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FOREST FIRE MONITORING USING THE NOAA SATELLITE SERIES

M.D. Flannigan

Canadian Forestry Service
Petawawa National Forestry Institute
Chalk River, Ontario, Canada KOJ 1JO

T.H. Vonder Haar

Department of Atmospheric Science
Colorado State University
Fort Collins, CO 80523

1. INTRODUCTION

Forest fires can pose a serious threat to communities, property, and valuable timber every year. In Canada, during the period 1973-82, there was a yearly average of 9,200 fires which burned 2.1 million hectares (ha) (Ramsey and Higgins, 1985) and cost $100 million to control. During that 10-year period, fires that were larger than 200 ha, which made up 3% of the total number of fires, were responsible for 97% of the area burned. Fire control agencies try to detect the fire as soon as possible after ignition and take appropriate action. If the action required is to extinguish the fire, the smaller the fire the easier the task. Detection is achieved by aircraft reconnaissance, observations from manned fire towers, and by the general public.

The ability to monitor forest fires by satellite has been possible for over two decades now. LANDSAT imagery has been used to calculate area burned in the Northwest Territories, Canada, at the end of a fire season. The LANDSAT satellites with a resolution of 30-80 m range would be ideal for fire monitoring were it not for the 18-day gap between passes over the same area. The Geostationary Operational Environmental Satellite (GOES) which has excellent temporal resolution, with imagery every half hour, has some drawbacks. First, the infrared resolution of 7 kilometers (km) at the subsatellite point makes it impossible to detect small fires; second, GOES VISSR has only one infrared channel, thereby eliminating the possibility of a multispectral approach.* It is, however, possible to detect fires indirectly by using the GOES visible channel to spot smoke plumes from the larger fires. This is because the resolution of the visible channel is considerably better (0.9 km at nadir). The National Oceanic and Atmospheric Administration (NOAA) satellites, with a resolution of near 1 km at nadir along with a pass every 12 hours over the same location, appear best equipped to monitor forest fires. Also, the NOAA satellites have multiple infrared channels which facilitate multispectral techniques. The National Weather Service has used the infrared channels from the NOAA satellites since 1981 to help identify forest fires in the western United States (Matson et al., 1984).

The technique of fire monitoring described in this report uses satellite data to monitor forest fire location and size and could be used to complement existing detection systems. Remote areas of North America, which include large segments of Canada's boreal forest, are ideally suited for fire monitoring by satellite because reports of fire detection by conventional means are usually slow and scarce.

2. THE ADVANCED VERY HIGH RESOLUTION RADIOMETER

The Advanced Very High Resolution Radiometer (AVHRR) has been on board NOAA satellites since 1979. The NOAA satellites were designed to operate in a near polar, sun synchronous orbit with a nominal altitude of 833 km. The orbital period is 104 minutes, which results in 14.2 orbits per day. The AVHRR provides one visible channel, one near-infrared channel, and two or three infrared channels. Table 1 from Kidwell (1984) shows the spectral interval and the Instantaneous Field of View (IFOV) for the AVHRR channels. The IFOV of each channel is approximately 1.4 milliradians leading to a resolution of 1.1 km at the subsatellite point for an altitude of 833 km. The AVHRR is a cross-track scanning radiometer with a scan rate of 360 scans per minute covering an angle of ±55.4° from the nadir, equivalent to a swath width of 2,600 km. Data is digitized onboard the spacecraft with a total of 2,048 samples per scan per channel. A more complete description of the NOAA satellite

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* Future GOES-I,J,K satellites will have multispectral capabilities as does the present VAS experiment on GOES.

series and the AVHRR can be found in Schwalb (1978, 1982) and Kidwell (1984).

Table 1. Bandwidth and IFOV of the AVHRR

Ch. #	Bandwidth (micrometers) NOAA-6, -8	NOAA-7, -9	IFOV (mrad.)
1	.58 - .68	.58 - .68	1.39
2	.725 - 1.10	.725 - 1.10	1.41
3	3.55 - 3.93	3.55 - 3.93	1.51
4	10.5 - 11.5	10.5 - 11.3	1.41
5	Ch. 4 Repeated	11.5 - 12.5	1.3

3. DATA

The satellite and forestry data were selected for the Slave Lake Forest Region for the period June 12 to June 21, 1982 to take advantage of a rapidly changing forest fire situation. On June 12 only a few small forest fires were burning in the Slave Lake Forest Region. By June 21, there were over 30 fires burning out of control, with some fires larger than 20,000 ha. The Slave Lake Forest Region, as shown in Figure 1, extends from latitude 54.5°N to 57.5°N and from longitude 113°W to 117°W.

