United States
Department of
Agriculture

Forest Service

Fire Management Notes

Volume 52, No. 3
1991

Fire Management Notes An international quarterly periodical devoted to forest fire management

United States Department of Agriculture

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Fire Management Notes is published by the Forest Service of the United States Department of Agriculture, Washington, DC. The Secretary of Agriculture has determined that the publication of this periodical is necessary in the transaction of the public business required by law of this Department.

Subscriptions may be obtained from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

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A Salute to Infrared Systems in Fire Detection and Mapping

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Forest Service Infrared Anniversaries—1991, the 25th in Fire Operations and, 1992, the 30th in Research

The USDA Forest Service has been using infrared (IR) systems since the mid-1960's for fire detection and mapping. In 1962, research in the Forest Service began on IR systems, and in 1966, the first IR airborne line scanning system was moved from research to operations. The year 1991 is the "silver anniversary" of Forest Service operational use of IR detection and mapping systems, and, 1992, the 30th anniversary of Forest Service IR research. These are milestones. It is time to look at where the Forest Service has been and where it is going in its use of infrared fire detection and mapping and a time to take stock of what IR advancements have been made and how those advancements are to be used.

The Research Beginnings

For 14 years—1962 to 1976—infrared research was successfully conducted by Project FIRESCAN at the Intermountain Forest and Range Experiment Station with Stanley N. Hirsch, electronics engineer, as project leader (Warren and Wilson 1981). Working with him were Ralph Wilson, physicist; Forrest Madden, electronics engineer; and Dale Gable, electronics technician.

Remarkably, during this period, the basic theory of fire mapping and detection with thermal IR systems was developed. There are now new technologies and methods available for use, but the basic tenets still apply.

The early research and development was carried out in cooperation with the Department of Defense (DOD) Office of Civil Defense and the Defense Advanced Research Projects Agency. Many of the systems and much of what is now common, commercially available technology was classified information then. The late Bob Bjornsen served as leader of a separate team to develop fire mapping operational procedures (Bjornsen 1989). Later, Bjornsen, as the Forest Service Boise Interagency Fire Center (BIFC) director, was instrumental in establishing IR mapping and detection as a standard operational procedure. The operational reliability of the IR systems has been extremely high, due largely to the competence and diligence of the operational IR technicians. Now retired, Bill Barrus, supervisory IR technician for many years, was influential in this success.

The Forest Service airborne IR line scanning systems have always used basic line scanner "front-end," rotating mirror optics and dewar-detector assemblies from military systems, with some unique, critical Forest Service modifications. The Forest Service IR systems are the only ones in the world known to be designed and developed specifically for fire detection and mapping. (See "Forest Service Special IR Requirements.") Some of the methods used seem fairly obvious now, but to develop them back then took a good deal of inspiration, and no doubt perspiration, from Hirsch, Wilson, and others.

With the exception of Wilson's innovative, dual polaroid image system, the Forest Service IR line scanners have produced the IR image via unique synchronous and signal conditioning circuits on a strip of film. The film is exposed, processed, and developed on board the aircraft so it is ready to use when delivered.

What is IR?

It happens that all objects above absolute zero (–273.16 °C) in temperature radiate energy. At absolute zero, all molecular activity ceases, and there is no radiation. Since we do not encounter objects at absolute zero, all objects are radiating energy called electromagnetic energy. However, we cannot see most of this energy, except energy radiated at a narrow range (visible spectrum), or if the temperature becomes hot enough, we can then feel the radiated energy, such as from a hot stove. (See "Electromagnetic Radiation" and "Infrared Radiation" in "Primer on Infrared" and in the accompanying boxes, "The Ten Most-Asked Questions on Infrared" and "Answers" and "The Five Most Misunderstood IR Notions" and "Discussion.")

Energy can also be generated and radiated by other means. We are constantly subjected to a large range of people-made radiation fields. Consider the electrical power fields. These fields are present all over the populated areas of the world. In the United States, these are 60-hertz fields. (One hertz is equivalent to one cycle per second, meaning the energy field is "changing direction" 60 times per second.)

Radio Waves. AM (amplitude modulation) radio waves range from 550 to 1600 kilohertz (radio waves change direction 550,000 to 1,600,000 times per second). People do not see AM radio waves, or signals, nor do they feel them or have any other natural way of knowing they are present. But a switched-on AM radio (electroacoustic transducer) detects radio waves, processes them as electrical signals, and transduces those signals by a speaker so people can hear them as sound.

FM (frequency modulation) radio operates from 88 to 108 megahertz, and television, on both sides of those frequencies. (A megahertz—moving right along—is 1 million hertz or cycles per second.) People also cannot see, hear, smell, or feel energy radiated by the television broadcast systems, but our television antennas can pick up those signals, which are at a very low energy level, and pass them on to the circuits that amplify and process them. Voila! Stereo sound and action in living color.

Microwaves and Infrared. Higher in frequency, or shorter in wavelength, than the radio wave is the microwave. (Energy in the microwave band is used in microwave ovens, satellite television, and radar (*ra*dio *d*etection *a*nd *r*anging).) Just beyond the microwave band is the millimeter waveband and then the infrared. When a frequency is as high as 30 million megahertz, as it is for the thermal IR

Forest Service Special Infrared Requirements

The Forest Service has special infrared requirements not available on military or commercial systems:

- **Dual-band detectors**—Gives the Forest Service a unique method with about a 10-to-1 advantage in the detection of small hot spots. The target detection method and circuitry, using a special combination of two thermal bands, are not known to exist in any other systems.
- **Rectilinearization of the imagery**—Aids in the interpretation and transposing of fire features to maps. (The interpretation task is still performed manually and requires specially trained interpreters.) The scale of imagery is different in both the X and Y dimensions from the scale of the maps, and the X scale of imagery is constantly changing in a nonlinear manner.
- **Roll compensation and mileage markers**—Assists in making images more useful and easily interpreted.
- **DC (direct current) response-coupled systems (rather than AC (alternating current) coupled systems**—Prints terrain features of low thermal differences quickly, following exposure to extended high temperatures of 600 °C or more. (Without DC coupling, the imagery is "washed out" around very hot areas, precluding accurate location of the firefront position with respect to firebreaks, roads, and other identifiable features.)
- **Target detection circuitry**—Through a special circuitry mentioned under "dual-band detectors," gives the capability of detecting very small hot spots (capability of detecting a hot spot of 600 °C as small as 0.0225 square meter (0.24 ft^2) against instantaneous terrain background variations between 0 to 50 °C from 5,000 meters (16,404 ft) altitude.
- **Rapid processing of imagery on board aircraft**—Produces good quality images to ensure the fire is adequately covered and to minimize aircraft and crew operational time. (Fire staff needs to have imagery interpreted within 1 hour of flight over active fire.)
- **A large total field of view**—Covers large areas in a short time for detection missions and large fires in a single frame of imagery, rather than a mosaic, for mapping missions.

The Five Most Misunderstood IR Notions

1. **Thermal IR imagery is like black-and-white photography.**
2. **IR imagery should be as good in the daytime as it is at night.**
3. **IR imagery is just like film—everything is right where you see it.**
4. **One brand of IR "sees" through moisture or clouds better than another brand.**
5. **(Converse of IR notion No. 4.) All IR systems are just alike; it doesn't matter which type is ordered.**

Discussion

1. Thermal IR images resemble black-and-white photos or black-and-white television, but the images represent radiated energy levels in the thermal IR part of the electromagnetic spectrum, not reflected energy levels in the visible part of the spectrum. Some thermal IR images look somewhat like black-and-white pictures, but others look completely different.
2. At night, all the energy received in the thermal IR bands is radiated

band, it is customary to refer to this energy in terms of equivalent wavelengths, such as 10 micrometers. The thermal infrared bands are defined as 3 to 5 micrometers (microns) and 8 to 14 micrometers. (Wavelength has an inverse relationship with frequency: The higher the frequency, the shorter the wavelength.)

Visible Spectrum. Eventually, as the frequency increases, or wavelength

energy, giving a true indication of temperature levels (when emissivity is accounted for). In the day, in addition to the radiated energy, reflected solar energy and energy radiated from solar-heated rocks or bare spots may be confused with fire spots.

3. IR imagery from the line scanners always has terrain distortions. FLIR imagery also can contain similar distortions but usually to a much smaller degree. When "looking" straight down or at a low angle, the distortion is much less.
4. IR systems, whether line scanner, FLIR, or other type, are all subject to the same laws of physics, including atmospheric attenuation of IR energy. For this condition, various brands do not differ much, as has been shown in side-by-side demonstrations.
5. Design concepts and designs of various types of IR systems differ appreciably. Some are better suited for certain applications and conditions than others. The best choice can usually be made by considering the situation and conditions and choosing the type of IR system based on its capabilities and limitations.

The Ten Most-Asked Questions on Infrared

1. **What is infrared radiation?**
2. **Does an object have to be "hot" to emit infrared radiation?**
3. **Does the amount of infrared radiation vary with temperature?**
4. **What is a blackbody?**
5. **What is emissivity?**
6. **What is the relationship between emissivity, reflectivity, transmissivity, and absorptivity?**
7. **Are the FLIR's and IR line scanners basically IR cameras?**
8. **Can we determine temperatures with IR?**
9. **Does white indicate hot or cool areas?**
10. **Can we "see" through clouds and smoke?**

Answers

1. Infrared radiation is electromagnetic radiation with wavelengths longer than those of the visible part of the spectrum and shorter than radio or microwave frequencies.
2. No. All objects emit infrared radiation, which is related to the temperature of the object. Only at absolute zero (–273 °C) will an object cease to emit any radiation, including infrared radiation.
3. Yes. Infrared radiation is emitted over a wide band of wavelengths, but the amount of energy emitted at any one wavelength increases as the temperature is increased.
4. A blackbody is an object that completely absorbs all of the radiant energy striking it; that is, it is a perfect absorber, and also emitter of energy.
5. Emissivity is the ratio of the radiant energy emitted by an object at temperature T to the radiant energy emitted by a blackbody at temperature T.
6. All radiant energy striking an object must be either absorbed, reflected, or transmitted (on through the object). The sum of energy absorbed, or A, reflected, or R, and transmitted, or T, must equal 100 percent of the total incident energy: $A + R + T = 1$.
7. No. Thermal IR sensors are not cameras. They do not directly expose film to electromagnetic energy and do not depend on reflected energy for their usefulness. They are fairly sophisticated electro-optical instruments, displaying information from a part of the electromagnetic spectrum that we do not perceive without instruments.
8. Yes and no. Temperatures can be determined with IR under some conditions using special instruments usually called radiometers, but in the usual application of thermal IR for fire purposes temperature cannot be determined. We can, however, distinguish relative temperature differences.
9. Either—with most forward-looking infrared (FLIR) systems. Usually, the user selects the polarity of the video display so that either white or black may indicate hot areas.
10. Most thermal IR systems "see" fairly well through smoke but not well at all through clouds.

shortens, an interesting phenomenon occurs: People can see the radiated energy. Our eyes can reasonably detect energy between about 0.37 and 0.75 micrometers in wavelength. (Remember, a micrometer is only 1 millionth of a meter.) In fact, our eyes can sort these wavelengths out into various segments and that is how we see color. Green, for example, is the part of the visible segment of the electromagnetic spectrum falling between 0.4930 and 0.5770 micrometers. Wavelengths beyond 0.37 micrometers (X-rays, gamma rays, and cosmic rays) are no longer visible. Thus our natural ability to detect radiated energy is limited to a small portion of the spectrum which we call the "visible spectrum," although as mentioned earlier, we can feel heat in certain circumstances.

The sources of energy in the visible spectrum are the sun, stars, and artificial sources, such as light bulbs. In the daytime, to see an object, our eyes detect energy generated by the sun and reflected by the object our eyes are focusing on. If that object only reflects energy in the green part of the visible spectrum, then our eyes will see it as green. If it reflects energy all across the visible spectrum, our eyes will see it as white—unless the object does not reflect energy well—then it will be some shade of gray.

Even though we see energy only in the visible spectrum and feel radiated heat at certain temperature levels in another part of the spectrum, we know energy is everywhere. Sir William Herschel found this out some time ago. (See "How IR Was Discovered" in "Primer on Infrared.") Physicists and engineers have developed materials and methods for detecting energy in most parts of the spectrum. Detectors are usually transducers (for example, the radio)—devices that change one type of energy into another. In IR systems, detectors turn radiated energy at low levels into electrical energy at low levels. These low-level electrical "signals" can then be amplified to more usable levels and processed in various ways until they can be used to expose film or be displayed on a cathode-ray tube (CRT) or television screen in the visible spectrum. That's something like how our television systems turn signals into images people can see and—occasionally—enjoy.

Why Use IR Imaging in Fire Detection?

The varying energy wavelengths, as defined within the electromagnetic spectrum, have their own special characteristics—and limits. Within the visible spectrum, for instance, an observer cannot tell whether an object is hot or cool, unless it is "red hot" (glowing or ablaze), nor see well through smoke. Within the IR band, IR systems can detect thermal energy (how hot something is) and produce what is essentially a "thermogram" or a picture of the thermal energy content of a scene. They can do this through smoke, to areas of various size, and from a distance. Both visible and thermal IR energy bands are severely attenuated by moisture such as fog or clouds. (See "The Ten Most-Asked Questions on Infrared" and "Answers" and "The Five Most Misunderstood IR Notions" and "Discussion" in the accompanying boxes.)

Extending Our Sight. The importance of IR systems to the fire manager is immediately clear: Is that spot hot? In a smoke-covered area, what is the fire's perimeter? Where are the hot spots? IR systems can detect a hot area or spot, unable to be seen or accurately assessed by the eye, that could take off into destructive fire. The IR systems can also detect the land features where those fires and hot spots are located. IR systems extend our capability to "see." (See "Interpretation Complexities" in accompanying box.) For the U.S. military, IR systems are indispensible for such operations as detecting activities carried on at night or under camouflage. Electromagnetic energy found in other bands of the EM spectrum also contributes similarly: Consider what radar means to air controllers and X-rays to doctors, dentists, and security checkers.

Saving Money, Saving Lives. Most incident commanders who have had an opportunity to use IR will confirm that it can save money. IR intelligence also saves lives, keeping firefighters out of jeopardy. Dick Montague, retired Forest Service regional fire and aviation director, tells many stories illustrating the value of IR:

- A fire, thought to be cold, takes off when winds come up and inflicts heavy damage on high-value property. IR used for reconnaissance around the fire perimeter could have found the hot areas and the damage avoided.
- In another incident, IR was used to confirm that there were no hot spots or areas that might flare up. Crews were confidently released, saving the costs of keeping crews in the area as a precaution in case of another outbreak.

Interpretation Complexities

How hot is that roof? Can the time of day mislead interpretation of IR imagery?

To know how hot something fairly simple, like a roof, is through IR imagery, more information than might be expected is needed. Consider these situations:

- A metal roof with a high reflectivity may appear very cool if it is reflecting the outer atmosphere or may appear very hot if it happens to be reflecting solar energy—regardless of what its actual temperature may be at the time.
- A roof made of material that is a good absorber may appear warm, if on a house that is heated but poorly insulated, or cold if the house is well insulated and the outside temperature is cold. However, if the sun is shining, the roof may have been warmed by solar energy and appear warm even with a cold outside temperature.
- On a warm, sunny afternoon, rocks or bare terrain may be heated so that they are radiating enough IR energy to make it difficult to distinguish them from fire-related hot spots and the warmer terrain severely limits IR detection capability. During the day, water bodies will usually be cooler than terrain and at night warmer than terrain. Therefore, twice a day, usually early morning and evening, the water and land temperatures will be about the same, and water features will be hard to distinguish. After a rain (both day or night), land temperature differences will be small, and roads and features hard to see.

Small fires previously unknown can be found with IR detection missions, and appropriate action taken. Large fires with poorly defined perimeters can be located regardless of smoke cover, day or night, with IR mapping missions. Knowing the exact location of the fire perimeter and hot spots is a prime necessity in planning the suppression and control actions.

What Kind of IR Instruments or Systems Are Available?

Airborne IR Line Scanning Systems. Airborne IR line scanning systems have been the primary source of Forest Service IR information for the last 25 years. (See tables 1 and 2 for chronology of systems, fig. 1, and "Line Scanning" in "Primer on Infrared.") These systems have been highly reliable with exceptional small hot spot detection capability. They are able to scan large areas, over 1,000 square miles (2.590 km^2) per hour from selected altitudes and produce excellent hard copy imagery. IR line scanning systems are installed on twin turboprop-sized aircraft, flown (usually at night) by pilots, and operated by IR technicians specially trained in IR line scanning. (See fig. 2 for comparison of area scanned by various systems.)

Two important limitations to airborne IR line scanning systems are connected to timeliness: The length of time it takes to deliver a film image product, usually by landing the aircraft at the nearest available air strip, and to manually interpret imagery to locate accurately the fire perimeter and hot spots on a map. (See "The Five Most Misunderstood IR Notions.") The capability to transmit information from air to ground exists. Starting in 1974, air-to-ground transmission of the imagery has been demonstrated in several ways. These systems, however, have not been widely implemented, primarily because of the cost and complexity of the ground-receiving stations. There are only two mobile ground stations in the Forest Service that can be used.

Forward-Looking Infrared Systems. Small handheld or turret-mounted forward-looking infrared (FLIR) systems became commercially available in 1979. (See "Imaging-Nonimaging" and "Line Scanning" in "Primer on Infrared.") The previous FLIR systems were military, large and expensive. Since FLIR systems have become available commercially, they have been used increasingly for fire detection and mapping and for a number of nonfire applications as well. They have a much smaller field of view than the airborne line scanning system, and thus cover a smaller area, but they produce a clear IR image that can be recorded on a standard portable videocassette recorder (VCR) for subsequent viewing if required. Used with helicopters, they are a versatile tactical information source. They may be mounted in a turret or held by hand out the open door of a helicopter or small fixed-wing aircraft. (Helicopter operations are usually restricted to daylight hours.) They can provide much more detail of selected areas than the line scanners. When kept near on the incident command post (ICP), they can be ready for use on short notice. Several contractors have added FLIR capability to their helicopters.

FIRE MOUSE TRAP (First Generation). FIRE MOUSE TRAP[1] (FMT) (a name inspired by the then-

[1]Flying InfraRed Enhanced Maneuverable Operational User Simple Electronic Tactical Reconnaissance and Patrol.

Table 1—*A 30-year review of achievements in infrared imaging and the equipment and aircraft used*[1]

Year	Aircraft	Equipment	Results
1962	Beechcraft AT–11	AAS/5 scanner	First imagery through smoke. Preliminary detection of small fires under forest canopy.
1964	Beechcraft AT–11	AAS/5 (modified for Polaroid readout)	16 flights over wildfires, imagery dropped to fire camp. Data collected on detection probability versus scan angle in four coniferous types.
1964	Aero Commander 500B	AAS/5, Polaroid	49 flights over wildfires, experience in use of imagery for fire control.
	Convair T–29	AAS/5, KD–14 rapid film processor	No data due to equipment problems.
1965	Aero Commander 500B	Reconofax XI scanner	Preliminary evaluation, no data due to equipment problems.
	Convair T–29	RS-7 scanner, Litton CRT, KD–14, tape recorder	Data collected on detection probability versus scan angle in three coniferous and three deciduous timber types.
1966	Aero Commander 500B	Reconofax XI, Dual Polaroid	System delivered to Division of Fire Control for operation.
	Convair T–29	RS–7, Litton CRT, KD–14, tape recorder, APN 81 Doppler	Data collected on detection probability versus scan angle in one coniferous and two deciduous timber types. First fire patrols.
1967	Aero Commander 500B	Reconofax XI, Dual Polaroid	Operational.
	Convair T–29	RS–7, Litton CRT, KD–14, target discrimination module (TDM), Bendix DRA–12 Doppler	21 fire detection patrols.
1968	Convair T–29	RS–7, Litton CRT, KD–14, TDM, DRA–12 Doppler	Equipment modified for 2-color system and to reduce size and weight for installation in smaller aircraft.
1969	Beechcraft King Air, B–90	RS–7, Litton CRT, KD–14, TDM, DRA–12 Doppler, 2-color temperature discriminator	Testing and 25 regular fire detection patrols. Two detector problems.
1970	Beechcraft King Air, B–90	Same as 1969	Detector problems solved. Successful test. 41 regular detection patrols and 15 large forest fires mapped.
1974	Sweringen Merlin	FFS–1 Forest Fire Surveillance (modified RS–7 to RS–25)	Procured for National Forest Systems.
1983	Beechcraft King Air, B–90	FLAME unit[2]	Built to Forest Service specifications of FIRESCAN Research. Forest Service supplied line scanner main frame and image recorder. Jet Propulsion Laboratory (JPL) updated electronics and assembled system.
1985	Beechcraft King Air, 200	FLAME unit[2]	(Older Beechcraft Queen Air was retired from IR service, reducing IR line scanner capability from 3 to 2 aircraft.)
1991	Sweringen Merlin	FLAME[2] and preliminary Firefly system equipment	Initial airborne testing of Firefly electronics, coupled with FLAME IR system.
1992	Sweringen Merlin	Firefly system No. 1 and No. 2	Acceptance testing of 2 operations. Firefly systems (scheduled).

