OPERATIONAL DETECTION OF FIRES IN BRAZIL WITH NOAA-AVHRR (1,2)

Alberto W. Setzer and Marcos C. Pereira

Instituto Nacional de Pesquisas Espaciais - INPE
C.Postal 515 - 12201 - S.J.Campos - SP - Brazil

ABSTRACT

Fire is used extensively in Brazil associated to agricultural practices, pasture renewal, and deforestation. Although the environmental concerns about its use are strong, no estimates of fire frequencies, locations or extent are available. This paper summarizes the relatively successful efforts using orbital remote sensing to detect fires on a continental scale and on a near real time operational basis. Thermal infrared images (3.6-3.9um) of AVHRR sensors are screened for "fire pixels" by a system operating on a standard personal computer. Messages for users containing the geographical location of the fires and maps with fire locations reach them soon after the satellite overpass. The accuracy and effectiveness of the system compared to other possibilities is discussed based on the experience of the last years.

1. INTRODUCTION

Biomass burning has been and still is extensively used in Brazil in association to pasture renewal, various agricultural uses, deforestation, or just to prevent growth of natural vegetation. About a third of the surface of the country already colonized, about 1.5 to 1.8 $*10^6 km^2$, presumably burns every year. During the dry season in Central Brazil, from June to October, thousands of fires ignited by man can be detected every day.

Three main reasons seem to be associated to the use of fire: it is a cultural tradition among the population, even within native Indians; it is the cheapest way to clear unwanted vegetation; and there is the popular belief that the ashes produced by the fire fertilize the soil. Fires are part of the environment in some regions of the country, such as in the short "cerrados" (savannas), where they occur naturally in periods of less than ten years and where the vegetation is adapted to such cycles (Coutinho, 1980). Environmental concerns start when the

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frequency of fires is changed to a quasi annual cycle and with its use in regions where it does no occur naturally. Burning of the cut forest in the intense Amazon deforestation of 1985-1988 emitted smoke clouds of continental scale causing severe pollution problems (Helfert and Lulla, 1990; Setzer and Pereira, 1991a). The burning of millions of hectares of sugar cane plantations every year as a pre-harvesting technique also generates significant amounts of pollutants (Kirchhoff and et al., 1989; Fernandes, 1988). As measured by Kirchhoff et al. (1989) and by Setzer et al. (1991), concentrations of biomass burning by-products such as ozone, increase dramatically in many regions of Brazil during the dry/burning season. Fires are also used to maintain immense areas of pastures that degraded or of poor quality and in mountainous terrains. In this case, rains that follow produce severe soil depletion and erosion problems. Arson fires in parks, forest reserves and in timber reserves are also common, causing economic losses. Except for few regions in the country with rich soils, the use of fires on a long term basis depletes the soils since the mineral-rich ashes that remain from fires are washed away by abundant rains, and the net balance of nutrients is negative

Scientific and administrative knowledge of fires is needed to understand their ecological effects of possible irreversible consequences, and also because of concerns related to global environmental changes (Crutzen and Andreae, 1990). Existing data about fires in Brazil is very limited and of little use (Soares, 1989; Setzer, 1990), and additional information is necessary. In this paper the use and main results of orbital remote sensing in Brazil to detect and assess fires is summarized.

2. AVHRR DETECTION OF FIRES

AVHRR is the Advanced Very High Resolution Radiometer instrument on board meteorological satellites of the NOAA (formerly TIROS-N) series (see Kidwell, 1985 and Needham, 1987 for more details). AVHRR Bands 3(3.6-3.9um) and 4(10.3-11.3um), and 5 (11.5-12.5um) in some satellites, were designed for infrared thermal sensing of clouds, oceans and land, up to the maximum nominal radiometric temperature of 320K. Although the AVHRR IFOV angle is constant, pixel resolution varies from 1.09km at nadir to more than 6km at the off-nadir limits of the image. Two operational satellites provide four overpasses per day (one in the afternoon) at any place in equatorial latitudes and a larger number of overpasses increasing with latitude. The AVHRR scanner swath of 110^{o} covers about 2,700km, giving therefore synoptic views of the earth. These last two characteristics make AVHRR very appropriate for environmental studies of large scale that also require good temporal resolution

Matson and Dozier (1981) suggested the combined use of AVHRR bands 3 and 4 to evaluate temperature and size of sub-pixel fires, and Matson et al. (1984) proposed that band 3 alone could be used in practical ways to detect fires. The use of AVHRR to study fires is a quite unique and unexpected application since AVHRR was never designed for such purposes and fire temperatures are one to two orders of magnitude above the sensor limit! Many others studies followed in different parts of the world, and the subject has been thoroughly reviewed by Robinson (1991) which clearly explains the physical background and points advantages and limitations of the technique. Kaufman et al (1990) have concentrated in emission estimates from fires using AVHRR, and Malingreau (1990) and Frederiksen et al.(1990) have proposed the use of AVHRR for continuous fire monitoring expanding the previous suggestion of Stephens and Matson (1987).

