Application of the FireMapper™ Thermal-Imaging Radiometer for Wildfire Suppression

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Abstract— Applications of a new thermal-imaging radiometer, the FireMapper™, have begun in support of fire research and tactical fire suppression. FireMapper is a unique three-channel, calibrated imaging system designed through a Research Joint Venture between the USDA Forest Service and Space Instruments, Inc. It has been designed to map the progress and intensity of wildland fires but has sufficient sensitivity to be useful in terrain mapping, disaster management, and natural-resource monitoring. FireMapper employs a microbolometer detector array that requires no cryogenic cooling, as do conventional mercury-cadmium-telluride detectors. Thus it offers a less complex and expensive thermal-imaging system. FireMapper has been deployed to wildfires in California aboard the Forest Service's Airborne Sciences Aircraft, N70Z, which is a twin-engine Piper Navajo. Results show that the FireMapper can successfully characterize flaming front environments and temperatures with the potential for improving tactical fire suppression operations, fire-fighter safety, and our understanding of fire behavior and the environmental impacts of wildland fire. It has proven useful in mapping fire outbreaks, detecting spot fires ahead of a fire front, characterizing rates of spread, and monitoring fire intensity. Data have been delivered to the Incident Command Team on major wildfires within 90 minutes of collection by employing satellite communications and posting of imagery on the Internet.

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IEEE AC paper #1523.

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INTRODUCTION

The USDA Forest Service, Pacific Southwest Research Station (PSW), is applying new remote-sensing technology to monitor the progress and intensity of major wildland fires and their impacts on the environment. Remote-sensing instruments previously used in fire operations are nationally deployed—and thus may not be readily available to a given incident—or lack the dynamic range necessary to measure the very bright infrared light emitted from major wildfires [1]. New technology is needed to measure the intensity and dynamics of fire fronts—properties that affect the rate of fire spread, smoke production, and forest damage—and make fire information readily and widely available.

PSW is flying the FireMapper thermal-imaging radiometer to map and monitor major wildfires in partnership with the Forest Service's Pacific Southwest Region in California. Incorporating a modern microbolometer detector array, which requires no cryogenic cooling, the FireMapper is designed to

accurately map fire intensity and provide fire intelligence to improve firefighter safety, make fire fighting more effective, and reduce wildfire damage to natural resources and society. Imaging with the FireMapper system is also being tested for use in burned-area rehabilitation and natural resource mapping. FireMapper has been developed through a Research Joint Venture between PSW and Space Instruments, Inc., of Encinitas, California.

FireMapper and associated mapping cameras are deployed aboard the PSW Airborne Sciences Aircraft, N70Z, which is a twin-engine Piper Navajo. In a companion paper [1] we discuss calibration, drift control, and use of thermal-infrared wavelengths for measuring fire properties. FireMapper measures upwelling radiance in two narrow-band channels, at 8.1 to 9 µm and 11.4 to 12.4 µm, and a broadband channel encompassing this range of the spectrum.

IMAGE INTERPRETATION

The 11.4- to 12.4-µm channel remained unsaturated over all wildland fires observed to date; blackbody temperatures estimated from that channel appear to reflect largely the surface temperature even within a fire front [1]. It thus provides a measure of immediate soil heating that is expected to scale with fire intensity. Surface temperatures at a given time after passage of a fire front should reflect the total radiant-energy flux from the fire. Variation behind a fire front in the reach of ground with high temperatures should also reflect the local rate of spread of the fire, even for areas of uniform fuel consumption per unit area.

IMAGE COLLECTION AND DISSEMINATION

In practice, we have disseminated fire data primarily from the 11.4- to 12.4-µm channel, but have also used the broadband channel when greater sensitivity of fire detection was required. Corrections to the upwelling radiance for changes in atmospheric transmittance and path radiance have been made with the PCModWin version of MODTRAN when radiosonde data have been available.

Upon arrival over a fire incident, we typically begin mapping any fire associated with strongly convective smoke columns and proceed to find the latitude and longitude of the furthest reaches of active fire or ash. A series of overlapping flight lines are then determined and waypoints are entered into the aircraft GPS-based navigation system. At the end of the first flight line or over pass, collected data are transferred by a local area network from the FireMapper server to a notebook computer. Data are then redisplayed and examined using the FireMapper Tools program, which was developed by the Forest Service. A range of images containing active fire is selected either visually or by application of critical temperature and fire-size criteria. Contiguous images of active fire are then extracted in a generic-binary format, compressed with JPEG 2000 wavelet-compression software, and transmitted by FTP to a dedicated FTP server via a 2400 bps data connection. This transmission is accomplished using a Motorola 9505 satellite telephone and the Iridium satellite-communications system.