[1]Updated table from John Warren's and Ralph A. Wilson's "Airborne Infrared Forest Fire Surveillance—a Chronology of USDA Forest Service Research and Development," U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, Gen. Tech. Rep. INT–115, August 1981. System and equipment development was conducted within Project FIRESCAN program from 1962–1974.

[2]Fire Logistics and Mapping Equipment, latest of the traditional line scanners.

Table 2—*Airborne line scanning systems*

Item	System				
	HRB Singer (Queen Air)	Texas Instruments RS–7 (King Air)	Texas Instruments RS–25 (Sweringen Merlin)	FLAME[1]	Firefly[1]
Scanner (receiver)					
Design age	1962	1962–69	1962–73	1962–81	1990
Date acquired	1964	1965	1974	1983	199
Operational date	1966	1971	1974	1983	1993
Source	Purchased by Office of Civil Defense and "given" to the Forest Service.	Purchased by Forest Service Research, used about 6 years, then transferred to National Forest System.	Modification of RS–7 and AAS–18 to produce RS–25	Basic RS–7 scanner with improved signal processing	Daedalus Corp.
Image producer					
Type	Polaroid	KD–14 wet chemical	Electro Mechanical Research dry silver.	Dry silver	No hard copy image. A video monitor is on aircraft. Fire data are transmitted to the ground on a map.
Design age	1965	Late 1960's	1969–1970	1981	1990
Source	Laboratory prototype built by Northern Forest Fire Laboratory (NFFL).	One of 14 military prototypes built and then dropped. Went to dry silver, then back to wet chemical.	Note: a later model dry silver image producer was procured by NFFL for FIRESCOPE in 1975. Modified for wet chemical in 1975–76.	EDO-Western	—

[1]Infrared systems can be operated in any Forest Service infrared aircraft.

Assistant Director of Fire Operations John Chambers when he compared the moving of a mouse around the fire perimeter on a computer screen to the flying of a helicopter along the fire perimeter) is a system using FLIR. In 1984, the FMT was conceived and, since then, developed into a useful fire mapping system (Dipert and Warren). (See fig. 3.) The first operational use of FMT was in 1985 with a system developed jointly by the Forest Service and the Alaska State Division of Forestry. That FMT system, named TROLL,[2] is described in detail in Ronald G. Hanks' doctoral dissertation (1986). The FMT has been used successfully on many fires in several regions each year since its introduction.

To gather information, a FLIR, mounted on the helicopter or small fixed-wing aircraft, is used to guide the pilot around the fire perimeter and to identity hot spots. On this flight, a LORAN-C navigation receiver determines the latitude and longitude coordinates of the aircraft every 2 seconds, and sends data via an RS-232 interface to be stored in a laptop personal computer (PC).

On completion of the flight, the PC is connected to a drafting plotter and the fire perimeter and hot spots are plotted to scale on a U.S. Geological Survey (USGS) quad-sheet size overlay in a matter of minutes. The plot is as accurate as the pilot's ability to fly over the fire perimeter, minus navigation and electronics error. This method of fire mapping does not depend on an intermediate, indirect step of producing a film strip image with a variable,

[2]Thermal Recorded Observation and Loran Locating.

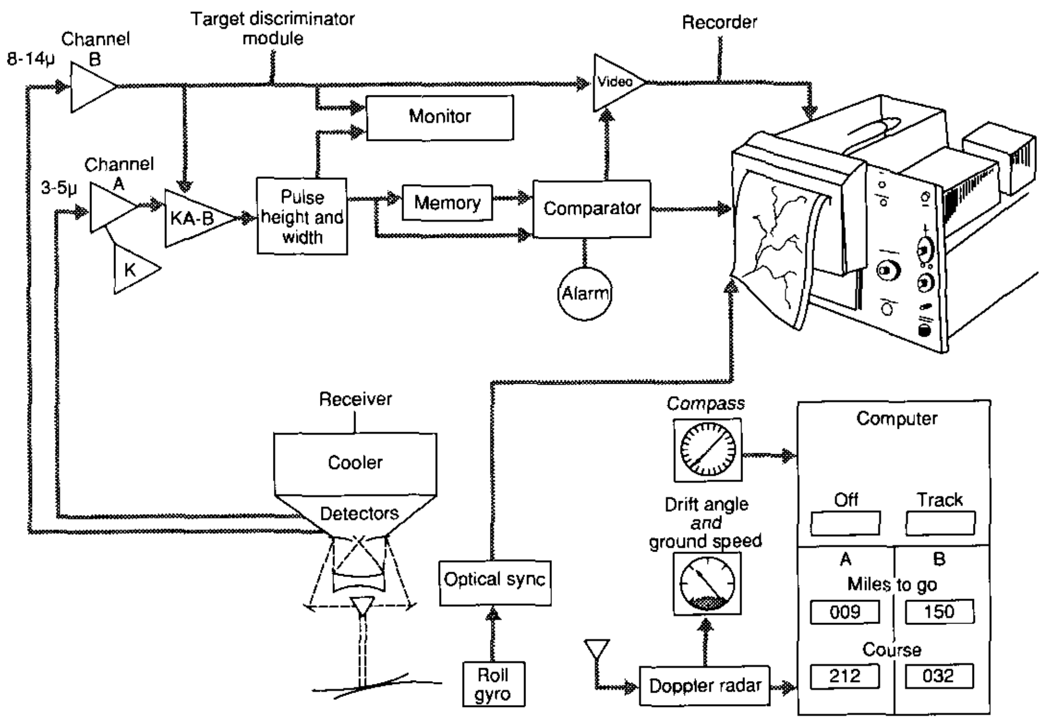

Figure 1—*The traditional infrared fire surveillance system used in airborne line scanning.*

nonlinear scale, which must be transposed to a map with a different scale. A video of the FLIR flight, which includes the latitude and longitude location from the LORAN-C, is made on a VCR for subsequent viewing. A color television video, particularly useful for viewing surrounding background terrain and foliage, can be used as an alternative to the FLIR video, but that video will not contain any thermal information.

The data can be transmitted from the aircraft to the ground, via a common Forest Service radio connected to the PC with a packet modem. Usually, when using a helicopter, the transmission capability will not be needed because the helicopter can land near the ICP and the notebook PC or a floppy disk with the data is readily available for plotting the perimeter and hot spots.

Some contractors have added the FMT capability to their helicopters. There are also a number of FMT systems and trained operators in various Forest Service regions.

FIRE MOUSE TRAP (Second Generation). The FMT has developed to a stage that might reasonably be called a second generation of FMT, or FMT II. The FMT IR mapping system, the "most modular" of all the IR mapping systems, can use new components as they are developed or become available commercially. The FMT II is a menu-driven system, uses MS-DOS, and consists of a GPS receiver, a notebook-sized PC, and a new, less expensive plotter.

Some regions have already successfully demonstrated the FMT method using GPS. Douglas Luepke of the Southern Region, Philip Drake of the Northern Region, and Byron Bonney of Clearwater National Forest are among those who have successfully used GPS (FMT style) for fire mapping (Drake and Luepke 1991; Bonney 1991). Others such as Gary Bergstrom of the Rogue River National Forest has used the method for nonfire area mapping (Bergstrom 1990). Tom Bobbe of the Nationwide Forestry Applications Program (NFAP) has demonstrated GPS with real-time differential correction (Bobbe 1992). Differential correction with post processing of the GPS data has also been demonstrated. Richard Myhre of the Methods Applications Group of Forest Pest Management, Washington Office, has also successfully mapped pest-infested areas using some of the GPS-FMT concept and equipment (Myhre 1990).

FMT "Super System." An FMT "super system" has the capability of transmitting a FLIR or color television video to an ICP or other location in real-time. Two super systems are available in Pacific Southwest Region; one, in Los Angeles County; and one, on the Eldorado National Forest. John Bryant of Pacific Southwest Region South Zone and Robert Woods of the Eldorado National Forest have been instrumental in establishing this capability. Both of these super systems work in conjunction with a mobile receiving station that can be driven to an appropriate location near the ICP. Fire staff on the ground can observe, in real-time, the fire in progress as shown by FLIR or color TV presentations. (It may not be national network, but it's not bad!) Alaska Region has a capability similar to the super FMT systems, but without the live video transmission capability. Dennis Pendleton, formerly of the Alaska Region and now in Fire Planning Cooperative Programs in the Washington Office, and Cathy Scofield, Alaska Region cooperative fire specialist, and the Alaska Department of Natural Resources, Division of Forestry, all actively supported the development of the FMT capability

Pyroelectric Units. The pyroelectric unit is an IR imaging system using a different physical phenomenon for IR

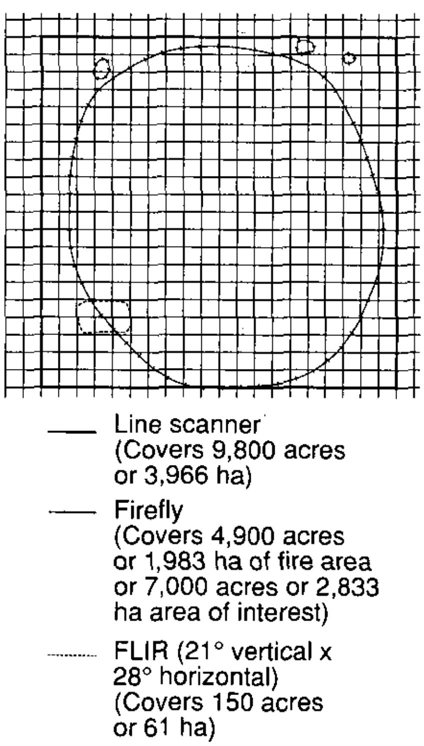

Figure 2—*Area coverage (6,000 ft or 1,829 m) from the airborne line scanning, the forward-looking infrared (FLIR), and the Firefly systems.*

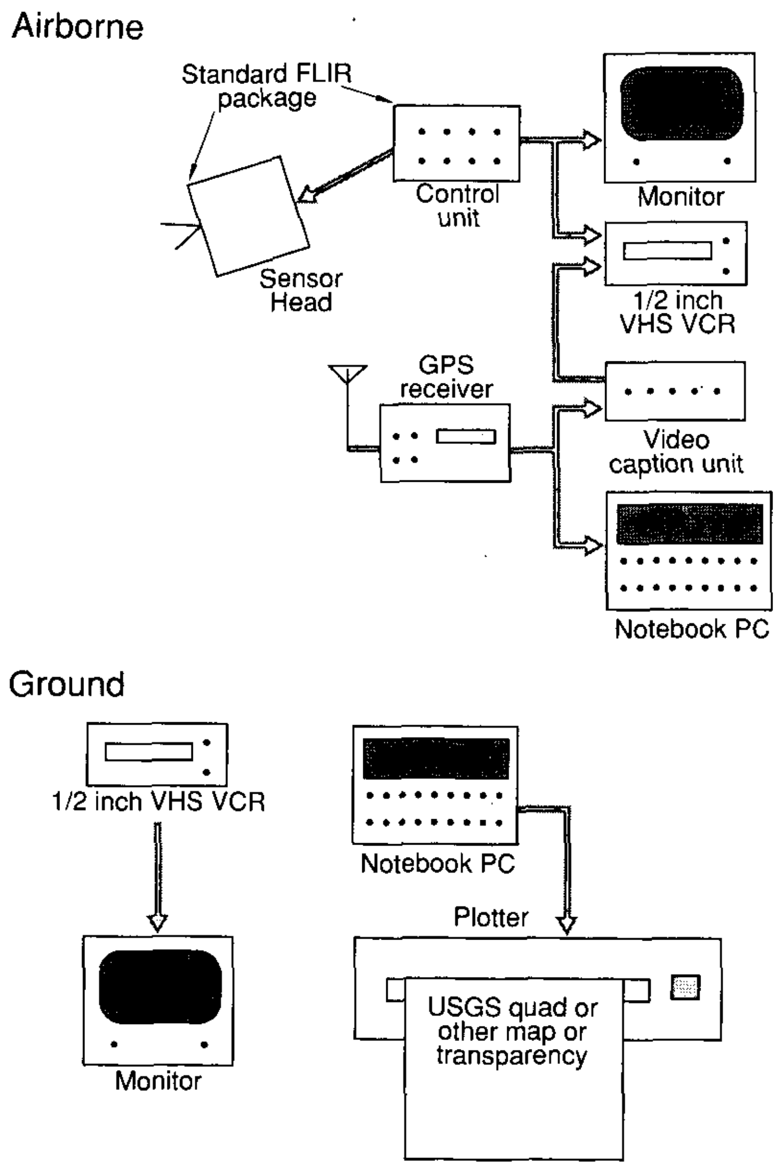

Figure 3—*FIRE MOUSE TRAP system (airborne and ground operations) using a forward-looking infrared (FLIR) system.*

detection called the pyroelectric effect. The pyroelectric unit uses a pyroelectric detector that depends on the rate of change of the detector temperature rather than the actual value of the temperature. The heating effect of the incident radiation causes a change in some physical or electrical property of the detector. (See "Infrared Detectors" in "Primer on Infrared.") The instruments used in this system are called pyroelectric vidicons (PEV's). The image quality of the PEV is not as good as that of FLIR imaging systems, but is adequate for many fire situations. Jim Scott of the Southern Region has used PEV's effectively on fires of various sizes and conditions. Pyroelectric units do not require liquid nitrogen like the line scanner or FLIR systems do; are handheld, portable, simple, and straightforward to operate; and produce a video image that can be recorded on a standard VCR.

Hughes Probeye and Nonimaging Units. The "venerable" Hughes Probeye produces only a rudimentary image. It is a cryogenically cooled instrument using pressurized argon gas as the coolant instead of liquid nitrogen or a mechanical refrigeration method. The output of the scanned detectors is displayed on an array of red light emitting diodes (LED's). The relative brightness of the LED array produces a basic image, characteristically red-tinted. The Probeye is portable and easy to use. Its main disadvantage is the lower quality image and the need to handle and keep a supply of pressurized argon gas.

The nonimaging units only give an indication by a light, noise, or meter that there is something hot in the direction that they are pointed. They can be helpful in examining previously burned piles of material or lines to see if there is any latent hot spot that cannot be seen visibly. (See "Imaging-Nonimaging" in "Primer on Infrared.")

Sources for Equipment. Forest Service IR systems seem to fall in that never-never land between military and commercial systems. Forest Service systems do not have the same performance needs as the military, but some needs, such as for airborne line scanners, exceed those of the military. For instance, the Forest Service need to detect very small hot spots exceeds that of the military. DC coupling is not usually needed by the U.S. military, but the Forest Service needs this feature to fly over large fires and retain the ability to see terrain details right next to the large hot areas, develop and review film on board the aircraft, and refly the fire if necessary. (The military might like that capability, but not dare fly back over an area too soon—they would probably get shot down!)

Forest Service systems have performance needs beyond what's available in the commercial market of line scanners, but the quantities we need are too low to get the attention of any manufacturer. In the case of the FLIR and PEV, we are able to use the commercial product line equipment as marketed. For FMT, we have been able to use all commercially available equipment, integrating and interfacing among the various subsystems so they all work together as planned. For instance, the FLIR can be interchanged with other FLIR's or PEV's; the GPS's and the LORAN-C's can be interchanged within kind and with each other; notebook computers can be substituted for laptop.

That we have adapted to commonly available commercial units lets us take advantage of a much lower price than what we would have to pay for specially developed equipment or items procured to mil specifications. We can take advantage of declining costs, usually associated with large quantity purchase. This also has the advantage of being able to adapt easily to new equipment as it comes along. The FMT II, incorporating new technology and components as they become available, for example, does not use any of the original FMT equipment, yet retains compatibility, while taking advantage of cost, size, weight reduction, and performance improvements.

Some contractors have added the FMT capability to their helicopters. There are also a number of FMT systems and trained operators in various Forest Service regions.

The Latest and Future IR Systems

Airborne IR Line Scanning Systems. The Firefly system is an airborne IR line scanner system with substantial changes from the traditional methods of processing and presenting IR data. Firefly uses the GPS satellite-based navigation system for aircraft location. In the future, Firefly will use aeronautical satellite communications for the transmission of IR data (see fig. 4).

In Firefly systems, IR technicians process data on board the IR planes, probably jet aircraft, and transmit this data by way of satellite. Then, within 30 minutes or so of a completed flight, the ICP receives fire and hot spot location information. While the data are being transmitted, the aircraft is able to go

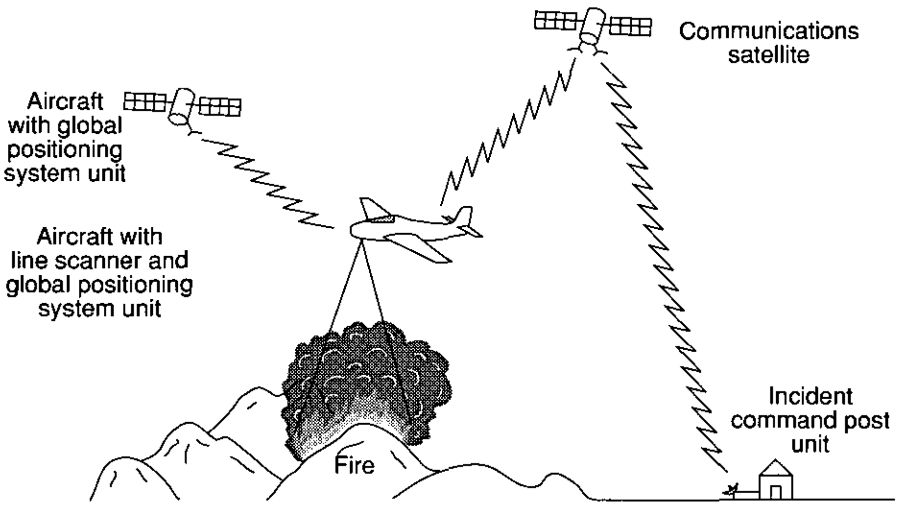

Figure 4(a)—*The Firefly concept.*

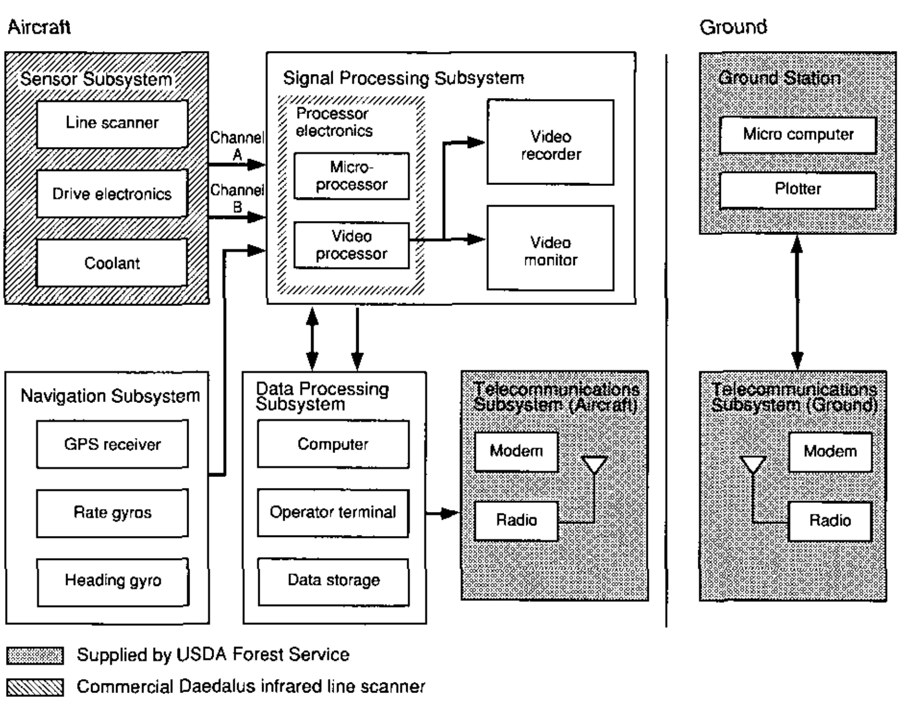

Figure 4(b)—*The Firefly system (airborne and ground operations.)*

directly to the next fire. Firefly eliminates the time-consuming aircraft landing at the nearest available field for physical delivery of the IR image.