Many unanswered questions and limitations exist about the use of AVHRR to detect fires (See also Robinson, 1991). The theoretically calculated size of a fire with about 30m x 30m needed to saturate an AVHRR pixel in band 3 seems to be far from experimental data. The experience gathered by the authors indicate that only fires with more than 100m x 100m may be detected by band 3 and they will not saturate the pixel. Even an active fire in Amazonia larger than the size of two pixels have not saturated a pixel. As shown by Pereira Jr. et al. (1991) in this proceedings, for NOAA-11 most fire pixels in cerrados present a nominal radiometric temperature of only 315K.

Since AVHRR records an almost instantaneous view of a region, it will miss fires lit after the overpass as well as those that had extinguished at that time. The recording of more than one image per day and the use of two satellite reduces this problem to some extent, but increases operational difficulties and costs. If two fires exist on the same pixel they will be detected as one, and in areas with many fires this situation will reduce the estimates of fires. Another factor that prevent detection of fires is the presence of clouds. Although thermal radiation penetrate smoke to some extent, fires will not be detected if located under thick smoke clouds, or if obscured by its own smoke. Massive smoke clouds have been found by the authors in fires in Amazonia, and have precluded AVHRR from detecting many fires. Regular meteorological clouds cause the same effect but fortunately, in the case of Brazil, fires usually do not occur under cloudy or partially clouded skies. Since fires are lit to clear vegetation, they are more efficient and lit on hot and sunny days !

Concerning the use of AVHRR thermal infrared data to estimate the extent of the areas that were burned, two other conditions must be considered. First, because of the coarse 1.1km resolution, small fires tend to be detected as large ones. As shown by Pereira Jr. et al (1991) in this proceedings, AVHRR overestimated areas burned in cerrados by 43%. A second situation causes the opposite effect and happens when fires spread during long periods. Pereira et al. (1990) showed that for the cerrado fires in the Emas National Park in 1988 which lasted several days, AVHRR underestimated the area burned by 87 % ! The growth of pixel size towards the borders of the image with the accompanying increase in the surface-sensor atmospheric path also introduces additional complications in the definition of fire temperature and area detection thresholds.

A difficulty also found by the authors in many AVHRR band 3 images is related to sun glint. Depending on the sun-earth-satellite angle, and also on the inclination of the terrain, sun glint may reach AVHRR completely saturating large amounts of contiguous pixels. This glint has been found in rivers in Amazônia, in slopes of barren mountains in the Andes, and in "caatingas" in semi-arid Northeast Brazil. Because of the NOAA satellite orbit precession and the North-South sun movement in the ecliptic the areas affected vary considerably from day to day.

The solution for the above limitations, of course, is in the use of an instrument properly designed to detect fires from space. Hopefully, MODIS-N, the Moderate Resolution Imaging Radiometer-Nadir planned for the first Earth Observing Platform (EOS-A) should solve some of the current problems, greatly improving the capability to monitor fires from space. But until then AVHRR should continue to provide extremely useful operational information about fires, as shown bellow.

3. HISTORY OF AVHRR DETECTION OF FIRES IN BRAZIL.

The detection of fires in Brazil using AVHRR began in July, 1985, when the authors decided to investigate if some long range transport of air pollution interfered in the measurements of the NASA-INPE GTE/ABLE 2A mission. This mission was designed to study interactions of a large tropical forest with the troposphere on a non polluted environment. The investigation was of paramount importance in explaining many of the measurements since contamination from biomass burning detected by AVHRR hundreds of kilometers upwind caused unexpected ABLE-2A results (Andreae et al., 1988). A detailed analysis of the 18 AVHRR-NOAA-9 images recorded was then conducted showing that band 3 could be used to detect and make rough area estimates of deforestation fires in Amazonia (Pereira, 1988). This work was presented to the former Brazilian Forest Institute (today, Brazilian Institute of Natural Resources -IBAMA), which approved support for a pilot work to detect fires and deforestation in Amazonia. This pilot work took place from July to October, 1987 when 46 AVHRR images were analyzed (Setzer et al., 1988; Setzer and Pereira, 1991a), producing quite unexpected results. About 350,000 independent fires were estimated, of which a significant number in areas of forests, proving that deforestation was taking place at unprecedented and unknown rates - maybe of the order of 80,000km^2 in that year. The AVHRR images and the results caught the attention of the national and international media, helping to create an enormous pressure to stop unplanned, irrational and unprofitable deforestation. After the results of the work resisted criticism from private, official, and even scientific sectors (Setzer and Pereira, 1991b), the Brazilian government finally took official steps to reduce deforestation, which today has been reduced to the order of 10,000km^2 per year.