Data are remotely accessed, ingested into the Erdas Imagine image-processing program, ordered into a mosaic with Erdas Orthobase Pro, registered to a digital elevation model, and displayed both as a shaded-relief map and three-dimensional image (using Erdas Virtual GIS) at www.fireimaging.com. These products then are available for downloading in JPEG or geo-TIFF format. From the latter, one can display latitude and longitude of individual spot fires or portions of a fire line with an Imagine viewer. During 2002, transmission and posting of image data could be completed for a pair of flight lines within 90 minutes of data collection. Imaging is possible at any time of day or night, although the best discrimination of background features is obtained during afternoon hours when temperature gradients on the terrain are greatest.

In the following sections we describe recent applications of the FireMapper with attention to use in spot-fire detection, characterization of intensity or activity of a fire front, and display of data for use by fire operations.

False-color images shown here depict the apparent surface temperature (in Celsius) as estimated from radiance and a simple blackbody model. Warmer tones (red-orange-yellow-white) represent recent or active combustion; areas of gray correspond to temperatures expected of cooling ash or warm bare ground. Low temperatures of unburned forest and cool ground are shown in green. Images have been geographically referenced. Vertical exaggeration in 3-d views is 1.5 to one unless otherwise noted.

STAR FIRE, TAHOE NATIONAL FOREST,
PLACER COUNTY, CALIFORNIA 29 AUGUST 2001

Image 1:
Apparent surface temperatures at 14:15 local time on 29 August 2001 as estimated from a simple blackbody model and radiances measured by the FireMapper. Data from a single flight line are combined in a mosaic, draped on a digital elevation model, and shown in three-dimensions as viewed from the west. Anderson Dam, part of French Meadows Reservoir, and cool riparian vegetation below the dam are visible at right. Gray areas here correspond closely with burned ground. Note the temperature gradient and wide reach of hot ground associated with a crown fire at center left and the cooler temperatures and narrow reach of the fire line burning beneath the canopy of the coniferous forest at the right of the dam.

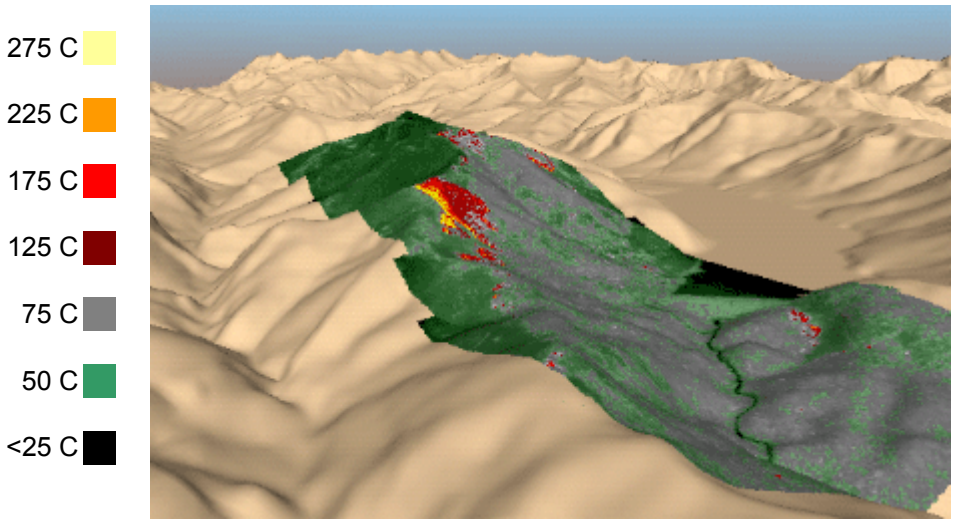


Image 2:
Post-fire digital aerial photography shown in false-color with reflected red light (650 nm) mapped in blue and red and reflected near-infrared light (850 nm) mapped in green. This 3-D mosaic from data collected on 29 September 2001 corresponds to the fire mosaic shown in Image 1. Postfire ash and burned forest, which have very low near-infrared reflectance, are shown in magenta; unburned forest with bright near-infrared reflectance is shown in green. Note that the crown fire at center-left in Image 1 corresponds to an area of denuded forest here. Also note that the narrow fire line at the right of the dam in Image 1 corresponds with an intact forest canopy in Image 2. Such data readily show areas of high fire intensity and may aid in planning post-fire emergency rehabilitation of burned watersheds.

