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Mapping and Estimating Forest Fuel with Radar Remote Sensing

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Joint Fire Science Program

Fire Science *Brief*

RESEARCH SUPPORTING SOUND DECISIONS

Yellowstone National Park is reborn 20 years after the fires of 1988.
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Mapping and Estimating Forest Fuel with Radar Remote Sensing

Summary

With an increase in the risk of large fires across much of the Western United States, along with a growing variety of fuel types that result from changes in the landscape and management strategies, there has never been a more pressing need for accurate, cost-efficient, large scale forest fuel maps. Emerging remote sensing technologies may yield exactly the kind of large scale maps needed to more accurately predict forest fuel loads, fire risk, and fire behavior.

With the Greater Yellowstone Ecosystem as their backdrop, Don Despain, Sasaan Saatchi, Kerry Halligan, Richard Aspinall, and Robert Crabtree worked together to acquire a detailed catalogue of remote sensing data for estimating forest fuel load, and creating subsequent maps. They retrieved passive (optical) and active (radar and LiDar) remote sensing data from a variety of sensors, interpreted the data, combined the data, and created maps—all with the intent of finding the most accurate remote sensing data in terms of its correlation with their “on the ground” field data. They found remarkably close accuracy with their airplane-retrieved radar data, showing that particular sensors could achieve about 70 percent accuracy compared to field data in predicting fuel load. This work helps mark a new era of potentially more accurate and cost-effective remote sensing technology specifically in regards to estimating forest fuel load, and related mapmaking.

Key Findings

- Data fusion was not found to be helpful for estimation of crown biomass or the fuel components that can be derived from crown biomass values.
- Radar images can be useful in estimating spatial distribution of fuel load classes.
- Radar data can be used to estimate fuel loads for previously created map units.

Introduction

There has never been a more pressing need for an efficient fuel mapping system that crosses state, administrative, and park boundaries and that is based on common data and methods. Many small scale mapping techniques rely on passive visual (optical) sensing data that can be mapped. But large scale mapping cannot rely on optical imagery alone as it is too cost prohibitive and not detailed enough at larger scales to accurately portray fuel load. To create such maps requires that researchers first accurately estimate forest fuel load. This can be thorny and complex, as it consists of many variables that may include canopy height, canopy biomass, moisture content and others.

Then there are the various ways that researchers can choose to acquire this varied information. To get "on the ground" estimates of all the variables needed for wildfire models is expensive, labor intensive, and not very efficient. But sensing many of these variables remotely—via satellite or airplane—can increase efficiency and cut down cost. The question is can remote sensing estimate these variables well enough to give managers and planners an accurate idea of actual fuel load in their models? If so, what are the best ways to use the various remote sensing options now available?

Don Despain, now retired from the U.S. Geological Survey in Bozeman, Montana, worked with his colleagues to assess some particular remote sensing tools and their effectiveness for mapping fuel loads. He also worked with Sasaan Saatchi of the Jet Propulsion Lab at the California Institute of Technology, Kerry Halligan at the Geology Department of the University of California in Santa Barbara, Richard Aspinall at the School of Geological Sciences at Arizona State University, and Robert Crabtree from the Yellowstone Ecological Research Center, also in Bozeman.

Despain and his colleagues wanted to find better ways to get accurate fuel load maps of large areas. Despain says, "Remote sensing has been tried in different ways—for instance satellites can sense large areas with fairly low cost. Airplanes may give more accurate data but they tend to be expensive and cost-prohibitive over large areas."

He also says that in general, visible (optical) wavelengths from passive sensors are not very successful because the accuracy is not very high, at least at large scales. So, he says, "We looked at the possibility of using radar remote sensing using different wavelengths from active sensors. These would give us different feedback on different variables." The team also wanted to see if combining different forms of radar and optical data, would help to create high-quality maps of fuel load that cover large areas.