Firefly locates all hot areas and hot spot positions and establishes an "intensity level" with each, but not the burned perimeter. The entire image, it is anticipated, can be transmitted by satellite eventually, along with the hot area and hot spot locations, so that relative positions can be readily determined. Firefly will use commercial line scanners, not the military line scanners that have been used for 25 years.

Firefly has been under development for the last 4 years. Tests of the system will be completed by the end of September 1992. Two operational Firefly systems are scheduled for delivery to the Forest Service in fiscal year 1992. Because the Department of Defense imposes accuracy limitations on GPS and aero satellite communications are not yet reasonably available, the Firefly system's potential may not be realized fully for a few years.

FLIR–FIRE MOUSE TRAP. The use of FLIR–FMT for fire mapping and detection will increase as fire managers recognize and understand its capability, handheld GPS units become more available, and people learn how to use them. The advantage of using FLIR in conjunction with aerial retardant drops has been shown and documented by Charles George, Intermountain Research Station's project leader for operational retardant evaluation (George 1989). That use is clearly needed and overdue.

Further Out in the Future

The use of various types of IR to provide adequate IR intelligence, coupled with satellite transmission of imagery and data, geographical information systems (GIS)-type IR layers compatible with Forest Service GIS (see fig. 5), INCINET (Incident Network), and fire behavior workstations operating in current and projected future conditions, will greatly enhance fire management effectiveness. This will result in more fires burning under prescribed conditions, fewer escaped fires, and less damage to all types of resources.

Low-earth-orbit (LEO) remote sensing satellites may someday be used for fire mapping and detection. Current satellite capabilities have been studied but are not used at this time. There is a bit of hyperbole about their use, and some fine looking images generated now and then, usually after such fires as the Greater Yellowstone Area or Oakland Hills, but high cost, lack of availability, and inflexible orbits (see "How Useful Are Satellites in Fire Detection and Mapping" in accompanying box) are some of the reasons why we do not use satellites for IR intelligence now.

More Effective Use of Infrared Systems

Improve Selection. Judicious selection of the best available IR system that can do an adequate job would ensure that the limited quantity of IR mapping systems can be available on all fires when needed. (See article in this issue entitled "Selecting the 'Right' Infrared System for a Firefighting Job.") Research efforts to confirm and formalize IR selection and also to establish and document equipment and procedures for retardant activities are needed now. A guide to selecting the best, or at least adequate, type of IR systems for the conditions being experienced has been explored, but as yet not realized. Cost, system performance, and information need are part of the selection process. Adequate and appropriate communications systems and equipment are taken for granted on all fires now, but IR intelligence gathering and use has not kept pace. It is entirely possible for all fires to have adequate IR intelligence at all times—the implementation costs for achieving this would be quickly returned.

Age-Old Question. If over 25 years ago, the Ranger space probes could send back color television pictures from the moon, why can't fire reconnaissance find fire and communicate that to fire managers? The answer to such a question is not technological capability, but the time and money invested to operate the IR intelligence. Just think

It is entirely possible for all fires to have adequate infrared intelligence at all times—the implementation costs for achieving this would be quickly returned.

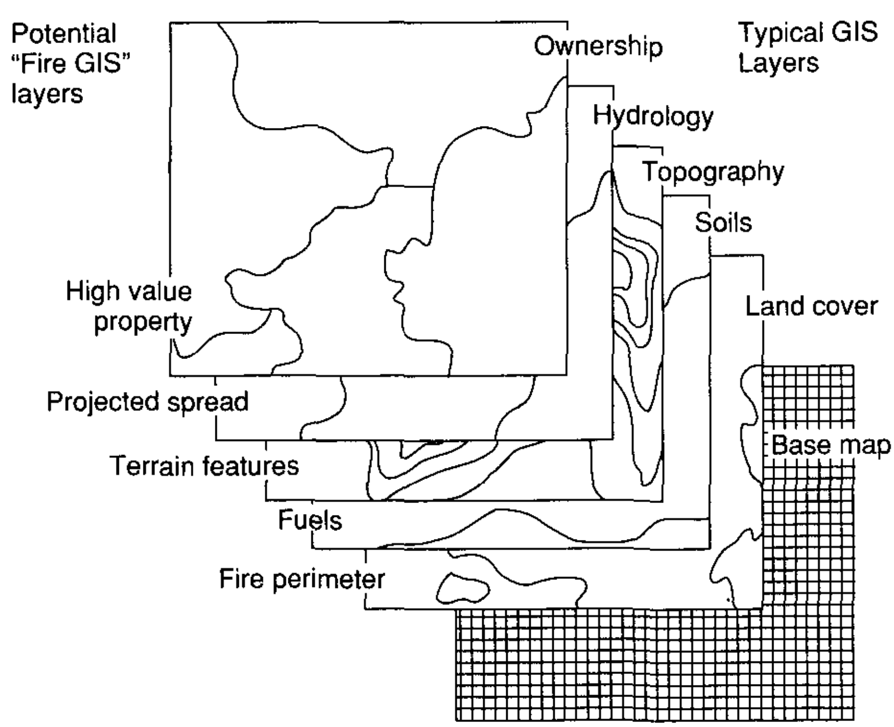

Figure 5—*Interpretation of the typical geographical information system (GIS) layers as potential "fire" GIS layers.*

what would happen with half the time and a small fraction of the money devoted to the lunar program! ■

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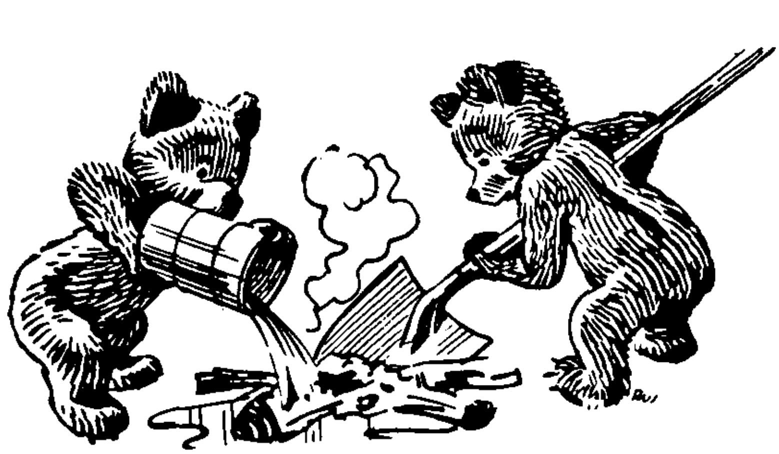
How Useful Are Satellites in Fire Detection and Mapping?

Drawbacks

- Spatial resolutions from orbital altitudes are not as good as those from aircraft altitudes (selected on the basis of fire size and conditions), even with a fairly low resolution, 2.5 milliradian airborne system.
- Orbiting satellites follow a fixed celestial track, oblivious to the fire mapping needs of fire managers. (Aircraft can be scheduled by fire managers to support operations.) Satellites in geostationary orbit, although available over a large given area, are too far out (22,300 mi or 35,887 km at the equator) for adequate resolution with current technology.
- Receiving satellite imagery at the incident command post (via direct or indirect means) is either too expensive or time consuming.
- Clouds may obscure area of interest from orbital altitudes. (Aircraft can often fly beneath clouds to obtain the needed imagery.)
- Detection of small hot spots, (less than 6 inches or .05 meter square) is not possible with any known, nonmilitary satellite at this time.
- A satellite's pass over an area of interest is fixed in time, direction, and orientation. (Aircraft normally make several passes from different directions over a fire to obtain several perspectives, an aid in the interpretation process.)

Advantages

- Satellite imagery is useful in tracking large fires in vast, remote areas such as Alaska, where suppression actions may not be feasible or warranted.
- The use of satellites for transmission of IR data or imagery from the IR aircraft to the ground should be reasonably available in the next few years. The use of satellites, as in the Global Positioning System for location of IR aircraft or helicopters, is in use now.



Primer on Infrared

Electromagnetic Radiation

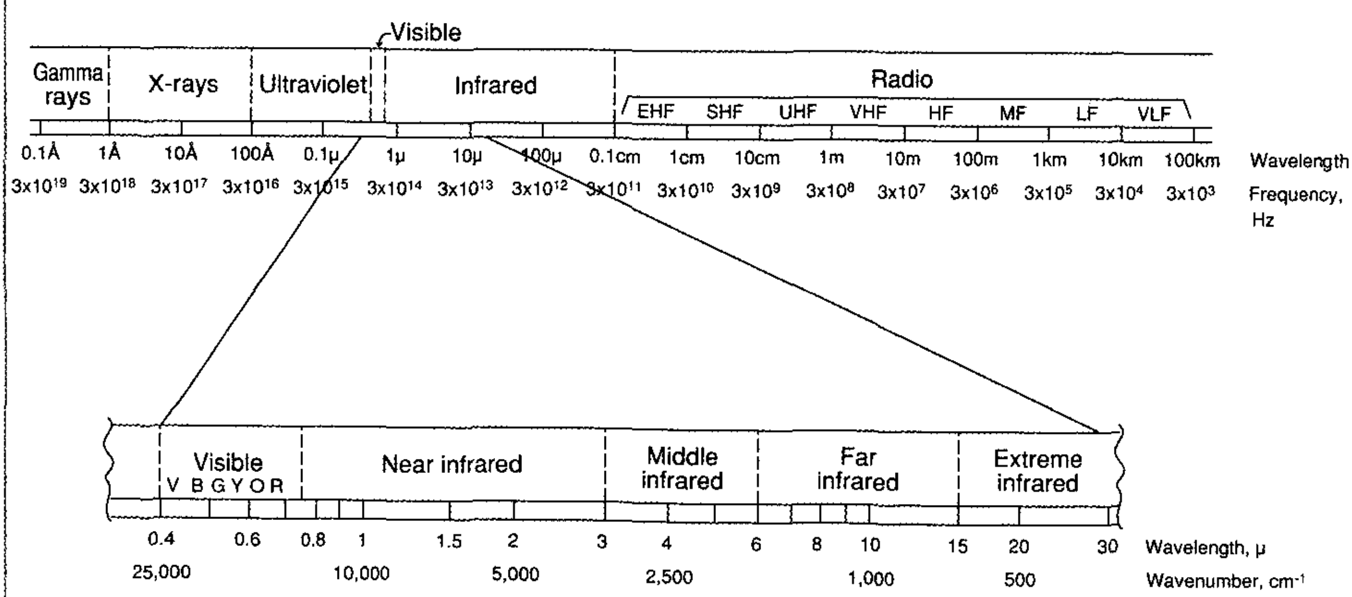
Electromagnetic radiation, or radiant energy, is the transmission of energy through space in a wave motion, or electromagnetic wave. Such a wave, consisting of an electric field and a magnetic field, occurs at a certain frequency (the number of to-and-fro motions per second) and wavelength (the distance traveled during this oscillation or from the top of one wave to the next). The range of electromagnetic waves, measured in micrometers (3×10^{-9} micrometers to infinity), or hertz (10^{23} to 0 cycles per second), is known as the electromagnetic spectrum. The chief kinds of electromagnetic waves are (from the shortest to the longest) gamma rays, X-rays, ultraviolet light, visible light, infrared rays, microwaves, and radio waves. (See diagram of spectrum.)

Infrared Radiation

Warm objects (an object or material at any temperature above absolute zero (–273 °C)) send out radiant energy at various wavelengths and frequencies. If wavelengths of that radiated energy, fall within the 0.72 to 1,000 micrometer band of the electromagnetic spectrum, they are below ("infra") the red limit of visible light.

Who First "Saw" the "Invisible" World of Infrared? In England in 1800, Sir William Herschel, a scientist and astronomer, using a prism and a thermometer, experimented with the heating power of the colors in a beam of light. Herschel placed a prism in a window to catch a lightray, shooting that ray with its color spectrum to a table holding a mercury-in-glass thermometer (heat detector). In his measuring of the heat of each color, he was surprised to find that the heating power increased toward the red end of the spectrum. He found that when he placed the thermometer beyond red where he could see no light it still gave a reading. He had discovered a form of radiant energy, able to be refracted by a prism, but invisible to the eye.

Radiant Energy and the Laws of Optics. Following up this discovery, Herschel showed that this radiant energy, or radiation, is reflected and refracted according to the laws of optics. He also showed that heat radiation from sources such as a candle, a fire, a red-hot poker, and even a domestic stove—with no visible radiation obeyed the same laws as solar radiation. Herschel conjectured this radiation was of the same nature as light, differing from it only in "momentum." He called it "invisible light."



Some Definitions of Essentials in Infrared Imaging

Infrared Detectors. Infrared detection has come a long way since Herschel's prism and mercury-in-the-glass thermometer experiment. A variety of detectors, available for sensing radiant energy, are used in infrared sensing equipment or systems. They can be classed into two main groups: thermal detectors and quantum detectors.

Thermal detectors absorb the radiant energy causing a rise in the element's temperature. The rise in temperature then causes a change in a physical or electrical property that can be measured. Some examples of thermal detectors are thermometers, thermocouples, thermistors, and pyroelectric devices. In the mercury thermometer, a thermal detector we all are familiar with, heating increases the volume of mercury in a graduated glass tube, calibrated to a determined scale. The thermocouple, two different metals, the junctions of which are at different temperatures, provides a way to measure heat. Thermal radiation changes its electrical characteristics. The thermocouple, for example, triggers the furnace to turn on. In a pyroelectric device a change in temperature creates a change in polarization or a change in electrical charge. A change in electrical charge with time is electrical current. A pyroelectric detector produces current as it experiences a temperature change.

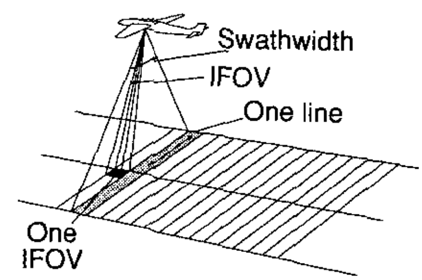
Quantum detectors or photon detectors directly use the energy contained in the photons arriving to cause electrons to go from a nonconducting state to a conducting state. There is a direct interaction between the incident photons, from the "heat source" and the electrons of the detector material. The change in voltage output or in the conductivity of a quantum detector is proportional to the number of photons of energy arriving from the heat source. Quantum detectors have high sensitivity and fast response times but usually require cryogenic, or low temperature, cooling.

Ways of Classifying Infrared Instruments or Systems. Infrared systems can be classified in various ways—for example—passive or active or imaging or nonimaging.

Passive-Active—Passive infrared sensors detect the natural emission of radiant energy that occurs in all objects and is directly related to the temperature of the object. Fire detection and mapping infrared systems are passive systems. An active sensor carries a radiation source along with a receiver. A common active sensor is a radar set, usually operated in microwave bands, not in the infrared bands, that transmits energy out and detects the energy reflected back to its receiver.

Imaging-Nonimaging—Nonimaging systems give an indication of the temperature of an object or area averaged over the field of view of the sensor. This information is provided in a qualitative (light or horn, for instance), quantitative (calibrated temperature reading), or relative (deflection of meter from an uncalibrated reference) manner. These are relatively inexpensive, low performance instruments useful for detecting heat differences in nearby (20-to-30-ft- or 6.1-to-9.4-m-range) hot spots that might not otherwise be detected by an observer. With this system, the operator cannot be sure an area has been adequately covered.

An imaging system such as a forward-looking infrared system (FLIR) is made up of these main parts: Optics such as lenses or mirrors to image the rays, a detector to sense them, and a means to communicate their messages. Imaging systems provide an image (not a photograph) of the scene by "scanning," or sweeping over a *field of view* (back and forth and up and down) to collect or map information. (See "Line Scanning.") From this information the temperature of objects or areas within the scene is deduced by comparing the "brightness" of those objects or areas to the background. In other words, hot objects are located based on their relationship to the total scene. The image of the covered area is shown on the sensor's display, on a video monitor, on a hard copy printout, or some combination of these. Video compatible systems can also record the infrared images with audio annotation.



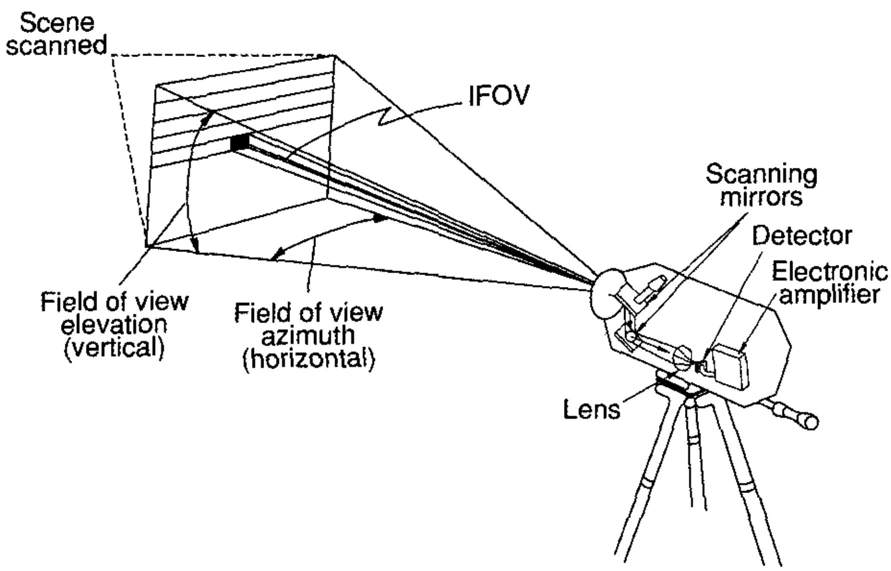
Line scanning from an airplane.

Line Scanning. A line scanner (scanning mirrors, lens, detector, and electronic amplifier) detects, or views, energy (thermal energy in the case of thermal IR systems) from the area of one *instantaneous field of view* (IFOV), also referred to as a *ground resolution element, ground pixel*, or simply *pixel* (the basic unit or picture element making up the image on a video screen) at a given instant. The scanner sweeps across these IFOV's horizontally "scanning the line."

Visualize "scanning" in terms of a grid superimposed on an image or picture. Each square of the grid is a pixel. One horizontal line of the grid is a line of pixels. The line scanner moves along a line of our hypothetically gridded area of the ground and then returns to the starting side of the image to sweep across the next line.

The line scanner constantly changes the thermal energy present into an electronic signal. The magnitude of the electronic signal at any given instant is analogous to the amount of thermal energy being emitted from the ground pixel. If the signal is processed in this analogous form throughout the system, we refer to it as an analog system. If the signal is converted to a digital electronic signal, or group of bits, along the way, it would usually be called a digital system. There are several advantages to digital signal processing, one of which is the ability to enter the digital signals into digital computers (most computers are digital) for processing, storage, and other operations. The results are usually then converted back to an analog display for viewing.

