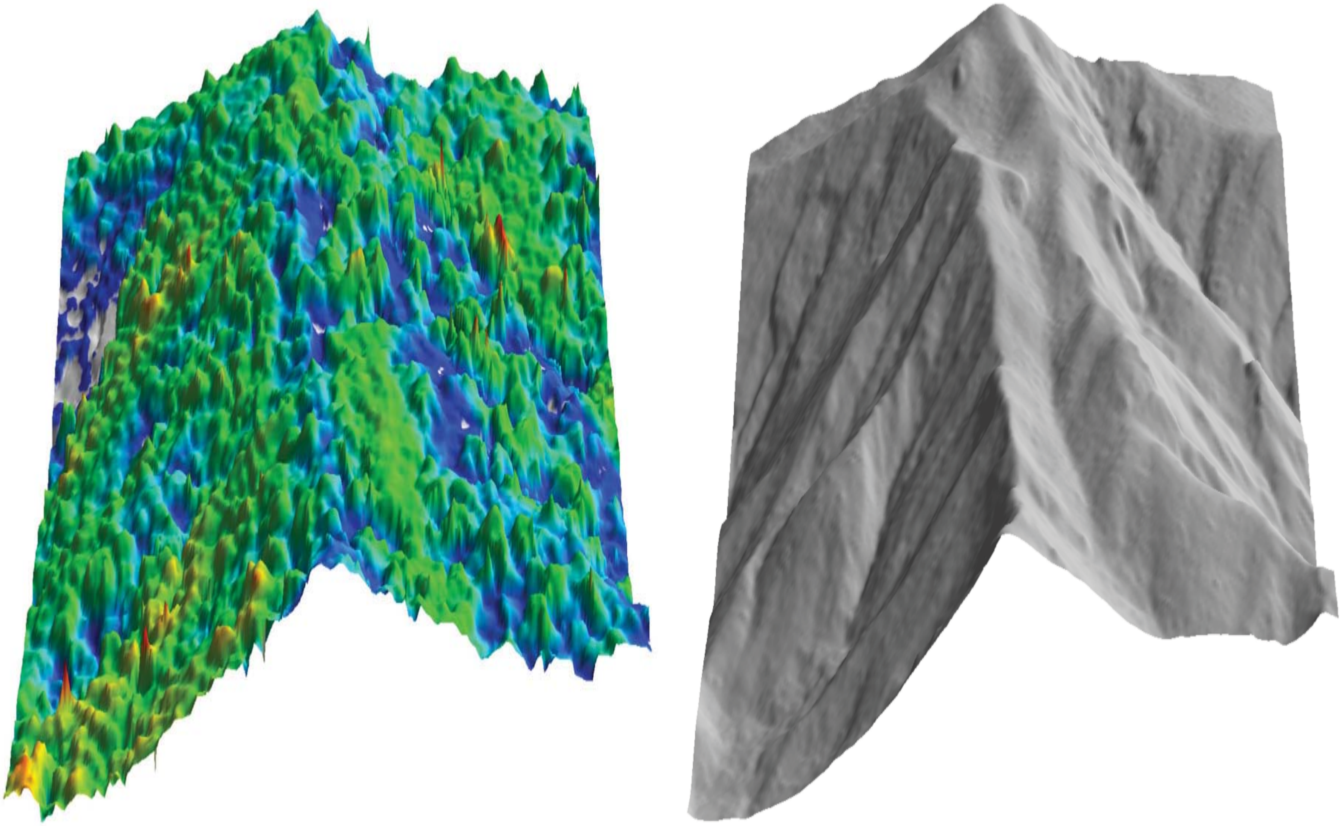
Joint Fire Science Program

Fire Science Brief

RESEARCH SUPPORTING SOUND DECISIONS



This project found that a combination of 'direct measurement' remote sensing technologies (IFSAR for canopy model [left] and LIDAR for terrain model [right]) provides useful landscape scale fuels measurements.

