Highlight Article

Project Sparkey: A Strategic Wildfire Monitoring Package Using AVHRR Satellites and GIS

David A. Prevedel

Wildfire is the ultimate agent of change. It is nature's way of ensuring diversity in the environment and has affected just about every aspect of terrestrial ecosystems. Historically, fires commonly occurred over much of the Western United States. Following settlement, we began to suppress fires and introduced factors such as livestock grazing which further reduced the fuels to carry widespread fires, or agriculture and irrigation which blocked such fires. After over 100 years of man's influence, the effect has been to increase the severity of wildfires, particularly in mountainous conifer forests. This is because with the absence of wildfire, fire fuels have been allowed to accumulate and build while the health of such forest ecosystems declined into older aged stands more susceptible to forest pathogen such as insects and disease. As a result, fires within the last decade in the Intermountain West have tended to become larger and more difficult to suppress (Yellowstone 1988, Central Idaho 1989, 1992, and 1994). Thus fire management has taken on the difficult task of trying to use fire as a tool to maintain natural ecosystem functions, while at the same time trying to protect a more dense urban interface within the forests (human life and property) and high resource values. Management of wildfire in the land management agencies such as the Forest Service, Bureau of Land Management, state organizations, etc. is a support activity which must recognize all these conditions. Fires can also be very costly to suppress and/or manage.

Wildfire managers need information for fire behavior prediction and planning. Such information includes weather, fuels, moisture conditions, fire activity, and actions underway. Entering as new tools to help us collect, manage, analyze, and display this information are Remote Sensing and Geographic Information Systems (GIS).

The 1994 fire season in the Intermountain Region of the Forest Service (Utah, Nevada, S. Idaho, W. Wyoming) was the largest since 1930 when the Forest Service began keeping accurate records. Early in June we recognized we were facing a critical wildfire situation. We earlier had used AVHRR (Advanced Very High Resolution Radiometer) data from the U.S. Tyros satellite series for post fire history (1988-89), and in 1992 we had utilized AVHRR to track the large Foothills fire on the Boise National Forest. Accessibility to timely data on this fire was delayed because we used overnight mail for computer tapes containing the satellite data. The ground receiving station in these early trials were through SEASPACE Corporation of San Diego, California.

In August, we made the decision to procure real time capabilities to access AVHRR data in support of the wildfire situation. As a result, during the last half of August and most of September of 1994, we monitored wildfire status in the Western United States for 45 consecutive days. The area monitored includes the states of Idaho, Utah, Nevada, Montana, Eastern Oregon and Washington, and Western Wyoming. Downlinked from a commercial receiving station (SEASPACE Corp.), satellite data was received in real time over a phone modem between San Diego, California and Ogden, Utah. In all, over 125 individual satellite passes were retrieved from the receiving facilities to the Ogden Utah site. The digital data was processed, enhanced, interpreted, and distributed over the Forest Service X25 dataline

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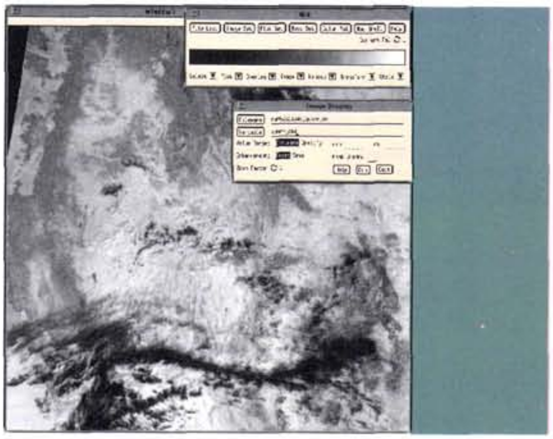
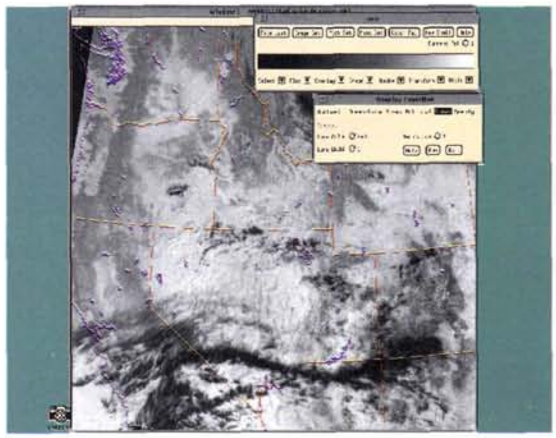
and/or in hard copy format, typically within one and one-half hours of a satellite pass. The X25 network connects over 800 Forest Service offices nation wide. Between three to four satellite passes were processed daily depending upon cloud cover and satellite angle (nadir) to specific fire locations.