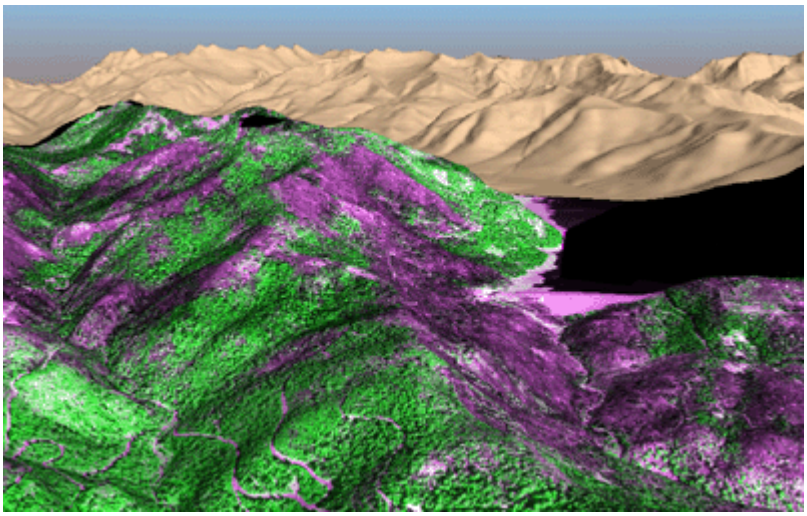


Image 3:
Surface temperatures at 14:15 local time as viewed from the northeast. Note the development of incipient spot fires along the ridge at lower left and across the north-facing slope at center. The higher temperatures and breadth of the fire line at left center are indicative of a crown fire. Also note the discrimination of ridgelines in this thermal scene.

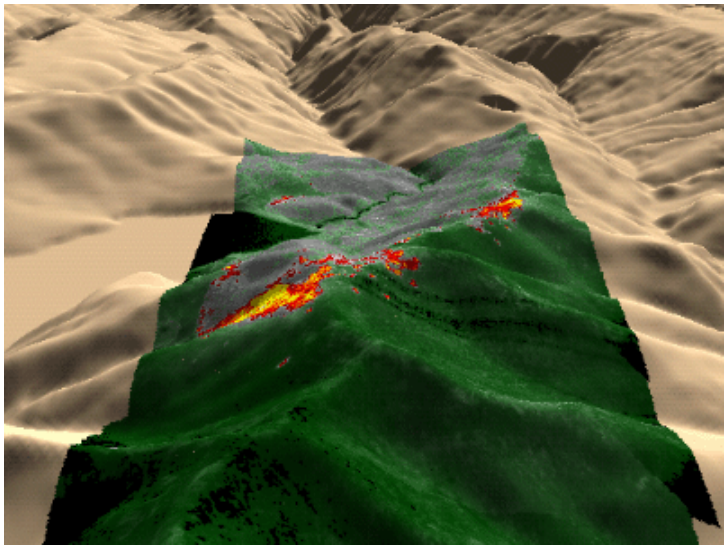


Image 4:
Surface temperatures at 17:52 local time as viewed from the northeast for the same geographic scene as in Image 3 (the aircraft track has changed). Note the main fire line at left center has crossed the ridge and the spot fires have grown along the ridge in the foreground. Temperatures associated with the fire front have also declined. Such a time series of imagery would provide fire fighters with a clear understanding of fire activity and rates of spread along the head of the fire as well as the location and growth of spot fires that may have jumped containment lines. At both times shown here and in Image 3 the fire was obscured from visual observation by heavy smoke. The more active fire at 14:15 was associated with an active convection column.

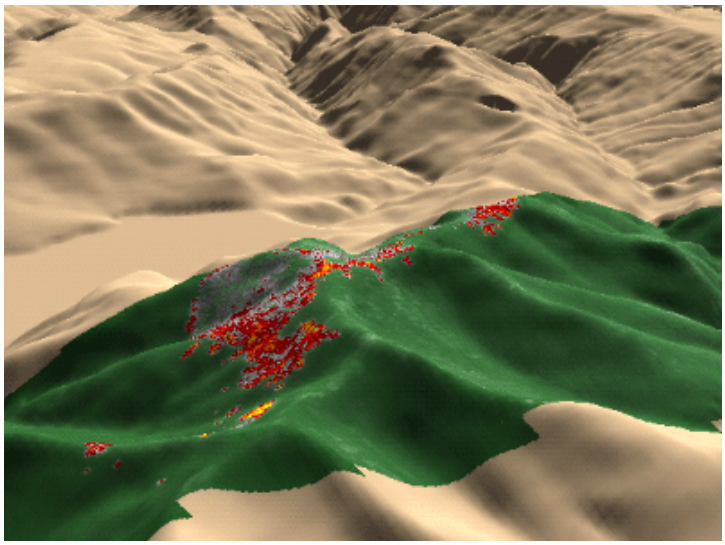


Image 5:
Surface temperatures at 17:52 local time as viewed from above. These are the same data as shown in Image 4. Map views such as this give fire fighters exact coordinates of fire lines and spot fires and a comparative view of relative fire activity along different portions of the fire perimeter. Note the meadows and gaps in the forest canopy at upper left that are visible in this false-color thermal image.