Frequencies, Lasers, and Wavelengths: A Quest for Affordable, Landscape Scale Remote Sensing

Summary

New developments in high-resolution remote sensing systems have demonstrated the potential for generating direct, more accurate, and efficient estimates of fuels and the vegetation characteristics that influence fire behavior at the landscape scale. Two of these direct measurement tools are operated from aircraft and known by their acronyms LIDAR (Light Detection and Ranging) and IFSAR (Interferometric Synthetic Aperture Radar). IFSAR is less costly than LIDAR, and unlike LIDAR, IFSAR sees through clouds and smoke. This project sought to evaluate the utility of IFSAR data for characterizing vegetation structure in the chaparral-dominated landscapes typical over much of southern California. The researchers found however, that current Federal Communications Commission (FCC) regulations severely limit IFSAR's ability to capture the detailed bare ground surface information necessary for accurate characterization of vegetation.
It turned out that a combination of LIDAR surface information and IFSAR vegetation measurements provide useful landscape scale fuels estimates.

Key Findings

- IFSAR (Interferometric Synthetic Aperture Radar) technology can provide the detailed information needed, but current communications restrictions degrade the information quality.
- LIDAR (Light Detection and Ranging) ground accuracy in dense shrub/chaparral vegetation types is sufficient to provide an accurate bare-ground surface.
- When combined with a LIDAR derived bare-ground surface, IFSAR produces reasonable vegetation height and density information.
- IFSAR technology development is still in its early stages and will continue to improve.

Wanted: Affordable, landscape scale details

In today's mind-boggling world of computers, software, satellites, pixels, and instant communication, we literally have the world at our fingertips. Despite easy access to these technologies, fire and forest managers need better tools to make informed decisions. They need a reliable, affordable method for obtaining quantitative information describing vegetation characteristics across large landscapes. In southern California, the 2003 fire season was a reminder of the urgency for meaningful, scientifically informed fuels information, especially in the wildland–urban interface. Over 650,000 acres burned in five counties highlighting the need for tools that can improve measurements and assessment of vegetation over large landscapes.

Remote sensing tools traditionally used for getting the big picture, like satellite imagery and aerial photos, have a drawback in that they don't provide a direct measurement of vegetation height and structure. They collect 'passive' measurements through which vegetation structure can only be inferred via the various wavelengths of sunlight reflecting off vegetation.

New developments in high-resolution remote sensing systems have demonstrated the potential for generating direct, more accurate, and efficient estimates of fuels and the vegetation characteristics that influence fire behavior at the landscape scale. They provide highly detailed information with spatial resolutions of under a meter. These high-tech, airborne eyes use everything from radio waves to lasers to probe the forest canopy, delivering detailed snapshots of vegetation density, height, quantity, distribution and moisture. But these tools have limitations too—including practicality, expense, and the conditions under which they can function.

Two of these direct measurement tools are operated from aircraft and known by their acronyms LIDAR and IFSAR. Use of LIDAR (Light Detection and Ranging) has become increasingly common. It is known for producing accurate, high-resolution terrain models. It works by measuring the time interval between the emission of laser pulses and their return to the sensor after they've bounced back from surfaces below. The power received by the sensor depends upon the physical characteristics of the targets, such as vegetation, ground surface, and buildings. Current LIDAR systems emit from 5,000 to 200,000 laser pulses per second, while varying the scan angle with oscillating mirrors to collect a continuous swath of measurements below the aircraft. In forested areas, the energy from LIDAR pulses can pass through gaps and provide measurements of the underlying terrain surface as well as vegetation and man-made structures.

But LIDAR has some drawbacks including high cost and an inability to collect data through cloud cover or smoke from active fires. IFSAR (Interferometric Synthetic Aperture Radar) is a lesser-known technology. It was developed during the height of the cold war in the mid 20th century to map large areas. At the time it was simply SAR—sans the interferometric—which emits microwave radio energy and records the reflected information. The U.S. military gave development a jumpstart, with natural resources applications coming much later along with the interferometric component. IFSAR uses a broad spectrum of microwave frequencies to measure different materials and surfaces. Shorter wavelengths measure the surface structure of the forest canopy, while longer wavelengths capture the surface of the ground beneath. Interferometric processing uses two overlapping two-dimensional images to generate 3D images of large areas. The IFSAR bonus? It can see through clouds and smoke at a fraction of the cost of LIDAR.