The potential for using AVHRR satellites to monitor wildfires is mentioned in several literature references, however, this application is one of the first quantitative applications of a daily, long-term series of AVHRR data to monitor fires in real time. The use of AVHRR satellite data is a tool for a broad area overview of wildfire status. Its primary use is strategic and not generally tactical for individual fire management.

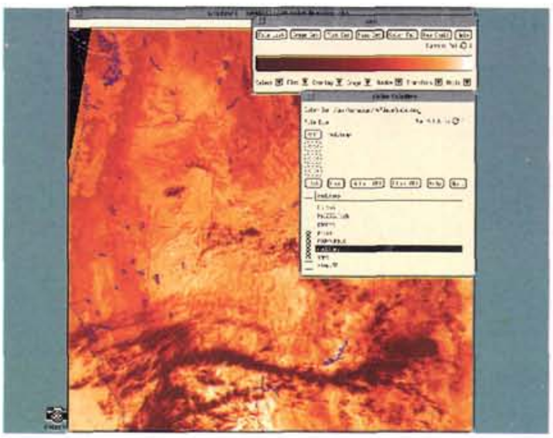
To understand the difference between strategic and tactical, one must understand the Multi-Agency Fire Management Organization. The Forest



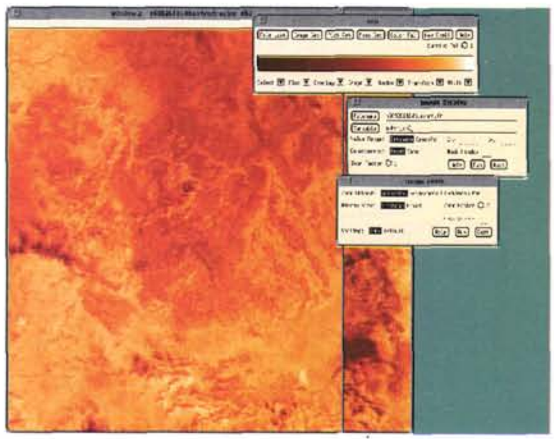
Geo-corrected image of Western United States.



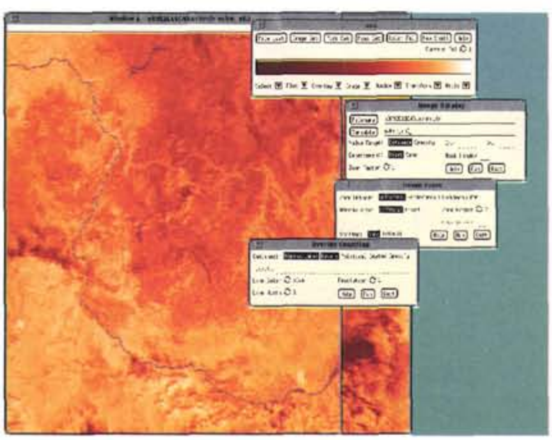
Adding State Lines for Reference.



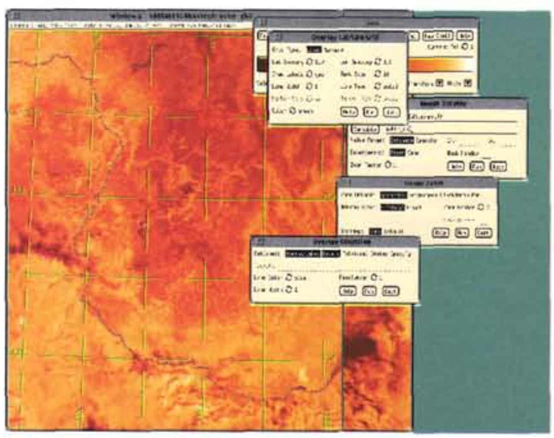
Color Enhancement (Contrast Stretch).



