A new approach for the detection of major fires caused by industrial accidents, using NOAA/AVHRR imagery

N. Chrysoulakis and C. Cartalis

Dept. of Applied Physics, Panepistiomopolis, Build. PHYS-V,
Athens 157 84, Greece

Abstract. The Advanced Very High Resolution (AVHRR) on board the NOAA satellites may be used for detecting major fires caused by industrial accidents through the combined use of the middle (3.55 - 3.93 μm) and thermal infrared (10.5 - 11.3 μm, 11.5 - 12.5 μm) channels of the AVHRR. In this study an algorithm was developed to identify the pixels which correspond to the sites of the industrial accidents where a major fire has developed. The algorithm was applied for two industrial accidents; in Lyon, France on June 2, 1987 and in Kalohori, Greece on 24 February 1986. The algorithm is based on the analysis of the differences between the brightness temperatures resulting from Channels 3 (3.55 - 3.93 μm) and 4 (10.5 - 11.3 μm) of AVHRR as well as on the use of two masking filters for clouds. The first filter takes advantage of the information provided by Channels 1 (0.58 - 0.68 μm) and 5 (11.5 - 12.5 μm) of AVHRR whereas the second one introduces a threshold value for cloud top temperature. The use of the algorithm for the selected industrial accidents demonstrates its capability to detect major fires caused by industrial accidents.


1. Introduction

The radiation reaching the satellite sensor at the event of a fire caused by an industrial accident is a combination of the radiation emitted from the resulting fire, the thermal radiation from the Earth's surface and the short wave (solar) radiation which is reflected at the surface of the Earth. Taken that: a) solar energy dominates the visible and near infrared parts of the spectrum, b) the radiation emitted from the surface of the Earth is the one which dominates in the middle and thermal infrared parts and c) in the middle infrared part of the spectrum, both the solar and terrestrial radiation provide weak signals, it yields that the spectral channel in the range from 3 to 5 µm has the maximum probability for detecting a fire on the basis of its temperature (Robinson 1991).

In several research studies the potential of Channel 3 (3.55 - 3.93 µm) of NOAA/AVHRR to detect areas at the surface with very high temperatures has been demonstrated (Dozier 1981, Matson and Dozier 1981, Muirhead and Cracknell 1984, 1985, Matson et al. 1987, Matson and Holben 1987, Scorer 1987, 1989, Bandinelli and Carlà 1993). Based on theory, the more intense the fire (the higher the temperature), the maximum of the emission curve shifts to shorter wavelengths; this implies that for areas at the surface with very high temperatures, the maximum amount of infrared radiation which is emitted, is recorded in Channel 3 of AVHRR. Furthermore, as brightness temperature computation, by inversion of Planck’s function, does not discriminate between
radiance emitted and solar radiance reflected at 3.7 µm, we have a large value for brightness temperature difference between Channels 3 and 4 (10.5 - 11.3 µm). At the locality of a fire this results in differences of 20 to 30 degrees Celsius in the brightness temperatures detected by Channels 3 and 4, when the usual differences for points/areas at the surface is between 1 and 2 degrees Celsius (Matson et al. 1987). Therefore the simultaneous use of Channels 3 and 4 of AVHRR allows the detection of surface points/areas with high temperature anomalies. The higher the temperature of those points/areas, the easier the detection as the brightness temperature differences between Channels 3 and 4 increase.

Flares at chemical works and on oil or gas rigs may have temperatures in the range 1000 - 1500 °K. They are incandescent because carbon particles in a large flame at 1000 °K may have an area of the order of 30 x 30 m². In this case the flame would give the pixel an intensity about three times the environmental intensity in channel 3, and would be detected. A much smaller fire with dark surroundings, such as at night or at the sea where there is no glint, could be detected at about one tenth of pixel size, say 10 x 10 m² (Scorer, 1987).

The presence of the plume can be extra confirmer of the site of the industrial accident. The extent to which and the manner in which smoke obscures fires varies with plume optics, geometry, emission rates, three-dimensional wind fields, and atmospheric stability, moisture and chemistry. If the plume were
displaced by a strong wind, imaging platforms might have a clear look at the flaming zone despite heavy smoke (Robinson, 1991).

It should be mentioned that a precondition for the use of an algorithm which takes advantage of the brightness temperature differences between channels 3 and 4 is a cloud free atmosphere. If this is not the case, the algorithm employs a special blocking filter for limiting the influence of clouds on the AVHRR image. The reason is that, in the case of clouds as well, we have a large value for brightness temperature difference between Channels 3 and 4, due to recorded reflected solar radiation in channel 3.

The developed algorithm carries the advantages of a multispectral analysis and provides valuable results for the detection of major fires caused by industrial accidents.

2. Data and methodology

The data used in this study are AVHRR images from NOAA-9; AVHRR has a spatial resolution of 1.1 km at the nadir, a temporal resolution of approximately six hours (for both the ascending and descending NOAA nodes), and a swath coverage of 2700 km. AVHRR records incoming radiation in five spectral channels (µm): 0.58-0.68 (visible), 0.72-1.10 (near infrared), 3.55-3.93 (mid-
infrared), 10.5-11.3 (thermal infrared) and 11.5-12.5 (thermal infrared). The two case studies examined in this study are for June 2, 1987 (13:55 UTC) and February 24, 1986 (12:55 UTC). The former date refers to the Lyon industrial accident at the Shell refineries, whereas the latter date relate to the Kalohori industrial accident at the Jet Oil refinery.