These features intrigued Bob McGaughey, a researcher with the Forest Service, Pacific Northwest Research Station in Seattle, WA, and Hans-Erik Andersen, then a research scientist at the University of Washington. McGaughey and Andersen were looking for affordable ways to characterize vegetation structure over large land areas.

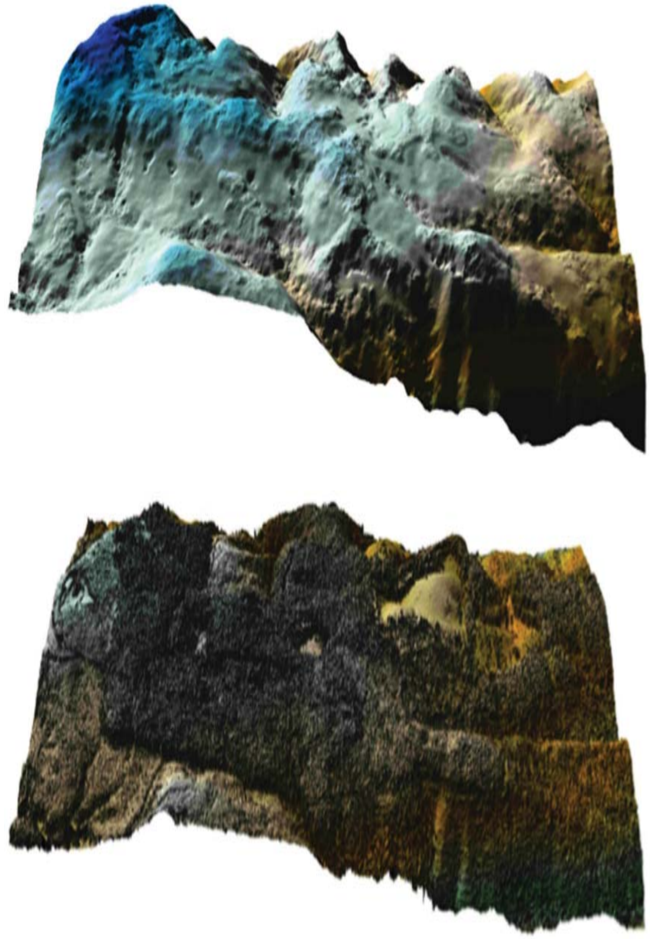
IFSAR filled the bill not only because of its low cost, but because it can see through clouds

IFSAR filled the bill not only because of its low cost, but because it can see through clouds for use in places like Alaska, where the weather often prohibits use of LIDAR. Because IFSAR also sees though smoke, it can be used map vegetation characteristics around active fire perimeters. The researchers wanted to see how well IFSAR could characterize vegetation, what level of detail it could produce, and how well it agreed with information obtained using other methods like field measurements, LIDAR, or other remote sensing technologies.