Zoom in to Area of Interest (Idaho Complexes).



Adding Major Rivers and Lakes Overlay.



Superimposing Lat-Long Grid for Final Display.

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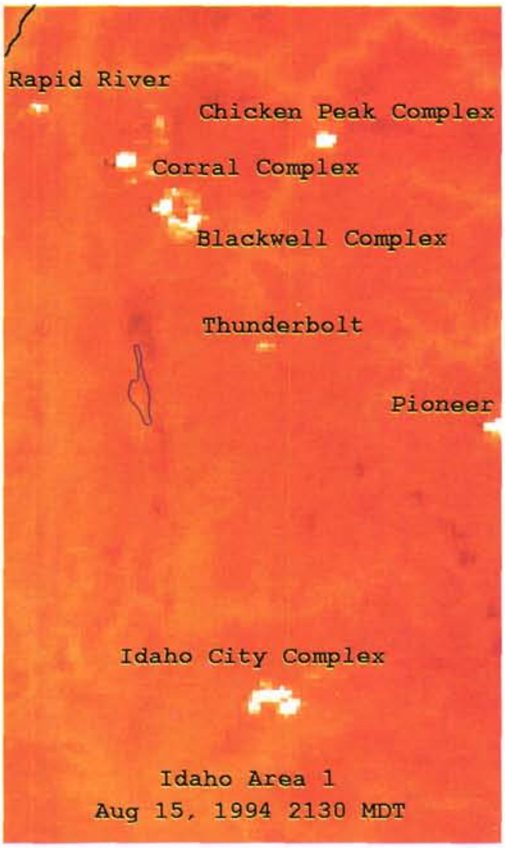
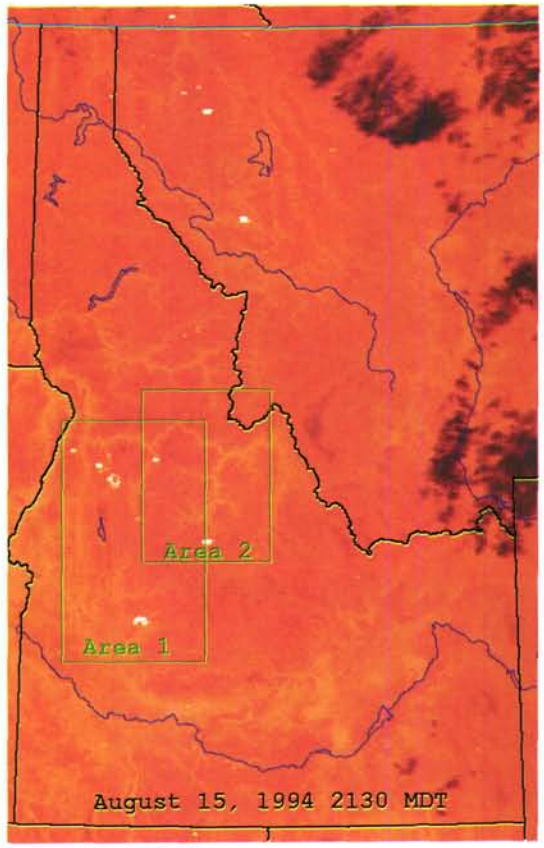


View of Idaho with Heat Intensities. White Areas Denote Fire; Dark Areas Are Clouds.



Zoom-in of Central Idaho.

Service and other agencies no longer manage wildfires as single entities. In this era of government efficiencies, federal and state agencies have merged facilities, equipment and personnel into wildfire management programs. The National Interagency Coordination Center (NICC) is located in Boise, Idaho. This unit has jurisdiction for the entire United States. Supporting NICC are several Coordination Centers. All the centers are considered the "Strategic" level and provide support for initial requests and orders for personnel, resources, and equipment to field units (Tactical) managing wildfires. During critical wildfire periods and the potential shortage of fire management resources such as existed in 1994, Multi-Agency Coordination (MAC) groups are formed at the Centers to develop management strategies to place limited equipment, fire crews, and other resources.