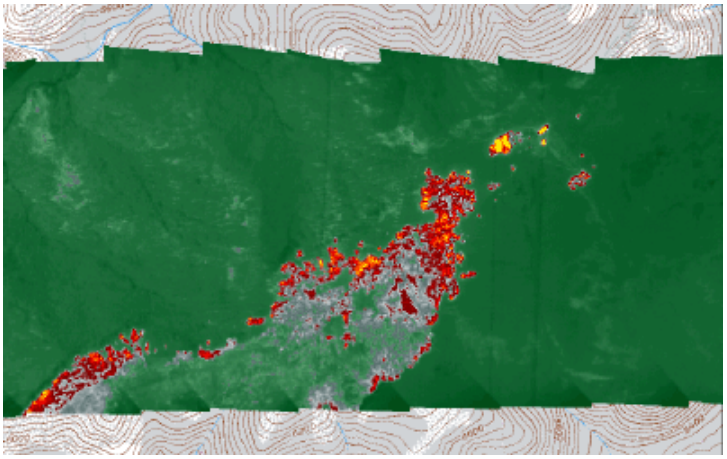


Image 6:
Mosaic of near-infrared light (850 nm) reflected from coniferous forest and smoke as viewed concurrently with Image 5. Here the obscuring effect of smoke is shown as a contrast to the fire information available at thermal-infrared wavelengths. Note the similarity of terrain effects between the sunlit and partially shaded slopes between this image and Image 5.

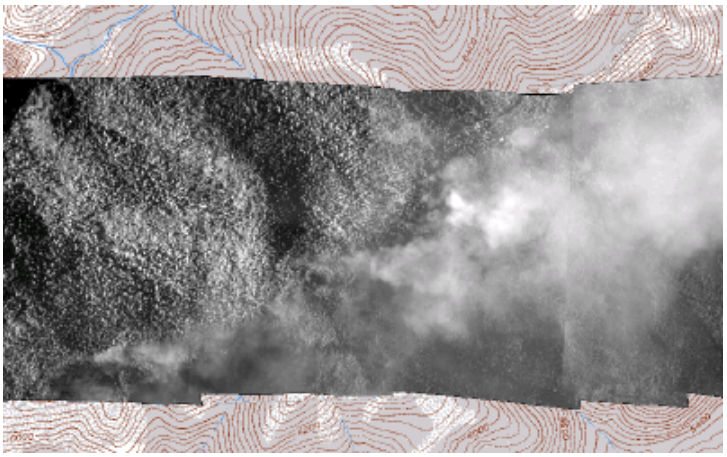
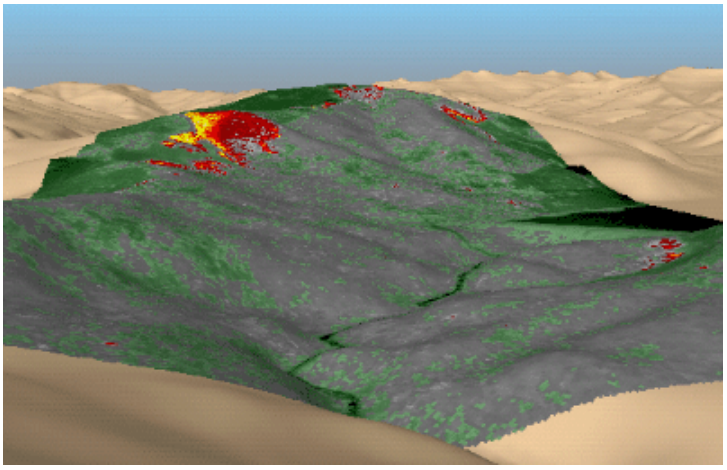
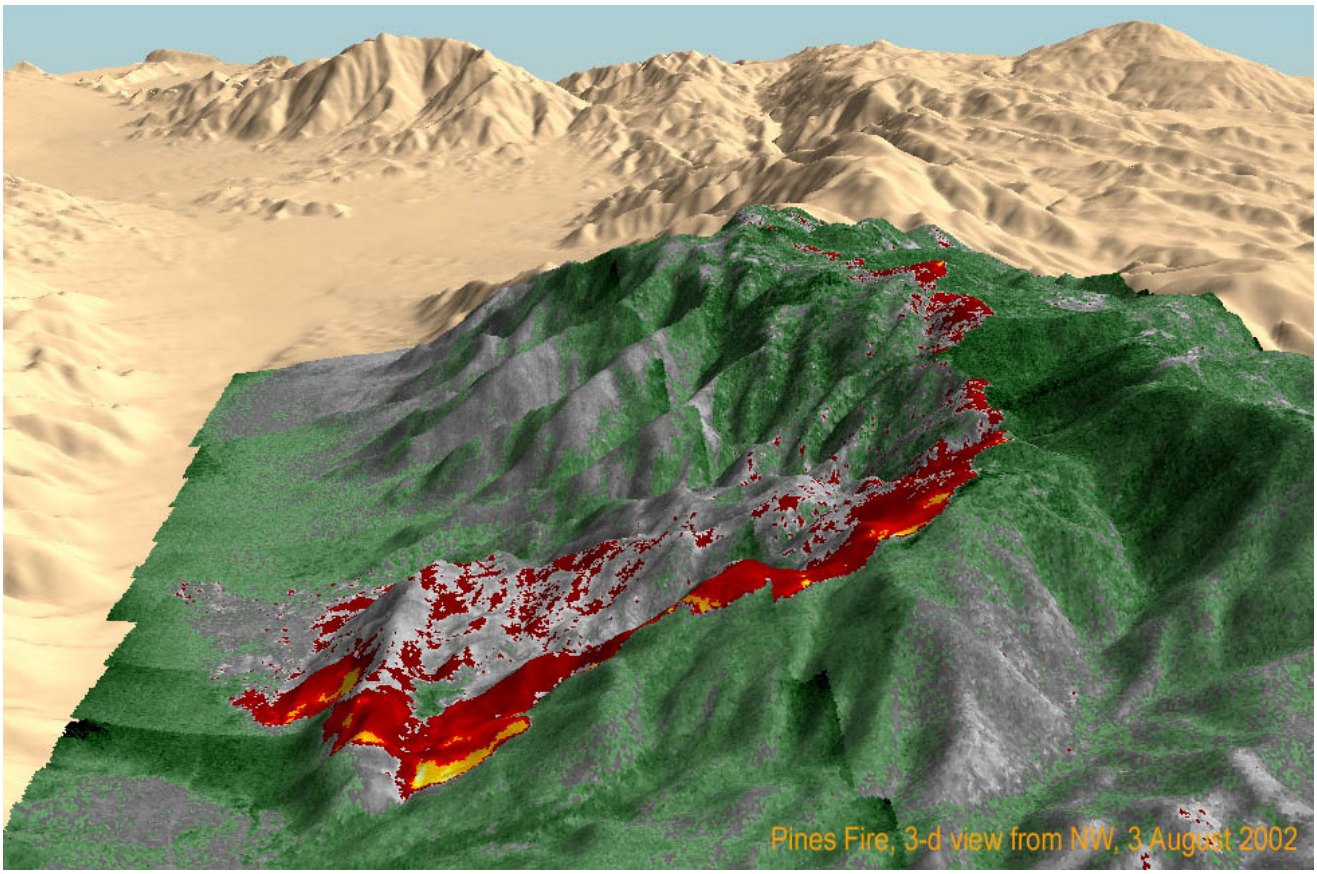