As Despain says, "The technology is now there to use radar to estimate fuel load." And the team recognized that a much more efficient, accurate, and cost effective approach to sensing fuels—and then mapping them—might lie at the heart of radar remote sensing technology. So, with a Joint Fire Science Program (JFSP)-funded proposal in hand, the team set out to (according to their final report) extract "fuel parameters using a combination of remote sensing types including radar and optical images," and to present "the results in a form readily useful to fire managers through Geographic Information System (GIS) processes."

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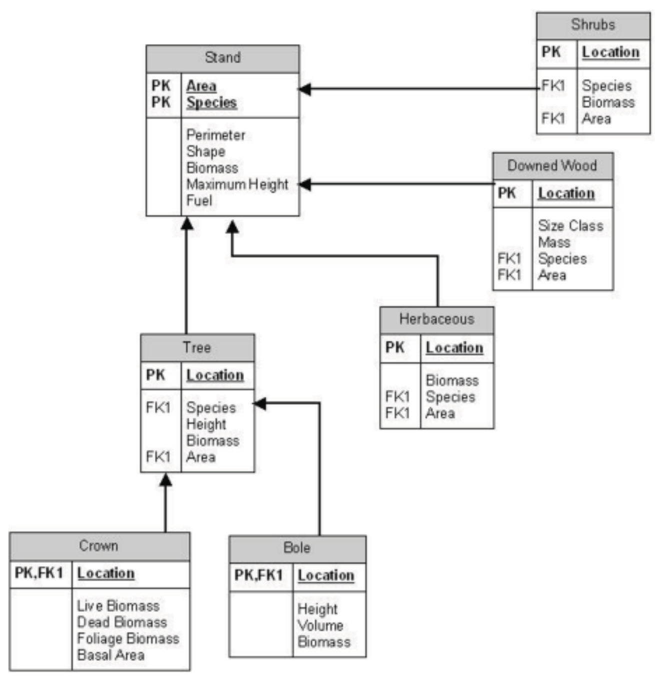

Visual description of a data model for forest fuel attributes measured from remotely sensed data. Elements can potentially be measured via remote sensing, and values can be computed using GIS (figure from JFSP final report).

An active need for active remote sensing

The technological capabilities of active remote sensing, including radar, have now improved to the point that active remote sensing may become one of the most important tactics available in wildfire modeling and fuel mapping. Yet even within the field of active remote sensing, a variety of approaches exist. A guiding question here is: What variables are most important and necessary in accurate, large-scale fuel mapping? And, similarly, which remote sensing techniques are most likely to efficiently access those data?

Knowing all this, Despain and his colleagues zeroed in on gaining more information of the value of radar remote sensing to accurate large-scale fuel mapping. They knew that those who track variables for wildfire modeling need to access data on canopy fuel characteristics. They also knew, as discussed in their recent 2007 paper in the Institute of Electrical and Electronics Engineers (IEEE) Transactions on Geoscience and Remote Sensing, that so-called "passive optical sensors" used for acquiring most forest and fire information via satellites, are unable to give researchers very detailed sensory information on the canopy fuel characteristics, especially at large scales. Yet, as they write, these are the characteristics that, "define the most important variables for predicting fire hazard and behavior."

In a sense, then, the team is helping to navigate a turning point in technology. To start out, the team knew that passive sensors are not very good at yielding canopy fuel and structural characteristics, so they wanted to find a more effective sensing technology for acquiring that detailed information on canopy fuels—again, this information is perhaps the most important for predicting fire risk and behavior. The researchers knew that active remote sensing technology—in this case, radar and LiDar (**LI**ght **D**etection **A**nd **R**anging, defined in *PC Magazine* as "a method of measuring atmospheric conditions including temperature and wind sensors)"—have now begun to offer scientists much more detailed information on various types of fuel structure information.

The team decided to work with polarized wavelengths to try for more accurate information of on the ground fuel loads. Despain says, "A polarized signal is one that goes vertically or horizontally. The signal itself is then changed when it comes back, and we can learn things about the surface by interpreting that reply signal. For instance, the shorter wavelengths interact with branches and needles, and so we may be able to get direct estimates of branches and needles from this kind of remote sensing." This would clearly be superior to estimates of the needles and branches based on making secondary estimates from data on tree trunk biomass. And this, in turn, would offer more detailed and accurate maps of fuel load.