The real time AVHRR processing capabilities were acquired in Ogden, Utah during 1994 to support MAC groups at the Eastern Great Basin Coordination Center in Salt Lake City, Utah and the Missoula Coordination Center in Missoula, Montana.

Other customers were Agency executives, fire support staffs, and public information centers. In this current application, only limited use was made of the platform for wildfire detection and tactical (actual fire site or complex) applications, even though fires as small as 10 to 15 acres in size were commonly observed. The primary mission was to monitor on-going activity and provide a timely "picture" to multiple agencies covering several states. The system did provide some valuable tactical intelligence to the Missoula MAC group during initial 1994 blow-up situations when smoke obscured areas and overhead-support organizations were not yet in place.

Tactical operations are conducted under an Incident Command System (ICS), again composed of multi-agency personnel and resources, in assignments of command, operations, planning, logistics, and finance/ administration. Jerry Greer did a good job of explaining how remote sensing and GIS can support tactical wildfire operations in the September 1994 issue of PE&RS, pages 1059-1064.

Tactical responsibilities include fire detection-initial attack by local units, escaped fire situation analysis, and selected suppression action. The ICS organization is expanded as wildfire management conditions warrant:

- Extended attack (type

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III organization) of short duration, low resource value, little socio-political impact, no serious safety hazards.

- Type II organization for high resource value, rapid growth, multi-agency jurisdiction, safety/hazards/urban interface.
- Type I team - for most complex incidents.
- Area command - used when there is competition for scarce resources, multiple incident teams.

Strategically, the Coordination Centers and NICC supply the Type II and Type I teams respectively. But regardless whether strategic or tactical, application of federal wildfire policy needs timely wildfire intelligence and monitoring capabilities of which AVHRR type data can be of value. Decisions need to be based on good information. Broadly, federal wildfire policy defines the type of decisions to be made and the followup monitoring required:

- *Fire Policy Outside of Wilderness*
  Suppression - immediate attack and suppression in areas of high risk, hazards, values, or other conditions;
  Prescribe Fire - (a) ignited by managers to burn a specified piece of land to achieve identified treatments that render desired changes on the site, or (b) ignited by natural means, (usually ligntning) and permitted to burn under specified conditions and times. The overall objective being to maintain naturally functioning ecosystems in places where fires have burned naturally beyond historic times.

This is one of the first quantitative applications of a daily, long-term series of AVHRR data to monitor fires in real time.

- *Wilderness Fire Management*[1]

  Permit lightning-caused fires to play as nearly as possible, their natural ecological role within wilderness;
  Reduce, to an acceptable level, the risks and consequences of wildfire within wilderness or escaping wilderness;
  Two types of prescribed fires may be approved for use within wilderness: those ignited by lightning and allowed to burn under prescribed conditions and those ignited by qualified Forest Service officers; No fire may be ignited or allowed to burn without documented, pre-planned, specified conditions.

Equipment and Operations

The AVHRR (Tyros) system, operated by NOAA, is a five frequency sensor system with one frequency in the visible spectrum (band 1), one in the near IR spectrum (band 2), a mid-IR frequency (band 3), and two frequencies in the thermal spectrum (bands 4 and 5). Generally, for fire monitoring, band 3 was used exclusively. Data resolution of individual pixels or grid cells is 1.1 kilometer by 1.1 kilometer (or approximately 200 acres). However, due to high fire temperatures influencing an overall pixel, fires of 10 to 15 acres in size could be detected, as were commercial heat plumes from point sources such as smelters and smoke stacks. Tyros 11 and 12 were the satellite platforms used during the 1994 fire season. In raw 10 bit format, Band 3 data for each pixel is recorded in degrees Celsius (0 to 100 degrees).

Processing was accomplished through a three staged program involving (1) a commercial receiving station (Seaspace of San Diego, Ca.) to capture satellite data (analog to digital); (2) retrieval, analysis, and enhancement of digital data with Seaspace's Terra Scan image analysis software, and (3) vectorization, mapping, and distribution on an ARC/INFO GIS. This latter system has been bundled into an automated package, using a graphic user interface (GUI), for transport and migration to other computer systems operating on RISC technology.