Image 7:
An air-attack view from the southwest at 14:15 local time shows the fire as it would appear from the perspective of an aircraft 200 meters above ground level. Generation of such images in nearly real-time could be useful in showing aircraft approaches and the relation of fire to terrain for planning fire retardant drops and for training flight crews. (This image has no vertical exaggeration.)





700 C
500 C
300 C
60 C
40 C
<40 C

Image 8:
False-color depiction of ground-surface temperatures as viewed from the northeast at 11.4- to 12.4-µm wavelength between 4:00 and 4:24 pm on 3 August 2002. The area shown is approximately 5 km from left to right. County Highway S2 is indicated by a faint track in the thermal imagery at lower left. Vulcan Mountain is the elevated terrain imaged at center and the right. The San Felipe Valley is the lowland at the left. The fire has burned from the left distance to the fire line indicated by high temperatures. Areas above 500° C at the left, shown in yellow, correspond with an active fire front burning in chaparral. Fire along the upper elevations of Vulcan Mountain is burning largely in understory vegetation and ground fuels of a mixed oak and conifer forest with lower attendant energy release rates and ground heating. Ambient wind is from the right with an inclined convection column reaching across Highway S2 on the left. Vegetation is sparse along the highway at lower left. An aerially applied fire-retardant line is visible as a dark-green stripe north of the bend in the fire line at right center. The color-coding of lower temperatures here shows some sparsely vegetated or solar facing slopes, such as at lower right, have similar temperatures to areas of cooled ash.

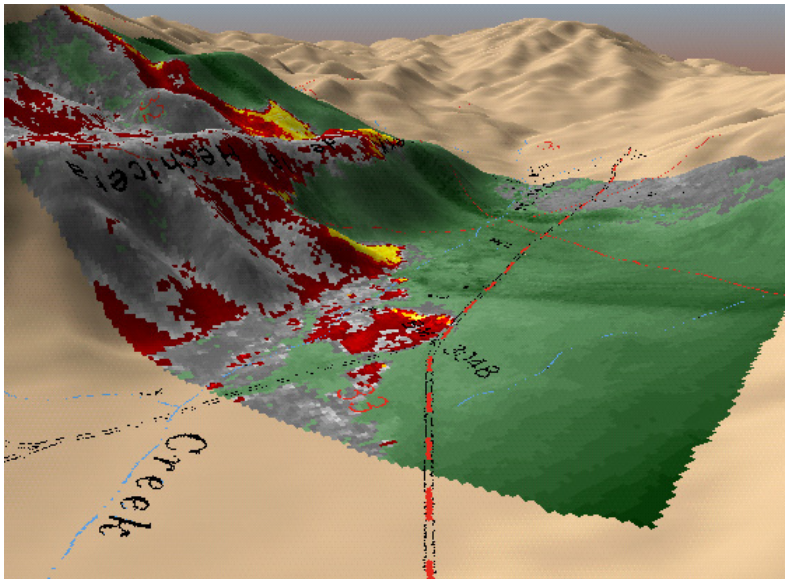


Image 9:
Ground-surface temperatures as viewed from the southeast at 8.1- to 12.4- µm wavelength (broadband thermal infrared) at 3:47 pm on 3 August 2002. County Highway S2 is shown by the dashed red line. Vulcan Mountain is on the left; lower elevation terrain is the head of San Felipe Valley. High temperature areas on the left correspond with an active fire front burning in chaparral. Areas along the highway are sparse vegetation. An aerial retardant line is visible as a dark-green stripe north of the fire line at upper left.

