DETECTION AND MONITORING OF ACTIVE FIRES USING REMOTE SENSING TECHNIQUES


by

Claire Riddell
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INTRODUCTION

The boreal forest zone is a contiguous band of coniferous and deciduous trees that stretches across most of northern Canada and part of Alaska (the Boreal Forest Network n.d.). “This forest ecosystem covers roughly 35% of Canada’s land mass and is the single largest land based ecosystem in North America. It also contains a significant proportion of Canada’s biodiversity and has long been recognized as an important global carbon sink” (the Boreal Forest Network n.d.). Figure 1 (Natural Resources Canada 2002) shows the distribution of the boreal forest.

Large, intense wildfires have a dominant influence on the successional pathways, productivity and carbon cycling within the boreal forest (Fraser et al. 2000). Given the significance of the boreal forest to Canada, and the impact that fires can have on it, it is important to detect and monitor active fires occurring within this biome.

Figure 1. Map showing the forest regions of Canada, including the Boreal forest region.
Source: Natural Resources Canada 2002
“Considering the remoteness and vast extent of the boreal biome, satellite remote sensing is particularly well suited to documenting the spatial and temporal distribution of fires so that these impacts may be quantified” (Fraser et al. 2000). The purpose of this report is to examine how the science of remote sensing is used in fire detection and monitoring procedures.

LITERATURE REVIEW

There are a number of ways through which information on forest fires can be collected; which include ground-based in situ observation, air-borne human and photographic observation, and space-borne remote sensing (Li et al. 2000b). Inaccessible terrain, smoke cover, and limitations to real time data collection are some of the reasons why the former two methods of data collection are unable to monitor active fires and accurately estimate the extent of their damage (Kimothi and Jadhav 1998). Furthermore, “the quality, density and frequency of ground-based and air-borne fire observations vary considerably from one country or region to another” (Li et al. 2000b). “The only way to accurately determine the exact location and extent of fire is to have a global perspective from space” (NASA 2004b). Satellites have the ability to collect global uniform fire information on a repetitive basis (Li et al. 2000b) in a mode that is multi-spectral (Kimothi and Jadhav 1998).

Although no satellite has ever been dedicated solely to the monitoring and measurement of fire, much fire data can be collected from satellites that were intended for other uses (NASA 2004b). “Several satellite systems are currently available for fire monitoring with different capabilities in terms of spatial resolution, sensitivity, spectral bands, and times and frequencies of overpasses” (NASA 2004b). In fact, there is no one
satellite system that exhibits all of the desired qualities for fire monitoring, as multisensor data fusion is recommended (NASA 2004b).

WILDFIRES AND REFLECTIVITY

“According to Plank’s equation, a flaming boreal fire at 1000ºK has a blackbody spectral existence of 3590 Wm⁻²μm⁻¹ at the centre of AVHRR’s 3.7 μm channel” (Fraser et al. 2000), which is located in the far infrared or thermal infrared portion of the electromagnetic spectrum. Figure 2 (Patterson 1999) displays the electromagnetic spectrum, and indicates the position of the visible and infrared portions.

Figure 2. The electromagnetic spectrum.

Source: Patterson 1999
The thermal infrared bands can be used to observe hotspots and active forest fires by directly detecting the heat of the fires (NASA 2004b). Since the thermal infrared band can confuse flaming fires with heated surfaces, such as asphalt and beaches, its ability to detect actual fires is greater at night, when surface temperatures are cooler (NASA 2004b).

The visible portion of the electromagnetic spectrum is also useful in the detection of forest fires. The visible bands of satellite imagery can be used to detect smoke plumes and burn scars (NASA 2004b), and are often used to verify that pixels marked as burning forest are actually active fires.

REMOTE SENSING APPLICATIONS AND ASSOCIATED CASE STUDIES

The Advanced Very High Resolution Radiometer (AVHRR) on the National Oceanic and Atmospheric Administration (NOAA) satellites are heavily relied on for thermal analysis of boreal forests. AVHRR is capable of providing daily information at 1.1 km spatial resolution (Fraser et al. 2000). Also, the AVHRR exhibits a 3.7 µm channel, which is highly sensitive to thermal emissions. Originally, the AVHRR was intended only as a meteorological satellite system; its purpose being to sense cloud cover, monitor sea surface temperature, and observe trends in vegetation, clouds, shorelines, lakes, snow and ice through its visible and infrared sensors (NASA 2004b). Figure 3 (NOAA) displays an AVHRR image that explains the pattern of sea surface temperatures for a given time. The AVHRR sensors are also very useful for the detection of active fires through the “co-location of hotspots on channel 3 images and the associated smoke plume patterns on channel 1” (Li et al. 2000a).
Li et al. (2000a) describes the use of a composite AVHRR image for a given day in order to develop a two step algorithm for the purpose of monitoring active fires. The two steps, identifying potential fire pixels and removing false fires, uses optimal threshold values, which were determined through the histogram analysis of reflectance and brightness temperatures corresponding to burning and non-burning pixels.

