Anais XIII Simpósio Brasileiro de Sensoriamento Remoto, Florianópolis, Brasil, 21-26 abril 2007, INPE, p. 4549-4556.

The use of hot pixels as an indicator of fires in the MAP region: tendencies in recent years in Acre, Brazil.

Sumaia Saldanha de Vasconcelos [1]
Irving Foster Brown [1,2]

[1]Universidade Federal do Acre, Parque Zoobotânico, Setor de Estudos do Uso da Terra e Mudanças Globais (UFAC/PZ/SETEM) Campus Universitário, BR-364 – km 04, CEP 69.915-900, Rio Branco, Acre
sumaiasv@yahoo.com.br

[2]Woods Hole Research Center (WHRC) P.O. Box 296 – Woods Hole – MA, EUA

Abstract. The aim of this article is to show fire patterns using hot pixel data from four satellites as an indicator of burning from 2003-2006 in the region of Madre de Dios/Peru, Acre/Brazil, and Pando/Bolivia (MAP region). In recent years, 60 % to 95 % of hot pixels in the MAP region occurred in the state of Acre, Brazil. NOAA-12 hot pixels indicate an increase in the temporal extent and number of fires between 1998 and 2005 in Acre, with a drop in 2006. In 2005, an explosion of uncontrolled fires in Acre affected > 470,000 ha of forest and open areas. During this period, satellites detected more than 12,000 hot pixels from GOES-12, AQUA, TERRA, and NOAA-12 satellites (95 % of the total of MAP region). Of this, 90 % occurred in the eastern portion of Acre, where the increase in number of hot pixels was five times the reported value in 2004. Hot pixels, however, were not associated with more than 155,000 ha of forests affected by fires, indicating that satellite sensors were not able to detect a large number of forest fires that occurred in Acre.

Key words: hot pixels, MAP region, Amazon, fires

1. Introduction

The MAP region is composed of the Peruvian department of Madre de Dios, the Brazilian state of Acre and the Bolivian department of Pando. This region is part of South American regional integration plans, and the advance of infrastructure and desire for a better life have led to an increased demand on natural resources and ecosystems. The most immediate response to this process is deforestation, which has increased rapidly in the last few years in this region (Vasconcelos et al., 2005).

In the Amazon, the process of deforestation is almost always accomplished with the intentional use of fire. Most of the time slash-and-burn activities are the direct result of social and economic factors where people transform forest to pasture or regenerate pastures and agricultural areas using fire (Nepstad et al., 1999; SEPLAND, 2000). However, in addition to intentional fires, wide stands of tropical forests have been burned as an unintended consequence of current land-use practices (Cochrane, 2003).

In the southwestern Amazon, the spread of uncontrolled fire into forests has been considered insignificant (Vasconcelos et. al, 2005). However, in 2005, the extended dry season and burning marked recent history in Acre. The dry season was the most severe and longest in the last 34 years. The volume of the Acre River, which supplies the regions of lower and upper Acre with water, was drastically reduced. Indeed, the lower relative air humidity (approximately 30%), strong winds, high temperature, and the absence of rains, contributed to the occurrence of thousands of intentional burns and uncontrolled fires in the forests and open areas in Acre (Brown et al., 2006a,b).

The hot pixels originating in satellite imagery data have been an indicator of when and where burning has occurred in the Amazon (Brown et al., 2004), and they have been used widely for monitoring fires in Acre and throughout the MAP region (Mendoza, 2003; Selhorst e Brown, 2004; Pantoja et al., 2005; Vasconcelos et al., 2005; Brown et al., 2006a,b).

The objective of this study is to show fire tendencies in the MAP region with an emphasis on the state of Acre, indicating the temporal and spatial distributions of hot pixels in 2003-2006 and changes in the pattern of fires. Understanding the dynamics of fire use has a great potential to influence public policy towards the prevention, combat, control, and monitoring of fires in the MAP region.

2. Methods

2.1. Study area

The study area compasses the region of Madre de Dios/Peru, Acre/Brazil and Pando/Bolivia, also known as the MAP region (**Figure 1**). This area covers approximately 300,000 km^2 and has a population of 700,000 people. The MAP region holds a great deal of cultural and biological diversity with more than 85 % of its forests preserved (Brown et al., 2004). Of the three states, Acre is the most populous, with approximately 600,000 people.