The Seaspace TerraScan HRPT Antenna Server at San Diego, California acquires, archives, processes, and displays HRPT telemetry data from the Tyros-N polar orbiting weather satellite sensors including:

AHVRR -	1 km resolution multi-spectrall imagery
TOVS -	vertical sounding of atmospheric temperature and moisture
ARGOS -	Earth location and data relay from small transmitters mounted on buoys, balloons, wildlife, etc.

All data from all instruments are acquired and stored at their fullest resolution, however, for the purpose of fire monitoring, only AVHRR data was downloaded. The Antenna Server operates in a stand-alone fashion, or linked via Local Area Network (LAN) to other computer systems. The antenna has a 1.2 meter tracking dish coupled with a workstation computer. The system software includes processing of AVHRR data for precision navigation, radiometric calibration, etc., and also includes algorithms for cloud-screened surface albedo, temperature, atmospheric aerosol optical depth over water surfaces, and vegetation index.

The part of the system in San Diego (1) provided maps of satellite passes, predicted the satellite overflight time, angle, and height; (2) allowed clipping out of an area of interest from a global scene (a 1500x1500 kilometer area with the center near the northwest corner of Utah); (3) allowed the retrieval of all 5 bands of data or individual bands; (4) allowed the retrieval of either 10 bit or 8 bit data (8 bit data was used to keep compatibility with our existing GIS systems). Data was then retrieved to Ogden Utah via telephone modem.

SeaSpace Corporation provided a "turnkey" application to the Ogden Utah site on a Sun Sparc workstation with their TerraScan software package. This application included the software to preview satellite schedule data at San Diego and to process raster data retrieved at Ogden Utah. Part of the product included a 9600 BAUD modem using data compression between San Diego and Ogden. Standard TCP/IP and TELNET protocol was used for all data migration between platforms. At the Ogden site, the Sun workstation was connected to the ethernet local area network.

The Terrascan software included a suite of general image processing and display functions including: (1) image display overlain with lakes, states boundaries, latitude-longitude grid, and contours (federal land ownership was added as an overlay during this fire monitoring process); (2) image color enhancement (contrast stretch), pan & zoom, animation, and annotation; (3) interpolation to standard map projections, math, statistics, filtering, and sampling.

Once data was received, initial geo-registration was done to an Albers Equal Area projection, using automated routines in the software. This included (1) a general registration program using the center point and corners of the Area of Interest and (2) a visual navigation routine for final correlation of the raster image with cartographic feature data. Using these routines, the fires could be geo-referenced to approximately two to three pixels of actual ground location.

Then, fire complex windows were cut out of the western US coverage; the image was enhanced in color to contrast fire areas; and overlays illustrating major rivers, land ownership, and longitude-latitude grids with annotations were added. The unenhanced raster full image, together with all raster enhanced and annotated window images were then moved by Local Area Network (LAN) to an ARC/INFO GIS workstation. Following formatting in GIS, all these same raster windows were also moved via LAN to the Intermountain Region's Data General computer system which allowed Fire Coordination Centers, National Forests, etc.) to retrieve immediate fire intelligence data.

GIS processing at Ogden, Utah involved moving the raster data via local area network to a ARC/INFO GIS environment. Applications were written in ARC/INFO macro language (AML) for vectorization, cataloging, and displaying in the GIS.

For the purpose of fire monitoring, only AVHRR data was downloaded.

The GIS environment operated from a Graphic User Interface (GUI) developed locally in AML language, to automate GIS processes and facilitate its operation. Once moved and the naming conventions established, pre-processed and raw raster images followed two separate pathways: (a) the pre-processed images received image headers and then were stored in both the executive browse library (automated viewing for managers) and the Regional Four Data General system for external unit retrieval of the data. Hard copy color prints were distributed. And (b) raw raster images received in the GIS from the TerraScan processing were processed to vectorize high temperature pixels. This involved several steps:

Step 1 — Re-registration of the image to an Albers Equal Area Projection. Unfortunately, the image formats between TerraScan and ARC/INFO do not support the transfer of geo-reference data. Therefore, a program was developed in TerraScan to read the X-Y coordinates of the upper left corner of the image. These coordinates were then used in ARC/INFO to "project" the image back to a geo-referenced status (the pixel dimensions and number of rows and columns of data in the image remained constant in both formats).