In the dry season of 1988 the detection of fires in Amazonia with AVHRR continued and 96 images were processed, yielding about 210,000 fires. As in the previous year, the location of fire pixels was done manually, matching geographical references in the original geometrically distorted images. Telex messages for the former Forest Institute containing the coordinates of the main fires were prepared manually, and usually sent in the next morning after the NOAA-9 overpass. The counting of fire pixels was done automatically on an interactive processing system. See Setzer and Pereira (1991b) for a detailed description of the work in 1988. As in 1987 the authors verifyed the location of many fires detected by AVHRR. Using the INPE twin engine aircraft for about a week, the geographical coordinates of fire pixels detected by AVHRR were checked. For about one hundred fires detected by AVHRR in different regions of the country, ranging from grasslands to tropical forest, a corresponding fire scar was found with the airplane within the accuracy limit of 2km for visual pixel location in the images.

4. OPERATIONAL DETECTION OF FIRES IN BRAZIL WITH AVHRR.

The work with AVHRR in 1989 used a more automatic system. This followed verification of the usefulness of the AVHRR information about fire detection and growing demand from users. In this year IBAMA and also the Environmental Agency of the State of São Paulo (DPRN) had established operational programs to combat unauthorized fires. Based on the AVHRR location of fire pixels IBAMA used helicopters to check fires in Amazonia and was able to give fines in a total equivalent to millions of dollars. DPRN had a more complex operation relying on information from AVHRR, civil aviation pilots, ground crews of the State Forest Police and State Forest Institute, and from private companies. In this case, radio and communications networks and the relatively small size of the areas of interest in the state resulted in quick and effective measures to control the fires.

Having in mind such operational needs of the users of the AVHRR fire information, the authors designed the automatic system based on available technology in the country at that time and also on their very limited budget. A personal computer (PC) with a 286 microprocessor and math co-processor hosts the Geographical Information System - GIS and the Interactive Image Treatment System - SITIM developed by INPE (Engespaço, 1990), and adapted for this specific use. A navigation software for AVHRR pixels with accuracy of 3km developed by Figueiredo (1990) based on the work of Medeiros et al.(1986) was also introduced in the processing. AVHRR processing then followed the steps given ahead.

1. Reception of bands 1, 2 and 3 of AVHRR's afternoon pass over Brazil in full HRPT 10-bit resolution by INPE's tracking antenna and receiving station at C.Paulista, $22^{o}27'S/45^{o}W$.

2. Image storage in the receiving station hard disk.

3. Image transfer to CCT.

4. Image transfer to the 286-PC (a 386AT will be used in 91) (for 1991 step 4 will follow step 1 through a special interface built for direct image ingestion)

5. Typing of satellite orbital parameters in the PC.

6. Location of two pre-determined control points in the band 2 (or 1) image using SITIM.

7. Adjustment of original equatorial longitude and crossing time orbital parameters to fit control points by software using numerical interactions.

8. Visual inspection of image and elimination of noise.

9. PC calculation of geographical coordinates for all band 3 fire pixels in the image . Ten levels corresponding to the lowest digital counts (highest temperatures) in a scale of 256 levels (eight bits degraded from the original ten) are the default range for NOAA-9. For NOAA-11 eleven levels should be used.

10. Ordering of the fire pixels by latitude and longitude, and archive in a file.

11. Location of fire pixels in regions of interest using GIS.

12. Sending of telex messages to users directly by the PC through special interface. Messages contain geographical location of each fire pixel in the region, the count level of the pixel, and a summary of the fires- see Figure 1. Messages are also made available on a main frame computer for later access by users. Messages are sent according to priority of the users: DPRN has eight regions and IBAMA, 140.

13. Plotting of maps with fire pixels in areas of interest for users who need this product - see Figure 2 and text bellow.

