Day and night-time active fire detection over North America using NOAA-16 AVHRR Data

Abdelgadir Abuelgasim[1] and Robert Fraser[2]
[1]Intermap Technologies Ltd., 588 Booth St., Ottawa, On, Canada K1A 0Y7
Tel: (613) 947-1231; Fax: (613) 947-1383; Abdelgadir.Abuelgasim@ccrs.nrcan.gc.ca
[2]Natural Resources Canada, Canada Centre for Remote Sensing, 588 Booth St., Ottawa, On, Canada K1A 0Y7
Tel: (613) 947-6613; Fax: (613) 947-1383; Robert.Fraser@ccrs.nrcan.gc.ca

Abstract

This paper presents an investigation of the applicability of NOAA-16/AVHRR (N-16) satellite data for detecting and mapping active wildfires across North American forest ecosystems. Two fire detection algorithms were developed for application to N-16 day and night-time daily imagery. The algorithms exploit both the multi-spectral and thermal information from the AVHRR daily images. For daytime data collection N-16 provides 3 reflective bands, namely, red, near infrared and short-wave infrared (SWIR), in addition to two thermal brightness temperature bands centred at 10.8µm and 12µm. During night's time data collection the short-wave infrared band is switched to the thermal brightness temperature band centred at 3.7µm. This band in particular has been extensively used for detecting active fires.

The fire algorithms have two major steps: detection of potential fires followed by false fire elimination. The threshold tests developed for fire identification and false fire removal were optimised through a trial-and-error approach using a database of active fire pixels over the whole of North America. The database was generated from a large number of single-daytime and night-time AVHRR scenes, where the fire pixels were identified visually on the images aided by the associated daytime smoke plumes. The SWIR band was found to be sensitive only to large burning fires leading to a noticeable spike in the measured reflectance. However, a serious limitation with the SWIR band is that small burning fires are not easily detectable and quite a number of active fires go undetected. Night detection does not pose such a limitation and has allowed for significantly higher detection rates. Overall night detection provides reasonably good alternative for the reduced sensitivity of the SWIR band.

The set of day and night algorithms was used to generate daily active fire maps across North America. Such a combined approach for fire detection leads to an improved detection rate. Selected validation sites in western Canada and the United States, showed reasonable correspondence with the location of fires mapped by the Canadian Forest Service and the USDA Forest Service using conventional means.

I. Introduction

Wild-fires in North American forest ecosystems are a major source of major natural and anthropogenic disturbance. Such fires have a tremendous impact on the local environment, humans and wildlife, ecosystem function, weather, and climate. Accurate monitoring and mapping of the spatial and temporal distribution of wild forest fires is important. For example, emissions of greenhouse gases and aerosols from burning forest fires is an important component in climate change studies. Information regarding the occurrence of fires, their spatial extent and distribution can be obtained via a variety of means. *In situ* observations, airborne and photographic surveillance, and satellite remote sensing are among the widely used techniques for mapping fires and burned areas. Only satellite based remote sensing techniques can provide continental to global coverage, continuous repetitive observations, and a relatively inexpensive technology.

In the past two decades images from the NOAA Advanced Very High Resolution Radiometer (AVHRR) have often been used to detect wild fires in forest ecosystems [1]. Most of these techniques for fire detection make use of the spectral, thermal and spatial information captured by the sensor.

This study is part of a research initiative aimed at developing fire detection algorithms that can be applied on continental scales over a variety of different forest cover types. The particular emphasis of the study is on continental North America with its diverse ecosystems and land cover types. In addition, we assessed the feasibility of near real-time fire detection based on a combination of day and night-times satellite images.

II. NOAA-16 AVHRR Data

The data used in this study comes from the AVHRR sensor carried on-board the NOAA satellites series. The N-16 provides measurements in 6 channels. The red channel 1 (R_1: centred at 0.58 µm), channel 2 near-infrared (R_2: centred at 0.9 µm), channel 3A short-wave infrared (SWIR) (R_3: centred at 1.65 µm) transmitted during daytime, channel 3B mid-infrared (T_3: centred at 3.7 µm) for night-time passes, channel 4 (T_4: centred at 10.5 µm) and channel 5 (T_5: centred at 11.5 µm). In this study "R" and "T" denote top-of-the-atmosphere reflectance and brightness temperatures respectively. The data covers the 2001 fire season May 1st to October 31st.