Airborne Line Scanners. By the time the sweep or scan of the first line is completed, the aircraft has moved to the start of the imaging area to scan the second line, adjacent to the first. Now there are two lines. This continues until each line of the grid is scanned and a complete thermal image of the total ground area completed. The speed necessary for contiguous scanned line



The forward-looking infrared system (FLIR)—how it works and its main parts.

locations can be calculated from the IFOV area, the altitude, and the velocity of the aircraft. It is usually adjustable to cover the range of altitudes and speeds that the aircraft can cover. It is even given a name, V/H, which is velocity divided by height (above ground level). Although contiguous scanning of lines is the most "efficient," Forest Service IR line scanners intentionally overscan so that each "line area" is covered at least twice. Overscanning builds in an effective false alarm rejection method, precluding random noise spikes from showing up as hot targets or fires.

Forward-Looking Infrared. Forward-looking infrared (FLIR) units do not rely on aircraft movement to "build up" the image. They still scan the IFOV one line at a time, but do so electronically, at a much faster rate, so that the entire image can be displayed on a video monitor. This is normally done at standard (NTSC) television rates (525 lines per image, 30 image frames per second, or about 15,750 lines per second).

Other Systems. Other systems, such as linear arrays, use an array of detectors in a line to output the total horizontal line signal without optical scanning. Area arrays have one small detector element for each IFOV, or square in the gridded area, so that neither vertical nor horizontal scanning is required. Although these eliminate or reduce the scanning, other characteristics of these systems must be considered before they become part of a system. ■

John R. Warren, *group leader, Advanced Electronics, USDA Forest Service, Boise Interagency Fire Center, Boise, ID.*

Selecting the "Right" Infrared System for a Firefighting Job

John R. Warren

Advanced electronics group leader, USDA Forest Service, Boise Interagency Fire Center, Boise, ID

Fire managers need to know the capabilities and limitations of the types of IR systems that are available for their use. Using the "right" or best-suited infrared system for a job is basic to sound fire management. What are the system types? How do you choose? What do the "right" systems cost?

The types of infrared (IR) systems and how they perform in 18 conditions were reviewed and rated by two experienced Class I Incident Commanders and the author. (See list of conditions in accompanying box and evaluation results in table 1.) The results clearly show that relying on only one type of IR system is not necessary or even reasonable. The main conclusions are as follows:

- More that one type of IR system can do a good job in similar conditions.
- Line scanners are not always the best type of system for all jobs.
- IR intelligence can be available on every fire when needed if fire managers properly select and use the IR system best suited for a job.

From this evaluation, for example, in all 18 conditions, two or more system types rated "very good" or "good." In 14 of the 18 conditions, 3 or more system types rated "adequate or better." Forest Service line scanners rated higher than the other system types in only 4 of the 18 conditions. FIRE MOUSE TRAP with a forward-looking infrared (FLIR) system rated higher than the other system types in 9 of the 18 cases.

Generally speaking, the Forest Service line scanners, best used for large area detection and first-time large fire mapping, should be considered, usually, as strategic information systems, to be used for future planning and general assessment of conditions over large areas. The FLIR–FMT should be thought of as a tactical system, useful for future planning perhaps, but available for gathering near-term or near real-time decisionmaking information and more specific details of a situation with its close-in IR viewing, coupled with the visual observation and judgment of on-the-scene fire staff personnel.

Judicious selection of the best available infrared system that can do an adequate job would ensure that the limited quantity of infrared mapping systems can be available on all fires when needed.

Asking cost questions are basic to an Incident Commander's selecting the best IR system for a fire situation (See table 2). Fire managers need to ask these questions before making decisions:

- What percentage of the total daily suppression cost will infrared flights be?
- What is potential loss and additional costs if fire location is not known?

Conditions in Which the Usefulness of Infrared Systems Were Evaluated

Detection

1. A reported new fire with approximate location (known within a mile or so).
2. Multiple (3 or more) new fires over a large (1,200-to-1,300-acre or 486-to-526-ha) area.
3. Possible multiple new fires over a very large (3,000-acre or 1,214-ha or more) area.

Mapping

4. First overall infrared view of a fire (up to 1,200 acres or 486 ha).
5. First overall infrared view of a large (over 1,200 acres or 486 ha) fire.
6. Subsequent updates of fire perimeter after its location is established.
7. Confirmation of fire perimeter or hot spot location from other observations.
8. Direct view of fire during or soon after runs or flareups and other tactical information needs.

Other Fire Applications

9. Retardant effectiveness verification.
10. Confirmation of fire behavior projections made by fire behavior analyses.
11. Intelligence for containment or control.
12. Mopup activities.
13. Documentation of fire activities and locations for subsequent legal needs.
14. Media releases to show that fire managers do know exact location of fires.
15. Prescribed burn monitoring.

Nonfire applications

16. Search and rescue.
17. Law enforcement.
18. Pest or disease or other visual mapping.

Table 1—*Results from infrared systems evaluation**

Condition	Forest Service IR line scanners	Contract IR line scanner	FLIR with FIRE MOUSE TRAP	FLIR
Detection				
1	B	C	A	A
2	A	B	C	—
3	A	B	—	—
Mapping				
4	A	B	B	—
5	A	B	C	—
6	A	B	A	C
7	A	B	A	A
8	C	C	A	B
Other				
9	—	—	A	A
10	B	C	A	—
11	A	B	A	B
12	C	C	A	A
13	A	B	A	B
14	A	B	A	A
15	B	C	A	A
16	—	—	A	B
17	B	C	A	B
18	—	—	A	B

*A = very good; B = good; C = adequate; no letter = not suitable. A remarks column was included in the evaluation but not collated here.

Table 2—*Hierarchy of infrared (IR) systems and equipment**

Systems and equipment	Estimated cost
Military airborne IR line scanners	—
Forest Service Firefly airborne IR line scanners	$2,000,000–3,000,000
Forest Service traditional airborne IR line scanners	400,000– 750,000
Commercial IR line scanners, general purpose	250,000– 500,000
Military FLIR	—
Commercial FLIR, turret mounted	55,000– 120,000
Commercial FLIR, handheld	30,000– 60,000
Pyroelectric vidicons	20,000– 25,000
Nonimaging heat indicators	500– 1,000
Additional equipment for FIRE MOUSE TRAP capability (used with any FLIR or pyroelectic vidicons)	4,200– 8,200

*Prices are approximate (not included for military systems). Note: Performance depends on the conditions and what needs to be known. In many cases, a "lower" performance system may do a much better or just as good a job as a "higher" performance system. It is easy to find situations where a pyroelectric vidicon will do a better job than a top-of-the-list airborne line scanner. The list is not all-inclusive, but is representative. Prices include hard copy or video image production.

- What money can be saved if suppression resources can be applied better?
- What might be the loss if crews are released too soon?
- What might be the cost if crews are held after there is no more fire danger?

Knowing about these systems—what's available, how they function, what their limitations and capabilities are, how much they cost (to purchase upfront and to operate)—will help fire managers make good decisions about what system to use. ■

Forest Fire Detection Systems[1]

Stanley N. Hirsch

Electronics engineer, USDA Forest Service, Intermountain Forest and Range Experiment Station, Northern Forest Fire Laboratory, Missoula, MT

In 1962, the FIRESCAN project, research in infrared fire detection, started at the Northern Forest Fire Laboratory. Stanley N. Hirsch, electronics engineer, was the project leader. In a presentation to the Western Forest Fire Committee, on December 1, 1964, at Spokane, WA, he outlines the attributes of an ideal fire detection system and evaluates those attributes in light of 1964 technology and vision. Hirsch's analysis is an enlightening benchmark in the ongoing discussion of infrared detection systems.

The 30 years since the FIRESCAN research began have shown that the "ideal" fire detection analysis system does not exist in isolation, but must be used together with other fire prediction analysis systems. Along with knowing where the fires are is the important information about fire danger, accessibility to fire, and values at risk. Hirsch makes this point when he states an ideal system "would be able to distinguish potentially dangerous fires from those that would never concern fire control forces." What is needed is the capability to deploy a proper detection system when the conditions indicate danger if a fire were to start. In this version of the "ideal" situation, fires would burn only under valid prescribed conditions. A potentially dangerous fire would be suppressed before it causes damage, while a fire not potentially dangerous would be allowed to burn under prescription and surveillance.
—John R. Warren

An ideal forest fire detection system would detect fires the instant they start, day or night, under any condition of visibility. Additionally, it could distinguish potentially dangerous fires from those that would not concern fire suppression forces. Although attainment of such an ideal system now appears to be well beyond the reach of modern technology, detailed study of the requirements for an ideal system may well show where space age technology could be applied effectively.

An Ideal Detection System

An ideal detection system—the sort of equipment a fire control man would dream about—would have four essential attributes related to the varied kinds of detection and control problems. Ideally it would be able to detect a fire the instant it started even though such instant detection might not always be critical. Second, it would be as effectively operable in darkness as in daylight. Likewise it would be operable despite low visibility caused by smoke, fog, or dense timber cover. Fourth and finally, it would be able to distinguish potentially dangerous fires from those that would never concern fire control forces. Admittedly, this is a large order, and each of these attributes requires some detailed explanation.

Hirsch's analysis is an enlightening benchmark in the ongoing discussion of infrared detection systems.

Instant Detection

The primary consideration for any control operation is: How big is the fire at the time of initial attack? This size depends on type and continuity of fuel, rate of spread, and time elapsed from ignition to detection and from detection to initial attack. Under some circumstances, instant detection might be desirable but not critical. The value of the area under protection would certainly influence the tolerability of delay; so would weather and fuel conditions at the point of ignition. If an interval of 2 to 4 hours between ignition and detection is tolerable, intermittent surveillance would be acceptable and an airborne system could be used. Frequently, though, a 2-to 4-hour delay would not be tolerable; then a fixed location continuous lookout is required. Probably there will always be need for some fixed lookouts. However, in many situations a 2-to 4-hour delay would be tolerable, and the inherent advantages of intermittent surveillance could be exploited. Hence, it is evident that the first major question to be answered in a detection analysis must be: Does the particular area under study require continuous or only intermittent surveillance?

[1]Purchased by the USDA Forest Service for official use, this article is reprinted from a reprint of Stanley N. Hirsch's presentation originally published in the proceedings of the December 1, 1964, annual meeting of the Western Forest Fire Committee, a permanent committee of the Western Forestry and Conservation Association, Portland OR.

Operability at Night

The second attribute of an ideal system is equal operability by day and night. Fires usually spread more slowly during nighttime hours, and quite often they could justifiably be ignored until daylight permitted detection by visual means. However, ability to detect fires during the hours of darkness would permit suppression forces to attack them at a time when control is easier to achieve. Visual systems such as manned lookouts, manned aerial patrol, and television require daylight for their operation. Infrared, microwave, or active optical systems work satisfactorily in either daylight or darkness, but infrared functions better in darkness. The second question to be answered is: Do we need a nighttime capability?

Operability Despite Low Visibility

A third attribute of an ideal system is operability under any condition of visibility. On many days during the fire season, the atmosphere is clear and smoke can be detected by various means. However, many of the days when visibility is obscured by smoke are days when fire conditions are most dangerous. When there is no smoke haze, no smog, or no cloud cover, detection of small smoke columns is easy. However, if the atmosphere is cluttered with smog or smoke, the detection of small smoke columns becomes very difficult for either the visual system or other systems that would attempt to detect the smoke column above a fire. Any attempt to develop systems capable of operating under all atmospheric conditions is doomed to failure if it relies upon the detection of smoke. But there is great promise for solving the problem of smoke-filled atmosphere if the detection device relies upon energy radiated directly from the fire. The third major decision in detection analysis must be whether we can tolerate loss of detection capability under conditions of poor visibility.

Distinguishing Dangerous from Harmless Fires

The fourth attribute of an ideal system would be ability to distinguish potentially dangerous fires from those that will not concern fire suppression forces. It would be desirable to be able to distinguish between a camper's fire and an incipient lightning-caused fire. It would be desirable to distinguish between a backyard barbecue that was preparing an evening meal from one that had "spilled" and was starting a major conflagration. However, these considerations hardly fall within the scope of forest fire detection. The essential role of a fire detection system should be to determine the existence of any combustion processes. The system should be capable of distinguishing between true combustion processes and such false indications as dust swirls and mist—in the use of visual systems—or reflections from bright objects— in the use of infrared systems. Any distinctions beyond this should properly fall within the province of the dispatching process.

Before evaluating these four attributes of an ideal fire detection system, we must ask one further question: Is a direct optical line of sight available between the detection system and the fire to be detected, or must the system rely upon some secondary phenomenon produced by the fire, such as the smoke column? It will be virtually impossible to achieve continuous surveillance of an area if the detection system must be placed in some position far above the earth's surface. Likewise, it will be extremely difficult to find many fixed locations that afford a direct line of sight to large areas where fires might start.

The foregoing discussion is not intended to imply that instant detection can always be achieved from the fixed locations. In many cases of interest, fires may burn for extended periods before enough smoke rises to permit detection. A detection system scanning intermittently to detect the primary heat source may detect a fire before a continuous surveillance system would detect a smoke column.

Continuous Versus Intermittent Surveillance

Within this framework I shall examine separately the problems of continuous surveillance and intermittent surveillance. In beginning with the situation requiring continuous surveillance, I assume that this precludes the use of any aircraft, satellite, or other means of placing the detection system at a very high vantage point above the surface of the earth. It would be impossible to find enough points on the earth's surface that would provide a direct optical line of sight between the detection system and the primary heat source—the fire itself. Therefore, wherever we require continuous surveillance, we must depend upon observation of some secondary phenomenon.

The manned lookout depends upon visual detection of the plume or smoke column above a fire. If we are limited to using visual systems—either manned, television, or a combination of both—we are limited to daylight operation unless we provide some active source of illumination. Optical radars, employing lasers for illumination, may usefully supplement manned lookouts by providing a capability for detecting small smoke columns at night, and by providing a very high accuracy in range and azimuth on smokes detected during either day or night.

I have seen no other good scheme proposed for detecting any secondary fire phenomena. There has been considerable discussion about detecting carbon dioxide content, the thermal energy radiated from the smoke column, condensation nuclei, and other phenomena; but even cursory examination of these allows one to eliminate them rather rapidly for operational use. From this, I conclude that continuous surveillance and freedom from atmospheric limitations are not compatible.

A television system installed at a lookout could do approximately what the human lookout can do, but it does not appear to add anything in terms of capability. If replacing a manned lookout with a television system reduces cost, then perhaps such a scheme has merit. If such replacement cannot be justified on purely economic grounds, I see no justification for considering it further.

In situations where delays of 2 to 4 hours between ignition and detection can be tolerated, the detection system can be placed in an airborne vehicle to obtain a direct look at the primary heat source. These are the situations where modern electronic technology can best be applied. Fires radiate large amounts of energy in portions of the electromagnetic spectrum where the eye has no sensitivity. Both infrared and microwave devices are sensitive to these portions of the spectrum and can be applied effectively to detect small fires both in daytime and at night. Theoretically, both types of devices can detect small fires when smoke or smog completely eliminates the use of visual systems.

Infrared Versus Microwave

In order to decide which of these systems to apply, we must look further at their similarities and differences. Microwave energy penetrates cloud cover—infrared energy does not. Microwave systems' performance is not degraded by the presence of strong sunlight—infrared performance is. Infrared systems are inherently simpler than microwave, but neither of them approaches the simplicity of the human observer. The present state of the art in microwave technology does not permit construction of airborne devices that have the angular resolution required in fire detection applications, but present technology can construct infrared systems that meet this requirement. For this reason, the current research in fire detection at the Northern Forest Fire Laboratory under Project Fire Scan has been directed towards implementing airborne infrared systems. Although microwave radiometry has the potential for operation under conditions of complete cloud cover and infrared does not, the current state of technology dictates the choice of infrared in spite of this one major drawback.

Discussion

Any practical airborne surveillance system must be capable of covering at least 5 miles to either side of the airborne vehicle. Coverage is determined by the altitude and scan angle used. Data accumulated during the past 3 years indicate that timber obscuration becomes a limiting factor beyond 60 degrees from vertical. Because of this angular limitation, an operational altitude of 15,000 feet above terrain is required to achieve 10-mile coverage. If

Table 1—*Rating of options available for use in fire detection systems*

	Continuous surveillance Fixed location		Intermittent surveillance Airborne		
Operating conditions	Visual passive	Optical radar	Visual passive	Infrared passive	Microwave passive
Day, clear	A	B	B	C	B
Day, smoke-smog	D	D	D	B	B
Night, clear	X	A	X	A	B
Night, smoke-smog	X	D	X	A	B
Cloud	B	B	C	D*	B
Simplicity	A	C	A	B	C
Status of technology	A	C	A	B	D

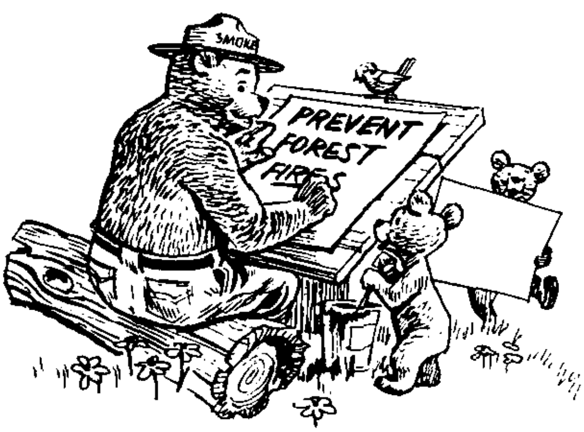
*Depends on degree, complete cloud cover would change this to X. A = excellent, B = good, C = fair, D = poor, X = unusable.

the frequency of cloud cover below this altitude is too great, infrared techniques must be abandoned in favor of microwave.

Figure 1 shows infrared imagery obtained in flight tests over small heat sources in a dense Engelmann spruce stand [not reproduced here].

Figure 2 shows a schematic of a method for using airborne infrared scanners in an operational system [not reproduced here].

Table 1 summarizes the options available in the design of fire detection systems with their attributes indicated in relative order.



Conclusions

Studies conducted by Project Fire Scan show great promise for improving detection capabilities where intermittent surveillance can be tolerated. If continuous surveillance is not required, then present infrared technology may achieve a detection capability during both daytime and nighttime hours and under conditions where smoke and smog eliminate conventional techniques. Although optical radars may have some application for continuous surveillance at night, no means are available for obtaining continuous surveillance when smoke or smog limit visual techniques. ■

Minimizing the Risk of Wildfire: A Symposium to Address Wildfire Problems in the Wildland-Urban Interface

Jasper Park Lodge, Jasper, Alberta, September 26–30, 1992. Partners in Protection, a multiagency group formed in the Province of Alberta to address collectively wildland-urban interface issues and concerns, hosted a major symposium on September 26–30, 1992, at Jasper Park Lodge, Jasper, AL. The symposium, "Minimizing the Risk of Wildfire" gave an opportunity to develop an international and in-depth view of the problems that wildfire can present in the wildland-urban interface. At least 250 representatives from participating agencies throughout Canada and from the United States and others interested in fire subjects attended.

Many Perspectives. The symposium consisted of a series of presentations that described the wildland-urban issue from a variety of perspectives. Presentations were made by leaders in firefighting, planning, public education, politics, insurance, and training. The event also included workshops that focused on developing solutions to problems such as public education and the role of the media, integrated planning, cooperative training, and influencing the political system. The program also included a field trip, exhibitor displays, social activities, and a program for spouses.

More Information. For further information on the symposium or the Partners in Protection committee, please contact: Partners in Protection, Box 249, Onoway, Alberta, TOE 1VO or call Ken Saulit, fire chief for the County of Parkland, Alberta, 403-963-2231 or Kelly O'Shea, forest protection officer for the Bow/Crow Forest, 403-297-8800. ■

Fire Mapping Using Airborne Global Positioning[1]

Philip L. Drake

Regional land surveyor, USDA Forest Service, Northern Region, Missoula, MT

On September 15, 1990, Ray Evans, Director of Fire and Aviation Management, Rocky Mountain Region (Region 2), ordered the region's global positioning units for use on the Swedlund Fire on the Black Hills National Forest. Blaine Cook, resource management forester, Black Hills National Forest; Doug Williams, land surveyor, Black Hills National Forest; and Phil Drake, regional land surveyor, formed a team to map the Swedlund Fire using Trimble Navigation's Pathfinder, a navigation system and position-logging system based on the Global Positioning System (GPS), a satellite network developed by the Department of Defense.