Figure 1: Region frontier of Madre de Dios-Peru, Acre-Brazil, and Pando-Bolivia, called MAP region. Source: INRENA/Madre de Dios, IMAC/Acre and ZONISIG/Pando.

2.2. The use of hot pixels in the fires monitoring

In this study, hot pixel data was used as detected in the MAP region in 2003, 2004, 2005, and 2006 by the following satellites: NOAA-12, which transports the AVHRR sensor, GOES-12, and AQUA and TERRA (both transport the MODIS sensor). These data have been made available daily by the *Centro de Previsão do Tempo e Estudos Climáticos* (CPTEC) of the *Instituto Nacional de Pesquisas Espaciais* (INPE) via the internet (www.cptec.inpe.br/queimadas). For mapping hot pixels and analysis of their distribution, the softwares ArcView GIS 9.0, ArcView 3.2 and TerraView 3.1.3 ware used.

Fire events can vary in size. In areas, such as Acre, where there is a large number of small rural producers in elongated properties of 150 m to 500 m in width many simultaneous slash and burn fires of 1 to 5 ha can be clustered in one pixel of 1 km by 1 km (NOAA-12, AQUA, TERRA) or 4 km by 4 km (GOES-12), resulting in an underestimate of the number of burn events. On the other hand, in areas with large ranches, a single fire event can extend over dozens to hundreds of hectares and burn for days, being detected by many satellites simultaneously. Such large-area burns have been relatively infrequent in the MAP region.

In addition to the relative size of the fire event versus pixel area, the detection of fires by satellites can also be influenced by many other factors including the varying times of passage of different satellites, cloud and smoke cover, incomplete coverage of certain satellites in determined areas, the off-nadir satellite observation which can reduce detection, different algorithms used in fire detection, and the cover of forest canopy. Serlhost and Brown (2004) showed that fires in Acre are five to ten times greater than those detected in hot pixels of satellite NOAA-12. Pantoja et al. (2005) found a similar pattern in satellites NOAA-12, NOAA-16, GOES-12, AQUA, and TERRA. Considering the variety of factors that tend to underestimate of the number of fires in the region, we used the total amount of hot pixels detected by satellites NOAA-12, GOES-12, AQUA, and TERRA as an indicator of fire frequency. Data from Pantoja and Brown (unpublished data) indicate that even summing all hot pixels of GOES-12, NOAA-12, AQUA and TERRA processed by CPTEC/INPE with those from MODIS sensors analyzed by the Univ. of Maryland and available from the CPTEC site still significantly underestimates fire frequency by roughly a factor of two, in spite of the apparent double counting.

3. Results and Discussion

3.1. Distribution of fires in the MAP region

Using the distribution of hot pixels detected by satellites AQUA, GOES-12, NOAA-12, and TERRA, in 2003 and 2004 in the MAP region, Vasconcelos et al. (2005) found that more than 75% of hot pixels detected in this period occurred in the state of Acre. In 2005, Acre continued in the lead with 95% of the total number of hot pixels detected in the MAP region (626 hot pixels in Madre de Dios, 12,670 in Acre and 2,336 in Pando). In 2006, in Acre, 2,519 hot pixels were detected (60% of total), with 1,349 in Pando and 310 in Madre de Dios (**Figure 2**).