III. ALGORITHMS FOR ACTIVE FIRE DETECTION

The algorithms for day and night-times detection are based on fixed thresholds. The threshold tests are optimised to cope with different ecosystems and environments found in North America for day and night N-16 data collection.

Night-time Fire Detection

The major steps required for fire detection are the same as those used by the Canada Centre for Remote Sensing (CCRS) algorithm [2], namely, fire detection, and false fire elimination. A database of fire pixels was generated from a large number of single-day N-14 AVHRR night-time scenes during the year 2000 fire season. The fire pixels were selected from a variety of land cover types over Canada, and the western and southern United States. Fire pixels were identified visually on the images based on smoke plumes visible in daytime imagery.

The N-16 channel 3B centred at 3.7μm is the most useful for fire detection. Flaming biomass usually saturates this channel or significantly elevates the measured sensor response. By contrast, the response from most non-fire pixels is significantly lower due to the lack of any reflectance contribution. A brightness temperature of T_3 = 294 K was chosen in this study to represent a fire pixel. This value was sufficiently sensitive to capture nearly all the fires in the fire database. It also produced very few false alarms, as night-time imagery does not suffer from problems caused by sun glint or reflective soil surfaces.

To remove false fire pixels caused by warm backgrounds we adopted the technique followed in [3]. The difference threshold ($T_3 - T_4$) was used to identify false fire pixels attributable to warm backgrounds. Such backgrounds normally correspond to land surfaces (i.e. bare soil) that can be extremely warm, which significantly elevates channel 3 during the day and night. Actively burning fires emit more radiant energy in channel 3 than channel 4, and hence the difference ($T_3 - T_4$) should be high. Through a trial and error approach an optimum value of $T_3 - T_4$ was found to be 14 K. Pixels with a $T_3 - T_4$ less than 14 K are eliminated as being false fire signals. Figure 1 summarizes the different threshold tests used for night-time detection.

Day-time Fire Detection

The spectral response in the SWIR region from active fires was investigated in [4] using SPOT VGT data of red, NIR and SWIR bands. The study demonstrated that, according to Plank's equation a flaming fire with a temperature of 1000 K has a blackbody spectral exitance of 1590 Wm^{-2} μm^{-1} measured using the N-16 channel 3A centred at 1.65 μm. This is a significantly weaker response compared to spectral exitance of 3590 Wm^{-2} μm^{-1} that would be recorded from channel 3B centred at 3.7 μm. Note that for daytime data acquisition channel 3B is switched for channel 3A. The spectral response of a burning forest pixel is characterized by an elevated signal in the SWIR channel, and low signal levels in the red and NIR bands. For the N-16 data, a pixel is designated as an active fire if SWIR reflectance is greater than 45% and the corresponding red and NIR reflectance are both less than 20%. Initially, lower threshold values were tested for the SWIR channel. While the lower values did identify the fire pixels, the number of false fire increased as well, especially in the western and southern US. The selected 45% threshold could identify active fires, while producing a very low level of false fire pixels. Figure 1 summarizes the different threshold tests used for the daytime fire detection.