How the System Was Set Up

To begin the mapping, the team first established a control station with geodetic coordinates at the Custer Airport where it was convenient to operate while mapping the fire. Presently, GPS units should be used in multiple units with one positioned on a station with a known position. This is done primarily to resolve errors of up to 100 meters (328 ft) imposed on the system by the Department of Defense. These errors are imposed ostensibly as a security measure to hinder real-time positioning. Due to inherent errors within the system, irrespective of the Defense Department's deliberate degradation of the GPS signals, use of multiple instruments improves positions from a 20-meter- (66-ft-) stated precision with one instrument to a 2-meter- (6.6-ft-) stated precision. The procedure of using a control GPS unit in conjunction with remote or roving units is called "differential positioning."

One of the GPS units was set on the control station established at the Custer Airport. The antenna of another GPS unit was attached to a Jet Ranger helicopter. The Pathfinder's antenna along with a foam backing was taped to the tail boom of the helicopter, just ahead of the horizontal stabilizer, and about 12 feet (4 m) back from the cabin. Duct tape overlaid with filament strapping was wrapped around the tail boom to hold the antenna in place on the boom. The entire length of the antenna cable outside the aircraft was taped to the aircraft skin.[2] Cook and Williams acted as spotters while I operated the instruments.

The Mapping Flights

The mapping flight was flown during a three-dimensional satellite window at about 50 to 100 feet (15 to 31 m) above the treetops. At this height above the treetops, it was relatively easy to spot the fireline. No reception problems were noticed due to the main rotor; in fact, 99 percent of the coordinate fixes were three-dimensional coordinates (latitude, longitude, and elevation). At this project latitude and longitude, there are presently about 8 hours during a 24-hour period when three-dimensional coverage is available. This window is continuing to expand as more of the NavStar satellites are launched. It should be noted that at least four satellites must be over 12 degrees above the horizon to receive three-dimensional coordinates. Two-dimensional coordinates (latitude and longitude) can be received with three available satellites. This extends the window by about 4 hours; however, this should be done cautiously. The error that the instrument is carrying in elevation while collecting data in a two-dimensional window will translate to at least that much error in the horizontal position. This can be overcome by updating the elevation within the instrument with an altimeter, but it is much more preferable to just plan the data collection for three-dimensional windows.

The entire 35-mile perimeter of the fire, enclosing 14,200 acres, was mapped in about 55 minutes of flight time.

The entire 35-mile (56-km) perimeter of the fire, enclosing 14,200 acres (5,747 ha), was mapped in about 55 minutes of flight time. The GPS instrument was configured to collect a position every one second, therefore approximately 3,000 coordinate positions were collected along the fireline or about one position every 60 feet (1.5 m). Within 2 hours of landing,

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[1]Philip Drake's and Douglas Luepke's ("Using the Global Positioning System in Firefighting on the Shorts Fire in the Okefenokee Swamp" also published in this issue) use of GPS was previously described in "GPS for Forest Fire Management and Cleanup" in the September 1991 issue of *GPS World*.

[2]Specific procedures for approval of mounting the GPS antenna have been outlined in a May 5, 1992, letter from the Director of Fire and Aviation Management in the Washington Office to each Regional Forester. If the mounting procedure described in this article is used, it must be submitted, with proper paperwork and log book entries, to the Federal Aviation Administration for approval. The FAA views mounting the antenna with tape as a temporary attachment procedure.

the data had been postprocessed, using the control station data, and an overlay plot at 1:24000 scale of the entire fireline, along with the acreage calculations, were delivered to the Plans Section of the fire.

The short turnaround time for the finished perimeter plot was impressive. The GPS fire map nearly agreed with the traditionally generated ground fire map. However, because there were some slight differences between the two maps, the Plans Section sent the airborne GPS fire mapping team out again to map the fire in the opposite direction as a redundant check to verify the accuracy of the GPS mapping system. The second GPS fire map overlay matched almost exactly with the first GPS map. The few differences that occurred between the two flights (+/– 50 ft or 15 m) arose, it seemed, from the difficulty of flying an aircraft over a sinuous line on the ground that was difficult to distinguish in some areas. The acreage calculations (which take about 2 minutes after the data is processed) for the second flight was 14,100 acres (5,706 ha), less than a 1-percent difference from the first. Although there were some minor differences when the GPS fire map was compared with the traditionally generated ground fire map, it appeared that the ground mappers had really done an excellent job of photo and map interpretation. About one-third of the area of this fire was on land administered by the State of South Dakota. A separate data file was created within the GPS software for this area. Acreage was then calculated for this area and will be used to prorate the cost of suppression.

On the second day, Darwin Hoeft, soil scientist on the Black Hills National Forest, acted as the spotter to map the high-intensity burn areas on the interior of the fire. This was done to obtain the acreages for reseeding and rehabilitation. Thirteen polygons of high-intensity burn (5,300 acres or 2,145 ha), interior to the fire, were mapped in 1 hour and 20 minutes of flying time. As a polygon was closed with the aircraft and GPS, an estimate was made of the percentage of intermingled green within the polygon. These estimates ranged from 10 to 30 percent. The post-processing and -plotting took a couple of hours. Plots were made at several scales for the rehabilitation, reseeding, and salvage sale plans as well as the final fire reports.

Bill Ewin of CEA Inc., Trimble Navigation manufacturer's representative from Tempe, AZ, arrived on the forest on Monday as a volunteer. He and Carol Thomas of Information Systems on the Black Hills National Forest, converted the Pathfinder data to AutoCAD® (Computer Aided Drafting and Design) and MOSS (Map Overlay Statistical System) digital formats. The software that is supplied with the instruments makes this task relatively easy with some basic computer knowledge. In this format, the polygons (in digital form), mapped with the GPS instruments, will be used to update the forest geographical information systems (GIS) and resource inventory system (RIS)[3] databases, silvicultural prescriptions, and other fire-related management activities.

The entire GPS operation for this particular fire was completed from the helicopter. However, there could be times when smoke would obscure the fireline visibility. At these times it may be necessary to carry out the operation from a ground-based vehicle or by walking the perimeter with the GPS unit. These methods would obviously increase the production time, and signal reception breaks would be more common. But based on the experience we have had with other applications, this is a viable option.

An interesting sidelight to this experience: The helicopter pilot and the mechanic were initially concerned that the duct tape might damage the aircraft paint, although this did not happen. The Trimble Navigation GPS units, in addition to storing positions for mapping, also provide real-time navigational information. Using the GPS instrument, the pilot was navigated to within 20 feet (6 m) of where he took off and was given his true ground speed along the way. This impressed him to the extent that the GPS crew had a hard time getting close to the ship to remove the instrument when the project was completed.

Other Applications and Advantages of GPS

The airborne application of GPS technology for mapping or the updating of maps could be cost effective for several other types of projects where a large area needs to be covered in a short amount of time and especially useful when time or visibility precludes traditional photogrammetric methods. Applications might include wildlife counts and mapping, road and trail inventory and mapping, wetland acreage measurements, stream-length

[3]Rocky Mountain Region timber stand record system.

surveys, timber surveys and mapping, law enforcement activities, and rescue operations. One of GPS's greatest assets is its repeatability and the fact that it works on a common geographic base, ensuring spatial compatibility between groups of data that are collected at different times and places. It is an understatement to say that this factor is important as we move further into the electronic information age. ■

Federal Excess Personal Property Information: Where to Find It in *Fire Management Notes*

Articles on Federal Excess Personal Property (FEPP) written by Francis Russ, property management specialist in the Fire and Aviation Management in the Washington Office, and listed here, appeared in *Fire Management Notes* during the past 2 ½ years. These articles focus on the basic requirements of the program—important information for every FEPP user.

If you need copies of any of the listed articles, please write Russ at the address on the inside front cover, call him at (202) 205-0891 or DG:F.Russ:WO1C. You are also invited to submit articles on FEPP use in fire protection.

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Cooperative agreements for the use of FEPP, 51(2): 4

Aircraft

Forest Service aircraft on loan to State forestry agencies, 51(3): 22–24.
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Francis R. Russ, *property management specialist, USDA Forest Service, Fire and Aviation Management, Washington, DC, and chairman of the FEPP Study Group*

Using the Global Positioning System in Firefighting on the Shorts Fire in the Okefenokee Swamp[1]

Douglas Luepke

Cartographer, USDA Forest Service, Region 8, Atlanta, GA

On October 12, 1990, an overview of Trimble's Navigation's Pathfinder, a navigation and position-logging system based on Global Positioning System (GPS) capabilities, was presented to the fire management team in the regional office of the Southern Region. The team decided to mobilize the Pathfinder on the Shorts Fire, a fire in the Okefenokee Swamp that had been burning for approximately 1 month. The fire was under control at this stage and mopup was the principal activity—an excellent time to integrate GPS into the operation.

Location of Hot Spots on Fire Perimeter

Equipment and Personnel. The GPS unit was first used on the fire on a flight with an infrared (IR) detection mission to locate hot spots along the fire perimeter. The IR interpreter sat in the back seat of the helicopter with a handheld forward-looking infrared scanner (FLIRS) unit. The Pathfinder operator was in the copilot's seat with the Pathfinder lying on the floor between his feet and the polycorder (recorder-display unit) in his lap. The antenna was fastened on top of the pilot's control panel with duct tape. In the back seat of the helicopter with the IR interpreter was an operator of the FIRE MOUSE TRAP, a system using the LORAN-C or GPS receiver to record a position every 2 seconds.

Flying the Perimeter and Collecting Data. As the flight began, the Pathfinder was turned on and began displaying latitude and longitude on the polycorder. At the fire edge, the Pathfinder was set in DATA LOGGING mode to mark position data every second. The pilot flew slowly at treetop level, following the sinuosity of the fire perimeter, while the Pathfinder logged a position per second.

Although the activity of the fire was not intense, there was a real chance for this fire to take off and run.

As the helicopter slowly moved along the fire perimeter, the IR interpreter identified a hot spot and the FMT operator pressed a computer function key to mark or flag the location in the data file. At the same time, the GPS operator documented on a pad of paper the time displayed by the polycorder and, if time permitted, the latitude and longitude. Recent hardware-software updates are now available for marking or flagging hot spot locations in a file, making recording by hand unnecessary.

Downloading Data and Plotting the Map. In 2 hours, using the methods described here, the east and south sides of the fire had been flown and information collected on the fire perimeter. On return to the camp, the data in the polycorder were downloaded to a laptop computer. The flight of the IR mission was then plotted using a Hewlett Packard 7475 plotter at 1:24000 scale. The plot consisted of a series of dots depicting points along the line of flight. Precise registration of the plot with a U.S. Geological Survey (USGS) topographic 7.5-minute quadrangle map is accomplished by aligning the 2.5-minute tick marks produced on the plot with the 2.5-minute ticks on the USGS quad.

Locating Hot Spots and Plotting Those Points on Fireline Map Overlay. The entire file was then graphically displayed on a computer monitor. Using the Pathfinder software PFINDER, the hot spots, as identified by the IR interpreter, were located in the file by matching the time tag of each position with the times recorded by the GPS operator. (As mentioned earlier, the latitude and longitude of the hot spots were recorded on a pad of paper by the GPS operator.) The LOCATER command allows the operator to move a pointer around freely on the screen with a mouse, and as the pointer is moved, the latitude and longitude is displayed in the upper portion of the screen. The pointer was moved around until the exact latitude and longitude of each previously recorded hot spot appears on the screen. As this was done, the pointer indicated on the screen where that hot spot was located in relation to the fire perimeter. The hot spot point was then visually transferred from the screen to the plotted 1:24000 scale fireline map overlay. With the hot spots located on the overlay, it was determined which spots were easily accessible by engine and which required water bucket drops.

Taking Suppression Action

During the detection flight, it was noted one hot spot was relatively small and not smoking. It was near a firebreak recently constructed with bulldozers. Considering the Pathfinder's navigating capability, it was decided to try to locate

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[1]Douglas Luepke's and Philip Drake's ("Fire Mapping Using Airborne Global Positioning" also published in this issue) use of GPS was previously described in "GPS for Forest Fire Management and Cleanup" in the September 1991 issue of *GPS World*.

this spot with an engine crew using GPS.

First Step—Finding the Hot Spot. The first step in locating this hot spot was to enter the recorded location into the Pathfinder's waypoint (the hot spot) file. The engine crew drove as close as they could to the spot navigating with the USGS quad map and the overlay plot. The Pathfinder was then used to navigate to the final location. With the Pathfinder position at the engine known, the NAVIGATE program was executed. This program calculates the azimuth and distance from where the user is to the previously entered coordinates of the waypoint, or hot spot. The polycorder displays the azimuth and distance from the current position to the hot spot. A compass was used to direct the crew toward the hot spot. As the engine crew approached the position, the distance displayed on the polycorder continued to decrease. At zero, indicating the location of the hot spot had been reached, there was no visible evidence of a hot spot. This confirmed the observation during the detection flight that this spot was not smoking. As the search for the hot spot narrowed, a pile of debris pushed up by the dozers was noticed. Using the "cold-touch" method, heat was detected coming from this pile. This was it—and within 10 to 15 feet (3.1 to 4.6 m) of where the GPS unit had zeroed out. Mission accomplished.

Calculating the Area of the Fire. Another task was to calculate the area of the fire. Because helicopter time was in high demand, it took the next 3 days to complete flying over the remaining portions of the fire perimeter. Although the flights were made at times when satellite visibility was not ideal, the data were collected as if this were a working fire situation and information was needed immediately. Due to antenna location within the helicopter and minimum satellite visibility, portions of the perimeter had to be flown in different directions to get adequate satellite signals. The PFINDER software has the capability of doing area calculation if all data are flown in the same direction. Flying portions of the perimeter in opposite directions requires additional steps to calculate the area.

Using the Pathfinder software, the data acquired during the 3 days were merged into one file using the utility program MULTISSF. This file was graphically displayed on the computer monitor. All overlapping data from each of the individual flights were then removed with the DELETE command. The final product was a single, clean file, depicting the fire perimeter of the Shorts Fire. Next, the utility program GISGENX was used to convert this data into AutoCAD® DXF format.

An AutoCAD® drawing file was then created and the data collected by the GPS unit were added by using the AutoCAD® command, DFXIN. Using the POLYLINE command, a line was drawn on a separate layer over the existing GPS points. It took about 30 minutes to do this. Once this line was closed on itself, the AREA command was used to calculate the acreage. The total area measured was 20,079 acres (8,126 ha) with a perimeter of 49.5 miles (80 km). This was less than the total fire acres of 20,779 (8,409 ha), because the small burn areas outside the main burn on the southern perimeter were not included in the GPS measurements. If these areas had been measured, the calculation would likely have been very close.

The Gain, the Downside, the Future

This fire situation provided an excellent opportunity to introduce GPS to the firefighting procedures. Although the activity of the fire was not intense, there was a real chance for this fire to take off and run. The experience proved that GPS can be used effectively in a helicopter. However, it was noted that the location for the antenna within the helicopter is critical. In some cases the loss of signal from one or more satellites created data gaps ranging from 50 to 200 feet (15 to 61 m). This was not critical because the detail of the fire perimeter was not lost.

The process used to record hot spots, download the data, and locate these spots on the map was a bit cumbersome. Future versions of the software will reportedly provide the capability to tag points by pressing a function key similar to the function key used in the FIRE MOUSE TRAP.

One more valuable feature of the GPS software is its ability to produce a plot with 2.5-minute tick marks, which allows easy registration with the USGS quads. This eliminates the need for "rubber sheeting" (aligning or adjusting the map with known physical features) the fire map to make it fit.

The navigation ability of the GPS unit can play a major role in firefighting. The new, low-cost, lightweight Pathfinder, Pathfinder Basic, now available seems to be an excellent tool to locate recorded hot spots. An individual in a spotter helicopter can record hot spots and transfer the information by radio to a ground crew for immediate response. Imagine the spotter directing 10 or more engine crews to hot spots and also directing water drops all at the same time using GPS.

Several people suggested flying the perimeter of the fire at a higher altitude. At the higher altitude, a less-detailed but acceptable perimeter could be defined in less time and eliminate the additional steps and software used for area calculations. However, the Shorts Fire experience provided an opportunity to demonstrate another way to calculate area and the flexibility of PFINDER in converting data into AutoCAD® format.

One of the activities associated with the fire was the consideration of an existing facility for a combination incident base and incident command post. The Pathfinder was used to create a quick, as-built plan of the existing features including roads, parking areas, and existing supply and motor pool locations. These data were collected, downloaded, and a 1-inch-equals-40-feet (0.3-m = 12.9-m) plot provided to the planning team in less than 2 hours. ■

Hallie Daggett: First Woman as Forest Service Fire Lookout[1]

In 1913, the Klamath National Forest Supervisor, W.B. Rider, had a big decision to make. The Eddy Gulch Fire Tower needed a new lookout, and according to M.H. McCarthy, assistant fire ranger, in his letter to Forest Supervisor Rider, there were only three applicants to choose from: One had poor eyesight, one was "no gentleman," and the other was "also 'no gentleman' " but "has all the requisites of a first-class Lookout."

With that rundown on the applicants, assistant fire ranger McCarthy recommended Hallie Daggett as the best qualified for this important job. As he did so, he hoped the supervisor's "heart was strong enough to stand the shock" of having a woman nominated since an appointment of that sort was unheard of at the time.

Hallie, "a wide-awake woman of 30 years," wrote McCarthy, "knows and has traversed every trail in the Salmon River watershed, and is thoroughly familiar with every foot of the district." She supported the Forest Service and promised to stick with the job until she was no longer needed. She was an excellent rifle marksman, rider, and trapper and was "not afraid of anything that walks, creeps, or flies."

Hallie was hired at a salary of $840 a year and spent the next 15 years on the job. Despite the rigors of such an assignment, except for riding to and from the lookout at the start and end of the fire season, Hallie continued to wear the popular ankle-length skirts and high-necked blouses fashionable in her day. But ". . . it was a rare experience," writes Rosemary Holsinger in her article, "A Novel Experiment: Hallie Comes to Eddy's Gulch," "to catch her without a revolver strapped to her belt," a weapon she readily used. During the fire season of 1915 for example, she killed one bear, four wildcats, and three coyotes.

Why did she choose to do such difficult work? As she said, "I love it! And that's why I'm here." ■

[1] Adapted from a handout in the Museum in the Schools Program jointly sponsored by the Siskiyou County Museum and the Klamath National Forest 1991 Program. Rosemary Holsinger's article on Hallie Daggett was published in Women in Forestry; 1983: 5(2) 21–25.

Clark County Goes Face-To-Face With Wildland-Urban Interface

The Problem and the Plan

One cool, damp spring night in 1990, facing another fire season in Clark County, WA, one of fastest growing counties in the Nation, Fire Chiefs Steve Wrightson, Pat Humphries, and Tom McDowell and Fire Commissioners Dave Campbell, Roy Bellcoff, and Fred Pickering developed a plan to manage the increasing wildland fire interface problem in Clark County. Forest lands of various ages and slash, combined with new homes, cause great concern for fire protection agencies.

The fire chiefs and commissioners submitted an application to the Washington State Department of Natural Resources for grant money from Washington's Fire District Support Program to finance visits to homeowners to assess risk and offer safety information. The Washington State legislature appropriated $200,000 in 1990 to be distributed to fire districts that support the Department of Natural Resources in wildland fire protection and suppression. Clark County was granted $18,000 to carry out its proposal.

The Project

Two people, Eric Sork and Linda Engel, were hired for 8 weeks to conduct a door-to-door risk assessment on each home in wildland-urban interface areas with a high risk of fire. The risk assessment considered road access, topography—especially with features increasing fire danger—fuels near homes, electrical utilities, building construction, water supply, distance from a fire station, landscaping, outdoor burning, and firewood storage.