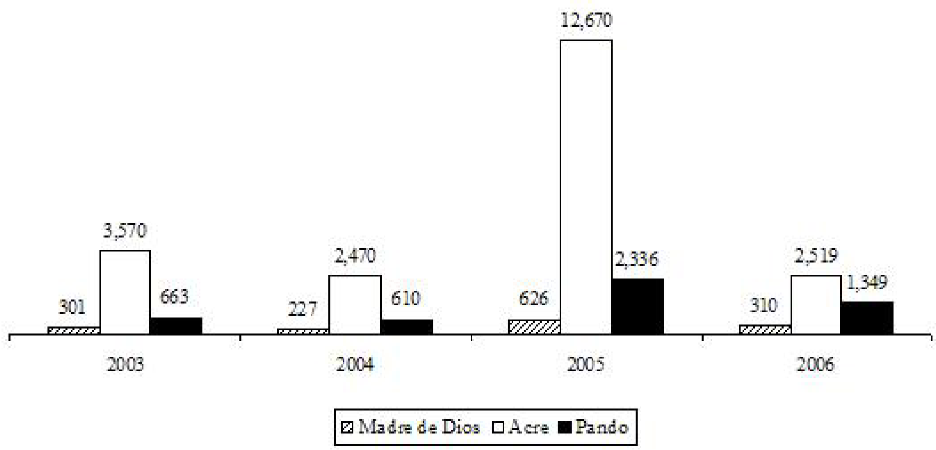

Figure 2: Sum of hot pixels detected in the MAP region by the satellites AQUA, GOES-12, NOAA-12, and TERRA in the years of 2003 to 2006. Source: www.cptec.inpe.br/queimadas

In the analysis of distribution of hot pixels in the MAP region, data from 2005 were not considered, since this was an atypical year with climatic anomalies and extreme fire events. Using the data of 2003 and 2004 for comparison, the number of hot pixels detected in Acre in 2006 is similar to that of 2004 and somewhat less than that of 2003. Madre de Dios maintained roughly the same number of hot pixels over the last three years, whereas Pando showed a significant increase in 2006.

The eastern portion of Acre holds more than 60% of the state's population. In this area, 40 of the 61 human settlements projects by *Instituto Nacional de Colonização e Reforma Agrária* (INCRA) were implemented (SEPLAND, 2000). This portion of Acre has been undergoing an accelerated process of landscape transformation, which explains, in part, the cause of the higher number of hot pixels (70%) detected in the last few years in this part of the MAP region. According to Cochrane and Schulze (1999), the risk of uncontrolled fire is increasing due the pressure of human settlements in forested areas. This is common throughout the Amazon and is enhanced by increased forest exploration, slash and burn agriculture and the conversion of primary forests to pasture, which also greatly increases the vulnerability of adjacent, intact forests.

3.2. When does burning begin and end in Acre?

Traditionally, burning has occurred with greatest frequency in Acre between late August and early September, the driest period of the year in this region. One conventional reference among producers was to burn on 7 September, Brazil's day of independence. To define the beginning and end of the burning period in Acre, we used an operational definition of a minimum number of 50 hot pixels detected by the AVHRR sensor of NOAA-12, sensor in a period of 15 days in the nine-year period from 1998 to 2006 (**Table 1**). The choice of data from NOAA-12 was due to its greater historical record when compared with other satellites, enabling comparisons over a longer time period. The number of hot pixels tends to increase from 1998 to 2006, with peaks in 1998, 2002 and 2005.

Table 1 – Distribution of hot pixels detected by satellite NOAA-12 in Acre, Brazil from 1998 to 2006 (data in bold refers to values above 50 hot pixels). Source: www.cptec.inpe.br/queimadas.

Period	Year								
	1998	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
01 – 15 Jul	6			1	1	4		**59**	11
16 – 31 Jul	30	1	1	2	16	**109**	11	**55**	17
01 – 15 Aug	35	8	5	**62**	**128**	**122**	**79**	**706**	29
16 – 31 Aug	**95**	**56**	**131**	**331**	**150**	**537**	**122**	**1,346**	**140**
01 – 15 Sep	**303**	**209**	**176**	**129**	**687**	**237**	**220**	**794**	**259**
16 – 30 Sep	**205**	**43**	**80**	**158**	**911**	**74**	**391**	**1,497**	**179**
01 – 15 Oct	42	17	18	**135**	**539**	**87**	**74**	**159**	21
16 – 31 Oct	2			2	**51**	34	5	13	
01 – 15 Nov					15			5	
16 – 30 Nov					15				
Total	**718**	**334**	**411**	**820**	**2,513**	**1,504**	**902**	**4,634**	**656**

Assuming that the hot pixels detected correlate with fire events, the temporal extent of burning in Acre is changing. Fires are beginning earlier and are more frequent. In 1998-2000, the burning period began around August 16th and finished by about September 30th. In 2001, 2002 and 2004, burning began around August 1st and ended by October 15th, with the exception of 2002, when fires ended effectively by October 31st. In 2003, fires began around July 16th and finished by October 15th. In 2005, fires started on July 1st and finished by October 15th. In 2006, fires began around August 16th and finished by September 30th.