IDENTIFYING POTENTIAL FIRE PIXELS

Automatic detection of fires using AVHRR data was accomplished by marking all pixels that were not obscured by cloud and that had a brightness temperature greater than the threshold value for channel 3, which was 315 °K. Figure 4 (NASA 2004a) shows an AVHRR image in which the heat of the active fires (marked red) and their associated smoke plumes (blue) can be seen.
Even though the AVHRR sensor was not designed to detect fires, and channel 3 begins to lose sensitivity, or become saturated at temperatures of approximately 320 °K, channel 3 is still the most useful AVHRR channel to use for fire detection because the brightness temperature for most non-burning pixels is significantly lower than 320 °K. Threshold values that are less than the saturation temperature for a channel are used for two reasons. Firstly, wildfires are characterized by a broad range of burning temperatures, from below 500 °K to above 1000 °K, and occupy variable fractions of a pixel. A low threshold value ensures the detection of all fires. Secondly, a glitch in the on-board processing of channel 3 data causes signals to be assigned values below the saturation limit, when in fact the signals greatly exceed the saturation limit. This means extremely hot areas can have a brightness temperature that is lower than 320 °K. The problem with using such a low threshold value is that it leads to the identification of
false fire pixels in channel 3; which are created due to the effect of sunglint, reflective soils, pixel overlap, and sensor degradation.

REMOVING FALSE FIRES

The second step of the fire detection algorithm developed by Li et al. (2000a) is to remove falsely identified fire pixels through the use of various tests. The first test uses the difference between the brightness temperatures of channels 3 and 4 \((T_3 - T_4)\). “Since the spectral window of channel 4 is located in the electromagnetic spectrum that has a maximum radiative emission for the ordinary earth temperatures”, and “channel 3 receives much more radiant energy than channel 4”, the value of \(T_3 - T_4\) should be high for burning biomass (Li et al. 2000a). All pixels with \(T_3 - T_4\) values that are less than 14 °K in the boreal forest are considered to be false fire pixels caused by warm backgrounds. A second test uses only channel 4 to reject pixels with \(T_4\) values less than 200 °K, which are falsely identified as fire pixels due to highly reflective clouds. The third test rejects fire pixels with reflectance values greater than 0.22 in channel 2, since fire hotspots would typically exhibit reflectance values lower than this due to ash and biomass consumption.

ALTERNATIVE METEOROLOGICAL SATELLITES

The Tropical Rainfall Measuring Mission (TRMM) contains a sensor known as the Visible and Infrared Scanner (VIRS), which is very similar to the AVHRR sensor (NASA 2004b). This system has five bands, from visible to thermal infrared, which are used to detect active fires as well as burn scars, and it provides data with 2 km resolution. TRMM was designed to measure rainfall over land and oceans, and is
unique due to the fact that it allows analysts to look into clouds, rather than just at their tops (NASA 2004b). “In addition to its other sensors, TRMM carries LIS, the Lightning Imaging Sensor. LIS provides information on both cloud to cloud and cloud to ground lightning strikes around the world” (NASA 2004b). Because this imager is capable of detecting the majority of lightning strikes, it is very useful in identifying areas that may be at high risk for fire outbreaks. Figure 5 shows an example of how the TRMM is able to provide three dimensional maps of storm structures (TRIMS 2004).

Figure 5. An example of how the TRMM is able to provide three-dimensional maps of storm structures.

Source: TRIMS 2004

FIRE SPREAD DIRECTION AND RATE

Kimothi and Jadhav (1998) studied the application of remote sensing techniques to forest fire monitoring in the Central Himalaya region. They found that by analyzing the overlap area of two Indian Remote Sensing (IRS) images, the direction and rate of fire spread could be determined. They indicated that the wind direction and fire spread information obtained from the overlapping images in the peak fire period was very useful in the absence of accurate meteorological data. The researchers also used the
overlap areas to prepare a fire spread change map in order to estimate rate of spread in fire free, under fire and burnt areas in different vegetation types.

EVALUATION OF HOTSPOT SATELLITE DATA

Li et al. (2000b) describes the creation of a patchy burned area mask for the entire Canadian boreal forest through the compositing of daily hotspot maps collected over the summer. When the mask was compared to burn polygons produced by fire agency data, the researchers found that most of the fire events were detected by the satellite systems, but burned areas were under estimated. The study indicated that the burn boundaries formed by the hotspot pixels were close to the polygon boundaries of the fire agency data.

CONCLUSION

It is clear that the AVHRR on NOAA satellites is heavily utilized for the thermal analysis of boreal forests in order to detect and monitor wildfires. Of course, there are a number of problems associated with this system. Firstly, it was indicated that cloud cover obscuring fires on the ground is the most limiting factor of the AVHRR-based fire detection method, especially if it is intended for real time fire surveillance (Li et al. 2000a). However, cloud cover becomes less of an issue if this method is intended for the collection of seasonal fire statistics, since cloud cover changes daily. Problems with sunglint can often arise in areas with many water bodies; however satellites can avoid this problem by avoiding measurements in certain directions (Li et al. 2000a). “A lack of temporal sampling and a limited range of radiometric sensitivity are the major shortcomings of the Advanced Very High Resolution Radiometer” (Li et al. 2000b).
However, “the system has the advantages of automatic operation, consistent data quality, cost-effective use, and rapid response over the vast territory of the Canadian boreal forest” (Li et al. 2000a). Overall, this makes the AVHRR-based fire detection method very useful. Researchers have used it to set up an operational satellite fire monitoring system on a near real time basis in order to take prompt fire control measures, and also to obtain fire statistics across Canada.
LITERATURE CITED