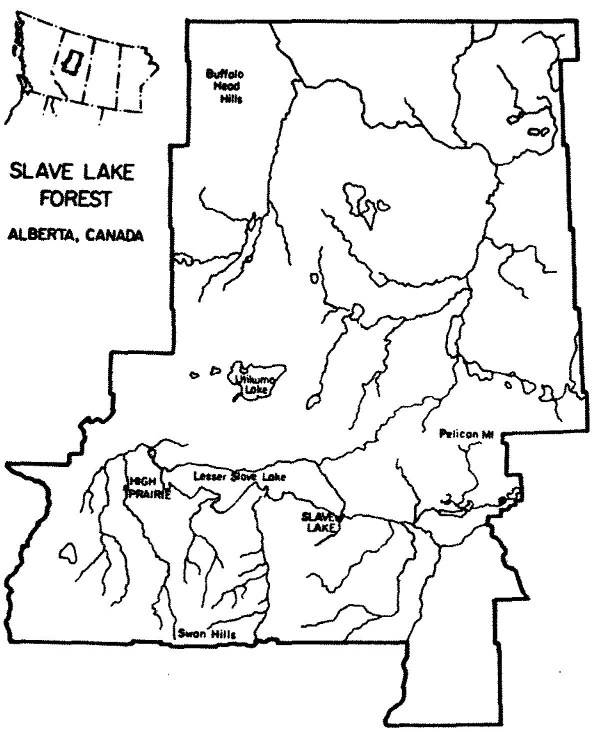

Fig. 1. Slave Lake Forest Region

NOAA-7 AVHRR data were obtained through the Atmospheric Environment Service (AES) from the ground station in Edmonton, Alberta. Data were retrieved from two passes a day from June 12 to June 21, 1982 unless the data were not saved or were at a large viewing angle from nadir. The ascending orbit (northbound equator crossing) for NOAA-7 is in the afternoon, while early morning passes are southbound. The AVHRR data recorded by the Edmonton ground station included channels 2, 3, and 4. The data has 2,048 samples per scan per channel, of which a few samples at the beginning and end are for calibration. The data for the infrared channels were calibrated according to to the procedure described by Lauritson et al. (1979). The data has full spatial resolution of 1.1 km at nadir.

The forest fire data were supplied by the Alberta Forestry Service for the period June 12-22, 1982. They are in the form of daily reports which, by forest region, list the name, location, size (acres), and status of the fire. Almost all fires in this case study were ignited by lightning. The size of the fire was estimated via aircraft reconnaissance, usually in the late afternoon or early evening.

4. FIRE MONITORING TECHNIQUE

Dozier (1981) showed that it was possible to use a multispectral approach to detect subpicture element (pixel)-sized elevated heat sources. He used data from AVHRR channels 3 and 4 to find the temperature of the elevated heat source and percentage of the pixel covered by the hot target. Matson and Dozier (1981) used this approach to detect steel mills in the midwestern United States. The multispectral technique developed by Dozier was used in this study to find the area and temperature of the forest fire within a pixel.

The fire monitoring technique is a result of the differences in the radiometric response of the AVHRR Channels 3 and 4. AVHRR channel 3 is very sensitive to high temperature sources. Figure 2 shows that, as temperature increases, the wavelength of the maximum value of the blackbody radiance shifts toward smaller wavelengths. Using this figure, a forest fire at 500°K compared with the unburned forest at 300°K, will produce a greater fractional contribution to the radiance sensed for Channel 3 than for Channel 4. Figure 3 shows integrated Planck radiances for NOAA-7 Channels 3 and 4. This figure shows the Channel 3 curve has a greater slope than Channel 4; thus, high temperatures for Channel 3 will make a greater contribution to the total radiance sensed. It follows that forest fires or any elevated heat sources are easier to detect on Channel 3 imagery.

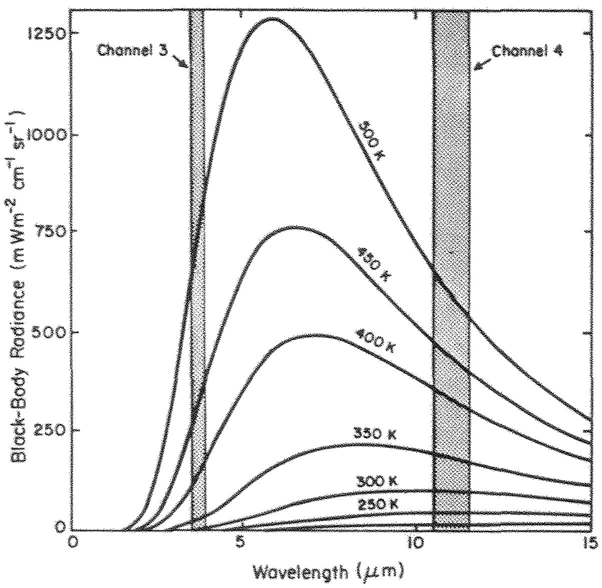

Fig. 2. Planck Radiances for Temperatures from 200° to 500°K.