"We developed a variety of remote sensing and GIS methods and products that map wildland fuels according to specific vegetation types (fuel models) and the horizontal and vertical position of biomass, two factors (that) significantly affect the intensity and spread of fires."

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Yellowstone National Park: On the ground and from the air

The team chose Yellowstone National Park (YNP) as their study area for its wealth of preexisting GIS and remote sensing data, its well recorded ecological and fire history, its protected status, and its variety of fuel types. They also knew they could take a wide variety of field measurements across different areas of the park to compare their "groundtruth" data to the information they gained from remote sensing.

Since they wanted to asses and combine passive and active remote sensing data, they were careful to use appropriate and comprehensive sensor types for their work. According to their final JFSP report, the passive optical data (hyperspectral and multispectral data) tend to accurately portray surface features in a two dimensional way, since they use "illumination of features with photons from sunlight (hence passive)" and as such, they simply cannot penetrate and assess three dimensional vegetation structure.

So, they acquired the passive optical data for the 2-D surface (airborne and hyperspectral, LiDar, and satellite-based multispectral ASTER), and then, according to the report, airborne polarimetric and interferometric Synthetic Aperture Radar (SAR) to access the third dimension. Both SAR and LiDar are capable of acquiring three-dimensional data on fuel structure, and according to the report, the team used airplane acquired SAR data "to conduct the bulk of the fuel load retrieval." They were also fortunate to include an analysis of high resolution LiDar data as an added boon to the original intent of the research. Meanwhile, says Despain, "We took *a lot* of on the ground measurements to compare to our radar measurements."

Indeed, over the course of two years (2002 and 2003), the team field-sampled 833 plots within 64 stands of various disturbance history, vegetation and fuel types. They noted whether each sample area could be matched with remotely sensed data, so that the field data could be easily compared. The point, of course, was to see how well the remote sensing data correlated to field measurements. To that end, the researchers measured an abundance of variables to help assess fuel load and fuel mapping. For instance, they measured, according to their IEEE paper, the "weight of the forest floor duff, forest floor litter, herbaceous vegetation, shrubs, small conifers, and downed woody material." They also measured basal area of trees and shrubs, and recorded vegetation type at each plot. Meanwhile, they recorded the Global Positioning System (GPS) locations of every plot. According to the report, these forest fuel ground validation data came from "four primary areas within

YNP that are representative of vegetation types in the Greater Yellowstone Ecosystem (GYE)."

Connecting many dots: Radar, algorithms and fuel load

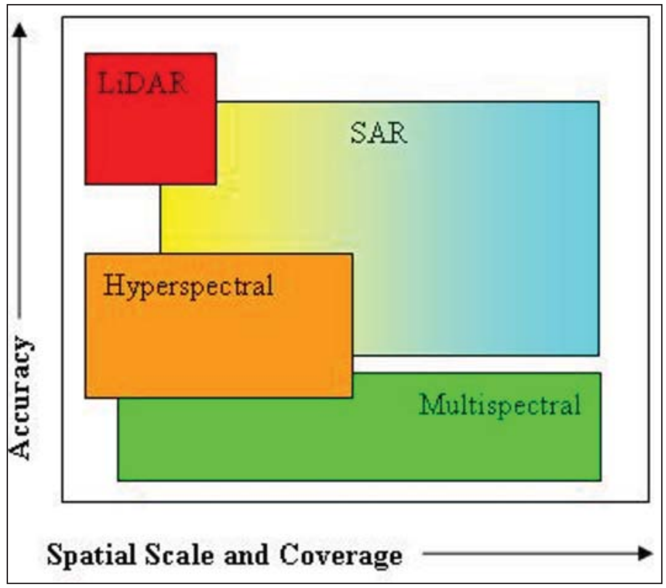
"We did find a high level of accuracy from our radar remote sensing," he adds. "When we compared our field measurements to what the airplane 'saw' we got close to 70 percent accuracy...that's pretty good correlation for remotely sensed data."