Sork and Engel visited with homeowners at their homes. They explained why they were there and asked if they could walk around the house to do a risk assessment. They gave the homeowners a copy of outdoor burning regulations, a home protection guide, fire resistant landscaping information, and the opportunity to get new glow-in-the-dark signs for their home address. They also handed out recycling information.

Only three times were Sork and Engel asked to leave, but the residents still took the information to rate their own homes. Eight hundred homes were visited in a 2-month period. When the home visits were completed, they followed up with a telephone survey, calling 400 people. The results indicated that 75 percent of the people surveyed by telephone had made some type of change to lessen their risk.

Homeowners made the following changes:

- Firewood moved away from buildings
- Lower limbs of trees removed
- Sprinkler systems installed
- Retardant applied to shake roofs
- Shake roofs replaced with a fire resistant roofing material
- Many glow-in-the-dark house numbering signs put up

Benefits to the Fire District

The fire district benefited in several significant ways:

- The community became aware of the danger of fire
- Homeowners took action—changed their behavior—to reduce fire hazard and enhance safety.
- Goodwill was built with the homeowners—impressed that the fire district cared enough to come to their homes. People who were not home during the home visits called the fire district to ask if they could be a part of the program. ■

Lane L. Jolly, *fire service specialist, Washington Department of Natural Resources, Olympia, WA*

The Pioneers (Some of Them) and Their Equipment (a Little of It) in Forest Service Infrared Fire Mapping and Detection Research and Operations

. . . basic theory of fire mapping and detection developed

. . . a remarkable achievement

. . . basic tenets still apply

From 1962–1976, through the research conducted by Project FIRESCAN under project leader Stanley N. Hirsch, electronics engineer, and physicist Ralph Wilson, electronics engineer Forrest Madden, and electronics technician Dale Gable at the Intermountain Forest and Range Experiment Station, the basic theory of fire mapping and detection with thermal infrared systems was developed. Under the leadership of Bob Bjornsen, as head of a separate group to develop procedures for fire mapping and as Forest Service director at Boise Interagency Fire Center, infrared mapping and detection was established as a standard part of fire operations.

J.S. Barrows in the 1950's pointed out, after studying fires in the western zone of the Northern Region, the high number of fires escaping and acreage burned and the need for improved detection methods. Barrows envisioned a detection system that could efficiently cover areas where fires were likely and locate those fires while they were small. The system he foresaw would, in his words "detect the greatest number of fires in the fastest time at the lowest cost."

Many people contributed to our understanding of the operation and the usefulness of infrared forest fire detection. Some of the researchers, besides those already mentioned, are P.H. Kourtz, Nonan Noste, Robert F. Kruckeberg, and B. John Losensky; some of the technicians and pilots, Robert A. Cook, John Voth, Ted Bishop, Eddie Downs, Bill Hodson, Nels Jensen, and John Holsman.

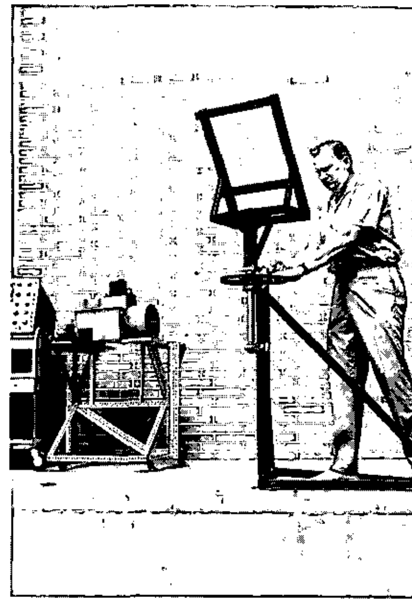
Stan Butrym, pilot, Robert Miller, project engineer, Captain D. Petersen, project officer, members of the U.S. Army Mohawk team, and Robert L. Bjornsen, project head of the Northern Forest Fire Laboratory forest fire mapping program, with aircraft prop jet ship equipped with infrared sensing and recording equipment. The U.S. Army team, temporarily assigned to the laboratory secured the image of the forest fire, located it, and then fire operations personnel mapped the fire. (Photo: Harold Pontecarvo, 1963)

Fire Surveillance Project aircraft crew, (left to right) Bill Hodson, copilot; Ted Bishoff, mechanic; and John Holsman, pilot, with Convair T-29. (Photo: Herman Wittman, 1968)

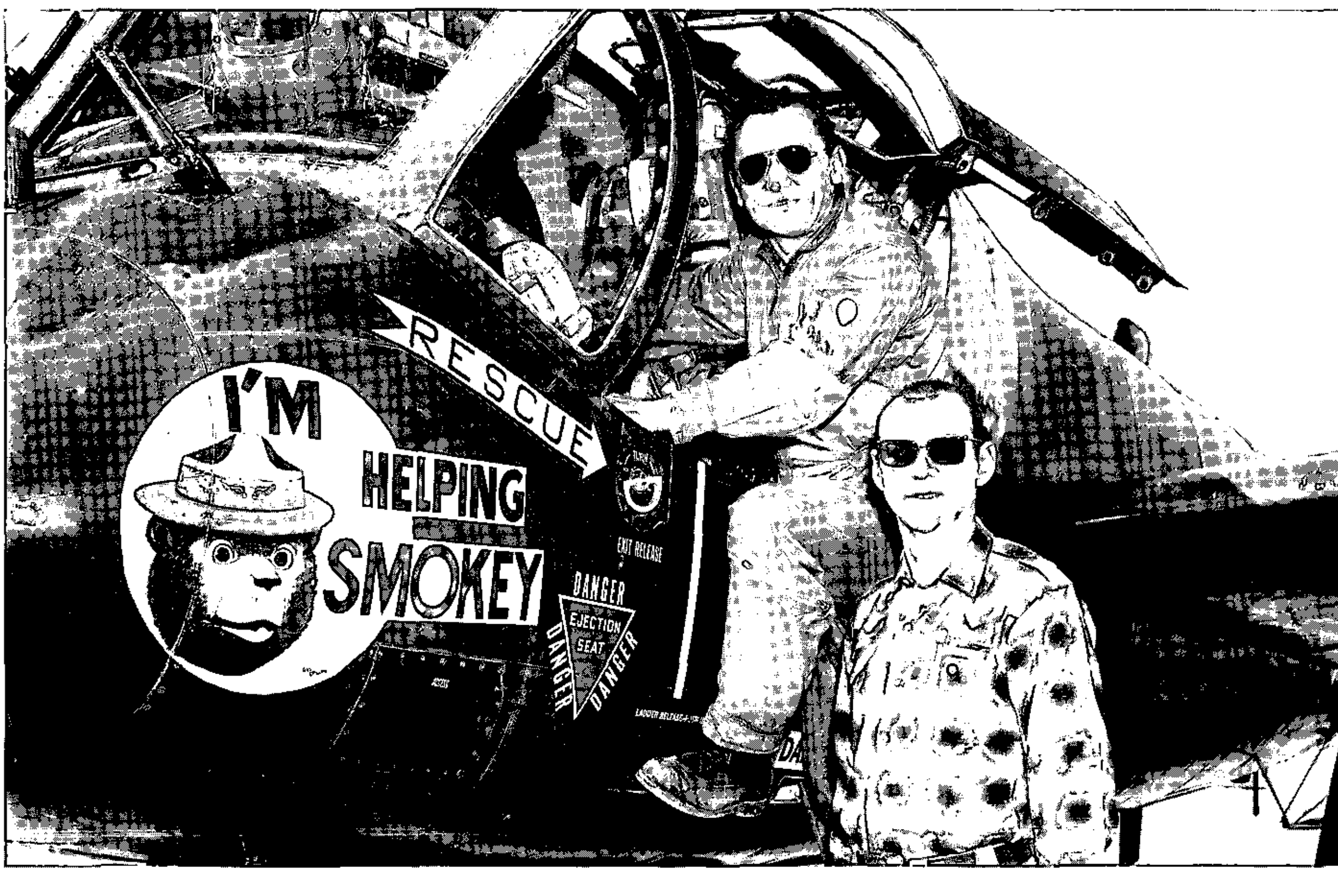
Special thanks to Roberta Hartford of the Intermountain Fire Sciences Laboratory, Missoula, MT, for her help in tracking down photographs for this story. Thanks also to Richard Rothermel, Francis Russ, Brenda Breslin, John Warren, Ralph Wilson, Charles George, and Dale Gable for their efforts.

Photographs: Courtesy of USDA Forest Service Intermountain Fire Sciences Laboratory in Missoula, MT.

Forrest Madden, FIRESCAN electronics engineer, points out the small infrared scanner attached to the light fixed-wing aircraft, which was developed by personnel at the Northern Forest Fire Laboratory (now known as the Intermountain Fire Sciences Laboratory, Missoula, MT) to detect small spot fires in small areas so the ground crew could locate exact fire position. (Photo: Herman Wittman, 1968)

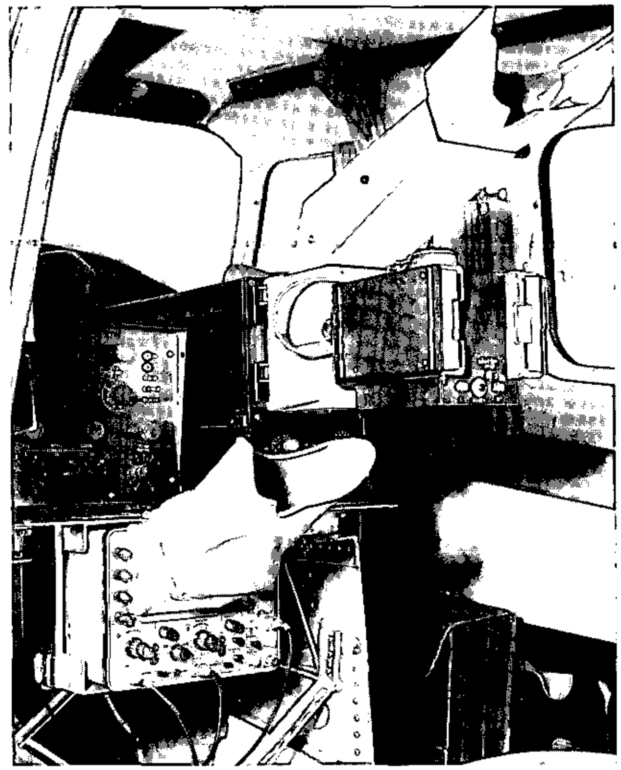


Ralph Wilson, physicist with the FIRESCAN group, examines a frame designed to hold the HRB Singer AAS-5 scanner.

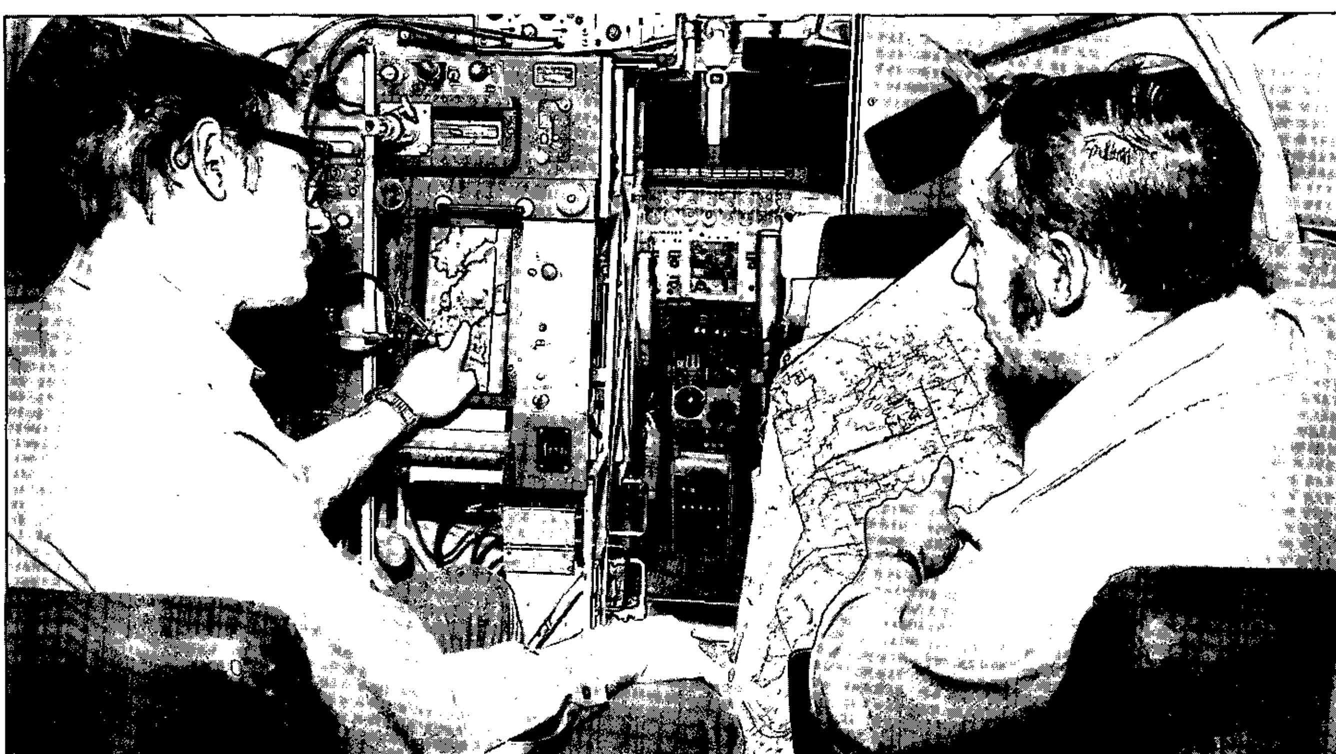


Stanley N. Hirsch, project leader of FIRESCAN of Northern Forest Fire Laboratory, and Stan Butryn, pilot, with U.S. Army's Mohawk aircraft, cooperatively used with the Northern Forest Fire Laboratory's FIRESCAN programs. (Photo: Harold Pontecarvo, 1963)

John Voth, FIRESCAN infrared electronics technician, using the photographic film processor to record infrared imagery during test runs to detect small fires. (Photo: Vance Price, 1967)



Interior of Aero-Commander aircraft showing control panel for infrared imagery detection equipment used in fire mapping operations. (Photo: Herman Wittman, 1966)



Infrared electronic technicians, John Voth (left) and Dale Gable (right) using an electronic infrared sensor within aircraft to locate small forest fires, record the imagery, and identify a ground location with the interpreter's map. (Photo: Herman Wittman, 1971)

Global Positioning System: Uses in Fire Management on the Clearwater National Forest

Byron J. Bonney

Fire staff officer, USDA Forest Service, Clearwater National Forest, Orofino, ID

The Clearwater National Forest had the opportunity in 1991 to test the Trimble Navigation's Pathfinder, a navigation system and position-logging system based on the Global Positioning System (GPS), in locating initial attack fires on normal aerial fire detection flights and in the mapping of prescribed natural fires within the Selway-Bitterroot Wilderness.

Randy Doman, fuels specialist on the Clearwater National Forest, read about the capabilities of the GPS in *Engineering Field Notes.* These capabilities were brought to the attention of the Clearwater fire coordinator, Chuck Petersen, who elected to try GPS in the aerial fire detection aircraft. The Clearwater Engineering Cadastral Survey staff had recently purchased two Pathfinders and was gracious enough to allow the Fire Management Systems staff to borrow one of these units to test its application in fire detection and mapping.

Aerial Fire Detection

The Clearwater National Fire Management team saw the need to improve the aerial fire detection program. The fire managers had a problem obtaining accurate legal descriptions on new fires from aerial observers and fixed lookouts. The LORAN-C in the aerial detection aircraft had not been the answer to this problem, as locations plotted by this instrument have been up to 3 miles (5 km) off. At best, LORAN-C would plot the locations within 1/2 mile (0.8 km). Due to this inaccuracy, the forest had been continuing with locating fires using the aerial observer's knowledge of the forest and using a 1/2 inch-to-the-mile-(1.3 cm-to-1.6-km-) forest map for plotting fire location. On many occasions, the lookouts would turn in a legal description, and the aerial detection aircraft would give a different legal description. The initial attack crew would then refine the location after finding the fire on the ground. Much time, energy, and money have been wasted in trying to obtain accurate legal descriptions to locate these fires.

The GPS Test

The Equipment and its Mounting in the Aircraft. Wanting to raise the level of accuracy in locating fires, fire managers decided to test the GPS in the aerial detection aircraft to see if it could improve performance. The system—consisting of an antenna, a polycorder, and a battery pack—does not take up much room in the aircraft. The antenna was mounted on the dash of a Cessna 185. It was determined later that to access the satellites properly, the antenna should be mounted on top of the wing of the aircraft. The problem with mounting on the dash of the aircraft is that the fuselage would block out some of the satellites and the system would not respond with a correct location.

Satellite Use. The system can be operated in two dimensions, using three satellites, or in three dimensions, using four satellites. The system can be checked, as the aircraft is flying, to ensure the proper number of satellites are being used for the operation underway. One mode within the program will tell you whether you are receiving in two or three dimensions. When receiving in two dimensions, the fixed elevation at which the aircraft is flying must be programmed into the GPS and the aircraft needs to stay at that elevation to obtain an accurate location. In three dimensions, a fixed elevation is not needed, as the elevation remains variable within the program. There are also only certain times during the day when the GPS will be able to receive in either two or three dimensions. A timetable listing available satellite access times is published daily. The cadastral engineer on the Clearwater National Forest helped the forest obtain these timetables.

From our estimates, the cost of GPS can be recovered after 2 to 3 years of operation and, depending on the circumstances, perhaps even after one fire.

Procedure and Use. The aerial observer detects a fire. The aircraft then flies on a straight north-south line directly over the fire. Before flying over the fire, the polycorder is programmed to record location by latitude and longitude. As the aircraft flies over the fire at a certain elevation, the aerial observer presses the ENTER key on the polycorder. The latitude and longitude recorded are accurate within plus or minus 10 meters (33 ft) of that fire. This information would be transmitted to the district, where it would be plotted on a 7.5-minute U.S. Geological Survey topographic map and given to the initial attack crew. GPS was used about 15 to 20 times in 1991 on flights to locate initial attack fires.

Under normal circumstances, without GPS, the aerial detection aircraft might make three to six passes around the fire to obtain accurate information on the fire location. In some cases these locations might be off as much as 1 mile (1.6 km) from where the fire is actually located. It is believed from the Clearwater experience that this technology will not only save precious time and money during detection but also time and money for initial attack crews in locating fires on the ground.

Use in Prescribed Natural Fire

The GPS was also used to map the perimeters of several prescribed natural fires within the Selway-Bitterroot Wilderness. For these fires, the GPS was used from a helicopter, Bell Jet Ranger 206C, on which foam-backed antenna was mounted to the nose of the helicopter on the battery door with duct tape, reinforced with filament tape.[1] The cable was then taped under the nose and sent up through the drain plug in the bottom of the bubble on the passenger side of the ship, for easy access to the operator.

The mapping flight was flown at 50 to 100 feet (15 to 30.5 m) above the tree tops. The GPS was operated within the three-dimensional satellite window timeframe. An easily recognizable starting point was identified, and the GPS was programmed before reaching that point. As soon as the helicopter passed over that point, the ENTER key was pressed and the GPS began recording points along the path of the helicopter at a rate of one point per second. Different time intervals for recording points can be programmed into the GPS.

After flying around the fire perimeter and reaching the starting point, the GPS is then programmed to "log off." If possible the fire perimeter should be flown with GPS another time in the opposite direction to obtain a double check on the first perimeter and acreage.

The perimeters of both the Two Mile and Blacktail prescribed natural fires were flown. In order to save flight time, only one flight was used around each fire. The final maps were printed and plotted on a 7.5-minute USGS map. These maps would aid fire managers with interpretation of fire growth on these fires later in the season if these fires continued to be active. The actual fire perimeter has been difficult to obtain from fixed-wing observation flights. The GPS answered many questions regarding fire perimeter location on these two fires.