Step 2 — A visual navigation routine was used for final correlation of the raster image with cartographic feature data. Like the routines in TerraScan, with the GIS routines, the fires could be geo-referenced to approximately two to three pixels.

Step 3 — Display of image and selection of pixel numeric range to represent fire temperatures. This isolated the individual high thermal reading areas or fires on the image.

Step 4 — Selection of fire areas to be vectorized by selection of individual pixel or groups of pixels, entering the fire name to be stored in the data base, and then executing the vectorization process.

Step 5 — Once the individual fires were vectorized, daily and/or cumulative plot maps were processed for the entire area of interest. Because of map accuracy considerations, output plots and supporting cartographic feature data scale was 1/2,500,000. The plots were then stored in the Data General system. Hard copy plots were also generated for distribution. Hardcopy size was 33" x 51".

Processing and Staffing

At the Ogden Utah site,

Images illustrating peak burn periods were used for vectorized fire mapping.

processing and workloads were organized into two primary objective areas once data was received. The goal was to (1) provide timely fire intelligence data, and (2) provide a cumulative fire history. In addition to attempting to get satellite views and enhancements on the Forest Service X25 network within one hour of a satellite pass, major daily products and enhancements were targeted to 7:00 am briefings at the Coordination Centers.

Before images were retrieved, they were preselected for Nadir angle. Images with angles to target fire complex area generally greater than 30 degrees were omitted. Once retrieved, they were geocorrected and enhanced by various techniques including histogram stretches and color. Overlays for geographical reference were also added. Specific windows or fire complexes by state were cut out. Fire names and other annotations were coordinated with National Inter-agency Center (NIC) reports every morning. The best views in reference to time of day, cloud cover, or other interference were then processed to hard copy. Images illustrating peak burn periods (between 5pm and 10pm daily) were used for vectorized fire mapping. Vectorized data was processed into maps showing daily and cumulative fire progress.

For the most part, NOAA-11 and NOAA-12 were used in the study. On Day 43, NOAA-11 ceased operating, and NOAA-9 was used to finish the final two days of data collection. NOAA-13 was not used because its orbit placed it almost directly behind NOAA-12 during the study period. Each platform, based on polar orbits of the Earth, made two passes each day of the Western US; however "true" nadir over exactly the same ground location was every five days. Each platform was at an altitude of approximately 430 miles. The passes between NOAA-11 and 12 were spaced approximately as follows:

NOAA-12	6:30 am MDT
NOAA-11	9:00 am MDT
NOAA-12	5:30 pm MDT
NOAA-11	8:00 pm MDT

Workforce management was divided among several primary tasks: (a) archive the data properly; (b) make the data available to other analysis sites and process; and (c) process the data for electronic and hardcopy distribution. Coordination with the NICC (National Inter-Agency Coordination Center) morning reports was imperative in proper fire identification, naming, and tracking.

Lessons Learned

Some sanitization of raw uninterpreted satellite data may be needed before it is made available for general use and display. For example, some scenes may be unacceptable for general distribution because of noise, interference, poor quality, clouds, etc. Therefore a screening process should be initiated wherein analysts receive and process the data, but general distribution to others is limited.

Considerations of Nadir are also important. Nadir refers to perpendicular position of the satellite to ground points of interest. The AVHRR system has a 55 degree angle of view from the satellite to the Earth horizons. However, an area of interest in the oblique view between 30 and 55 degrees would be highly distorted in the geo-correction process. This is because the interpreting software must interspace pixels into the area of interest image to meet Earth coordinate points (rubber-sheeting). Fire data can still be carefully interpreted from such scenes, however distribution of the raw image may cause confusion to the reviewer. As a general rule, selected images should be under 30 degrees satellite view angle to the Earth location.

The time of day of satellite overpass is important for several factors: (a) In fire detection and monitoring, fire activity (and thus visibility) is highly influenced by daytime heating and nighttime cooling with humidity gain and loss, and (b) Peak burn periods (around 3-5 pm) are also the times of greatest solar heating of the Earth surface. This high solar heating tends to make bare areas, rocks, lakes, etc., warmer than surrounding areas and thus more visible on thermal sensors. Based on general experience it is preferable to analyze images collected in the 9-10 pm timeframe (daylight saving time) of the fire area before nighttime humidity recovery suppress fire activity and after areas receiving direct solar heating have cooled down.