3.2. Temporal and spatial distribution of hot pixels in Acre

Combining the AVHRR data from NOAA-12 with those of GOES-12, AQUA and TERRA for the period of 2003 to 2006 (15 October), it is possible to refine the pattern of fire detected in the AVHRR/NOAA-12 data, as shown in **Figure 3**. In 2003, the highest incidence of burning occurred from August 16th to September 15th. In 2004, the temporal distribution of hot pixels showed a delay in the critical period of fires in the eastern portion of Acre (this period showed the highest hot pixels detection by satellites). The highest number of hot pixels occurred between the 16th and 30th of September, with 995 hot pixels. In 2005, began earlier burning activities, and the critical period occurred from August 1st to September 30th. In this period, 9,824 hot pixels were detected by satellites in the eastern portion of Acre. In the same period, there were two peaks of burning: the first from the 16th to 31st of August and the second between the 16th and 30th of September. In 2006, 1,683 hot pixels were detected during September, which represented 70% of the total amount of hot pixels in the state (**Figure 3).**

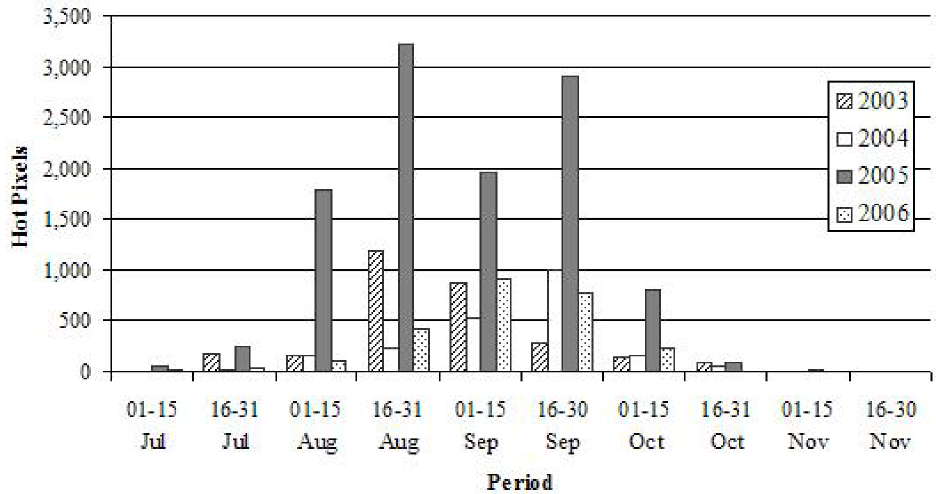

Figure 3: Temporal distribution (intervals of 15 days) of hot pixels detected by satellites AQUA, GOES-12, NOAA-12, and TERRA, in the eastern region of Acre State, in the years 2003, 2004, 2005, and 2006. Source: http://www.dpi.inpe.br/proarco/queimadas.

Table 2 shows the spatial distribution of hot pixels detected by satellites GOES-12, NOAA-12, AQUA, and TERRA. In 2003, more than 80% (2,945) hot pixels were detected in the municipalities located in the eastern portion of Acre. In 2004, there was a reduction to 2,185 hot pixels. However, this lower number still represents about 90% of the total amount of hot pixels detected in Acre in 2004.

Table 2 – Spatial distribution of hot pixels detected by satellites GOES-12, NOAA-12, AQUA, and TERRA in the municipalities of eastern region of Acre State, in the years 2003, 2004, 2005, and 2006 (until 15 October). Source: http://www.dpi.inpe.br/queimadas.

Municipality	**Year**			
	2003	**2004**	**2005**	**2006**
Acrelândia	170	216	1,581	237
Assis Brasil	68	55	163	3
Brasiléia	237	268	842	88
Bujari	305	79	621	98
Capixaba	169	149	507	140
Epitaciolândia	101	148	445	100
Plácido de Castro	360	243	1,380	109
Porto Acre	278	112	943	241
Rio Branco	484	337	1,358	121
Sena Madureira	286	118	1,180	173
Senador Guiomard	270	201	1,350	225
Xapuri	217	259	727	239
Total Eastern Region	**2,945**	**2,185**	**11,097**	**1,774**
Total of Acre State	**3,570**	**2,470**	**12,670**	**2,519**
Relative proportion of Eastern Region to State (%)	**~80**	**~90**	**~90**	**~70**