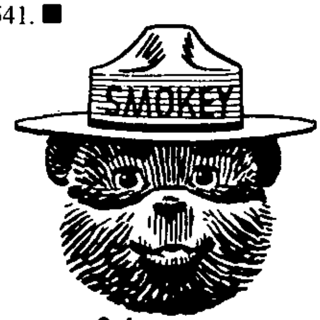
Did GPS Work for the Clearwater?

GPS has many uses in fire management. Systems such as the Pathfinder can save time and money and lead to our being more confident in our information on fire location—the start, hot spots, and perimeter. Furthermore, this system has the potential for many other applications on large fires. Incident management teams could utilize the system in many different ways:

- Plot accurate fire perimeters daily.
- Locate certain points within or around the fire for rescue, helispots, critical areas, and so on.
- Gain accurate locations of hot spots when used in conjunction with infrared imagery.
- Plot location of any new fire starts or spotfires within the area of responsibility.

The Clearwater National Forest has completed its GPS test and is convinced that this system needs to be used as an operational tool for the 1992 fire season. The system costs approximately $8,400. Estimates indicate that this cost could be recovered after 2 to 3 years of operation and, depending on the circumstances, perhaps even after one fire. The forest is sold on GPS and would strongly recommend that other fire management teams consider this system.

If you have experiences to share or any questions about the Clearwater National Forest's use of this system, please give me a call at (208) 476-4541. ■



[1] Specific procedures for approval of mounting the GPS antenna have been outlined in a May 5, 1992, letter from the Director of Fire and Aviation Management in the Washington Office to each Regional Forester. If the mounting procedure described in this article is used, it must be submitted, with proper paperwork and log book entries, to the Federal Aviation Administration for approval. The FAA views mounting the antenna with tape as a temporary attachment procedure.

FIRE MOUSE TRAP Use in the Southern Region

James P. Scott

Forest land surveyor, USDA Forest Service, Francis Marion-Sumter National Forests, Columbia, SC

The Startup

The FIRE MOUSE TRAP (FMT) mapping system was introduced to the Southern Region of the USDA Forest Service in the spring of 1989, when John Warren, electronics engineer, and Dale Gable, electronics technician, at Boise Interagency Fire Center (BIFC) gave a thorough 3-day training session in the operation and maintenance of the system in Columbia, SC. The original class consisted of eight students: three from the Francis Marion-Sumter National Forests, two from the National Forests in Florida, one from the National Forests in North Carolina, and two from the Chattahoochee-Oconee National Forests in Georgia. A second training class was held in the spring of 1991 at the Witherbee Ranger District, Francis Marion National Forest, where five more Southern Region Forest Service and four U.S. Department of the Interior personnel (three U.S. Fish and Wildlife and one National Park Service) received training. A third training class was held at Tallahassee, FL, during January 1992 where seven more Forest Service personnel were trained.

System Components and Their Functions

The Southern Region's FMT system contains an ARNAV R–15 LORAN-C navigation receiver with an RS–232C output cable, a Hewlett-Packard Portable Plus laptop computer and a Houston Instruments DMP–56 plotter capable of being used on a full-size 7.5-minute topographic quadrangle map, a map specially created for the Forest Service by the U.S. Geological Survey. The latitude and longitude points calculated by the LORAN-C are stored in the laptop computer at selected intervals, usually at 2 seconds, while the helicopter flies the perimeter of the area to be mapped. If the mapping is to be done on foot or by all-terrain or other vehicle, the recording interval can be set according to the speed over ground. When the project is completed, the laptop computer is connected to the plotter and the plotter scaled to the map or transparencies of the area covered by the LORAN-C traverse. The laptop will then drive the plotter pen to plot to scale on the map the perimeter, hot spots, or other spots of interest.

The first use of the FIRE MOUSE TRAP system in the Southern Region was on the Pinhook Fire on the Osceola National Forest. It was an instant success.

First Uses in the Southern Region

Osceola National Forest—Pinhook Fire. The first use of the FMT system in the Southern Region was on the Pinhook Fire on the Osceola National Forest. It was an instant success. The fire was mostly in a low, swampy area with undefinable mapping features. Twenty minutes after the fire perimeter flight, a fire map mylar overlay showing the fire boundaries was in the hands of the plans chief. The accuracy of the information was outstanding. Where the topographic features were identifiable on the 7.5-minute quadrangle, we were able to verify that FMT put the fireline precisely where it belonged. This verification gave users confidence in the system's ability to locate fireline in areas with little mapping definition.

Okefenokee National Wildlife Refuge—the Shorts Fire. The system was used twice a day to map the Shorts Fire on the Okefenokee National Wildlife Refuge in south Georgia. Even though the quadrangle maps lacked identifiable topographic features, the FMT system successfully mapped the fireline. At one point on the Shorts Fire, two incident bases needed good fire location maps. The decision was made to cut the mylar plot into eight inchwide (2.5-cm) strips and transmit the plot to the second base over a FAX machine. The results were satisfactory and delivery time was immediate. During the fire, more than 60 FMT maps were plotted, providing an excellent record of fire growth.

The FMT system was used to fly the fire perimeter, mapping the numerous helispots and dip tank sites. We then produced a perimeter map that located each helispot and dip tank (along with latitude and longitude) on the fire perimeter, identifying each by name and number. These maps were a great service to helicopter pilots who would then load this data into their LORAN-C's and fly directly to the location. At one point, several large areas of peat bog were burning underground. The refuge requested a map be made showing the location of the underground fire. A handheld infrared scanner was used to detect the underground burning with the infrared operator directing the helicopter pilot around the bogs while the FMT recorded the line of flight. The final product was a map of the underground fires related directly to the fire perimeter map.

Other Fire Projects and Uses

The Southern Region's FMT system has now been used on six project fires within the region and one project fire in the Pacific Southwest Region. We have also used it to locate bug infestations, hiking and motorcycle trails, and forest roads.

We have found that the system is a great tool when used with a handheld infrared scanner in mopping up a fire. One person operates the infrared scanner, while a second operates the FMT system. The infrared operator spots a hot spot (many of which are not visible to the human eye) and calls out "Hot spot!" to the mousetrap operator, who then types a function key on the computer, recording the geodetic position of the hot spot in the computer. After the return to the helibase, a plot is made on mylar from the system with the hot spots plotted in their true location on the fireline. This accurate plot becomes a valuable tool to the handcrews and helicopter water bucket operation, saving handcrews a lot of time "cold trailing" along a fireline. We have walked the fireline with the handheld infrared and the FMT map and found every hot spot located from the air. This accurate information about hot spots makes the handcrew's day a little easier and gives the crew confidence in their work.

A Few Problems

In its 2 years of use, the Southern Region has encountered a few problems with the system. The first problem: The effect of a high-powered military radar station on fire mapping. While mapping a fire in the Everglades National Park close to Homestead Air Force Base, the base aircraft radar making a sweep in the direction of the helicopter, destroyed the LORAN plot at that instant. The second problem: The effect of high voltage power lines on a ground mapping project. The plot was disrupted when the LORAN antennae was directly under the wires, but returned to normal once we were 100 feet (30.1 m) from power lines.

The Southern Region expects to use the FMT system for more activities in the future and awaits the arrival of the new global positioning system (GPS) once the satellites needed for GPS use are in place for 24-hour three-dimensional coverage throughout the United States. ■

Max Planck, Infrared, and Quantum Mechanics

Max Planck, in 1900, working with Wein's Displacement Law and the Rayleigh-Jeans Law (both partially explaining infrared (IR) radiation), concluded that the laws of classical physics were inadequate to describe the process taking place in the thermal IR bands at the atomic level. Planck agreed that oscillations could be allowed for all possible frequencies but introduced the idea that the amplitudes, and hence the energy, could increase only in discrete steps, differing by the quantity hv, now called a quantum of energy. Planck called h the quantum of action and later experiments showed that it is a universal constant, now called Planck's constant. In less than 2 months, Planck developed the concept of quantum physics, now known as quantum mechanics, the basis for a whole area of modern physics.

Integrating Planck's Law

$$W_\lambda = \frac{2\pi hc^2}{\lambda 5} \qquad \frac{1}{e^{(ch/\lambda^{rt})}-1}$$

W = spectral radiant emittance, $WCM^{-2}\mu^{-1}$
λ = wavelength, μ
h = Planck's constant = 6.6×10^{-34}, W sec^2
T = absolute temp, K
C = velocity of light, 3×10^8 m sec^{-1}
K = Boltzman's constant 1.4×10^{-23}W sec K^{-1}

over wavelengths from zero to infinity gives an expression for the radiant emittance in a hemisphere above a blackbody 1 cm^2 and is known as Stefan-Boltzman's law. Differentiating Planck's Law and solving for the maximum gives Wein's Displacement Law. Stefan-Boltzman's Law describes the area under the curve; Wein's Law, the position on the wavelength scale; and Planck's equation, the shape of the curve. ■

John R. Warren, *group leader, Advanced Electronics, USDA Forest Service, Boise Interagency Fire Center, Boise, ID*

Evaluating The Hummer®

Brian Hutchins

Unit leader and mechanical engineer, Michigan Department of Natural Resources, Michigan Forest Fire Experiment Station, Roscommon, MI

Need for Heavier Off-Road Vehicle

Like many wildfire agencies, the Michigan Department of Natural Resources (MDNR) has been searching for good vehicles for the rigors of off-road forest fire use. Recent truck design has moved to meet the needs of the highway user. The newer vehicles exhibit lighter frames, reduced ground clearance, and larger profiles—characteristics that make the vehicle less useful for wildland fire use. In a national engine study, the National Wildfire Coordinating Group (NWCG) Fire Equipment Working Team, surveying wildland engine user needs, documented the disparity between those needs and current truck design.

From NWCG's survey, a set of vehicle standards criteria was developed. The U.S. military's multipurpose-wheeled vehicle (HMMWV), produced by the AM General Corporation, meets many of these criteria for one size class. The "HUMMER®" as this vehicle is called is best known for its recent success in the Persian Gulf War.

Testing the HUMMER®

In January 1989, the MDNR began negotiating with AM General to purchase one vehicle for evaluation. In July 1990, the MDNR took delivery of the first HUMMER® obtained through a nonmilitary procurement. Engineers and staff at the Michigan Forest Fire Experiment Station developed a fire package for initial testing of the vehicle. Project goals are to evaluate the effectiveness of the vehicle compared with other wildfire control vehicles,

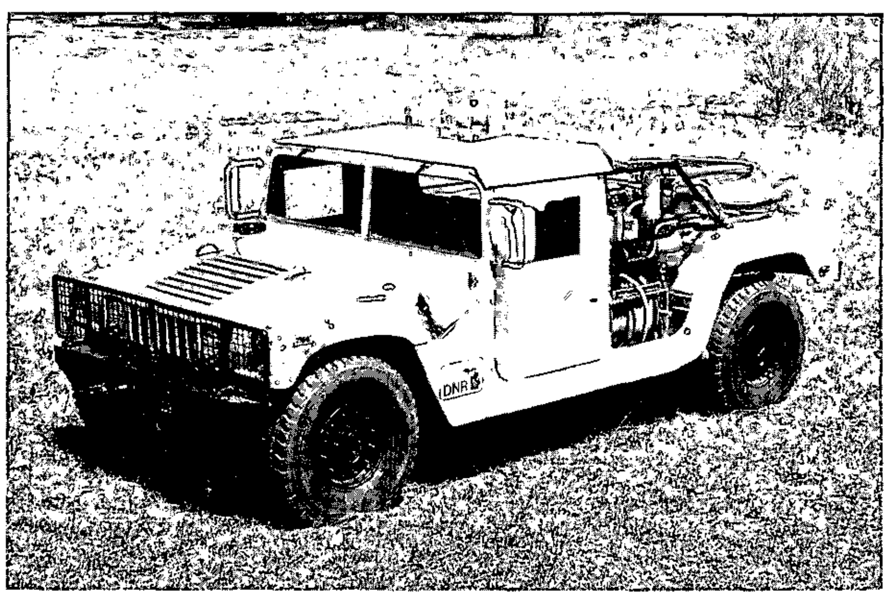
In a national engine study, the National Wildfire Coordinating Group (NWCG) Fire Equipment Working Team, surveying wildland engine user needs, documented the disparity between those needs and current truck design.

determine the usefulness of the vehicle before its availability through Federal Excess Personal Property (FEPP), and to develop a design concept for agencies interested in utilizing the vehicle.

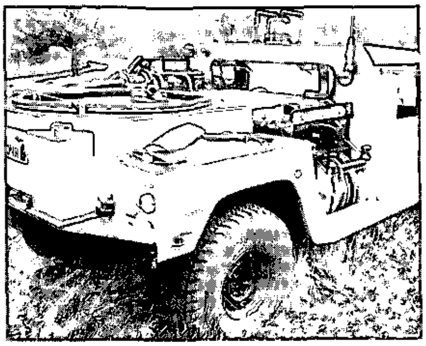
Up to now, the HUMMER® has 21 military versions. These include troop, shelter and armament carriers, ambulances, and light artillery prime movers. Gross vehicle weight (GVW) of these vehicles ranges from 7,700 to 9,400 pounds (3,493 to 4,264 kg). In recent years, AM General began investigating marketing the HUMMER® commercially. The MDNR purchase was one step in this process. In June 1991, AM General announced that it will eventually sell the vehicle to the general public.

Differences Between the Commercial and Military HUMMER®

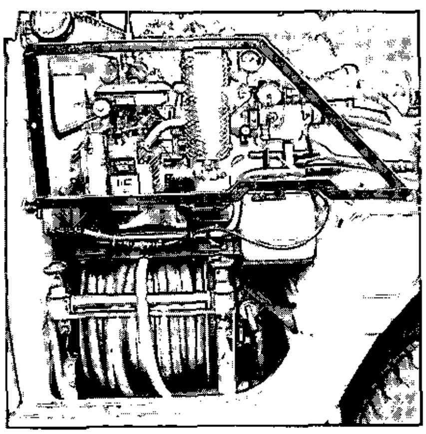
The commercial HUMMER® has several significant differences from the military version. For instance, the commercial vehicle has greater load capacity (a GVW of 10,300 lb or 4,674 kg), "civilian" style seats, a 12-volt electrical system, and a hard cab top in 2- and 4-person cab styles. Some of these changes were made to meet Federal safety and environmental standards. The MDNR unit is a prototype of the commercial version, which includes upgraded load capacity, seating, and safety items.



Michigan Department of Natural Resources-AM General Corporation HUMMER® prototype with 300-gallon (1,136-L) engine.



The rear view of the HUMMER®, showing the 5-gallon (19-L) foam tank, right hose reel, and storage areas.



Leftside view of the HUMMER® with hydraulic pump and left hose reel located in the rear occupant area.

Publishing the Field Test Results and Designs for FEPP Users

The prototype vehicle is currently in field test. Information will be published in about 1 year in Roscommon Equipment Center Report No. 56. For FEPP users, the report will include a cab design for retrofitting soft cabs with a hard version, improved bumper and grill protection, and an assessment of water capacities for the various military models. Potential commercial purchasers will get an assessment of the HEAVY HUMMER®'s performance in wildfire conditions. See tables 1 and 2 for information on some of the features of MDNR's HEAVY HUMMER® prototype. ■

Table 1—*Michigan Department of Natural Resources-HUMMER® prototype unit features*

Features from AM General	Features from Michigan DNR
HEAVY HUMMER® capacity (10,300 lb or 4,672 kg GVWR)	Two-person hard cab 300-gallon (1,136-L), 3-point suspended water tank
Central tire inflation	KK Products foam proportioner with 5-gallon (19-L) concentrate tank
Radial tires	Extended front bumper and grill guard
12,000-pound (5,443 kg) electric winch	Hose storage tray
Cab doors	Shovel and axe holder
Automatic transmission with high-low and 4-wheel drive	Right and left hose reels
Detroit diesel 6.2 L engine	Wajax-Pacific BB–4 pump fender nozzles and trigger-type cab gun

Table 2—*Vehicle weight and dimensional information of Michigan Department of Natural Resources—HUMMER® prototype*

Specifications	Data
Weight (300 gal nominal capacity)	
Front	3,880 lb (1,760 kg)
Rear	6,080 lb (2,758 kg)
Total	9,980 lb (4,518 kg)
Weight rating	
Front axle (FAWR)	4,100 lb (1,861 kg)
Rear axle (RAWR)	6,800 lb (3,085 kg)
Total	10,300 lb (4,672 kg)
Vertical center of gravity	35.3 inches (0.9 m) above ground
Height (ground to top of cab)	72 inches (1.8 m)
Width	85 inches (2.2 m)
Wheelbase	130 inches (3.9 m)

Monthly Fire Weather Forecasts

Morris H. McCutchan, Bernard N. Meisner, and Francis M. Fujioka and John W. Benoit and Benjamin Ly

USDA Forest Service, respectively, research meteorologists and computer programmers, Pacific Southwest Research Station, Riverside, CA

Fire Management Planning and the Fire Weather Forecast

An important objective of fire management planning is to identify the resources and activities needed for an expected fire danger period. Improved fire danger prediction capabilities, in which fire weather forecasting plays a vital part, can greatly aid fire managers in their planning.

Fire danger is predicted with the aid of fire weather forecasts, typically covering 1 to 3 days. Long-term fire planning has traditionally been based on fire climatology and historical experience, since long-range fire weather forecasts were not available. Although the National Weather Service (NWS) routinely produces monthly and seasonal outlooks of average temperature and precipitation, those forecasts were not designed to represent fire weather.

Now a system has been developed specifically to forecast monthly fire weather. This monthly forecast differs fundamentally from the traditional daily fire weather forecast, which identifies the trends and the expected worst condition in a 24-hour period. Rather, the monthly forecast represents the *average* fire weather over the month. It does not fit the requirements of the National Fire-Danger Rating System.

This paper describes the NWS forecasts and the forecasting process briefly, examines the monthly fire weather forecast in detail, and explains how the monthly fire weather forecast may be accessed. Current limitations to the monthly forecasts are presented, together with suggestions for dealing with the limitations in decisionmaking.

National Weather Service Extended Forecasts

Medium-Range Forecasts. The NWS's medium-range (6- to 10-day) forecasts produce daily data of the type used in the National Fire-Danger Rating System (NFDRS) (Deeming and others 1977). The core of these medium-range weather forecasts is the output from computer models of the atmosphere, using information gathered through a worldwide network of observations. These models generate forecasts of future weather elements by applying physical laws to the current state of the atmosphere. The products that are typically produced from these forecasts and disseminated are manually modified maps that show much above, above, near normal, below, and much below average temperature and precipitation expected for the forecast period. These categories are determined by comparing the expected temperature and precipitation with climatological norms.

Monthly fire weather forecasts may not be the fire planner's magic bullets, but they do provide scientifically based long-range forecasts.

Monthly Outlooks. The NWS Climate Analysis Center (CAC) issues 30-day average weather outlooks at the beginning and middle of each month. These outlooks are prepared using both computer model output and statistical techniques:

- The forecaster first prepares a chart of the expected airflow over the Northern Hemisphere at an altitude of approximately 10,000 feet (3,048 m) (where the air pressure is 700 millibars). The airflow at that altitude reflects patterns in both the overlying jet stream and the temperature of the underlying air.
- Then, maps of expected average temperature and precipitation totals are generated from equations, based on the expected 700 millibar airflow and persistence (the departures from normal observed in the previous month are expected to continue in the current month).
- The forecaster adjusts the temperature and precipitation outlooks and produces maps showing the probability that the temperature and precipitation will be either above or below normal during the month.

Seasonal Outlooks. Prepared by CAC once each calendar month, the seasonal outlooks are based solely on statistical techniques, since the accuracy of computer model forecasts deteriorates rapidly over time. A group of forecasters prepares a consensus 700 millibar airflow chart, considering the following factors: Correlations in the airflow from one season to the next; correlations (teleconnection) between the airflow at one location and that at a distant site; extent of snow cover; sea surface temperature patterns, such as those associated with El Niño and La Niña; and persistence. As with the monthly outlooks, a map of expected temperatures consistent with the airflow chart and persistence is generated using a set of equations. Because seasonal precipitation patterns show little persistence, an objective routine identifies the 5 previous years with temperature patterns most similar to those forecast for the season of interest. The precipitation amounts that were observed during those years are used as guidance for the seasonal precipitation outlook. As with the monthly outlooks, the final products are categorical probability maps of temperature and precipitation.