14. Location of fire pixels in other regions of interest for research purposes such as in all Brazilian states, in the cerrado regions and in more South American countries.

15. Compilation of statistics for daily AVHRR fire detection for each region of interest - see Figure 3 and text bellow.

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P0509904NOAA11 174113174910 542127A 985934 102.060 7228.837
2272 1370
RAL - IBAMA - PREVFOGO - ALAGOAS
  NADA A INFORMAR
RPI - IBAMA - PREVFOGO - PIAUI
L08S
4245131
L09S
0945543/0945560/4445451/4545451
  int.pontos
  0     1
  1     3
  2     0
  3     1
  4     0
  5     0
  6     0
  7     0
  8     0
  9     0
  Tot.=  5
```

Figure 1. Example of telex message with AVHRR band 3 fire pixels of 05/September/90 sent to IBAMA as part of operation "PREVFOGO". The 1st and 2nd lines contain satellite orbital information. No fires detected in Alagoas state. Five fires in Piaui state, the first one at latitude 08°42'S and 45°13'W, with intensity 1.

Figure 2 is an example of maps with AVHRR fire pixels supplied to users. The maps are made for small regions of interest with a few dozen km^2 as well as for the whole country. This particular case shows over 8,700 fire pixels on 25 September 90 detected on a single AVHRR band 3 image that covered most of the country. Because of the very small scale of the map, fire pixels in Central Brazil cerrados (savannas) give the impression of a continuous area in fire. Enlargement of the area shows that the distance between individual fire pixels is of many kilometers. Such maps for Brazil were regularly published during the dry/burning season in 1990 by "Jornal da Tarde", a major newspaper in Sáo Paulo. These publications, and hundreds of others related to fire in Brazil, have helped the development of

Figure 2. Map with 8,747 fire pixels detected in AVHRR band 3 on 25/September/90.

public environmental awareness, which will eventually contribute to solutions of the country's severe environmental problems.

Figure 3 shows a sample of the statistics of AVHRR fire detection for the state of Mato Grosso during August/90. This state has presented the largest numbers of fires in Brazil in the

FIRES DETECTED IN AUGUST/1990 AVHRR/NOAA IMAGES

STATE	DAY	EQUATOR CROSSING LONG.	EQUATOR CROSSING GMT HOUR	INTENSITY 0	1	2	3	4	5	6	7	8	9	TOTAL
MATO	1	304.8	174837	214	191	118	109	116	102	112	112	128	223	1425
GROSSO	2	307.6	173743	20	16	11	14	9	8	7	11	14	17	127
	3	310.4	172604	19	3	4	2	3	2	3	13	4	9	62
	4	313.2	171504	17	14	5	10	9	7	9	8	4	11	94
	5	316.0	170359	13	3	3	6	2	3	2	2	7	4	45
	6	293.4	183516	61	26	23	18	19	15	18	15	12	26	233
	7													
	8	298.9	181305	342	283	241	235	299	312	275	313	324	677	3301
	9	301.7	180159	434	325	272	240	256	246	206	237	295	550	3061
	10	304.4	175053	502	469	397	352	426	441	413	437	467	959	4863
	11	307.2	173958	468	480	360	315	342	334	339	347	359	711	4055
	12													
	13													
	14	290.1	184834	19	10	10	4	13	13	13	8	7	16	113
	15	293.0	183728											
	16	295.7	182622	144	71	56	46	42	35	55	38	35	75	597
	17	298.5	181516	159	77	65	52	68	60	46	62	56	96	741
	18	301.3	180410	269	196	179	139	182	176	204	191	179	362	2077
	19	304.1	175304	214	164	138	121	129	133	159	132	155	295	1640
	20	306.9	174158	196	170	147	147	181	169	146	164	171	342	1833
	21	309.5	173051	155	168	160	133	155	123	163	145	164	283	1649
	22	312.5	171945	0	0	0	0	0	0	0	0	0	0	0
	23	315.2	170839	29	29	21	22	26	13	12	13	15	18	198
	24	292.7	183937	109	68	57	32	34	39	42	37	36	73	527
	25													
	26	298.2	181724	387	259	219	185	213	165	158	210	194	411	2401
	27	300.9	180618	755	669	564	440	550	450	484	424	465	938	5739
	28	303.7	175511	50	28	27	20	24	14	19	25	30	53	290
	29	306.5	174405	77	64	57	48	53	55	66	61	79	134	694
	30													
	31	312.1	172152	18	8	10	4	4	7	7	7	5	7	77

Figure 3. Summary of AVHRR fire detection in the state of Mato Grosso for August 1990.

past years because of intense cerrado/forest deforestation and extensive use of fires in agriculture. The intensity of fires refers to digital counts in band 3 and has been inverted, so intensity 0 corresponds to the 10th level of the AVHRR scale of 256 levels.

5.ACCURACY AND VALIDITY OF AVHRR FIRE DETECTION

If one considers the limitations behind AVHRR detection of fires mentioned above and those indicated by other authors (Robinson, 1991), the following question must be asked: after all, how good is AVHRR to detect fires ?