In 2005, all satellites simultaneously showed an increase of two to five times the number of hot pixels detected as compared with 2004. The total number for the eastern portion of Acre was 11,097 hot pixels, which represents 90% of the state's total. In 2006, in the same area, approximately 1,774 hot pixels were detected, corresponding to 70% of the total detected in Acre. Notably, when comparing hot pixel data from 2004 and 2005, the high percentage of total fire occurring in the eastern portion of the state is practically identical, but in 2006 more hot pixels were observed occurring in central and western Acre. This is consistent with the pattern of increased burning associated with the improvement of highways (Nepstad et al. 1999), in this case BR-364, which is currently being paved.

In 2003, about 50% of hot pixels were detected in the municipalities of Rio Branco – the capital of Acre, Plácido de Castro, Bujari, Porto Acre, and Sena Madureira. In 2004, approximately 50% of the hot pixels were detected in the municipalities of Rio Branco, Plácido de Castro, Acrelândia – located in the lower Acre-, Brasiléia and Xapuri – located in upper Acre. In 2005, there was a large increase in fires, with 55 % of the hot pixels detected in the municipalities of Acrelândia, Plácido de Castro, Rio Branco, Senador Guiomard – municipalities pertaining to lower Acre, along with Sena Madureira. In 2006, more hot pixels were detected in the municipalities of Porto Acre, Xapuri, Acrelândia, and Senador Guiomard.

In 2005, the dry season began earlier and was more severe in the MAP region: from July to September, rainfall was lower than 30 mm. This maximized the effects of increasing human activities, facilitating fires in agricultural and forest systems in the eastern portion of Acre and causing accidental fires.

According to an analysis by Brown et al. (2006b), more than 267,000 ha of forests had their canopy affected (FCA) by fires and more than 200,000 ha of open areas used for agriculture and pastures were burned accidentally in the eastern portion of Acre in 2005. Vasconcelos and Brown (unpublished data) compared FCA polygons with hot pixels detected in 2005 and found that more than 155,000 ha of areas of FCA were not associated with hot pixels. This pattern confirms that below-canopy forest fires are basically invisible to the sensors used in this study. This omission reinforces the need for the scientific community to develop new approaches to monitor understory fires.

Based on the devastation caused by uncontrolled forest fires in 2005 and considering that areas of FCA in 2006 would be more susceptible to fire, the Public Ministry of Acre prohibited burning in eastern of Acre for 75 days in 2006, which may have influenced the reduction of hot pixels detected this year.

4. Conclusion

In the MAP region, hot pixel counts are increasing, particularly in years of climatic anomalies. The state of Acre is the leader in hot pixel counts for the region, with 60% to 95% of the total. In Acre, the active burning period has begun earlier over time: late August (1998-2006), early August (2001-2004) and July (2003, 2005).

In 2005, this region faced a severe dry season. In Acre, fires affected 470,000 hectares of open areas and forests. In this period, approximately 11,000 hot pixels (90% of the total of state) were detected in the eastern portion of Acre, corresponding to five times the value detected in 2004. In 2006, fires were prohibited in Acre, and hot pixels dropped by 80% from the level in 2005. However, the number of hot pixels detected in the eastern portion of Acre was 20% lower than 2004 and 85% less than 2005. In more than 155,000 ha of FCA no hot pixels from GOES-12, NOAA-12, AQUA and TERRA were detected. This suggests that hot pixel data alone are not an adequate indicator to evaluate forest fires in the MAP region.

Acknowledgements

This work would not have been possible without the dedicated efforts of researchers and technicians at CPTEC/INPE and other institutions that made hot pixel data available via Internet. In particular, we thank Alberto Setzer, Wilfrid Schroeder, Emy Duchelle, Marcelo Menin and Carlos Franco. Funding for this research came from the Large-Scale Biosphere Atmosphere Experiment (LBA) scholarship RHAE/ Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), National Aeronautics and Space Administration (NASA), LBA-ECO LC-02, United States Agency for International Development (USAID), Gordon & Betty Moore Foundation, Blue Moon Foundation, the Federal University of Acre.