The Monthly Fire Weather Forecast

The monthly fire weather forecasts are prepared by the USDA Forest Service at the Pacific Southwest Research Station's Forest Fire Laboratory in Riverside, CA. Unlike the daily weather forecast for NFDRS, which describes the expected worst-case local conditions for a particular day, the monthly fire weather forecast predicts *average* conditions over a broad area for a month.

The monthly fire weather forecast characterizes the weather-induced fire potential using equations developed for the contiguous United States and Alaska (Klein and Whistler 1991). These equations relate the expected 700 millibar airflow and persistence to 30-day forecast percentiles of the following variables: Afternoon (1300 LST) surface temperature, relative humidity, Chandler Burning Index (CBI), and windspeed at 127 NWS stations (fig. 1), and the precipitation frequency and amount over 60 climate areas (fig. 2) (Englehart and Douglas 1985). Our CBI is a modified version of the burning index developed by Chandler and others (1983) and is given by:

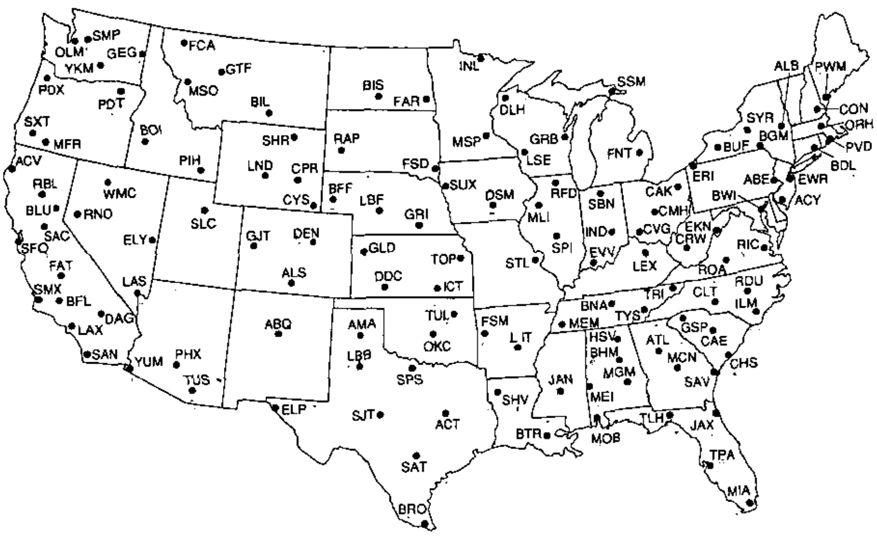


Figure 1—*Locations of National Weather Service stations for which average afternoon (1300 LST) surface temperature, dew point temperature, and windspeed are forecast.*

Figure 2—*Locations of climate areas for which precipitation frequency and amount are forecast. Approximately 15 reporting stations are in each climate area. Areas are numbered in alphabetical order by state.*

$$CBI = (110 - 1.373(RH)) - 0.54(10.2 - T)) (124 \times 10^{-0.0142(RH)})/60 \quad (1)$$

where RH = monthly mean afternoon relative humidity (percent) and

T = monthly mean afternoon surface temperature (°C)

The CBI is a weather-driven fire index that is highly correlated with fire activity on five of fourteen *nearby* national forests examined in a previous study (McCutchan and Main 1989).

The forecasts are made in terms of percentiles because percentiles express how frequently the forecast value actually occurred in the climatic data for any given location. Percentiles also translate readily into severity levels which can be tied to appropriate preparedness actions (Chase 1991; Mees and Chase 1991).

The percentiles are determined completely by climatology. For example, a 90th percentile of CBI would equal or exceed 90 percent of the CBI values in the climatological record. To have the high percentages signify high fire potential, the percentiles of precipitation frequency, precipitation amount and relative humidity are reversed, since low values of these parameters contribute to high fire danger. In other words, higher percentiles represent lower precipitation frequencies. Thus, in our forecasts, the 90th percentile of precipitation amount would be *less than* 90 percent of the amounts in the climatological record.

Maps of forecast percentiles of temperature, relative humidity, CBI, windspeed, and precipitation frequency are prepared. Examples for June 1991

Figure 3—*Maps plotting forecast percentiles for June 1991: (a) average afternoon temperature, (b) average afternoon modified Chandler Burning Index, (c) average afternoon windspeed, and (d) precipitation frequency. (Note: For precipitation frequency, higher percentiles represent lower frequencies.)*

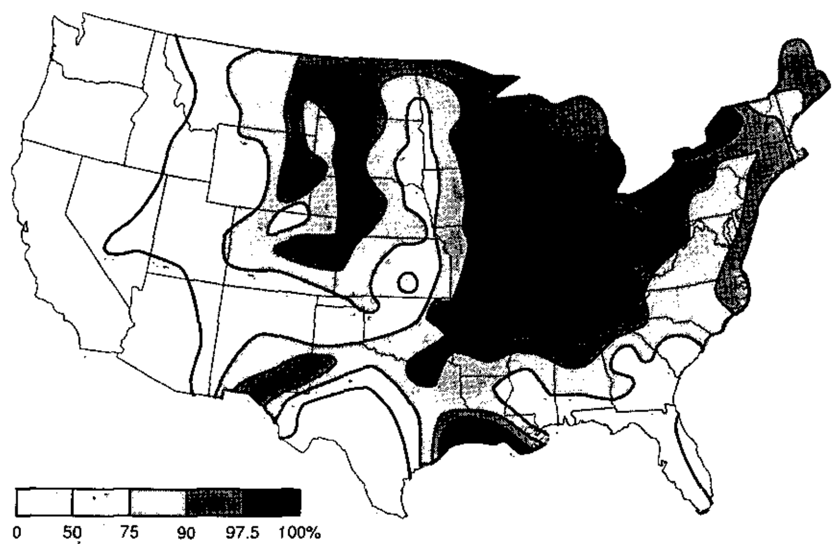


Figure 3a—*Average afternoon temperature.*

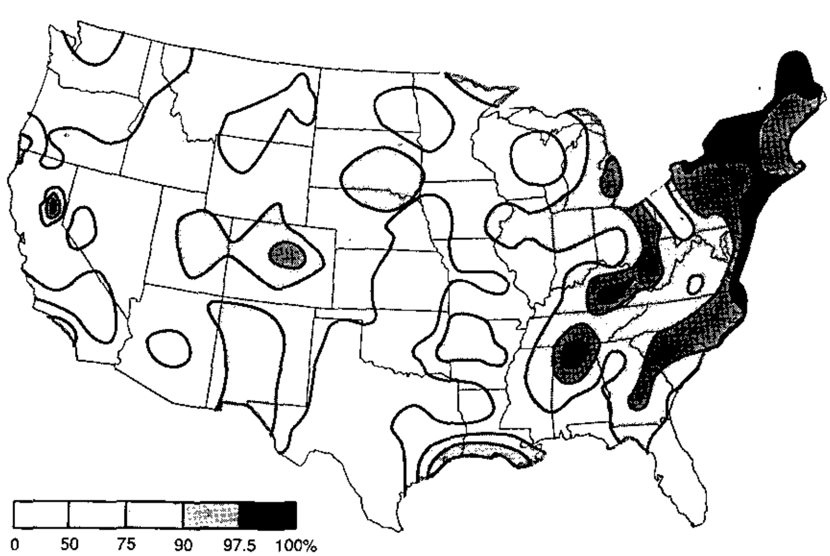


Figure 3b—*Average afternoon modified Chandler Burning Index.*

are shown in figure 3. The temperature map (fig. 3a) shows one large area (extending from northern Arkansas to the eastern Great Lakes) and two small areas (in northern Minnesota and along the east Texas and Louisiana coast) that were forecast to have extremely high percentiles (≥97.5 percent). A large area forecast to be cooler than normal (<50 percent) covered the Western United States. The forecast values of the CBI (fig. 3b) were higher than normal, particularly for the eastern third of the country. The map depicts several centers of extremely high percentiles extending from northern Mississippi to New England. The forecast windspeed map (fig. 3c) shows above-normal percentiles (≥50 percent) over the central and southern Rockies, the Great Basin, the Southwest desert, and scattered small areas elsewhere. The precipitation frequency map (fig. 3c) shows below-normal frequencies (≥50 percent) over most of the area east of the Mississippi River. Very low precipitation frequencies (≥90 percent) were forecast for New England, the upper Ohio Valley, and the coast of North Carolina.

Instructions for accessing the monthly fire weather forecasts are printed in the screened box accompanying this article.

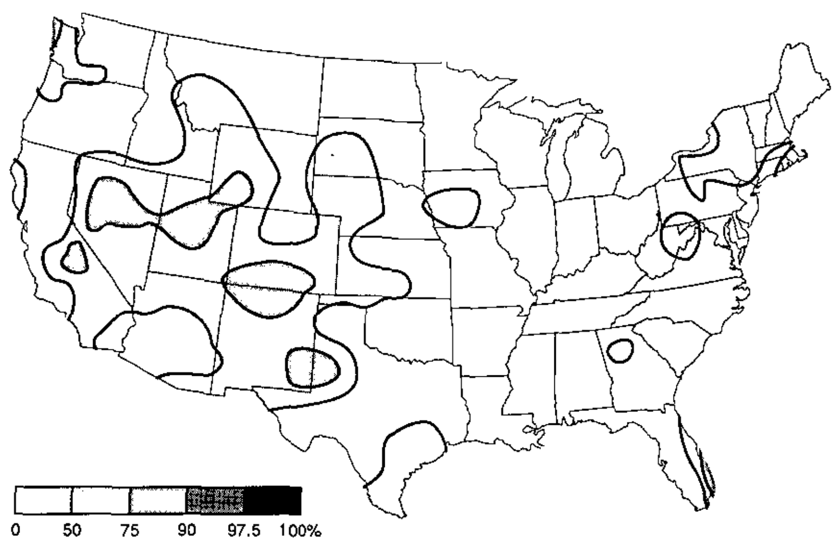


Figure 3c—*Average afternoon windspeed.*

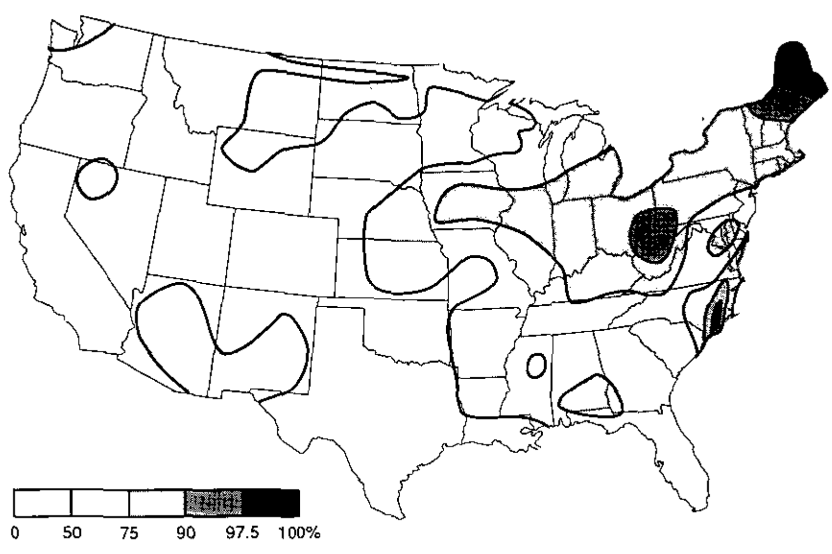


Figure 3d—*Precipitation frequency.*

Limitations of the Forecasts

In both the CAC monthly weather outlooks and our monthly fire weather forecasts, each station represents an area of about 30,000 square miles (77,770 km²). The average weather may vary greatly over relatively short distances not captured by the forecasts. In addition, the forecast values represent averages over the course of a 30-day period; significant variations could occur within that period. Work is currently underway at the Forest Fire Laboratory to develop a technique for converting the monthly fire weather forecasts made for the NWS stations to forecasts for given forest locations.

Experience with extended-range forecasts has shown that they tend to be most accurate in winter and least accurate during spring and fall, when the day-to-day weather is most variable (Wagner 1989). Temperature is more predictable than precipitation or relative humidity, and monthly windspeeds are the most difficult to predict. Of particular interest for fire managers and planners is the fact that summer and winter precipitation forecasts have comparable skill.

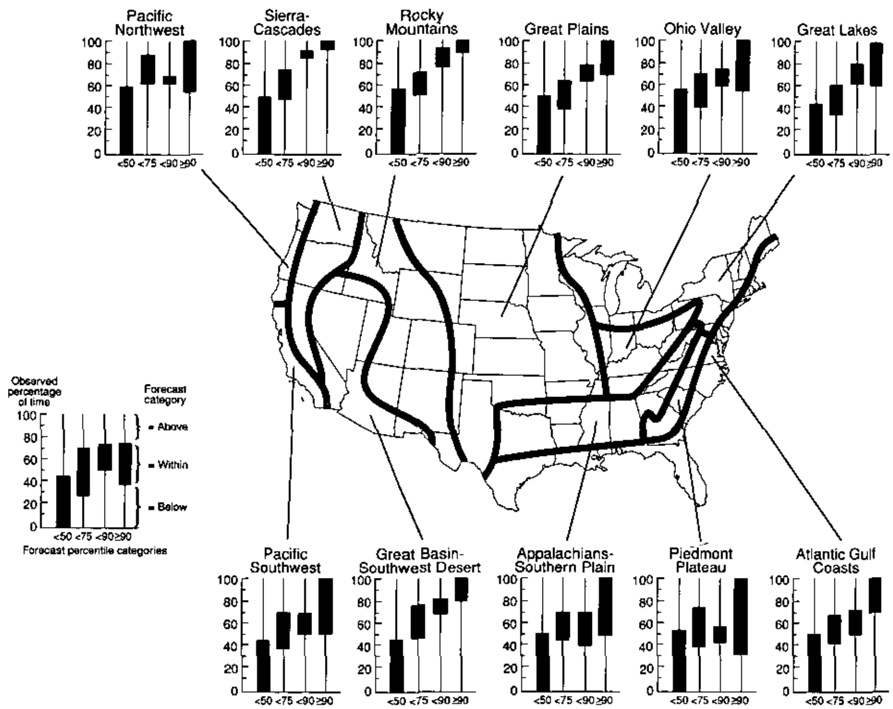


Figure 4—*Relative accuracy of the fire weather temperature forecasts for various regions of the United States for summer months for the period 1973–83. For each of the four forecast percentile categories, the bar represents the percentage of the time that the forecasts were correct. The line below the bar represents the percentage of the time that the observed temperatures were less than those forecast, and the line above the bar represents the percentage of the time that the observed temperatures were greater than those forecast.*

Preliminary Verification of the Fire Weather Forecasts

Forecasts can best be used when their accuracy is known. The accuracy of our fire weather forecasts varies from one parameter to another, from one season to another, and from one location to another. A contingency table, or its graphical representation, provides a useful format for expressing the likelihood of success in forecasting. Figure 4 shows the relative accuracy of our afternoon temperature forecasts for different regions of the country for the summer months for the period of 1973 to 1983. The forecasts were grouped into four percentile categories: less than 50 percent, 50–75 percent, 75–90 percent and greater than or equal to 90 percent. The stations were combined into 11 regions that are both climatologically and statistically consistent. The diagram accompanying each region shows the percentage of the time that the actual temperature was below, within, or above the forecast category. For each category, the wide bar represents the percentage of the time that the observed temperature was within the forecast category—a correct forecast. The line below the bar represents the percentage of the time that the observed temperature was less than the forecast category, and the line above the bar represents the percentage of the time that the observed temperature was greater than the forecast category. For example, in figure 4, when the temperature in the Pacific Northwest was forecast to lie between the 50th and 75th percentiles, the forecast was correct 25 percent of the time (bar). The observed temperature was less than that forecast 63 percent of the time (lower line) and was greater than that forecast only 12 percent of the time (upper line).

Our fire weather forecasts of below normal temperatures (<50 percent) are generally the most accurate. For most regions, when slightly higher than normal temperatures (50–75 percent) are forecast, the actual conditions are as likely to be below normal as above normal. Forecasts of the temperature category that would contribute to moderate fire danger (75–90 percent) are least accurate, with the observed temperatures more likely to be lower than higher. However, particularly in the Eastern States and along the Pacific Coast, our forecasts of extreme temperature (≥90 percent) have been accurate more than half the time.

Conclusions

Monthly fire weather forecasts that can be used in fire management planning are now available; medium-range and seasonal fire weather forecasts are being developed. These forecasts will not be the fire planner's magic bullets, but they do provide scientifically based long-range forecasts. Because the fire weather forecast is inherently less accurate in the long-range than the short-range, the user must consider the impact of variable forecast accuracy. The accuracy of these forecasts also varies with location, time of year, and the parameter that is forecast.

Planning activities require weather predictions to go further into the future. To maintain some level of accuracy, forecasts are made for larger geographic areas and for longer periods of time. At some point, however, the accuracy will be so severely degraded that the forecast will provide no useful information. The intent of providing accuracy information, along with the forecast, is to assist the user in determining when that point has been reached. ■

How To Access the Monthly Fire Weather Forecasts

The set of five forecast percentile maps, two tables of the forecast values and their percentiles, and a narrative description of the CBI percentile map are combined into a single computer file that is available shortly after the 1st and 15th of each month. Those with access to the Forest Service's Data General computer system can obtain these forecasts electronically. Those who do not have access to the Data General can access a file through the Automated Forest Fire Information Management and Retrieval System (AFFIRMS), a user-oriented interactive computer program designed to permit entry of fire-weather observations and forecasts from field locations. The file accessible from AFFIRMS includes the two tables of forecast values and the narrative description of the CBI percentile map.

Data General

Go to the IS Main Menu:

INFORMATION SYSTEM 6.42

Select option 3. Utilities (Tapes, Dumpfiles, Import, Remote Access)
Select option 6. Transfer (Information Transfer and DCC Access)
Select option 1. Info transfer (Transfer Information between FS offices)

INFORMATION TRANSFER UTILITY Screen 1 of 2

Transfer Type (1. Send, 2. Retrieve): 2
Local information structure

Level (1. Public, 2. Staff): 2
Drawer Name: (e.g., MYDRAWER)
Folder Name: (e.g., MYFOLDER)
File Name: CURMAPS.DMP

Staff Name: (e.g., MYSTAFF)
[Respond here as appropriate for your location]

Local transfer action (Y/N)? N

Literature Cited

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Chase, Richard A. 1991. Incorporating seasonal severity into annual fire program planning. In: Andrews, P., ed. Proceedings of the 11th Conference on Fire and Forest Meteorology;

INFORMATION TRANSFER UTILITY Screen 2 of 2

Host name : S27L05A
Remote information structure
Level (1. Public, 2. Staff): 2 Staff Name: MET
Drawer Name: FORECAST
Folder Name: MAPS
File Name: CURMAPS.DMP
Remote information (Y/N)? N
Do you want to omit CEO mail notification (Y/N)? N
Do you want to submit transfer request NOW (Y/N)? Y

Note: To obtain the forecasts for the previous period, substitute PRVMAPS.DMP for CURMAPS.DMP.

Wait for mail message from IS_MGR: "Request: CURMAPS.DMP queued to retrieve . . . ."

To extract the files: At the IS_CLI) prompt, type *LOAD CURMAPS.DMP*. This extracts the maps, text, and narrative files from the dumpfile, and they will then appear in your directory.

To print the maps: At the IS_CLI) prompt, type *QPR/BIN/QUE=3D JUN91TEMP* where, for example, 3D is a Data General laser printer queue name and JUN91TEMP is the map of forecast afternoon temperature percentiles for June 1991.

To print the text files: At the IS_CLI) prompt, type *QPR/QUE=3D JUN91FW.TXT* where, for example, JUN91FW.TXT is the table of forecast fire weather variables at the 127 stations.

AFFIRMS

The AFFIRMS file name of the current month's tables of forecast values and percentiles is MOFCU530, and, for the previous month's forecast values, is MOFPV530.

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