The experience of DPRN through operation "mata-fogo" after two years receiving daily AVHRR fire information from INPE during the dry/burning seasons of 1989 and 1990 provides an answer to the question (CETESB, 1990). In 1989, 96% of the AVHRR fire pixels verifyed by ground crews were found in fire scars within about 500m of the coordinates of the pixels. Fires were detected in pastures, grasslands, natural forests, sugar cane plantations, timber reserves, etc. For the remaining 4% fire pixels, two possibilities exist: the AVHRR information was wrong, or, the ground crews did not reach the right location. Of the 5,290 fires reported to DPRN , 98.6% were detected only by AVHRR, 1.1% by ground crews and calls from the population, and 0.3% by civil aircraft pilots. Results for the 1990 fires are not yet available, but preliminary analysis indicate similar results as in 1989. Therefore, despite all limitations considered, AVHRR was the best tool available for fire location, and provided useful information for ground crews which in many cases arrived on time to extinguish the fires.

IBAMA employees and helicopter crews hired that went after the locations of hundreds of AVHRR fire pixels from 1987 to 1990 also informed that no errors were found. Thousands of fires in remote regions of Brazil were thus detected and would have gone unnoticed if it were not for AVHRR. The authors themselves, as explained above, also checked the existence of hundreds of fire scars at the coordinates obtained from fire pixels in many parts of the country, without a single error in AVHRR detection.

The estimate of areas actually burned is a more complex problem, but even in this case indications exist that AVHRR can provide the order of magnitude of the areas. Preliminary tests are presented by Pereira Jr. et al.(1991) in this proceedings, and other estimates made by the authors (Setzer and Pereira, 1991a) may be correct within reasonable limits despite all uncertainties involved. AVHRR bands 1(0.58-0.68um) and 2(0.72-1.1um) could possibly be also used to estimate areas burned. These bands, through "vegetation index" products or other band combinations, can detect changes in vegetation patterns.

Therefore, an approximation of areas burned could be obtained by examining areas around fire pixels with bands 1 and 2 one day after the fire pixels were detected. No such work was found in the literature and the authors hope to conduct it in the future.

The estimate of fire numbers and statistics in general (ECE/FAO) is a difficult task, and for most cases existing data is gathered from people who visually spotted fires. Consequently, countries or regions with better forest and fire services and with denser population have more reliable data. It is in this context that AVHRR detection of fires has to be considered. With all its current limitations AVHRR is indeed a tool that can be used anywhere in the planet providing regular and consistent information about fires. If AVHRR advantages and limitations are properly understood and considered, fire numbers and ecology will be much better known.

As a final remark, one of the needs in AVHRR detection of fires is the introduction of error bars in the numbers of fires detected as well as in the estimates of areas burned. This problem will have to be addressed based on ground truth and considering all sources of AVHRR errors together. Since large areas are needed to test a significant number of fires, orbital remote sensing will have to be used. A viable solution could be found through the analysis of fire scars in LANDSAT/TM images of the same regions obtained at intervals of 16 days (the minimum one) in relation to all AVHRR images of the same regions and periods. Although of simple conception this analysis is limited by unavoidable cloud cover in the images and by the nine day cycle of NOAA/AVHRR. With this cycle, every nine days a region is imaged for one or two days in the side limits of the image, with strong geometric distortion and subject longer atmospheric paths as viewed by AVHRR.

CONCLUSIONS

A system to detect fires in near real time using AVHRR band 3 has been developed and is in operational use in Brazil during dry seasons, from June trough November. The system employs relatively simple PC technology and straightforward fast processing. Users receive telex messages with coordinates of fires, and maps of regions of interest with fires. Thousands of fires have been identified with AVHRR and many of them were controlled through the information provided. 96% of the fires detected by AVHRR were found by ground crews within 500m of the coordinates estimated and hundreds of fines given to unauthorized fires. AVHRR band 3 fire detection has strong limitations to detect fires which can be reduced with additional research. Adequate fire detection from space depends on future satellites.

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