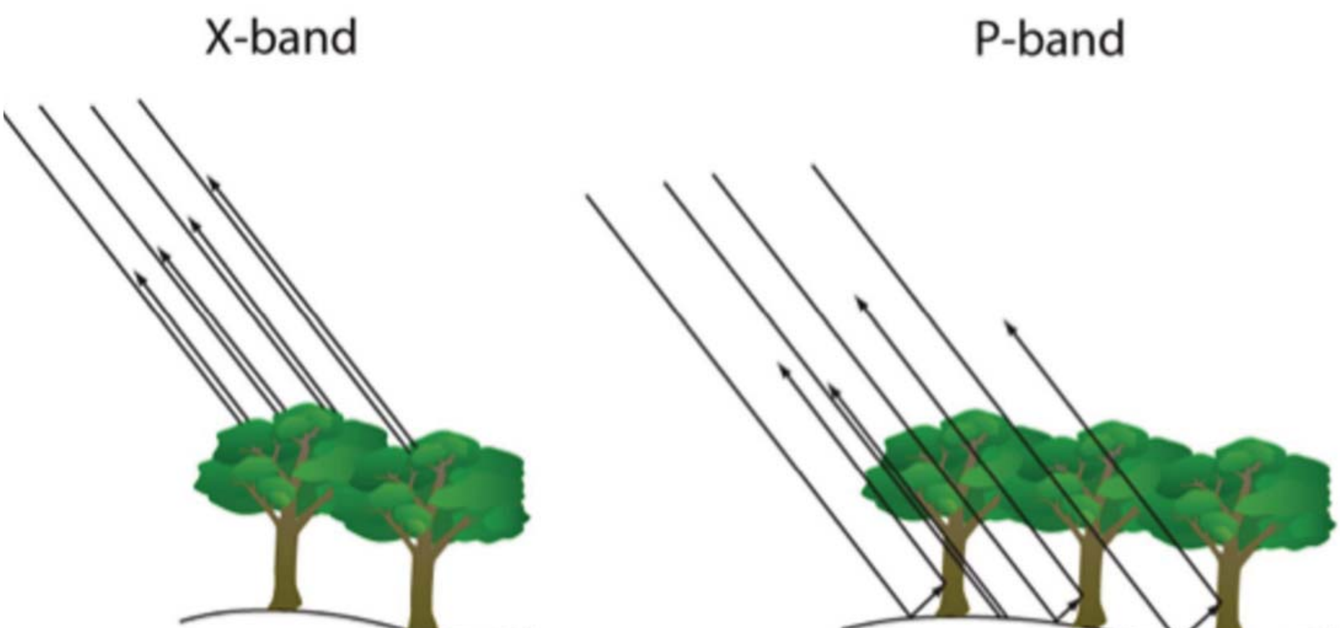
"The names of these technologies sound like rocket science," Andersen says, "but the data we interpret is actually a lot simpler than that. LIDAR is optical. It's light—a laser. IFSAR uses microwaves." He explains that because the diameter of LIDAR's laser pulse is so small, 10 to 50 centimeters across, it can pass through gaps in the canopy. Most LIDAR returns in forested areas are reflections from trees, but enough points pass through gaps that reflections off the understory and the terrain surface are obtained as well, providing a very good terrain model. IFSAR obtains readings of ground and canopy too, by emitting microwaves in long and short wavelengths. The shorter wavelengths, known as the "X-band," reflect off of the first thing they hit—usually the canopy surface. The longer wavelengths, known as the "P-band," reflect off of large tree stems and/or the ground.

Foiled by frequencies

In their quest for an affordable imaging tool that could function under a broader range of conditions than LIDAR, the researchers acquired a sample of IFSAR data for a study area in western Washington. They found that IFSAR did indeed do a respectable job of capturing both the ground and the vegetation conditions. This triggered some hope that IFSAR could possibly be used in lieu of the more expensive LIDAR, and their research project was born.



The researchers found that IFSAR did a respectable job of capturing both the bare ground surface (top) and vegetation (bottom) at the landscape scale.



Short wavelength X-band IFSAR signals reflect from the canopy surface while long wavelength P-band signals penetrate through canopy and reflect from stems and terrain surface.

"This was one of the reasons we put this project together. We acquired this fantastic IFSAR dataset that was flown over one of our study areas in Washington. We have very nice images that show very clearly the X-band canopy surface and the P-band ground surface. It looked like we could get accurate fuels information out of it."

Unfortunately, a snafu involving federal regulations was lurking beneath the Washington dataset. It turns out that the atmosphere around us is a very crowded place, teeming with radio waves of all kinds, from a myriad of sources, for a myriad of purposes. Many of the long wavelength frequencies (P-band) that allow IFSAR to obtain such great terrain data are also used for civilian and military communication systems here in the U.S. Because of this, the Federal Communications Commission (FCC) restricts their use for anything other than these communication purposes. The Washington dataset was obtained using the full spectrum of frequencies so the full impact of the FCC restrictions was not discovered until they started working on this research project.