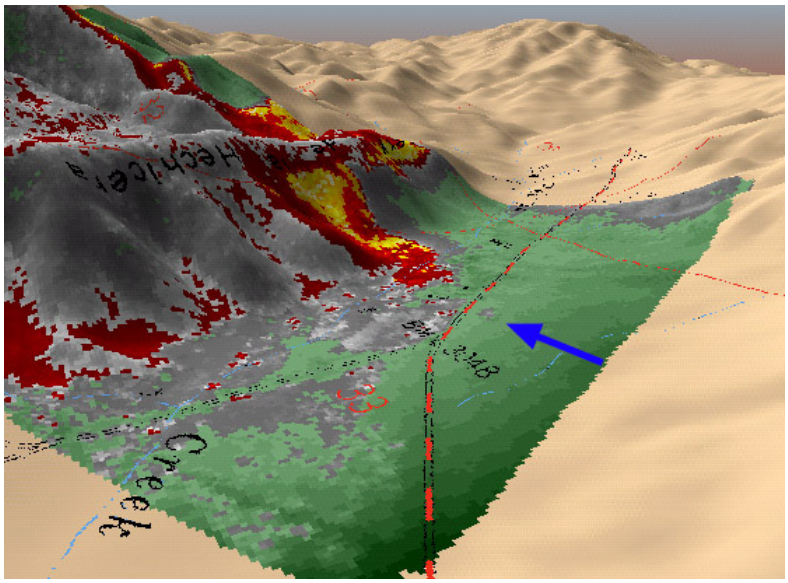
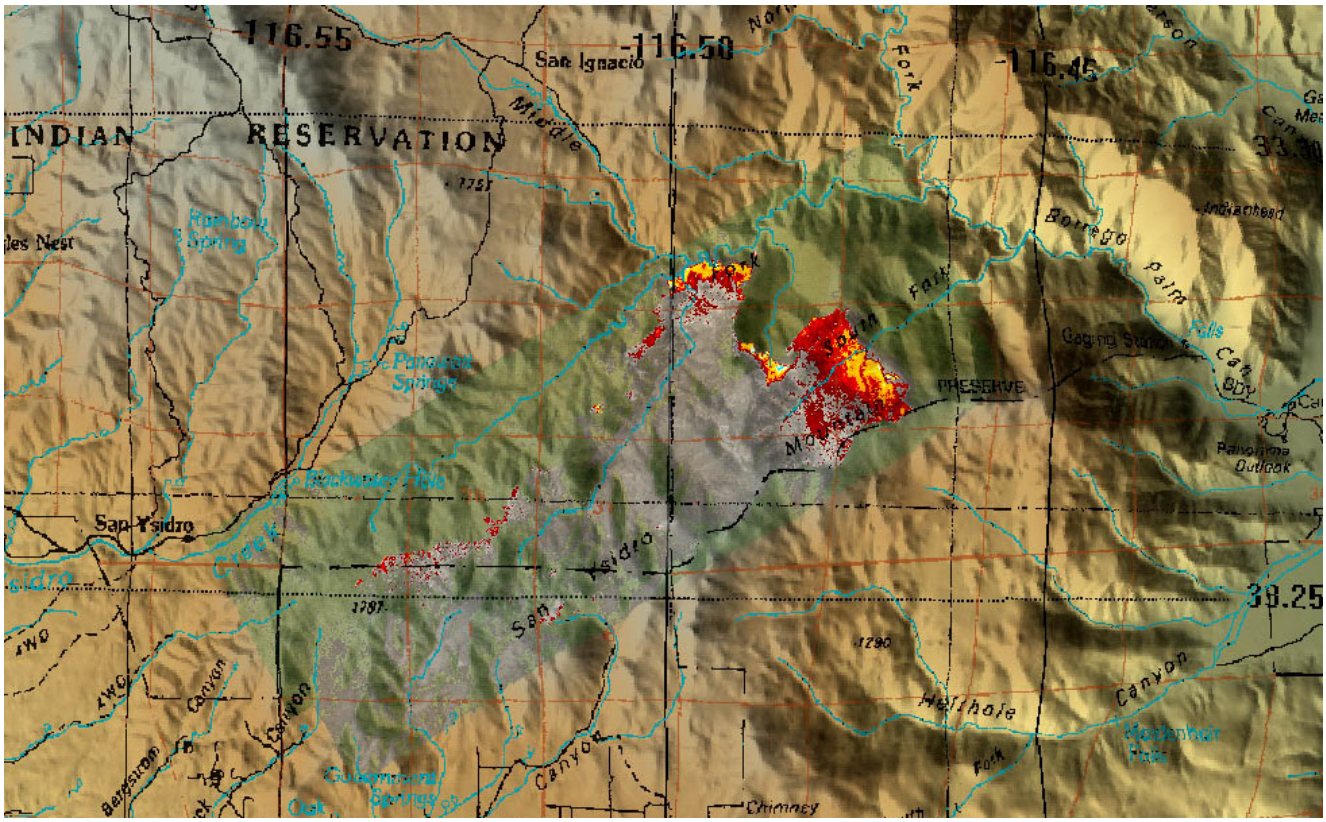