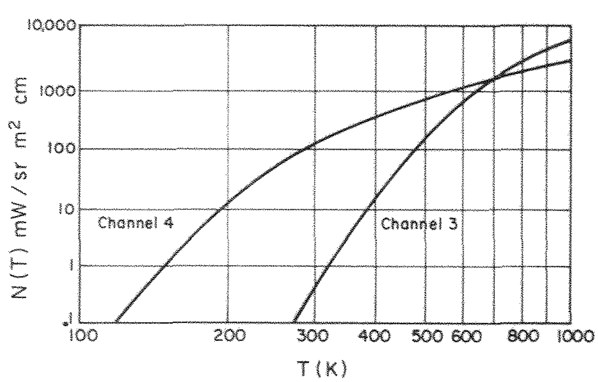

Fig. 3. Integrated Planck radiances for NOAA-7 AVHRR Channels 3 and 4.

To calculate fire size and temperature within a pixel, let $N_3(T)$ and $N_4(T)$ represent NOAA-7 Channels 3 and 4 radiances sensed by the satellite. A pixel may be composed of an elevated heat source, in this example a forest fire at temperature T_f, which occupies portion p of the pixel (where $0 \leq p \leq 1$). The remaining portion (1-p) of the pixel is covered by forest with a background temperature T_b. Therefore, the radiances sensed by the radiometer can be written as follows for Channel 3 and Channel 4:

$$N_3(T_3) = pN_3(T_f) + (1-p)\, N_3(T_b) \quad (1)$$

$$N_4(T_4) = pN_4(T_f) + (1-p)\, N_4(T_b) \quad (2)$$

where $N_3(T_3)$ and $N_4(T_4)$ are known. If T_b is known, then p and T_f can be found by solving the two equations. This technique will not determine the location of the fire within the pixel. One limitation of this method is that the Channel 3 sensor will saturate at 322°K. Fortunately, saturation will only occur when the fire is intense or covers a significant portion of the pixel.

Figure 4 shows a sample NOAA-7 AVHRR Channel 3 image from June 19, 1982, 2110 GMT. The image covers an area of about 360,000 km² (600 km x 600 km). The enhancement scale is such that black is hot and white is cold.

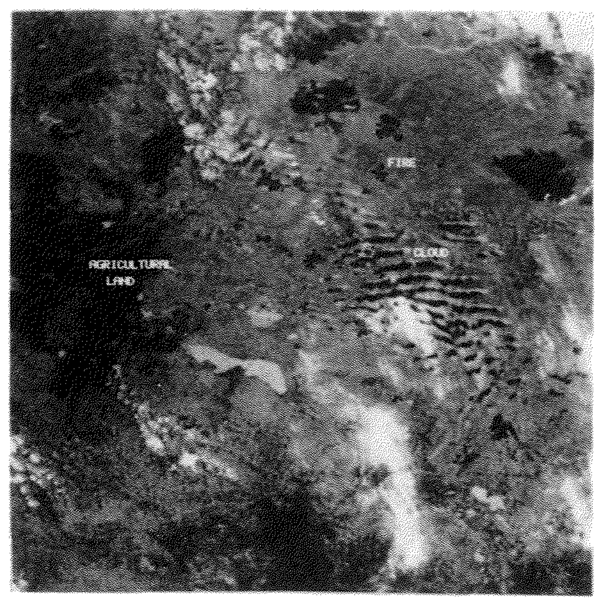

Fig. 4. NOAA-7 AVHRR Channel 3, June 19, 1982, 2110 GMT.

Traditionally, Channel 3 imagery has not been used during daylight hours due to the reflection of solar radiation. This solar contamination is evident in figure 4 as some clouds appear very warm. Even though the relative intensity of solar radiation in the AVHRR channel 3 range (3.55 - 3.93μm) is small, the reflection from clouds can compare to the radiation emitted by cloud tops. The reflected radiation is dependent upon the albedo of the illuminated surface. The albedo of clouds in the 3.5-4.0 μm region is high and pixels with some cloud are contaminated. Therefore, cloud-contaminated pixels were eliminated through a cloud discrimination technique based on the spatial coherence method of Coakley and

Bretherton (1982). The reflectivity of a typical hardwood leaf in the 3.0-4.0 μm range was shown by Lee (1978), based on data from Gates (1965), to be zero. Wong and Blevin (1967) found reflectances of plant leaves in the 3.0-4.0 μm region are less than .05 for the majority of leaves. From the above information the amount of solar radiation reflected by the forest was considered insignificant. Therefore, Channel 3 imagery was used during daylight hours to monitor the forest.