References

Brown, I.F., Selhorst, D., Pantoja, N.V., Mendoza, E.R.H., Vasconcelos, S.S. de, Rocha, K. da S. Os desafios do monitoramento de desmatamento, queimadas e atividade madeireira na região MAP – área fronteiriça de Bolívia, Peru e Brasil. In: **Aplicações de Geotecnologia na Engenharia Florestal**, eds. A.A. Disperati & J.R. dos Santos, Curitiba, Brazil: Copiadora Gabardo Ltda. 2004, pp. 70-77.

Brown, I. F., Schroeder, W., Setzer A., Maldonado, M. J. R., Pantoja, N., Duarte, A. F., Marengo, J. Monitoring fires in Southwestern Amazônia rain forest. **EOS**, Transaction American Geophysical Union **87** (26): 253-264, 2006 a.

Brown, I. F., Moulard, E. M. N. P., Nakamura, J., Schroeder, W., Maldonado, M. j. R., Vasconcelos, S. S., Serlhost, D. **Relatório preliminar do mapeamento de áreas de risco para incêndios no leste do Estado do Acre**. UFAC/FUNTAC. Rio Branco, Brazil, 20p., 2006 b.

Cochrane, M.A. Fire science for rainforests**. Nature 421**: 913-919, 2003.

Cochrane, M.A. & Schulze, M.D. Fire as a recurrent event in tropical forests of the eastern Amazon: Effects on forest structure, biomass, and species composition. **Biotropica 31** (1): 2-16, 1999.

Mendoza, E.R.H. **Susceptibilidade da floresta primária ao fogo em 1998 e 1999: Estudo de caso no Acre, Amazonia Sul-Ocidental, Brasil**. Dissertação de Mestrado. Curso de Mestrado em Ecologia e Manejo de Recursos Naturais. Universidade Federal do Acre, Rio Branco, Acre, Brasil. 2003.

Nepstad, D.C., Moreira, A.G. & Alencar, A.A. **Flames in the rain forest: origins, impacts and alternatives to Amazonian fire**. Brasilia, Brazil Pilot Program to Conserve the Brazilian Rain Forest. 1999, 161p.

Pantoja, N.V., Selhorst, D., Rocha, K. da S., Lopes, F.M. da C., Vasconcelos, S.S. de & Brown, I.F. Observações de queimadas no leste do Acre: subsídios para validação de focos de calor derivados de dados de satélites. In: Simpósio Brasileiro de Sensoriamento Remoto 12., 2005, Goiânia. **Anais**... São José dos Campos: INPE, 2005. Artigos, p. 3215-3222. CD-ROM, On-line. ISBN 85-17-00018-8. Disponível em: <http://marte.dpi.inpe.br/col/ltid.inpe.br/sbsr/2004/11.21.21.16/doc/3215. pdf> Acesso em: 23 out. 2006.

Secretaria de Estado de Planejamento e Coordenação Estado do Acre - SEPLAND. **Zoneamento Ecológico-Econômico do Estado do Acre (ZEE)**. Aspectos Socioeconômicos e ocupação territorial. Rio Branco, Brazil. Vol. II, 2000, 313p.

Selhorst, D. & Brown, I. F. Queimadas na Amazônia Sul-Ocidental, Estado do Acre - Brasil: Comparação entre produtos de satélite (GOES-8 e NOAA-12) e observações de campo. In: Simpósio Brasileiro de Sensoriamento Remoto 11., 2004, Belo Horizonte. **Anais**... São José dos Campos: INPE, 2004. Artigos, p. 517-524.

Vasconcelos, S.S. de, Rocha, K. da S, Selhorst, D., Pantoja, N. & Brown, I.F. Evolução de focos de calor nos anos de 2003 e 2004 na região de Madre de Dios/Peru-Acre/Brasil-Pando/Bolívia (MAP): uma aplicação regional do banco de dados do INPE/IBAMA. In: Simpósio Brasileiro de Sensoriamento Remoto 12., 2005, Goiânia. **Anais**... São José dos Campos: INPE, 2005. Artigos, p. 3411-3417. CD-ROM, On-line. ISBN 85-17-00018-8. Disponível em: <http://marte.dpi.inpe.br/col/ltid.inpe.br/sbsr/2004/11.22.22.47/doc/3411.pdf>. Acesso em: 23 out. 2006.