Image 10:
Ground-surface temperatures as viewed from the southeast at 8.1- to 12.4- µm wavelength at 4:13 pm on 3 August 2002. Note the elevated activity of the fire front along the fore slope of Vulcan Mountain and the reduced fire activity west of Highway S2. Wind direction is generally from left to right. Highway S2 formed an important firebreak for possibly containing this wildfire. Unfortunately, the fire spotted across the highway, in an area removed from the primary fire front, shortly before 4:13 pm (as shown by the blue arrow). From that point it continued through the community of Ranchita and burned to the edge of the Anza-Borrego Desert. Near-real-time thermal-infrared imaging with data dissemination to the Incident Command could prove useful, as in this case, for monitoring fire activity in critical locations around a major fire.



500 C
300 C
200 C
60 C
40 C
<40 C

Image 11:
Ground surface temperatures as viewed from above at 11.4- to 12.4- µm wavelength by two flight lines on 7 August 2002, between 5:24 pm and 5:32 pm, approximately 14 km northeast of the fire as shown in Image 8. Here the head of the Pines Fire has broken into three primary fronts in the South Fork and Middle Fork of Borrego Palm Canyon with widely varying rates of spread as indicated by the reach of hot ground behind the front. Each of the fronts is running with the ambient wind downhill. Also note the low level of activity on the extended lateral fire line running to the southwest from the more northerly head of the fire. This standard depiction of FireMapper imagery shows color-coded surface temperatures overlaid on a shaded relief map showing primary drainages, broad elevation, section lines, and latitude and longitude. The lower-temperature regions in the image have been made semi-transparent to show the map relief beneath. The temperature scale for the 7 August 2002 images is shown at left.

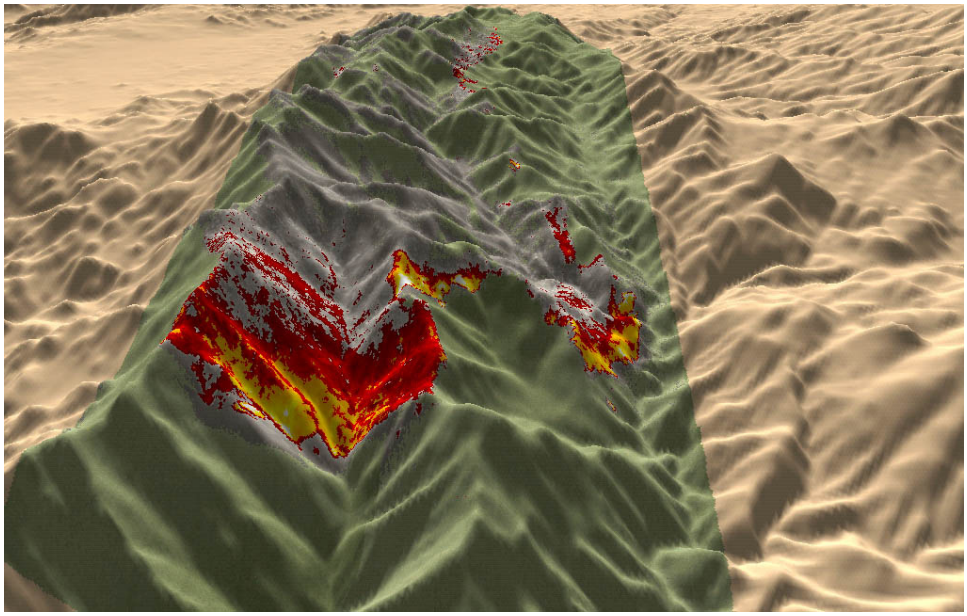


Image 12:
Topographic view as seen from the northeast of Image 11 between 5:24 and 5:32 pm.