Clouds, particularly those containing moisture and ice, restrict the monitoring of fires. Smoke is not a major factor in fire monitoring and appears transparent when using Band 3 of the AVHRR series. Many of the images included in this article contain clouds which appear as the darker areas (cooler) whereas hot thermal areas, such as fires appear bright.

Two principle types of interference or data confusion were also noted during the project. These were lightning and sun reflection.

Lightning was noted and correlated to other lightning monitoring platforms on several occasions. Because it was impossible to separate or distinguish lightning strikes from new fire starts of a pixel or less in size, prediction of new fire occurrences required conformation on two or more individual satellite passes.

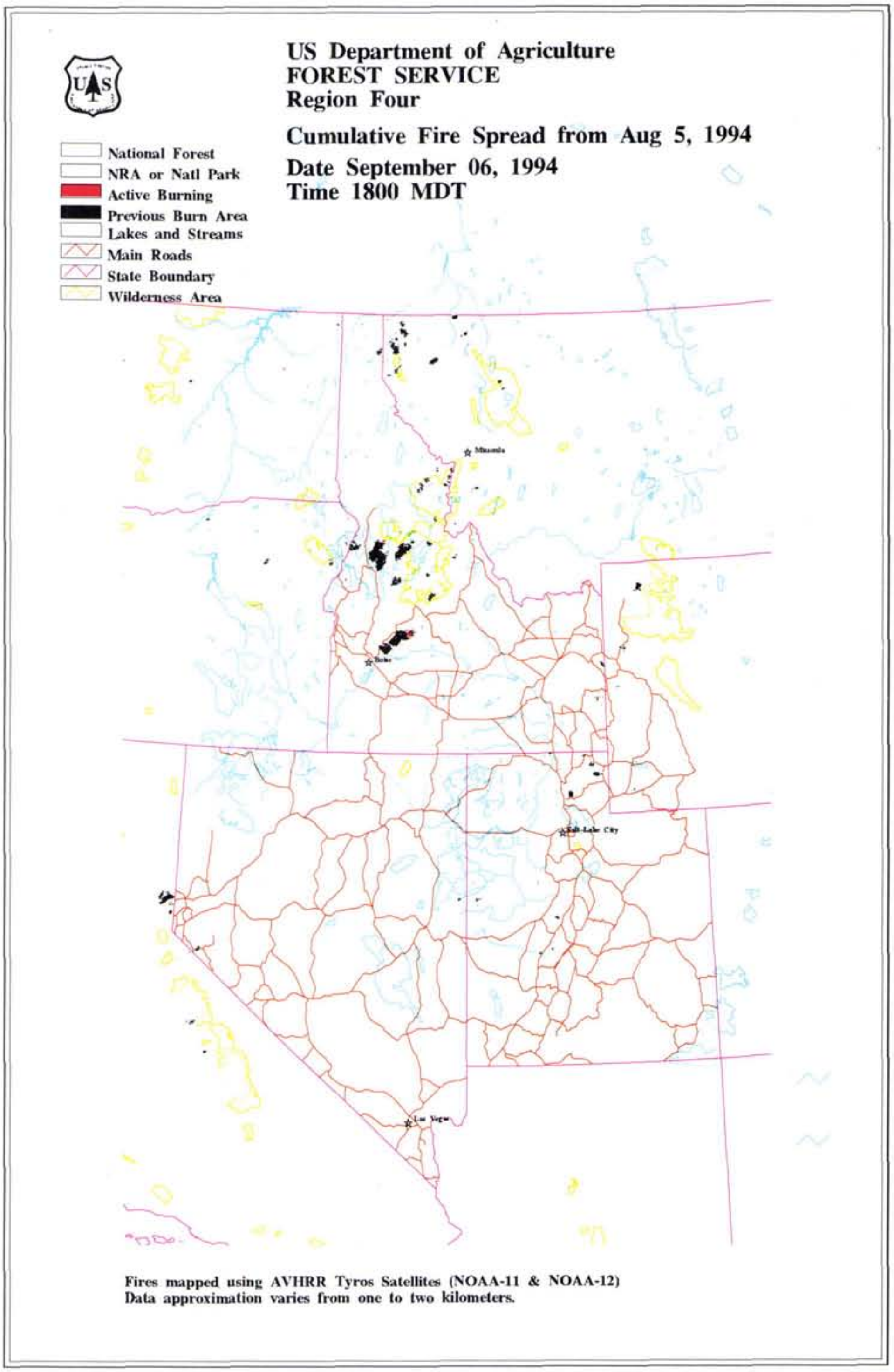
Sun reflection that highly confused image interpretations was noted as occurring about once a week on single images. This reflection appeared much the same as solar warming of specific ground features such as rock, bare soil, etc. except that water bodies, including small lakes and ponds, were most dramatically effected. Because the reflection was confused with high thermal readings, some images were difficult to use. Reflection problems occurred with both late in the afternoon and early morning satellite passes when for instance; (a) the satellite nadir was west of the target area and the sun was coming up in the East, or (b) the satellite nadir was east of the target area and the sun was setting in the West.