Given the encouraging results from Washington State obtained using X- and P-band IFSAR data, the researchers wanted to see if they could apply similar techniques and obtain accurate fuels information using IFSAR data acquired over a very large area of southern California during 2002 and 2003. The project was sponsored by the National Oceanic and Atmospheric Administration Coastal Services Center (NOAA), and the Southern California Wetland Recovery Project (SCWRP), who had contracted with the aerial mapping company *EarthData International* to collect IFSAR data over coastal watersheds from Point Conception, CA, to the U.S. border with Mexico using their GeoSAR system. The researchers knew the range of wavelengths would be incomplete due to elimination of the restricted frequencies, but *EarthData* held out hope that they could somehow work around the missing information and produce valuable fuels information. Although the dataset was collected to examine riparian and wetland conditions, it covered all the areas burned by the 2003 southern California fires in their pre-burn condition which made it exceptionally relevant to McGaughey and Andersen. They wanted to evaluate the utility of the X- and P-band IFSAR data for characterizing vegetation structure in the chaparral-dominated landscapes typical over much of southern California. They also hoped it would be useful enough to develop of pre-fire vegetation maps for several areas burned in 2003.

Try, try again

As they started working with the data for southern California, it became obvious that the frequency restrictions were so severe that data were worthless for rendering the useable terrain surface needed to give the canopy information a reference point. The P-band IFSAR data couldn't be processed to produce accurate bare-earth ground surfaces. Hence, direct measurement of vegetation heights was impossible. Unfortunately, the frequency restrictions are in effect for most areas in the continental U.S. This severely limits IFSAR's application for measuring bare ground. "The positive side of this is that it was worthwhile to find that out," Andersen says. "But needless to say we were extremely disappointed. We didn't anticipate the poor quality."

Rather than dismiss the technology, the team focused on combining the IFSAR data with other data that could accurately measure the ground surface.

Rather than dismiss the technology, the team focused on combining the IFSAR data with other data that could accurately measure the ground surface. The vegetation data from the allowable short wave X-band was very good. They just needed another method to provide the essential terrain component. They turned their sights full circle and addressed the possibility of combining the data from IFSAR's unrestricted, useful, short wave frequencies with LIDAR's proven ability to measure the ground surface. Would the best of both technologies provide the required accuracy with a lower price tag than using LIDAR exclusively? To find out, they obtained LIDAR data over a portion of the study area and used the resulting bare-earth surface with IFSAR canopy height measurements. They found that indeed, when combined with the quality, bare-ground surface from LIDAR, IFSAR produced reasonable information describing vegetation height and density. They found that accuracy of IFSAR's vegetation height measurements is influenced by overall vegetation density. IFSAR tends to underestimate overall vegetation height regardless of the vegetation density because there is not a sufficient amount of material near the top of the vegetation to reflect the radio waves. The waves are reflected off of branches and leaves further down the plant resulting in lower overall vegetation heights.

Additional problems occur in areas covered by low-density vegetation because IFSAR doesn't measure small gaps or clumps of trees very well. In general, areas covered by low-density vegetation have larger errors compared to areas with higher vegetation densities. For the most accurate height measurements, especially in mountainous terrain, data from multiple angles should be combined to minimize gaps in information due to radar shadows caused by topography, localized canopy features and the influence of terrain slope.

Park the plane and look to the stars

Results of this research show the potential for combining data obtained using LIDAR and IFSAR technologies to obtain accurate estimates of vegetation heights and densities. This is especially good news as many state and local governments are currently obtaining LIDAR data to update their bare earth surface layers and model flood risk. These high-resolution bare earth surfaces will be useful for years, even decades to come, because the ground doesn't change much over time compared to vegetation changes. These LIDAR collections can provide the baseline data for applications concerned with detecting change over large land areas. In this context, IFSAR can provide a cost effective, relatively high-resolution tool to obtain the raw measurements needed to monitor vegetation changes.

IFSAR technology is still being proven, and there are only a few vendors that provide acquisition services via aircraft. In the mean time, IFSAR has made the jump from an aircraft-based technology to space-based technology. A German system is already generating X-band IFSAR images from a satellite with a resolution of one to two meters. It's up there collecting data as you read this. The next step will involve two X-band satellites working in tandem to develop terrain models. "We will eventually end up getting our ground surface models from satellites, using either space-borne LIDAR or space-borne IFSAR," Andersen concludes. "They'll be of slightly lower resolution and accuracy than what we would get from aircraft but will still be very, very high quality surface information at a lower cost than that of using an aircraft—over much larger areas."