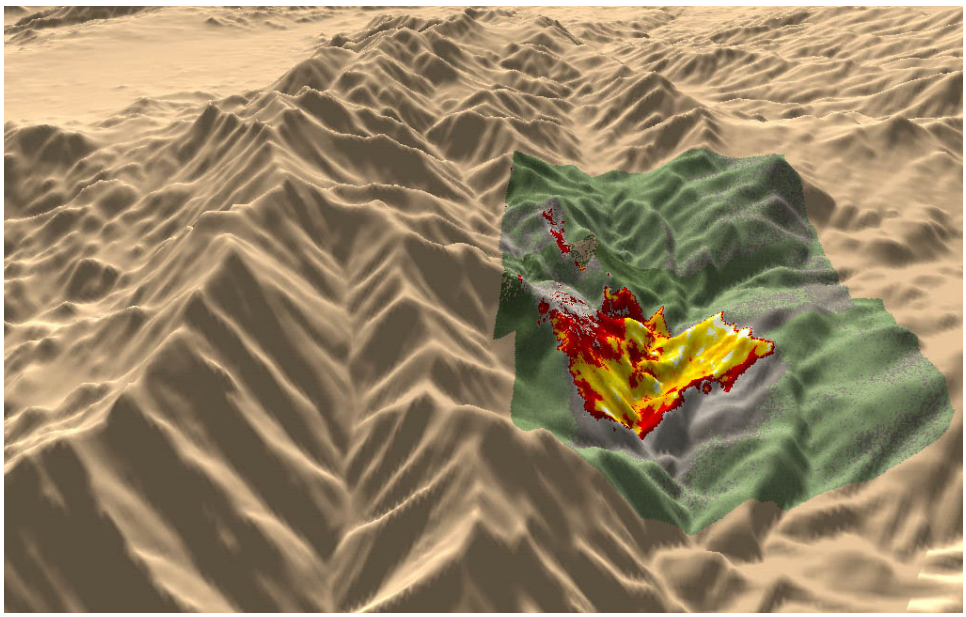


Image 13:
Topographic view, as in Image 12, between 5:54 and 5:57 pm. Here the northern-most section of the head of the fire has crossed the Middle Fork of Borrego Palm Canyon and is spreading rapidly up the south-facing slope of the canyon. (The southern portion of the fire was not imaged again at this time). Note the elevated temperatures at the leading edge of the fire and the wide reach of hot ground associated with this fast-moving fire with long flame lengths.

CONCLUSIONS

The FireMapper has been shown in practice to provide readily interpretable thermal imagery that can depict a wide range in fire-line activity. It can quantitatively measure surface temperatures across the range of wildfire conditions likely to be encountered from understory burning in coniferous forest to high-intensity fires in California chaparral. The FireMapper also has sufficient sensitivity to detect small spot fires and differentiate landscape surfaces by differences in their temperature signatures. As configured and operated, it can map substantial areas at a rate sufficient to characterize major fires. Delivery of compressed image data by satellite-based communication has proven practical and capable of providing timely and readily interpretable fire data to the Incident Command on major fires. Further improvements in the delivery rate are expected to allow near-real-time fire monitoring with attendant gains in fire-fighter safety and the efficiency of fire suppression operations.

ACKNOWLEDGMENTS

Development of the FireMapper has been supported by a grant from the USDA Small Business Innovative Research Program, the U.S. National Fire Plan, Forest Service International Programs, and Research Joint Venture Agreements between the Forest Service Pacific Southwest Research Station and Space Instruments, Inc. We wish to acknowledge the technical support of FireMapper operations by Robert Lockwood and Robert Lamar and the contributions made by Ron Grush, George Houghton, Lee Scotese, Gary Noyes, Glen Mounce, Bill Grush, and Ken Cashman of Space Instruments, Inc., in the design and fabrication of the FireMapper system.

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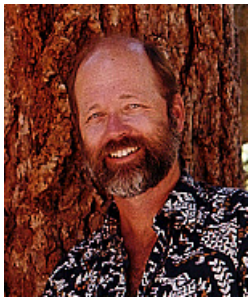

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Robert Tissell *is a computer specialist and image analyst for the USDA Forest Service, Pacific Southwest Research Station, stationed at Seattle, Washington. He earned a Bachelor of Science degree in Biology from the University of California, Riverside, in 1986 and has been employed by the Forest Service since that time. He has been principal analyst on projects with the FireMapper and for the Forest Service/IBAMA cooperation on fire and environmental change in tropical ecosystems.*

James Hoffman *has been Technical Director for Space Instruments, Inc., since 1980. He has over 25 years of experience in the design of electro-optical instruments for remote sensing and surveillance. He earned a B.E.E. degree from Cornell University and a M.S.E.E. degree from the University of Hawaii. He has been the principal investigator on contracts developing the Infrared Spectral Imaging Radiometer, the Thermal Imaging Radiometer, the NASA Cloud Top Radiometer and Earth Radiation Array, and Hi-Camp II. Previously he was a Senior Systems Engineer for Hughes Aircraft Company where he was systems engineer for the design of the Landsat Thematic Mapper. He received a DARPA Strategic Technology Office Special Award in 1987.*