To find this correlation the team took the data from the sensors and compared it to the field data. But they had to do it one piece at a time—and one sensor-type at a time. The sheer range and scale of the detailed results the team achieved is largely beyond the scope of this article. As a case in point, their final report says, "Given the large quantity of datasets, data types and analysis approaches used in this research we attempt here to provide a useful summary of our findings as a companion to the final data products." Many of these final data products, as well as a roadmap for managers and planners are available in the JFSP final report.

In general, the remotely sensed data had to be interpreted into meaningful information that described forest biomass and fuel. This is possible because of the way that radar "backscatter" measurements relate to forest structure and biomass. For a detailed description of these mathematical relationships, refer to the IEEE paper and the JFSP final report cited above. The main point here is that the remotely sensed data had to be translated into meaningful information on forest structure and biomass. Similarly, the team also estimated fuels—as in the parts of forest biomass that can contribute to wildfire—from the remotely sensed data.

Then—after retrieving the remotely sensed data and using mathematical algorithms to translate the data to meaningful information—they could begin to see how well the remotely sensed data correlated with their field measurements.

The researchers outline their extensive analysis of all the sensors and combinations of different data sets in their final JFSP report. In addition to SAR data, they also review the results for their multispectral (ASTER), hyperspectral, and LiDar data, as well as an analysis of data temporal frequency, spatial scale, spatial extent, and overview of the optimal data set decisions. With so much data and various possible analysis routes to recovering accurate fuel load information, they even created a matrix and schematic to aid in decisions for how to use remote sensing data.



Generalized schematic of the relative tradeoff between accuracy and spatial scale for various types of remotely sensed data used in the analysis.

Mapmaker, mapmaker—Make me a map (and a model)

"One thing to note," says Despain, "is that we used an airplane to get the SAR data. Satellite data does not have as many frequencies as we can get with an airplane. It would be nice to know whether satellites can get a useable answer relative to an aircraft. We did not test this, but in the future it would be good information to know. I'm looking ahead to when satellites that use more frequencies (like their radar study) can be used over even larger areas."

One of the team's first recommendations is to create a "base map" (e.g., an ecosystem-wide remote sensing derived base map). They suggest it be developed using SAR data

The table below illustrates a qualitative matrix to aid in decisions to use remote sensing data types.

Sensor	Cost to Acquire	Data Reliability	Resolution (m)	Accuracy (% or r2)	Analysis Costs	Species ID?	Cover Type?	Biomass?	Stand Height?
SAR (satellite)	Moderate	High	1 to 30	0.50 to 0.90	High	Moderate/ Low	Moderate/ High	Moderate/ High	Moderate
SAR (airborne)	High	Moderate High	1 to 10	0.60 to 0.95	High	Moderate/ Low	Moderate/ High	Moderate/ High	Moderate
Multispectral (satellite)	Low/ Variable	Low	3 to 30	50 to 90	Moderate	Low	Moderate	Low	Low
Hyperspectral (airborne)	Moderate/ High	Moderate	1 to 20	70 to 95	Moderate/ High	Moderate/ High	High	Moderate	Low
LiDar (airborne)	High	Moderate	1 to 3	0.80 to 0.98	Moderate	Low	High	High	High

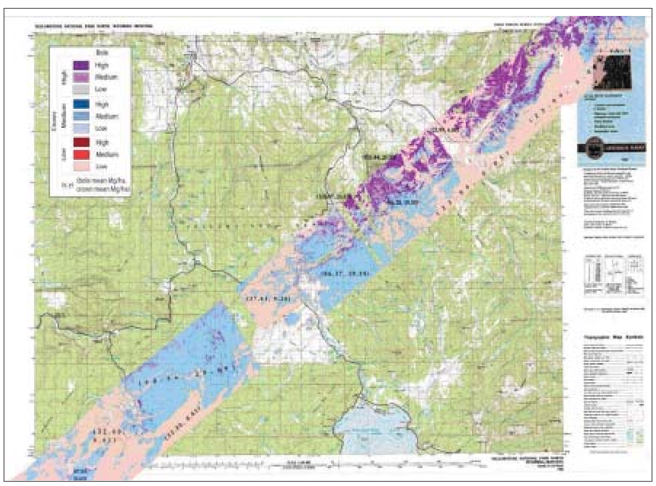
from a satellite platform. They also include a discussion of GIS data modeling and data management—both important in achieving data usability when handling such large and complex sets of information.