Initially the images were geometrically corrected and calibrated. The calibration procedure was based on the conversion of digital numbers of the image to brightness temperature for the infrared channels and to albedos for visible channels on the basis of lookup tables. Values of lookup tables were calculated using the equations given in the NOAA Polar Orbiter Data Users Guide (Kidwell, 1991). Following an algorithm was applied, its main elements being the use of filters for masking the prevailing clouds and for examining whether the brightness temperature difference between channels 3 and 4 exceeds a pre-determined threshold. Masking of clouds is necessary because the difference between channels 3 and 4 is large for pixels which correspond to clouds. Failure to mask these pixels results in being erroneously considered as pixels of high surface temperatures.

The first masking filter for clouds takes into account the received radiation in Channels 1 and 5:

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\text{Masking filter} = \frac{\text{Channel 5} - \text{Channel 1}}{\text{Channel 5} + \text{Channel 1}}
\]
This masking filter has resulted from two dimensional feature space data processing (Channel 5 vs. Channel 1). The value of the masking filter was calculated for each pixel in the image producing a range of values from 0 to 1. Visual inspection of the images indicated that values smaller than 0.95 corresponded to cloudy pixels. This value can then be used as a threshold value for filtering out prevailing clouds in all image channels.

The second masking filter uses Channel 4 and examines whether the brightness temperature which corresponds to a pixel, exceeds a given value, which for this study was set to 280 ° K. This threshold has resulted empirically from data processing. Pixels which fail to satisfy this criterion were disregarded.

Following a criterion for examining whether the brightness temperature difference between Channels 3 and 4 exceeds a certain threshold (the temperature difference for this study has been set at 20 ° K and was defined empirically) was applied from data processing. This criterion is of significant importance since it allows the final definition of the areas in the image where very high temperatures are detected. Potential causes for these high temperatures being industrial accidents.
3. Results

3.1. The Shell accident at Lyon, France

Figure 1, a result of the application of the algorithm, shows the points at the surface for which the brightness temperatures difference for Channels 3 and 4 is greater than 20 ° K. These points correspond to the Lyon area and in particular to the area where the industrial accident took place.

In Figure 2a the wider Lyon area is selected (rectangle abcd which represents an area of about 160 square miles) and in Figure 2b the digital values in this area are plotted; they correspond to the brightness temperature differences between channels 3 and 4. The peak shown (brightness temperature difference greater than 20 ° K) corresponds to the area where the industrial accident took place, whereas in the nearby areas temperature differences also exhibit high values. In distant areas to the accident, temperature differences are limited to less than 5 ° K, i.e. typical differences found at the surface.

The case study is concluded with Figure 3 which shows the wider geographic area from Channel 2. The presence of a plume (depicted by the arrow) immediately over the pixels which were defined in Figures 2a and 2b, confirms a surface fire caused by an industrial accident. The plume is displaced by a strong wind, so the satellite can have a clear look at the flaming zone.
3.2 The Jet Oil accident at Kalohori, Greece

Similar analysis as in 3.1 is followed for the accident which took place at the Jet Oil refinery at Kalohori, Greece on February 24, 1986 (12:55 UTC).

In Figure 4, the result of the application of the algorithm, shows the points at the surface for which brightness temperature differences for Channels 3 and 4 are greater than 20 ° K. These points correspond to the Kalohori area and in particular to the area where the industrial accident took place.

In Figure 5a the wider Kalohori area is selected (rectangle abcd which represents an area of about 85 square miles) and in Figure 5b the digital values in the area under examination were plotted; they correspond to the brightness temperature differences between channels 3 and 4. The peak shown (brightness temperature difference greater than 20 ° K) corresponds to the area where the industrial accident took place.

The case study is concluded with Figure 6 which shows the wider geographic area from Channel 2. The presence of the plume (shown with the arrow) over the pixels which were defined in Figures 5a and 5b are being the ones where the industrial accident took place. The plume is displaced by a strong wind, so the satellite can have a clear look at the flaming zone.
Conclusions

The detection of fires caused by industrial accidents from satellite depends on the availability of a channel sensor operating in the middle infrared part of the spectrum. This is because the very high temperatures which correspond to an industrial fire give an intense signal in the middle infrared.

It was found that NOAA/AVHRR carries the potential for detecting industrial fires, even though the spatial resolution of this satellite sensor is 1.1 km at the nadir. This is due to the fact that the high temperatures in an industrial accident result in the saturation of the infrared channels of the sensor, thus highlighting fully the respective pixels.

This algorithm based on the brightness temperature differences between channels 3 and 4, carries the advantages of a multispectral analysis and provides valuable results for the detection of industrial fires. A critical precondition for the successful application of the methodology is the use of masking filters for clouds prevailing in the satellite image.

Although the method carries significant innovation and demonstrates the inexhaustible applications of satellite remote sensing, it may be considered of limited use if applied for simply detecting a major fire caused by an industrial accident. The method may be of considerable importance if linked to the
monitoring of the produced plume, a task which constitutes the next stage of this research study. In this case the implementation of Directive 82/501/EEC (known as the Seveso Directive) may be supported with respect to the operational plans which need to be developed - by the competent authorities - for the abatement of major technological accidents. In addition if the images are received in frequent time intervals, then the method becomes operational, a fact which furthers enhances its potential.

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References


Captions

Figure 1. Detection of an industrial accident in the Lyon area. The area covered by this AVHRR image is 140 x 130 Km.

Figure 2. a) Rectangle area selection around the detected incident. The area covered by this AVHRR image is 670 x 630 Km. b) Spatial distribution of the difference in brightness temperature between channels 3 and 4 in the selected area.

Figure 3. AVHRR channel 2 image, 1225 x 1015 Km, on 2 June 1987 (13:55 UTC). Arrow indicates surface smoke plume.