Management Implications

- IFSAR alone can't currently provide adequate data for detailed vegetation assessments.
- In areas where an accurate bare-earth model is available, perhaps from a previous large area LIDAR acquisition, vegetation height and volume can be computed using the X-band IFSAR surface.
- Because the ground surface changes very little compared to vegetation over time, it's possible to use a LIDAR-derived bare earth model produced years, or even decades prior to the acquisition of IFSAR data.
- LIDAR continues to improve in its ability to provide high-resolution, accurate measurements of vegetation and the cost continues to decline.

Further Information: Publications and Web Resources

Andersen, H.-E., R.J. McGaughey, S.E. Reutebuch, G.F. Schreuder, J. Agee, and B. Mercer. 2004. Estimating canopy fuel parameters in a Pacific Northwest conifer forest using multifrequency polarimetric IFSAR. *International Archives of Photogrammetry and Remote Sensing, Istanbul, Turkey*, Vol. XXXV, Part B.

Andersen, H.-E., S.E. Reutebuch, and R.J. McGaughey. 2005. Accuracy of an IFSAR-derived digital terrain model under a conifer forest canopy. *Canadian Journal of Remote Sensing* 31(4):283-288.

Andersen, H.-E., S.E. Reutebuch, and R.J. McGaughey. 2006. Chapter 3: Active remote sensing. In: G. Shao, and K. Reynolds, eds., *Computer Applications in Sustainable Forest Management*, Springer-Verlag, Dordrecht.

Andersen, H.-E., R.J. McGaughey, and S.E. Reutebuch. 2008. Assessing the influence of flight parameters, interferometric processing, slope, and canopy density on the accuracy of X-band IFSAR-derived forest canopy height models. *International Journal of Remote Sensing* 29(5): 1495-1510.

Joint Fire Science Project #04-1-2-02. http://www.firescience.gov/JFSP_Search_ProjectID_Results.cfm. Mapping and analysis of pre-fire fuels loading and burn intensity using pre-fire interferometric synthetic aperture radar data combined with burn intensity derived from post-fire multispectral imagery for the 2003 southern California fires.

Scientist Profiles

Bob McGaughey is a Research Forester with the USDA Forest Service, Pacific Northwest Research Station in Seattle, WA. His research interests include using high-resolution, remotely-sensed data to describe vegetation characteristics and the visualization and processing of the huge volumes of data common with such technologies.

Bob McGaughey can be reached at:
USDA Forest Service
University of Washington
PO Box 352100
Seattle, WA 98195-2100
Phone: 206-543-4713
Email: bmcgaughey@fs.fed.us

Hans-Erik Andersen is a Research Forester with the USDA Forest Service, Pacific Northwest Research Station in Anchorage, AK. His research interests include developing new applications of advanced geospatial technologies, including LIDAR, IFSAR, imagery, and GPS, to improve the efficiency of forest inventory and monitoring.

Hans-Erik Andersen can be reached at:
Anchorage Forestry Sciences Laboratory
3301 C Street, Suite 200
Anchorage, AK 99503
Phone: 907-743-9407
Email: handersen@fs.fed.us

Cooperators

National Oceanic and Atmospheric Administration, Coastal Services Center
San Bernardino National Forest
Los Padres National Forest
Angeles National Forest
Washington Department of Natural Resources

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.

The information in this Brief is written from JFSP Project Number 04-1-2-02, which is available at www.firescience.gov.

An Interagency Research, Development, and Applications Partnership

JFSP *Fire Science Brief*
is published monthly.
Our goal is to help managers
find and use the best available
fire science information.

Learn more about the
Joint Fire Science Program at
www.firescience.gov

John Cissel
Program Manager
208-387-5349
National Interagency Fire Center
3833 S. Development Ave.
Boise, ID 83705-5354

Tim Swedberg
Communication Director
Timothy_Swedberg@nifc.blm.gov
208-387-5865

Writer
Marjie Brown
marjieb@xmission.com

Design and Layout
RED, Inc. Communications
red@redinc.com
208-528-0051