Furthermore, they highlight a data model for forest fuel that is capable of not only storing and using the large volumes of data acquired, but to also use the model to represent various forest stands.

They suggest there may be better data to link forest data models with fire models, as well as including descriptions of how they mapped such large and complex data sets. The maps, in particular, are important as, the "goal of this part of the project is to produce cartographic representations at 1:24,000 and 1:100,000 scales as maps that display both the detailed local content and regional summaries of the database in a format that can be used by fire managers."

Still, they note that the sheer magnitude of the remotely sensed data make it impossible to fully translate the information into paper maps. The information content is simply "too high for visual use." But even so, the value of paper maps cannot be overstated, even when some information is lost, when people need a visual display of forest fuel loads.

To create their maps the team made a simple classification of fuel load based on biomass of the bole and crown layers taken from the radar data (but see the JFSP final report for more details). Briefly, they analyzed these generalizations for low, medium, and high biomass and applied these to their maps. This map is one example.



An example of a paper map made to show a general representation of fuel load at the 1:100,000 scale.

They further discuss mapping options, and ways that researchers may approach these very large, complex data sets to yield the most accurate and efficient large-scale maps of fuel load.

"Radar could be quite useful if people begin using it more," says Despain. He adds, "There are a lot of knowledgeable people working on remote sensing," and it's likely that this work will be a quite useful to those working to build better remote sensing methods for estimating fuel load across wide areas of landscape. Until recently radar has been an "up and coming" technology when it comes to its use in this kind of remote sensing work. Thanks to Despain and his team, and others, that is beginning to change.

Management Implications

- Radar remote sensing can give useable fuel load and spatial data over fairly large areas.
- This study serves as a boost to those interested in using satellite remote sensing over much larger areas. Using a wide range of frequencies in this study allowed a fairly high degree of accuracy in terms of estimating fuel variables. If satellite remote sensing could do the same, it would be far more powerful in terms of its ability to help to managers and planners who want common, efficient, and accurate ways to predict and understand fuel load across large areas.
- This was not cost-prohibitive. Given that an aircraft was used, it was expensive, but the accuracy of the data made it a very valuable use of aircraft remote sensing time.

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NOTE: *For those interested in working with the extensive data files gained from this research, see the location and instructions for working with it in the "Data files" section of the team's JFSP final report (listed below).*

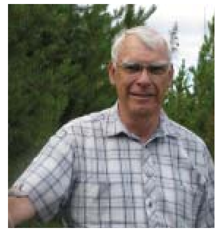
Further Information: Publications and Web Resources

Crabtree, R., K. Halligan, S. Saatchi, R. Aspinall, and D. Despain. 2006. Mapping Horizontal and Vertical Distribution of Fuel by Fusing High-Resolution Hyperspectral and Polarimetric Data, JFSP Project No. 01-1-4-15, JFSP Final Report.

JFSP Project No. 01-1-4-15, Final Report: http://jfsp.nifc.gov/JFSP_Completed_Projects_6.htm

Saatchi, S., K. Halligan, D. Despain, and R. Crabtree. June 2007. Estimation of Forest Fuel Load From Radar Remote Sensing, IEEE Transactions on Geoscience and Remote Sensing, Vol. 45, No. 6.

Scientist Profile



Don G. Despain is an Emeritus Scientist with the U.S. Geological Survey after working as a Research Ecologist for 34 years in Yellowstone National Park. He has mapped the vegetation of Yellowstone, studied fire and vegetation interactions, and been active in implementing Yellowstone's fire management that allows fire to burn under natural conditions since it's inception in 1972.

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Results presented in JFSP Final Reports may not have been peer-reviewed and should be interpreted as tentative until published in a peer-reviewed source.

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