are going to be rolled into that computer program, and that computer program will then be used as a decision tool to decide whether or not to let a wildfire burn. There are few other tools that actually address and quantify the non-market value of ecosystems” in such a decision. The new WFAT will be usable throughout the continental United States with data from LANDFIRE.

Management Implications

- Satellite imagery and computer burn severity simulation can be used together to provide a more comprehensive burn severity map.
- Fire severity simulation modeling provides a viable platform for planning and real-time fire severity evaluations.
- Results of this study are currently being integrated into a comprehensive spatial software package for wildland fire decision support.

Further Information: Publications and Web Resources

Karau, E.C. and R.E. Keane. in press. Burn severity mapping using simulation modeling and satellite imagery. *International Journal of Wildland Fire*.

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Keane, R.E., S.A. Drury, E.C. Karau, P.F. Hessburg, and K.M. Reynolds. 2010. A method for mapping fire hazard and risk across multiple scales and its application in fire management. *Ecological Modelling* 221: 2-18.

Keane, R.E. and E.C. Karau. 2008. Burn severity mapping using simulation modeling and satellite imagery. Final Report - Joint Fire Science Program. http://www.firescience.gov/projects/05-1-1-12/project/05-1-1-12_satsevJFSPFinalReport.pdf

Scientist Profiles

Robert Keane is a Research Ecologist with the Forest Service, Rocky Mountain Research Station at the Missoula Fire Sciences Laboratory. In addition to the above work, his most recent research involves (i) sampling, describing, modeling, and mapping fuel characteristics, and (ii) investigating the ecology and restoration of whitebark pine.

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Eva Karau is an Ecologist with the Forest Service, Rocky Mountain Research Station at the Missoula Fire Sciences Laboratory. Her research involves fire effects and landscape simulation modeling, burn severity mapping, and questions of scale in landscape ecology.

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