Detecting fire in a pixel was accomplished through a temperature differencing technique. The effective infrared temperature of each cloud-free pixel was calculated for both Channels 3 and 4. If the calculated temperature exceeded the mean background temperature of the forest and if the Channel 3 temperature was greater than that of Channel 4 by a critical value, it was assumed that fire was present. The threshold value of the temperature difference was 8°K for night passes, and 10°K for day passes. After this technique was applied to the region of interest in the image, contiguous pixels with fire present were grouped together as one fire. The fire area in any given pixel was calculated by the multispectral approach (Dozier, 1981) except when a pixel was surrounded by other fire pixels. In such a case it was assumed the pixel was totally burned over.

5. RESULTS

Verification of fire identification for two class sizes are shown: Class 1 included fires 40 ha or less, and Class 2 was for fires over 40 ha. During the 10-day period June 12 - June 21, a total of 355 fire observations were reported by the Alberta Forest Service. Many of these were repeated observations of the same fire in several satellite passes. For example, if the same fire was present for three passes it was counted as three fire observations. Table 2 displays the total fire observations for class type and for day and night cases, as well as unobstructed fire observations. Cloud and smoke were responsible for obstructing the satellite view in many cases. Table 3 shows the number of fire identifications made by satellite for those fire observations that were not obscured.

Table 2. Total fire observations by class and time of pass

	Class 1 (≤ 40 ha)	Class 2 (> 40 ha)	Total
Day	66 (16)	117 (62)	183 (78)
Night	73 (20)	99 (49)	172 (69)
Total	139 (36)	216 (111)	355 (147)

The ( ) number indicates those fire observations which were unobstructed for satellite viewing.

Table 3. Unobstructed fire observations identified by satellite.

	Class 1 (≤ 40 ha) (%)	Class 3 (> 40 ha) (%)	Total
Day	9/16 (56)	59/62 (95)	68/78 (87)
Night	9/20 (45)	41/49 (84)	50/69 (73)
Total	18/36 (50)	100/111 (90)	118/147 (80)

The results from table 3 show that 80% (118/147) of the unobstructed fire observations were identified. However, only 33% (118/355) of total fire observations were identified, with almost 59% (355-147/355) unavailable for satellite viewing due to obscuration by cloud or smoke. The results also show that afternoon passes had a higher per cent of fires identified 87% (68/78) than morning passes 73% (50/69). The better performance of fire identification during afternoon passes was not surprising as fires generally burn more vigorously due to lower relative humidities, higher temperatures, and stronger winds at that time of day. As one would expect, a higher percentage of larger fires (Class 2) were identified. Fires as small as 0.5 ha were also properly identified by this technique.

As evident from the results, a significant number of fires were obscured by smoke and/or cloud. During a major forest fire outbreak vast quantities of smoke were to be anticipated. Thus this fire monitoring system was tested under difficult conditions. On the other hand, fire monitoring would be most beneficial in this kind of situation. Cloudiness was also a problem, particularly with the development of afternoon cumulus.

Forest fire area was calculated for each fire observation. The technique tended to overestimate the size of small fires and underestimate the size of large fires. A more detailed account of forest fire area calculation is given in Flannigan (1985).

6. DISCUSSION

The automated fire monitored system described here has two inherent weaknesses. A fire may go undetected because, (1) the temperature difference between Channels 3 and 4 is below the threshold, and (2) thin cloud or smoke may be obscuring the fire. Automated monitoring could be improved by visual inspection. The image analyst could verify new fires and scan for any undetected fires. It would not be necessary to monitor all forested areas every day during the fire season. Using the Canadian Forest Fire Danger Rating System (Canadian Forestry Service 1984, Van Wagner and Pickett 1985) which evaluates fire danger and predicts fire behaviour, close forest fire monitoring is warranted only in forested regions with a high fire danger rating.

Problems with fire identification can be dependent on the type of fire. A surface fire can be very difficult to detect as the forest canopy can effectively block the view of the satellite. We have assumed that an entire pixel was composed of a constant background or fire temperature. Actually, the pixel could be composed of fire, smoldering burned over forest, smoke, water, small clouds, as well as unburned forest.

7. CONCLUSIONS

The fire monitoring system described in this study has some limitations, the most serious being obscuration of fires by smoke and cloud. Despite these limitations, the system identified most unobstructed fire observations in the Slave Lake Forest Region during a major fire outbreak.

Fire monitoring over remote areas of the forest has been hindered by the cost and logistics of spatial and temporal coverage. Use of this fire monitoring system would enable the detection of fire location and size over large areas of forest.

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