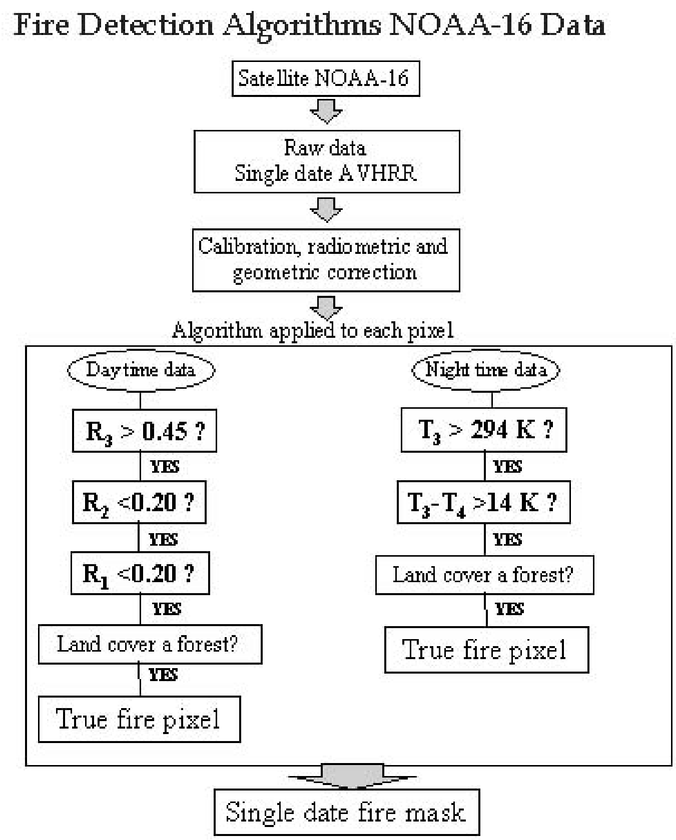

Figure 1: Fire Detection Flow Charts

IV. SUMMARY OF RESULTS AND VALIDATION

The combination of day and night-times data used for fire detection was fairly effective in identifying large active fires within the study area. The use of night-time data has greatly augmented the relatively poor day-time detection rate attributable to the low sensitivity of the SWIR channel 3A to fires. Figure 2, shows the results of both day and night-times fire detection in the North American study area. Night-time active fires are coded in the figure as dark stars while daytime fires as grey cross signs.

Figures 3a and 3b show selected areas in western Canada (Alberta) where active fires detected from the satellite data are superimposed on a conventional burned survey produced by Alberta Environment. The area highlighted in figure 3a is shown enlarged in figure 3b. We will validate the fire detection results with ground survey fire polygons from the US when they become available.

There is good agreement between the field polygons and the active fire hotspots detected by the algorithms. However, most of the detection correspond to night imagery. This is due primarily to two reasons; first the greater cloud coverage during the day, and second the weaker signals from the burning fires detected in the SWIR region.

Figure 2: Day and night fire detection results

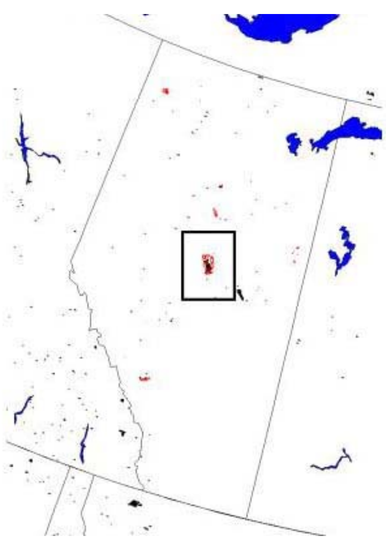

Figure 3a: Western Canada Fires (Alberta)

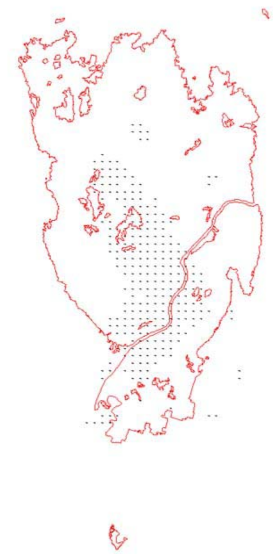

Figure 3b: Ground survey fire polygons shown in solid line and satellite fire pixels (points).

V. Conclusions

Detection of large fires at continental scales can be performed on daily basis using coarse resolution N-16/AVHRR data.

The study has shown that the new SWIR channel for daytime detection is sensitive only to very large flaming fires.

Night-time detection is significantly more efficient than day-time detection, due to the high sensitivity of channel 3B to fires.

A combination of N-16 night detection and daytime from another sensor (e.g. MODIS) would better capture the diurnal cycle of fire and provide improved detection rates.

REFERENCES

[1] Robinson, J.M., (1991), Fire from Space: global fire evaluation using infrared remote sensing, *Int. J. Rem. Sens.*,12:3-24.

[2] Li, Z..,S, Nadon, and J. Cihlar, (2000), Satellite-based detection of Canadian forest fires: development and application of the algorithm, *Int. J.Rem. Sens.*,21(16): 3057-3069.

[3] Kaufman, Y.J., A Setzer, C. Justice. C.J.Tucker, and I. Fung, Remote sensing of biomass burning in the tropics, in Fires in the Tropical Biota, Ecosystem Processes and Global Changes, eds J.G. Goldammer, pp 371-399, Springer-Verlag 1990.

[4] Fraser, R.H., Z., Li and R. Landry (2000), SPOT VEGETATION for characterizing boreal forest fires, *Int. J.Rem. Sens*, 21(18): 3525-3532.