Future Developments and Applications

Future development would logically include expansion of the technology toward fire detection through the development of algorithms to separate background reflections from fire heat sources. Some preliminary work has been accomplished on this subject. The addition of 24-bit monitors versus 8-bit monitors also would significantly enhance spot fire visualization.

Major contributions to fire management can be made with the AVHRR tool in smoke management. Prescribed fire managers must exercise their responsibilities in a way that meets Clean Air Act standards (Public Law 95-95) and best serves the public interest. Prescribed fire stewardship emphasizes the immediate safety aspects of personnel conducting the burn; the health, safety, and property of others that may be directly affected by the fire, and the potential for off-site effects of smoke on public health and visibility. Prescribed fires produce varying quantities of smoke, an elusive by-product which can be a major concern. Land managers have been held liable and paid for damages caused by smoke from planned ignitions that impaired visibility causing traffic accidents, property damage, injuries, and fatalities.

AVHRR data, because of its wide view of several hundred miles and multiple platforms over target areas a few hours apart, can contribute to monitoring smoke impact, and



Fires mapped using AVHRR Tyros Satellites (NOAA-11 & NOAA-12)
Data approximation varies from one to two kilometers.

over-see favorable meteorological conditons to keep smoke emissions to a minimum. The visible, near IR, and thermal bands from AVHRR would be used to monitor smoke.

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AVHRR data has great potential as a public information tool. Public Affairs offices of the federal agencies, news agencies, and other media have much to gain from this broad strategic overview.

Additional fire applications could include expansion of wilderness prescribed fire monitoring to exclude manning some fires, mapping broad fire fuels or fuel loading ahead of fires, fuel moisture readings (greenness), and terrain analysis incorporated with fire behavior analysis. Vector files could easily be superimposed over shaded-relief topography maps, display in 3-D, and rotated in animation.

Other applications include vegetation monitoring, snow cover monitoring, hydrology, day/night temperature differentiation, and ARGOS animal tracking. Use could also be made of the AVHRR platforms for national emergency monitoring including floods, hurricanes, weather, and volcanic activity.

New satellite platforms to be launched in the immediate future would include the ability to map ambiant humidity, and not to be overlooked is the acquisition of data from military satellite platforms.

Products Displayed

Raster products were produced with the TerraScan system. Only band 3 was used for display with a contrast stretch to enhance the visibility of heat sources or fires. For ease of viewing in the concept of time, examples concentrate on the Idaho Fire Complexes for the duration of the monitoring program with scenes displayed progressively every four to five days.

Fires or high temperature pixels can be seen in white, while clouds are the dark reds and blacks. Note that smoke is basically transparent with this band frequency. Landforms can be distinguished in the orange colors. These raster images were processed with the SEASPACE TerraScan system.

Vector products were produced on the ARC/INFO GIS system using the GRID and ARC PLOT modules. Following vectorization of individual fires, cumulative fire progression maps were produced by state or region. Map scale is 1/2,500,000.

Map products produced at this scale covering several states were printed at 33 inches x 51 inches size for hard copy distribution.

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CERTIFICATION

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